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CONTENTS

INVITED LECTURES

PROGRESS REPORTS

POSTERS

Invited Lectures

Publ. Astron. Obs. Belgrade No. 98 (2018), 11 - 20 *Invited Lecture*

TESTS OF GRAVITY AT GALACTIC AND EXTRAGALACTIC SCALES: THEORY VS OBSERVATIONS

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Abstract. We present a short overview of our results considering a possibility to explain the observed galactic and extragalactic dynamics using gravitational potentials derived from Extended Theories of Gravity (ETGs) without dark matter (DM) hypothesis. These theories can have observational signatures at astrophysical and cosmological scales, and thus we consider different ETG potentials within the Galactic Central Parsec, as well as on extragalactic scales. The simulated stellar orbits, obtained by modified gravity potentials, are compared with astrometric observations of S2 star orbit around the central suppermassive black hole of the Milky Way. The obtained results give strong constraints on the gravity interaction parameters. We also used ETGs to investigate the baryonic Tully-Fisher relation of spiral galaxies and the fundamental plane of ellipticals, and found that these empirical relations could be theoretically explained by the existence of a further gravitational radius predicted by ETGs and without the DM hypothesis. This gravitational radius plays an analogous role, in the case of weak gravitational field, like the Schwarzschild radius in the case of strong gravitational field.

1. INTRODUCTION

In this paper we present the primary scientific objectives of the project 176003 "Gravitation and the large scale structure of the Universe", as well as the research team of the project, and we describe realized scientific aims. The project is proposed in the frame of fundamental research programme for 2011-2017 period and it is supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

The results of the work within the project are presented at many national and international conferences (poster sections, talks, invited lectures) and at the seminars, and there are published papers in national and international refereed journals.

2. BASIC RESEARCH PROJECT 176003

Research team. Our research team consists of seven researchers:

- Dr. Predrag P. Jovanović, leader of the project, Full Research Professor, Astronomical Observatory (AOB), engaged with 10 research months (RM) per year
- Dr. Luka Č. Popović, Full Research Professor, AOB, 2 RM
- Dr. Edi A. Bon, Assistant Research Professor, AOB, 6 RM
- Dr. Nataša Ž. Bon, Assistant Research Professor, AOB, 4 RM
- Dr. Marko T. Stalevski, Assistant Research Professor, AOB, 6 RM
- Dr. Duško V. Borka, Full Research Professor, Vinča Institute of Nuclear Sciences, 4 RM
- Dr. Vesna V. Borka Jovanović, Assistant Research Professor, Vinča Institute of Nuclear Sciences, 8 RM

We are a team of seven researchers, with total 40 research months per year, which would correspond to about 3.33×12 research months per year.

As it can be seen from the list of authors in our published papers, we developed international collaboration with colleagues from abroad, which had multiple benefits in the sense of transfer of knowledge, improving learning performances, as well as the professional training and development of young researchers.

Project tasks within 176003. One part of the project topics is organized into three project tasks:

1. "*Variability of the radiation in the spectra of active galaxies.*" (leader Dr. Edi Bon)
2. "*Radio sources and structure of the matter at cosmological scales.*" (leader Dr. Vesna Borka Jovanović)
3. "*Effects of the modified theories of gravity at large scales.*" (leader Dr. Duško Borka)

Theses and awards. In the frame of the project, during the period 2011-2017, several researchers defended their PhD theses and were awarded for their scientific contribution. Also, a number of foreign students defended their MSc theses under the supervision by the members of our research team. Below is a list of these results regarding the professional training and development of researchers.

defended PhD theses

- Dr. Nataša Bon, 2011: *The contribution of stellar populations to AGN spectra.*
- Dr. Marko Stalevski, 2012: *Research of the structure of AGNs: dusty torus.*

awards

- Dr. Vesna Borka Jovanović, 2008: Annual Award of the Institute of Nuclear Sciences "Vinča", for scientific contributions in basic research.
- Dr. Duško Borka, 2012: Annual Award of the Institute of Nuclear Sciences "Vinča", for scientific contributions in basic research.
- Dr. Predrag Jovanović, 2012: Annual Award of the Astronomical Observatory Belgrade, for scientific contributions in basic research.

defended MSc theses - AstroMundus students

- MSc. Miika Pursiainen (Finland), 2017: *The shape of the broad iron Kα line and the effect of the accretion disc parameters.*
- MSc. Miriam Gudino (Mexico), 2017: *The Hubble constant from time-delays of gravitationally lensed quasars.*

defended MSc theses - ERASMUS students

- MSc. Stefania Gravina (Italy), 2017: *The Galactic Center as a gravitational laboratory.*
- MSc. Anna D'Addio (Italy), 2017: *Testing theories of gravity by Sgr A*.*

Participations in European projects. Members of our research team had very intensive international collaboration and actively participated in several European projects which are listed below.

ERASMUS+ Mobility Program

- For higher education student and staff mobility (2016-2018);
- inter-institutional agreement between: Dipartimento di Fisica, Università di Napoli "Federico II", Italy and Vinča Institute of Nuclear Sciences, University of Belgrade, Serbia.

Bilateral cooperation

- No. 451-03-01231/2015-09/1, "Testing Extended Theories of Gravity at different astrophysical scales", for period 2016-2018;
- between Serbia and Italy.

COST actions

- MP1304: "Exploring fundamental physics with compact stars" (NewCompStar), 2014-2017.

- CA15117: "Cosmology and Astrophysics Network for Theoretical Advances and Training Actions" (CANTATA), 2016-2019.

AstroMundus

- A 2-years Erasmus programme, with joint masters degree in Astronomy and Astrophysics (Austria, Italy, Germany, Serbia), 2012-2018.

3. OBJECTIVES OF THE PROJECT 176003

In the scope of our project there are several lines of research (theoretical investigations, numerical simulations and the comparison of the modelled results with astronomical observations) which include the following gravitational phenomena at galactic and extragalactic scales:

1. supermassive black holes,
2. supermassive black hole binaries,
3. gravitational lenses, and
4. modified gravity as alternative to dark matter.

Here, we will just briefly mention the main results from the first three topics, while the last one will be discussed in more detail.

3. 1. SUPERMASSIVE BLACK HOLES

Supermassive black holes (SMBHs) are considered to be located in the centers of most of galaxies, and therefore, the formation and evolution of host galaxies is fundamentally influenced by properties of their central SMBHs. Within our project, we investigate the effects of strong gravity in the vicinity of SMBHs, their activity and radiation from their accretion disks. Also, there are investigations of infrared radiation from the dusty torus and polarization in active galactic nuclei and in quasars.

For more details about obtained results see Jovanović et al. 2011, 2016, Jovanović 2012, Popović et al. 2012, Stalevski et al. 2016, 2017, Peest et al. 2017, and references therein.

3. 2. SUPERMASSIVE BLACK HOLE BINARIES

Supermassive black hole binaries (SMBHBs) originate in the galactic mergers, and their coalescences represent the most powerful sources of gravitational waves. We study electromagnetic counterparts of gravitational waves because SMBHBs in Active Galactic Nuclei (AGNs) can be detected by periodicity in electromagnetic radiation from their host-galaxies.

From this field, the significant results were obtained and published in Bon et al. 2012, 2016 and Jovanović et al. 2014.

3. 3. GRAVITATIONAL LENSES

Gravitational lenses (GLs) are massive astronomical objects in which gravitational field light bending is induced and as a consequence, either the appearance of multiple images of some background source (macrolensing), or its amplification (microlensing). We focus on gravitational lensing effects on radiation from AGN in different spectral bands, and on application of GL in observational cosmology.

For an example about the investigations and the obtained results in this field, see e.g. Stalevski et al. 2012.

3. 4. MODIFIED GRAVITY AS ALTERNATIVE TO DARK MATTER

Modified gravity gives the possibility for explaining the observed galactic and extragalactic dynamics using gravitational potentials derived from Extended Theories of Gravity (ETGs), without taking into account presence of dark matter (DM). ETGs may have observational effects at astronomical and cosmological scales. We tested the following modified gravities: R^n, Yukawa, Sanders, hybrid, scalar-tensor, nonlocal gravity, using astronomical observations of motion of S-stars around SMBH in the center of our Galaxy, as well as at extragalactic scales. Here we present a short overview of these investigations.

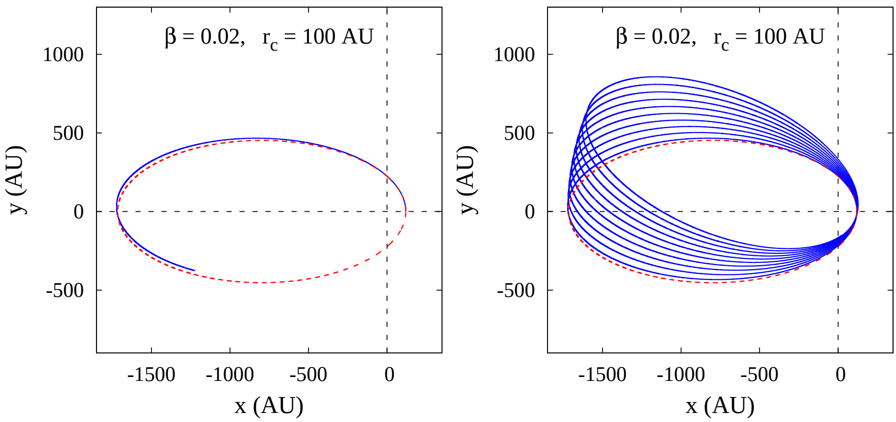

Figure 1: The orbits of S2-like star around massive black hole in R^n gravity (blue solid line) and in Newtonian gravity (red dashed line) for $r_c = 100$ AU and $\beta = 0.02$ during 0.8 periods (left) and 10 periods (right) (Borka et al. 2012).

R^n modified gravity. One of the straightforward generalizations of Einstein's General Relativity, where the function $f(R)$ is not linear in the Ricci scalar R ($f(R) \neq$ R), would be $f(R)$ modified gravity. Furthermore, there is the power-law version of this gravity: R^n modified gravity, which we used in our investigations. About considerations of the power-law fourth-order theories of gravity see in Capozziello et al. 2007. In the weak field limit, R^n gravity potential (generated by a pointlike mass m at the distance r) is Capozziello et al. (2007):

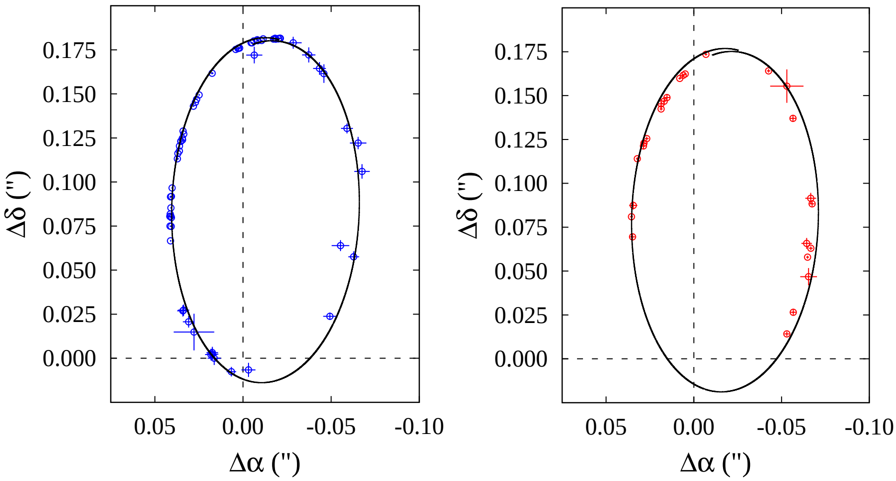

Figure 2: The fitted orbit of S2 star around massive black hole in R^n gravity for r_c = 100 AU and β = 0.01 (black solid lines in both panels). The NTT/VLT astrometric observations are presented in the left panel by blue circles, while the Keck measurements are denoted by red circles in the right panel (Borka et al. 2012).

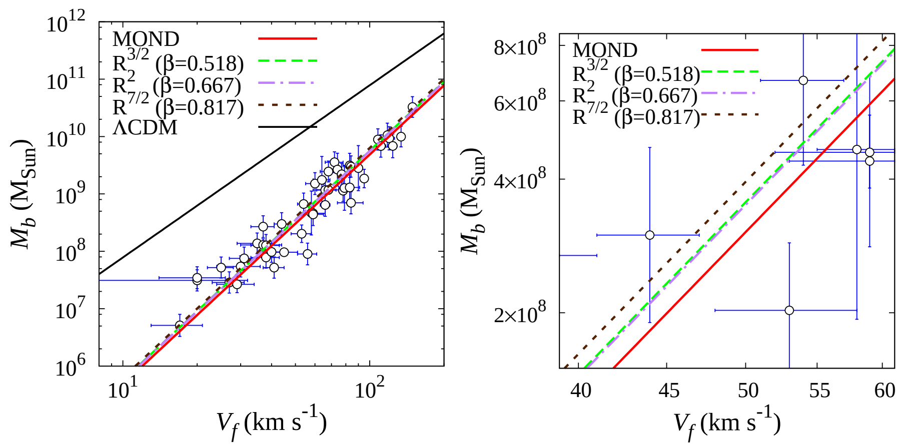

Figure 3: *Left*: Comparison between best fit BTF relations of gas-rich galaxies, in MOND, R^n gravity for values of n = 1.5, 2 and 3.5 (corresponding β are 0.518, 0.667 and 0.817, respectively) and ΛCDM. *Right*: A zoomed part of the figure, for one small range of parameters (Capozziello et al. 2017).

$$\Phi(r) = -\frac{Gm}{2r}\left[1 + \left(\frac{r}{r_c}\right)^{\beta}\right], \tag{1}$$

where r_c is scalelength depending on the gravitating system properties and β is universal constant which depends on power n:

$$\beta = \frac{12n^2 - 7n - 1 - \sqrt{36n^4 + 12n^3 - 83n^2 + 50n + 1}}{6n^2 - 4n + 2}. \tag{2}$$

Our results considering the simulated S2 star orbits around the SMBH in the Galactic Center (GC), obtained using the power-law fourth-order theories of gravity, as well as about determining of the parameter space of $f(R)$ gravity, can be found in the following papers: Borka et al. 2012, Borka et al. 2013, Zakharov et al. 2014, Borka et al. 2015. The comparison between the observed and simulated orbit of S2 star is given in Figs. 1 and 2. We obtained that the orbital precession is about -1° per orbital period.

In the paper Borka Jovanović et al. 2016 we showed that the fundamental plane (FP) of galaxies can be recovered in the framework of $f(R)$ gravity, avoiding the issues related to DM, to fit the observations. Also, our results point out that the gravitational corrections induced by $f(R)$ can lead photometry and dynamics of the system, i.e. the effective radius (observationally derived from photometry), actually is a gravitational radius. In Capozziello et al. 2017 we showed that it is possible to explain the baryonic Tully-Fisher relation and the rotation curve of gas-rich galaxies without the dark matter hypothesis. A graphical comparison between the best fit BTF relations in R^n gravity, MOND and ΛCDM is presented in Fig. 3.

Yukawa-like and Sanders-like modified gravity. We also investigated the possibility of explaining theoretically the observed deviations of S2 star orbit around the GC using gravitational potentials derived from modified gravity models in the absence of DM. To this aim, an analytic fourth-order theory of gravity, nonminimally coupled with a massive scalar field, is considered (Capozziello et al. 2014). As discussed in that paper, in $f(R)$-gravity, the scalar curvature R of the Hilbert - Einstein action, is replaced by a generic function $f(R)$. As a result, in the weak field limit, the gravitational potential is found to be Yukawa-like:

$$\Phi\left(r\right) = -\frac{GM}{(1+\delta)r}\left[1 + \delta e^{-\left(\dfrac{r}{\Lambda}\right)}\right], \tag{3}$$

where Λ is an arbitrary parameter (usually referred to as the range of interaction), depending on the typical scale of the system under consideration and δ is a universal constant.

In case of $f(R,\phi)$-gravity, we can consider a generic function of Ricci scalar and scalar field (e.g. Stabile & Capozziello 2013). The gravitational potential is found by setting the gravitational constant as

$$G = \left(\frac{2\,\omega(\phi^{(0)})\,\phi^{(0)} - 4}{2\,\omega(\phi^{(0)})\,\phi^{(0)} - 3}\right)\frac{G_\infty}{\phi^{(0)}}, \tag{4}$$

where $\phi^{(0)}$ is the first term of the series expansion of the scalar field ϕ, and G_∞ is the gravitational constant as measured at infinity, and by imposing $\alpha^{-1} = 3 - 2\,\omega(\phi^{(0)})\,\phi^{(0)}$ and $\omega(\phi^{(0)}) = 1/2$, the gravity potential is (see e.g. Stabile & Capozziello 2013, Capozziello et al. 2014):

$$\Phi_{ST}(\mathbf{x}) = -\frac{G_\infty M}{|\mathbf{x}|}\left\{1 + \alpha\, e^{-\sqrt{1-3\alpha}\, m_\phi |\mathbf{x}|}\right\}. \tag{5}$$

In case of $f(R, \phi)$-gravity, parameters that we want to determine are α and m_ϕ.

The simulated orbits of S2 star around the Galactic Centre in Sanders gravity potential are shown in Fig. 4. The orbital precession is about 3.1° per orbital period.

In Zakharov et al. 2016 we considered opportunity to evaluate a graviton mass from χ^2 statistical test of fitting the S2-star orbit around central SMBH of our Galaxy in the gravitational potential which was derived from Yukawa theory of massive gravity. The obtained results showed that such stellar trajectories could constrain the range of Yukawa interaction i.e. the Compton wavelength of graviton, and hence its mass. The derived upper bound for graviton mass was consistent with the corresponding constraints obtained from a gravitation wave signal recently detected by LIGO (Abbott et al. 2016).

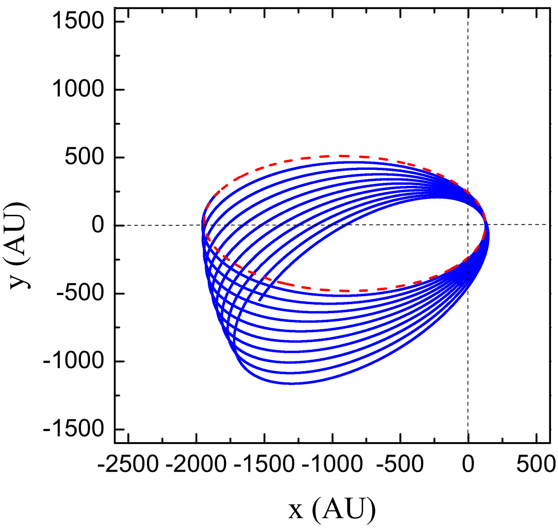

Figure 4: Comparison between the orbit of S2 star in Newtonian potential (red dashed line) and Sanders-like potential for the best fit parameters (the absolute minimum of reduced χ^2 = 1.5011) α = 0.00018 and m_ϕ = -0.0026 during 10 orbital periods (blue solid line) (Capozziello et al. 2014).

Hybrid modified gravity. The possible signatures for the so called hybrid gravity within the Galactic Central Parsec, are considered in Borka et al. 2016. The simulations of S2 star orbital precession resulted with constraints on the range of hybrid gravity interaction parameter ϕ_0. We used the modified gravitational potential, with the leading parameters m_ϕ and ϕ_0, in the form:

$$\Phi\left(r\right)=-\frac{G}{1+\phi_0}\left[1-\left(\phi_0/3\right)e^{-m_\phi r}\right]M/r. \tag{6}$$

The hybrid gravity effective potential is very good candidate among the other considered models of gravity because it is able to explain gravitational phenomena at different astronomical scales.

Scalar-tensor modified gravity. In Gravina et al. 2017, D'Addio et al. 2017 we discussed the general case of scalar-tensor-higher-order gravity, where the standard Hilbert-Einstein action is replaced by a more general action containing a scalar field and curvature invariants, like the Ricci scalar R and the Ricci tensor $R_{\alpha\beta}$.

All these results show that theories of modified gravity represent a good alternative to DM, and they are a good basis to construct an effective theory of gravity.

4. THE PLANS FOR FUTURE WORK

This was an overview of some of the most important results within the project 176003 "Gravitation and the large scale structure of the Universe", and the remaining ones can be seen from the bibliography of the published papers. Our plan for future work would be (a) to continue with the investigations of gravitation at different scales, as well (b) to continue and improve our international collaboration. Therefore, our plans for future work include the following issues:

(a)
- further research of possible alternatives to DM through different theories of modified gravity,
- testing these theories using astronomical observations in our Galaxy, and also at large, extragalactic scales,
- research of the observed effects of the strong gravitational field in the vicinity of SMBHs - single and binaries,
- theoretical models of areas in the vicinity of central SMBHs in active galaxies;

(b)
- achieving partnerships between educational institutions,
- foster of collaboration,
- mobility of young researchers.

Acknowledgment

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OBSERVATIONAL STUDIES OF CLOSE BINARY STARS

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Abstract. The Stellar Physics Group at Astronomical Observatory of Belgrade conducts observational studies at the forefront of binary star research with the aim to improve understanding and modeling of complex physical processes within close, interacting binaries on both ends of the stellar mass scale. On the intermediate to high mass end, we study double-periodic variables – close binaries featuring accretion disks, gas streams and various circumbinary structures, characterized by two strongly correlated photometric periodicities; on the low mass end, we study W UMa contact binaries as well as semi-detached and detached binaries in pre- and post-common-envelope stages of evolution. In this review, I will showcase some of our recent results and publications, and present our plans to enter the scene of automated processing of massive data sets using machine learning and advanced model optimization methods.

1. INTRODUCTION

The Stellar Physics Group at Astronomical Observatory of Belgrade is a government-funded research unit, or project, coordinating the work of several smaller groups in different areas of stellar physics. These areas include the observational studies of close binary stars, the theory and numerical methods related to the problem of radiation transfer and spectral synthesis (recently including transfer of polarized radiation), and the studies of stellar rotation and stellar oscillations in single and binary stars. This review will focus on the observational studies of close binary stars.

In this section, I will enumerate some reasons why studying binary stars is still interesting, challenging, and necessary to support other fields of astrophysics. Next, I will describe the typical process of characterization of an individual binary star. Within our group, this is done using software tools that we develop and maintain ourselves. These will be the subject of the Section 2.

In Sections 3 and 4, I will turn to the two subjects that our group has recently been focused on: the double-periodic variables – close binaries in the stage of active mass transfer through an accretion disk, with many poorly understood observational characteristics; and contact binaries of the W UMa type.

Dealing with both these topics, we witnessed the need to develop procedures for automated processing of massive data sets. I will conclude the review by describing our first steps in that direction, related to applications of machine learning and advanced model optimization techniques in automated analysis of binary star observations from ongoing and future space- and ground-base surveys.

1. 1. WHY ARE WE STILL INTERESTED IN BINARY STARS?

The fraction of stars with one or more companions is above 50% for solar type stars, and above 80% for O and B type stars (see ee.g. Duchêne & Kraus, 2013). Stellar multiplicity is obviously an omnipresent outcome of star formation. Knowledge of the frequency and main properties of binary and multiple stars, and the dependence of these properties on the environment, are powerful tools to probe the process of star formation.

Binary stars remain the most reliable source of precisely determined stellar masses and radii (Stassun & Torres, 2016). With the instrumental and analytical advances made during the past decades – like the advent of space telescopes and all-sky surveys, as well as advances in automated analysis – the census of binary and multiple stars has increased (and keeps increasing) by orders of magnitude. Our ability to reliably estimate the orbital and stellar parameters of this growing sample and construct distributions of these parameters is key for many population synthesis studies (see e.g. Abate et al. 2015, Anderson et al. 2016).

Those same instrumental and analytical advances showed us that there are still new discoveries to be made within this old and well-established field. Previously unknown phenomena, such as heartbeat stars (Barclay et al. 2012) and double-periodic variables (Mennickent, 2017) have been discovered in the past few decades thanks to ultra-precise space-based photometry and long-term survey data.

1. 2. SOLVING INDIVIDUAL BINARIES

The contribution of our group to the studies of binary stars is in analyzing, or as it's customary to say, "solving" individual objects.

The first step in this process is to gather observational data. We work first and foremost with multicolor CCD photometric observations, or light curves, folded in phases according to the orbital period (see Figure 1). For a complete characterization of most binary stars, it is also necessary to observe them spectroscopically and construct radial velocity curves. Radial velocity curves can be fitted with a simple Keplerian two-body model to determine with good precision the mass ratio, eccentricity and maximum separation of the stars, all of which are key for measuring the masses and sizes of the components in Solar units.

With mass ratio and orbital separation fixed, we typically proceed to construct a detailed mathematical model of the system. By fitting the synthetic light curves calculated from the model to the observations, we can determine the other important orbital and stellar parameters of the system, such as the orbital inclination, temperatures of the stars, their masses and sizes. A more detailed look at the model follows in the next section.

In the three decades since the founder of our group, dr Gojko Djurašević, started to work in the field of binary stars, we have published the results of analysis for more than 85 individual binary stars in more than 50 research papers. And most of this work was done using software tools that we develop and maintain ourselves.

2. OUR MODELING SOFTWARE

The binary system modeling software that we use the most in day to day research was created by dr Gojko Djurasevic in the nineties (Djurašević, 1992a; Djurašević et

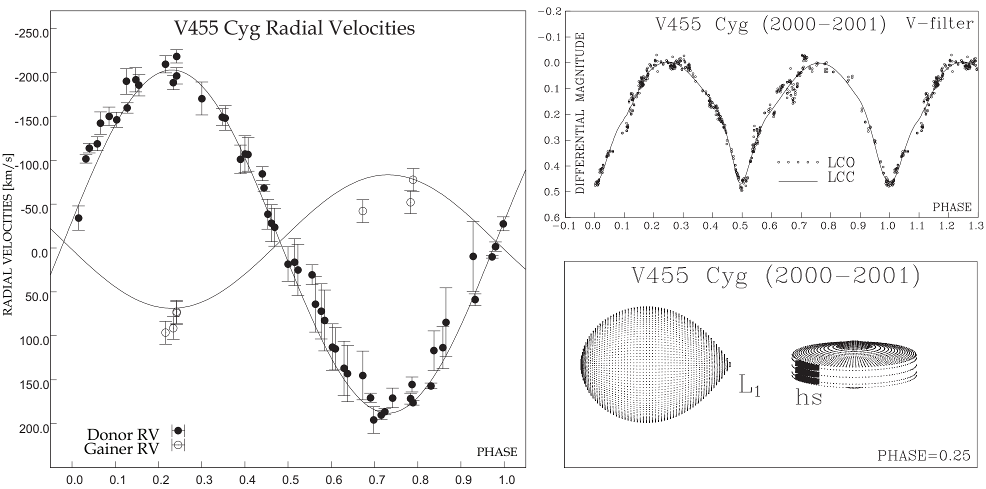

Figure 1: Radial velocities (left), light curve (top right) and geometric configuration (bottom right) of V455 Cyg, a massive, close binary with a geometrically and optically thick accretion disk that completely obscures the gainer. Points indicate observations, and solid lines represent the model. From Djurašević et al. (2012).

al. 1998). It is based on the Roche model, promoted in studies of binary stars by Kopal (1959). Initially the software was not principally different from the popular Willson-Devinney code (Wilson & Devinney, 1971). However, it has been in constant development since its inception, and presently has several unique capabilities, among which the ability to model accretion disks around one of the system components has proven to be the most sought-after feature in various collaborations. Another important feature of this software is its speed in solving the direct problem (constructing synthetic observables such as light curves based on given parameters) and the inverse problem (estimating parameter values by optimizing the fit of the synthetic observables to actual observations). Created during an era when every numerical operation was precious, this software is remarkably well optimized and executes in milliseconds on modern desktop computers.

Recently we made an effort to modernize the model and re-implement it as a new software tool called *Infinity* (Latković & Cséki, 2014). While based on the same principles as the original model, *Infinity* differs from it in several key points. It allows simultaneous fitting of light and radial-velocity curves, modeling of eccentric systems and modeling non-radial stellar oscillations on the components. These and other generalizations and improvements came at the cost of speed, however, and the original software remains our go-to modeling tool in most applications.

Some other directions in which we would like to expand the capabilities of our modeling are: modeling of various additional system components, such as the gas stream feeding into the accretion disk or falling directly onto the gainer; modeling of circumbinary structures, such as disks of escaped or infalling material. We would also like to add synthetic spectra and polarized light curves to the outputs of the model. These improvements require the combined expertise of the whole Stellar Physics Group and will be a part of our planned proposal for the next round of government funding.

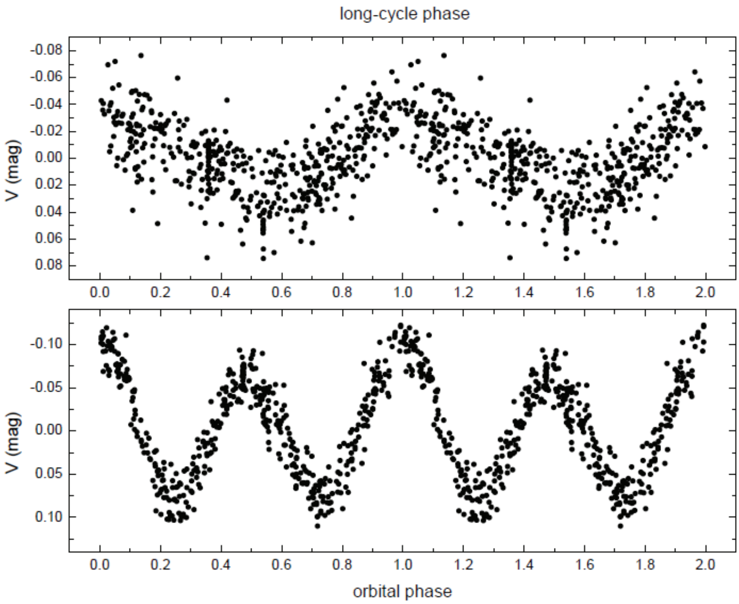

Figure 2: Disentangled ASAS light curves of the double-periodic variable HD 170582 folded with the long period (top) and the orbital period (bottom). From Mennickent et al. (2015).

Now I move on to the overview of two research topics that most of our recent work has been focused on: double-periodic variables, and contact binaries of W UMa type.

3. DOUBLE-PERIODIC VARIABLES

Double-periodic variables (DPV) are a recently discovered group of interacting binaries whose identifying characteristic is the existence of two photometric periodicities. The shorter periodicity, of the order of days, is due to the orbital motion of the two stars and in most cases it's easily recognizable from the eclipses or the ellipsoidal variation.

The longer periodicity, of the order of hundreds of days, is roughly 33 times longer than the orbital period for all discovered double-periodic variables and its origin has not yet been definitively established. Figure 2 shows the disentangled light curves of the double-periodic variable HD 170582 folded according to the orbital and long period.

Since their discovery it has gradually become clear that double-periodic variables are semidetached Algol type binaries of intermediate to high mass and low mass ratio; all the individually analyzed cases have proven to be in a phase of active mass transfer through an optically and geometrically thick accretion disk around the more massive star. Additional system components, such as the gas stream, a hot spot where the gas stream meets the accretion disk, winds or jets from the hot spot, have been detected in some of the well-studied systems. Our binary system model was crucial in establishing these properties of DPVs (Mennickent et al. 2012; Garrido et al. 2013; Mennickent et al. 2015; Garrido et al. 2016).

About 200 double-periodic variables have been detected in the Magellanic Clouds and of about 20 in our Galaxy. The number of known Algol type semidetached binaries is about 400, which suggests that the DPV phenomenon is a relatively long-lasting stage in the lifetime of a close binary. Yet there remains much about them that remains unexplained, such as the constancy of orbital period despite the active mass transfer, absence of chromospheric emission related to magnetic activity expected from the donor, and finally, the long cycle itself (Mennickent, 2017).

Several hypotheses have been explored in the attempts to explain the long cycle, and specifically, its enigmatic linear dependence on the orbital cycle. The latest, and the most promising, is that the long cycle is related to the magnetic activity of the donor star. Internal magnetic field can affect the structure and the shape of a star, and cause cyclic changes of the orbital period through spin-orbit coupling. This phenomenon is known as the Applegate mechanism (Applegate, 1992) and has been detected in many close binaries. In the case of double-periodic variables, the variation in the shape of the donor, specifically the increase in oblateness due to the Applegate mechanism, is suspected to cause periodic phases of enhanced mass transfer, which would lead to cycles of brightening and attenuation of the accretion disk and the hot spot, and create the long cycle (Schleicher & Mennickent, 2017). Although this theory awaits confirmation from studies of magnetic fields in double-periodic variables, the initial comparison of predicted and observed ratio of long orbital period from the orbital period looks satisfactory.

4. CONTACT BINARIES OF W UMA TYPE

W UMa stars are low mass, low temperature, short period contact binaries in one of the most extreme and least understood stages of binary evolution. Components of a close binary system may come in contact when the more massive (and thus more quickly evolving) star fills its Roche lobe during its normal post main sequence expansion, and deposits a large amount of material on its companion, which then in turn fills its own Roche lobe, so that a common envelope is formed. This stage binary of evolution follows the mass transfer phase such as we have with double-periodic variables (Yakut & Eggleton, 2005; Eggleton, 2006).

Light curves of W UMa stars are distinguished by continuous changes in brightness resulting from ellipsoidal variation, minima of nearly equal depths, and maxima that are not always symmetric due to the presence of dark spots that arise from magnetic activity typical for late type stars (see Figure 3). Many of these systems have variable orbital periods, either due to the action of the Applegate mechanism, or to the whole system being a component of a wider binary.

Among other properties that make W UMa stars attractive subjects for photometric studies, such as the short orbital period which means it is possible to observe the entire light curve in only a few nights, and the existence of a period-luminosity relation that makes them a useful distance indicator (Rucinski, 2004), possibly the most interesting is that their mass ratios can be inferred even in the absence of complementary spectroscopic data (Terrell & Wilson, 2005). This is a trivial consequence of the Roche geometry: in a contact system, both components are bounded by the same equipotential surface of the combined gravitational and rotational potential, and its shape is a function of the mass ratio.

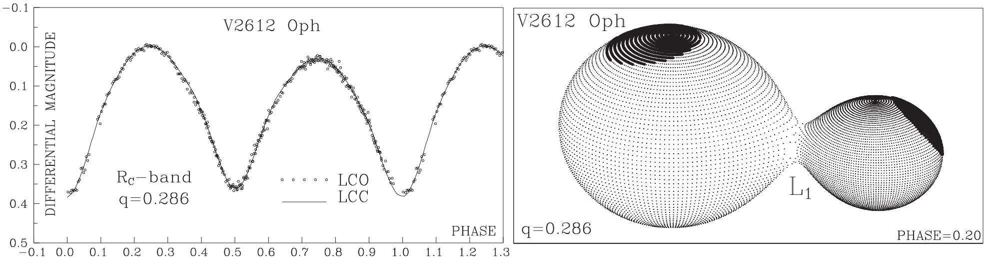

Figure 3: Light curve (left), and the geometrical configuration (right) of the spotted W UMa contact binary V2612 Oph. Points indicate observations, and solid lines represent the model. From Çalışkan et al. (2014).

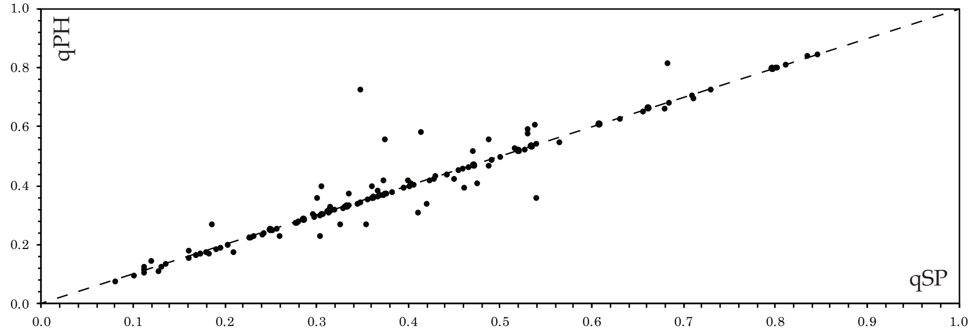

Figure 4: Relation of spectroscopically (qSP) and photometrically (qPH) determined mass ratios for a sample of around 100 well-studied W UMa stars. The dashed line indicates equality. The sample is discussed in Djurašević et al. (2016).

In terms of observables, the mass ratio of contact binaries can be estimated from the ratio of radii, which are measurable from the light curves. Mass ratios determined this way are most reliable for systems exhibiting total eclipses, but can be estimated regardless of inclination as long as the eclipses are present. Figure 4 shows a sample of about 100 well-studied W UMa stars with mass ratios determined both from spectroscopy and from photometry. Apart from several outliers, the photometric estimates typically do not deviate far from the spectroscopic measurements. The importance of this lies in the possibility to reliably characterize a contact binary from photometry only, a trait that earns contact binaries a special status in the context of amassing of unprocessed photometric data.

5. LOOKING FORWARD: AUTOMATED ANALYSIS

The volume of data already at the disposal of the binary star community is constantly increasing thanks to ongoing and future space missions and sky surveys. It has become obvious even before the advent of Kepler space telescope that studying individual objects “by hand” cannot keep up with the data accumulation rate.

And the community has been working out automated approaches. In their seminal work, the Kepler eclipsing binaries team used machine learning to automatically classify and derive basic parameters for the 3000 binaries in Kepler catalogue by fitting the light curves with parametrized chained polynomials (Prša et al. 2011). However, much of the work to make that result possible, such as fine-tuning the ephemerides, was still done by hand; and all the additions to the catalogue, from later quarters of the Kepler main mission and from the K2 mission, were also partly processed by hand (Kirk et al. 2016). A more recent example of successful automation is the work of Lee (2015a; 2015b), who used a simplified but fast-to-compute physical binary system model for automated light curve analysis of more than 3000 detached binaries identified in several surveys.

5. 1. AUTOMATED LIGHT CURVE ANALYSIS OF W UMA STARS

We plan to do something similar with W UMa stars identified in various light curve repositories. Where variability classification and a reliable orbital period are already provided, we can use our binary system model for automatic analysis.

Together with colleagues from the Mathematical Institute of the Serbian Academy of Sciences, we are developing a heuristic model optimization scheme that will be fast enough to process thousands of light curves, and at the same time robust enough to provide the most likely model parameters. Software tools for modeling binary stars solve the inverse probelm by minimizing the sum of squared residuals between the observations and model outputs; traditionally, this is done using the "greedy" optimization algorithms such as the gradient descent, implemented as part of the Willson-Devinney code (Wilson & Devinney, 1971), or the Marquardt-Levenberg method, implemented as part of our own modeling software (Djurašević, 1992b), that quickly converge to the closest local minimum which might not be the only or the best solution, and parameter correlations leading to degenerate solutions abound. Heuristics are one way to deal with this in the absence of a human operator who may use experience and intuition (for better or for worse) to choose between different models that fit the observations equally well. Coupled with a heuristic optimization method, our model can deliver the principal parameters of contact binaries, which can then be converted to absolute parameters (stellar masses and radii in solar units) using empirical calibrations, based on light curves alone. We hope to use these results to expand the existing sample of solved W UMa binaries by an order of magnitude.

5. 2. APPLICATIONS FOR MACHINE LEARNING

Machine learning techniques can be applied to tackle huge light curve repositories, such as WASP, where variability classification and periods are not provided. Automated period determination could also be applied in relation to a previous topic, namely for detection of double-periodic variables, since many of the ongoing surveys collect long-cadence, long-term data well suited for discovering cyclic phenomena with periods of the order of years.

Were only just embarking on this multidisciplinary research adventure and it is hard to predict how much time and effort it will take to get to first results, but we are excited and looking forward to the challenges ahead.

6. CONCLUSION

The Stellar Physics group at the Astronomical Observatory of Belgrade has a long tradition and a great deal of experience in observational studies of close binary stars. We have our own modeling tools that can handle a wide diversity of objects and complex phenomena. Recently, our work has mainly been focused on double-periodic variables and W UMa contact binaries, but now we are considering automated classification, period determination and modeling in order to keep up with the accumulation of observational data from ongoing and future space- and ground-based surveys.

Acknowledgment

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EMISSION NEBULAE: STRUCTURE AND EVOLUTION – A BRIEF REVIEW OF THE RESULTS

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Abstract. We describe in this paper some of the most important results achieved by the researchers who participate in the project "Emission nebulae: structure and evolution", financed by the Ministry of Education, Science, and Technological Development of the Republic of Serbia. Most of these results pertain to the radio and hydrodynamical evolution of the supernova remnants (SNRs), to the appearance of their radio-spectra in continuum, to the computation of the equipartition of the energy density of the magnetic field and of the energy density of the ultra-relativistic particles and to the optical detection of emission nebulae in nearby galaxies. In addition, we also present the results of other very interesting and important research, more or less connected to the process of charged particle acceleration at collisionless shocks in Space.

1. INTRODUCTION

Since its beginning, the project "Emission nebulae: structure and evolution", that is supported by the Ministry of Education, Science, and Technological Development of the Republic of Serbia, has gathered researchers from several different institutions: the Department of Astronomy at the Faculty of Mathematics of Belgrade University, the Astronomical Observatory of Belgrade, and the Physics Department at the Faculty of Sciences of the University of Novi Sad. Our group consists of the following members: Dejan Urošević (project principal investigator), Bojan Arbutina, Dragana Ilić, Tijana Prodanović, Branislav Vukotić, Dušan Onić, Milica Vučetić (maiden name Andjelić), Aleksandra Ćiprijanović, Marko Pavlović, Vladimir Zeković, Jovana Petrović and Petar Kostić. In addition, some of our dear foreign associates are M. Filipović (Western Sydney University), T. G. Pannuti (Department of Earth and Space Sciences, Space Science Center, Morehead State University, USA), D. Leahy (Department of Physics and Astronomy, University of Calgary, Canada), O. Salvatore (INAF Osservatorio Astronomico di Palermo), K. Stavrev and N. Petrov (National Astronomical Observatory Rozhen, Institute of Astronomy, Bulgarian Academy of Science, Bulgaria), Ü. D. Göker and E. N. Ercan (Department of Physics, Boğaziçi University, Turkey), I. Bojičić (Department of Physics, Macquarie University, Sydney), A. Moiseev and A. Smirnova (Special Astrophysical Observatory of the Russian Academy of Science), O. Egorov (Department of Radioastronomy, Lomonosov Moscow State University, Moscow), G. Zaharijaš (University of Nova Gorica), B. D. Fields (University of Illinois at Urbana-Champaign), V. Pavlidou (University of Crete), J. Beacom (Ohio State University), and many others.

The theoretical research, as well as the results obtained by the observations conducted by astronomers from our project and in cooperation with fellow colleagues from several different institutions from abroad, are mainly focused on emission nebulae, particularly on SNRs. This paper reviews some of the recent results of our investigations.

2. SUPERNOVA REMNANTS AS PARTICLE ACCELERATORS

Supernova remnants are formed after the so-called supernova explosion. In fact, a strong collisionless shock wave is created ahead of the ejected material from the supernova explosion. SNRs strongly influence the interstellar medium (ISM) through which they expand. On the other hand, the ISM has a great impact on their evolution. These spectacular objects are the most powerful Galactic sources of electromagnetic radiation (prominent at low as well as at high frequencies). A forward shock that spreads through the ISM, the compressed ISM and ejecta, the reverse shock, and in some cases pulsar and its wind nebula (plerion), are all sometimes visible, in the case of a relatively young remnant.

SNRs are responsible for the creation of cosmic-rays, so that they represent the most efficient particle accelerators in our galaxy, as well as in other galaxies throughout the Space (see e.g. Urošević 2014 for a review). Particles that repeatedly cross the powerful shock front (that moves through the ISM) can gain energy via the so-called first-order Fermi mechanism or diffusive shock acceleration (DSA) process (Fermi 1949; Bell 1978a,b; Blandford & Ostriker 1978; Reynolds, Gaensler, & Bocchino 2012). This is the most probable and efficient mechanism for a production of high energy particle ensemble in SNRs. It actually produces the non-thermal ensemble of charged particles which in the simplest test-particle case has a power-law energy distribution. The particle energy spectral index, derived from the theory is in a good accordance with the observations. It seems that SNRs are efficient particle accelerators possibly up to the so-called knee in the cosmic-ray particle spectrum.

2. 1. RADIO CONTINUUM EMISSION FROM SUPERNOVA REMNANTS

Whenever there are ultra-relativistic charged particles moving in the external global magnetic field we can expect a production of synchrotron radiation. In that sense, the radio-continuum spectra of SNRs are generally mainly shaped by the (non-thermal) synchrotron emission. For a standard value of the mean Galactic magnetic field (order of μG), GeV electrons are responsible for the observed synchrotron emission at higher radio-frequencies, and TeV electrons for X-rays.

The analysis of the integrated radio up to microwave continuum of SNRs is very important as any possible deviations from the known theoretical predictions can give us new insights into physics behind the observed radiation. Observational verification of several different theoretical models (such as non-linear particle acceleration effects in young SNRs, questions related to the significant intrinsic thermal bremsstrahlung emission from the SNRs expanding in a dense environment of molecular clouds, contribution of different dust emission processes linked to the SNRs, etc) rely on a good quality (reliable flux density estimates at so much as possible different continuum frequencies) of the high-frequency part of the radio, as well as the microwave continuum of SNRs (see the following papers for more details: Onić et al. 2012; Onić 2013; Onić 2015; Onić & Urošević 2015; Onić, Urošević, & Leahy 2017). This is connected with serious observational problems due to the transparency issues regarding the Earth's atmosphere. Recent observations of the microwave sky by the space telescopes such as *Wilkinson Microwave Anisotropy Probe* and *Planck Space Telescope* have opened a new window into the analysis of continuum emission from the SNRs.

For example, in the case of young SNRs, we expect that the effects of the non-linear DSA process can cause a concave up synchrotron spectrum (Reynolds & Ellison 1992; Jones et al. 2003; de Looze et al. 2017). Actually, a non-linear DSA theory predicts that the particle energy spectrum steepens at low energies and flattens at higher energies. To that end, we have analyzed the radio to microwave continuum emission of famous SNR Cas A. The results of this analysis show that the shape of the known spectrum of Cas A is very well represented by a simple model that includes the effects of the (non-linear DSA) synchrotron curvature, as well as of the thermal absorption at lowest radio-frequencies, and a simple, one-component thermal dust emission at the highest continuum microwave-frequencies (see Onić & Urošević 2015 for details).

Another example is related to the group of SNRs with flat radio-spectral indices. Generally, there are several possible explanations for such a flat radio-continuum spectra: significant imprints of the Fermi II (stochastic) acceleration mechanism, contribution of the secondary electrons left over from the decay of charged pions (if an SNR is interacting with a molecular cloud environment), simple thermal contamination, the intrinsic thermal bremsstrahlung radiation from the SNRs (see Schlickeiser & Fürst 1989; Ostrowski 1999; Uchiyama et al. 2010; Onić 2013 for more details about these explanations).

In Figure 1, the radio to microwave continuum of the mixed-morphology (Rho & Petre 1998) SNR IC 443 is shown. The thermal absorption, that is linked to the SNR (see Castelletti et al. 2011 for more details) is behind the low-frequency turnover. The results of the analysis also show that the thermal dust emission, as well as the apparent bump, possibly due to the spinning dust emission, very well explain the SNR's radiation in the analyzed frequency range (see Onić et al. 2017 for a detailed discussion; but see also Egron et al. 2017, for an alternative description).

Finally, we would also like to stress the importance of furthering our understanding of the dynamics and emission processes from the mixed-morphology SNRs, in general.

2. 2. EQUIPARTITION CALCULATION

It is apparent that magnetic field plays an important part in various related phenomena in ISM (collisionless shock-formation and compression, particle acceleration, radiation, etc). Each of the four forms of ISM (thermalized particles, cosmic-rays, radiation, and the magnetic field) contain similar energy density of about 1 eV cm^{-3} in the vicinity of the Sun. The determination of the magnetic field strength in the ISM is one of the most complicated tasks of modern astrophysics. In fact, only a few methods, that are very limited in their applicabilities, have been proposed so far.

Apart from the Zeeman effect and the so-called Faraday rotation, the equipartition or minimum energy calculation is a widespread method for estimating magnetic field strength and energy contained in the magnetic field and cosmic-rays by using only the radio-synchrotron emission of the, particular source (Pacholczyk 1970; Duric 1990; Govoni & Feretti 2004; Beck & Krause 2005). It should be noted that the

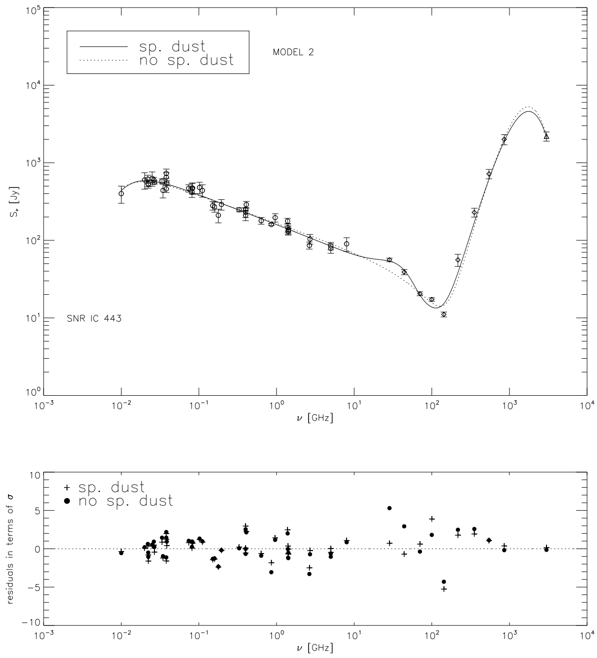

Figure 1: The weighted least-squares fit to the known, radio to microwave continuum, of the SNR IC 443 (taken from Onić et al. 2017). Solid line represents the fit when the so-called spinning dust emission is included in the model, while dashed line correspond to the fit without spinning dust emission, made for a comparison.

assumption of equipartition (constancy in order of magnitude) between the energy density of cosmic-rays and the energy density of magnetic field is, actually equivalent to the minimum energy requirement. Despite its approximate character, this method remains a useful tool, especially when there are no other estimates of a magnetic field.

Incorporating the theory of DSA process, a newly modified equipartition calculation for estimating magnetic field strengths and energetics in SNRs, with spectral indices in [0.5, 1] range is derived by our group (see Arbutina et al. 2012,2013 for a thorough description of a model and its application). In addition, the web application for calculation of the magnetic field strengths and energetics in the SNRs is created and is available for free usage[1].

2. 3. SIMULATIONS

The physical justification of the equipartition between the energy density of cosmic-rays and the energy density of magnetic field is usually questioned. On the other hand, the new results of our group, based on the 3D hydrodynamic simulations of SNR evo-

[1] Available at `http://poincare.matf.bg.ac.rs/~arbo/eqp/`.

lution, coupled with a non-linear DSA model of particle acceleration and accompanied magnetic field amplification (MFA), seems to suggest, that (equi)partition between cosmic-rays and magnetic fields really does exist, in all but the youngest SNRs (see Urošević, Pavlović & Arbutina 2017 for much more details).

Our simulations also provide the evidence that evolved SNRs, at the end of the Sedov phase of evolution, especially those embedded in a rarefied ambient medium, can maintain equipartition similar to those in the ISM (see Figure 2). In that sense, SNRs are likely responsible for maintaining the known equipartition between cosmic-rays and magnetic fields in the ISM. In addition, we can say that the equipartition is a physically justified assumption especially between the cosmic-ray electrons and the magnetic fields in evolved SNRs, in the Sedov phase of evolution. In that sense, the equipartition between the electron component of cosmic-rays and magnetic field can be used for calculation of the magnetic field strength directly from observations of synchrotron emission from SNRs.

In Figure 2, the results of our simulations, for two representative SNRs, one expanding in the high-density environment (HB 3), and another spreading in the rarefied medium (G1.9+0.3), are presented. In our future work, we will extend the analysis to a much larger sample of SNRs.

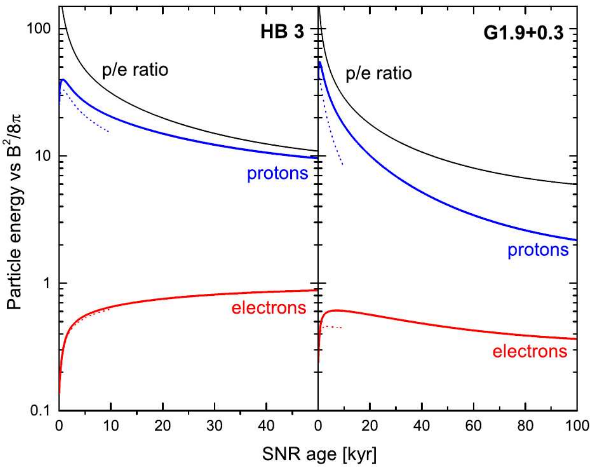

Figure 2: Temporal evolution of the ratio between cosmic-ray proton (electron) kinetic energy density and magnetic field energy density at the SNR shock front, represented with thick blue (red) lines. Dotted lines represent previous ratios in the case when Alfén drift is included in numerical model. Simulation parameters are carefully tuned to reproduce current observational properties of the two particular SNRs, namely SNR HB 3, evolving in dense medium and the youngest known Galactic SNR G1.9+0.3, evolving in a rarefied medium. We also give the ratios between proton and electron kinetic energy densities during the lives of the SNRs (thin black line).

In addition, the radio evolution of the youngest known Galactic SNR G1.9+0.3 is investigated by using the 3D hydrodynamic modeling and non-linear kinetic theory of cosmic-ray acceleration in SNRs (see Pavlović 2017 for much more details). The current age of the SNR is estimated to be slightly over 120 yr. It expands in an ambient medium of number density of around 0.02 cm^{-3}. Our numerical model predicts increasing radio-emission from the SNR during the free expansion phase, reaching its maximum value around the age of 600 yr, and then decreasing during late free expansion and in the beginning of Sedov phase. Interestingly, it seems that we are currently witnessing approximately the fastest radio-emission increase than it will ever be. In addition, the steep radio-spectral index (steeper than linear DSA theory prediction of 0.5) for this, young SNR is explained only by the means of efficient non-linear DSA process and accompanying strong MFA. Finally, in a light of a new γ-ray observatories, we show that it may be visible in TeV γ-rays by future instruments including the *Cherenkov Telescope Array*.

3. COLLISIONLESS SHOCKS AS PARTICLE ACCELERATORS

Collisionless shock waves are very important phenomena as they represent the places of a particle acceleration in Space. The SNRs are linked to the collisionless shock waves that expand through the ISM. The formation of such a shock wave, particle acceleration and magnetic field amplification are coupled processes and we do not fully understand the physics behind these phenomena yet (Nikolić et al. 2013). Our group is interested in these issues, particularly in possible resonant microinstabilities that trigger such colissionless shock-formation and evolution (Zeković 2017).

We are not just interested in the SNRs but also in some other, more exotic candidates for significant particle acceleration sights in the Universe. These include the so called tidal cosmic-ray population, formed by the tidal shock waves that result from the galactic interactions. Furthermore, the existence of hypothetical structure-formation cosmic-rays, produced by the large-scale accretion shocks during the process of large-scale structure-formation is also part of our research (see Fields, Pavlidou & Prodanović 2010; Prodanović, Bogdanović & Urošević 2013 for more details).

Galactic interactions and mergers have been known to give rise to the tidal shocks and disrupt morphologies especially in the smaller of the interacting components. These shocks can also heat the gas and dust and will inevitably accelerate charged particles and result in a so-called tidal cosmic-ray population, in addition to standard galactic cosmic-rays. Both, tidal heating and additional non-thermal radiation will affect the so-called far-infrared (FIR) to radio correlation of these systems (a well-established empirical connection between a continuum radio and dust emission of star-forming galaxies, that is often used as a tool in determining star-formation rates). We were interested to check the hypothesis that the FIR-radio correlation is not stable in interacting galaxies, but rather evolves as the interaction/merger progresses. From the analysis of a sample of 43 infrared bright star-forming interacting galaxies at different merger stages, we have found that the FIR-radio correlation parameter and radio-emission spectral index vary noticeably over different merger stages and behave as it would be expected from our hypothesis (see Donevski & Prodanović 2015 for much more details).

We would also like to mention that our researchers are involved in some other investigations that will not be further elaborated here (see Dobardžić & Prodanović 2014,2015; Ćiprijanović 2016,...). For instance, some of them include very interesting topics in γ-ray astronomy, as well as in nucleosynthesis of light, primordial, elements

(D, Li) (that is part of the COST action project ChETEC – Chemical Elements as Tracers of the Evolution of the Cosmos).

4. $\Sigma - D$ RELATIONS AND RADIO OBSERVATIONS OF SUPERNOVA REMNANTS AND PLANETARY NEBULAE

From the very beginning of our project, we have been interested in the study of the theoretical and empirical radio $\Sigma - D$ relations for the SNRs. This research is important for understanding the evolution of the synchrotron radiation from SNRs and related phenomena occurring at collisionless shock waves. Additionally, this kind of a relation is often used for determining distances to SNRs in the Milky Way (Shklovsky 1960).

The $\Sigma - D$ relation depends on different properties of the supernova explosion (the explosion energy, mass of the ejected matter), as well as on the properties of the the ISM (density, magnetic field strength, etc). One of the main drawbacks of this relation is the severe data scatter, that basically occurs due to the spread in the relevant parameters, in addition to the measurement uncertainties and selection effects.

We have applied a robust analysis of the collected data sample for the calibration of empirical radio $\Sigma - D$ relation, with various fitting methods. Our Monte Carlo simulations verified that the slopes of the empirical $\Sigma - D$ relation should be determined by using the so-called orthogonal regression, because of its good performances for data sets with severe scatter (see Urošević et al. 2010; Pavlović et al 2013,2014; Bozzetto et al. 2017 for more details).

The random resampling for reconstruction of the probability density function (PDF) of ($\Sigma - D$ relation) calibration data points in the fitting plane was also applied by our researchers. The resulting PDF can be used to estimate distance-related properties. This PDF-based method for calibration can provide more accurate and more reliable calculations than those obtained by standard linear fitting procedures (see Vukotić et al. 2014 about this new PDF-based method for distance calibration without using standard fitting procedures).

Furthermore, we have analyzed the impact of ISM structure on the slope of the radio $\Sigma - D$ relation assuming the fractal ISM structure. It has been found that the empirical radio $\Sigma - D$ slopes, being steeper than the ones derived from theory, might be partly explained with the fractal structure of the ambient medium into which the SNRs expand (see Kostić et al. 2016 for more details).

The $\Sigma - D$ relation for the SNRs, as a useful distance determination tool, can be significantly improved if the radio-evolution is better understood. Numerical simulations should provide a better understanding of underlying physics and explanation of the observed statistical properties (see Pavlović et al. 2017 for a detailed discussion and new results).

In addition to the $\Sigma - D$ relation for the SNRs, we were also interested in the theoretical and empirical radio $\Sigma - D$ relation for planetary nebulae. We have derived both theoretical and calibrated the empirical $\Sigma - D$ relation for different samples of planetary nebulae (see Urošević et al. 2009; Vukotić et al. 2009,2014; Leverenz at al. 2017 for more details).

Finally, we participate in the overall, detailed theoretical interpretation of the particular observations of the emission nebulae (i.e. from the Magellanic clouds and from our own galaxy), which are performed by our colleagues from the Western Sydney University in Australia. The analysis of the shape of the radio-continuum spectrum and position of the SNR in the so-called $\Sigma - D$ diagram, complemented with the calculation of the magnetic field strength, enables us to determine the evolutionary status of a remnant (see also Payne et al. 2008; de Horta et al. 2012; Bozzetto et al. 2012a,b; de Horta et al. 2013; Bozzetto et al. 2013, 2014a,b; Crawford et al. 2014).

5. OPTICAL OBSERVATIONS OF EMISSION NEBULAE IN NEARBY GALAXIES

The researchers from our project are also interested in the optical observations of the emission nebulae in the nearby galaxies (such as the nearby spiral galaxy IC 342, Holmberg IX dwarf galaxy, dwarf galaxy NGC 3077, elliptical galaxy NGC 185, etc). The most of our observations were conducted by the 2m RCC-telescope at the National Astronomical Observatory (NAO) Rozhen in Bulgaria. Furthermore, members of our group participate in a joint project of the Serbian Academy of Sciences and Arts and the Bulgarian Academy of Sciences called "Optical search for supernova remnants and H II regions in nearby galaxies (M81 group and IC 342)". In addition, we are also engaged in the collaboration with colleagues from Turkey, regarding the observations of galaxies NGC 1569, NGC 6946, IC 1613 with 1.5m telescope of Tübitak National Observatory. Our plans, for the near future, include the observations by the so-called Milanković telescope at the Astronomical Station Vidojevica in Serbia. Finally, we have recently participated in the long slit spectroscopic observations of emission nebulae in NGC 185 with our Russian colleagues, as a complement to our previous photometric observations. The observations were conducted using the 6m telescope of Special Astrophysical Observatory of the Russian Academy of Sciences.

The actual search for new SNRs and H II regions (candidates) is often based on the analysis of optical observations with narrow band [S II] and Hα filters (see Arbutina et al. 2009; Andjelić 2011; Andjelić et al. 2011; Vučetić et al. 2013, 2015b for a thorough discussion). It is known that optical spectra of SNRs have elevated [S II] to Hα emission line ratios, as compared to the spectra of normal H II regions (Matonick & Fesen 1997; Blair & Long 2004). This emission ratio has been used to differentiate between shock heated SNRs (collisional excitation inducted by shocks) and photoionized nebulae. Of course, the Balmer-dominated SNRs, which are thought to be related to type Ia supernovae, will be missed by optical searches using this [S II]/Hα criterion.

As the star-formation in nearby galaxies can be mapped at high-resolution, even with small telescopes, besides the identification of new emission nebulae, we are interested in the star-formation rates (SFRs), derived from Hα flux. It is very important to eliminate Hα flux contaminants when calculating SFRs from Hα emission. We have analyzed the contribution of the Hα flux from the SNRs to the total Hα flux and its influence on the derived SFR. The average SNR contamination to the total Hα flux and derived SFRs for a particular set of nearby galaxies (18 of 25 galaxies with optically detected SNRs, excluding the Milky Way) was found to be around 5% (see Vučetić et al. 2015a for more details). Due to the observational selection effects, the SNR contamination of SFRs obtained represents only a lower limit.

6. CONCLUSIONS

As we have already mentioned earlier, the researchers participating in the project "Emission nebulae: structure and evolution", supported by the Ministry of Education, Science, and Technological Development of the Republic of Serbia, have achieved many interesting results related to different phenomena in the ISM of Milky Way and nearby galaxies, and to processes of particle acceleration at collisionless shocks in Space. We plan to continue our ongoing research and to extend the list of our existing collaborators in the future.

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DYNAMICS AND KINEMATICS OF CELESTIAL BODIES AND SYSTEMS

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Abstract. The most important results achieved and published by the participants in the project "Dynamics and Kinematics of Celestial Bodies and Systems" from 2011 to 2017 are presented. The results are numerous and significant, they cover the following four fields: dynamics of Solar-System minor bodies, observations of double and multiple stars and analysis of orbital motion, kinematical properties of stars from the solar neighborhood and photometric observations of WEBT objects and morphology of quasars.

1. INTRODUCTION

Project No. 176011 "Dynamics and Kinematics of Celestial Bodies and Systems" is financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia. In its realisation the following researchers have taken part: Dr. Rade Pavlović, Dr. Zorica Cvetković, Dr. Goran Damljanović, M. D. Jovanović (joined the project in April 2015), Dr. Zoran Knežević (first leader of this project, retired in August 2016), Ivana Milić Žitnik, Dr. Slobodan Ninković (retired in August 2017), Dr. Milan Stojanović and Dr. Nataša Todorović from the Astronomical Observatory in Belgrade, Prof. Dr. Mike Kuzmanoski (retired in October 2011), Dr. Bojan Novaković and Dr. Dušan Marčeta (joined the project in January 2017) from the Faculty of Mathematics of the Belgrade University. During the project realisation three PhD theses were defended: B. Novaković, N. Todorović and M. Stojanović, whereas one thesis is very near its completion (I. Milić Žitnik). Between 2011 and 2016 the project participants published 47 papers in prestigious international journals. The project research comprises the following topics: dynamics of small solar system bodies, observations of double and multiple stars and analysis of orbital motion, statistical investigation of local kinematics of our Galaxy in solar neighbourhood and astrometry and photometry of quasar and Whole Earth Blazar Telescope (WEBT) objects.

2. DYNAMICS OF SMALL SOLAR SYSTEM BODIES

Most of our research of this topic in the period of the project realisation has been devoted to the various problems of asteroid dynamics and to the identification, interpretation, age determination and study of dynamical and physical properties of individual asteroid families.

The discovery of new small Solar System bodies in the images taken by modern wide-field surveys has been made more efficient by introducing an algorithm to first identify observations belonging to known Solar System objects and remove them for the observation files (Knežević and Milani 2012, Milani et al. 2012). This is an attribution problem that occurs when a well constrained least squares orbit already exists for the object and the new data are sparse. The new algorithm introduces quality metrics to control biases in the astrometric residuals which arise from the stellar catalogs used in the reduction of asteroid observations. It has been shown that a simple debiasing with regional catalog biases removed significantly improves the results. The attribution algorithm was tested using data from the PanSTARRS-1 survey that relied on the 2MASS star catalog for the astrometric reduction. Small but statistically significant biases of up to 0.1 arcsec have been found in the data. The false attribution rate was $< 1/1000$, while the attribution efficiency is rated as consistent with 100 %.

To cope with the problem of rapidly increasing number of asteroids with accurate orbits in asteroid family classification, a new approach combining the Hierarchical Clustering Method (HCM) with a method to add new members to existing families has been proposed (Milani et al. 2014). By first segmenting the problem and selecting from the catalog a smaller number of large asteroids, a number of core families is identified; to these the next layer of smaller objects is attributed. Next, all the already identified family members are removed from the catalog, and the HCM is applied to the rest. This provides satellite families of the previously found cores, as well as the new independent families consisting mainly of small asteroids. These two cases are discriminated by another step of attribution of new members and by merging intersecting families. The resulting initial classification contained 128 families and 87,095 members. The membership is then increased automatically with each update of the proper elements catalog; changes in the list of families occur more seldom, while only once in a while it is necessary to repeat the whole classification procedure from the scratch.

The results from the classification are then analyzed, using information on asteroid physical properties, in particular albedos and color indexes. This allowed us to solve some difficult cases of families overlapping in the proper elements space, and to obtain information on the geometrical properties of the family forming impact events. The families formed by one or more cratering events turned out to be more numerous than previously believed, and some examples of cratering families (Massalia, Vesta, Eunomia) were analyzed, which show internal structures interpreted as multiple collisions.

In the subsequent papers (Knežević et al. 2014, Milani et al. 2016), the operation of the automated attribution of newly numbered asteroids has been demonstrated, and the inclusion of the multiopposition asteroids into the classification procedure described. Enough evidence was found to perform 9 mergers of the previously independent families. Also, using by an improved method of estimation of the expected family growth in the less populous regions (e.g. at high inclination) reliable decision was possible on rejection of one tiny group as a probable statistical fluke. Thus the current list is reduced to 115 families.

Asteroid family ages (Spoto et al. 2015) have been determined by a new rigorous method, consisting of a least squares fit of the two sides of a V-shape, formed by a size dependent non gravitational Yarkovsky drift, in the proper semimajor axis, inverse diameter plane. An advanced error model for the uncertainties of asteroid diameters, an iterative outlier rejection scheme and quality control were also applied, and the best available Yarkovsky measurement was used to estimate a calibration of the Yarkovsky effect for each family. The results are presented separately for the families originated in fragmentation or cratering events, for the young, compact families and for the truncated, one-sided families. For all the computed ages the corresponding uncertainties are provided. The ages of several families have been estimated for the first time, in other cases the accuracy of the estimate has been improved.

The results were as follows: ages for old families were successfully determined, some useful results were obtained for young and ancient families, however, a little evidence was found for primordial ones. In two cases two separate dynamical families were found to form a single V-shape with similar slopes, thus indicating a single collisional event, while in three cases dynamical families were shown to be formed in multiple collisional events: for these different slopes for the two sides of the V-shape resulted in distinct ages. Two families exhibit a conspicuous subfamily, such that it was possible to determine the slope of a distinct V-shape, thus the age of the secondary collision. The family ages were derived with a uniform methodology, thus they could be compared among different families, providing a first example of collisional chronology of the asteroid main belt.

Additional 10 collisional ages were estimated for 9 families for which for different reasons the previous attempts failed (Milani et al. 2017). In general, these are difficult cases that required dedicated effort, such as a new family classifications for asteroids in mean motion resonances, in particular the 1/1 and 2/1 with Jupiter, as well as a revision of the classification inside the 3/2 resonance. Asteroid families affected by secular resonances and those infested by interlopers were also considered. Overall, 53 ages for a total of 49 families were computed.

Two papers (Paolicchi & Knežević 2016, Paolicchi et al. 2017) were dedicated to revealing the footprints of the YORP non gravitational effect in asteroid families, which manifest itself as a depletion of objects ("YORP[1] eye") in the central part of the family, visible in the absolute magnitude vs. semimajor axis V-plot. Not all the V-plots exhibit the expected depletion, thus the concept of the YORP eye and a general method of analysis have been introduced to tackle the problem. It is shown that the effect may sometimes be located in the low H tail, and thus difficult to detect. Moreover, it may be hindered by several anomalous physical properties of the family (asymmetry, cratering origin, multiple collisions history and so on). With a new method of analysis, the footprints of the effect are clearly identified for most of the analyzed families, obtaining also an independent estimate of their ages. A very good agreement was obtained between these ages and those estimated on the basis of the Yarkovsky slopes of the V-plot – a result which supports both methods and the underlying physics.

[1]YarkovskyO'KeefeRadzievskiiPaddack effect

For the strongly asymmetric families, for which it is difficult to assess the existence and location of a YORP eye, a special "mirroring tool" technique has been developed and applied in combination with the age determination method. The results show that the mirroring tool can, in some cases, be satisfactorily effective. A better calibration against the results obtained by means of other techniques proved to be necessary, including the age determination techniques based on the analyzis of the size dependent Yarkovsky–driven family spreading in semi-major axis.

In Novaković et al. (2015) it was reported on the significant role of a so far overlooked dynamical aspect, namely, a secular resonance between the dwarf planet Ceres and other asteroids (Figure 1). They demonstrate that this type of secular resonance can be the dominant dynamical factor in certain regions of the main asteroid belt. Specifically, a dynamical analysis of the asteroids belonging to the (1726) Hoffmeister family was performed. To identify what kind of dynamical mechanisms are actually at work in this part of the main asteroid belt, i.e. to isolate the main perturber(s), they study the evolution of this family in time. The study is accomplished using numerical integrations of test particles performed within different dynamical models. The obtained results reveal that the post-impact evolution of the Hoffmeister asteroid family is a direct consequence of the nodal secular resonance with Ceres. This leads us to the conclusion that similar effects must exist in other parts of the asteroid belt. In this respect, the obtained results shed light on an important and entirely new aspect of the long-term dynamics of small bodies. Ceres' fingerprint in asteroid dynamics, expressed through the discovered secular resonance effect, completely changes our understanding of the way in which perturbations by Ceres-like objects affect the orbits of nearby bodies.

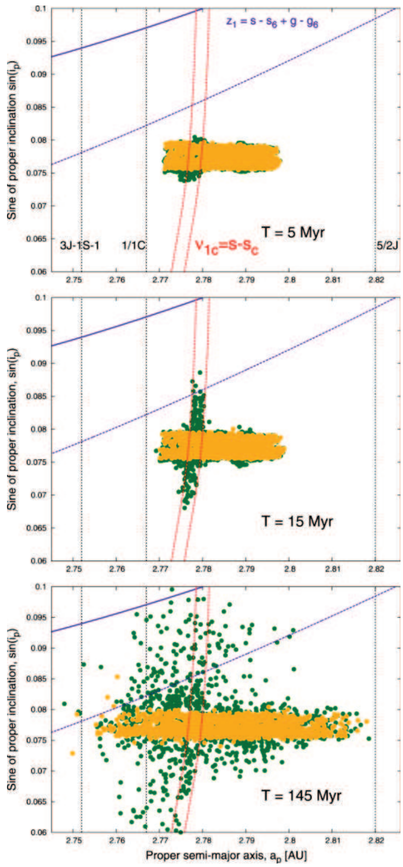

Figure 1: Evolution of the Hoffmeister family in the space of proper orbital elements. The three panels show the distribution of the test particles after 5, 15, and 145 Myr of the evolution, from top to bottom, respectively. The orange dots represent the evolution of the particles within the dynamical model that includes the four giant planets, from Jupiter to Neptune, and accounts for the Yarkovsky effect. The dark green dots show the evolution when Ceres is added to the previous model.

More detailed consideration of the role of the dwarf planet Ceres on the secular dynamics of the asteroid main belt could be found in Novaković et al. (2016). Specifically, they examine the post impact evolution of asteroid families due to the interaction of their members with the linear nodal secular resonance with Ceres. First, they find the location of this resonance and identify which asteroid families are crossed by its path. Next, they summarize their results for three asteroid families, namely (1726) Hoffmeister, (1128) Astrid and (1521) Seinajoki which have irregular distributions of their members in the space of the proper elements, indicative of the resonance effect. They confirm this by performing a set of numerical simulations, showcasing that the perturbing action of Ceres through its linear nodal secular resonance is essential to reproduce the actual shape of the families.

In Milić Žitnik and Novaković (2015), two specific characteristics of the Phocaea region were studied. The first was the presence of the secular resonances involving the inner planets. The results show that some of these are present, and relevant for the dynamics of asteroids in this region. The most important seems to be the $s-s_4+g_3-g_7$ resonance. The second one was the role of the 7/2 mean motion resonance with Jupiter as a border of the region in terms of semimajor axis. In particular, they check whether or not this resonance could be crossed under the combined influence of gravitational and non-gravitational forces. The obtained results show that a significant fraction of test particles successfully transit across the resonance, without being removed from the region. Moreover, they found that most of the asteroids below a few hundred meters in diameter should be able to cross the 7/2 resonance. This means, despite being relatively effective in pumping up asteroid eccentricities in this region, that this resonance is not an absolute dynamical boundary. More details can be found in Milić Žitnik (2018).

Using sophisticated numerical methods, very precise stability maps for some parts of the Solar System could be produced. In this methodology, using the so-called Fast Lyapunov Indicator (FLI), a quick and efficient chaos detection tool was introduced in the late 90s. The first application FLI to the Solar System using this method was performed in Todorović and Novaković (2015) where they mapped the region of the asteroid family, Pallas. They identified not only the most important resonances in the domain, but also many weak resonances such as the 1–1 mean motion resonance with the dwarf planet Ceres or the secular resonance nu_6 whose presence in the Pallas region was not detected in the earlier studies. Also, they have tested how the choice of initial orbital angles affects the computed maps.

The same methodology was applied to the 5:2 mean motion resonance with Jupiter in Todorović (2017). The computation time of the maps was significantly shortened, which enabled the detection of chaotic structures inside the resonance. We have observed the so-called normally hyperbolic invariant manifolds, often identified as natural transportation routes in the Solar System. In order to verify this hypothesis, some test particles along the structures were chosen and their orbital evolution was tracked over 5 million years. As many as 99.5 % of the particles interacted with the resonance and migrated close to the Earth. Let us mention that in the earlier studies the rate was below 10 percent. A large fraction of particles was removed from the Solar System by an unknown direction defined by a perihelion distance line close to $q \sim 0.26$ AU whose origin is still unexplained. And finally, we have counted the test bodies reaching the orbit of the asteroid Phaethon, the parent body of Geminides meteor showers and observed that 5:2 mean motion resonance (MMR) – Phaethon dynamical link is several times stronger than the previous results which was confirmed through the high transportation efficiency of the observed structures.

3. OBSERVATIONS OF DOUBLE AND MULTIPLE STARS AND ANALYSIS OF ORBITAL MOTION

Binary stars have been studied for decades for the purpose of accurate determination of stellar masses, verification of the evolutionary models and star formation theories. Washington Double Star Catalog (WDS)[2] contains data for more than 120,000 star pairs, but only for a small fraction of them (about 2%) there are orbital solutions. Because of this, as many as possible new observations of double stars should be performed.

With CCD observations it is not possible to resolve systems with small separation between the components. Closer pairs are monitored using high angular resolution techniques such as speckle interferometry, adaptive optics, etc. Wide stellar systems have large orbital periods in general. For many of them there are few observations, the observations over a short orbital arc or they have a low accuracy. Our programme is to observe such pairs. In the framework of the collaboration between the Bulgarian Academy of Sciences and Serbian Academy of Sciences and Arts our joint research project "Investigation of visual double and multiple stars" was started in 2012. This collaboration has enabled us to utilise in addition to our telescopes at Vidojevica, also the 2 m telescope at NAO Rozhen. In this period more than 25,000 CCD frames were obtained. This resulted in the publishing of five measuring series of double and multiple stars Cvetković et al. (2011, 2015, 2016 i 2017) and Pavlović et al. (2013). All our results (measurements) have been included in the WDS Catalog.

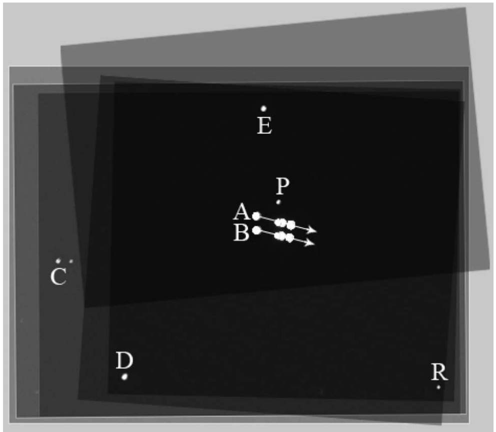

Figure 2: CCD frames of the multiple system ADS 48 are overlapped in order to have at the same position images of the components C, D, E, P, and R for which the configuration is invariable. The motion of pair AB in the view field is clearly seen; the direction and sense are indicated by the arrow.

Newly purchased very quick EMCCD Andor iXon 897 camera (Pavlović et al. (2018), in this publication) will be use as a part of the equipment for the speckle-interferometric technique of observing double stars with separations less than 1 arcsec. But, for the beginning it will be utilized for obtaining frames by applying lucky imaging.

We examine the dependence of correlation coefficients of orbital elements on the length of the orbital arc covered by measurements, on measurements of different accuracies, and on the number of measurements. The obtained correlation coefficients for the orbital elements are found to decrease with the orbital arc length covered by measurements, they are independent of the measurement precision, and they do not depend on the number of measurements for long arcs and they decrease with the

[2] `http://www.astro.gsu.edu/wds/`

number of measurements for short arcs. In addition, we plan to use this for developing a new method to compute the orbit grades.

We discuss the software developed for the purpose of determining the relative coordinates (position angle and separation) for visual double or multiple stars. It is based on application of Fourier transforms in treating CCD frames of these systems. The objective was to determine the relative coordinates automatically to an extent as large as possible. In this way the time needed for the reduction of many CCD frames becomes shorter. The capabilities and limitations of the software are examined. Besides, the possibility of improving is also considered. The software has been tested and checked on a sample consisting of CCD frames of 165 double or multiple stars obtained with the 2 m telescope at NAO Rozhen in Bulgaria. The results have been compared with the corresponding results obtained by applying different software and the agreement is found to be very good.

Using the measurements obtained by us from the CCD observations at NAO Rozhen (NAOR) and Astronomical Station Vidojevica (ASV) we have calculated the first orbits and masses for about 20 binaries and more than 30 linear solutions were presented for the first time. These orbits have been included in the Sixth Catalog of Orbits of Visual Binary Stars[3] and the linear solutions have been included in the Catalog of Rectilinear Elements[4]. Two linear elements, X_A and Y_A, are used to calculate the velocity V of relative motion of the secondary with respect to the primary. We can calculate the relative proper motion, $\mu_{\rm rel}$, for the same pairs by using the proper motion in right ascension and the proper motion in declination. Then, we can compare the proper motion $\mu_{\rm rel}$ with the values of the relative velocity, V, for all components in linear solutions. An agreement between them is an argument in favour of pairs not being gravitationally bound, i. e. they are optical pairs.

Also, we studied an interesting multiple system, ADS 48, using the data obtained at the Astronomical Observatory of Belgrade between 1994 and 1996, and at Rozhen and at the Vidojevica Station during the last eight years. Our aim was to establish which of the seven components are gravitationally bound, i.e. have an orbital motion around the mass center, and which of them are mutually very distant in space so that only their projections are close in the field of view. The detailed analysis of the system ADS 48 is given in the paper Cvetković et al. (2012a). The conclusions combined with the criteria based on celestial mechanics lead us to the following: i) within the system ADS 48 only stars A and B are gravitationally bound (Figure 2); ii) component F has common proper motion with A and B, but is not bound to them; iii) all the other components considered here form optical pairs with AB.

During the autumn of 2011, we observed the same objects at both NAOR and ASV. We noticed that the measured separations ($\rho_{\rm NAOR}$, $\rho_{\rm ASV}$) differ for the same pairs of stars and the differences increase with increasing angular separation. Therefore, we measured the angular separations between the images of stars visible in our CCD frames. The separation depends on the angle corresponding to one pixel, i.e. the focal length of the telescope. We determined the focal length of the 60 cm telescope at the ASV and for the 2 m NAOR telescope more precisely. The differences are relatively small: of the order of 1.4%. For pairs of stars with angular separations smaller than 10 arcseconds, the differences are approximately equal to measurement

[3] `http://www.astro.gsu.edu/wds/orb6.html`

[4] `http://www.astro.gsu.edu/wds/lin1.html`

errors. Our observational programme of double and multiple stars contains mainly pairs with angular separations less than 10 arcseconds and therefore small deviations in separations resulting from inaccurate telescope focal length could not be previously noted. Much more about determining the focal length of the 60 cm telescope at the ASV more is given in the paper Cvetković et al. (2012b), and for the 2 m NAOR telescope in the paper Cvetković et al. (2013).

4. KINEMATICAL PROPERTIES OF STARS FROM THE SOLAR NEIGHBORHOOD

The Galactocentric orbit of a Milky Way star is obtained by applying the Lagrange equations. If, as usually, for the Milky Way potential the axial symmetry is assumed, the motion of a star can be described by solving the following two differential equations

$$\ddot{R} - J_Z^2/R^3 = \frac{\partial \Pi}{\partial R} \tag{1}$$
$$\ddot{Z} = \frac{\partial \Pi}{\partial Z}.$$

The designations are: Π - potential, R - distance to the symmetry axis, $|Z|$ - distance to the symmetry plane, J_Z - component of specific angular momentum ($J_Z = \mathrm{const}$).

In oder to solve system of equations (1) one needs the potential. The most favourable situation is if the potential is given analytically. Then the system is solved numerically (by applying a well known procedure). Since the steady state is also assumed, the energy conservation can serve for the purpose of algorithm control.

Since the Milky Way has a composite structure, its potential should be given as a sum of the contributing potentials. Each contributing potential is due to a subsystem of the Milky Way. Very often as relevant subsystems the bulge, the disc and the dark halo are assumed.

In the case of the bulge the flattening may be neglected, i. e. the spherical symmetry is sufficient. There exists the problem of a cusp within the core. A general mass distribution involving different possibilities for the cusp has been proposed (Ninković 2014).

In the case of the disc the Miyamoto-Nagai formula has been usually used. However, as incompatible with the exponential model (almost generally assumed for the disc), this formula requires to be modified. In the framework of our project two modifications were proposed (Ninković 2015, 2017a).

In the case of the subsystem formed by the dark matter the spherical symmetry has been generally adopted.There exists the problem of cuspy core versus almost constant density one. A discussion comprising this topic wherein a specific mass distribution with a core of almost constant density is proposed can be found in Ninković (2017b).

Each contributing potential contains some constants referred to as parameters. The consequence is that the total number of parameters for a potential consisting of three components is not small. The values adopted for the parameters are related to the values of the quantities known as Milky Way constants (Galactocentric distance of the Sun, Oort constants, etc.). The values of these constants are known within some limits. Therefore, their varying can be of interest. However, in the case of a mass distribution model which may contain almost 10 parameters, the varying procedure is not simple. In addition, the numerical procedure used in the orbit determination also requires time. Fortunately, if a star of the thin disc is considered, then the Galactocentric orbit is simply described (e. g. Stojanović 2015). In other words, the orbital eccentricity becomes the principal orbit parameter. It can be simply related to the assumed quantities where the $A/|B|$ ratio (A and B are the Oort constants) is the most influential parameter (Ninković 2011). In this way it becomes possible to determine the orbital eccentricity (also $R_\odot/R_m$, R_m is arithmetic mean between extremal distances) for many stars of the thin disc within a rather short time in the conditions of varying $A/|B|$ (Stojanović 2015).

With the simple formulae derived by Ninković a new formula which explains the ratio of the mean squares of the random velocity for thin disc stars has been obtained. It contains the old formula (usually referred to as epicyclic one) as its special case. A brief description of the new formula is given in Ninković (2018).

5. PHOTOMETRIC OBSERVATIONS OF WEBT OBJECTS AND MORPHOLOGY OF QUASARS

From the begining of the project, CCD observations of quasi stellar objects (QSOs) visible in the optical domain were started in accordance with the tasks of the astrometric mission Gaia. QSOs, as one type of objects with active galactic nuclei (AGN), having a compact radio and optical core, without complex structures and stable flux, are of interest to Gaia. This is the reason for monitoring such QSOs in the optical domain, and to follow the changes of their morphology and photometry over time. The position stability of QSOs depends on the structures and photometry of QSOs and it makes the morphology and photometry investigations of these objects very important for astrometry and astrophysics. These observations are used for construction of the relation between radio and optical reference systems. The observational results concerning AGN objects can be used to study their physical features. Our observations are part of a more general project of astrophotometric and astrophysical studies of extragalactic radio sources for the purpose of obtaining more reliable reference systems.

In the framework of the PhD thesis by M. Jovanović the observations on three telescopes were initiated: ASV 1.4m and 60cm and 2m RCC Rozhen NAO BAS are used. The very first results can be found in Jovanović et al. (2018).

6. CONCLUSIONS

Here a brief summary of the results achieved by the participants of project No. 176011 in the period 2011–2017 is presented. We shall continue the research in all the four fields mentioned above, and it is planned to include new participants in the project.

For the future we plan to procure an additional CCD detector and new optical equipment which, together with the existing Andor iXon ultra 897 CCD camera, would be attached to the 1.4 m telescope "Milanković" and enable us to begin speckle interferometric measurements at the Astronomical Station Vidojevica.

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SPECTROSCOPY AND SPECTROPOLARIMETRY OF AGN: FROM OBSERVATIONS TO MODELLING

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Abstract. Active galactic nuclei (AGN) are one of the most luminous objects in the Universe, emitting powerful continuum and line emission across all wavelength bands. They represent an important link in the investigations of the galaxy evolution and cosmology. The resolving of the AGN inner structure is still a difficult task with current instruments, therefore the spectroscopy and spectropolarimetry are crucial tools to investigate these objects and their components, such as the properties of the supermassive black hole, the broad line region, and the dusty torus. In this review, we present the results of the project "Astrophysical spectroscopy of extragalactic objects", from the observations, data processing and analysis, to the modelling of different regions in AGN.

1. INTRODUCTION

Active galactic nuclei (AGN) are in the focus of the modern astrophysical investigation, since it is widely believed that all galaxies had at least one phase of high activity (AGN phase) in their life-time. Moreover, the AGN feed back huge amount of energy into surrounding medium, which may have influence on all scales, from the host galaxy to the intergalactic medium. Therefore, it is important to understand the structure of AGN and their radiation processes.

AGN host in their center super-massive black hole (SMBH) which is actively fueled by gas through the accretion disk. The accretion disk is emitting the X-ray continuum (and also Fe Kα line) that is a powerful source of radiation which ionize the surrounding gas. The ionized gas that is very close to the central SMBH emits broad emission lines (with full width at half maximum - FWHM of > 1000 km s^{-1}), that is called the broad line region (BLR), whereas the ionized gas far from the center emits narrow lines (FWHM < 1000 km s^{-1}), and consequently it is called the narrow line region (NLR). The BLR sometimes can be obscured by the dusty torus-like region, depending on the orientation of the system. Using the obscuration as a criterion, we can divide AGN into two classes: the type 1 AGN (the BLR is not obscured), which show the broad and narrow emission lines in the UV/optical/IR spectra, and type 2 (the BLR is obscured) AGN, which have only narrow emission lines. Even though we know the general model of these objects, there are still many open questions. Some important ones are: i) what is the structure and kinematics of the BLR; ii) how to estimate the mass of the central SMBH, iii) are there present and how to detect binary SMBH, iv) what is the structure of the dusty torus, and many others. In order to answer these, the spectroscopic and spectropolarimetric observations can give us great insight into these hidden regions.

The investigation the AGN structure using spectroscopy, spectropolarimetry and other methods/effects (simulations, gravitational milli- and micro-lensing, etc.) have been a subject of the project "Astrophysical spectroscopy of extragalactic objects" (P.I. L.Č. Popović), that was accepted in 2010, and has been funded (until the end of 2017) by the Ministry of Education, Science and Technological Development of Republic of Serbia. In our research we try to fix some questions given above and here we give an overview of recently obtained results.

2. LONG-TERM OPTICAL MONITORING OF AN AGN SAMPLE

AGN show high variability in their spectra, that can be used to probe the kinematics and physics of the BLR by comparing the variability of the continuum and broad emission line fluxes. Therefore we performed the long-term optical monitoring campaign of several type 1 AGN, whose broad emission lines have different spectral characteristics: Seyfert 1 galaxies (NGC 5548, NGC 4151, NGC 7469), Narrow-line Seyfert 1 galaxy - NLSy 1 (Ark 564), double-peaked line radio loud (3C 390.3) and radio quiet (Arp 102B) galaxy, and a luminous quasar (E1821+643). Additionally, we explore variability of two AGN in spectro-polarization: 3C390.3 and Mrk 6. The spectral observations were done with six telescopes based at four different observatories: the Special Astrophysical Observatory (SAO) of the Russian Academy of Science in Russia (1-m and 6-m telescopes), the Guillermo Haro Astrophysical Observatory in Mexico (2.1-m telescope), the Observatorio Astronomico Nacional at San Pedro Martir in Mexico (2.1-m telescope), and the Calar Alto Observatory in Spain (3.5-m and 2.2-m telescopes). The spectro-polarimetric observations were performed with 6m telescope of the SAO using the modified spectrograph SCORPIO.

To study AGN, we use reverberation mapping that uses temporal fluctuations of the central continuum source, and the subsequent response of the BLR emission. The time delay between the continuum and the broad line fluctuations provides an estimate of the size of the BLR, and can also be used to estimate the black hole mass. Our reverberation mapping measurements of the radius of the BLR are based on the Z-transformed Discrete Correlation Function and procedures that model the statistically likely behavior of the light curves in the gaps between observations (e. g. JAVELIN, Gaussian process regression-GP). These procedures were applied on the continuum and line flux light-curves of our objects. We used either observed or simulated light-curves to get the most reliable result (see Kovačević et al. 2014b, 2015). Our reverberation measurements are included in the AGN Black Hole Mass Database (http://www.astro.gsu.edu/AGNmass/) hosted at Georgia State University, USA. It contains all AGN with published spectroscopic reverberation mapping results in the refereed journals.

Any tool describing the AGN variability has to handle irregular sampling and measurement errors in observed light curves, in order to produce physical results. Since AGN light curves are too sparsely sampled to resolve day variability, using simple linear interpolation between data points are impossible. Linear interpolation also incorrectly assumes that there is no uncertainty associated with the interpolation process or the measurements. For these reasons, we model the AGN continuum light curve using a stochastic model of AGN variability, such as Gaussian process (GP) regression, allowing us to evaluate the light curve at arbitrarily small timescales. The ability of GP is demonstrated in Fig. 1 (see Shapovalova et al. 2016 for details) where the flares become clearer in the GP light curves then in the observed curves alone. We also introduced GP for determination of periodicity in AGN light curves (Kovačević et al. 2017).

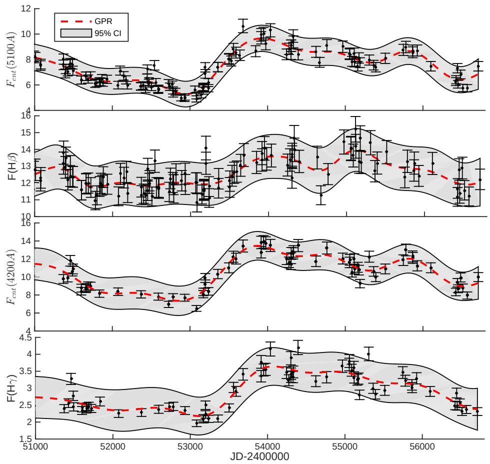

Figure 1: GP best fit (dashed line) to the observed light curves (dots with error bars) of the continuum at 5100 Å, Hβ, continuum at 4200 Å and Hγ (from top to bottom) in quasar E1821+643. The shaded band represents the 95% confidence interval (CI) for the GP predicted curve (Shapovalova et al. 2016).

The spectral data have been presented and analyzed in Shapovalova et al. (2001, 2004, 2008, 2010a, 2010b, 2012, 2013, 2016, 2017), Popović et al. (2008, 2011, 2014) and Afanasiev (2014, 2015). Some of the important results in this part are: i) published online spectral data (line and continuum fluxes obtained using uniform procedures) from several decades of monitoring for seven type 1 AGN; ii) estimated the size of the BLR and the mass of the SMBH; iii) the BLR is probably of a disk-like shape, but with complex structure, in the sense that the single geometry cannot explain the whole BLR (e.g. outflows or hot-spots are present, etc.). Also, the BLR is mainly heated by the photoionization from the central source, but other mechanisms may be present, which is seen in the lack of correlation between line and continuum fluxes; iv) it seems that polarization region in AGN is smaller than we expected. A short review of these investigations and a comparative analysis of the results are given in Ilić et al. (2015, 2017).

One important part of these investigations was the analysis of the long- term light curves of different emission lines and continuum searching for periodicities (Bon et al. 2012, 2016, Kovačević et al. 2017).

3. SUPER-MASSIVE BINARY BLACK HOLES

Long term observations can indicate some type of variability in the continuum and line flux which has quasi-periodical (see Shapovalova et al. 2010b), or periodical behavior (see Bon et al. 2012, 2016, Shapovalova et al. 2016, Kovačević et al. 2017). This periodicity can be caused by perturbations in the emission line region (see e.g. Jovanović et al. 2010), but also may indicate a presence of the SMBH binary system in the center of an AGN (for a review see Popović 2012).

The binary SMBH are expected to be in the center of some galaxies (Begerman et al. 1980, Gaskell 1983), and since they are a result of galactic mergers, they are probably surrounded by gas, therefore one can expect that one or both black holes in the system are accreting matter producing radiation similar to the AGN emission (Popović 2012). The observations of the binary SMBH is possible on kpc-scale (see e.g. Woo 2014), however on the distances between components of order smaller than pc it is not possible to resolve the components by available telescopes. Therefore the spectroscopy is the only way to detect the SMBH binary candidates.

Our investigations of the sub-pc SMBH binaries using spectroscopy have been performed in two directions: i) modeling the sub-pc SMBH binary systems in order to detect specific feature in the spectral lines and their shifts (Popović et al. 2000, Jovanović et al. 2014, Smailagić & Bon 2015, Simić & Popović 2016), and ii) exploring the long-term variability in the line shapes (Bon et al. 2012, 2016, Shapovalova et al. 2016; Kovačević et al. 2017). Note here that we made a discovery of the first spectroscopically resolved sub-parsec orbit of a SMBH binary (see Bon at al. 2012) that was obtained by investigating the long term monitoring spectra of NGC 4151. This investigations continued with a serious of papers where many other AGN appeared to show periodicity in their light curves (Bon et al. 2017, Kovačević et al. 2017, Marziani et al. 2017, etc.).

The main results that we obtained in this investigation are: i) there are indications in spectral variation (periodicity and line shape varriations) that in some AGN a SMBH binary can be present, especially in NGC 4151 where spectral variability can be explained by SMBH binary dynamics; ii) from modeling of the SMBH binaries, taking different parameters of a SMBH binary system, we concluded that the line shapes and shifts can indicate a SMBH binary, but the dynamical effect of a binary system can be hidden by other processes in the BLR.

4. AGN SPECTRAL CHARACTERISTICS: FROM THE UV TO THE MIR

As it was noted in the Introduction, basically AGN can be divided in type 1 (with broad lines) and type 2 (without broad lines). However, the spectral properties in a wide spectral range from the ultraviolet (UV) to the mid-infrared (MIR) can be quite different in type 1 AGN. As an obvious case is a difference between the narrow line and broad line Seyfert 1.

The investigation of the type 1 AGN spectral characteristics is important from two reasons: first is that the correlations between different spectral properties indicate some physical processes (Boroson & Green 1992); and second is to find some constrains and relationships between spectral characteristics and luminosity, in order to use quasars as standard candles (see e.g. Lusso & Risaliti 2017).

In our research of AGN spectral characteristics we started from the optical, exploring the relationships between the broad Balmer lines (mostly Hβ and Hα) and Fe II features around the Hβ (Kovačević et al. 2010, Popović & Kovačević 2011) as well between the ratios of Balmer lines and connection with the continuum (Ilić et al. 2012, Rafanelli et al. 2014, Rakić et al. 2017). The next step was to connect the spectral characteristics in the optical and UV (Kovačević et al. 2014a, Kovačević-Dojčinović & Popović 2015, Jonić et al. 2016, Kovačević-Dojčinović et al. 2017) and then to connect the spectral properties between the optical and MIR (Lakićević et al. 2017).

One of very important tasks in this part was to find the stellar population influence on AGN spectra. With this goal we developed a code for full spectrum fitting of AGN spectra (Bon et al. 2014, Bon et al. 2016) using ULYSS code (Koleva et al. 2009) - the code for stellar population analysis, that enable us to analyse simultaneously complex emission line models, Fe II pseudo continuum, AGN continuum and host galaxy. Using this code we investigated properties of Type 2 (see Bon et al. 2014) and some Type 1 AGN as well (see Bon et al. 2016, Marziani et al. 2017a).

Additionally, in type 1 AGN we can extract broad line profiles which are important for investigation of the BLR structure, especially an accretion disk contribution to broad emission line profiles (see e.g. Popović et al. 2004, Bon et al. 2006, Bon et al. 2009a, 2009b). We investigated the contribution of accretion disk emission using Hamburg-ESO (HE) sample of intermediate to high redshift quasars, that are some of the most luminous quasars known, hosting very massive black holes. We matched simulated relativistic ray tracing accretion disk profiles (see Jovanović 2012), with the optical emission Hβ broad emission line profiles from HE sample, selected to have centroids of line widths measured at 1/4 of maximum line intensity significantly shifted to the red, in order to investigate gravitational redshift in these spectra (see Bon et al. 2015).

The most important obtained results in this part are: i) we constructed a unique Fe II template in the optical and UV part of AGN spectra (an online program for Fe II fitting is available on SerVO site, see http://servo.aob.rs/FeII_AGN/); ii) we proposed a model for Balmer quasi-continuum in the UV part of AGN spectra and also find that the nature of the optical Fe II lines is different than the UV Fe II ones; iii) using polycyclic aromatic hydrocarbons (PAH) in the MIR we found that the division between type 1 and type 2 AGN using optical criteria does not follow the MIR characteristics; iv) we developed a code for fitting the stellar population simultaneously with the spectrum of an AGN (type 1 and type 2) that can be used in investigation of the characteristics of AGN emission and host stellar population.

5. EXPLORING AGN STRUCTURE: MODELING AND GRAVITATIONAL LENSING

One of the important way to explore the structure of AGN is by modeling their emission regions. In this part we developed a model of relativistic accretion disk around SMBH, and simulated its X-ray radiation in the Fe Kα line (see Jovanović 2012, and references therein). Comparisons between the simulated and observed Fe Kα line profiles were then used to determine the parameters of the relativistic accretion disk, such as inclination, emissivity, inner and outer radius, as well as the spin of the central SMBH (see e.g. Jovanović et al. 2011, 2016).

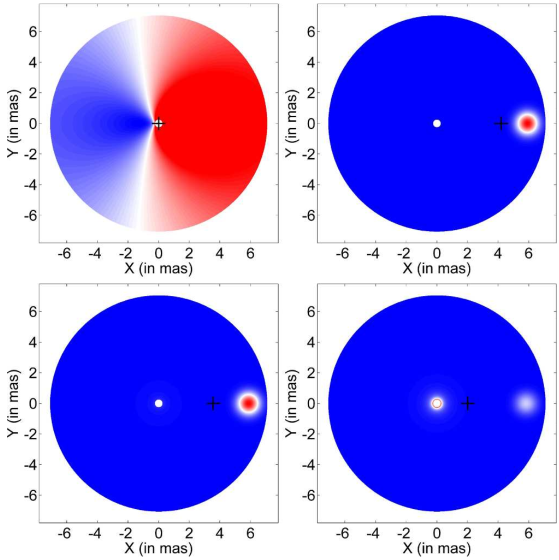

Figure 2: Photocenter positions (crosses) in the case of an accretion disk without (top left) and with perturbation (next three panels) for three different values of emissivity index (Popović et al. 2012).

The accretion disk model can be applied to the optical line emission, and comparing the observations and disk-models we demonstrated that the variability in broad line shapes can be explained by the hot-spot motion in the disk (Jovanović et al. 2010).

On the other hand, we also constructed a model for the dusty torus that was developed within SKIRT code, a state-of-the-art radiative transfer code based on Monte Carlo technique (Stalevski et al. 2011, Stalevski et al. 2012a), and explore the emission of the dusty torus with different physical parameters. More recently, dust emission models were used to study the relation between the ratio of the torus and AGN luminosities and the dust covering factor. This study (Stalevski et al. 2016) found that the observed luminosity ratio very often under- or overestimates the actual covering factor and provided a novel way to correct it and obtain the true values. In another recent study, the detailed modeling of the dust emission of the archetypal type 2 AGN in Circinus galaxy was performed, showing that contrary to the expectations, a major part of the dust emission is coming from the polar region, in a form of cone-like outflows (Stalevski et al. 2017).

The models of accretion disk (which emits in X-ray and optical) and dusty torus are used to explore some variability that can be seen in quasars, which is important for the Gaia reference frame (Popović et al. 2012). As an example of the photo-center variability we illustrate in Fig. 2 the displacement of disk's photo-center as a function of the bright spot emissivity.

The AGN central part model (disk+torus, described above) allowed us to explore gravitational lensing effects on the spectra of lensed quasars. Additionally we modeled milli- and micro-lens maps, and simulate the lens transition across the inner part of an AGN, modeling the spectral variations (Simić et al. 2011, Stalevski et al. 2012b, Popović & Simić 2013, Simić & Popović 2014). Also we performed observations of several lensed quasars with 6m SAO telescope in order to compare our models with observations (Popović et al. 2010)

In this part we can outline the following results: i) we developed a unique model for the AGN torus (note here that paper of Stalevski et al. 2012 has been cited more than 100 times); and a library of emission models of the AGN dusty torus is available online (https://sites.google.com/site/skirtorus/); ii) we give prediction for variation in the quasar position using the models from accretion disk to torus that is very useful for the Gaia reference frame; iii) we give predictions in spectral variation due to microlensing that can be used in the separation between the intrinsic quasar variation (see Section 2) and a microlensing event.

6. BLACK HOLE MASSES - MEASUREMENT AND VIRIALIZATION

As noted in the Introduction, it seems that the central SMBH has influence on the structure of host galaxy and its evolution. Therefore the measurement of SMBH masses in center of galaxies is a very important task in astronomy today. In difference with "normal" galaxies, galaxies with AGN in the center give us possibility to measure the mass of central black hole exploring the gas motion in the BLR. There are several direct and indirect methods for the black hole measurement (see review of Peterson 2014), among them the reverberation is one of the direct methods, but it is also telescope time consuming.

In this part, we worked in two directions: i) exploring the geometry and structure of the BLR using variability (see references in Section 2) and comparing virialization in different broad lines (Mg II and Hβ, see Jonić et al. 2016), and ii) exploring polarization in broad lines as a tool to measure the SMBH mass (Afanasiev et al. 2014, Afanasiev & Popović 2015, Savić et al. 2017).

To measure SMBH masses using polarization in the emission line we performed observations of a number of AGN with 6-m SAO telescope and we explore observed data to find black hole masses. Additionally, we did simulations using STOKES code (Goosmann et al. 2013) and find that the proposed method can give very good results (Savić et al. 2017).

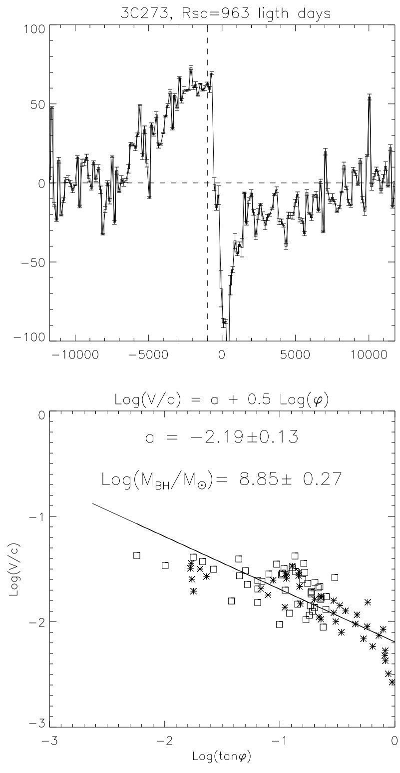

Figure 3: The polarization angle - PA observed in quasar 3C 273 (upper panel), and estimation of the black hole mass of quasar (bottom panel) as given in Afanasiev & Popović (2015).

The important results we obtained in this part is that we give a new method for AGN black hole mass measurements using the polarization in broad lines (illustrated in Fig. 3). The method can explore virialization in the BLR, and can be applied on the one-epoch observations (see Afanasiev & Popović 2015 for more details).

7. AGN GAMMA RAY EMISSION, GAMMA RAY BURSTS AND THEIR IMPACT ON THE LOW IONOSPHERE

The gamma ray radiation can be observed in objects with jets, as e.g. blazars, but also can be produced by exotic objects (as e.g. black hole collisions) which emit enormous gamma ray flux, known as gamma ray bursts (GRBs). Gamma ray emission is mostly connected with violent processes in the Universe, and has been the subject of investigation for the last several decades (after the lunching of gamma ray telescopes).

In this part we investigate the gamma-ray emission in blazars. First we explore the extraordinary gamma-ray activity of the gravitationally lensed blazar PKS 1830-211 (Donnarumma et al. 2011), finding also that this variability can be caused by microlensing (since the source of gamma radiation is very compact), that was a direct application of our AGN and lens models (see Section 5). Second, we explore flare-like variability of the Mg II emission line in the gamma-ray blazar 3C 454.3 (León-Tavares et al. 2013), connecting the Mg II emission variability and variability in gamma ray emission. It was interesting that we found a good correlation between gamma-ray and Mg II variability, indicating that Mg II originates from the jet.

To explore the origin of the gamma-rays in shock-waves, we developed a shock wave model and fit 30 GRBs (Simić & Popović 2012). We found some characteristics of GRBs, and divide them in two groups - short and long lasting GRBs.

A GRB emits the huge amount of energy that impacts the upper parts of Earth atmosphere, and this opens a question: how much a GRB can affect the Earth atmosphere, especially the low ionosphere? This was a subject of our research (Nina et al. 2015), and we found that GRBs perturb the low ionosphere, and its reaction is significant in a short period of several seconds after the GRB has been detected by satellites.

The most important results in these investigations are: i) we found that gamma ray emission in some AGN correlates with the broad Mg II line, this indicates that in some cases broad Mg II line is originated in the jet-like region, that it is not connected with the classical BLR – this should be taken into account when Mg II line is used for black hole mass measurements; ii) we found statistical significance that GRBs have influence on the ionosphere, since we found that reaction of ionosphere is several seconds after the GRB detection by satellites (this discovery was noted as 'research spotlight' in March, 2016, see https://eos.org/research-spotlights/gamma-ray-bursts-leave-their-mark- in-the-low-ionosphere).

8. SUMMARY AND FUTURE PLANS

Here we present the most important results of the spectro-polarimetric observations and modeling of different parts of AGN (accretion disk, BLR, dusty torus), obtained in the last several years. We also note, that beside the scientific part, the project was a base for worldwide collaboration and some research subjects were PhD and master thesis for several students. Additionally, we organized several workshops (see http://servo.aob.rs/eeditions/Workshops.php) and spectral line shapes conferences (see http://servo.aob.rs/scslsa11/).

Probably the project will finish at the end of this year or during the next one, but we are going to continue our activities in the field of spectroscopy of extragalactic objects. We are going to: i) continue with the monitoring of several broad line AGN in order to find the geometry and size of the BLRs and estimate SMBH masses; ii) continue with spectropolarimetric observations of several type 1 AGN in order to measure masses and find the inclination of the BLR; iii) develop models of AGN central part and gravitational lenses in order to explore the influence of milli- and micro-lensing to the spectra of lensed quasars; iv) explore spectral properties of type 1 AGN, including also X-ray emission, in order to find some relationships which can be used for cosmological investigations.

At the end let us note that we are included in the Large Synoptic Survey Telescope - LSST project (in scientific part for AGN investigation), that will give us opportunity to extend our investigations. Also, we are going to provide low resolution spectrograph which can be installed at 1.4m telescope Milanković, and can be actively involved in AGN monitoring campaign.

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SHOCK WAVES IN INTERSTELLAR GAS AND THE SOLAR CORONA

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Abstract. A shock wave is a sharp transition from supersonic to subsonic flow in a narrow interval. The shock transition in neutral gas occurs by means of collisions, and those collisions bring the gas to a new thermodynamic equilibrium. Shocks in plasmas are governed by electromagnetic fields and plasma turbulence, and they do not generally lead to thermal equilibrium. Electron, proton and ion temperatures can be very different, and the shocks can produce non-thermal velocity distributions, including cosmic rays or solar energetic particles. This paper will review observations of shocks in supernova remnants and the solar corona that indicate those non-equilibrium conditions.

1. INTRODUCTION

Shock waves in the Earth's atmosphere and in most textbooks are collisional. That is, they are jumps in the fluid velocity, density and temperature that occur over a narrow layer whose thickness is approximately the collisional mean free path. For most purposes, they are simply described by the Rankine-Hugoniot jump conditions, which give the changes in speed, density and temperature as functions of the ratio of shock speed to pre-shock sound speed, known as the Mach number, M. In the high Mach number limit, a strong shock compresses the gas by a factor of 4. The post-shock temperature of a strong shock depends on the mean mass of the particles, and for an ionized gas of typical astrophysical abundances it is about $1.4 \times 10^5\ V_{100}^2$ Kelvin, where V_{100} is the shock speed in units of 100 km/s. If the magnetic field strength is significant, these relations are modified to the magnetohydrodynamics jump conditions. Draine & McKee (1993) review astrophysical shocks.

While a collisional shock by definition is mediated by collisions and therefore maximizes entropy by establishing thermal equilibrium, the shocks in most astrophysical plasmas are collisionless. That is, the shock jump occurs by way of interactions between the particles and electromagnetic fields or turbulence over a scale comparable to the proton gyroradius or the ion skin depth, $\omega_{\rm pi}/c$, where $\omega_{\rm pi}$ is the ion plasma frequency and c is the speed of light. For typical ISM conditions of 1 cm^{-3} and 3 μG, the collisional mean free path is on the order of 3×10^{14} cm, while the collisionless shock thickness is around 10^8 to 10^9 cm.

A collisionless shock should still satisfy the Rankine-Hugoniot jump conditions, since those simply express conservation of mass, momentum and energy fluxes plus the perfect gas equation of state. However, there is no reason to expect thermal equilibrium in the sense of equal temperatures of different species, or even in the sense of Maxwellian velocity distributions. For example, a collisionless shock might thermalize a fraction (1-1/X) of the bulk velocity of each particle species entering the shock, where X is the shock compression ratio. Then, if there is no exchange of energy among the species, each species would have a thermal energy and temperature proportional to its mass, $T_\alpha = m_\alpha/m_{\rm p} \ \ T_{\rm p}$. Moreover, supernova remnant shocks produce non-thermal emission detected in the radio, X-ray and gamma-ray bands, indicating extreme departures from Maxwellian distributions at high energies. These power-law tails in velocity account for cosmic rays (CRs) and the synchrotron emission at the boundaries of supernova remnants (SNRs) seen in the radio and in some cases in X-rays. Shock waves in the solar corona and solar wind also accelerate particles, solar energetic particles, or SEPs, though not to such high energies. The acceleration is generally explained by diffusive shock acceleration (DSA), in which particles scatter between the shock and a precursor region of plasma turbulence, gaining energy with successive scattering events.

It is important to understand collisionless shocks for several reasons. These shocks seem to generate cosmic rays at least up to around 10^{14} or 10^{15} eV in SNRs, and the SEPs produced by shocks driven by coronal mass ejections (CMEs) can affect satellites and astronauts. These shocks produce radiation that affects the evolution and heating of the ambient plasma. And finally, it is necessary to understand how observable diagnostics are related to shock parameters to correctly diagnose shock conditions in order to understand the basic energetics and evolution of the events that drive the shocks.

One important distinction for the discussion that follows is between radiative and non-radiative shocks. A radiative shock converts some fraction of the flow kinetic energy into thermal energy. The gas then radiates that energy away, returning to roughly the initial temperature. Because the radiation is usually generated by electron-ion collisions, it occurs over a collisional scale, and the plasma is able to approach thermal equilibrium. Therefore, most signatures of the physical processes at the shock are erased, and the emission spectrum is dominated by the bright emission generated far downstream.

On the other hand, a non-radiative shock is one in which the radiative cooling time is long compared to the important dynamical time scales such as the supernova remnant age. In that case, radiative cooling does not affect the dynamics, and radiation from far downstream does not dominate the spectra. In particular, H I Balmer lines and UV lines of He, C, N and O are produced in a narrow ionization zone just behind the shock front, so these lines carry the signatures of the plasma processes in the shock itself.

2. SHOCK DIAGNOSTICS

Very different diagnostics are available for investigating shocks in the solar wind, shocks in the ISM and shocks in the corona. The first can be studied *in situ*, while those in the ISM and corona are observed with remote sensing techniques.

Solar wind: Shocks in the solar wind can be detected by spacecraft carrying instruments that directly measure particle velocity distributions and electromagnetic fields. This has the enormous advantages that the observed quantities are not smeared out over a range of shock conditions, that magnetic fields and plasma waves can be measured rather than inferred, and that complex non-Maxwellian velocity distributions can be measured in detail. Some limitations are that it can be difficult to determine the direction of the shock normal and that a single passage through a non-steady shock gives a snapshot that may be less useful than an average would be. Measurements by multiple spacecraft such as MMS can alleviate the difficulties, for instance in the study of whistler waves and non-thermal electrons (Oka et al. 2017). Another limitation is that shocks in the solar wind do not typically exceed Mach numbers of about 10, limiting the parameter space open to investigation. Measurements made *in situ* often have excellent time resolution, and they can cover a variety of particle species.

Solar Corona: Shocks in the solar corona have been observed for many years as type II radio bursts – bright emission in a narrow frequency range that drifts toward lower frequency as the shock propagates outward. A comprehensive review of solar radio emission is given by Pick & Vilmer (2008). Energetic electrons produced by the shock propagate through the plasma, forming an unstable bump-on-tail velocity distribution that can produce Langmuir waves at the electron plasma frequency, 9000 $n_e^{1/2}$ Hz. These waves, in turn, interact with low frequency waves or with other Langmuir waves to create radio waves at the plasma frequency or its harmonic, so the frequency gives the coronal density. Splitting of these bands has been interpreted in terms of the pre-shock and post-shock densities, which gives the shock compression. This can be combined with the shock speed and coronal density to estimate the coronal magnetic field (Vršnak et al. 2002; Mancuso et al. 2003).

Coronal shocks are also observed in white light with coronagraphs. With some modeling of the shape of the shock front, the intensity increase gives the compression (Ontiveros & Vourlidas 2009), and the standoff distance between the shock and the CME loops gives an estimate of the magnetic field strength (Gopalswamy & Yashiro 2011; Gopalswamy et al. 2012). The properties of the shock vary around its surface because both the shock speed and the strength of the perpendicular magnetic field change, so for instance the shock can have very different properties at the nose and on the flanks (Bemporad & Mancuso 2013; Susino, Bemporad & Mancuso 2015).

UV spectra of coronal shocks have been obtained with the UVCS instrument aboard the SOHO satellite (e.g. Raymond et al. 2000; Mancuso et al. 2002). The emission in the Lyα line dims, because H I atoms are accelerated and ionized, while Si XII emission brightens because of compression and ionization of lower silicon ions. O VI shows intermediate behavior, and its line width becomes larger as the kinetic temperature of oxygen increases. EUV images of coronal shocks have also been obtained with the AIA instrument aboard SDO. AIA bands corresponding to successively higher ionization states of iron brighten and dim as the iron is ionized, giving an estimate of the electron temperature (Ma et al. 2011).

Interstellar Medium: Non-radiative supernova remnant shocks are observed in the X-ray, optical and UV bands, though the optical and UV emission is rather faint. X-ray spectra give the electron temperature, and in some cases X-ray synchrotron emission reveals the population of non-thermal electrons. UV spectra give the line widths and kinetic temperatures of He, C, N and O. Shocks in partially neutral gas produce pure Balmer line optical filaments, and the two- or three-component profiles of the Hα line yield the proton kinetic temperatures, the post-shock electron

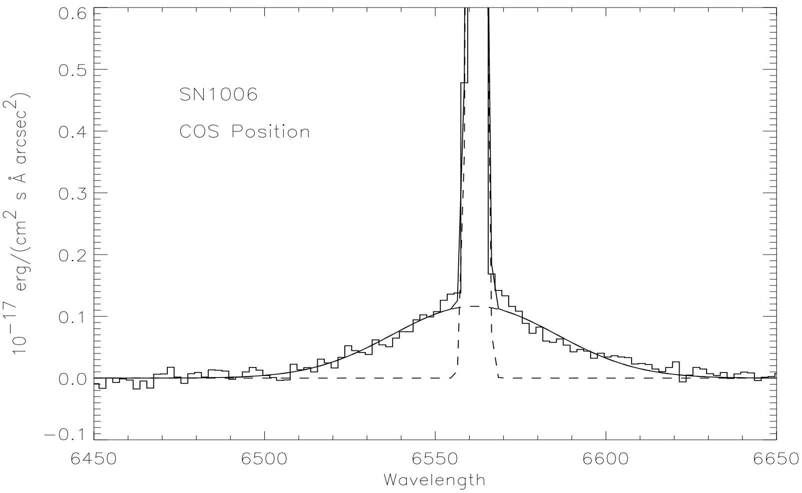

Figure 1: Two component profile of Hα from a 3000 km/s shock in SN1006 (Raymond et al. 2017). The narrow component is unresolved, while the broad component FWHM is 2600 km/s.

temperatures, and signatures of heating in shock precursors (Fig. 1). Radio and gamma-ray observations show high energy electrons and hadrons.

3. COLLISIONLESS SHOCK THEORY

A distinction is made between sub-critical and super-critical shocks. Sub-critical shocks are low Mach number shocks in which thermal conduction or viscosity can dissipate the energy in a smooth manner, while super-critical shocks rely on reflection of protons from the shock and streaming instabilities to produce plasma turbulence, and they are unstable. The critical Mach number depends on the angle between the magnetic field and the shock normal, and it can be up to 2.7. Treumann (2009) gives a comprehensive review of the physics of collisionless shocks.

Acceleration of cosmic rays and SEPs is a broadly important aspect of collisionless shock theory. It is a first order Fermi (1949) process in which particles are reflected from the shock itself and are scattered back to the shock by turbulence in a precursor region where streaming cosmic rays excite Alfvén waves or other modes. Blandford & Eichler (1987) review the analytic theory, which is known as Diffusive Shock Acceleration (DSA). The theory is appealing because a strong shock has a compression ratio of 4, and that gives a power law spectrum whose index is close to that measured in cosmic rays. An important question historically has been whether shocks that move parallel or perpendicular to the field accelerate particles more effectively. Quasi-perpendicular shocks accelerate particles quickly, but few particles are injected into the acceleration process, while the opposite is true for quasi-parallel shocks. Rippled shock structures or pre-shock fluctuations may combine the favorable aspects of both (Giacalone 2015).

Numerical investigations have extended the basic analytic theory. These include Monte Carlo and hybrid simulations that treat the protons as particles and the electrons as a neutralizing fluid (e.g. Ellison et al. 1996; Caprioli & Spitkovsky 2014). Particle-in-cell simulations treat both electrons and ions as particles, permitting self-consistent computation of the electromagnetic fields. (e.g. Sironi & Spitkovsky 2011). The results from kinetic models can be assimilated into analytic forms and then coupled with hydrodynamics codes to simulate SNRs (e.g. Slane et al. 2014).

4. ELECTRON-ION EQUILIBRATION

Early studies of shock waves assumed equal electron and ion temperatures behind shocks. Under that assumption electron temperatures, $T_{\rm e}$, derived from X-ray spectra were used to determine shock speeds and study SNR evolution. More recently it has become apparent that electron-ion equilibrium is a good assumption for slow shocks, but the proton temperatures, $T_{\rm p}$, are much higher than $T_{\rm e}$ in faster shocks.

In SNRs, this is seen in the Hα profiles of shocks in partially neutral gas. When hydrogen atoms and other neutrals pass through a collisionless shock they do not feel the effects of plasma turbulence or electromagnetic fields. Once they find themselves in the hot downstream plasma, they can be excited to produce Hα, they can be ionized, or they can undergo charge transfer reactions. Once they are ionized, they effectively become invisible. Those atoms that are excited before a charge transfer event produce Hα with a narrow velocity width corresponding to the pre-shock temperature, of order 10^4 K. On the other hand, roughly half the H atoms undergo charge transfer with post-shock protons, producing a population of H atoms with approximately the proton velocity distribution (Chevalier & Raymond 1978; Chevalier et al. 1980). Thus the proton temperature can be obtained from the width of the Hα broad component. The intensity ratio of the broad and narrow components depends on the relative rates of ionization and charge transfer, which in turn depends on $T_{\rm e}$.

Ghavamian et al. (2001, 2002) used that method to show that $T_{\rm e}/T_{\rm p}$ is about 1 in the 350 km/s shock in the Cygnus Loop, but only 0.4-0.5 in the $\sim$ 600 km/s shocks in RCW 86, less than 0.2 in Tycho's 2000 km/s shock and less than 0.07 in the 2500 km/s shock in SN1006. These trends are confirmed by comparing $T_{\rm e}$ determined X-ray spectra with the temperatures given by the Rankine-Hugoniot jump conditions and the shock speeds derived from proper motions and SNR distances for the Cygnus Loop (Medina et al. 2014) and SN1006 (Long et al. 2003).

In solar wind shocks, $T_{\rm e}$ and $T_{\rm p}$ can be measured directly, though there is considerable scatter in the ratio at any shock speed or Mach number. Schwartz (1988) found electron heating such that $T_{\rm e}/T_{\rm p}$ is around 0.2 in solar wind shocks. More extensive measurements are presented in Ghavamian et al. (2013). They show a strong trend of $T_{\rm e}/T_{\rm p}$ declining from close to 1 for very weak shocks to less than 0.1 for shock speeds above about 500 km/s or Mach numbers above about 10. The trend is similar to that observed in supernova remnants, but offset by about a factor of 3-4 in shock speed or 10 in Mach number, in the sense that the drop occurs at higher speeds in SNR shocks.

It is more difficult to determine electron and ion temperatures in shocks in the solar corona. Ma et al. (2011) observed a shock with AIA and used the ionization times of the Fe IX/X, Fe XII and Fe XIV that dominate several of the EUV bands to infer the electron temperature. The result suggested that $T_{\rm e}/T_{\rm p} \sim 0.25$. Also, UVCS

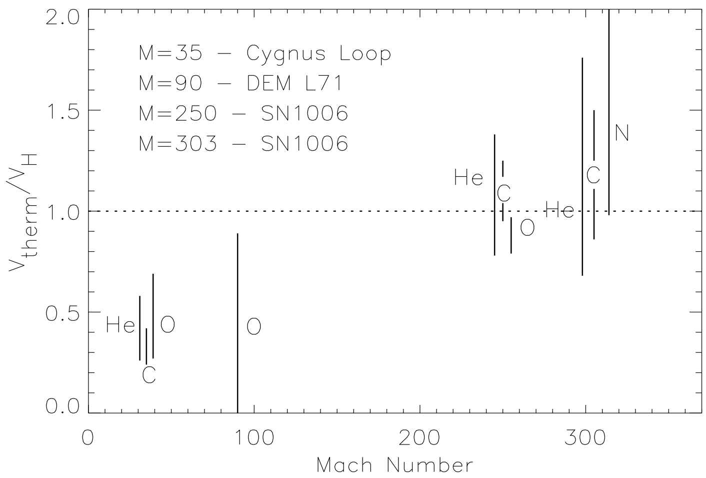

Figure 2: The ratios of the thermal velocities of He, C, N and O ions compared to those of hydrogen as a function of Mach number. The Cygnus Loop shock is close to thermal equilibrium, while both the SN1006 shocks are close to mass-proportional temperatures (Raymond et al. 2017).

spectra of coronal shocks generally show T_e/T_p or T_e/T_O less than one (Mancuso et al. 2002; Raouafi et al. 2004; Bemporad & Mancuso 2013; Bemporad, Susino & Lapenta 2014). The Mach numbers of these coronal shocks are modest, generally less than 2 or 3.

Although the electric field in the shock can play a role, efficient transfer of heat from protons to electrons requires some variety of plasma turbulence. Such turbulence can be effectively produced by two-stream instabilities between incident protons and protons reflected from the shock. The difficulty is that few wave modes can interact resonantly with both protons and electrons. Cargill & Papadopoulos (1988) proposed a two step process involving the Buneman and ion acoustic instabilities to heat the electrons to about 20% of the proton temperature. Lower-hybrid waves are able to interact with both protons and electrons, and Rakowski et al. (2008) show that LH waves in a cosmic ray-driven precursor could explain the observed decline of T_e/T_p with shock speed in SNRs.

5. ION-ION EQUILIBRATION

The temperatures of different ion species in SNR shocks can be measured from their line widths, which generally requires the observation of UV lines for comparison with the H I Balmer lines. Even modest reddening makes the UV lines too faint to observe. To date only the non-radiative shocks in the Cygnus Loop, DEM L71 in the LMC, and SN1006 have been observed (Raymond et al. 2015; Ghavamian et al. 2007; Korreck et al. 2004; Raymond et al. 1995, 2017). Figure 2 shows the thermal line widths of lines of He, C, N and O compared with the thermal width of hydrogen. The lowest Mach number shock, the one in the Cygnus Loop, shows thermal speeds consistent with $m_\mathrm{i}^{-1/2}$, which is to say that the temperatures are equal. The fastest shocks are those in SN1006, where all the velocities are consistent with the same value, meaning that $T_\mathrm{i} \propto m_\mathrm{i}$. In other words, there seems to be no exchange of energy among the different particle species in fast shocks, so the kinetic energy of each species is thermalized independently. The observational constraints are not extremely tight, however.

Only a few measurements are available for solar wind shocks. Berdichevsky et al. (1997) and Korreck et al. (2007) found that ions of He, C, O and Fe are preferentially heated in interplanetary shocks, that is the temperatures are more than mass-proportional. The heating depends on the upstream plasma β, the mass-to-charge ratio M/Q, and the angle between the shock and the magnetic field, but there is considerable scatter.

Ion-ion equilibration has received less theoretical attention than electron-ion equilibration because it is less crucial for diagnostic applications, though the post-shock proton temperature depends significantly on whether He and H equilibrate. Fuselier & Schmidt (1994) studied preferential heating of higher M/Q ions, whose larger gyroradii cause them to experience a larger potential change in the electric field of the shock. Zimbardo (2011) studied the reflection of heavy ions at a shock, finding that the reflected ions reached more than mass-proportional temperatures and that the distributions are highly asymmetric in the sense that $T_\perp > T_\parallel$.

6. PARTICLE ACCELERATION

Particle acceleration is one of the most important processes in collisionless shocks. The central questions are what fraction of the energy dissipated by a shock goes into energetic particles and how it is distributed among the particle species. The latter focuses on electrons vs. protons, but elemental abundance anomalies offer clues to the acceleration process and the location of the accelerating shocks.

One approach is to determine the shock speed from a proper motion and distance, then compare the thermal energy predicted by the jump conditions with the measured proton and electron temperatures. Salvesen et al. (2009) and Medina et al. (2014) applied this method to ∼350 km/s shocks in the Cygnus Loop and found that in some cases there was not even enough energy to account for the electron and proton temperatures, probably due to an underestimate of the distance. Hovey et al. (2017) studied two Balmer line SNRs in the LMC, taking advantage of the reliably known distance. They obtained upper limits of 7% of the energy of 1800 - 4000 km/s shocks going into non-thermal particles.

In both the Cygnus Loop and LMC SNR cases, the proton temperature was determined from the Hα profiles in Balmer line shocks, and it is expected that neutrals in the pre-shock gas will damp the plasma turbulence needed to scatter energetic particles. Also, neutrals formed by charge exchange can pass back through the shock, depositing energy and momentum upstream. These processes can limit the maximum particle energy, reduce the efficiency of CR acceleration and steepen the spectrum (e.g. Drury, Duffy & Kirk 1996; Ohira 2012; Morlino & Blasi 2016). The presence of neutrals can also provide fast particles for injection into the DSA process (Ohira 2106). The acceleration efficiency also depends on the Mach number (Blasi et al. 2005; Vink et al. 2010)

A key part of DSA theory is the turbulent precursor where particles are scattered back toward the shock jump. Heating in the precursor broadens the narrow component of the Hα line beyond the normal width of the ISM line (Hester et al. 1994; Sollerman et al. 2003; Medina et al. 2014), but the interpretation is complicated by heating due to neutrals that cross into the precursor from the downstream region (Morlino et al. 2012). The thickness of the precursor tends to be around $1''$, and it has been spatially resolved in Tycho's SNR (Lee et al. 2007) and the Cygnus Loop (Katsuda et al. 2016).

As far as shocks in the heliosphere, Giacalone (2012) found that essentially all interplanetary shocks with Alfvén Mach numbers above 3 produce energetic particles whose spectrum is consistent with the diffusive shock acceleration picture. Mewaldt et al. (2005) found that fast CMEs put about 10% of their energy into SEPs.

The composition of CRs and SEPs can show the effects of the Q/M depedendence of diffusive shock acceleration, but in the case of heliospheric shocks there are large variations in ratios such as Fe/O and in the abundance of ^{3}He. This is attributed to more efficient injection of suprathermal particles into the diffusive acceleration process and differences in the populations of these suprathermals in the solar wind (e.g. Tylka & Lee 2006).

7. NON-MAXWELLIAN VELOCITY DISTRIBUTIONS

Any velocity distribution containing a thermal core and a power law cosmic ray tail is non-Maxwellian by definition, but it is interesting to ask whether the core itself is Maxwellian. This is a difficult observational question because the observable emission lines are generally faint, and the Hα profiles consist of at least two components. Raymond et al. (2010) obtained a very deep spectrum of a shock in Tycho's SNR, and found that the broad component could not be fit with a Gaussian. Raymond et al. (2017) found a similar departure from Gaussian in a 3000 km/s shock in SN1006.

There are at least 5 explanations for these observations. There could simply be two or more shocks with different speeds within the spectrograph field of view. The shock could have a precursor strong enough to heat some neutrals to a substantial fraction of the post-shock temperature (Ohira 2014, Raymond et al. 2011). The neutrals that pass through the shock will become pickup ions, which have a non-Gaussian velocity distribution (Raymond et al. 2008). The beginning of a power law tail may affect the wings of the line. Or, finally, the velocity dependence of the charge transfer cross section produces an intrinsically non-Maxwellian profile in very fast shocks (Morlino et al. 2013). Kropotina et al. (2016) computed the relaxation of heavy ions in a shock in SNR ejecta, and the theory and observations are reviewed by Bykov et al. (2013).

8. MAGNETIC FIELD AMPLIFICATION

There is strong evidence for amplification of the magnetic field in the faster SNR shocks from the thickness of the X-ray synchrotron filaments (Vink & Laming 2003; Bamba et al. 2005). Post-shock fields above 100 μG are inferred, which is far more than expected from simple compression of the pre-shock interstellar field. The amplification is believed to result from currents generated by the streaming of cosmic rays in the precursor (Bell 2004). The mechanism may also be involved in density inhomogenties (Rakowski et al. 2011; Ohira 2016) and stripes of non-thermal X-ray emission in Tycho's SNR (Eriksen et al. 2011; Bykov et al. 2011). Another mechanism for amplifying magnetic fields is the vorticity associated with density inhomogeneities overtaken by the shock (Giacalone & Jokipii 2007).

9. SUMMARY

The physics of collisionless shock waves is important for understanding structures in the ISM and in the heliosphere. The lack of thermal equilibrium, the amplification of magnetic fields and the acceleration of energetic particles play important roles in the evolution of explosive events and in the interpretation of observations. These phenomena are understood qualitatively, but a more quantitative understanding is needed.

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VISIBLE AND INVISIBLE MATTER IN NEARBY GALAXIES: THEORY AND OBSERVATIONS

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Abstract. We describe the main accomplishments of the project "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations" (no. 176021) funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia. We have studied both visible (stars, gas, dust) and invisible (dark) matter in nearby galaxies of various morphological types. One of the main tasks of the project was to define the sample which includes both early- (elliptical) and late- (spiral) type galaxies and this was accomplished successfully. The galaxies from our sample were studied using their photometric and spectroscopic (also radio) data that come from available catalogs and databases. We studied in detail their kinematics and dynamics and we analyzed the anisotropies in stellar motions. We decomposed photometric profiles to discover various structures in those objects. Dark matter was especially analyzed in the case of elliptical galaxies using various observational techniques and theoretical approaches. This project also included several sub-projects, where the most important one was dedicated to the purchase and the construction of the 1.40 m telescope "Milanković" mounted at the Vidojevica Astronomical Station. The remaining three sub-projects include the work on i) the Galactic habitable zone and its features connected with the kinematics and dynamics of the Milky Way and nearby spiral galaxies, ii) blazars and iii) cosmological simulations related to supermassive black holes, massive and dwarf galaxies and semi-analytic analysis of cosmological simulations.

1. INTRODUCTION

Project "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations" (no. 176021) funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia (MESTDRS) gathered 24 researchers from 5 institutes: the Astronomical Observatory Belgrade (AOB), the Faculty of Mathematics (University of Belgrade), the Institute of Physics (Belgrade), the Faculty of Natural Sciences (University of Niš) and the Faculty of Electronics (University of Niš). The project was ranked 8th of 435 submitted basic research projects after the call of the MESTDRS (then Ministry of Science and Technological Development) in 2010 and has been led from the beginning (2011) by the author of this contribution. The following researchers took part in the realization of the project from the beginning to this conference: Dr. Srdjan Samurović, Dr. Milan Ćirković, Dr. Branislav Vukotić, Dr. Ana Vudragović (née Lalović), Dr. Oliver Vince, Dr. Ištvan Vince, Dr. Attila Cséki, Dr. Milan Bogosavljević, Dr. Zoran Knežević, Dr. Zorica Cvetković, Dr. Rade

Pavlović, Dr. Nemanja Martinović, Milena Jovanović, Dr. Miroslav Mićić, Dr. Milica Mićić, Dr. Majda Smole, Ana Mitrašinović (AOB), Prof. Dr. Olga Atanacković (Department of Astronomy, Faculty of Mathematics, University of Belgrade), Dr. Dragan Lukić (Institute of Physics, Belgrade), Prof. Dr. Goran Djordjević, Prof. Dr. Ljubiša Nešić, Dr. Milan Milošević (Faculty of Sciences and Mathematics, University of Niš), Prof. Dr. Goran Djordjević and Darko Todorović (Faculty of Electronics, University of Niš). During the realization of the project four PhD theses related to the project were defended (A. Vudragović, M. Milošević, M. Smole and N. Martinović, see these Proceedings for the details) and 2 more PhD theses are near completion (M. Jovanović and A. Mitrašinović). Between 2011 and 2016 the participants published 76 refereed papers related to the project in various journals and also numerous contributions in various books of proceedings.

From the very beginning of the work of the project special attention was given to the sub-project (led by Dr. Milan Bogosavljević) related to the construction and mounting of the 1.40 m telescope "Milanković" and the most important details regarding these activities will be presented below. Additional 3 sub-projects were launched over the course of the project and will also be described below.

This contribution will necessarily, due to a limited available space, present a condensed description of the research performed within project "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations". The reader is referred to the papers listed in the reference list at the end as well as to the contributions at the Serbian Astronomical Conference by the participants of the project.[1]

2. THE "MILANKOVIĆ" TELESCOPE

From the very beginning of the project we began to work on the selection of the optimal configuration of the 1.50 m-class telescope to be purchased and mounted at the top of Vidojevica and the decision was made to name it "Milanković" after the famous Serbian astronomer. The activities related to the construction and procurement of the "Milanković" telescope were synchronized with activities of the BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract no. 256772) project. We described the activities related to the procurement earlier (see Samurović 2016c, 2017a) and here only the most important information is presented.

The 1.40 m "Milanković" telescope was produced by the reputable Austrian company ASA (AstroSysteme Austria GmbH) using the optics from another eminent company, LOMO, from the Russian Federation. See the details about the final stages of the procurement and the features of the telescope in Samurović et al. (2018). The telescope has been used for various observations and some were part of the project described in that contribution (see below). The extensive tests proved that both the mechanics and the optics were of excellent quality. The telescope was delivered to the Astronomical Station Vidojevica (ASV) on 28 April 2016 when the mounting procedure started and was completed several days later. After some adjustments that were completed at the beginning of June 2016 the first light was taken on 7 June 2016. The image is shown in Samurović et al. (2018, see Fig. 2 there) and we refer the

[1] Note that all contributions in these Proceedings made within project no. 176021 can be traced through the acknowledgment sections present at the end of each paper printed in this volume.

reader to that contribution for more details regarding the present situation (detectors, observational projects) with the "Milanković" telescope. See also two contributions by Vince et al. (2018a,b).

The funds for the telescope were provided by the European Commission through BELISSIMA (76 %) and Serbian MESTDRS (24 %). The MESTDRS provided the funds for the construction of the temporary pavilion where the telescope is currently mounted and the future professional pavilion where the telescope will be mounted in spring 2018. At the time of this writing (late November 2017) the construction works on the building of the new pavilion have been successfully completed and the dome for the new pavilion is currently in the final stages of production by the reputable Italian company Gambato.

The significant help and efforts in the realization of all the activities related to the "Milanković" telescope and its pavilions were provided by Dr. Zoran Knežević and Dr. Gojko Djurašević in their role as Director of the AOB.

3. THE STUDY OF THE VISIBLE MATTER IN NEARBY GALAXIES

We studied the visible matter in nearby galaxies: we analyze both late-type galaxies (hereafter LTGs, i.e. spirals) and early-type galaxies (hereafter ETGs, i.e. ellipticals and lenticulars) using various archives and also the "Milanković" telescope. We constructed the reliable sample of nearby galaxies. Here, some of the most important details are provided and the reader is referred to Vudragović (2018) and also to the paper by Vudragović, Samurović & Jovanović (2016) for more details and relevant references. We used $\alpha.40$ catalog that is cross-matched with the Sloan Digital Sky Survey (SDSS DR7) spectroscopic catalog and the Galaxy Evolution Explorer (GALEX GR6), Two Micron All Sky Survey (2MASS XSC) to add a multiwavelength photometry to the radio and optical spectroscopy originally provided with the $\alpha.40$ catalog. Our final sample has 2180 galaxies and it has radio and optical spectroscopy and photometry from the ultraviolet, through the optical to the near-infrared passband. The morphological distribution of galaxies in our sample suggests that we have about 1/3 of ETGs: the ratio 1:3 reflects the contribution of ETGs to the galaxy population in the local Universe. The remaining fraction (2/3) of the galaxies in the sample are LTGs. For all the galaxies in our sample the following quantities were measured: the velocity dispersions, the Gauss-Hermite coefficients (h_3 and h_4) which describe departures (asymmetric and symmetric) from the Gaussian function, the Sersic indices and the effective radii (R_e) in order to calculate dynamical mass of the galaxies. This is most probably the largest available sample of galaxies for which the kinematics of the inner regions analyzed includes the departures from the Gaussian. We have also measured the Lick indices important for the estimates of ages and metallicities of the galaxies in our sample. In the study of the kinematics of the nearby galaxies we relied on two stellar libraries: the synthetic library based on the empirical library STELIB (with 39 template stars) and the empirical library which is Elodie low resolution stellar library (with 998 template stars). Regarding the analysis of the stellar spectra, we mention here one important result: we studied the distribution of the h_4 parameter and we found that there is an increase of its value going from LTGs to ETGs, which means that in ETGs the radial orbits dominate (see Figs. 13 and 14 in Vudragović et al. 2016). We used various statistical tests on the h_4 distribution and compared various morphological types. We found that the distribution of early-type vs. late-type and Sab vs. Scd galaxies do not come from the same distribution, whereas when ellipticals are confronted with lenticulars, we have a hint that they come from the same distribution; this may mean that they share the similar formation scenario thus leading to an interesting constraint important for models of galaxy evolution.

In our study of dark matter (hereafter, DM, see below) we needed to estimate the contribution of the visible, stellar, component. In Samurović, Vudragović & Jovanović (2015) we analyzed the massive spiral galaxy NGC 2841 and we took into account predictions from various stellar population synthesis (SPS) models based on different initial mass function (IMFs). Various SPS models were also used when we analyzed the problem of the contribution of DM in ETGs. In the case of spiral galaxies we also analyzed their photometry. In the case of the aforementioned NGC 2841 in the attempt of the decomposition of its surface brightness profile we first relied on the archival data (Samurović et al. 2015) and recently, we used the “Milanković” telescope to obtain the deep near-infrared photometry (I-band), see Vudragović et al. (2018). More details about the use of photometry on our sample is available in Vudragović (2018).

4. DARK MATTER IN EARLY-TYPE GALAXIES

One of the main research topic of the project is the study of DM in ETGs. Here, it is important to note that ETGs are studied to a lesser degree than their spiral counterparts. The following list includes some of the most important reasons for such a situation: i) there is a lack of cool gas in early-types necessary for obtaining rotation curves, ii) ETGs are faint in their outer parts, which require long exposures to obtain high quality spectra and iii) there is no accurate knowledge of the shape of orbits in these galaxies which leads to the mass-anisotropy degeneracy (see e.g. Samurović 2007). For the study of the DM problem one can rely on different studies: one can analyze long-slit and/or integral field unit (IFU) spectra which is related to the study of the contribution of the visible (i.e. stellar) component to the total dynamical mass, one can study the kinematics of various tracers of the total dynamical mass such as planetary nebulae (PNe) and globular clusters (GCs), one can study the X-rays in ETGs and one can rely on gravitation lensing when studying DM in ETGs.

In the project no. 176021 we studied different aspects of DM in ETGs. We used two different methodologies to study several ETGs out to several effective radii: Newtonian (mass-follows-light and DM models) and the MOND (MOdified Newtonian Dynamics). From the beginning of project no. 176021 we analyzed the following ETGs: NGC 4472 (M 49) in Samurović (2012), NGC 821 in Samurović et al. (2014), NGC 1400, NGC 1407, NGC 2768, NGC 3115, NGC 3377, NGC 4278, NGC 4365, NGC 4486, NGC 4494 and NGC 5846 in Samurović (2014, hereafter S14), NGC 1399 in Samurović (2016a), NGC 5128 in Samurović (2016b) and NGC 1023 and NGC 4526 in Samurović (2017b); see also Samurović (2018). For all the galaxies we use GCs as a tracer of the gravitational potential and also rely on the PNe data, where available. We use the radial velocities of the GCs in ETGs and we extract the full kinematical profiles of our galaxies out to several effective radii: the velocity dispersion and s_3 and s_4 parameters which describe asymmetric and symmetric departures from the Gaussian (analogous to h_3 and h_4 parameters mentioned above). We did not split the GCs of each galaxy into blue and red population and work with a *total* sample of GCs for each galaxy in order to have more clusters per bin because our goal is to

Table 1: The list of ETGs used in the analysis of Bílek & Samurović (2018). Columns are as follows (the references will be available in our forthcoming paper). (1): name of the galaxy. (2): distance to the galaxy in Mpc. (3): B-band absolute magnitude. (4): morphological type. (5): environment of each galaxy ("G" means that the galaxy belongs to a group, "F" is a field galaxy and "C" means that the galaxy belongs to a cluster). (6) central rotator type ("s" indicates slow and "f" indicates slow rotators). (7): isophotes ("D" are disky isophotes, "B" are boxy isophotes and "0" are pure ellipses) (8): corrected $B-V$ colors. The objects for which the names are given in italics follow the AR of the LTGs.

name (1)	D[Mpc] (2)	M_B (3)	Type (4)	Env (5)	Rot (6)	Iso (7)	$B-V$ (8)
NGC 0821	23.4	-20.82	E6	F	f	D	0.87
NGC 1399	19.0	-20.81	E1pec	C	s	D	0.93
NGC 1400	26.8	-20.35	S0/E0	G	f	0	0.89
NGC 1407	26.8	-21.49	E0	G	s	0	0.95
NGC 2768	21.8	-21.26	E6/S0_1/2	G	f	D	0.91
NGC 3115	9.4	-19.94	S0	F	f	D	0.90
NGC 3377	10.9	-19.32	E6	G	f	D	0.82
NGC 4278	15.6	-19.50	E1-2	G	f	B	0.90
NGC 4365	23.3	-21.00	E3	G	s	B	0.93
NGC 4472	16.7	-21.71	E2	C	s	B	0.93
NGC 4486	17.2	-22.05	E0	C	s	B	0.92
NGC 4494	16.6	-21.07	E1-E2	G	f	D	0.85
NGC 4649	17.3	-21.59	E2/S0	C	f	B	0.93
NGC 5128	3.8	-20.55	S0pec(Epec)	G	f	?	0.87
NGC 5846	24.2	-21.34	E0	G	s	B	0.94

determine as accurately as possible the velocity dispersion and departures of the GC radial velocity distribution from a Gaussian.

The procedure of solving of the Jeans equation (e.g. Binney & Tremaine 2008) in a spherical approximation for both Newtonian and MOND approaches is given in S14. The fact that there exists the mass/anisotropy degeneracy is one of the main problems for the Jeans analysis: for all ETGs from our sample we calculated the departures from the Gaussian and in our dynamical models we analyze isotropic case, tangentiallly dominated case and radially dominated case based on numerical simulations. In all our dynamical models we fit the velocity dispersion profies of ETGs.

In establishing the amount of DM in ETGs we relied on various SPS models: we used seven different models with several IMFs (see S14 for more details). For the sake of brevity, we will here describe only the major findings from S14 and the reader is referred to the papers mentioned above for more details regarding individual ETGs. S14 is the work with the largest number of galaxies simultaneously analyzed in Newtonian and MOND approaches. We found that only one out of ten ETGs can be modeled with a single value of the constant mass-to-light ratio that is approximately consistent with the value of the stellar component, NGC 2768, showing the lack of significant amount of DM. Three more galaxies (NGC 1400, NGC 3377, and NGC 4494) show an increase of the total mass-to-light ratio with radius between the innermost and outermost radii, which suggests the existence of DM in them. The object NGC 4486 is the only galaxy that needs significant amount of DM in its inner region. When we solved the Jeans equation in the spherical approximation for three different MOND models (standard, simple and toy) we discovered that the standard model required the largest mass-to-light ratio while the toy MOND model required the smallest. We found that only few ETGs could be modeled with a mass-to-light ratio consistent with the no-DM hypothesis, assuming the values of the mass-to-light ratios that are consistent with the stellar mass only: NGC 1400, NGC 2768, NGC 3377, and NGC 4494. In the case of NGC 4486 we found that it requires DM in MOND even in its inner region (interior to $\sim 0.35R_{\mathrm{e}}$). The following galaxies require DM even in the MOND approach in their outer parts: NGC 1407, NGC 4278, NGC 5846 and NGC 3115 require DM beyond $\sim 3R_{\mathrm{e}}$, and NGC 4365 and NGC 4486 require DM beyond $\sim 1R_{\mathrm{e}}$ and $\sim 0.35R_{\mathrm{e}}$, respectively. Thus we reached the conclusion that in the MOND modeling of the ETGs in the sample some galaxies can be fitted with the visible matter only, whereas, in some cases, the additional dark component is needed. This represents the problem for MOND which is based on one free parameter only (mass-to-light ratio). The important conclusion that we obtained is the fact that the MOND approach cannot provide a successful fit for ETGs that are slow rotators.

In Bílek & Samurović (2018) we analyzed the sample of 15 ETGs and our focus is on the relation between the dynamically inferred gravitational acceleration and the acceleration expected from the distribution of the visible matter (the acceleration relation, AR). The AR is nearly universal for LTGs, in agreement with the MOND. The reader is referred to that contribution and in Table 1 we present the most important details for the ETGs of our sample: the galaxies listed are objects with a wide range of luminosities, morphological types (within the early-type class) and belong to different environments (from field galaxies to members of groups and clusters).

5. DARK MATTER IN SPIRAL GALAXIES

At the very beginning of the project the kinematics of the Milky Way was studied using the measurements of the radial velocities of the blue horizontal branch (BHB) halo stars: the predictions of Newtonian gravity and different MOND models were tested, taking orbital anisotropies into account. We used halo stars of our Galaxy as a tracer of its gravitational potential and then we solved the Jeans equation for both the Newtonian and the MOND approaches. In the Newtonian approach we found that the truncated flat model with DM can provide good fit to the observed velocity dispersion, whereas for the MOND models we found that two models can provide a fit to the data without significant anisotropies whereas two other tested models need various anisotropies to obtain the same result (see Samurović & Lalović 2011 for details about the models).

In our work from 2015 we analyzed in detail the dynamical models of the massive spiral galaxy NGC 2841 using both the Newtonian models with Navarro-Frenk-White (NFW) and isothermal dark haloes, as well as various MOND models (Samurović et al. 2015). We relied on the observations coming from several publicly available data bases and we used radio data, near-infrared photometry as well as spectroscopic observations and found that both tested Newtonian DM approaches can successfully fit the observed rotational curve of NGC 2841. We again (as in the case of ETGs, see above) used three MOND models (standard, simple and, for the first time in the literature applied to another spiral galaxy than the Milky Way, Bekenstein's toy model). We found that the best result was obtained with the standard MOND model. It is interesting to note that we found that the best-fitting NFW model is inconsistent with the predictions of the cold dark matter (CDM) cosmology, because the inferred concentration index is too high for the established virial mass (see Fig. 10 of Samurović et al. 2015).

In the recent paper Jovanović (2017) analyzed the dynamical models for two galaxies, the massive spiral galaxy NGC 5055 and the dwarf irregular DDO 154. She used THINGS (The HI Nearby Galaxy Survey) HI observations to determine the rotation curves of the two galaxies and gas contributions, and Spitzer Survey of Stellar Structure in Galaxies (S4G) photometric observations in the 3.6 μm band to decompose the surface brightness profiles of the galaxies. Jovanović (2017) studied NFW and isothermal halo models for the DM distribution, together with the most recent and reliable radio observations of HI to determine the rotation curves of these galaxies taking into account the contributions from the neutral gas and the luminous matter. Jovanović (2017) found that the isothermal DM model successfully fitted both observed rotation curves with realistic values for stellar mass-to-light ratio, while the NFW model needed further constraints for mass-to-light ratio to fit the rotation curve of DDO 154.

6. NUMERICAL SIMULATIONS OF THE EVOLUTION OF GALAXIES AND SUPERMASSIVE BLACK HOLES

Within this sub-project (active from 2013, led by Dr. Miroslav Mićić) various numerical simulations were performed at the Institute of Physics (also, the Millennium and Millennium-II simulations were used). The following phenomena were studied: elliptical galaxy formation using the activity of supermassive black holes (SMBHs) in their centres, evolution of dwarf galaxies in clusters of galaxies and formation of SMBHs and role of galaxy mergers in their evolution. The list of references includes: Smole, Mićić & Martinović (2015), Mićić, Martinović & Sinha (2016) and Martinović & Mićić (2017); see also Martinović & Mićić (2018), Smole et al. (2018), Mitrašinović et al. (2018) and, Milošević et al. (2018).

7. STUDY OF BLAZARS

The goal of this sub-project (active from 2014, led by Dr. O. Vince) is to study the origin and physics of high flux variability in all spectral domains using multi-wavelength observarions. The recent results of optical-to-radio monitoring of the blazar CTA 102 by the Whole Earth Blazar Telescope Collaboration show that the observed long-term flux and spectral variability is best explained by an inhomogeneous, curved jet that undergoes orientation changes. The work within this sub-project was done in collaboration with the researchers from Italy (Astrophysical Observatory of Torino) and Bulgaria (Bulgarian National Astronomical Observatory). Telescope "Milanković" was used and will continue to be used for the study of blazars, using both photometry and spectroscopy (see Vince et al. 2018b). Some of the most recent references include: Gupta et al. (2017) and Raiteri et al. (2017).

8. GALACTIC HABITABILITY: NUMERICAL SIMULATIONS AND BASIC QUESTIONS

The main research goal of this sub-project (active from 2015, led by Dr. B. Vukotić) was to investigate the history of galactic habitability and relevant time scales. Special attention was given to the influence of dynamics of matter in the Galactic disk to Milky Way habitability. The most important result so far is that the analysis of snapshots from the N-body simulation of an isolated Milky Way-like galaxy points that the galactic regions with the highest habitability potential lies in the outskirts of the Galactic disk at galactocentric distances in excess of 10 kpc. In a separate work it was argued that the life-threatening risk of radiation from energetic explosions (such as γ-ray bursts) can be mitigated by sufficiently advanced technological societies using swarm shields constructed from stellar system small bodies. The related results are presented in two research papers (Ćirković & Vukotić 2016; Vukotić et al. 2016). Also, an overview of using N-body simulations as a novel tool to investigate galactic habitability is presented in a book chapter (Vukotić 2017); see also Djošović, Vukotić & Ćirković (2018).

9. THEORETICAL COSMOLOGY

The group of researchers from the Faculty of Sciences and Mathematics, University of Niš led by Prof. Dr. Goran Djordjević studied various theoretical aspects of modern cosmology, such as braneworld cosmology and theory of inflation. They also organized a network of international collaborations with the ICTP from Trieste and CERN through SEENET-MTP (Southeastern European Network in Mathematical and Theoretical Physics). Some recent papers include: Bilić et al. (2017a), Bilić, Domazet & Djordjević (2017b,c).

10. POPULARIZATION ACTIVITIES

The participants of the project took part in education and popularization of astronomy through organization and participation in various meetings and exhibitions, printing of the material related to the popularization of science as well as guests in various radio and TV programs. We here mention only some of the most important meetings (see Samurović 2017a): the BELISSIMA executive meeting, two BELISSIMA workshops, the international BELISSIMA conference and the Serbian-Italian Astronomical Workshop, held in October 2017, after the Serbian Astronomical Conference. Within the activities within the BELISSIMA projects, six episodes of TV programme dedicated to the popularization of astronomy and the presentation of the AOB and "Milanković" telescope were filmed: 4 episodes are present in the BELISSIMA multimedia DVD and the last two ones dedicated to the ASV, telescope "Milanković" and future observational project are available at the BELISSIMA Web site[2].

[2] `http://belissima.aob.rs`

Special attention was given to present the material of interest for foreign spectators and thus some episodes are subtitled in English. See also Atanacković (2018).

11. CONCLUSIONS

In this contribution we briefly presented the most important results of the national project "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations" (no. 176021) active at the AOB from 2011. We have studied the visible matter in various types of galaxies represented by the stellar component. We described our contribution to the analysis of the problem of DM in spiral and early-type galaxies using different methodologies, such as Newtonian and MOND. The interesting result based on the study of the nearby early-type galaxies is that while some galaxies show the lack of DM there are numerous examples that DM dominates in their outer parts and in some galaxies the dark component is dominant even in their inner regions. We described the activities of all the sub-projects, especially the activities that led to the successful construction and mounting of the 1.40 m telescope "Milanković" at the Astronomical Station Vidojevica. For the future we plan: to continue and improve the present theoretical and observational work, to mount the "Milanković" telescope in the new pavilion, to procure new detectors for the "Milanković" telescope, to expand and strengthen the existing collaborations and, finally, we intend to include new researchers (experienced researchers, PhD students) in the existing project and in the project that will be launched in the next project cycle of the MESTDRS which is expected to start soon.

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COSMIC RAY ORIGIN: BEYOND THE STANDARD MODEL(S). THE CASE OF PULSAR WIND NEBULAE AND UNIDENTIFIED VERY HIGH ENERGY GAMMA-RAY SOURCES.

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Abstract. The riddle of the origin of Cosmic Rays is open since one century. Recently we got the experimental proof of hadronic acceleration in Supernovae Remnants, however new questions rised and no final answer has been provided so far. Gamma ray observations above 100 MeV reveal the sites of cosmic ray acceleration to energies where they are unaffected by solar modulation. In the last years the knowledge in this field of research widely increased, however almost 50% of the TeV ($> 10^{12}$ eV) Galactic sources are still unidentified; at GeV ($> 10^{9}$ eV) energies, 67% of EGRET sources were unidentified and also with the newer generation of gamma-ray satellites we have the same result: in fact, at low Galactic latitudes (b <10 deg), 62% of the Fermi LAT detected sources have no formal counterpart. Hence understanding the high energy unidentified sources will be a crucial brick in solving the whole riddle of Cosmic Rays origin. Several examples will be shown, underlining the importance of the so-called "dark sources". Both theoretical aspects (with particular emphasis to the so-called Ancient Pulsar Wind Nebulae scenario) and their observational proofs will be discussed.

1. COSMIC RAY ORIGIN: STANDARD MODEL(S) AND BEYOND

In this short article we are summarizing one of the oldest questions in astrophysics: where the cosmic rays (CRs) come from? In which astrophysical objects are they accelerated? Entire international conferences have been devoted to try to answer this question, such as the two editions of the "Cosmic Ray Origin - beyond the standard models" international conference (CRBTSM [1]); this answer is long and can be complex (e.g. Tibolla & Drury 2014).

CRs have been discovered more than one century ago with different experimental procedures. Their discovery in water (in the Bracciano lake and in the Tirreno sea) in the years 1907-1912 can be attributed to the Italian physicist Domenico Pacini (Pacini 1912). Their discovery utilizing an electroscope on the Eiffel Tower can be attributed to the German gesuit physicist Theodor Wulf (Wulf 1909), who was also the first who spoke about "Hoehenstrahlung" (i.e. "radiation from above"). The

[1] http://crbtsm.eu

invention of electroscopes by Wulf led to much more precise experiments, i.e. the balloon flights at 5 km of altitude by the Austrian physicist Victor Hess (Hess 1912) and at 9 km of altitude by the German physicist Werner Heinrich Gustav Kolhörster (Kolhörster 1913). In particular, the first flight by Hess convinced everybody that CRs are an astrophysical phenomenon (and in 1936 Hess was awarded by the Nobel prize for CR discovery) or, better, almost everybody. In fact, the U.S. physicist Robert Andrews Millikan was continuing being skeptical about the conclusions of his European colleagues and disputed them for several years, before confirming their discovery; ironically the term "cosmic rays" originated with Millikan. All in all, more than one century after their discovery, we still ignore the origin of CRs.

Since the discovery of the Supernovae (SN) phenomenon, a connection with CRs has been suggested (Baade & Zwicky 1934). The terms "standard picture" or "standard model" generally refer to the majestic mongraph book of Ginzburg and Syrovatskii (Ginzburg & Syrovatskii 1964). In order to summarize extremely much their conclusions, we could say that according to the standard model: primary Galactic CRs up to energies of the so called "knee" at about 10^{15} eV, are accelerated in Supernovae Remnants (SNRs) shells. One expects about one supernova event every $30-50$ years, and, in order to account for the energy density of CRs (about 1 eV/cm^3) and the CRs confinement time deduced from spallation, the typical non-thermal energy release per supernova has to be about 10^{50} ergs, which is about 10% of the total energy released in the SN explosions; in other words at least 10% of the kinetic energy of the SN explosion has to go into CRs acceleration.

This idea was significantly strengthened at the end of the eighties by the fact that the prediction of the "standard model" seemed in astonishing good agreement with the typical amount of energy predicted to be produced during the acceleration of relativistic particles in SNR shocks (Völk and Biermann 1988, Drury et al. 1989, Drury et al. 1994).

The detection by the Imaging Atmospheric Cherenkov Telescopes (IACTs) of TeV gamma-rays from SNRs spatially coincident with the sites of non-thermal X-ray emission, has strengthened the hypothesis of the "standard" picture of CR origin for up to the "knee" energies; the most remarkable examples of it are given by the SNRs RX J1713.7-3946 (Aharonian et al. 2006) and RX J0852.0-4622 (Aharonian et al. 2005), the so-called Vela Jr SNR.

However the TeV gamma ray signal, can be explained in two ways:

- Inverse Compton scattering of relativistic electrons/positrons on background photons (CMB, infrared, X-rays, etc.); i.e. leponic models.
- Neutral pion decay (due to proton-proton inelastic interactions); i.e. hadronic models.

Moreover hadronic and leptonic models are basically indistinguishable at TeV gamma-rays (e.g. Aharonian & Atoyan 1999). It is important to underline here that the hadronic models have to be the focus of our researches: in fact protons are more than 90% of the total amount of CRs. SNRs proved to be sources of CR electrons decades ago, because of the detected radio and X-ray emissions; what is missing here is the compelling evidence for the acceleration of hadrons in SNRs. However, once we fix the TeV gamma-ray energy spectra by means of IACTs observations, we can note that hadronic and leptonic models should have very different signatures in the adjacent GeV gamma-ray band (e.g. Aharonian & Atoyan 1999). So, utilizing a GeV gamma-ray observatory, we should be able to finally prove or disprove the "standard picture" of CR origin. And this study was indeed among the main scientific purposes (GLAST Science Brochure 1996) of *Fermi-LAT*, that was built (also) to be a great observatory for SNRs (e.g. Tibolla 2007). In fact *Fermi-LAT* detected several SNRs (and SNR/Molecular Clouds (MCs) interactions): e.g. Cygnus Loop (Katagiri et al. 2011), RX J0852.04622 (Tanaka et al. 2011), Tycho (Giordano et al. 2012), W51C (Abdo et al. 2009), W44 (Abdo et al. 2010), Cassiopeia A – Cas A (Abdo et al. 2010b), RX J1713.73946 (Abdo et al. 2011), G8.70.1 (Ajello et al. 2012), W28 (Abdo et al. 2010c), W49B (Abdo et al. 2010d).

In particular, in the *Fermi-LAT* SNR sample, a very important discovery is represented by Tycho SNR. In fact, in the case of Tycho, leptonic models are basically disproved; i.e. Tycho represents the "smoking gun", the "hadronic fingerprint", i.e. the answer to a 60-100 years old question about the origin of CRs (Giordano et al. 2012). Moreover the efficiency of CR acceleration (i.e. the percent of kinetic energy of the SN explosion which have to go into CR acceleration) in Tycho SNR is more than the 10% needed to confirm the "standard" model: e.g. Slane et al. 2014 calculated it to be ∼16%. So everything would look solved, the standard model confirmed and every question answered; but it is not so.

In addition, with *Fermi-LAT* we could detect the characteristic neutral pion "shoulder" around 100 MeV for IC 443 and W44 (Ackermann et al. 2013). However, in my opinion, these two exceptional measurements, which are indeed very important (especially under a particle physics point of view), are less relevant than Tycho SNR since they deal with SNRs/MCs interacting systems, in which hadronic accelerations are quite obvious and unavoidable, and not with "naked SNRs", which would instead go straight to the core of the CR origin riddle. Nevertheless these two discoveries seem to underline that everything look solved, the standard model confirmed and every question answered.

Instead *Fermi-LAT* observations on one of the most promising targets to confirm the standard model of CR origin seems to go in a totally opposite direction. In fact, thanks to IACTs discoveries, before *Fermi-LAT* launch in 2008, the SNR RX J1713.7-3946 was considered one of the most promising targets and moreover one of the best threated by theoretical models (e.g. the majestic theory by Berezhko & Völk 2006). *Fermi-LAT* observations showed that leptonic models are fitting very well the energy spectrum of RX J1713.7-3946, while hadronic models seem disproved. This is considered one of the deepest problems for the standard model after *Fermi-LAT* observations, however, in my point of view, there is a bigger issue, the so-called "efficiency problem". In fact, also the SNRs that look more likely hadronic (and indeed in most of the *LAT* detected SNRs, hadronic models are favored, even if leptonic ones cannot be fully discarded so far) do not seem efficient enough to reach the 10% mentioned above. On this regards, let us take Cas A (i.e. together with the Crab, one of the two most powerful explosions in our side of the Galaxy) as an example: even assuming that the whole GeV and TeV gamma-ray spectrum would be originated by hadronic processes, the total energy of the CRs accelerated in Cas A would correspond to ∼2% of the kinetic energy of the initial SN explosion (e.g. Abdo et al. 2010b; Tibolla et al. 2011): far too few to support the standard model of CR origin.

Hence the one century old question about CR orgin is still open and we basically have two ways to proceed:

- we can modify the "standard model" (e.g. Vink 2012). However such modifications could even be drastic and lead to exotic solutions: e.g. what if the local density of CRs (i.e. the density inside the local bubble) is different from the CR density in the rest of the Galaxy, outside the local bubble? This would change totally the vision of the problem.

- we can search alternative sources which might help us in closing the gap (if any), such as binary systems (e.g. Bednarek et al. 2014), protostellar jets (e.g. Araudo & del Valle 2014), Galactic center (e.g. Thoudam 2014), Pulsar (e.g. Kotera 2014) and Pulsar Wind Nebulae (e.g. Weinstein 2014; Tibolla & Drury 2014). However we must keep in mind that extragalactic sources, such as gamma-ray bursts (e.g. Meszaros 2014) and active galactic nuclei (e.g. Mannheim 2014), play a role as well.

and I personally think that we should actually do both.

A very natural support could come from Pulsar Wind Nebulae (PWNe). In fact, looking the high energy sky (i.e. the "non-thermal sky"), the dominant population is not represented by shell-type SNRs. Among the known gamma-ray sources, PWNe are the most numerous. And indeed it was proposed that at the termination shock of the Pulsar Wind, also hadrons could be accelerated as well as leptons (e.g. Bednarek & Protheroe 1997; Atoyan & Aharonian 1996; Cheng et al. 1990; Bednarek & Bartosik 2003). Moreover, since in general the total energy of PWNe is comparable with the one of SNRs (or, at least, we can easily reach $\sim$10% of it), if hadrons can really be accelerated at the termination shock of Pulsar wind, this could indeed help the global picture of CR origin.

But the most numerous (by far) population in absolute terms is represented by Unidentified Galactic sources. In fact almost 50% of the TeV Galactic sources are still unidentified. At GeV energies, this percent is even increasing; in fact 67% of EGRET sources were unidentified (Hartman et al. 1999) and also with the newer generation of gamma-ray satellites we reach the same result: in fact, at low Galactic latitudes (b < 10 deg), 62% of the Fermi LAT detected sources have no formal counterpart (Ackermann et al. 2012). Hence understanding the high energy unidentified sources could be a crucial brick in solving the whole riddle of CRs origin. Moreover the correlation between unidentified Galactic sources and PWNe could be very close, at least for the so called "dark sources".

2. UNIDENTIFIED VERY-HIGH ENERGY GAMMA-RAY SOURCES

With the famous H.E.S.S. Galactic Plane Survey (Aharonian et al. 2006) of 2004/2005, many new TeV gamma-ray sources have been discovered; however $\sim$50% of the newely discovered sources were unidentified: e.g. HESS J1614-518, HESS J1616-508, HESS J1632-478, HESS J1634-472, HESS J1702-420, HESS J1708-410, HESS J1745-303 and HESS J1837-069.

In the meaning while H.E.S.S. collaboration, in 2006-2017, extended the successful Galactic survey of 2004/2005, discovering a number of new gamma-ray emitting sources, many of which are unidentified; VERITAS, another Imaging Atmospheric Cherenkov Telescope (IACT) observatory, in 2009-2017, started the scan of the northern part of the Galactic Plane. Moreover the "water Cherenkov technique" is reaching, with the HAWC (High Altitude Water Cherenkov) experiment, sensitivities comparable to IACTs ones (however reaching higher energies); Water Cherenkov experiments have the advantage to be "full sky" experiments and to not have limited duty cicles (i.e. observations are not stopped during the day or for not favorable weather conditions), so the number of sources is going to increase (e.g. the 2HAWC catalog; Abeysekara et al. 2017). Anyway the ratio does not seem to change: $\sim 50\%$ of the TeV Galactic gamma-ray sources seem still unidentified (e.g. Tam et al 2010).

The "zoo" of Galactic unidentified TeV gamma-ray sources is pretty various:

- we have the so-called "dark sources", i.e. sources which do not show any kind of counterparts at lower energies (such as HESS J1427-608 or HESS J1708-410);
- sources which show possible lower energies counterparts, but these lower energies counterparts are unidentified as well (such as HESS J1626-490);
- sources which seemed to be of clear and quick identification, but deeper multiwavelength campaigns disproved those hypothesis (such as HESS J1702-420, which seemed a clear example of middle-age PWN powered by the high spindown luminosity pulsar PSR J1702-4128; however deeper X-ray campaigns disproved this idea);
- unidentified sources which can be identified with deep multiwavelength campaigns (such as HESS J1731-347, which is the first SNR discovery triggered by TeV gamma-ray observations);
- very extended sources which show loads of possible lower energies counterparts (such as HESS J1841-055 or HESS J1843-033, which might have very exotic counterparts as well);
- very extended sources which, thanks to deeper IACTs observations, are discovered to be the convolution of several close-by sources instead (such as HESS J1745-303, which consists of three distinct sources);
- and unidentified sources which might have very exotic possible counterparts.

3. THE DISCOVERY OF HESS J1507-622 AND PULSAR WIND NEBULAE EVOLUTION

The discovery of HESS J1507-622 obliged us to re-think about the time evolution of PWNe. In fact HESS J1507-622 is a unique Galactic unidentified TeV gamma-ray source, very bright ($\sim 8\%$ of the Crab; 9.3 σ of peak significance in 9.7 hours of observations) and slightly extended, $\sim 0^\circ\!.16$ (H.E.S.S. collaboration 2011). The uniqueness of HESS J1507-622 is given by its offset from the Galactic plane ($\sim 3^\circ\!.5$) and by the fact that it does not show any plausible counterparts at any wavelength. Given the brightness and the offset from the Galactic plane, it is really surprising to not find any counterpart especially at X-rays energies, because this Galactic latitude implies almost one order of magnitude less absorption than in the Galactic plane.

At IR and radio wavelengths, there is no Southern Galactic Plane Survey and Spitzer GLIMPSE coverage of this part of the sky. The Midcourse Space Experiment (MSX) and the MOLONGLO Galactic plane survey observed this region, but without evidencing any plausible counterparts. It is located on a very long ($\sim 8°$) radio filament at 2.4 GHz (Duncan et al. 1995). Looking into the complete CO survey (Dame et al. 2001), this H.E.S.S. source lies near the edge of a large ($\sim 5° \times \sim 2°$) nearby CO molecular cloud (moreover the peak velocity of this cloud, around -5 km/s, would most likely place it quite near at a distance of ~ 400 pc); however, also in this case the substantial difference in extension and, in the case of the CO molecular cloud, the offset of $\sim 1°$ from the H.E.S.S. source centroid, suggested no obvious scenario for an association.

At X-rays it was very surprising to not find any X-ray counterpart, given the much lower absorption than in the Galactic plane. *ROSAT* observations did not show any counterparts, but three near point sources were detected; in the case that one of them (especially 1RXS J150841.2-621006) could be discovered to be a pulsar, one can easily imagine an offset PWN scenario. We obtained twice *XMM-Newton* observations; the first observations (Proposal ID 05563102 - AO 7) were very severely affected by soft proton flare and so 35 ks re-observation has been obtained (Proposal ID 06516201 - AO 9). We obtained Chandra observations (Proposal ID 10400599 - AO 10) as well and twice a deep (80 ks) Suzaku campaign: 80 ks the first time (priority C) and, even deeper, 120 ks the second, a couple of years ago later. More details on the deep X-ray campaigns can be found in Tibolla et al. (2014). These X-rays observations evidenced that the source 1RXS J150841.2-621006 / CXOU J150850.6-621018 slightly extended over the PSF of the instrument and it is coincident with the radio source MGPS J150850-621025; this source could be either a SNR or a PWN (Tibolla et al. 2014), however cannot be a plausible counterpart of HESS J1507-622.

The absence of counterparts, especially in X-rays, would suggest a purely hadronic scenario. However hadronic scenarios would appear very disfavored, unless we would place HESS J1507-622 at a very small distance (less than 1 kpc!), since the density of target material off the plane is very low; and, given the very small absorption at this Galactic latitude, it would be really challenging to explain the absence of lower energies counterparts.

The offset from the Galactic plane (could imply a low density and so) would suggest a leptonic scenario. A PWN powered by a very old pulsar could be a possible explanation for this source (in this case a small distance of the object is disfavored and HESS J1507-622 had to be placed at 6 kpc or farther). This particular scenario was called Ancient PWN scenario (H.E.S.S. collaboration 2011; de Jager et al. 2009) and Ancient PWNe are indeed a recent idea that could explain a large fraction of the TeV gamma-ray unidentified sources.

In a scenario where the magnetic field decays as a function of time, the synchrotron emission will also fade as the PWN evolves. And the magnetic field is indeed expected to decay as a function of time and the power-law index of the decay of the average nebular field strength has been calculated by means of MHD simulations (Ferreira & de Jager 2008).

Hence, while the synchrotron emission is fading as the PWN evolves, the very high energy (VHE, $E > 10^{11}$ eV) emission depends on the CMB radiation field, which is constant on timescales relevant for PWN evolution. For timescales shorter than the inverse-Compton lifetime of the electrons ($t_{\rm IC} \simeq 1.2 \times 10^6 (E_{\rm e}/1~{\rm TeV})^{-1}$ years), this will result in an accumulation of VHE electrons which will also lead to an increased gamma-ray production due to up-scattering of CMB photons. Such accumulation of very-high energy electrons in a PWN has indeed been observed in several VHE PWNe (such as the source HESS J1825-137).

This idea seems supported by the fact that the VHE PWN sizes generally increase with pulsar age while the X-ray PWN sizes show the opposite trend. Moreover, for pulsars older than $\sim 10^3$ years the VHE PWNe are typically $100-1000$ times larger than the sizes of the X-ray PWNe, while the difference is only a factor 2 for some younger PWNe, like the Crab Nebula (e.g. Kargaltsev & Pavlov 2010). To summarize, during their evolution, PWN may appear as gamma-ray sources with only very faint low-energy counterparts and this may represent a viable model for many unidentified TeV sources. This effect can be clearly seen in the several examples shown by Okkie de Jager in 2008 and published in Tibolla et al. (2011b), where this model was applied to HESS J1507-622 to model for the first time the full spectral energy distribution of this unique TeV gamma-ray source. The basic idea shown in those above-mentioned articles was developed into much more stringent models, such as a “leaky box” model (e.g. Tibolla et al. 2012) and our newest time dependent PWN model (Vorster et al. 2013), obtaining comparable results. In particular this latest model showed to be a particularily powerful tool to describe young PWN systems, such as G21.5-0.9 (Vorster et al. 2013) and HESS J1420-607 (Kaufmann & Tibolla 2017), as well as most of the unidentified TeV gamma-ray sources which have been treated by this model as aged/relic PWN systems, such as:

- HESS J1507-622 and HESS J1427-608 (Vorster et al. 2013);
- HESS J1837-069, HESS J1616-508, HESS J1702-420 and HESS J1708-410 (Tibolla et al. 2013);
- IGR J1849-0000 (Kaufmann & Tibolla 2017).

Another important corollary of these long-living gamma-ray sources regards starburst galaxies: in fact, it has been recently shown (Mannheim, Elsässer & Tibolla 2012) that PWNe are important and not negligible in explaining the TeV gamma-ray emission detected from NGC 253 and from M82. PWNe associated with core-collapse supernovae can readily explain the observed high TeV luminosities. The final proof of this could arrive from deeper gamma-ray observations on other galaxies.

4. CONCLUSIONS AND FINAL REMARKS

Ancient PWNe are a very natural way to explain unidentified very high energy sources. Moreover the ancient PWN models seem to be able to explain most of these unidentified sources (e.g. Vorster et. al. 2013, Tibolla et al. 2013, Kaufmann & Tibolla 2017). If indeed, at the termination shock of the Pulsar Wind also hadrons could be accelerated as well as leptons, as discussed in the first section, not only PWNe but also unidentified sources (i.e. the dominant population at high energies and very high energies gamma-rays) can help in solving the CRs riddle. We want to remark that, since in general PWNe Total Energy is comparable with SNRs Total Energy (or, at least, we can easily reach ∼10% of it), if hadrons can really be accelerated at the termination shock of Pulsar wind, this could indeed help to solve the riddle of the global picture of CR origin.

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Progress Reports

ASTRONOMY EDUCATION IN SERBIA 2014-2017

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Abstract. A triennial review is given on astronomy education in Serbia at all levels: primary and secondary schools, and universities. Emphasis is put on the activities of the Petnica Science Center, the participation of the Serbian team in the International Astronomy Olympiads, newly accredited study programs, the School of Astronomy organized by the students of the Department of Astronomy (Faculty of Mathematics, University of Belgrade), the Astronomical Student Workshops, as well as on the activities of numerous amateur astronomical societies.

The changes in astronomy education in Serbia that occurred in the period from 1 November 2014 to 1 November 2017 are described in this paper. The previous period was covered in the papers by Atanacković (2009, 2012, 2017), Atanacković-Vukmanović (2006a,b) and Milogradov-Turin (2002), and in the references therein.

1. PRIMARY SCHOOLS

Astronomy topics in the elementary school curricula are mostly taught as part of the courses of Geography (V). Having in mind the importance of astronomy education at early age and an increasing interest of pupils in astronomy, in 2015 the Department of Astronomy, Faculty of Mathematics, University of Belgrade, has undertaken the first activities in the introduction of Astronomy as a separate elective course in the elementary schools.

2. SECONDARY SCHOOLS

We should recall again that after 25 years (from 1969 to 1994) of being a separate and compulsory, one hour per week, course in the fourth year of the secondary schools, in 1990 astronomy topics became incorporated in the final (fourth) year physics course. Only a few special schools in Serbia (e.g. Mathematical High School in Belgrade, "Jovan Jovanović Zmaj" in Novi Sad, "Svetozar Marković" in Niš) have astronomy as a separate subject. Numerous attempts made to reintroduce astronomy as a separate subject still remained with no success. New standards for teaching of Physics were introduced in the framework of the reform of the secondary school education in 2014, but, unfortunately, astronomy is still regarded as a part of Physics.

At regular annual meeting of physics teachers organized by the Serbian Physical Society that was held in 2017 in Šabac, prof. Tijana Prodanović gave a talk "Teacher as a science communicator", stressing the fact that teachers in Physics have to be acquainted with the discoveries and news in astronomy.

An extremely small part of the primary and secondary schools curricula in Serbia is devoted to astronomy. Astronomical community has been trying to compensate for this lack by means of three very important extracurricular activities: (a) the activities of the Department of Astronomy in Petnica Science Center, (b) the activities of National Astronomical Olympic Committee (NAOC) in training the Serbian team for participation at the International Astronomy olympiad and (c) the School of Astronomy organized by the students of the Department of Astronomy of the Faculty of Mathematics in Belgrade.

The new textbook "Astronomy" for the 4th year of secondary schools, written by Olga Atanacković, is published in 2016 by Klett.

2. 1. PETNICA SCIENCE CENTER (PSC)

The activities of Petnica Science Center are very important in additional, extracurricular astronomy education of the gifted secondary-school students.

In the past three years the Program of Astronomy in PSC included 21 seminars for secondary school students interested in astronomy and involved 153 participants in total. Twenty eight researchers from the Department of Astronomy at Belgrade University, Astronomical Observatory Belgrade and other institutes, as well as 18 students of astronomy, physics and electrical engineering took part in their realization (Božić, 2017). The two cycles of seminars in astronomy organized by the PSC are described in more detail in Atanacković (2009) and in the paper by Bošković et al. (2018, this volume). Twenty individual research projects were realized by 26 participants of the seminars that belong to the most advanced group. They were presented at the annual conferences "A step into science" (in December) and published in "Petnica notebooks" (Vukadinović, 2017).

Petnica Summer Institute (PSI) - an annual international summer school for undergraduate and early graduate students has been organized since 2013 by a group of senior associates of the Department of Astronomy at PSC. It covers topics in theoretical (astro)physics that change in a four year cycle (cosmology, high energy physics, astrophysics and astroparticle physics and general relativity). In the past three years three summer schools were held: the 3rd Summer School on Astrophysics and Astroparticles in 2015, the 4th Summer School on General Relativity in 2016 and the 5th Summer School on Cosmology in 2017. Lecturers are mainly senior PhD students and postdoc researchers. The organizers are Petnica Science Center, ICTP (Trieste), SISSA (Trieste), CERN (Geneva), ETH (Zurich), University of Nova Gorica (Slovenija), Princeton University (US).

More details on activities of PSC can be found in the paper by Bošković et al. (2018) and at: http://www.psc.ac.rs.

2. 2. INTERNATIONAL ASTRONOMY OLYMPIADS

Let us recall that in 2002 Professor J. Milogradov-Turin (Milogradov-Turin 2003), then president of the Society of Astronomers of Serbia (SAS), initiated the participation of Serbia in the International Astronomy Olympiads. Since then Serbian teams won 10 gold, 22 silver and 34 bronze medals, as well as 2 special prizes and 15 honorable mentions in total (Vidojević et al. 2017, 2018).

In the past three years (2015-2017) Serbian teams participated at the IOAA (International Olympiad on Astronomy and Astrophysics) and won 3 silver and 9 bronze medals in total, as well as 7 honorable mentions.

Since 2013 Serbia participates in the Saint-Petersburg Astronomical Olympiad, which represents the correspondence type competition. Since then Serbia won 1 gold, 3 silver and 1 bronze medals, as well as 1 honorable mention (Vidojević et al. 2018).

Two books that have been used in preparations for astronomy olympiad are translated by Sonja Vidojević and published by the Society of Astronomers of Serbia in 2014 and 2017 (Vidojević, 2014, 2017).

In 2013, at the 7th IOAA, Serbia was nominated as the host for 15th IOAA in 2021. In November 2017 the Minister of Education, Science and Technological Development of the Republic of Serbia, Mr. Šarčević, addressed a letter to the President of IOAA informing that the Ministry will participate in organization and hosting of the 15th IOAA in 2021 (see Fig. 1 in the paper by Vidojević et al. 2018).

2. 3. SCHOOL OF ASTRONOMY

Since May 2014 the students of the Department of Astronomy of the Faculty of Mathematics in Belgrade have organized four Schools of Astronomy for young people (age 15 to 25), mainly for high school students. Two-hour lectures have been given twice a week. The 1st School was held in May and June 2014 (16 lectures, 5 workshops, 30 participants), the 2nd in October-December 2014 (15 lectures, 5 workshops, 35 participants), the 3rd in April-June 2015 (12 lectures, 3 workshops, 47 participants), and the 4th in November-December 2016 and April-June 2017 (18 lectures, 5 workshops, 40 participants). Each lecture is given by a pair of students (junior and senior). The lectures were held in "Dom omladine" (the first two schools), Belgrade and in the Society "Milutin Milankovic", Belgrade. The last School was supported by the CPN (Center for the promotion of science) as one of the top ten independent scientific-popular projects and by ESO (Šarković, 2017).

3. UNIVERSITY EDUCATION

Astronomy courses are taught at five state universities in Serbia (University of Belgrade, University of Novi Sad, University of Niš, University of Kragujevac and University of Priština in Kosovska Mitrovica).

At the Department of Astronomy, Faculty of Mathematics, **The University of Belgrade** (UB) since early 1960's students can major in Astronomy and Astrophysics from the first study year. So far 297 students have graduated from the Department of Astronomy at the University of Belgrade (since 1936), 36 students received Master degree (since 2007), 69 students received MSc degree (1968-2010), and 56 students - PhD degree (since 1958). In the past three years, 18 students graduated, 15 students received master degree and 10 students received PhD degree.

New study programs, accredited by the end of 2014, started in 2015/2016. The study program "Astronomy and astrophysics" consists of 2 modules (Astrophysics, Astroinformatics) at undergraduate and Master levels. At PhD level there is only one module "Astronomy and astrophysics" with more than 30 elective courses. Within the study program "Mathematics" there is a module "Astronomy" at undergraduate level, and module "Astronomy and Mechanics" at Master level.

In 2017 the Department of Astronomy is included in the University Heritage of Serbia (Kovačević, 2017).

The students had summer practice - training in observations and data reduction at the Ondřejov Observatory in 2014 (2 students from Belgrade and 1 student from Novi Sad), in 2015 (5 students from Belgrade and 1 student from Novi Sad), whereas in summer 2017 only one student from Belgrade worked under the supervision of Czech colleague prof. Michaela Kraus (Marčeta, 2017).

Three summer practices lasting 3 days have been organized at the Astronomical Station Vidojevica (ASV): in May 2015 (14 students), in April 2016 (10) and in June 2017 (8). Twenty three students from Belgrade and nine students from Novi Sad in total participated in these three practices at ASV (Ilić, 2017). The students practices at ASV were organized by prof. Dragana Ilić (Department of Astronomy, Belgrade) and prof. Tijana Prodanović (Department of Physics, Novi Sad).

The Astronomy Students Workshops (ASWs), organized since 2007 by the Department of Astronomy in Belgrade and the Department of Physics in Novi Sad are growing in popularity among students. The ASWs give the students of undergraduate, master and PhD studies an opportunity to present their work (seminars, master/PhD thesis research, and summer practices). The 8th ASW was held in April 2015 at the Department of Physics in Novi Sad (38 students), the 9th ASW in April 2016 at the Society "Milutin Milanković" in Belgrade (35 students) and the 10th ASW in November 2017 in Novi Sad with 36 students (Ilić, 2017; Petrović, 2017).

Since 2011/2012 the Faculty of Mathematics of the University of Belgrade participates in "AstroMundus", a 2-year European Erasmus Mundus Joint Master program in astronomy and astrophysics of 5 universities: Innsbruck (coordinator), "Tor Vergata" Rome, Padova, Gottingen and Belgrade (see website www.astromundus.eu). The University of Belgrade (Faculty of Mathematics) offers the 3rd and 4th semester of the Master program. Since 2011/2012 thirty five students enrolled a semester at the Faculty of Mathematics, 5 students defended the Master thesis in Belgrade (3 in 2011/2012, 1 in 2015/2016 and 1 in 2016/2017), 11 master theses were co-mentored by UB out of which 3 got the award for the best master thesis in generation. In 2014 AstroMundus was included in EMJMD catalogue as one of the best programs, getting the possibility to apply for additional three academic years (until 2018/2019). In the new cycle, five more associate partners are included in the project: Max-Planck Institute for solar system research, National Institute for Astrophysics - Astronomical Observatories of Rome and Padova, Astronomical Observatory Belgrade and Gran Sasso Science Institute. In June 2017 AstroMundus was announced as one of the most successful programs by the group of experts from Directorate-General for Education, Youth, Sport and Culture of the European Commission (Ilić, 2017).

The Department of Astronomy continued to organize regular seminars on different topics in astronomy on every second Tuesday throughout the academic year, so that 40 seminars have been held in this triennial period. Sixteen seminars were also held at the Astronomical Observatory in Belgrade.

At the Faculty of Mathematics astronomy is also taught as a compulsory course "Introduction to astronomy" (3rd study year) for the students of L division (mathematics and informatics teachers), and as an optional course "Selected topics in astronomy" (4th year) for all modules of the study program "Mathematics". Until 2015/2016 two optional courses "Stellar astronomy" and "Ephemeris astronomy" were offered to the students (1st/2nd year) of the study program "Informatics". Since 2015/2016 two optional courses "Fundamentals of Astronomy" and "Fundamentals of Mechanics" have been offered to the 2nd year students of Informatics.

Lectures in optional courses "Introduction to Theoretical Mechanics" (for the 4th year students of mathematics) and "Continuum Mechanics" (for the master students of theoretical mathematics and astronomy) are given by professors of the Department of Astronomy. The first master thesis in Mechanics was defended at the Department of Astronomy in September 2017. This thesis was selected among the five best theses at the contest of students works organized by Mathematical Institute of Serbian Academy of Sciences (Kovačević, 2017).

At the Faculty of Physics astronomy is taught as part of the curriculum with a compulsory one-semester course Fundamentals of astrophysics at the 1st year of master studies for physics teachers division, and an optional one-semester course under the same name for the students of the 1st year of B (theoretical) division and for the students of the 2nd or 3rd year of A (general) division. In three school years, from 2014/2015 to 2016/2017, on average 35 students per year took this course. Since 2015 (new accreditation) Fundamentals of astrophysics is a compulsory one-semester course for the students of the 4th year of A (General Physics) division. Additionally, a course "Fundamentals of astronomy" is introduced as a one-semester optional course at the master studies for A division.

At the Faculty of Civil Engineering, a compulsory course "Geodetic astronomy" (4th year) is taught to the students of geodesy. At the Faculty of Geography, basic astronomical topics are taught within the first-year course "Mathematical Geography" for the students of General division and Geography teachers division (Tadić, 2017).

Two new university textbooks: "Astrobiology" by Andjelka Kovačević and "Active galactic nuclei" by Luka Č. Popović and Dragana Ilić are published by the Faculty of Mathematics in 2016 and 2017, respectively.

New accreditation at the Department of Physics of the Faculty of Natural Sciences (FNS) at **the University of Novi Sad** is in progress. According to new programs, which are expected to start in 2018/2019, eleven optional courses in astronomy and astrophysics will be offered at the undergraduate studies in Physics (there will be no more a division physicist-astronomer-astrophysicist at undergraduate studies), whereas the master studies in astrophysics will have focus on high energy astrophysics. In the past three years 27 students enrolled astronomy undergraduate studies and 5 students enrolled master studies at the Faculty of Natural Sciences in Novi Sad. Five students graduated and no students received the Master degree (Prodanović 2017).

In 2016 the FNS obtained COST project "Chemical Elements as Tracers of the Evolution of the Cosmos" (prof. Tijana Prodanović is a project manager), as well as a bilateral cooperation with Slovenia (2016-2017). In 2017 the FNS signed the cooperation agreement with ICRANET (International Center for Relativistic Astrophysics

Network) with the aim of networking, linking, common databases, cooperation in research, study exchanges, organization of joint events and cooperation on doctoral studies.

At the Department of Geography of the FNS in Novi Sad, a course "Mathematical geography with the fundamentals of astronomy" (3+2) is taught in the first study year (Tadić, 2017).

At the Institute of Physics of the Faculty of Natural Sciences of **the University of Kragujevac** there is a one-semester (2+2) optional course, "Astrophysics and Astronomy", for the 5th-year (master) students of all three modules of Physics (Simić, 2017). Almost all the students choose this course.

New accreditation is in progress. The course "Astrophysics and Astronomy" is expected to be a compulsory course for the module A1.

New university textbook "Fundamentals of Astronomy and Astrophysics for the students of Physics (Part I)" by Luka Č. Popović and Saša Simić is published by the Faculty of Natural Sciences of the University of Kragujevac in 2017.

At the Department of Physics at the Faculty of Natural Sciences (FNS) of **the University of Niš**, an elective course "Introduction to Cosmology" is taught at the 3rd study year of undergraduate studies. At Master studies, a compulsory course "Fundamentals of Astrophysics" (2nd year) for the students of General Physics is taught. Two hours per week have been added for tutorials. Two optional courses "Fundamentals of planetology" and "Stars and stellar systems" are introduced at Master level. The course "Fundamentals of Astrophysics" is elective for the master students (1st year) of Physics - Informatics. At the PhD level, there are two elective courses: "Cosmic plasma" and "Fundamentals of cosmology" (Gajić, 2017).

At the Department of Biology, an optional course "Fundamentals of astrophysics with astrobiology" is taught at the third study year. At the Department of Geography, an elective course "Astronomy" is offered to the first-year master students. About 50-70 students attend the astronomical courses at the University of Niš. At the Department of Geography, a course "Mathematical geography" (2+2) includes some basic astronomical topics (Tadić, 2017).

The Department of Physics possesses five amateur telescopes (Mead LX 200, Skywatcher 120 X 1000, Lunt telescope LS60T, Vixen refractor and school Russian spyglass). Apart from a dome that is installed on the roof of the Faculty, the Department of Physics now has a new Laboratory for astrophysics, astrobiology and astronomy located in the attic of the Faculty. It is used for seminars and lectures. Moreover, it is connected to the observatory, so that it can be used for the telescope control. There is a permanent photo exhibition (about 30 astrophotographs) by Miodrag Sekulić (Gajić, 2017).

At **the University of Priština in Kosovska Mitrovica** a one-semester 2-hour per week compulsory course, "Fundamentals of astronomy and astrophysics", is taught to the second year students of physics.

At the Department of Geography at the FNS in Kosovska Mitrovica, a course "Mathematical geography" (2+2) includes some astronomical topics (Tadić, 2017).

3. 1. RESEARCH IN ASTRONOMY

The big news for astronomy research and education in Serbia is the mounting of new 1,4 m telescope "Milanković" on the mountain Vidojevica in June 2016.

4. PUBLIC OUTREACH

Public astronomy education in Serbia was realized mainly through the lectures held in: Kolarac, Belgrade Youth Center, Students Cultural Center, Serbian Academy of Sciences and Arts, in two Planetaria (Belgrade and Novi Sad) and in public observatories, through special events (Festival of Science, Night of Researchers, Night of Museums, Book Fair, etc.) and various activities of 24 amateur astronomical societies.

The AS "Eureka" from Kruševac (active since 2010) was registered in 2016. New astronomical society "Vlašići" for archeoastronomical and etnoastronomical research was founded in 2014 in Belgrade.

Apart from its usual activities: Astronomy courses for beginners, Belgrade astronomical weekends, Summer Schools of Astronomy (in August) and Special topical meetings "Summer Astronomical Meetings" (the 18th on Small Solar System Bodies held in 2015, and the 19th on Serbian Astronomical Cultural Heritage, held in 2017), the AS "Rudjer Bošković" (Belgrade) organized the 1st Belgrade Summer School of Astronomy in August 2017 (Simonović, 2017).

In the past three years the Astronomical Society "Rudjer Bosković" and the Society of Astronomers of Serbia used the mobile planetarium as a tool for astronomy communication. Also, lectures were held in many primary schools all over Serbia. The societies had cooperation with Serbian scientific television, Center for the promotion of science, Mensa, Serbia, etc. (Aleksić, 2017).

Regular lectures on Thursdays have been held by ADNOS in Planetarium within Petrovaradin fortress. Since 2016 Stargate stage has been organized by ADNOS during EXIT. Twenty two lectures were given during the "Novi Sad School of Astronomy" to about 30 participants. In 2017 ADNOS organized the Festival of Night Sky with the Academy of Art of Novi Sad. Since December 2015 ADNOS has made and used digital planetarium under the dome of Planetarium. ADNOS became a part of the focus group for the future of Petrovaradin fortress (Prodanović, 2017).

Astronomical Meetings of Vršac (AMV) have been organized by the Astronomical group within the Natural History Society "Gea", Autumn and Spring Schools of Astronomy by the AS "Andromeda" (Knjaževac), and astronomical camps in Sivčina by the AS "Orion" (Ivanjica). "Eureka" from Kruševac organized Eureka Days and Eureka Picnic. There are several examples of an intensive collaboration among the amateur astronomical societies in Serbia - astronomical camps Letenka, Sivčina, Golija and Jastrebac. The international astronomical camp "Letenka" is one of the biggest camps for the popularization of astronomy in Europe. About 200 people (mostly secondary school and university students) take part in "Letenka", which takes place every year in July on the mountain of Fruška gora.

More details on the activities of the amateur astronomical societies in Serbia can be found on their web sites given in Table 1 of the paper by Atanacković (2017), in the paper by Zorkić (2017), as well as on the Astronomical Magazine (AM) web site. Their usual activities and equipment are described in detail in the paper by Atanacković (2012).

Astronomy has also been popularized by the "Mladi fizičar" ("Young Physicist"), a quarterly magazine for the elementary and secondary school students.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 101 - 108 *Progress Report*

DEPARTMENT OF ASTRONOMY AT PETNICA SCIENCE CENTER: 2013-2017

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Abstract. We review the activities of the Department of Astronomy at Petnica Science Center (PSC) within the years 2013-2017. The Department of Astronomy's dominant activities are aimed at high school students. The main educational principle of PSC is "education of students by other students" as high school students are taught and mentored mostly by undergraduate students. The full educational cycle at the Department of Astronomy presumes two years during which participants are introduced to the basics of astronomy and research methodology and, as a result of that, finish a research project. We will outline the present structure of the astronomical educational activities at PSC, topics of the participants' research projects and other activities in the mentioned period and future plans.

1. NATURE OF THE EDUCATIONAL ACTIVITIES

Petnica Science Center (PSC) is the biggest and one of the oldest (established in 1982.) independent nonprofit organizations for extracurricular, informal science education in South Eastern Europe for highly motivated high school students. It is located near a village Petnica, close to Valjevo (Serbia). Educational activities are realized by a series of seminars on an annual basis. Organisation of the seminars is done by sixteen departments, one of which beeing the Department of Astronomy (AST), formed at the beginning of PSC. Besides its primary focus, PSC also organizes seminars and camps for elementary school and undergraduate students, as well as science teachers. This progress report focuses on the present structure of the educational activities at AST, topics of the participants research projects and other activities during the period between 2013. and 2017. and future plans. More information on PSC can be found elsewhere (Majić 2006) as well as a historical background of AST (Salim 1997, Božić 2009, Milić et al. 2013). During 2011. and 2012. PSC went through infrastructure expansion, some information on which can be found at `http://almanah.petnica.rs/27/pdf/B27-WEB.pdf` (pp. 84-95).

There are four pillars upon which are educational activities at the PSC organized - learning through research, tutoring, peer education and informal work atmosphere (Majić 2008). The central aspect of the PSC programs is individual work on research projects. All other activities - lectures, exercises, workshops, discussions etc. are intended to facilitate this proces. In this way the participants can focus on concrete problems, during the whole year. These problems are research problems by their nature and not artificially prepared textbook problems (Hogg 2007). Participants learn about the theoretical context of the problem, methodology needed for its solution but also how to work in team, discuss ideas with their peers and tutors and communicate their results via oral presentation, poster and article. Work on projects is, in AST, done during the second (and beyond) year of participants attendance of the department seminars - Astronomija 2 (see Section 2.2; further in the text - AST2). First year (Astronomija 1, see section 2.1; further in the text - AST1) is intended to prepare students, theoretically and methodologically, for the work that is to be done on AST2. After four seminars of AST2, students, who finish their projects until stated time limit, will present their results on annual Petnica students' conference - "Korak u nauku" ["A Step into Science"] and prepare their articles to be published at Petničke sveske [Petnica papers], proceedings of the students conference. Starting from 2016., participants of AST have an opportunity to also present their work to the members of the Serbian astronomical community at the University of Belgrade.

Tutoring is the most effective type of education (Bloom 1984) and in PSC is realized through a peer process - education of (high school) students by (undergraduate) students. Undergraduate students are in PSC terminology known as the junior associates and are mostly recruited from former participants. In this way, they are familiar with the type of work and the atmosphere at the PSC, and their stay is a continuation of their participants days. Postgraduate students, university lecturers and researchers (senior associates in PSC terminology) deliver most of the lectures on seminars and supervise and council undergraduate students on their work with participants. In this way, junior associates are also beneficiaries of the PSC activities. Most of the junior and senior assosites at AST are affiliated with the Serbian astronomical community. On the other hand, a large number of both junior and senior associates are affiliated with the physics and computer science communities and sometimes others. This fact is responsible for the multidisciplinary character of the AST, as it is simultaneously part of the astronomical community and independent from it. Consequence of this fact is that projects on AST are sometimes focused on, astronomy-related, topics and methods in theoretical physics, computer science and instrument building not necessarily present in the research and educational program of the domicile astronomical community. More details on partner institutions can be found in Section 3.

PSC does not issue diplomas or certificates for the participants of its programs, nor are the participants given tests, exams, marks and public rankings. In this way we want to eliminate unnecessary stress, turn mutual competition into cooperation and focus on everyone doing their best work on their own pace (MacKay 2005). The participants are neither selected on the basis of their school marks, type of school programs nor number of competitions they participated in. The selection process is inclusive and does not discriminate on any of the applicants identities or their financial means. After the initial selection process, all further selection is minimal and dictated by financial and infrastructural limitations of the PSC as well as the effort and the participants level of interest. Participants are encouraged to ask questions, debate their peers, but also associates. As opposed to the dominant architecture of the school and university programs, in PSC we intend to show science as a "living creature", happening right here and now, which must not be held as some fixed dogma and is immersed in the social context.

Program and the activities of the individual seminars on the AST are proposed by the head(s) of the department and discussed on regular meetings of junior and frequent senior associates during the year. In that way, educational process is fluid and subject to self-criticism (Verbić 2008). On the annual basis meeting of the program comission, whose members are some of the senior associates, with the head(s) of the department takes place, during which are previous activities and future plans discused. Heads of the department in the period on which this report focuses were Andrej Obuljen (2013 and 2014.), Mateja Bošković (2015-2017.) and Dušan Vukadinović (2017.)

2. STRUCTURE OF THE SEMINARS

2. 1. SEMINARS FOR THE FIRST TIME PARTICIPANTS - AST1

The AST1 program consists of three seminars - the winter seminar (lasting six days), practical seminar (lasting eight days) and the autumn seminar (four days).

The winter seminar focuses on walking the participants through the basics of astronomy, as well as the mathematical and physical methodological background. The activities are divided between lectures, collective and individual discussion sessions, as well as practical exercises covering stargazing and basic telescope handling. Before coming to AST1, participants are not satisfactory introduced to astronomy at the public school level, as it is covered as a part of other subjects (physics and geography), where only certain aspects of the science are discussed (Atanacković 2018.).

During the first part of the winter seminar, taking place on the first day, participants get introduced with distance-scales in astronomy, main astrophysical objects, qualitative spherical astronomy and Order of Magnitude estimation techniques.

The second part of the winter seminar lasts three days and focuses on establishing a methodological basis needed for a more serious understanding on astrophysics. This includes lectures on elementary mathematics, basics of calculus, newtonian mechanics, optics, more formal introduction to spherical astronomy, astronomical photometry and spectroscopy and astronomical instruments. Mathematical techniques are motivated through (astro)physical problems, with a different approach than the one being commonly used in high schools and universities in order to be effectively covered for short period of time and avoid too much mathematical rigor.

The third part of the winter seminar, lasting two days, focuses on the main astrophysical disciplines - study of the stellar strucure and evolution, planetary sciences, galactic and extragalactic astronomy and cosmology.

Participants also engage in individual work during the seminar - by solving simple problems and/or writing short essays on some (astro)physical concepts and preparing group presentations covering certain aspects of discussed concepts. These activities, amongst other things, represent a powerful educational tool for acquainting the students with scientific literature and presentation techniques.

The *practical seminar* focuses on a hands-on approach to the theoretical concepts introduced during the winter seminar, as well as providing an introduction to data analysis, astronomical image processing and numerical simulations. This is accomplished through exercises, workshops and lectures. Data analysis is often, in undergraduate and sometimes even postgraduate education and research practice, being presented as a list of procedures with, often problematic, intuitive explanations (Hogg et al. 2010). To avoid these problems, we have been trying to incorporate the basics of statistical inference into our seminars in the last couple of years.

Exercises focus on measurement and data analysis methodology and participant work on them in small groups. Some examples of such exercises are: "Determining the gravitational acceleration of the Earth with a mathematical pendulum", "Determining the distance to M100 using Cepheid light curves","Determining the solar noon and geographical coordinates of Petnica using a gnomon" and "Establishing the relation between thermal noise and temperature of a CCD camera". Participants also write reports for some of the exercises, which are subsequently and iteratively corrected through discussions with junior associates.

During the workshops, that take place at the seminar, junior associates are tutoring participants, as opposed to exercises, which are more independently done. Workshops methodologically cover introduction to programming and numerical methods and observations and image processing. Examples of the workshops are: "Performing the astronomical observations", "Astrophotometrical image processing of an asteroid and determination of its period", "Programming basics" and "Determining the equivalent width of a spectral line". Introduction to exercises and workshops are mostly done through series of problem solving sessions, in order to avoid the standard "cookbook" approach of the most of the schools and universities to practical exercises.

The *autumn seminar* serves to conclude the whole year and starts the process of defining student projects which will be worked on during the following year. Thus, the students listen to lectures which could serve as an inspiration for their projects. The seminar also includes a good deal of thematically organized discussions with the junior and senior associates, aiming to support the project selection process. The students also work on small projects in groups, which serve as a "simulation" of the work they would put in on their project during AST2. Some examples of small projects are: "Modelling limb darkening", "Determining the Chandrasekhar limit", "Exoplanet transit light curve image processing and analysis".

2. 2. SEMINARS FOR THE LATER YEARS OF PARTICIPANTS ATTENDANCE - AST2

Program of AST2 seminars are shaped by participants' chosen topic of research. Topics range from ones more theoretically minded, over those where participants apply statistical methods for observational data reduction to observations and instrumentation building. Many of these projects span objects and phenomena from planetary to cosmological scales. AST2 seminars are organized four times a year.

The *winter seminar* lasts four days and is the seminar in which participants start active work on their projects. They also have lectures on advanced mathematical methods (linear algebra and numerical methods) and have an opportunity to hear about important discoveries in astronomy from the previous year. *The spring seminar* lasts for three days and has a similar structure to the winter seminar, but focuses more on advancing participants programing skills and data analysis techniques.

The central part of AST2 is the *summer seminar*, lasting for two weeks, when participants have nearly the whole day to work on their projects. There is only one lecture on a daily basis. These lectures are given mostly by senior associates and their topics cover modern research in astronomy and related disciplines. The purpose of these lectures is to give the participants an insight into modern research, possibly leading to new ideas for their projects.

The last seminar of AST2 is the *autumn seminar*, lasting three days, during which participants finish their work, discuss results and begin to write a final report about their work.

Between seminars on both AST1 and AST2 the participants are given small exercises to do at home. They are mostly intended for them to develop some technique like mathematical and numerical methods, data reduction etc. Also, between each seminar of AST2 participants are asked to write a progress report on their project.

2. 3. OVERVIEW OF THE RESEARCH PROJECT TOPICS

We will now give a description of selected projects, representing various astronomical subjects, which were most developed and/or give best representation of the type of work on AST2 in the relevant period. Exception is 2017., because these projects are presently being prepared for submission and will be the subject of the next report.

Research projects in *stellar structure and evolution* focused on compact objects and globular clusters. A recent project regarding compact objects explored the question of universality of I-Love-Q relations for white dwarfs (Đukić 2017). I-Love-Q relations are relations between moment of inertia, quadrupole moment and Love number. These relations were found not to be sensitive to the change of the (realistic) equation of state for neutron stars, when describing their structure. Participant showed that this is also the case in white dwarfs. In the late stages of his work, a similar result was published in one of the high-impact astrophysical journals (Boshkayev et al. 2016).

As for globular clusters, several projects examined ways of obtaining parameters of globular clusters, by matching their Color-Magnitude diagrams with stellar isochrones. In one of them (Vukadinović 2014) problem was approached by means of the nearest member method and chi- square minimization and in the other (Milić and Kološnjaji 2016) by use of neural networks.

Theoretical research in *astronomical spectroscopy* and stellar and planetary atmospheres has been mostly focused on radiative transfer problems, but also issues around spectral line broadening. For example, Petković and Kresović (2016) examined forming of the D2 emission line of sodium in the comets atmosphere. They used simple models for the nucleus and coma of the comet and generated sodium line profiles for different heliocentric distances. They established a one-to-one correspondence between the heliocentric distance and flux of the spectral line.

Projects in *celestial mechanics* have historically been dominant in the Department, even leading to one of the projects beeing presented at the Colloquium of the International Astronomical Union (Čubrović 2005). One of the projects in the period on which we report focused on the dynamics of small Solar System objects (Kostić 2015). Participant examined the dynamics of ejected dust particles from the surface of the cometary nucleus. He developed a model that enables the simulation of the comets head and dust tail formation, as well as the prediction of the comets potential meteor stream. This model was applied to the C/2012 S1 (ISON) and C/2011 W3 (Lovejoy) comets. Comets dust tail morphology was compared with the observations of these comets from the SOHO satellite.

N-body simulations, an important aspect of a lot of celestial mechanics projects, are also constitutive part of most projects in *extragalactic astronomy*. One example being the project which investigated the impact of the direction of rotation on the formation of tidal tails on the example of the Antennae galaxies (NGC 4038/4039) (Saulić 2015). During the recent years, a lot of the projects in extragalactic astronomy used GADGET and GalactICS software packages, this one being no exception. In order for the participants not to use these packages as a "black box", it is expected of them to develop rudimentary N-body codes. In the case of the mentioned project, participant wrote Barnes-Hutt tree algorithm and compared results with the GADGET/GalactICS packages.

In one of the *astrobiological* projects (Mihajlović 2015), the Daisyworld model has been implemented with probabilistic cellular automata, in order to examine the influence of biotic factors on the global thermoregulation and consequently the habitability of a planet. Biotic factors were represented with two types of daisies: black and white, with different albedos. The model has been tested for a flat planet and for a planet modeled as a sphere.

Projects in *observational astronomy* were historically mostly focused on photometric observations and analysis of light curves of various systems - meteors, asteroids, stars during planet or another star occultation, variable stars, close binary systems etc. In one of these projects (Milanović and Grašić 2015), F parameter of meteor light curve, which indicates a location of the maximum of the light curve, was estimated from the meteor video data of Geminids and Orionids. This parameter is related to the internal structure of the meteor. Participants developed a method for calculating F parameter based only on one-station video data. Continuation of this work has been presented at the annual conference of the International Meteor Organization (IMO) (Grašić et al. 2016). Observational projects where the participants themselves were doing observations where rarer in this period than previously (Milić et al. 2013). The main reason for this is the absence of usable astronomical equipment in PSC during the reported interval.

3. PARTNER PROGRAMS AND COLLABORATIONS

A partner group at PSC but independent from it is the *Petnica Meteor Group* (PMG). This group is concerned with meteor astronomy and related topics in celestial mechanics and planetary sciences. During its existence, officially from 1993. (Pavlović et al. 2016) but unofficially even before the beginnings of PSC (Salim 1997), PMG organized observational camps for different meteor showers (Geminids, Perseids, Orionids etc.) and has also done work in processing this observational data. Since the first observational camps, PMG reports observation logs to IMO. PMG also organizes (since 2009.) the School of Meteor Astronomy, intended for high- school and undergraduate students. School lasts one week and is organized during the summer with the aim of covering theoretical and data-reduction basics of meteoric astronomy. Several of PMG members are or were participants and junior associates at AST. PSC and PMG were two times hosts of annual IMO conference - in 1997. and 2017. More on activities of PMG can be found on `www.meteori.rs`.

Since 2013, a group of senior associates of AST has been organizing *Petnica Summer Institute* (PSI) - an annual international summer school for undergraduate and early graduate students covering topics in theoretical (astro)physics. PSI is primarily oriented towards students in the Balkans region, but international students also apply as the school is in English. The topics of the school change in a four year cycle in a respective order - cosmology, high energy physics, astrophysics and astroparticle physics and general relativity. Lectures at the school are mostly given by senior PhD students and postdoc researchers from various European and US institutions, but also by some senior researchers. Alongside lectures, problem solving sessions and small workshops are also part of the activities at PSI. PSI has been supported by ICTP, SISSA, ETH, CERN and University of Nova Gorica so far and these are also institutions at which a substantial number of school lecturers work. Significant percentage of the participants of PSI every year are junior associates of PSC, mostly from AST but also Departments of Physics and Mathematics, making PSI a part of continuing education for them. More on activities of PSI can be found on `psi.petnica.rs`.

PSI is only one of the examples of former participants and junior associates of PSC working at foreign institutions that continue collaborating with PSC. Every year, but mostly during the summer seminars, several of senior associates working at prestigious foreign institutions come to PSC and give lectures or participate in participants' projects' tutoring. Some of the examples, in the case of AST, are Institute for Advanced Study, Max Planck Institute for Solar System Research, SISSA, Aix-Marseille University, Stevens Institute of Technology, SETI Institute etc.

Most of the senior associates at AST work at the Department of Astronomy at the Faculty of Mathematics (University of Belgrade), Astronomical Observatory in Belgrade and affiliated to it - Astronomical Station Vidojevica (ASV). Other domicile institutions at which senior associates work are Department of Physics at the Faculty of Mathematics and Natural Sciences (University of Novi Sad) and Institute of Physics in Belgrade. AST also collaborates with ameteur astronomical organizatons, most notably Astronomical societies "Vladimir Mandić Manda" from Valjevo and "Univerzum" from Bačka Palanka.

During the past few years, observational work for participants' projects was done at the ASV and Astronomical society "Univerzum". Some of the highliths of collaborations with ASV were participants' involvment in MONECOM project of observing main belt comets activity (Bogdanović et al. 2013) and observations of extrasolar planets transit several times during 2017.

4. FUTURE PLANS

At the end of the last year we have formed, revised from Milić et al. (2013), a list of necessary mobile equipment for observational exercises and projects. Previous list has never been ordered because of technical and financial problems. Equipment is intended for variable stars observations, exoplanet transits and observations of small bodies of the Solar System. The most important part of equipment includes SBIG STF-8300 monochrome CCD, SBIG ST-i guiding kit and Celestron CGX EQ mount and tripods for Celestron C8 and C11 Schmidt-Cassegrain telescopes which are part of the set of astronomical instruments at PSC. We hope to have this equipment until mid 2018. With this equipment in the future we intend to raise the number of hands-on observational activities and facilitate participants going through the whole of the observational process as explained in Milić et al. (2013).

During the Winter semester in 2014. and Summer semester in 2017. journal club for the associates of AST has been organized in order to generate ideas for both the participants and junior associates projects. Some of these ideas are continuation of the former participants project work. We also plan to intensify this activity.

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TESTING EXTENDED THEORY OF GRAVITY BY Sgr A*

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Abstract. Here we analyze an Extended Gravity Theory model, in which there is non-minimal coupling between the geometry and a scalar field. We derived a particular theory among the class of scalar-tensor theories of gravity, and then tested it by studying dynamics of S2 star around supermassive black hole at the Galactic Center. We also discuss the Newtonian limit of this class of scalar-tensor theories of gravity, as well as its parameters. To constrain these parameters, we compare the observed orbit of S2 star with our simulated orbit which we obtained theoretically with the derived potential.

1. INTRODUCTION

In this study, we consider possible signatures for a Scalar Tensor (ST) theory within the Galactic Central Parsec, not tested at these scales yet. This theory of gravity contains two arbitrary functions of the scalar field: $F(\phi)$, which underlines a non-minimal coupling between the scalar field and the geometry, and $V(\phi)$, which implies a self-interaction of the field. The specific form of these functions is determined by the parameters (m, n, ξ, λ). In order to constrain these parameters observationally, we derived the modified gravitational potential of the central object in the weak field limit to simulate orbits of S2 star, and then we compared the results with the set of S2 star orbit observations obtained by the Very Large Telescope (VLT). This is a continuation of our previous studies where we considered different extended gravities models: $f(R)$ gravity (Borka et al. 2012, Zakharov et al. 2014, Zakharov et al. 2016), $f(R, \phi)$ gravity (Borka et al. 2013, Capozziello et al. 2014, Borka et al. 2016).

Sagittarius A (or Sgr A) is a complex radio source that consists of three components, which overlap: (1) Sgr A East (the supernova remnant), (2) Sgr A West (the spiral structure), (3) Sgr A* (a very bright compact radio source at the center of the spiral) (Ghez et al. 2000, Ghez et al. 2008, Genzel et al. 2010). Sgr A* is very compact and motionless source, and its location coincides with the dynamical center of the Galaxy. The massive black hole Sgr A* at the Galactic center (GC) is surrounded by a cluster of stars orbiting around it: S-star cluster. Light from these stars is bent by the gravitational field of the black hole. S-stars are orbiting with large velocities ($v > 1000$ km/s), and have very eccentric orbits around central supermassive black hole (SMBH) at GC. S2 star is one of the brightest members of the S-star cluster. It has about 15 Solar masses and seven times its diameter, with orbital period of approximately 15.8 yr (Genzel et al. 2010, Gillessen et al. 2012). There are a few indications that S2 star orbit really deviates from the Newtonian case. Some recent studies (Gillessen et al. 2009a, Gillessen et al. 2009b, Meyer et al. 2012, Gillessen et al. 2017, Boehle et al. 2016) provide evidence that the orbit of S2 star is not closing.

2. THEORY

Extended Theories of Gravity (ETGs) are physical theories that attempt to describe the phenomena of gravitation in competition to Einstein's theory of general relativity, by preserving the undoubtedly positive results of Einstein's theory. Instead of introducing Dark Matter (DM), a hypothetical type of matter, some theories, which modify the laws of gravity, could explain in a very natural fashion several astrophysical and cosmological observations: for short distances, Solar system, spiral galaxies, galaxy clusters and cosmology. See reviews in: Capozziello & Faraoni 2010, Capozziello & De Laurentis 2011, Nojiri & Odintsov 2011, Capozziello & De Laurentis 2012, Clifton et al. 2012.

The ST theory of gravity contains the metric tensor $g_{\mu\nu}$ and a fundamental scalar field ϕ (Capozziello et al. 1996). The coupling $F(\phi)$ and the potential $V(\phi)$ are generic functions of the scalar field ϕ. In this study we take the action of the form:

$$S = S_M + \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}[F(\phi)R + \frac{3}{2\phi}g^{\mu\nu}\phi_{,\mu}\phi_{,\nu} - V(\phi)]. \tag{1}$$

We choose a specific form for $F(\phi) = \xi\phi^m$, $V(\phi) = \lambda\phi^n$, where ξ is a coupling constant, λ gives the self-interaction potential strength, m and n are arbitrary parameters.

We obtained solutions for few different cases $h_{00} = 0.5\Phi$, where Φ is Newtonian potential.

In case of $n \neq 0$ and $n \neq 2m$, we obtain:

$$h_{00} \simeq \frac{\kappa^2}{4\pi\xi\varphi_0^m}\frac{M}{r} - \frac{\lambda}{2\xi}\varphi_0^{n-m}r^2 - \frac{\kappa^2 m^2 M}{3(1-m^2\varphi_0^{m-1}\xi)}\frac{e^{-pr}}{4\pi r}, \tag{2}$$

where κ is a coupling constant and M is central mass.

In case of $n = 2m$, we obtain:

$$h_{00} \simeq \frac{\kappa^2 M}{4\pi r}[\frac{3 - 3m^2\varphi_0^{m-1}\xi - m^2\xi\varphi_0^m}{3\xi\varphi_0^m(1-m^2\varphi_0^{m-1}\xi)}] - \frac{\lambda\varphi_0^m}{2\xi}r^2. \tag{3}$$

In case of $n = 1$, we obtain:

$$h_{00} \simeq \frac{\kappa^2 M}{4\pi r}\left[\frac{3 - 3m^2\varphi_0^{m-1}\xi - m^2\xi\varphi_0^m}{3\xi\varphi_0^m(1 - m^2\varphi_0^{m-1}\xi)}\right] - \frac{\lambda\varphi_0^{1-m}}{2\xi} r^2. \tag{4}$$

3. RESULTS AND DISCUSSION

We derived the modified gravitational potential of the central object in the weak field limit to simulate orbits of S2 star, and then we compared the results with the set of S2 star observations obtained by VLT. The ST gravitation potential in the weak field limit can be written in the form:

$$U_{ST} = \frac{\widetilde{G}}{\xi\varphi_0^m}\frac{M}{r} - \frac{\lambda}{4\xi}\varphi_0^{n-m} r^2 - \frac{\widetilde{G}m^2 M}{3(1 - m^2\varphi_0^{m-1}\xi)}\frac{e^{-pr}}{r}, \tag{5}$$

where p is function of the ST gravity parameters ξ, λ, m and n:

$$p = \sqrt{\frac{\lambda n\varphi_0^{n-1}(2m - \lambda n)}{3(m^2\xi\varphi_0^{m-1} - 1)}}, \tag{6}$$

and $\widetilde{G}$ is related with a gravitation constant G_N through relation:

$$\tilde{G} = -\left[\frac{3(1 - m^2\varphi_0^{m-1}\xi)\xi\varphi_0^m}{3 - \xi(3m^2\varphi_0^{m-1} + m^2\varphi_0^m)}\right] G_N. \tag{7}$$

In order to constrain parameters λ, ξ, m and n observationally, we performed two-body simulations of S2 star orbit in ST gravity potential by numerical integration of the following two differential equations of motion:

$$\dot{\overrightarrow{r}} = \overrightarrow{v}, \qquad \mu\ddot{\overrightarrow{r}} = -\overrightarrow{\bigtriangledown} U_{ST}(\overrightarrow{r}), \tag{8}$$

where $\mu = M_{BH} \cdot m_S/(M_{BH} + m_S)$ is the reduced mass in the two-body problem (m_{BH} being the mass of the central black hole and m_S the mass of the S2 star).

The positions of the S2 star along its true orbit are calculated at the observed epochs using two-body simulations in the ST gravity potential, assuming that distance to the S2 star is $d = 8.3$ kpc and mass of central black hole $M_{BH} = 4.3\ \times 10^6 M_S$ (Gillessen et al. 2009a).

All the above two-body simulations in ST gravity potential resulted with the true orbits of S2-like stars, i.e. the simulated positions of S2-like stars. In order to compare them with observed positions, the first step is to project them to the observer's sky plane, i.e. to calculate the corresponding apparent orbits (x, y).

We chose some values for ϕ_0, m and n, with the following conditions: ϕ_0 is positive real number close to 1, m and n are integer numbers, for which: $n \neq 2m$ and $n \neq 0$. The initial values for true position (x_0, y_0) and orbital velocity $(\dot{x}_0, \dot{y}_0)$ of S2 star at the epoch of the first observation are specified and the positions (x_i, y_i) and velocities $(\dot{x}_i, \dot{y}_i)$ of S2 star along its true orbit are calculated for all observed epochs by numerical integration of equations of motion in the ST gravity potential. The observed

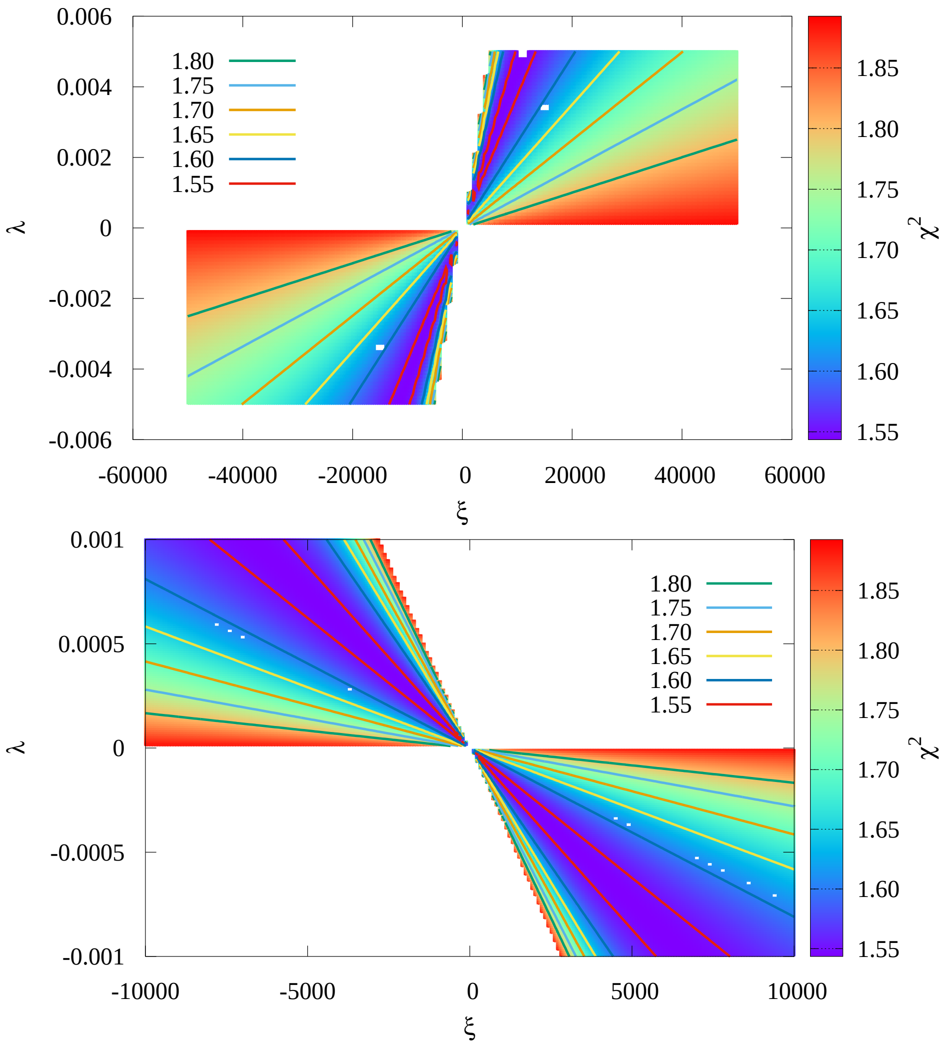

Figure 1: *Top*: The map of the reduced χ^2 over the parameter space $\{\xi, \lambda\}$ of ST gravity in case of NTT/VLT observations of S2 star which give at least the same (χ^2 =1.89) or better fits ($\chi^2 < 1.89$) than the Keplerian orbits. Figure represents case for $(m, n) = (2, 2)$. *Bottom*: The case for $(m, n) = (1, 3)$. A few contours are presented for specific values of reduced χ^2 given in the upper left part of the top figure, and in the upper right part of the bottom figure.

values we denote with (x_i^o, y_i^o), the calculated with (x_i^c, y_i^c), and the variances are σ_{xi}, σ_{yi}. The reduced χ^2 of the fit is estimated according to the following expression:

$$\chi^2 = \frac{1}{2N - \nu} \sum_{i=1}^{N} \left[\left(\frac{x_i^o - x_i^c}{\sigma_{xi}} \right)^2 + \left(\frac{y_i^o - y_i^c}{\sigma_{yi}} \right)^2 \right]. \tag{9}$$

Table 1: χ^2 for different values of m, n, ξ and λ gravity parameters (for all these calculations we used $\phi_0 = 1$).

χ^2	m	n	$\{\xi, \lambda\}$
1.5434359	1	1	-11000, -0.0049
1.5434454	1	3	33000, -0.0049
1.5434454	2	1	-9000, -0.0050
1.5434363	2	2	11000, 0.0049
1.5434474	2	3	-1000, -0.0006
1.5434336	3	1	1000, 0.0008
1.5434383	3	2	1000, 0.0005
1.5434454	3	3	33000, -0.0049
1.5434317	4	1	4000, 0.0041
1.5434478	4	2	-1000, -0.0006
1.5434454	4	3	33000, -0.0049

We vary the parameters ξ and λ over some intervals, and search for those solutions which for the simulated orbits in ST gravity give at least the same ($\chi^2 = 1.89$) or better fits ($\chi^2 < 1.89$) than the Keplerian orbits. We repeat the procedure for different combinations of parameters m and n (see some examples in Table 1). For more detailed description about fitting procedure and numerics see in papers (Moré et al. 1980, Borka et al. 2013).

The map of the reduced χ^2 over the parameter space $\{\xi, \lambda\}$ for $(m, n) = (2, 2)$ is given in Fig. 1 (top). This map shows an area of all the parameter values $\{\xi, \lambda\}$ for which the simulated orbits of S2 star give at least the same or better fits than the Keplerian orbits. The map of the reduced χ^2 over the parameter space $\{\xi, \lambda\}$, but for $(m, n) = (1, 3)$, is given in Fig. 1 (bottom). According to Fig. 1 we can notice that different choice of parameters m and n position of the region of allowed values of the parameters $\{\xi, \lambda\}$.

4. CONCLUSIONS

In this paper, orbit of S2 star has been investigated in the framework of the ST gravity potentials. Using the observed positions of S2 star around the GC we constrained the parameters of these gravity potentials.

We derived a particular theory among the class of ST theories of gravity, and then tested it by studying dynamics of S2 star around SMBH at GC.

We also discuss the Newtonian limit of this class of scalar-tensor theories of gravity, as well as its parameters.

We constrained the parameters of ST gravitational potential.

To constrain these parameters, we compare the observed orbit of S2 star with our simulated orbit which we obtained theoretically with the derived potential.

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ANATOLY ANATOLYEVICH MIHAJLOV
(1941-2016)

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Abstract. Life and work of Anatoly Anatolyevich Mihajlov (1941-2017) is presented.

After severe illness, on September 27, 2016, in the 75 years, Anatoly Anatolyevich Mihajlov, a prominent Serbian physicist and astrophysicist, a retired Research Professor at the Institute of Physics, a long-term external associate of the Astronomical Observatory, abandoned us forever. His life was full of creative dedication and was adorned by a great professional enthusiasm and research passion.

Mihailov was born on October 20, 1941 in Krasnoyarsk, Russia. He studied in Leningrad, where he lived since 1947. He graduated in 1967 at the Faculty of Physics, at the Department of Optics, and also passed all exams at the Department of Quantum Mechanics, where from the middle of the second year until the end of his studies, he worked on the project of creating current-free gas plasmas, and from this topic, in December 1967 he defended Diploma work, which was the basis for the paper Voroncev et al. (1970). After graduation, he was employed at the State Optical Institute and until 1976 published six papers in journals. Particularly significant is the article Smirnov and Mikhajlov (1971), in which, for the first time, a new mechanism of energy conversion within the electronic component of the atomic system - the Ridberg atom was introduced. It was immediately accepted as one of the two basic mechanisms of inelastic processes in the slow collisions of Ridberg's atoms with atoms of the same kind in the ground state.

He married in 1975 with Dr. Jelica Jokanović Mihajlov, who is today a professor of Serbian language at the Faculty of Philology, and in 1976 he and his family settled in Belgrade, where his son Anatolij was born that year. He was employed in the Institute of Physics in 1977, where he obtained a permanent position in March 1978. He completed his postgraduate studies in 1977 - Theoretical physics at the Faculty of Natural Sciences and Mathematics, defended his MSc thesis in 1979 and his PhD dissertation in 1981. The basic results of these theses were published in the articles Janev and Mihajlov (1979, 1980) (master's) and, Mihajlov and Janev (1981) and Mihajlov and Popović (1981) (doctoral).

In works Janev and Mihajlov (1979, 1980) and Mihajlov and Janev (1981), based on the aforementioned new mechanism, have been elaborated, in practice, applicable constructive methods for calculation of effective cross sections and rate coefficients for processes of (n - n') mixing and of chemi-ionization processes in slow collisions of Ridberg's atoms with the atoms of the same kind in the ground state. The method developed in Mihajlov and Janev (1981) for symmetric and weakly asymmetric chemi-ionization processes began to be referred to as DShMJ (Duman, Shamaev, Mihajlov, Janev) method, together with the method independently developed by Duman and Shamaev in the 1980s.

In 1981, Mihailov was elected a scientific associate, in 1987 associate professor, and in 1994 he received the title of Research Professor. From 1991 to 1995, he led the subproject "Transport Processes in Low Temperature Plasma", at the Republic Community for Science, and from 1996-2001 the subproject "Radiation and Transport properties of low temperature plasmas". From 2002 to 2005 he was leader of the project "Radiation and Transport Properties of Nonideal Laboratory and Ionospheric Plasma" and from 2006 until retirement he led the project "Nonideal Laboratory and Ionospheric Plasma".

He has developed a broad and impressive international cooperation. With universities in Rostock and Greifswald, in 1982-1995 he has an intensive scientific collaboration (W. D. Kraeft, M. Luft) in the topic of physics of nonideal plasmas and obtained results has been published in Kraeft et al. (1983), Mihajlov et al. (1986, 1987, 1989), in which a model way of describing the screening in dense plasma, using the so-called cut-off potential of Coulomb, has been developed. Mihailov was invited there in 1992 as a visiting professor and in 1995 he was in research mission.

From 1990 to 2010, he collaborated with Odessa State University, which later included and the Polytechnic University of Valencia (V. M. Adamyan, I. M. Tkachenko). The collaboration was in the topic of physics of dense nonideal plasma, including extremely dense plasmas. The results were published in Djurić et al. (1991), Adamyan et al. (1994a,b, 2004, 2006, 2009), Mihajlov et al. (1991), Tkachenko et al. (2006) and Srećković et al. (2010). In these publications has been developed the original modified RPA (Random Phase Approximation) method for the calculation of electrical conductivity and other transport properties of extremely dense nonideal plasmas, which are in good agreement with the existing experimental data.

From 1988 to 1996, Mihailov co-operated with the University of Durham in England (A. M. Ermolaev) in the topic of ion-atomic radiation collisional processes and electron-ion scattering in plasma, until 1992 within the frame of the project with the British Council in Belgrade. The result is eight papers in international journals (Ermolaev and Mihajlov 1991, Mihajlov et al. 1993a,b, 2004a,b, Adamyan 1994a,b, Ermolaev et al. 1995). Thanks to this collaboration, which enabled to him and his collaborators to have study missions in England and access to, at that time, one of the most powerful computer systems (Cray), the equations in Drukarev and Mikhajlov (1974), were transmitted in a constructive quantum-electrodynamic method for the calculation of the spectral characteristics of spontaneous electromagnetic emissions in symmetric ion-atom collisions at mean collision energies (10-50 keV in a hydrogen case).

Collaboration with the University of Pierre and Marie Curie in Paris (Yves Vitel) takes place between 1996 and 2011, on the research of intra-plasma electrostatic screening and the obtained results are published in Vitel et al. (2001) and Mihajlov et al. (2008, 2009a,b, 2011a,b). In Vitel et al. (2001), the elaborated before semi-classical method for the calculation of electrical conductivity of the nonideal plasma

Figure 1: Anatolij Anatolyevich Mihajlov.

(Mihajlov et al. 1993b) has been verified experimentally. The other significant result is the development of a new, non-Debayan method for describing intra-plasma electrostatic screening, formulated when Mihajlov, as a guest professor, was in Paris in October 2003 and has been published in Mihajlov et al. (2008, 2009a,b).

Cooperation with the Institute V. A. Fok, of the Physics Faculty of the University of St. Petersburg (A. N. Klyucharev, N. N. Bezuglov), dedicated to atom-atomic (primarily chemi-ionization) collision processes, started in 2005, took place until the death of Anatolij in 2017, and continued further by his co-workers (V. A. Srećković, M. S. Dimitrijević). The basic results are published in Klyucharev et al. (2007), Ignjatović et al. (2008a,b), Gnedin et al. (2009), Srećković et al. (2012), Bezuglov et al. (2014), Mihajlov et al. (2015) and Arefieff et al. (2015, 2017). Since May 2008, Pulkovo Observatory (Yu. N. Gnedin, paper Gnedin et al. 2009) was also included in this cooperation.

Mihailov also collaborated with the Institute of Physics in Zagreb, where he held a series of lectures, often followed by useful discussions.

Anatoly Anatolyevich Mihajlov payed great attention to the scientific development of young people. He relentlessly transferred his rich experience to collaborators and encouraged their development, both through mentoring dissertations and by engaging youngs in his own research and preparation of scientific papers for top international scientific journals. As a mentor or co-mentor he led four master's theses (N. Ljepojević, Z. Djurić, Lj. Ignjatović and N. Sakan), and four PhD dissertations (N. Ljepojević, Z. Djurić, Lj. Ignjatović and N. Sakan).

A very important result of Anatoly is the creation of new Laboratory for the physics of nonideal plasma, becoming its Head in 1986, the modernization of the

Spectrochemical laboratory, as well as the creation of the first in the region Laboratory for the Physics of the ionosphere (Earth-ionosphere waveguide) and its interaction with the solar emission, which enabled to begin the work on the study of the effects of solar eruptions on the Earth's ionosphere and the possibilities of forecasting seismic events. Mihajlov was dedicated to this task since mid-1995 and with the help of the Ministry of Science, in mid-2003, the laboratory received the first ionospheric station. This enabled to start, in cooperation with the University of Nova Gorica (Slovenia) studies of the impact of solar eruptions on the Earth's ionosphere within the frame of the European project COST-724 (Space Weather). In the period 2003-2007 cooperation with Slovenia took place on the basis of two-year bilateral agreements.

I would especially like to point out his collaboration with the Astronomical Observatory since 1985 in the field of atomic collisions in weakly ionized plasmas, and especially in the plasma of stellar atmospheres. From the 96 scientific papers in international journals, cited several hundred times, 39 are in international astronomical journals, usually of the highest rank. In these papers, the effects of various atomic collisions on radiation of the Sun, cold stars and white dwarfs - one of the final phases in the evolution of a star, are analyzed. From mid-80s until the mid-90s, Mihailov is an external associate of the Astronomical Observatory, and until 2006 he is a member of the Joint scientific council of the Astronomical Observatory, Geomagnetic and Seismological Institute.

Figure 2: Anatolij Anatolyevich Mihajlov.

Mihailov was awarded for his scientific work by the Institute of Physics in 1994 and by Astronomical Observatory in 1999. He is a member of the governmental board of the Eurasian Astronomical Society, based in Moscow, and he founded, together with Milan S. Dimitrijević, its Serbian branch in 2008, and the representative office in Belgrade. He is a member of the European Physical Society and the International Astronomical Union. He always worked tirelessly, developped and transferred new knowledge, confirming the idea that "work is the first human need and greatest satisfaction". He loved life, people, things big and small. His work was always devoted to the service of everything that elevates the thought and dignity of man. With his knowledge, directness, inexhaustible energy, he attracted and enchanted interlocutors and enriched his students and associates. His works and scientific contributions make an honor to Serbian science, both physics and astronomy.

I met Tolya in 1976, and since then, we have been working together and collaborating creatively. And when a severe illness began to overcome him, behaving in the spirit of Njegos' message - "let the struggle be constant, let it be what is impossible", he continued to work on his dreams and raise life to meaning and value, so that from Sickbed he sent two scientific papers to astronomical journals of highest rank. He is an example of how to rise above life's troubles, find strength for work, life and friends, despite all bad circumstances, and will remain in our lasting memory as a model of dignified and honorable life.

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PROBING THE GALACTIC HABITABILITY TIMESCALES

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Abstract. There has been a surge of interest in numerical modelling of habitability in the last couple of years. Here we implement a probabilistic toy model of the Galactic disk astrobiological history, including colonization of habitable sites by hypothetical extraterrestrial intelligent species. Characteristic times for the emergence of catastrophic and colonization events are varied in the relevant range. The results averaged over three runs show an emerging pattern of astrobiological landscape which can be used to quantify the probability of various models for evolution and expansion of Galactic civilizations. Various approaches to building numerical models of Galactic habitability are briefly compared, and some potentially fruitful direction for the further work outlined.

1. INTRODUCTION

Numerical astrobiology and Search for Extra-terrestrial Intelligence (SETI) studies are still in their infancy and there are many possible approaches to be tested. This particular work is motivated, among other things, by the apparent absence of extraterrestrial life detections within Earth's past light cone, usually labelled as Fermi's Paradox. Developed over the past years, numerous hypotheses for resolution of Fermi's Paradox are summarized in the popular book by Webb (2015) while a robust review and scientific significance are given in Ćirković (2018).

The results of the contemporary space missions make the paradox even more appealing. Despite the abundance of confirmed extrasolar worlds all our SETI efforts did not yield the Detection. The future space missions like Transiting Exoplanet Survey Satellite or James Webb Space Telescope might provide a far better insight into the atmospheres of exoplanets and expand on our modelling of biological signatures (possibly pointing to the existence of simple life forms). The studies that relate the evolution of galactic parameters to habitability, such as metallicity, star formation rate, etc. are becoming numerous (for a review on some of them see e.g. Vukotić 2017). However, all of this might not directly contribute to the resolution of the Fermi's Paradox but rather stimulate and constrain further SETI efforts and rethinking of the existing SETI strategies.

Even with the rapid development of modern astrobiological studies in the last couple of decades neither of the 75 solutions from Webb (2015), or some combination of them, cannot be supported to be far more plausible than the alternatives: the paradox is still undoubtedly unresolved! The primary goal of this pilot study is to establish a fresh angle of view that would hopefully take us a step closer in resolving one of the greatest scientific puzzles of the modern era.

The operational foundation of the approach presented here is probabilistic simulation. A simple, fast running simulation is required to evolve the highest possible number of objects in three independent sets of probabilistic runs. The timescales that are indicative of hindering and degrading the evolution of objects towards the present day (or some fiducial epoch in the future), like the state of Earth's biosphere, as well as the ones that are relevant for spatial spreading via colonization, are varied. In contrast to our previous work (e.g. Vukotić & Ćirković 2007, 2010, 2012), simulation presented here has the most efficient and simplistic implementation that offered the best time resolution we were able to achieve so far, namely by neglecting the spatial aspects of the model. The achieved 10^4 yr simulation time step is comparable to the historical time span of the human civilization and is drastically shorter than the astronomical or evolutionary timescales. This opens several new possibilities. Not only biologicaly relevant timescales (that are usually very long compared to other relevant phenomena) but also a socio-technological ones, indicative of the development of our (or some other similar) civilization, can be discussed and modelled with such simulations, at least in principle.

Next section gives a detailed description of the simulation and model followed by the presentation of results (Section 3). The summary and some guidelines for future work are given in the concluding section 4.

2. MODEL DESCRIPTION

We simulate the evolution of Earth-like life by temporal propagation of simulation entities, for the sake of simplicity dubbed as objects. The state of each object is evolved in time according to the timescales relevant for life on Earth and development of human civilization. Each object can have 4 different discrete states labelled as: **0** – object represents the lifeless planet, **1** – object has a biosphere with simple life, **2** – biosphere has complex organisms, **3** – a technological civilization.

Objects are activated and assigned a state 0 in the probabilistic manner. For this purpose, we used random sampling from the probability density function. This function is derived from the Earth-like planet formation rate over cosmological timescales. For better compatibility with our previous works we used the rates from Lineweaver (2001), although more recent estimates are available (e.g. see Zackrisson et al. 2016).

Unlike the activation probability described above, the probability of changing the state is calculated for each object using the cumulative density function (CDF) derived by integrating the Epanechnikov (1969) kernel function:

$$p(u) = \frac{3}{4}(1 - u^2), \quad |u| \leq 1, \tag{1}$$

where argument u is calculated as:

$$u = \frac{t - \tau}{\sigma}. \tag{2}$$

Table 1: Simulated transitions and parameters of the corresponding probability functions with mean τ and standard deviation σ_τ. The entries under numbers 4, 5 and 6 are varied in the given interval on the logarithmic scale with a step of 0.2. While almost all of the transitions are towards states designated with higher numbers, the transition #4 represents the degradation of the achieved complexity possibly caused by the following or any other reason: local (e.g. asteroid impact), self-induced (e.g. nuclear armageddon), global factors that are related to galactic parameters (a nearby supernova explosion, stellar collison, etc.).

#	transition	τ[yr]	σ_τ [yr]	cause
1	$0 \rightarrow 1$	5×10^8	1×10^8	evolution
2	$1 \rightarrow 2$	1×10^9	3×10^8	evolution
3	$2 \rightarrow 3$	6×10^8	1×10^8	evolution
4	$3 \rightarrow 2$	$[10^4, 10^{10}]$	0.1τ	catastrophism
5	$2 \rightarrow 3$	$[10^4, 10^{10}]$	0.1τ	colonization
6	$1 \rightarrow 3$	$[10^4, 10^{10}]$	0.1τ	colonization

Here, t is the time that object have spent in current state, τ is the length of the relevant timescale and σ controls the kernel width. The derived CDF has the form:

$$0.25(-u^3 + 3.0u + 2.0), \quad |u| \leq 1. \tag{3}$$

This is a parabolic function and has a higher computation efficiency when compared to more commonly used kernels (such as the error function derived from integration of a Gaussian kernel, or the uniform kernel). Parameters of the used CDFs for all simulated change of object states are given in Table 1.

During the activation of the objects each object is assigned a set of 6 random numbers (one for every allowed transition). In each step of the simulation the number for the relevant transition is compared against the probability derived from the CDF as described above. After activation, objects in state 0 are examined for transition to state 1. Objects in states 1 and 2 are first examined for colonization induced transitions to state 3 (transitions induced when other objects in state 3 colonize objects in question that are in state 1 or 2, see transitions 5 and 6 in Table 1).

To calculate if a given object in state 1 or 2 is colonized to state 3 by other objects that are already in state 3, the CDF argument u depends on the average time that objects spent in state 3 in the current instant of the simulation (t_{av3}), current number of objects in state 3 (n_3), total number of simulated objects n_{tot} and $\sigma_{\tau_{\mathrm{col}}}$ as:

$$u = \frac{n_3}{n_{\mathrm{tot}}} \frac{t_{\mathrm{av3}} - \tau_{\mathrm{col}}}{\sigma_{\tau_{\mathrm{col}}}}. \tag{4}$$

Fr the sake of simplicity, our model implements only time variable while colonization also has a spatial character. Since the distances between objects in our simulation are not considered we use time averages of colonization relevant quantities (Equation 4), to make the overall estimate of colonization activity. Unlike Equation 2, where variable u is calculated for each object in each time step, variable u in Equation 4 is calculated only once per time step and is the same for all objects at the given time step since it depends on average values. The further treatment of this variable for calculating transition probabilities using CDF is the same as in the case of Equation 2. The difference between these two cases stems from the fact that a colonization of an object does not depend on that object evolution (except the condition that it should be in state 1 or higher), but on the evolution of colonization conducting objects.

3. MODEL PARAMETERS

In each run of the simulation we have evolved 500 objects and the simulation output is averaged over 3 runs for each set of input timescales. At the beginning of the 10 Gyr simulated time span there are no active objects.

We use biological timescales inferred from Earth's Fossil Record. After the formation of Earth, 4.556 billion years ago, it took the next several 10^8 yr for the appearance of the earliest single-celled life (cf., Dodd et al. 2017). Complex metazoan lifeforms took very long time (about 3.5×10^9 yr, Maloof et al. 2010) to appear and take hold in the so-called Cambrian Explosion. This left cca. 5×10^8 yr until present (Maloof et al. 2010) and the appearance of a technological civilization on Earth. Our ignorance of extraterrestrial civilizations limits our knowledge about civilizations in general. From the fossil record we can argue about the beginnings of the civilized era on Earth, but it is much more complicated to predict if or when such a civilization might experience an extinction, possibly in a self-destruction (for analyses of such scenarios see Bostrom & Ćirković 2012). Also, there is an uncertainty about the time scale for such a civilization to develop a potential for colonizing the other worlds. In our model we are probing different values for the timescales indicative of colonization, as well as hazardous events that might degrade the state of simulated objects (see Table 1 for the coverage of the parameter space).

In Table 1, the entries in rows 1-3 are representative of the timescales inferred from the Earth's fossil and historical records and should be understood as the fiducial values (Copernicanism suggests that we should regard ourselves as typical, i.e. close to mean values of whatever is the underlying distribution). Timescale from row 4 ($\tau_{\rm cat}$) is varied independently of transitions from rows 5 and 6 which are varied together as they both represent the colonization phenomena and since they are varied in the same manner the related timescale is labelled as $\tau_{\rm col}$ in the further text.

The upper limit for the time intervals of transitions 4-6 (Table 1) is the time span of our simulation which corresponds to the present age of the Galaxy. The lower limit for the same transitions is the best achieved time resolution of our simulations which is realistic in terms of our current understanding of interstellar travel and Earth civilization time scales. It is important to emphasize how the drastic difference between civilization-related and astrophysical timescales erases any specific uncertainty as too the numerical values of the former (e.g. Lipunov 1997).

4. RESULTS AND ANALYSIS

For each set of input timescales given in Table 1 we made 3 runs of the simulation. While this is obviously not enough for obtaining statistically valid conclusions, the purpose of this exercise has been primarily to test the general soundness of the procedure and obtain an estimate of the computational load. The averaged results are given in Figures 1 and 2.

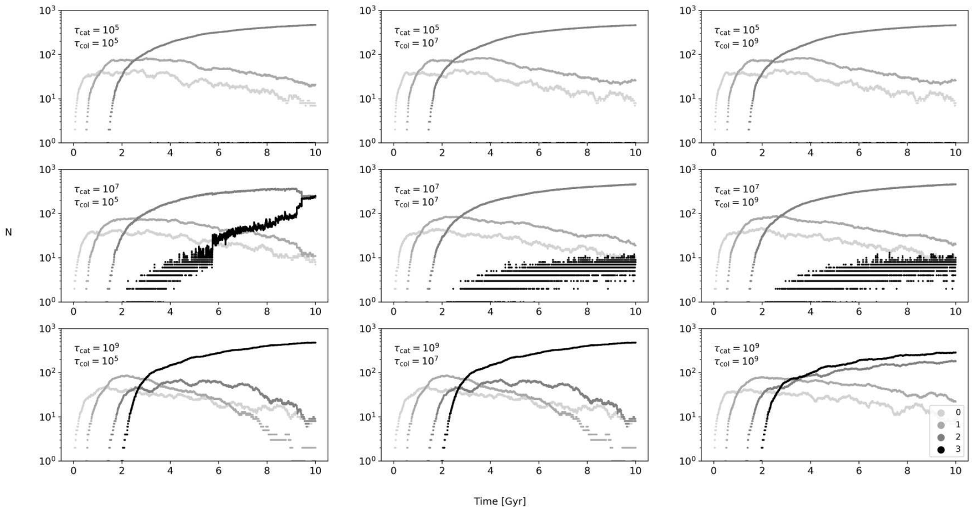

Figure 1: Number of objects in a given state (N, vertical axes of panel plots) at each time step (horizontal axes). Legend in the lower right panel is applicable to all panels. It indicates the gray- scale coding of the object's state. Each panel gives a different combination of τ_{cat} and τ_{col}, the values indicated on the panels are given in years. Results are averaged over 3 runs.

The bottom row of panels in figure 1, gives the highest number of objects in state 3 which is expected since the τ_{cat} is long. Interesting case of $\tau_{\text{cat}} = \tau_{\text{col}} = 1$ Gyr gives the lowest number of objects in state 3 (for the bottom row of panels) since it has the least efficient colonization which results in higher number of objects in state 2. The upper panel row gives almost none objects in state 3 due to low value for τ_{cat} that degrades objects from state 3 to state 2. The results are similar for all panels in this row even when scales are comparable $\tau_{\text{cat}} = \tau_{\text{col}} = 10^5$ yr. The results from bottom and upper rows indicate that in the current simulation the hazardous events are somewhat more dominant at $\tau_{\text{cat}} = 10^5$ yr over colonization than vice versa for the $\tau_{\text{col}} = 1$ Gyr case. This might be even more appealing since the colonization is implemented via two transitions while the catastrophic events are only in one ($3 \to 2$) transition.

However, the most interesting from the standpoint of resolving the Fermi's paradox might be the middle row of panels. When $\tau_{\text{cat}} = \tau_{\text{col}} = 10^7$ yr apparently does not differ from $\tau_{\text{cat}} = 10^7$ yr and $\tau_{\text{col}} = 1$ Gyr. Even such a small number of objects in state 3 might point towards the regime that should be investigated for the purpose of resolving the Fermi's paradox. In addition, this regime shows rapid relative oscillations in the number of objects in state 3, when that number is small. This produces parallel horizontal black lines, since the N scale is logaritmic and N is an integer variable. The much higher number of state 3 objects for $\tau_{\text{cat}} = 10^7$ yr and $\tau_{\text{col}} = 10^5$ yr case implies that colonization might just have an upper hand over catastrophic events, unlike the catastrophic regimes from upper and bottom rows.

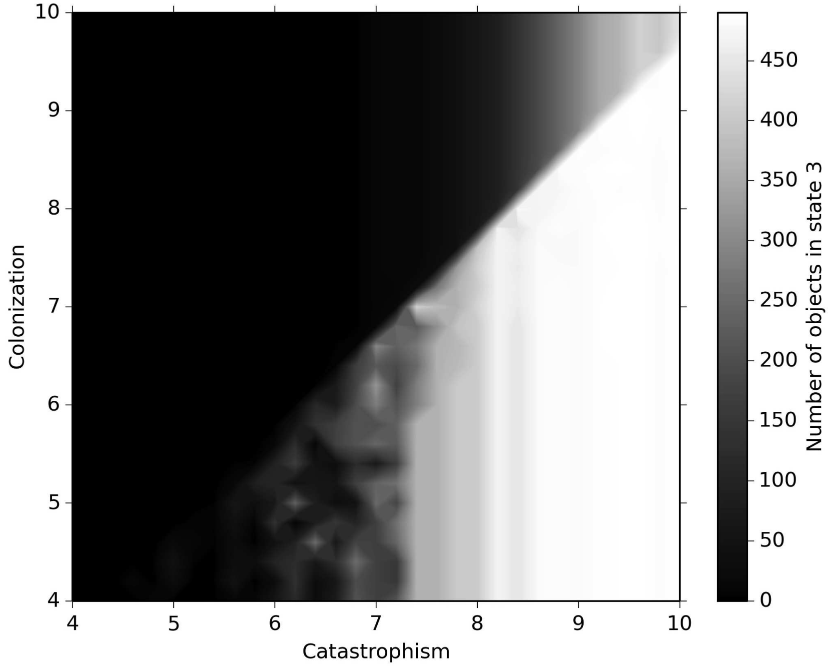

Figure 2: Gray-scale coded averaged number of objects in state 3 at the end of the simulation for all simulated combinations of $\tau_{\rm cat}$, axis labelled "Catastrophism and $\tau_{\rm col}$, axis labelled "Colonization".

This means that if the catastrophic events operate on the scales of tens of millions of years, which is very likely for physical timescales induced from Earth's records (e.g. global climate and magnetic field changes), studies of the Sun and other bodies in the Solar system. The sensitivity of number of state 3 objects to $\tau_{\rm col}$ in $\tau_{\rm cat} = 10^7$ indicate that colonization might be a much harder task than originally thought through by Enrico Fermi during his famous Los Alamos lunch time saying.

Figure 2 is a filled contour plot, gray-scale coded. Location of the turbulent region, that might offer the most fruitful research on resolving the Paradox is clearly seen in Figure 2, $\tau_{\rm cat} \approx (10^6, 10^7)$ and $\tau_{\rm col} \approx (10^4, 10^7)$. In addition to findings from Figure 1, Figure 2 implies that for the lower catastrophic timescales lower colonization timescales are in the turbulent regime, but still the diagonal feature on the plot (separating brighter from darker part) is somewhat below the $\tau_{\rm cat} = \tau_{\rm col}$ line which supports the findings from Figure 1 that longer colonization times (when compared to catastrophic timescales) are likely for the efficient resolution of the Paradox.

Other features, although less pronounced than the turbulent region, are also evident in Figure 2 and this requires more investigation with simulations of higher resolution. However, the turbulent region is the most interesting part of our investigation, which needs more detailed analyses.

5. CONCLUSION

We made a simplistic simulation calibrated to relevant timescales of evolution of life on Earth. Multiple sets of runs (3 for each point in the relevant parameter space) are performed varying the timescales relevant for colonization and catastrophic events. If confirmed by subsequent detailed implementation in many runs, our results will imply that likely resolution to Fermi's paradox is in the regime where catastrophic events are somewhat more dominant over colonization events. This implies that current absence of detecting other civilizations in the Milky Way might be explained with the fact that colonization and expansion are a really hard to perform tasks, while the amplitude of risk is higher than hitherto assumed. These tentative conclusions are in accordance with the astrobiological phase transition hypothesis (Annis 1999; Ćirković & Vukotić 2008). Also, we have outlined the region of the parameter space that offers the most fruitful direction for future research.

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STELLAR KINEMATICS AROUND GALACTIC CENTER

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Abstract. In this paper we discuss the deviations between the observed and Keplerian orbit of S2 star around the Galactic Center (GC), using the gravitational potential that we derived from the modified theories of gravity. S2 star is one the brightest among S-stars, with the short orbital period, and also with the smallest uncertainties in determining the orbital parameters. So we use it as a good candidate for investigating the precession of the orbit, deviations from the Keplerian orbits, as well as stellar kinematics around supermassive black hole at GC.

1. INTRODUCTION

The different anomalous astrophysical and cosmological phenomena like the cosmic acceleration, the dynamics of galaxies and gas in clusters of galaxies, the galactic rotation curves, etc. did not find satisfactory explanations in terms of the standard Newton-Einstein gravitational physics, unless exotic and still undetected forms of matter-energy are postulated: dark matter and dark energy. Alternative approaches using well-motivated generalization and extensions of General Relativity (GR) are proposed in order to try to explain these phenomena without using dark matter and dark energy. In this perspective, star kinematics and dynamics around the Galactic Centre could be a useful test bed to probe the effective gravitational potentials coming from the theory.

S-stars are the young bright stars which move around the centre of our Galaxy (Ghez et al. 2000, Ghez et al. 2008, Genzel et al. 2010) where the compact radio source Sgr A* is located. S2 is one of the bright S-stars moving around Sgr A* source in the center of our Galaxy. A Keplerian orbit could be determined for the S2 (a star with one of the shortest orbital period of 16 years), after passing the periapse. This star can now be traced in its motion around the Galactic Center with the smallest uncertainties in determining the orbital parameters and a complete phase coverage. No other star has so far been reported covered by data with more than ∼40% of its orbit. The astrometric limit is constantly improving from around 10 mas, during the first part of the observational period, currently reaching less than 1 mas. This limit is still not sufficient to definitely confirm that S2 star orbit really deviates from the Newtonian case. However, some recent studies (Gillessen et al. 2009a, Gillessen et al. 2009b, Meyer et al. 2012, Gillessen et al. 2017, Boehle et al. 2016) provide evidence that the orbit of S2 star is not closing. The orbital precession can occur due to relativistic effects, resulting in a prograde pericentre shift or due to a possible extended mass distribution, producing a retrograde shift. Both prograde relativistic and retrograde Newtonian pericentre shifts will result in rosette shaped orbits. We consider a possible application of modified gravity within Galactic Central Parsec, in order to explain the observed precession of S2 star orbit, in particular the Newtonian limit of a class of scalar-tensor (ST) theories of gravity, where a scalar field is nonminimally coupled to the geometry. For more details about S2 star see Genzel et al. (2010) and Gillessen et al. (2012).

Here we study a possible application of ST theories of gravity within Galactic Central Parsec, in order to explain the observed precession of orbits of S2-star. This investigation is a continuation of our previous studies where we considered different extended gravities, such as power law $f(R)$ gravity (Borka et al. 2012, Zakharov et al. 2014), $f(R, \phi)$ gravity implying Yukawa and Sanders-like gravitational potentials in the weak field limit (Borka et al. 2013, Capozziello et al. 2014, Borka et al. 2016, Zakharov et al. 2016).

2. THEORY

Extended Theories of Gravity have been proposed like alternative approaches to Newtonian gravity in order to explain galactic and extragalactic dynamics without introducing dark matter. In the case of $f(R)$ gravity, one assumes a generic function f of the Ricci scalar R (in particular, analytic functions) and searches for a theory of gravity having suitable behavior at different astrophysical and cosmological scales: for short distances, Solar system, spiral galaxies, galaxy clusters and cosmology. See reviews in: Capozziello & Faraoni 2010, Capozziello & De Laurentis 2011, Nojiri & Odintsov 2011, Capozziello & De Laurentis 2012, Clifton et al. 2012.

The ST theories of gravity are theories, in which both the metric tensor $g_{\mu\nu}$ and a fundamental scalar field ϕ are involved (Capozziello et al. 1996). In our investigation we take the action of the form:

$$S = S_M + \frac{1}{2\kappa^2} \int d^4x \sqrt{-g}[F(\phi)R + \frac{3}{2\phi} g^{\mu\nu}\phi_{,\mu}\phi_{,\nu} - V(\phi)]. \tag{1}$$

where the coupling $F(\phi)$ and the potential $V(\phi)$ are generic functions of the scalar field ϕ, and κ is a coupling constant.

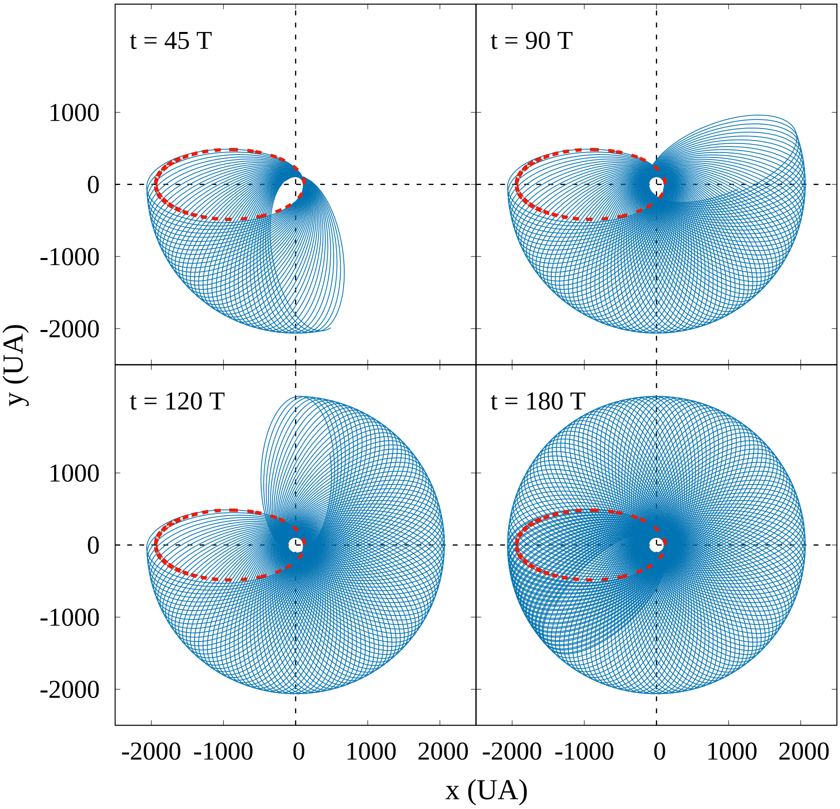

Figure 1: Comparison between the orbit of S2 star in Newtonian potential (red dashed line) and ST potential (blue solid line) for parameters (m,n) = (2,2) and (ξ,λ)=(-9000, 0.005) during the time t = 45, 90, 120 and 180 T.

3. RESULTS AND DISCUSSION

The ST gravitation potential in the weak field limit can be written in the form:

$$U_{ST} = \frac{\widetilde{G}}{\xi\varphi_0^m}\frac{M}{r} - \frac{\lambda}{4\xi}\varphi_0^{n-m}r^2 - \frac{\widetilde{G}m^2M}{3(1-m^2\varphi_0^{m-1}\xi)}\frac{e^{-pr}}{r}, \tag{2}$$

where M is central mass, and p is function of the ST gravity parameters ξ, λ, m and n:

$$p = \sqrt{\frac{\lambda n\varphi_0^{n-1}(2m-\lambda n)}{3(m^2\xi\varphi_0^{m-1}-1)}}, \tag{3}$$

and $\widetilde{G}$ is related with a gravitation constant G_N through relation:

$$\tilde{G} = -\left[\frac{3(1-m^2\varphi_0^{m-1}\xi)\xi\varphi_0^m}{3-\xi(3m^2\varphi_0^{m-1}+m^2\varphi_0^m)}\right]G_N. \tag{4}$$

The parameters λ, ξ, m and n define the specific form of function $F(\phi)$ and interaction potential $V(\phi)$, since before starting the linearization of field and scalar

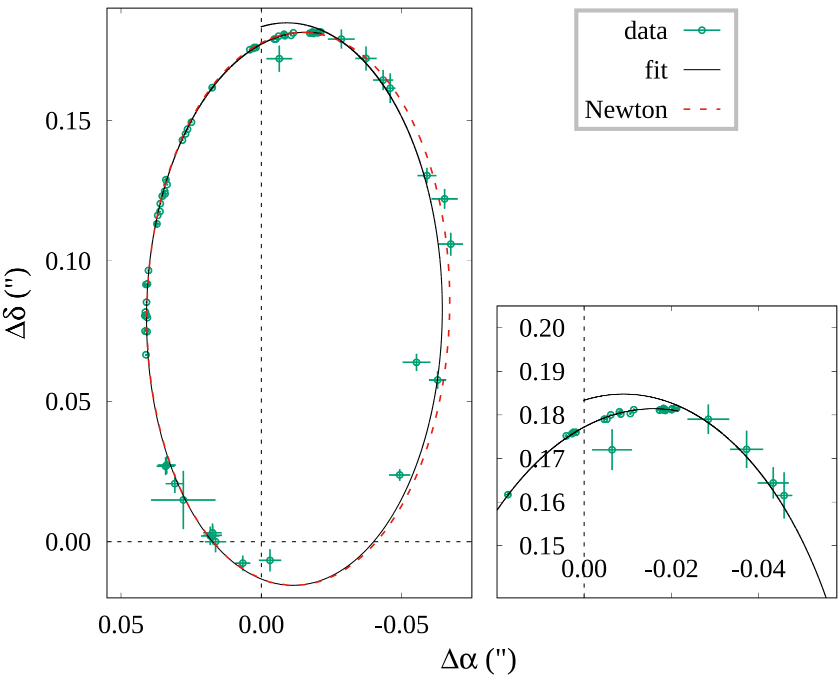

Figure 2: Comparison of the observations and the fitted orbit of S2 star around the Galactic Center, for (m,n)=(2,2) and (ξ,λ)=(-9000, 0.005). *Left*: S2 orbit in the modified gravity (black solid line) and Newtonian orbit (red dashed line). The VLT astrometric observations are presented by green circles. *Right*: Zoom of the orbital part showing the precession.

field equations, we choose a specific form for the up to now arbitrary functions, that is $F(\phi) = \xi\phi^m$, $V(\phi) = \lambda\phi^n$, where ξ is a coupling constant, λ gives the self-interaction potential strength, m and n are arbitrary parameters. Our aim is to determine these parameters using astrometric data for S2 star orbit. We are simulating orbit of S2 star in the ST modified gravity potential by numerical integration of equations of motion:

$$\dot{\overrightarrow{r}} = \overrightarrow{v}, \qquad\qquad \mu\ddot{\overrightarrow{r}} = -\overrightarrow{\bigtriangledown}U_{ST}(\overrightarrow{r}) \tag{5}$$

where $\mu = M_{BH} \cdot m_S/(M_{BH} + m_S)$ is the reduced mass in the two-body problem due to the mass M_{BH} of the central black hole and the mass m_S of the S2 star.

We put in advance the parameters m and n. The initial values for true position (x_0, y_0) and orbital velocity $(\dot{x}_0, \dot{y}_0)$ of S2 star at the epoch of the first observation are specified and the positions (x_i, y_i) and velocities $(\dot{x}_i, \dot{y}_i)$ of S2 star along its true orbit are calculated for all observed epochs by numerical integration of equations of motion in the ST gravity potential. The reduced χ^2 of fit is estimated according the following expression:

$$\chi^2 = \frac{1}{2N - \nu}\sum_{i=1}^{N}\left[\left(\frac{x_i^o - x_i^c}{\sigma_{xi}}\right)^2 + \left(\frac{y_i^o - y_i^c}{\sigma_{yi}}\right)^2\right], \tag{6}$$

where (x_i^o, y_i^o) are the observed values of the true positions, (x_i^c, y_i^c) are the calculated values, and σ_{xi}, σ_{yi} are the variances.

At the end, we kept the value of ξ and λ which resulted with the smallest value of minimized reduced χ^2. More detailed description about fitting procedure is given in Borka et al. (2013).

We have made a comparison of VLT observations and theoretically fitted orbit of S2 star around the Galactic Center. We calculated the S2 orbit in the modified gravity potential of a ST Theory. Comparison between the orbit of S2 star in Newtonian potential and ST potential for parameters (m, n) = (2,2) and (ξ,λ)=(-9000, 0.005) during the time t = 45, 90, 120 and 180 T (T - orbital period) is shown in Fig. 1. Comparison of the observations and the fitted orbit of S2 star around the Galactic Center is shown in Fig. 2, and from the zoomed part of the figure it can be clearly seen that the precession exists.

In order to calculate orbital precession in ST modified gravity we assume that ST potential does not differ significantly from Newtonian potential and we derived the perturbing potential:

$$V(r) = U_{ST} - U_N; \qquad\qquad U_N = -\frac{GM}{r}. \tag{7}$$

The obtained perturbing potential is of the form:

$$V(r) = -\frac{GM}{r}\frac{\xi m^2\varphi_0^m}{3-\xi(3m^2\varphi_0^{m-1}+m^2\varphi_0^m} - \frac{\lambda}{4\xi}\varphi_0^{n-m}r^2 - \frac{\widetilde{G}m^2M}{3(1-m^2\varphi_0^{m-1}\xi)}\frac{e^{-pr}}{r}. \tag{8}$$

Table 1: Precession angle for different values of m and n gravity parameters.

m	n	$\Delta\theta(^\circ)$
1	1	2.5
1	4	2.5
1	10	2.7
2	1	2.5
2	2	2.5
2	6	2.5
3	4	2.2
4	2	2.5
4	4	2.8
10	10	2.5

The particular form of the chosen Lagrangian among the class of ST theories of gravity induces the precession of S2 star orbit in the same direction with respect to GR and produces a prograde shift that results in rosette-shaped orbits. In the case when the simulated revolution of S2 star is in positive mathematical direction (counter clockwise), the simulated precession of S2 star orbit has positive mathematical direction too, and vice versa. The pericenter advances by 2.5° per orbital revolution, while in GR the shift is 0.18°.

4. CONCLUSIONS

In this paper orbit of S2 star has been investigated in the framework of the ST gravity potentials. Using the observed positions of S2 star around the Galactic Centre we constrained the parameters of these gravity potentials.

We obtained the values for parameters ξ and λ for different parameters m and n when S2 star orbit in ST gravity better fits astronomy data than Keplerian orbit.

The precession of S2 star orbit obtained for the best fit parameter values has the positive direction, as in GR.

We obtained much larger orbital precession of the S2 star in ST gravity than the corresponding value predicted by GR.

The approach we are proposing can be used to constrain the different modified gravity models from stellar orbits around Galactic Centre.

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REGULUS OBSERVED WITH VLTI/AMBER

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Abstract. The rapidly rotating primary component of Regulus A system has been observed, for the first time, using the technique of differential interferometry at high spectral resolution. The observations have been performed across the Br_γ spectral line with the VLTI/AMBER focal instrument in high spectral resolution mode (R $\approx$ 12 000) at $\approx 80 - 130$m (projected on the sky) Auxiliary Telescopes triplet baseline configurations. We confirm, within the uncertainties, the results previously obtained using the techniques of classical long-baseline interferometry, although the question of anomalous gravity darkening remains open for the future study.

1. INTRODUCTION

Located at a distance of 23.76 ± 0.04 pc (van Belle & von Braun 2009), α Leo is a multiple stellar system composed of at least two binaries. The A component of the system (α Leo A, HD 87901) has been recently discovered to be a spectroscopic binary where the fainter companion is probably a white dwarf or a M4 V star of mass $\approx 0.3\mathrm{M}_\odot$ and an orbital period of 40.11 days (Gies et al. 2008) . The brighter companion (hereafter Regulus) was classified as a main sequence B7V star by Johnson & Morgan (1953), and more recently as a sub-geant B8IV star by Gray et al. (2003) of mass $\approx 4\ \mathrm{M}_\odot$ (Che et al. 2011, and references therein).

It is well known (by observing even with an amateur telescope) that α Leo A has another companion which is in fact a system of two other components (B and C) which together form a binary system (McAlister et al. 2005). This B-C subsystem is located $\approx 3'$ from the A component. The B component (α Leo B; HD 87884) is a $\sim 0.8\ \mathrm{M}_\odot$ star of spectral type K2 V, while the C component is a very faint M4 V star with a mass of $\sim 0.2\ \mathrm{M}_\odot$. The Washington Double Star Catalog (Mason et al. 2001) lists a D component, also having a common proper motion with the system and a separation of $\approx 3.6'$ from the A component. At such separations the B-C subsystem and D component have never directly interacted with Regulus, but the fainter component of the α Leo A subsystem influences profoundly its evolution through mass exchange between two stars (Rappaport, Podsiadlowski, & Horev 2009). Considering a scenario where the initial masses of the progenitors of fainter component and Regulus are 2.3 ± 0.2 $M_\odot$ and 1.7 $\pm$ 0.2 $M_\odot$ respectively, they infer the age of the system which exceeds 1 Gyr. They also consider a possibility that the mass transfer is the cause of the current rapid rotation of Regulus.

Regulus has been identified as a fast rotator by Slettebak (1954), who determined spectroscopically its high rotational velocity Veq $\sin i$ = 352 $\pm$ 8 km/s. The first interferometric observations of the star weredone with the Narrabri Intensity Interferometer by Hanbury Brown et al. (1974), but only the information about its size could be obtained. They derived the equatorial angular diameter 1.32 $\pm$ 0.06 mas. Such a diamater, together with the high apparent brightness of Regulus made it a very good interferometric target allowing to reveal its extremely oblate shape (McAlister et al. 2005), and to confirm the spectacular discovery of the extremely oblateness of Achernar (Domiciano et al. 2003). A very important consequence of stellar oblateness is the associated gravity darkening (von Zeipel 1924a,b) which implies a variation of associated effective temperature over the stellar surface. For Regulus McAlister et al. (2005) determined a difference of $\sim$ 5000 K between the poles and the equator, a finding which has been confirmed by Che et al. (2011). Such a large difference in associated effective surface temperatures make the spectral classification quite a challenging task, and should be taken into account in the modeling of observations as well as in theoretical analysis concerning the evolutionary status of the entire binary system.

By the other hand Regulus is very challenging object for investigation because of its almost equator-on orientation which makes the situation where the minimization procedures can produce the degenerated solutions. For this reason we observed the star, for the first time, with the VLTI/AMBER instrument which provides the differential interferometry data, in order to check the results previously published using the classical interferometry instruments.

2. OBSERVATIONS

Regulus was observed with the AMBER an interferometric near infrared focal instrument for the Very Large Telescope Interferometer (VLTI), using the Auxiliary Telescopes (AT). The observations have been performed in the high spectral resolution mode of AMBER (≈ 12000), centered on the Br_γ spectral line. The corresponding u, v (Fourier space) coverage is shown in Fig.1, while the Table 1 provides our observing log.

The interferometric fringes were stabilized using a fringe tracker FINITO (Mérand et al. 2012). The instrument AMBER provides both the intensity spectrum and the relative phase of the interferometric signal, and it is described in detail by Petrov et al. (2007), Robbe-Dubois et al. (2007) and in references therein.

Thye intensity spectrum is the *zero order moment* of the sky brightness distribution while the photocenter shift spectrum is the *first order moment* of the sky brightness distribution (Jankov et al. 2001, and references therein). *It is a vectorial function* and can be evaluated measuring the relative phase of the interferometric

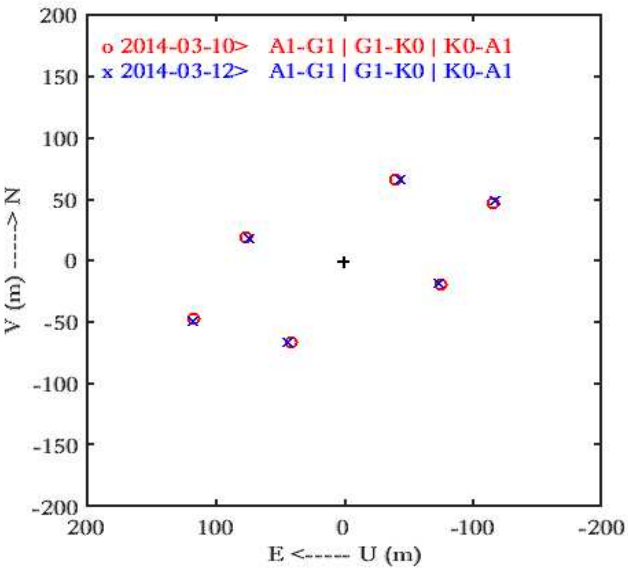

Figure 1: (u,v) coverage of VLTI/AMBER observations of Regulus; spanned over 1.5 h/night. Note the rather poor sampling of the Fourier space. According to the Table 1, the (u, v) points for the date 2014-03-10 are represented by circles and by crosses for the date 2014-03-12.

signal along a spectral line with respect to the continuum. In order to study the physics of a star the photocenter shift measurements should be evaluated in the coordinate system related to the stellar rotational axis (ϵ_{eq} & ϵ_{p}), equatorial and polar components respectively.

However, *a priori* only the components related to the celestial coordinate system (ϵ_α & ϵ_α) can be evaluated. Figure 2. shows these components as observed in our observing run.

In order to evaluate the components related to the stellar rotational axis, the position angle of the axis (PArot) should be determined. It can be done in the global procedure for determination of stellar parameters as well as independently based on the method described by Petrov & Lagarde (1992), as shown in the Fig. 3. Then the equatorial and polar components of the photocenter shift (see Fig. 4) can be obtained by simple rotation of the coordinate system. The Fig 5. shows the 3D representation of the observed photocenter shift components of Regulus.

3. RESULTS

To interpret the observations, we use the semi-analytical model for fast rotators: Simulation Code of Interferometric observations for ROtators and CirCumstellar Objects (SCIROCCO). This code written in Matlab, allows to compute monochromatic intensity maps of uniformly rotating, flattened, and gravity darkened stars using the semi-analytical approach. The code SCIROCCO, which is a parametric description of the velocity field and the intensity map for line profile modelisation, is described in detail in Hadjara et al. (2014); Hadjara (2015).

Table 1: VLTI/AMBER observations of Regulus and its calibration stars using the AT triplet A1-G1- K0.

Object	Date and time	Baseline (m)	Baseline PA (°)
60 Cnc	2014-03-10T03:09	75,81,128	103,34,67
Regulus	2014-03-10T03:48	78,77,125	104,32,68
w Cen	2014-03-10T04:30	73,87,129	88,14,47
w Cen	2014-03-10T04:44	74,87,129	90,16,50
ϵ Cma	2014-03-12T02:15	75,87,116	124,36,76
Regulus	2014-03-12T03:59	76,79,127	104,33,68
w Cen	2014-03-12T04:45	75,87,129	92,17,51
ι Cen	2014-03-12T07:17	80,88,126	113,30,69

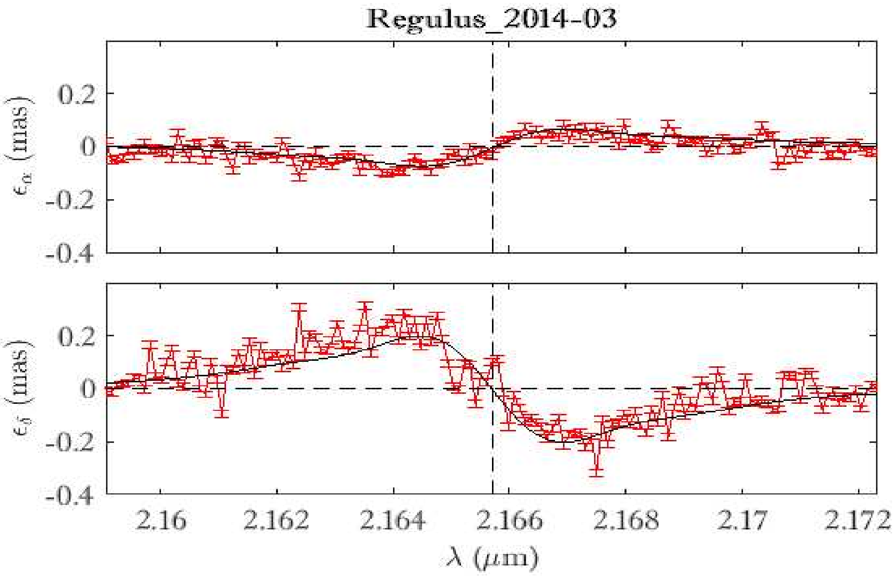

Figure 2: The spectra of perpendicular photocenter components ϵ_α & ϵ_δ.

In order to deduce the best parameters we perform a χ^2 minimization, and the corresponding modeled photocenter shifts are shown in the Fig. 6. To check whether the correct global minimum is achieved, in addition to the non-stochastic χ^2 minimization method, we use a stochastic Markov Chain Monte Carlo (MCMC) method as well. The results are summarized and compared to the previously published results in the Table 2.

We complete our study by examining the coupling of gravity darkening coefficient and inclination (β, i). We deduce the probability space that shows the degeneracy of corresponding stellar parameters in the Fig. 7, where we superimposed the Regulus probability space (β, i) of Che et al. (2011) to ours. We can observe a strong de-

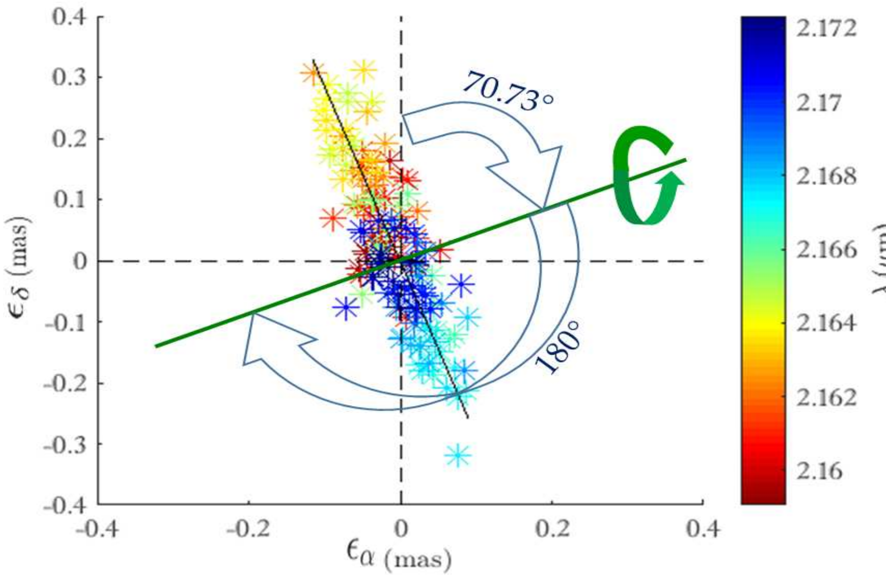

Figure 3: The position angle of the rotational axis from observed photocenter shifts.

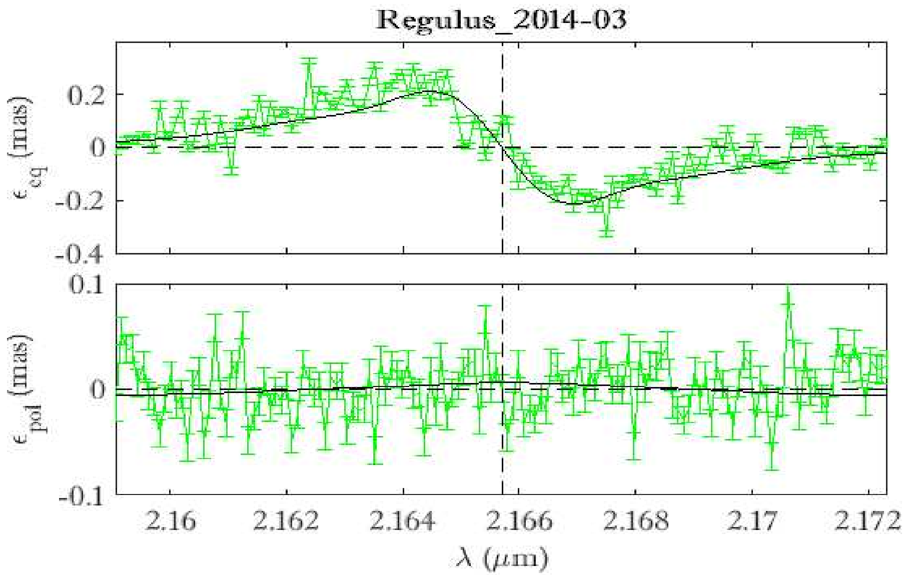

Figure 4: The spectra perpendicular photocenter components $\epsilon_{\rm eq}$ & $\epsilon_{\rm p}$.

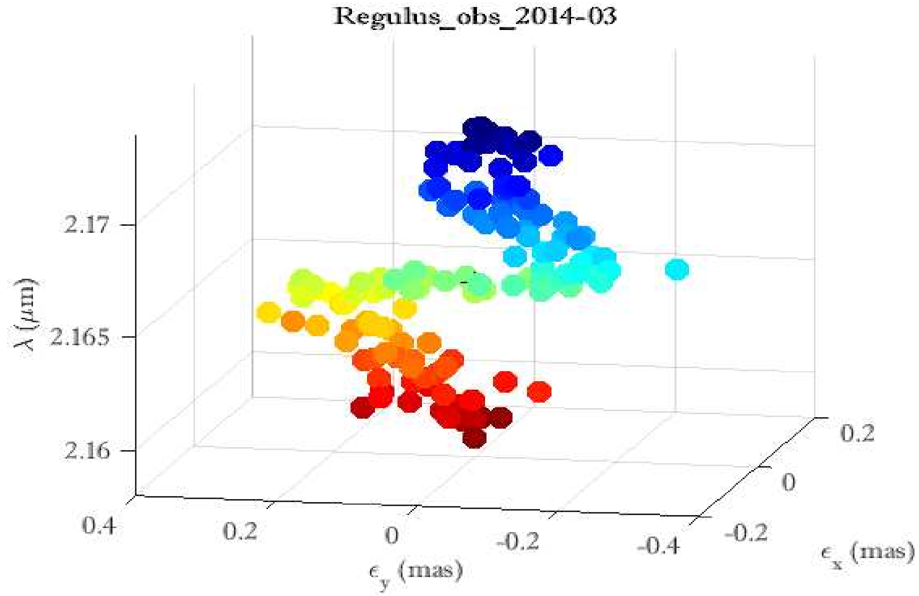

Figure 5: Observed photocenter shifts of Regulus.

generation between the couple. This figure shows a strongly enlarged contour of the probability, implying an important correlation between β and i, which means that we must not rely only on the χ^2 minima. This subject has beeen studied in more details by Hadjara et al. (2017).

4. CONCLUSIONS

Using, for the first time, the approach of spectrally resolved differential interferometry we confirm the results previously obtained for Regulus by long-baseline interferometry (McAlister et al. 2005; Che et al. 2011). However we note that the results obtained for the gravity darkening coefficient should be considered with a great caution which makes this subject open for the future study.

Table 2: The parameters deduced with χ^2 & MCMC minimization as well as previously published data.

	χ^2	MCMC	Mc Alister et al. (2005)	Che et al. (2011)
Req [$R_\odot$]	4.2 ± 0.1	4.2 ± 0.3	4.16 ± 0.08	$4.21^{+0.07}_{-0.06}$
Veq sin i [km/s]	350 ± 15	360 ± 30	317^{+3}_{-85}	340^{+20}_{-30}
PArot [°]	251 ± 4	253 ± 2	266 ± 3	258^{+2}_{-1}
i	86 ± 2	86 ± 10	90^{+0}_{-15}	86^{+1}_{-2}
Teq [K]	10600 ± 600	10600 ± 800	10300 ± 1000	11000^{+400}_{-500}
Tp [K]	144000 ± 800	14400 ± 1100	154000 ± 1400	14500^{+600}_{-700}

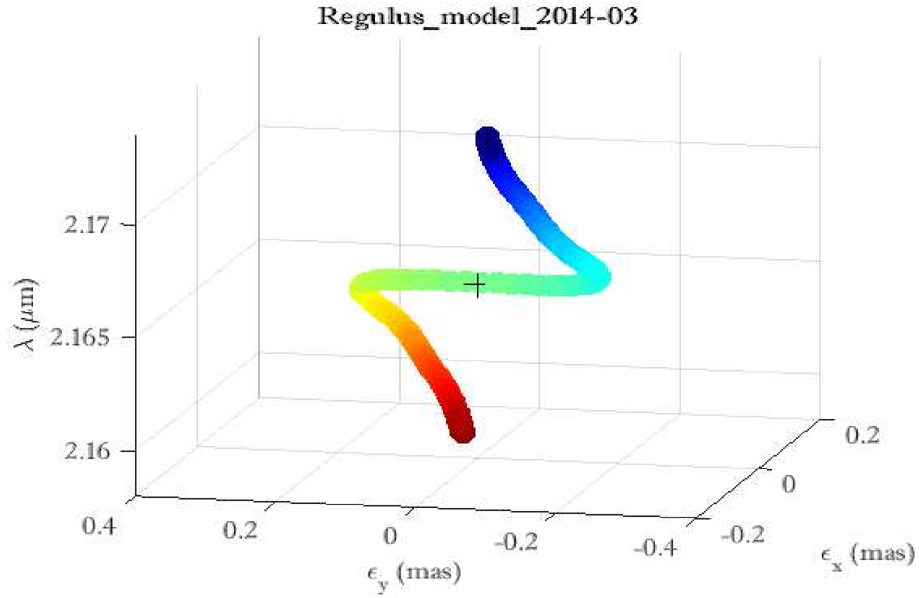

Figure 6: Modeled photocenter shifts of Regulus.

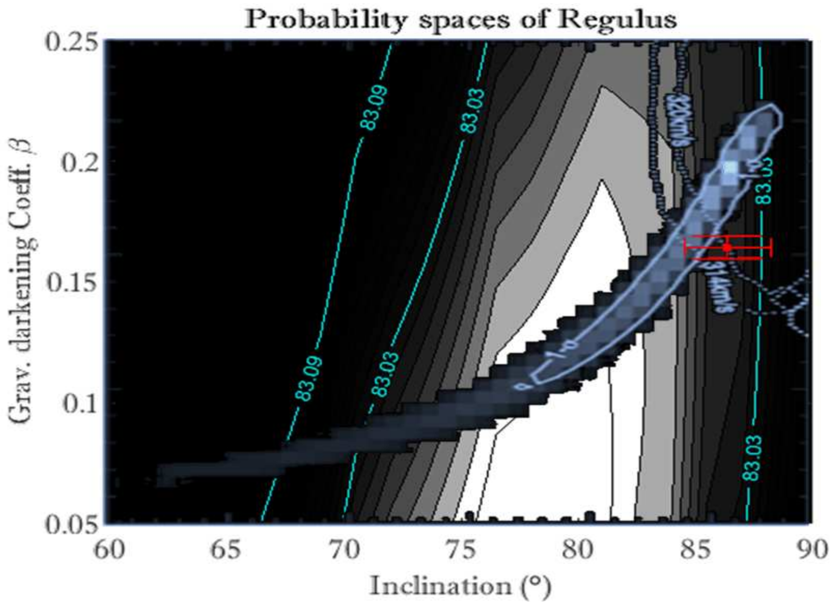

Figure 7: Probability space for Regulus that shows the degeneracy between the stellar parameters β and i in shades of gray. The solid contours represent the 83% probability, and the with the error bars is the best model fitting result for i and β from Espinoza Lara & Rieutord (2011).

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RECONSTRUCTING FORMATION AND EVOLUTION OF COMPACT DWARF CANDIDATES IN CLUSTERS OF GALAXIES

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Abstract. We present results from recently published paper in which we have identified a possible solution for the question of formation and evolution of compact dwarf galaxies in clusters of galaxies. We will present a process, involving halo catalogue and particle data, used to reconstruct formation and evolution histories from Illustris-1 cosmological simulation for objects which were not found in merger tree data. This has lead to the discovery of two channels for formation of compact objects in vicinity of the simulation's most massive cluster galaxies.

1. INTRODUCTION

In recent years discovery of the new classes of compact dwarfs, which are populating the link between dwarf ellipticals (dEs) and globular clusters (GCs) in the galaxy mass-size diagram stirred new interest for their evolution and formation. Here we present results from the recently published paper (Martinović and Micic, 2017) and PhD thesis.

Results were obtained from the Illustris-1 simulation, a cosmological hydrodynamical simulation with a complete model for galaxy formation physics (Vogelsberger et al. 2014). For the identification of the gravitationally bound substructures SUBFIND algorithm was used (Springel et al, 2001). Merger tree was generated with the SUBLINK code (Rodriguez et al. 2015). It should be noted that these results would not be possible without public release of the data and ingenious API system for retrieval of specific informations from each of the results (Nelson et al. 2015).

2. SELECTION OF DATA AND METHOD OF ANALYSIS

Our interest was to look for the compact dwarf galaxy candidates in the vicinity (inside of 106 kpc) of the most massive galaxies in clusters at $z = 0$ in Illustris-1 simulation. This parameter space was inspired by results of Zhang and Bell (2017) paper.

For that purpose (identification of compact dwarf candidates), we have used the data from the group catalogue of the Illustris-1 simulation, which gave us information about identified halos at $z = 0$. Considering that compact dwarf galaxies are near the reliable resolution limit of the Illustris-1 simulation, idea was to ensure that we indeed have a significant population. To avoid resolution limit we have searched for halos which have at least the stellar mass of $\sim 10^8 M_\odot$ and total mass less than $\sim 10^{11} M_\odot$ (all found objects are represented with several hundreds of particles). To keep the search confined only to compact objects, we have also used upper limit for the half-mass radius lower than 1.4 kpc (1 kpc/h). As our interest was inspired by Zhang and Bell (2017) paper (as previously stated) we have searched only for objects inside of 106 kpc from most massive galaxies in clusters at $z = 0$. Operating near the resolution limit of the simulation most likely reduced number of compact objects found. This might be seen on Fig. 1, where we have plotted our compact objects against Norris et al. (2014) dwarf population data. From the Fig. 1 it is obvious that these objects (compact dwarfs) populate parameter space which goes well below the resolution limit of the Illustris-1 simulation (shown by position of our objects).

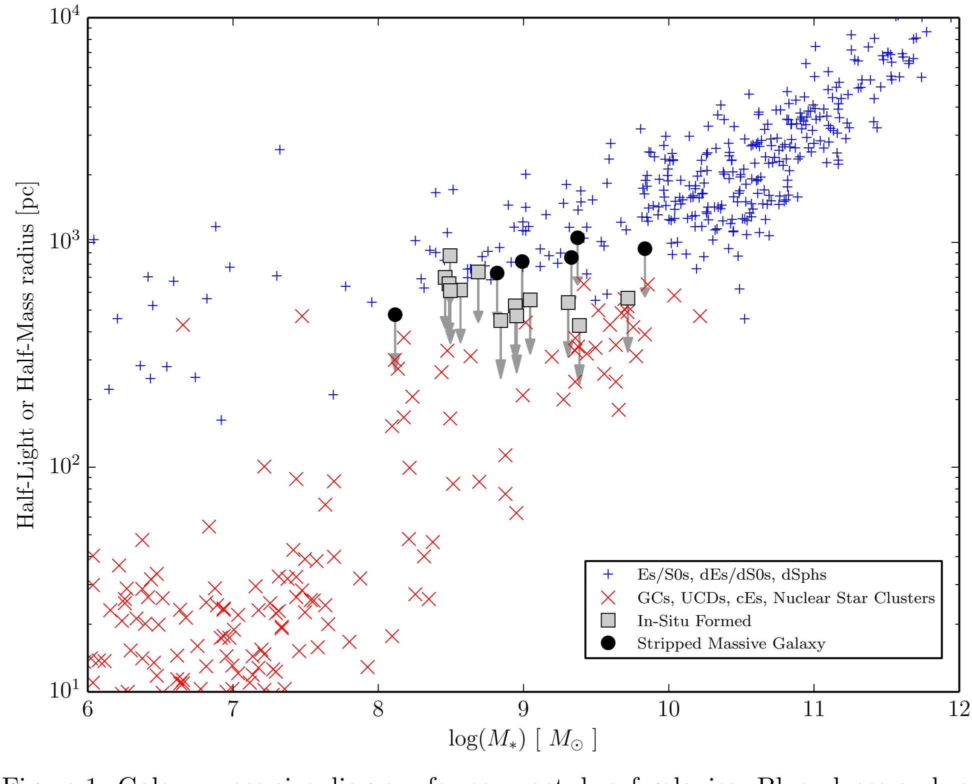

Figure 1: Galaxy mass-size diagram for compact dwarf galaxies. Blue pluses and red crosses are data points from (Norris, 2014) presented with half-light radius. Overplotted are candidate compact dwarfs at $z = 0$ from Illustris-1 presented with 2D projected half-mass radius (averaged over 1000 projections). Black circles represent objects which are remnants of tidally stripped Milky Way mass galaxies, while gray squares represent remnants of dwarf-like objects formed inside clusters of galaxies. Arrows convey that for these populations half-light radius is smaller than half-mass radius. Taken from Martinović and Micic (2017).

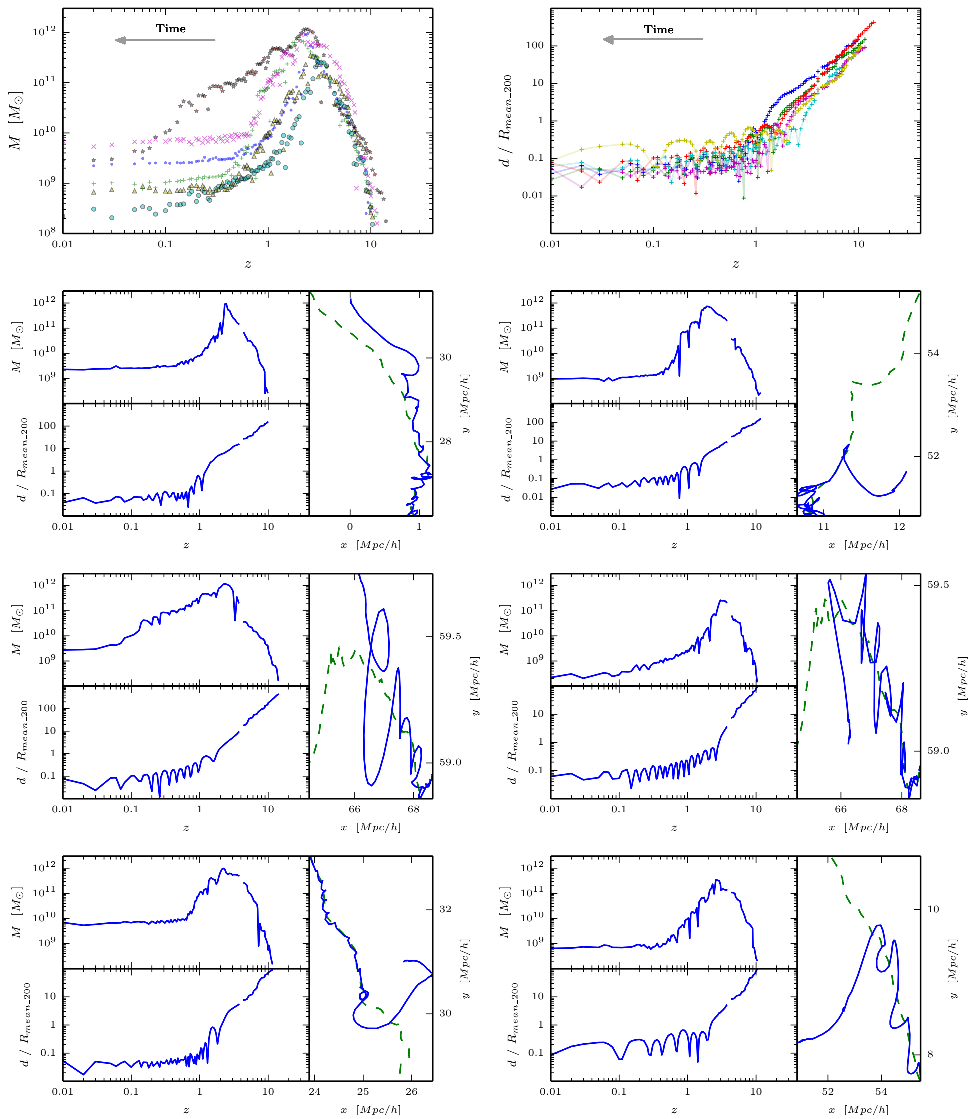

Figure 2: External formation population. Evolution of mass and distance of compact dwarfs from the center of the cluster, relative to the cluster's R_{mean_200} in a same snapshot. Top row represents the total mass and distance evolution, combined for all candidates. Candidates start loosing mass as they enter the cluster at redshift $z \sim 2$. By redshift $z \sim 1$ they are already deep inside the cluster as compact dwarf galaxies. Each of the compact dwarf candidates is featured on its own set of mass and distance evolution plots for clear overview. Additional orbit in x-y plane is outlined for easier visualization, where blue line represents motion of dwarf candidate and green dashed line motion of most massive galaxy inside of cluster of galaxies. Taken from Martinović and Micic (2017).

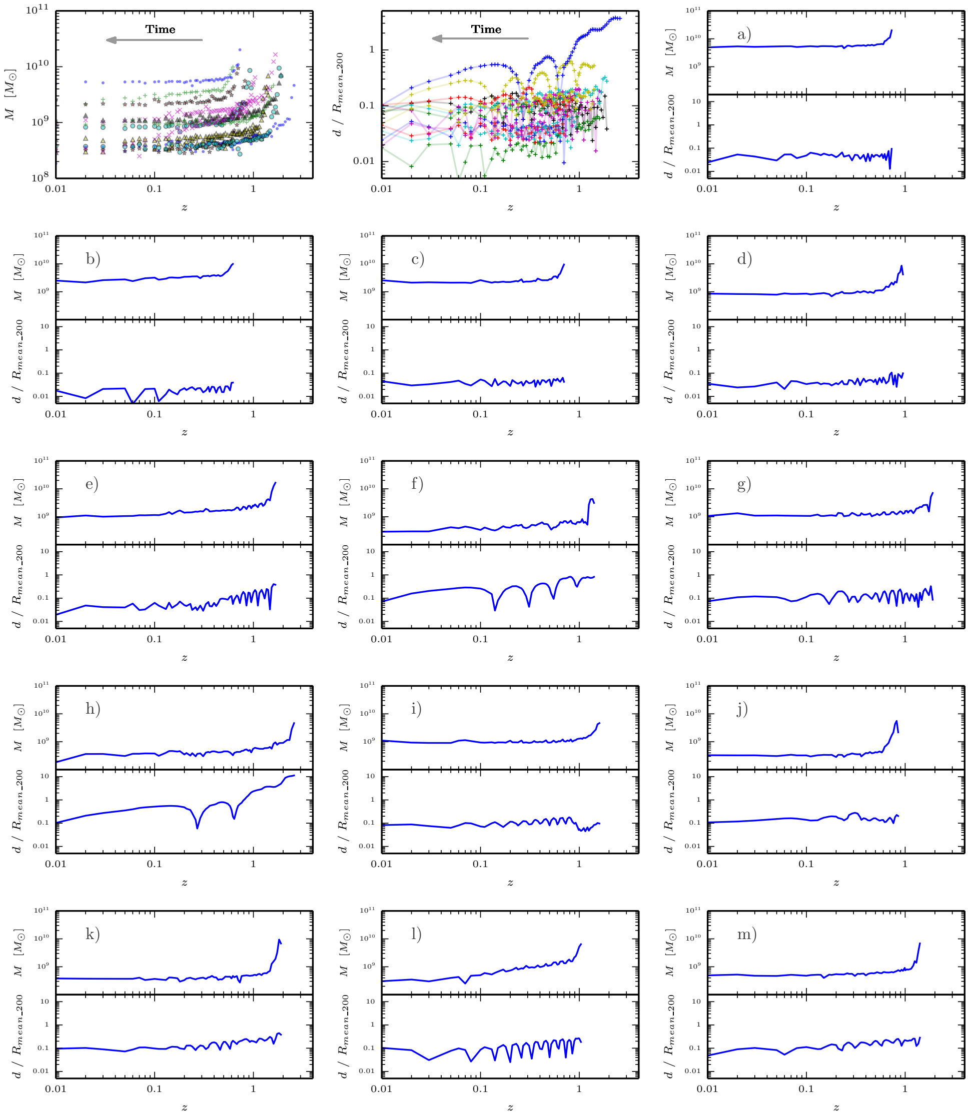

Figure 3: In-situ cluster formed population. Evolution of mass and distance of compact dwarfs from the center of the cluster, relative to the cluster's R_{mean_200} in a same snapshot. Similar as in Fig. 2, first two plots of top row represent the total mass and distance evolution, combined for all candidates. Here we can see that galaxies in this population form within clusters and have less dramatic mass evolution than external population presented in Fig. 2. Each of the compact dwarf candidates is featured on its own set of mass and distance evolution plots for clear overview. Orbit outline is omitted here because of additional area it would necessitate.

As noted in Martinović and Micic (2017) we have found 22 objects that satisfy our criteria. Next came the search for evolutionary paths for those objects with idea that it may reveal to us a preferred path or channel of their formation. For retrieving that data we have relied extensively on snapshots or more precisely on temporal data that is a part of each numerical simulation. Considering that Illustris team also released complete merger tree for Illustris-1 simulation initial search for evolutionary paths of our objects was searched within it.

We have chosen several objects randomly and for them initial search in merger tree yielded no information about connection between halos that were identified in previous snapshots, that is, there was no found evolutionary paths for identified objects. At that point, we were ready to dismiss our objects as numerical artifacts or products of recent dynamical mergers or processes within clusters (considering that they were all close to the major halos within clusters). But interestingly, after running the analysis for all objects within merger tree, for two of them there was significant evolutionary informations going far toward the start of the simulation. This gave us clue that missing merger tree data was consequence of the analysis itself that lead to the creation of the merger tree for the whole simulation (more than 4 million halos identified at $z = 0$). This was most likely because analysis had to incorporate as broad range of scenarios as possible thus sacrificing very specific cases as these turned out to be.

Ultimately we have reconstructed the history of each object manually. For that purpose we have relied on full snapshot information provided by the Illutris team and on the ingenious API system which enabled us to probe specific snapshot data without the need to retrieve terabytes of snapshots. As noted in Martinović and Micic (2017) we have extracted particle IDs and position and velocities for each object. Idea was to look for progenitor information in previous snapshot and to repeat the process as long as possible (toward the start of the simulation).

To constrict the search on manageable number of candidates for progenitors (and to limit the load on API) from the position and velocity data we have predicted where would object be located in previous snapshot after which we would retrieve all the objects in vicinity of that location (cutting out small box where object should have been located previously and finding the objects within it). Then we used initial particle IDs and compared them to particle IDs of the identified objects in the previous snapshot. To speed the process up, initial location probability box was smaller (with sides of 100 kpc/h) and we checked only particle IDs of stellar component (as most of our objects at $z = 0$ had majority of particles of that type). If there was a match, percentage of the found particles was checked. If it was high enough (at least 80% of same particle types) analysis for that snapshot was stopped. Object with matching particle data would be flagged as progenitor and the whole process was repeated for the next snapshot, where now particle IDs of the flagged progenitor were used as primer. Thus iteratively we would search for progenitors in each snapshot, by repeating that process until the start of the simulation.

If in a certain snapshot no progenitor was identified, additional analysis was performed. It consisted of checking other particle IDs in those objects - first dark matter particles, and then gas particles. If no significant number of particles of any type was found (at least 10%), then we would repeat the whole process but for a slightly larger probability box. Box was enlarged until it reached 400 kpc/h around estimated location. After no progenitor objects were found even in a very large box for all particle IDs, then we would flagged that we have retrieved furthest information as possible for the object.

If matching particles were found but with matching percentage between 10% and 80% we would manually stop and analysed all of the particle IDs for the object to decide if that object is a progenitor and how to proceed further (case by case basis). In merger situations (though not many were found until early in the simulation) we would choose main progenitor branch which we declared as progenitor with greatest particle matching percentage (usually above 50% of matching particle IDs).

The whole process was tested against the main progenitor branch within merger tree of two objects which had evolutionary informations and it yielded the same results. Curiously, if during analysis we came upon objects with matching dark matter particles in adjacent snapshots (during random phase of searching for progenitors) that would usually coincide with a link between those objects in merger tree data which exists for few snapshots, thus showing that Illustris team analysis relying heavily on dark matter particles. Considering that objects on $z = 0$ had few dark matter particles, that might explain why they were omitted from merger tree to begin with.

Ultimately from 22 initially selected objects, 3 were dismissed with no progenitor history (probably numerical artefacts) and 19 have been identified to have significant evolutionary data. Their parameters are given in the Table 1. which was taken from the (Martinović and Micic, 2017).

3. RESULTS AND CONCLUSION

After successfully retrieving the evolutionary history of the 19 obtained compact dwarfs in vicinity of most massive galaxies of clusters at $z = 0$ in Illustris simulation it became obvious that there were two channels for their creation.

First channel of formation was the channel which identified a population of compact dwarfs whose formation comes from the tidal stripping of the Milky Way mass galaxies that have been created outside of the clusters and which lost most of their material during spiraling toward cluster center (Figure 1.). This was more exciting to us because dynamics of galaxies of these sizes is not sensitive to simulations underlaying physics.

Second channel was formation which comes from the gas clouds which are located inside clusters with no dark matter component at earlier redshifts, the so called in-situ formation channel (Figure 2.). Although there are explanations for their creation (see Martinović and Micic, 2017) prevalence of this mode of formation might be sensitive to hydrodynamics incorporated in the simulation core and it remains to be seen how sensitive this mode of creation is to the slight differences of an implemented underlaying hydrodynamical model.

In total, 19 compact dwarf candidates from 14 clusters were identified. Around 30% of candidates (in central parts of the clusters) have been formed by tidal stripping of Milky Way mass galaxies spiraling into the cluster, while around 70% are in-situ cluster formed from dwarf like progenitors. These result are consistent with the observational results presented by Zhang and Bell (2017). For further discussion of the results we refer the reader to the paper of Martinović and Micic (2017).

Table 1: Parameters for compact dwarf galaxy candidates from Illustris-1 simulation at $z = 0$: label on plot (if applicable), distance to the most massive cluster galaxy (*kpc*), total mass (given in log), total stellar mass (given in log), maximum stellar mass of the candidate during its existence (given in log), maximum total mass of the candidate during its existence (given in log), stellar half-mass radius (*pc*), a 2D projected stellar half-mass radius (*pc*) (averaged over 1000 projections), minimal retrieved 2D projected stellar half-mass radius (*pc*) and maximum retrieved 2D projected stellar half-mass radius (*pc*). Above the horizontal line are parameters for external population and below the line for the in-situ population. Taken from Martinović and Micic (2017).

Label	d	$\log(M_\odot)$ ($z=0$ total)	$\log(M_\odot)$ ($z=0$ stellar)	$\log(M_\odot)$ (max stellar)	$\log(M_\odot)$ (max total)	R	R_{proj}	R_{min}	R_{max}
	45	9.3	9.3	10.3	12.0	1136	857	778	928
	91	9.0	9.0	10.5	11.9	1074	822	757	892
	99	9.4	9.3	10.8	12.1	1395	1049	1016	1078
	21	8.1	8.1	10.0	11.4	656	477	419	527
	92	9.8	9.8	10.8	12.0	1257	938	888	994
	73	8.8	8.8	9.9	11.5	943	731	626	855
a)	71	9.7	9.7	9.8	10.3	739	565	374	685
b)	32	9.4	9.4	9.7	10.0	558	427	338	479
c)	76	9.3	9.3	9.6	10.0	692	540	332	636
d)	71	8.8	8.8	9.4	9.9	587	449	432	463
e)	83	8.9	8.9	9.6	10.2	679	522	411	615
f)	80	8.5	8.5	9.0	9.6	895	699	567	778
g)	64	9.0	9.0	9.4	9.9	730	555	479	634
h)	85	8.6	8.6	9.2	9.7	808	614	538	688
i)	76	9.0	8.9	9.3	9.7	618	471	452	493
j)	104	8.5	8.5	8.9	9.7	1125	873	813	926
k)	88	8.5	8.5	8.9	10.0	847	655	563	741
l)	93	8.5	8.5	9.3	9.8	787	610	516	669
m)	58	8.7	8.7	9.1	9.8	967	739	548	855

It also needs to be noted that these results would not be possible without public data release of Illustris simulations and without manually reconstructing the evolutionary paths. In the era of big data we need to be aware that broadest analysis applied to full scope of data might overlook important peculiar results.

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IMPACT OF YARKOVSKY EFFECT AND MEAN MOTION RESONANCES ON MAIN BELT ASTEROID'S TRANSPORT

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Abstract. We analyzed the effect of two body mean motion resonances with Jupiter on the mobility of an asteroid's semi-major axis induced by the Yarkovsky thermal mechanism. So far, the impact of the resonance on the semi-major axis drift speed has not been studied to that extent neither from that point of view. We established for the first time a functional relation that determine the connection between the average time spent inside the mean motion resonance, the strength of the resonance and the semi-major axis drift speed. Also, we analyzed how the time spent inside the resonance depends on orbital eccentricity and found a precise functional relation that describes dependence of the average time on the eccentricity, on the strength of the resonance and on the semi-major axis drift speed.

1. INTRODUCTION

The dynamics of asteroids is ruled by interaction between gravitational and non-gravitational forces. It is well known that the most important gravitational mechanism is orbital resonance, especially mean motion resonance (MMR) and, on the other side, the most important non-gravitational effect is Yarkovsky. Very important consequence of MMR is slow evolution (Nesvorný & Morbidelli 1998) in some orbital elements of asteroids. During the last two decades, the Yarkovsky effect has been used to study and explain many unsolved problems in dynamics of asteroids (Vokrouhlický et al. 2015). The Yarkovsky thermal effect is a non-gravitational force due to the anisotropic emission of thermal energy by a rotating body around source of heat (Farinella & Vokrouhlický 1999). For a detailed understanding of the Yarkovsky effect role in the evolution of asteroids, an analysis of the interaction between the Yarkovsky-drifting orbits and MMRs would be very useful (Vokrouhlický et al. 2001). This interaction happens when an asteroid due to the modification of its orbital semi-major axis (caused by the Yarkovsky effect) reach the resonance. The resonance induces a periodic oscillations in the asteroid's semi-major axis around its center. The Yarkovsky effect exactly causes the permanent (secular) evolution of the semi-major axis. As a result of their interaction the mean semi-major axis drift speed is modified with respect to the one caused solely by Yarkovsky. This motivated us to study the effect of different MMRs on an asteroid's semi-major axis changing due to the Yarkovsky effect. The most important results of our research were presented in Milić Žitnik & Novaković (2016) when we had derived functional relation among the time that asteroid spent inside MMR, the strength of the resonance and the semi-major axis drift speed. Soon after, we made an extended analysis of interaction between these two effects that improved previous functional relation including orbital eccentricity in calculating time that asteroid spent in MMR (Milić Žitnik 2016).

2. METHODS

Our methods were explained in Milić Žitnik & Novaković (2015, 2016) in details, so we refer the reader to these papers for additional explanations. Here, we will describe our methodology very shortly. In order to study the aforementioned interaction, the orbital motion of test particles across the resonances is numerically simulated. We performed a set of numerical integrations of 72 000 test asteroids in order to examine the semi-major axis drift delay inside the MMR in a public domain integrator *ORBIT9* (Milani & Nobili 1988). The orbital motion of test objects was simulated between 40 and 120 Myr, depending on the resonance's strength and on the Yarkovsky drift speed. All our analysis are obtained using mean proper orbital elements, that are mostly free from the short-periodic perturbations. The mean proper elements are obtained directly from the *ORBIT9* which has an option to perform online digital filtering in order to remove short-periodic oscillations. We decided to test a range of believable values of the Yarkovsky effect for kilometer-sized Main belt asteroids (Vokrouhlický et al. 2015). The orbit of every test asteroid was propagated using ten equidistant values of da/dt from -4×10^{-5} to -2.0×10^{-3} AU/Myr. In order to compare results for different resonances, we need to chose MMRs whose mutual comparison is direct, so we used two-body resonances always with the Jupiter. We analyzed 12 isolated MMRs with Jupiter, because that is the most massive planet in our Solar system (Figure 1).

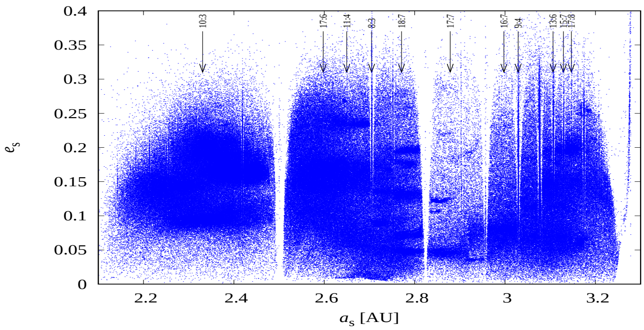

Figure 1: Locations of 11 MMRs with Jupiter shown in the proper semi-major axis vs. the proper eccentricity plane (except 7:3).

Powerful MMRs with Jupiter (2:1, 3:1 or 5:2) are not appropriate for our methods. These resonances quickly throw out asteroids locked inside them (Vokrouhlický et al. 2001) due to close approach with planets. Also, due to their large width they overlap weaker nearby resonances, thus do not satisfy the condition to be isolated (Figure 2). Also, in resonances 3:1, 5:2 and 7:3 exist overlapping of secular resonances that causes increasing in eccentricity to 1 (Moons & Morbidelli 1995).

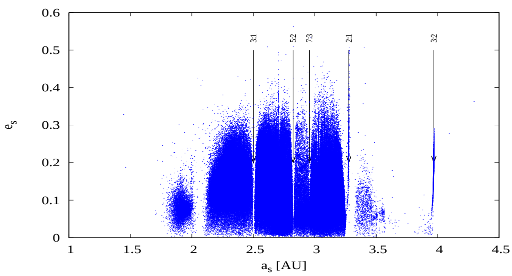

Figure 2: Some of the strongest two-body resonances with Jupiter shown in the proper semi- major axis vs. the proper eccentricity plane, that we excluded from our results.

To estimate strength of resonances, we applied a numerical method proposed by Gallardo (2006). Strength of our MMRs spreads over a range of even seven orders of magnitudes. We used our numerical method to estimate resonance width because of nature of our work, in order to measure time spent inside a resonance. The initial positions of our test asteroids resembled a shape of a MMR in the mean semi-major axis vs. the mean eccentricity plane. In Figure 3 are presented borders of resonance 9:4 as an example of our determination of borders.

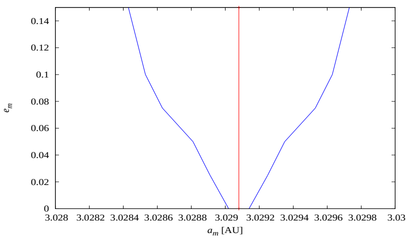

Figure 3: Inner and outer borders of resonance 9:4 in the mean semi-major axis vs. the mean eccentricity plane (broken lines). The center of this resonance is located 3.0291 AU from the Sun (vertical line).

In order to measure the time spent inside a resonance it was necessary to determine the instants of entering, t_1, and exiting, t_2, from the resonance (Figure 4). Further, if Δt and $\Delta \mathrm{a}$ are defined as $\Delta t = t_2 - t_1$ and $\Delta \mathrm{a} = \mathrm{a}_2 - \mathrm{a}_1$, where a_1 and a_2 are semi-major axes at moments t_1 and t_2 respectively, then the time interval $\mathrm{d}tr$ used in our analysis is defined with (Milić Žitnik & Novaković 2016):

$$\mathrm{d}tr = \Delta t - \frac{\Delta \mathrm{a}}{\mathrm{da}/\mathrm{d}t}. \tag{1}$$

We used $\mathrm{d}tr$ instead of Δt because $\mathrm{d}tr$ is not sensitive to the criteria for resonance entering and exiting. It follows from Equation (1): when Δt increases than $\Delta \mathrm{a}$ is increasing, so $\mathrm{d}tr$ measures time for which asteroid crossed strictly one whole resonance and also measures speed up or slow down of that asteroid. It is very important to say that in this way, we bypassed problem with determination instant t_2, that exists only in some cases, and as a consequence is not precisely enough determination of time interval Δt.

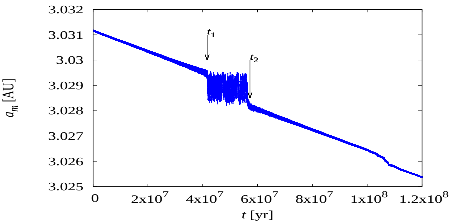

Figure 4: An example of behaviour of test asteroid with the slowest Yarkovsky drift speed da/dt=-4×10^{-5} AU/Myr, that entering in resonance 9:4 at the instant t_1=41 602 600 years and exiting at the instant t_2=57 253 000 years.

3. RESULTS

Now, we present the results of our numerical investigation about estimation effect of the resonances on the semi-major axis drift. We were considered only asteroids that crossed MMRs. Our results had discovered that exists function between the average time $\langle \mathrm{d}tr \rangle$, the strength of the resonance SR and the semi-major axis drift speed da/dt. For 9 (out of 10) values of da/dt analyzed, we found that $\langle \mathrm{d}tr \rangle$ increases when SR is increasing. For the slowest drift speed an opposite trend exists and all values $\langle \mathrm{d}tr \rangle$ are negative (Figure 5). This result might indicate that below some limiting value of da/dt objects typically rapidly jump across the resonance, so we excluded this value from all further analysis presented here. However, behaviour of asteroids with small Yarkovsky drift speeds will be theme of our future work. The same trend exists for the strongest resonance 7:3 (Figure 5), that we excluded also from the results presented here. All asteroids that crossed 7:3 have negative values of the average time $\langle \mathrm{d}tr \rangle$. This is the very interesting result that should be further investigated in the future.

In Figure 6 we used a logarithmic scale to show the correlation between $\langle \mathrm{d}tr \rangle$ and SR (left panel) and between $\langle \mathrm{d}tr \rangle$ and da/dt (right panel). It is obvious that $\langle \mathrm{d}tr \rangle$ time increases while resonance strength SR is increasing. In the log-log plane, this dependence is almost linear, displaying an exponential relation between $\langle \mathrm{d}tr \rangle$ and SR. Some deviation from this trend might exists for weaker resonances (left panel in Figure 6), because of poor signal-to-noise ratio in calculation of $\langle \mathrm{d}tr \rangle$. Similar linear dependence $\langle \mathrm{d}tr \rangle$ shows with changes in da/dt, but in this case with an opposite trend (right panel in Figure 6) and an exponential relation between $\langle \mathrm{d}tr \rangle$ and da/dt was again suggested.

According to Milić Žitnik & Novaković (2016), there is an unique functional relation between $\langle \mathrm{d}tr \rangle$, SR and da/dt, that follows from the above described results:

$$\langle \mathrm{d}tr \rangle = c_1 \; (SR)^{\beta} \; (\frac{\mathrm{d}a}{\mathrm{d}t})^{\gamma}. \tag{2}$$

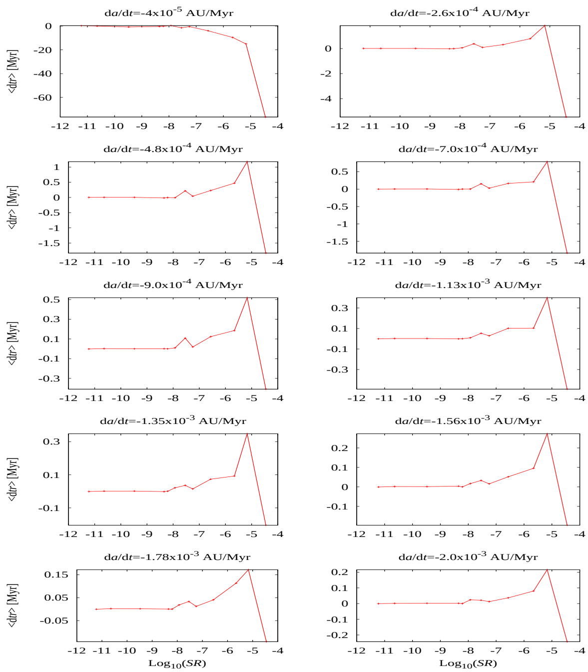

Figure 5: Changes of average time $\langle \mathrm{d}tr \rangle$ in MMRs as a function of $\mathrm{Log}_{10}SR$. Here are shown asteroids that crossed 12 MMRs for every of 10 different values of Yarkovsky drift speed.

These unknown parameters (c_1, β, γ) could be found by numerically fitting data. We found that it is the most convenient to apply the method of least squares fitting using Equation (3) to the data shown in Figure 6:

$$\log_{10}(\langle \mathrm{d}tr \rangle) = \beta \log_{10}(SR) + \gamma \log_{10}(\frac{\mathrm{da}}{\mathrm{d}t}) + c_2. \tag{3}$$

We found fitting parameters that describe the best relation between $\langle \mathrm{d}tr \rangle$, SR and $\mathrm{da}/\mathrm{d}t$ are: $\beta = 0.44 \pm 0.03$, $\gamma = -1.09 \pm 0.20$ and $c_2 = 4.35 \pm 0.66$. Data presented in Figure 6 indicate that the trend of $\langle \mathrm{d}tr \rangle$ might change for smaller values of SR. In order to check it, we repeated the same fitting procedure to the data that exclude the five weakest resonances and the values of the parameters are obtained: $\beta = 0.47 \pm 0.04$, $\gamma = -0.97 \pm 0.15$, $c_2 = 5.11 \pm 0.54$. Conclusion is that the two sets of parameters are statistically the same and we decided to use fitting parameters for 11 resonances in Equation (3). Equation (3) is valid only for eccentricities around 0.1 (approximately for $0.08 \leq e \leq 0.12$), for which SR was estimated. It is well known that SR depends on eccentricity (Gallardo 2006, Lykawka & Mukai 2007). This problem we have bypassed by involving one more parameter in Equation (3) that depends on eccentricity. After that, we calculated SR for equidistant values of eccentricity $0.025 \leq e \leq 0.4$ with step of 0.025. We took these boundaries for

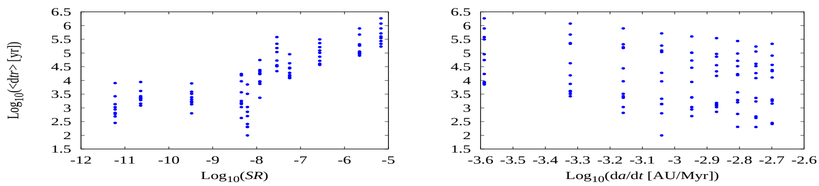

Figure 6: Dependence of average time delay caused by the resonance $\langle \mathrm{d}tr\rangle$ on the 11 resonance strength SR (left panel) and on the 9 semi-major axis drift speed da/dt (right panel).

eccentricity, because most of the asteroids have values of eccentricity in this range. Than, we calculated unknown fitting parameters for these new values of e and SR. Unknown coefficient β defines the relation between e and SR. We got that β depends on eccentricity linearly, $\beta = ae + b$. The parameters a and b could be found by the least-squares method of fitting the obtained data as shown in left panel in Figure 7. We found that their values are $a = 2.06 \pm 0.02$ and $b = 0.24 \pm 0.01$. The parameter γ has the same value for all eccentricity ≈ 1.09 (see Table 3 in Milić Žitnik 2016) because it depends only on the Yarkovsky drift speed. Values of c_2 increases with increasing eccentricity except for $e = 0.025$ (right panel in Figure 7). This function has some oscillations around linear trend. So, we did not look for precise functional relation between e and c_2 and decided to use values of c_2 for appropriate interval of e from Table 3 (see Milić Žitnik 2016). At the end, we got general equation that includes asteroid's eccentricity:

$$\log_{10}(\langle \mathrm{d}tr\rangle) = (2.06e + 0.24)\log_{10}(SR) - 1.09\log_{10}(\frac{\mathrm{da}}{\mathrm{d}t}) + c_2. \tag{4}$$

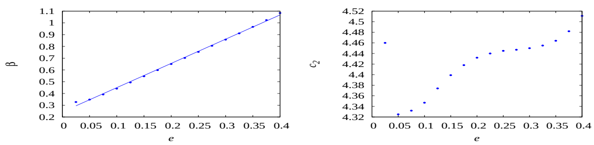

Figure 7: Dependence between e and β (left panel) and between e and c_2 (right panel) for resonance's strength calculated for $0.025 \leq e \leq 0.4$.

In order to understand accuracy of Equation (4), also in order to define its limitations, we calculated standard errors of $\langle \mathrm{d}tr\rangle$ from this equation. We got standard error $\sigma(\langle \mathrm{d}tr\rangle)$ from the total differential of the first order of Equation (4). In this way, we had:

$$\sigma(\langle \mathrm{d}tr\rangle) = \langle \mathrm{d}tr\rangle \times \ln(10) \times [\mathrm{d}\beta\log_{10}(SR) + \mathrm{d}\gamma\log_{10}(\mathrm{da}/\mathrm{d}t) + \mathrm{d}c_2]. \tag{5}$$

With Equation (5) we calculated 3σ standard errors for $\langle \mathrm{d}tr\rangle$ (Figure 8). We concluded that acceptable disagreement between the results obtained by the Equation

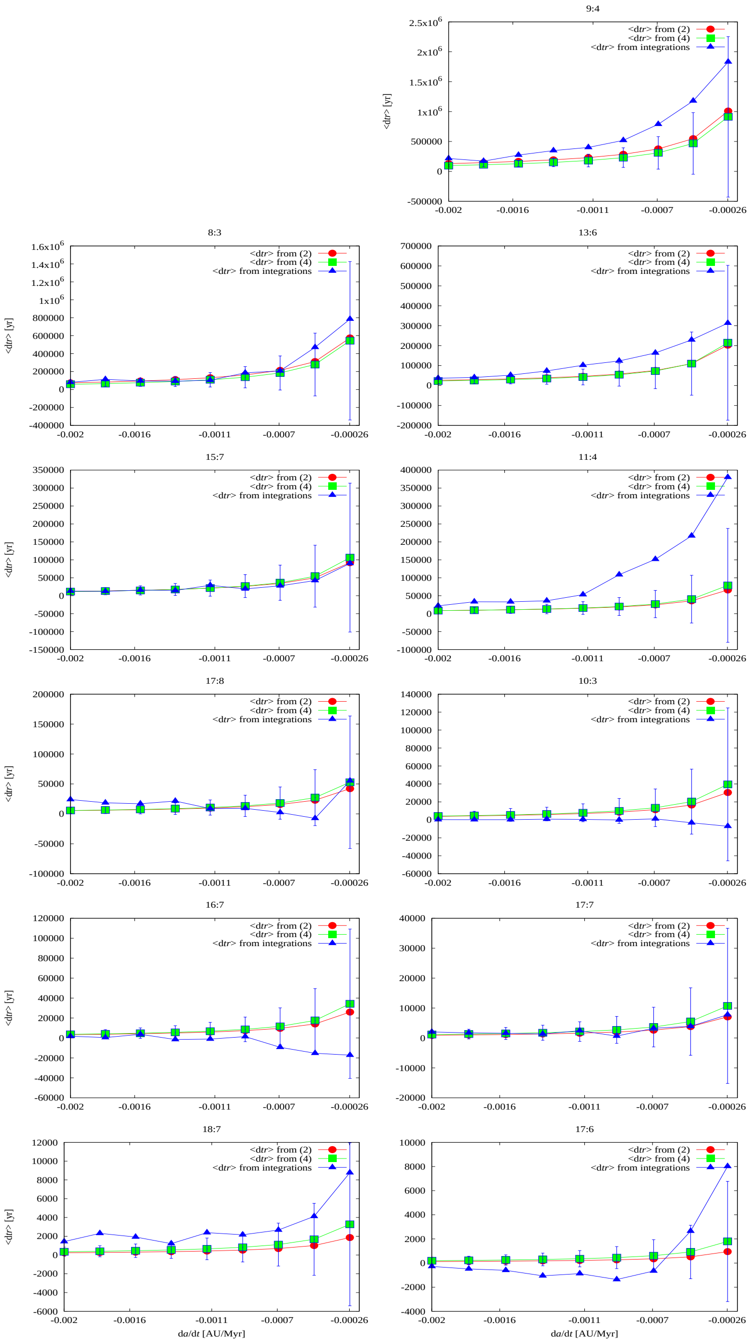

Figure 8: Values $\langle dtr \rangle$ for 9 the largest Yarkovsky drift speeds calculated with Equation (2) and Equation (4), also from numerical integrations. Results from Equation (4) are presented with 3σ interval of standard error calculated using Equation (5).

(4) (with $e = 0.1$), Equation (2) (with average rounded values: $\beta = 0.5$, $\gamma = -1$ and $c_1 = 10^{-1}$) and numerical integrations, can be explained with poor signal-to-noise ratio in determination of single values dtr in weak MMRs (see Figure 6) and because these equations represent approximation of $\langle \mathrm{d}tr \rangle$.

Based on the previous analysis of results (Figure 8), we came to the conclusion that Equation (4) is possible to use for asteroids in MMR with strength $[6 \times 10^{-12}, 6.7 \times 10^{-6}]$ and with Yarkovsky drift speed $[2.6 \times 10^{-4}, 2 \times 10^{-3}]$ AU/Myr.

4. CONCLUSIONS AND FUTURE WORK

This paper briefly review results presented in Milić Žitnik & Novaković (2016) and Milić Žitnik (2016) about the average time spent inside a resonance, the strength of the resonance, eccentricity, the semi-major axis drift speed. Now, it would be easy to calculate the average time that an object spent inside a MMR with given the resonance's strength, the Yarkovsky drift speed and an asteroid's eccentricity. These equations can be applied only to asteroids that entered and exited from MMRs. Work on the remaining issues continues. For instance, we plan to examine the possibility of finding a functional relation between dtr and da/dt, SR, e, i.

Acknowledgment

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INFLUENCE OF THE SOFTENING LENGTH ON STABILITY OF SPIRAL GALAXIES IN N-BODY SIMULATIONS

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Abstract. Softening length is a numerical parameter which is included in calculation of gravitational force between two bodies, in N-body simulations, in order to avoid divergence on small distances and ensure smooth function for gravitational potential. It depends on number of particles in simulations, mass of the particles, dimension of the system and timestep. In this paper we presented how specific choice of values for the softening length affects stability of spiral galaxies like Milky Way and M31. Galaxies in our simulations are consisted of three components: bulge, disk and dark matter halo. Components have different number of particles, dimension and particle mass. Differences between rotation curves, density profiles and energy conservation for different values of softening length were investigated.

1. INTRODUCTION

In order to explore Galaxy, Local group, clusters of galaxies and Universe, various types of numerical simulations were developed last almost half of the century. The main goal of these simulations is studying and describing galaxy formation and evolution. Part of these processes are interactions between galaxies. Unlike stars, interactions between galaxies are very often and very important for evolution if we assume bottom-up model for formation of large galaxies. Mergers, flybys, tidal stripping, etc. can be represented through numerical simulations. Values for some parameters for model constructing are known from observations and the other one are free parameters. Model which is numerical N-body representation of galaxy, or galaxy interaction is better if it differs from observed quantity as less as possible.

Galaxies have large number of stars, so these systems can be threaten through statistical mechanics (Binney & Tremaine, 2011). We can represent galaxy as N-body system (without gas) and only force in the system is gravitational force. Number of bodies, or "particles" is several orders of magnitude smaller then a number of stars in galaxy. Particles are used to represent a mass distribution of real system. As we assume collisionless system, we can use Boltcman's equation for distribution function

(Binney & Tremaine, 2011):

$$\frac{Df}{Dt} = 0 \tag{1}$$

Density of the system and gravitational potential are connected with Poisson equation:

$$\bigtriangledown^2 \Phi = 4\pi G \rho \tag{2}$$

The evolution of isolated self-gravitating collisionless system is described with two previous equations. In N-body simulation, particles of the system are moving due to gravitational attraction and dynamical description assume known coordinates and velocities of every particle at the end of each timestep. Equations that are integrated are equations of motion:

$$\frac{\overrightarrow{dr_i}}{dt} = \overrightarrow{v_i} \tag{3}$$

$$\frac{\overrightarrow{dv_i}}{dt} = \sum_{j \neq i}^{N} G m_j \frac{\overrightarrow{r_j} - \overrightarrow{r_i}}{(|\overrightarrow{r_j} - \overrightarrow{r_i}|^2 + \epsilon^2)^{3/2}} \tag{4}$$

The quantity ϵ in equation (4) is called softening length. We assume that force is softened in order to get smooth gravitational potential and to avoid singularity as $r \rightarrow 0$. This modifies law of gravity at small distances. There is no optimal value for softening length, even if adaptive value is used(Iannuzzi & Dolag, 2011). In N-body codes value of softening length depends on number of particles in the system, mass of the particle (particle type), volume of the system. We need to adjust values for baryonic matter and dark matter if these particles have different masses in simulation and occupy different volumes. Also, timestep need to be adjusted. In practice there are many proposals for choosing a value for softening length: mean distance between particles, distance which is several orders of magnitude less then mean distance in most dense region of the galaxy, softening length for dark matter particle ten times larger then for baryonic particle, if this ratio is equal for masses (Sadoun et al. 2013),...

Stable model predicts conservation of energy and angular momentum (equations (5) and (6)) and virial theorem (equation (7)) should be satisfied.

$$E_{tot} = \frac{1}{2} m_{tot} v_{com}^2 - \frac{1}{2} \sum_{i=1}^{N} \sum_{j=1, j \neq i}^{N} \frac{G m_i m_j}{r_{ij}} + \sum_{i=1}^{N} \frac{1}{2} m_i v_i^2 \tag{5}$$

$$L_{tot} = \sum_{i=1}^{N} m_i (\overrightarrow{r} \times \overrightarrow{v}) \tag{6}$$

$$\frac{2T}{|U|} = 1 \tag{7}$$

where T is kinetic and U is potential energy.

In this paper we investigate influence of softening length on stability of spiral galaxy in isolation. Particulary we investigate changing of density profiles for disk and dark matter halo with changing of softening length under condition that we have equal softening for different components of galaxy. We constructed stable N-body model of spiral galaxy and observe its evolution for several Gyrs in isolation in several runs of simulation with different values of softening length in each simulation.

2. METHOD

Model of spiral galaxy is consisted of disk, bulge and halo, as it is done for M31 in (Sadoun et al. 2013) and (Fardal et al. 2007). For density profiles of disk we used exponential profile in radial direction in the plane of the disk and $sech^2$ profile in orthogonal direction (z-axis). These profiles are given with equations (8) and (9).

$$\Sigma(R) = \Sigma_0 e^{\frac{-R}{R_d}} = \frac{M_d}{2\pi R_d^2} e^{\frac{-R}{R_d}} \tag{8}$$

where Σ_0 is central surface density of the disk and R_d is a scale length.

$$\rho_z \propto sech^2 \frac{z}{z_0} \tag{9}$$

where z_0 is scale length in direction orthogonal to disk.

Composit profile for the disk is given:

$$\rho(R, z) = \frac{\Sigma(R)}{2z_0} sech^2 \frac{z}{z_0} \tag{10}$$

For bulge, we used Hernquist profile (Hernquist, 1993) for mass distribution:

$$\rho_b = \frac{M_b r_b}{2\pi r(r + r_b)^3} \tag{11}$$

where ρ_b is central density of the bulge, and r_b is scale length for bulge.

Dark matter halo is a spherical structure which surrounds disk and bulge. Mass distribution is represented with NFW profile (Navaro, et al. 1996).

$$\rho_h = \frac{\rho_0}{\frac{r}{r_h}(1 + \frac{r}{r_h})^2} \tag{12}$$

where ρ_h is central density of the halo and r_h is scale length. NFW profile in theory ends to infinity, so it is necessary to cut off this function at some point. In many

Table 1: Table I: Parameters for disk, bulge and halo

N_d	108929	M_d	$3.71 \cdot 10^{10} M_\odot$	r_d	6.82 kpc
N_b	96347	M_b	$3.19 \cdot 10^{10} M_\odot$	r_b	1.23 kpc
N_h	261905	M_{halo}	$8.85 \cdot 10^{11} M_\odot$	r_h	122.5 kpc

Table 2: Table II: Different values for softening length in three cases

Model	ϵ_{bulge} (pc)	ϵ_{disk} (pc)	ϵ_{halo} (pc)
I	10	10	10
II	100	100	100
III	10	10	1000

papers (Fardal et al. 2007, Sadoun et al. 2013) it is done on the distance where density drop to $200\rho_{crit}$, where ρ_{crit} is given with:

$$\rho_{crit} = \frac{3H^2}{8\pi G} \tag{13}$$

Truncated density profile for dark matter halo is given with:

$$\rho(r) = \frac{2^{2-\alpha}\sigma_h^2}{4\pi r_s^2} \frac{\rho_0}{(r/r_s)^\alpha (1 + r/r_s)^{3-\alpha}} \frac{1}{2} erfc\left(\frac{r - r_h}{\sqrt{2}\delta r_h}\right) \tag{14}$$

Error function gives truncation after r_h. Some values for the parameters are summarised in Table 1.

We used GalactICs (Widrow, et al. 2005, Widrow, et al. 2008) for constructing initial conditions (distribution of particles at the beginning of the simulation). Content of the output file are masses, coordinates and velocities of the particles. Simulation were running with Gadget2 code (Springel, et al. 2005). Gadget2 code is Three-PM code. Timestep is adjusted to values of softening length:

$$\Delta t = min\left[\Delta t_{max}, \left(\frac{2\eta\epsilon}{|\overrightarrow{a}|}\right)^{1/2}\right] \tag{15}$$

Three different simulation were running, for different values of softening length (Table 2), for 3 Gyrs. This timescale is enough for several rotational periods and we used this model for further investigation of formation of streams during mergers.

3. DISCUSSION

We will discuss density profiles for disks and halos (bulges have drift that is not due to softening length, so it won't be discuss here) and energy conservation for working examples of stable spiral galaxies.

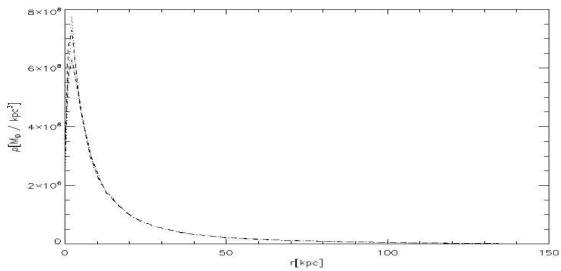

Figure 1: Density profile of dark matter halo for different values of softening length, models: I dot, II dash, III dash-dot.

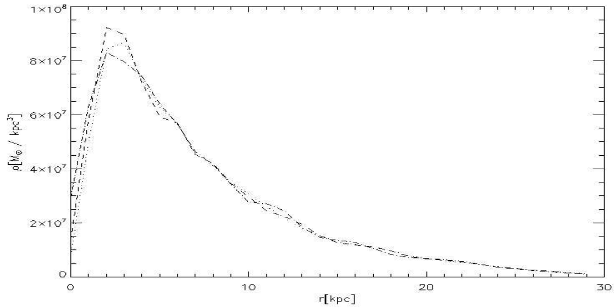

Figure 2: Density profile of disk for different values of softening length, models: I dot, II dash, III dash-dot.

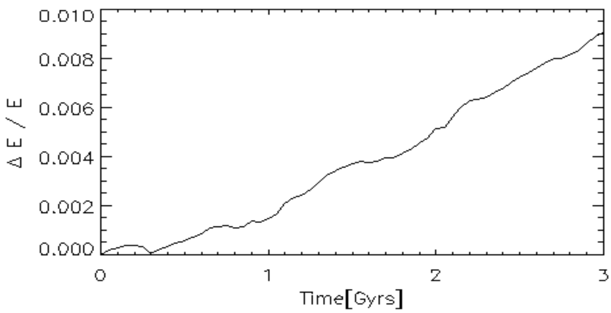

Figure 3: Changing of total energy for model I.

Softening length is a numerical parameter which is necessary for calculating gravitational force at small distances. We have modified law of gravity only at small distances and used classical Newtonian gravity above value of ϵ. From previous graphs we can conclude that softening length has no significant influence on stability of galaxy, in special case energy conservation and density profiles. Changes in density profiles are due to initial conditions and small dynamical instability after several Gyrs. We

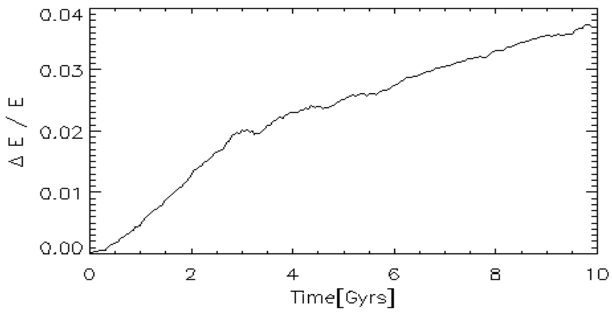

Figure 4: Changing of total energy for model II.

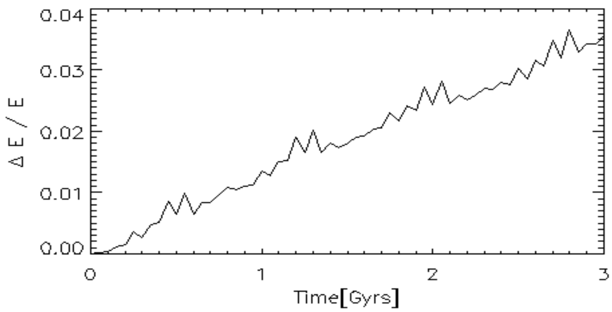

Figure 5: Changing of total energy for model III.

can see a very small differences between cases with equal and non equal values of softening length for different components of galaxy. In the case III, time duration for executing simulation is larger then in cases I and II, because at each step code is checking particle ID in order to choose value for the softening length. This results can be used for this specific type of simulation with Gadget2 code: N-body simulation with number of particles less then 10^6.

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BAR DETECTION IN N-BODY SIMULATIONS USING FOURIER ANALYSIS

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Abstract. Bars are considered to be a common feature in disk galaxies. Since their formation and evolution can be fully studied only using N-body simulations, it is important to refine and improve methods for bar detection and determination of its properties. The most practical and frequently used method is based on Fourier analysis of the face-on density distribution of disk particles. However, criteria for positive bar detection and determination of its parameters are usually biased toward long and strong bars or cases where no other feature is present in the disk (e.g. spiral structure, tidal tails). We propose a new criterion which enables positive bar detection for both weak and short bars, and also successfully distinguishes bar region from other possibly present features.

1. INTRODUCTION

Measurements of the fraction of barred galaxies can vary depending on the definition of the bar, methods of its detection, and the sample of observed galaxies, but it is undoubtful that bars are a common feature in disk galaxies. Moreover, bar can play a major role in secular evolution of its host galaxy (e.g. Cheung et al. 2013, and references therein). For these reasons, there is still ongoing research, both observational and theoretical, focusing on different aspects of bars in galaxies: their formation, evolution and effects they have on host galaxy (e.g. Galloway et al. 2015; Cheung et al. 2015; Berrier & Sellwood 2016; Gajda et al. 2017).

Observational studies can provide useful information about statistical properties of barred galaxies, or detailed analysis of specific galaxies. However, in depth and temporal analysis of bar and its host galaxy is only possible using N-body simulations. Large amount of data acquired by simulations dictates that the method for analysis must be fully automated and efficient in usage of resources. Since method based on Fourier analysis satisfies these requirements, it is frequently used for detection of bars in N-body simulations. We will briefly review common criteria for bar detection using this method, and propose a new, more general criterion with appropriate examples.

2. FOURIER METHOD

When disk is decomposed in Fourier modes, prominent features (like bars and two armed spirals) contribute the most to second mode C_2. Relative (mass normalized, since zeroth mode C_0 yields total mass) second Fourier mode $m = 2$, in general, is calculated as:

$$\frac{C_2}{C_0} = \frac{1}{M} \sum_{j=1}^{N} m_j e^{2i\phi_j} = C_{21} + iC_{22} \tag{1}$$

where M is total mass, and summation is performed over all particles with masses m_j and angles ϕ_j in $x-y$ plane. With C_{21} and C_{22} representing real and imaginary part respectively, of its complex form, amplitude A_2 and phase ϕ_2 are then calculated as:

$$A_2 = \sqrt{{C_{21}}^2 + {C_{22}}^2} \quad \text{and} \quad \phi_2 = \arctan\left(\frac{C_{22}}{C_{21}}\right) \tag{2}$$

This calculation can be done globally (for all disk particles) but high amplitude A_2 will, in that case, indicate that some kind of axisymmetric feature or more of them are present, and phase ϕ_2 will give rough estimate of position angle for the most prominent feature or its part.

In order to get more detailed information about the feature type and its region, this calculation must be performed locally, by slicing the disk in annuli in $x-y$ plane.

2. 1. COMMON CRITERIA FOR BAR DETECTION

Strength of the bar is characterized by local maximum value of amplitude A_2. Determining whether that local maximum really indicates that the bar is present is a bit more complicated. The most common method is to set lower limit for maximum amplitude to 0.2. Since this can be biased toward strong bars, usage of some lower value for the limit is not uncommon. Position angle of the bar is determined either by phase angle of the local amplitude maximum, or by mean phase angle in the bar region.

Determination of the bar length is the most complicated part of bar detection procedure. It is usually determined by the radius where amplitude A_2 drops to half maximum value after detected maximum, or by the end of region where phase angle ϕ_2 does not deviate more than some fixed value (either 10° or 20°) from the mean phase in the region (e.g. Aguerri et al. 2009). In ideal cases where there is only strong long bar present in the disk, all of these methods will give similar bar length as a result. However, if another feature (e.g. spiral arms, rings) is present, measuring bar length using half maximum amplitude is not viable due to amplitude not dropping to its half maximum value or not dropping fast enough. Introducing condition for fixed phase deviation must be done with caution and some prior knowledge of the bar. For example, choosing lower value for phase deviation will give realistic length for longer bars but shorter bars can go undetected. Alternatively, choosing higher value will make it possible to detect shorter bars but it will overestimate length of longer bars. All of these problems make it clear that the process of bar detection cannot be fully automated using these common criteria.

2. 2. NEW ALGORITHM OUTLINE

Basic concepts of our bar detection algorithm are presented on the flowchart (Figure 1). We start by identifying all local peaks of $A_2(R)$ profile as $A_{2,\mathrm{max}}$ with respective radius R_{max}, and run the procedure for each of them.

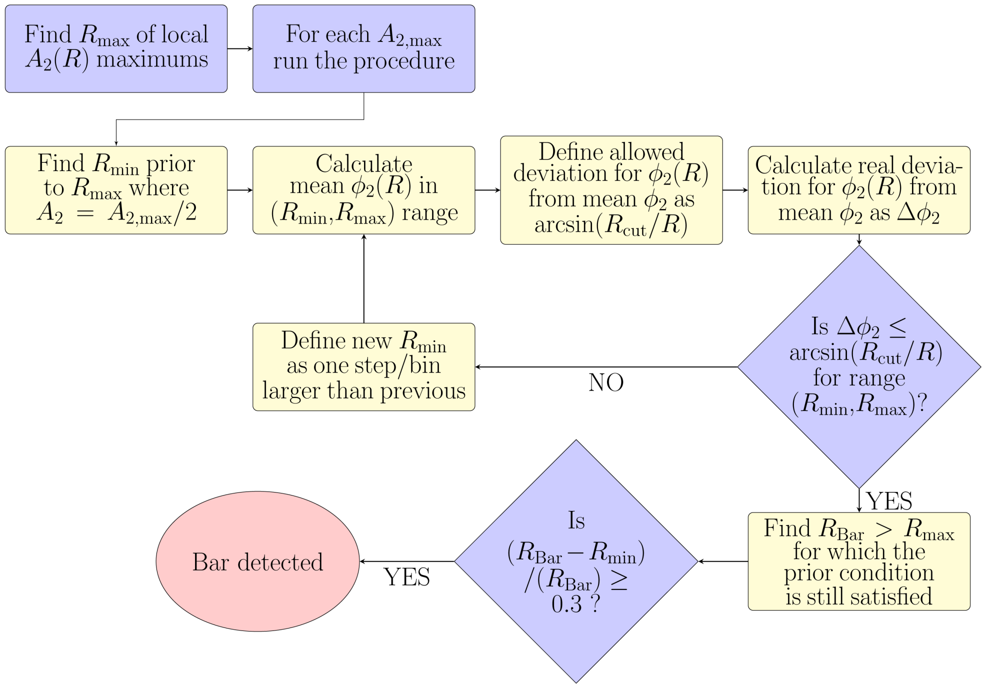

Figure 1: Our bar detection algorithm.

We use $A_{2,\mathrm{max}}$, R_{min}, R_{bar} and $\phi_{2,\mathrm{mean}}$ as measures of bar strength, width, length and position angle, respectively. Allowed deviation of $\phi_2(R)$ from mean phase $\phi_{2,\mathrm{mean}}$ is defined and calculated as $\arcsin(R_{\mathrm{cut}}/R)$ where R_{cut} is a free parameter. Generally, R_{cut} can take any fixed value, either arbitrary chosen or estimated based on some characteristics of amplitude and phase profiles. It represents fixed maximum allowed distance from fixed angle at any given radius, resulting in variable allowed angle distance on different radii. That way we can get rid of the bias toward long or short bars raised by fixed allowed angle deviation, and detect bars regardless of any prior assumptions about bar length. Additional condition examines flattening (or ellipticity) of the bar. We chose rather high value of 0.3 for the second condition in order to avoid getting false positives for bar as much as possible.

3. RESULTS

As mentioned previously, in ideal cases with strong long bar every criterion for bar detection will give similar results for bar strength and length. We will present two special cases where every common criterion fails to either detect the bar, or determine its properties but our algorithm detects the bar and gives decent rough estimate of its properties.

3. 1. TWO ARMED SPIRAL WITH SHORT BAR

Amplitude and phase profiles for the case of two armed spiral with short bar are presented on Figure 2. Red dashed line on amplitude profile plot represents bar width and red solid line represents bar length. Dashed red lines on phase profile plot represent allowed deviation from fixed phase angle (black solid line). Method based on amplitude half maximum value would, in this case, give significantly larger bar length, whereas method based on fixed phase deviation would fail to detect the bar (if not set to higher value, e.g. $> 40°$).

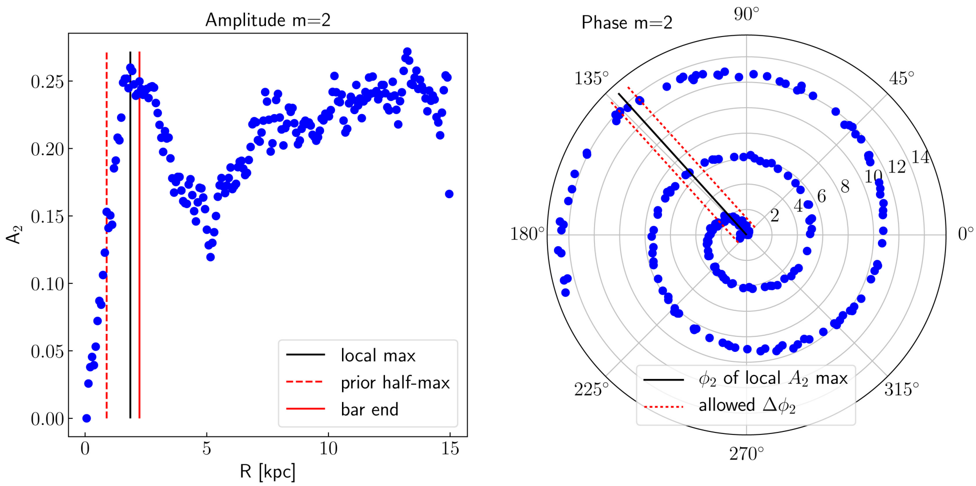

Figure 2: Amplitude and phase profiles for the case of two armed spiral with short bar. Left (amplitude) panel: solid black line represents radius of local A_2 maximum, dashed red line radius of prior half maximum (i.e. bar width), and solid red line radius of the bar end (i.e. bar length). Right (phase) panel: solid black line represents phase angle of local A_2 maxium, and dashed red lines allowed deviation.

Disk surface density map is given on Figure 3. Radius of solid circle is equal to determined bar width, and radius of dashed one to bar length. Solid line corresponds to bar position angle. It is clear that these parameters are estimated quite precisely and bar region is cut from spiral region successfully.

3. 2. BAR WITHIN BAR

Dispositioned shorter bar within larger bar is a quite interesting and unique feature. Amplitude and phase profiles are presented on Figure 4. with the same line notation like in previous example. Solid lines on phase profile plot correspond to phase angles of local amplitude peaks. However, as a final estimate of bar position angle we use mean phase angle in the bar region. Inner, shorter bar cannot be detected by any of the common criteria. For outer, larger bar method based on amplitude half maximum value gives slightly shorter bar length, and method based on fixed phase deviation

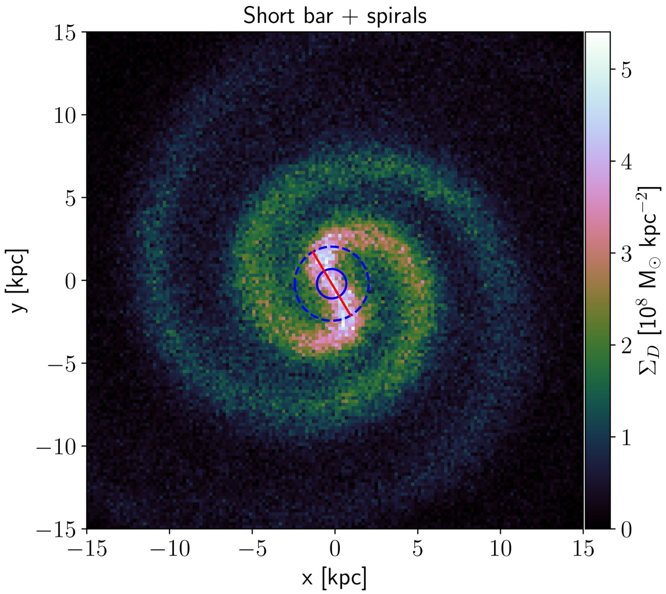

Figure 3: Disk surface density for the case of two armed spiral with short bar. Radius of solid blue circle is equal to determined bar width, and radius of dashed blue circle to determined bar length. Solid red line represents determined bar phase angle.

requires allowed deviation to be set to somewhat higher value (20°) in order to detect bar due to a few scattered points in the bar region.

Disk surface density maps are given on Figure 5. In order to avoid confusion, determined parameters are shown separately for inner bar (left panel) and outer bar (right panel). Due to overlap between bars regions, inner bar phase angles are highly affected by outer bar so inner bar position angle cannot be estimated by mean phase angle in the region. We encountered this issue in every similar case with dispositioned overlapping bars. However, *ad hoc* fix for this particular issue - simple subtraction of the angles in question seems to give more accurate estimate of inner bar position angle (dashed line on left panel).

4. SUMMARY

We modified the conditions for bar detection based on the analysis of amplitude and phase profiles of relative second Fourier mode. Instead of using maximum of amplitude, with a lower limit, in some radial range as a measure of bar strength, we detect all local peaks of amplitude and wrap our further analysis around those. For every of those peaks, we use position of half maximum amplitude prior to every local maximum as a measure of bar width. With determined width we define the condition for allowed deviation of phase from mean phase angle in the possible bar region. Upper radial limit of the region where the condition for phase deviation is satisfied is used as a measure of bar length and if the two measures (width and length) satisfy the ellipticity condition, we conclude that the bar is detected.

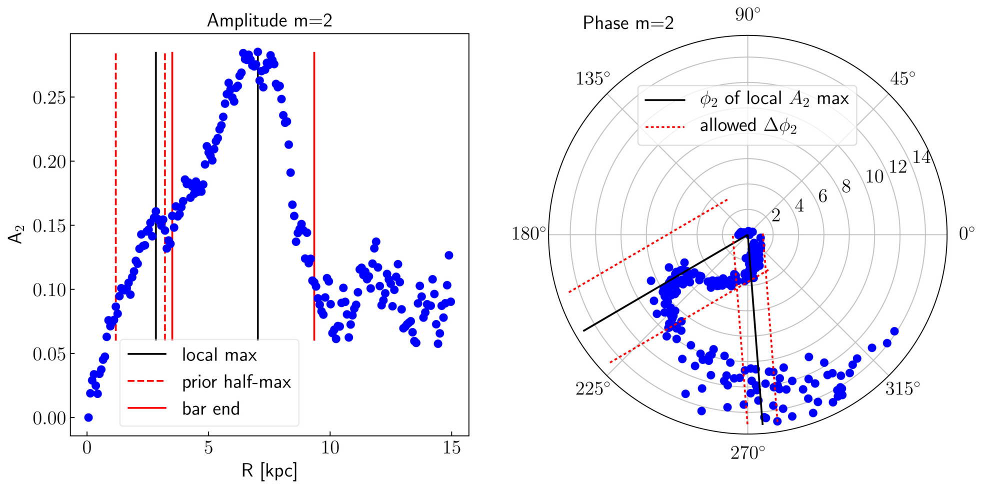

Figure 4: Amplitude and phase profiles for the case of short bar within larger bar. Left (amplitude) panel: solid black lines represent radiuses of local A_2 maximums, dashed red lines radiuses of prior half maximum (i.e. bar widths), and solid red lines radiuses of the bar ends (i.e. bar lengths). Right (phase) panel: solid black lines represent phase angles of local A_2 maxiums, and dashed red lines allowed deviation.

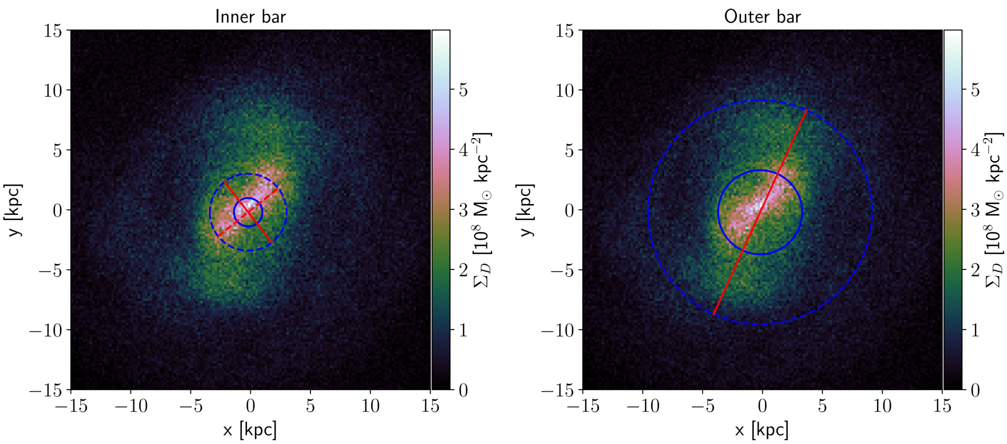

Figure 5: Disk surface density for the case of short bar within larger bar. Left panel shows detailed line plots for inner, short bar, and right panel shows detailed line plots for outer, larger bar - radiuses of solid blue circles are equal to determined bar widths, and radiuses of dashed blue circles to determined bar lengths. Solid red lines represent determined bar phase angles, and dashed red line *ad hoc* fixed phase angle for inner bar.

These changes enable bar detection for both short and long, weak and strong bars, and algorithm successfully distinguishes bar region from spirals. In addition, unique and short lived structures like dispositioned short bar within larger bar can also be detected.

Applied to over 8000 snapshots of galaxy flyby simulations, done using GADGET2 code (Springel 2005), we had less than 2% of false positives for bar, all of which were the cases with either inner region of tightly winded spirals or thick rings. Discarding those cases is possible with additional analysis of disk surface density profiles. Compared to the results of other bar detection methods and criteria, we did not have false negatives. Lowering the value for ellipticity condition in our algorithm might show that the value we chose to use results in some amount of false negatives. However, it is questionable whether low ellipticity bar-like features can be considered as bars.

Analysis and plotting scripts were written in `Python` but simplicity of our algorithm allows it to be written and executed in any programming or scripting language. Our full method, currently in testing, will be able to detect regions of different features present in the disk and recognize them as bars, spirals and rings or arcs.

Acknowledgment

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DISSECTING THE GALACTIC TeV EXCESS

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Abstract. Diffuse gamma-ray emission has been studied in detail by the Fermi LAT telescope. Most of the emission comes from the interactions of galactic cosmic rays with the interstellar gas, as well as interactions with fields. However, at least a portion of the emission belongs to unresolved point sources. Another eye-on-the-sky in the past years, focusing on the high energy range (TeV), was the Milagro Cherenkov telescope and its last report of the diffuse Galactic disk emission for the region $30^\circ \leq l \leq 65^\circ, -2^\circ \leq b \leq 2^\circ$ states a gamma-ray differential flux differential flux of $F_{\gamma,\mathrm{diff,MGO}} = 4.1 \pm 1.0 \times 10^{-12}\,\mathrm{photons\ TeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$ on 12 TeV, adopting a spectral index of 2.62. We compare this value to the Fermi LAT diffuse model and find an excess in gamma-rays dubbed the TeV excess. After removing all known point sources found in catalogues, such as the Fermi LAT and TeVCat catalogues, the TeV excess remains. Our goal was to give possible explanation of this excess by modeling point source candidates - pulsars and supernova remnants, that are still unresolved.

1. INTRODUCTION

Diffuse gamma emission from our galaxy - the Milky Way, has been measured in the recent years using several telescopes. Most of the measured emission above 1 GeV originates from cosmic ray interactions with the interstellar medium, resulting in neutral pion production and latter decay into two gamma rays. Another dominant source of gamma rays is from leptonic cosmic ray interactions via the inverse Compton scattering and Bremsstrahlung emission. Last guaranteed contributing source are the unresolved point sources. There are still open questions concerning the gamma-ray sky such as the galactic centre gamma-ray excess, as well as the high energy Milagro excess - still unexplained emission of gamma rays in the Milky Way.

Our goal was to give possible explanations for the unresolved excess measured at 12 TeV by the Milagro telescope, taking into account the newest diffuse gamma ray data from the Fermi LAT telescope, as well as all recorded point sources in the area of the sky that was observed by this Cherenkov telescope ($30^\circ \leq l \leq 65^\circ, -2^\circ \leq b \leq 2^\circ$) by modeling point source populations - supernova remnants and pulsars/pulsar wind nebulae.

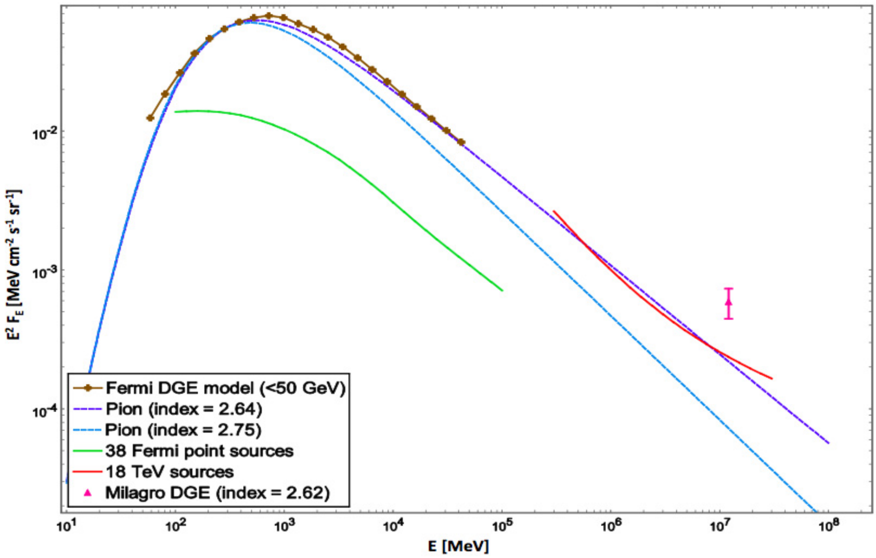

Figure 1: All selected data for the $30° \leq l \leq 65°, -2° \leq b \leq 2°$ sky region, including the Fermi LAT diffuse emission model, 38 Fermi point sources, 18 TeV TeVCat sources and the Milagro 12 TeV data point.

2. DIFFUSE AND POINT SOURCE GAMMA RAY DATA

In our analysis we have used the latest Milagro collaboration data for the Galactic region$30° \leq l \leq 65°, -2° \leq b \leq 2°$ observed above 12 TeV, from where the measured differential gamma ray flux at 12 TeV was derived to be $F_{\gamma,\mathrm{diff,MGO}} = 4.1 \pm 1.0 \times 10^{-12}\,\mathrm{photons\ TeV^{-1}\,cm^{-2}\,s^{-1}\,sr^{-1}}$, assuming a spectral index of 2.62. Spectral indices we use are are linked to the gamma-ray flux as $F_{\gamma,\mathrm{diff,MGO}} \sim -\Gamma$, thus taking only positive values. The Fermi LAT Pass 7 Galactic Diffuse Model [1] has been adopted from the Fermi collaboration, and extrapolated over 50 GeV, selecting the data with in the Milagro field of view and our region of interest.

From the measured diffuse flux, we subtract the smoothed contribution of all measured gamma ray point sources in out ROI from the Fermi LAT 4-year Point Source Catalog (3FGL) [2] and the eVCat catalog of TeV sources [3].

In Figure 1. we plot all the data we selected - the Fermi LAT diffuse emission model, 38 Fermi point sources, 18 TeV TeVCat sources and the Milagro 12 TeV data point after subtracting all known point sources (the Milagro excess data point).

[1] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html
[2] https://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/
[3] http://tevcat.uchicago.edu

It can be concluded, that even after subtracting all known sources of gamma rays at high energies, the 12 TeV Milagro data point still stays well above all modeled gamma rays emission coming from diffuse and point source contributions, meaning it still stays unexplained.

3. SOURCE POPULATIONS AS TEV EXCESS EXPLANATIONS

We move to investigating the possibility that the explanation for this excess can be found in the population of unresolved galactic point sources. One of the most commonly identified sources in the Milky Way, that are a good candidate for the Milagro excess explanation, would be unresolved supernova remnants (see e.g. Wakely & Horan 2008).

For Galactic distribution of supernova remnants we take the distribution given in Green 2015, while for their fluxes we adopt a function from Pfrommer and Ensslin 2003, and their luminosity ($L_\gamma \sim -\Gamma + 1$) from the 3FGL Fermi LAT collaboration paper.

We do not at this stage assume any luminosity function but rather leave luminosity as a free parameter doing the analysis with maximal and minimal luminosity take for all sources, that we adopt from what has already been measured for Galactic supernova remnants by Fermi LAT in 3FGL. We also leave spectral index Γ as a free parameter.

We adopt their galactic distributions and luminosity functions, leaving the spectral indices in both cases as a free parameter in order to cover a larger range of potential sources.

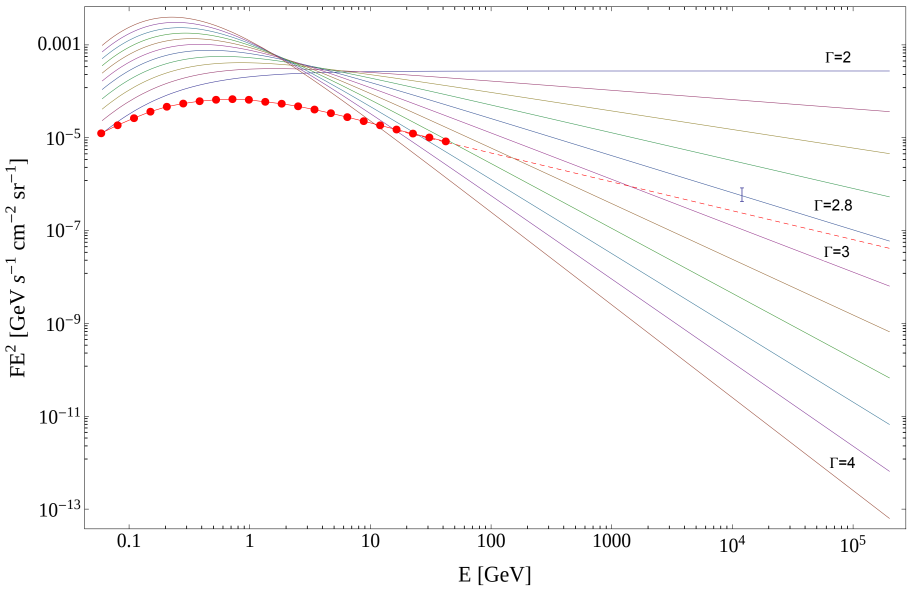

Figure 2: Modeled gamma ray flux for a population of supernova remnants with the maximal luminosity, where the spectral index takes values in the range $2 \leq \Gamma \leq 4$. Red points are the Pass 7 galactic diffuse emission measurement adopted from the Fermi LAT, and extrapolated to higher energies (dashed red), the blue data point is the Milagro 12 TeV excess.

In Figures 2. and 3. we present our results for supernova remnants where we implement the highest and lowest values for their luminosities that we adopt from the 3FGL catalogue of sources. We assume that the production of gamma rays from these sources is purely hadronic in nature and leave the spectral index Γ as a free parameter.

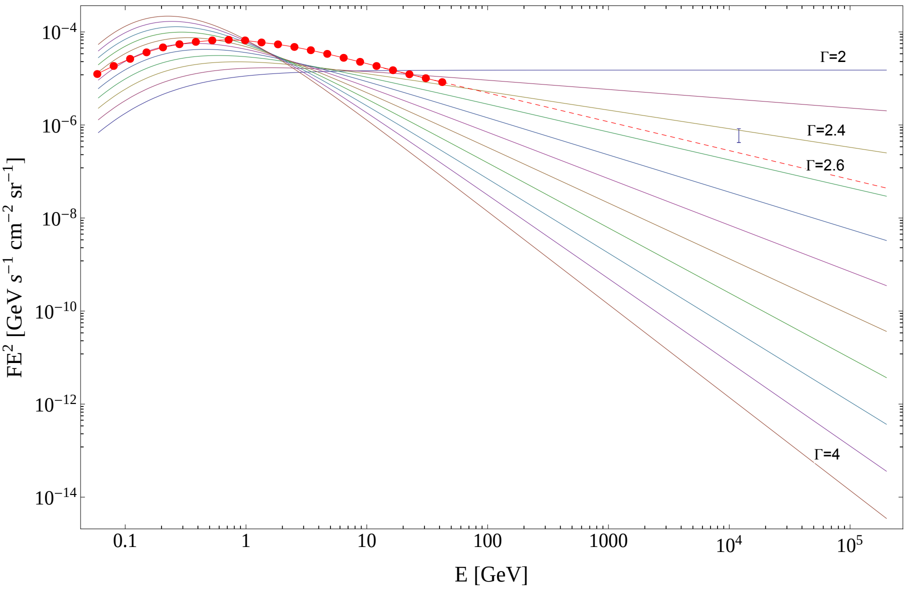

Figure 3: Modeled gamma ray flux for a population of supernova remnants with the minimal luminosity, where the spectral index takes values in the range $2 \leq \Gamma \leq 4$. Red points are the Pass 7 galactic diffuse emission measured by the Fermi LAT, and extrapolated to higher energies (dashed red), the blue data point is the Milagro 12 TeV excess.

As can be concluded from the Figures 2. and 3. above, for certain values of luminosity (minimal luminosity value) and spectral indices ($\Gamma = 2.4$ and $\Gamma = 2.6$), the Milagro excess data point (the Milagro derived flux at 12 TeV from which we subtract all known point sources) is reached by our modeled population of supernova remnants, while not overshooting the measured Fermi LAT diffuse foreground. Therefore we conclude that the Milagro excess could be explained by point sources - in this case supernova remnants, that remain undetected.

We have confirmed the existence of the Milagro gamma-ray TeV excess in the light of the most recent data from both the Milagro collaboration, the Fermi LAT Pass 7 diffuse galactic emission and 3FGL, as well as TeVCat point source data. We then modeled a population of sources that could potentially explain this excess in gamma rays - supernova remnants adopting their Galactic distribution and fluxes, varying the luminosity function value and spectral indices. We see that for some choices of the free parameters supernova remnants can indeed reach, and thus explain, the Milagro excess data point at 12 TeV.

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COSMIC-RAY ACCELERATION IN GALACTIC INTERACTIONS AND ITS IMPLICATIONS

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Abstract. It has been shown that galactic interactions and mergers can result in large-scale tidal shocks that propagate through interstellar gas. As a result, this can give rise to a new population of cosmic rays, additional to standard galactic cosmic rays present in star-forming galaxies. We investigate the impact of this tidal cosmic-ray population on the nucleosynthesis of lithium in interacting systems (such is the Small Magellanic clod for example) in the context of the cosmological lithium problem. Moreover we also demonstrate that the presence of these tidal shock-waves and may also have far reaching consequences on our understanding of galactic evolution by affecting the far-infrared radio correlation observed in star-forming galaxies and impacting star formation rates estimates. We discuss how these effects can be further probed through numerical simulations and used to on high-redshift observations of interacting systems.

1. INTRODUCTION

Particle acceleration in astrophysical environments occurs at some level everywhere where there are shock, magnetic fields and charged particles present, through the mechanism called diffusive shock acceleration (Bell 1978). It is generally accepted that the dominant population of cosmic rays in star-forming galaxies are accelerated in strong shocks of supernova remnants, since these sources have sufficient energy to explain observed cosmic-ray fluxes and spectra. For this reason, cosmic rays are perfect probes of galactic star-formation and supernova rates.

Though we can directly detect cosmic rays only at Earth, we can indirectly learn about their current and past fluxes through observing the consequences of their interactions. Specifically, interaction of cosmic-ray protons with ambient hydrogen produces neutral pions which decay into two gamma rays. Most of the diffuse Galactic gamma ray emission from the disk of the Milky Way observed by the Fermi-LAT (Ackermann et al. 2012) is due to this process (Strong et al. 2010). Furthermore, fusion reaction between cosmic-ray alpha particles and ambient helium results in production of lithium nuclei (Reeves 1970). While ^{7}Li is produced in big bang nucleosynthesis and the neutrino process as well as in cosmic-ray interactions, light isotope ^{6}Li is only made by cosmic rays, making it a perfect cosmic-ray dosimeter (Reeves 1970).

Lithium was first observed outside of the Milky Way in the interstellar medium of the Small Magellanic Cloud (Howk et al. 2012). This observation was to test the origin of the long-standing "lithium problem" where pre-galactic ^{7}Li observed in low-metallicity halo stars (Ryan et al. 2000) in the Milky Way is 2-4 times lower than the predicted primordial ^{7}Li abundance (Cyburt et al 2016). However, observation of lithium in the Small Magellanic Cloud showed also that the abundance of ^{6}Li is larger than what would be expected from based on its metallicity, indicating a larger cosmic-ray exposure over its history (Prodanovic et al. 2013). This was furthermore confirmed by predictions of its ^{6}Li abundance (Ciprijanovic 2016, Fields and Prodanovic 2005) based on its observed gamma ray emission (Abdo et al. 2010).

Motivated by the problems related to lithium in both the Milky Way and the SMC, Prodanovic et al. (2012) explored the possibility of existence of another population of cosmic rays in star-forming galaxies that would be in addition to already present galactic cosmic rays (GCRs), and which would result in overall larger ^{6}Li production. These tidal cosmic rays (TCRs) would be accelerated in large-scale tidal shocks that appear the interstellar medium of the host galaxy due to galactic interactions, mergers and close fly-bys (Cox et al. 2006). Extending on the owrk of Murphy (2013), Prodanovic et al. (2012) showed that it would be possible to account for the entire observed ^{6}Li abundance if the entire gas of the SMC was shocked only twice, which would be plausible given that the SMC has experienced close fly-bys with both Milky Way and the Large Magellanic Cloud, evidence of which is a tidal stream of gas seen the between Magellanic clouds (Diaz and Bekki 2011).

In order to further explore the possibility and the impact that this additional cosmic ray population would have on our understanding of star forming galaxies, Donevski and Prodanovic (2015) explored the behavior of the correlation that exist between far infrared and radio emission in star- forming galaxies, during different merger stages of these system. They found that variations found in this correlation, analyzed on a small sample of interacting galaxies, were consistent with additional heating and particle acceleration due to presence of large tidal shocks.

In this work we continue to explore the possible cosmic-ray acceleration in shocks due to galactic mergers and interactions, and present some preliminary results on how this extra TCR population would impact the evolution of the radio emission in star-forming galaxies over redshifts.

2. EVOLUTION OF THE FAR-INFRARED RADIO CORRELATION

Observation have established that there is a strong correlation between radio and far infrared (FIR) emission in star-forming galaxies (van der Kruit 1971). It is understood that the origin of this correlation is in the star-formation itself where the FIR emission is coming from dust heated by the UV radiation of young stars, while radio emission is dominantly due to synchrotron emission of electrons accelerated in supernova remnants. This FIR-radio correlation is often represented through parameter

$$q_{\rm FIR} = \log\left(\frac{F_{\rm FIR}}{3.75\times10^{12}{\rm Wm}^{-2}}\right) - \log\left(\frac{S_{1.4}}{{\rm Wm}^{-2}{\rm Hz}^{-1}}\right) \tag{1}$$

where $F_{\rm FIR}$ and $S_{1.4}$ dust emission flux and radio emission flux at 1.4 GHz respectively (Helou et al. 1985). The value of this parameter analyzed on the sample of 1800 star-forming galaxies including interacting was found to be $q_{\rm FIR} = 2.34 \pm 0.01$ (Yun et al. 2001). Though Murphy (2009) that the value of this parameter should increase going to higher redshifts due to increased importance of inverse Compton energy losses of electrons onto increasing density cosmic microwave background photons, results of numerous studies showed that this correlation parameter was relatively stable and unchanging over redshifts (Sargent et al. 2010). However, the infrared-radio correlation has recently been investigated on a large sample containing more that 12000 star-forming galaxies up to redshift $z < 6$ in the COSMOS field (Delhaize et al. 2017). They found that, contrary to previous predictions, the FIR-radio parameter decreases with redshift as (Delhaize et al. 2017):

$$q_{\rm FIR}(z) = (2.52 \pm 0.03)^{-0.21\pm0.01}. \tag{2}$$

In the light of results of Donevski and Prodanovic (2015) we can say that the presence of interacting systems in this sample is guaranteed to add to the scatter in $q_{\rm FIR}$ values in the observed sample at some level. Here we explore how would the determined FIR-radio parameter change if analysis was done on a sample of star-forming galaxies that contains some fraction of interacting systems and we allow that the value of this parameter changes over different merger stages as was shown in Donevski and Prodanovic (2015). Assume that at any epoch, a sample of analyzed star-forming galaxies contains a fraction of interacting galaxies where that fraction is a function of redshift. Interacting galaxies in that sample will be in different merger stages, where each stage will have different characteristic value of the $q_{\rm FIR}$ parameter: early interaction stages will be shortest and characterized by extra shock heating causing the increase in $q_{\rm FIR}$ value, later stages will be longer and characterized by additional particle acceleration and dominance of the TCR population and decrease in the $q_{\rm FIR}$ value, while in final stages the FIR-radio parameter should return back to its "‘unperturbed"’ value (Donevski and Prodanovci 2015). Thus due to different timescales of these interaction stages, overall effect should be systematic decrease in the $q_{\rm FIR}$ determined from a sample of interacting galaxies. And the larger the fraction of interacting systems is in the sample, the more prominent would this decrease be, and we assume that this fraction evolves as $f_m = 0.008(1+z)^3$ (Bluck 2011). On the other hand, as star-formation rate also evolves, galactic cosmic ray flux will evolve as well, and as tidal cosmic-ray population is competing with it, this will result in lessening the decrease in the $q_{\rm FIR}$ due to interactions as star-formation rate increases, and strengthening the decrease in the $q_{\rm FIR}$ as it decreases. To include the effects of star-formation we adopt cosmic star formation rate from Madau and Dickinson (2014). Finally, we also take into account the expected increase in $q_{\rm FIR}$ due to decrease of synchrotron emission as a result of increased inverse Compton losses on the cosmic microwave background photons (Murphy 2009).

One example of our results is presented on Figure 1. The bottom magenta curve is the FIR-radio correlation parameter evolution found in Delhaize et al. (2017), while the blue curve above is the evolution that follows from our assumption that interacting galaxies introduce an overall decrease of the $q_{\rm FIR}$ and modeled evolution of the fraction of interacting galaxies, where we also include the effects of cosmic star-formation rate evolution and increase in cosmic microwave background photon density which will impact relative importance between inverse Compton an synchrotron energy losses. The last effect is sensitive to the choice of galactic magnetic field which was for the purpose of demonstration here taken to be 500μG. Though the exact behavior does depend on model details like choice of evolution of interaction fraction, choice of cosmic star-formation rate, galactic magnetic field, timescales of interaction phases as well as the magnitude of deviation of $q_{\rm FIR}$ value from its nominal, non-interacting value, we see that the observed decrease in $q_{\rm FIR}$ can be modeled.

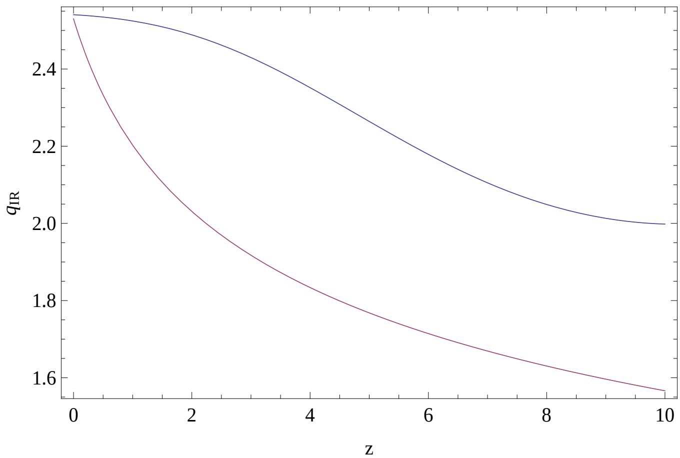

Figure 1: Evolution of the $q_{\rm FIR}$ over redshift. The bottom magenta curve is the evolution found from the sample of star-forming galaxies in the COSMOS filed (Delhaize et al. 2017. The top blue curve is the evolution expected if we assume that sample contains some fraction of interacting galaxies where the value of the $q_{\rm FIR}$ is systematically lower compared to non- interacting galaxies (Donevski and Prodanovic 2015).

3. DISCUSSION

Following the results of Donevski and Prodanovic (2015) where it was found that the FIR-radio correlation parameter varies across merger stages for interacting galaxies, and motivated by the recent findings of Delhaize et al. (2017) that this parameter decreases with redshift, we have explored how this parameter would change when analyzed sample includes an evolving fraction of interacting systems. Our preliminary results indicate that, when effects of galactic interactions are taken into account, specifically when cosmic rays are allowed to be accelerated in tidal shocks that arise in interactions, the FIR-radio correlation parameter can decrease in a manner similar to what was observed. Though the results are indeed strongly model dependent, it is clear that presence of interacting systems will not only add to the scatter in the observed sample, but that it can also have observable effect, which will be better quantified in publication to follow.

Acknowledgment

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EARLY GROWTH OF SUPERMASSIVE BLACK HOLES AND GRAVITATIONAL WAVE RECOIL

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Abstract. Formation mechanism of supermassive black holes (SMBHs) observed in the early Universe is still not fully understood. At hight redshifts black holes (BHs) primarily grow through mergers with other BHs and through episodes of gas accretion triggered by major mergers of dark matter (DM) haloes . Combining Millennium-II and Millennium N-body cosmological simulations we find that BH remnants of Pop III stars could explain BH mass function observed at redshift $z = 6$ if Eddington ratio is fixed at $f_{\mathrm{Edd}} = 3.7$.

During BH mergers asymmetric emission of gravitational radiation can lead to BH kicks. Gravitational wave recoil can completely eject BH from it's host if the kick velocity is larger than the escape velocity from the galaxy. This process could affect formation of SMBHs if BH mergers are dominant growth mode. Recoiling BHs are investigated in analytical and numerical models of various host galaxies.

This work is a review of several publications that have been included in the PhD thesis.

1. INTRODUCTION

Observations of quasars powered by SMBHs with masses $\sim 10^9\,\mathrm{M}_\odot$ at redshifts $z > 6$ put strong constrains on their formation and growth mechanisms. One of the most extreme examples of such SMBHs is one with mass $2 \times 10^9\,\mathrm{M}_\odot$ detected at $z = 7.085$ (Mortlock et al. 2011). In order to explain the existence of such SMBHs, formation of BH seeds had to occur at very high redshifts ($z \gtrsim 15$). Further episodes of intense gas accretion and mergers with other BHs are believed to be the main path for their growth to SMBHs.

1. 1. BH SEEDS AND ACCRETION PARAMETERS

In this thesis remnants of Pop III stars are investigated as seeds of SMBHs. Pop III stars are the first stars that started to form at redshift $z \sim 20$. At that time gas had primordial composition which enabled first stars to have masses in range 10–1000$\,\mathrm{M}_\odot$, with typical mass of $\sim$ 100 $\mathrm{M}_\odot$ (Hirano et al. 2014). Previous works have shown that remnants of Pop III stars require continuous accretion close to or exceeding the Eddington limit in order to explain the mass function of SMBHs in distant quasars (e.g. Johnson et al. 2012, 2013). BH mergers could have significant contribution to

BH growth, but even with the combination of BHs mergers and accretion, low-mass BH seeds would require prolonged accretion episodes at the Eddington limit or early stages of super-Eddington accretion (e.g. Madau et al. 2014).

BH growth due to gas accretion depends on three gas accretion parameters: radiative efficiency ϵ, Eddington ratio $f_{\rm Edd}$ and accretion time. After one accretion episode the final BH mass $M_{\rm BH}$, as a function of its initial mass $M_{\rm BH,0}$ is:

$$M_{\rm BH} = M_{\rm BH,0} \times \exp\left[\frac{f_{\rm Edd}(1-\epsilon)}{\epsilon}\frac{t_{\rm f}-t_{\rm i}}{t_{\rm Edd}}\right] \tag{1}$$

where $f_{\rm Edd} = 450$ Myr, $t_{\rm i}$ and $t_{\rm f}$ are the ages of the Universe at the beginning and the end of accretion episode, respectively (Johnson et al. 2013). Mean values of the radiative efficiency and quasars lifetime can be estimated using the Soltan's argument (Soltan 1982). The mean value of radiative efficiency during accretion is $\epsilon \gtrsim 0.1$ (e.g. Davis & Laor 2011). Quasars lifetime is comparable to Salpeter's time (Salpeter 1964): $t_{\rm s} = 4.5 \times 10^7(\epsilon/0.1)(L/L_{\rm Edd})^{-1}$, which gives 45 Myr for radiative efficiency $\epsilon = 0.1$ and accretion at the Eddington limit.

BH growth models based on the standard thin accretion disc usually assume that BH cannot accrete gas above the Eddington limit. However, recent observations suggest that super-Eddington accretion with values $f_{\rm Edd} \sim 1-5$ might be possible in the early Universe (e.g. Kelly & Shen 2013; Du et al. 2014; Page et al. 2014).

1. 2. ROLE OF GALAXY MERGERS AND BH KICKS

During the merger of two galaxies that host SMBHs, due to the dynamical friction force, BHs sink to the merger remnant centre where they form a binary system. Further interactions with stars and gas carry away energy of the system which leads to the binary hardening (Begelman et al. 1980).

Once the separation between BHs becomes $\lesssim 10^{-3}$ pc, the energy losses due to gravitational radiation cause them to merge. If the merging BHs have unequal masses or spins the asymmetric emission of gravitational radiation can lead to BH kick. Gravitational waves propagate in a preferential direction due to non-zero net linear momentum and the centre of mass of the binary recoils in the opposite direction (Redmount & Rees 1989).

Gravitational wave recoil can displace a newly formed BH from the galaxy core or completely eject it if the BH speed is larger than the escape velocity from the halo centre. The magnitude of the gravitational wave recoil depends on the mass ratio of BHs, the spin magnitude and orientation with respect to the binary orbital plane, and the eccentricity of the orbit. Gravitational wave recoil can significantly affect the SMBH growth through mergers, since ejected BHs are less likely to merge with other BHs.

The aim of this work is to review the results of several publications in order to investigate the influence of gravitational wave recoil on the formation of SMBHs at high redshifts.

In section 2 growth of SMBHs at hight redshift is investigated. In sections 3 and 4 we calculate trajectories of recoiling BHs in static and evolving DM halo potential, and in analytical and numerical models of merger remnant galaxies, respectively. We summarize and discuss the results in Section 5.

2. FORMATION OF SMBHs AT HIGH REDSHIFTS

2. 1. METHOD

We investigate if low-mass BH seeds (100 $M_\odot$) planted into haloes of Millennium simulation (Springel et al. 2005) and Millennium-II simulation (Boylan-Kolchin et al. 2009) can grow into SMBHs that have been observed at $z \sim 7$.

We develop a novel method how to combine these two simulations together in order to have both: early halo formation history with low-mass haloes (to track BH growth history); and a large enough box with high abundancy of largest mass halos (in which $10^9 M_\odot$ SMBH at $z \sim 7$ can be produced). First we place $100 M_\odot$ BH seeds in haloes of Millennium-II simulation which has 125 times better mass resolution then Millennium simulation in order to make BH growth history. Then we take most common BHs from Millennium-II simulation as seeds for Millennium simulation to produce $10^9 M_\odot$ SMBH at $z \sim 7$. For further details on how simulations were combined we refer to Smole et al. 2015.

We make merger trees which track merger history of DM haloes and associated BHs. Accretion episodes are triggered after every major merger, which is defined as $\frac{M_{\rm halo,1}}{M_{\rm halo,2}} \geq 0.3$, for $M_{\rm halo,1} < M_{\rm halo,2}$. After each accretion episode BH mass depends on the initial BH mass, Eddington ratio, radiative efficiency and accretion time-scale (Eq. 1.) For radiative efficiency we choose commonly accepted value $\epsilon = 0.1$. Every accretion episode is limited to 50 Myr, which is $\sim$ Salpeters time for accretion at the Eddington limit. The only free parameter in our model is the Eddington ratio. We assign a fixed value of this parameter to each accretion episode in one simulation run.

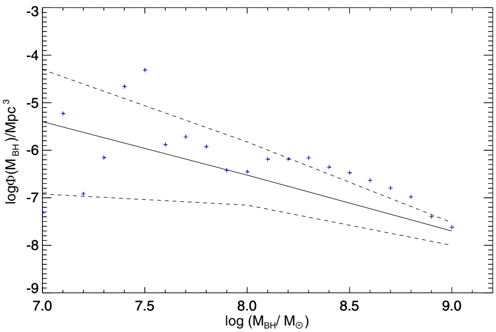

Figure 1: Mass function of BHs in our model (blue pluses), compared to the BH mass function given by Willott et al. (2010) at $z \sim 6$, dashed lines show their upper and lower limit, while the solid line shows their best-fitting (image reproduced from Smole et al. 2015).

We use the observed BH mass function at $z \sim 6$ as a constraint for our model. We run a set of semi-analytical simulations for different values of the Eddington ratio. In each run we assign the same values for the Eddington ratio to each accretion episode. We make sure not to overproduce SMBH at $z = 6$ and once this condition is satisfied, we check if we have 10^9 $M_\odot$ SMBH at $z = 7$ for the specific choice of the Eddington ratio.

2. 2. RESULTS

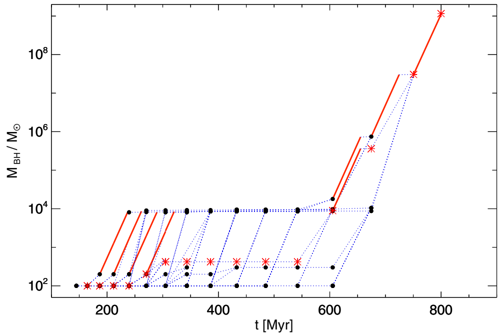

Figure 2: Merger tree of a 10^9 M$_\odot$ SMBH at redshift $z = 7$ for $f_{\rm Edd} = 3.7$. It follows the entire growth of a SMBH through all mergers and accretion episodes, as a function of the age of the Universe, see text for details (image reproduced from Smole et al. 2015).

We find that if the Eddington ratio is $f_{\rm Edd} = 3.7$ both conditions of our model are satisfied: BH mass function is consistent with the observed BH mass function at $z \sim 6$ (Willott et al. 2010) and our merger tree produces 10^9 M$_\odot$ SMBH at $z = 7$. Fig. 1 shows mass function of BHs that populate haloes of Millennium Simulation at $z \sim 6$. We compare our BH mass function to the BH mass function at $z = 6$ given by Willott et al. (2010). Dashed lines in Fig. 1 represent their upper and lower limits, while the solid line is their best fitting to the data.

Fig. 2 shows the merger tree of a 10^9 M$_\odot$ SMBH at redshift $z = 7$. It follows the entire growth of a SMBH through all mergers and accretion episodes, as a function of the age of the Universe. Black circles represent BH masses in side haloes, while red asterisks represent BH masses in the main halo, i.e the halo that host SMBH at $z = 7$. Dotted blue lines follow BH growth by minor mergers and solid red lines show growth through the gas accretion which occurs after every major merger. From Fig 2. it is clear that the BH gains most of its mass in major mergers when accretion is triggered.

In the following sections we investigate if gravitational wave recoil could prevent the formation of SMBH through BH mergers.

3. RECOILING BHs IN STATIC AND EVOLVING DM HALO POTENTIAL

3. 1. METHOD

We follow trajectories of recoiling BHs in a DM halo which is distributed according to a Navarro-Frenk-White (NFW) profile (Navarro et al. 1997). A BH is placed at the halos centre and kicked with recoil velocity $v_{\rm kick}$ at redshift $z_{\rm kick}$. Two different cases are explored: The BH orbits in a static, and in evolving potential. The evolving NFW density profile is modeled using a code given by van den Bosch et al. (2014), which calculates the growth of DM halo for a given DM halo mass and cosmology.

At multiple runs, various kick velocities are assigned to BHs at different redshifts. The consider DM halo has mass of $10^{12}\,\mathrm{M}_{\odot}$ at redshift $z = 0$ and it represents a Milky Way-type host.

3. 2. RESULTS

Fig. 3 shows displacement r for the static (left) and evolving (right) NFW potential of a kicked BH from a host halo's centre at $z = 0$, as a function of v_{kick} and z_{kick}. In the case of static potential, the gravitational well is deep even at high redshifts and moderate kick velocities cannot eject BH from the host halo. BHs kicked from the halo's centre will return to the bottom of the potential well if $v_{\mathrm{kick}} \leq 500$ km/s, independent of z_{kick}. On the other side, if halo evolution is taken into account, the BH displacement is sensitive to z_{kick}. Amplitude of a kick necessary to remove BH from it's host halo varies from 300 km/s at $z = 7$ to 500 km/s at $z = 1$. Black region in Fig. 3 represents the parameter space where a recoiling BH will stay on bound orbits.

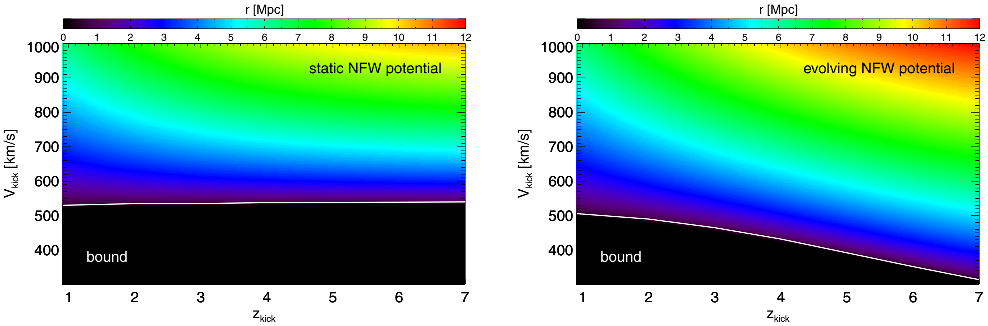

Figure 3: Displacement r of a kicked BH from a host halos centre at $z = 0$ as a function of v_{kick} and z_{kick}, for the static (left) and evolving (right) NFW potential. White lines represent critical velocity for complete BH ejection (reproduced from Smole 2015).

Evolution and mass growth of the parent halos clearly impact their capability to retain recoiling BHs. In order to remove BH from it's host at redshift $z = 0$ kick velocity need to have $\sim 40\%$ larger amplitude at $z_{\mathrm{kick}} = 1$ compared to $z_{\mathrm{kick}} = 7$. Furthermore, at higher redshifts mergers were more common which makes the difference between the static and evolving potential even more pronounced. Growth of the SMBH by mergers might be suppressed in an evolving NFW halo potential, while ejections from a static NFW potential would be rare.

4. RECOILING BHs IN ANALYTICAL AND NUMERICAL GALAXY POTENTIAL

4. 1. METHOD

We follow trajectories of recoiling BHs in analytical and numerical merger remnant galaxy whose components are dark matter halo, bulge and disc. The considered galaxy is similar to Milky Way and has a mass of $10^{12}\,\mathrm{M}_{\odot}$. In order to investigate if BH trajectories are sensitive to the mass ratio of the progenitor galaxies we separately model major (1:1) and minor (1:10) mergers. Since dynamical friction force increases with the recoiling BH mass, we consider two different galaxy models whose central BH has mass of $10^7\ \mathrm{M}_\odot$ and $10^9\ \mathrm{M}_\odot$.

First we construct analytical merger remnants for each of the galaxy models described above and assign various kick velocities to their central BHs, whose trajectories are then integrated in the given potential. DM halo is described by the NFW density profile. The stellar component is modeled as a spherical bulge with density profile $\rho_* = \sigma_*^2/(2\pi G(r^2 + r_{\rm soft}^2))$, with velocity dispersion $\sigma_*^2 = GM_*/R_{\rm bulge}$ (M_* and $R_{\rm bulge}$ are mass and radius of the spherical bulge) and $r_{\rm soft} = r_{\rm infl}$, where $r_{\rm infl} = GM_{\rm BH}/\sigma_*^2$ is influence radius of the BH. Circumnuclear gas disc composed of cold, star-forming gas is modeled as a Mestel surface density profile $\Sigma = \Sigma_0 R_0/R$. Surface density at radius $R_0 = 0.1$ pc is $\log\Sigma_0 = 2\log(f_{\rm gas,sf}/0.1) + 12$, where $f_{\rm gas,sf}$ is star-forming gas fraction. Stellar dynamical friction is also included via the Chandrasekhar formula (Chandrasekhar 1943).

Further, we construct numerical models of galaxies and repeat the same procedure in order to test how redistribution of mass within post-merger galaxy affects its capability to retain a recoiling BH. Our procedure for constructing numerical merger remnants is following: 1) generate initial conditions for each pre-merger galaxy model, 2) evolve galaxy in isolation in order to test stability of each galaxy component, 3) simulate galaxy merger, 4) place a BH in the merger remnant centre and follow the recoiling BH trajectory in numerical potential. Initial conditions are generated using GalactICS code (e.g. Widrow et al. 2008), while galaxy evolution, mergers and trajectories of kicked BHs are simulated using N-body GADGET-2 code (Springel 2015). Each progenitor galaxy is represented with $N = 10^6$ particles.

We assign various kick velocities to BHs in our models and integrate their trajectories until the recoiling BH returns to the galaxy centre or until the integration reaches a Hubble time. Galaxy escape velocity $v_{\rm esc}$ is defined as a BH kick velocity necessary for a BH to return to its host centre after $\gtrsim 10$ Gyr.

For more detailed description of our analytical and numerical models we refer to Smole (2017).

4. 2. RESULTS

Fig. 4 shows galaxy escape velocity in analytical models as a function of escape velocity in numerical models for galaxy with mass of $M_{\rm gal} = 10^{12}\ \mathrm{M}_\odot$. Triangles and squares represent major and minor merger remnants, respectively. Filled symbols show galaxy models with massive central BH ($M_{\rm BH} = 10^9\ \mathrm{M}_\odot$) and open symbols galaxies with a BH with mass ($M_{\rm BH} = 10^7\ \mathrm{M}_\odot$).

If different analytical models are compared with each other, Fig. 4 shows that galaxies with massive BHs have greater escape velocities than galaxies whose BH mass is $M_{\rm BH} = 10^7\,\mathrm{M}_\odot$. This is the consequence of two effects: 1) galaxy models with massive BHs also have massive bulges and thus greater central density, and 2) more massive BHs experience greater drag force due to dynamical friction. For a given galaxy mass, major and minor merger remnants with massive BHs have equal escape velocities. This directly follows from the accepted analytical model since mass ratio of the merging galaxies influence only the disc density profile, while disc component is neglected in galaxies with massive central BH (for further explanation of analytical

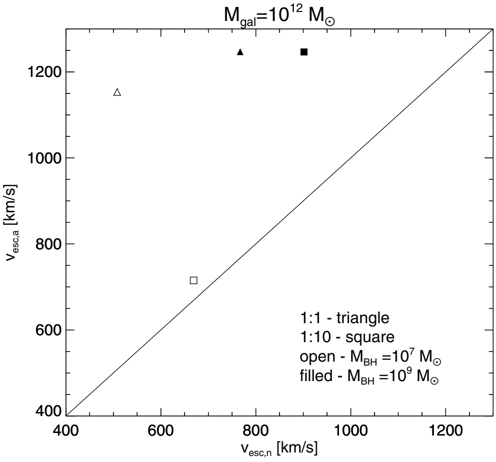

Figure 4: Escape velocities in analytical models as a function of escape velocities in numerical models, for galaxy with different central BH masses.

models see Smole 2017). On the other hand, less massive BHs can be displaced from their host centre more easily, but escape velocities from major and minor remnants differ (open symbols on Fig. 4). This difference is due to the presence of dense circumnuclear disc which is expected to form after major mergers of gas rich galaxies.

In numerical models, during galaxy mergers, a part of gravitational potential energy is converted into the kinetic energy of individual particles. Once a merger process is completed, particles gradually return to the bottom of the potential well, their kinetic energy is converted back into gravitational potential energy and the system becomes virialized. Since BH ejection occurs before the virialization finishes, the recoiling BH trajectory in numerical models is expected to differ from a trajectory of a BH moving through post-merger galaxy with stable, analytical potential.

When different numerical models are compared, Fig. 4 shows that major merger remnants have lower escape velocities than galaxies formed in minor mergers. Even though merger remnant masses are equal, major mergers lead to more significant redistribution of mass within centre of the newly formed galaxy, which results in lower escape velocity. Massive BHs in numerical models also need larger kick velocities in order to leave their host centre, due to the presence of massive bulge and greater influence of dynamical friction force.

Finally, if analytical models are compared with numerical models, Fig. 4 shows that analytical galaxies have greater escape velocities. This occurs because in the numerical models, BHs are ejected before post-merger galaxy establishes virialized potential which should correspond to the potential of the isolated analytical galaxy.

5. SUMMARY

In this work we explore the growth of the first SMBH using Millennium and Millennium-II cosmological simulations. Also, we calculated trajectories of recoiling BHs in different galaxy models in order to investigate if gravitational wave recoil could prevent the formation of SMBHs.

We find that BH seeds with masses $100\mathrm{M}_{\odot}$ could grow to SMBHs in distant quasars if Eddington ratio is fixed at $f_{\mathrm{Edd}} = 3.7$ and each accretion episode is limited to 50 Myr. We show that BHs gain most of their mass in major mergers when accretion is triggered. On the other side, we show that major merger remnants in numerical models have the lowest escape velocities which could slow down the BH growth.

However, BH kick amplitudes strongly depend on the binary characteristics and BH spin parameters. Our model is not considerably sensitive to the gravitational wave recoil except for mergers of equal mass BHs in the least massive haloes at high redshifts where kick velocities $\lesssim$ 100 km/s could permanently eject BHs from their hosts.

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RADIATIVE AND COLLISIONAL ATOMIC/MOLECULAR DATA FOR ASTROPHYSICS

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Abstract. The main aim of this article is to introduce the data management and services of the MOLecular Dissociation (MolD) database, which consists of user friendly and productive cross-correlation service, and data sharing interface based on international standards and protocols. MolD is a web service within the Serbian virtual observatory (SerVO) and node within Virtual Atomic and Molecular Data Center (VAMDC). MolD is an atomic and molecular (A&M) database devoted to the modelling of astrophysical plasmas. Data are important for the modeling of stellar and solar atmospheres, exploring of the interstellar medium as well as for the early Universe chemistry investigation. In this contribution, we present our ongoing work and plans for the future.

1. INTRODUCTION

Nowadays, the atomic and molecular (A&M) data are especially important for simulations/calculations in the field of astrophysics modeling. For example A&M data are needed for development of atmosphere models of solar and near solar type stars and for radiative transport investigations. Modern codes for stellar atmosphere modelling, like e.g. PHOENIX (see e.g. Hauschildt & Baron 2010) require the knowledge of atomic data, so that the access to such atomic data, via online databases become very important. Recently, in Marinković et al. (2017a) it has been highlighted the importance of atomic processes for the understanding of observations in coma, the tenuous atmosphere and on the surface of 67P/Churyumov-Gerasimenko during Rosetta mission. It has been shown the need for closer interactions and joint projects between the cometary, electron communities and IT software specialists.

On the other hand, the produced data volumes in nowadays astronomical sky surveys can range from several terabytes to petabytes and will increase even faster.

In some cases such as campaigns, surveys may generate terabytes of data per day (Brunner et al. 2001). The sky with billions of stars, galaxies, quasars, and other objects is being surveyed, detected and measured with an incredible level of details. As a consequence, the status of data-oriented science, research methods, algorithms, and techniques become very important (Brescia & Longo 2013). This has led to integration of computer science, physics, statistics, astrophysics on operative processing, scientific exploitation of such large data sets and developing state-of-the-art infrastructures such as the Virtual Observatories (VO). VO is a platform for launching astronomical investigations. It provides access to huge data banks, software systems with user-friendly interfaces for data processing, analysis, visualization and etc. (Borne 2013).

In this contribution, we give an overview of the motivations, current stage, and technological principles of A&M MolD database within Virtual Observatories.

Figure 1: The home page of the VAMDC consortium, SerVO and MolD database.

2. MOLD DATABASE, SERVO AND VAMDC

MolD database is a collection of cross-sections and rate coefficients for specific collisional processes (see e.g. Vujčić et al. 2015 or Srećković et al. 2017a). It can be accessed via http://servo.aob.rs/mold/ of Serbian Virtual Observatory (SerVO) or accessed as a web service http://portal.vamdc.eu/ which is part of the Virtual Atomic and Molecular Data Center (VAMDC), (see Fig.1).

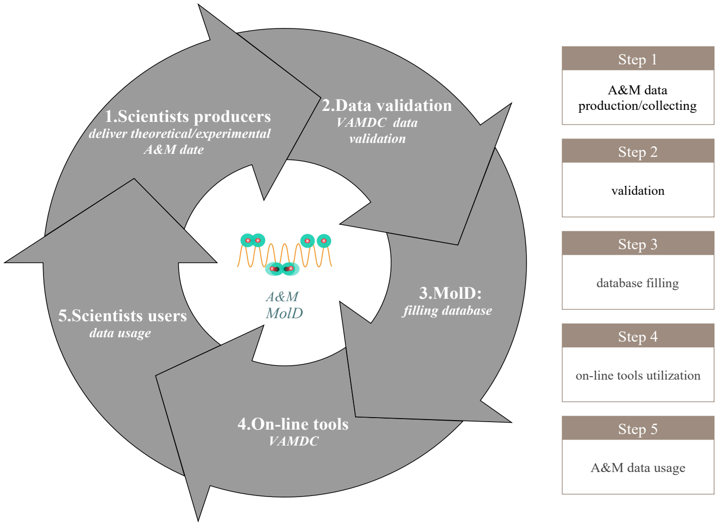

Figure 2: A&M data workflow.

The web interface offers access to data for photodissociation cross-sections of specific molecular ions (see Tab 1.) as well as the corresponding averaged thermal photodissociation cross-sections for hydrogen H_2^+ and helium He_2^+ molecular ions for the requested wavelength and temperature.

VAMDC is an international consortium which has built a well documented, secure, flexible interoperable e-science platform permitting an automated exchange of atomic and molecular data (Dubernet et al. 2016). VAMDC started as EU FP7 e-infrastructure project of developing communication between different A&M databases and providing a common portal for accessing all registered data. VAMDC e-infrastructure defines protocols for retrieving remote data as well as format for representing these data. The ultimate goal is interoperability of the data along various distributed nodes.

Project "Serbian Virtual Observatory" was funded in year 2008 (see Jevremović et al. 2009). This project was funded as technological developement project. The main goals of this project were digitization and publishing of old photo plates in Virtual Observatory, development of BelData, Stark broadening database (it became StarkB database), contribution to Darthmouth Stellar Evolution Database and collection of other Serbian data. Idea was that all these would be accessible at http://servo.aob.rs. Today, many services are currently running on the SerVO. The Belgrade nodes of VAMDC are hosted by SerVO and presently consists of two databases BEAMDB (http://servo.aob.rs/emol) (Marinković et al. 2015) and MolD (http://servo.aob.rs/mold) (Srećković et al. 2017b, Marinković et al. 2017b).

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Figure 3: Data set is represented in XSAMS (Extensible Markup Language (XML) Schema for Atoms, Molecules and Solids) format for He_2^+ photo-dissociation cross-sections for the individual ro-vibrational state.

2. 1. LEVEL 3 RELEASE

At the end of 2017 MolD is in the *stage 3* of development (Srećković et al. 2017a). At this moment, the database includes cross-section data for processes which involve species such as H_2^+, He_2^+, MgH^+, HeH^+, LiH^+, NaH^+ as can be seen in Tab. 1. These processes are important for exploring of the interstellar medium, the early Universe chemistry as well as the modeling of different stellar and solar atmospheres (see Srećković et al. 2014, Coppola et al. 2016). Currently we are including new cross-sections and rate coefficients data for processes which involve species such as SiH^+, Na_2^+, Li_2^+ which are important for the exploring of the geo-cosmical plasmas (Klycharev et al. 2007).

Table 1: Summary of species and states included in Belgrade MolD database as of October 2017. Additional data will successively be added.

Molecules					
Stoichiometric formula	Node	Types of reaction	States	InChI	InChIKey
H_2^+	MolD	photo-dissociation	424	1S/H2/h1H/q+1	ZZIJOQHRUPVPQC-UHFFFAOYSA-N
He_2^+	MolD	photo-dissociation	834	1S/He2/c1-2/q+1	ZAJTYDXIUNGESO-UHFFFAOYSA-N
HeH^+	MolD	photo-dissociation	150	1S/HHe/h1H/q+1	HSFAAVLNFOAYQX-UHFFFAOYSA-N
LiH^+	MolD	photo-dissociation	60	1S/Li.H/q+1	HSOYNNFNUCWPIZ-UHFFFAOYSA-N
MgH^+	MolD	photo-dissociation	600	1S/Mg.H/q+1	LMAKMUADRKEOEM-UHFFFAOYSA-N
NaH^+	MolD	photo-dissociation	50	1S/Na.H/q+1	FYDBACYJBJQTSN-UHFFFAOYSA-N

Our plans are incremental inclusion of data from our papers concerning A&M processes important for modeling different stellar atmospheres and laboratory plasmas as they become published (see Fig 2. for data workflow). Together with database updates, we intend to develop new services as well as new web interface of MolD on SerVO.

2. 2. SERVICES, DATABASE DESCRIPTION AND STRUCTURE

The principal structure of the Belgrade MOL-D database is shown schematically in Fig. 4 using UML (Unified Modelling Language) notation.

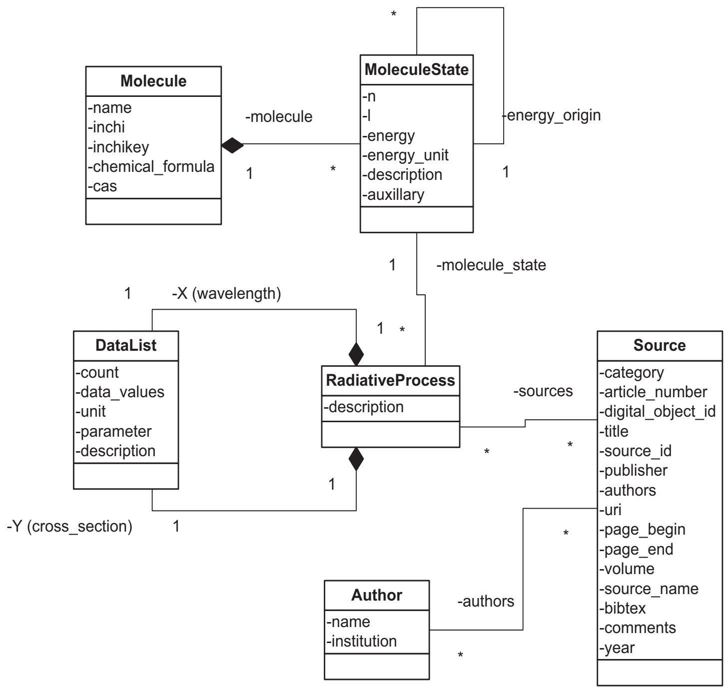

Figure 4: Static structure of the MolD database. Relationships between entities are shown by connected lines with designated cardinalities ('1' and '*' denote one and many, respectively), i.e. a molecule can have multiple states.

MolD services are compatible with VAMDC standards and act as a VAMDC "node" (for the list of nodes, see http://www.vamdc.org/structure/ databases/).

Access to the MolD data is possible in several ways:

- Via standalone applications which support VAMDC-TAP (Table Access Protocol) for data access and transformation to VAMDC-XSAMS.

- via AJAX (Asynchronous JavaScript and XML)-enabled web interface[1].

[1]http://servo.aob.rs/mold

- Via VAMDC portal[2], with query to 32 databases across the European scientific institutes.

All queries return data in XSAMS (XML Schema for Atoms, Molecules and Solids) format (see Fig. 3). The XSAMS schema provides a framework for a structured presentation of atomic, molecular, and particle-solid-interaction data in an XML file. Underlying application is written in Django, a Python web framework and represents a customization and extension of VAMDCs NodeSoftware (Marinković et al. 2017a). Additional on-site utilities include:

- data selection based on molecule name and QNJ/QNv numbers
- average thermal cross section calculation based on temperature for a specific molecule and wavelength
- plotting average thermal cross sections along available wavelengths for a given temperature

AJAX enabled queries and visualizations.

3. CONCLUDING REMARKS AND FUTURE DEVELOPMENT

A&M databases have become essential for the stellar modeling and for the interpretation of data provided by observations and laboratory measurements. As a consequence the full exploitation of such data is crucial. Therefore the further development of MolD database within SerVO and VAMDC is our main task.

The next step of development i.e. the stage four of MolD development will be the implementation of possibility to fit the tabulated data, before a major upgrade of the MolD database.

Acknowledgment

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[2] http://portal.vamdc.eu

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PECULIAR MID-INFRARED MORPHOLOGY OF ACTIVE GALACTIC NUCLEUS IN CIRCINUS

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Abstract. Recent high angular resolution observations resolved for the first time the mid-infrared (MIR) structure of nearby active galactic nuclei (AGN). Surprisingly, they revealed that a major fraction of their MIR emission comes from the polar regions. This is at odds with the expectation based on AGN unification, which postulates a dusty torus in the equatorial region. The nearby, archetypical AGN in the Circinus galaxy offers one of the best opportunities to study the MIR emission in greater detail. New, high quality MIR images obtained with the upgraded VISIR instrument at the Very Large Telescope show that the previously detected bar-like structure extends up to at least 40 pc on both sides of the nucleus along the edges of the ionization cone. Motivated by observations across a wide wavelength range and on different spatial scales, we propose a phenomenological dust emission model for the AGN in the Circinus galaxy consisting of a compact dusty disk and a large-scale dusty cone shell, illuminated by a tilted accretion disk with an anisotropic emission pattern. Undertaking detailed radiative transfer simulations, we demonstrate that such a model is able to explain the peculiar MIR morphology and account for the entire IR spectral energy distribution. Our results call for caution when attributing dust emission of unresolved sources entirely to the torus and warrant further investigation of the MIR emission in the polar regions of AGN.

1. INTRODUCTION

During the lifetime of a galactic nucleus, the supermassive black hole (SMBH) in its center may accrete significant amounts of matter at a relatively high rate. This phenomenon, know as an active galactic nucleus (AGN), manifests itself through a number of energetic phenomena such as: a compact X-ray source, a strong UV/optical continuum, a number of broad and/or narrow emission lines, a radio-jet, to name a few. Approximately half of the luminosity radiated by the matter spiraling onto the SMBH in an accretion disk is absorbed by the surrounding dust and reemited in the infrared (IR). The distribution of dust and the viewing angle determine how an AGN appears to an observer as they combine to reveal or hide the accretion disk and broad line region (AGN type 1 and type 2, respectively; see Antonucci, 1993). This dusty material, postulated to be found preferentially in the equatorial plane of the system and roughly in a toroidal shape, has been rooted in AGN jargon as "the dusty torus", even though a number of both theoretical and observational pieces of evidence suggest that it is more likely to resemble a complex multiphase medium, possibly associated to dusty outflows or failed winds. A bulk of observational evidence has been accumulated over the years in support of this scenario (Netzer, 2015).

Owing to their small angular sizes, only with recent advances of IR interferometry several nearby sources could be resolved, surprising revealing that the mid-infrared (MIR) emission of these sources appears elongated in the polar direction, perpendicular to the plane of the dusty torus (Lopez-Gonzaga et al. 2016 and references therein). Extended MIR polar emission was detected even in single dish data on the scales of tens to hundreds of parsecs, virtually in all sources with sufficient S/N data and favorable viewing angle (Asmus et al. 2016). These findings challenge the use of standard dusty torus models to interpret the IR emission and demand a new paradigm for the dust structure in AGN. Crucial steps towards the new paradigm are case studies of nearby objects that can be resolved and studied extensively across a broad range of wavelengths. One such object is the archetypal type 2 AGN at the distance of 4.2 Mpc in the Circinus galaxy. Being the second brightest AGN in the MIR and allowing high intrinsic spatial resolution ($1'' = 20\,\mathrm{pc}$), Circinus is a prime target for a large number of studies across a wide wavelength range. These observations revealed a number of features expected from a prototypical type 2 AGN. [OIII] and Hα emission reveal the ionization cone on the West side (Wilson et al. 2000); the East cone is covered by the host galaxy disk but was detected in polarized near-infrared light (Ruiz et al. 2000). Water maser emission traces a near-Keplerian, warped disk seen edge-on (Greenhill et al. 2003). A bar-like extended emission at was detected at 8.7 and 18.3 μm extending up to $\sim 2''$ from each side of the nucleus, roughly in east-west direction. Modeling of the MIR interferometric data obtained with the MID-infrared Interferometric instrument (MIDI) at the Very Large Telescope Interferometer (VLTI) reveals two components on parsec-scale: a disk-like component in the equatorial plane of the system, and a larger structure elongated in the polar direction (Tristram et al. 2007, Tristram et al. 2014). The disk-like component is likely a molecular, dusty extension of the accretion disk. Furthermore, it well matches the orientation and scale of the warped maser disk. The association of the polar-extended component is less clear. It could be the inner wall of the torus, which then would need to have a very large scale height, or it could be the base of a polar dusty wind, which is forming a large cone shell.

The upgraded Imager and Spectrometer for mid-Infrared (VISIR) mounted on the Very Large Telescope (VLT) provided up-to-date highest quality MIR images of Circinus. These images show a previously detected, prominent bar extending 40 pc on both sides of the unresolved nucleus. This bar cannot be explained by the torus: it is aligned with the polar component inferred by interferometric data and with the edge of the ionization cone seen at optical wavelengths. In this work we proposed a model for dust emitting regions of AGN in Circinus that may explain this puzzling finding.

2. OBSERVATIONS

We selected the highest quality MIR data available for Circinus. In particular, two new images at 8.6 μm and 11.9 μm (Fig. 1, top left panel) were obtained with the upgraded VISIR[1], allowing us to achieve diffraction-limited image quality. We complement them with archival VISIR images in the filters (10.5 μm) and Q2 (18.7 μm) tracing the two

[1]Program ID 60.A-9629

silicate features at ~ 10 and $\sim 18\,\mu$m (Fig. 2). Here, we simply take the reduced data from Asmus et al. (2014) and refer the reader to that work for more details on these data. Resolved emission in the form of a bar stretching out from the center at a position angle of roughly 100° both to the East and West is revealed. This emission structure is well visible at all four wavelengths out to ~ 40 pc on both sides, and coincides with the edge of the ionization cone seen at visible wavelengths on the Western side. For comparison of the model and the data over a wider wavelength range, we also assemble the observed nuclear SED and spectra of Circinus from data available in the literature. Finally, we also include so far unpublished L-band data[2] from VLT/ISAAC to obtain a contemporary estimate for the $3.8\,\mu$m flux.

3. MODEL

The large scale MIR bar (extending up to 40 pc on both sides of the nucleus) seen by VISIR is aligned with the polar-elongated component on parsec-scale, suggesting that both are part of the same physical structure. The big surprise is that this structure is dominating the MIR emission: $\sim 10\%$ of the total flux in the MIR is coming from the disk-like component ($\sim 0.2 - 1.1$ pc), about 40-50% from the parsec-scale polar component ($\sim 0.8 - 1.9$ pc), and another 40-50% from the large-scale polar bar (Tristram et al. 2014; Asmus et al. 2016). On the other hand, if the large-scale polar bar is part of a hollow dusty cone, one would expect this cone to appear as an X-shaped structure. Hence the question arises: why the other side of the cone wall does not appear in the VISIR images? *Our hypothesis is that the inner accretion disk is significantly tilted (and/or warped) so that it preferentially illuminates only one side of the dusty cone wall.* This picture is supported by the orientation of the inner part of the warped water maser disk and by the anisotropic illumination pattern imprinted in the ionization cone. In Fig. 1, we present a schematic of our model that has the potential to explain the MIR bar seen with VISIR, and at the same time fits well into the picture placed by the previous observations at different wavelengths, both on small and large scales. The overall geometry is well constrained by observations: a parsec-scale dusty disk, co-spatial with the warped maser disk seen edge-on (upper right panel), and an ionization cone seen in the optical, extending out to ~ 40 pc from the nucleus (lower right panel). The illumination pattern of the ionization cone (brighter toward the western edge) is indicative of the anisotropic emission pattern of the ionizing source. This is corroborated by the orientation of the inner part of the maser disk, which is roughly perpendicular to the cone edge. An optically-thick, geometrically-thin accretion disk displays a $\cos\theta$ angular-dependent luminosity profile (Stalevski et al. 2016). Aligned with the inner part of the warped maser disk, such a disk will emit more strongly into or close to the western edge of the cone. If the cone wall is dusty, then the described setup could naturally produce the dusty bar seen in the VISIR image. The opposite side of the cone wall would remain cold and invisible, as the tilted anisotropic accretion disk would emit very little in that direction (see temperature profile in the lower left panel).

In a summary, the model consists of two components whose parameters take fiducial values implied by the different observations discussed above: a compact flared dusty disk and a hollow dusty cone. The accretion disk, described by a standard

[2]Programmes 385.B-0896(B), 386.B-0026(B), 087.B-0746(B), 088.B-0159(B), 089.B-0070(B)

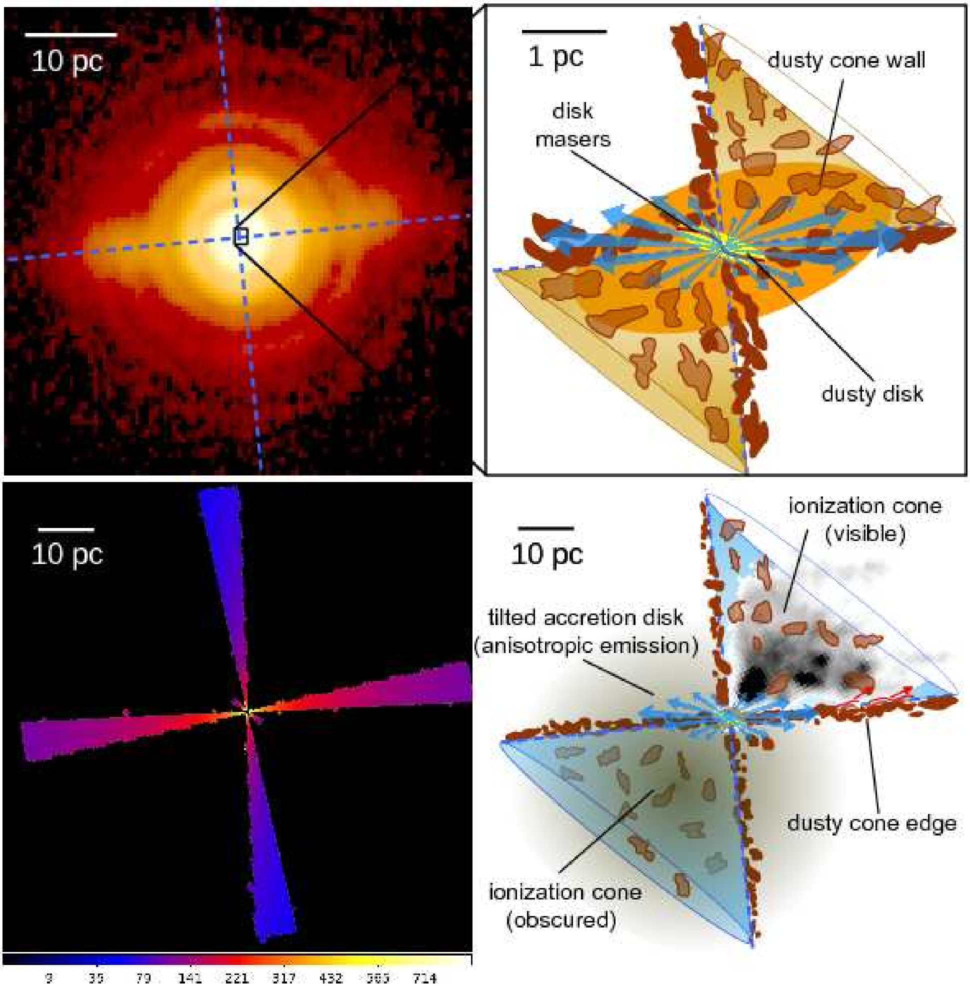

Figure 1: Schematic of the model proposed here for the nuclear dust distribution in Circinus consisting of a compact dusty disk and a large scale dusty cone, compared with observations at different wavelengths and scales. *Upper left panel*: 12 μm VLT/VISIR image revealing the prominent bar. *Upper right panel:* inner region on scales of a few parsecs resolved by VLT/MIDI into the disk and polar components (yellow and orange ellipsoids). The red line within the yellow disk component traces the warped disk in water maser emission (Greenhill et al., 2003). *Lower right panel*: The large scale structure, with the optical ionization cone image (from Wilson et al., 2000; in gray scale) overlaid with the model schematic. The blue arrows illustrate the anisotropic emission pattern of the accretion disk, whose orientation matches the orientation of the inner part of the warped maser disk. Dashed blue lines in all the panels are tracing the edges of the ionization cone. *Lower left panel*: A slice of the temperature map in the vertical plane of the disk with cone model obtained from Monte Carlo radiative transfer simulations.

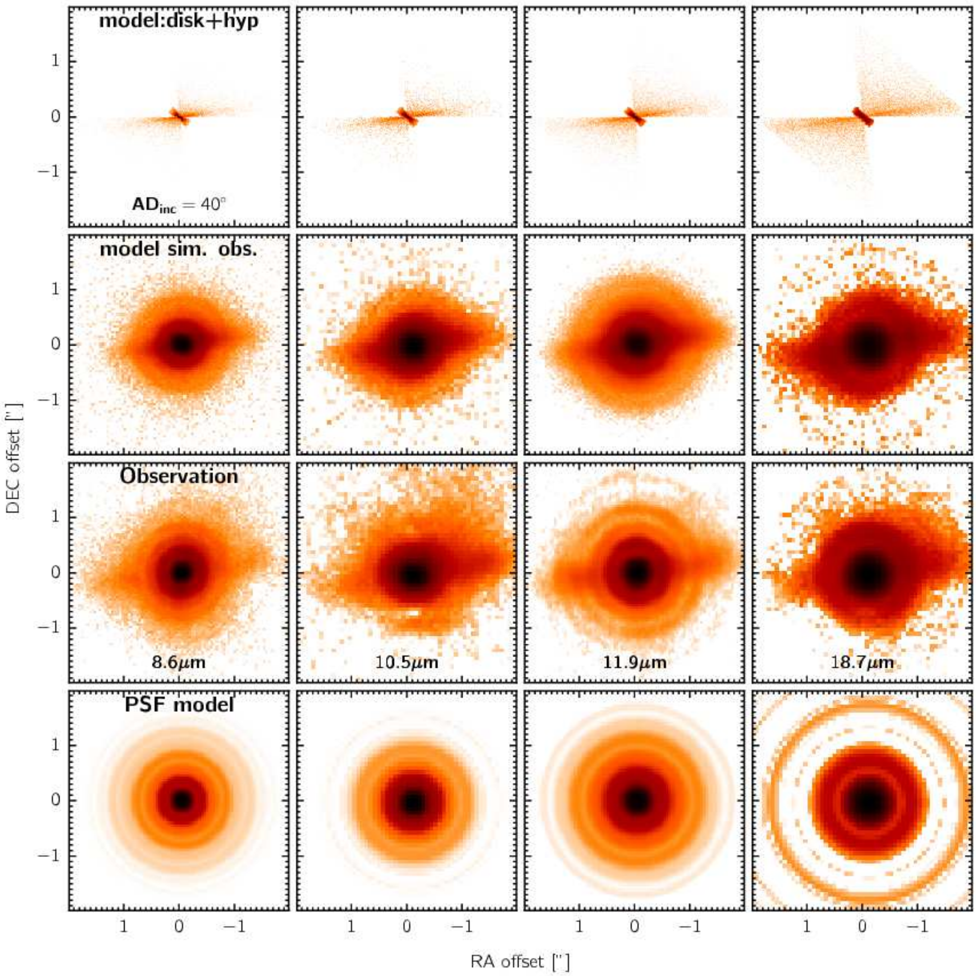

Figure 2: Comparison of the VISIR images of Circinus with the representative model (whose SED is shown in Fig. 3), including foreground extinction. From top to bottom, the rows show: (1) the model images; (2) the model images as they would appear when observed with VISIR; (3) the images of Circinus acquired with VISIR; (4) our approximation of the observed PSF.

"blue bump" composition of power-laws with an anisotropic emission pattern, is tilted to match the orientation of the inner part of the warped maser disk. We adopt the dust composition consisting of a mixture of graphite and silicates in the disk and only graphite in the cone shell. The dust grain size is in the range of $a = 0.1 - 1\,\mu$m with the size distribution following the standard MRN power-law $\propto a^{-3.5}$ (Mathis, Rumpl & Nordsieck 1977). For a full description of the model and its parameters, see Stalevski et al. (2017).

4. RESULTS

To obtain realistic images and SEDs for the proposed model, we employed SKIRT[3], a state–of–the–art 3D radiative transfer code based on the Monte Carlo technique (Baes et al. 2011; Baes & Camps, 2015; Camps & Baes, 2015). The code uses the Monte Carlo technique to emulate the relevant physical processes including multiple anisotropic scattering and absorption, and computes the temperature distribution of the dust and the thermal dust re-emission self-consistently. In Fig. 3, we show the AGN in Circinus galaxy model SED decomposed into its scattered and dust emission

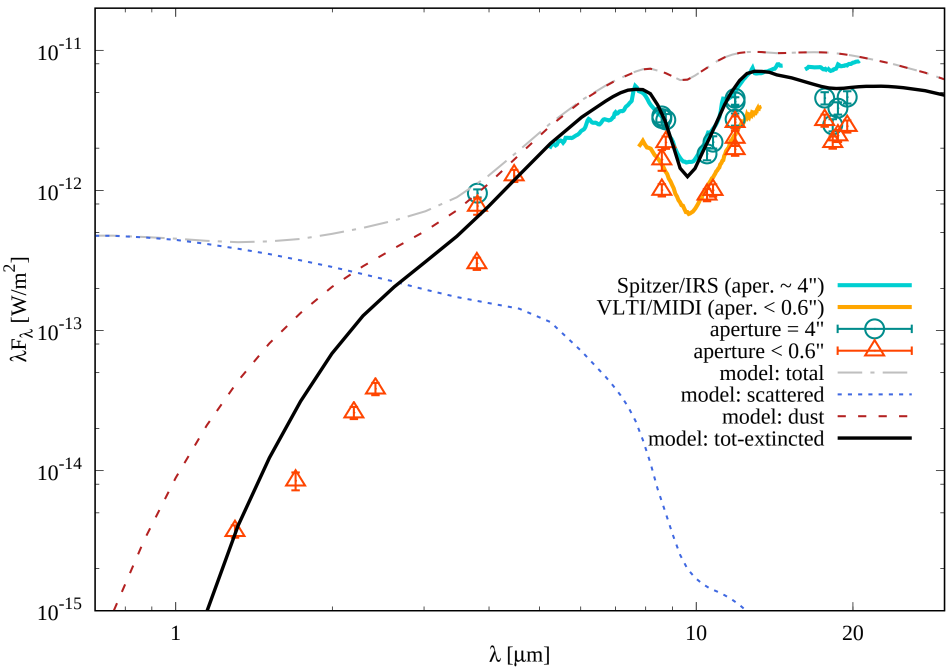

Figure 3: AGN in Circinus galaxy: comparison of the observed SED compiled from the literature with one representative model SED. Large-scale aperture photometry (4″) is shown in green circles, while photometry extracted from apertures comparable or smaller than the resolution limit of VISIR (0.6″) is marked by red up-pointing triangles. The measurement uncertainties are smaller or comparable to the plotted symbol size. The aperture of the Spitzer/IRS spectrum from Asmus et al. (2014) is comparable to the total aperture of VISIR in the $5.2 - 14.5\,\mu$m range, while significantly larger at longer wavelengths. The MIDI spectrum from Tristram et al. (2014) corresponds to the unresolved nucleus with VISIR. The model SED is decomposed into its total (dash-dotted gray), scattered (dotted blue) and dust (dashed dark red) components. For a realistic comparison, foreground absorption must be taken into account: the total model flux extincted by foreground screen of average $\tau_{9.7} = 1.6$ is shown in solid black line.

[3]`http://www.skirt.ugent.be`

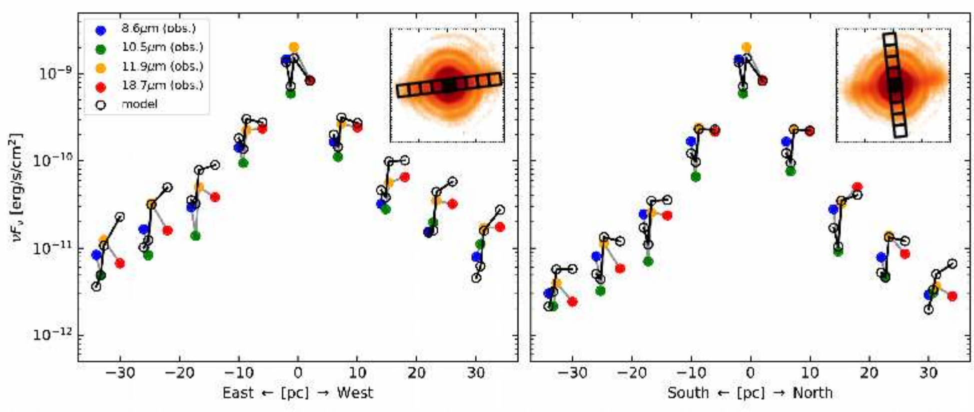

Figure 4: Comparison of observed and model photometry (from images shown in Fig. 2) extracted in $0.4'' \times 0.4''$ aperture fields in the directions along the bar (left) and perpendicular to it (right), as indicated in the inset plots. The central position corresponds to the unresolved nucleus.

components, and attenuated by dust of the host galaxy. We see that scattered light has a significant contribution shortward of $3\,\mu$m; however, it is completely extinguished by the foreground dust screen. The model SED has a weak silicate absorption feature, which becomes much deeper and matches the data after the foreground extinction screen is applied. We note that there are models featuring silicate absorption profiles that could fit the data with much less or without the foreground extinction screen. However, foreground absorption is robustly established by the very deep off-center optical depth values (Roche et al. 2006), and we consider realistic only those models which provide a good match including the inferred amount of extinction. In Fig. 2, we compare the VISIR images of Circinus with the simulated observations of our representative model, including background noise and foreground extinction. Since the observations are diffraction-limited, we include in the plot the instrumental PSF, approximated by an azimuthally symmetric structure of the reference star, to allow easier interpretation of the images. We see that the simulated model images provide a good match to the observed morphology in all filters. We compare the VISIR images and the simulated observations of the model in more detail in Fig. 4 by measuring fluxes at different positions extracted from $0.4'' \times 0.4''$ apertures along the MIR bar and perpendicular to it. An overall qualitatively good agreement is evident, especially at the central position and close to it. All the presented comparison and analysis is leading us to conclude that the here presented model consisting of a compact dusty disk and large scale dusty cone shell illuminated by a tilted accretion disk with anisotropic emission pattern plausibly represents the actual dust structure in Circinus.

5. SUMMARY AND CONCLUSIONS

Recent findings of significant MIR emission in the polar regions of local AGN challenge the widely accepted picture in which the parsec-sized "torus" is responsible for the entire AGN dust emission and may demand a change of paradigm. One of the sources showing clear polar extended dust is the archetypal type 2 AGN in the Circinus galaxy. Up-to-date highest quality images obtained with the upgraded VLT/VISIR instrument feature a prominent bar extending in the polar direction of the system. In this work, we presented a phenomenological model for the dust emitting regions in this source consisting of a compact dusty disk and a large scale dusty hollow cone region illuminated by a tilted accretion disk with anisotropic emission. The model is supported by observations across a range of different wavelengths and spatial scales. Using Monte Carlo radiative transfer simulations we produced the images and SEDs of this model. Based on the comparison with the observed MIR morphology and the measured SED we find that the model of the polar dust in the form of a hollow cone is able to reproduce the observed MIR morphology at all wavelengths. Furthermore, the model provides a good match to the entire IR SED of Circinus, including resolved photometry extracted from apertures at different positions along the polar bar and perpendicular to it. We conclude that our model consisting of a compact dusty disk with a large scale dusty cone shell is plausibly a good representation of the dust structure of the AGN in the Circinus galaxy. Our results call for caution when attributing thermal dust emission of unresolved sources entirely to the torus and warrant further investigation, including detailed modeling of other sources showing polar elongation of their MIR emission as well as developing a theoretical framework that would explain the origin of the dust in the polar regions. Our model of the AGN in Circinus can be used as a prototype and as a guideline for such studies. Full investigation with more detailed analysis, including a wider range of the model parameters and different geometries, can be found in Stalevski et al. (2017).

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PROJECT OF PROMOTION OF ASTRONOMY: "SKY IS THE LIMIT"

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Abstract. Project 'Sky is the limit' is realized within the framework of SUPERSTE program as one of the ten winners of the program for 2016. The project itself is realized in rural areas of the Kruševac Municipality, where public observations and lectures are organized. In this way, in addition to promoting astronomy as science, astronomy is also promoted as a potential offer for rural tourism in the Kruševac area. Also, the first astronomical camp, as well as the training of 25 young people to become young "ambassadors" of astronomy will be done, so they can work on promotion of astronomy in Kruševac in the future. The project was completed by the end of 2017. This paper presents the results achieved in the project so far.

1. INTRODUCTION

Astronomical Association Eureka was founded in 2010 with the aim to promote astronomy and science in Kruševac and its surroundings. The Society was officially registered in 2016. The Society now has ten active members who are actively working on implementation of standard activities in the promotion of astronomy (lectures and observing), but also deal with writing projects through which they can realize activities for promotion of astronomy in Kruševac. The final objective of the Society is to build an astronomical observatory on the Bagdala hill in Kruševac.

In its work, most of the time is devoted to organizing astronomical observation events. From the start, the Society has used telescope as the main instrument of promotion of astronomy. When the Society started working, it used a telescope that was owned by Gymnasium Kruševac and founders of the Society. After 7 years of work the Society has managed to procure additional equipment, receiving some as donation. Now Eureka has 5 telescopes including: 127/1500 on AZ GoTo mounting, 130/650 on EQ2 mounting, 60/900 on EQ1 mounting, TeleScience 60/700 and 150/750 telescope mounted on motorized mount EQ3 and NEQ5 computerized mount. The telescopes are equipped with a special filter which makes it possible to use them in day-light observations. The Society also has two CCD (DBK 21AF04.AS and 120MC ASI) 3 that can be used to capture planets, but deep sky objects as well. The observation events are mainly organized in the center of Kruševac or on the Bagdala hill, while in 2017 the Society started activities of astronomy promotion in rural areas around the city of Kruševac.

In addition to observations, Eureka organizes scientific and popular lectures. The lectures are mainly organized in schools or in the Center for Professional Development and the National Library of Kruševac at the invitation of professors and teachers. The lecture topics are mainly current developments in the world of astronomy and physics, while for younger generations the lectures are organized on the topic of our Solar System, telescope and night sky. Also, the Society has hosted a large number of lecturers outside Kruševac, who had the opportunity to hold their lectures for audience in Kruševac.

In addition to these activities the Society is active in national and international projects. Some of the projects Eureka initiated to be implemented at the national level. In this period, the Society has taken part in the following projects: Serbia photographed Moon 2016, Science Festival Days of Eureka in Kruševac, NOU fest in Ćuprija, the realization of a large number of projects concerning the youth are the Law of the Ministry of Youth and Sports and project 'Sky is the limit' under the program SUPERSTE. On the international scene, the Society took part in the following projects: International observe of the Moon night, World Space Week, Great World Wide Star Count, the International Asteroid Search Campaign, Asteroid Day, etc.

In addition to the above-mentioned Eureka actively participates in events and camps, such as Letenka, but also cooperates with other associations in the field of astronomy and other field of science. Eureka has established a cooperation with the Air Force Academy in Belgrade which will be discussed in the last part of the paper.

The aim of this paper is to present results of project 'Sky is the limit', which was implemented during 2017 in the area of Kruševac.

2. PROJECT "SKY IS THE LIMIT"

'Sky is the limit' is one of the ten winners of the Club SUPERSTE 2016 program. The aim of project 'Sky is the limit' is to strengthen the capacity of the Astronomical Society Eureka for further successful promotion of astronomy. The project includes the following activities: acquiring the necessary astronomical equipment for further successful work of the Society (NEQ5 installation and CCD camera); organized and carried out visits to a minimum of 25 rural local communities around the city of Kruševac; a competition for the selection of new promoter of astronomy which will be included in the work of the Society and have the opportunity to organize independently the following training astronomical activities in their regions; organization and implementation of training, popular science lectures and astronomical observations in the city.

The target groups are young people aged 14 to 30, with emphasis on the rural area around the town of Kruševac. The project is being implemented now and will continue until the end of 2017 when the first results will be presented.

2. 1. WHAT HAS BEEN DONE SO FAR?

So far, the project team have carried out a tour encompassing 17 rural and two urban local communities and organized two public lectures in the city and held a large number of public observations. The procurement of equipment allowed the activities of the Society to be raised to a much higher level.

The first observation was organized on the Bagdala hill on March 4. That was the time when the new equipment was tested. About 150 people had the opportunity to observe Venus, Mars, the Moon and Jupiter. Also, the Pleiades star cluster (M45), the star Sirius, a double star in the Great Bear and the M42 nebula in Orion were observed. While observers were eagerly waiting to look through a telescope, the members of Eureka took this opportunity to explain how easy it was to use constellations in the night sky for the purpose of space orientation.

Protocols on cooperation with the Tourist Organization of Kruševac and National Library of Kruševac that help in the project have been signed. Also during this period, a protocol was signed on cooperation with the Air Force Academy in Belgrade.

Astronomical Society Eureka has taken an active part in this year's second edition of the International Balloon Festival in Kruševac. The festival was held from June 30 to July 2 on the Bagdala hill. It is estimated that the festival was attended by over 20,000 people from Kruševac and the region. During the festival, in addition to the activities related to ballooning, parachuting and aircraft, the visitors were enabled to attend concerts, visit the dino park, meet bikers, learn to deal with archery and many other attractions. Eureka organized during the day-light observing the Sun, and by night observations of the Moon, Jupiter and Saturn.

During day-light we organized observing the Sun through a special solar telescope that we had gotten to use by the Astronomical Society "Alpha" from Niš. Although the Sun was not too active, i. e. we failed to notice more than one sunspot, it was excellent to see the granular structure of the Sun and the protuberance. A large number of photographs was made during the festival. By night we used the telescope that had been purchased through project 'Sky is the limit' under the program Superste.net. We could observe the Moon, Jupiter and Saturn.

The reviewer thinks: which was photographed many times. The reviewer's question: Did I understand coorectly?

According to our estimates, over 3000 people looked through our telescopes and had the opportunity to learn about astronomy and the work of Eureka. We are pleased with the results we have achieved thanks to the Tourist Organization of Kruševac that gave us the opportunity to be part of this event. We expect a successful further cooperation and we will certainly respond again next year.

The Society has taken part in other activities, so has held a lecture for the participants of ecological camp EKOBUDUĆNOST held in Ribarska Banja. Also members have contributed to the realization of project 'My piece of the Universe'. My piece of the Universe, which was implemented by members of the Astronomical Society Eureka. After five days of intensive work with the 20 workshop participants have successfully mastered the basics of astronomy. Young astronomers led by Angela Petrović realized workshops for pupils of 'Veselin Nikolić' school.

2. 2. ASTRONOMICAL CAMP EUREKA CORNER

The camp was organized on the Jastrebac mountain in the period 11 – 13 August. The camp was organized as part of the project 'Sky is the limit', which is realized with the financial support of Mensa Serbia. For the camp attendance 60 applications were submitted, while at the camp there was a total of 40 participants.

The distribution of the participants according to their places of living is: Belgrade 16, Kruševac 13, Jagodina 4, Smederevo, whereas for Vršac, Kragujevac, Paraćin, Vlasotince, Nova Pazova and Novi Bečej each had 1 representative. The accommodation of the participants was organized in mountain hut 'Žarko Zarić' on Jastrebac. The camp program included interesting lectures on astronomy, especially observations, as well as aerospace and econophysics. Lecturers were Jovan Aleksić member AD Rudjer Bošković, Marko Veljković professor at the Air Force Academy and Zoran Tomić from Eureka.

The camp itself was covered by the media and on that occasion the local television reports on the camp were made by the regional TV Kruševac, TV Plus and RTS. RTS aired show 'This is Serbia'. The camp was also mentioned in the show on YouTube channel Gabatron. At the end of the camp we organized for the participants a visit to the National Museum in Kruševac.

Based on the survey the camp received an average rating of 4.20 out of people who filled in the questionnaire. The camp realization was supported by the Tourist Organization of Kruševac, the representatives of which visited the camp during the course and assisted in the promotion, the National Museum of Kruševac, which provided to the campers to visit free the museum and by the PE "Water supply" Kruševac, which provided bus for the campers. Also, large contributions by the members of AS "Eureka" Miloš Stanković, Aleksandar Ristić, Darko Jovanović and Miona Jovanović should be mentioned, who helped in the realization of the camp.

In the end it can be concluded that the implementation of the first astronomical camp Eureka corner was successful and that we hope that Mensa Serbia will help organize this camp next year again.

2. 3. SCIENCE FESTIVAL EUREKA PICNIC

On 7th of October Eureka organizaed Science Festival "Eureka picnic". Over 80 participants of the festival of science from Kruševac, Belgrade, Niš and Ćuprija enabled people on that day to learn about science through interesting experiments, workshops, exhibitions and lectures. The festival also had a competition character because the audience voted for the best science setting. Over 1000 people had the opportunity to experience the Eureka moment in elementary school 'Vuk Karadžić'. Although initially the festival was scheduled to take place in Milicina street, because of rain it was realized in primary school 'Vuk Karadžić' and exceeded the expectations of the organizing team. Below we briefly describe the event itself. More about settings of the Science Festival you can see on web site or Eureka www.eureka.nebjak.net.

In addition to the settings the participants in large numbers attended the lectures. The lectures were opened by Prof. Dr. Milan Dimitrijević, Astronomical Observatory of Belgrade, who is still very keen in Kruševac and thanks to whose support in the previous years, the festival Days of Eureka was held in the Gymnasium. Besides prof. Dr Milan Dimitrijević interesting lectures by prof. Dr Dragan Gajić, prof. Dr. Saša Bubanj, Jovan Aleksić, Nevena Ćirković and Aleksandra Bajić also took place. All the lecturers are awarded for participation in the festival, in addition to AS Eureka badges in gratitude for all our great promoters of science in Serbia.

During a break from the tour, the visitors had the opportunity to visit our Scientific cafe which is located immediately next to the room where lectures were held. You are able to sit down and with some of our eminent speakers to talk topics related to science, research and other things. Of course they could drink coffee, juice or water to refresh and prepare for the further tour of the festival or going to the planetarium.

In the school gym, there is a large planetarium Center for the Promotion of Science, which can accommodate 50 people. For the planetarium, as always, ruled the huge interest, so it can be said that often during the festival came a crowd in front of the planetarium. A large number of visitors attended the lectures, and at the end of the lecture organized for volunteers and participants of the festival. The lecturer was Jovan Aleksić, who in a masterly way put closer the concepts of the universe. Around the Planetarium an exhibition of photographs was organized by AD "Ruder Bošković" dedicated to the Universe and astronautics.

3. ASTRONOMICAL OBSERVATORY IN KRUŠEVAC

One of the goals of the members AU "Eureka" is to form an astronomical observatory in Kruševac. In fact, every astronomer wants to have her/his own corner where it will be possible to monitor the activities taking place in the night sky. Our hope is that following an example of colleagues from AD "Alfa" from Niš and AD "Universe" from Bačka Palanka we shall be able to build our astronomical observatory and thus classify Kruševac among those 5 cities in Serbia, which have their public observatories. Therefore AU "Eureka" is actively working on the preparation of projects aimed at purchasing an astronomical dome in that a telescope would be placed. In the past interviewed city officials supported this initiative. The idea is that the observatory sohould be on the Bagdala hill and that, in addition to promoting the benefits of astronomy, it also contributes to the development of tourism in Kruševac.

4. CONCLUSION

The project 'Sky is the limit' is certainly the most successful project of the Society Eureka implemented so far. A large number of villages visited where astronomy was popularized, a number of activities that have contributed to familiarize young people with science was organized, but certainly a great contribution in the field of promoting tourism and educational potential that it has in Kruševac. This is certainly the beginning of activities of Eureka on the realization of the final goal, which is to build the observatory, where project 'Sky is the limit' has had a major contribution in realization of the idea.

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www.eureka.nebjak.net

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ASTRONOMY COMPETITIONS AND THEIR ROLE IN ASTRONOMY EDUCATION IN SERBIA

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Abstract. For many years astronomy was taught as a separate subject (one hour per week) in the final form of the secondary school education. However, since about quarter a century ago it has been taught as part of physics, only in special schools (like Mathematical High School in Belgrade) it still exists as a separate subject in the final form (also one hour per week). In order to fill the gap NAOC (National Astronomical Olympic Committee, a working group within Serbian Astronomical Society – SAC) organises extra-teaching of astronomy. In this way it becomes possible to prepare the interested pupils for astronomical contests both within Serbia and international ones. During the period between the two last National Conferences, from 2014 to 2017, contestants from Serbia participated in the following international contests: 8th IOAA (International Olympiad in Astronomy and Astrophysics) in Romania 2014, 9th IOAA in Indonesia 2015, 10th IOAA in India 2016, 11th IOAA in Thailand 2017 and the Saint-Petersburg Olympiad $2014 - 2017$.

1. INTRODUCTION

In the period of 25 years between 1969 and 1994 astronomy was taught as a separate subject (one hour per week) in the final form of the secondary school education. After this period astronomy became a part of syllabus in physics with one class per week in final year (4th) of cecondary education. Only in special schools, which are rare, like Mathematical High School in Belgrade, astronomy still exists as a separate subject in the final form. For more extensive reports about formal astronomical education in Serbia see e.g. Atanacković-Vukmanović, 2006, Atanacković,2012, 2016, 2018.

The first participation of Serbia in an international astronomical competition for secondary school pupils was in 2002. Professor Jelena Milogradov-Turin learned about

International Astronomy Olympiad and she prepared two pupils (mozda dati imena ucenika, ipak su oni prvi) from Mathematical grammar school, Belgrade, they went to the Olympiad (Russia, grad????) and won 2 bronze medals! The beginning of national astronomical competitions for secondary school pupils in Serbia comes after 2002 because the participation in an international competition (International Astronomy Olympiad) required selection on the national level. From that time the number of interested pupils has increased and pupils who are not from the capital have been also included. Since astronomy is very insufficiently present in the regular teaching, extra-teaching has had to be organised. All these problems have been solved in the framework of activity of the National Astronomical Olympic Committee (NAOC) of Serbia that was founded in 2004. The present paper deals with the feedback on the line competitions – education, especially on the secondary school level. The primary school level is not neglected because it is very important to start the preparation for competitions as early as possible.

2. WHY ARE COMPETITIONS IMPORTANT?

There are several reasons for which competitions are important. For an exceptionally gifted pupil this is a stimulus to learn more in astronomy than it would be possible if only the regular material were followed. Through participating in a competition a gifted pupil can test her/his knowledge level in astronomy. In addition, the current curricula in Serbia generally give a small space to astronomy and a few special schools have astronomy as separate subject (one class per week, IV, final, year). Extra-teaching becomes necessary. It requires both qualified teachers and adequate literature. Since in Serbian schools there are no qualified teachers for astronomy extra-teaching, NAOC has to engage itself in organising extra-teaching. The same is true for the literature. In both cases the situation in, for example, physics is more favourable, there are many qualified teachers and the total number of physicists in Serbia is much higher than the number of astronomers so that there exists a sufficient number of persons capable of writing the proper literature (handbooks, collection of problems with solutions). Astronomical topics are well covered in a rich and high quality literature in other languages (e.g. Russian and English), thus, for the first aid some of that literature can be used in source languages, or, better, to be translated in Serbian especially the literature which is frequently used in astronomy extra-teaching and preparations for national and international competitions. Two such books have been already translated and published in the Serbian language one from English, Vidojević, 2014 and one from Russian, Vidojević, 2017.

NAOC with its entire activity contributes to the spreading of interest of young people in Serbia in astronomy. Once they are informed on existence of extra-teaching, literature and competitions, then their mere interest can result in real acquiring of knowledge. The most successful among them can participate in international competitions where they make personal contacts with young people who have similar interest from all over the world and make connections for their professional future. This is also the most important benefit from the participation in international competitions.

2. 1. COMPETITIONS IN THE SCOPE OF NAOC

The founder of the astronomical competitions in Serbia is Jelena Milogradov Turin (1935–2011). Due to her initiative the first participation of the Serbian team in an international competition was organised in 2002. Soon after her death NAOC introduced a special award named after her for the absolute winner of the National competition in Serbia. Table 1 contains the names of all winners from 2011 till 2017, it is to be noted that all of them are from Mathematical High School in Belgrade. Since 2004 the National Astronomical Olympic Committee (NAOC) has been in charge of training, testing and selection of the national team. Serbia has participated in several International olympiads: IOAA – International Olympiad on Astronomy and Astrophysics (from 2009); Structure of the competition: theoretical part + practical (data analysis + observation) + group competition. IAO – International Astronomy Olympiad (2002 – 2011); Structure: similar to IOAA except group competition. StPb – Saint Petersburg Astronomical Olympiad (from 2013) correspondence type of competition; structure: theoretical part + data analysis part. For detailed reports from various olympiads see e.g. Eskin et al. 2012, Miler, R., 2009, 2011, Ninković & Milić, 2011, 2014, Vidojević & Ninković, 2016.

Table 1: Jelena Milogradov-Turin award, from 2011 till 2017.

Year	Name (year of birth)
2011	Stefan Andjelković (1992)
2012	Luka Bojović (1996) & Ivan Tanasijević (1995)
2013	Ivan Tanasijević (1995)
2014	Ivan Tanasijević (1995)
2015	Vuk Radović (1998)
2016	Vuk Radović (1998)
2017	Igor Medvedev (1999)

Within Serbia the competitions are organised on two levels: regional and national. Regional: only theoretical part (3 questions + 4 tasks). Selection for higher competition level: every participant who achieves 30% of total number of points, or has right of direct participation, if in the previous year a medal at International olympiad was obtained. National: theoretical part (5 tasks) + practical part (data analysis & observations-indoor or outdoor depending on weather) Selection: 5 to 10 best participants become members of the Serbian national team for international competitions. The achievements of the Serbian participants at international competitions during 15 years, 2002 – 2017, are presented in Table 2. For a more detailed report from recent international olympiads , 2014–2017, see Vidojević et al. 2018(1), 2018(2).

During the first few years the participants of the competitions within Serbia were almost exclusively from the Mathematical High School in Belgrade. NAOC endeavoured to also involve pupils from both other Belgrade schools and schools beyond Belgrade. So we have had participants from other schools in Belgrade; also participants from Novi Sad, Bečej (District of South Bačka), Sremska Mitrovica, Stara Pazova (Srem District), Pančevo, Kovačica (District of South Banat), Šabac (Mačva District), Valjevo (Kolubara District), Priboj na Limu (Zlatibor District), Kraljevo (Raška District), Kragujevac (Šumadija District), Jagodina (Pomoravlje District), Požarevac (Braničevo District), Niš (Nišava District), Pirot (Pirot District) and Prokuplje (Toplica District).

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TO THE PRESIDENT OF THE INTERNATIONAL OLYMPIAD
ON ASTRONOMY AND ASTROPHYSICS
Professor Dr Grzegorz S. Stachowski

Dear Dr Stachowski,

We are deeply honored to be invited to contribute to the hosting and organizing of the 15th International Olympiad on Astronomy and Astrophysics and I would like to thank you for taking into account Serbia's application.

I wish to officially inform you that the Ministry of Education, Science and Technological Development of the Republic of Serbia will participate in organization and hosting of the International Olympiad on Astronomy and Astrophysics in 2021. I wish to assure you and the International Board that we will do our best to contribute in order to make certain that the organization of the competition is in accordance with the highest standards.

In this regard, we would like to assure you in our readiness to organize this event in 2021 in Serbia, and I believe that this will encourage the development of astronomy and astrophysics education in the region. If you require any additional information, please do not hesitate to contact us. We look forward to hear from you.

Please receive my gratitude and consideration and our best wishes, together with the cordial invitation to join the 15th IOAA in Serbia.

Yours respectfully,

Mladen Sarcevic, Minister

Figure 1: Minister's letter to IOAA President.

Table 2: Olympiad achievements. The number of participants (4th column) pertains to senior+junior+automatically qualified (winners from previous Olympiad); the last column (Special prize+Honourable mention).

Year	Olympiad	Country	Participants	Gold	Silver	Bronze	Recognition
2002	IAO	Russia	$2+0$	0	0	2	$0+0$
2004	IAO	Ukraine	$2+0$	0	1	1	$0+0$
2005	IAO	China	$2+3$	0	0	2	$0+0$
2006	IAO	India	$2+3$	2	0	2	$1+0$
2007	IAO	Ukraine	$2+3+2$	2	2	3	$0+0$
2008	IAO	Italy	$2+3+3$	0	2	3	$0+0$
2009	IOAA	Iran	4	0	3	0	$1+1$
2009	IAO	China	$2+2$	0	0	1	$0+0$
2010	IOAA	China	5	1	2	1	$0+1$
2010	IAO	Ukraine	$2+3$	1	1	2	$0+0$
2011	IOAA	Poland	5	0	2	1	$0+1$
2011	IAO	Kazakhstan	$2+1+2$	0	0	3	$0+0$
2012	IOAA	Brazil	3	0	1	1	$0+1$
2013	IOAA	Greece	5	2	1	0	$0+2$
2013	StPb		2	1	0	0	$0+0$
2014	IOAA	Romania	5	1	1	2	$0+1$
2014	StPb		2	0	0	1	$0+1$
2015	IOAA	Indonesia	5	0	1	1	$0+3$
2015	StPb		2	0	1	0	$0+0$
2016	IOAA	India	10	0	2	6	$0+1$
2016	StPb		5	0	2	0	$0+0$
2017	IOAA	Thailand	5	0	0	2	$0+3$
2017	StPb		1	0	0	0	$0+0$
Total				10	22	34	$2+15$

3. Astronomy extra-teaching and International Achievements

NAOC established a syllabus for astronomy extra-teaching following the official IOAA syllabus:

– Basic Astrophysics (Celestial Mechanics, Electromagnetic Theory & Quantum Physics, Thermodynamics, Spectroscopy and Atomic Physics, Nuclear Physics);

– Coordinates and Time (Celestial Sphere, Concept of Time);

– Solar System (Sun, Solar System, Space Exploration, Phenomena);

– Stars (Stellar Properties, Stellar Interior and Atmospheres, Evolution);

– Stellar Systems (Binary Star Systems, Exoplanets, Star Clusters, Milky Way, Interstellar Medium, Galaxies, Accretion Processes);

– Cosmology (Elementary Cosmology);

– Instruments and Space Technologies (Multi-wavelength Astronomy).

Interested pupils are divided into 2 groups: experienced contestants and beginners. The introductory course starts from the basics, but covers the entire syllabus. The advanced lectures are focused on deepening the understanding of astrophysical phenomena and applications of mathematics and physics. During a school year lessons are usually held on weekends. The instructors are school teachers and university students, mostly former contestants. The instructors work mostly voluntarily.

Unlike theory and data analysis the extra-teaching in observations requires special conditions because of its complexness: naked eye observations, telescope observations, star charts and planetarium lectures. The observational extra-teaching has been successfully realised due to distinguished NAOC member Branko Simonović.

The extra-teaching involves intensive preparations where the participants selected for the international competition stay together at the same place for up to 7 days. This contributes to the strengthening of the team spirit. Their schedule comprises working on theory, data analysis and blind star charts during day time and observing by night. Such preparations have been regularly carried out in a student resort place on the Avala mountain.

NAOC Observational Equipment. Telescope 1 (Newton type, 200/1000 mm with equatorial mounting EQ5, purchased in 2015); Telescope 2 (Newton type, 150/750 mm with equatorial mounting EQ3) was lent in 2016 by Vuk Radović, distinguished participant, to NAOC to be used for the purpose of extra-teaching only.

4. 15th IOAA 2021 IN SERBIA

In 2010 Serbia was offered by the International Board of IOAA to be the host country for 2021. In 2014 NAOC informed the Ministry of Education, Science and Technological Development about this and very recently an official letter signed by the current Minister, Mr. Šarčević, was addressed to the President of IOAA wherein the Ministry expressed its support to the hosting and organising of the 15th IOAA in 2021 (Fig. 1). The 10th anniversary of death of Jelena Milogradov- Turin, the founder of the astronomical competitions in Serbia, will be properly notated by such an important event.

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ILLUMINANCE AND VISIBILITY AT TWILIGHTS

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Abstract. Visibility is important in diverse human activities, among others in roadway traffic, where the good visibility is very important for safe driving. Decrease of visibility during the twilight-time is the cause of increased number of traffic accidents. Determination of the visibility under which the accident occurred is essential for accident analysis. Visibility of an object (target) depends on its illumination and on ability of human vision system to detect it. Here, the methods of determination of illuminance during twilight-time by sky brightness and some important factors of human visual system for visibility determination, like contrast sensitivity, are briefly presented.

1. INTRODUCTION

There is an increasing require of community for information about some astronomical events, since they have an important influence on human everyday activities. The most frequently needed information are the rise and set times of the Sun and Moon, the beginning and ending times of twilights, duration of daylight, azimuth and height above the horizon of the Sun or Moon, the amount of natural light at a designated time of day, at twilight or night etc. The determination of these quantities is the duty of astronomers. In this article I would like to concentrate on the determination of illumination of outdoor objects by solar scattered light in Earth atmosphere. It is very important information since it determines, along artificial light sources, the visibility of outdoor objects during twilight-time. Besides, the influence of human visual system on visibility will be discussed. Here the visibility is defined as the largest distance ($D_{\max}$) at which a target or object can be seen.

In every-day situations the visibility can be very important to detect, recognize or identify a given object (target). One of such every-day situation is the roadway traffic, where the good visibility is very important for safe driving conditions. Unfortunately, during the twilights this conditions decline very rapidly. Degradation of visual performance during these periods of the day is a leading contributor to increasing number of roadway accidents. Determination of the visibility under which the accident occurred is interesting for judicial system, insurance companies, low firms etc. Therefore it is often necessary to reconstruct the visibility at a given date, time and geographical position. The visibility is a very complex phenomenon, which depends on many factors, first of all on illuminance (total luminous flux incident on a surface, per unit area), luminance (photometric measure of the luminous intensity per unit area) and vision. Consequently, the estimation of visibility is affected by many physical (objective) and subjective factors.

In this article I would like to show some basic steps of illuminance and visibility determination during the twilight-time. The major determinant of the amount of natural light during moonless twilight is the atmosphere, which is a very complex physical (optical) medium. The illuminance of Earth surface by moon depends on its phase and can reach about 0.3 lux at full moon. It becomes a dominant source of illuminance and determines the outdoor visibility during nautical and astronomical twilights. The illuminance by starlight, zodiacal light and airglow is about 2 millilux. They are important light sources during a moonless night and determine the outdoor visibility. The detector is the human visual system (HVS), which is a very complex psychophysical system. I will present only the basics mathematical description of illuminance determination in implicit form. Similarly, the role of the human visual system in visibility determination will be described mainly by implicit mathematical equations and qualitatively by block diagram of processing of visual information.

2. OBJECTIVE FACTORS

2. 1. TWILIGHT ILLUMINANCE

The twilight-time of the day is occurring when the upper edge of apparent solar disk (uesd) is just graze the horizon (its elevation, $h_{\mathrm{uesd}} = 0°$), but the elevation of solar disk center (h_s) is larger than $-18°$). Twilight-time is divided, to a certain extent artificially, into three periods: civil twilight ($-6° \leq h_s < 0°$) nautical twilight ($-12° \leq h_s < -6°$) and astronomical twilight ($-18° \leq h_s < -12°$). During the twilight-time the ambient is not illuminated by direct sunlight any longer, but by other light sources, like solar scattered light (sky), Moon and other celestial objects.

The target visibility during the twilight-time without moonlight (especially in civil and nautical twilight) depends on illumination by sky brightness. Therefore, I will deal with sky brightness determination caused by solar scattered light in Earth atmosphere. Let's, firstly, consider the geometry of solar light scattering (Figure 1). The position of an illuminated target or object (N) on the Earth is determined by its geographical coordinates: longitude, latitude and high above the sea level (L). The position of the Sun is determined by celestial horizontal coordinates: zenith distance (z) and azimuth (A). Let the light scattering occur on air particles in elementary volume (dV) at position P. The position of this elementary volume is determined by its zenith distance (z_P) and azimuth (A_P). The azimuth is measured from vertical of the Sun. In this case the azimuth of the Sun is equal to zero.

The most correct way of determination the sky brightness in one arbitrary direction is to solve the radiative transfer equation for each beam of light from Sun to the target trough scattering by the elementary volume. The observed brightness from a given direction (sight path) is the sum of scattered solar light by atmospheric particles along line-of-sight from twilight ray region toward target. The implicit mathematical solution of this problem will be described following the description given by Розенберг (1963).

Let the intensity of solar radiation, outside of the atmosphere,is $I_0(\lambda)$ and ω_0 is the Solar disk surface measured in angular units from point P. The illuminance (E_0) at point P without presence of Earth's atmosphere is:

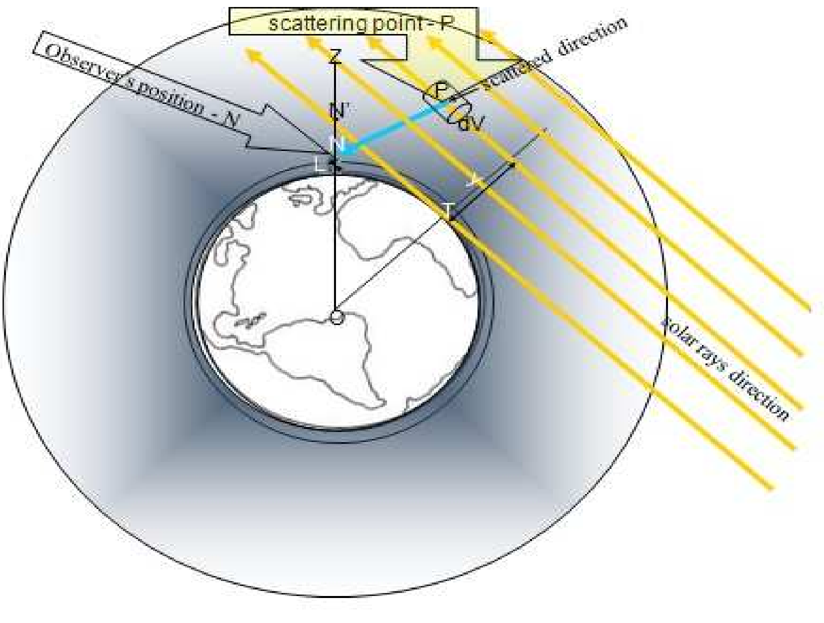

Figure 1: Geometry of scattered solar light in twilight-time (adopted from Розенберг, 1963).

$$E_0(\lambda, t) = I_0(\lambda) \cdot \omega_0(t). \tag{1}$$

For our purpose, we can consider that $I_0(\lambda) = \text{const.}$, but ω_0 varies about 6% during the year due to the elliptical orbit of the Earth, achieving its maximum at the beginning of the year and its minimum at the beginning of July. The mean solar illuminance is around 128×10^3 lx.

Due to extinction of Earth atmosphere the illuminance of particles at point P is:

$$E_P = \frac{T_P(z, z_P, A_P, h_P, \lambda) \cdot E_0(\lambda, t)}{\nu(z, y, r)} \tag{2}$$

where T_P is the atmospheric transmission coefficient along solar light ray path to point P. It depends on optical properties of atmospheric particles along (refracted) path of solar ray trough atmosphere up to the point P. That is to say, it depends on air mass or optical thickness of atmosphere along solar light path. ν is the correction factor due to refraction of light.

On atmospheric particles in an elementary volume dV, formed around the point P, the light scatters in all direction. The characteristics of scattered radiation in a specific direction are defined by Stock's parameters dS_i (Розенберг, 1963):

$$dS_i \cdot d\omega = \frac{1}{l^2} \sum_j D_{i,j}(\vec{l}, \vec{l_0}) \cdot S_j^0(\vec{l_0}) \cdot dV \cdot d\omega_0, \tag{3}$$

where $D_{i,j}$ is the scattering matrix, vectors $\vec{l}$ and $\vec{l_0}$ defined the scattered and the incident light directions, respectively. S_j^0 is the Stock's parameter of incident light. l

is the distance between the scattering point and target, $d\omega$ and $d\omega_0$ are the solid angle of dV with vertex at target and the light source (Sun) with vertex in P, respectively.

Stock's parameters of scattered light from elementary volume dV toward target's position (N) are defined by

$$dS_i(z, z_P, A_P, h_P, \lambda) = \frac{D_{i,1} \cdot T_N(z_P, A_P, L, \lambda) \cdot T_P(z, z_P, A_P, h_P, \lambda) \cdot E_0 \cdot d\vec{l}}{\nu(z, y, r)}, \quad (4)$$

where T_N is the coefficient of atmospheric transparency along the sight path toward the target N. Finally, Stock's parameters from line of sight direction (A_P, h_P) are

$$S_i(z, z_P, A_P, h_P, \lambda) = \int_0^{l_{\max}} dS_i(z, z_P, A_P, h_P, \lambda), \quad (5)$$

The illuminance (E) of horizontal surface at position N is defined as the light collected from the entire hemisphere:

$$E(z, \lambda) = \int_0^{2\pi} \int_0^1 S_1(z, z_P, A_P, \lambda) \cos z_P \cdot d(\cos z_P) dA; \qquad S_1 = I. \quad (6)$$

Since the illumination of scattered solar light depends on sun zenith distance and wavelength, the illumination of the horizontal surface undergoes both intensity and spectral changes during the twilight. At geographical position of our country, during twilight-time the illumination changes rather rapidly by a factor of about 10^7: decreases at dusk and increases at dawn as a function of time. In the case of arbitrary oriented surface, the limits of integrals are different. For example, in the case of vertical target surface, which is regular situation in roadway traffic, the interval of azimuth limit decreases to π (instead of 2π).

2. 2. ANGULAR SIZE

The target size, or more exactly its angular size with vertex at eye lens, is also a very important factor in determining visibility. It has an influence on pupil diameter, too (see the next section). If the size is too small, then the object cannot be seen regardless how high the contrast is. Besides brightness of sky and target size, there are many other objective factors (clouds, raining, snowing, fog, windscreen, glasses etc.), which determine the visibility. Their influence on visibility will be discussed in separate paper (in preparation). It has to be note that some objective and subjective factors affect the visibility simultaneously.

3. SUBJECTIVE FACTORS

I will present only some of the most important subjective factors, following Barten's (1999) model of spatio-temporal contrast sensitivity function of human visual system.

3. 1. LUMINANCE (L)

Light from the twilight sky falls on a target surface, a fraction of which reflects from it and illuminate the observer's eye pupil. The amount of light falling on the pupil is the luminance of target (L_t). The luminance depends on target reflectance (objective

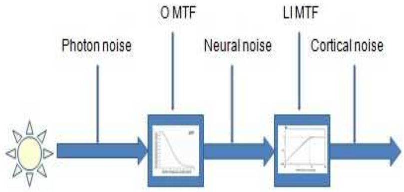

Figure 2: Block diagram of signal modulation and degradation in HVS.

factor), on target size (objective factor) and on eye pupil solid angle viewing from the target (subjective factor). If the luminance is lover than the sensitive threshold level of human visual system (HVS) the target will be invisible.

3. 2. CONTRAST (C)

Human eye can distinguish objects from each other or from their background (see the object), if the difference in their luminance or color is large enough. Here the luminance difference will be discussed, while the color difference will be considered in separate article. For an observer the ability to detect a target (object) mainly depends on target luminance (L_t), background luminance (L_b) and adaptation luminance (L_a). The visibility of a target at a given adaptation luminance level ($L_a = \text{const}$) is directly related to the contrast between the target and its surroundings. The quantification of this fact can be done by contrast coefficient (C), which is defined as

$$C = \frac{L_t - L_b}{L_b}, \tag{7}$$

C can be determined by measuring the luminance of the target and the luminance of its background. If $C > 0$ (positive contrast) the observer detect the target in reflected light. If $C < 0$ (contrast is negative) the observer detect the target's silhouette. If $C = 0$ the target is invisible.

Whereas, due to the degradation of light signal while propagate trough HVS from optical to visual cortex, a minimal luminance difference between target and background ($\Delta L_{\min}$) is needed to perceive the target with a certain probability level. Consequently the target becomes undetected even if the contrast differs from zero, but it is lover than a certain contrast value. This minimal contrast value is the threshold contrast (C_{th}). The threshold contrast is the ratio of minimal luminance difference ($\Delta L_{\min}$) and the background luminance L_b. Therefore, the threshold contrast can be defined as (Adrian 1989):

$$C_{\text{th}} = \frac{L_{\text{th}} - L_b}{L_b}, \tag{8}$$

where L_{th} is the object luminance at threshold contrast. The inverse of threshold contrast is the contrast sensitivity (CS). Threshold contrast is related to the fluctuation (noise) of luminosity (photon flux) and signal modulation, mathematically, describe by modulation transfer functions (MTFs), while propagate along human visual system path. The block diagram in Figure 2 illustrates the main degradation sources of target (objective) contrast by HVS.

As it noticed on block diagram, beside photon noise the neural and cortical noise is injected into the visual signal during the signal transfer from eye detecting system to visual center of brain. Therefore, threshold contrast depends not only on physical properties of observed object and its background but also from psychophysical properties of human visual system.

Now we can define a refined visibility criteria. If $C < C_{\mathrm{th}}$ the object is irresolvable from noise, which practically means that it is invisible. If an object's contrast is too low to be seen, then other visual factors are irrelevant. If $C > C_{\mathrm{th}}$ the object signal is resolved and might be visible.

In following sections the determination of factors designated in the block diagram will be shortly considered.

3. 3. PHOTON NOISE

The threshold contrast is directly related to the power spectral density of photon noise (Φ_{ph}). Namely, photon noise generates fluctuation in signal of photo-detectors in retina and increase the threshold contrast. At low luminance level photon noise can be the major contribution to threshold contrast level. The power spectral density of photon noise, as it can be proved, is

$$\Phi_{\mathrm{ph}} = \frac{1}{Q_e f_n E}, \qquad \text{where} \qquad E = \frac{\pi d^2}{4} L, \tag{9}$$

Q_e is the quantum efficiency of the eye, E is the retinal illuminance, f_n is the conversion factor between light units and photon flux density, d is the pupil diameter and L is the target luminance.

3. 4. OMTF

Human visual system consists of optical, photoelectric conversion and information transmission part. The optical part of HVS focuses light on the retina and forms an object image. Optical modulation transfer function (OMTF) is the measure of eye's ability to transfer the contrast from the object to the image at a given resolution. The OMTF usually includes the modulation transfer functions (MTF) of the eye lens, the scattered light in eye media, light-sensitive detectors in retina (rods and cons) etc. The resulting MTF of optical part of HVS is a convolution of all these individual effects. Therefore, according to central limit theorem, the resulting MTF versus spatial frequency (u) can be describes by Gaussian function (Barten 1999):

$$\mathrm{OMTF} = e^{-2\pi^2\sigma^2u^2}, \tag{10}$$

σ is the standard deviation of the line-spread function resulting from the convolution of different elements of the convolution process. Its value depends on eye pupil diameter and the light-sensor density. Eye pupil diameter, otherwise, depends on luminance and angular field size of the object and viewer's age (decreases with age).

3. 5. NEURAL NOISE

Neurons in visual system consist of photoreceptor cells (rods and cons), cells for signal transmission and cells for processing the visual information. In modeling the neural noise we can assume that it is caused by statistical fluctuation of transported visual

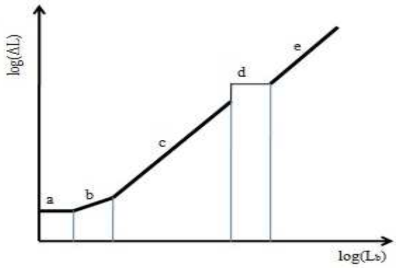

Figure 3: Schematic draw of luminance increment versus background luminance.

signal from retina to visual cortex in nerve fibers. This fluctuation can be described by standard deviation of signal in nerve fibers as (Barten, 1999):

$$\sigma = \sqrt{\frac{\Phi_0}{\Delta S \cdot \Delta t}}, \tag{11}$$

Φ_0 is the relative power spectral density of neural noise, ΔS is the angular area covered by a nerve fiber and Δt is the integration time of HVS. In equation (11) it was assumed that neural noise is independent on background luminosity. Whereas, in the case of increasing background luminosity, for successful target detection, the increase of minimal luminosity increment ($\Delta L_{\min}$) is needed. Figure 3 schematically shows the log–log dependence of target luminosity increment on background luminosity.[1] Short comments on properties of different segments (signed by letters) of luminance increment variation with background luminance level showed in Figure 3:

a) Very low dark background: neural noises define the luminance increment.

b) Photon noise is the main source of the luminance increment. The DeVries-Rose law is applicable, which predict that increment increases with the square root of background luminance.

c) The slope of linear function in log–log representation is equal to 1. The ratio of increment to background luminance is constant. Here the Weber's law is valid.

d) At this point the photosensitive detectors (cone type) are saturated by background luminosity ($\Delta L/L = \infty$).

e) At these background levels the rod type detectors in retina are activated. Again, the Weber's law is valid in this section.

3. 6. LATERAL INHIBITION MTF

In signal conduction process there exist an inhibition mechanism, which lowered the signal and noise in neighboring neural cells in lateral direction. Its efficiency increases with decreasing spatial frequency. This process can be modeled by the following modulation transfer function (Barten 1999):

[1]Adopted from Figure 1 in `https://www.yumpu.com/en/document/view/18209058/lecture-11-light-adaptation-webers-law-arapaho-nsuok`.

$$\mathrm{MTF} = \sqrt{1 - \mathrm{e}^{-(\frac{\mathrm{u}}{\mathrm{u}_0})^2}}, \tag{12}$$

where u is the current spatial frequency and u_0 is the frequency at which the modulation practically stopped. According to measurements it happens at $u_0 \approx 7$.

4. VISIBILITY LEVEL

Visibility level (VL) is a measure of actual visibility in units of threshold contrast:

$$\mathrm{VL} = \frac{C}{C_{\mathrm{th}}}. \tag{13}$$

It can be used for mapping the visibility distribution on a target and its background. By comparing VL maps of different light sources it is possible to distinguish in which part of illuminated area the illumination of individual sources are dominant. Such situation can take place for example at twilight-time with moonlight, or twilight illumination combined with illumination by artificial light sources, like car headlamps or street-light.

5. DISCUSSION AND CONCLUSION

For our purpose of determination the maximal distance ($D_{\max}$) to which a given observer (a car driver, for instance), with a given acuity and a given contrast sensitivity may detect with a given probability a given object (a car or a pedestrian, for instance) illuminated by twilight sky can be calculated from condition VL = 1. Since ($D_{\max} = f(\mathrm{VL}((D_{\max}))$, for determination of ($D_{\max}$) we need to introduce iteration procedure. Moreover, as we can see from equations (6), (10), (11) and (13) the calculation of VL is a very tedious job since these equations depends on many parameters like air chemical composition and its density distribution, optical characteristics of target, observer's visual system parameters (acuity, sensitivity, and contrast sensitivity), which are not available in everyday situations, for instance at position and time of traffic accident. Consequently, we are forced to introduce in calculation some approximations, which can significantly lower the accuracy of visibility determination.

I have developed a computer program for visibility calculation, named VIDO (VIsibility Determination of Objects). VIDO takes into account the light sources characteristics (e.g. sky brightness distribution, Sun and Moon illuminance), the optical properties of Earth atmosphere (including also clouds, rain, fog, aerosols etc.), the physical properties of observed objects (size, shape, orientation, albedo, color), the optical and psychophysical properties of viewer's eye (observer's pupil diameter, its variation with observer's age, viewer adaptation state, viewer optical correction, light sensitivity, viewer eye disease).

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THE FIRST YEAR OF THE "MILANKOVIĆ" TELESCOPE

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Abstract. Telescope Milanković is a 1.4m Nasmyth telescope installed at the Astronomical Station Vidojevica (ASV) named after the famous Serbian scientist Milutin Milanković. The telescope was installed in May 2016 and immediately delivered the first astronomical images. The Commisioning period (CP) for the telescope was defined to last one year. In this paper we summarize the telescope status after the CP. We announce the possibility of using our telescopes at ASV and summarize the rules that are defined in the Statute of telescope time allocation.

1. INTRODUCTION

Most of the observational activities on the telescopes at the Astronomical Observatory of Belgrade (AOB) were terminated in 1980's due to severe light pollution in Belgrade. Despite our lasting efforts to move our observational activities to more appropriate place, a new observational site was established only in 2003. It is located on the summit of the mountain Vidojevica (South-East Serbia) and it is named Astronomical Station Vidojevica (ASV). At altitude of about 1150 m, the astro-climate measurements shows excellent conditions for observations (Jovanović et al. 2012). The yearly mean of clear days is 80-100 (Arsenijević, 1981) and the median seeing is 1.2 arcsec. Only a small percentage of nights suffer strong winds when we are not allowed to open the pavilions for observation.

We started observations at ASV with the 60cm Cassagrain telescope, which was purchased from Astro Systeme Austria (ASA) company in 2005. Due to various construction works on the site, it was installed only in 2010. Although we have provided equipment both for astrometric, photometric and spectroscopic measurements, the later was abandoned due to technical difficulties to properly run the spectrograph.

Important turning point at ASV was the installation of 1.4 m telescope in May 2016. The telescope was purchased through the BELISSIMA FP7 project with the support of Ministry of Education, Science and Technological Development of the Republic of Serbia (Samurović, 2016 and Samurović, 2017). Like the 60cm telescope, it was also purchased from ASA company.

In this paper, we provide technical details on Milanković telescope and instruments that are currently used for observations. We specify observational projects that are performed on the telescope. After the Commissioning period (CP) of the telescope, we have formed the Time allocation committee (TAC) whose main task is to evaluate applications for observing time on our telescopes. This new program starts on 1st of January 2018 and we briefly discuss the main elements of the Statute of telescope time allocation.

2. CURRENT STATUS OF THE TELESCOPE MILANKOVIĆ

Telescope Milanković is a Nasmyth telescope with four usable stages, that is, Nasmyth ports. The telescope mount is Alt-Azimuth, with the characteristic of image rotation in the focal plane of the telescope while slewing. The mount is direct drive motor and provides maximal slewing speed of 6 degree/second on the sky. All moving parts of the telescope (Atl-Az rotational axis, secondary mirror for focusing, tertiary mirror, and de-rotators) are equipped with absolute encoders which enables their extremely precise positioning.

The telescope control system (TCS) is entirely placed inside the telescope fork which is an unique feature of the instrument. The telescope is easy to run via ethernet connection by terminal computer. Currently, all software run under the Windows operating system but Linux version will be also possible in the future.

Only two ports (toward the left and right forks of the telescope) are equipped with de-rotators which corrects for image rotation. One of the ports with the de-rotator is additionally equipped with field corrector which provides about half a degree field of view without significant optical aberrations at focal distance of 10.5 m. The other port with de-rotator is free of any additional optics and has 11.2 m focal distance. Ports without de-rotator can be also used for observational projects with short exposure time (e.g. planetary imaging, seeing measurement etc.).

We take an advantage of multiple Nasmyth ports to run various observational programs. One of the ports with de-rotator is equipped with iKonL CCD camera and 9 positions filter wheel from Andor company. The silicone chip resolution is 2048x2048 and provides about 9 square arcmin field of view (FOV) at 10.5 m focal distance. In principle, the only way to take advantage of full 30 arcmin aberration-free FOV is a CCD camera with 14 cm diagonal chip size which is currently a very expensive solution. Nevertheless, we plan to purchase a 0.5x focal reducer which will increase the available FOV to about 17 square arcmin with the available camera.

The second port with de-rotator is currently equipped with a portable fibre-feed low resolution spectrograph SpectraPro 2750 from Princeton Instruments company. It has a rotating turret with three gratings of 300, 600 and 1200 grooves per millimeter providing 44, 22, and 10 $\AA$/mm spectral resolution. The CCD camera with 1024 pixels in the dispersion direction and 26 μm in pixel size provide spectral coverage of about 1120, 560 and 250 $\AA$ in the tree grating mode. Due to tracking errors of the telescope, the maximal exposure time for a single shot is limited to about 5 minutes, which is sufficient for detection of about 8 magnitude stars (in V band) with a relatively good signal to noise ratio.

We also procured the iXon897 EMCCD camera from Andor company. With fast readout (56 fps) it will be used for speckle imaging but other observational programs are also feasible. We plan to attach it to the telescope port along with our portable spectrograph.

Figure 1 illustrates the current instrumental setup of the Milanković telescope. Although the instruments have already been provided, not all of them are attached to telescope due to some technical difficulties at this moment. For instance, we still seek

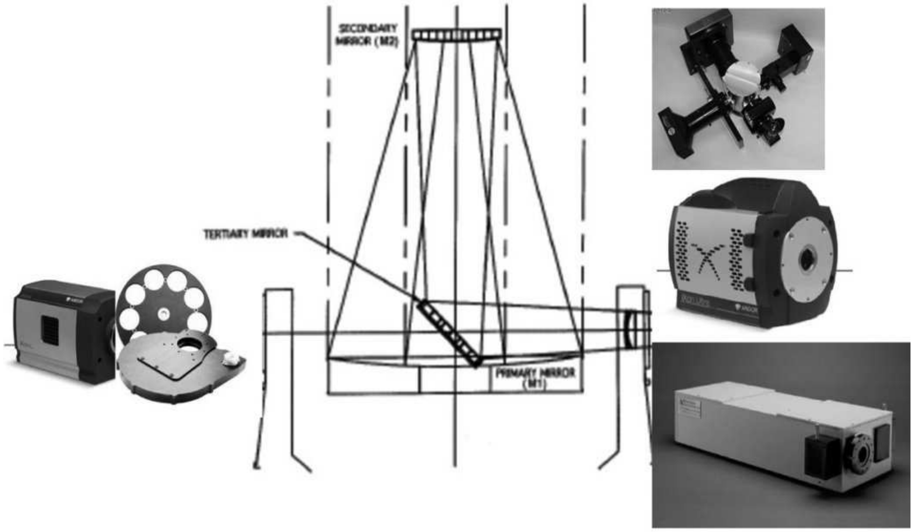

Figure 1: Current instrumental setup of the 1.4m telescope.

for solution on how to attach iXon897 camera on telescope along with the portable spectrograph. One proposed solution is shown by the most upper picture on the right which is an OPTEC Pegasus instrument selector that enables to attach 4 instruments in to the telescope at the same time.

Milanković telescope is currently installed in the roll-roof pavilion but it will be mounted in the pavilion with a rotating dome in the first half of 2018. While the construction works are carried out by Serbian company, the dome is purchased by Italian company Gambato. The pavilion and the telescope will be suitable for automatisation (or robotization) which is the ultimate goal for this telescope.

3. COMMISSIONING PERIOD OF THE TELESCOPE

After installation of the Milanković telescope in May 2016 we started with the CP that was defined to last one year. First several days of the CP were used to calibrate the telescope (mirrors collimation and making pointing model). It was followed by training, that is, learning how to handle the telescope. The rest of the CP was used for regular observational programs within AOB projects that were performed earlier on the 60cm telescope. No major issues with the telescopes mechanics and electronics were noted.

Figure 2 shows the first images taken with the telescope. The image is a combination of images made in B, V and R standard Johnson filters. At the time the images were taken, the seeing was exceptionally good with 0.7 arcsec measured on focused stellar images.

Figure 2: The first light images taken with the 1.4m telescope.

4. OBSERVATIONAL PROJECTS

Currently, we have ten observational projects that are performed systematically with the 60cm and the 1.4m telescopes at ASV. They can be summarized as follows:

1. Study of eclipsing binary stars. The project uses observations and performs modeling of the light curves of close binary stars with the aim to determine orbital elements and some fundamental parameters of stellar components and inter-binary and circum-binary gas components. These models are based on Roche geometry and incorporate a number of orbital and physical parameters of binaries. For more details see for example Djurašević et al. (2013).

2. Study of visual double and multiple stars. This project is aimed at determining the orbital elements of binary/multiple stars by measuring the position angles together with the angular separations between components. Generally, double/multiple stars with separations between 1.8 and 10 arcsec are observed but with new iXon897 fast-readout CCD camera the lower limit will be pushed below 1". For more details see Pavlović et al. (2018).

3. Gaia photometric follow-up program. There are several Science Alerts Working Groups within Gaia project aimed at real-time detection of variable sources. We joined the Photometric Follow-up Science Alerts Group in 2013. The main goal of this group is to make photometric observations of alerted targets with the aim to characterize and study the source. More details about the project can be found in Damljanović, Vince & Boeva (2014).

4. Whole Earth Blazars Telescope (WEBT) follow-up progaram. The project involves a large number of telescopes all around the globe with the aim to monitor a list of 28 blazars. We joined WEBT in 2013. These objects are highly variable in

all spectral domains and in high activity state, when they may change in brightness by several magnitudes in optical within several days, alert is triggered for intensive observations with all kind of telescopes from radio to gamma ray. More details about the project can be found in Vince & Damljanović (2014).

5. Study of asteroids. The project is aimed at photometric investigations of asteroids which allows to determine very important rotation and physical characteristics which are crucial for understanding of the conditions during the creation of our planetary system. For more details see Hanush (2011).

6. Study of cataclismic variable (CV) stars. CVs are studied by simultaneous observations (using the Bulgarian-Serbian telescopes or just Bulgarian Belogradchik-Rozhen ones) to determine and to make analysis of color changes, flickering amplitude and some other properties of the fast variations in the light curve in different states of cataclysmic objects. For more details see Boeva et al. (2011).

7. Study of galaxy formation and evolution. The project is using our telescopes to detect dwarfs galaxies and tidal streams of nearby spiral galaxies with the aim to study galaxy formation and evolution. More detail can be found in Javanmardi et al. (2016).

Three projects are part of PhD and MSc thesis and they are also performed systematically with our telescopes:

1. Study of Gaia quasars flux variability. The main objective of the PhD thesis is to test Gaia quasars for flux variability for astrometry purposes. For more details see Taris et al. (2016).

2. Study of Gaia quasars morphology. The objective of this PhD thesis is similar to the previous one except that instead of flux variability, changes in morphology are studied. For more details see Malkin (2016).

3. Observational characteristics of the SpectraPro portable spectrograph. The main goal of the MSc thesis is to study spectral characteristics of our portable spectrograph which is attached onto 1.4m telescope (throughput and spectral resolution). This is part of the bigger picture to introduce spectrograph into astronomical research. More details can be found in Vince et al. (in this publication)

Beside these projects we have several projects that are related to education and popularization of astronomy. Student practice is of particular importance, which is organized every year and involves students from different Universities with the aim to educate our student on working with telescopes/instruments and image reduction/measurements. We also organize workshops with amateur astronomers with the aim to define and develop common observational projects.

There are also observations on our telescopes that are not systematically performed.

5. TIME ALLOCATION

One of the tasks of the BELISSIMA project was to form a Time Allocation Committee (TAC) that will administrate the usage of the telescopes according to the submitted proposals. We start to operate the telescope in this regime on 1st of January 2018 and the rules are regulated with the Statute of telescopes time allocation at ASV. Main items in the Statute can be summarized as follows:

- One semester is provided for Proposals submission (4 months), Proposals evaluation by TAC (1 month) and final preparations for observations (1 month). The subsequent semester is an open time, that is, used for observations according to allocated telescope time.

- Proposals are read and evaluated by the TAC which consist of five permanent members employed at the AOB and consultative members who will be contacted in necessary.

- The telescopes are run by telescope operators but applicants are responsible to guide/control the observations either in live or remotely via internet.

Proposals are evaluated and ranked by TAC according to the following criteria:

1. Scientific background and technical capability of the Proposal.
2. Bilateral agreement on collaboration between AOB and institute which employs the applicant.
3. Efficiency in delivering papers based on data previously acquired with ASV telescopes.
4. Agreement on exchange of observation time on telescopes between AOB and institute which employs the applicant.
5. Donation of instruments to ASV.

There are different application types and they can be shortly summarized as follows:

1. Research applications.
2. PhD applications.
3. Educational applications.
4. Instrumental applications.
5. Target of opportunity applications.
6. Director's granted time.

We note that all relevant information related to time allocation on our telescopes will be publicly available by 1st of January 2018 at our web site http://vidojevica.aob.rs/

6. CONCLUSIONS

The main goal of the BELISSIMA FP7 project was to provide a 1.5m-class telescope which will enforce astronomical observations in Serbia and encourage collaboration in the region and wider. The project started in 2010 and, after two extensions, ended in 2016 with installation of 1.4m telescope called Milanković. This event was followed by precise calibration of the instrument and training. The Commissioning period of the telescope lasted one year. In this paper, we shortly describe the Commissioning period and the current status of the telescope regarding instrumentation and its usage. At the end, we introduce the main elements of the Statute of telescope time allocation.

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Physics", and no. 176011 "Dynamics and Kinematics of Celestial Bodies and Systems". We thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for the continued support related to the construction works at the Astronomical Station Vidojevica. We acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modeling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772).

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SPECTROSCOPICAL AND PHOTOMETRICAL ANALYSIS OF NEARBY GALAXIES OF DIFFERENT MORPHOLOGICAL TYPE

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Abstract. Galaxies show high degree of organization, proven by numerous scaling relations. However, most of these relations hold either for early- or late- type galaxies. There is a need for a study of galactic properties regardless of their morphological type, but driven from the sample representative of the galactic morphology in the local Universe. HI blind surveys sample galaxies based solely on their gas content, regardless of their luminosity in the optical. This is why we have extracted our sample from the latest HI blind survey, the Arecibo Legacy Fast ALFA Survey (ALFALFA). The first data release referring to the 40% of the planned survey was the alfa.40 catalog (Haynes et al. 2011), counting about 10 000 extragalactic sources. We have cross-matched this catalog with the sixth data release of the Galex Evolutionary Explorer (GALEX) and Two Micron All-Sky Survey (2MASS) catalogs to add ultraviolet and near-infrared photometry. Our final sample counts 2180 galaxies with radio and optical spectroscopy and ultraviolet through optical to near- infrared photometry.

Numerous empirical relations between galactic properties imply that there is a final number of parameters whose continuous change is responsible and may describe diversity of galactic types in the local Universe. The question that naturally arises is how many independent parameters are sufficient to describe galaxies we see today, i.e. the dimensionality of the problem and whether there is a single driving force responsible for their present distribution. To this end, we have applied the principal component analysis in order to reveal the true dimensionality of the problem. This method was applied earlier by Disney et al. 2008 on the sample of 200 galaxies chosen from the earlier HI blind survey, the HI Parkes All-Sky Survey (HIPASS). The authors analyse six galactic properties: dynamical mass, HI mass, luminosity, Petrosian radii R50 and R90 and the colour and find that there is a single dimension that is statistically significant. We have explored larger parametric space, including in addition: stellar mass, age, metallicity, colours with both ultraviolet and near infrared components, velocity dispersion, maximal rotational velocity and the mass of the dark halo. The parameters measured in the thesis are: dynamical mass, velocity dispersion, age and metallicity. Other parameters are taken from the existing catalogs. We have successfully reduced our parametric space to ten parameters: dynamical mass, stellar mass, HI mass, age, luminosity, colour with ultraviolet component, velocity dispersion, maximal rotational velocity and two Petrosian radii enclosing 50% and 90% of the flux, respectively. As the result of the principal component analysis, we have found *three* statistically significant components (dimensions), the first being the "size" of the galaxy, the second being the galaxy colour and the third being the galaxy age. The fourth component, although not statistically significant is dominated by the maximal rotational velocity. To conclude, there are at least three and possibly four "driving forces" that could explain the diversity of galaxies we see today.

1. INTRODUCTION

Pioneering studies of galactic properties with measured rotation curves (Brosche 1973; Bujarrabal et al. 1981; Whitmore 1984) were severely biased in several respects - galaxies were chosen a priori, for they optical luminosity and were all spiral and moderately irregular. In these early statistical studies, galaxy samples were heterogenous and very moderate (< 100 galaxies). However, applying statistical analysis (principal component analysis), previous workers found that the multidimensional space populated with very broad range of galactic properties may be reduced to only two fundamental and independent (uncorrelated) dimensions, i.e. properties – the first being the "size" of the galaxy and the other being the "aspect" of the galaxy.

With the advent of all-sky HI surveys, that mapped the whole sky in the radio L-band (1420 MHz), all the astronomical objects with measurable gas content were imaged, regardless on their optical luminosity. The first such a blind HI survey was the HI Parkes All Sky Survey (HIPPAS; Meyer et al. 2004) that mapped ~ 30000 deg^2 of the sky with the 64m Parkes radio-telescope and detected ~ 5000 objects with gas masses $M_{\mathrm{HI}} > 10^7 M_\odot$. Disney et al. 2008 applied the principal component analysis on a subsample of about 200 galaxies from this survey and found that there is a single galactic property guiding the variety of galaxies, with very different morphologies and colors. This property is equally well correlated with the galaxy mass, luminosity, Petrosian radii etc. and cannot be identified with a single property.

The second and the latest, most sensitive radio survey is the Arecibo Legacy Fast ALFA Survey (ALFALFA; Giovanelli et al. 2005) that detected more then 30000 extragalactic HI line sources with masses as low as $10^6 M_\odot$ out to z$\sim$0.06. The first data release (α.40; Haynes et al. 2011) was used in this contribution which describes my PhD thesis (defended in 2016 at the Department of Astronomy, University of Belgrade) in synergy with other wide area surveys conducted at other wavelengths to explore the widest range of galactic properties and to reduce the number of dimensions of this multiparametric space to the smallest number of statistically significant dimensions, given the unbiased and large sample of galaxies.

2. GALAXY SAMPLE

To build a large sample of galaxies without optical bias, we used α.40 catalog that is already cross-matched with the Sloan Digital Sky Survey (SDSS DR7; Abazajian et al. 2009) spectroscopic catalog. This catalog was further cross-matched to the Galaxy Evolution Explorer (GALEX GR6), Two Micron All Sky Survey (2MASS XSC; Jarrett et al. 2003) and the SDSS DR7 catalogs to add a multiwavelength photometry to the radio and optical spectroscopy originally provided with the α.40 catalog. The final sample has 2180 galaxies and we will refer to it as an α- sample, hereafter. α-sample has radio and optical spectroscopy and photometry from the ultraviolet, trough the optical to the near-infrared passband.

Morphological distribution of galaxies, based on the concentration index alone (C_{95}), suggests that there is about 1/3 of early-type galaxies in the α-sample for which $C_{95} > 2.6$ (Fig. 1). The ratio 1:3 reflects the contribution of early-type galaxies to the galaxy population in the local Universe (Shimasaku et al. 2001). On the other hand, Huertas- Company et al. (2011) made an automatic morphological classification of all the galaxies from the SDSS DR7, dividing them into two canonical types (early

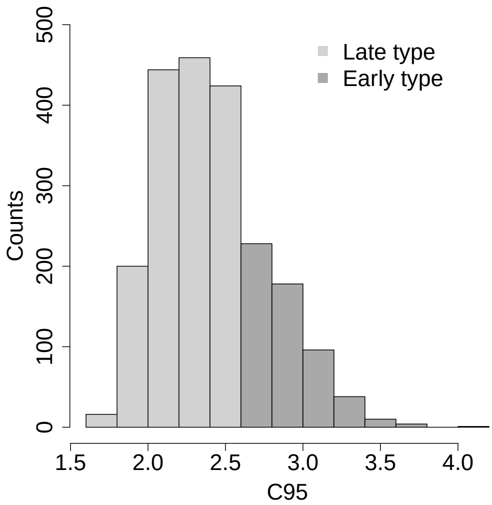

Figure 1: Morphological classification of galaxies based on the concentration index C_{95} (see Vudragović et al. 2016.): $C_{95} \leq 2.6$ are late-type galaxies (lighter) and $C_{95} > 2.6$ are early-type galaxies (darker).

and late) and then each of these types into two subtypes: ellipticals and lenticulars as subtypes of early-type galaxies and spiral Sab and Scd as subtypes of late-type galaxies. The affiliation is given as a continuous probability, normalized to the unity. For example, a galaxy is an early-type galaxy if pE> 0.5, with all different non-zero probabilities probabilities normalized to unity (pE + pS0 + pSab + pScd = 0.7 + 0.2 + 0.05 + 0.05 = 1). According to this classification, α-sample has 13% of early- and 87% of late-type galaxies.

For all the galaxies in the α-sample, we have measured velocity dispersions, Sersic indices and effective radii to obtain dynamical mass of galaxies. Also, we have measured the Lick indices since some of them are good proxies to galaxies' ages and metallicities. These parameters will be used in the final statistical analysis.

3. STELLAR KINEMATICS

Line-of-sight velocity distribution (LOSVD, hereafter) function is the distribution of stellar velocities in the galaxy spectrum responsible for the final shape of the spectral lines and reflects the motion of stars in the gravitational potential field defined by the dark matter distribution. The LOSVD function may often be well represented with the Gaussian function, but in early-type galaxies and bulges of late-type galaxies, when random velocity component takes over the rotationally supported component of velocity of stars binned to the disk, the Gaussian approximation breaks down and additional velocity components are needed to describe the LOSVD function accurately. van der Marel & Franx (1993) proposed decomposing the LOSVD function into orthogonal polynomials (see also Gerhard 1993), the so-called Gauss-Hermite series: introducing two new parameters describing asymmetric (h_3) and symmetric (h_4) departures from the Gaussian function.

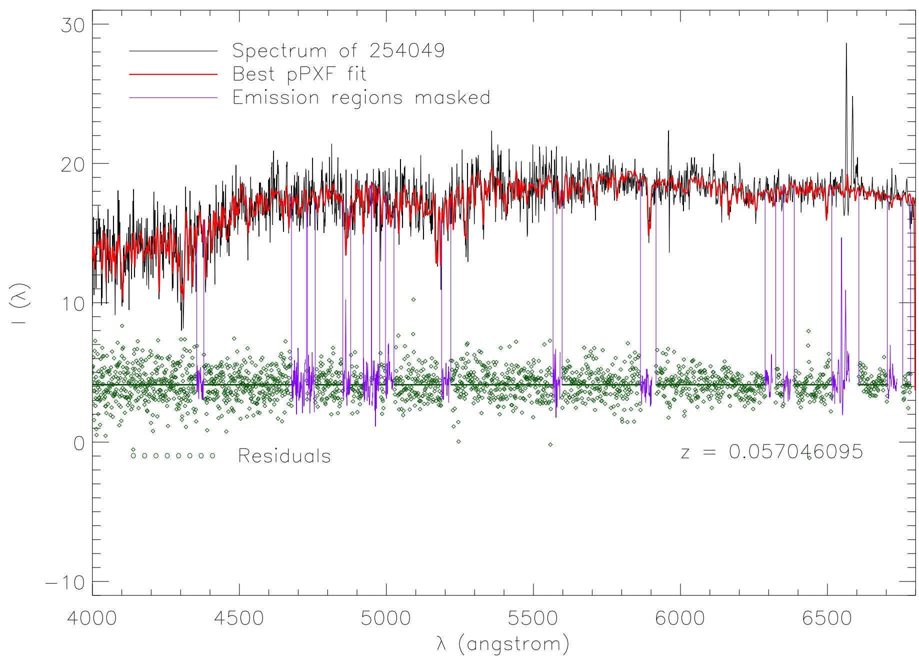

Figure 2: Spectrum of one of the galaxies (Alfalfa 254049) with the best fitting model overplotted. The residuals are given by dots at the bottom. Emission lines are masked (regions between vertical lines). The redshift is indicated in the bottom right.

Using the publicly available penalized piXel Fitting (pPXF) code (Cappellari & Emsellem 2004), we have measured velocity dispersion and the two higher moments (h_3 and h_4) from the LOSVD function represented with the Gauss-Hermite series, using the empirical Elodie stellar library (Prugniel et al. 2007) of 998 stars in total. We have tested several empirical and one synthetic stellar library to choose the Elodie library for its better agreement with the literature.

The measured velocity dispersion and the h_4 Gauss-Hermite coefficient will be used in dynamical mass calculation. The velocity dispersion needs to be aperture corrected (Jorgensen et al. 1995), but also corrected ($\sigma_{\rm corr}$) for the departure of the Gaussian function trough:

$$\sigma_{\rm corr} = \sigma^{\rm GH}(1 + \sqrt{6}\ \mathrm{h}_4^{\rm GH}), \tag{1}$$

where $\sigma^{\rm GH}$ is the uncorrected velocity dispersion and $\mathrm{h}_4^{\rm GH}$ Gauss-Hermite coefficient.

Given the sample size, we were able to study the behavior of the Gauss-Hermite coefficients across the Hubble sequence. We have established an increasing trend in h_4 parameter going from late- to early-type galaxies (Fig. 3), i.e. going from $\mathrm{pE0} = \mathrm{pE} + \mathrm{pE0} = 0$ to $\mathrm{pE0} = 1$. The results are obtained using the empirical stellar library. This implies the dominance of radial orbits in early-type galaxies.

Also, we have applied several statistical tests to the Gauss-Hermite h_4 coefficient

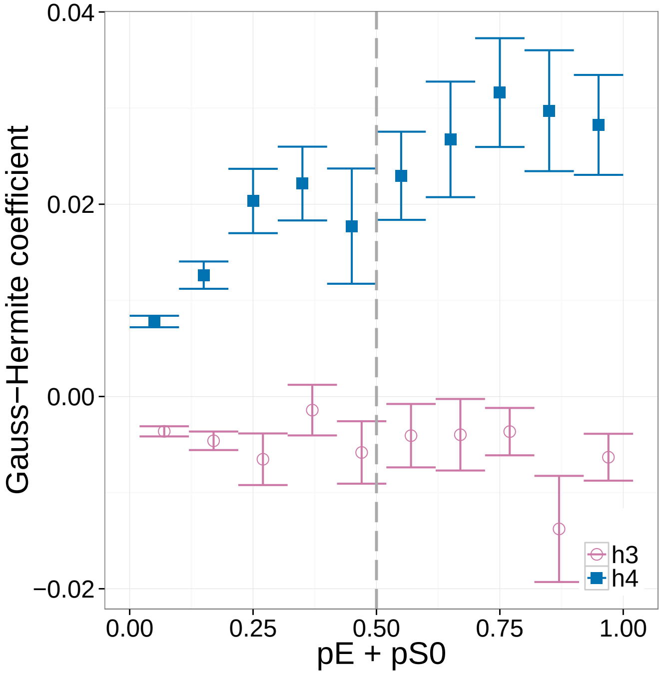

Figure 3: Measured Gauss-Hermite coefficients along the Hubble sequence (see Vudragović et al. 2016): h_3 (open circles) and h_4 (full squares). pE + pES0 $\equiv$ pE0 is the probability that galaxy belongs to early-type galaxies if pE + pES0 = pE0 > 0.5. Vertical dashed line is splitting late- from early-type galaxies.

going from the null hypothesis that early- and late-type galaxies share the origin. Also, we have confronted all subtypes in this way, e.g. E vs. S0 and S0 vs. Sab and Sab vs. Scd. The following statistical tests were performed: Anderson-Darling (Scholz & Stephens 1987; Darling 1957; Anderson & Darling 1952), Kolmogorov-Smirnov (Hoel 1971) and Cramer-von Mises (Anderson 1962). The results give a hint that elliptical and lenticular galaxies have the same origin, unlike all other (sub)types, for which the results were negative.

4. THE LICK INDICES

Two fundamental properties of galaxies, age and metallicity may be estimated from the width of specific absorption lines. To find those specific lines, we have measured all 25 Lick indices (Faber et al. 1985; Worthey & Ottaviani, 1997). On the other hand, we did full spectral fitting with the publicly available `ulyss` code (Koleva et al. 2008, 2009), that fits linear combination of single stellar populations of various ages and metallicities and finds a global χ^2 minimum that corresponds to a single age and metallicity.

Comparing the Lick indices to the measured (modelled) ages and metallicities, we have found that $<$ Fe $>'$=1/3 (Fe_{5015} + Fe_{5270}+Fe_{5335}) best correlates with metal-

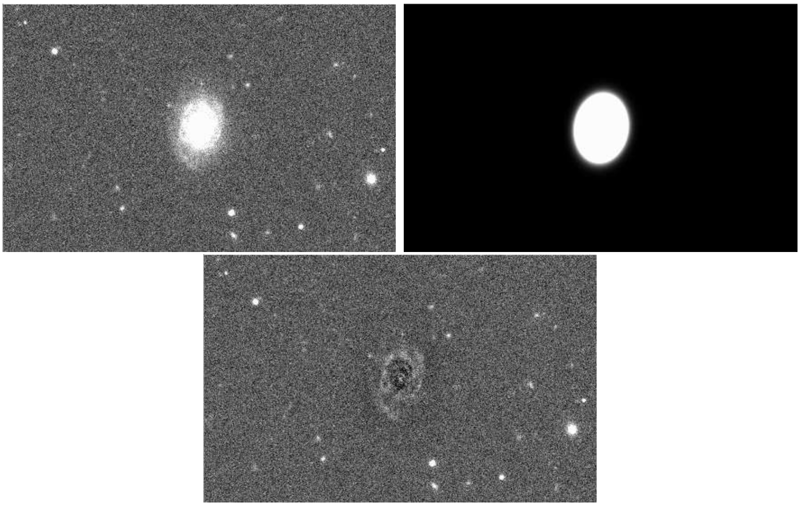

Figure 4: Surface brightness modelling trough steps. Up: input galaxy image (left) and galaxy model (right). Down: the fitting residuals from the modelling with the Sersic law.

licity and H_β best correlates with age. These two Lick indices ($< \mathrm{Fe} >'$ and H_β) will be used in the final statistical analysis as proxies for galaxy metallicity and age, respectively.

5. SURFACE BRIGHTNESS MODELLING

Surface brightness modelling with the Sersic law (Binney & Merrifield, 1998) was done using publicly available `galfit` code (Peng 2012), that is based on the non-linear least square method iteratively searching for the solution (global minimum). An example is given in the Fig. 4.

We needed to calculate Sersic index (n) and effective radius ($\mathrm{r_{eff}}$) of all the galaxies from the α-sample for dynamical mass derivation, following (Taylor et al. 2010):

$$GM_{\mathrm{dyn}} = K_V(n)\sigma_0^2 r_e,\ K_V(n) = \frac{73.32}{10.456 + (n - 0.95)^2} + 0.954, \tag{2}$$

where σ_0 is the central velocity dispersion, corrected for the departure from the Gaussian function (Eq. 1) and also aperture corrected, n Sersic index and r_e effective radius.

6. PRINCIPAL COMPONENT ANALYSIS

One of the main goals of the thesis is the reduction of the multidimensional space of galactic properties to the smaller number of dimensions, sufficient to describe them. To this end, the principal component analysis (Venables & Ripley 2002) was applied on the large set of galactic properties: Petrosian radii $\mathrm{R_{50}}$ and $\mathrm{R_{90}}$, colors made from all the combinations of magnitudes from ultraviolet to near-infrared, luminosity in g-band $\mathrm{L_g}$, gas mass $\mathrm{M_{HI}}$, the width of HI line at 20% of the peak $\mathrm{W_{20}}$, dynamical mass of the galaxy M_{dyn}, Lick indices $< Fe >'$ and H_β as indicators of galaxy's metallicity and age and velocity dispersion σ.

After applying regression analysis where all the parameters except for the colors and the Lick indices were put in the logarithmic scale, the linear relations that were too tight were used to exclude redundant parameters. Ten galactic properties were chosen in the final set: Petrosian radii R_{50} and R_{90}, NUV-r color that well correlates with the specific star formation rate, M_{dyn} dynamical mass, M_k stellar mass, M_{HI} gas mass, luminosity in g- band L_g, Lick index H_β as a proxy for galaxy ages, maximum rotation velocity V_r as an indicator of a specific angular momentum and velocity dispersion σ.

The principal component analysis gave the same number of components as in the input parametric set, with "amplitudes" describing how relevant is the contribution of each of the input parameters to that very component. Given that only those eigenvectors with eigenvalues $\lambda > 1$ (Guttman 1954) are statistically important, there are only three independent and statistically significant components: the first one being the "size" of the galaxy that has an equal contribution from Petrosian radii, dynamical, stellar and gas masses and luminosity, the second one being the "aspect" of the galaxy with the color NUV-r as the one that most contributes and is poorly correlated with any of the other properties and the third one being the age of the galaxy (H_β).

7. RESULTS

For the sample of 2180 galaxies, selected from the HI blind survey after cross-matching with several photometric and one spectroscopic catalog, we assembled various information on galactic properties from radio and optical spectroscopy and ultraviolet, optical and near-infrared photometry. The sample is morphologically representative in the local Universe. For all the galaxies in this sample we measured velocity dispersions and higher moments of the line-of-sight velocity distribution function (3^{rd} and 4^{th} moment), the Lick indices and Sersic law parameters (Sersic index and effective radius). We have created the largest catalog of full stellar kinematics including higher moments of velocity distribution function. The sample size enables us to perform various statistical tests to make insights into galactic properties in the local Universe. The main points are:

- The increasing trend of Gauss-Hermite h_4 parameter along the Hubble sequence suggests that stellar orbits are dominantly radial and this trend increases going from late- to early- type galaxies.
- We confirm an indication that elliptical and lenticular galaxies share the origin from the statistical analysis of h_4 parameter.
- We have found a new combination of iron indices that better correlates with metallicity of galaxies than the one used in the literature ($< Fe >$).
- There are three dimensions of multidimensional space of galactic properties responsible for the present day galaxy distribution. The first two are more descriptive and may be understood as the "size" and the "aspect" of the galaxy and the third one can be identified with the galaxy ages.

In the near future, we plan to use facilities at the Astronomical Station Vidojevica, in particular the Milanković telescope, to obtain deeper photometry to study nearby galaxies in more detail.

Acknowledgment

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through project no. 176021, "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations", which we also thank for the continued support related to the construction works at the Astronomical Station Vidojevica. We acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772).

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THE APPLICATION OF NINE DEGREES OF FREEDOM SENSOR IN DETERMINATION OF TELESCOPE POSITION

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Abstract. This paper shows the application of nine degrees of freedom sensor to determine the position of the telescope. Nine degrees of freedom sensor is consisted of three sensors: gyroscope, accelerometer, and magnetometer. By using DCM algorithm for sensor data fusion, Euler angles are calculated, upon which the coordinates of horizontal coordinate system are calculated as well. The coordinates of equatorial coordinate system are retrieved by using these coordinates together with time data and sensor location, which can be gotten either via GPS or by manually entering them. The PC application is written in C# programming language for retrieval of data from sensor and calculation of horizontal and equatorial coordinates. Furthermore, the errors and imprecisions that have emerged are explained, together with some of the ways of their elimination.

1. INTRODUCTION

This paper shows the problem of determination of celestial equatorial coordinates of the point the telescope is aiming at. In order to achieve that, the horizontal coordinates of the point have to be known, together with mean sidereal Greenwich time and geographic longitude and latitude of the place where the telescope is located. A nine degrees of freedom (9DOF) sensor is used to obtain these data. This sensor incorporates three sensors: gyroscope, accelerometer, and magnetometer which enable determination of the sensor plate orientation in the horizontal coordinate system. The data about exact time and geographic longitude and latitude are obtained with GPS receiver. However, if the environmental conditions do not allow sufficient precision of the GPS receiver, the time gotten from computer can be used, along with manually entered coordinates of the telescope position.

In order to determine celestial equatorial coordinates of the point, the PC application is written. It receives the sensor data via Bluetooth and then calculates the equatorial coordinates.

2. EULER ANGLES

Euler angles (yaw, pitch, and roll) are the most suitable form of representation of the rigid body position. They represent the rotations of the one coordinate system relative to the other coordinate system around all three axes. These two coordinate systems are world coordinate system (x, y, z), fixed in inertial space, and body-fixed coordinate system (X, Y, Z), which is related to the object and relative to the world coordinate system [Diebel 2006].

The rotation matrix $\mathbf{R}$ describes the orientation of one coordinate system relative to the other. The columns of this matrix are unit vectors of one coordinate system as seen from another. The vector in one coordinate system can be transformed to the vector in another coordinate system by multiplying it with the rotation matrix. The opposite transformation is done with transpose rotation matrix. The rotation matrix elements represent combinations of the trigonometrical functions of Euler angles.

The rotation matrix is also known as direction cosine matrix, since it is consisted of sines and cosines of the angles between the axes of the two coordinate systems.

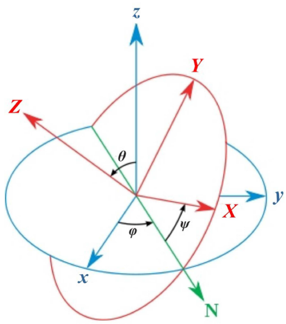

Figure 1: Geometrical definition of Euler angles.

In order to geometrically define Euler angles, it is necessary to define an additional axis, line of nodes ($\mathbf{N}$). The line of nodes is defined as the intersection between $\mathbf{xy}$ and $\mathbf{XY}$ coordinate plates. With this representation, the Euler angles are defined as follows (Fig. 1):

- α (or φ) is the angle between the $\mathbf{x}$ axis and the $\mathbf{N}$ axis, and represents a rotation around the $\mathbf{z}$ axis.
- β (or θ) is the angle between the $\mathbf{z}$ axis and the $\mathbf{Z}$ axis, and represents a rotation around the $\mathbf{N}$ axis.
- γ (or ψ) is the angle between the $\mathbf{N}$ axis and the $\mathbf{X}$ axis, and represents a rotation around the $\mathbf{Z}$ axis.

The Euler angles φ, θ, and ψ, are known respectively as spin, nutation, and precession. However, the commonly used terms are roll, pitch, and yaw, respectively, which originate from the theory of aerodynamics.

The direction cosine matrix, expressed in the terms of trigonometrical functions of Euler angles, can be expressed as [Premerlani and Bizard 2009]:

$$\mathbf{R} = \begin{bmatrix} \cos\theta\cos\psi & \sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & \cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi \\ \cos\theta\sin\psi & \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi \\ -\sin\theta & \sin\varphi\cos\theta & \cos\varphi\cos\theta \end{bmatrix} \quad (1)$$

3. DCM ALGORITHM

DCM (Direct Cosine Matrix) algorithm was developed for applications in modeling aviation technologies. In this context, the axes of an airplane are denoted as yaw (perpendicular axis), pitch (lateral axis), and roll (longitudinal axis), as shown in Fig. 2.

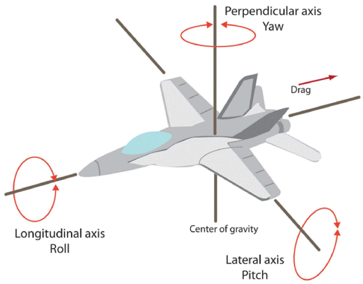

Figure 2: Orientation of axes on airplanes.

DCM algorithm uses data from accelerometer, gyroscope, and GPS receiver or magnetometer in order to determine the attitude of an object. The initial version of the algorithm was using GPS data as it was intended for usage with moving objects. However, if the object is still, then magnetometer has to be used. The working principle block diagram of the DCM algorithm is shown in Fig. 3 [Premerlani and Bizard 2009]

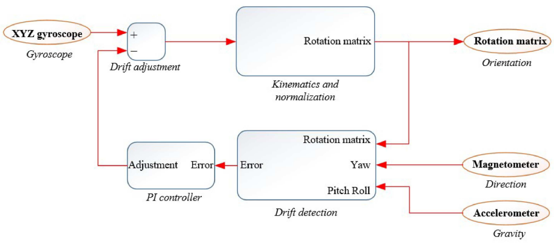

Figure 3: The block diagram of the DCM algorithm.

The accuracy of DCM algorithm mostly depends on characteristics of the gyroscope, such as sensitivity (gyroscope gain for converting rotation rate to voltage), offset (output of the gyroscope in the absence of rotation), drift (integrated effects over time of a slowly varying offset and noise), calibration (application of correct gain multipliers to the gyroscope signal), and saturation (happens when the rotation rate of the object passes the maximum range of the gyroscope).

Gyroscope is used for gathering the information about the orientation of the object. These information are produced by integrating nonlinear differential kinematic equations that show relation between the orientation change time rate and the rotation rate of the object. This process of integration eventually accumulates numerical errors, so the process of normalization has to take place. With normalization, the small adjustment to the rotation matrix are made.

In order to detect errors in DCM elements, the reference vectors have to exist. The main request for reference vectors is that the drift is not present. As reference vectors are used vectors obtained from accelerometer and magnetometer. Magnetometer is used to detect errors in yaw, and accelerometer for detection of errors in roll and pitch. Beside numerical errors, there are also errors due to gyroscope drift and offset. Based on measured errors, a PI (Proportional-Integral) controller is used for making adjustments to the gyroscope outputs. The PI controller adjusts the rotation rate of the gyroscope.

4. CHARACTERISTICS AND WORKING PRINCIPLE OF 9DOF SENSOR

The SparkFun 9DOF RAZOR IMU SEN-10736 sensor board [SparkFun 2016] was used as 9DOF sensor. It incorporates 3-axes ADXL345 accelerometer, 3-axes ITG-3200 gyroscope, and 3-axes HMC8553L magnetometer. The onboard processor is ATMega 328 @ 8MHz, and can be programmed with Arduino software suite. Its appearance is shown in Fig. 4.

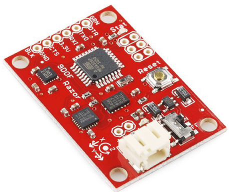

Figure 4: SparkFun 9DOF RAZOR IMU SEN-10736 sensor board.

For Bluetooth transmission of data to the computer, the SparkFun Bluetooth Mate Gold device is used, and as a GPS receiver, the GlobalTop FGPMMOPA6B device is used.

The firmware which incorporates DCM algorithm for this device can be downloaded from [GitHub 2016]. The system has the ability to send data either via USB serial connection or via Bluetooth. The output of the sensor readings are in the following format:

#YPR=yaw,pitch,roll

where yaw, pitch, and roll represent the actual values of those angles (e.g. #YPR = 10.15, -2.56, 71.25). These values are shown in degrees, and can have negative values.

Since the sensors incorporated in the 9DOF IMU (Inertial Measurement Unit) possess some irregularities due to its fabrication process, they have to be calibrated. For accelerometer calibration, the sensor plate has to move in every one of nine possible directions of the axes and the minimum and maximum values of acceleration are given. In order to calibrate the gyroscope, the sensor plate has to remains still for a period of ten seconds, and this also gives minimum and maximum readings of the average noise in the sensor. The magnetometer calibration process is somewhat more complicated and involves loading the Processing sketch for collection of magnetometer data. The sensor has to be moved in all possible directions until the unit sphere is evenly covered with readings [GitHub 2016]. This calibration output is presented in the Fig. 5.

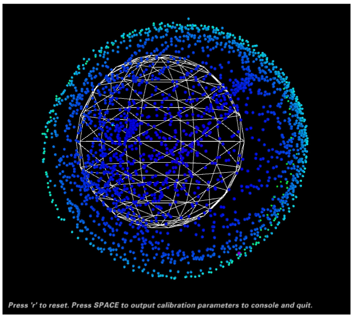

Figure 5: Appearance of the calibration sphere in mostly undisrupted environment.

The disturbances in the magnetic field that can corrupt magnetometer readings have to be annulled or at least minimized. They can be divided in hard iron and soft iron disturbances.

Hard iron disturbances may occur if the environment is occupied with objects with their own magnetic field. The magnetic field distribution on the unit sphere shows misaligned measurements with the center of the sphere. Soft iron disturbances may occur if the environment is prone to perturbations in the magnetic field, due to some iron or nickel materials present. The magnetic field distribution on the unit sphere shows an ellipse.

5. THE APPLICATION OF 9DOF SENSOR FOR DETERMINATION OF TELESCOPE POSITION

In order to show sensor orientation information (yaw, pitch, and roll) and to determine azimuth, altitude, right ascension and declination, the PC application was written in C# programming language.

5. 1. DESCRIPTION OF THE PC APPLICATION

The appearance of this application is shown in Fig. 6. As can be seen, the PC application consists of several sections: **Bluetooth veza (Bluetooth connection)**, the system searches for Bluetooth module on 9DOF sensor in order to establish connection; **Uspostavljanje veze sa senzorom (Sensor connection)**, the user chooses the serial port on which the data is received at the speed of 57,000bps; **Ojlerovi uglovi (Euler angles)**, yaw, pitch, and roll values read from the sensor; **Horizontske koordinate (Horizontal coordinates)**, azimuth (azimut) and elevation (visina) in degrees. Azimuth is calculated from yaw, and elevation from pitch; **JD, GMST, LMST, HA**, calculations of Julian day, Greenwich mean sidereal time, Local mean sidereal time and hour angle; **Ekvatorske koordinate (Equatorial coordinates)**, right ascension (rektascenzija) and declination (deklinacija), together with the stability assessments of their calculations (Stabilnost odredjivanja); **GPS**

prijemnik (GPS receiver), data gathered from GPS receiver. The user chooses the serial port on which the data are received at the speed of 9.600bps and the information about UTC time (UTC vreme), geographic longitude and latitude (geografska dužina, geografska širina), altitude (nadmorska visina), etc. are displayed; **Local time and coordinates (lokalno vreme i koordinate)**, the system doesn't have to use GPS receiver, but instead can locally save geographic longitude and latitude of the telescope positions and to gather time from the computer. It also has possibilities to delete and add new locations; **Location map info (prikaz lokacije na mapi)**, it shows the map location based on selected geographic coordinates, with Google Maps API implementation. It also possess the slider for zooming in and out the map.

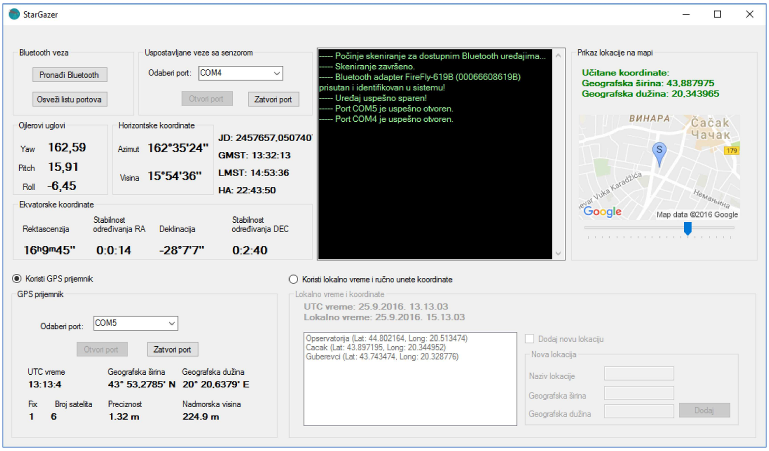

Figure 6: The appearance of the PC application.

5. 2. CALCULATION OF EQUATORIAL COORDINATES AND TIME PARAMETERS

Julian day number is calculated based on Meeus's algorithm [Meeus 1998] as follows:

Let Y be the year, M the month, and D the day. Let INT(x) be the function that gives largest integer that is less or equal to the number x.

If M > 2, then Y and M don't change. If M = 1 or M = 2, then Y = Y - 1, and M = M + 12. The following values are calculated:

$$A = INT(\frac{Y}{100}) \tag{2}$$

$$B = 2 - A + INT(\frac{A}{4}) \tag{3}$$

Julian day is then calculated as follows:

$$JD = INT(365.25(Y + 4716)) + INT(30.6001(M + 1)) + D + B - 1524.5 \tag{4}$$

If the current time is different from 12^h UT, then it is needed an additional factor (h is for hours, m for minutes, and s for seconds) that sums up with JD above:

$$add\_factor = \frac{h}{24} + \frac{m}{1440} + \frac{s}{86400} \tag{5}$$

Greenwich mean sidereal time (GMST) is calculated based on the following algorithm [Meeus 1998]:

Calculate the value of T:

$$T = \frac{JD - 2451545.0}{36525} \tag{6}$$

GMST in degrees is then:

$$\theta_0 = 280.46061837 + 360.98564736629(JD - 2451545.0) + 0.0003879337T^2 - \frac{T^3}{38710000} \tag{7}$$

The given value is fitted into interval from 0° to 360°, and then divided with 15 to get a value in hours.

Local mean sidereal time (LMST) is calculated as follows:

$$LMST = GMST + \frac{longitude}{15} \tag{8}$$

Declination is calculated as follows:

$$\delta = \arcsin(\sin\varphi \sin h - \cos\varphi \cos h \cos A) \tag{9}$$

and hour angle as follows:

$$H = \arctan(\frac{\sin A}{\cos A \sin\varphi + \tan h \cos\varphi}) \tag{10}$$

where α is right ascension, δ declination, h elevation, A azimuth, φ latitude, and H local hour angle.

Right ascension is given as:

$$\alpha = LMST - H \tag{11}$$

5. 3. THE RESULTS AND DISCUSSION

The system is tested on the private telescope in the village of Guberevci, Lučani municipality. The tests were conducted by pointing the telescope to the seven stars (Polaris, Capella, Mirfak, Mizar, Altair, Vega, and Fomalhaut). The absolute error is calculated for readings of azimuth, elevation, right ascension and declination, and their average values are given in Table 1.

Table 1: The average values of absolute errors of horizontal coordinates measurements in the format degrees : (arc) minutes : (arc) seconds

Coordinate	Azimuth	Elevation	Right Ascension	Declination
Average absolute error	8:43:05	2:00:03	02:25:33	5:33:59

The absolute error of azimuth determination varies from 1° to almost 14°, primarily due to nonlinearity and imprecision in magnetometer measurements. The absolute error of elevation determination is somewhat constant and around 2°. If we exclude Polaris from right ascension measurements, then the absolute error doesn't supersede 1°. The absolute error of declination measurements also varies a lot, from 1° to over 9°.

The some form of stability assessment is done by creating a buffer with ten current values of declination and right ascension. The buffer data is averaged, and then the total variation around average value and standard deviation are calculated.

The possible solutions for improvement of sensor reading might be linearization of magnetometer [Sreejith et al. 2014], creation of look-up table with corresponding values of correct and measured azimuth, or usage of another algorithm for Euler angles determination, such as Madgwick filter with quaternions [Madgwick 2010], Extended Kalman filter [Caron et al. 2006] or Complementary filter [Mahony et al. 2008].

6. CONCLUSION

This paper presented the usage of 9DOF sensor in the determination of the coordinates of the point the telescope is oriented at. The DCM algorithm for sensor data fusion enables the calculation of Euler angles based on data received from 3-axes gyroscope, accelerometer, and magnetometer.

The sensor that was used in the measurements is relatively cheap and not sufficiently precise. Because of that, the errors on the sensor outputs are relatively high. In order to improve the precision of the measurements, some filtering has to be done. The other solution would be the usage of more expensive and accurate devices that come shielded from magnetic and other disturbances. Of course, these systems come at much greater price, so a balance between price and accuracy has to be made.

Acknowledgment

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DENSITY PROFILE OF THE MILKY WAY: COMPARISON OF DYNAMICAL MODEL AND MONTE CARLO METHOD FOR DETERMINING STELLAR SPACE DENSITIES

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Abstract. We derived stellar space density of K giants in Milky Way in direction of galactic center and south galactic pole using Monte Carlo (MC) approach for solving equations of stellar statistics. For luminosity function of K giants we assumed gaussian distribution with mean magnitude of M = 1 and standard deviation $\sigma = 0.7$. Monte Carlo method for solving equation of stellar statistics is based on randomly assigning absolute magnitudes from assumed luminosity function corrected for Malmquist bias to star with measured apparent magnitude, which leads to randomly assigned distance module. The mean value of this quantity is used to calculate distance. This way we estimated mean stellar space density in given direction. We compared derived densities in direction of galactic pole, where influence of extinction is negligible to densities derived in direction of galactic center, where influence of extinction can not be neglected. Also we compared our results with density profiles derived from N-body simulation of Milky Way like galaxy in isolation.

1. INTRODUCTION

We can observe a large number of stars and make star count for Milky Way because it is possible to separate stars in the field of view. By determaining distances to stars we can make assumpions about their space distribution. In a unit solid angle there is a very large number of stars, so we can use statistical approach for determining distances in order to derive stellar space dencities (Angelov 2013). To determine the number of stars in solid angle ω, up to some limited magnitude, we need to solve fundamental equation of stellar statistics (Spaenhauer, 1978):

$$N(m) = \omega \int_0^\infty D(r)\phi(M)r^2 dr \ , \tag{1}$$

where $N(m)$ is number of stars with apparent magnitudes between m and $m + dm$, $\phi(M)$ is known or assumed luminosity function if there is no absorption and $D(r)$ is space density at distance r.

If luminosity function is given as gaussian distribution with assumed mean luminosity and standard deviation, we have:

$$\phi(M) = \frac{1}{\sigma\sqrt{2\pi}} \exp \frac{(M- < M >)^2}{-2\sigma^2}. \tag{2}$$

Malmquist (1920) showed that this can not be assumed for arbitrary sample of stars **S**, but rather the distribution function $\phi_m(M)$ is given by:

$$\phi_m(M) = \frac{1}{\sigma\sqrt{2\pi}} \exp \frac{(M - (< M > -k_m))^2}{-2\sigma^2} \ , \tag{3}$$

where k_m is

$$k_m = \sigma^2 \ln 10 \cdot \frac{d \log(N)}{dm}. \tag{4}$$

This means that sample **S** of stars is limited by apparent-magnitude intervals which are brighter than distance-limited intervals. This deviation k_m is dependent on function $N(m)$ and standard deviation of luminosity function. We used Monte Carlo method for solving eqaution (1) and tested it in two direction.

2. MONTE CARLO METHOD

Monte Carlo (MC) method is statistical method for solving problem which is based on repeated random sampling of some quantity to obtain numerical result. A method to solve fundamental equation of stellar statistics numerically is to apply MC method on equidistant intervals of apparent magnitudes while sampling absolute magnitudes from Malmaquist corrected luminosity function and finding empirical mean of calculated distance via Pogson's law.

Let us define equidistant intervals of apparent magnitudes with $\alpha = m_\nu - m_{\nu-1}$ and let N_ν be the number of stars with apparent magnitudes in this intervals. Figures 3 and 4 show apparent magnitudes samples for two directions. Absolute magnitudes for those stars are sampled from luminosity function corrected for Malmaquist bias. Dividing our sample into multiple apparent magnitudes intervals starting from $m = 6$ with steps of $\alpha = 0.5$ and defining limiting magnitude of the sample as defined in (Gschwind 1974)

$$m_{\text{lim}} =< M > -3 * \sigma + 5log(r) - 5 \ , \tag{5}$$

where m_{lim} is expected as we want to cover our luminosity distribution up to 3σ of population, we get samples as shown in figure 3.

We can numerically calculate k_m as

$$k_\nu = \frac{\sigma^2 \ln(10)}{2\alpha} (\log N_{\nu+1} - \log N_{\nu-1}) \ , \tag{6}$$

which is second order numerical derivative of k_m. Combining sampled absolute magnitude with observed apparent magnitudes and calculating distance to every star via Pogson's law, we derive possible distance to each star. We can derive possible stellar space density in that line of sight. Executing multiple runs on set of stars **S** we find multiple space density functions. We get the most probable density function and its deviation by finding mean and standard deviation of those functions.

3. N-BODY MODEL

We construct stable N-body model of spiral galaxy using GalactICs package (Widrow, et al. 2005, Widrow et al. 2007). There are three components that are included in N-body representation: disk and bulge represent baryonic matter and the third component is dark matter halo. Galaxy were evolved for 2 Gyrs with Gadget2 code (Springel et al. 2005). Parameters for N-body realisation are combination of values given in (Widrow et al. 2005). We assumed exponential profile of the disk in radial direction, with scale length of 2.8 kpc and mass $4.58 \cdot 10^{10} M_{\odot}$. This is done in order to compare with stellar space densities derived from MC method. We wanted to see if K giants follow density profile of baryonic matter derived from numerical model, or can we make more stable galaxy with parameters calculated from observed distribution of giants.

4. RESULTS AND DISCUSSION

We applied MC method on K type giants in direction of south galactic pole and galactic center using catalogues from SIMBAD database (we mostly used objects from SDSS and 2MASS surveys). Direction of galactic pole is chosen because the influence of interstellar absorption is smaller then in direction of galactic center. We use absolute magnitude $M = 1$ and standard deviation of $\sigma = 0.7$, for luminosity function corrected for Malmquist bias. Distributions of absolute magnitudes are given in figures 5 and 6.

Because field of view is not round, thus we could not use ω as solid angle, we selected only stars which are in 10 degrees radius around center of FOV, this is shown in figures 1 and 2.

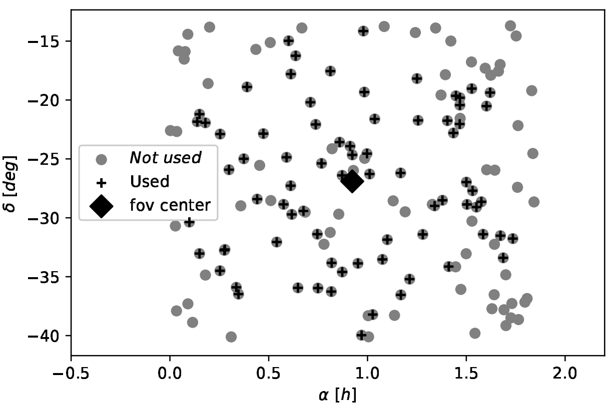

Figure 1: Field of view in direction of south galactic pole.

Using MC method described in previous section we can derive stellar space density and compare them to true density derived from catalog in which we have absolute magnitudes.

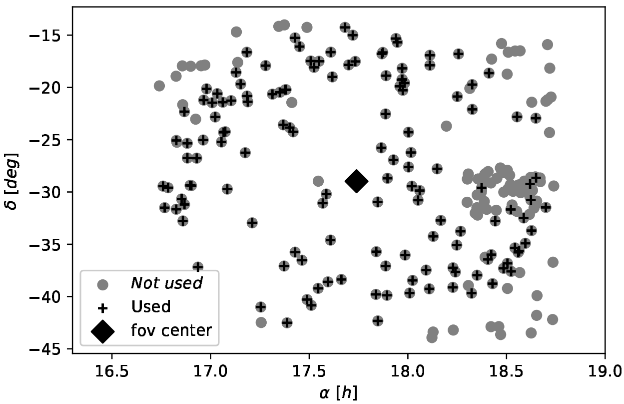

Figure 2: Field of view in direction of galactic center.

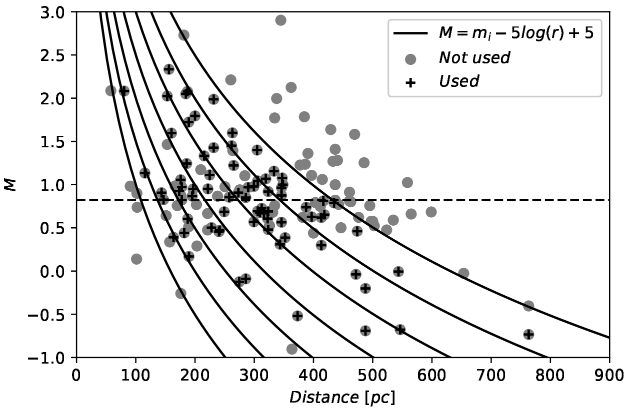

Figure 3: Apparent magnitude samples (south galactic pole).

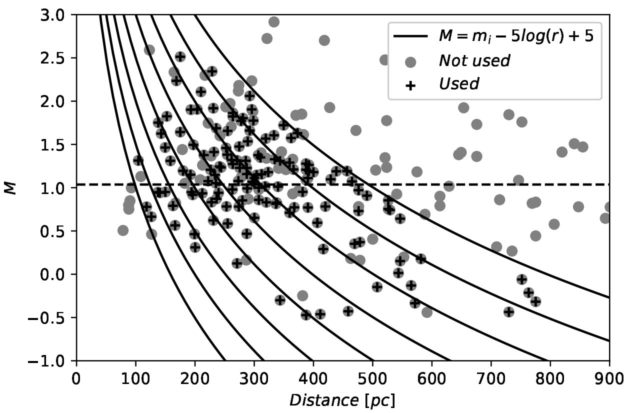

Figure 4: Apparent magnitude samples (galactic center).

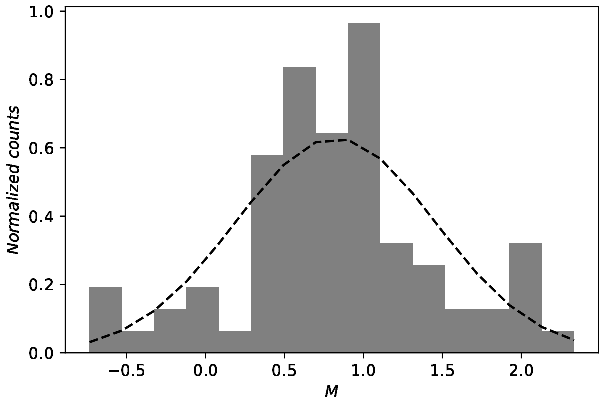

Figure 5: Distribution of absolute magnitudes, direction of south galactic pole.

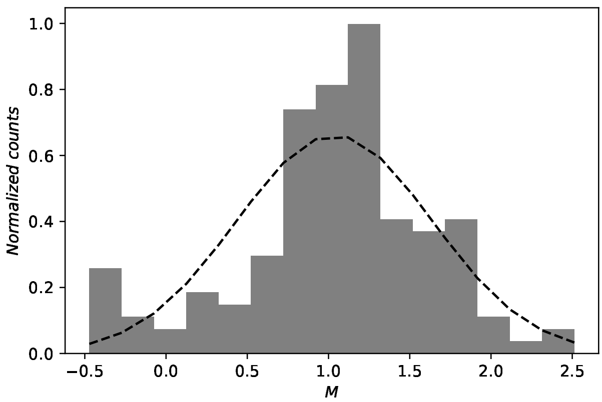

Figure 6: Distribution of absolute magnitudes, direction of galactic center.

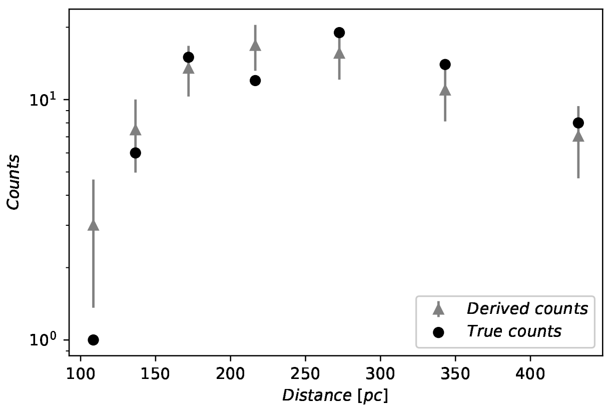

Figure 7: Derived stellar space density in direction of south galactic pole.

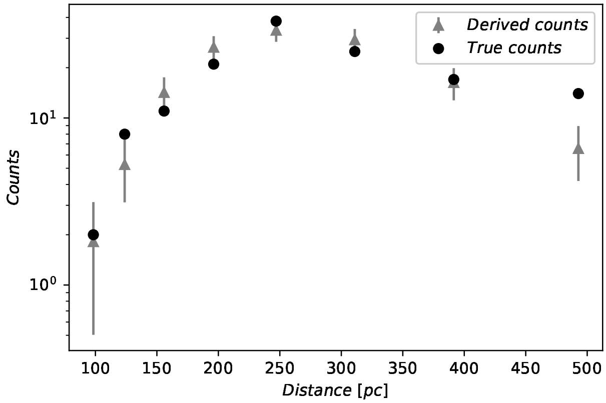

Figure 8: Derived stellar space density in direction of galactic center.

As we can see from figures 7 and 8 density function derived via MC method are in good agreement with true density function derived from observerd absolute magnitudes.

5. SUMMARY

For determining stellar space densities, we can use Monte Carlo method. It is tested on K giants, because giants are bright stars, so we can measure distances on large scales inside Galaxy (not only vicinity of the Sun). If we compare results from two directions: galactic pole and galactic center, we would expect disagreement between predicted and observed stellar counts, in the direction to center because of extinction. In this paper it is shown that there is no difference between this two directions, because the method was tested for stars with distances up to 1 kpc. Testing of the method on larger distances and bigger samples is need to be done. The nature of distinction between these two directions can be a tracer for gas and dust. Also, we constructed numerical model of spiral galaxy similar to Milky Way and Andromeda in order to test parameters against observed space distribution of stellar mass in the disk.

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Posters

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OVID, FASTI, SUN AND STARS

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Abstract. The paper discusses the Ovid's poem Fasti and its translation in Serbian language, with special emphasis on the interpretation of astronomical content and motives and difficulties of translators.

At the beginning of January 2017, the translation on Serbian, by the authors of this contribution, of Ovid's book "Fasti", has been published by the Society for Archaeoastronomical and Ethnoastronomical Research "Vlašići". "Fasti" of Publius Ovid Naso has not been translated into Serbian so far, but the english translation was widely available on the Internet. However, one fact has to be taken into account: reading in a foreign language, which the reader knows well, will be understandable. However, the flow of free associations will not be as fast as if it was read in its mother tongue and it will not have a full emotional response to the information it receives. This is well known to psychologists and psychiatrists, neurologists and lawyers: the polygraphic examination can not be performed in a foreign language, the apparatus will not be able to record those fine variations of the emotional response. If it is read in mother tongue, it is easier to understand the different layers of the message in the text.

On the other hand, each translation necessarily contains a personal note, since the translator gives his personal view of the text. Therefore, translations and translators should be more.

This translation was made primarily for personal curiosity of translators. Members of the Society for Archaeoastronomical and Ethnoastronomical Research "Vlaii" were naturally interested in the matter, given in this Ovid's work: this is the religious calendar of ancient Rome, based on the astronomically significant risings and settings of the Sun and stars, during the morning or evening dusk, just before the sunrise or immediately after the sunset. Ovid gives over forty holiday dates, firmly connected to certain astronomical events. In such a way, he offered significant material for exploring the astronomical knowledge available to the Romans in the time between old and new era. Consequently, one, who has to translate this text, must understand the astronomical data in it and must be able to explain them to the reader.

This is not the only difficulty. Ovid connects Roman holidays for the corresponding deities and myths, and often states rituals that should be performed on a particular holiday. His Roman readers were much better informed in their own religion than those of today, who often need additional information and explanations concerning the mythology and religion of ancient Rome.

Finally, on certain holidays significant historical events have been happened, which the poet also mentions in his work, which obligates the translators to remind the reader of the aforementioned historical events, and about the structure of the Roman state, the battles, the significant buildings ... It is completely clear that the translation of one such work requires an interdisciplinary approach. This translation, presented to the readership, for the first time in the Serbian language, was created as a comparative one, from the English language, with the use of the translation of James George Fraser, with a strict control of the text using the Latin transcript from the 10th century (which used Frejzer as well). It should be noted that the original of this Ovid's work is not preserved, but only a few later transcriptions, which differ in details.

The poem "Fasti" of Publius Ovid Naso presents an interesting source of information on the celestial phenomena, from the time of the transition between old and new era, and although his stellar calendar is not accurate today, since due to the precession celestial events mentioned by the poet are happening now almost a month later, this not diminishs the importance of this. On the contrary, it offers precious informations about astronomical knowledge, which was available to Romans on the transition between the old and new era and the ways in which that knowledge was understood.

Ovid's work testifies of the importance that the observation of heaven had for the ancient Romans. It is seen from the text that he attended many rituals, got into direct contact with the highest priesthood, and had information about the events in heaven, at least while writing a part of "Fasti" that is available to us. It only covers the first six months of the Roman solar year. Until today it is unknown whether the other part, for the remaining six months, has existed or not.

Ovid was born on March 20, 47 B.C. in the Sulmo (today's Sulmona), a city east of Rome, in a rich, educated and influential family, which has allowed him a great education and a good social position. In his youth he was engaged in law and has participated in the work of important legal institutions, as decemvir. Because of his love for poetry, he had neglected his profession early. He is known to have traveled to Greece, Thrace and Asia Minor, visiting Troy, a city for which the Romans link their origin. He had a high status of a "state" poet and was famous in his time. By the order of Augustus, the eighth year of the new era, in his 55th year, he was banished to the Roman province on the Black Sea, and the reason for this persecution to date is not quite known. Neither the Senate nor any other state body has given any act, to approve or justify his persecution. In all likelihood, there was some personal reason for Augustus angry. He never returned from exile and died in Tomis, 17th or 18th year of the new era and it is believed that he have been buried somewhere near this town. His work "Fasti", which he surely partially changed during his exile, was published posthumously, though never completed. Nowadays it is considered that, since in the exile, for Ovid were no longer available Roman libraries or contacts with the highest priesthood, he was without access to sources of information, needed to complete his work. It consists of a short introduction, in which is the dedication to

Germanicus, followed by six books, each dedicated to one month of the Roman year. Only six months are covered, from January to June. Poet's idea to include all year with 12 books, was unrealizable.

1. OVID'S ASTRONOMICAL GUIDELINES

Ovid's work Fasti has long time inspired not only fans of classical literature, but also astronomers, historians of religion, mythology, mathematicians and those who investigate chronology. The poet in this work gives over 40 dates, firmly associated with certain astronomical events. Astronomers and mathematicians first assumed the need for an exact check of the calendar and astronomical phenomena reported by the poet.

The first check was made by German mathematician and chronologist Ideler (Christian Ludwig Ideler, 1766-1846), who lived and worked in the eighteenth and nineteenth centuries. According to his calculations, Ovid made many mistakes,why his credibility regarding astronomical events is doubtful. Ideler considered that the poet occasionally manipulated with the dates of astronomical events, since the aesthetic and literary value was far more important to him.

The work of Ideler discouraged further research and brought a flurry of criticism of this work of Ovid. Over the next hundred years, there were few researchers willing to invest a tremendous effort and make up their own calculations for the astronomical events mentioned in the book and to correct the results to the epoch when the poet lived. This is quite understandable knowing the difficulties faced by those who want to make such calculations.

There are no precise formulas for the calculation of the date of a star's heliacal rise: the exact position of the point of observation and the characteristics of the horizon of that place must be taken into account, as well as the value of atmospheric refraction on it, in order to obtain the result for the present time. In addition, it is very important whether the observed star is on the northern or southern celestial hemisphere and how far away from the ecliptic. Very important are also brightness and apparent magnitude. The brighter stars are more easily detected in the morning dusk, so their appearance will be noticed earlier, while the weaker stars must be further away from the sun and the horizon in order to be noticed. One should also take into account the season of the year when a star is observed, because the night is shorter in the summer and in the winter is longer. In addition, atmospheric conditions (artificial illumination, dust, smoke and water vapor in the air) can make the less brightg stars invisible. As for the heliacal rise of the whole constellations, it can not be determined in one day, as it lasts for several days (and up to 30 for a larger constellation such as, for example, Pegasus), as it depends directly on the surface on the heavens the constellation covers. Finally, it is necessary to correct all the calculations for about 2000 years back, because of the precession of the equinoxes due to the periodic change in the direction of the Earth's axis, and it should be taken into account its inclination, which changes slightly over time, but the results of these changes are not negligible. It should also be noted that Ovid's Rome had 700,000 inhabitants, that all households had a fireplace, as well as every temple, thermae, blacksmith or pottery workshop, where torches and lamps smoked at night, and that there had to be significant amount of smoke in the lowest layers of the atmosphere, so that the visibility of the sky could not be ideal, especially in the situations when there is no wind. Besides all this, the atmospheric refraction at the horizon 2000 years ago remains unknown.

With the advent of computer era, things have changed significantly. Now exist powerful astronomical softwares, which include calculations for the time period from 3000 years B.C. up to 6000 years A.D., for any place of observation on Earth. In this book, Red Shift 7 and the third version of PLSV (Planetary, Lunar and Stellar Visibility) were used. Both software proved to be very useful, although their authors warn that minor deviations from the results are possible, due to the many variables.

At the time when Ovid lived and worked, those who watched the sky did not have practically any optical aids, but were relied on their good vision and experience, as well as on the notes of people who did it before them. When certain "wandering" in the first fifty years since the introduction of the Julian calendar is added, for example that the inserted day was added every third and not the fourth year, and that the priests had the right to introduce an additional, intercalary day, we understand that Ovid's dates are not quite fixed, like those we are using now.

Therefore, we consider that we do not have the right to seek scientific rigor in this work, in the present sense of the word. We believe that Ovid, despite some inaccuracies, performed his task the best he could at that moment. The poet himself praises those who observe the sky, but he does not say that he is himself one of those devotees. Therefore, we rightly assume that most of his descriptions were based on the testimonies and records stored in libraries. According to research by Matthew Robinson (Robinson M, 2005), some Ovidi's "mistakes" are repeated in other ancient Roman sources (Pliny, Columela). We can not even think about the mistakes that could have been made in rewriting the work (since the original was not preserved).

May be that an astronomer from Alexandria would have done more precisely the astronomical part of this work. But then the work would surely have lost its literary value. We can only regret that the poet could not finish what he started. Moreover, how many poets, respected in his midst as much as Ovid was in Rome, would be able to write a work similar to this?

Archeoastronomy and astronomy in culture are relatively young sciences, which experience their rise in the last thirty years. The translation on Serbian of Ovid's work "Fasti", enabled new, small insights into astronomical knowledge and ways to acquire and preserve these knowledges in ancient Rome. Of course, this is not the end. Research will continue, we hope, not only arheoastronomical. Some other researchers from various scientific disciplines will follow their free associations while reading it.

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TWO TYPES OF DARK MATTER DISTRIBUTION IN EARLY-TYPE GALAXIES

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Abstract. If one wants to explain the observed dynamics of galaxies, one is faced with the fact that gravitational force needed is greater than that which is produced by the visible matter. This leads to the introduction of the dark matter (DM) hypothesis. In this contribution we describe our sample of 15 early-type galaxies (ETGs) which includes both ellipticals and lenticulars. For all the galaxies in our sample we extract full kinematic profiles out to several effective radii: we rely on globular clusters (GCs) and we calculate the mass-to-light ratios of all the galaxies using the Jeans equation. We parametrize the gravitational field by that produced by the stars and a Navarro-Frenk-White DM halo. We focus on the relation between the dynamically inferred gravitational acceleration and the acceleration expected from the distribution of the visible matter (the acceleration relation, AR). The AR is nearly universal for the spiral galaxies, in agreement with the MOND modified dynamics theory. Up to now, observational difficulties precluded investigating the AR in the ETGs. Here we show that a few of our ETGs also follow very tightly the AR for the spiral galaxies, while the majority shows substantial deviations. That the first group might be spiral galaxies that lost their gas support the facts that they rotate, have disky isophotes, appear mostly very elongated and have blue colors. The galaxies deviating from the AR for the spirals either disprove MOND or contain unobserved matter.

1. INTRODUCTION

The missing mass problem is far from being solved. While the usual explanation is the dark matter (DM), the theories suggesting modifications of the standard laws of physics are still viable. Among these theories, MOND (Milgrom 1983) is particularly popular and successful. It roughly states that the actual gravitational acceleration, a, is a function of the gravitational acceleration calculated in the Newtonian way from the distribution of the visible matter, $a_{\rm N}$. The acceleration a differs from $a_{\rm N}$ only when $a_{\rm N}$ is lower than about $a_0 = 1.35^{+0.28}_{-0.42} \times 10^{-8}$ cm s^{-2} (Famaey et al. 2007). This functional dependence has been tested many times (see the review by Famaey & McGaugh, 2012), mainly in the late-type galaxies (LTGs, i.e. the spiral galaxies). Indeed, observations show that the relation between a and $a_{\rm N}$ (the acceleration relation, AR) has a very low scatter for the LTGs independently of their properties or environment. The best available observations of the LTGs are consistent with no intrinsic scatter in the AR (McGaugh et al. 2016), as expected by MOND. The tightness of the AR for the LTGs remains unexplained with the DM hypothesis.

Investigations of the AR in the early-type galaxies (ETGs, i.e. the elliptical and lenticular galaxies) is much less advanced. These galaxies typically lack the disks of rotating gas that enable measuring the rotational velocity, and hence the acceleration a, in the LTGs up to large radii. There are ways to investigate the gravitational fields near the ETG centers, such as from the velocity dispersion profiles of stars or from the temperature and luminosity profiles of the hot gas coronas. These measurements are however available only in the regions where the acceleration a is high compared to break acceleration a_0. To probe the weak gravitational field at the outskirts of the ETGs, we can rely, more or less, only on the Jeans analysis of the tracers such as planetary nebulae and globular clusters (GCs) (see, e.g. Samurović 2007). With this method, we are looking for an analytical profile of the gravitational field of the galaxy that can explain the observed velocity-dispersion profiles of the GCs. This method requires measuring radial velocities of many GCs that have to be obtained by very time consuming observations at large telescopes. This is the reason why the number of the ETGs studied using the Jeans analysis slowly increases.

Here we study using the Jeans analysis the gravitational field profiles up to 5 effective radii ($R_{\rm e}$) for 15 ETGs, which is close to the largest sample possible today. We use these profiles to investigate the AR in ETGs in unprecedented detail. We find that only 4 or 5 of our ETGs follow the same AR as the LTGs.

2. OBSERVATIONAL DATA

The ETGs in our sample are objects with a wide range of luminosities, morphologies and environments (field, group and cluster galaxies). We used observational data from several sources that will be listed in our prepared paper (most of them came from Pota et al. 2013). We work with a *total* sample of GCs for each galaxy (not splitting into red and blue sub- populations) in order to have more clusters per bin because our goal is to determine as accurately as possible the velocity dispersion and departures of the GC radial velocity distribution from a Gaussian. The table of our ETGs and their properties is presented in these Proceedings (Samurović, invited lecture).

3. OUR METHOD

3. 1. DYNAMICAL MODELS

For all 15 ETGs in our sample we solve the Jeans equation in a spherical approximation (e.g. Binney & Tremaine 2008). For each galaxy we consider 3 cases of the anisotropy parameter (isotropic, radially and tangentially dominated) as in Samurović

(2014, hereafter S14). We model the gravitational potential of our galaxies as $\phi = \phi_* + \phi_{\rm NFW}$, where ϕ_* is the Newtonian gravitational potential generated by the stars observed in the galaxy and $\phi_{\rm NFW}$ is the Newtonian potential of an NFW DM halo (Navarro, Frank & White 1997). There are three free parameters: the stellar mass-to-light ratio and the characteristic radius and density of the halo. We substitute ϕ in the Jeans equation and find the free parameters so that the deviation of the observed velocity dispersion profile from the velocity dispersion profile given by the Jeans equation is minimized. Such a potential is then adopted as the real gravitational potential of the galaxy.

3. 2. BARYONIC MODELS

In order to obtain the acceleration $a_{\rm N}$, we had to derive the stellar mass-to-light ratio, M/L_*, of every galaxy. When it is known and the galaxy is assumed to be spherical, then the acceleration $a_{\rm N}$ can be calculated from the observed luminosity distribution easily. We used several methods to derive M/L_*: 1) From the color index of the galaxy and stellar population synthesis (SPS) models, 2) from the dynamical models as the dynamical mass cumulated under $0.5\,R_{\rm e}$ divided by the cumulated luminosity under the same radius; this is based on the fact that no DM is usually needed in ETG centers and 3) similarly, we estimate M/L_* from the dynamical mass cumulated below $1\,R_{\rm e}$.

4. RESULTS AND DISCUSSION

The plot below shows the ARs found for the ETGs in our sample. The gray area shows the common AR for the 153 LTGs from McGaugh et al. (2016) where the vertical thickness corresponds to the $\pm 1\,\sigma$ average scatter. We can see that only 4 of our 15 ETGs have their AR common with the AR of the LTGs. They are NGC 821, NGC 1400, NGC 2768 and NGC 3377. This result does not change for any choice of the dynamical or baryonic models discussed above; possibly only NGC 4494 could be added to the four common galaxies.

We note that our ETGs following the AR of the LTGs resemble the LTGs also in other regards (see the aforementioned table): their stellar content is supported more by ordered rotation than velocity dispersion, they have disky isophotes, they sometimes appear very flattened in projection, they have the bluest colors in our sample and avoid galaxy clusters. These facts suggest that their formation history is related to the formation history of the LTGs. They could, for example be spiral galaxies which lose their gas by a starburst. We also note they can be modeled in MOND without additional DM, see S14, Samurović et al. (2014) and also our forthcoming paper. On the other hand, massive ETGs, such as NGC 3115, NGC 4365 and NGC 5846 which deviate significantly from the AR of the LTGs, need copious amounts of DM in their outer regions even in the MOND approach (see S14).

One possibility is that our results exclude MOND. Given its previous success, including in ETGs, our results should be verified for our galaxies by an independent method and the reliability of the Jeans analysis should tested against numerical simulations. It is possible to reconcile MOND with our results by supposing additional invisible matter in the galaxies. MOND is already known to require some DM in galaxy clusters.

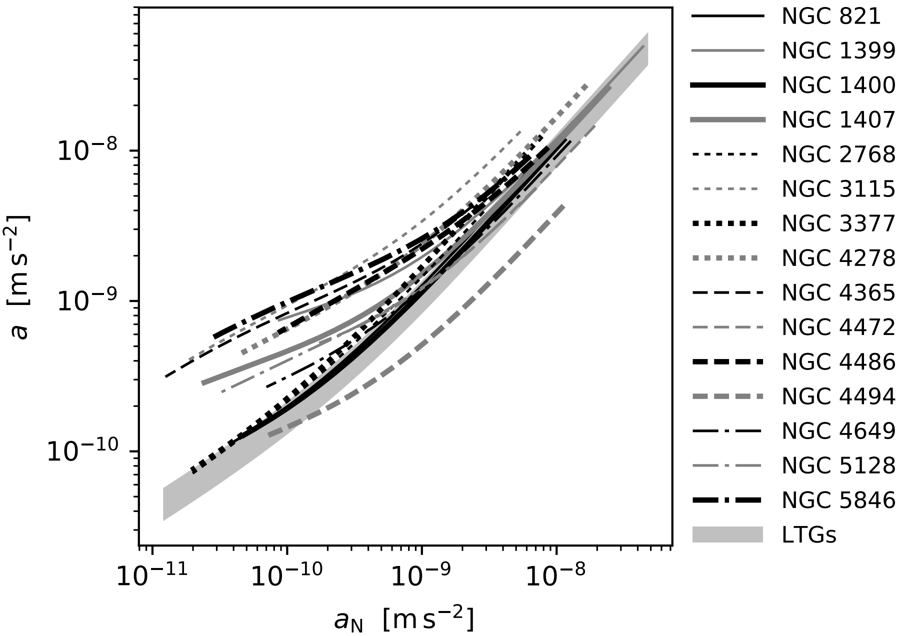

Figure 1: The acceleration relation for the 15 ETGs.

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CONSTRAINING THE COLLECTIVE RADIO EMISSION OF LARGE SCALE ACCRETION SHOCKS

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Abstract. Accretion of gas onto already virialized structures like galaxy clusters should give rise to accretion shocks which can potentially accelerate cosmic rays. Here, we use the radio emission detected from Coma cluster and models of evolution of cosmic accretion shocks, to constrain the possible contribution of unresolved galaxy clusters to the cosmic radio background. We assume that Coma is a typical galaxy cluster and that its entire radio emission is produced by cosmic rays accelerated in accretion shocks, making our prediction an upper limit. Our models predict that at lower frequencies accretion shocks can have a potentially large contribution to the cosmic radio background, while on larger frequencies, e.g. 5 GHz, their contribution must be lower than $\lesssim 2 - 35\%$, depending on the models of evolution of accretion shocks that we use.

1. INTRODUCTION

The ARCADE 2 (Absolute Radiometer for Cosmology, Astrophysics and Diffuse Emission) observations of the radio sky show an excess in addition to the Cosmic Microwave Background (CMB) temperature of $T_{\rm CMB} = 2.725 \pm 0.001\,{\rm K}$ (Fixsen et al. 2011). The existence of this excess radio emission (Cosmic Radio Background - CRB) is supported by the observations at lower frequencies (Haslam et al. 1981; Reich & Reich 1986; Roger et al. 1999; Maeda et al. 1999). The observed excess extends from 22 MHz to 10 GHz, and is well fitted by a power law $T_{\rm CRB} = T_{\rm R}\left(\frac{\nu}{310\,{\rm MHz}}\right)^{\beta}\,{\rm K}$, where $T_{\rm CRB}$ is the brightness temperature of the CRB, $T_{\rm R} = (24.1 \pm 2.1)\,{\rm K}$ is the normalization temperature of the CRB, ν is the frequency, and $\beta = -2.599 \pm 0.036$ is the power law index (Fixsen et al. 2011). The measured CRB is several times higher than the contribution from currently observed radio sources like galaxy clusters and the intergalactic medium, radio supernovae, radio quiet quasars, and star forming galaxies (Singal et al. 2010; Vernstrom et al. 2011). This leaves room for possible dark matter contribution (Fornengo et al. 2011; Hooper et al. 2012; Cline & Vincent 2013) or some other unresolved radio sources.

Here, we consider cosmic-ray acceleration in large-scale accretion shocks (Miniati et al. 2000; Furlanetto & Loeb 2004), present around galaxy clusters (Pinzke &

Pfrommer 2010). Recent detection of X-ray and gamma-ray signal around the Coma cluster could be a potential evidence for the presence of accretion shocks (Keshet et al. 2017; Keshet & Reiss 2017). Constrains on their contribution to the gamma-ray and neutrino backgrounds are still weak, but they cannot yet be ruled out (Dobardžić & Prodanović 2014; 2015). Synchrotron emission from electrons accelerated in large-scale accretion shocks, should produce radio signal (Ensslin et al. 1998; Kushnir et al. 2009), but also contribute to the CRB (Keshet & Waxman 2004).

2. FORMALISM AND RESULTS

We follow models from Dobardžić & Prodanović (2014), who have calculated the contribution of unresolved galaxy clusters to the *Fermi*-LAT isotropic gamma-ray background (Ackermann et al. 2015). The observable quantity that can be compared to the CRB is the differential radio intensity $\mathrm{d}I_{\mathrm{r}}/\mathrm{d}\Omega\,[\mathrm{Jy\,sr^{-1}}]$ coming from all unresolved galaxy clusters:

$$\frac{\mathrm{d}I_{\mathrm{r}}}{\mathrm{d}\Omega} = \frac{c}{4\pi H_0 J_0(z_0)} \int_0^{z_{\mathrm{vir}}} \mathrm{d}z \frac{\dot{\rho}_{\mathrm{sf}}(z) L_{\mathrm{r}}(\nu)}{\sqrt{\Omega_\Lambda + \Omega_{\mathrm{m}}(1+z)^3}} \times \left[\frac{\epsilon}{\epsilon+1} + (\epsilon+1)^{-1} \frac{\int_{z_{\mathrm{vir}}}^{z} \mathrm{d}z\,(\mathrm{d}t/\mathrm{d}z)\,\dot{\rho}_{\mathrm{sf}}(z)}{\int_{z_{\mathrm{vir}}}^{z_0} \mathrm{d}z\,(\mathrm{d}t/\mathrm{d}z)\,\dot{\rho}_{\mathrm{sf}}(z)} \right], \tag{1}$$

where H_0 is the present value of the Hubble parameter, c speed of light, z redshift and z_{vir} virialization redshift of the source, and matter and vacuum energy density parameters are Ω_{m} and Ω_Λ. The evolution of cosmic accretion shocks is described by the cosmic accretion rate $\dot{\rho}_{\mathrm{sf}}(z)$ $\left[M_\odot \mathrm{yr^{-1} Mpc^{-3}}\right]$ (Pavlidou & Fields 2006). The accretion rate of a single object at redshift z_0 to which we normalize our models is $J_0\,[\mathrm{M_\odot yr^{-1}}]$, and ϵ is the initial gas fraction of the object accreting gas. The detailed derivation of this equation and parameter values are given in Dobardžić & Prodanović (2014). Finally, $L_{\mathrm{r}}(\nu)\,[\mathrm{erg\,s^{-1}Hz^{-1}}]$ is the radio spectrum of some typical galaxy cluster. For this we use Coma cluster, since it is a well studied galaxy cluster with the observed diffuse radio emission (Large et al. 1959; Schlickeiser et al. 1987). We use fitted Coma radio spectrum by Brunetti et al. (2012), which was derived using power law in momentum $\propto p^{-2.6}$ hadronic models. Compilation of observed Coma radio data, that was used for the fitting, can be found in Pizzo (2010).

In Figure 1 we present the resulting differential radio intensity of unresolved galaxy clusters, derived using Equation (1) and integrated over the whole solid angle, I_{r} [Jy]. Dashed curve was derived using the simplest Model 1 (model depends only on the distribution of accreting objects by mass) for the evolution of accretion shocks (Pavlidou & Fields 2006), while dotted and dash dotted curves use more realistic Models 2 and 3 (models depend on the distribution of accreting objects by mass and properties of the surrounding medium), respectively. The data points represent the CRB derived by subtracting the T_{CMB} (Fixsen et al. 2011) from the observed radio emission (Fixsen et al. 2011; Roger et al. 1999; Maeda et al. 1999; Reich & Reich 1986; Haslam et al. 1981). The solid black line is the best fit CRB spectrum that corresponds to $T_{\mathrm{CRB}} \propto \nu^{-2.599}$ from Fixsen et al. (2011). Both T_{CRB} data points and the best fit spectrum were converted using $I_{\mathrm{CRB}}\,[\mathrm{Jy}] = 10^{26} \times 4\pi \times \frac{2\nu^2 k T_{\mathrm{CRB}}}{c^2}$, where k is the Boltzmann constant. Our models predict that the contribution of unresolved

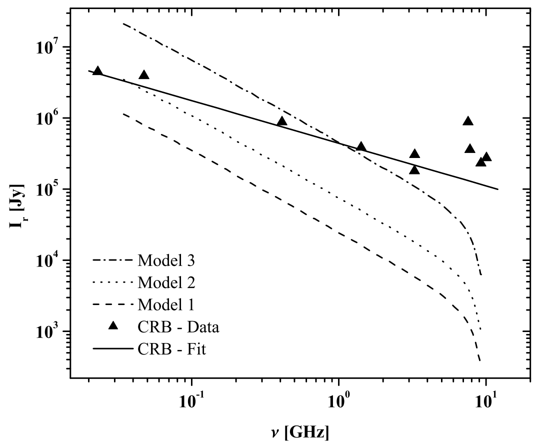

Figure 1: Radio intensity of unresolved galaxy clusters derived using Model 1 for the evolution of cosmic accretion shocks (dashed line), Model 2 (dotted line), Model 3 (dash dotted line). Data points correspond to the measured CRB on various frequencies, from Fixsen et al. (2011), and the solid black line corresponds to their best fit CRB spectrum. Both data points and best fit CRB spectrum were converted to $I_{\rm CRB}$ [Jy].

galaxy clusters can be high on low frequencies, although one has to keep in mind that synchrotron self-absorption will reduce the possible contribution at even lower frequencies (not included here, since these losses aren't visible in the observed Coma radio spectrum). On 5 GHz the contribution should be $\lesssim 2-35\%$ (upper limit range corresponds to the use of different accretion shock models). Finally, around 10 GHz the possible contribution sharply drops.

3. DISCUSSION AND CONCLUSION

The model presented in this paper shows that large scale accretion shocks can potentially be an important contributor to the CRB. We assume that the observed radio spectrum of the Coma cluster is entirely produced by accretion shock cosmic rays, which makes our predictions an upper limit. We also assume that the Coma cluster is a typical cluster, and that clusters similar to Coma produce the bulk of the radio waves coming from large-scale accretion shocks. Our upper limits show that clusters can contribute $\lesssim 2-35\%$ at 5 GHz, but after 10 GHz their contribution sharply drops.

The highest curve on Figure 1 overshoots the observed CRB at lower frequencies, which suggests that there should be a brake in the CRB spectrum at lower frequencies, which is not observed. This indicates that the Coma might not be a typical cluster, or that its entire radio emission cannot be coming from accretion shock cosmic rays. Brunetti et al. (2012) have tried to explain the Coma radio halo by synchrotron emission of secondary electrons produced via proton-proton collisions in the intra-cluster medium, or secondary electrons reaccelerated by MHD turbulence during cluster mergers. Also, not all clusters have the associated diffuse radio emission (Giovannini & Feretti 2000; Rudnick & Lemmerman 2009). The presence of the radio emission is often related to merging clusters and merger shocks (Fang & Linden 2016), which are not included in our model. Contribution can also be lower if most of the radio halos have much steeper spectral indices than Coma (Liang et al. 2000).

Better understanding of accretion shocks can come from linking cluster observations at different wavelengths. Of course, one has to keep in mind that the same processes inside galaxy clusters might not be responsible for the bulk of their emitted radiation at different wavelengths. After the recent possible detection of the Coma cluster in gamma rays (Xi et al. 2017; Keshet et al. 2017) and hopefully forthcoming detections of other galaxy clusters, it will be easier to distinguish between different cosmic-ray populations inside these objects, but also better understand their possible role in the production of measured background radiation at different wavelengths.

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OBSERVATIONS OF GAIA-FUN-TO FROM 2014 USING SERBIAN AND BULGARIAN TELESCOPES

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Abstract. The Gaia mission is the cornerstone of the European Space Agency – ESA. It is astrometrically, photometrically and spectroscopically surveying the full sky. The satellite was launched at the end of 2013 and the observations were started in July 2014. In October 2014, the Gaia Photometric Science Alerts published first alerts. Three years after that (October 2017), the Gaia Science Alerts is among the leading transient surveys in the world; about 3000 transients were discovered. The transients are: supernovae, cataclysmic variables, microlensing events, other rare phenomena. On the other hand, the installation of the first instrument, the 60 cm telescope, at the Serbian new site, the Astronomical Station Vidojevica (ASV) of Astronomical Observatory in Belgrade (AOB), was in 2010. Since mid-2016, we started to use the new 1.4 m ASV (via Belissima project). Also, two Bulgarian sites (Belogradchik and Rozhen), with 4 instruments, are of our interest. Using these 6 instruments, in line with "Serbian – Bulgarian mini-network telescopes", astronomical cooperation in our region (the head is G. Damljanović), we observed about 45 Gaia Alerts objects or Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO) until October 2017.

1. INTRODUCTION

After the Hipparcos (ESA 1997, van Leeuwen 2007), the Gaia is another big mission of the European Space Agency – ESA and the next step of the European pioneering high-accuracy astrometry. During its 5-year lifetime, it is going to repeatedly map all sky. As result, it will be a unique time-domain space survey. The first Gaia data release (DR1) was publicly available on September 14^{th}, 2016. That Gaia catalogue is an important step in the realisation of the Gaia reference frame in the future. The Gaia is doing revolution in astronomy, our understanding of the Milky Way galaxy, stellar physics and the Solar System bodies. The Gaia has got an interdisciplinary character, and Gaia-based results are useful for all the relevant scientific communities. This survey will be complete to $V = 20$ mag in astronomy and photometry (≈ 1 billion sources) and to 16 mag in spectroscopy (≈ 150 million ones).

Since October 2014 the Gaia Photometric Science Alerts started to publish alerts. Three years after that (until October 2017), about 3000 alerts were published: cataclysmic variables, supernovae, candidate microlensing events, etc. At 2013, we es-

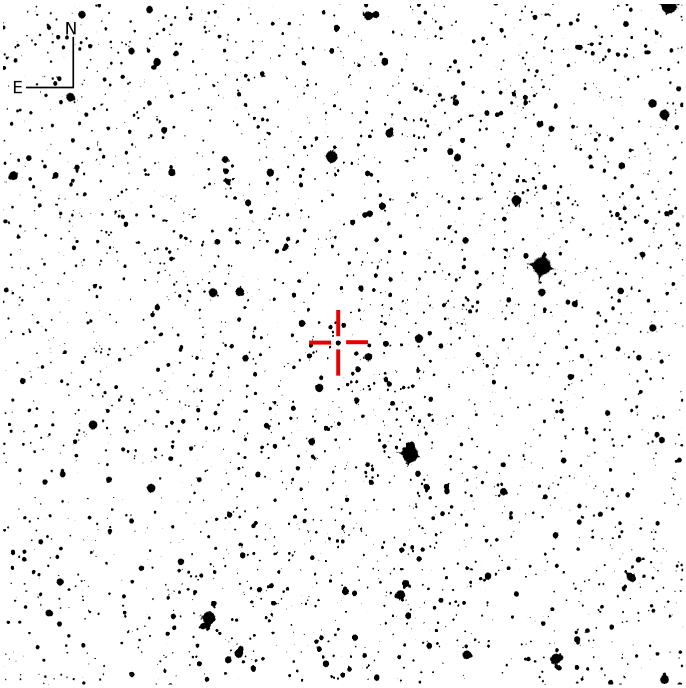

Figure 1: The Gaia16aye using the 1.4 m ASV telescope.

tablished the "Serbian – Bulgarian mini-network telescopes" (now, there are 6 instruments) to do observations of a few objects during the test phase (in 2013 and 2014) of the Gaia-Follow-Up Network for Transients Objects (Gaia-FUN-TO). And we continued the observations of Gaia Alerts (Gaia-FUN-TO) objects from the end of 2014. The main information about the instruments has been published (Damljanović et al. 2014), and is presented in Table 1 (for the 1.4 m ASV telescope). Our activities about Gaia-FUN-TO are in line with the bilateral Serbian-Bulgarian joint research projects "Observations of ICRF radio-sources visible in optical domain" (during three years period 2014-2016) and "Study of ICRF radio-sources and fast variable astronomical objects" (for the period 2017-2019); the head is G.Damljanović. Until October 2017, we observed about 45 Gaia Alerts objects (nearly 1700 CCD images).

2. OBSERVATIONS AND RESULTS

There are a few years, the astrometry with ground-based optical telescopes (of small and medium size) has become very actual part of astronomical investigation. The main reason is the Gaia satellite and the possibilities of ground-based instruments which are in accordance with the ESA mission: the astrometric monitoring of Gaia satellite, the photometry of Gaia Alerts objects, the link between radio and optical positions of quasars (QSOs), the realisation of a catalogue of QSOs, etc. Also, new sensitive CCD cameras are of importance for good results of ground-based astronomy.

In Table 1, there is the main information about the ASV 1.4 m telescope: the Ritchey-Chrétien $D = 140$ cm instrument at ASV site with its geographic coordinates

Table 1: The main information on the ASV 1.4 m telescope.

Site Telescope $D(cm)/F(cm)$	longitude - $\lambda(^o)$ latitude - $\varphi(^o)$ altitude - h (m)	CCD camera pixel array and scale $('')$ pixel size (μm) and field of view - FoV $(')$
ASV (AOB)	21.5	Apogee Alta U42
Ritchey-Chrétien	43.1	2048x2048, 0.24
140/1142	1150	13.5x13.5, 8.3x8.3

is presented in the left part, and the CCD camera Apogee Alta U42 (with its pixel size, pixel array, etc.) on the right side. The other Serbian – Bulgarian instruments, as well as another Serbian the 60 cm ASV telescope and Bulgarian ones (at Belogradchik and Rozhen sites) are presented in published paper (Damljanović et al. 2014).

In Fig. 1, the CCD image of Gaia16aye (Ayers Rock), after standard reduction, using the 1.4 m ASV telescope is presented. The object is marked with a cross. That image was done with the CCD Apogee Alta U42 at June 19^{th} 2017: R – filter, Exp.=40^s, benning=1x1. The coordinates of that object are $RA = 295.^o00474$ (19^h:40^m:$01.^s14$) and $Dec. = 30.^o13149$ (30^o:$07^{'}$:$53.^{''}36$); the Galactic ones are $64.^o99988$ and $3.^o83903$. The alerting date is August 8^{th} 2016. That object is the binary microlensing event and the first discovered towards the Galactic Plane. We observed the Gaia16aye 41 times (epochs): 18 times in 2016 and 23 times during 2017 (until 9^{th} October); about 490 CCD images. On 25^{th} October 2016 we did it using three instruments: a 2 m Rozhen, 50/70 cm Schmidt – camera (Rozhen) and 1.4 m ASV; it was good coordination of the "Serbian – Bulgarian mini-network telescopes". Also, in line with our cooperation with Dr. Alok Gupta (India) that object was observed for 5 nights (21^{st}-25^{th} November 2016) using the 1.31 m ARIES telescope (Aryabhatta Research Institute of observational sciencES, Manora Peak, Nainital) in the central Himalayan region: $\lambda = 79.^o7E$, $\varphi = 29.^o4N$, $h = 2420$ m. The CCD Andor DZ436 was used: 2048x2048 pixels, 13.5x13.5 μm, FoV=$18.^{'}5$x$18.^{'}5$, scale=$0.^{''}54$ per pixel. In Table 2, the photometry results of Gaia16aye (at June 19^{th} 2017) are done. The Jhonson – Cousins BVRI filters were available, and usually we did 3 images per filter.

We did about 1700 images for about 45 Gaia-FAN-TO objects during three years period (October 2014 – October 2017). After the standard bias, dark and flat-fielded corrections (also, hot/dead pixels were removed), the Astrometry.Net[1] and Source Extractor were applied. The output is supposed to be submitted to the Cambridge Photometric Calibration Server (CPCS)[2] for further calibration. In Table 2, the Modified Julian Date (MJD=JD-2400000.5) and magnitude of Gaia16aye (1^{st} and 2^{nd} columns) were calculated after the CPCS step, and we took them from the mentioned server after all steps of calibration and computation procedures. The CPCS matches instrumental magnitudes of all stars (3^{rd} column) in the CCD field with known data from other catalogue, as the APASS catalogue in Table 2 (4^{th} column).

As a result, during 2017 (until October) we observed about 15 Gaia-FUN-TO objects. Mostly, using the 60 cm ASV (9 objects): Gaia16aye (8 times), Gaia17bsu(1), Gaia17bsp(1), Gaia17bsr(1), Gaia17bts(4), Gaia17bxh(1), Gaia17chf(1), Gaia17cgo(1)

[1] http://astrometry.net
[2] http://www.ast.cam.ac.uk/ioa/wikis/gsawgwiki/index.php/Follow-up

Table 2: Photometry results of Gaia16aye, June 19^{th} 2017.

MJD	Magnitude (mag_{err})	n points	Catalogue
57924.00453	V=15.71 (0.01)	29	APASS
57924.00778	r=14.99 (0.01)	29	APASS
57924.00977	V=15.72 (0.01)	29	APASS
57924.01104	i=14.21 (0.01)	29	APASS
57924.00389	B=17.27 (0.04)	27	APASS
57924.01041	r=14.99 (0.01)	30	APASS
57924.00712	V=15.72 (0.01)	29	APASS
57924.00579	i=14.21 (0.01)	28	APASS
57924.00847	i=14.19 (0.01)	29	APASS
57924.00914	B=17.25 (0.04)	28	APASS
57924.00515	r=14.97 (0.01)	29	APASS
57924.00645	B=17.19 (0.05)	27	APASS

and Gaia17che(1). With the 1.4 m ASV, we did 5 objects: Gaia16aye(11), Gaia17arv(1), Gaia17asa(1), Gaia17asc(1) and Gaia17aru(1). With the 60 cm Belograchik, just Gaia17ade(2). Also, 1 object using the 2 m Rozhen (it is Gaia16aye(4)), but 5 objects with the Schmidt – camera 50/70 cm: Gaia17asc(1), Gaia17arv(1), Gaia17asa(1), Gaia17chf(1) and Gaia17bts(1). No data from the 60 cm Rozhen.

3. CONCLUSIONS

About 3000 alerts have been issued by the Gaia Science Alerts group during 3 years (until October 2017), and we observed about 45 objects (near 1700 CCD images) using 6 instruments of the "Serbian – Bulgarian mini-network telescopes". We could get the magnitudes of the Gaia Alerts objects with small errors (of the order of 0.01 mag, see in Table 2). Our paper (Campbell et al. 2015) about rare object, the eclipsing AM CVn Gaia14aae, was published and some of our results were presented at a few conferences. From mid-2016, we took part in the big campaign about the Gaia16aye.

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ON THE ASTRONOMICAL SYMBOLS ON ROMAN REPUBLICAN AND IMPERIAL COINS

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Abstract. We present examples of astronomical symbols, like stars, the Sun, the crescent Moon and comets on coins of Roman republic and Empire.

Various astronomical symbols like stars, crescent Moon, comets, personifications of constellations, meteorites... may be found on ancient roman coins and its appearance has been considered and described many times (see e.g. Faintich (2008), McIvor (2005), Rovithis-Livaniou and Rovithis (2014, 2015a,b)). Here we present several examples.

Figure 1: Silver denarius of Julius Caesar struck by moneyer P. Sepullius Macer in Rome in January and february 44 BC, the year when Caesar has been murdered. Obverse: Wreathed head of Caesar right, behind, eight-rayed star. Inscription: CAESAR IMP. Reverse: Venus, protectrice and mythic ancestor of Caesar, standing left, holding Victory and sceptre resting on star. Inscription: P SEPVLLIVS MACER. C(Cohen) 41. Sydenham 1071. Portraits of living people did not exist on Roman republican coins until Julius Caesar's portrait which appeared on denarii in january 44 BC. This was an additional reason for his assassination on the Ides of March (15 March).

Figure 2: Four months after the assassination of Julius Caesar in July 44 BC, during the traditional funeral games (Ludi Victoriae Caesaris) for him, a bright comet (C/-43 K1) appeared. Octavian supported belief of Romans that this was Caesar's soul ascending the heavens and a divine manifestation of his apotheosis. The comet is known as Sidus Iulium (”Julian Star”). According to Suetonius, when games started, “a comet shone for seven successive days, rising about the eleventh hour, and was believed to be the soul of Caesar.” Octavian build a temple of Divus Iulius, with a colossal statue of Caesar surmounted by comet. Silver denarius struck for Octavian 19 - 18 B.C. in Spain (Caesareaugusta (Zaragoza)?). Obverse: Head of Augustus with oak wreath (corona civica - During the Roman Republic this was a decoration “for Roman citizens who saved the lives of fellow citizens by slaying an enemy on a spot held by the enemy that same day”), left. Inscription: CAESAR AVGVSTVS. Reverse: Comet Sidus Iulium of eight rays, a central dot and flaming tail. Inscription: DIVVS - IVLIVS (horizontal). RIC I 37a, BMCRE I 323.

Figure 3: Silver denarius struck in Rome in 17 BC by the moneyer M. Sanquinius, for Octavian Augustus, commemorating Julius Caesar,in connection with Ludi Saeculares (Games after a period of 100 or 110 years, revived in 17 BC by Octavian) held in 17 B.C. Obverse: Bare head of Augustus to right. Inscription: AVGVSTVS DIVI F (Augustus son of the God). Reverse: Laureate head of Julius Caesarto right, Above comet showing four rays and tail (Rovithis-Livaniu and Rovithis (2015a - Fig. 1b) write that this is a star but in Fig. is clearly represented a comet with tail). Inscription: M SANQVI NIVS III VIR. RIC I 338, BMCRE 71.

Figure 4: Silver denarius struck 128 in Rome by Hadrian (24. January 76 - 10. July 138, Emperor 117-138). Obverse: Laureate head of Hadrian right. Inscription: HADRIANVS AVGVSTVS. Reverse: Star within and above crescent, pellet below crescent Moon. Inscription: COS III, which means that he has the third consulship. RSC II 460a, RIC II 200.

Figure 5: Silver denarius struck late 125 - early 128 in Rome by Hadrian. Obverse: Laureate head of Hadrian right. Inscription: HADRIANVS AVGVSTVS. Reverse: Seven stars within and above crescent Moon. Inscription: COS III. RSC II 465, RIC II 202(c), BMCRE III 463.

Figure 6: In the year 215, Caracalla (4. IV 188 - 8. IV 217, Emperor 211-217) introduced a new coin, which was considered to have been worth two denars, but by weight and quantity of silver, it corresponded to one denar and half. It is not known how it was then called, and today it is called antoninianus in the numismatics. It is denoted by a radiated crown, symbol of the Sun on the head of the ruler, and the bust of emperess was on a crescent, because she “shines” by the reflected light of her husband, like the Moon. Left: Antoninianus minted 215-217 in Rome. 216 AD. Draped and cuirassed bust of Caracalla with radiated crown, right. Inscription: ANTONINVS PIVS AVG GERM. RIC IVa 312c, C 612. Right: Antoninianus of Julia Domna (c. 180 - spring 217) mother of Caracalla, minted in Rome 215-217. Her diademed and draped bust right on a crescent. Inscription: IVLIA PIA FELIX AVG (Emperess Julia pious and happy). RIC IVa 388 (Caracalla), C 211. Both coins are from the former collection of Sergije Dimitrijević.

Figur 7: Double majorina, struck in Sirmium (Sremska Mitrovica) within the period summer 361 - 26 June 363 by Julian Apostate (331 or 332 - 26/27 June 363, Emperor (360 usurper) 361-363). Obverse: Pearl-diademed, draped, and cuirassed bust of Julian right. Inscription: DN FL CL IVLI-ANVS P F AVG (Dominus noster Flavius Claudius Iulianus pius felix Augustus). Reverse: Bull standing right; two stars above. Inscription: SECVRITAS REIPVB (security of the state). Below mark of the Sirmium mint: star ASIRM wreath. A denote the first of two officinas. RIC VIII 106 (Sirmium). Coin from the former collection of Sergije Dimitrijević. The usual interpretation is that this is egyptian god Apis and two stars are symbolizing its divine nature. Other hypothesis, because always are present two stars, is by Marshall Faintich (2008 and http://www.faintich.net/primer.htm), who noticed that "on 4 May 360, Venus joined Mars to form a single star between the horns of Taurus... Two weeks earlier, Mars was between the horns, and Venus rested on the shoulder of the bull". Since in the spring 360. Julian has been proclamed Augustus by his soldiers, as usurper, obviously for him this was a very important celestial sign. Also, it is worth to mention that in Taurus constellation there are two impresive star clusters Hyades and Pleiades.

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THE STARK-B DATABASE, A NODE OF VIRTUAL ATOMIC AND MOLECULAR DATA CENTER (VAMDC)

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Abstract. STARK-B database (http://stark-b.obspm.fr), a collaborative project between the "Laboratoire d'Étude du Rayonnement et de la matière en Astrophysique" (LERMA) of the Paris Observatory and CNRS, and the Astronomical Observatory of Belgrade (AOB), is described as it was on 1. August 2017 . Database contains widths and shifts of isolated lines of atoms and ions due to electron and ion impacts (Stark broadening parameters) determined theoretically in more than 150 papers by Dimitrijević, Sahal-Bréchot, and colleagues. STARK-B enters also in Virtual Atomic and Molecular Data Center (VAMDC http://www.vamdc.eu).

1. INTRODUCTION

Stark broadening of spectral lines is due to perturbation of emitting or absorbing atom or ion by interactions with surrounding charged particles. The corresponding Stark broadening parameters, line width and shift, are needed for different applications in Astrophysics (e.g. for stellar atmospheres modelling, analyzis and synthesis of stellar spectra, radiative transfer calculations, abundance determination...), Physics (e.g. laboratory plasma diagnostics, laser produced plasmas, inertial fusion plasmas), and for industrial plasmas (discharge lighting, laser welding and piercing of metals...).

More than thirty five years, two of us (MSD-SSB) were calculated at a large scale Stark broadening parameters using the semiclassical perturbation theory and the corresponding computer code (Sahal-Bréchot 1969a, 1969b, see the review of theory and updates in Sahal-Bréchot et al. 2014). During this period the obtained results were published in more than 150 papers so that the need of creation of an on-line database was obvious. So, the creation of a database BELDATA has been initiated in the Astronomical Observatory of Belgrade (AOB), and it was available on-line. A history of BELDATA is presented in detail in Popović et al. (1999a,b), Milovanović et al. (2000a,b), Dimitrijević et al. (2003) and Dimitrijević and Popović (2006). Consequently, we continued this work in Paris as a collaborative project between AOB and LERMA which led to the present database - STARK-B, which is on-line in

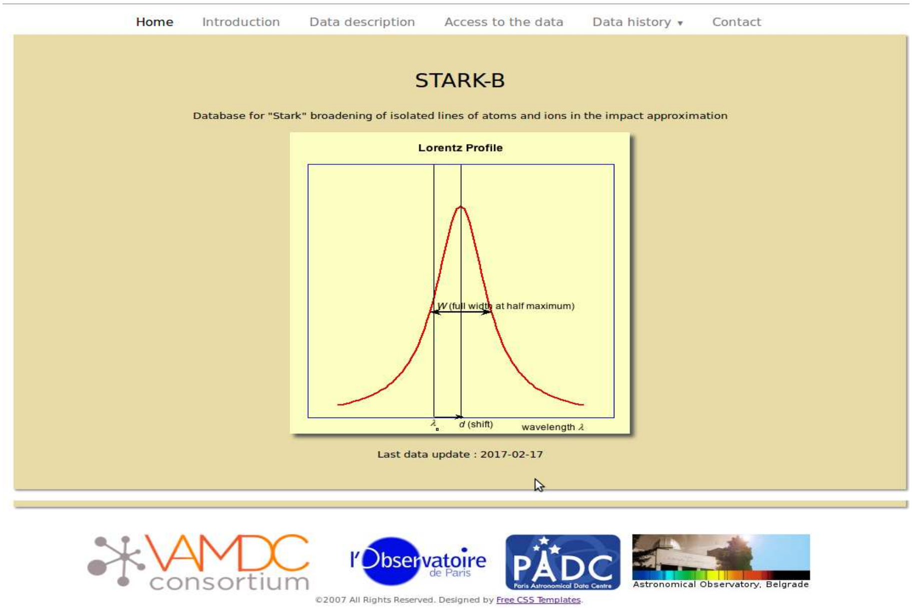

Figure 1: Home page of STARK-B.

free access, since the end of 2008 (http://stark-b.obspm.fr Sahal-Brchot et al. 2015, 2017).We note also, that due to STARK-B database authors of this article entered in the team of the FP7 European project "Research Infrastructures" for creation of the VAMDC (Virtual Atomic and Molecular Data Centre). This project started in the summer of 2009 for 3.5 years and now, VAMDC is an interoperable e-infrastructure for search and exchange of atomic and molecular data (Dubernet et al. 2011, 2016 - http://www.vamdc.eu, and http://portal.vamdc.eu).

In this contribution, the STARK-B database is presented and described.

2. STARK-B DATABASE

Starting from the homepage of STARK-B database, the menu offers: "Introduction", "Data Description", "Access to the Data", "Data history" and "Contact". In "Introduction", after a brief discussion of purpose of database, are explained the impact-, isolated line-, and semiclassical perturbation (SCP) - approximations and the modified semiempirical (MSE) method. "Data Description" offers a detailed description of the tabulated data. "Access to the Data" is a graphical interface which enables to click on the choosen atom in the Mendeleev periodic table when appear the available ionization stages. Stark broadening parameters are present only for elements in yellow cells, with characters written by boldface. After choosing the element, ionization stage, the colliding perturber(s), the perturber density, the transition(s) (or a domain of wavelegths) and the plasma temperature(s), a table with the Stark full widths at half maximum of intensity and shifts appears. On the beginning is an instruction how to cite the STARK-B, and the bibliographic references for the data in the Table, linked to the publications via the SAO/NASA ADS Physics Abstract Ser-

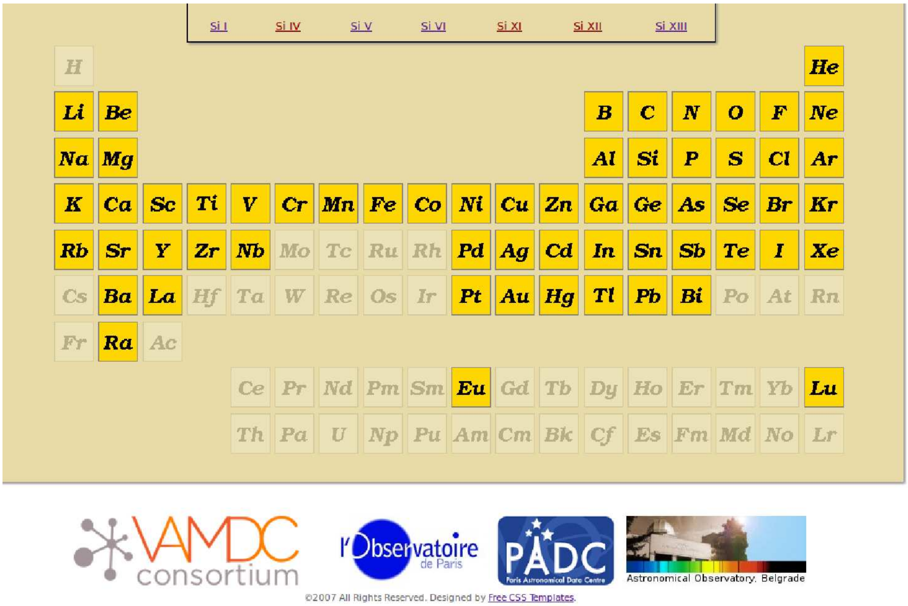

Figure 2: Access to the data: the graphical interface.The status on 1. 08. 2017. After click on an element, available ionisation stages appear, like in this examplee for Si.

vice (http://www.adsabs.harvard.edu/) and/or within DOI. Besides the html table, Stark broadening parameters can be extracted as an ASCII text or in XML format for Virtual Observatories (VOTable). Moreover, under each table with Stark broadening parameters, a table with coefficients a0 , a1, a2 and b0 , b1, b2, is added, in order to enable fitting with the temperature with formula based on a least-square method derived in Sahal-Bréchot et al. (2011).

Actually (1st of August 2017) in the STARK-B are implemented Stark broadening parameters obtained by using the SCP method for 79 transitions of He, 61 Li, 29 Li II, 19 Be, 30 Be II, 27 Be III, 1 B II, 12 B III, 157 B IV, 148 C II, 1 C III, 90 C IV, 25 C V, 1 N, 7 N II, 2 N III, 1 N IV, 30 N V, 4 O I, 12 O II, 5 O III, 5 O IV, 19 O V, 30 O VI, 14 O VII, 8 F I, 5 F II, 5 F III, 2 F V, 2 F VI, 10 F VII, 30 Ne I, 22 Ne II, 5 Ne III, 2 Ne IV, 26 Ne V, 20 Ne VIII, 62 Na, 8 Na IX, 57 Na X, 270 Mg, 66 Mg II, 18 Mg XI, 25 Al, 23 Al III, 7 Al XI, 3 Si, 19 Si II, 39 Si IV, 16 Si V, 15 Si VI, 4 Si XI, 9 Si XII, 61 Si XIII, 114 P IV, 51 P V, 6 S III, 1 S IV, 34 S V, 21 S VI,2 Cl, 10 Cl VII, 18 Ar, 2 Ar II, 9 Ar VIII, 32 Ar III, 51 K, 4 K VIII, 30 K IX, 189 Ca I, 28 Ca II, 8 Ca V, 4 Ca IX, 48 Ca X, 10 Sc III, 4 Sc X, 10 Sc XI,10 Ti IV, 4 Ti XI, 27 Ti XII, 26 V V, 33 V XIII, 9 Cr I, 7 Cr II, 6 Mn II, 3 Fe II, 2 Ni II, 9 Cu I, 32 Zn, 18 Ga, 11 Ge, 3 Ge IV, 16 Se, 4 Br, 11 Kr, 1 Kr II, 6 Kr VIII, 24 Rb, 33 Sr, 32 Y III, 3 Pd, 48 Ag, 70 Cd, 1 Cd II, 18 In II, 20 In III,1 Sn III, 4 Te, 4 I, 4 Xe VI, 14 Ba, 64 Ba II, 6 Au, 7 Hg II, 2 Tl III and 2 Pb IV, in total 2929 transitions.

In STARK-B are also implemented Stark broadening data obtained with the Modified semiempirical method (MSE) (Dimitrijević and Konjević 1980; Dimitrijević and Kršljanin 1986, Dimitrijević and Popović 2001). This method is suitable when the needed atomic data set is not sufficiently complete to perform an adequate semiclassical perturbation calculation. Stark line widths and in some cases also shifts of spectral lines of the following emitters have been implemented up to 1 August 2017 :

Ag II, Al III, Al V, Ar II, Ar III, Ar IV, As II, As III, Au II, B III, B IV, Ba II, Be III, Bi II, Bi III, Br II, C III, C IV, C V, Ca II, Cd II, Cl III, Cl IV, Cl VI, Co II, Cu III, Cu IV, Eu II, Eu III, F III, F V, F VI, Fe II, Ga II, Ga III, Ge III, Ge IV, I II, Kr II, Kr III, La II, La III, Mg II, Mg III, Mg IV, Mn II, N II, N III, N IV, N VI, Na III, Na VI, Nb III, Nd II, Ne III, Ne IV, Ne V, Ne VI,Ne VII, Ne VIII, O II, O III, O IV, O V, P III, P IV, P VI, Pt II, Ra II, S II, S III, S IV, Sb II, Sc II, Se III, Si II, Si III, Si IV, Si V, Si VI, Si XI, Sn III, Sr II, Sr III, Ti II, Ti III, V II, V III, V IV, Xe II, Y II, Zn II, Zn III, Zr II and Zr III.

Under the option "Data history" there are "New datasets" and "Updated datasets" with the description of newly added data with the date of importation as well as the eventual date of the first importation and the importation of the modification for revised data.

At the end, for enquiries or user support, is option "Contact" enabling to send an e-mail with questions.

STARK-B database is devoted to modelling and spectroscopic diagnostics of stellar atmospheres and envelopes, but the implemented data are also of interest for laboratory plasmas, fusion plasma, laser equipment design and technological plasmas investigations and will be useful for a number of different topics not only in astrophysics, but also in physics and technology.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 289 - 291 *Poster*

RADIO ODJEK DELTA AURIGIDS U PERIODU 2006-2016 GODINE

Ž. DISTERLO
DMI-Bor

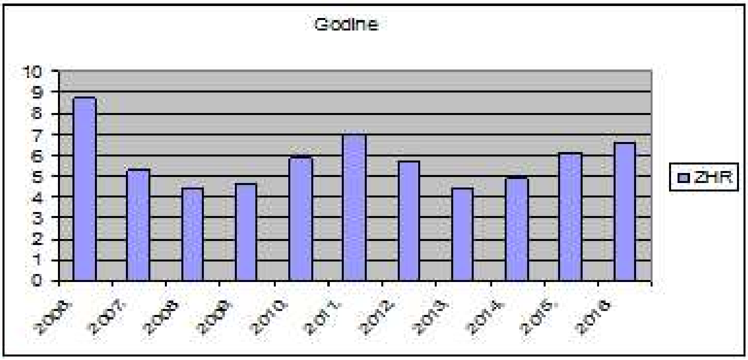
Delta Aurigids su prvi put otkriveni 50-tih godina XIX veka, da bi prva ozbiljnija posmatranja i zapažanja krenula 1979.godine. Već 1981. godine grupa ruskih i američkih istraživača zaključuju da je srednja orbita meteorskog potoka retrogradna sa periodom od 115 godina. Radijant roja prikazan je na slici 1. (95.7^o, dec. +52.5^o).

Radio posmatranje Delta Aurigids u radio-astronomskom Klubu-DMI, prati se od 2004. godine, matična kometa je C/1911 N1 čiji period nije tačno utvrdjen (1800.-200.). U periodu od 2006. g. - 2016.g. ukazuje na asimetričnost, tj. broj refleksija posle maksimuma opada znatno brže, nego što se povećava prema maksimumu. Sam maksimum je veoma brz, i kratkotrajan prema broju i dužini odjeka. Pretpostavljam da je to posledica krupnijih meteora, koji duže gore na većim visinama. Takodje je znatno veća i elevacija antene radioteleskopskopa (>30^o). Posmatranje je vršeno na frekvenciji (148 MHz), što nam ukazuje, da Delta Aurigidi pripadaju grupi brzih meteora, kao i velikog elevacionog ugla, i dužine radio-odjeka. Tehničke podatke radioteleskopskopa prikazuje tabela 3. Delta Aurigidi obično daju mali broj meteora na sat, što je razlog da su praćeni kontinuirano više godina, kako bi se donekle ustanovila njihova aktivnost, što ih još uvek svrstava u sporadične meteore. Godine povećanog broja meteora u jednom satu prikazuje tabela 1. a broj meteora u periodu aktivnosti tabela 2.

Tabela 1.

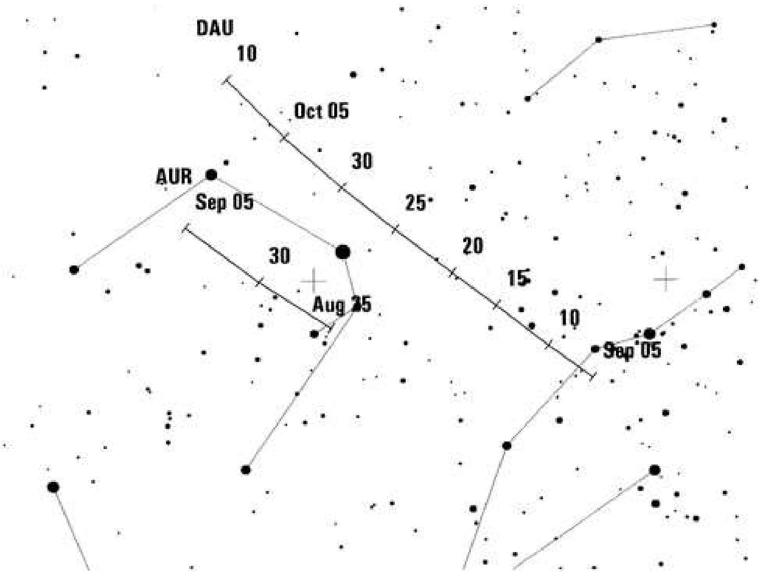
Godina	Vreme/h	ZHR	Krupni meteori
2006	21-22	133	41
2011	15-16	87	23
2014	23-24	70	20
2015	22-23	76	12

Tabela 2.



Delta-Aurigids

Aktivnost	Maksimum	ZHR	Radiant	Brzina km/s
5.9-10.10	8.9	6	$+47^o$	64

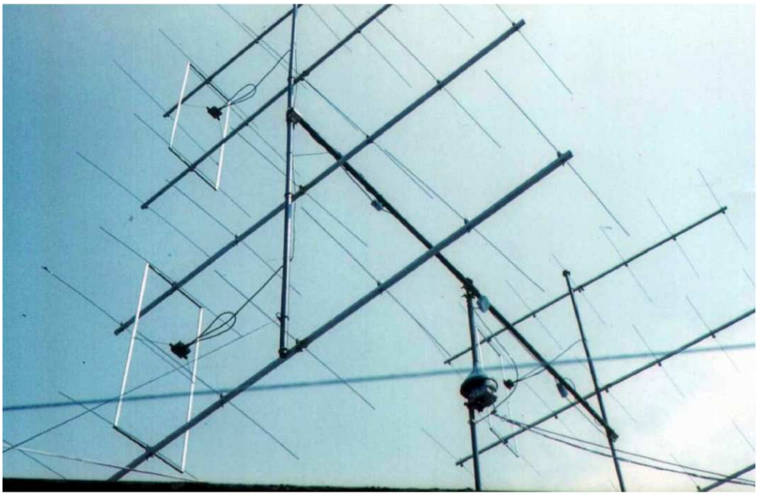


Slika 1: Radiant-pozicija i drift za alpha- i delta-Aurigids.

Tehnički podaci radioteleskopske-sonde

Tabela 3.

Prijemnik	Sensitivity	Selectivity	Ant.	UgaoH/V	AZ/EL	Ant/dB	LONG/LAT	Softver
Japan,FT221R	0,5µV/10dB S/N	2,4kHz/6dB	64 el.Yagi	45º/70º	360º/90º	18,5	44º03´45´´ 22º02´56´´	HROFFT



Slika 2: Radioteleskopska-antena YAGI (64 elementa).

Slika 3: Radioastronomski prijemnici: 30MHz, 150MHz, 12GHz.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 293 - 296 *Poster*

MONITORING OF QUASARS IMPORTANT FOR THE LINK BETWEEN ICRF AND THE FUTURE GAIA CRF IN V AND R BAND

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Abstract. The Gaia mission of the European Space Agency (ESA) was launched at the end of 2013. It should provide a catalog of about 600000 quasars (QSOs) and nearly billion stars. Some of these QSOs could be the basis of a new optical reference frame. The current International Celestial Reference Frame (ICRF) is based on the VLBI observations of QSOs at radio wavelengths, but Gaia is doing in optical domain. It is necessary to observe a set of common QSOs at both optical and radio wavelengths to link the future Gaia Celestial Reference Frame - Gaia CRF with the ICRF. Only 10% of the ICRF sources (nearly 70 sources) are suitable to establish that link, and because of that other 47 sources were added which have high astrometric quality, as required for the alignment. Our observations of those 47 sources have been carried out since July 2016 using three telescopes: two of them with D=0.6 m and D=1.4 m are at the Serbian new site the Astronomical Station Vidojevica – ASV, and the third instrument with D=2 m is at the Rozhen Observatory (Bulgaria). In this paper, the main steps of our observations, reduction, and some results (as light curves in V and R bands) of two objects are presented.

1. INTRODUCTION

The European astrometric space mission Gaia was launched on December 2013. The first Gaia Data Release (Gaia DR1) was made publicly available on September 2016 (Mignard et al. 2016, Liu et al. 2017). One of the most important results of the Gaia mission will be a new highly-accurate optical Gaia Celestial Reference Frame (GCRF) at the same level of accuracy as the VLBI International Celestial Reference Frame (ICRF). Because of that, the link between the ICRF and GCRF should be realized at a similar level of accuracy. The basic idea to tie the Gaia catalog to the ICRF is using Gaia observations of compact extragalactic ICRF objects, visible in optical domain, which have accurate radio positions. About 90% of the ICRF sources are not suitable to establish this link. Because of that the remaining 10% of the ICRF sources have been extended by 47 ones, mostly quasars – QSOs (out of the ICRF list), which have high astrometric quality (Bourda et al. 2011).

One of the properties of QSOs is their flux variability, which may have multiple origins: variation in the accretion rate, jet instabilities, gravitational microlensing, etc. There is a correlation between the flux variability and photocentre motion in QSOs (Popović et al. 2012). On the other hand, the stability of QSO photocenter is of importance during optical observations. The QSOs with stable flux should be the base for the link between ICRF and Gaia CRF. Thus, the monitoring of magnitude stability of QSOs over longer period of time is necessary to determine stable QSOs as much as possible and eliminate objects with variable photocenter.

2. OBSERVATIONS AND RESULTS

Our observations of 47 sources have been carried out since July 2016 using two telescopes at the Astronomical Station Vidojevica of the Astronomical Observatory of Belgrade and one at the Rozhen Observatory. The characteristics of the 1.4 m ASV telescope (longitude $\lambda = 21.5^o E$, latitude $\varphi = 43.1^o N$, altitude h=1150 m) and CCD camera are presented in Table 1, and for the other instruments are in paper (Damljanović et al. 2014). The Johnson-Cousins BVRI filters were available.

Table 1: The main information about the 1.4 m telescope and used CCD camera.

Site ASV	CCD camera Apogee Alta U42
Telescope Ritchey-Chrétien	pixel array 2048x2048, scale 0.″24
D/F = 140/1142 cm	pixel size 13.5x13.5μm and $FoV = 8.'3\text{x}8.'3$

The standard bias, dark and flat-fielded corrections (plus hot/dead pixels, cosmic rays, etc.) are done using IRAF scripting language. The magnitudes of objects were calculated using differential photometry with MaxIm DL software.

We presented two examples, for objects 1556+335 and 1741+597, and chose suitable comparison stars from the Sloan Digital Sky Survey Data Release 14 (SDSS DR14) catalogue following several criteria: not too far from the objects, not so bright or faint stars in accordance with object (with g, r and i magnitudes in the range of 14.5 − 19.5), not very blue or red stars (in the ranges $0.08 < (r - i) < 0.5$ and $0.2 < (g - r) < 1.4$). We transformed the SDSS point-spread function *ugriz* magnitudes of the comparison stars into the Johnson-Cousins V and R ones (Chonis & Gaskell 2008) using equations:

$$V = g - (0.587 \pm 0.022)(g - r) - (0.011 \pm 0.013) \tag{1}$$

$$R = r - (0.272 \pm 0.092)(r - i) - (0.159 \pm 0.022) \tag{2}$$

Tables 2 shows the number of each comparison star, its equatorial coordinates, V$\pm\sigma_V$ and R$\pm\sigma_R$ magnitudes with suitable errors obtained from equations (1) and (2) for objects 1556+335 and 1741+597.

Table 2: Comparison stars and their V and R magnitudes with errors for objects 1556+335 and 1741+597.

Object	No.	$\alpha_{J2000.0}[^o]$	$\delta_{J2000.0}[^o]$	V$\pm\sigma_V$[mag]	R$\pm\sigma_R$[mag]
1556+335					
	2	239.719511	33.39111	17.336 ±0.066	16.850 ±0.073
	3	239.690368	33.40961	16.381 ±0.057	16.095 ±0.056
	5	239.767998	33.38780	16.271 ±0.063	15.916 ±0.060
	6	239.745631	33.39005	16.198 ±0.064	15.825 ±0.061
	7	239.743191	33.37371	15.552 ±0.063	15.188 ±0.060
	8	239.733993	33.37219	15.743 ±0.082	14.897 ±0.104
1741+597					
	2	265.623308	59.75173	15.565 ±0.062	15.204 ±0.063
	3	265.570839	59.75384	16.673 ±0.063	16.314 ±0.062
	4	265.684139	59.76858	16.376 ±0.073	15.795 ±0.073
	5	265.614598	59.79544	16.154 ±0.067	15.704 ±0.064
	6	265.682834	59.71898	16.126 ±0.082	15.684 ±0.085
	7	265.597679	59.71684	16.633 ±0.085	16.124 ±0.091

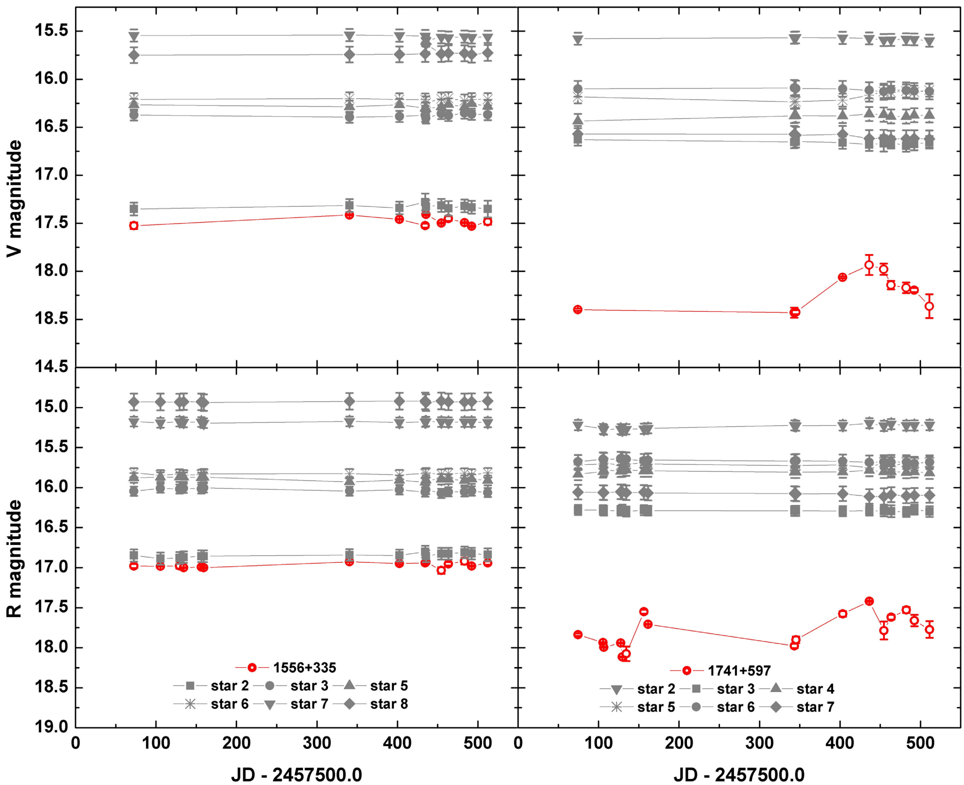

Figure 1: The light curves of V and R magnitudes of the objects 1556+335 (left) and 1741+597 (right) with light curves of the comparison stars, since July 2016 until September 2017.

Calculated V and R magnitudes were input values as the analysis tool Photometry in MaxIm DL software. With that tool, useful for the differential photometry, the magnitudes of selected objects and their comparison stars were calculated for each epoch of observation. Usually, we obtained two CCD images per filter, and calculated V and R magnitudes are average values with suitable standard deviation (σ_{cV}, σ_{cR}). The obtained magnitudes of comparison stars should be in good agreement with the input ones. Here, it was the case. The light curves of objects 1556+335 and 1741+597 together with their comparison stars are shown in Fig. . The error bars of V represent the root sum squared of input error σ_V and st.dev. σ_{cV}. The same is for R magnitude.

3. CONCLUSION

For the period mid-2016 - Sept. 2017, it seems that comparison stars have no changes in the brightness. The same could be said for object 1556+335. Unlike them object 1741+597 has had some changes. We plan to check the V and R magnitudes of the comparison stars and objects using a suitable statistical criterion. After that, our next step is to examine magnitude stability of stars and objects, and quasiperiodicity of object 1741+597. The mentioned procedure will be applied to the other objects.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 297 - 301 *Poster*

ACTIVE SETI IN SOL NEIGHBORHOOD

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Abstract. In the search for habitable planets, the ultimate aspiration is finding an extraterrestrial technical civilization. Already, more than a half of century is spent on for an active search for extraterrestrial civilizations. We shall propose a scientifically based METI(Messaging to Extra-Terrestrial Intelligence) program.

1. INTRODUCTION

The projects for sending messages realized so far (Zaitsev 2012) are non-compatible with the scientific search for extraterrestrial civilizations. The targets are not well selected and the messages are not easy to decipher, and there are no possible reply listening programs. The biggest problem is that these messages were sent for very short time period contrary to the expectation (Cocconi & Morrison 1959). The longest emitted message was sent during only 960 minutes in four sesions (Zaitsev 2012). It is hard to expect that anyone received our radio emission. Therefore, we shall present a proposal for the active SETI (Search for Extra-Terrestrial Intelligence) program. We have answered all questions from (Zaitsev 2011).

2. WHERE TO MAKE EMISSION?

More than 50 years have passed since the first article concerning the search for the extraterrestrial civilizations was published (Cocconi & Morrison 1959). We are in line with the first article. We propose sending messages to stellar systems around Solar with at least one star in the spectral range from K5V up to F6V (from 0.7 Solar masses up to 1.2 Solar masses) up to 50 ly, similar to (Soderblom 1986), and receiving signals from them. Star systems should be older than 1 Gyr with no spectroscopic or close orbitting binaries. We have a hundred and ten potential targets. This task is time-consuming; we need to wait at least one century for a reply from possible civilization on an outermost stellar system and to occupy at least two generations of radio astronomers, that is why we put our cut-off limit at this distance. More distant stars need more time for a possible reply. Receiving radio antennas can be placed around existing big radio telescopes where there is enough skilled manpower and good locations for radio antennas.

All stellar systems can be rated as to whether they are good, fair or poor candidates for the search for habitable planets. Such ratings will assist in ensuring our messaging are concentrated on the correct choice of targets. Beside yellow dwarfs we choose yellow-white dwarfs with a lifetime comparable to Earth's and we choose orange dwarfs with masses close to yellow dwarfs, with a smaller probability that a planet in Goldilocks zone is tidally locked. Red dwarfs, although the most promising for the habitable planets (Dressing & Charbonneau 2015, Kopparapu 2013) due to their abundance and longevity, should not be our targets because there is little chance that they can produce exoplanets with highly technological civilization. The problem of retaining water on the surface can prevent life formation on planets around M-dwarfs. During flares, water in the atmosphere can be ionized and solar wind can take oxygen from planet (Collinson et al. 2016, Atri 2017, Airapetian et al. 2017). The new exoplanets' atmosphere dynamics modelling (Carone et al. 2015), shows that even tidal locked exoplanets can be habitable. The problem with irradiation without permanent blue and ultraviolet components of spectra from a star is much bigger. The transition from prokaryotes toward photosynthesizing bacteria could be hampered or it is extremely unlikely. Photosynthetic organisms' productivity would be limited to less than ten percent on that on the Earth depending on star's flares activity (Kiang et al. 2007) combined with low water supply. While we can not rule out the existence of life on planets around the M-dwarf stars (Shields et al. 2016), we can almost certainly assume that there have not been any major changes in the atmosphere. Around M-dwarfs, Earth-mass planets with comparable water contents show up 10-100 times less frequently than around G dwarfs (Feng & Shigeru 2015). Therefore transformation of the planetary atmosphere which happened on Earth is unlikely on dry tidally locked planets around M-dwarfs.

3. WHAT IS SCHEDULE FOR TRANSMISSION?

With one emission system per hemisphere, we will have around half an hour a day per stellar target for emission of our message. Receiving a reply message from the targeted stars can be problematic. It is hard to find universal time synchronization of messaging in deep space. We have experience from previous SETI that it is necessary to recheck potential candidates (Horowitz & Sagan 1993). It would be good to have at least two receiving antennas per hemisphere to enhance our chances to receive a reply from targets. Receiving systems as the Allen Telescope array (Tarter et al. 2011) are now feasible. This part of the project will benefit if international financing remains stable. Other sky surveys besides of METI could be performed, as well as SETI for all stars up to one hundred light years distance.

4. THE PARAMETERS OF OUR EMITTED SIGNAL

Judging by our extraterrestrial search programs that applied modulation, the emitted signal should have a clear spectral signature, allowing decoding with minimal ambiguity, by the parallel spectral analyzers. We need to make emission with a narrow band frequency modulation between five centimeters and twenty-one centimeter wavelength and to keep it as simple as possible, with circular polarization. Changing the polarization of signals can reveal intelligent life but we should keep our emission as simple as possible at least till the first contact. Emission power should be comparable with present 70-100 m diameter dish antennas around 500 kW (Zaitsev 2011) or with recently proposed transmitter sistems (Scheffer 2005). The cost of required emitting and receiving radio astronomy systems should not be larger than several billions of dollars. Funding should come from international cooperation by donation of national governments. After detection of exoplanets, the time of stigma against radio astronomers searching for extraterrestrial civilizations or life is hopefully over now.

5. WHAT TO SEND?

What is the optimum structure for transmitted messages? Message emitted toward stars should be made from three parts. The first part of the message should be digitally modulated signal with a varying length of signal and pause. The second part is textual part of the message and third should be the visual one in form of pictograms. It is more or less in line with the proposal for interstellar radio messaging of Dr. Alexander Zaitsev with less artistic details (Zaitsev 2011). More complicated messages can be applied later in case that we establish contact. Once a day emission can reveal to extraterrestrial civilizations our planet's rotational period.

6. IS IT SAFE TO MESSAGE TO AN EXTRATERRESTRIAL CIVILIZATION?

What are the dangers of pursuing METI? Despite we do not have much activity in sending messages to the stars we have growing concern about it. Recently, opponents of METI strongly raised voice against messaging to the extraterrestrial civilizations. However, the concerns do not seem justified. If such civilization is able to bring all technical equipment needed to conquer our civilization, from an enormous distance, they probably already have superior detecting technique in all spectral ranges and, for example, they can detect our leaked radio signals without big problems. Moreover, the METI opponents' scenario leads to living in permanent fear with or without messaging, since potential extraterrestrial civilization is much more powerful than ours. We did not hide our radio emission presence in space in the last half century. The radio emission of powerful military radars in the USA and Russia formed the basis of their national ballistic missile warning systems, continuously working since the sixties of the last century. Although there is a big difference between narrow-angle targeted and broad angle dissipated radiation this should not make the big problem to civilization more advanced than ours. The big question is if someone receives our early warning radar signals will they really understand their meaning, but it is sure they will recognize their artificial origin. We also searched for asteroids, comets, and planets with emission from big radio antennas, but in this process, we did not aim at any star (Zaitsev 2011). With our active and targeted signaling, we show that we want to make a contact and initiate communication.

Comparing interstellar voyage with sending three caravels to India is not possible; the scale of economy is different. In the first case the econoomy scale is on the magnitude of one state, while in the second it might require to mobilize the resources and expertize of the entire planet. Interstellar travel is not simple and there will be no immense movements of aliens to our planet. Interstellar space is far from being empty (Crawford 2009) and we actually do not know how to avoid radiation hazards during a relativistic interstellar flight (Semyon 2009). It is just a speculation that potential extraterrestrial civilization has such knowledge. We can only theoretically send one-way probe spaceships with low v/c ratio (Hoanget al. 2016, Obousy et al. 2011, Long et al. 2011). While sending a message is usually strongly opposed, there is no opposition to randomly spraying nearby stellar systems with probes. We did not observe any manifestation of something like an exotic wormhole in our vicinity either. We can conclude that fear from extraterrestrials cannot be based on physical reality.

7. PROSPECTS FOR INTERSTELLAR RADIO MESSAGES

It is not our intention to spread overly optimistic veiw on this subject. We did not extrapolate our signals to the thousands of light years away, we just want to search in our neighborhood where there is some possibility to make meaningful bidirectional communication with unavoidable big delay. Otherwise, we can wait to build a bigger antenna and to receive dissipated radiation from possible technological civilization but this signals will be deteriorated. If we never send the message, the chance of success is close to zero. Our chances to find an advanced extraterrestrial civilization in our neighborhood are extremely slim but this should not stop our active search for them. Even if we succeed exchange of information will be difficult. Since it is hard to expect any exchange of the material with extraterrestrial civilisation, the fear of our sudden collapse after the contact of the civilisations is not justified.

Apart from the above proposition for new section title the section could benefit from a bit of discussion on conducting a SETI data analysis on present and future large data sets from big surveys.

8. CONCLUSIONS

The main difference between our plan for METI and others SETI and METI plans is that we selected only targets up to 50 ly for messaging and we want to be persistent in listening. Stable funding from international cooperation by donation of national governments is essential for the accomplishment of our plan. We do not know if it is possible but we are still in the quest with very small chances for success.

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SEARCH FOR POSSIBLE EXOMOONS WITH FAST TELESCOPE

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Abstract. Our knowledge of the Solar System, encourage us to beleive that we might expect exomoons to be present around some of the known exoplanets. With present hardware we shall not be able to find exomoons with existing optical astronomy methods at least 10 years from now and even then, it will be hard task to detect them. We suggest radio astronomy based methods to search for possible exomoons around these exoplanets. Using data from the Exoplanet Orbit Database (EOD) we find 2 stars with Jovian exoplanets within 50 light years fully accessible by the new radio telescope, The Five-hundred-meter Aperture Spherical radio Telescope (FAST).

1. INTRODUCTION

Discovery of the 51 Pegasi b (Mayor & Queloz 1995), exoplanet orbiting the Sun-like Main Sequence star, was only the first in the series of many exoplanets discovered thenceforth. The progress is made thanks to advanced detection techniques and instrumentation. Nowadays, the result is hundreds of confirmed and thousands of potential exoplanets, the most of them identified by the NASAs Kepler space telescope. Every prudent connoisseur of the Solar System would expect the presence of the exomoons close to the known exoplanets. The Solar System's planets and dwarf planets are known to be orbited by 182 natural satellites. In our solar system, Jovian planets have the biggest collections of moons and we expect similar position for gas giants planets in extrasolar systems. Nonetheless, contemporary techniques for observation haven't made a single detection of any exomoon so far. One of the leading models describing planetary satellites formation is the actively supplied gaseous accretion disk model (Canup & Ward 2006). In this model, the final total mass of satellite system, approximately $10^{-4}M_P$ (M_P mass of planet) is given by a balance of the supply of material to the satellites, and satellite loss through orbital decay driven by the gas.

2. SELECTION OF DATA AND METHOD OF ANALYSIS

Many of the detected exoplanets are the gas giants located in the habitable zone of their stars. These big planets cannot support life, but it is believed that some of their exomoons could be habitable. In our analysis, assuming that scaling law (Canup & Ward 2006) observed in the solar system also applies for extrasolar super-Jupiters (Heller & Pudritz 2014), we used planet's data from the Exoplanet Orbit

Database catalog (Wright et al. 2011 and Han et al 2014). We selected only exoplanets closer than 50 light years which have comparable mass or are more massive than Jupiter within declination limits of full sensitivity of new radio telescope in China. Approximately a half of them are hot or warm Jupiters. According to (Heller & Pudritz 2015) if these planets migrated in to the stellar habitable zones from beyond a few AU, they could be orbited by large, water rich satellites. The liquid water on surface is possible on sufficiently massive satellites.

Besides telescopes explained in (Griessmeier et al. 2011, Noyola 2015) we have additional radio telescope in final phase of construction, The Five-hundred-meter Aperture Spherical radio Telescope (FAST) (Nan et al. 2011) and latter SKA telescope. FAST is located at a great depression with a diameter of about 800 m at $25^o.647$N and $106^o.856$E, near the village of Dawodang, in Guizhou Province. FAST will be capable of covering the skywithin 40^o from the zenith with full sensitivity. Set of nine receivers covers a frequency range from 70 MHz to 3 GHz. It has an illuminated aperture of 300 m diameter. FAST is an order of magnitude more sensitive than 100-m telescopes at Green Bank, USA, and Effelsberg, Germany and about two times more than Giant Meterwave Radio Telescope (GMRT), India.

We count on interaction of magnetic field of extrasolar planets with plasmas from exomoons (Zarka 2007). In Solar system, e.g. the particles from Io's volcanic eruptions interact with the Jupiter's magnetosphere to produce intense decameter radio waves. From the ground, these radio waves are detectable in the frequency range from 10 to 40 MHz (Zarka 1998). The generation mechanism is the cyclotron-maser instability (Wu et al. 1979). Listed frequencies in Table 1 are maximum values reported in (Griessmeieret al. 2007). In Table 2 we compare frequencies f_{mG} calculated by (Griessmeier et al. 2007), with other models of extrasolar planets radio emission f_{mL} (Lazio et al. 2004) and f_{mR} (Reiners & Christiansen 2010) and expected radio fluxes. Other radio telescopes with the most suitable frequency range are: super LOFAR extension (NenuFAR, 10-80 MHz) in France, 1-2 mJy at 4MHz bandwidth, Giant Meterwave Radio Telescope (GMRT, 153 MHz) in India, 0.2 $mJy/(t/15minutes)^{0.5}$ in a 4 MHz bandwith, and Ukrainian T-shaped Radio telescope (UTR-2, 8-40 MHz).

Table 1. Possible exomoons.

Planet Name	*Mass*	*Star type*	*Semimajor Axis*	*Distance* [pc]	*Satellite mass*	*Declination*	Frequency
eps Eridani b	1.55 M_J	K2V	3.4 AU	3.22	0.049 $M_\oplus$	-09^o 27′ 29.7312″	33.2 MHz
Gliese 876 b	2.27 M_J	M4V	0.2 AU	4.69	0.072 $M_\oplus$	-14^o 15′ 49.32″	38.2 MHz
Gliese 876 c	0.7 M_J	M4V	0.13 AU	4.69	0.022 $M_\oplus$	-14^o 15′ 49.32″	16.4 MHz
Gliese 849 b	0.91 M_J	M3.5V	2.39 AU	9.1	0.0289 $M_\oplus$	-4^o 38′ 26.62″	21.8 MHz
Gliese 849 c	0.94 M_J	M3.5V	4.82 AU	9.1	0.0298 $M_\oplus$	-4^o 38′ 26.62″	
HD 62509 b	2.9 M_J	K0III	1.64 AU	10.3	0.092 $M_\oplus$	+28^o 01′ 35″	49.5 MHz
55 Cnc b	0.8 M_J	G8V	0.11 AU	12.3	0.025 $M_\oplus$	+28^o 19′ 51″	18.9 MHz
55 Cnc d	3.878 M_J	G8V	5.74 AU	12.3	0.123 $M_\oplus$	+28^o 19′ 51″	61.4 MHz
HD 147513 b	1.21 M_J	G1VH-04	1.32 AU	12.9	0.038 $M_\oplus$	+39^o 11′ 34.7121″	24.5 MHz
ups And A b	0.62 M_J	F8V	0.059 AU	13.47	0.019 $M_\oplus$	+41^o 24′ 19.6443″	2.4 MHz
ups And A c	13.98 M_J	F8V	0.832 AU	13.47	0.44 $M_\oplus$	+41^o 24′ 19.6443″	38.4 MHz
ups And A d	10.25 M_J	F8V	2.53 AU	13.47	0.33 $M_\oplus$	+41^o 24′ 19.6443″	61.4 MHz
ups And A e	0.96 M_J	F8V	5.25 AU	13.470	0.031 $M_\oplus$	+41^o 24′ 19.6443″	
47 UMa b	2.5 M_J	G1V	2.1 AU	14.06	0.079 $M_\oplus$	+40^o 25′ 27.97″	46.6 MHz
HIP 79431 b	2.00 M_J	M3V	0.36 AU	14.4	0.064 $M_\oplus$	-18^o 52′ 31.8″	40 MHz
HD 176051 b	1.5 M_J	F9V	1.76 AU	15	0.047 $M_\oplus$	+32^o 54′ 5″	

A selected planets are presented in Table 1. We can see that the selected planets orbit stars from M to F star type. Since these planets most likely were not formed at those distances, but have migrated from larger ones, posibble exomoons could also be captured rocky planets. Now if the possible exomoons are captured they can survive enough time for all stars presented in Table 1 (Barnes & O' Brien 2002). These captured satellites can be more massive than formed ones (Porter & Grundy 2011) but we do not consider them. Even if 50 percent planets are falsely detected (Santerne et al. 2015) we still have enough candidates. We will have most likely high mean plasma density between ρS$\sim 10^6$amu cm^{-3} and ρS$\sim 10^7$amu cm^{-3} due to the presence of some exomoons in star's habitable zone and closer to stars (Schunk & Nagy 2009). The main problem is that the distances of the possible exomoons we are suggesting are greater than one selected in the previous radioastronomy searches (George & Stevens 2008, Noyola 2015). The closest planets are eps Eridani b at 3.22 pc and Gliese 876 b and c at 4.69 pc distance.

All stars fully accessible by the FAST are: eps Eridani, Gliese 876, Gliese 849, HD 62509, 55 Cancri, HD 147513, Upsilon And A, 47 UMa b, HIP 79431 and HD 176051, have enough lifetime to be listed in HabCat (Turnbull & Tarter 2003). If, as we can see in Table 1, these stars do not have exomoon emitters with frequency above 70 MHz our next chance is the low-end Low-Frequency Array (LOFAR). Present LOFAR has frequency range $10-240$ MHz which is the best for exomoons and exoplanets detection. The super LOFAR extension (NenuFAR, 10-80 MHz) has frequency range of our interest. Sensitivity in this range is a few mJy. We can see that most suitable radio telescope for search for the closest possible exomoons is NenuFAR, the super LOFAR extension and FAST telescope especcialy for two extrasolar planets, 55 Cancri d and υ And A d, where it can be very useful. As we can see in Table 2. for other models of extrasolar planets radio emission (Lazio et al. 2004), and (Reiners & Christiansen 2010) second set of FAST receivers (Nan et al. 2011) is also suitable for these two extrasolar planets and plans for radioastronomy methods search for exoplanet (Li et al. 2012). To our best knowledge we do not know for exoplant detection by radioastronomy methods.

Table 2. Possible maximum frequencies for exomoons and exoplanets.

Planet Name	*Star type* [M_J]	*SemiMajor Axis*	f_{mG} [MHz]	R. flux [mJy]	f_{mL} [MHz]	R. flux [mJy]	f_{mR} [MHz]	R. flux [mJy]
eps Eridani b	K2V	3.4 AU	33.2	0	53	6.3	18.3	6
Gliese 876 b	M4V	0.2 AU	38.2	6.3	66	3.1	68	160
Gliese 876 c	M4V	0.13 AU	16.4	61.7	16	2.1	8.9	630
Gliese 849 b	M3.5V	2.39 AU	21.8	0	-	-	-	-
Gliese 849 c	M3.5V	4.82 AU	-	-	-	-	-	-
HD 62509 b	K0III	1.64 AU	49.5	0	68	0.1	-	-
55 Cnc b	G8V	0.11 AU	18.9	3	-	-	17.6	80
55 Cnc d	G8V	5.74 AU	61.4	0	-	-	242	0
HD 147513 b	G1VH-04	1.32 AU	24.5	2	43	4.1	23.5	0.2
ups And A b	F8V	0.059 AU	2.4	178.5	27	41.8	2.2	200
ups And A c	F8V	0.832 AU	38.4	0	84	2.8	68	2.5
ups And A d	F8V	2.53 AU	61.4	0	163	0.1	213	0.3
ups And A e	F8V	5.25 AU	-	-	-	-	-	-
47 UMa b	G1V	2.1 AU	46.6	0	-	-	111	0.5
HIP 79431 b	M3V	0.36 AU	40	0	-	-	-	-
HD 176051 b	F9V	1.76 AU	-	-	-	-	-	-

3. CONCLUSION

Since we shall not be able to find exomoons with existing optical astronomy methods at least 10 years from now (Kipping 2014), and even then it will be hard task to detect them (Hippke & Angerhausenet 2015, Heller et al. 2016), we suggest to search for exomoons around these planets with radio astronomy based methods (see Noyola et al. 2014, Noyola 2015). The main problem is that the distances of the possible exomoons we are suggesting are greater than one selected in the first searches (George & Stevens 2008, Noyola 2015). The closest promising planets are 55 Cancri d at 12.3 pc and υ And A d at a distance of 13.47 pc. At present such sensitivity can be expected only from the radio telescope the super LOFAR extension (NenuFAR, 10-80 MHz) and the just finished radio telescope FAST.

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CAN WE AFFORD AN INTERSTELLAR FLIGHT?

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Abstract. What is a price of interstellar flight? How are we prepared for such grandiose task? Let me sum up main costs for three projects. We calculated only the most basic things, a price of building the sail and energy to power the laser system. We can see that only one adjusted system has a chance to be financed.

1. INTRODUCTION

For 1000 kg probe and sail (Forward 1984) sent to next star price of electrical energy for powering 65 GW laser per three years is today's 85 billion of dollars at 5 cents per kWh (Forward 1984). It is not clear how much electrical energy we need. If we assume one-third efficiency this increase our energy bill to 255 billion dollars just for price of energy, not for the power plants which can cost additionaly up to 200 billion dollars. We estimate based on United Launch Alliance's costs for Atlas V551 rocket (United Launch Alliance) for 560,000 tonns big Fresnel lens in Sun's orbit 16 trillion of dollars to build and launch it. Building and launching solar sail with probe around Sun another 100 billions of dollars based on costs of International Space Station (Lafleur). For other two flight proposals in (Forward 1984), we do not know how they can be performed with a big time delay due to huge interstellar distance. These all add up to approximately 17.5 trillion of dollars. Producing, launching and financing 100000 rockets do not seem feasible for our Earth's economy.

For Breakthrough Starshot (Lubin 2016) main expense is a cost of propelling small sail for up to four hours (Kipping 2017a). Power generation and storage at the launch site is the challenge. Developing a site with adequate infrastructure to generate the energy at a high altitude site is difficult. In the project, they claim: "Generating 100 GW class of power and delivering for several minutes at a low price is achievable with the currently available technology. Natural gas-fired power plants can generate this power easily at a price of less than 10 cents per kWh." This power needs to be delivered and stored. Relatively low cost is $ 1200 per kWh for energy system from the paper (Lubin 2016) which amount up to 360 billion dollars if we assume the same one-third efficiency. It is significantly smaller for (Kipping 2017a) but in latter version (Kipping 2017b) author included divergence of laser beam and more efficient coating, power is revised to 500 GW which amount up to 50 billion of dolars just for storing enough energy for 10 minutes and the same one-third efficiency. We estimate power generating station up to 2 GW and filling time about 48 hours. Technology and costs for conectors for such huge energy transfer in short period of time is not the aim of this paper as well as lasers.

Setting up a dedicated electricity generating system, energy storage and then using it only once for 10 minutes is obviously a bit pricey. A possible solution is to send a fleet of postal card size probes one every third day. Also, the problem is to build enough small radioisotope thermo-electric generator.

Sending solar sail proposed in (Heller & Hippke 2017) is not feasible in one man's life. Authors underestimated the thickness of the reflective coating. Covering 10^5 m^2 graphene mono-layer sail with one adsorbed He atom per heksagonal cell amounts to 12.4 g and this will not increase reflectivity enough. The cost of building such big sail in space we cannot estimate, but it cannot be less than 100 billions of dollars. Also, the problem is to build a radioisotope thermo-electric generator which will provide energy after longer time needed to sail to next star.

We can see that only system proposed in (Kipping 2017b) has a chance to be financed if we really can produce 500 GW laser. This is not too big amount of money to be spent by government with a sense of economic responsibility.

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LOW IONOSPHERE RESPONSE ON ASTRO- AND GEO-PHENOMENA - RECENT RESEARCH

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Abstract. This paper overviews our recent studies of low ionospheric perturbations caused by numerous astrophysical and geophysical phenomena. We present theoretical and numerical procedures developed for modeling the spatial and time distributions of plasma parameters and for detecting the ionospheric disturbances. Here, we examine the effects of solar X-ray flares, gamma ray bursts and tropical depressions preceding a hurricanes. The analyses are based on data of very low and low frequency (VLF/LF) radio signals collected by the receiver located at the Institute of Physics in Belgrade.

1. INTRODUCTION

Processes in the terrestrial atmosphere are very complex due to occurrence of different events and their affects at the considered geographical locations (Mihajlović, 2017, Mihajlović et al, 2017). As a part of the atmosphere, the low ionosphere is under permanent influences of events coming from outer space and Earth's layers. These terrestrial and extraterrestrial phenomena induce variations in the low ionospheric plasma characteristics which can be detected in the ionospheric monitoring by radio waves as well as in radar and rocket measurements. Such variations can further be used for detection of different events and for modeling the low ionospheric plasma.

In this paper we present studies of the low ionosphere based on data collected by the Belgrade VLF/LF receiver station since 2004. We give an overview of the direction in our research and show the most important results published in international journals.

2. EXPERIMENTAL SETUP

The Belgrade VLF station consists of two receivers with one electrical (AbsPAL - Absolute Phase and Amplitude Logger) and two magnetic loop (AWESOME - Atmospheric Weather Electromagnetic System for Observation Modeling and Education) antennas, respectively. They can simultaneously register 6 and 15 signals emitted by different transmitters at fixed frequencies, respectively. These AbsPAL and AWESOME antennas have been operating since 2004 and 2008, respectively. During this period we have collected a large data base containing a written information about numerous low ionospheric responses to different natural and human-induced events allowing for making statistical analyses of considered phenomena and to detect differences within a long-term period.

3. OBSERVATIONS AND RESULTS

Our research is based on detections of the low ionospheric responses to different asro and geophysical phenomena and modeling of the D-region plasma parameters during the corresponding perturbation periods. Examples of detected events and modeled D-region plasma parameters are presented in Figure 1 and Figure 2, respectively.

3. 1. DETECTIONS OF ASTRO AND GEO EVENTS

In our studies we present procedures for detections of signal perturbation signatures which are based on extractions of short-term amplitude peaks from the amplitude noise and on comparison of amplitudes showing in possible perturbed and quiet periods. In addition, we developed a procedure for detection of acoustic and gravity waves (AGWs) induced by a strong sudden impact of radiation. The derived procedures are applied to:

- Confirmation of short-term ionospheric disturbances induced by gamma ray bursts (GRBs) (Nina et al. 2015).

- Statistical analysis of no short-term disturbances in time periods when tropical depressions start to form (Nina et al. 2017a).

- Determination of periods of AGW induced by a solar terminator (Nina and Čadež, 2013).

A detailed review of these procedures is given in Nina et al. (2017b).

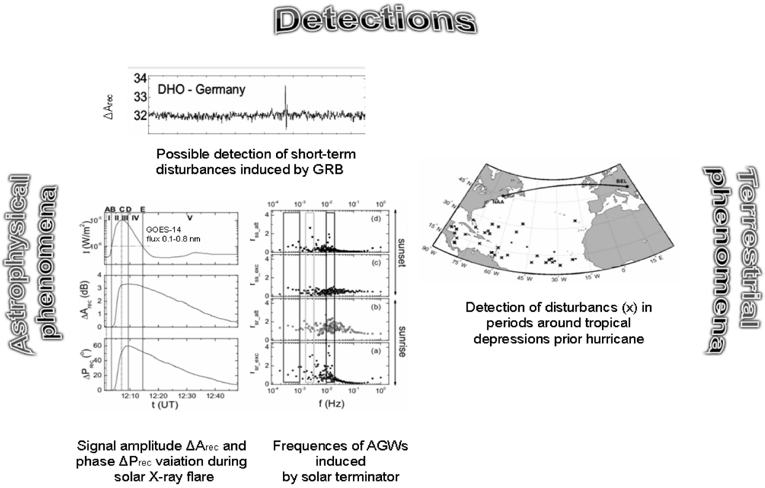

Figure 1: Examples of detected events.

3. 2. LOW IONOSPHERIC PLASMA MODELING

Modeling of the time evolution of the D-region plasma parameters during perturbations is presented in numerous studies where we considered solar X-ray flares influences on:

- The electron density (Nina et al. 2012, Kolarski and Grubor, 2014, Šulić et al. 2016).
- The temperature and refractive index (Bajčetić et al. 2015).
- The electron loss coefficient (Nina and Čadež, 2014).
- The D-region electron content (Todorović Drakul et al. 2016).

Some of these procedures are restricted to specific periods of the D-region responses and their expansion to the entire perturbation period will be in focus of our upcoming studies.

4. SUMMARY

In this paper we presented a review of our recent studies of low ionospheric perturbations caused by various astrophysical and geophysical phenomena. The presented theoretical and numerical procedures for modeling the spatial and temporal distributions of plasma parameters and for detecting the ionospheric disturbances are based

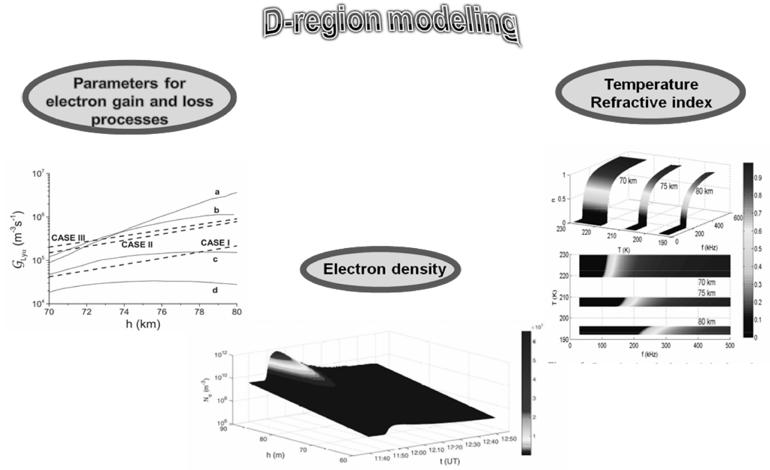

Figure 2: The resulting modeling of the D-region physical parameters.

on analyses of data collected by the radio signal receiver located at the Institute of Physics in Belgrade, Serbia. The obtained results of these investigations are of scientific importance in astro and geo sciences as well as in a practical application in telecommunications and numerous new open questions require studies which will be the subject of our future research.

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LOCAL VELOCITY DISPERSION RATIO DESCRIBED BY MEANS OF A NEW FORMULA

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Abstract. The ratio of two mean random velocity squares (dispersions) in the Galactic plane is revisited. A new formula is obtained. It contains the classical one (known as epicyclic) as a special case. Like the classical formula the new one is also applicable to the thin disc (low orbital eccentricities). However, in the new formula the influences of the ratio of the Oort constants moduli and that of the distribution of orbital phases and eccentricities are clearly separated.

1. INTRODUCTION

Among the subsystems of the Milky Way the existence of which has been confirmed through kinematical studies for the solar neighbourhood the thin disc is, certainly, the most important. The Sun is also a thin disc star. Stars of the thin disc are known to orbit the centre of the Milky Way in nearly circular orbits. Their motion can be successfully decomposed into the motion in the Galactic plane and perpendicularly to it. The random velocities of thin disc stars are obtainable on the basis of kinematical studies, of importance are the second-order moments. They form a symmetric tensor. The subject of the present paper concerns the two diagonal elements in the plane, more precisely its ratio, for which a new formula is proposed. What is given here is a shortened presentation only. The full account is to be given elsewhere.

2. THE OBJECTIVE

A coordinate system centred on the projection of the Sun onto the Galactic plane x, y, z is introduced. The orientation of the axes is: x positive towards $l = 0°$, $b = 0°$; y positive towards $l = 90°$, $b = 0°$; z positive towards $b = 90°$. Due to such a choice of the coordinate axes it will be valid: $|v_R| = |v_x|$, $|v_\theta| = |v_y|$, $\vec{v}$ is random velocity, R is distance to the Z axis (parallel to z through the Galactic centre), θ is the angle in the Galactic plane. According to the formula well known from the literature (e. g. Angelov 2013, (29.14), p. 149) the mean squares taken at the projection of the Sun should satisfy the following relation

$$\frac{\overline{v_\theta^2}(R_\odot, 0)}{\overline{v_R^2}(R_\odot, 0)} = (1+\alpha)^{-1} \ , \quad \alpha = \frac{A}{|B|} \ ; \tag{1}$$

A and B are the Oort constants. Since the evidence usually suggests for this ratio to be about 0.4 (e. g. Dehnen & Binney 1998), on the basis of (1) one derives $\alpha = 1.5$. However, more recent evidence, especially the rotation curve, is in favour of smaller values, slightly exceeding 1.0 (e. g. Iocco et al. 2015). The new formula which is proposed here shows that the relationship between the ratio of the mean squares of random velocity and that of the moduli of the Oort constants is not as straightforward as it seems to be on the basis of (1).

3. RESULTS

The potential of the Milky Way is assumed to be stationary and axially symmetric. Since the motion of disc stars is the subject, the motion in R is assumed to be unaffected by that in Z. The consequence is a quasi integral of motion - specific (per unit mass) energy in the plane - $\frac{1}{2}V_p^2 - \Pi(0) \approx const$ (Π - potential, $V_p^2 = V_R^2 + V_\theta^2$). This integral together with the component J_Z of the specific angular momentum (exact integral) leads to approximately constant extremal distances, R_p and R_a which are replaced by the following quantities

$$R_m = \frac{R_p + R_a}{2} \ , \quad e = \frac{R_a - R_p}{R_p + R_a}. \tag{2}$$

Since all stars of a sample are at the Sun, the present distance is the same (equal to $R_\odot$). Because of this a dimensionless quantity χ, $\chi = R_\odot / R_m$, is introduced. If the eccentricity e (equation 2) is the same for all sample stars, then it will be: $1 - e \leq \chi \leq 1 + e$. Let the dependence of the potential on R for $Z = 0$ correspond to a power law for the circular speed u_c, $u_c \propto R^\delta$. Since $R_\odot$ lies within the interval $[R_{p\,\mathrm{min}}, R_{a\,\mathrm{max}}]$ (minimum and maximum for individual extremal distances in the sample), it will be $\delta = (1-\alpha)/(1+\alpha)$. Such a case for $-0.5 \leq \delta \leq 1$ has been studied by the present author (Ninkovich 1986). In this way expressions for V_p^2, V_θ^2 and $|V_\theta|$ as functions of χ with α and e as parameters and $u_c^2(R_\odot)$ or $u_c(R_\odot)$ as units can be obtained. Then the obtaining of all mean values, which are necessary, is reduced to the determination of the mean values of the corresponding functions of χ. Since stars of the thin disc are of interest, it will be: $e \approx 0$. This circumstance offers the possibility to obtain simplified expressions wherein χ is replaced by a new variable φ, $\varphi = (\chi - 1)e^{-1}$. It is clear that: $-1 \leq \varphi \leq 1$. It should be added that the mean value of v_R^2 is equal to the mean value of V_R^2 because $\overline{V_R} = 0$; $\overline{v_\theta^2} = \overline{V_\theta^2} - \overline{|V_\theta|}^2$. Finally it is obtained

$$\begin{aligned} \overline{v_R^2}(R_\odot, 0)_e &= 4(1+\alpha)^{-1} u_c^2(R_\odot)(1 - \overline{\varphi^2})e^2 \ , \\ \overline{v_\theta^2}(R_\odot, 0)_e &= 4(1+\alpha)^{-2} u_c^2(R_\odot)(\overline{\varphi^2} - \overline{\varphi}^2)e^2 \ . \end{aligned} \tag{3}$$

The subscript e in (3) means that the mean values are taken for a sample of thin-disc stars with the same orbital eccentricity. For a sample of thin disc stars of various eccentricities distributed following a function f(e) the corresponding mean values will be

$$
\begin{aligned}
\overline{v_R^2}(R_\odot, 0) &= 4(1+\alpha)^{-1} u_c^2(R_\odot) \int_0^{e_l} (1 - \overline{\varphi^2}) e^2 \mathrm{f}(e) de \ , \\
\overline{v_\theta^2}(R_\odot, 0) &= 4(1+\alpha)^{-2} u_c^2(R_\odot) \int_0^{e_l} (\overline{\varphi^2} - \overline{\varphi}^2) e^2 \mathrm{f}(e) de \ .
\end{aligned}
\tag{4}
$$

4. DISCUSSION AND CONCLUSIONS

The ratio of the two mean velocity squares which are subject in (4) reduces to (1) provided that $\overline{\varphi}$ and $\overline{\varphi^2}$ are independent of eccentricity and have the following values $\overline{\varphi} = 0$, $\overline{\varphi^2} = 0.5$. In both cases we have the middles of the allowed intervals.

In the present paper only the behaviour of $\overline{\varphi}$ will be considered. It affects the asymmetric drift, i. e. the difference $\delta u = u_c - \overline{|V_\theta|}$. The quantity $\overline{|V_\theta|}$ is obtained from an integral, analogously to (4), wherein $f(e)de$ is multiplied by $\overline{|V_\theta|}(e)$, a quantity which depends on both $\overline{\varphi}$ and $\overline{\varphi^2}$, but the influence of the former one is much more significant.

On the other hand in view of the relations $\overline{V_p^2} = \overline{v_R^2} + \overline{|V_\theta|}^2 + \overline{v_\theta^2}$ and $\overline{|V_\theta|} = u_c - \delta u$, mentioned above, and neglecting δu^2 one may write

$$
\begin{aligned}
\delta u &= \frac{\nu + 1 + \mu}{2u_c} \overline{v_R^2} \ , \\
\nu &= \frac{u_c^2 - \overline{V_p^2}}{\overline{v_R^2}} \ , \\
\mu &= \frac{\overline{v_\theta^2}}{\overline{v_R^2}} \ .
\end{aligned}
\tag{5}
$$

Relation (5) can be applied to a sequence of samples consisting of thin-disc stars. The sense of the word sequence is the condition that the quantities δu, $\overline{v_R^2}$ and $\overline{v_\theta^2}$ increase simultaneously. If the ratio μ were approximately the same for all sequence samples, as the literature shows (e. g. Dehnen & Binney 1998), then according to (5) δu would be proportional to $\overline{v_R^2}$, provided that the other ratio ν were also approximately the same. Examinations done by the present author show i) simultaneous increase of all the three δu, $\overline{v_R^2}$ and $\overline{v_\theta^2}$ is a consequence of $\overline{\varphi}$ as an increasing function of eccentricity; ii) such a $\overline{\varphi}$ is not consistent with $\nu \approx const$ in conditions when $\mu \approx const$.

A comparison of the samples studied in the paper by Dehnen and Binney (1998) with some of the samples from the paper by Cubarsi et al. (2017) for which the ratio μ is approximately the same (about 0.4) indicates that they also have approximately the same mean motion in θ with respect to the Sun and $\overline{v_R^2}$. This can be interpreted by assuming the same eccentricity distribution $f(e)$ for all these samples. A preliminary formula proposed by the present author is

$$
f(e) = Ce^n \exp(-e/c) \tag{6}
$$

The parameters of (6) are C, n and c. The value for n seems to be about 3, c is obtained from the condition for the maximum of $f(e)$ (most likely the maximum occurs at about $e = 0.1$). Samples within the thin disc would differ by the value for e_l (equation (4)), the smaller $\overline{v_R^2}$ and δu are, the lower is the corresponding e_l.

At the end it should be pointed out that $\overline{\varphi^2} = const = 0.5$, as required for the old formula (equation (1)), may be acceptable, but $\overline{\varphi} = const = 0$ is inconsistent with the asymmetric drift, i. e. it is not acceptable. Therefore, any clear correspondence between the ratios of the moduli of the Oort constants (α) and that of the mean velocity squares (μ - equation (5)), as follows from (1), does not exist.

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A SIMPLE FORMULA FOR CALENDARS

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Abstract. A simple formula which comprises and unifies the three calendars originating from the Roman calendar is proposed. Its significance is rather pedagogical than scientific because the purpose is to explain, in a way as simple as possible, the contributions of the Gregorian and Neojulian reforms.

1. INTRODUCTION

The calendar question is an old one and very well known. Calendars can be based in many ways, so that there exist, e. g. lunar, luni-solar and solar calendars. For instance, the Muslim calendar is lunar, that of the Jews luni-solar, etc. The calendar adopted by the Christians is solar, but it is due to the Romans. The version of the Roman calendar which was adopted in the Christianity is referred to as the Julian calendar. It was approved by Julius Caesar in 46 BC. An improved version of the Julian calendar was approved by Pope Gregory XIII in 1582. It is known as Gregorian calendar after him. From the time of its proclamation the use of the Gregorian calendar was increasing so that it has become, practically, a universal (world) calendar. On the other hand, it is also well known that some Christian churches still use the Julian calendar as the official one (for instance, Serbian Orthodox Church). There was an initiative among the Greek Orthodox Christians, almost a hundred years ago, aimed at introducing a new calendar which should be better than the Gregorian one. More precisely, the calendar question was considered at a Pan-Orthodox congress held in Constantinople in 1923. A new calendar, mainly referred to as Neojulian, was accepted and recommended. This calendar was the official proposal of the Serbian Church (except it only the Romanian Church had a proposal). Its first version is due to Maksim Trpković (1864-1924); later the second version, slightly changed in order to make 2000 a leap year, was proposed by Milutin Milanković (1879-1958). This is the version valid today; in more detail how this proposal was finally accepted see in, e. g. Milanković (1997).

The intention followed in the present contribution is to facilitate the explanation of the three calendars (say in teaching at levels of primary and secondary school). Here it is borne in mind that, in fact, they are three different versions of the same calendar. To this end a simple formula is proposed, which includes all the three calendars.

Table 1: Basic characteristics of calendars according to equation (1)

calendar	k	l
Julian	1	
Gregorian	100	3
Neojulian	225	7

2. THE APPROACH

As solar calendars the three calendars are based on the same time interval - tropical year. The tropical year expressed, as usually, in terms of the mean solar day is not an integer (or better a natural number). Its value lies between 365 and 366. Clearly, there can be no calendar wherein a year does not have an integral number of days. This was the reason why in the Julian calendar the concept of leap year was introduced. A leap year, unlike an ordinary one, has 366 days. The value by which the tropical year exceeds 365 is represented in a particular calendar by assuming a suitable frequency of leap years. The formula proposed here has namely this value as its subject.

3. RESULTS

Let the value by which the tropical year exceeds 365 be denoted as x. In principle x should be an irrational number. However, the value for x is established empirically, which implies a finite number of digits after the decimal point in accordance with the achieved accuracy. Therefore, x will be treated as a fraction. This fraction is the subject of the formula proposed here. Its form is

$$x = \frac{k-l}{4k}, \; k \in \mathbb{N}, \; l \in \mathbb{Z}, \; l \geq 0, \; l < k \; . \tag{1}$$

The designations mean: $\mathbb{N}$ - set of natural numbers, $\mathbb{Z}$ - set of integers.

On the basis of equation (1) each of the three calendars can be described by means of its values for k and l. The corresponding values are given in Table 1.

The value for l in the case of the Julian calendar is not given because it is evident from the conditions of (1).

4. DISCUSSION AND CONCLUSIONS

The duration of the tropical year is $365 + x$ mean solar days, x $(0 < x < 1)$ is a fraction given in (1). Its value obtained after substituting assumed values for k and l should yield a fit to the empirical values which is as good as possible. In the case of the three calendars a sufficiently good fit is achieved by introducing leap years. The circumstance that in the case of the Julian calendar (which preceded all others) x is equal to $1/4$ means that every fourth year, with no exception, is a leap one. Therefore, l is a correction aimed at improving the fit. The improvement is achieved by decreasing the number of leap years which would be obtained within an assumed cycle of $4k$ years if the Julian calendar were applied. This number is decreased exactly by l; for instance, in the case of the Gregorian calendar within its

400-year cycle there are 97 (100-3) leap years, instead of 100 as it is given in the Julian calendar. What years change the status in order to become ordinary is determined by means of a convention. In the Gregorian convention it is foreseen that secular years, in particular those wherein the factor multiplying 100 is not divisible by four without remainder (for instance in 1601-2000 these are 1700, 1800 and 1900) become ordinary. A similar principle is applied in the case of the Neojulian calendar, within 900 years seven secular years ($l = 7$) become ordinary, in practice the fourth and ninth in the sequence remain to be leap. In its first version (Trpković's one) the initial cycle was 1801-2700. As a consequence, out of the nine secular years only 2200 and 2700 would have been leap. As said above, in its current (Milanković's) version this is changed, the cycle is 2001-2900, 2000 remains to be leap, 2400 (in common with Gregorian calendar) is also leap, and finally 2900. This means that only in 2800 the discrepancy with the Gregorian calendar will occur, instead of 2000, which would have occured if Trpković's version had been accepted. In addition, out of the three calendars the Neojulian one yields the best fit, the value obtained for x (equation (1), Table 1) is $x = 0.2422$, as the evidence shows. On this matter there exist other articles (e. g. Simovljević 1996, Kečkić 2001).

Equation (1) has a pedagogical significance. By using (1) it becomes possible to give a simple explanation which includes all the three calendars. This is an advantage because the three calendars are in fact three versions of the same calendar, of that due to the Romans. Therefore, equation (1) is to be recommended in formation of the school curricula.

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THE FIRST TEST OF NEW ANDOR IXON 897 EMCCD CAMERA

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Abstract. Here the results of the testing of a new, very quick, EMCCD Andor iXon 897 camera are reported. The camera was examined in early June and September 2017. The CCD frames of low-separation visual double stars were obtained with short exposures of a few milliseconds. The camera was mounted on the 60 cm telescope in June and on the 1.4 m telescope in September at Astronomical Station Vidojevica (ASV). This quick camera will be part of the equipment for the speckle-interferometric technique of observing double stars and for the beginning it will be utilized for obtaining frames by applying lucky imaging.

1. INTRODUCTION

The basic task in studying visual double and multiple stars is to determine the orbital or linear elements from the time series of the measurement of the position angles and the angular separations between the components. In other words, observers need to answer the question concerning the nature of their motion. Therefore, we need observations covering very long time intervals. Only for a small number of pairs, about 2200, the orbital elements have been calculated, i.e. a Keplerian motion has been confirmed. In the case of many pairs no change in position angle and/or angular separation over a sufficiently long time interval has been registered. Such pairs are probably not gravitationally bound, i.e. they are optical pairs.

Binary stars have been studied for decades for the purpose of accurate determination of stellar masses, verification of the evolutionary models and star formation theories. With a CCD camera it is impossible to detach too close pairs (less than 1.5 arcsec). Close pairs are observed by using speckle interferometric technique. Due to their small separations, they have been mostly observed with speckle cameras on larger telescopes. These techniques can dramatically increase the resolution of ground-based telescopes. Use of these techniques has led to a number of discoveries, including thousands of binary stars.

Speckle interferometry of close double stars avoids seeing limitations through a series of diffraction-limited high speed observations made faster than the atmospheric coherence time scale. This technique not only allowed observations of binaries (stars gravitationally bound to each other) with angular separations below the seeing limit, but the observations were generally an order of magnitude more accurate than visual observations (McAlister 1985).

Lucky imaging is one form of speckle imaging. Speckle imaging techniques use a high-speed camera with exposure times short enough (100 ms or less) so that the changes in the Earth's atmosphere during the exposure are minimal. With lucky imaging, those exposures least affected by the atmosphere (typically around 10%) are chosen and combined into a single image by shifting and adding the short exposures, yielding a much higher resolution than it would be possible with a single, longer exposure which includes all the frames. Lucky imaging is one of several methods used to remove atmospheric blurring. Used at a 1% selection or less, lucky imaging can reach the diffraction limit of even 2.5 m aperture telescopes, a resolution improvement factor of at least five over standard imaging systems.

This quick EMCCD Andor iXon 897 camera will be part of the equipment for the speckle-interferometric technique of observing double stars and for the beginning it will be utilized for obtaining frames by applying lucky imaging.

2. EMCCD ANDOR IXON 897 CAMERA

The iXon Ultra 897 platform takes the popular back-illuminated 512 x 512 frame transfer sensor and overclocks readout to 17 MHz, pushing speed performance to an outstanding 56 full frame per second (fps), whilst maintaining single photon sensitivity and quantitative stability throughout. New Optically Centred Crop Mode unlocks unparalleled frame rate performance from centrally located ROIs, ideal for the particular speed and sensitivity requirements of super-resolution microscopy.

The iXon Ultra maintains all the advanced performance attributes that have defined the industry-leading iXon range, such as deep vacuum cooling to -100°C, extremely low spurious noise, and Andors patented EM gain recalibration technology (EMCA^{TM}).

New, very quick, EMCCD Andor iXon 897 camera was procured in April 2017. It was tested in early June for the first time 2017 and at late September 2017 more one.

The main characteristics of the EMCCD Andor iXon 897 camera[1] are given in Table 1.

Table 1: The main characteristics of the EMCCD Andor iXon 897 camera.

Active pixels (H x V)	512 $\times$ 512
Pixel size (W x H; μm)	16 x 16 μm
Image area (mm)	8.2 x 8.2 mm
Active Area Pixel Well Depth (e$^-$)	180,000 e$^-$
Max Readout Rate (MHz)	17 MHz
Frame rates (fps)	56 (full frame) - 11,074
Read noise (e$^-$)	$<$ 1 with EM gain e$^-$
QE Max	$>$ 95%

[1] http://www.andor.com/cameras/ixon-emccd-camera-series

Figure 1: EMCCD Andor iXon 897 camera was mounted on the 60 cm telescope in early June 2017 (left) and on the 1.4 m telescope at the end of September 2017 (right) at ASV.

3. TESTING OF CAMERA

The new EMCCD Andor iXon 897 camera was first tested on a 60 cm telescope (Figure 1, left panel) at the beginning of June 2017. The camera is successfully mounted on the telescope using a specially-built adapter. By applying the appropriate drivers the camera is linked to MaximDL software that allows the telescope to be operated simultaneously. After that, the problem of placing the camera's chip in the focal plane of the telescope (focusing) is successfully solved. More details of determining the focal length for different detectors can be found in Cvetković et al. (2012). The pixel scale for 0.6 m telescope is 0.55 arcsec/pixel and field of view is 4.7 arcminutes. During the night, more than 500 CCD frames of double stars were made. As an illustration we give two CCD images of multiple star ADS 48 made with different exposures: 1 second (Figure 2 – left panel) and 0.001 second (Figure 2 – right panel). Separation of the brightest pair is 6 arcsec and its apparent magnitudes of the components are $m_A = 8.98$ and $m_B = 9.15$.

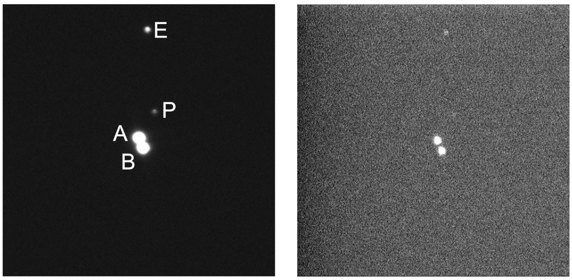

Figure 2: The CCD frames of multiple system ADS 48 were obtained with two different exposures: 1 second (left) and 0.001 second (right).

We repeated the same procedure for testing this camera on the 1.4 m telescope "Milanković" (Figure 1, right panel) at the end of September 2017. Then there were better weather conditions, so we made many more high quality frames with very short exposures. As an illustration, CCD images of two double stars, BRT 2465 and J 201, are presented. Their separations are 3.0 and 2.7 arcsec, respectively (Figure 3). Pixel scale for a 1.4 m telescope is 0.29 arcsec/pixel and field of view is 2.5 arcminutes.

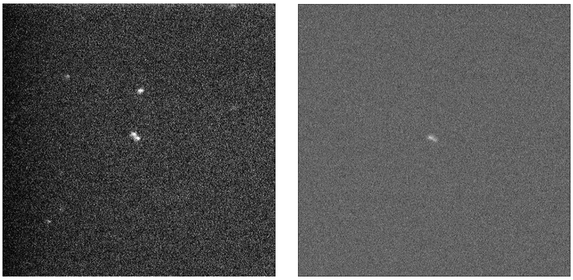

Figure 3: The CCD frames of two visual double stars, BRT 2465 (left) and J 201 (right).

We made stacked image (each one is 0.001 second) of the best 20% frames for double star J 555 (Figure 4).

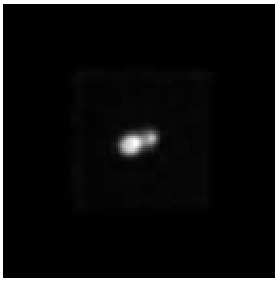

Figure 4: Stacked and croped image of the best 20% frames for double star J 555.

4. CONCLUSION

The next step is to find optimal driver parameters which give the best CCD frames for very short exposures. Also, we plan to procure optical equipment which will make it possible to do speckle interferometry of double stars with separations less than 1 arcsec.

Acknowledgment

This research has made use of the database of the US Naval Observatory (Washington Visual Double Star Catalog). This research has been supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Projects No 176011 "Dynamics and kinematics of celestial bodies and systems and No 176021 Visible and Invisible Matter in Nearby Galaxies: Theory and Observations.)

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THE SPECTRAL COEFFICIENTS OF ABSORPTION PROCESSES IN DENSE STRONGLY IONIZED ASTROPHYSICAL PLASMAS

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Abstract. In this contribution we present a new model method of describing atomic photo-absorption processes in dense strongly ionized astrophysical plasmas, which is based on the approximation of cut-off Coulomb potential. By now this approximation has been used in order to describe transport properties of dense plasmas, but it was clear that it could be applied to some absorption processes in non-ideal plasmas. The presented results cover a wide region of the plasma electron densities and temperatures. Such plasmas are of interest from both the laboratory and the astrophysical aspect. Here, we have in mind the plasma of inner layers of the solar atmosphere, as well as of partially ionized layers of other stellar atmospheres, for example the atmospheres of DA white dwarfs with effective temperatures between 4 500 K and 30 000 K.

1. INTRODUCTION

The problems of plasma opacity, energy transport and radiative transfer under moderate and strong non-ideality are of interest in theoretical and experimental research (Fortov et al. 1999, Rogers et al. 1998, Mihajlov et al. 2011a, 2013). The strong coupling and density effects in plasma radiation were the subject of numerous experimental and theoretical studies in the last decades. Here, we keep in mind the plasma of the inner layers of the solar atmosphere, as well as of partially ionized layers of other stellar atmospheres, for example the atmospheres of DA white dwarfs with effective temperatures between 4 500 K and 30 000 K.

In this paper we presented a continuation of work on a model way of describing atomic photo-absorption processes in dense strongly ionized hydrogen plasmas, which is based on the approximation of the cut-off Coulomb potential. By now this approximation has been used to describe transport properties of dense plasmas (see e.g. Fortov et al. 1999, Mihajlov et al. 1989, Ignjatović et al. 2017), but it was clear that it could be applied to some absorption processes in non-ideal plasmas too (Mihajlov et al. 2011a,b, 2015, Sakan et al. 2005).

As a continuation of the previous work, the bound-bound absorption processes, i.e. photo absorption are investigated:

$$\varepsilon_\lambda + \mathrm{H}^*(n_i, l_i) \rightarrow \mathrm{H}^*(n_f, l_f), \tag{1}$$

where n and l are the principal and the orbital quantum number of hydrogen-atom excited states, hydrogen atom in it's initial state $|n_i, l_i>$ is presented by $\mathrm{H}^*(n_i, l_i)$, it's final state $|n_f, l_f>$ by $\mathrm{H}^*(n_f, l_f)$, and ε_λ presents absorbed photon energy.

The absorption processes (1) in astrophysical plasma are considered here as a result of radiative transition in the whole system "electron-ion pair (atom) + the neighborhood", namely: $\varepsilon_\lambda + (\mathrm{H}^+ + e)_i + S_{rest} \rightarrow (\mathrm{H}^+ + e)_f + S_{rest}^{'}$, where S_{rest} and $S_{rest}^{'}$ denote the rest of the considered plasma. However, as it is well known, many-body processes can sometimes be simplified by their transformation to the corresponding single-particle processes in an adequately chosen model potential.

Here the model potential is used in form

$$U_c(r) = \begin{cases} -\dfrac{e^2}{r} + \dfrac{e^2}{r_c}, & 0 < r \leq r_c, \\ 0, & r_c < r < \infty, \end{cases} \tag{2}$$

Within the frame of the presented model the results for the bound-bound transitions are sought. In accordance with that, the behavior of the dipole matrix element is investigated. It is given by

$$\hat{D}(r; r_c; n_i, l_i; n_f, l_f) =< n_f, l_f|\mathbf{r}|n_i, l_i >, \tag{3}$$

where the wave functions $|n_i, l_i>$ and $|n_f, l_f>$ are initial and final state wave functions obtained within the model of cut-off Coulomb potential 2, for calculations of plasma characteristics, or the theoretical hydrogen ones in order to check the model additionally.

For the calculation of oscillator strength we use expressions from (Sobelman 1979, Hoang-Binh, D., 2005).

$$f(n_f, l_f; n_i, l_i; r_c) = \frac{1}{3}\frac{\nu}{Ry}\left[\frac{max(l_f, l_i)}{2l_f + 1}\right]\hat{D}(r; r_c; n_i, l_i; n_f, l_f)^2, \tag{4}$$

where Ry is the Rydberg constant, in the same units as the frequency ν of the transition $|n_i, l_i>\rightarrow |n_f, l_f>$.

The analysis of the results took place in dimensionless units, where the fraction of the calculated osccilator strength value $f(n_f, l_f; n_i, l_i; r_c)$ and the $f_t(n_f, l_f; n_i, l_i)$, the theoretical hydrogen case calculated by code from (Hoang-Binh, D., 2005) is used.

$$f^*(n_f, l_f; n_i, l_i; r_c) = \frac{f(n_f, l_f; n_i, l_i; r_c)}{f_t(n_f, l_f; n_i, l_i)}. \tag{5}$$

The theoretical oscillator strength values. $f_t(n_f, l_f; n_i, l_i)$ for the presented results are calculated by code from (Hoang-Binh, D., 2005).

The presented results are easily fitted with the rational functions, but with the order not smaller than of fifth degree,

$$f^{fit}(r_c) = \begin{cases} 0, & r_c < r_c^{min}, \\ \left(1 - \displaystyle\sum_{i=0}^{n} \frac{b_i}{(r_c - x_0)^i}\right), & r_c > r_c^{min}, \quad n \geq 5 \end{cases} . \tag{6}$$

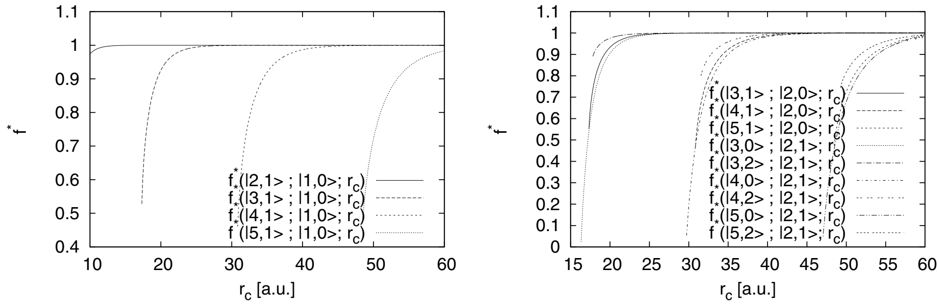

Figure 1: *Left*: The behavior of the $f^*(n_f, l_f; n_i, l_i; r_c)$ for the $n_i = 1$. *Right:* The behavior of the $f^*(n_f, l_f; n_i, l_i; r_c)$ for the $n_i = 2$

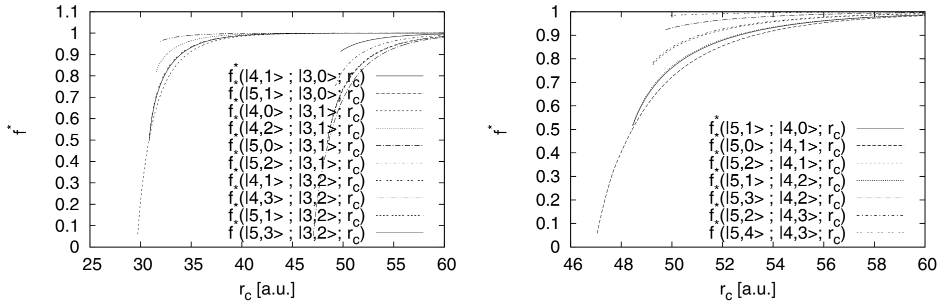

Figure 2: *Left*: The behavior of the $f^*(n_f, l_f; n_i, l_i; r_c)$ for the $n_i = 3$ *Right:* The behavior of the $f^*(n_f, l_f; n_i, l_i; r_c)$ for the $n_i = 4$

Here, r_c^{min} is the cut-off radii on which the upper level appears. Also the rational function is defined in such a matter that the first coefficient b_0 has a meaning of the probing does the fit function posses a usable solution in area of large cut-off radii r_c. Since the asymptotical behavior of the solutions is investigated and the limiting values for the osccilator strength is almost exact to the theoretical one, if the coefficient b_0 differs significantlly from zero, the fit is not usable in area of large r_c.

2. RESULTS AND DISCUSSION

The results in Figs. 1 and 2 show the behavior of the $f^*(n_f, l_f; n_i, l_i; r_c)$ for the $n_i = 1, 2, 3, 4$. It could be seen that there are some numerical effects needed to be analysed and carried out for the transitions from $n_i = 2$ to $n_f = 5$. Also from Fig. 3 it could be seen that such artefacts affects the fit to be usable only in vicinity of the r_c^{min}.

Presented results include the plasma influence into the account, and as such are usable for the hydrogen plasmas of moderate and high non-ideality. Since it was studied before that even for the transitions from $n_i = 2$ to $n_f = 5$ for the huge r_c values the oscillator strengths converge towards the theoretical values from (Hoang-Binh, D., 2005) there is a posibility that the adequate artefacts visible in the Fig. 1

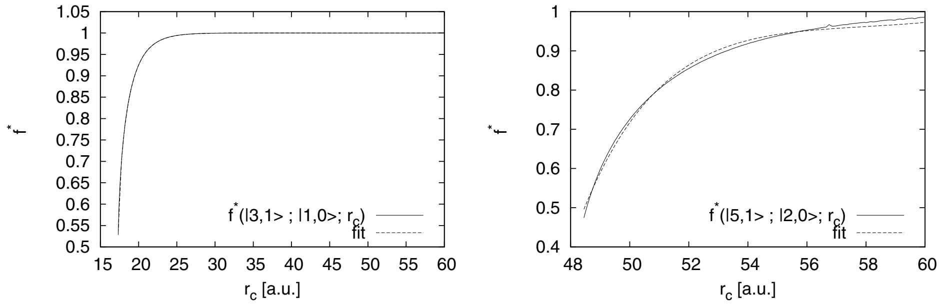

Figure 3: *Left*: The good fit example $f^*(|3,1>;|1,0>;r_c)$ and fit. *Right:* The acceptable fit example $f^*(|5,1>;|2,0>;r_c)$.

right, are of purely numerical form and are avoidable.

The work on obtaining the well defined fitting function for the bound-bound oscillator strengths is still in progress. The goal is to reduce computational time for the absorption coefficients, as well as to produce the usable form of presenting the results for further usage in theoretical and experimental practise.

Acknowledgment

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DYNAMICAL MODELS OF THREE LENTICULAR GALAXIES: NGC 1023, NGC 3115 AND NGC 4526

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Abstract. Lenticular galaxies (S0s) together with elliptical galaxies belong to the class of early-type galaxies (ETGs). The main features of S0s are a visible disk component and a prominent bulge component. In this contribution we study the kinematics and dynamics of three S0 galaxies which possess globular clusters (GCs) which extend beyond approximately five effective radii. We analyze NGC 1023, NGC 3115 and NGC 4526 based on their GCs. We use the kinematics of these galaxies which we extracted in order to construct the dynamical models of these objects. We use the Jeans equation based on both Newtonian and MOND methodologies. In the Newtonian case we use mass-follows-light assumption and we also test the models with dark matter (DM) in the Navarro-Frenk-White form. We find that while NGC 1023 does not need a significant amount of DM, for the remaining two galaxies, NGC 3115 and NGC 4526 the dark component fully dominates stellar matter. Three MOND models that we tested show that while NGC 1023 can be modeled without DM in MOND, for NGC 4526 there is a hint of an additional dark component and NGC 3115 needs a significant amount of DM in its outer parts. Finally, we compare our findings with the predictions of the Λ cold dark matter cosmology.

1. INTRODUCTION

The problem of the contribution of dark matter (DM) in the total dynamical mass of various types of galaxies remains one of the most important unsolved question of the contemporary astronomy. The fact that DM dominates the mass of spiral galaxies is well-known, although, very recently, the discovery that the rotation curves for the outer disks of six massive star-forming galaxies at redshifts z between approximately 0.6 and 2.6 are not constant, as observed in the local Universe, but decrease with radius (Genzel et al. 2017). This new finding may suggest the lack of DM in spirals beyond the local (low-redshift) Universe. As for the problem of DM in the other class of galaxies, early-type galaxies (ETGs, made of ellipticals and lenticulars), in the local Universe, the situation is more complex. More than 10 years ago, in at least in some galaxies (see e.g. Samurović and Danziger 2005) the lack of DM in these objects was detected. This has led to the intense observational and theoretical works which suggest that the situation is not simple; there possibly exist two classes of ETGs, one in which the DM content is negligible and the other in which DM dominates the visible, stellar, matter in the outer parts of these galaxies (see e.g. Samurović 2014, hereafter S14). An important obstacle in the analysis of DM in ETGs is the fact that the detection of DM there is much more complicated than in the case of their spiral counterparts. ETGs lack cool gas in most cases and the usage of 21-cm observations to trace kinematics of neutral hydrogen is not feasible. Therefore, different techniques were tested and other methodologies were used in order to measure the total dynamical mass out to large galactocentric radii in ETGs. This is especially important because DM is expected to dominate luminous matter there, i.e. beyond $2-3$ effective radii (R_e). We described various observational techniques and the theoretical approaches for the study of DM in ETGs in Samurović (2007) and the update is provided in S14. In this contribution we employ both methodologies, Newtonian and MOND (Modified Newtonian Dynamics, Milgrom 1983).

Here, we rely on globular clusters (GCs) which are a very useful tool in the study of DM in ETGs and the reconstruction of the evolutionary history of galaxies in the local Universe. They extend out to several R_e. In S14 we used a sample of 10 ETGs coming from the SLUGGS (SAGES Legacy Unifying Globulars and Galaxies Survey, where SAGES is the Study of the Astrophysics of Globular Clusters in Extragalactic Systems) sample of Pota et al. (2013) as tracers of the gravitational potential in both the Newtonian (mass-follows-light and DM models) and the MOND approaches. We found that Newtonian mass-follows-light models without a significant amount of DM can provide successful fits for only one galaxy (NGC 2768) whereas the remaining nine ETGs require various amounts of DM in their outer parts (beyond $2-3R_e$); in the same paper various MOND models were also studied and it was found that MOND alone is not sufficient to fully explain the dynamics of six galaxies in the sample. Only one of the galaxies in S14 was a lenticular galaxy (S0), NGC 3115, and this object will be presented below. The additional two S0 galaxies come from our recent paper (Samurović 2017, hereafter S17): NGC 1023 and NGC 4526.

2. OBSERVATIONAL DATA

In this contribution we will analyze three S0 galaxies with GCs taken from the SLUGGS database (see S14 an S17 for references). The SLUGGS survey uses the combination of Subaru/Suprime-Cam wide-field imaging with spectra from the Keck/DEep Imaging Multi-Object Spectrograph (DEIMOS) multi-object spectrograph. We extract full kinematic profiles out to several effective radii: we determine the velocity dispersion and the symmetric and asymmeteric departures from the Gaussian distribution of their GC radial velocities.

2. 1. NGC 1023

NGC 1023 is a lenticular galaxy at the distance $D = 11.1$ Mpc which means that $1' \approx 3.23$ kpc and $1'' \approx 53.83$ pc. The effective radius is $R_e = 48$ arcsec and the systemic velocity is $v_{\rm sys} = 602$ km s^{-1}. The Sérsic index used in dynamical models is $n_* = 4.2$. The absolute B-band magnitude of NGC 1023, $M_B = -20.61$ and its total apparent corrected $B-V$ color is equal to 0.91 (from the HyperLeda database). We used 113 GCs belonging to NGC 1023 in our dynamical analysis and the slope of their GCs ($N \propto R^{-\gamma}$) is $\gamma = 1.416$. The rotational velocity of GCs is $v_{\rm rot} = 119$ km s^{-1}.

2. 2. NGC 3115

NGC 3115 is a S0 galaxy and is found at the distance $D = 9.4$ Mpc which means that $1' \approx 2.74$ kpc and $1'' \approx 45.59$ pc. The effective radius is $R_e = 85$ arcsec and the systemic velocity is $v_{\rm sys} = 663$ km s^{-1}. The Sérsic index is $n_* = 4.4$ and the absolute B-band magnitude of NGC 3115, $M_B = -19.94$. Its total apparent corrected $B - V$ color is equal to 0.89 (from the HyperLeda database). We used 150 GCs belonging to NGC 3115 in our dynamical analysis and two different slopes were used in our dynamical models, $\gamma_{\rm in} = 1.34$ in the inner region, interior to $\sim 2R_e$ and $\gamma_{\rm out} = 4.17$ in the outer region, beyond $\sim 2R_e$ (see S14 for details). The rotational velocity of GCs is $v_{\rm rot} = 100$ km s^{-1}.

2. 3. NGC 4526

NGC 4526 is a S0 galaxy and is found at the distance $D = 16.4$ Mpc which means that $1' \approx 4.77$ kpc and $1'' \approx 79.54$ pc. The effective radius is $R_e = 32.4$ arcsec and the systemic velocity is $v_{\rm sys} = 617$ km s^{-1}. The Sérsic index is $n_* = 3.6$ and the absolute B-band magnitude of NGC 4526, $M_B = -20.48$. Its total apparent corrected $B - V$ color is equal to 0.98 (from the HyperLeda database). 107 GCs belonging to NGC 1023 were used in our dynamical analysis and the slope of their GCs is $\gamma = 1.420$. The rotational velocity of GCs is $v_{\rm rot} = 142$ km s^{-1}.

3. DYNAMICAL MODELS

For all three S0 galaxies we solve the Jeans equation (e.g. Binney & Tremaine 2008) in a spherical approximation for both abovementioned approaches, Newtonian and MOND:

$$\frac{{\rm d}\sigma_r^2}{{\rm d}r} + (\alpha + 2\beta)\frac{\sigma_r^2}{r} = a_{\rm N;M} + \frac{v_{\rm rot}^2}{r}, \tag{1}$$

where $a_{\rm N;M}$ is an acceleration term which is different for each approach: in the Newtonian ('N') approach it is equal to $a_{\rm N} = -GM(r)/r^2$ and for MOND ('M'), $a_{\rm M}$ satisfies (Milgrom 1983): $a_{\rm M}\ \mu\left(\frac{a_{\rm M}}{a_0}\right) = a_{\rm N}$. In eq. 1, σ_r is the radial stellar velocity dispersion, $\alpha = {\rm d}\ln\nu/{\rm d}\ln r$ is the slope of tracer density ν. More details are available in S14.

The non-spherical nature of the GC dispersion is expressed through the following well-known equation, $\beta = 1 - \frac{\overline{v_\theta^2}}{\sigma_r^2},$. Three different cases of β were tested (purely isotropic case, radially and tangentially anisotropic cases) and the details are given in S14 and S17. The rotation and the dispersion profile are both folded into a root mean square velocity profile $v_{\rm rms} = \sqrt{v_{\rm rot}^2 + \sigma^2}$ where $v_{\rm rot}$ is the rotation velocity of each S0 galaxy studied here and σ is the dispersion. As can be seen above (Sections 2.1-2.3) all three S0 galaxies have non-negligible rotational velocities ($v_{\rm rot} \geq 100$ km s^{-1}).

4. RESULTS AND CONCLUSIONS

In Newtonian approach, for a constant mass-to-light ratio model we used a constant mass-to-light ratio (M/L_*) Sérsic model that uses a galaxy's field stars and DM is added to the stellar component in the form of an NFW (Navarro, Frank & White 1997) DM halo (see S14 and S17 for details). We also tested several MOND models using the Jeans equation in the spherical approximation, the "simple" MOND formula, the “standard” formula and the “toy” formula. The expressions and references are given in S14. The best-fit values for each tested model (all three cases of anisotropy were tested for all three S0 galaxies) are compared with the estimates coming from several stellar population synthesis (SPS) models (see S14 and S17 for details). Also, in S14 and S17 the details about the best-fitting NFW models are presented.

To summarize, we here used GCs as a tracer of the potential of three S0 galaxies. To infer the existence of DM we used the Newtonian (mass-follows-light and stars + NFW DM) models and MOND models to calculate the mass-to-light ratios, which were compared with the predictions of various SPS models based on the stellar matter.

Our most important conclusions are:

- We found that NGC 1023 does not need a significant amount of DM. On the other hand, for NGC 3115 and NGC 4526 the dark component completely dominates visible matter (for NGC 3115 even in the inner regions). The NFW models provided good fits for all three S0 galaxies. If one plots the concentration parameter of each galaxy as a function the virial mass one can see that while NGC 1023 and NGC 4526 can be found in the region predicted by the ΛCDM cosmology, the galaxy NGC 3115 has a very large concentration parameter inconsistent with its virial mass (see Fig. 8 in S17).

- We also solved the Jeans equation in the spherical approximation for three different MOND models (standard, simple and toy) and found that while for NGC 1023 all three MOND models can successfully fit the velocity dispersion without DM, both NGC 3115 and NGC 4526 need DM even using the MOND approach, although for NGC 4526 there is a hint that MOND can fit the velocity dispersion throughout the whole galaxy.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 333 - 336 *Poster*

TELESCOPE "MILANKOVIĆ": MOUNTING, PRESENT AND FUTURE WORK

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Abstract. In this contribution we present the final stages of the procurement of the telescope "Milanković" purchased by the Astronomical Observatory of Belgrade (AOB) using the funds of the FP7 REGPOT project BELISSIMA with the support of the Ministry of Education, Science and Technological Development of the Republic of Serbia. The final activities of the BELISSIMA project and the successful mounting of the 1.40 m telescope "Milanković" at the Astronomical Station Vidojevica (ASV) in 2016 are presented. We outline the present activities related to the ASV and we also describe observational projects currently active. Finally, we present the plans for the future related to the purchase of new instruments, continuation of present and initiation of new observational projects and future collaborations.

1. INTRODUCTION

The initial phases of the purchase of the 1.40 m telescope "Milanković" were described in Samurović (2017). We update here the information presented at the last National Conference of Astronomers of Serbia. The telescope "Milanković" was purchased through the BELISSIMA FP7 (Seventh Framework Programme) project (call FP7-REGPOT-2010-5) with the support of the Ministry of Education, Science and Technological Development of the Republic of Serbia. BELISSIMA started in July 2010 and was, due to the problems in the purchase and manufacturing, extended by the European Commission twice: first in 2013 and then in 2015. BELISSIMA successfully completed all the foreseen activities on 30 June 2016: the most important task was the mounting of the "Milanković" telescope, and this was done at the beginning of June 2016 (see Figure 1). The telescope was manufactured by the Austrian company Astrosysteme Austria (ASA) using the LOMO optics from Russia for the mirrors.

First light of the "Milanković" telescope showed that the observing conditions at Vidojevica are excellent: the seeing measured was found to be equal to 0.7 arc seconds which is comparable to the best observing sites in the world, such as Chile. These first results confirmed that both mechanics and optics are of excellent quality. In Figure 2 the first light image is shown (taken on 7 June 2016): this is the well-known spiral galaxy M51. The results also strongly suggest that the choice of the Vidojevica mountain was the right option for the new observing site of the Astronomical Obser-

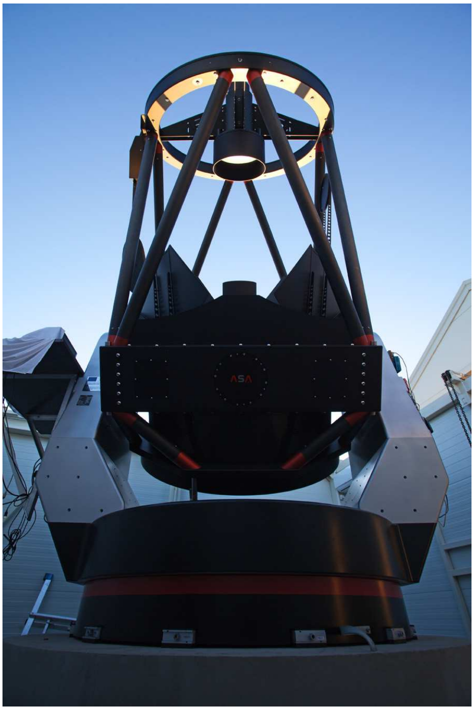

Figure 1: The "Milanković" telescope in the temporary pavilion.

vatory of Belgrade. The telescope was mounted in the temporary pavilion procured using the funds of the Serbian Ministry of Education, Science and Technological Development. Presently (Autumn 2017) it is still there, but as soon as the new pavilion is completed, the "Milanković" telescope will be transferred to the new building (see below).

2. TELESCOPE "MILANKOVIĆ": MAIN CHARACTERISTICS

The main characteristics of the "Milanković" telescope are:

- Mechanics: Astrosysteme Austria (ASA)
- Optics: LOMO, St. Petersburg, Russia
- Primary mirror diameter: 1.40 m
- Focal length: 11.2 m (f/8)
- Mount: alt-azimuth
- Weight: 8.5 tonnes
- Height: 4.5 meters
- Tubus: Open Truss Tube
- Motorized main and secondary mirror covering (computer-controlled)
- Motorized secondary mirror focuser (computer-controlled)
- Drive: Direct Drive Torque motors
- Nasmyth and "bent" Cassegrain foci

Figure 2: First light image: M51.

At the time of this writing (early November 2017) the building of the new pavilion is nearly completed and it is expected that the new, professional dome, manufactured by the reputable Italian company Gambato will be mounted in spring 2018. This will allow full robotization of the "Milanković" telescope.

3. TELESCOPE "MILANKOVIĆ": INSTRUMENTS

The following instruments are presently available for use with the "Milanković" telescope.

- New ANDOR iKonL CCD camera: 2048×2048 pixels, pixel size is 13.5×13.5 μm, field of view at the telescope $9' \times 9'$. The camera was procured in September 2017 and is being tested.
- Backup CCD camera Apogee U42 with the same characteristics as the above-mentioned iKonL CCD camera.
- New ANDOR iXon3 Ultra 897 CCD camera: 512×512 pixels, size of the pixel 16×16 μm. The camera was procured in April 2017 and is presently being tested.
- Spectrograph SpectraPro 2750 by the Princeton Instruments. Type: Cherny-Turner with 3 gratings 300, 600, 1200 lines/mm, with resolutions 44, 22, 10 $\mathring{A}$/mm and spectral ranges 1120, 560, 250 $\mathring{A}$.

4. OBSERVATIONAL PROJECTS

The presently active (and currently planned) observational projects are: (1) Eclipsing binary systems, (2) Visual double and multiple stars, (3) WEBT, GAIA follow-up,

(4) Asteroids, (5) Defining of the absolute coordinate system using quasars, (6) Photometry/spectroscopy of nearby spiral and elliptical galaxies, (7) Dwarf galaxies and tidal streams and (8) Shell galaxies.

In the future, it is planned that the already existing collaborations will continue (such as the work with the researchers from the Bulgarian Academy of Science on cataclysmic variable stars) and the new ones will start. In the Book of Proceedings of the international BELISSIMA conference (Samurović, Vukotić & Mićić 2013), as well as in proceedings of the two BELISSIMA workshops (Samurović, Vukotić & Martinović 2013, Samurović et al. 2016) various useful observational projects are presented. The rulebook for observations with the "Milanković" telescope is in its final stages of preparations and will be available soon for potential observers.

One important event related to the future observational projects from the Astronomical Station Vidojevica took place in Autumn 2017, immediately after the Serbian Astronomical Conference: the Serbian-Italian Astronomical Workshop (SIAR) was held on on 31 October 2017 at the Pupin Institute in Belgrade with approximately 50 participants. The prominent astronomers from Italy came to Belgrade to discuss the future observing projects and shared their experiences related to various astronomical observations, and other astronomical and technical and computational possibilities which include the usage of astronomical instruments, reductions, storage and analysis of the observed material.[1].

Acknowledgment

This work was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia through project no. 176021, "Visible and Invisible Matter in Nearby Galaxies: Theory and Observations". We thank the Ministry of Education, Science and Technological Development of the Republic of Serbia for the continued support related to the construction works at the Astronomical Station Vidojevica. We acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772).

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[1]The Web site of the workshop is `http://siar.aob.rs`

Publ. Astron. Obs. Belgrade No. 98 (2018), 337 - 340 *Poster*

STRONG SOLAR X-RAY FLARES: INFLUENCE ON THE IONOSPHERE

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Abstract. The perturbations in the D-region induced by solar flares were studied using monitored amplitude and phase data from Very Low Frequency (VLF, 3 - 30 kHz) and Low frequency (LF, 30 - 300 kHz) radio waves. All data were recorded by Belgrade stations system (44.85^0 N, 20.38^0 E). The focus of this work is on the study of perturbed amplitude on VLF/LF signal caused by strong solar flares. Results show that the magnitude of the VLF perturbations is in correlation with intensity of X-ray. The model computations applied to obtain the electron density enhancement induced by intense solar radiation.

1. INTRODUCTION

The monitoring of the lower ionosphere layers by the mean of the VLF/LF technique can play an important role for a better understanding of space weather conditions. It is now recognized that the plasma in the ionospheric D-region ($50 \leq h \leq 90$ km) is a very sensitive medium to external forcing like moderate solar influence, stellar explosive radiation, energetic particle intrusion (Šulić & Srećković 2014, Nina et al. 2011). Processes like solar emission in far-UV and EUV regions (Srećković et al. 2014) strongly affect the Earths atmosphere (Mitra, 1974). This intense solar radiation and activity can cause sudden ionospheric disturbances (SIDs) and further create ground telecommunication interferences, blackouts as well as natural disasters (Šulić et al. 2016).

2. RESULTS AND DISCUSSION

In this contribution we focus our attention to the analysis of amplitude and phase data, acquired by monitoring Very Low Frequency (VLF, 3 - 30 kHz) and Low Frequency (LF, 30 - 300 kHz) radio signals emitted by worldwide transmitters during SIDs. All the data were recorded at a Belgrade site by two receiver systems: Absolute Phase and Amplitude Logger (AbsPAL) system (Šulić et al. 2016) and Atmospheric Weather Electromagnetic System for Observation Modeling and Education (AWESOME)[1].

[1] http://solar-center.stanford.edu/SID/AWESOME/

The analysis and comparison of VLF data has been carried out together with the examination of the corresponding solar X-ray fluxes. The intensity of solar X-ray flux is recorded by the GOES satellites (Geostationary Operational Environmental Satellite)[2].

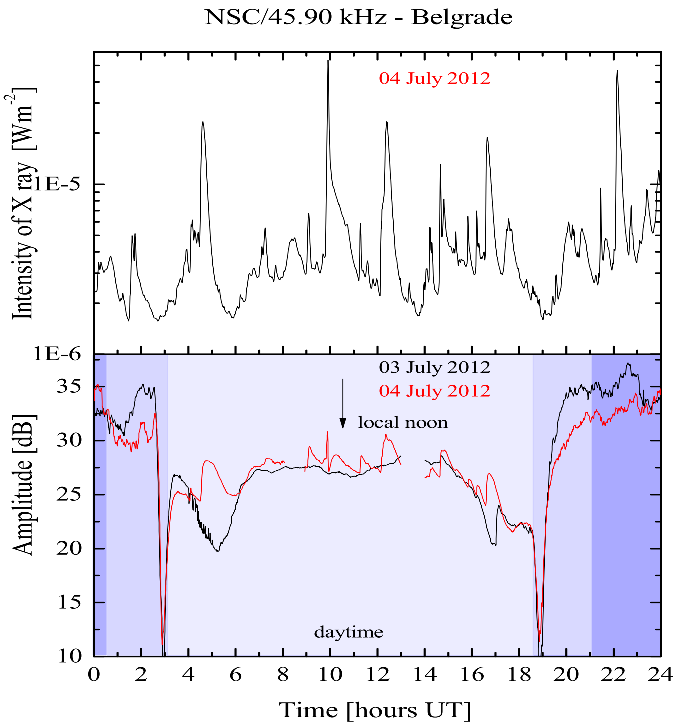

Figure 1: Variation of X-ray irradiance (panel 1), and amplitude (panel 2) on NSC/45.90 kHz radio signal recorded at Belgrade against universal time on 03 (normal day) and 04 July 2012.

Simultaneous observations of amplitude (A) and phase (ϕ) in VLF/LF radio signals during solar flares could be applied for calculation of electron density profile. Therefore, the perturbation of amplitude was estimated as a difference between values of the perturbed amplitude induced by flare and amplitude in the normal ionospheric condition: $\Delta A = A_{per}$ - A_{nor}, where "per" means the perturbed and "nor" means normal condition. In the same way the perturbation of phase was estimated as: $\Delta\phi$ = ϕ_{per} - ϕ_{nor}. During the occurrence of solar flares, classified as a minor and small flare up to the C3 class, the amplitude of the signal GQD/22.10 kHz and NSC/45.90 kHz does not have significant perturbations. A solar flare in the range from C3 to M3 classes induced an increase of the amplitude, which corresponds nearly proportional to the logarithm of the X-ray irradiance maximum (Šulić & Srećković, 2014). A numerical procedure for the calculation electron density from the Waits parame-

[2]https://satdat.ngdc.noaa.gov/sem/goes/data

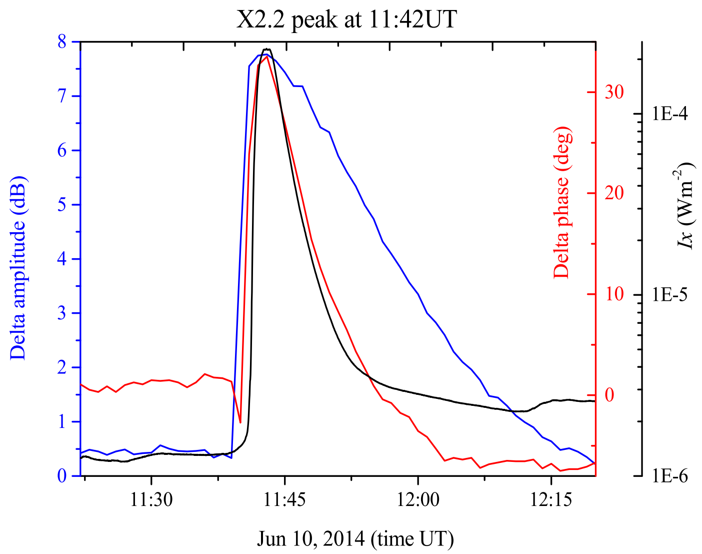

Figure 2: Variation of X-ray irradiance, phase increase and amplitude increase on GQD/22.10 kHz radio signal recorded at Belgrade against universal time on 10 Jun 2014.

ters is based on comparison of the recorded changes of amplitude and phase with the corresponding values obtained in simulations using the Long-Wave Propagation Capability (LWPC) numerical software package (Ferguson, 1998) as explained in (Šulić et al. 2014).

2. 1. AMPLITUDE PERTURBATIONS ON VLF/LF RADIO SIGNAL INDUCED BY SMALL AND MEDIUM CLASS SOLAR FLARES.

Fig.1 shows time variation of X ray irradiance and measured amplitudes on NSC/45.90 kHz radio signal for 03 and 04 July 2012 for time interval of 24 hours. Measured data for 03 July 2012 are given as reference level for normal ionospheric condition. Results show that the magnitude of the VLF perturbations is in correlation with intensity of solar X-ray.

2. 2. AMPLITUDE PERTURBATIONS ON VLF/LF RADIO SIGNAL INDUCED BY STRONG SOLAR FLARES.

For studding SID VLF/LF signatures we have selected solar flare events whose occurrences where in time intervals of few hours around local noon at Belgrade. All selected events (X2.2 class and X3.81 class) were recorded under similar solar zenith angles. Our results are presented on Figs. 2 and 3. Perturbations of the GQD/22.10 kHz radio signal are presented as temporal changes of ΔA and $\Delta\phi$ during solar flare event. From the figures we conclude:

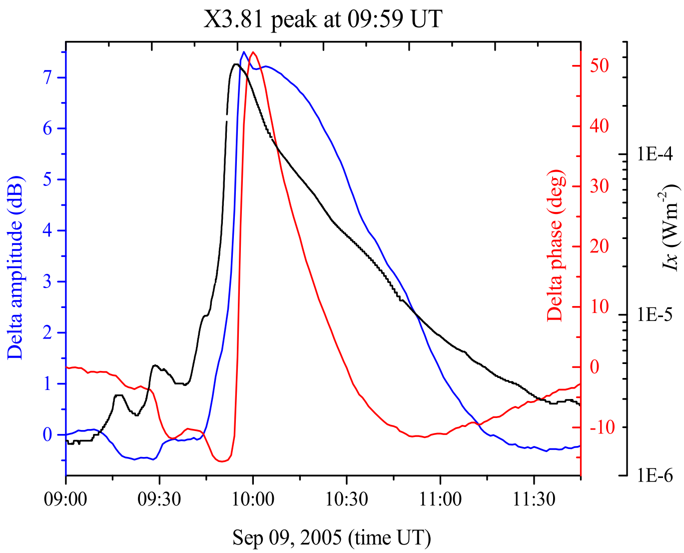

Figure 3: Variation of X-ray irradiance, phase increase and amplitude increase on GQD/22.10 kHz radio signal recorded at Belgrade against universal time on 9 September 2005.

- Changes of amplitude on radio signals during X class solar flares perform as well defined enhancement that follow the development of the maximum in X-ray radiation.
- During X2.2, and X3.81 class solar flare event electron density changes for three order of value at reference height $h = 74$ km in according to ambient value.

3. CONCLUSIONS

In this contribution the effect during the enhancements of X-ray flux due to the solar flares, on the propagating radio signal have been studied. The obtained results confirmed the successful use of applied technique for detecting space weather phenomena such as solar explosive events as well for describing and modeling the ionospheric electron density which are important as the part of electric terrestrial-conductor environment.

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Publ. Astron. Obs. Belgrade No. 98 (2018), 341 - 348 *Poster*

FIRST SPECTRA FROM THE TELESCOPE MILANKOVIĆ

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Abstract. Telescope Milanković is a 1.4m Nasmyth telescope that installed at Astronomical Station Vidojevica in May 2016. The telescope has 4 Nasmyth ports, thus it is suitable for using multiple instruments. Two Nasmyth ports are equipped with field de-rotators. While one port is used for photometrical/astrometrical measurements, the other was used to setup and calibrate a portable spectrograph SpectraPro 2750. In this paper, we present the first spectra obtained by this instrument.

1. INTRODUCTION

Astronomical Station Vidojevica (ASV) is an observational site of the Astronomical Observatory of Belgrade (AOB). It is located on the mountain Vidojevice (South-East Serbia) at altitude of about 1150 meters. ASV exist since 2003 but the first telescope, the 60cm Cassegrain telescope, was installed only in 2010 due to construction works on the site.

In line with preliminary plans, AOB purchased several CCD cameras for photometrical/astrometrical observations and one portable spectrograph for low resolution spectroscopy for the 60cm telescope. Using solar scattered light and HgAr calibration lamp Vince & Lalović (2005) tested the spectrograph for some basic spectral parameters - reciprocal linear dispersion and spectral resolution. They also proposed a method to link the spectrograph to the telescope using fibre optic bundle (FOB). However, the spectrograph has never been systematically used on 60cm telescope because of some technical difficulties out of which two most importants are: 1) relativelly small telescope primary mirror along with light losses that are common on spectrographs, it was usable only for very bright sources and 2) the optical connection between telescope and the spectrograph has never been solved properly.

However, with installation of the 1.4m telescope at ASV in May 2016, we have reconsidered the possibility to install again the spectrograph. We were motivated by the fact that primary mirror has much larger collecting area than the 60cm telescope and by the convenience to setup all the necessary equipment onto the Nasmyth platform.

In this paper we describe the spectrograph setup present the first spectra obtained on the 1.4m telescope Milanković

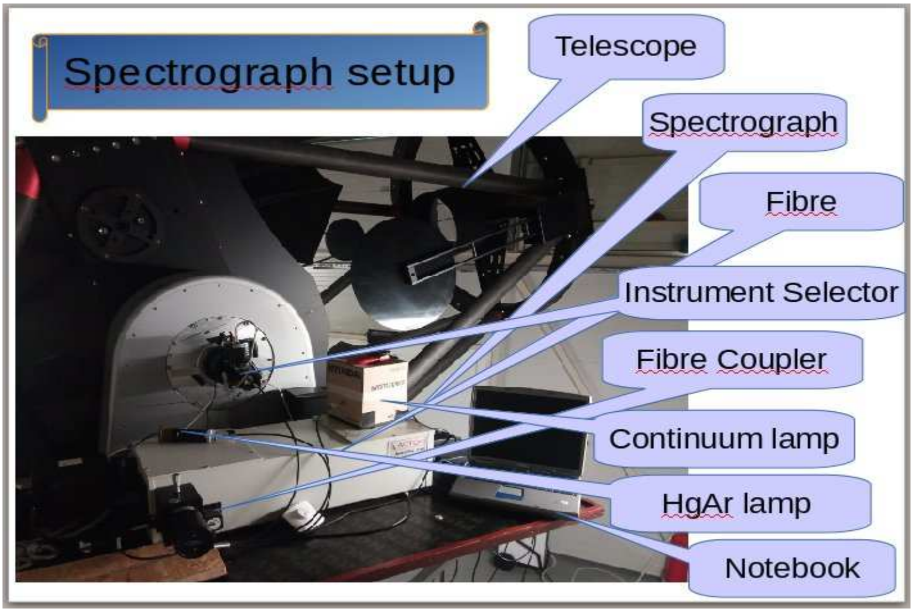

Figure 1: Spectrograph setup installed on the 1.4m telescope.

2. SPECTROGRAPH SETUP

The Figure 1 shows the spectrograph setup. Main element are labeled on the figure and they will be outlined in the following sections.

2. 1. TELESCOPE

Telescope Milanković is a 1.4m Nasmyth telescope which is thoroughly described in (at least) two papers in this proceedings - Vince et al. and Samurović et al. Therefore, only elements of the telescope that are specifically related to the spectrograph will be described in this section.

Milanković is a Nasmyth type of telescope and has 4 usable ports - two ports toward the telescope fork (classical Nasmyth) and two perpendicular to the fork (bent Cassegrain). The two classical Nasmyth ports are equipped with image de-rotator. While one of then is provided with field corrector, the other is free of any additional optics and is, therefore, suitable for installation of light-starwing instruments such as spectrograph. Additionaly, the port is oriented toward the telescope fork, so it is convenient to install a platform which can carry the portable spectrograph.

By design, the telescope was built to be a compact and easy-to-handle instrument. Therefore, all the electronics, along with the personal computer that run the telescope, are installed in the fork of the telescope. There are all souts of ports (ethernet, USB, power supply and so on) on the telescope that made easier to run the spectrograph.

2. 2. SPECTROGRAPH

Vince & Lalović (2005) described thoroughly the spectrograph, for that reason we only summarize its characteristics in this section as follows:

- The spectrograph is Cherny-Turner type.
- The focal ration of the spectrograph is 9.7.
- As a dispersion elements three gratings with different groove numbers are available - 300, 600 and 1200 grooves per millimeter. Gratings are installed on rotating turret and can be changed by software. Gratings are 68x68 square centimeters in size.
- Focal distances of both, collimator and camera mirrors are 750 cm.
- For detector, Spec-10 CCD camera from Princeton Instruments is used. The chip resolution is 1024x256 pixels and pixel size is 26 μm.
- According to specification, linear dispersion is 44, 22, and 10 $\AA$/mm for three gratings respectively.
- Spectral coverage with our detector is 1120, 560, 250 $\AA$ for the three grating modes.

The mechanical calibration of the spectrograph was performed in two steps:
- First, the CCD camera was focused and aligned with the entrance slit. The entrance slit was directly lightened by lamp for this calibrations. CCD adapter for the spectrograph allows both processes to be handled.
- Secondly, the FOB on the spectrograph side was focused and, since fibres are in slit arrangement, aligned with the entrance slit. For this purposes, the FOB was lightened by lamp.

The spectrograph was provided along with 32bit Windows software called WinSpec32. Except the entrance slit, all parts of the spectrograph are automated so it can be easily run remotely. Unfortunately, the software does not support FITS format but several non-commercial programs can be found on the internet. Unfortunately, the converter that we use for these purposes doesn't fill the FIST header with all parameters that are needed for later in image reduction (RA, DEC, OBS-TIME, DATE and so on). The observation time is the most critical one and must be recorded independently from the spectrograph software.

2. 3. FIBRE OPTICS

The optical connection between the 1.4m telescope and spectrograph is a FOB. There are several firm reasons to use FOB but the most important one in our case is that we found difficult to install the heavy (22kg) and big spectrograph directly on the de-rotator.

AOB procured several different types of FOBs from Acton Research Corporation (ARC) but only two types were used in our instrument setup. Both types include 200 μm diameter fibres but they differ in their number and arrangement. Left panel of the Figure 2 shows the 4-leg FOB (model QFB-455-3) with 3 fibres per leg. Right panel of the figure shows the 1-leg FOB (model code is LG-455-020) with 19 fibres in the leg. The illumination and slit ends of the two FOBs are shown in the small inserted images in the figure. As can be seen, fibres at the illumination end (or telescope end) have circular arrangement, whereas at slit end they have slit arrangement for both FOBs.

Four groups containing three fibres in the 4-legs FOB are separated at the slit end, so the FOB can be used to detect spectra from 4 different sources (even simultaneously if their brightness are similar). In our setup, we use this feature to detect spectra

Figure 2: Two FOBs that were used with spectrograph: 4-legs FOB (left) and 1-leg FOB (right).

from 1) a target, 2) HgAr lamp, 3) continuum lamp, and 4) pencil laser (laser is used for spectrograph calibration only). In general case, if adapter is carefully designed, it can be used to detect four different sources on the sky simultaneously (Multi-Object Spectrograph). This is the main advantage of the 4-leg FOB over the 1-leg one but there are numerous disadvantages as well. For example, due to telescope tracking errors, it is easier to keep the 1-leg FOB with 19 fibres on the target (200 μm diameter fibre scale about 4 arcsec of the sky at the focal plane of the telescope). Also, the flatfielding in classical way is meaningless because the spectrum of the tungsten lamp cover different pixels than spectrum from a target (or HgAr lamp).

We made spectral observations with both FOBs. However, we note that the 1-leg FOB must be setup manually during the night to acquire spectra from different sources (target and calibration lamps), so it is more difficult to use. More importantly, we don't know how these manual intervention influence the FOB characteristics. Theoretically, both, the throughput and the focal ratio degradation (see bellow) depends on FOB curvature.

It is important to note that the telescope beam is f/8 and the spectrograph acceptance cone is f/9.7. Due to this difference, there would be flux losses even if the spectrograph would be directly attached to the telescope (without fibre bundles). Relative to that, FOB increase light losses at least in two ways:

1) Focal ratio degradation (FRD) which "speeds up" the input focal ratio. In our case, f/8 telescope beam enters the FOB but only a portion of the incoming flux will leave the fibre bundle at f/8 due to FDR. Theoretically, the 100 % of the flux should be inside the numerical aperture of the fibre which is in our case of silica fibres and cladding 0.22 (that is f/2.22). More details on FRD can be found in Brodie et al. (1988).

2) Fresnel reflection occurs at the air-fibre interface at input and output ends of the FOB (about 4% per interface).

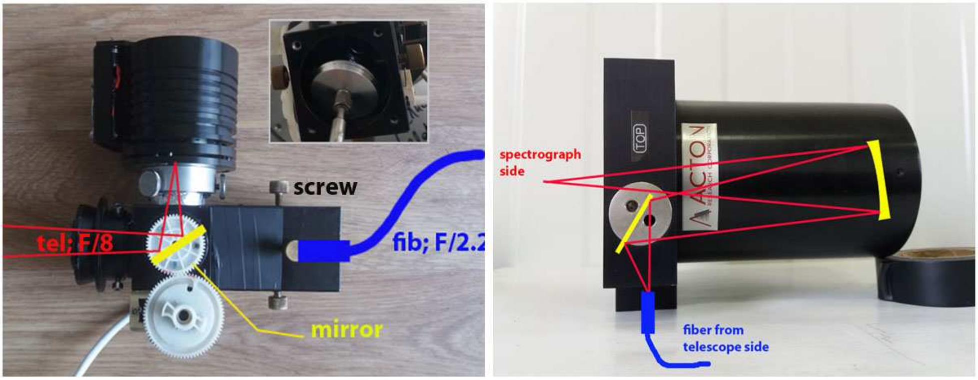

Figure 3: Instrument selector (left) and fibre coupler (right).

Flux losses due to FRD is usually mitigated by setting an adequate optical lens between FOB and spectograph. Vince & Lalović (2005) proposed a method to decrease light losses due to FRD in this manner. We didn't apply any correction for this effect but we have estimated the FOB output focal ratio to be about f/7 (the method will be described elsewhere) which means that we may expect photon losses due this effect.

2. 4. INSTRUMENT SELECTOR

At the telescope end, the FOB is connected to the telescope by instrument selector (IS) which is shown in the left panel of the Figure 3. IS is a home-made device with a flipping mirror which has two extreme positions - in one position, the mirror allows the light beam to hit the FOB and in the second position, the mirror redirects the light beam toward the CCD camera. The distance between the mirror and CCD chip is equal to the distance between the mirror and FOB, so the CCD has an essential role in focusing the stellar image on the FOB.

The second very important role of the IS is to enable precise pointing of the FOB to a star on the sky. The calibration of the IS for precise pointing is done by help of star image and consist of two steps: (1) the star image is centered on the CCD field of view and (2) the FOB is moved in the plane perpendicular to light beam until the largest flux is detected in the spectrograph (in zero order for example). Shifting a FOB is enabled by a disc which holds the bundle (show in the inserted image on the left panel of the Figure 3) which is grooved on the edge and can be moved in the plane by 4 screws on the ID.

Originally, the IS was an old OPTEC polarimeter and the fliping mirror was movable manually. For needs of the spectrograph, the mirror was motorized and can be controlled via serial port of the PC. Automatization of the IS was an essential part of the spectrograph setup.

2. 5. FIBRE COUPLER

At the spectrograph end, the FOB is connected to spectrograph by fibre coupler (FC) which was procured from ARC company (right panel of the Figure 3.). The

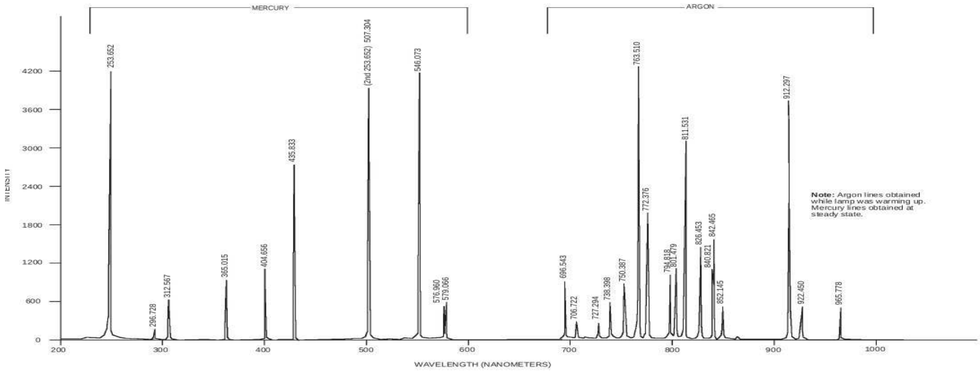

Figure 4: Emission line spectrum of the HgAr calibration lamp.

device eliminates chromatic aberrations and the aspheric mirror cancels astigmatism allowing precise imaging of fibers at slit.

2. 6. CALIBRATION LAMPS

We use two lamps for calibration of spectral images: (1) HgAr emission line lamp, which was purchased from Oriel Instruments Corporation, for wavelength calibration and (2) Tungsten continuum lamp for flatfielding. HgAr lamp has a drawback that spectrum is poorly populated with emission lines for λ¡700nm (see Figure 4.). This deficiency is especially noticeable when we work with 1200 groowes/mm grating where the spectral range is the lowest.

2. 7. NOTEBOOK

Unfortunately, the 64bit computer inside the fork of telescope couldn't run the WinSpec32 software, so we use a Dell Noteook to control the spectrograph and CCD. We communicate with the Notebook via WiFi internet connection.

3. RESULTS AND CONCLUSIONS

In this section, we show the first spectra made with our spectrograph on the 1.4m telescope. Results on measurements of some spectral parameters, as well as more spectral analysis, will be presented elsewhere.

Stellar spectra were acquired on several occasions in period from May to August 2017. We chose relatively bright targets (from 0 to 8 magnitudes in V band). We included in the sample photometric standard stars with the aim to measure spectrograph throughput and to compare our results with the catalog values.

For reduction purposes we acquired the following calibration images:

- Bias images for zero level correction.

- Dark images with the same exposure time as the target for dark current calibration.

- Flat images. Tungsten lamp was used as a light source for these images

- Emission line lamp images for wavelength calibration.

- Twilight sky images for illumination correction.

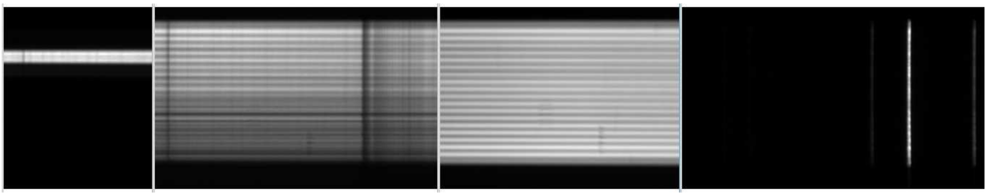

Figure 5: Raw calibration spectra. From left to right: target, twilight sky, flatfield lamp and emission line lamp images are presented

- Sky images. They were taken near the target with the aim to subtract sky background.
- Target images.

Due to ability of the CCD to cool down the sensor to -70 ^{o}C, dark images turned out unnecessary. Also, the night sky images, which were taken close background subtraction, were at the level of bias images even for the longest exposure time we applied (10 min), so they were also not used in the reduction process. Reduction and calibration of spectra were done in IRAF package.

Figure 5 shows raw spectra of the a target, twilight sky, tungsten lamp and emission line lamp from left to right. Spectra were made by 4-leg FOB. As can be seen, spectra from individual fibres in the FOB are clearly noticeable in the flatfield spectrum for example. Individual fibres sample about 4 arcsec of the sky, so this feature can be used for Integral Field Spectroscopy of extended sources.

From the target spectrum, we may see that the target is sampled by (only) two fibres in the FOB and the rest of the fibres sample the nearby sky. This feature can be used for background sky subtraction if needed (e.g. very bright sources may have extended scattered light under certain atmospheric conditions).

Figure 6. shows the spectrum of the HD192281 photometric standard star. The spectrum was first calibrated for bias and flatfield images. It was then extracted to one dimensional spectrum and wavelength calibrated. Lastly, relative intensities are converted to flux units to be able to compare to catalog values (star-like points). As can be seen, our spectrum agree well with the catalog values which indicates that the calibration was performed in a good way.

We note several important drawbacks of the spectrograph that observer should be aware of when using our spectrograph:

- At this point, we haven't guiding system on the telescope and the longest exposure time is limited to about 5 minutes. Consequently, one can't be sure if the FOB is pointing the target after 5 minutes due to tracking errors. This time period is based on experience and it depends on many factors (pointing model, wind and so on).

- As we have already mentioned, HgAr lamp is not the best one for calibration of 1200 g/mm grating spectra in the red part of the spectrum due to lack of strong (reliable) emission lines in the lamp spectrum. Telluric absorption lines may be used for calibration in some cases.

- There are certainly flux losses on different telescope/spectrograph elements but the most dominant one is the mismatch of instruments focal ratio. Still, with 5 min exposure, one may detect 8 magnitude star with relatively good signal to noise ratio

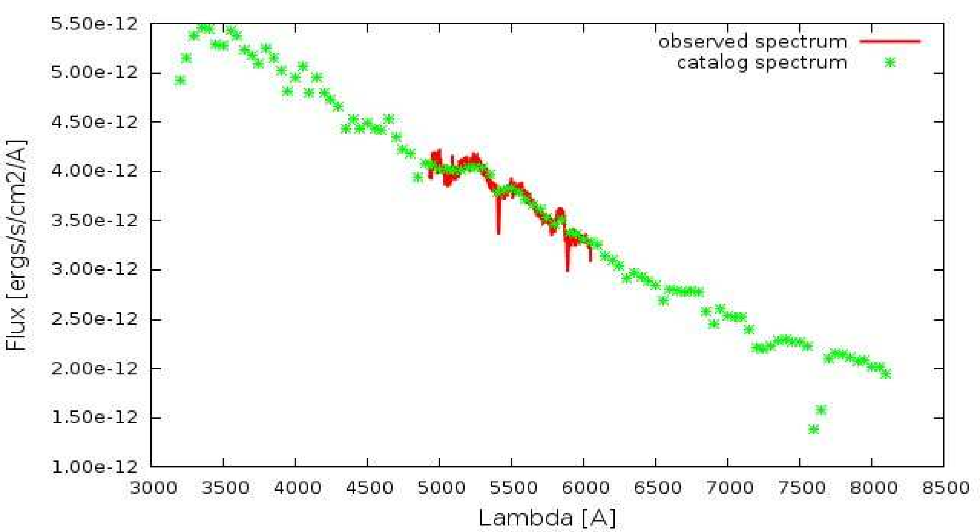

Figure 6: Flux calibrated spectrum of the HD192281 photometric standard star compared with catalog values

(SNR). If the spectrograph is well calibrated, the SNR mainly depends on seeing and it can be improved by fanning the primary mirror and airconditioning the pavilion before observations.

It is important to note that all the mentioned elements that badly influence our observations can be mitigated. Guiding system for example is out of function because the roll-roof of the pavilion can't be opened/closed when it is installed. Likewise, photon losses can be cured by adequate optics (see above).

Acknowledgment

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NEAR-INFRARED PHOTOMETRY OF THE NEARBY SPIRAL GALAXY NGC 2841

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Abstract. We present near-infrared photometry (Johnson-Cousins I passband) of the nearby spiral galaxy NGC 2841 obtained with the Apogee U42 CCD camera mounted on the 1.4m Milanković telescope at Astronomical Station Vidojevica (ASV) of Astronomical Observatory Belgrade (AOB). The methodology of observation given the sensitivity of the near-infrared I band to the sky background variations and fringing is presented in more details. The background model is created from a set of dithered exposures of a non-crowded field, avoiding the galaxy itself as an extended object by pointing the telescope 1 degree away from the galaxy to create the correct fringing pattern. The galaxy frames are corrected for this effect by subtracting the fringing pattern from each of them. The galaxy images are also taken with dithering to enable the creation of large mosaic, thus enlarging the field of view (FoV). This may be particularly useful in searching for dwarf candidates around nearby galaxies. The astrometric calibration was done using publicly available Astrometry code. Also, the photometric calibration was done using The Whole-Sky USNO-B1.0 catalog of stars. Finally, the surface brightness of NGC 2841 galaxy was decomposed into the bulge and the disk. The results are compared to the previous work in the infrared 3.6μm band.

1. INTRODUCTION

We have obtained deep near-infrared photometry (I band) with the use of the Apogee U42 CCD camera mounted on the 1.4m Milanković telescope. We selected the nearby giant, spiral galaxy NGC 2841, with the existing photometry, for the comparison. For this galaxy, the mid-infrared photometry is available from the Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al. 2003), but also the optical photometry from the Sloan Digital Sky Survey (SDSS-DR6; Adelman- McCarthy et al. 2008) and near-infrared photometry from the Two Micron All Sky Survey (2MASS) Large Galaxy Atlas (LGA; Jarrett et al. 2003). We compare derived surface brightness profile with the available optical, trough the near-infrared to the mid-infrared surface brightness profiles, from the literature.

2. DATA REDUCTION

We acquired 20 images of NGC 2841 galaxy in the I passband, dithered by one and a half of its semi major axis (1365 pixels or $220''$) in many directions. The optimal exposure time was 60 seconds. The reduction was done following the standard procedure in IRAF.

Astrometric calibration was done using `astrometry` software[1] (Hogg et al. 2010) and applied to all the images. Then, the IRAF's `imcombine` task was used to create a large mosaic of input images using WCS information in each of the image's header to determine the shift between the images. Afterwards, they were combined using median filter creating in addition the sigma image as the standard deviation of the input pixel values. Finally, we obtained FoV = $18' \times 18'$ out of the individual image FoV = $8' \times 8'$ (native). The point spread function image was created following the standard procedure in IRAF (`psf`) and will be used for the final surface brightness decomposition.

3. PHOTOMETRIC CALIBRATION

Relative photometry requires calibration using the set of standard stars. However, since we were not keen to achieve accuracy better than few percents, we used the simplified method. We relied on the existing stellar photometry in the I band from The Whole-Sky USNO-B1.0 catalog of stars (USNO-B.1; Monet et al. 2003) matching our field of view. First, we have created a catalog of stars with IRAF's `daofind` procedure, then measured aperture magnitudes of all the stars inside 20 pixels aperture (found using the curve-of-growth analysis). Then, we used `xy2sky` programme (Mink 1997) distributed as a part of a World Coordinate System Tools package (WCSTools) to produce a list of RA(2000) and Dec.(J2000) from the pixel coordinates using the WCS information in the image header for all the stars in the image.

Finally, the `Topcat` tool (Taylor 2005) was used to load a part of the USNO-B.1 catalog in the circle of $20'$ in radius around our image centre (NGC 2841), since our FoV was $\sim 18'$. Then we preformed the so-called "pair-match" between two catalogs and found 55 stars in common. However, after closer examination and exclusion of a few very faint stars and those lying close to the edge of the image and also a few faint galaxies, only 37 stars were left. We applied a weighted least-square fit in R 3.1.2 software, weighting these 37 stars by the number of their observations. We also required the slope to be equal to one exactly, since the offset (i.e. the intercept) is the zero-point magnitude. We found this offset to be 22.83 ± 0.03, including extinction correction, since the difference in magnitudes includes both zero-point and extinction correction.

4. IMAGE DECOMPOSITION

Surface brightness profile of the galaxy NGC 2841 was decomposed into bulge and disk component using publicly available `GALFIT` code (Peng 2010), that fits 2-D analytic functions to image objects (galaxies and point sources) based on the Levenberg-Marquardt algorithm. Initial fitting parameters (center coordinates, major-to-minor axes ratio and position angle) were estimated from the `Sextractor` (Bertin & Arnouts 1996) run on the mosaic image, providing also the mask image (with all the objects masked but the galaxy itself).

We kept the image center fixed, along with position angle to minimize the number of free parameters. Our best fit model has a bulge: $\mu_{\rm eff}[{\rm mag}/''^2] = 19.2, n = 3.7, R_{\rm eff}[''] = 28.0$ and a disk: $\mu_{\rm h}[{\rm mag}/''^2] = 20.6, R_{\rm h}[''] = 74.25$. In Samurović et

[1] `http://nova.astrometry.net`

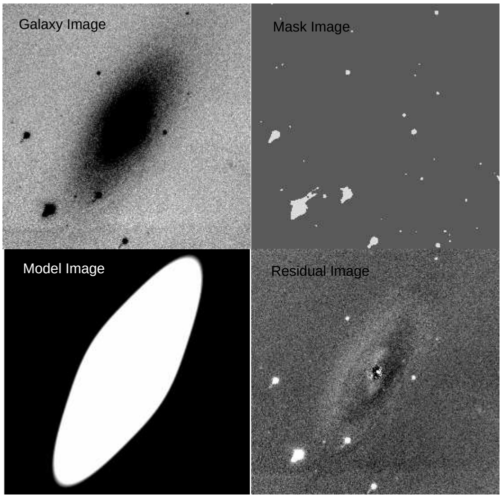

Figure 1: Image decomposition into a bulge and a disk. Upper-left: input galaxy image; upper-right: image of all the objects masked; lower-left: best-fitting model; lower-right: image residuals.

al. (2015) we derived structural parameters of the same galaxy in the mid- infrared (3.6 μm) using `Galfit` code and obtained disk scale length $R_h[''] = 56.69 \pm 1.1$ and the Sersic index $n = 3.22$ and the effective radius of the bulge $R_{\rm eff}[''] = 17.95 \pm 0.02$. The difference with the results obtained using the same procedure only in the near-infrared may be due to the different passband and/or different exposure time. In Fig. 1 decomposition is shown trough the steps included in the fitting procedure: the galaxy image (upper left) is modelled using a bulge and a disk component (lower left) starting from the initial parameters, masking all the objects in the mask image (upper right) and then convolved with the PSF to get the realistic model that is subtracted from the galaxy image to produce the fitting residuals (lower right). The fitting is done iteratively. In each step fine tuning initial galaxy parameters reduces the χ^2 until, at some point, this change becomes negligible.

Furthermore, the surface brightness was azimuthally averaged and modelled with the IRAF's `ellipse` procedure for the comparison with the previous work (Fig. 2).

5. RESULTS

This work was done to test the capabilities of the newly installed 1.4m Milankovic telescope, in particular enlarging the existing field of view ($\sim 8'$) trough mosaic creation to $18' \times 18'$ and, a part from that, inspecting large-scale variations of the sky in the near- infrared (I band). Two-dimensional decomposition is done. The radial surface brightness profile is in the good agreement with the previous work (Fig. 2).

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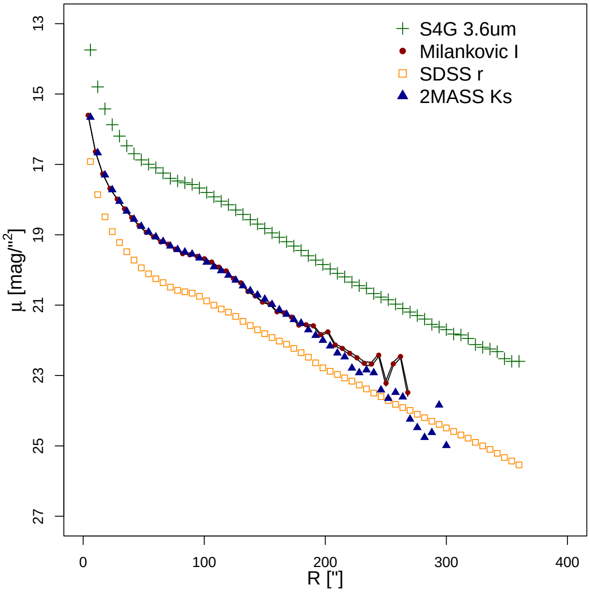

Figure 2: Radial surface brightness profile of galaxy NGC 2841: Milankovic I - this work (full circles); S4G 3.6μm - Spitzer's mid-infrared profile (crosses); SDSS r - optical SDSS profile in the r-band (empty boxes) and 2MASS Ks - near-infrared 2MASS data in the Ks-band (full triangles).

visible Matter in Nearby Galaxies: Theory and Observations", which we thank also for the continued support related to the construction works at the Astronomical Station Vidojevica. We acknowledge the financial support by the European Commission through project BELISSIMA (BELgrade Initiative for Space Science, Instrumentation and Modelling in Astrophysics, call FP7-REGPOT-2010-5, contract No. 256772).

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125th Anniversary of the Birth of Vojislav V. Mišković

Publ. Astron. Obs. Belgrade No. 98 (2018), 355 - 366 *Invited Lecture*

125 YEARS FROM THE BIRTH OF VOJISLAV V. MIŠKOVIĆ

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Abstract. The life and work of Academician Vojislav V. Mišković (1892–1976) are presented on the occasion of the 125th anniversary of his birth. His main scientific achievements, his roles as one of the first professors of astronomy at the University of Belgrade and the builder and director of the contemporary Astronomical Observatory of Belgrade are briefly mentioned and acknowledged. Particular attention is, however, paid to numerous activities and important duties he carried out in the Serbian Royal Academy (later Serbian Academy of Sciences, nowadays Serbian Academy of Sciences and Arts), after being elected its corresponding member in 1929, and the full member in 1939.

1. INTRODUCTION

As a famous French writer and occupant of the seat 29 in Académie française Amin Maalouf witnesses in his book "Un fauteuil sur la Seine : Quatre siècles d'histoire de France" (Maalouf 2016) in French Academy it is customary that the newly elected member in the inaugural speech pays a tribute to his/her predecessor in the Academy's seat. Such custom does not exist in the Serbian Academy of Sciences and Arts (SASA) as the newly elected members do not inherit the enumerated seat in the Academy. However, being only the second astronomer of all times, member of SASA, I found it more than appropriate to honor my "predecessor", the first ever astronomer in the Academy, Vojislav V. Mišković (Figure 1), on the occasion of the 125th anniversary of his birth.

Although I used to follow in his footsteps as the Director of the Astronomical Observatory of Belgrade too, while preparing my talk for the 18th Serbian Astronomical Conference, I realized that so much has already been written and said about Mišković's scientific work, his roles of the professor of the University of Belgrade and a builder of the present Astronomical Observatory of Belgrade (e.g. Protitch–Benishek and Djokić 1989, 1996; Protić–Benišek 2002) that little if anything new remains to be said. Let me just assert that Astronomical Observatory would certainly not be what it is today — one of the leading scientific institutions in our country and a recognizable distinct point on the world astronomy map, without a clever and skillful leadership of Vojislav Mišković in the crucial period of its development.

On the contrary, however, even with some surprise I learned that on his reach and important activities in the Serbian Royal Academy, later Serbian Academy of Sciences, and finally, nowadays, Serbian Academy of Sciences and Arts, comparatively little is published and known. Hence, I decided to devote my talk and this paper to this scarcely discussed and mostly undocumented aspect of Mišković's life and work, to browse the archives of the Academy and bring to light treasures hidden in the piles of folders, documents and memories stored therein.

2. A BRIEF BIOGRAPHY

Vojislav V. Mišković was born on January 18, 1892 in Fužine, Austro-Hungary (Primorje-Gorski Kotar County in todays Croatia, Figure 2). Soon, however, his family moved to Serbia, and he attended elementary school in Belgrade, Čačak, Priboj and Sukovo near Pirot, where his father used to work as a railway employee. In 1910 he graduated from the high school in Novi Sad, and subsequently enrolled at the University in Budapest to study astronomy. Since astronomy courses at the University were delayed for organizational reasons and did not start that very year, prompted by his strong desire to learn about stars and heavenly worlds, he leaves Budapest to continue studies first at the University of Götingen, and then in Vienna. Two years later he returns to Budapest, where the Chair of Astronomy has in the meantime enrolled its first students.

Led by strong national feelings, just before the outbreak of the First World War, he flees to Serbia and joins the military. During the war he shares the first great victories of the Serbian Army in 1914, but also the tragic experience and hardships of retreat of the Army across Albania to the Greek island of Corfu in 1915. He spent a brief period of time healing in France, only to rush back to the front in 1916. In the following years he witnesses the triumphant return of Serbian forces and liberation of the country.

Soon after the end of war, he has from Thessaloniki been sent for France to complete his studies, and graduates from the University of Marseille on June 21, 1920. Already in 1919 he began to work as an assistant at the Astronomical Observatory of Marseille, but leaves for Nice in 1922 where he becomes an astronomer at the local Observatory. There he commences his successful scientific career and publishes a number of papers devoted to observation, data reduction and determination of orbits of minor planets and comets, to stellar statistics, improvement of impersonal astrolabe with prism, etc. For the studies in stellar statistics he wins a prestigious *Prix Valtz* of the French Academy of Sciences. In the same field he completes thesis "Etudes de statistique stellaire" for the "state doctorate", which he successfully defends on July 17, 1924 at the University of Montpellier, thus becoming the first doctor of astronomy with Serbs.

In 1925, Mišković was "by invitation" elected associate professor of Theoretical and Practical Astronomy at the Faculty of Philosophy of the University of Belgrade and put in charge of managing the Astronomical Observatory of Belgrade. The letter of invitation was signed by three distinguished scientists, professors and academicians of the time: Milutin Milanković, Bogdan Gavrilović and Mihailo Petrović.

Upon return to Serbia, Mišković devoted all his time and strength to the new duties. He organizes and teaches the courses at the University, prepares and later manages building of the new Observatory, mounting of its instruments, organizing the observational work and astronomical services, commences editorial activities by initiating a number of Observatory's publications, and, in general, works hard to make the Observatory a fully functional scientific institute. The Astronomical Observatory, at which he served as director in two periods 1925—1946 and 1951—1953, remains his lifetime achievement for which he is best remembered by the contemporary Serbian astronomers and will be appreciated by the generations to come.

After the German occupation of the country, Mišković was in 1941 removed from the University, retaining, however, the position of the acting Director of Astronomical Observatory. Throughout the war he struggled to keep the Observatory running, as this was the condition to preserve its instruments and the Observatory itself. While Belgrade was being liberated from Germans in 1944 the Observatory suffered severe damages, but almost all of its principal instruments were saved, and in good enough condition to be, after necessary repairs, put back to work. For the most part this was Mišković's personal merit.

In the first turbulent post-war years, the Observatory has become an institute of the Serbian Academy of Sciences, and its Director was for a short while Milutin Milanković. Already in 1950, Mišković was elected President of the Council in charge of managing the Observatory, then appointed its Director when in 1951 Milanković, on behalf of Academy signed such a decision (Figure 3a), and appointed again in 1952, when Observatory became an independent scientific institute. He finally resigned from the post in 1953.

Dedicating most of his time and interest in the subsequent years to the teaching duties at the University and important activities in the Academy, on August 24, 1962 he applies for retirement, after 46 years, 1 month and 5 days of service of which 3 years, 5 months and 26 days in military service in the First World War (Figure 3b).

Vojislav V. Mišković passed away on November 25, 1976 in Belgrade, at the age of 84. For his achievements he was awarded a "Saint Sava" medal of the third order; asteroid (2348) Michkovitch, discovered at the Astronomical Observatory of Belgrade, bears his name.

3. MIŠKOVIĆ IN THE ACADEMY

In January 1929, three distinguished members of the Serbian Royal Academy, the same ones who previously invited Mišković to take over the professorship at the University of Belgrade, Bogdan Gavrilović, Milutin Milanković and Mihailo Petrović signed the proposal to elect Vojislav Mišković a corresponding member of the Academy (Figure 4).

The proposal was accepted and Mišković becomes corresponding member of the Academy on February 16, 1929.

A much shorter proposal (Figure 5a) for Mišković to be elected a full member, dated January 1, 1939, was on behalf of the Academy of Natural Sciences[1] signed by its 6 full members — Milutin Milanković, Bogdan Gavrilović, Mihailo Petrović, Anton Bilimović, Ivan Djaja, and Živojin Djordjević. After unanimous vote in favor of the proposal, which took place on February 16, 1939, King Petar II formally declares Vojislav Mišković a full member of the Academy on February 8, 1940 (Figure 5b). At the inaugural ceremony Mišković deliveres the speech entitled "The role of astronomy in collaboration with other sciences", which was later published in Academy's Glas (Mišković 1941).

[1] The Academy of Natural Sciences, together with three other Academies made part of the Serbian Royal Academy; they precede the present day Departments

The chronology of Mišković's appointments to various official positions in Academy begins in 1943 when he was elected Secretary of the Academy of Natural Sciences, in 1945 he becomes Secretary of the entire Serbian Royal Academy, in 1947 deputy Director of the newly founded Mathematical Institute of the Serbian Academy of Sciences, in 1950 he establishes the Numerical Institute of the Academy with a specific task to regularly produce the Nautical Almanac, and manages it in subsequent years. In the period 1956–1960 he serves as the Secretary of the Department of Natural Sciences of the Serbian Academy of Sciences and Arts, remaining a deputy Secretary until his final retirement from Academy's official positions in 1963.

Out of the plethora of activities and duties Mišković has been trusted with in the Academy, I'll here present only a few, which I found particularly interesting and important not only for the Academy itself, but also for revealing of Mišković's role in various Academy's affairs.

Let us begin with a Herculean task of moving the Storage of Academy's publications, as well as of the Library and Archive, from a nearby temporary location back to the permanent one in the building of the Academy in Brankova street 15, after the building was successfully repeared from the damage it suffered in the bombardment of Belgrade on April 6, 1941. Moving and complete reorganization of the Academy's services were, due to Mišković's extraordinary organizational skills and experience, completed in only 6 months, from August 1943 to January 1944. To illustrate how huge and complex this task was, it is enough to quote a few figures from his report to the Presidency of the Academy where he states that in the Storage there were 14 editions with 753 volumes of different content and 309 special printouts, a total of 357 240 books. All these books were counted, registered and stored, the corresponding rule books prepared, and all the necessary conditions for the regular sale of the Academy's editions created. Upon the completion of the task, appropriate recognition and acknowledgment was given to Mišković by the grateful Presidency.

The next thing I would like to present is the proposal of the then Secretary of Academy, Vojislav V. Mišković, to the Academy of Natural Sciences, of May 30, 1945, that is immediately after the end of the Second World War, regarding the organization of scientific work in the post-war Yugoslavia. In Figure 6 only three most interesting, out of the 10 pages of this handwritten proposal, are shown. In his recognizable ordered manner, he opens the document with a few general remarks on the need to use the human spiritual abilities and available energies for the organization of people's life and work after the war, to proceed with a list of seven items which are, according to him, necessary to organize properly the scientific work: delimitation of scientific disciplines, organization and founding of new scientific institutions, setting of the main directions and goals for scientific work in each research area, coordination of work, supervision of work, issuing initiatives and directives for work, maintaining relations with foreign institutions. Each item is thoroughly explained and justified, thus representing a well thought-out whole. Wouldn't these seven items easily make part of any, even quite contemporary, attempt at the national strategy of organization and development of scientific work?

Continuing along the same line of reasoning, Mišković concludes that to have a functional and efficient organization of scientific work, what is necessary is a strong bond between the state and the scientists, and this is best achieved through a dedicated scientifically highly competent body, capable of organizing and handling the scientific work in the country. Explaining convincingly why neither of the then existing academies of Yugoslav republics (Serbian – SANU, Croatian – JAZU, Slovenian – SAZU), nor a possible new, federal one, would represent a suitable choice for the task, he proposes founding of a special independent body, which he terms Federal Scientific Council, that would have a highest degree of freedom of action and the best chance of success in fulfilling such a complex task. Considering its possible structure, functions and responsibilities, he outlines the principal tasks of the main constituent organs and suggests that they should be composed of the most distinguished scientists, representatives of individual scientific disciplines. Eventually, he completes the proposal with a tentative list of Council's Scientific Departments. Doesn't this very much resemble the current proposal, supported by many Serbian scientists, to establish in Serbia an independent funding agency for science?

Let me conclude that it is indeed impressive how modern are Mišković's views regarding the efficient organization of scientific work he was promoting more than 70 years ago.

Such an interest in a large scale organization of scientific work and in the possible place of the national academies in the general scheme, as well as the position of the Secretary of the Serbian Academy of Sciences he occupied at the time, recommended him to take part in the talks regarding the foundation of the Yugoslav Academic Council, held in Zagreb in 1948. Representatives of the three above mentioned academies of Yugoslav republics agreed to establish close relations between the academies and strengthen their collaboration. Mišković took part in preparation of some of the documents for the Council, intended to define forms and modes, and to regulate the means of this collaboration. In the Mišković's bequest in the Archive of the Academy there are several photographs which preserve the memory of this meeting, out of which in Figure 7 we reproduce only one where all the participants of the meeting are shown in the garden of JAZU. On the back side of the photograph Michkovitch wrote the names of the people shown, among others those of Aleksandar Belić, president of SANU, Vladimir Nazor, president of JAZU, well known Croatian writer Miroslav Krleža, Pavle Savić, later president of SANU, and of Mišković himself.

The final piece in the mosaic of Mišković's activities and achievements in the Serbian Academy of Sciences, which I selected for this occasion, witnesses on his extraordinary skills in handling the crisis which nearly resulted in closing down of the Academy and in his masterful dealing with challenges of the duty of the Secretary of Academy in such a situation.

In the 1947 elections, Academy received recommendation from the political authorities to elect at least one foreign member from each Slavic country in order to show also in this way the friendly feelings of our people towards these countries. However, in elections held on April 9, a couple of candidates – "the most important contemporary representative" of Croatian literature, and the President of the Bulgarian Academy of Sciences – did not get enough votes and were not elected. To show his strong disagreement with the outcome of elections and with such a disrespect towards the new authorities, President of the Academy Aleksandar Belić, deeply concerned that this could be misinterpreted by the authorities and jeopardize the Academy, decides to resign not only from the position of the President, but also from the membership of the Academy itself. He was joined by other 10 members, among others Veljko Petrović, Toma Rosandić, Pavle Savić and Ivo Andrić.

The meeting at which their resignation (Figure 8a) was discussed was held on April 25, 1947. The discussion was quite lively, several critical opinions and sharp reactions were expressed, in particular by, e.g. Milutin Milanković, Anton Bilimović, and Ivan Djaja. The discussion, however, ended up when those who signed the resignation collectively left the room. At this point, since President was not there to chair the session, Secretary of the Academy Vojislav Mišković takes over, competently resolves the administrative problems regarding the continuation of the session in the form of the Academy Conference and smoothly brings it to a regular end. The conclusion, in the form of resolution (Figure 8b) signed by the 15 remaining members present at the Conference, states that the Conference cannot accept the motivation for the resignation of 11 academicians, since none of the Academy members which took part in the elections had been guided by the wish or intent implied in the resignation text. The Conference expressed its wish that those who signed the resignation consider withdrawing it, and declares that it does not accept the resignations.

The period following the April 25 meeting was turbulent for the Academy. Mišković continues to fulfill his duty of the Secretary and on May 3 sends a circular information (Figure 9a) to all the members of the Academy (including himself) about the letter of the Committee for Scientific Institutions, Universities and High Schools of the Government of the People's Republic of Serbia in which this Committee expresses opinion that after resignation of 11 members including the President of the Academy, the Serbian Academy of Sciences cannot successfully fulfill the tasks which are set before it as the highest scientific institution in the country; hence, the status of all the remaining members is to be "on hold", which practically means that the Academy is closed down. The only glimmer of hope was the concluding sentence of the letter which stated that the whole problem will be presented to the Government of PR Serbia for the final decision.

Luckily enough, on August 29, Mišković was able to send to the members of the Academy the decision of the Government (Figure 9b) which states "that Serbian Academy of Sciences should resume all its chores in the composition as before April 25". Together with this decision, the Government adopted a new law for the Academy, with which its status was fully regulated. The crisis was over.

4. CONCLUDING REMARKS

In this paper the biography of Vojislav V. Mišković is briefly outlined, with an emphasis to his activities in the Serbian Academy of Sciences and Arts and to his achievements and contributions he made serving as a member, and the more so as a high official of the Academy, of its constituent Academy of Natural Sciences and of its Department of Natural and Mathematical Sciences. Obviously, facts and events described here represent only a minute fraction of Mišković's legacy. It was simply not possible to include here all the documents kept in the Archive of the Academy, witnessing of many other important accomplishments of his: let me mention just his thorough report on the state and work of the Academy in the period 1941–1945, which he, in his capacity of the Secretary of Academy, delivered on March 28, 1946 at the Academy's regular annual assembly (Mišković 1948), a more detailed account of his founding and managing of the Numerical Institute, his scientific papers published in the Academy's publications (see, however, paper by S. Petrović and M. Čolaković in this volume), his editorial work, the important role he had in founding of the National

Committee for Astronomy of Yugoslavia, his official and personal correspondence, etc.

Most of the documents shown in this paper make part of the "hidden treasures" of the archives of the Serbian Academy of Sciences and Arts, and some of these are, to my knowledge, presented here for the first time. Thus, I believe, the goal beyond this writing – paying tribute to a great man on the occasion of the 125th anniversary of his birth – is successfully accomplished.

Acknowledgment

I am indebted to an anonymous referee for a careful reading of the manuscript and suggesting numerous corrections and improvements. This paper makes part of research carried out in the framework of the Serbian Academy of Sciences and Arts' project F-187.

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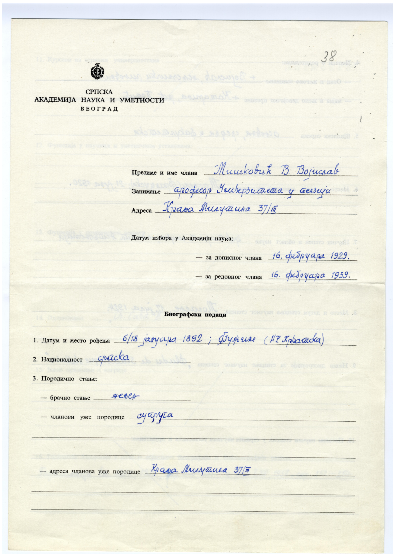
Protitch-Benishek, V. and Djokić, M.: 1996, From the notes on academician Vojislav V. Mišković, *Publ. Astron. Obs. Belgrade*, **No 54**, 171–174.

Figure 1: Vojislav V. Mišković, first PhD in astronomy with Serbs, professor of the University of Belgrade, builder of the present Astronomical Observatory of Belgrade, academician.



38

СРПСКА
АКАДЕМИЈА НАУКА И УМЕТНОСТИ
БЕОГРАД

Презиме и име члана Мишковић В. Војислав

Занимање професор Универзитета у пензији

Адреса Краља Милутина 37/III

Датум избора у Академији наука:

— за дописног члана 16. фебруара 1929.

— за редовног члана 16. фебруара 1939.

Биографски подаци

1. Датум и место рођења 6/18 јануара 1892 ; Фужине (НР Хрватска)

2. Националност српска

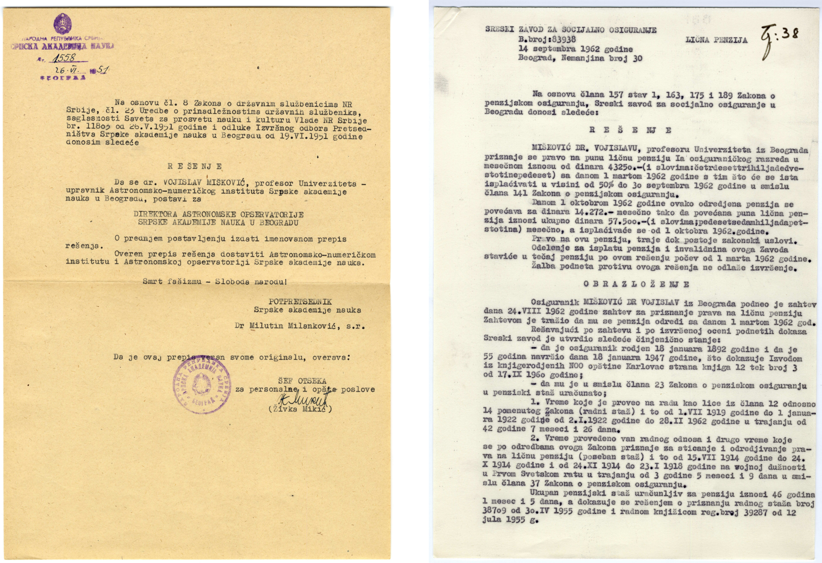
3. Породично стање:

— брачно стање ожењен

— чланови уже породице супруга

— адреса чланова уже породице Краља Милутина 37/III

Figure 2: Form filled in by Mišković, containing personal and biographical data (courtesy SASA Archive).



НАРОДНА РЕПУБЛИКА СРБИЈА
СРПСКА АКАДЕМИЈА НАУКА
Бр. 1558
26. VI. 1951
БЕОГРАД

Na osnovu čl. 8 Zakona o državnim službenicima NR Srbije, čl. 23 Uredbe o prinadležnostima državnih službenika, saglasnosti Saveta za prosvetu nauku i kulturu Vlade NR Srbije br. 11803 od 26.V.1951 godine i odluke Izvršnog odbora Pretsedništva Srpske akademije nauka u Beogradu od 19.VI.1951 godine donosim sledeće

R E ŠE NJ E

Da se dr. VOJISLAV MIŠKOVIĆ, profesor Univerziteta - upravnik Astronomsko-numeričkog instituta Srpske akademije nauka u Beogradu, postavi za

DIREKTORA ASTRONOMSKE OPSERVATORIJE
SRPSKE AKADEMIJE NAUKA U BEOGRADU

O prednjem postavljenju izdati imenovanom prepis rešenja.

Overen prepis rešenja dostaviti Astronomsko-numeričkom institutu i Astronomskoj opservatoriji Srpske akademije nauka.

Smrt fašizmu - Sloboda narodu!

POTPRETSEDNIK
Srpske akademije nauka

Dr Milutin Milanković, s.r.

Da je ovaj prepis veran svome originalu, overava:

ŠEF OTSEKA
za personalne i opšte poslove
(Živka Mikić)

SRESKI ZAVOD ZA SOCIJALNO OSIGURANJE
B.broj:83938
14 septembra 1962 godine
Beograd, Nemanjina broj 30

LIČNA PENZIJA

Na osnovu člana 157 stav 1, 163, 175 i 189 Zakona o penzijskom osiguranju, Sreski zavod za socijalno osiguranje u Beogradu donosi sledeće:

R E Š E NJ E

MIŠKOVIĆ DR. VOJISLAVU, profesoru Univerziteta iz Beograda priznaje se pravo na punu ličnu penziju Ia osiguraničkog razreda u mesečnom iznosu od dinara 43250.-(i slovima:četrdesettrihiljadedvestotinepedeset) sa danom 1 martom 1962 godine s tim što će se ista isplaćivati u visini od 50% do 30 septembra 1962 godine u smislu člana 141 Zakona o penzijskom osiguranju.

Danom 1 oktobrom 1962 godine ovako odredjena penzija se povećava za dinara 14.272.- mesečno tako da povećana puna lična penzija iznosi ukupno dinara 57.500.-(i slovima;pedesetsedamhiljadapetstotina) mesečno, a isplaćivaće se od 1 oktobra 1962.godine.

Pravo na ovu penziju, traje dok postoje zakonski uslovi.

Odelenje za isplatu penzija i invalidnina ovoga Zavoda staviće u tečaj penziju po ovom rešenju počev od 1 marta 1962 godine.

Žalba podneta protivu ovoga rešenja ne odlaže izvršenje.

O B R A Z L O Ž E NJ E

Osiguranik MIŠKOVIĆ DR VOJISLAV iz Beograda podneo je zahtev dana 24.VIII 1962 godine zahtev za priznanje prava na ličnu penziju Zahtevom je tražio da mu se penzija odredi sa danom 1 martom 1962 god.

Rešavajući po zahtevu i po izvršenoj oceni podnetih dokaza Sreski zavod je utvrdio sledeće činjenično stanje:

- da je osiguranik rodjen 18 januara 1892 godine i da je 55 godina navršio dana 18 januara 1947 godine, što dokazuje Izvodom iz knjigerodjenih NOO opštine Karlovac strana knjiga 12 tek broj 3 od 17.IX 1960 godine;

- da mu je u smislu člana 23 Zakona o penziskom osiguranju u penziski staž uračunato;

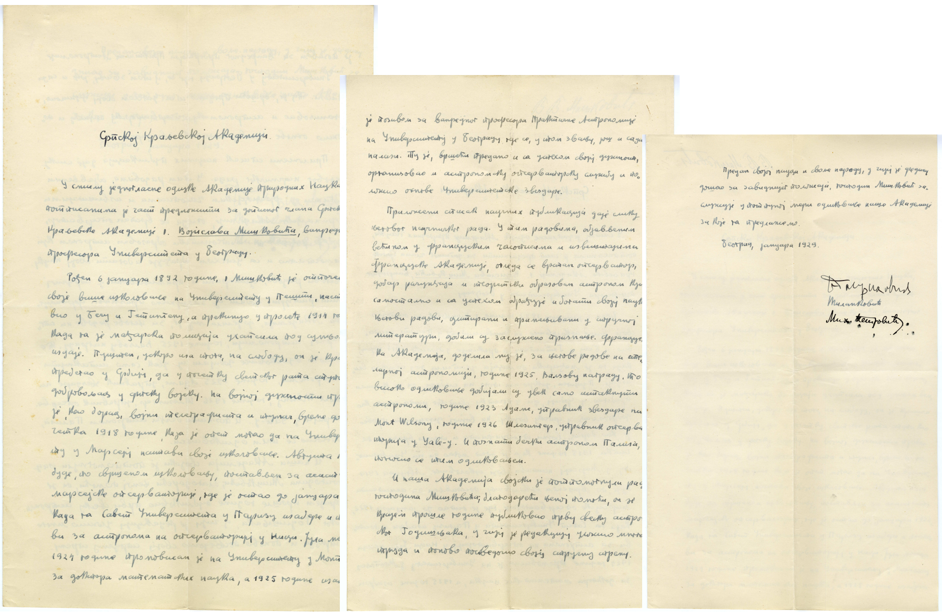
1. Vreme koje je proveo na radu kao lice iz člana 12 odnosno 14 pomenutog Zakona (radni staž) i to od 1.VII 1919 godine do 1 januara 1922 godine od 2.I.1922 godine do 28.II 1962 godine u trajanju od 42 godine 7 meseci i 26 dana.

2. Vreme provedeno van radnog odnosa i drugo vreme koje se po odredbama ovoga Zakona priznaje za sticanje i odredjivanje prava na ličnu penziju (poseban staž) i to od 15.VII 1914 godine do 24. X 1914 godine i od 24.XI 1914 do 23.I 1918 godine na vojnoj dužnosti u Prvom Svetskom ratu u trajanju od 3 godine 5 meseci i 9 dana u smislu člana 37 Zakona o penziskom osiguranju.

Ukupan penzijski staž uračunljiv za penziju iznosi 46 godina 1 mesec i 5 dana, a dokazuje se rešenjem o priznanju radnog staža broj 38709 od 30.IV 1955 godine i radnom knjižicom reg.broj 39287 od 12 jula 1955 g.

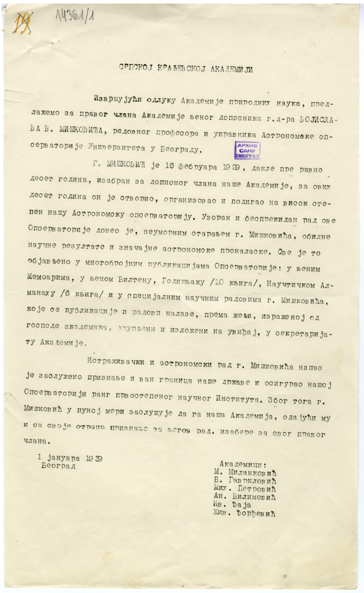
(a) (b)

Figure 3: (a) Document by which Milanković appoints Mišković Director of the Observatory. (b) Decision on Mišković's retirement (courtesy SASA Archive).



(a) (b) (c)

Figure 4: Proposal to the Serbian Royal Academy to elect Vojislav Mišković its corresponding member (courtesy SASA Archive).



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СРПСКОЈ КРАЉЕВСКОЈ АКАДЕМИЈИ

Извршујући одлуку Академије природних наука, предлажемо за правог члана Академије њеног дописника г.д-ра ВОЈИСЛАВА В. МИШКОВИЋА, редовног професора и управника Астрономске опсерваторије Универзитета у Београду.

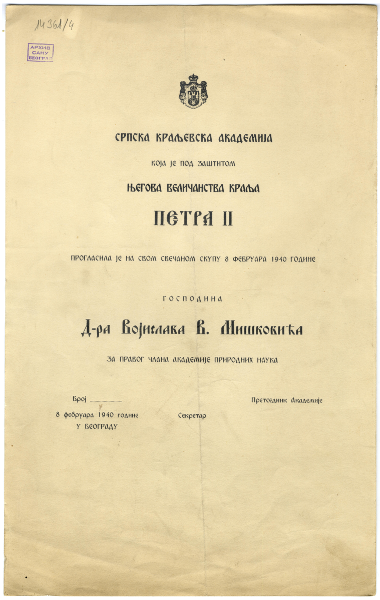
АРХИВ САНУ БЕОГРАД

Г. МИШКОВИЋ је 16 фебруара 1929, дакле пре равно десет година, изабран за дописног члана наше Академије, за ових десет година он је створио, организовао и подигао на висок степен нашу Астрономску опсерваторију. Узоран и беспрекидан рад ове Опсерваторије донео је, неуморним старањем г. Мишковића, обилне научне резултате и значајне астрономске проналаске. Све је то објављено у многобројним публикацијама Опсерваторије: у њеним Мемоарима, у њеном Билтену, Годишњаку /10 књига/, Научничком Алманаху /6 књига/ и у специјалним научним радовима г. Мишковића, које се публикације и радови налазе, према жељи, израженој од господе академика, скупљени и изложени на увиђај, у секретаријату Академије.

Истраживачки и астрономски рад г. Мишковића нашао је заслужено признање и ван граница наше државе и осигурао нашој Опсерваторији ранг првостепеног научног Института. Због тога г. Мишковић у пуној мери заслужује да га наша Академија, одајући му и са своје стране признање за његов рад, изабере за свог правог члана.

1 јануара 1939
Београд

Академици:
М. Миланковић
Б. Гавриловић
Мих. Петровић
Ан. Билимовић
Ив. Ђаја
Жив. Ђорђевић



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АРХИВ САНУ БЕОГРАД

СРПСКА КРАЉЕВСКА АКАДЕМИЈА

КОЈА ЈЕ ПОД ЗАШТИТОМ

ЊЕГОВА ВЕЛИЧАНСТВА КРАЉА

ПЕТРА II

ПРОГЛАСИЛА ЈЕ НА СВОМ СВЕЧАНОМ СКУПУ 8 ФЕБРУАРА 1940 ГОДИНЕ

ГОСПОДИНА

Д-ра Војислава В. Мишковића

ЗА ПРАВОГ ЧЛАНА АКАДЕМИЈЕ ПРИРОДНИХ НАУКА

Број ....

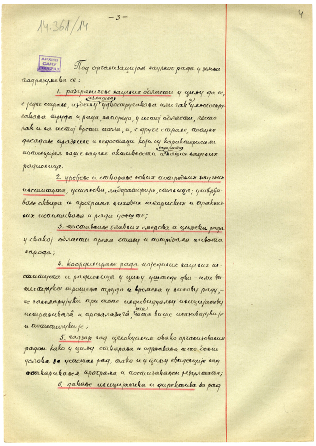
Претседник Академије

8 фебруара 1940 године
У БЕОГРАДУ

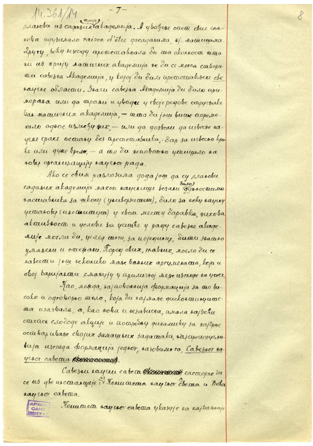
Секретар

(a) (b)

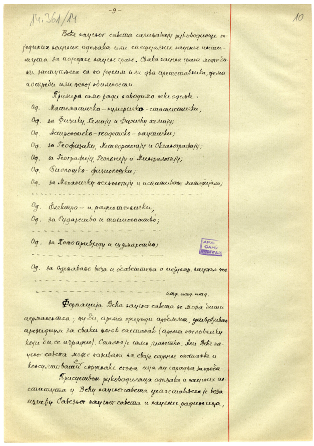
Figure 5: (a) Proposal for Mišković to be elected a full member of the Academy. (b) King's declaration (courtesy SASA Archive).



(a) Page 3



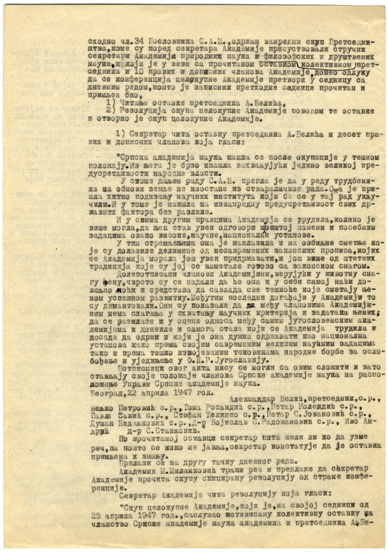
(b) Page 7



(c) Page 9

Figure 6: The three pages from the Mišković's proposal regarding the organization of scientific work (courtesy SASA Archive).

Figure 7: Participants of the meeting in Zagreb, April 1947 (courtesy SASA Archive).



сходно чл.34 Пословника С.А.Н.,одржан ванредни скуп Претседништва,коме су поред секретара Академије присуствовали стручни секретари Академија природиих наука и филозофских и друштвених наука,и који је у вези са прочитаном оставком колективном претседника и 10 правих и дописних чланова Академије,донео одлуку да се конференција целокупне Академије претвори у седницу са дневним редом,пошто је записник претходне седнице прочитан и примљен био,

1) Читање оставке претседника А.Белића,
2) Резолуција скупа целокупне Академије поводом те оставке

и отворио је скуп целокупне Академије.

1) Секретар чита оставку претседника А.Белића и десет правих и дописних чланова која гласи:

"Српска академија наука нашла се после окупације у тешком положају.Из њега је брзо изашла захваљујући једино великој предусретљивости народне власти.

У своме даљем раду С.А.Н. прегла је да у реду трудбеника на обнови земље не изостане из стваралачког рада.Она је пришла хитно подизању научних института који би се у тај рад укључили.И у томе је наишла на изванредну предусретљивост свих државних фактора без разлике.

И у свима другим правцима Академија се трудила,колико је више могла,да њен став увек одговори њеној намени и посебним задацима овако високе,научне,националне установе.

У тим стремљењима она је наилазила и на озбиљне сметње које су долазиле делимице од несавремених законских прописа,којих се Академија морала још увек придржавати,и још више од штетних традиција које су јој се наметале готово са законском снагом.

Долепотписани чланови Академијини,верујући у животну снагу њену,чврсто су се надали да ће она и у себи самој наћи довољно моћи и средстава да савлада све тешкоће које сметају њеном успешном развитку.Међутим последни догађаји у Академији то су демантовали.Они су показали да међу члановима Академијиним нема слагања у схватању научних критерија и задатака њених; да се разилазе и у оцени односа међу самим југословенским академијама и донекле и самога става који се Академија трудила и досада да одржи и који је она дужна одржавати као национална установа како према својим савременим великим научним задацима тако и према тешко извојеваним тековинама народне борбе за ослобођење и уједињење у Ф.Н.Р.Југославију.

Потписници овог акта нису се могли са овим сложити и зато стављају своје положаје чланова Српске академије наука на располагање Управи Српске академије наука.

Београд,22 априла 1947 год.

Александар Белић,претседник,с.р.,

Вељко Петровић с.р.,Тома Росандић с.р.,Петар Колендић с.р., Павле Савић с.р., Стефан Јелинек с.р.,Петар С.Јовановић с.р., Душан Недељковић с.р.,Д-р Војислав С.Радовановић с.р., Иво Андрић д-р С.Станковић.

По прочитаној оставци секретар пита жели ли ко да узме реч,па пошто се нико не јавља,секретар констатује да је оставка примљена к знању.

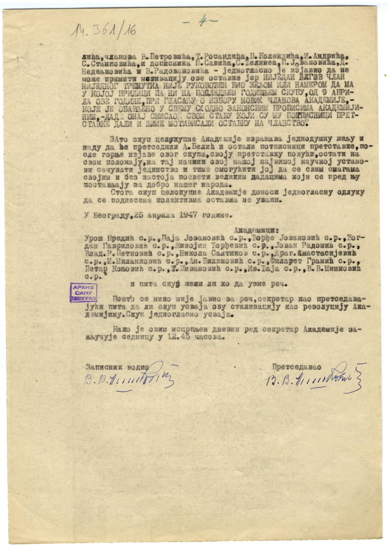
Прелази се на другу тачку дневног реда.

Академик М.Миланковић тражи реч и предлаже да секретар Академије прочита скупу стилизирану резолуцију од стране конференције.

Секретар Академије чита резолуцију која гласи:

"Скуп целокупне Академије,који је,на својој седници од 25 априла 1947 год.,саслушао мотивисану колективну оставку на чланство Српске академије наука академика и претседника А.Бе-

(a)



14.361/16

-4-

лића,чланова В.Петровића,Т.Росандића,П.Колендића,И.Андрића, С.Станковића,и дописника П.Савића,С.Јелинеа,П.Јовановића,Д. Недељковића и В.Радовановића - једногласно је изјавио да не може примити мотивацију ове оставке јер НИЈЕДАН ЊЕГОВ ЧЛАН НИЈЕДНОГ ТРЕНУТКА НИЈЕ РУКОВОЂЕН БИО ЖЕЉОМ ИЛИ НАМЕРОМ ДА МА У КОЈОЈ ПРИЛИЦИ ПА НИ НА ПОСЛЕДЊЕМ ГОДИШЊЕМ СКУПУ,ОД 9 АПРИЛА ОВЕ ГОДИНЕ,ПРИ ГЛАСАЊУ О ИЗБОРУ НОВИХ ЧЛАНОВА АКАДЕМИЈЕ,-КОЈЕ ЈЕ ОБАВЉЕНО У СВЕМУ СХОДНО ЗАКОНСКИМ ПРОПИСИМА АКАДЕМИЈИНИМ,-ДАДЕ ОНАЈ СМИСАО СВОМ СТАВУ КОЈИ СУ МУ ПОТПИСНИЦИ ПРЕТСТАВКЕ ДАЛИ И ЊИМЕ МОТИВИСАЛИ ОСТАВКУ НА ЧЛАНСТВО.

ЗАто скуп целокупне Академије изражава једнодушну жељу и наду да ће претседник А.Белић и остали потписници претставке,после горње изјаве овог скупа,своју претставку повући,остати на свом положају,на тај начини овој нашој највишој научној установи сачувати јединство и тиме омогућити јој да се свим снагама својим и без застоја посвети великим дадацима који се пред њу постављају за добро нашег народа.

Стога скуп целокупне Академије доноси једногласну одлуку да се поднесена колективна оставка не уважи.

У Београду,25 априла 1947 године.

Академици:

Урош Предић с.р.,Паја Јовановић с.р.,Ђорђе Јовановић с.р.,Богдан Гавриловић с.р.,Живојин Ђорђевић с.р.,Јован Радонић с.р., Влад.Р.Петковић с.р.,Никола Салтиков с.р.,Драг.Анастасијевић с.р.,М.Миланковић с.р.,Ан.Билимовић с.р.,Филарет Гранић с.р., Петар Коњовић с.р.,Т.Живановић с.р.,Ив.Ђаја с.р.,В.В.Мишковић с.р."

и пита скуп жели ли ко да узме реч.

АРХИВ САНУ БЕОГРАД

Пошто се нико није јавио за реч,секретар као претседавајући пита да ли скуп усваја ову стилизацију као резолуцију Академијину.Скуп једногласно усваја.

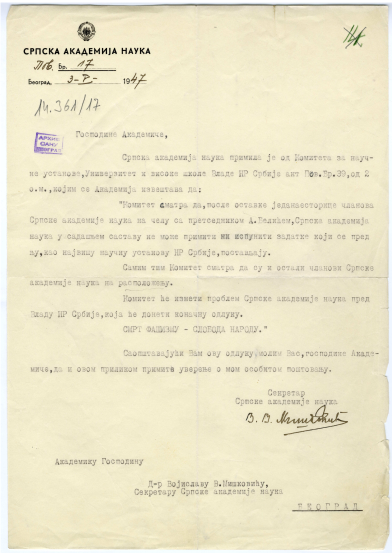
Како је овим исцрпљен дневни ред секретар Академије закључује седницу у 12.45 часова.

Записник водио В.В.Мишковић

Претседавао В.В.Мишковић

(b)

Figure 8: The two final pages of the minutes of the April 25, 1947 meeting, containing the text of the resignation with the signatories (a), and the text of the resolution of the Academy Conference with its signatories (b) (courtesy SASA Archive).



СРПСКА АКАДЕМИЈА НАУКА
Пов. Бр. 17
Београд, 3-V- 1947

14.361/17

АРХИВ САНУ БЕОГРАД

Господине Академиче,

Српска академија наука примила је од Комитета за научне установе,Универзитет и високе школе Владе НР Србије акт Пов.Бр.39,од 2 о.м.,којим се Академија извештава да:

"Комитет сматра да,после оставке једанаесторице чланова Српске академије наука на челу са претседником А.Белићем,Српска академија наука у садашњем саставу не може примити ни испунити задатке који се пред њу,као највишу научну установу НР Србије,постављају.

Самим тим Комитет сматра да су и остали чланови Српске академије наука на расположењу.

Комитет ће изнети проблем Српске академије наука пред Владу НР Србије,која ће донети коначну одлуку.

СМРТ ФАШИЗМУ - СЛОБОДА НАРОДУ."

Саопштавајући Вам ову одлуку,молим Вас,господине Академиче,да и овом приликом примите уверење о мом особитом поштовању.

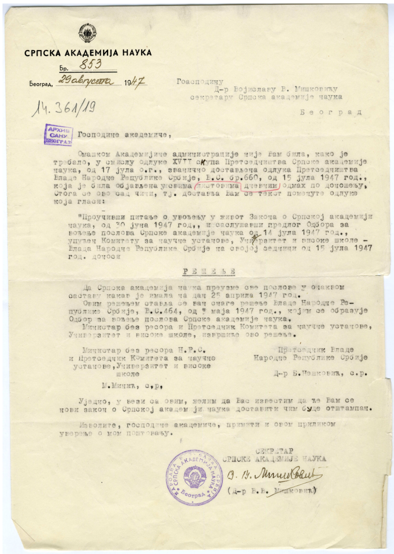
Секретар
Српске академије наука
В. В. Мишковић

Академику Господину

Д-р Војиславу В.Мишковићу,
Секретару Српске академије наука

БЕОГРАД

(a)



СРПСКА АКАДЕМИЈА НАУКА
Бр. 853
Београд, 29 августа 1947

Гоасподину
Д-р Војиславу В. Мишковићу
секретару Српска академије наука
Београд

14.361/19

АРХИВ САНУ БЕОГРАД

Господине академиче,

Омашком Академијине администрације није Вам била, како је требало, у смислу одлуке XVIII скупа Претседништва Српске академије наука, од 17 јула о.г., званично достављена одлука Претседништва Владе Народне Републике Србије, В.С. бр.660, од 15 јула 1947 год., која је била објављена у свима листовима дневним одмах по доношењу. Стога се ово сад чини, тј. доставља Вам се текст поменуте одлуке која гласи:

"Проучивши питање о увођењу у живот Закона о Српској академији наука, од 30 јуна 1947 год., и саслушавши предлог Одбора за вођење послова Српске академије наука од 14 јула 1947 год., упућен Комитету за научне установе, Универзитет и високе школе - Влада Народне Републике Србије на својој седници од 15 јула 1947 год. доноси

РЕШЕЊЕ

Да Српска академија наука преузме све послове у оноаквом саставу какав је имала на дан 25 априла 1947 год.

Овим решењем ставља се ван снаге решење Владе Народне Републике Србије, В.С.464, од 7 маја 1947 год., којим се образује Одбор за вођење послова Српске академије наука.

Министар без ресора и Претседник Комитета за научне установе, Универзитет и високе школе, извршиће ово решење.

Министар без ресора Н.Р.С. и Претседник Комитета за научне установе,Универзитет и високе школе
М.Минић, с.р.

Претседник Владе Народне Републике Србије
Д-р Б.Нешковић, с.р.

Уједно, у вези са овим, желим да Вас известим да ће Вам се нови закон о Српској академији наука доставити чим буде отштампан.

Изволите, господине академиче, примити и овом приликом уверење о мом поштовању.

СЕКРЕТАР
СРПСКЕ АКАДЕМИЈЕ НАУКА
В. В. Мишковић
(Д-р В.В. Мишковић)

НАРОДНА РЕПУБЛИКА СРБИЈА СРПСКА АКАДЕМИЈА НАУКА Београд

(b)

Figure 9: The circular information sent to all the academicians by the Secretary Mišković: (a) the Academy is closed down; (b) the Academy continues as before. (courtesy SASA Archive).

Publ. Astron. Obs. Belgrade No. 98 (2018), 367 - 370 *Contributed Paper*

TRAGOVI VOJISLAVA MIŠKOVIĆA U BIBLIOTECI SANU

M. ČOLAKOVIĆ and S. PETROVIĆ

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E–mail: sanja.petrovic@bib.sanu.ac.rs

Razmatranje naučnog rada i doprinosa akademika Vojislava Miškovića neodvojivo je od njegovog rada i angažmana u okviru Srpske akademije nauka i umetnosti, pa samim tim i njene biblioteke, koja svakako u to vreme nije postojala ni radila u obimu u kom radi danas ali jeste bila značajna.

Akademik Vojislav Mišković studirao je na univerzitetima u Getingenu i Budimpešti, a pred izbijanje Prvog svetskog rata prebegao je u Srbiju. U ratu je učestvovao sve do 1918. godine, kada je oslobođen vojne obaveze da bi u Francuskoj završio započete studije. Diplomirao je astronomiju na Univerzitetu u Marseju 1919. godine i postao asistent pri tamošnjoj Astronomskoj opservatoriji. Doktorski ispit iz astronomije položio je u Monpeljeu 1924. sa disertacijom "Etudes de statistique stellaire". Na predlog profesora Mihaila Petrovića, Bogdana Gavrilovića i Milutina Milankovića, izabran je 1925. godine za vanrednog profesora teorijske i praktične astronomije na Univerzitetu u Beogradu i postao upravnik Astronomske opservatorije. Za dopisnog člana Srpske kraljevske akademije izabran je već 1929. godine, a 1939. postao i njen redovni član. Pristupnu akademsku besedu pod nazivom "Uloga astronomije u saradnji sa ostalim naukama" održao je 8. februara 1940. Posvetio se izgradnji današnje Astronomske opservatorije na Zvezdari, čiji je upravnik bio do 1945. iako je u raznim vidovima učestvovao u njenom radu sve do 1953. godine. Bio je među osnivačima Matematičkog instituta 1946. godine i osnivač Astronomsko–numeričkog instituta 1950. godine, čiji je bio i prvi upravnik.

Kao jedan od najaktivnijih članova Srpske akademije nauka i umetnosti, a od 1943. i sekretar Odeljenja prirodno–matematičkih nauka (u to vreme Akademije prirodnih nauka) kao i član Komisije za obezbeđenje Akademijine arhive, Vojislav Mišković je tokom 1943. imao izuzetno važnu ulogu u uređenju arhive i biblioteke i njihovom preseljenju iz zgrade u Brankovoj br. 13, gde su bile privremeno smeštene, u oporavljenu zgradu u Brankovoj br. 15. O tome postoji i vrlo detaljan izveštaj akademika Vojislava Miškovića koji je podneo Predsedništvu. Takođe, u februaru 1944. godine, Predsedništvo mu je poverilo i izradu novog Pravilnika o biblioteci Srpske akademije nauka.

Kao intelektualac školovan u inostranstvu, Mišković je nastojao da našu astronomiju uvede u evropske naučne krugove i dobro je razumeo važnost objavljivanja domaćih radova na stranim jezicima te je tako još pre rata pokrenuo mnoge publikacije Astronomske opservatorije na stranim jezicima, koje se čuvaju u Biblioteci SANU. To su: Mémoires de l'Observatoire astronomique de Belgrade (1932-1949), Bulletin de l'Observatoire astronomique de Belgrade (1936-1991), koji od 1992. izlazi pod imenom Bulletin astronomique de Belgrade, a od 1998. kao Serbian Astronomical Journal, zatim Annuaire de l'Observatoire astronomique de Belgrade (1928–). Navedene serijske publikacije stekle su međunarodni ugled, a i sam akademik Mišković u njima je redovno objavljivao radove i pisao priloge. Kao izuzetno značajne za astronomsku nauku, treba svakako pomenuti i Godišnjak Astronomske opservatorije Univerziteta u Beogradu (Godišnjak našeg neba) (1929-1961) i Nautički godišnjak (1934-1941), koji je takođe pokrenuo i oko čijeg se izdavanja zalagao. Osim tih stručnih časopisa, u takozvanom opštem fondu Biblioteke SANU čuvaju se primerci Miškovićevih udžbenika, kao i radovi koje je objavljivao u Akademijinim izdanjima, mahom u Glasu Odeljenja prirodno–matematičkih nauka.

U dokumentaciji Biblioteke SANU, o kojoj se stara Bibliografsko odeljenje, čuvaju se, između ostalog, portretske fotografije akademika Miškovića i jedno pismo u kome se obraća Odeljenju prirodno–matematičkih nauka sa stručnim pozitivnim mišljenjem o radu Dragutina Đurovića "Sistematske promene longituda i latituda" i njegovoj naučnoj podobnosti za štampanje u nekom od Akademijinih izdanja. Preostala pisma čuvaju se u Arhivu SANU.

U Biblioteci SANU čuva se i Posebna biblioteka Vojislava Miškovića, koja nosi signaturnu oznaku PB 7. Svoju biblioteku akademik Vojislav Mišković je lično poklonio Akademijinoj biblioteci 1971. godine, zajedno sa originalnim ormanom u kome se nalazila, a u kojem se i danas čuva. Isprva je bila smeštena u Sali akademika a danas se nalazi u čitaonici Biblioteke SANU: "Na VI sednici Izvršnog odbora Predsedništva SANU od 6. jula 1971. godine, IO se upoznao sa predlogom Biblioteke u pogledu smeštaja biblioteke akademika V. Miškovića pa je zaključeno da se ova biblioteka s ormanom smesti u Salu akademika." (Godišnjak LXXVIII za 1971, 1973, str. 198). U toj biblioteci čuva se 26 naslova časopisa na francuskom, engleskom, nemačkom, srpskom, ruskom i jedan i na portugalskom jeziku, ukupno 344 monografije i 105 zbirnih dela, odnosno separata, članaka i isečaka iz novina, koje je akademik Mišković lično koričio pod različitim naslovima – Varia astronomica, Mélanges astronomiques, Les Planétes, Observatoires, Petit planètes, Photométrie, Cométes, Eclipse, Temps itd. iz oblasti astronomije, istorije astronomije i popularne astronomije. Uz neka od navedenih zbirnih dela dat je sadržaj priloga, ali u nekim sadržajima nisu obuhvaćeni svi povezani prilozi. U okviru tih svezaka s raznim radovima postoje Miškovićevi rukopisni prevodi ili prepisi članaka iz naučnih časopisa iz oblasti prirodno–matematičkih nauka. Većina knjiga i časopisa ima ex libris ili samo Miškovićev potpis, a uz neke knjige postoji i podatak koji je akademik Mišković beležio o poreklu knjige, odnosno mestu i državi u kojoj je pribavljena. U Biblioteci se čuva i primerak Miškovićeve doktorske teze "Etudes de statistique stellaire" s njegovim ex-libris-om i potpisom. Najstarija izdanja u toj biblioteci jesu dva toma Njutnovih "Mathematical principles of natural philosophy", objavljena u Londonu 1803. godine (Matematički principi prirodne filozofije, lat. Philosophiae naturalis principia mathematica, jedno od najvažnijih dela u istoriji nauke, prvi put štampano 1687. godine u tri toma). Veliki broj monografija, separata i članaka sadrži i posvete autora, Miškovićevih studenata, kolega i saradnika. Tu su i monografije sa posvetama akademika Milutina Milankovića i Aleksandra Deroka. Što se tiče posveta samog akademika Miškovića, u Posebnoj biblioteci Miodraga Ibrovca čuva se primerak Miškovićevog dela "Johannes Kepler" s autorovom posvetom. Još jedan primerak Miškovićeve doktorske teze čuva se i u privatnoj biblioteci Antona Bilimovića i sadrži autorovu posvetu akademiku Bilimoviću.

Posebna biblioteka Vojislava Miškovića obrađena je i dostupna onlajn u elektronskoj bazi podataka COBIB.SR (deo sistema COBISS).

U avgustu tekuće 2017. godine, u Biblioteci SANU priređena je kamerna izložba o akademiku Vojislavu Miškoviću, povodom 125 godina od njegovog rođenja. Tom prilikom izloženi su izabrani radovi akademika Miškovića, kao i publikacije i članci o njemu koje Biblioteka SANU čuva.

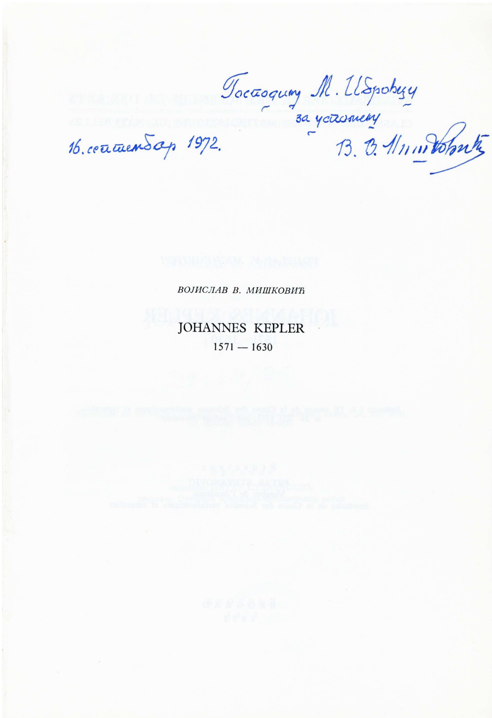
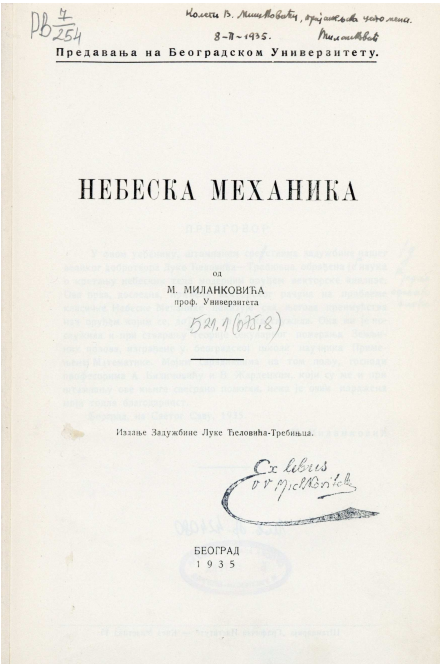


Figure 1: Posveta akademika V. Miškovića akademiku Miodragu Ibrovcu: Gospodinu M. Ibrovcu za uspomenu, V. V. Mišković, 16. septembar 1972.

Figure 2: Posveta akademika Aleksandra Deroka akademiku Vojislavu Miškoviću: Gospodinu g. Voji Miškoviću sa potsećanjem na mučne dane od A. Deroka.


Колеги В. Мишковићу, пријатељска успомена.
8-II-1935. Миланковић

Предавања на Београдском Универзитету.

НЕБЕСКА МЕХАНИКА

од

М. МИЛАНКОВИЋА

проф. Универзитета

Издање Задужбине Луке Ћеловића-Требињца.

Ex libris

БЕОГРАД

1935

Figure 3: Posveta akademika Milutina Milankovića akademiku Vojislavu Miškoviću: Kolegi V. Miškoviću, prijateljska uspomena M. Milanković 8-II-1935.

Publ. Astron. Obs. Belgrade No. 98 (2018), 371 - 377 *Contributed Paper*

CORRESPONDENCE OF VOJISLAV V. MIŠKOVIĆ ABOUT HIS DOCTORATE WITH MILUTIN MILANKOVIĆ, MIODRAG IBROVAC AND OTON KUČERA

N. JANC[1], V. PROTIĆ BENIŠEK[2], V. BENIŠEK[2], L. Č. POPOVIĆ[2], M. B. GAVRILOV[3] and S. B. MARKOVIĆ[3]

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Abstract. Many letters from the correspondence of Vojislav V. Mišković with leading scientists such as Milutin Milanković, Miodrag Ibrovac and Oton Kučera from 1916 to 1952 have been preserved. Most often he corresponded with Milutin Milanković who was informed about all phases of his Ph.D, from its writing, to defense, promotion and publication. The title of Mišković's doctoral thesis in mathematical sciences was "Statistical Methods in the Study of the Stars" ("Études de statistique stellaire") and was defended on 12 July 1924 at the University of Montpelier in front of a panel chaired by Professor Pierre Humbert. Mišković also informed Miodrag Ibrovac about the dissertation and asked him to see with the Secretary of Education about funding he needed to print the thesis. Mišković sent the printed thesis to Milanković, Ibrovac and Kučera. They congratulated him and praised his work. Milanković read it and passed it to Professor Anton Bilimović, who was the second Mišković's committee member at the University of Belgrade. Oton Kučera intended to write a review of the Mišković's dissertation in "Nastavni Vjesnik" ("Teacher's Newsletter"), but the printing of the magazine was postponed and was not sent along with the letter, as Kučera planned.

1. INTRODUCTION

Vojislav Mišković (Fužine, 1892–Belgrade, 1976) was the first doctor in astronomy among the Serbs. Doctoral thesis of Mišković in mathematical sciences "Statistical Methods in Studying the Stars" ("Etudes de statistique stellaire") was defended on 12 July 1924 at the University of Montpellier and the President of the Committee was Pierre Humbert (Paris, 1891–Paris 1953) (Andjelić 1977). The thesis was considered as belonging to mathematical sciences "Le grade de docteur es sciences mathematiques" as written on his printed doctoral paper (Mišković, 1924) since Astronomy was a part of the same department, and the thesis is very theoretical because it studies statistical methods related to the radiance of the variable stars like Algol.

There exists a correspondence wherein Vojislav Mišković wrote, among other topics, about his thesis to Milutin Milanković (Dalj, 1879–Belgrade, 1958), Miodrag Ibrovac (Gornji Milanovac, 1885–Belgrade, 1973) and Oton Kučera (Petrinja, 1857–Zagreb, 1931). In his letters he covered various aspects of his doctorate since the nature of cooperation of Mišković with them was dependent on the interests and expertise of the particualr correspondent. His most detailed reports about the progress of his thesis were sent to Milutin Milanković who was his unofficial mentor, then to Miodrag Ibrovac whom he asked for financial contribution for publishing the thesis. To Oton Kučera he sent a printed copy of the thesis.

2. CORRESPONDENCE

The first letter from the collection Vojislav Mišković wrote to Milutin Milanković on 4 January 1924, although it is not known whether it was the really the first piece of correspondence between them. At the beginning of the letter, he congratulated Milanković the New Year 1924 and then commented on his doctorate that he had submitted to the mentor, Professor Humbert. He stated that he did not have any problems with the thesis and that it had been accepted without modifications. The Mentor, Professor Humbert, only asked that it be complemented with the bibliography from all previously printed papers on stellar astronomy and short terminological dictionary in French, English and German.

Observatoire du Mt. Gros, Nice, 4 January 1924

Mr. Professor,.....

I can tell you that I do not have any difficulties about my thesis: it was accepted without any modifications, but not without additions. Nothing significant, but it postpones the date of my exam. Professor Humbert requires that I add the following:

1. Bibliography, as complete as possible, of all already published papers related to stellar astronomy

2. Short terminological vocabulary with simultaneous terms in French, English and German.

Your source greatly helped me—merci. I thank you also on this occasion for your kindness and your effort. Mr. Professor, please accept the expressions of my personal respect.

Mišković

At the same day, on January 4, 1924, Mišković also wrote to Miodrag Ibrovac, literature historian, romanist, Professor of the University in Belgrade and became an academician. The two of them also communicated during the First World War. On this occasion, Mišković sent his best wishes to him and his wife for the New Year, but he also contacted him for financial help.

4 January 1924

Dear Mr. Ibrovac,

I certainly never received anything from anywhere, vous pensez bien si on se f(aut??)....un peu pardone des clients comme moi. That is why I withdrew my application. These days you were ill and could not go out. To wait, I could not. And to leave it, I thought, a quoi bon!?. Today I can tell you how colossal it could be for me *if I could get something. If it is agreeable to you and if you think it might succeed, I would be thankful to you if you could influence that some assistance be given to me. I could send you another application, if you had lost the first one, since it is missing in the Ministry.*

. . . . *Yours,*

Mišković

It is not known what Ibrovac answered, but the letter that Mišković sent to him was preserved,

Observatoire du Mr. Gros, Nice, 12 March 1924

Dear Mr. Ibrovac,

. . . Excuse me, I will not keep you long.

I just want to inform you that the printing of my thesis will start on the 15th of this month. I got bon a sirer. I am only waiting for the printer to tell me exact conditions and time when he could send me the first epreuves.

100–110 printed pages with 8", with 12 printing plates will cost me around 2500–3000 fr.. Out of that I secured 750 fr. that local Universities gave me. And the rest I must provide myself. If it only were to take care about it, I would do it, but it has to be found and paid. It would take me 10 months to collect that from my salary.

Mr. Ibrovac, can I have any hopes from our Ministry? Have they told you anything positive? Please inform me as soon as possible. If there is nothing to hope for (which would not surprise me very much), I could look on some other possibility. I have to try, at least, although the outlook is not very promising.

I again kindly ask you to pardon me if I disturbed you with my letter and plea.

Please convey my regards to Mrs. Ibrovac and you, dear Mr. Ibrovac, please accept my cordial greetings from your

Mišković

In his letter of 28 September 1924 from Bourg-St.Maurice (Savoie) Mišković informs Milanković that as a member of state mission of France participates in the defining of the geographic coordinates of southeastern French Alpes. He also informs him that the promotion of his doctorate was held on 12 July 1924 and that he sent him one copy of the dissertation. It was obvious that Mišković seriously intended to return to Belgrade and be engaged at the University and Milanković wholeheartedly helped him with that.

Bourg-St. Maurice (Savoie), 28 September 1924

Mr. Professor,

. . .

It is probably known to you that my promotion was held on 12 July since I immediately after the exam sent you one copy of my thesis and I presume that my parcel had arrived.

V. Mišković

Milanković replied him very soon, on 4 October from Belgrade and congratulated Mišković on his passed exam, defense of his doctoral thesis, with the promise to very gladly read it. He wrote to him that there was no need for him to come that year to Belgrade, possibly only when "his post had been accepted at the University". Milanković advised him not to leave his present post in Nica, but to patiently wait to be invited to the Department of Philosophy, and that the two of them should discuss the conditions of the return of Mišković that would secure him future existence and work conditions.

4 October 1924

Dear Mr. Mišković,

I left Belgrade already at the beginning of May and returned recently after spending the last months in Austria. In a large pile of letters and various parcels waiting for me on the table I found your thesis and today I received your dear letter.

I wholeheartedly congratulate you on passing the exam, and I will recommend your thesis with the outmost interest. When I do that, I will write you in more detail.

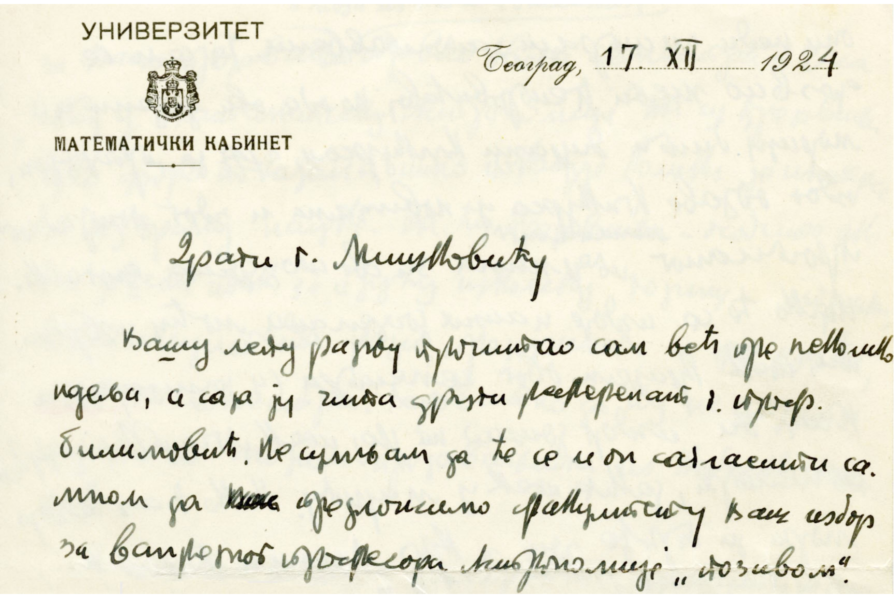
Yours truly,

Milanković

The letter of Milanković of 17 December 1924 (written on eight pages) was very significant for Mišković. Mišković mentioned it in his eulogy speech that he held at the grave of Milanković on 17 December 1958. In that letter Milanković wrote about the doctoral thesis, about the proposal that he should get a post of invited Associate Professor, about the foundation of Astronomical Observatory in Belgrade and about the cooperation with Alfred Wegener (Berlin, 1880–Greenland, 1930).

He started his letter informing Mišković that he had read his thesis (Figure 1.).

17 December 1924



УНИВЕРЗИТЕТ

МАТЕМАТИЧКИ КАБИНЕТ

Београд, 17. XII 1924

Драги г. Мишковићу

Вашу лепу радњу прочитао сам већ пре неколико недеља, а сада ју чита други референат г. проф. Билимовић. Не сумњам да ће се и он сагласити са мном да предложимо факултету ваш избор за ванредног професора астрономије „позивом“.

Figure 1: Facsimile of the beginning of the Milutin Milanković's letter were informing Vojislav V. Mišković that he had read his thesis written 17. December 1924.

Dear Mr. Mišković,

I had read you nice paper several weeks ago and now other colleague, Mr. Professor Bilimović is reading it. I do not doubt that he will agree with me to propose to the Faculty to elect you as Associate Professor of Astronomy by "invitation".

Faithfully yours,
Milanković

The other responsible Professor for the choice for the University was Anton Bilimović (Žitomir, 1879–Belgrade, 1970). He came from Russia and was Professor at the University of Belgrade from 1920 to 1955, and a Member of the Serbian Academy of Sciences and Arts from 1925.

In his letter of 31 December 1924 Mišković asked Milanković whether he thought it necessary and appropriate to send, before his election for the Professor of the Faculty, several copies of his thesis to professors who do not deal with Mathematics. He mentioned that he had already sent them to Professors of Mathematics and Technical Sciences whom had known, or at least had known their names..

Nice, 31 December 1924

Mr. Professor,

Before even starting to answer your dear letter of the 17th of this month, I would like to express to you my friendliness and obligation for your kindness to me and for the interest that you had in our future cooperation.

. . . .

It would suffice (at least I hope), for example, that we, at the very beginning, present at a minimal cost, to our scientists and wider circles, two or three results of obvious practical value. And that is not difficult, I assure you. Our world does not know Serbian astronomers, it does not believe that they exist. They should be shown, if not the astronomers themselves, but their work and they will be acknowledged.

Do you think it necessary and appropriate that before being elected, I send several copies of my thesis to Professors of non-mathematical faculties? I have sent it so far only to Faculties of Mathematic and Engineering that I knew, even only by name. In general, I would be very grateful if you could be willing to give me your advice and instructions on what should be done before the time of the election.

Yours truly, Mišković

Milanković replied to that on 23 January 1925 that there was no need to send by post the copies of his thesis, but to personally give them upon coming to Belgrade from France.

University, Mathematical Office, Belgrade, 23 January 1925

Dear Colleague,

Congratulations to you!

At the last night session, the Philosophical Faculty elected you based on my proposal (also signed by Mr. Petrović) as invited Assistant Professor of Practical Astronomy.

. . .

Sending of the copies of thesis is not necessary now. Soon you will be able to hand them personally.

...

Cordial gretings by your Milanković

Mišković sent his doctoral thesis to Oton Kučera, physicist and promoter of natural sciences (Internet 1 2016). He was one of the founders of Astronomical Observatory in Zagreb and its Director in the period from 1920 to 1926 and also the editor of the calendar "Bošković" for the years 1924, 1925 and 1926 (Internet 2 2017).

Letter from Oton Kučera to Mišković written in July 1925 (Figure 2):

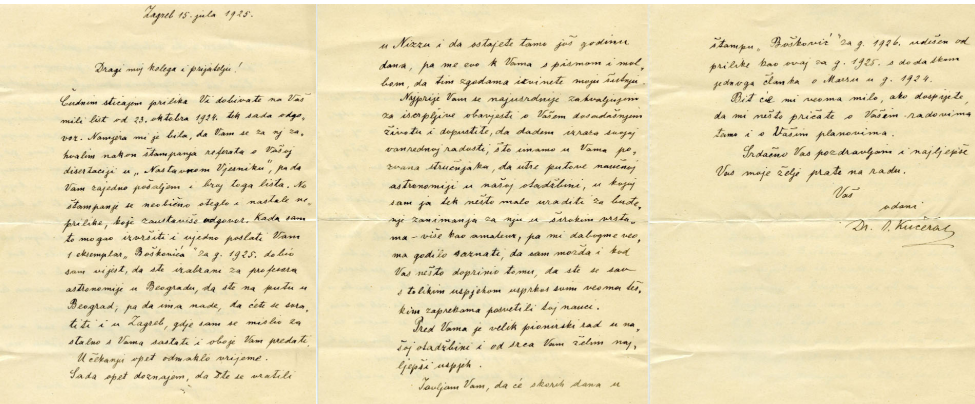
Zagreb, 15 July 1925

My dear colleague and friend!

As events turned out, you are only now getting the reply to your dear letter of 23 October 1924. My intention was to thank you for it after printing report on your dissertation in "Nastavni Vjesnik" and to also send you several copies of it. But, printing took an unusually long time and difficulties arose that prevented my reply. When I was able to do that and send you at the same time a copy of "Bošković" for 1925, I was told that you were elected as Professor of Astronomy in Belgrade, that you are on your way to Belgrade and that there was hope that you would come to Zagreb where I intended to meet you and hand you both things. And the time passed in waiting.

Now I hear that you returned to Nice to stay there for another year, so I am sending you this letter with the kind request to forgive my not answering because of the above.

I first want to most cordially thank you for detailed information on recent events in your life and let me add the expression of my exceptional joy to have you as chosen expert to pave the way of scientific astronomy in our homeland. In it, I did but a little for arousing wide interest for it - more as an amateur and, thus, it would certainly


Zagreb 15. jula 1925.

Dragi moj kolega i prijatelju!

Čudnim sticajem prilika Vi dobivate na Vaš
mili list od 23. oktobra 1924. tek sada odgo-
vor. Namjera mi je bila, da Vam se za nj za-
hvalim nakon štampanja referata o Vašoj
disertaciji u „Nastavnom Vjesniku", pa da
Vam zajedno pošaljem i broj toga lista. No
štampanje se neobično oteglo i nastale ne-
prilike, koje zaustaviše odgovor. Kada sam
to mogao izvršiti i ujedno poslati Vam
1 eksemplar „Boškovića" za g. 1925. dobio
sam vijest, da ste izabrani za profesora
astronomije u Beogradu, da ste na putu u
Beograd, pa da ima nade, da ćete se svra-
titi i u Zagreb, gdje sam se mislio za
stalno s Vama sastati i oboje Vam predati.
U čekanju opet odmaklo vrijeme.
Sada opet doznajem, da ste se vratili

u Nizzu i da ostajete tamo još godinu
dana, pa me evo k Vama s pismom i mol-
bom, da tim zgodama izvinete moju šutnju.
Najprije Vam se najusrdnije zahvaljujem
za iscrpljive obavjesti o Vašem dosadašnjem
životu i dopustite, da dadem izraza svojoj
vanrednoj radosti, što imamo u Vama po-
zvana stručnjaka, da utre putove naučnoj
astronomiji u našoj otadžbini, u kojoj
sam ja tek nešto malo uradio za bude-
nje zanimanja za nju u širokim vrsta-
ma - više kao amateur, pa mi dabogme veo-
ma godilo saznati, da sam možda i kod
Vas nešto doprinio tomu, da ste se sav
s tolikim uspjehom usprkos svim veoma teš-
kim zaprekama posvetili toj nauci.
Pred Vama je velik pionirski rad u na-
šoj otadžbini i od srca Vam želim naj-
ljepši uspjeh.
Javljam Vam, da će skorih dana u

štampu „Bošković" za g. 1926. udešen od
prilike kao ovaj za g. 1925. s dodatkom
jednoga članka o Marsu u g. 1924.
Bit će mi veoma milo, ako dospijete,
da mi nešto pričate o Vašem radovima
tamo i o Vašim planovima.
Srdačno Vas pozdravljam i najljepše
Vas moje želje prate na radu.
Vaš
odani
Dr. O. Kučera

Figure 2: Facsimile of the letter from Oton Kučera to Vojislav V. Mišković written in 15 July 1925.

feel good to know that I might have influenced you, too, in that direction, so that you very successfully devoted yourself to that science despite all the obstacles.

Great pioneering work is awaiting you in our homeland and I wish you great success from the bottom of my heart.

I inform you that very soon "Bošković" will go in print for the year 1926, compiled similarly to the one for the year 1925 with the addition of one article on Mars in the year 1924.

I would be very glad if you could talk to me about your papers there and about your plans.

I cordially greet you and may my best wishes follow you in your work.

Sincerely yours, *Dr. O. Kučera*

Review of the PhD dissertation of Vojislav V. Mišković by Oton Kučera was published in the magazine "Nastavni vjesnik" in the column "Literary notifications" (Kučera, 1924).

3. CONCLUSION

At the University of Montpellier Vojislav Mišković defended in 1924 the state doctoral dissertation with the topic "Statistical Studies of the Stars". In the period from the final phase of the doctorate until its defense and publishing he kept correspondence with Milutin Milanković, Miodrag Ibrovac and Oton Kučera. Milutin Milanković was mostly informed about it. After defending the dissertation Mišković sent each of them a copy of his dissertation. All of them praised it and supported his work.

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ETUDES DE STATISTIQUE STELLAIRE - MIŠKOVIĆ'S PhD THESIS

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Abstract. The PhD thesis of Vojislav V. Mišković (1892-1976), who was the founder and first director of the new Astronomical Observatory in Belgrade, situated at Laudonov Šanac, is presented.

1. INTRODUCTION

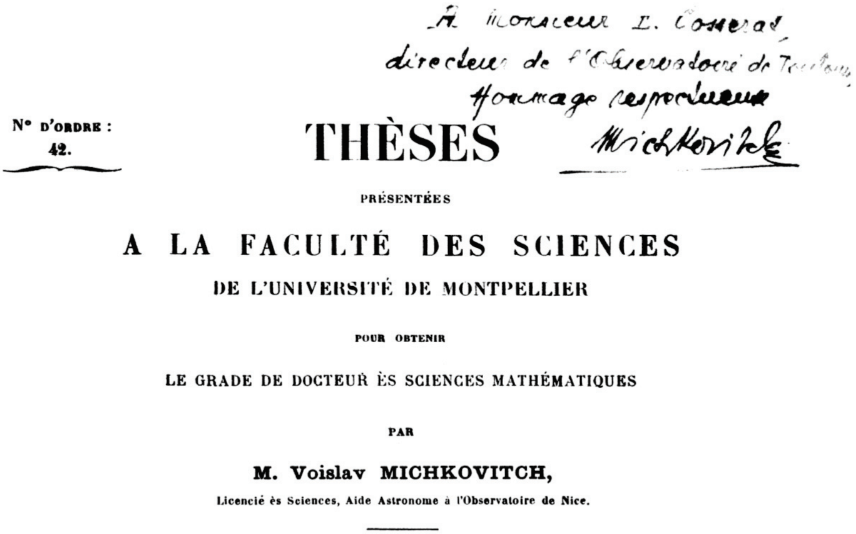
Vojislav Mišković is an important name in Serbian science. He started his university education in Budapest, but because of his keen interest in astronomy he soon left this city, to continue his studies in Goettingen and Vienna where astronomy departments existed. Due to the First World War, wherein Mišković took part, there was a break in his studies. Only after its end Mišković could recommence his studies of astronomy which he did in France. Already in 1919 he took his degree at the University of Marseille and joined the staff of the Marseille Observatory. In 1922 he moved to the Nice Observatory. The Nice period of Mišković's life was namely the period when he obtained his PhD degree. This occured in 1924 at the University of Montpellier.

Mišković's thesis is the subject of the present contribution. In what follows a brief description of the thesis is presented. The present contribution does not contain many data on Mišković's biography. The reason is that there are other papers which deal with his activity, first of all in this proceedings, so there is no need to repeat the facts. Besides, there exists an article (Indjić 1996) which can serve as a very good data source for all who want to study Mišković's life and career.

2. BASIC DATA ON THE THESIS

The University, as said in Introduction, is that of Montpellier. The thesis was approved by the Dean of the Faculty on March 21, 1924, on the very next day, March 22, the University Rector gave the printing permission. The examination took place on July 12, 1924 before the following Comission: Humbert (chairperson), Cabannes and Soula (examinators). The official degree of the thesis is PhD in mathematics (grade de docteur ès sciences mathématiques). The front page of the thesis is presented in Fig. 1.

The text is, of course, written in French. The number of pages is 137. there are many formulae, but they have no numbers, as is the case with the tables. Therefore,



A Monsieur E. Cosserat
directeur de l'Observatoire de Toulouse
Hommage respectueux
Michkovitch

N° D'ORDRE :
42.

THÈSES

PRÉSENTÉES

A LA FACULTÉ DES SCIENCES

DE L'UNIVERSITÉ DE MONTPELLIER

POUR OBTENIR

LE GRADE DE DOCTEUR ÈS SCIENCES MATHÉMATIQUES

PAR

M. Voislav MICHKOVITCH,

Licencié ès Sciences, Aide Astronome à l'Observatoire de Nice.

Figure 1: The front page of Mišković's thesis.

it may be noted that the thesis contains several tables. Figures have numbers, the last one is Figure 16. The citations are given in the form of footnotes, as it was usual at that time. However, in the end there is a rich list of references. The references also have no numbers. The title of the list - "Liste des travaux de statistique stellaire" - indicates that this is rather a general (informative) list of the literature on stellar statistics, than a list comprising only the references necessary to the work itself. The references do not contain the year of publishing. For this reason it becomes difficult to establish the period covered by their publishing. The mentioned title is followed by a footnote wherein the author says that for the purpose of making this list he had at his disposal the libraries of the Observatories at Nice and Marseille.

The thesis text is organised as follows: preface, introduction and three essential parts - Part I: Mathematical Statistics, 36 pages, Part II: Stellar Statistics, 49 pages, Part III: Study of Algol Type Variable Stars, 34 pages.

3. UNIVERSITY OF MONTPELLIER

Montpellier is a city in southern France, situated very near the Mediterranean coast. It is the third largest city in the Mediterranean part of France, after Marseille and Nice (population about 250,000). The University of Montpellier was founded in 1289, but during its history it ceased to exist twice, in 1793 and in 1970. Both times it was renewed, in 1896 and in 2015. Thus Mišković's thesis belongs to the second period (1896-1970). The faculty at which the thesis was defended is Faculty of Sciences (Faculté des sciences). A more specific information about the faculty can be obtained from the list of teaching staff (Fig. 2). In this figure we can see, not only the particular position, but also the profession of every staff member. It is seen that a

FACULTÉ DES SCIENCES DE L'UNIVERSITÉ DE MONTPELLIER

	MM.	
Doyen	GODECHOT, Professeur de Chimie.	
Doyen honoraire	DAUTHEVILLE.	
Professeurs honoraires	FABRY, DUBOSCQ.	
Professeurs	FLAHAULT	Botanique.
	de FORCRAND	Chimie.
	CURIE	Minéralogie.
	BEAULARD DE LENAIZAN	Physique.
	BLAYAC	Géologie.
	TURRIÈRE	Mécanique rationnelle.
	HUMBERT	Mathématiques pures.
	BATAILLON	Zoologie et Anatomie comparée.
	SOULIER	Zoologie.
	PAVILLARD	Cryptogamie et Cytologie végétale.
	GAY	Chimie.
	CABANNES	Physique.
Maîtres de Conférences	SOULA	Mathématiques.
	BEGHIN	—
	CARRIÈRE	Chimie.
Secrétaire	DUBOIS.	

Figure 2: Faculty of Sciences in Montpellier in 1924 - teaching staff.

wide class of sciences was present, mathematics, physics, chemistry, but also geology, mineralogy, zoology as well. Astronomy is not mentioned, the members of Mišković's commission were mathematicians (Humbert, Professor, and Soula, Lecturer) and a physicist (Cabannes, Professor). The French names for the university levels are here translated as Professor (professeur) and Lecturer (maître de conférences). From Fig. 2 we see the family name of the then faculty dean - Godechot, a chemist, who signed the approval, as mentioned above. The Rector's name, who also gave the corresponding approval (Jules Coulet), we do not see from Fig. 1, which leads to a conclusion that he was from another faculty. The importance of the Commission chairman, Humbert, to Mišković is seen from the fact that he is one of the two persons to whom the thesis was dedicated, the other one is Mišković's father.

3. 1. STELLAR STATISTICS I

The Preface begins with the necessary explanations, for instance, what is stellar statistics, the observational data and methods used in it. The data comprise spatial distribution of celestial bodies ("distribution des astres dans l'espace"), their distances and heliocentric displacements. In addition Mišković mentions the physical properties, in particular brightness, colour, spectrum, density, mass, size, temperature. This, according to Mišković, forms the field of stellar astronomy. Further, he says that "this branch, still a new one, but which has already proved to be sufficiently fertile in its results, recommends itself in studying the laws governing these diverse elements and realtions which can unify them, aimed at establishing a general theory concerning the structure and evolution of the stellar universe". Here it should be pointed out that in the time of this thesis (1924) the question of whether the Milky Way appears as the whole Universe or is only a constituent of its was still unresolved.

In the further text Mišković says that the data treatment is relied on mathematical statistics, where the contributions of Bernouli, Laplace, Lexis and Pearson are mentioned. However, as for its application to astronomy, Mišković points out the contribution of Charlier[1] and his pupils as "a completely remarcable set of important achievements" (un ensemble tout à fait remarquable de recherches importantes).

This is not a mere note. As the objective of his work Mišković says: 1. giving a general idea of the employed statistical methods and the results obtained by Charlier and his coworkers; 2. furnishing a presentation detailed enough which permits young astronomers full of desire to carry out successful applications of these methods without being obliged to consult the numerous articles published in "Meddelande från Lunds Astronomiska Observatorium".

In the last paragraph of Preface there is an acknowledgement which concerns Prof. Humbert (valuable information and advices) and G. Fayet, the then Director of the Nice Observatory (unselfish aid in composing the manuscript).

Following what he had written in the Preface in the Introduction Mišković presented a short description of mathematical statistics and probability theory where one finds notions such as: theory of errors, frequency curve, moment, correlation coefficient and homograde and heterograde statistics, given as subtitles at the beginning of a paragraph. At the very end of Introduction Mišković points out that "due to the complexity of the data it was necessary to create a new theory based on some hypotheses on one hand and on the other hand on the procedures and theorems known from mathematical analysis, instead of some elementary theorems of probability theory". In the next sentence (final in Introduction) he says that "this is exactly the development of this second set of statistical methods, which is his subject and appears as a constituent of the important contribution of Charlier's school".

3. 2. STELLAR STATISTICS II

As said above, Part I is written on 36 pages. It concerns mathematical statistics. It contains many formulae, also followed by explanations and derivations. The material is organised in a similar way as in Introduction, but the subjects are treated in more detail. There are numerical examples presented by use of tables. For instance Tables II and III contain results of Mišković's own calculations, as he says a scheme which he adopted from a paper of Charlier published in "Meddelande från Lunds Astronomiska Observatorium", but with some modifications believed by Mišković to be useful.

In the second part in view of the intensive application of mathematical statistics stellar kinematics is also included in stellar statistics. Taking into account our modern terminology the subject in this part is in fact statistics of the Milky Way and the kinematics in the solar neighbourhood.

In the time of Mišković's thesis both the global structure of the Milky Way and the interstellar extinction were unknown. The stress was done on the distribution of stars in apparent magnitude, the number of stars brighter than the value corresponding to a given apparent magnitude and the mean distance of the stars with the same apparent magnitudes. Since the first two quantities are obtainable by treating the observations, it is possible to study the distribution of stars in absolute magnitude and their spatial distribution (number density as function of distance). The equations used in this procedure are rather complicated, therefore some hypotheses actual at

[1] Carl Charlier (1862-1934), a Swedish astronomer from the Observatory at Lund.

that time are discussed, the results following from them are compared to the results for the two star numbers obtained from observations. The agreement was found to be satisfactory.

Then there is a part dealing with heliocentric distances of stars. In 1924 the trigonometric method was, practically, the only one in determining the distances, whereas sufficiently reliable parallaxes were available for a small number of stars. For this reason statistical relations between parallaxes and apparent magnitudes and between parallaxes and proper motions were very welcome and it is quite understandable why this subject finds its place in the thesis.

In the last lines of the second-part text the kimenatical problems are considered. Correlations with physical characteristics are also analysed. For this reason apparent magnitudes and spectral types are added to the proper motions appearing as the basic observational material. It is pointed out that the discussion concerning stellar motions should be based not on the angular displacements, but on the velocities of celestial bodies. The velocity is estimated by applying to the observed proper motions a numerical parameter. Though, at first glance, such an approach seems rather different from that used today, the results indicate a distinction among spectral types; the used parameter shows a wavy behaviour between O and G, to show an increase afterwards, but the author draws attention that the determination for M type is very uncertain because of a small fraction of such stars in the treated sample.

Of a special interest may be the position concerning the comparison of the hypotheses of two streams and ellipsoidal one. Based on the earlier studies Mišković infers that "all seems to indicate that the two stream hypothesis is not sufficient to reflect in a satisfactory way the facts concerning the observed stellar motions" (tout semble donc indiquer que l'hypothèse des deux courants stellaires n'est pas suffisante pour représenter, d'une manière satisfaisante, les faits relatifs aux mouvements stellaires observés).

At the end of the second part one finds a list of papers referred to as "studies on stellar statistics" published in "Meddelanden från Lunds Astronomiska Observatorium". These papers are divided into theoretical ones and applications in stellar astronomy.

3. 3. VARIABLE STARS

As said above (Subsection Basic data on the text), the third and last part is devoted to variable stars of Algol type. In the title, except Algol type, there is also short period. Thus it can be inferred that Algol type and short period are the two main caharacteristics, which should unify the kinds of stars under study. Due to the short period Mišković also includes the types of β Lyrae and δ Cephei. He further says that "these three categories are most likely (fort probablement) nothing else but the three principal stages in the evolution of binary systems". This standpoint should be viewed as something obsolete, probably as a consequence of the then (in 1924) state of the art. The relationship with stellar statistics is found in the author's objective to "apply the method of stellar statistics to the study of binaries". In addition Mišković says that here he had to "limit himself to the Algol type variables".

Mišković examined the data concerning the Algol type stars and formed a list containing 152 such stars (all of them known till the end of 1923). At the disposal he had the following data: period, eclipse duration and the extremal values of the apparent magnitude. The quality of data were not always satisfactory, this is especially true for the case of the eclipse duration. Mišković carried out a statistical analysis which included the correlation study.

At the time of Mišković's thesis moving groups were already known. Therefore, another question was if the Algol type stars formed a moving group. Mišković performed a kinematical analysis, though the proper motions were available for 17 stars only. On the other hand, in the case of 86 stars the spectral type was known, it was largely B or A. Combining the spectral types and proper motions Mišković was able to estimate the distances. He gave a final table including all 152 stars. This table has 17 columns. In addition to the ordinal number, star designation, the four quantities mentioned above (period, eclipse duration, ...) there are also right ascension, declination, the estimated distances, the quantities derived from them and spectral types (where available). The quantities derived from the distances (also from angular coordinates) are the rectangular coordinates and parallaxes. All of this was a basis for a statistical analysis focused on, first of all, studying the spatial distribution of the Algol type stars. Mišković found a distribution practically symmetric with respect to the Milky Way plane. As distance unit Mišković used siriometer. This, now almost completely forgotten unit, is equal to 10^6 astronomical units. Its name is due to the fact that Sirius is about half siriometer away from the Sun. It is also curious to note that Mišković uses the word "grandeur" for magnitude (brightness measure). Such a word seems to have been characteristic for that time. For instance in the titles of some references in Mišković's thesis written in German one finds "Groesse" which completely corresponds to "grandeur" in French. However, in both modern French and German other terms are used, in particular "magnitude" and "Helligkeit", respectively.

4. CONCLUSION

Mišković's PhD thesis is, undoubtedly, a serious work. Mišković treated much of that which is now known as stellar astronomy, more precisely Galactic astronomy. The time when the thesis was prepared was on the eve of the important discoveries concerning the structure and dynamics of the Milky Way. In the numerous references cited in Mišković's thesis one cannot find, for instance, the names of the two classics in Galactic astronomy, B. Lindblad and J. H. Oort. Unfortunately, for the well known reasons Mišković could not continue his work in that field.

Acknowledgment

This research has been supported by the Ministry of Education, Science and Technological Development (Project No 176011 "Dynamics and Kinematics of Celestial Bodies and Systems"). The author expresses his sincere gratitude to Monika I. Jurković for a valuable discussion on variable stars.

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AUTHORS' INDEX

Organizers

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