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DEPARTMENT OF ASTRONOMY AT PETNICA SCIENCE CENTER: 2018-2020

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Abstract. We review the activities of the Department of Astronomy at Petnica Science Center (PSC) within the years 2018-2020. 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. INTRODUCTION

Petnica Science Center (PSC) is the biggest and one of the oldest (established in 1982) independent nonprofit organization for extracurricular, informal science education in South Eastern Europe for highly motivated high school students. It is located near the village Petnica, close to Valjevo (Serbia). Educational activities are realized by a series of seminars on an annual basis. The organisation of the seminars is done by sixteen departments, one of which being 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 2018. and 2020. and future plans.

The extensive description of the organization and work of AST at PSC is given in previous publications (see Bošković et al. 2018 and reference therein). In this progress

report, we will outline the difference in the organization of AST seminars and describe high-school student projects done in the previous years. Since this years' projects are in the preparation for publication, we will describe them in a future progress report. Heads of the AST department in the period on which this report focuses were Dušan Vukadinović (2018 and 2019), Nikolina Milanović (end of 2019 and the beginning of 2020) and Stanislav Milošević (2020).

2. RESEARCH PROJECT TOPICS

Topics of most of the high-school student projects done at AST are: planetary science, stellar astrophysics, extragalactic astronomy, astroparticle physics and cosmology and observational astronomy.

Research projects in *extragalactic astronomy* studied galaxy mergers and interactions via N-body simulations. Majority of these projects are using GADGET2 N-body code (Springel 2005) for simulating galaxy mergers. Before using the GADGET2 (or other complex codes) for their projects, students would write a rudimentary N-body code in order to understand basic features of the integrator.

One student project (Ristić 2018) focused on the formation of polar ring galaxies - massive spiral galaxies around which we observe ring in a plane normal to the galaxy disk. The student simulated the process of ring formation through the minor merger of spiral and dwarf galaxies and found that these structures could be transient events. This finding led to the follow-up research (Ristić 2019) where Illustris simulation (Vogelsberger et. al 2014) was used to investigate how often do polar ring galaxies form. Participant found that it is more probable to have a formation of polar ring galaxies in a minor than in a major merger which was in contrast to the previously known formation process of this type of galaxies. Dodović (2018) simulated the formation of bars inside spiral galaxies through galaxy fly-by. It was found that the strongest bar is produced if the two interacting spiral galaxies have the same rotation direction. Question of how the galaxy merger influences formation of elliptical galaxies was investigated in Vrhovac (2019). In this project, the student focused on the merger of galaxies with two different directions of rotation. In the case of the co-rotating galaxies, a boxy elliptical galaxy would form, while in the opposite case, a disky galaxy would form. In Dodović and Despotović (2019) students analyzed the formation of Giant Southern Stream in the Andromeda galaxy. Through the interaction of the simulated Andromeda galaxy with a dwarf galaxy, students managed to reproduce the observed stream structure and obtain a rough estimate of the dwarf galaxy mass.

Projects in *astroparticle physics and cosmology* investigated observational imprints of various dark matter models on different scales using semi-analytical methods. Savić and Jevtović (2019) argued that the rotation of halos, made from ultra-light bosons, could stabilize them against the attractive self-interaction. Angular momentum of dark halos was estimated via cosmological perturbation theory. Projects of Jevtović (2018) and Stepanović and Ćeranić (2019) studied phenomenology of ultra-light dark matter on smaller scales. Stepanović and Ćeranić (2019) investigated orbital properties and in particular occurence and properties of resonances of stars in halos of this kind of dark matter. Jevtovic (2018) modeled the gravitational wave signal from an inspiral of stellar-mass compact object into supermassive black hole mimicker made from particles in the dark sector. Finally, Đurić (2020), in the spirit of effective field theory, tried to understand what aspects of general relativity could have been antic-

ipated in the Newtonian era from the precession of Mercury perihelion, deflection of starlight passing near the Sun and the Shapiro time delay.

Student projects in *planetary sciences* analyzed the dynamics of Solar system small bodies and the planetary structure. Anastasijević (2018) modelled the tidal interaction between Saturn and it's satellite Enceladus. Model was used to calculate internal heating of the Enceladus as a check. Another student project focused on asteroid transport from the asteroid belt to the near Earth region (Ranisović 2020). Here, the student used numerical code Mercury (Chambers 1999) to simulate the ejection of asteroids from the asteroid belt due to mean-motion resonance with Jupiter.

Research in *stellar astrophysics* was focused on the analysis of stellar and the exoplanet atmospheres as well as stellar structure and evolution. One project (Srećković 2020) investigated the difference between theoretical atmosphere models in 1D and empirical models on the example of star HD 209458. Using the limb darkening coefficients obtained from the transit observations, the student derived the temperature, electron pressure and gas pressure profiles. One group of students (Savić, Obradović and Herček 2018) modelled the photometric signal of the exoplanet - cepheid binary. First, they modelled the oscillations in the outer layers of cepheid and then estimated the part of the parameter space of exoplanet radius - orbital semi-major axis in which the Kepler telescope would detect exoplanet around δ Cep star. Another project examined the planet habitability taking into account the thermal properties of the planet's surface and the atmosphere (Bulaja 2018).

In previous years, stellar clusters have been a frequent topic of our students projects and the period that we report on is not an exception. Dakić (2019) estimated the age of the M92 cluster and the distance to it from the luminosity function. Bulaja (2019) used publicly available data from MUSE spectrograph (at the VLT telescopes) to infer the electron temperature and concentration in the central part of Orion nebula.

The majority of students have their first experience with a telescope during astronomy seminars at PSC and naturally, a group of projects done are *observational*. Špegar (2018) used Nedeljković telescope at astronomical observatory Vidojevica to observe the transit of the WASP-69 system and infer the transit parameters by MCMC fitting procedure. Photometric observations are mostly recorded on CCD cameras which have large quantum efficiency and low thermal noise. However, Jevtić (2018) performed a photometric observation of V2455 Cyg using a DSLR camera. He was able to obtain the light curve in the green filter and estimate the period of the star. In the following years, the student wrote a code for reducing the observations and extracting the light curve of the observed variable star with a DSLR camera as a follow-up project (Jevtić 2020).

3. PARTNER PROGRAMS AND COLLABORATIONS

Senior and junior associates from the Department of Astronomy are also involved in other programs as participants and organizers. Petnica Summer Institute (PSI) is organized every summer (from 2013) in PSC and it covers several topics in a four years cycle: cosmology, particle physics, astrophysics, and general relativity. PSI brings together senior undergraduate/master students of astronomy, physics and mathematics from former Yugoslavia and other countries to meet each other and learn about the

novel results in modern science. Lecturers are mostly senior PhD students and post-docs (as well as some senior researchers) in the spirit of Petnica principle - education of students by other students.

One of the oldest groups in Petnica is Petnica Meteor Group (PMG). Like PSI, PMG also gathered many participants from AST but also participants and associates from other departments. PMG organizes meteor observing camps. The largest camp is in August for observing the Perseid meteor shower. Every year the School of Meteor Astronomy is also organized in Petnica and for several years the journal "Perseids" was published.

Our senior and junior associates are students or staff at the Department of Astronomy (Faculty of Mathematics) and Astronomical Observatory in Belgrade. These institutions have been major partners of the AST department for many years. However, some of our student-assistants are studying theoretical physics, electrical engineering and mathematics. Also, some of our senior associates work at the Faculty of Science in Novi Sad, Mathematical Institute of the Serbian Academy of Sciences and Arts, various foreign universities and institutes (e.g. CERN, SISSA in Trieste, Max Planck Institutes in Göttingen and Munich) and for software companies.

4. COVID YEAR AND FUTURE PLANS

In the year 2020, due to the COVID-19 pandemic, there were only two AST seminars on site in Petnica in March and October for high-school students who are in their first year of attendance. All other seminars were organized online in August and October. Three student projects were presented online at the conference "A Step into Science". Although the pandemic interrupted regular activities at PSC we tried to substitute them with online lectures and discussions as much as possible.

During the past several years AST has organized "R&D astronomy workshops" - informal lectures by and for our associates on the topics of interest and relevance for the seminar. In 2018 a workshop was organized on the topic of relativistic astrophysics and cosmology and appropriate "scaled-down" version of these lectures was presented to the participants in the second year of attendance during the Summer seminar of 2019. We plan to continue with these activities in the following period.

The number of observational projects is rising in recent years. New observational equipment has arrived in 2018 - Celestron CGX EQ mount and SBIG STF-8300 monochrome CCD. We have also upgraded our computational facilities with a new computer named "Prometej". This computer is available for our participants if they work on the projects that demand high CPU power as well as to our senior and junior associates.

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