COSMOLOGY MARCHES ON

A report on The Cosmic Ray Research Project conducted at SIUE in the summer of 2001.

Advisors

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Participants

High School Teachers: Cliff Parker & Julie Breden

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Cosmic Ray Project goals as stated in a June 11, 2001 report issued by Oluwafemi Osidipe, Drew Thomas, and Elizabeth Weber. Three undergraduate student participants in the project.

This cosmic ray project is a development that hopes to detect such high-energy rays with the usage of simple detection devices. It is the hope of this project that through the collection of data more can be learned about cosmic rays, specifically the higher energy particles and their potential origins outside our galaxy. The ultimate goal of this project is to create a cost-effective detection system, in order to gather the appropriate data for use in high schools with analytical capabilities and GPS time stamping to involve high school students more heavily in hands on scientific research, experimentation, and learning.

Personal goals for Cliff Parker one of two high school teachers who participated in the Cosmic Ray Project.

When I began this experience I had two primary goals. 1) To learn as much as I could about cosmic rays. 2) To contribute toward the successful completion of a scientific research project. I felt that if I could accomplish these two things I would be in a better position to communicate to my students yet another of the many wonders of the universe we live in and the way that the scientific community explores new frontiers. I will attempt to share some of the things that have been accomplished this summer as I worked towards these two goals.

To learn as much as I can about cosmic rays.

From the very first day it was clear that Dave Kraus would be a valuable source of information. He has an extensive background in experimental physics having spent his career working with the hardware and software required to collect and analyze experimental data. Each day he spent time providing background information on cosmic rays and their detection, pointing out good resources and describing the things he was doing to prepare and or manufacture the equipment required. The following is a sampling of things that I have learned through discussions with Dave and or reading various sources.

- Cosmic Rays are subatomic particles and radiation of extra-terrestrial origin. First discovered in 1912 by Austrian scientist Victor Hess, measuring radiation levels aboard a balloon at up to 17,500 feet. This radiation was measured by means of an electroscope. His electroscope discharged more rapidly at higher elevations. This indicated the presence of particle with ionizing energy in greater amounts at higher altitudes. He named these particles Cosmic Radiation http://www-http://www.nobel.se/physics/laureates/1936/hess-bio.html

- What are they made from? In the 10^{12} - 10^{15} eV range: ~50% protons, ~25% alpha particles ~13% C/N/O nuclei, 1% electrons, 0.1% gamma rays. Cosmic Rays with energy > 10^{18} eV are referred to as "Ultra-High Energy (UHE) Cosmic Rays. We think they are protons "http://hires.physics.utah.edu/sbf/tsld003.htm

- Where do they come from? There are many theories for their creation. Among them is that they are formed from the shock wave of a super nova, maybe a black hole emits a few when it gets too full, or another theory suggests that they are the result of the decay of superheavy particles which existed in the early days of the universe; maybe a series of somewhat normal events acting in a row on the same particle could do it. If they came from a single source like a super nova or a black hole or any kind of violent whirly thing in space you would probably be able to see a relatively well-defined stream of cosmic rays pointing back to the source. If they were from the decay of a type of particle that was once spread throughout the universe, you would find much less uniform directions. http://hires.physics.utah.edu/popular/intro.htm

- The main problem with understanding the origin of ultra-high energy cosmic rays is the following. To start with, one does not know if astrophysical sources can really accelerate protons up to energies close to 10^{21} eV. Even then, it is expected that protons of energies greater than ~ $5x10^{19}$ eV lose their energy by photopion production on the cosmic microwave background, when propagating more than a few megaparsecs. Similar considerations apply to photons or heavy nuclei. One would thus expect to see a cut-off, known as the Greisen-Zatsepin-Kuzmin cut-off

- Why look for coincidental showers spread over a large (>3 km) area? LAAS group has found a pair of showers separated by long distance with an arrival time only 195 us different. The pair also came from the same narrow 5-degree window. A Swiss group also reports a correlation in arrival time of cosmic ray showers separated by more than 50 km.

- How common are they? At < 10^{14} eV: flux is large enough to allow DIRECT measurement on balloons, satellites, shuttle missions. At > 10^{17} eV, we expect a flux < 10-10/m^2 Sr s: A 1 m^2, 2p Sr. detector sees < 1 event/50 yrs. Direct measurement is impractical! http://hires.physics.utah.edu/sbf/tsld003.htm

- How can they be detected? When Cosmic rays hit our atmosphere they initiate a cascade of particles (called an airshower) as they lose their energy through subsequent interactions. The initial energy of the incoming cosmic ray gets distributed throughout the shower.

Florescence

CR's interact with materials they pass nearby. Energy is transferred to electrons of substances within the atmosphere some of these electrons leave the atom or molecule they were associated with and may cause gasses in the atmosphere to fluoresces as they fall back down to ground state energy levels.

Cherenkov Radiation

Particles produce cherenkov radiation when they pass through medians at speeds faster than light in that median. Cherenkov Radiation is a "shockwave" of light produced similarly to the shockwave of sound produced in "a sonic boom."

Plastic scintillators

Plastic scintillators produce fluorescing light by interactions between CR's and materials within the plastic. The plastic is "doped" with other materials that allow the photons produced to be converted to frequencies that more easily pass through the scintillator. Usually a photo multiplier is used to detect photons produced in the scintillator.

- What is being done now? Thee HiRes Detector — an Atmospheric Fluorescence Detector A set of fixed mirrors with 256 photomultipliers (light amplification devices) at the focus of each mirror is used to grid the sky to 1-degree resolution. It is from this gridding of the sky that we obtain the name of the fly's eye, since our detector resembles the ability of the fly's multifaceted eye to look at multiple directions at one time.

- On the night of October 15, 1991, the Fly's Eye detected a proton with an energy of $3.2 \pm 0.9 \times 10^{20}$ electron volts.[1,2] By comparison, the recently canceled Superconducting Super Collider (SSC) would have accelerated protons to an energy of 20 TeV, or 2×10^{13} electron volts — ten million times less. The energy of the Oh-My-God particle seen by the Fly's Eye is equivalent to 51 joules — enough to light a 40watt light bulb for more than a second — equivalent, in the words of Utah physicist Pierre Sokolsky, to "a brick falling on your toe." The particle's energy is equivalent to an American baseball travelling fifty-five miles an hour. http://hires.physics.utah.edu/popular/ohmygodpart.htm

- Thus this single subatomic particle had a mass-energy equivalent to a bacterium. http://hires.physics.utah.edu/popular/ohmygodpart.htm

- v = 0.9999999999999999999999951 c So taking 3×10^8 meters per second as the speed of light, we find that the particle was traveling $2.99999999999999999999999853 \times 10^8$ meters per second, thus 1.467×10^{-15} meters per second slower than light — one and a half femtometres per second slower than light. If God's radar gun is slightly out of calibration, this puppy's gonna be doin' hard time for speeding. After traveling one light year, the particle would be only 0.15 femtoseconds — 46 nanometres — behind a photon that left at the same time. http://hires.physics.utah.edu/popular/ohmygodpart.htm

- UHCR experiments planned --- RaysPierre Auger Observatory --- Large international collaboration --- Southern Site in Argentina to start operation in ~2004 --- Northern Site proposed for Millard County, Utah (~2006?) --- Telescope Array (~2005?) U.S. - Japan -Australia collaboration Proposed site: 11 stations stretching from Dugway down to Millard County, Utah --- Wide-angle Orbiting Lens (OWL) --- Fluorescence detectors on high Earth-orbit satellites --- Development effort underway, coordinated by NASA (~2010?) --- Prototype experiment aboard International Space Station approved by ESA (~2006?) --- University of Utah scientists are major participants in all of these efforts.
  http://hires.physics.utah.edu/sbf/tsld003.htm

To contribute toward the successful completion of a scientific research project.

Measured the length of cables.

- This was an interesting process because instead of measuring the length by comparison with a standard unit of length they were measured by finding the time interval required for a signal to reach one the end of the cable be reflected and return to the other end. Therefore lengths were recorded in nanoseconds rather than more standard units of length. Since the information we were after was the time delay of a signal passing through each cable this method was more useful.

Measured the one PE gain of each available photomultiplier.

- One PE gain is the amount of charge that the photomultiplier obtains from the displacement of one electron from the first plate. As that electron passes through the photomultiplier it causes a cascade of electrons to be produced as each collision with subsequent plates produces more free electrons.

- Each photomultiplier was placed into a sealed box so that light from the environment would be minimized. Then the electric gain was measured for each tube was measured. Since there was no light striking the tube it was assumed that any activity within the tube was caused by thermal activity as occasionally one electron would become dissociated from its molecule.

- The device used to measure the electric gain measured the time it took to discharge a capacitor that had been charged by the photomultiplier tube. Once again I found it interesting that time was measured to obtain other information indirectly.

Retrofit of photomultipliers.

- The photomultipliers used were not originally designed for our purposes. In order to protect the equipment and maintain safety one of the two power connections was removed and the opening into the photomultiplier tube sealed from light leaks.

Building of frames for scintillators.

- When I began working with the project six frames to hold the scintillators had already constructed by Dave and Drew. When the need for six additional frames became apparent I used the plans developed for the original frames and built six more. My three sons assisted me in the construction of these frames and in this small way became part of the team working on this project.

Assisted in the instillation of scintillators into the frames.

- Scintillators and photomultipliers had to be coupled and held in place in order to collect data. The scintillators were held in place by gravity and by fitting rather snugly into the frame. The coupling to the photomultiplier was accomplished by use of a spring loaded device built into each tube. The tubes therefore had to be held in compression against the scintillators. This was accomplished by means of a simple clamp device.

Sealed collection devices against light leaks.

- Elizabeth and I set about to accomplish the rather tedious task of sealing the scintillators against light leaks. In order to do this Elizabeth covered any obvious holes in the protective covering on each device. I then connected each device to the same equipment used to measure the one PE gain of the photomultipliers and looked for excess signal. If such were found then attempts were made to find leaks and seal them. It was discovered that the joint between the scintillators and the photomultiplier tube which had originally been sealed with one layer of black plastic required a second layer of plastic to adequately seal the connection from light.

How can high school students participate in this project?

It seems to me that high school students could gain from participation in this project in basically the same way that I have. Interaction with a group of people with the common goal of detecting the fall out from cosmic rays and analyzing the data produced has the potential to give students incentive to learn about cosmic rays. It can also provide experiences that will help students to understand what kinds of things must be done to conduct a scientific study. In my opinion this can only be done if the project has clearly defined real and useful scientific objectives which are attainable. It is not clear to me at this point that such is the case. In many ways it seems that the used scintillators obtained from Brokhaven are scientific devices in search of their best purpose. To find such a purpose for the available equipment may very well be a useful endeavor but at this time it is not clear to me that their best purpose would be found in my classroom. That is not to say that they never will be classroom friendly. When these devices function fairly reliably and in well understood ways and links that allow easy sharing of information from one school to another are in place we may be on the verge of something quite useful.

In any event I think that the primary purpose for installing cosmic ray detection equipment in high schools must be based on the need to collect honest to goodness real useful data. The benefit to students of having access to this equipment and the ability to interact with others about this project should only be viewed as a positive side effect. Otherwise the scientific importance of the project becomes diminished and its usefulness as a good learning experience that teaches about how science works disappears. If the project depends on local teachers and students participation very much for its successful data collection I don't believe it can succeed. Interest in such projects can not be forced upon teachers or students and even when sufficient interest is present in one building with one teacher and a group of students that same interest is not likely to be found elsewhere on a consistent basis.

Having an actual functioning part of an important experiment attached to a high school science classrooms that teachers and students can choose to interact with or simply become aware of can be a great thing.

Volcano Ranch Array -- Volcano Ranch, New Mexico, 1959 - 1963

- First giant shower array.
- 19 3.3-m^2 plastic scintillation counters with 5 inch photomultiplier
- Covered an enclosed area of 8.1 km^2
- The first measurements of the energy spectrum of CR's above 10^{18} eV.
- The most energetic event was recorded to be 1.4×10^{20} eV. One of the largest ever recorded. This event was recorded before the discovery of 2.7-K cosmic microwave background radiation

Haverah Park Array -- Haverah Park, UK, 1967 - 1987

- Large array of 280 Cerenkov detectors, water tanks 2.25 ~54 m^2, with a 5 inch photomultiplier. Along with 30 -- 1 m^2 detectors near the center of array
- Covered an enclosed area of 12 km^2
- Recorded a large 10^{20} eV event
- Late in the life of the project an array of eight scintillators was operated within 150 m of the array center to allow cross calibration between other giant arrays.

(SUGAR) The Sydney University Array - Narribri, New South Wales Australia, , 1968 - 1979

- Operated close to sea level.
- Only giant array to have operated in Southern Hemisphere
- An array of 54 -- 6m^2 scintillators with 7-in photomultipliers, buried 1.7 m below ground in order to respond preferentially to muons.
- Covered an area of 100 km2
- For the ten largest events the mean number of stations struck was only 4.7.
- After-pulsing in the photomultipliers was a serious problem.
- Precision contrasts poorly with that of other arrays.

The Yakutsk Array - Yakutsk, Siberia, 1970 - present

- The array consists of 58 ground-based and six underground detectors of charged particles (electrons and muons), 50 detectors of the atmospheric Cherenkov light; 11 antennas to detect EAS radio emission at 32 MHz.
- Covers an area of 12 km^2
- It was first revealed that the energy spectrum is irregular (with dip and bump) in the range $3 \cdot 10^{18}$-$5 \cdot 10^{19}$ eV.

Fly'Eye Detector - Dugway Proving Grounds near Salt Lake City Utah, 1981 - 1992

- Two detectors Fly's Eye I (FE I) and Fly's Eye II (FE II) detect florescence light from an air shower.
- FE I consisted of 67 mirrors each focused on 12 - 14 photomultiplier tubes. Each viewed a 5.5° diameter hexagonal area of the sky. In total 880 photomultipliers covered the entire sky.
- FE II consisted of 36 mirrors and 464 photomultiplier tubes and viewed half the sky.
- Data from both devices gives a stereo picture of cosmic ray showers.
- Observed the highest energy so far by any detector. 3.0×10^{20} eV, The OH-MY-GOD-PARTICLE.

(AGASA) Akeno Giant Air-Shower Array - Akeno, Japan, 1990 - present

- Largest array constructed so far
- 111 scintillation detectors 2.2 m2 each
- Muon detectors are installed at 27 of the 111 sites
- Covers an area of 100 Km2
- Recorded a 1.5 x 1020 eV event
- Particles of shower are seen to be distributed over 3 km range from the core.

Large Area Air Shower (LAAS) group - Department of Physics, Okayama University, Okayama Japan.

- Eleven air shower arrays, and each of them has four to 22 scintillation counters.
- Each station is equipped with BPS as a common clock.
- Shower direction can be determined with resolution of typically five degrees.
- One pair of air showers which had an arrival time difference of 195 *us* with shower direction adjacent to Crab Nebula.

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