Form 8

# Research Result Report
# ICRR Inter-University Research Program 2023

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| Research Subject: Ultra High Energy Cosmic Ray Research with the Telescope Array | |
| Principal Investigator: | John Matthews |
| Participating Researchers: | John Matthews, Charles Jui, JiHyun Kim, Gordon Thomson, Dmitri Ivanov, Jeremy Smith for the University of Utah group |

Summary of Research Result :

The University of Utah group received an Inter-University award to assist with data collection and analysis, especially with respect to comparison to the Pierre Auger Observatory. The Telescope Array is located about 39° N in the United States near Delta, Utah. The Auger Observatory is located in the southern hemisphere near Malargue, in Argentina. One of the differences between the data of the two experiments is the spectra observed by the Telescope Array observatory and the Pierre Auger Observatory. This has long been a source of controversy.

For some time it has been known that there is a ~9% difference in the normalization of the two spectra and by shifting the Telescope Array data down 4.5% in energy and the Auger data up 4.5% the two spectra could be made to agree over much of the energy region. Professor Shoichi Ogio and Dr. Keitaro Fujita of the Telescope Array showed that this difference could be accounted for by the differences in the fluorescence yield and missing energy correction assumptions that the two experiments used. If the Telescope Array used the Auger assumptions, the two spectra could be made to agree in the lower energy range ($E < \sim 10^{19.5}$ eV). See Figure 1. For energies greater than this, the two spectra diverge. The Auger spectra begins to drop off, while the Telescope Array data continues and has a higher cutoff energy.

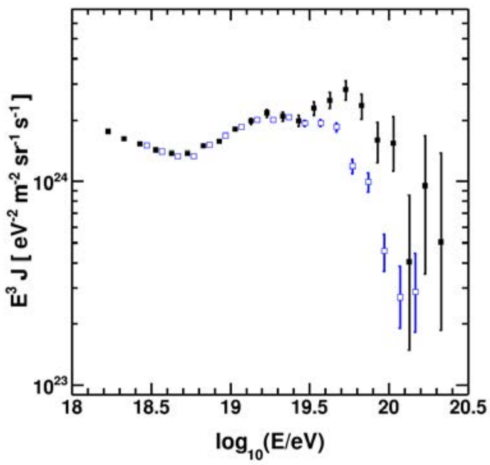


Figure 1. *The UHECR spectra of Telescope Array (black full circles) and the Pierre Auger (open blue circles). When Telescope Array data is shifted down 4.5% and Auger data is shifted down 4.5%, the two spectra agree for $E < 10^{19.5}$ eV. For energies greater than this, the two spectra diverge. The Auger spectra begins to drop off, while the Telescope Array data continues and has a higher cutoff energy.*

Part of the reason for this difference originates in the regions of anisotropy that the Telescope Array observes. The Telescope Array first observed an excess of events E > 5.7x$10^{19}$ eV. This is known as the Telescope Array Hot Spot. Later, while trying to understand the difference in the cut-off energies of the experiments, an excess of high energy events was found in the direction of the Perseus-Pisces Super-Cluster and then a smaller excess in the direction of NGC-1068 (See Figure 2.) The Auger Observatory sees no such anisotropies in the southern hemisphere. This raises the question of whether these excesses are significant or simple statistical fluctuations.

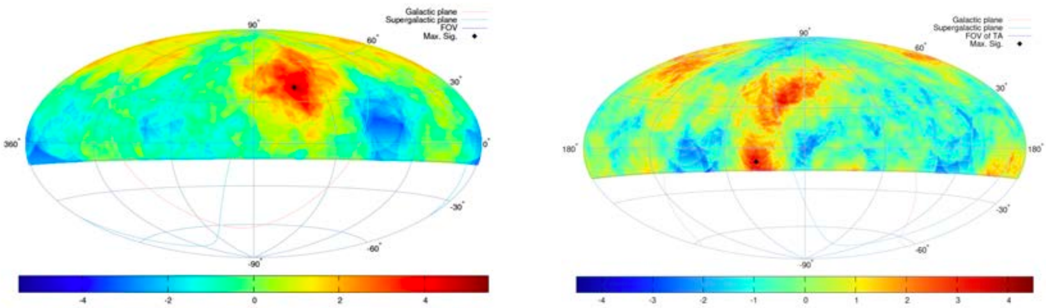


Figure 2. *Anisotropy/Excess regions in the Telescope Array14 year data. Left: The Telescope Array Hot Spot showing the excess for E>$10^{19.75}$ eV. There is a 3.2 sigma post-trial excess. Right: The excesses for the Perseus-Pisces Super Cluster and NGC 1068 for E>$10^{19.6}$ eV. These have a significance of 3.5 and 3.7 sigma.*

If one compares the spectra inside to that outside the three excesses. They are quite different, See Figure 3. The spectrum of data INSIDE the excesses has a much bigger bump for E>$10^{19.5}$ eV. The spectrum of data OUTSIDE the excesses looks much more like the spectrum observed by the Auger observatory in the southern hemisphere. There remains a discrepancy between the TA and Auger spectra above E>$10^{19.5}$ eV but it is significantly smaller, perhaps indicating that there is yet another source.

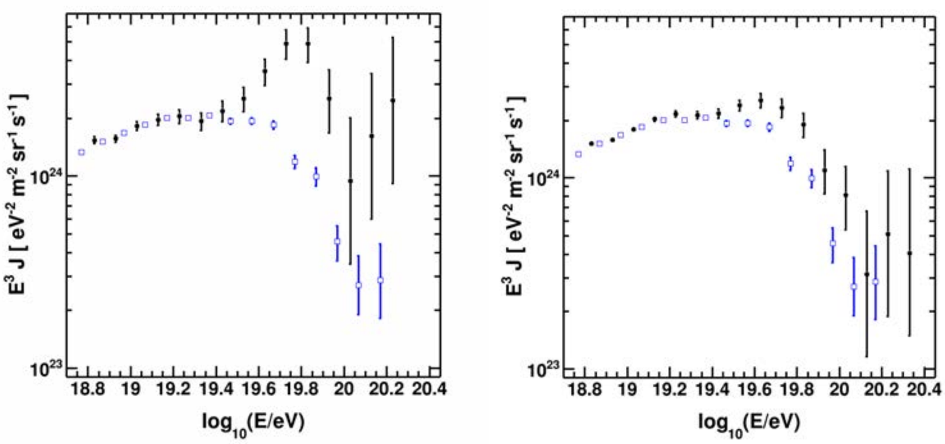


Figure 3. *Telescope Array spectra compared to that of the Auger Observatory. Left: The Telescope Array spectrum of data INSIDE the*

*three excesses (black full circles) compared to the Auger spectrum (open blue circles). Right: The Telescope Array spectrum OUTSIDE the three excesses (black) compared with Auger (blue). The three excesses contribute the vast majority of the difference from Auger for $E>10^{19.5}$ eV.*

We have been working with the Auger collaboration to better understand the difference between the Telescope Array and Auger data. Part of this includes joint working groups to dig through the data and try to identify potential issues in analysis or assumptions. Another effort involves bringing a small array of Auger detectors to the Telescope Array and incorporating it inside the Telescope Array scintillator array. The Auger array incorporates seven Auger North prototype detectors instrumented with a single PMT as well as one Auger South detector instrumented with three PMTs just like the detectors in Argentina. The Auger group has also sent scintillator detectors of the type that they are adding in Argentina. (See Figure 4.) With these detectors we will be able to compare pulse heights and shapes on an event by event basis. The Inter-University award supports this effort in particular by helping to “harden” the Telescope Array detectors near the Auger mini array to insure that they participate in joint data.

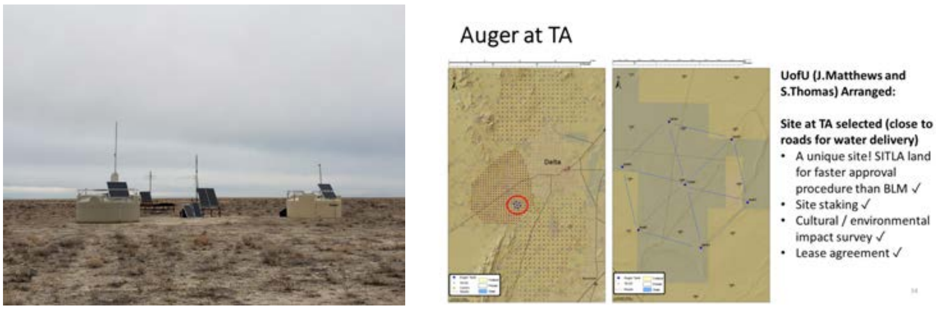


Figure 4. *Auger at Telescope Array. The Telescope Array is collaborating with the Auger collaboration to compare the detector response of the differing detectors. While the Telescope Array surface detectors are two layers of scintillator, the Auger detectors are water tanks utilizing Cerenkov light. Recently the Auger collaboration is adding a single layer scintillator on top of the water tanks. A small array of Auger detectors has been deployed within the Telescope Array scintillator array. The Auger array incorporates seven Auger North prototype detectors instrumented with a single PMT as well as one Auger South detector instrumented with three PMTs just like the detectors in Argentina. Left: At the center of the test array are an Auger South tank, an Auger North tank, and a Telescope Array scintillator detector. Right: maps showing the deployment locations of the Auger mini array.*