NSF Annual Report: Grant 0601088: Report for Year Two

Corbin E. Covault, Principle Investigator

Department of Physics, Case Western Reserve University

May 14, 2008

Contents

1 Activities

Here we describe the scientific activities supported by NSF grant 0601088 during the period corresponding to Year 2 of the grant: (06/01/2007 through 05/31/2008). Activities include participation on the STACEE and Auger experiments. We include a brief review of the scientific goals of each experiment, a description of the instruments, and a summary of particular research activities and plans for the future.

1.1 Activities Summary

The PI leads the High Energy Astrophysics (HEA) group in the physics department at Case Western Reserve University. During the past year, the HEA group at Case Western has played a major role on the Pierre Auger Cosmic Ray Observatory (PAO). The PI has also been involved in the Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE) which concluded all operations during this past year. In terms of the PI's research effort and that of the HEA group as a whole, approximately 10 percent of the effort has been devoted to STACEE and about 90 percent to Auger during Year 2 of this grant cycle.

Activity on the STACEE project has been directed toward the decommisioning and dismantling of the experiment, completing final analysis for completion of publications, and final data and software archiving.

Activity on the Pierre Auger Observatory has been directed toward several areas including anisotropy analysis, precision timing using GPS receivers, overseeing wireless communications, and increasing R&D activities for the development of Auger North.

For Auger analysis, the PI was the only US member of a team of three collaborators charged with writing and editing both a letter to *Science* [1] and a longer paper submitted to *Astroparticle Physics* [2] which describe the detection of anisotropy in the arrival directions of the highest energy cosmic rays which are found to be correlated with nearby Active Galactic Nuclei (AGN).

The Case Western group has also been very active in the arena of GPS event timing, which is critical for Auger shower direction reconstruction. We have developed and continue to apply a set of portable timing systems which check calibrations to better than 20 nanoseconds for any electronic or optical signal at any position in the field. We continue to improve our understanding of the timing performance of Auger, working closely with the Auger group at Colorado School of Mines to develop and deploy a new set of timing systems for the new Xtra Laser Facility (XLF) located at the center of the Auger array.

The PI also serves on the Auger Observatory Technical Board as the Task Leader for Communnications (Comms), dealing with the extensive wireless communication network connecting all detectors to the central campus. The PI has direct and ongoing responsibility for the operation and performance of the surface detector station wireless radio transmitters, a set of four communications towers, and an associated microwave backbone data transfer system.

Finally, the PI and members of the HEA group have become increasing active in R&D activities for the future deployment of Auger North which is planned for deployment in southeastern Colorado. Auger North will consist of 4,400 surface detector stations spead out over an area of more than 20,000 square kilometers, essentially a 7-fold multiplying the acceptance for high energy relative to Auger South. As Comms Task Leader, the PI is in particular responsible for coordinating the effort to develop a new communications system for Auger North that will be based on data transfer via peer-to-peer wireless system, different from the line-of-sight (comms towers) scheme that was used for Auger South. The PI is also responsible for GPS receivers for surface detector stations and is planning for thermal stress tests for Auger North electronics components, including power distribution electronics.

1.2 Activities on the Solar Tower Atmospheric Cherenkov Experiment (STACEE)

Since 2001, the PI and several members of the HEA group at Case have been major contributors to the STACEE collaboration. Together with Rene Ong at the University of Chicago (now at UCLA) the PI proposed, developed, and constructed the STACEE instrument during the period 1996-2000. Initial support for STACEE was first provided by the NSF through a CAREER young investigator award to the PI. As a founding member of this relatively small collaboration, the PI and the Case Western HEA group have been involved in many central aspects of the development, observations, and analyses for STACEE.

STACEE has been a major component of the activity of the group up until the Summer of 2008. As of June 2008, in accordance with our plans as described to the NSF, all STACEE observations were stopped and the experiment was dismantled. Here we briefly summarize the science goals of STACEE and the activities which we have conducted during the past year to close out this experimental program.

1.2.1 STACEE Detector Concept

Details of the STACEE detector concept have been described elsewhere and in detail in previous proposal and annual reports to the NSF [3, 4, 5, 6]. Figure 1 shows the STACEE concept. Figure 2 shows the plan view of the heliostats field at the NSTTF at Sandia, showing the locations of the 64 heliostats used for STACEE. Light from each heliostat mirror is reflected onto one of five secondary mirrors on the tower and then onto a PMT camera. Signals from PMTs are discriminated and then delayed and gated to form a coincidence trigger and then digitized to allow for detailed reconstruction of energy and direction for each event. By using a large mirror area, STACEE is able to achieve low energy thresholds (< 100 GeV) to gamma-rays from most observered sources.

1.2.2 STACEE Science Goals and Past Observing Program

The scientific objectives for STACEE have been described in detail elsewhere, and in previously submitted proposals and annual reports. Gamma-ray astronomy remains an exciting and vibrant field with new instruments and new discoveries reported during the past several years. At energies above 100 GeV, at least 32 sources have been detected by atmospheric Cherenkov telescopes, such as STACEE. Figure 3 shows a sky map of these very high-energy sources.

In the past, STACEE has carried out detailed observations on a number of sources, and these observations have made important contributions to our understanding of high energy astrophysics. The STACEE detection of the Crab in 2000[7] was the first measurement of the flux of gamma-rays from this important object in the energy range between 50 and 250 GeV and provided a stringent limit on the fraction of the emission associated with the pulsar itself. The STACEE detection of the AGN Markarian 421 in 2001 [8] provided spectral data near the maximum of the inverse-Compton peak in the spectral energy distribution. This detection also found evidence for correlated X-ray,

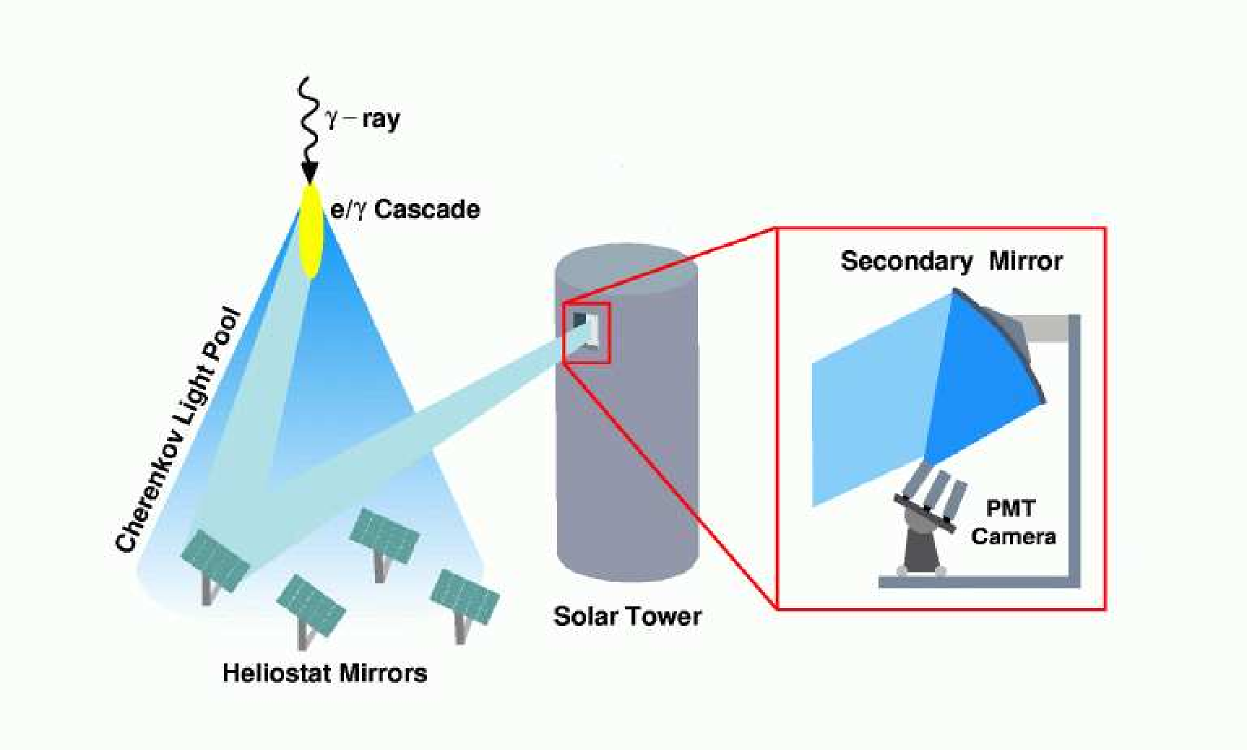


Figure 1: The STACEE experiment concept. A high-energy gamma-ray interacts near the top of the atmosphere to produce an electromagnetic air shower. Cherenkov radiation produced in the air shower is beamed to the ground whereupon it is reflected by solar heliostats mirrors to secondary mirrors on the central tower. The secondary mirrors image the Cherenkov light onto photomultiplier tube (PMT) cameras. There is a one-to-one correspondence between the 64 heliostats used and the 64 PMTs in the cameras.

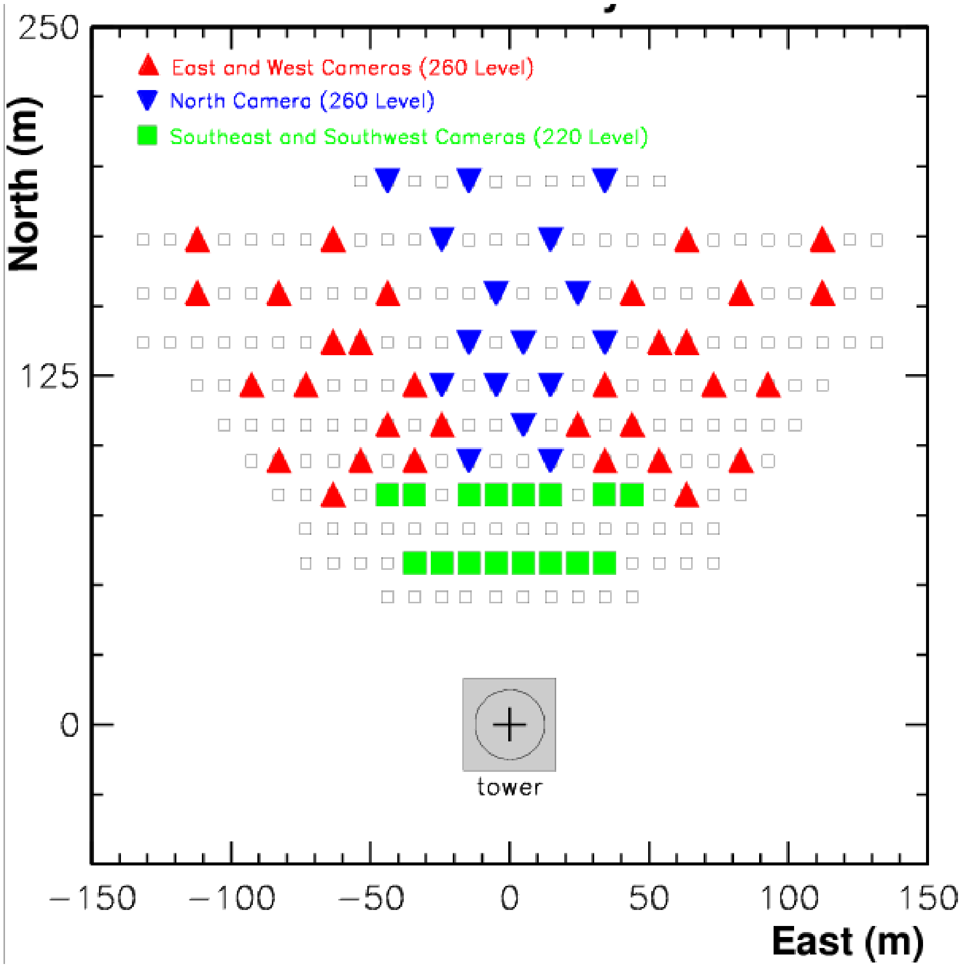


Figure 2: Plan view of the NSTTF site showing the locations of the 64 heliostats used for STACEE.

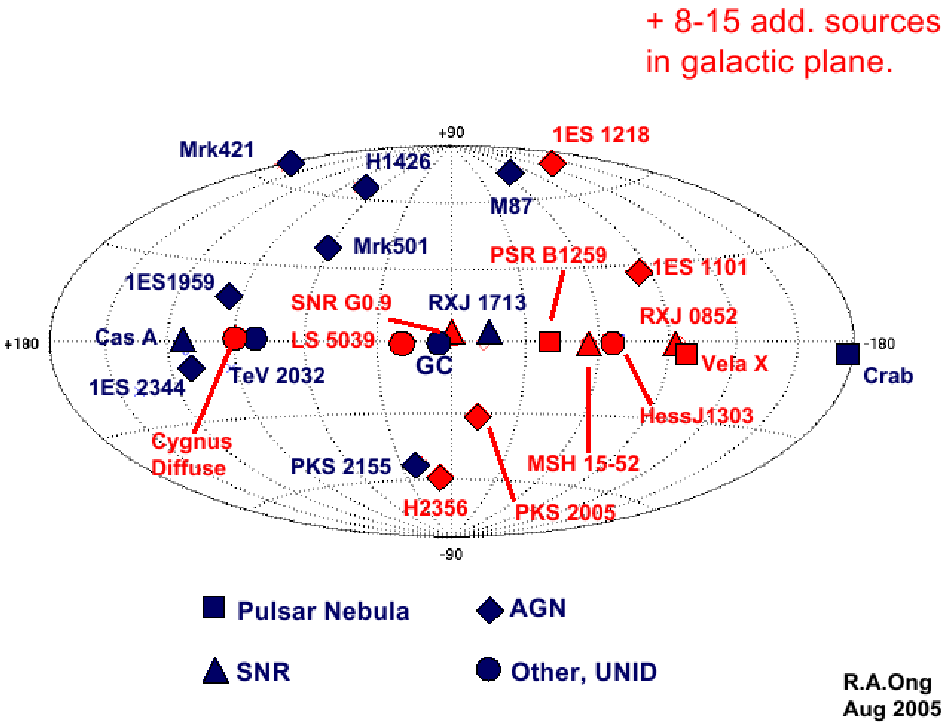


Figure 3: Sky map of astrophysical sources detected by ground-based gamma-ray telescopes at energies above 100 GeV. The legend at the bottom indicates the type of source and its detection confidence. Figure from Ong (2005) [11].

GeV, and TeV emission from the source, on daily time periods. STACEE observations of several AGN, including Markarian 501, W Comae, 3C66A, and 1ES1959+650, have provided constraints on models describing the underlying physical processes leading to very high-energy emission in these very jet-like systems [9, 10].

1.2.3 STACEE Observations During Year 2

By Spring of 2007 STACEE operated on a reduced observing schedule. Observational targets included additional observations of active galaxies and targets of opportunity, especially gamma-ray burst positions report by the NASA Swift satellite via the GRB Coordinates Network (GCN) internet alert system [13]. STACEE operations also included atmospheric monitoring and system performance monitoring. Although operating at a reduced level, STACEE logged over 150 hours of observing time during calendar year 2007 (see Figure 4. All STACEE science operations stopped after final observation on June 11, 2007, UTC.

1.2.4 STACEE Experiment Shutdown

The STACEE was proposed and designed as a "niche experiment" for gamma-ray astronomy. When STACEE started construction and observations in the late 1990s, we promised a unique approach to extend the reach of ground-based detectors to lower energy thresholds by making economical use of an existing facility at relatively low cost. The STACEE collaboration successfully constructed and operated the experiment at the designed performance level for several years, and our results have been presented in numerous publications. By every measure, STACEE has been a very succesful experimental program.

However, duing recent years, new methods and new technologies have been developed to expand the sensitivity and lower the energy threshold for imaging atomspheric Cherenkov telescopes. At present there are several new ground-based instruments newly operating, under construction, or recently commissioned. These include the next-generation multi-telescope Cherenkov arrays, such as VERITAS, HESS, and CANGAROO, and large area imagers such as MAGIC (for summary, see [11]) The community is also waiting for the much anticipated next-generation space experiment, the Gamma Ray Large Area Telescope (GLAST), now scheduled for launch in late 2008 [12]. With the launch of GLAST and the advent of new ground-based experiments with lower thresholds and better sensitivity, the "unopened window" in the range from 50 to 500 GeV (which STACEE first moved into) is now closing. Thus a new generation of instruments will take up the pursuite of those science aims that STACEE has previously addressed.

Since the STACEE concept is based on a pre-existing heliostat facility, there is no attractive upgrade or expansion to the concept that seems practical. Therefore, the collaboration decided to end the STACEE program by mid-2007.

During late June, July, and August of 2007, the STACEE experiment was decommissioned and dismantled. The Case Western group in particular was responsible for dismantling all aspects of the experiment with the sole exceptions of the detector electronics (UCLA and McGill) and removal of the cabling and large superstructure frame to hold the STACEE secondary mirror and camera

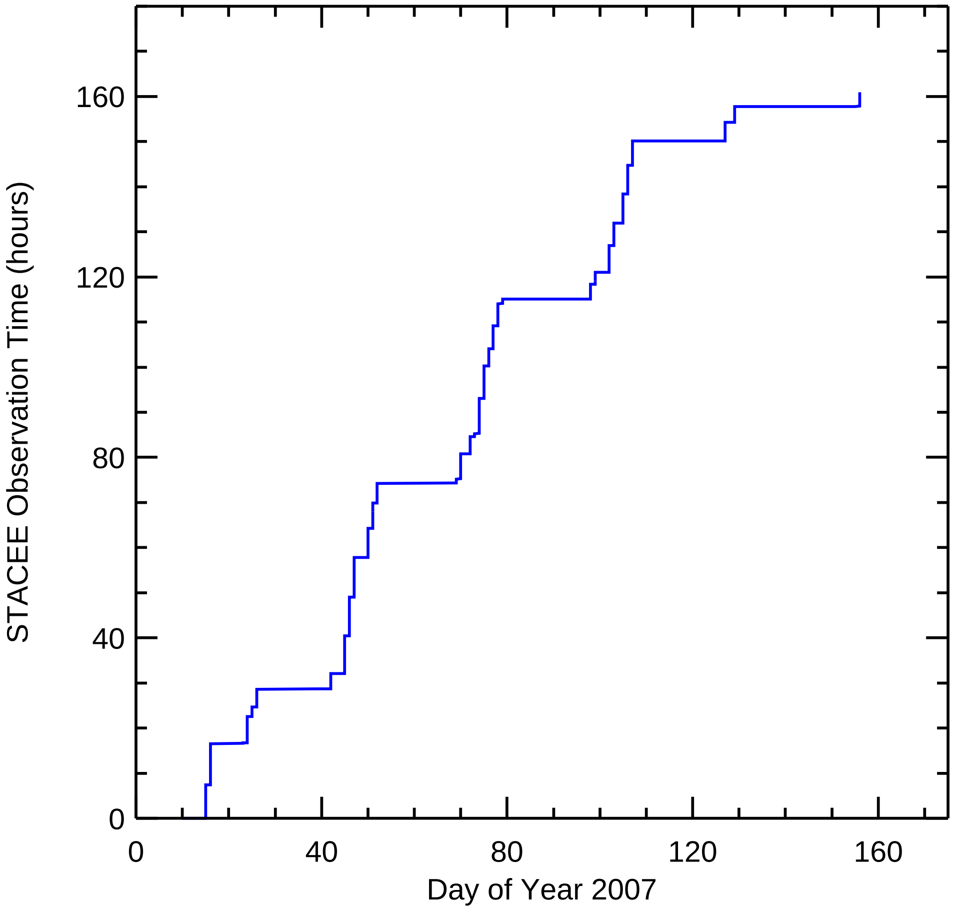


Figure 4: STACEE Observation hours during calendar year 2007. Observations include active galaxies, GRBs, and calibrations (zenith, star drift scans). STACEE was shut down after observations on June 11, 2007.

systems (Sandia). All components of the STACEE system have been remove from the Sandia site and redistributed among the collaborators for application in future experiment development. As of August, 2007, no further STACEE activities have taken place at the Sandia site by any collaborator.

1.2.5 STACEE Analysis software and data archiving

During the past year, members of the HEA group at CWRU have continued to be involved with the analysis of the STACEE data so as to realize the final science results from this experiment. Several papers delineating these results have been published and/or are in final preparation as a result of this work (see Findings section of this report).

The HEA group at Case Western also maintains a local copy of the complete STACEE data set and associated production and analysis software tools. All of these have been archived to durable media.

As of the writing of this report, all activities on STACEE that are supported by this grant have been completed. No further activities on STACEE are planned for the future.

1.3 Activities on the Pierre Auger Observatory

Details of the scientific goals and central concept of the Pierre Auger Observatory have been outlined in detail elsewhere. Here we provide a brief overview of the motivation for Auger and the instrument itself, and then summarize particular activities of the Case Western HEA group on the Auger experimental program.

1.3.1 Scientific Motivations and Overview of Auger

The Pierre Auger Observatory, which is under construction in Malargue, Argentina, is already the world's largest and most sensitive detector for Ultra-High Energy Cosmic Rays (UHECRs). Figure 5 shows the cosmic ray spectrum over many energies. The origin of cosmic rays with energies up to 10^{20} eV and beyond is a profound mystery in astrophysics. Measurement of the form of the spectrum and the arrival directions of cosmic rays at these energies could provide critical clues to their origins. In particular, at energies around 6×10^{19} eV, interactions between particles and the cosmic microwave background radiation might be expected to influence the form of the observed spectrum, possibly resulting in the 'GZK cutoff'. Furthermore, particles with such energies are only weakly deflected by intergalactic magnetic fields, which means that arrival directions might be used to achieve 'cosmic ray astronomy' allowing us to look back to the directions of particular sources. However, previous experiments give ambiguous results in on both of these measurements, mostly due to the very low statistics at the top of the energy spectrum and possible concerns over uncontrolled systematics.

Auger is specifically designed to measure detailed properties of a statistically large sample of UHECRs and thereby provide a major push forward toward answering this puzzle. In particular, each reconstructed air shower provides a measure of the energy, arrival direction and (statistically) some information on the composition of the primary cosmic ray. By carefully analyzing the distributions of these properties, we aim to pursue an identification of the sources of these cosmic rays.

Auger is a "hybrid" experiment [14] consisting of two functionally independent but co-located instruments:

- The Surface Detector (SD), an air shower array consisting of 1,600 individual water-Cherenkov detectors placed in a hexagonal grid to cover a surface area of 3,000 square kilometers, and
- The Fluorescence Detector (FD), an constellation of 24 telescopes installed in four building to detect nitrogen gas fluorescence from showers propagating in the atmosphere.

Figure 6 shows plan view of the Auger experiment as it orignally planned for installation in Malargue. With such a large area Auger collects a much larger sample of UHECRs in a much shorted time than has been accomplished previously. Furthermore, the 'hybrid' approach of detecting showers with both a surface air shower array *and* a fluorescence detector will allow for an unprecedented accuracy in event reconstruction and energy calibration, with each technique cross-checking systematics on the other.

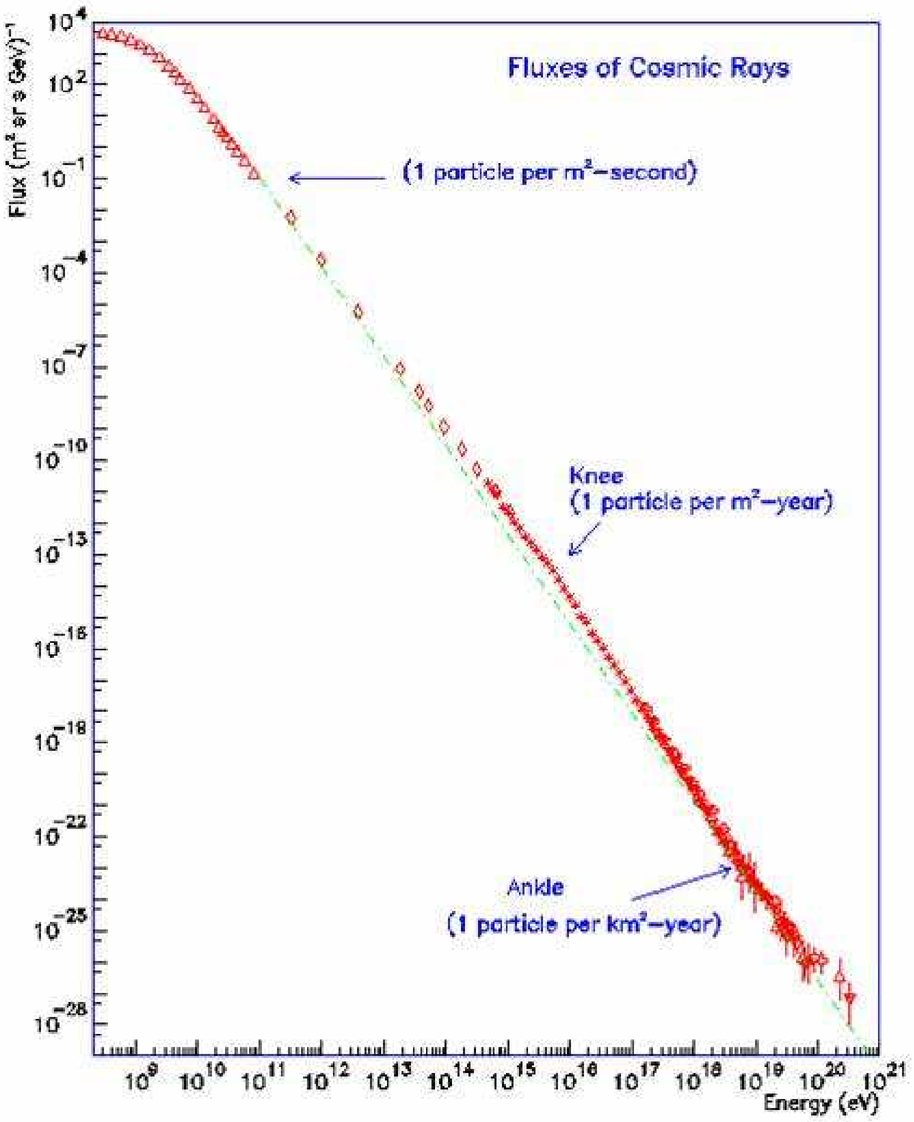


Figure 5: This plot, complied by Simon Swordy at the University of Chicago, shows the spectrum of cosmic rays spanning an enormous range of energies and flux. The origin of the highest energy cosmic rays, especially at the highest energies, is unknown and has remained a profound puzzle to astrophysics for decades.

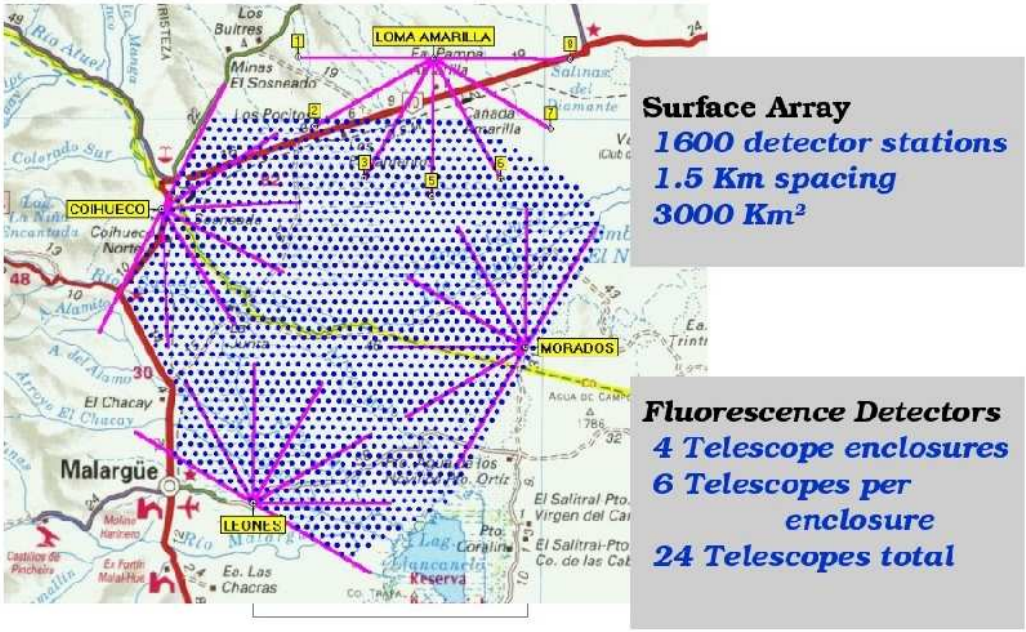


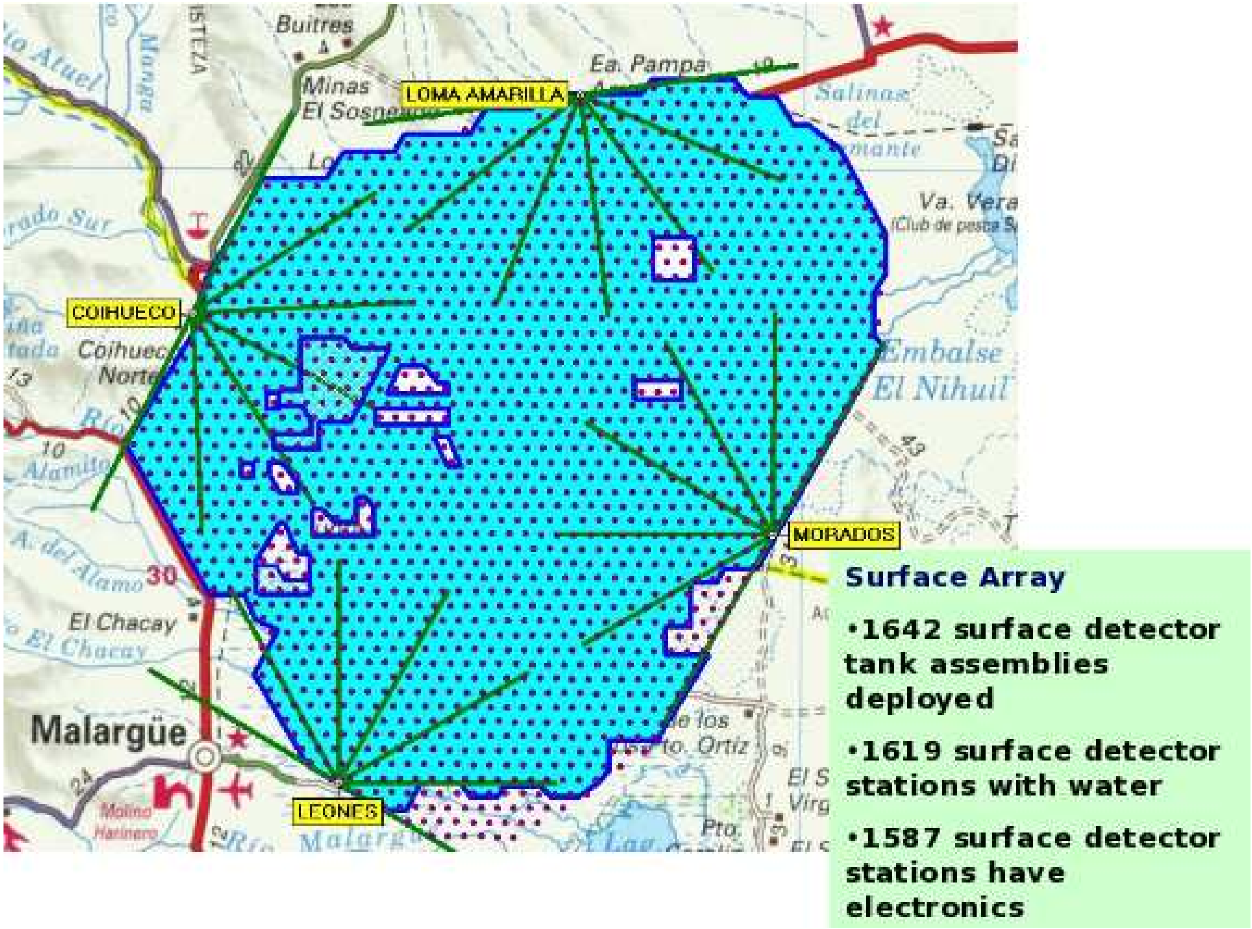
Figure 6: Plan view of Auger Observatory near Malargue, Argentina. Each dot represents one of 1,600 detector stations.

1.3.2 Current Status of the Auger Observatory

The first major phase of the Auger Observatory which is deployed in Argentina (known as "Auger South") is now virtually complete. Figure 7 shows a map indicating the positions of deployed and operating stations as of May 14, 2008. At the time of this report (May 14, 2008) 1,642 Surface Detectors (SD) have been deployed and four complete Fluorescence Detector (FD) stations have been commissioned. Of the deployed stations, 1,619 have been filled with water and 1,587 stations are fully outfitted with electronics and are taking data. Thus by any measure, Auger is the world's largest detector for Ultra-High Energy Cosmic Rays (UHECRs). At present, all subsystems on the array are working well. The collaboration has effectively constructed the array in Argentina very nearly on budget and on time.

1.3.3 Auger Operations, Performance, and Observations

The operations, performance and observational strategy of the Pierre Auger Obesrvatory has been described in detail elsewhere [15, 16, 17]. The Auger Observatory in Argentina has been operating very smoothly with a nearly continuous duty cycle during the past three years. Figure 8 show a plot of the number of event triggers collected since the start of regular observations January 1, 2004 through May 14, 2008. Over 1.2 million events have been detected by Auger. Of these, just under half correspond to "well-contructed" events that satisfy all quality cuts. Because of the steeply falling spectrum, most of these events have energies near the threshold value of about $10^{17.5}$ eV.



Surface Array

- •1642 surface detector tank assemblies deployed
- •1619 surface detector stations with water
- •1587 surface detector stations have electronics

Figure 7: Current status of the Pierre Auger Observatory as of May 14, 2008. Note that with the exception of a few minor “holes”, construction of the full surface array is complete.

The event rate for the highest energy events is considerably lower, corresponding to just under one event per month above about 50 EeV.

1.3.4 Surface Detector Instrumentation for Auger South

Until fairly recently Case Western activities on Auger have been mostly focused on the critical instrumentation program for the Surface Detector Electronics (SDE) sub-task on Auger. Past activities included the calibration and testing of over 1,600 GPS receiver units for deployment in the Auger SD stations, thermal stress testing for the Auger Tank Power Control Boards (TPCBs). Details have been described in past reports to the NSF. The HEA group continues to support detector instrumentation by diagnosing and repairing broken electronics componenents, particular GPS receivers and TPCBs.

1.3.5 Development of a Portable Dual-Channel Time Tagging Station.

In addition to the development and testing of instrumental subsystems deployed at surface detectors, the HEA group has also been very active in the development of unique test equipment for important in-the-field calibrations.

For example, one of the central and most powerful aspects of the Auger experiment is the ‘hybrid’ nature of the observatory with both SD and FD systems detecting a subset of all triggering showers. These two systems each trigger independently and each use their timing system for tagging events. In order to obtain the most accurate event reconstruction, it is imperative to calibrate any fixed or variable timing offsets between triggers generated in the two systems.

At present, timing offsets are determined using a calibrating laser system in the center of the array that triggers both detector systems with a single light pulse. This has allowed for a determination of fixed offsets, between each FD site and the overall SD array of between 50 and 350 nanosecond. Also this approach is quite effective, the instrumental origin of these offsets is not understood, and more direct measurement of the offsets is desired.

To address this issue, the Case HEA group has designed and fabricated two portable GPS time-tagging systems that can be used to measure absolute timing of arbitrary TTL input pulses on each of two channels to an accuracy of better than 20 ns. Figure 9 shows a photo of the test stand and some data verifying the performance of the system in our lab.

During the past two years, the HEA group has used these portable time tagging systems together with a portable PMT system to measure the arrival time of laser light flashes at both SD and FD systems. These measurements are part of a series that will continue through this coming year, which all together should provide a comprehensive determination and instrumental isolation of the SD-FD timing offsets. At present we are developing a somewhat modified version of our detector/timing system for permanent installation in the array during Summer 2008 so as to provide a continuous set of measurements on the timing stability of the entire array.

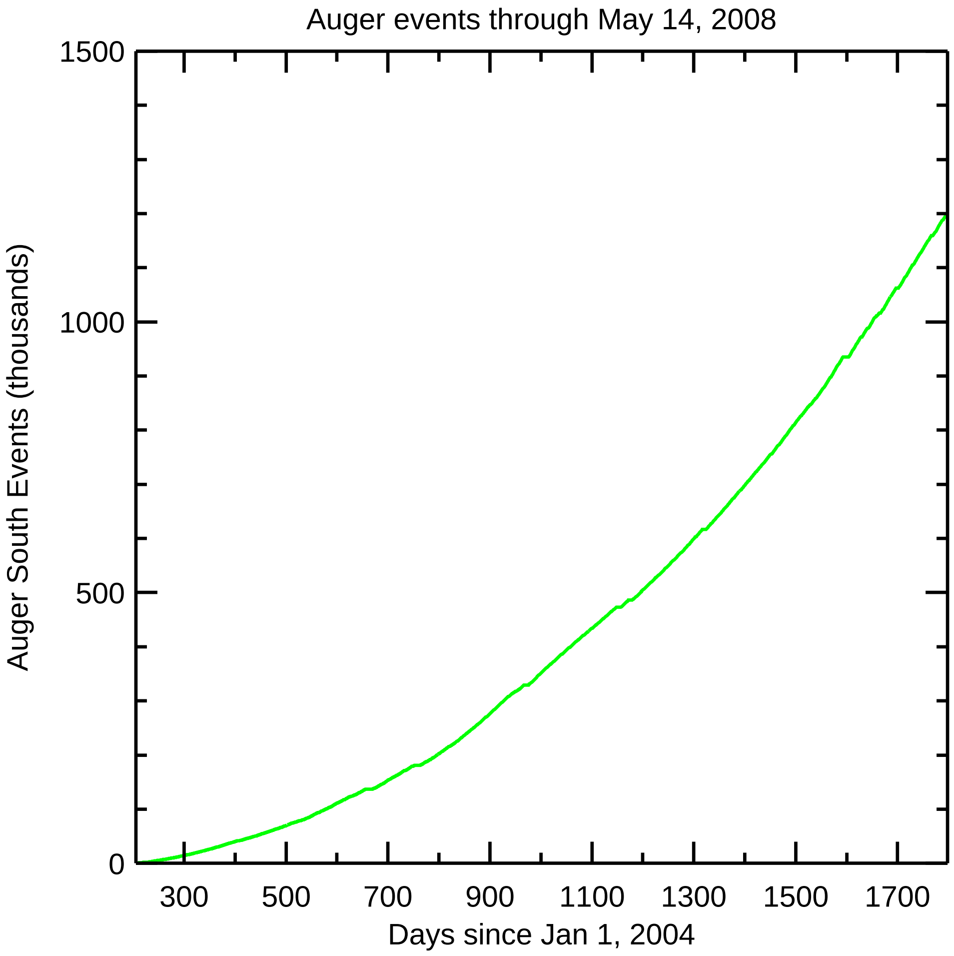
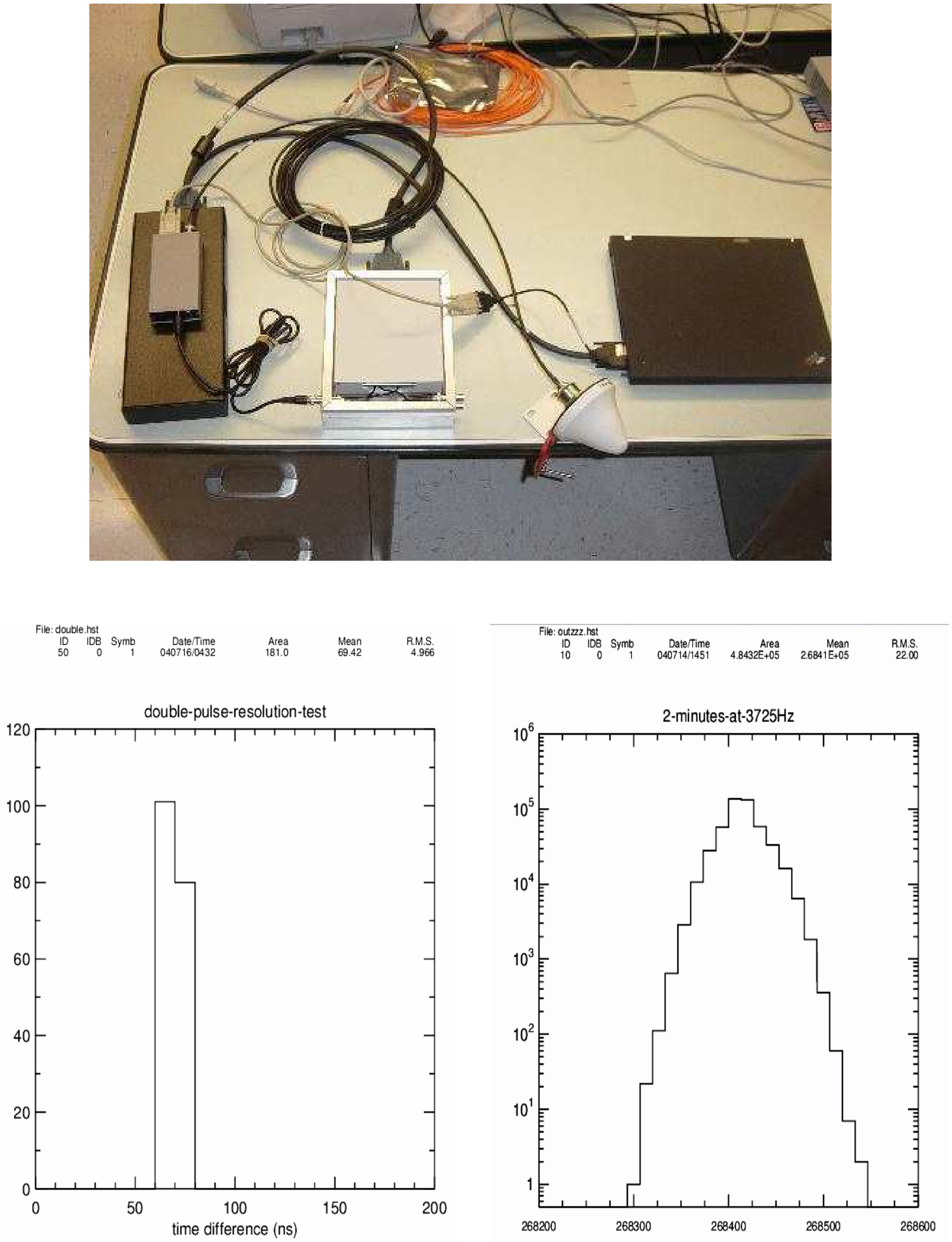


Figure 8: Raw events collected from the Pierre Auger Observatory (South) since January 1, 2004. As of May 14th, 2008, over 1.2 million events have been detected by Auger.



```
File: double.hst
       ID    IDB  Symb      Date/Time          Area        Mean        R.M.S.
       50      0     1   040716/0432          181.0       69.42         4.966
```

```
File: outzzz.hst
       ID    IDB  Symb      Date/Time          Area        Mean        R.M.S.
       10      0     1   040714/1451     4.8432E+05  2.6841E+05         22.00
```

Figure 9: Top: photo showing Dual-Channel Portable Time-Tagging Station developed and constructed at Case Western. Bottom: Summary of performance tests on this device: Two-pulse time resolution better 70 ns (left) and 22 ns RMS timing resolution on 3735 Hz pulser rep rate (right).

Figure 10: Photo showing new GPSY2 system and associated “compact PC”. This system is being developed in coordination with our collaborators at Colorado School of Mines and will be used for timing, command and control for the new XLF laser facility at Auger South.

1.3.6 Development of a GPSY2 control system for the XLF

In addition to the continued application of the portable systems developed at Case Western, the HEA group at CWRU is also working closely with collaborators at the Colorado School of Mines to develop a new GPS time-tagging system based on a custom-built timing board (the GPSY2) integrated into a “compact PC” (see Figure 10). This new system will be deployed in the center of the array for timing, and command and control of the “Xtra Laser Facility” (XLF) which will fire laser shots for energy and timing calibration of the Auger fluorescence detectors [18].

1.3.7 Auger Communications Task Leader

Effective November 2006, the PI was endorsed by the Auger Collaboration as the “Communication Systems Task Leader”. Communication corresponds to one of about ten major tasks within the general management and organization structure of the collaboration, as shown in Figure 11. The Comms Task is responsible for the deployment, operation, and maintenance of all equipment for wireless and network communication between individual Auger SD and FD detector stations and also the central campus at each site. Wireless communications are relied upon as the only link

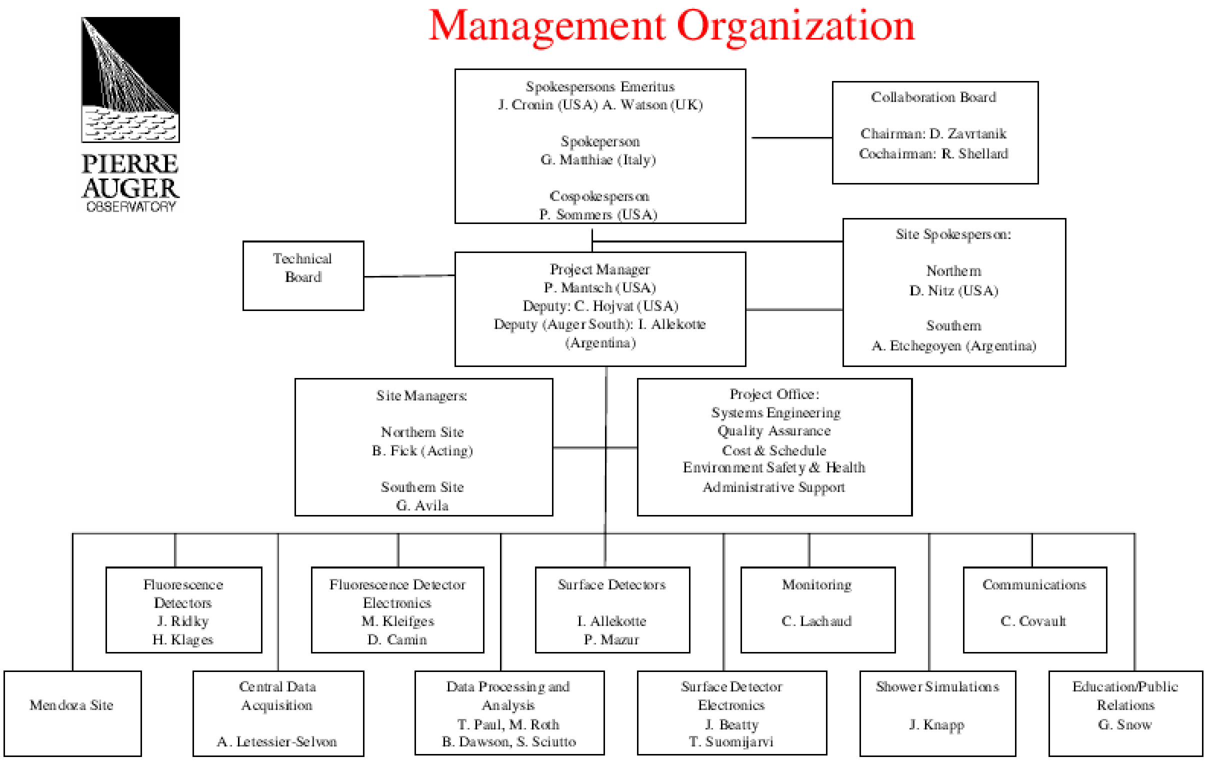


Figure 11: Organizational charge delineating the management structure of the Pierre Auger Collaboration. The PI serves as the Comms Task Leader. Several members of the HEA group suppprt activities in Comms as well. Note that this organizational structure applies to the entire Auger collaboration which includes both Auger South (Argentina) and Auger North (Colorado).

between the observatory operators and the 1,600 stations and four fluorescence detectors deployed in the field. All data, including station command and control, housekeeping, trigger alerts, and science data from each and every detector in the Auger experiment depend directly on the Comms system functioning continuously and reliably.

The original Comms task leader (Paul Clark, Leeds University, UK) left the Auger Collaboration in mid-2006, after having completed all major design, fabrication, and coordinated deployment activities for all Comms subsystems deployed into the field in Malargue, Argentina. Figure 12 shows a schematic overview of the Comms system deployed in Argentina for Auger South. Each component of the Comms system has been custom-designed to meet the specifications of the Auger detector system.

With deployment complete, the major effort of the Comms task for the next several years for Auger South will be the monitoring of performance of all Comms subsystems and a proactive response to provide maintenance and spares to address potential problems in the communications

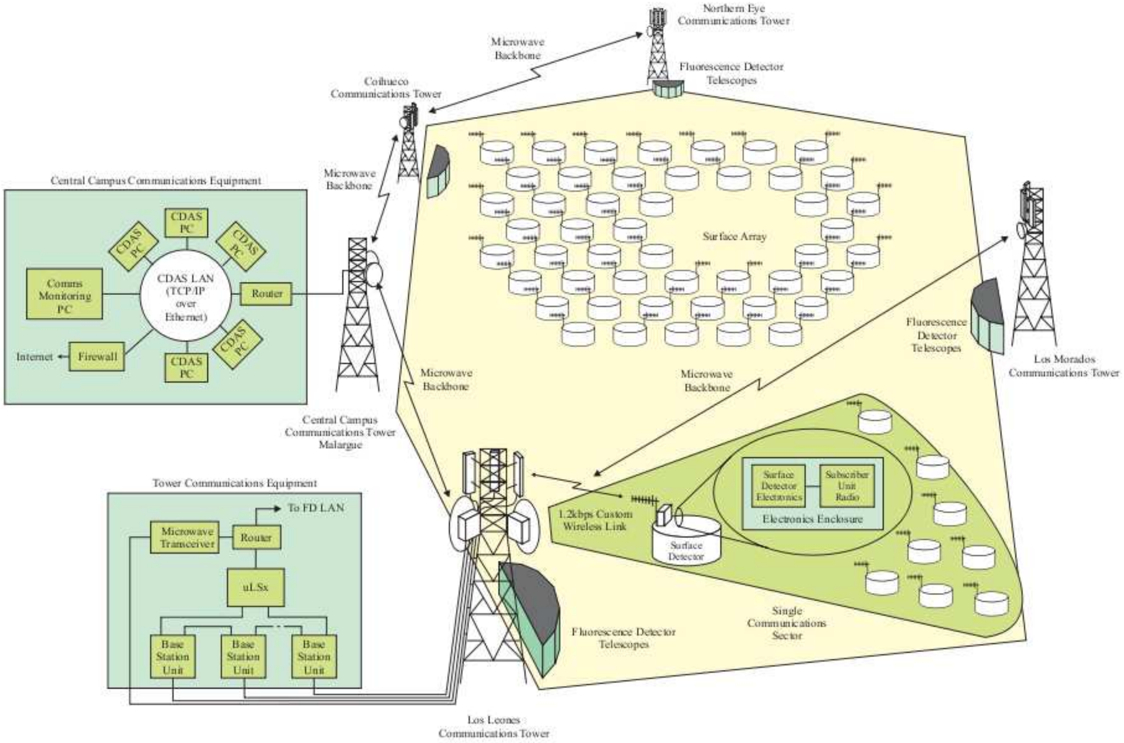


Figure 12: Overview of complete communication system ("Comms") network topology for the Pierre Auger Observatory (South). Primary Comms systems include subscriber unit radio receiver/transmitters on each Auger SD station and a network of five communications towers linked by a high-speed microwave data communications backbone.

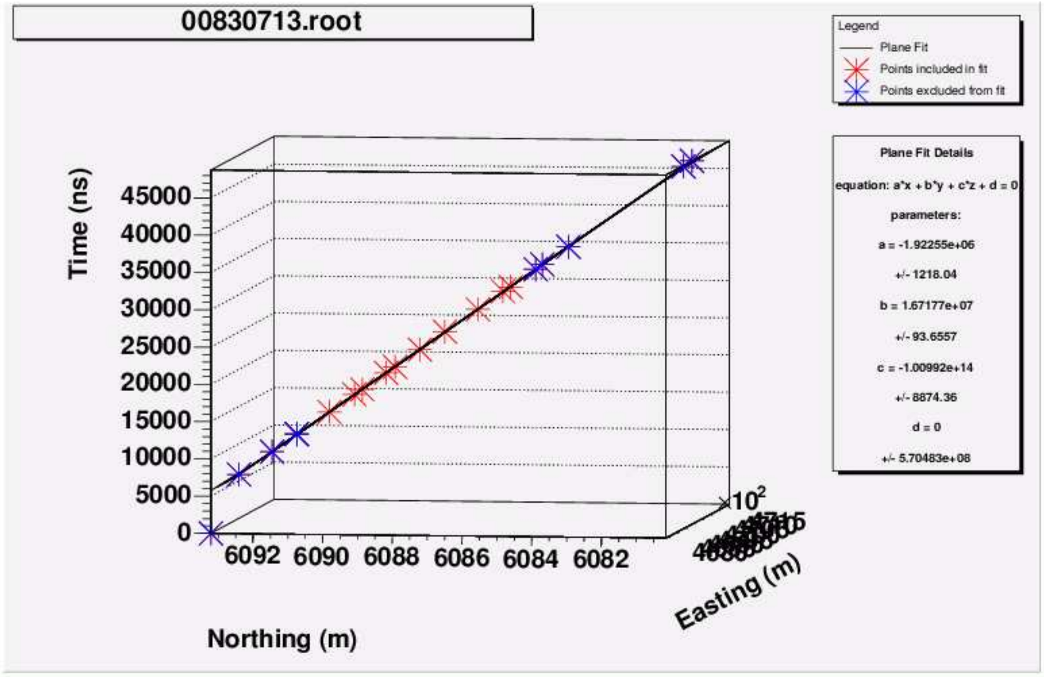


Figure 13: Plot showing event arrival direction reconstruction based on planar timing reconstruction for Auger SD stations.

system before they become more serious. Another important activity is the supervision of other secondary comms links that have been deployed into the array (e.g., for calibration systems, audio “walkie-talkie” radio, atmospheric monitoring systems). Likewise, considerable effort has been expended this year in working closely with Observatory staff to address the somewhat byzantine operational and licensing rules of the Argentina regulatory agencies that may apply to activities using wireless transmissions at the Auger South site.

Finally, with the level of planning activity increasing for Auger North the PI has become increasingly involved is R&D for the new communications system that will be deployed in a prototype array in Colorado by mid-2009. These activities are described in section 1.3.9.

1.3.8 Analysis: Angular Resolution and Anisotropy Studies

With the advent of a stable array configuration and increasingly powerful analysis tools, the scientific importance of involvement in data analyses for Auger is growing. A new graduate student, Ross Burton, joined the HEA group in 2006 and is currently working to complete a systematic study in detail event reconstruction methods to verify timing offsets and to accurately determine event arrival directions. Figure 13 shows preliminary plane reconstruction techniques that have been developed for Auger.

Auger has been collecting data for science analysis since January 1, 2004. This past year marks the release of several major science results from Auger including limits on the photon fraction of cosmic rays, an energy spectrum with a feature consistent with the anticipated GZK phenomena, and – most importantly – the detection of anisotropy in the arrival directions of the highest energy cosmic rays.

Cosmic Ray Correlations with AGN: The discovery of anisotropy in the arrival directions of cosmic rays is perhaps the most important breakthrough that the field has enjoyed for many years. The Case Western HEA group played a major role in the development of this particular result. Specifically, the PI was selected to moderate between several similar yet internally competing approaches to the analysis. In particular:

- During late 2006 and early 2007, the PI served with a handful of other collaborators to develop a strategy for confirmation and publication of the correlation result.
- The PI was charged with drafting the text of an internal note that served to document the "prescription" for confirming the AGN correlation result. This document fixes all cuts and defines *a priori* probability thresholds for consideration of publication based on confirmation of a tentative signal in future data.
- Once the prescription was fullfilled, the PI was selected by the collaboration to serve as one member of a three-person team charged with drafting a Letter to Science to announce our result. The PI was the only US Auger collaborator on this team.
- The PI served on the same three-person team in late 2007 and early 2008 to complete what we called the "long paper" delineating the correlation result with all pertinent analysis details and a tabulation of the events.

1.3.9 Future Plans: Preliminary R&D for Auger North

Auger North Overview: With the completion of the installation in Argentina and 1,600 operating surface detector station this year, the collaboration is enjoying a wealth of new data and many analyses efforts are bearing fruit in several different arenas, including anisotropy, energy spectrum, and composition studies. Most of the effort of the collaboration remains focused on exploiting the results from Auger South and applying these to advance our understand the sources of cosmic rays. The Auger collaborators remain committed to the analysis of data and the publication of results from Auger South as the top priority of the collaboration for at least the next several years.

However, since inception, Auger has been envisioned as a set of *two* detector systems: one in the Northern Hemisphere and one in the Southern Hemisphere. Two detectors are required to obtain full sky coverage (critical for anisotropy studies) and to allow for careful measurement of the form of the spectrum as a function of position (since local source distributions are likely to be very different in the North vs. the South.) The full collaboration is already committed to pursuing the installation of Northern Auger in the USA at a proposed site in southeastern Colorado. A detailed technical design report for Auger North is in draft form and will be released by August 2008. The design report makes the science case for Auger North and delineates every details of the

Auger North system design. This document will be used as a basis for future proposals in every collaboration country to their respective funding agencies.

Auger North will consist of 4,400 surface detector stations spead out over an area of more than 20,000 square kilometers, essentially a 7-fold multiplying the acceptance for high energy cosmic rays relative to what we have achieved with Auger South. Baseline plans also call for full fluorescence coverage of the detector area to maximize the number of extremely well-reconstructed hybrid events. Auger North will be located in southeastern Colorado near the town of Lamar. The design of Auger North will be configured to take advantage both of our experience operating in the South and our correlation result at the highest energies. In particular, we plan to move to a configuration of one PMT per tank (instead of the 3 per tank used for Auger South) and increased spacing between tanks. These measures will allow us to achieve a much larger effective area while maintaining a comparable overall cost for Auger North relative to Auger South.

The case for Auger North is being prepared by the collaboration for consideration by the funding agencies. Every Auger collaborating country will be contributing funding to support the construction of Auger North. In the US, representatives from the Auger collaboration were present at the recent P5 particle and particle astrophysics review panel. Although the report from P5 panel is not yet available, panel members encouraged the Auger Collaboration to submit a proposal for Auger North to the US funding agencies by not later than Fall of 2008. The collaboration is actively working to prepare this proposal.

The Auger North Comms System: The Case Western group is involved in several aspects of advanced planning for consideration of Auger North. The PI is particularly involved in development and deployment of the RDA (Research and Development Array) which is a critical first step toward demonstrating the capabilities of the collaboration for deploying the newly planned array. Figure 14 shows the layout of 21 stations to be deployed into southeastern Colorado not later than mid-2009. The key demonstration aspects of the RDA include:

- Verification of performance with an increased detector spacing ($sqrt2$-mile square grid for Auger North vs. 1-km triangular grid for Auger South),
- Verification of performance with only one PMT per tank for Auger North (vs. three per tank for Auger South),
- Verification of the effectiveness of additional insulation on the tanks to mitigate effects of colder winters at site in Colorado vs. Argentina, and
- Verification of performance of a new wireless communinication system (Comms) for Auger North based on peer-to-peer packet relaying.

In particular, the custom-developed Comms system used for Auger South, based on line-of-sight (station-to-tower) communications, cannot be practically expanded to the size required for Auger North at the Colorado site. Therefore, a new Comms system concept has been developed.

One of our primary goals with the RDA will be to verify that the new Comms system will work in the field as expected.

The new Comms system, essentially a multiply-redundant local-area-network overlays a deterministic data relay scheme on top of a standard wireless protocol very similar to standard “WiFi” networks. Within the array, communications will be relayed between neighboring stations. In this scheme, the stations act as a “sensor net” with information being relay to a set of central concentrators. The system is designed to be both “deterministic” and “redundant”, so that we can depend on data to arrive at the central received on time.

As Comms Task Leader for the entire Auger collaboration, the PIs has organizational responsibility for include *both* Auger South and Auger North. Although the main technical effort to develop the new comms system resides elsewhere (mostly with collaborators at Michigan Technical University), our group will be actively working to review, deploy and test the new system, in coordination with an increasingly larger number of collaborators who will be asked to support this effort in the case that Auger North is ultimately given the green light to procede.

Other Activities for Auger North: In addition to the work on Comms for Auger North, the HEA group also has responsibility for R&D on GPS receivers that will be used for Auger North. We have selected the I-Lotus M12M receiver shown in Figure 15. The M12M is the latest in a series of “drop-in compatibles” that are derived from the original Motorola Oncore series that has been successfully used in Auger South, but which is no longer available. The M12M features timing resolution (GPS relative) to better than 2 ns.

The HEA group developed, constructed, and operated a system for calibration, testing, and environmental stress testing of all GPS units for Auger South. We have already begun to modify our test equipment to accommodate the new M12M GPS receivers that will be used for Auger North.

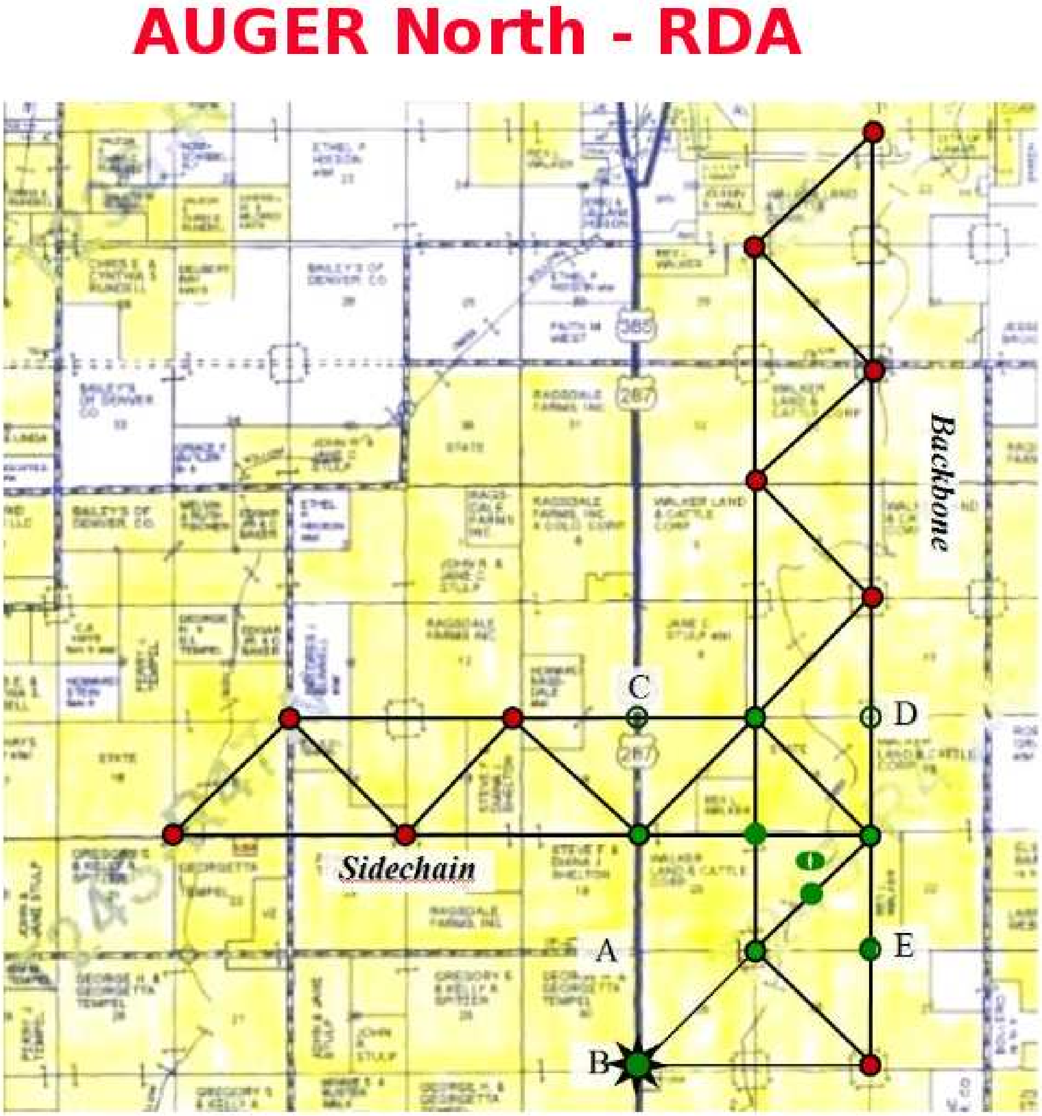


Figure 14: Planned layout for the Auger North Research and Development Array (RDA) planned for deployment in June, 2009 near Lamar, Colorado. Communication links are shown as black lines interconnecting neighboring stations.

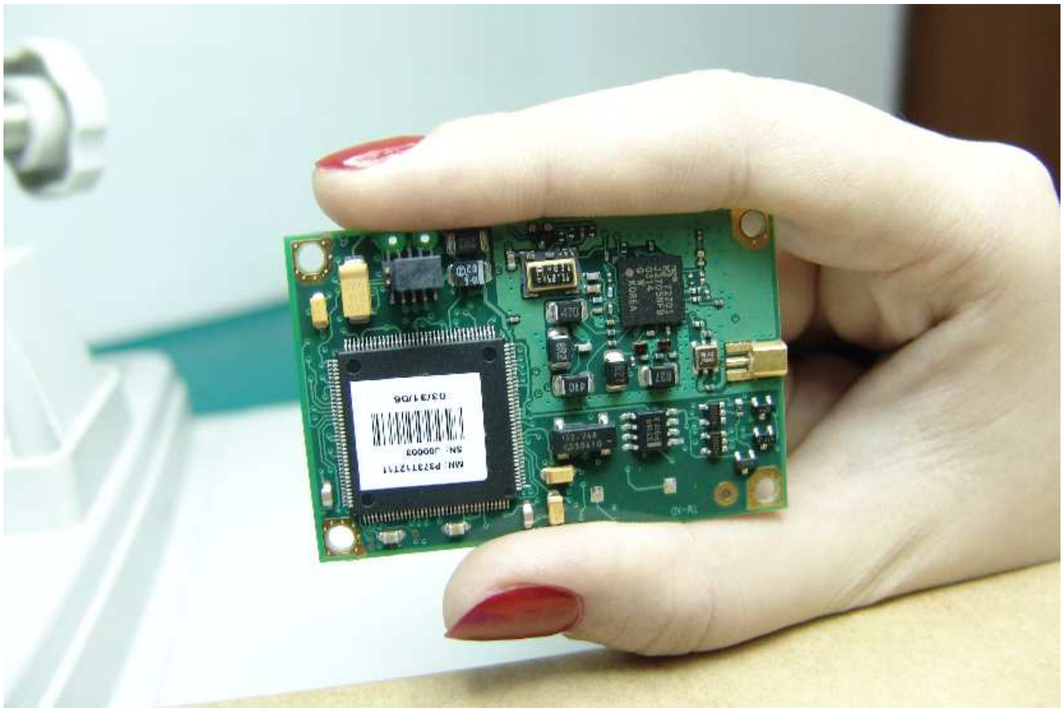


Figure 15: Photo of the I-Lotus M12M GPS receiver which will be used for GPS time-tagging in Auger North.

1.4 Budget and Expenditures for NSF Grant 0601088

The overall budget for Year 2 for grant was $140,000. A summary budget breakdown is as follows:

Budget Area	Year 2 Amount
Personnel (with fringe)	$73,333
Equipment	$0
Travel	$11,962
Supplies, parts, shipping	$ 5,320
Indirect	$49,385
Total	$140,000

By May 31, 2008, actual expenditures during Year 2 will approximately match the prescribed budget. No significant deviations are anticipated.

For Year 3, the submitted budget is very similar to Year 2:

Budget Area	Year 3 Amount
Personnel (with fringe)	$76,138
Equipment	$0
Travel	$9,800
Supplies, parts, shipping	$ 4,677
Indirect	$49,385
Total	$140,000

We expect to implement the budget for Year 3 as anticipated with the following adjustment: Because the PI is no longer obligated to participate as an instructor for the Cleveland Math and Science Partnership (MPS) for Summer 2008, we request that the the summer salary line for the PI be increased from 1.0 months to 1.5 months, corresponding to an increased time commitment to this project. The additional cost for this will be offset by support by a Department of Education (GAANN) grant for one graduate student (Ross Burton) and direct departmental support for a second graduate student (Andrew Ferguson) so that the overall impact on this proposal budget due to this change will be neutral.

1.5 References for Activities

References

[1] Pierre Auger Collaboration [J. Abraham et al.], “Correlation of the highest energy cosmic rays with nearby extragalactic objects,” *Science* **318**, 939 (9 November 2007) [arXiv:astro-ph/0711.2256v1].

[2] Pierre Auger Collaboration [J. Abraham et al.], “Correlation of the highest-energy cosmic rays with the positions of nearby active galactic nuclei”, Astroparticle Physics **29**, 188 (2008) [(arXiv:astro-ph/0712.2843]).

[3] R.A. Ong, et al., “STACEE-32: Design, Performance, and Preliminary Results”, in GeV-TeV Gamma Ray Astrophysics Workshop, Toward a Major Atmospheric Cherenkov Detector-VI (Snowbird, UT), (July 1999). available online at: http://www.astro.ucla.edu/~stacee/papers/snowbird1999_ong.ps.gz.

[4] M.C. Chantell, et al., “Prototype Test Results of the Solar Tower Atmospheric Cherenkov Effect Experiment (STACEE)”, Nucl. Instr. Meth. **A408**, 468 (1998).

[5] D.S. Hanna, et al., “The STACEE-32 Ground Based Gamma-Ray Detector”,*Nucl. Inst. Meth.* **A 491**, 126 (2003).

[6] D.M. Gingrich, et al., “The STACEE Ground Based Gamma-ray Detector”, *IEEE Transactions on Nuclear Science*, 52, p. 2977-2985 (2005) available online at http://www.astro.ucla.edu/~stacee/talks_n_pubs/nss04-n4-2-record.pdf.

[7] S. Oser, et al., “High Energy Gamma-Ray Observations of the Crab Nebula and Pulsar with the Solar Tower Atmospheric Cherenkov Effect Experiment”, *Astrophysical Journal* **547**, 949 (2001) [arXiv:astro-ph/0006304v1]

[8] L.M. Boone, et al., “STACEE Observations of Markarian 421 During an Extended Gamma-Ray Outburst”, *The Astrophysical Journal, Letters*, 579, L5 (2002) available online at .

[9] R.A. Scalzo, et al., “High-Energy Gamma-Ray Observations of W Comae with the Solar Tower Atomospheric Cerenkov Effect Experiment (STACEE),” *The Astrophysical Journal* **607**, 778-787 (June 1, 2004) [arXiv:astro-ph/0403114].

[10] D.A. Bramel, et al., “Observations of the BL Lac Object 3C 66A with STACEE,” *The Astrophysical Journal* **629**, 108-114 (2005) [arXiv:astro-ph/0504515].

[11] R.A. Ong, “The Status of VHE Gamma-Ray Astronomy,” in Proc. 29th International Cosmic Ray Conference, Pune, India, (3-11 Aug 2005), (Rapporteur Talk) [arXiv:astro-ph/0605191].

[12] K. Grady, et al., “GLAST Project Status Review, Dec 5, 2003”, (GLAST Monthly Project Status Reports January 2004) available online at http://glast.gsfc.nasa.gov/project/reports/

[13] http://gcn.gsfc.nasa.gov/.

[14] Pierre Auger Collaboration [J. Abraham et al.], “Properties and performance of the prototype instrument for the Pierre Auger Observatory,” *Nuclear Instruments and Methods* **A523**, 50 (2004).

[15] B.R. Dawson, “Hybrid Performance of the Pierre Auger Observatory”, [Pierre Auger Collaboration], 30th International Cosmic Ray Conference (ICRC 07), Mérida, Yucatan, Mexico (3-11 July 2007)[arXiv:0706.1105].

[16] M. Ave, et al., “The accuracy of signal measurements with the water-Cherenkov detectors of the Pierre Auger Observatory”, *Nuclear Instruments and Methods in Physics Research*, **A578** 180 (2007).

[17] I. Allekotte, et al., “The Surface Detector System of the Pierre Auger Observatory”, *Nuclear Instruments and Methods in Physics Research* **A586**, 409 (2008).

[18] B. Fick, et al., “The Central Laser Facility at the Pierre Auger Observatory”, Journal of Instrumentation (JINST) **1** P11003 (2006).