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The Telescope Array Low Energy Extension

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The Telescope Array Low Energy Extension (TALE) is a series of detectors to be added to the Telescope Array (TA) experiment to increase its aperture at high energies and extend its energy coverage to lower energies. The combination of TA and TALE will be able to measure the spectrum of ultrahigh energy cosmic rays from $10^{16.5}$ to $10^{20.5}$ eV. At each energy in this range, TA/TALE will be able to measure, in a model independent way, the average depth of shower maximum - and hence the composition of cosmic rays. TA/TALE will have excellent pointing resolution for anisotropy studies. The TALE detectors will consist of two fluorescence detectors located 6 km from two TA fluorescence detectors (6 km spacing produces a flat stereo aperture in the region of the ankle), a third fluorescence detector with larger mirrors observing at higher elevation angles (which will observe cosmic rays at lower energies), and an infill array.

1. Introduction

The TA and TALE experiments are being built by a collaboration of research groups from Japan and the United States. The experiment is designed to study the spectrum, composition, and anisotropy of ultrahigh energy cosmic rays, over a wide energy range, with a large aperture, and with good control of systematic uncertainties.

The experiment will be located in Millard County, Utah. It will consist of TA detectors (a ground array with three fluorescence detectors overlooking it), two TALE fluorescence detectors, and an infill array. The TALE fluorescence detectors will be located a distance of 6 km from two of the TA fluorescence detectors. This spacing is optimum for studying the ankle of the cosmic ray spectrum with a nearly flat stereo aperture. All these fluorescence detectors will observe at elevation angles from 3 to 31 degrees above the horizon. Associated with one of the TALE detector sites will be a “tower detector” which will observe at higher elevations, from 31 to 72 degrees. The tower detector will have larger mirrors and be able to detect cosmic rays down to about $10^{16.5}$ eV. A ground array of about 100 scintillation counters, of 400 m spacing, will be deployed in front of the tower detector for hybrid coverage at low energies.

Together the TA and TALE detectors will make an experiment that has good sensitivity over four orders of magnitude in energy, where the same events will seen by different detectors and cross normalization of energy scales will be possible.

Addition of the TALE detectors will enhance the high-energy aperture of TA by about a factor of 2. This aperture will be about 3000 km^2 ster, and the events collected will be about half surface array events and half fluorescence events (where the fluorescence events are seen in mono, stereo, hybrid, or hybrid stereo).

This suite of detectors will study cosmic rays over a very wide energy range, from well below the second knee through the area of the GZK suppression [1].

2. Physics of TA/TALE

The aim of the TA/TALE experiment is to study ALL the physics in the ultrahigh energy region. Measuring the spectrum over four orders of magnitude will allow the experiment to see the three features in this region: the second knee, the ankle, and the GZK suppression. No experiment has seen all three features, and the energy at which the second knee occurs is not known, even relatively, much less absolutely.

The ankle is very important for learning about extragalactic sources of the highest energy cosmic rays. Many physicists now think that the ankle is made by e^+e^- pair production when photons of the cosmic microwave background radiation strike cosmic ray protons. Studies of the detailed shape of the ankle allow one to determine the average spectral index of these sources, and also their average evolution.

At the highest energies, the HiRes experiment has an indication that a simple model of extragalactic sources does not fit the data in the region of $10^{19.4} - 10^{19.7}$ eV: a model with a constant power-law spectrum at the source predicts a higher flux than the data will allow [2]. So the spectrum in the highest energy region, in addition to shedding light on the GZK suppression, may contain information on extragalactic sources' distribution of maximum energies.

In the region of the second knee and below, the light component of cosmic rays are presumably of extragalactic origin. The sources that produce these particles are a long distance away: they reach out to redshifts of two to three. Beyond a redshift of about 1.5 some candidate sources, like QSO's and AGN's, show a break in their evolution [3]. One interpretation of this break is that at earlier times the large black holes that power these sources were just forming. The possibility exists of doing cosmology with cosmic rays of energy $10^{16.5} - 10^{17.6}$ eV; i.e., observing the evolution of cosmic ray sources.

Composition studies are very important, and will continue to be so in the future. The Fly's Eye stereo measurement of mean depth of shower maximum, $< X_{max} >$, and those of HiRes (the HiRes/MIA hybrid experiment and HiRes stereo), are consistent, and show an elongation rate of 93 g/cm^2 at lower energies giving way to one of 55 g/cm^2 at about $10^{17.9}$ eV. The heavier composition giving way to the lighter is considered a sign of the transition from galactic cosmic rays to ones from extragalactic sources. TA/TALE is designed to measure $< X_{max} >$ in hybrid and stereo modes over its entire four decade wide energy range.

At the lowest energies a mix of heavy elements of galactic origin is expected to be seen. The direct observation of $< X_{max} >$ by the fluorescence detectors of TA/TALE is a model-independent measurement. Other experiments will be carrying out model-dependent measurements of the composition in this energy range, e.g., Kascade and Kascade-Grande measuring the electron and muon component of showers. Checking their observations with TA/TALE data will be very important.

In the 10^{17} eV decade the heavy component disappears, and at higher energies a light composition dominates. Observing this transition all in one experiment will be very important. There is growing consensus that the extragalactic cosmic rays should be almost all protons. So the HiRes measurement of $< X_{max} >$ is likely very close to the value for protons (perhaps protons are 10-15 g/cm^2 higher). Confirmation of this by future fluorescence experiments like TA/TALE, and Auger above 10^{19} eV, will be an important step forward.

In the search for the origins of ultrahigh energy cosmic rays, anisotropy studies play an important role. In the northern hemisphere, the AGASA experiment observed clusters of events, and a hint of galactic extended anisotropy, and HiRes data seems to confirm some of these results [4].

HiRes has also seen correlations between arrival directions of events (seen in stereo, over a wide energy range) with BL Lac sources. There are also events that point back to sources seen in TeV gamma ray experiments [5]. The HiRes collaboration plans to collect more data to confirm or reject these correlations. But if true, these correlations would be startling since these are extragalactic sources and one would expect magnetic fields to wash out these correlations at the level of the 0.5 degree angular resolution of HiRes stereo events. It may be that there are regions of extragalactic space with very small magnetic fields - or that some cosmic rays are neutral. The BL Lac correlations are also a northern hemisphere effect since most identified BL Lac sources are in the northern hemisphere.

TA/TALE will have excellent angular resolution. The stereo aperture will be larger than that of HiRes, and about 85% of stereo events will also be seen in hybrid mode, improving the angular resolution from 0.5 to 0.1 degrees. If the BL Lac correlations are confirmed by HiRes then TA/TALE, which will collect the largest number of hybrid stereo events in the world, will be just the experiment to study anisotropy of this kind.

3. TALE Detectors

In 2006, we plan to move the HiRes detectors from the U.S. Army Dugway Proving Ground about 150 km south to Millard County, Utah, to become TA and TALE detectors. Fourteen HiRes mirrors will become one of the TA fluorescence detectors overlooking the ground array.

The remaining 50 mirrors will be redeployed to two locations near the other TA fluorescence detectors to form stereo pairs with the TA detectors. The spacing for stereo will be about 6 km, which is optimized for studies of the ankle region. These detectors will be observing partly in directions away from the TA detectors, and will increase the aperture of TA at high energies by about a factor of 2. The energy range covered by these detectors will be from about $10^{17.5}$ to $10^{20.5}$ eV.

We plan to build a tower detector to extend the coverage to lower energies. This will consist of 15 mirrors that will cover elevation angles from 31 to 72 degrees, and cover about 90 degrees in azimuth. Looking higher in elevation with HiRes mirrors would lower the minimum energy observed to about 10^{17} eV. The tower mirrors will be about 12.6 m^2 in area, three times larger than HiRes mirrors, which will lower the minimum energy to about $10^{16.5}$ eV.

We plan to deploy an infill array of about 110 scintillation counters in front of the tower detector. With about 400 m separation (1/3 of the separation of the TA scintillation counters) they will have good efficiency at $10^{16.5}$ eV. The infill array will be used for hybrid observation with the tower detector, and will improve its energy resolution, its X_{max} resolution, and its pointing resolution. The infill array will reach up in energy to about 10^{18} eV.

Events between $10^{16.5}$ and 10^{18} eV will be collected by the tower detector, TALE fluorescence detector, and infill array. Many will be seen in stereo with one of the TA fluorescence detectors and in hybrid with the main TA ground array. Cross calibration of all of these detectors will be performed using these events. At higher energies, events will be seen monocularly, in stereo, in hybrid, and in hybrid and stereo, between the TA and TALE fluorescence detectors and the TA ground array. Thus cross calibration will be possible throughout the entire energy range of the experiment.

4. Conclusions

The physics of ultrahigh energy cosmic rays in the energy range above $10^{16.5}$ eV is very rich. Three spectral features are present, in contrast to the almost featureless spectrum at lower energies. In addition the galactic - extragalactic transition occurs here.

The composition of the primaries at the lower end of this energy range should be heavy and of galactic origin, then at higher energies make a transition to become light and of extragalactic origin. This will occur just where the TALE detectors are at their optimum efficiency. The highest energy events should continue this light composition.

By making composition-tagged measurements of the spectrum we will be able to study both galactic and extra-galactic sources independently. We will determine the distribution of maximum energies of galactic sources, and how their composition varies. For extragalactic sources we will measure the spectral index at the source, the distribution of end-point energies, and the detailed evolution out to a redshift z=3.

The TA/TALE detector will be very powerful for anisotropy studies. The experiment has a large aperture and excellent pointing accuracy at all energies. The large fraction of events seen in stereo and hybrid modes simultaneously, with pointing accuracies about 0.1 degrees, is an unprecedented advantage of the TA/TALE design. The northern hemisphere sky is a very rich field for anisotropy studies. The possible observation of the first point sources by AGASA and HiRes will be pursued by TA/TALE, and the correlation with BL Lac sources will be investigated.

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