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Cosmic Rays

# High schools focus on the extreme universe

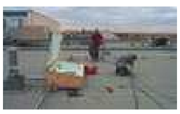
**James Pinfold reports on the large number of projects that are forging a connection between research in ultra-high-energy cosmic rays and practical scientific experience in schools.**

***RÃ©sumÃ©***

*Les lycÃ©ens explorent l'univers des Ã©nergies extrÃªmes*

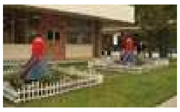
*En Europe comme en AmÃ©rique du Nord, la recherche sur le rayonnement cosmique prend depuis quelques annÃ©es de nouvelles formes, avec des rÃ©seaux de dÃ©tecteurs dissÃ©minÃ©s sur de trÃ¨s grandes surfaces. Ce qui est nouveau, c'est que les dÃ©tecteurs sont installÃ©s dans des Ã©tablissements scolaires. Il s'agit d'atteindre deux objectifs distincts mais Ã©galement importants: le premier est d'Ã©tudier l'univers Ã  des Ã©nergies extrÃªmement Ã©levÃ©es en recherchant sur de grandes surfaces des rayons cosmique arrivant en coÃ¯ncidence pour en dÃ©couvrir l'origine; le deuxiÃ¨me est d'initier les lycÃ©ens et leurs professeurs aux joies de la recherche fondamentale.*

On 15 October 1991 the highest-energy cosmic-ray particle ever measured struck Earth's atmosphere tens of kilometres above the Utah Desert. Colliding with a nucleus, it lit up the night for an instant and then was gone. The Fly's Eye detector at the Dugway Proving Grounds in Utah captured the trail of light emitted as the cascade of secondary particles created in the collision made the atmosphere fluoresce. The Fly's Eye researchers measured the energy of the unusual ultra-high-energy cosmic-ray event - dubbed the "Oh-My-God (OMG) event" - at 320 exa-electron-volts (EeV), or 320 Ã— $10^{18}$ eV. In SI units, the particle, probably a proton, hit the atmosphere with a total kinetic energy of about 5 J. For a microscopic particle this is a truly macroscopic energy - enough to lift a mass of 1 kg half a metre against gravity. On 3 December 1993, on the opposite side of the world, the Akeno Giant Air Shower Array (AGASA) in Japan recorded another OMG event with an energy of 200 EeV. In this case the cosmic ray was recorded using a large array of detectors on the ground to measure the extended air shower (EAS) resulting from the primary cosmic ray interacting with the atmosphere.



Since these first observations at least a dozen OMG events have been recorded, confirming the phenomenon and mystifying cosmic-ray physicists. It seemed that particles with energies more than about 50 EeV should not reach Earth from any plausible source in the universe more than around 100 million parsecs distant, as they should rapidly lose their energy in collisions with the 2.7 K cosmic-microwave background radiation from the Big Bang - the Greisen-Zatsepin- Kuzmin limit. While many explanations have been proposed, experiments have so far failed to decipher a clear message from these highly energetic messengers, and the existence of the OMG events has become a profound puzzle. Now a new eye on these ultra-high-energy events has come into focus, based on the great plain of the Pampa Amarilla in western Argentina. The Pierre Auger Observatory (PAO), with its unprecedented collecting power, has begun to study cosmic rays at the highest energies (see *CERN Courier* March 2006 p6 and *CERN Courier* January/February 2006 p8).

**Cosmic-ray array**

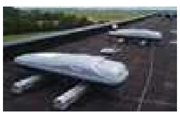


**Detectors**

However signs of the extreme-energy universe may also come in a different guise - not as a single OMG event but rather as bursts of events of more-modest energy. On 20 January 1981, near Winnipeg, a cluster of 32 EASs - with an estimated mean energy of 3000 tera-electron-volts - was observed within 5 min (Smith *et al*. 1983). Only one such event would have been expected. This observation was the only one of its kind during an experiment that recorded 150,000 showers in 18 months. In the same year an Irish group reported an unusual simultaneous increase in the cosmic-ray shower rate at two recording stations 250 km apart (Fegan *et al*. 1983). The event, recorded in 1975, lasted 20 s and was the only one of its kind detected in three years of observation.

**Scintillator detector**

There have since been a few hints of such "correlated" cosmic-ray phenomena seen by some small cosmic-ray experiments dotted around the world, such as a Swiss experiment that deployed four detector systems in Basel, Bern, Geneva and Le Locle, with a total enclosed area of around 5000 $km^2$. In addition, the Baksan air-shower-array group has presented evidence from data from 1992 to 1996 for short bursts of super-high-energy gamma rays from the direction of the active galactic nucleus Markarian 501. The AGASA collaboration has also reported small-scale clustering in arrival directions, and possibly in the arrival times of these clustering events.



**Cosmic-ray detectors**

One mechanism that could generate correlated showers over hundreds of kilometres is the photodisintegration of high-energy cosmic-ray nuclei passing through the vicinity of the Sun, first proposed by N M Gerasimova and Georgy Zatsepin back in the 1950s. Other more recent and more exotic examples of phenomena that could give rise to large-area non-random cosmic-ray correlations include relativistic dust grains, antineutrino bursts from collapsing stellar systems, primordial black-hole evaporation and even mechanisms arising from the presence of extra dimensions.

### Working together

MRPC muon chamber

Whichever way the high-energy universe is incarnated on Earth, the signs should be exceedingly rare, requiring large numbers of detectors deployed over vast areas to provide a reasonable signal. The detection of a single OMG particle requires dense EAS arrays and/or atmospheric fluorescence detectors, with detector spacings of the order of a kilometre, as in the PAO. Detection of cosmic-ray phenomena correlated over very large areas requires even bigger detection areas, which at present are economically feasible only with more sparse EAS arrays (on average much fewer than one detector per $km^2$). In fact, global positioning system (GPS) technology makes it possible to perform precision timing over ultra-large areas, enabling a number of detector networks to be deployed as essentially one huge array. An example is the Large Area Air Shower array, which started taking data in the mid-1990s. It comprises around 10 compact EAS arrays spread across Japan, forming a sparse detector network with an unprecedented enclosed area of the order of 30,000 $km^2$.

Now, however a new dimension to cosmic-ray research has opened up. In 1998 in Alberta, building on a proposal first presented in 1995, the first node of a new kind of sparse very-large-area network of cosmic-ray detectors began to take data. The innovative aspect of the Alberta Large-area Time-coincidence Array (ALTA) is that it is deployed in high schools. By the end of 1999 three high-school sites were operating, each communicating with the central site at the University of Alberta. In 2000 the Cosmic Ray Observatory Project (CROP), centred at the University of Nebraska, set up five schools with detectors from the decommissioned Chicago Air Shower Array. Around the same time the Washington Large-area Time-coincidence Array (WALTA) installed its first detectors.

The ALTA, CROP and WALTA projects have a distinct purpose - to forge a connection between two seemingly unrelated but equally important aims. The first is to study the extreme-energy universe by searching for large-area cosmic-ray coincidences and their sources; the second is to involve high-school students and teachers in the excitement of fundamental research. These "educational arrays", with their serious research purpose, provide a unique educational experience, and the paradigm has spread to many other sites in North America. The detector systems are simple but effective. Following the ALTA/CROP model they use a small local array of plastic scintillators, which are read by custom-made electronics and which use GPS for precise coincidence timing with other nodes in a network of local arrays over a large area. Most of the local systems forming an array use three or more detectors, which, with a separation of the order of 10 m and a hard-wired coincidence, allow accurate pointing at each local site. Today the ALTA/CROP/WALTA arrays involve more than 60 high schools and there are three further

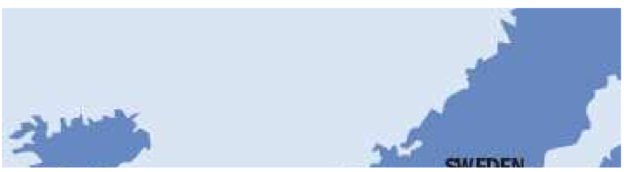
North American educational arrays in operation: the California High School Cosmic Ray Observatory (CHICOS) and the Snowmass Area Large-scale Time-coincidence Array (SALTA) in the US, and the Victoria Time-coincidence Array (VICTA) in Canada. At least seven more North American projects are planned.

The CHICOS array is the largest ground-based array in the Northern Hemisphere. Its detectors, donated by the CYGNUS collaboration, are deployed on more than 70 high-school rooftops across 400 $km^2$ in the Los Angeles area. Each site has two 1 $m^2$ plastic scintillator detectors separated by a few metres. Local pointing at each site is not possible, nor is it required as CHICOS uses GPS pointing across multiple sites to concentrate on the search for single ultra-high-energy cosmic-ray air showers. Recently the collaboration reported their results at the 29th International Cosmic Ray Conference in Pune, India (McKeown *et al*. 2005).

Innovative detection techniques have also been employed in this burgeoning collaboration between researchers and high-school students and teachers in North America. A prime example is the project for Mixed Apparatus for Radar Investigation of Cosmic Rays of High Ionization (MARIACHI), based at Brookhaven National Laboratory, New York. The plan is for the experiment to detect ultra-high-energy cosmic rays using the passive bistatic radar technique, where stations continuously listen to a radio frequency that illuminates the sky above it. The ionization trails of ultra-high-energy cosmic-ray showers - as well as meteors, micro-meteors and even aeroplanes - in the field of the radio beam will reflect radio waves into the high-school-based detectors. These schools will also be equipped with conventional cosmic-ray air-shower detectors. The technique, if successful, will speed the construction of ultra-large-area cosmic-ray detectors.

### The European endeavour

Across the Atlantic, schools in many European countries are also getting involved in studying the extreme-energy universe (see figure 1). In 2001 physicists from the University of Wuppertal proposed SkyView - the first European project to suggest using high-school-based cosmic-ray detectors. This ambitious project proposed an immense 5000 $km^2$ array, the size of the PAO, using thousands of universities, colleges, schools and other public buildings in the North Rhine-Westphalia area. Roughly a year later CERN entered the field with a collaborative effort to distribute cosmic-ray detectors from the terminated High Energy Gamma Ray Astronomy project in schools around Dusseldorf. A test array of 20 counters was set up at Point 4 on the tunnel for the Large Electron-Positron (LEP) collider, with the aim of studying coincidences with counters installed about 5 km away at Point 3 as part of cosmic-ray studies by the L3 experiment on the LEP.



Also in 2002 the High

School Project on Astrophysics Research with Cosmics (HiSPARC), initiated by physicists from the University of Nijmegen in the Netherlands, joined the European effort (see *CERN Courier* July/August 2004 p35). HiSPARC now has five regional clusters of detectors being developed in the areas of Amsterdam, Groningen, Leiden, Nijmegan and Utrecht. Around 40 high schools are participating so far and more are joining. In March 2005 the HiSPARC array registered an event of energy 8 Ã— $10^{19}$ eV, in the ultra-high-energy "ankle" region of the cosmic-ray energy spectrum, which was also reported at the international conference in Pune (Timmermans 2005).

The HiSPARC collaboration is also planning to use a recent and exciting development of the Low Frequency Array (LOFAR) Prototype Station (LOPES) experiment in Karlsruhe. Using a relatively simple radio antenna, LOPES detects the coherent low-frequency radio signal that accompanies the showers of secondary particles from ultra-high-energy cosmic rays. A large array of these low-frequency radio antennas, the LOFAR observatory, is already being constructed in the Netherlands. Such technology can also be exploited by high-school-based observatories around the world to expand their capability rapidly to become effective partners in the search for point sources of ultra-high-energy particles.

Elsewhere, the School Physics Project was initiated in Finland and is now under development. Also in 2002 the Stockholm Educational Air Shower Array (SEASA) was proposed to the Royal Institute of Technology in Stockholm. SEASA has two stations of cosmic-ray detectors running at the AlbaNova University Centre and the first cluster of stations for schools in the Stockholm area is now in the production stage. Meanwhile, in the Czech Republic the Technical University in Prague and the University of Opava in the province of Silesia - working closely with the ALTA collaboration - each have a detector system taking data, with a third to be deployed this summer.

A number of other European efforts are gearing up, including two that have links to the discovery of cosmic-ray air showers in 1938 by Pierre Auger, Roland Maze and ThÃ©rÃ¨se Grivet-Meyer working at the Paris Observatory. The Reseau de LycÃ©es pour Cosmiques (RELYC) project, centred on the College de France/Laboratoire Astroparticule et Cosmologie in Paris, is preparing to install detectors in high schools close to where Auger and colleagues performed their ground-breaking experiments. The Roland Maze project is centred on the Cosmic Ray Laboratory of the Andrzej Soltan Institute for Nuclear Studies in Lodz, Poland, where it continues a long tradition in studies of cosmic-ray air showers initiated in partnership with Maze some 50 years ago. The plans are to deploy detectors in more than 30 local high schools. In the UK, physicists from King's College London in collaboration with the Canadian ALTA group will place detector systems in the London area during 2006. In northern England, Preston College is continuing to work on a pilot project, initiated in 2001, to develop an affordable cosmic-ray detection system as part of the Cosmic Schools Group Proposal, involving the University of Liverpool and John Moores University in Liverpool. Finally, a project to set up cosmic-ray telescopes with GPS in 10 Portuguese high schools is underway, spearheaded by the LaboratÃ³rio de InstrumentaÃ§Ã£o e FÃsica Experimental de PartÃculas and the engineering faculty of the Technical University in Lisbon.

While the majority of the European projects are based on plastic scintillators, the Italian Extreme Energy Events (EEE) project has opted instead for multigap resistive plate chambers (MRPCs) as their basic detector element. These allow a precise measurement of the direction and time of arrival of a cosmic ray. The aim of this project, the roots of which date back to 1996, is to have a system of MRPC telescopes distributed over a surface of 106 $km^2$, for precise detection of extreme-energy events (Zichichi 1996). These chambers are similar to those that will be used in the time-of-flight detector for the ALICE experiment at CERN's Large Hadron Collider. Three MRPC chambers form a detector "telescope" that can reconstruct the trajectories of cosmic muons in a shower. At present 23 schools from across Italy are involved in the pilot project, with around 100 others on a waiting list from the length and breadth of the Italian peninsula. More than 60 MRPCs have been built at CERN by teams of high-school students and teachers under the guidance of experts from Italian universities and the INFN.

### A worldwide network

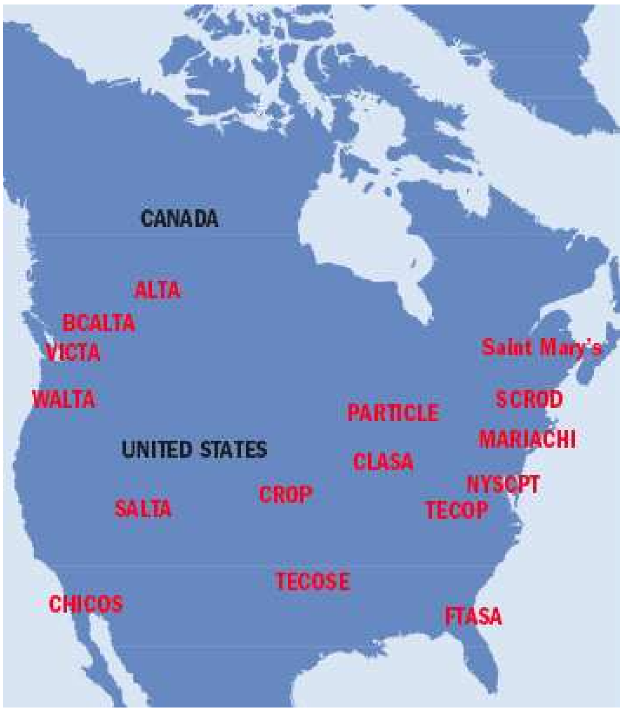



Fig. 2

Most of the major groups in Canada and the US have formed a loose collaboration - the North American Large-area Time Coincidence Arrays (NALTA) - with more than 100 detector stations spread across North America (figure 2). The aim is to share educational resources and information. However, it is also planned to have one central access point where students and researchers can use data from all of the NALTA sites, creating in effect a single giant array. Such a combined network across North America could eventually consist of thousands of cosmic-ray detectors, with the primary research aim of studying ultra-high-energy cosmic-ray showers and correlated cosmic-ray phenomena over a very large area. Until the PAO collaboration constructs its second array in Colorado, US, the NALTA arrays, along with their European counterparts, will dominate the ground-based investigation of the extreme-energy universe in the Northern Hemisphere.

The European groups are also developing a similar collaboration, called Eurocosmics. It is clear that a natural next step is to combine the North American and European networks into a worldwide network that could contribute significantly to elucidating the extreme-energy universe. Such a network could aid and encompass other efforts throughout the world, including in developing countries where it could provide a natural bridgehead into the global scientific culture (see *CERN Courier* May 2006 p46).

### Further reading

Further information about many of the projects in North America can be found at http://csr.phys.ualberta.ca/nalta/, and for Europe at www.nikhef.nl/extern/eurocosmics/.

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