Bridging the Gap Between Research and Education:
The μNet Project and High School Science Education in Greece

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Abstract
Many educators believe that hands-on experience is more effective than classroom learning for science education. However, incorporating rapidly-evolving branches of science, such as Astronomy and Astroparticle Physics, into secondary education can be challenging due to the complexity and cost of equipment and the need for advanced scientific methodologies. To address this issue, the Physics Laboratory of the Hellenic Open University created the μNet project. This project engages Greek high school students in the experimental methodology of Particle and Astroparticle Physics by having them build, test, and operate their own telescope to observe high-energy cosmic rays. The project also aims to develop a school network of educational cosmic ray telescopes throughout Greece, allowing for collaboration and idea exchange among students. The project engaged over 500 students and 70 science teachers in its first year of operation during the 2022-2023 school year. This report presents the status and latest developments of the μNet project, as well as the results of the first year of operation, including the tools and methods that have been developed, such as gamification methods used to enhance attendees' interest.

Keywords: Physics Education, Cosmic Ray Physics, Remote Laboratories, Distance Learning

Introduction

In classical Astronomy, astrophysical objects are observed by detecting the emitted light which may be visible (i.e. optical telescopes) or not (i.e. radio astronomy). However, not only light is emitted by such objects; in many interesting cases high energy particles like protons, nuclei and neutrinos, are also produced and propagate through space until they enter the Earth's atmosphere (Gaisser, 2016). These high energy subatomic particles and atomic nuclei that reach the Earth from all directions in the sky are called cosmic rays. When such an energetic cosmic ray enters the Earth's atmosphere interacts with a nucleus in the atmosphere and produces many new particles (secondary) in cascade interactions, usually called an air shower (Fig, 1).

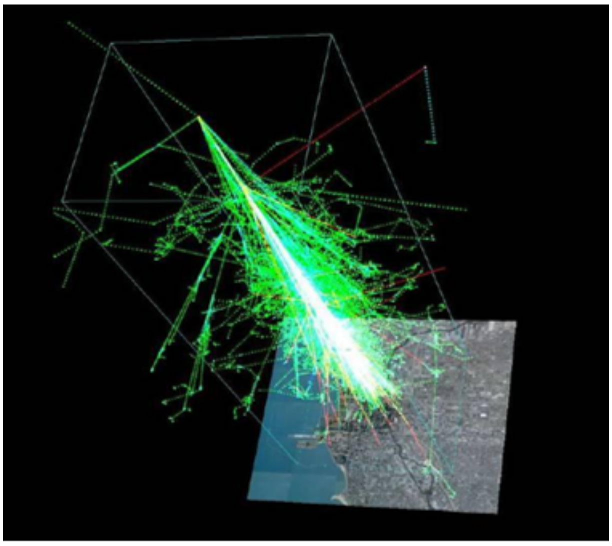

Figure 1: An artistic view of an Air Shower above a city.

The generation and absorption of particles is continuous and as a result a very thin (a few meters) but large disk (the radius can reach hundreds of meters) is formed that is perpendicular to the direction of the initial (primary) cosmic ray moving with the speed light (Fig. 2). If the energy of the primary particle is big, the disk can reach the ground level and the particles spread in an area hundred or even thousands of meters in radius. In this case we call the shower Extensive Air Shower (EAS).

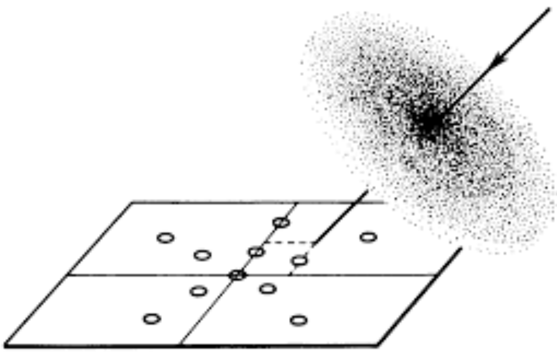

Figure 2: The EAS disk of particles.

Educational Cosmic Ray Telescopes

An educational telescope designed for cosmic ray observation typically consists of three particle detectors arranged in a horizontal triangle on the ground, spaced around 10 to 20 meters apart. By analyzing the relative timing of shower particles passing through these detectors (information provided by the particle detectors) and employing basic geometric principles, it becomes possible to accurately reconstruct the direction of the shower axis and, consequently, the trajectory of the primary cosmic particle. This reconstruction can be achieved with a precision of a few degrees (Leisos, 2019).

The Physics Laboratory at HOU has developed an affordable (approximately 3000 Euros), compact, and portable cosmic ray telescope called the μCosmics detector (Tsirigotis, 2019). The μCosmics detector (shown in Figure 3) consists of three detector units, a PC-based oscilloscope, and a PC for real-time data monitoring and storage. The detector unit itself is quite small, easily portable, and weighs approximately 6 kilograms. The μCosmics telescope offers a resolution of around 5 degrees and can record approximately 10 cosmic ray showers per hour. This recording rate is sufficient even for the relatively short duration of a high school class period.

Figure 3: The μCosmics telescope with 3 detection units (white boxes) and the interior of the detection unit (right).

The μNet Project

The development of the μCosmics detector, coupled with the creation of corresponding educational initiatives during summer schools, gave rise to the inception of the μNet project. μNet's primary objective is to actively engage high school students in hands-on experimental procedures within the field of Astroparticle physics, particularly focusing on Cosmic Ray physics (Petropoulos, 2020a). Within the framework of μNet, 20 educational cosmic ray telescopes have been set up in Greek high school laboratories. Moreover, remotely operated instruments deployed on the HOU campus are accessible to over 50 schools annually. These institutions equipped with μCosmics detectors, along with those participating in distance education efforts, collectively form the μNet network (depicted in Figure 4) - the first Greek school network dedicated to educational cosmic ray telescopes.

The central facet of the educational curriculum lies in students' active involvement in constructing and operating the detection units themselves. Pupils from different schools collaborate on assembling the detection unit, gaining a deeper comprehension of its operational principles. The functioning of these stations takes place via an online web-based application. Participating students access the application to either operate their local station or choose a remote telescope (situated at HOU) to work with. The tasks related to data management encompass unit calibration and describing the attributes of showers based on the collected data.

The comprehensive μNet educational program comprises a sequence of structured educational tasks, executed by students under the guidance of their educators (Petropoulos, 2020b). This program encompasses seven primary educational activities:

- Construction of the detection unit
- Calibration of the telescope
- Estimation of atmospheric muon flux characteristics
- Operation of the Data Acquisition System and Online Monitoring
- Exploration of Detector Geometry
- Telescope Operation

Upon the conclusion of data collection (at the end of the school year), students proceed to assess the detection rate as well as the distribution of air shower arrivals, subsequently comparing their findings with measurements conducted by other schools.

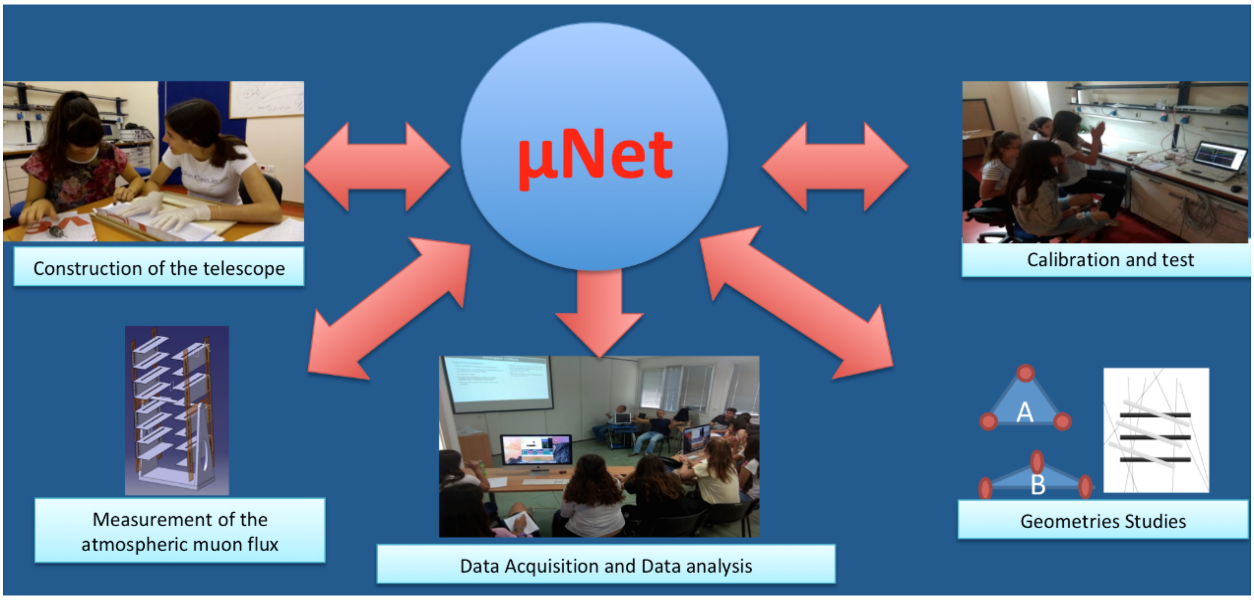

Figure 4: The μNet educational activities with the μCosmics detector.

The μNet in Action

The μNet project has demonstrated continuous evolution over the past several years, notwithstanding certain challenges faced during the pandemic. The initial phase of the μNet project involved a five-day educational initiative conducted in 2018 and 2019, as part of two summer schools organized by the Physics Laboratory at HOU. During this inaugural endeavor, student feedback was highly positive, and the overall outcomes were notably encouraging.

In 2020, a pilot program was launched for the academic year 2020-2021. This pilot initiative aimed at establishing a small network of educational cosmic ray telescopes within five high schools located in the Achaia prefecture, the same region where HOU is situated. However, due to the constraints posed by COVID-19, the entire training program had to be executed remotely. Despite this challenge, the evaluation revealed that the pilot program's objectives were achieved to a significant extent.

More recently, the μNet project secured funding from the Hellenic Foundation for Research and Innovation, earning the top rank among proposals in the thematic area of "Research & Innovation Hubs in Education." As a preliminary phase of the project, a modest network of schools was organized for the academic term 2021-2022. The aim was to establish experimental educational activities and develop the requisite educational materials.

The inaugural year of μNet's full operation occurred during the academic year 2022-2023. Over 500 students from 60 schools across Greece participated in these educational activities. Among these, 40 schools engaged with the educational telescopes through remote access, while 20 schools were afforded the opportunity to host a telescope within their own laboratory setting. The progressive journey of the μNet project is illustrated in Figure 5.

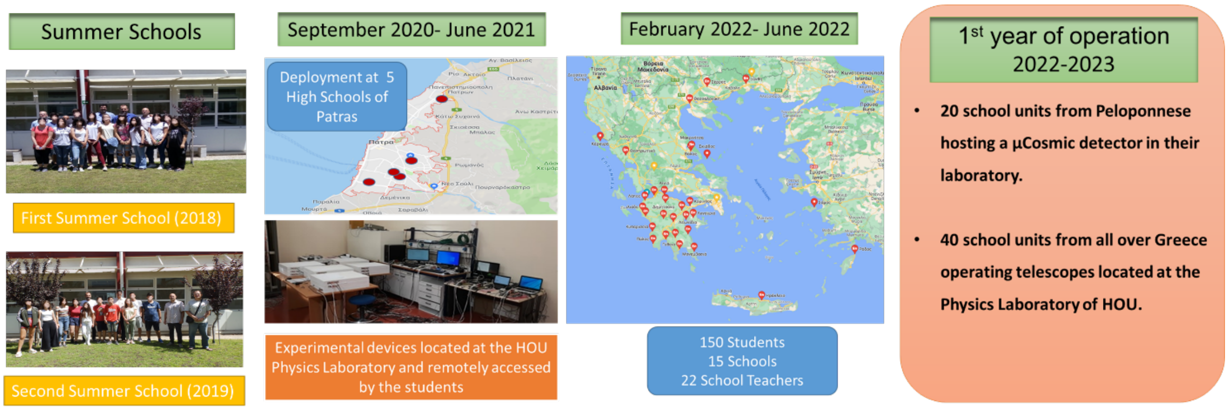

Figure 5: The evolution of the μNet project

The primary instrument utilized in the educational curriculum was a web-based application (depicted in Figure 6), which facilitated the calibration and operation of the telescopes (accessible at https://mnet-online.eap.gr). Each participating school employed this platform to monitor various aspects, including the detection rate and the reconstruction rate of air showers. Furthermore, the application provided access to acquired pulse data for each detected shower. An animation showcased the reconstructed shower direction, and the final tab of the online monitoring interface displayed histograms illustrating the data quality of the telescope.

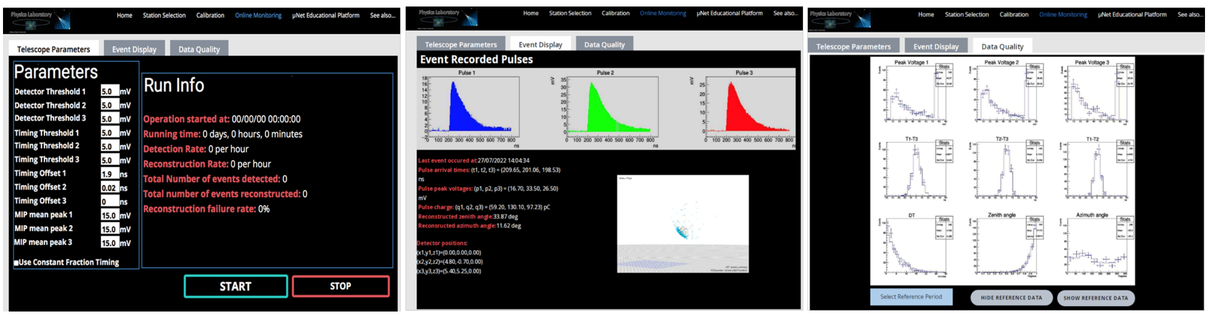

Figure 6: The online web app for the telescope operation (left, middle) and the LMS educational platform (right)

For the educational program, we developed an LMS platform (Blas, 2009) that included many sessions each one with a series of analytical and short, videos, avoiding any (written) manuals. The enrollment of the students was based in gamification methods where each student collected badges, items and points either for her/himself or for her/his school. Additionally, game contests where organized where the schools were competing each other answering questions.

The general outcome was that the schoolteachers as well as the students improved substantially their knowledge about cosmic rays (Xiros, 2023). The score for each answer of the questionnaire was given based on a Likert Scale: 1 corresponded to the answer “not at all,” 2 corresponded to the answer “a little,” 3 corresponded to the answer “moderate,” 4 corresponded to the answer “quite a lot,” and 5 corresponded to the answer “very much.” For the students the score for the knowledge about cosmic rays before the educational program was 1.6 ± 0.2, while after the completion of the program 3.7 ± 0.2. On the other hand, for the teachers the relevant scores were 2.6 ± 0.3 (before) and 4.1 ± 0.2 (after).

Conclusion

In conclusion, the μNet project, initiated by the Physics Laboratory of Hellenic Open University, addresses the challenge of integrating complex sciences like Astronomy and Astroparticle Physics into secondary education. Recognizing the efficacy of hands-on learning, the project engages Greek high school students in constructing, testing, and operating their own telescopes to observe high-energy cosmic rays, promoting experiential learning. This initiative has not only established a school network of educational cosmic ray telescopes across Greece, enabling collaboration and idea exchange among students, but has also yielded impressive outcomes in its inaugural year, engaging over 500 students and 70 teachers. The project's innovative use of web-based applications, gamification techniques, and remote-operated devices has facilitated an enriched learning experience, leading to significant improvements in both students' and teachers' understanding of cosmic rays. The μNet project stands as a remarkable model for enhancing science education in a dynamic and interactive manner.

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