Overview of the Telescope Array Experiment

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***Abstract*. The Telescope Array (TA) Experiment is the largest Ultra-High Energy (UHE) cosmic ray detector in the northern hemisphere. The Telescope Array is a follow up to the High Resolution Fly's Eye (HiRes) and Akeno Giant Air Shower Array (AGASA) experiments. It is located near Delta, Utah, about 200 kilometers southwest of Salt Lake City. The surface detector consists of 507 three square meter scintillator counters distributed in a square grid with 1.2 km spacing. Three fluorescence detector stations (12, 12, and 14 telescopes) sit on the corners of a ∼30 km equilateral triangle overlooking the array of surface detectors. The stations view 108, 108, and 114 degrees in azimuth and 3-31 degrees in elevation. They provide full hybrid coverage with the scintillator array above 10 EeV. The Telescope Array underwent commissioning in 2007 and began routine data collection operations at the beginning of 2008. A low energy extension to TA (TALE) will add a fourth fluorescence site 6 kilometers from the station at Long Ridge. An array of 24 telescopes covering 200 degrees in azimuth will provide stereo observation in the 1-10 EeV decade. A tower detector with four meter diameter mirrors viewing between 31 and 73 degrees in elevation will extend fluorescence and hybrid observations down to 0.03 EeV, in conjunction with an infill array of scintillator counters and muon detectors. An overview of the experiment and its capabilities will be presented.**

***Keywords*: UHECR, second knee, ankle, GZK, Telescope Array, TA, TALE, fluorescence, detector**

I. Introduction

The Telescope Array (TA) experiment is being performed by a collaboration of research groups from the United States, Japan, Korea, and Russia. It is located just west of the town of Delta in the west Utah desert. The center of the array (the Central Laser Facility / CLF) is located at 39.30° Latitude, -112.91° Longitude, and is 1382 m A.S.L. The existing Telescope Array is a hybrid detector currently consisting of a combination of fluorescence telescopes (ala HiRes) and scintillation surface detectors (ala AGASA). It is also instrumented with a variety of systems to control systematic uncertainties. These include monitoring of the relative and absolute calibration, atmospheric monitoring, cloud identification, and so on. The existing detectors are optimized for the observation of cosmic rays with a primary energy $>10^{19}$ eV.

A planned addition to the Telescope Array (TALE) will expand its reach down to $\sim 3\times10^{16}$ eV. The experiment is designed to study the sources of cosmic rays by measuring the characteristics, spectrum, composition, and anisotropy of Ultra High Energy Cosmic Rays (UHECR) over a wide energy range, with a large aperture, good resolution, and with good control of systematic uncertainties. The physics issues, what is the nature of the sources, and how do they accelerate particles to such high energies, form one of the most important questions in physics today.

II. The Telescope Array

Three fluorescence telescope sites currently provide coverage of the air space over the scintillator array. These sites are known as Middle Drum, Black Rock Mesa, and Long Ridge. The Middle Drum site is instrumented with 14 refurbished telescopes from the HiRes-I site of the High Resolution Fly's Eye experiment. [1] The cameras each contain 256 hexangonal Photonis PMTs in a 16×16 array. Each PMT views ∼1° of sky. The telescopes are arranged in a "two ring" geometry with the first ring viewing from 3-17° above horizon and the second ring viewing from 17-31° above horizon. The seven pairs of telescopes view 114° in azimuth. They have 2 m × 2 m mirrors which have 3.75 m^2 of effective area after taking obscuration into account and are instrumented with the same sample and hold electronics which they had for the HiRes experiment. This site provides a direct link back to the HiRes analysis and spectrum - see the paper by C.C.H. Jui *et al.* of this conference.

The Middle Drum site began data standard collection 9/2007. Between 12/16/2007 - 12/07/2008, the site collected 13500 telescope-hours of data. This represents a duty cycle of better than 10%. Of this, approximately 11,000 telescope-hours of data was collected under good weather conditions as reported by the observers.

The each camera at the Middle Drum site is calibrated nightly via a temperature stabilized UV LED which sits at the center of the telescope mirror. The 14 telescopes are housed in a concave building and are arranged so that they all overlook a common point at the focus of the building. The relative calibration of all of the telescopes at the site can be compared directly since they all overlook a verical beam from a single xenon flash lamp. In addition, a Roving Xenon Flasher (RXF) is used to illuminate all cameras periodically. This "standard candle" is known to be stable to better than 2% over the course of a night and is itself calibrated using NIST calibrated hybrid photo-diodes. The Middle Drum site is also instrumented with 30° field of view microwave sensors which measure the sky temperature in a search for clouds.

The Black Rock Mesa and Long Ridge sites are each instrumented with 12 new telescopes. The cameras use a Hamamatsu PMT, but the optics maintain the 1° field of view for the PMTs. [2] The sites again use a "two ring geometry" and have a field of view which is 3-33° above horizon and 108° in azimuth. The telescopes at these sites use a larger, 3 m diameter, multifaceted mirror and the cameras are read out with new FADC electronics. The data is sampled at 40 MHz, but four time bins are summed so that, in the end, 12 bit - 10 MHz samples are stored. (See the papers of H. Tokuno *et al.* and L.M. Scott *et al.* of this conference.)

The Black Rock and Long Ridge sites started standard data collection 6/2007. As of 1/2009, the total observation time is about 860 hours for the Black Rock Mesa site and 760 hours for the Long Ridge site. These sites have a duty cycle of about 8%. As of 1/2009, the Telescope Array has an exposure of about 1/3 of AGASA and 1/15 of HiRes.

The Black Rock and Long Ridge sites are calibrated nightly via built in xenon flashers. In addition, some PMTs in each camera are instrumented with small sources on a small piece of scintillator. (See the paper by Finally, the RXF from the Middle Drum site periodically visits all cameras at all sites so that the calibrations can be cross checked.

The Black Rock Mesa site is also home to a several pieces of equipment to assist with the control of systematic issues associated with understanding of the atmosphere and calibration of the telescopes. The first of these is a steerable monostatic lidar system located in a rotating dome 100 m to the side of the telescope building. The laser is a 4 mJ, 355 nm, energy tripled YAG laser. The receiver is a 10 inch Meade telescope with a PMT at its focal point. (See paper by T. Tomida *et al.* of this conference, also see the paper by M. Chikawa of the Merida ICRC.) [3]

The Black Rock site also has an Infra-Red camera mounted on a computer controlled mount. The calorimetric camera has a field of view of 26° × 20° (slightly larger than the field of view of a fluorescence telescope) and takes photos which are 320 × 236 pixels. The computer steers the IR camera around so that it takes 12 pictures covering the entire Telescope Array each hour. With the camera, it is possible to identify even relatively thin clouds within the experimental aperture. More than 17,000 photos were taken during 164 nights of observation. These are being analyzed (See the paper of M. Chikawa *et al.* of this conference).

A laser facility sits at the center of the three fluorescence telescope sites. The CLF also uses an energy tripled YAG to fire a beam of 355 nm light into the sky. [4] While eventually there will be a steerable beam in addition to a fixed vertical beam, at the moment only the vertical beam exists. The laser fires 40 shots every half hour at a variety of energies. This allows one to both measure the atmospheric transmission parameters (VAOD and horizontal extinction length) as well as to directly compare the reconstruction of the three fluorescence sites.

The scintillator surface array consists of 507 detectors, each 3 m^2 in area. They sit on a 1.2 km square grid and occupy more than 700 sq km. Each sincillator detector has two layers of 1 cm thick scintillator. The light is gathered by wavelength shifting fibers and brought out to a PMT, one for each layer. FADC electronics are used to read out the PMTs. The scintillator detectors are divided into three sub-array which communicate via radios with towers where triggers are formed.

The energy region above 10^{19} eV is well covered by the Telescope Array. The scintillator array plateaus and becomes fully efficient at about 5×10^{18} eV. In addition, the three fluorescence telescopes provide full hybrid coverage of the scintillator array above 10^{19} eV. However, Stage-1 of the Telescope Array was not designed for physics below 10^{19} eV. There is no overlap at all of the three fluorescence telescopes at 10^{18} eV and the ground array efficiency is dropping quickly in the 10^{18} - 10^{19} eV decade. This brings us to TALE.

III. TALE - THE TELESCOPE ARRAY LOW ENERGY EXTENSION

The possibility of post-GZK flux as a signpost to new physics has dominated discussion in the UHE cosmic ray community over the past ∼15 years. The collective interest of the field has resulted in the construction of several experiments specializing in this energy region. However, the HiRes experiment has observed the GZK cutoff [7] , and the Pierre Auger experiment has confirmed the appearance of the cutoff [8]. The observation of the GZK cutoff tells us several important things: first, the maximum energy of extra-galactic sources is higher than the GZK energy; second, at the highest energies cosmic rays are at least 90% protons: if the proton fraction were smaller, the flux above the GZK cutoff would be higher.

While finding specific sources of cosmic rays is clearly important, determining the maximum energy, spectral index, and evolution parameter of the sources is equally significant. The details of the spectral shape, measured with sufficient precision, have the potential of giving us this information. The ankle is a very important feature of the spectrum. It also provides a calibration point for the energy scales of experiments, as was emphasized by V. Berezinsky at the 2007 ICRC in Mexico. [9]

In addition, the second knee has been observed by four previous experiments (Fly's Eye, HiRes-MIA, Akeno, and Yakutsk). [10], [11], [12], [13], [14], [15] The energy scales of these detectors differed by about a factor of two, so the energy at which this spectral break occurs is quite uncertain. However, each data set shows a definite softening (break) in the power law spectral index (that we call the second knee). When the energy scales are adjusted, the four spectra can be made to align simultaneously in normalization (flux) and in the location of the break. Thus, while we know the break in the spectrum exists, its energy is uncertain, except that it occurs somewhere in the mid-10^{17}eV decade. No real progress on understanding this important feature can occur until one single experiment measures all three spectral features of the UHE cosmic ray regime. In order to understand the second knee, one will need to fit the spectrum near it to power laws, and to an energy-loss model. This is a process that will require a good lever arm below as well as above the break.

The Low Energy Extension to the Telesccope Array will give us the ability to make these and other measurements from $\sim 3\times 10^{16}$ eV to the highest energies. To do this, we will build a forth fluorescence telescope station, an infill scintillator array and a graded muon array. At the low energy range fluorescence stations suffer from too great a separation distance. Therefore the first part of the additional fluorescence station adds 24 telescopes at a distance of 6 km from the current Long Ridge fluorescence site. These telescopes will observe from 3-31° in elevation. These will be provided by refurbishing HiRes-II telescopes and hence the mirrors will have the same effective area as the HiRes or Auger Telescopes. This will provide a much flatter stereo aperture than HiRes did in the 10^{18} - 10^{19} eV decade as well as a factor of 10 increase (over HiRes) at 10^{18} eV.

To go much lower in energy, where we expect the elongation rate to change, we will need to look higher in the sky (lower energy showers are shallower and iron showers are even more shallow). We will also need larger mirrors to gather the light from the dimmer showers. Thus, second component of the additional fluorescence station is a tower of 15 telescopes looking from 31-73° in elevation above the 6 km stereo telescopes. By making the mirrors 4.4 m in diameter, enough light will be collected to push the threshold down to $\sim 10^{16.5}$ eV. Figure 1 shows the layout of the TA and TALE detectors and their apertures as a function of energy.

Below 10^{17} eV, the stereo overlap with the main Long Ridge fluorescence station is to small in aperture to do much but validate Monte Carlo resolutions. The tower can operate in monocular mode, but it would have a limited Xmax resolution of about 50 gm/cm^2. more information is needed.

To get hybrid detection at these lower energies, we will place 111 additional scintillator array counters at 400 m spacing overlapping with the main array. This will make a 4 km $\times$ 4 km infill array. See Figure 2 One possibility it to reuse the AGASA scintillators for this infill array.

By adding a graded muon array of 25 detectors, 3 m below the infill array, TALE can measure the electron to muon ratio and get a measurement of the compostion which is orthogonal to the Xmax measurement. In this way, we can also study the cosmic ray composition over the full energy range. This will enable the Telescope Array to determine where the galactic (heavy) flux gives way to the extra-galactic (light) flux.

IV. Conclusion

The Telescope Array (Stage-1) has been up and collecting data for more than a year now. It will make excellent measurements in the northern hemisphere above 10^{19} eV. By adding TALE, we will bring together four different detector systems with overlapping energy ranges to give continuous coverage of cosmic rays from $10^{16.5}$ eV to the highest energies. TA/TALE will be able to study all three spectral features in the UHECR regime in addition to measureing the composition over the full range.

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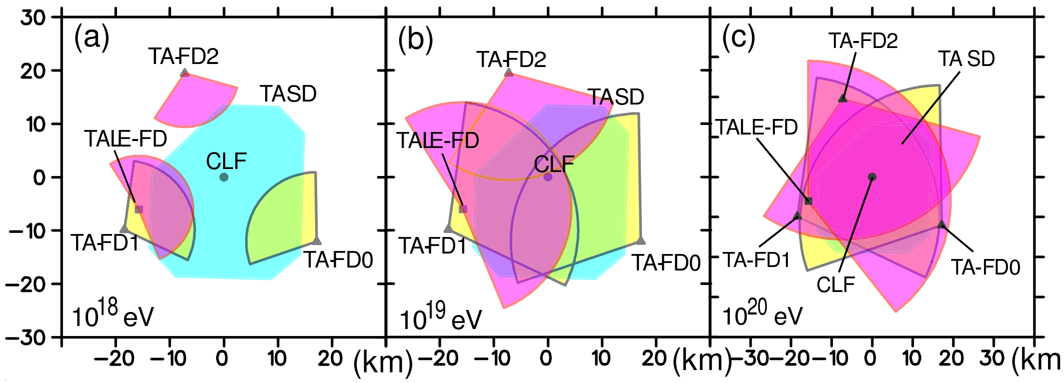

Fig. 1. Maps showing the layout of the TA and TALE detectors, and illustrations of combined TA/TALE fluorescence apertures at (a)10^{18} eV, (b) 10^{19} eV, and (c) 10^{20} eV. The circle at the origin of the coordinates marks the central laser facility (CLF). The scale shown is in units of kilometers. The blue octagon shows the perimeter of the surface array (SD). The TA fluorescence sites (TA-0, TA-1, and TA-2) are shown with triangles, and the TALE site is represented by a square. The apertures of the TA and TALE fluorescence detectors are indicated as pie wedges.

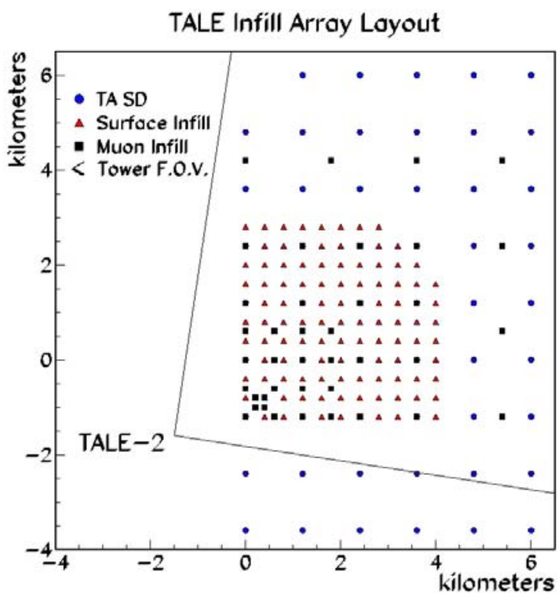

Fig. 2. Maps showing the layout of the TA and TALE detectors, and illustrations of combined TA/TALE fluorescence apertures at (a)10^{18} eV, (b) 10^{19} eV, and (c) 10^{20} eV. The circle at the origin of the coordinates marks the central laser facility (CLF). The scale shown is in units of kilometers. The blue octagon shows the perimeter of the surface array (SD). The TA fluorescence sites (TA-0, TA-1, and TA-2) are shown with triangles, and the TALE site is represented by a square. The apertures of the TA and TALE fluorescence detectors are indicated as pie wedges.

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