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The Cosmic Ray Observatory Project – a statewide education and outreach experiment in Nebraska, USA

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Abstract.

The Cosmic Ray Observatory Project (CROP) is a statewide education and research experiment which involves Nebraska high school students, teachers, and college undergraduates in the study of extended cosmic-ray air showers. A network of high school teams construct, install, and operate school-based detectors in coordination with University of Nebraska physics professors and graduate students. Funded by the U.S. National Science Foundation, CROP enlisted its first 5 school teams in the summer of 2000, with the aim of expanding to the 314 high schools in the state over several years. The organization of the project and its scientific potential are discussed. Preliminary measurements from CROP's pilot schools and results from the assessment of CROP's educational impact are presented. Similar school-based cosmic-ray efforts in the U.S. and Europe are also described.

1 Introduction

The National Research Council's National Science Education Standards call for enhanced "science as process" in which students actively develop an understanding of the scientific process as combining knowledge with reasoning skills. This "process" should include opportunities for students to engage in extended investigations. The cookbook style "experiments" through which high school students are often led tend to give the expectation that scientific results should follow 40-minute exercises, or worse, that such efforts are best finished by fudging easily predicted data.

At the University of Nebraska-Lincoln (UNL), an innovative program is underway to build high school teachers' technical skills and knowledge base, as well as provide for student participation in a genuine long-term research experience. UNL's Cosmic Ray Observatory Project was launched in earnest in the summer 2000 when 20 participants from five Lincoln/Omaha area schools attended the first summer

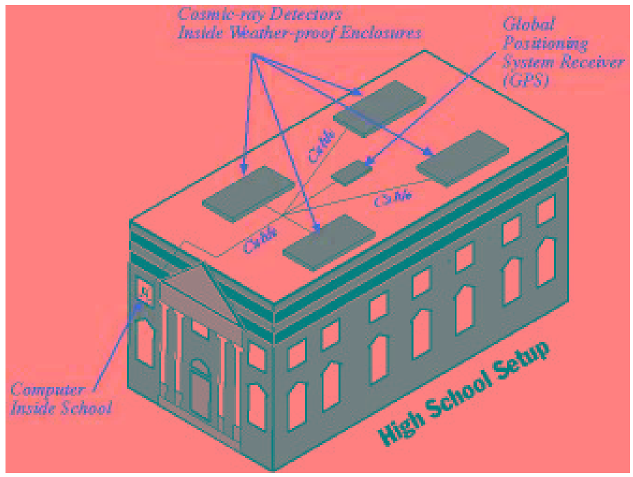

Fig. 1. Generic high school set-up with detector array and GPS receiver.

research program. CROP is a statewide outreach experiment whose goal is to involve Nebraska high school students, teachers, and college undergraduates in a multi-faceted, hands-on research effort to study extended cosmic ray air showers. We like to think of CROP as a means of merging the three primary missions of professors at a land grant institution: research, teaching, and outreach.

Particles from extended showers will be sampled by arrays of student-built and maintained scintillation counters placed on high school rooftops, while a PC-based data acquisition system located inside the school building records events. A GPS receiver will provide a time stamp so that time coincidences with other sites, signaling the presence of extended cosmic ray showers, can be detected. Student participants will compare data with other sites via the Internet and share experiences through regional workshops organized around the state's 19 Educational Service Units. A schematic of a typical high school setup is shown in Figure 1.

In 4-week summer research experiences, CROP will pro-

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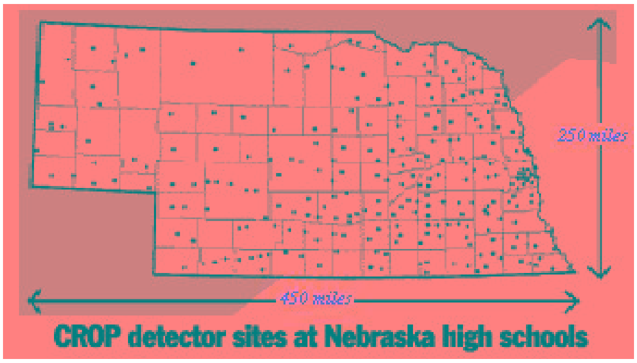

Fig. 2. Dots indicate high school locations.

vide intensive teacher/student training in state-of-the-art particle detection and computer monitoring. This will be followed by year-round, long-term studies of cosmic rays. The experiments begin right in the classroom, continue through the school year, and via coordinated Internet sharing of data, extend beyond the schoolyard's boundaries. Conceived as a genuine research project, CROP will be developed in stages, and its success measured incrementally.

2 The Scientific Potential of CROP

Although the main thrust of CROP is to expose its participants to the physics of cosmic rays, air showers, particle detectors, data acquisition and analysis, CROP addresses physics topics which will complement the major ground-based arrays (CASA, AGASA, the Pierre Auger Observatory, etc.) in three areas. Primary cosmic ray energies and direction-of-origin distributions will be collected for (i) building-sized showers ($E > 10^{15}$ eV, plenty of rate) using the detector array at each school and (ii) city-sized showers ($E > 10^{19}$ eV, much lower rate) using time-coincidences among schools in populated areas like Omaha and Lincoln for comparison with the above experiments. In addition, CROP will make a unique scientific contribution, since CROP detector sites will eventually cover the 75,000 mi^2 area of the state, many times the coverage of the above arrays. Figure 2 is a map of Nebraska with dots showing the locations of the state's 314 high schools. The sparsely-spaced sites in western Nebraska will allow CROP participants to investigate very long-distance correlations which would indicate extensive cosmic-ray bursts. In simple terms, when an Omaha school detects an energetic shower, does the whole state light up? The scientific impact of CROP will be strengthened in proportion to the number of sites collecting data simultaneously, making expansion across the state the primary goal after the pilot year.

3 Recycling Hardware

The main CROP detector components - acrylic scintillator tiles, photomultiplier tubes (PMTs), and power supplies - are being recycled from the now-complete Chicago Air Shower Array (CASA). CASA employed 1089 separate detector stations arranged in a 0.25 km^2 grid within the Dugway Proving Grounds (operated by the U.S. Army) in western Utah. Each station housed four 61cm $\times$ 61cm scintillation counters and a low- and high-voltage power supply. The retired CASA equipment has been donated to CROP free of charge. Spare CASA counters formed the basis for prototype detector development at UNL, led by our undergraduate assistants.

In late September 1999, a CROP team traveled to the CASA site and loaded a rented truck with sufficient hardware to outfit the first 10 CROP schools. Most of the equipment was found to be in good working order. In a second larger-scale retrieval effort in May 2001, the CROP team removed over half of the CASA array, yielding sufficient detectors to outfit all the high schools in Nebraska.

4 NALTA, and Other CROP-Like Projects

A number of similar university/high-school cosmic-ray partnerships are emerging in other locations in the U.S., Canada, and abroad. CROP's closest relative is the Washington Large-area Time-coincidence Array (WALTA) based at the University of Washington and the Seattle area since both CROP and WALTA employ retired scintillators from CASA. Other established programs include the Alberta Large-area Time-coincidence Array at the University of Edmonton and the California High School Cosmic Ray Observatory based in the Los Angeles area. The attraction of sharing curriculum and technical developments and, eventually, the data collected over very long baselines led the groups to establish the North American Large-area Time-coincidence Array (NALTA). Web sites for the individual efforts in this continent-wide consortium can be accessed through the NALTA home page,

http://csr.phys.ualberta.ca/nalta/

5 Funding History

During the R&D years prior to 2000, CROP caught the attention of UNL administrators and was awarded seed grants from various internal sources. A major boost came with the award of a 4-year, $1.34 million grant from the National Science Foundation. The grant is funded jointly by the Division of Elementary, Secondary, and Informal Education and the Division of Physics. CROP's unique collaboration between university researchers and high schools in a long-term, viable experimental program has been recognized by the NSF as having great potential to increase the impact of experimental physics research on the nation.

The NSF grant primarily supports the participant workshops (stipends, lodging and travel for remote participants) and educational assessment activities described below. We have had success finding funds for supplementary hardware from individual school districts and state of Nebraska sources. Identifying funding sources to ensure our expansion across the state and the continuation of CROP post-NSF funding is a primary goal of our institutionalization plan.

6 CROP's Inaugural Year

6.1 Recruitment

First-year recruitment focussed on the Lincoln and Omaha metropolitan areas through presentations at regional Nebraska Association of Teachers of Science and Nebraska-AAPT meetings as well as a special Lincoln Public School in-service day conducted at UNL. This local focus has facilitated frequent meetings and maximized the supervision necessary in the initial effort to get multiple detector sites up and running.

Through blanket E-mail solicitations to Nebraska high-school physics teachers and word of mouth, we have accumulated a waiting list of schools across the state which are anxious to become CROP participants. Almost daily, we also receive inquiries from schools in adjacent states, across the country, and abroad. In the next few years, teams will be recruited from each of Nebraska's 19 Educational Service Units, with ESU Directors providing insight into the unique needs of their region. We place high priority on the recruitment of teachers and students from groups underrepresented in science, which in western Nebraska includes schools in very remote, rural locations.

6.2 The Summer Research Experience

The first annual summer session was held in July-August 2000. Six physics teachers with a total of 14 students represented five participating high schools: Lincoln Northeast High School, the Lincoln Science Focus Program, Mount Michael Benedictine High School in Elkhorn, Marian High School in Omaha, and Norfolk High School.

Days were typically were divided between morning classroom sessions and afternoon lab work. Mini-courses explored relevant topics in high-energy physics, astronomy, particle detectors, Monte Carlo applications, triggering, data acquisition, and the Global Positioning System. Afternoons were devoted to hands-on work with prototype detectors. Participants polished scintillator and glued PMTs, wrapping and checking their assemblies for light leaks which required them to learn to use an oscilloscope. They also measured the detection efficiency of each counter. Through these exercises, they became familiar with the assembly, testing, and operation of the detectors they now use at their own high school. Teacher input has proven crucial to the evolution of the detector set-up which we feel helps guarantee its safe, durable, and foolproof operation. The logistics of, and possible problems with, the installation and operation in a variety of school settings were discussed in the summer session.

6.3 First-Year Mini-Experiments

The schools have embarked on two mini-experiments to be performed during the 2000-01 academic year. The first – measuring the (small) variation of cosmic-ray rate vs. barometric pressure – will help us determine how well the school teams, working independently, can measure the same effect. The second – measuring coincidence rates with detectors spread horizontally in various configurations – will help us optimize the detector set-up for each school's study of extended air showers. Figure 3 shows Marian High School's preliminary measurement of 4-fold coincidence rate vs. barometric pressure using 4 refurbished CASA detectors in a vertical telescope during January and February 2001. The horizontal scale ranges from 727 to 751 mmHg and the vertical scale is 4-fold counts measured over a 2-hour period. They measure, roughly, a 1.3% decrease in rate per mmHg, consistent with other measurements.

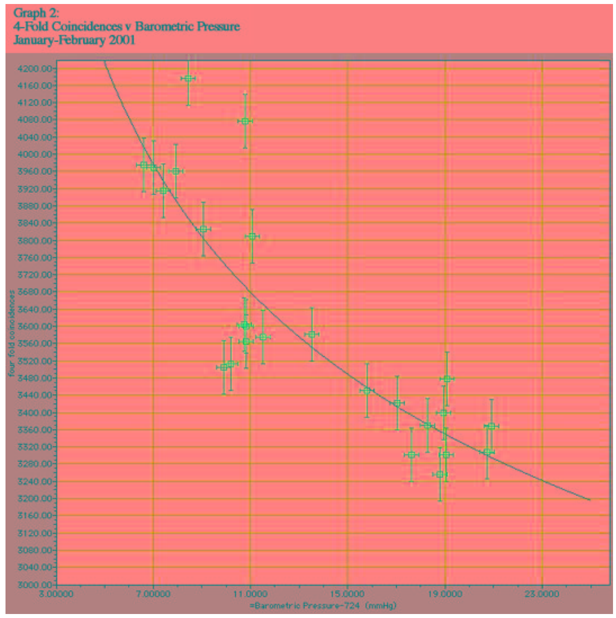

Fig. 3. Marian High School's measurement of cosmic-ray rate vs. barometric pressure. The horizontal scale ranges from 727 to 751 mmHg and the vertical scale ranges from 3000 to 4200 4-fold coincidences over a 2-hour period. The data points show statistical errors.

The school teams have impressed us with their ideas for supplementary measurements which become independent student projects. Mount Michael H.S. is busy checking for diurnal variations with 15 minute runs made six times a day. Norfolk H.S. varies the detector separation in their vertical telescope, effectively controlling how narrow a window they view of the sky. Marian H.S. is assembling small trigger counters to map the light-collection efficiency across the face of their scintillator tiles (studying signal attenuation).

6.4 Academic Year Workshops

Twice each school year, nominally December and April, one-day workshops will be scheduled as an opportunity for team leaders to meet, share experiences, critically evaluate the program, and make plans for both continued data-taking and statewide expansion. On December 2, 2000, our first academic year workshop was held at UNL, attended by the summer participants, the UNL CROP staff, and the project's Advisory Panel. Students from each school reported on their progress, and collectively we discussed how to complete the mini-experiments that were just getting underway. Some of the teachers whose school teams will join CROP in the summer 2001 also attended as a preview of the upcoming year.

7 The CROP Advisory Panel

CROP is guided by an 8-member Advisory Panel with varied expertise in high-energy and cosmic-ray physics, secondary science education, hands-on science museums, other science outreach programs, and high school science teaching. One full Panel meeting per year overlaps with the autumn participant workshop, and selected Panel representatives observe the summer and spring workshops. At its meeting in December 2000, the Panel heard progress reports from the first-year school teams, witnessed their enthusiasm, and joined a business meeting with the CROP staff. The Panel's report provided a valuable critique of the pilot year and suggestions for the future. The report included ideas for ensuring effective communication with the schools during the academic year, technical development hints, and a program of supplementary experiments the teams can perform with their cosmic-ray detectors.

8 Educational Evaluation

Significant energy is devoted to formative and summative assessment. CROP has enlisted an external evaluator whose activities are supported by NSF funds. The Advisory Panel and UNL's Center for Instructional Innovation also contribute to project assessment. While critiquing CROP's success at establishing a statewide network of detector sites, the evaluation's primary focus is the educational value that CROP experiences provide participating teachers and students, using established assessment tools. Among other topics, the evaluation team will study teachers' self-efficacy for conducting CROP research and classroom activities and changes in students' interest and attitudes about science.

Pre- and post-testing at the 2000 summer workshop revealed that the participants improved their knowledge of cosmic ray physics and particle detection techniques and gained sufficient expertise in operating their detectors to perform the assigned mini-experiments during the upcoming academic year. Participant exit interviews identified which content presentations were deemed most useful and a number of ways to enhance the laboratory activities of the workshop. There is also evidence that participating in CROP leads some students to look more favorably on majoring in physics or another science in college.

9 Technical Developments in Progress

The ability to link GPS time-stamped data collected by participating schools depends on an inexpensive electronics card designed to handle the triggering, signal processing, GPS timing, and data acquisition. In the upcoming year, CROP will draw on the volunteered expertise of Fermilab electrical engineers and other colleagues in high-energy physics to develop this crucial component. The card will interface directly to the data-taking PC. The GPS-timing part of this card has been developed by our CROP affiliates at Iowa State University.

10 Statewide Expansion

During each of the remaining years covered by our NSF grant, we will add 5-6 schools, drawing participants from each of the state's ESUs. A wide geographical distribution of strategically placed sites will facilitate our expansion across the state. By identifying and training local leaders to serve as regional experts, we will form the centers around which CROP will grow post-NSF funding.

As installation and training become streamlined, more will be handled through long-distance learning: web-based help pages, videotaped installation and testing instructions, hotline response phone numbers. By the conclusion of this project's NSF funding, we hope to be able to reduce the duration of the summer workshops and gradually replace them by small regional workshops operated in part by experienced teachers in the area.

11 Conclusion

CROP started as a dream by two high-energy physicists – use existing high-school sites as the grid for a ground-based cosmic-ray experiment, and train teams of remote teacher and student investigators. Now that the project has begun, the reality is more exciting than the dream. High school physics teachers represent an untapped source of enthusiasm and resourcefulness for frontier physics research. CROP is participant-driven, and the teachers and students guide the project step-by-step in both its technical and educational aspects. We are forming a true collaboration, not unlike a large high-energy physics experiment with collaborating institutions spread all over the country and the world. We look forward to our first Physical Review publication, some few years from now, authored by the CROP staff and our large team of high-school colleagues.

More information about CROP, including milestones passed to date, can be found on the web site:

http://www.physics.unl.edu/research/crop/crop.html