MARIACHI: A MULTIDISCIPLINARY EFFORT TO BRING SCIENCE AND ENGINEERING TO THE CLASSROOM

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ABSTRACT

MARIACHI[1] is a unique endeavor that integrates research at the frontier of our knowledge of the universe, with a broad program of training, education, advancement, and mentoring. Its scientific goal is to detect ultra-high-energy cosmic rays whose origin may provide insight into the evolution of the universe. The detection technique is novel and is based on radar-like technology (where signal processing plays a crucial role) and traditional scintillator ground detectors. The wide educational program flows from the research concept and involves students at all levels (high-school, undergraduate and graduate) working with a multidisciplinary team of scientists, engineers and educators.

Index Terms— MARIACHI, ultra-high-energy cosmic rays, multidisciplinary education, radar-based techniques, scintillator ground detector.

1. INTRODUCTION

The MARIACHI project, initiated by physics teachers, scientists and engineers, has developed an innovative method to integrate the research of detection and study of ultra-high-energy cosmic rays (UHECRs) in the classroom. The science of MARIACHI requires the collection, processing and correlation of signals using radar-based technology and scintillator ground detector sites located over wide geographical areas. The physical separation of both the detecting sites and the participants require implementation of a reliable and secure data collection system and efficient tools for information exchange and communication. Emerging cyberinfrastructure based on grid technology allows for secure data exchange as well as for sharing of common knowledge and interactions among participants through dynamic services as wiki[2], blog, and Internet-based video conferencing.

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[1]Mixed Apparatus for Radar Investigation of Cosmic-rays of High Ionization.

[2]A wiki is software that allows to create, edit, and link web pages easily.

The MARIACHI philosophy, "learning by doing", is embraced all the participants. Physics teachers in the project experience first hand how a scientific experiment is conducted. They take part in all the phases of the experiment and develop their skills in hands-on workshops and by directly collaborating with the physicists and engineers, who are in charge of the research part of the project. This interaction allows for development of courses with rich content tied to their schools' curriculum. Students from all levels (high school, undergraduate, graduate) participate in research projects, regular courses, workshops and other classroom activities, where they can learn to use tools needed in MARIACHI. To broaden the impact of the project, many of the activities are offered to a wide audience, with particular emphasis on traditionally underrepresented groups. The latter commitment has been possible primarily due to the partnership of MARIACHI with Long Island Group Advancing Science Education (LIGASE) [1], which provides facilities, extensive experience, and a large network of over 100 high schools, many of whom are high-needs.

In this paper we describe in some detail the efforts in this multidisciplinary project and the interplay of the ongoing research and educational activities. The remainder of the paper is as follows. The next section describes the science in the project and its main challenges. In Section 3 the educational activities are explained in detail. Section 4 addresses the evaluation methods, and finally, Section 5 includes some concluding remarks.

2. THE MARIACHI EXPERIMENT

The scientific goal of MARIACHI is the detection of UHECRs, which are subatomic particles with extreme kinetic energy extremely large energies far beyond energies typical of other cosmic rays [2, 3].

The source of UHECRs is a deep mystery. There are no known astrophysical sources within our galaxy or those close to us that could accelerate particles to such enormous energies. Yet, interactions of such particles with the cosmic microwave background would not allow their propagation

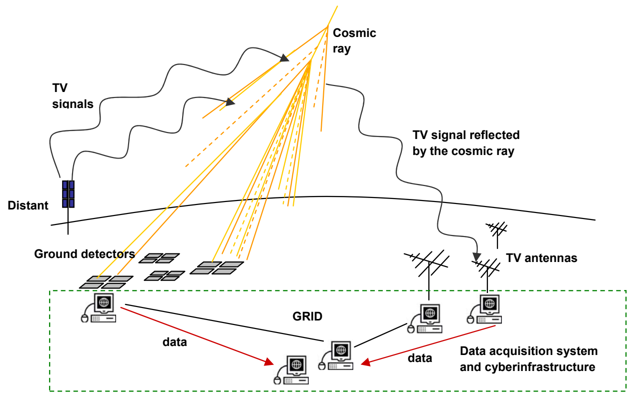

Fig. 1. Pictorial description of the MARIACHI experiment.

Fig. 2. Collection sites of the MARIACHI experiment. The picture was generated by using www.maps.google.com.

from greater distances. So, where do they come from? This is a question that has engaged astrophysicists and cosmologists since the discovery of UHECRs. Without a doubt, if we could identify the location of their source, we would get a highly valuable insight about the origins and evolution of the universe. Scientists throughout the world therefore put significant efforts to collect information about UHECRs, that is, the rate of their occurrence and the location where they originate. Since the observed rate of these rays is one per square kilometer per century, current experiments are designed to cover huge areas for data collection. Examples are the Pierre Auger Observatory [4], which occupies 3,000 square kilometers of the Argentine pampas, and was built by scientists from 15 countries, and the Telescope Array in Utah [5], which will cover an area of 800 square kilometers.

The MARIACHI project searches for UHECRs by detecting reflected broadcast TV or FM radio signals originating from distant transmitters. An important component of the research work is the processing of the received signals. Detection of reflected signal, estimation of the parameters of the reflected signal, classification of the reflector, and location of the reflector are some of the (interrelated) problems that have to be addressed. Once a signal is detected, confirmation that it is due to reflections from ionized trails created by UHECRs is accomplished using scintillator arrays which are built and operated by high school students and teachers, thus integrating the science and educational components. Figure 1 illustrates the experimental setup. Radio and scintillator sites around Long Island are synchronized by global positioning system (GPS) and use grid computing to collect, display, and analyze the data (see Figure 2 for a map of current collection sites). The network provides the means for students to engage in cosmic ray research utilizing advanced computing tools and infrastructure from their own schools.

3. BRINGING SCIENCE AND ENGINEERING INTO THE CLASSROOM

MARIACHI uses its scientific goals to attract research students at university and high school levels. More than 40 participants including professionals in physics, electrical engineering, computer science, and education currently participate in the project. MARIACHI has a contingent of 15 high school teachers representing a dozen schools with diverse student bodies, as well as faculty and researchers from Brookhaven National Laboratory (BNL), Stony Brook University and two Suffolk County Community College campuses.

3.1. High schools

The MARIACHI scintillator ground detector concept was developed through a series of workshops for high school teachers and students held at BNL. The design of the detector has evolved to the point that a team of one teacher and several students can assemble the detector in a one day workshop (see Figure 3).

Each scintillator ground detector is composed of four scintillators, each of 0.25 m^2, located at the corners of a high school classroom, with an additional identical counter mounted in one of the corners. The signals from the five detectors are fed into a dedicated electronics circuit. This circuit has a Field Programmable Gate Array (FPGA) that allows for programming of any desired logic between the counters. In particular, coincidence signals from the corner with the counter pair provide a continuous monitor of the local cosmic ray rate. Figure 4 shows examples of signals and information (timing and height of the event) collected from the detectors in four different corners of a classroom.

As schools take ownership of their equipment, they must understand in great detail the functioning of each detector

Fig. 3. Workshop with high school students and teachers for building the scintillator ground detector.

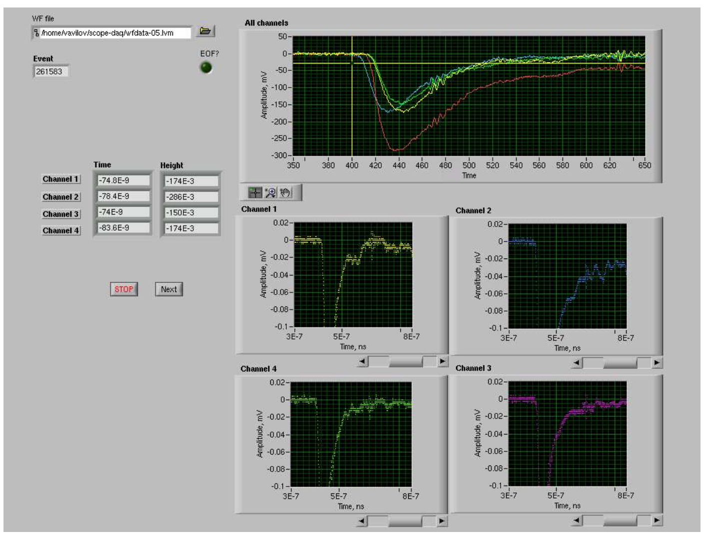

Fig. 4. Oscillogram of signals and data collected from four detectors in a classroom.

component, thus these workshops are essential. Once the setup is properly running in the classroom, students are assigned various data analysis tasks including evaluating the number of events per time interval, which is used to check if the data are truly random (Poisson Distribution); counting the number of events per hour, which allows for verification if there are day/night differences (Student's T test); or calculation of cosmic ray rates as function of barometric pressure, which seeks to find a correlation with atmospheric pressure and the number of cosmic ray events detected. As result of these activities, some students have developed their Intel projects[3] under the supervision of MARIACHI researchers.

MARIACHI researchers also offer courses to in-service physics teachers who want to learn and develop hands-on experiments in modern physics. This course is geared towards the use of computers at application level to collect, process and analyze data, and the use of the wiki for record keeping.

Finally, a summer workshop comprising all the elements of MARIACHI, i.e., radio processing, scintillator ground detectors and cyberinsfrastructure was implemented in a novel way. High school teachers were asked to participate together with several of their students so they all could bring the expertise back to their classrooms. The one-week course combined lectures and seminars with practical experiments which included collection of signals using the radio receiver and basic signal processing. The response of the participants to the course was very positive as evidenced by their comments on surveys and the wiki.

3.2. Undergraduate students

The undergraduate activities combine regular course offerings with research projects:

- We are imparting various eight-session four-week research and inquiry-based courses through the Stony Brook Women in Science & Engineering (WISE) mentoring program. These courses are in two topics: "basic radar processing" and "cosmic rays, particle detectors, and data analysis", corresponding to the main two lines of research part of the project. Freshmen students are introduced to the MARIACHI research components and are tasked with developing and making a series of experiments and measurements to understand the essence of the project. They, too, are introduced to new ideas in computing and learn to use a wiki to record results, write reports, and interact with instructors and other students. The courses are instructed by faculty, a post-doc associate, high school teachers, and graduate students. Students are encouraged to ask and find answers of their own research questions by means of discussion-based classes.

- We are currently offering an introductory course on scientific method, technology and modern cyberinfrastructure, which uses the phenomena of cosmic rays and meteors as a vehicle to motivate students in research activities. The course is offered for both undergraduate science majors to fulfill their science breadth requirement and concurrently to in-service teachers.

- Several students have approached MARIACHI to develop summer activities under various programs including those from LIGASE or the NSF-funded Research Experiences for Undergraduates (REU) from the Physics Department at Stony Brook University and BNL.

- Engineering students have also shown interest for the radar-like detector research and have conducted their

[3] The Intel Science Talent Search is a US pre-college science competition.

senior design project under the supervision of our engineering team. Last year a group of them worked on calibration of the instrumentation for signal acquisition.

3.3. Graduate students

The involvement of graduate students includes three fronts:

- They closely participate in the scientific part of the project related to radar-like detectors. The main purpose of this activity is to exploit the potential of forward-scattering techniques for detecting and analyzing signals that are set off by UHECRs. The methods used are based on similar principles as those of radar and allow for building inexpensive stations that can achieve the pursued objective and can easily cover very large geographical areas. The research activities revolve around three themes: (a) development of an improved forward-scattered signal model using existing theory as a starting point, (b) design and building of hardware architecture for signal acquisition based on feasibility computations, and (c) processing of the forward-scattered signals, which includes detection, estimation, classification, and localization. Two students are working on the signal processing problems, another one is helping with the hardware implementation, which includes design of antennas, and one more is involved in data acquisition and cyberinfrastructure. Figure 5 depicts a snapshot of a spectrum of signals collected by the radio receiver at Stony Brook University, which is being processed and analyzed by the MARIACHI students.

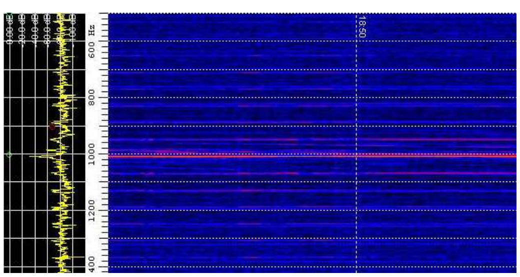

Fig. 5. Example of time-frequency spectrum of a signal obtained by a radio receiver.

- They mentor undergraduate and high-school students with their senior design and Intel projects, respectively. They have also collaborated with REU undergraduates.

- They instruct some of the WISE offerings as well as parts of the seminars and workshops offered by MARIACHI.

4. DISSEMINATION AND EVALUATION

Demonstrations that illustrate the experimental setup and the underlying science have been developed by MARIACHI participants. These complement the material offered in the school curriculum, courses, and workshops, and are accessible on the project website [6]. This portal also gathers information on the most recent data collected and shows live data collected at the radio receiver and the scintillator ground array located at Stony Brook.

The underlying project and related activities are presented at seminars at various universities, colleges, high schools and at amateur astronomy clubs. National and foreign institutions have already shown interest to join the project and have consulted MARIACHI researchers to initiate similar efforts.

The evaluation of the project includes online surveys which are completed at the conclusion of courses and seminars, site visits for observations, focus groups, and student and staff interviews by an external evaluator.

5. CONCLUSIONS

MARIACHI has built a research, education and cyberinfrastructure team that is well positioned to carry out its mission of detecting ultra-high-energy cosmic rays. Current efforts include establishing the seed experiment on Long Island through the grid-enabled data collection system, imparting workshops to enable participants to perform analysis, and offering a broad range of educational activities with particular emphasis on inclusion of traditionally underrepresented groups. Future activities include the replication of the seed infrastructure at selected colleges and universities beyond Long Island.

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