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# DEPARTMENT OF ASTRONOMY AT PETNICA SCIENCE CENTER: 2021-2023

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**Abstract.** The main topic of our review will be the activities held by the Astronomy Department at the Petnica Science Center (PSC) from 2021 to 2023. The focus of the Astronomy Department has been on high school students as participants and the programs created for them. During the whole of the educational cycle at the Astronomy Department, conceived as a two-year program, participants are introduced to the fundamentals of astronomy and its research methodology in the first year, which ultimately leads to the completion of their first research projects by the end of the second year. Therefore, in this review, we will present the current structure of the Astronomy Department at PSC, the topics of the participants' research projects, some of the other activities carried out during the mentioned period, and the outline of our plans for the future.

## 1. INTRODUCTION

Petnica Science Center (PSC) stands as a pioneering and well-established nonprofit organization dedicated to providing extracurricular science education for highly motivated high school students in Southeastern Europe. Since its establishment in 1982, PSC has been a beacon for informal science education, and its location near the village of Petnica, close to Valjevo in Serbia, serves as the hub for a range of educational activities, including annual seminars. The coordination of these seminars falls under the purview of sixteen departments, with the Department of Astronomy (AST) being a foundational contributor to PSC.

Beyond its core focus, PSC extends its reach to organize seminars and camps tailored to elementary school and undergraduate students, as well as science teachers. This progress report provides insight into the current structure of educational activities within AST, shedding light on the topics of research projects undertaken by participants and summarizing various activities spanning the period from 2021 to 2023, while also offering a glimpse into future plans.

To gain a more thorough understanding of AST's organizational structure and activities at PSC, we suggest interested readers refer to previous publications (refer to Vukadinović et al. 2021 and references therein). This progress report will specifically detail modifications in the organization of AST seminars and highlight high-school

student projects from previous years. All student projects results will soon be published and featured in a subsequent progress report. Head of the AST department during the period covered in this report waere Damnjan Milić (2021 - 2023) and Stanislav Milošević during the year 2021.

## 2. RESEARCH PROJECT TOPIC

High-school student projects conducted at AST typically encompass themes such as planetary science, stellar astrophysics, extragalactic astronomy, astroparticle physics, cosmology, and observational astronomy.

In the following text we will present several student projects that were also shown on the conference "Step into science" which is organized annually at Petnica science center.

In the period 2021-2023, due to the pandemic of COVID-19, there was a notable absence of student publications at conferences, deviating from the usual situation.

### 2. 1. EXTRAGALACTIC ASTRONOMY

Projects in this domain focused on studying galaxy interactions and mergers using N-body simulations. Many students use the GADGET1 N-Body code (Springer 2005) for conducting these simulations.

In 2021, Andjela Šaljić concentrated on the analysis of gas motion at various moments during the collision of two spiral galaxies. It was assumed that the gas is located within the disk. Numerical simulations were conducted, wherein identical galaxies were represented as N-body systems.

In 2022, student Katarina Gavrilović, focus to determine the dynamic future of the Magellanic Clouds, specifically investigating their orbits and decay times within the Milky Way's halo. The future of the Magellanic Clouds is explored through numerical N-body simulations. Three galaxies participate in the simulations – the Milky Way, the Small Magellanic Cloud, and the Large Magellanic Cloud. The galaxies are modeled as N-particle systems based on known observational data. All three galaxies are represented by spheroidal models, comprising three components – a disk, a central oval, and a halo of dark matter.

In 2023, student Aleksandar Todorović focused on investigating the influence of the intensity and angle of the initial velocity during galaxy collisions on the formation of structures. The objective of this research is to determine and analyze some of the structures that arise as a consequence of the collision between two galaxies, one resembling characteristics of the Milky Way and the other a dwarf galaxy. The simulations involved variations in the parameters of the velocity vector of the dwarf galaxy.

The study examined the possibility of the formation of globular clusters, galactic streams, and their intermediate structures (structures located at the transition between a globular cluster and a galactic stream) in the vicinity of the Milky Way. The analysis included density profiles and velocity profiles of baryonic matter.

All created structures are considered relatively stable. These structures were exclusively formed from the baryonic matter of the dwarf galaxy, while the Milky Way did not undergo significant changes. It is postulated that the significant mass difference between the Milky Way and the dwarf galaxy is the reason for this observation.

### 2. 2. STELLAR ASTROPHYSICS

Research endeavors in stellar astrophysics were concentrated on the analysis of stellar and exoplanet atmospheres, as well as the investigation of stellar structure and evolution.

In 2021, student Nataš a Radmilović focused on the simultaneous fitting of light curves of transits in multiple filters, using the example of the transit of the exoplanet Kepler-488 b. This study involved the analysis of photometric images of the Kepler-488 b system in the B and V filters. With fixed values for eccentricity, orbital period, and stellar radius, light curves were individually fitted for these two filters. From these fits, transit parameters were calculated, including inclination, semi-major axis length, planet radius, and coefficients for limb darkening.

In 2022, Filip Mitić focused on determining exoplanet parameters using both light curves and radial velocity curves. Consequently, these curves were modeled and simultaneously fitted to the data. The modeling of the light curve involved describing the planetary motion over time, calculating the obscured surface of the star at any given moment, and elucidating the phenomenon of limb darkening.

### 2. 3. MULTIPLE STAR SYSTEM

Several participants have engaged in the dynamics and evolution of binary and multiple systems.

In 2021, participants Vesna Milošević and Aleksija Milošević conducted an analysis of the O-C diagram of multiple star systems to classify the orbital parameters of the third companion.

This study presents a statistical analysis of parameters defining the orbit of the third companion in eclipsing binary systems. A total of 256 systems were analyzed, assumed to be triple systems, out of which 84 had insufficient data or period changes that could not be explained by the presence of a third companion. It was determined that the periods of binary systems with a third companion are less than three days, confirming the assumption that the orbits of the third bodies are nearly circular, i.e., with eccentricity close to zero.

In the following year, 2022, student Andrea Milosević continued the project initiated by Vesna and Aleksija, focusing on the investigation of the stability of triple systems through numerical integrations.

The project's objective is to examine the long-term stability of potential triple systems explored by Vesna and Aleksija, taking into account the calculated third components. System stability, in this context, refers to the absence of system disintegration (ejection of one or more components) or collisions over an extended period. Stability is assessed by examining the motion of the stars within the system. If the system is found to be unstable, it can be inferred that the presence of a third body does not account for deviations in the O-C diagram, suggesting that these irregularities are caused by some other process.

Triple systems, by their nature, exemplify three-body problems for which analytical solutions to the equations of motion are not feasible. Therefore, numerical methods have been employed to investigate their motion.

Students Anastasija Pavlović and Jana Mitrović at 2022. conducted an investigation into the Influence of mass transfer on close binary systems of massive stars.

Throughout the evolution, system parameters were varied using the numerical code MESA (Modules for Experiments in Stellar Astrophysics) for their determination. Two models were tracked, with star masses ranging from 30 to 40 solar masses, starting from their main sequence phase, progressing through the Wolf-Rayet (helium) star phase, until reaching the stage of a neutron star or a black hole. The analysis takes into consideration mass loss through solar winds and mass transfer during this evolutionary process.

In 2023, Andrea Milošević engaged in the analysis of the dynamic evolution of the protoplanetary disk within the triple stellar system GW Orionis. The objective was to determine whether the mass distribution among the three components in triple star systems influences the structures that form within the disk. The simulation results of the protoplanetary disk of GW Orionis were compared with those of a protoplanetary disk in a single star system, with a central star of mass equal to the total mass of all three stars in GW Orionis.

### 2. 4. ASTROBIOLOGY

In 2022, Ksenija Bubanja and Martinov Dunja focused on determining the habitable zone of the Milky Way galaxy.

The project aimed to establish the radial probability distribution for the emergence and sustenance of life, specifically identifying the distance interval at which these factors exhibit optimal values. The study assumed that the star formation rate is proportional to the number of molecular clouds, and the number of supernovae is proportional to the number of stars within a distance interval.

The results indicate that this region within the Milky Way is situated at a distance between 9 and 11 kiloparsecs from the Galactic center.

### 2. 5. COSMOLOGY

In 2023, student Nikola Stambolić engaged in the determination of the speed of sound in the effective string theory on cosmological scales. The description of the evolution of this distribution is based on the fact that, on the largest scales, the Universe is homogeneous and isotropic, with small corrections in the form of inhomogeneities in the density of dark matter that become significant (nonlinear) on small scales. Through gravitational interaction, these inhomogeneities grow over time. In the regime of small inhomogeneities that holds on large scales, their evolution can be analytically described using the effective theory of structures on large (cosmological) scales. This description is based on the equations of motion of a (self-gravitating) fluid, systematically incorporating the influence of small scales necessary to describe the evolution of inhomogeneities.

The evolution of inhomogeneities can also be modeled numerically using N-body simulations of the Universe composed of particles that interact gravitationally. The speed of sound can be determined by statistically comparing the distributions of dark matter obtained from theory and simulation, requiring the difference between the results obtained by these methods to be minimal.

### 2. 6. INTERGALACTIC MEDIUM

In the same year, Affan Kaknjo focused on determining extinction parameters in spiral galaxies using Type Ia supernovae. The objective of this research was to investigate

whether Type Ia supernovae could be employed to ascertain extinction parameters in spiral galaxies. Parameters of Type Ia supernovae obtained from literature, based on light curves modeled by the SALT2 (Guy et al. 2007) model, were utilized, along with the mass and radius of the galaxy hosting the Type Ia supernova. For each supernova, its associated galaxy, along with the galaxy's mass and radius, were determined. Global model parameters were calculated based on the relationships describing the brightness of supernovae in the SALT2 model and the aforementioned galaxy characteristics.

## 3. PARTNER PROGRAMS AND COLLABORATIONS

Senior and junior affiliates associated with the Department of Astronomy actively engage in a diverse array of programs, assuming roles as both contributors and organizers. The Petnica Summer Institute (PSI), an annual event since 2013 at the Petnica Science Center, systematically explores a spectrum of topics over a four-year cycle: cosmology, particle physics, astrophysics, and general relativity. This initiative annually brings together senior undergraduate and master's students specializing in astronomy, physics, and mathematics, hailing from the Balkan countries and beyond. It serves as a platform for meaningful interactions, providing exposure to cutting-edge advancements in modern science. The lecturers predominantly include seasoned PhD students, postdocs, and occasionally, experienced researchers, adhering to the foundational principle of Petnica in peer-to-peer education.

Our senior and junior affiliates encompass individuals who are either students or staff members affiliated with the Department of Astronomy (Faculty of Mathematics) and the Astronomical Observatory in Belgrade. These institutions have maintained longstanding collaborations with the AST department. However, some student-assistants pursue studies in theoretical physics, electrical engineering, and mathematics. Furthermore, several senior associates hold positions at the Faculty of Science in Novi Sad, the Mathematical Institute of the Serbian Academy of Sciences and Arts, various international universities and institutes (such as CERN, SISSA in Trieste, Max Planck Institutes in Göttingen and Munich, Université Paris-Saclay, CNRS, CEA, Institut de Physique Théorique), and within software companies.

## 4. OVERVIEW AND FUTURE PLANS

After 2020, due to the consequences of the COVID-19 pandemic, in 2021 and 2022, we organized winter and summer schools for students at the Petnica Science Center. Additionally, with the collaboration of the Department of Astronomy and the Society of Astronomers of Serbia, we conducted fall schools outside of Petnica. In 2023, three programs for students were organized within the PSC.

Over the first two years of this period, students presented their research online at the "A Step into Science" conference. In the initial year, three students presented, while in 2022, five students showcased their research. In 2023, five students are scheduled to present their research live at the conference in the Petnica Science Center.

Throughout the past period, senior and young assistants organized "R&D Astronomy Workshops," offering informal lectures for our associates on topics relevant to the seminar. The subjects covered a wide range, from the implementation of machine learning in astronomical data to cosmology and lectures on gravity waves.

Our younger assistants proposed and scheduled time for astronomical observations Vidojevica, contributing over 15 nights on the "Nedeljković" telescope. These observer nights are valuable for both students and assistants, and we plan to continue these activities in the upcoming period.

In 2023, senior assistants collaborated with the Astronomical Society Aristarh to equip an astronomical observatory near city of Kragujevac where they allocated a space for a single telescope. Currently we are planning to install Paramount ME MKS 5000 mount and telescope Meade APO 178ED. Assistants participated in obtaining an Eagle 5 remote computer for mentioned equipment. The ultimate goal is to establish a remote observatory for our students and assistants.

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## References

Bošković, M., Obulejn, A., Vukadinović, D., Milošević., Milić, I., Božić, N.: 2018, *Publications de l'Observatoire Astronomique de Beograd*, **98**, 101.

Chambers, J.E.: 1999, *Monthly Notices of the Royal Astronomical Society*, **304**, 793.

Guy, J. et al.: 2007, *A&A*, **466 No 1**, 11.

Springel, V.: 2005, *Monthly Notices of the Royal Astronomical Society,*, **364**, 1105.

Vukadinović, D., Milovanović, N., Milošević, S., Bošković, M., Božić, N.: 2021, *Publications de l'Observatoire Astronomique de Beograd*, **100**, 363.