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.

Acknowledgment

We would like to thank all of the junior and senior associates, for their continuing work at AST. We would also like to thank participants, to whom are our efforts aimed, who shaped educational activities with their comments. Text limits are forbidding us in thanking all of the responsible for the shape of the program individualy, so we must single out project tutors and few others being most responsible in the period upon which we report - Aleksandra Arsovski, Ivana Bešlić, Jovan Božuta, Darko Donevski, Vladan Đukić, Stevan Golubović, Vladisav Jelisavčić, Miša Jovanović, Andrija Kostić, Boris Majić, Nemanja Martinović, Nikolina Milanović, Sanja Mihajlović, Bojan Novaković, Dušan Pavlović, Jovana Petrović, Petar Saulić, Marko Simonović, Sonja Smiljanić, Igor Smolić, Branislav Vukotić, Lazar Živadinović and Filip Živanović.

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