Curricular Sequence in Astronomy & Astrophysics (*CSAA*)

Department of Physics
R.U.M.

1. Introduction

The proposed Curricular Sequence in Astronomy & Astrophysics (henceforth *CSAA*) will emphasize a mixture of theory, phenomenology and experiment and offer students the possibility to perform small research projects. The *CSAA* will start with a general overview of Astronomy and Astrophysics, introduce more advanced topics in courses on stellar evolution and radio astronomy and finally have elective courses in specialized topics. Research opportunities at the Arecibo Radio Telescope could be offered. The Physics Planetarium and Observatory, both of which have served the Puerto Rican community since 1973, will provide additional valuable resources. The *CSAA* could potentially benefit a large student population, such as physics, physical science, geology or engineering students. Furthermore, conveying knowledge in astronomy and astrophysics will produce informed citizens that will be able to recognize the many misleading or erroneous presentations in sci-fi media or the internet.

The proposed 15-credit *CSAA* formalizes a curricular offer of the Physics Department at no additional costs, with all frequently offered courses in place and available faculty.

2. Vision

The proposed *CSAA* will connect fundamentally with the vision of the University of Puerto Rico Mayagüez in *"[...] transforming society through the pursuit of knowledge [...]"*. The pursuit of understanding the heavens has systematically begun at least 5,000 years ago with recording positions, cataloging events and developing calendars.

As much as astronomy is an ancient science, it also evolves into the future. One of many examples are the space missions that visited all planets in our solar system and are culminating with the flyby of the most distant of them all, the dwarf planet Pluto in 2015. Space agencies are investing billions of dollars into missions to Mars or hitchhiking asteroids. Other observational projects are searching for exoplanets that would maintain liquid water and could potentially harbor life. This clearly shows that astronomy has always been and always will be fueling our imagination, challenging our scientists and engineers, and asking the profound question: *How did the universe begin and evolve?*

Another important mission of the University of Puerto Rico Mayagüez is to ensure that *"[...] both the academic and research components [...] share a common perspective [...]"*. The proposed *CSAA* is a complete learning experience, comprising a theoretical and a hands-on demonstration component and also offering an optional research component. In the theoretical component a general introduction to astronomy will be followed by a course on astrophysics, emphasizing the physical and

mathematical perspective. Additionally, modern observational techniques are introduced. The two more advanced core courses will discuss stellar evolution in detail and provide a comprehensive introduction to radio astronomy. Radio astronomy is an important part of the *CSAA* and will include a discussion of the fundamentals of radio signal emission by celestial objects as well as detection by telescopes and signal processing.

The demonstration component includes the use of optical telescopes and radio telescopes. For the optical demonstration, use will be made of the in-house 16-inch optical telescope located in the observatory of the Physics Department. For the radio astronomical demonstrations, data from a 20-meter diameter radio telescope of the National Radio Astronomy Observatory in Green Bank, West Virginia, will be used. Some Physics faculty members have remote access privileges to use that telescope for educational purposes. The optional research component could offer research possibilities with the Arecibo Radio Telescope, which is part of the National Astronomy and Ionosphere Center or more commonly known as the "Arecibo Observatory". There are professors in the Department of Physics that have maintained research collaborations with the Arecibo Observatory for several decades, including research projects with undergraduate and graduate students. These collaborations can provide observatory staff co-advisors for students doing research. The students can also choose to work on theoretical or computational aspects of astrophysics with the advice of participating faculty.

The previous discussion leads directly to yet another University mission, which is to *"Assist government agencies [...]"* and concurrent to this the Physics Department states that one of its objectives is to *"Promote interactions [...] with national laboratories [...]"*. The *CSAA* can provide on-site interaction with the Arecibo telescope and its staff through the optional undergraduate research course. Research projects may be provided for students, which may be jointly supervised by departmental faculty and observatory staff and may include observing time with the telescope. Additionally, we will organize one student tour of the Arecibo Observatory each semester including access to the control room and the edge-of-the-dish. With each passing semester we will continue to develop research collaboration between physics faculty and observatory scientists.

The interaction with the Arecibo Observatory highlights another important aspect: it is a local effort. The observatory is a state-of-the-art national research facility with local staff and support and actively promotes STEM research in Puerto Rico as part of their educational and public engagement efforts. This could motivate our students to engage in a lifelong exchange with the local scientific community. Lastly, the acquired experimental skills and techniques, together with the theoretical knowledge will be an important asset to students seeking employment with NASA and other research agencies and institutions. It can be expected that the *CSAA* will provide a constant flow of undergraduate students into internships or graduate programs.

Summarizing the previous discussion, the vision of the proposed *CSAA* is:

Pursuing scientific knowledge in Astronomy.

Providing a complete learning experience by offering an academic program including theoretical knowledge, observational techniques, and experimental research.

Promoting strong interactions with national observatories**,** including the Arecibo Observatory.

3. Specific Objectives

At the end of the proposed *CSAA*, the successful student will be able to:

Locate and identify celestial objects**.** Looking through a telescope one can see planets, stars, star clusters, nebulae and galaxies, each with different size, characteristics and distance. The student will be able to appreciate and describe those differences and will be able to locate celestial objects, identify its main characteristics and to track the daily apparent motion of visible stellar objects.

Explain and compare the properties of stars**.** There is a substantial range of sizes, masses and temperatures among stars. The classification of stars in the so-called Hertzsprung-Russell diagram has provided an understanding of their birth, life and death. The student will be able to explain basic concepts in the complete life cycle of stars in the context of nuclear reactions, particles and forces, as well as quantum mechanics and thermal physics.

Describe and discuss the structure of the universe**.** Our solar system is part of the Milky Way galaxy, which is part of the local cluster of galaxies, that belongs to a local supercluster, within the universe. Each of these sub-structures has its own particular dynamics and evolution. Through the discussion of this hierarchy, the student will be able to understand the universe from its beginnings in the Big Bang through the present day.

Evaluate and interpret information across the electromagnetic spectrum**.** Visible light represents only a tiny fraction of the entire electromagnetic spectrum, ranging from very long radio waves to gamma-rays. Celestial objects can emit across the entire spectrum through different generating physical processes and its study permits constructing a complete picture of the respective object. The student will realize that we need a variety of observational techniques and that each provides a look through a different "window" into the universe.

Assess and differentiate astronomical telescopes**.** There are only two spectral ranges that can fully penetrate the Earth's atmosphere, the optical (visible) range and the radio range, which represent the two "windows" that ground-based telescopes can utilize. The student will be able to assess these two observational techniques, the main characteristics of the respective telescopes and the recording and processing of information.

Review and reference astronomical research literature (optional). The optional research component of the program will have students work with astronomical and astrophysical scientific literature. All of the required journals are available on-line. The student will be able to locate and search journals, extract relevant information and reference scientific publications.

4. Student Preparation

The proposed *CSAA* is primarily aimed at physics and physical sciences students, however, it is open to all qualified students. The program could potentially be of interest to geology and chemistry students from Arts & Sciences and to electrical, computer, and aerospace students from Engineering. After successful completion of the program, students will be prepared for a variety of future studies and work as briefly sampled in the following.

One aim is to prepare students to pursue a graduate degree in astronomy and astrophysics. The courses will provide a solid knowledge base and help in deciding which specific field to enter. The number of program credit hours and selection of courses is on par with Minor programs at Universities in the U.S. mainland and internationally. BS programs in Astronomy are not widely available and graduate programs often admit students with different BS degrees, particularly Physics degrees. The students will have obtained the necessary knowledge to compete for Research Experience for Undergraduates (REU) programs offered at many universities and observatories across the U.S. mainland, Hawaii and Puerto Rico (Arecibo Observatory) and which are very competitive due to the limited number of places and slots. A very rewarding and important educational job is high-school teacher and for which there is currently a shortage of qualified science teachers in Puerto Rico. The *CSAA* could be a much valuable addition to the standard physics courses for aspiring school teachers and provide them with a broad knowledge in history, phenomenology, and observational techniques in astronomy.

There is a widely held belief that an undergraduate degree in physics necessarily implies entering graduate school in order to find work. While this is the traditional path of many physicists-to-be, there are professions that can be taken up with just a bachelor degree. With the additional *CSAA* one can become a science writer/editor, public outreach official, astrophotographer, or planetarium/observatory assistant, just to name a few.

5. Justifications

Filling an academic gap. While the University of Puerto Rico system has a broad academic offer, currently there is no degree or program in Astronomy & Astrophysics. There do exist individual courses, many of which can be found in the Physics Department in Mayagüez, however, they do not lead to a degree or even to a certificate in this field. The proposed *CSAA* will be the first of its kind, filling an academic gap as well as having a strong impact on education and research in Mayagüez. Furthermore, the *CSAA* shares many objectives stated by the Physics Department and the UPR-M and is acknowledged as an academic option of interest for many students, as the letter from the SPS (Society of Physics

Students) signifies.

Complementing the Physics Department planetarium and observatory. The Physics Department features an observatory with a 16-inch optical telescope and a 64-seat planetarium, both of which were installed in 1973. Both facilities provide educational experiences yearly to thousands of high-school students and the general public. Open House events are held monthly. Additionally, the telescope is also used for undergraduate investigation and for demonstrations during astronomy courses. Clearly, the observatory and planetarium will complement the proposed *CSAA* and contribute toward a complete learning experience.

Collaborating with the Arecibo Observatory. Students will have the opportunity to visit and collaborate with the Arecibo Observatory; the Physics Department has maintained a collaboration at the educational and research levels. The scientific staff of the Arecibo Observatory has expressed willingness to support this type endeavors. These personnel from the scientific staff may serve as co-advisors in small research projects.

Strengthening the physics curriculum. The proposed *CSAA* could potentially connect with the existing curricular sequence in Atmospheric Sciences & Meteorology, since both are space sciences. Furthermore, astrophysics uses concepts of particle physics and will potentially be able to connect with the high-energy physics group. Interestingly, the high-energy physics group may work on the so-called dark matter problem; dark matter is believed to be present in the Milky Way galaxy, but has so far eluded direct experimental observation. Hence, the *CSAA* could be able to connect with several branches in the Physics Department and significantly strengthen its academic and research missions.

Fulfilling a "social need". An essential mission of all universities is to produce informed citizens. In astronomy and astrophysics there is a flood of misinformation or simply nonsense, while on the other hand, there is huge genuine public interest in many recent space missions, *e.g.*, the water-searching missions to Mars and to one of the comets. The proposed *CSAA* will provide fact-based teaching and help clarify many doubts and so prepare well-informed citizens. At the same time, it will cater to the physical sciences students, who are preparing to enter our schools as science teachers and who need to receive the best possible and most accurate education.

Serving the global community. Space exploration is an endeavor of interest across all continents and organizations and is conducted mostly in pursuit of knowledge or for strategic reasons. Space missions satisfy a human need in exploring, and overcoming our limitations, while also collecting a wealth of experimental observations that provide input for astronomical research. On the other hand, the preparation and administration of space missions crucially depend upon a deeper understanding of the processes in the solar system and Milky Way galaxy. The proposed *CSAA* will provide the basic knowledge to potentially be part of the global space community and therefore could attract students across all STEM disciplines.

6. Courses and Curricular Sequence

The proposed *CSAA* requires a minimum of 15 credit hours for completion distributed in 4 core courses and a minimum of one recommended optional course. We have 5 full-time faculty members from the Department of Physics that can contribute to the *CSAA*. The student can take more than one of the recommended optional courses. The core courses, codifications and lists of topics discussed are as follows:

Course	Title	Pre-requisites
ASTR 4005	Astronomy I	FISI 3151 o FISI3161 o FISI 3171
ASTR 4006	Astronomy II	ASTR 4005 y FISI 3152 0 FISI3162 o FISI3172
ASTR 4015	Radio Astronomy	FISI 4020
ASTR 4017	Stellar Evolution	FISI 4105

ASTR 4005 (Astronomy I): motion of celestial objects, historical perspective, Kepler's and Newton's laws, matter and radiation, types of telescopes, the Earth-Moon system, overview of the solar system, the Sun, properties of stars.
ASTR 4006 (Astronomy II): blackbody radiation and line spectra, optical and radio telescopes, binary stars, the Sun and main sequence stars, stars at the end of their life cycle, interstellar medium and star formation, the Milky Way and other galaxies.
ASTR 4015 (Radio Astronomy): radio astronomy fundamentals and wave propagation, telescope antennas and receivers, single-dish and interferometry basics, galactic and extragalactic radio sources, data acquisition and processing.
ASTR 4017 (Stellar Evolution): basic concepts in astrophysics, properties of matter and radiation, stellar interiors and atmospheres, heat transfer in stars, thermonuclear fusion in stars, beyond hydrogen burning, stellar structure calculations, endpoints of stellar evolution.

Recommended optional courses (other courses may be considered upon approval):
ASTR 4xxx (Radio Pulsars)
ASTR 4999 (Undergraduate Research)
ASTR 5005 (Formation and Evolution of Galaxies)
ASTR 5007 (Planetary Astronomy)
FISI 4997 (Special Topics: *e.g.*, Introduction to General Relativity)

Since both programs, for the Physics B.S. and the Physical Sciences B.S., allow for 18 or more credits in electives (including free and recommended) in their programs, the proposed *CSAA* can be taken without the necessity of additional coursework.

ASTR 4015 (Radio Astronomy) has as prerequisite FISI 4020 (Physics of Waves) and ASTR 4017 (Stellar Evolution) has as prerequisite FISI 4105 (Modern Physics), while both of these ASTR courses have ASTR 4006 as prerequisite. Furthermore, the courses ASTR 4015 (Radio Astronomy), ASTR 4xxx (Radio Pulsars) and ASTR 4999 (Undergraduate Research)

make use of some topics discussed in ASTR 4017 (Stellar Evolution). The student can complete the *CSAA* by a wise selection of his/her electives in the primary program. FISI 4020 is a pre-requisite for ASTR 4015 and FISI4105 is a pre-requisite of ASTR 4017. The *CSAA* is following a 4-semester cycle. A sample of the required coursework is as follows:

1st Semester		2nd Semester	
ASTR 4005	Astronomy I	ASTR 4006	Astronomy II
FISI 4105	Modern Physics	FISI 4020	Physics of Waves

3rd Semester		4th Semester	
ASTR 4017	Radio Astronomy	ASTR 4015	Stellar Evolution
		****	Recommended Elective

7. Admission Requirements and Classifications

To enter the *CSAA*, all of the following requirements have to be met. This curricular sequence is mainly considered for students who are enrolled in a STEM undergraduate program as a primary program, although students from other programs who satisfy the requirements may be considered. The student must:

1. have a minimum general GPA of 2.50 on a scale from 0 to 4.00.
2. have approved FISI 3161 and FISI 3162 (or equivalent) with a minimum grade of C.
3. have approved MATE 3031 and MATE 3032 (or equivalent) with a minimum grade of C.
4. students that have a STEM bachelor's degree can be considered for admission to the *CSAA* if they comply with points 2 – 3 above.
5. apply for admission to the *CSAA*.

If a student is enrolled in a College or University other than the University of Puerto Rico, then the final decision for admission is made by the chairman of the Physics Department after consultation with the Astronomy & Astrophysics committee.

8. Successful Program Completion and Residence Requirement

To successfully complete the *CSAA* and obtain a certificate, the student must approve satisfactorily the 4 core courses and at least one of the recommended optional courses for a total of 15 credit hours. Additionally, for a course to count toward the *CSAA*, it must be approved with a minimum grade of C, and the required minimum *CSAA* GPA across all coursework must be 2.50. All courses which appear in the list of possible courses for the *CSAA* taken by a student, will count towards the *CSAA* minimum requirement, regardless of the final grade obtained by the student.

The student must finish all the requirements of his/her primary program before or simultaneously with the successful completion of the *CSAA*.

If a student has taken the course *Astronomy I* in any of the other UPR campuses and approved with a minimum grade of C, then a validation can be considered. The student has to submit a written request for the validation, enclose the official syllabus, and present an official transcript showing a minimum grade of C. The final decision for validation is made by the chairman of the Physics Department after consultation with the Astronomy & Astrophysics committee.

The residence requirement is that all *CSAA* courses except *Astronomy I* must be taken and approved in the Physics Department at UPRM.

The student that successfully completes all *CSAA* requirements will obtain a certificate and an annotation in his/her academic records. The registrar's annotation in the student's transcript will be:
"Successfully completed all requirements for the Curricular Sequence in Astronomy and Astrophysics."

9. Resources and Assessment Plan

The proposed *CSAA* has 5 full-time faculty members from the Physics Department participating: Drs. L. Nowakowski, H. Radovan, E. Roura, S. Santana and P. Marrero. All faculty members are available for teaching the courses and supervising undergraduate research projects. The *CSAA* currently offers 8 courses with the ASTR codification, 4 of which were newly created, which is sufficient to support the 15-credit sequence. It is anticipated that more courses will be prepared in the near future, e.g., a course on General Relativity/Cosmology. Furthermore, the Physics Department houses an observatory with a 16-inch optical telescope as well as a 64-seat planetarium, both of which can be used to supplement the academic and research components. Students registering for the *Undergraduate Research* course may opt to perform research projects in collaboration with Physics Department faculty and Arecibo Observatory scientific staff. No other resources are necessary and no other costs are anticipated to start and maintain the *CSAA*.

To maintain a high quality *CSAA*, a series of assessments will be performed periodically. The following items will be assessed:

- ***admission requirements:*** particularly important at the beginning is to evaluate how well the admitted students perform and use these observations to adjust, if necessary, the admission requirements. The goal is to establish admission criteria that would be realistic indicators for the success of the *CSAA*.

- ***students' choice of electives:*** depending on which electives are chosen and on the respective enrollment numbers, popular electives can be offered more frequently, while new electives could be created if demand arises.

- ***overall satisfaction level:*** an important mechanism in improving the *CSAA* is feedback provided by students as well as by faculty. The feedback could be about any aspect of the

program, such as course content, research project topics or course prerequisites.

• ***completion-to-entry ratio:*** it is desirable that the majority of the entering students successfully complete the sequence. This "completion-to-entry ratio" can provide a valuable marker about the technical level, organization and administration of the program.

• ***tendency in student numbers:*** this is an indicator that provides feedback for the long run and could be evaluated, e.g., over a 5-year period. We will try to correlate these numbers with the freshman enrollment in Physics.

• ***contact with alumni:*** yearly surveys of alumni having taken the *CSAA* could provide general input such as effectiveness, attractiveness and usefulness of the program, now evaluated with a more mature and professional eye of the alumni.