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The Telescope Array and its Low Energy Extension

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The Telescope Array (TA) experiment is being built in Millard County, Utah. In its basic configuration it will combine a scintillator ground array with HiRes-type fluorescence detectors for the highest energy cosmic rays in the northern hemisphere. Beyond the aims of this basic configuration we will discuss plans to expand TA's reach towards lower energies for systematic studies of cosmic ray spectrum and composition.

1. Where are we after HiRes and AGASA?

The two pioneering experiments on Ultra High Energy Cosmic Rays (UHECR) beyond the GZK cutoff, the HiRes stereoscopic fluorescence detector and the AGASA scintillator ground array, both have concluded their data taking. Both were situated in the northern hemisphere and left a legacy that inspired the construction of a next generation of hybrid detectors, integrating both the fluorescence technique and a ground array.

In 1966 Greisen, Kuzmin, and Zatzepin pointed out that protons at energies above $\approx 6 \times 10^{19}$ eV will no longer penetrate the Cosmic Microwave Background (CMB) unhindered [1,2]. The Lorentz-boosted CMB photons excite the Δ resonance so that the protons loose energy to the pions that are emitted in the subsequent decay. The process imprints structure on the spectrum: the so-called GZK feature.

AGASA was the first experiment to extend its spectrum measurement beyond the GZK feature. Their result sparked enormous interest, as it found no indication of the expected GZK feature [3]. As reported in this conference by M. Teshima, a new analysis of the AGASA data changes the energy scale enough to void the old conclusion about the absence of the GZK feature. While that new analysis now too is based on Corsika, the air shower Monte Carlo code that is most widely used in the community, AGASA warns that unlike their old Monte Carlo the new one does not reproduce well some basic angular dependence of variables in the ground array.

In the meantime HiRes' exposure at the highest energies has overcome the AGASA experiment's. The HiRes data show strong evidence for the expected GZK feature [8]. This conclusion is also supported by preliminary results from the Auger collaboration from the ICRC in Pune. Yet like in the two separate experiments AGASA and HiRes, the energy scales between the surface array and the fluorescence detectors can not be reconciled. Auger chose to trust the fluorescence based energy scale and impose it on its high statistics surface array data. Figure 1 shows this general agreement between HiRes and Auger with its fluorescence energy scale. It also shows the AGASA data for reference. So one of the great legacies of HiRes and AGASA is still unresolved: What in our modelling of extensive air showers causes the energy scales derived for surface arrays and fluorescence experiments to be so different?

In its data AGASA found clustering of the highest energy events, in particular one triplet and five doublets (three of these are reported in [4]). While HiRes found no such small scale clustering [5], HiRes has one event at a reconstructed energy lower than the nominal AGASA cutoff that coincides with the AGASA triplet. It will take a larger follow-up experiment in the northern Hemisphere to fully explore this curious coincidence.

Gorbunov et. al. published a paper in 2004 where they correlated HiRes stereoscopic event directions with BL-Lacertae objects [6]. In [7]

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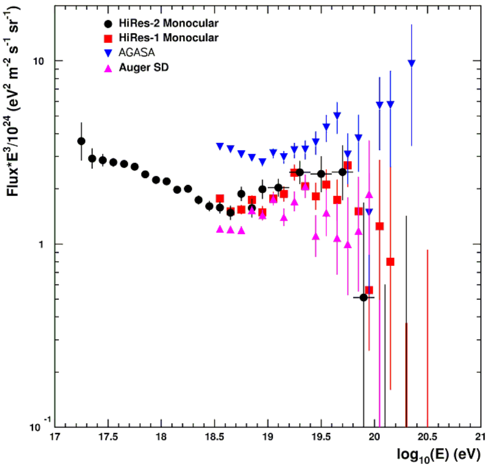

Figure 1. The UHECR spectra of HiRes1, HiRes2, AGASA, and Auger compared.

we outline a way to cross check their claim with HiRes data not used in the original analysis.

2. What can we do with TA?

The Telescope Array (TA) experiment was conceived by our Japanese colleagues to address the issues discussed above. Unlike Auger it does not strive for full sky coverage, but in the northern hemisphere, which is of importance for the small scale clustering issue as it stands and the BL-Lac correlations, it will be ahead of the larger anticipated northern Auger detector.

Like Auger TA harnesses the weather independent 24/7 data taking advantage of the ground array and seeks to control its dependence on air shower simulation through combination with the systematic controls that stereo and/or hybrid observation with a fluorescence detector allows. With respect to the standing AGASA/HiRes controversy over the UHECR spectrum at the highest energies, TA has the advantage that it combines the groups and very techniques that AGASA and HiRes brought to bear in raising the problem: Unlike Auger but like AGASA TA uses scintillation detectors on the ground. These respond mainly to the electromagnetic component of the air showers, allowing to compare the fluorescence and ground array signals without additional ambiguity introduced by the muon component in the showers. In that way TA directly addresses the AGASA/HiRes controversy at the highest energies. Together with the ongoing efforts to verify our assumptions about air fluorescence yield TA should allow us to finally fix the energy scale for the highest energy cosmic rays through the electromagnetic shower component alone. Integrating this information to further isolate the muonic component in the Auger data should be of great benefit for the field.

3. Where do we want to go with TA/TALE?

In [8] HiRes follows the interpretation favored by Berezinsky and co-workers in [9] to extract parameters for the UHECR sources and their redshift evolution in a simple model. The fit to the measured cosmic ray spectrum is informed by an extrapolation of the measured composition [10], using composition to tag galactic versus extragalactic sources. In this kind of fit the aim is to separate out the information the spectrum carries about the physics of the galactic and the extragalactic sources.

To extract this kind of physics information must be the next bold aim of cosmic ray research. As the nature of the messengers forbids astronomy, i.e. direct pointing to individually identifiable sources except maybe at the very highest energies, this kind of inference is the only viable way forward. The confidence with which this strategy can be employed clearly depends on the quality of the data such fits are based on. The main ingredients are spectral shape, composition, and the range over which the fit can be extended. TA and Auger both address the first two of these ingredients. Augmenting TA with TALE addresses the third in a way that allows to connect the dots as it keeps track of the systematic uncertainties as the spectrum is followed through a range of optimized detector components. The

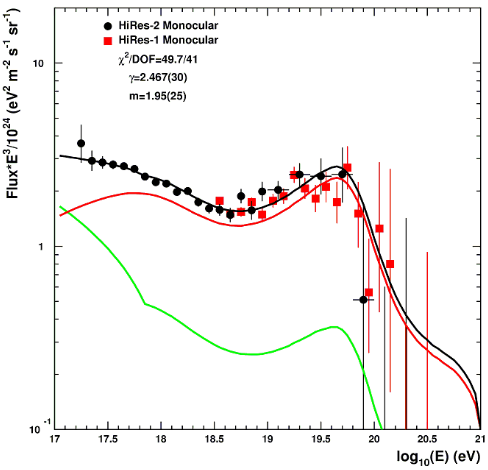

Figure 2. Fit to HiRes monocular data: Green line is Fe (galactic + extragalactic), red line is protons (extragalactic), and black line is the sum Fe+p.

largely Japanese funded TA is fully efficient above 10^{19} eV. Figure 3 shows the proposed augmented layout: The blue outline delineates the ground array boundaries, TA-1, TA-2, and TA-3 mark the three TA fluorescence detector locations. TALE-1 and TALE-2 are additional fluorescence detector sites that will be needed for the TALE expansion.

3.1. Intermediate energy stereo fluorescence pairs

HiRes has shown how stereoscopic viewing from separate detector locations provides excellent control over systematic uncertainties. The threshold for the stereo operation is determined by the site separation. HiRes with a separation of 12.6 km has a threshold of roughly $10^{18.3}$ eV. At a separation of 6 km from the TA-1 and TA-2 fluorescence detector sites respectively, TALE-1 and TALE-2 will each build such a stereo pair with their TA counterpart. 6 km is optimized to explore the ankle region in stereo. A gap in azimuthal coverage along the line of sight avoids instrumenting a region where stereo angles de-

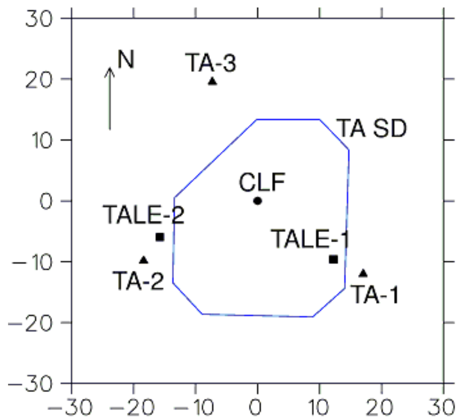

Figure 3. General layout of TA and TALE sites. The blue outline is that of the TA surface array (TA-SD). The scales are in km.

generate to zero. Figure 4 shows the proposed site layouts for TALE-1 and TALE-2. The basic configuration is TALE-2, where we find the relevant azimuth angles covered by two rings of HiRes-type fluorescence telescopes, covering elevation angles between 3 and 31 degrees above the horizon.

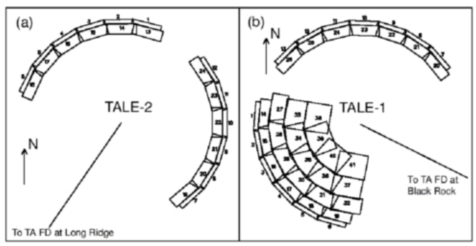

Figure 4. Site layouts for the two TALE sites.

3.2. Low energy hybrid tower

The site layout for TALE-1 shows three more rings above half of the azimuthal coverage at that site. This tower detector covers elevations from 31 through 72 degrees with larger area mirrors to collect more light from the lower energy showers developing higher in the atmosphere. Triggering in this tower detector is often helped by the forward Cherenkov light from the showers. This tower detector moves the TALE energy threshold down to $10^{16.5}$ eV. An infill array for the surface detector under the field of view of this tower arrangement provides a hybrid timing constraint on the monocular reconstruction. At the higher energies the aperture of the tower detector overlaps with the stereo aperture of TA-1 the TALE-1 pair.

4. Conclusions

Figure 5 sums up our expectations for this powerful arrangement of detectors. Overlapping apertures will allow for stringent controls of the systematics between the various detector components. Fluorescence measurements will allow to determine the average elongation rates as our best handle on composition over the whole energy range of the spectrum measurement: from $10^{16.5}$ to 10^{21} eV.

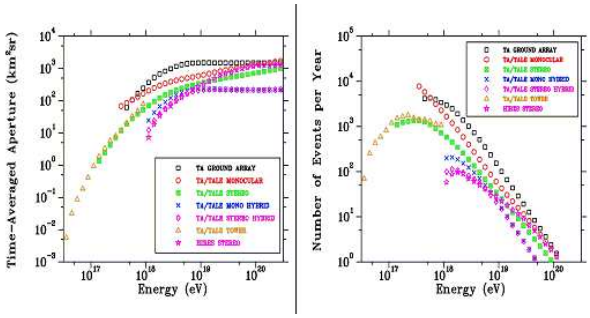

Figure 5. Time averaged aperture and expected yearly event rates for the fully integrated TA/TALE experiment.

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