Detectors of the Telescope Array Experiment

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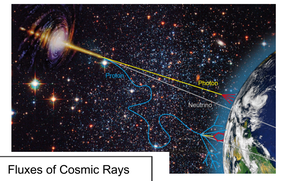
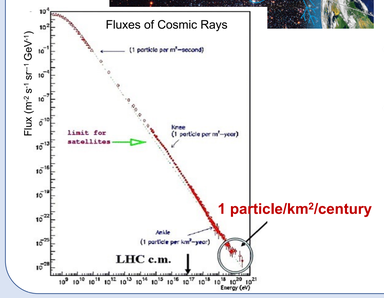
The Telescope Array (TA) experiment, located near Delta, Utah, USA, is the largest ultra-high energy cosmic ray (UHECR) observatory in the northern hemisphere. When a UHECR primary particle arrives at the Earth, it collides with the atmosphere and produces a cascade of secondary particles known as an extensive air shower (EAS). The Telescope Array is designed to observe the EAS using a hybrid of techniques: fluorescence detectors (FDs) and surface detectors (SDs). The FDs measure the nitrogen fluorescence light emitted when the secondary particles excite the gas of the atmosphere as they pass through it. They utilize telescopes consisting of large area mirrors and photo-multiplier tube cameras. Meanwhile, the SDs use two-layer plastic scintillators to sample the density of charged particles in the showers when it reaches the Earth's surface. Using data from both the FDs and SDs, we explore the nature and origin of UHECRs by investigating the energy spectrum, mass composition, and arrival direction distribution. In this presentation, we describe the design and technical features as well as some of the measurements of the Telescope Array detectors.

Introduction

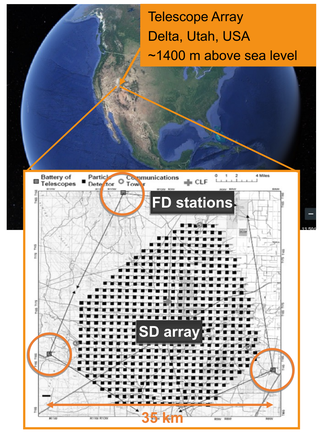
Ultra-high energy Cosmic Rays





- Cosmic rays (CRs): Energetic particles that impinge on Earth's atmosphere from outer space
- Ultra-high energy cosmic rays (UHECRs): Cosmic rays with energies greater than 10^{18} eV
- Overall, the flux of CRs appears to follow a single power law ~ E^{-3}.
- In the ultra-high-energy regime, direct detection is not feasible due to the extremely low flux
  - → Indirect observation is necessary!
  - → A gigantic observation facility is essential to gather sufficient data

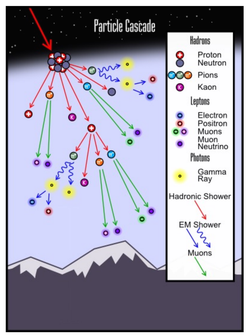
Telescope Array Experiment



- The largest cosmic ray observatory in the northern hemisphere, deployed near Delta, Utah.
- Designed to detect extensive air showers (EAS) induced by a primary UHECR colliding with the atmosphere using hybrid techniques:
  - fluorescence detectors (FDs)
  - surface detectors (SDs)
- Using data from both sets of detectors, we explore the nature and origin of UHECRs by investigating
  - Energy spectrum
  - Mass composition
  - Arrival direction distribution

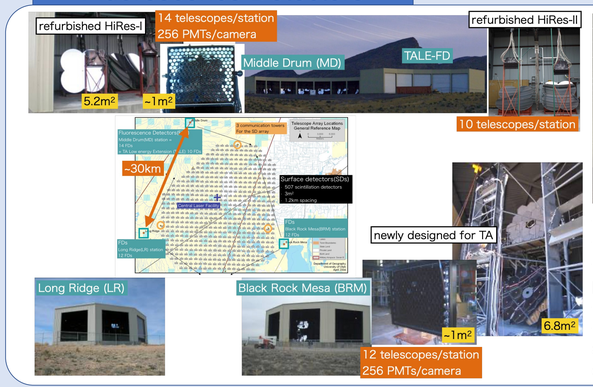
Observation of UHECRs

Extensive Air Shower



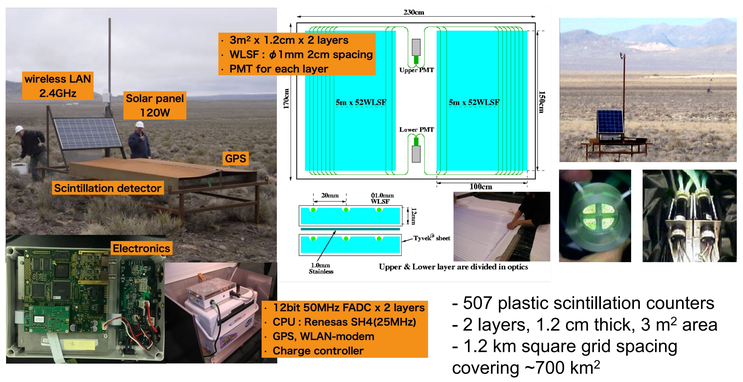
- Extensive Air Shower (EAS):
  A cascade of millions of subatomic particles initiated when a single UHECR collides with a nucleus in the atmosphere
- Fluorescence detectors (FDs):
  - Telescopes observe nitrogen fluorescence lights in the atmosphere emitted by when charged particles pass through the atmosphere
  - clear, moonless nights: ~10% on-time
  - Measure the longitudinal development of the EAS
- Surface detectors (SDs):
  - Scintillators sample the density of charged particles in the shower when it reaches the Earth's surface
  - ~100% on-time
  - Measure the lateral footprint of the EAS

Fluorescence Detectors



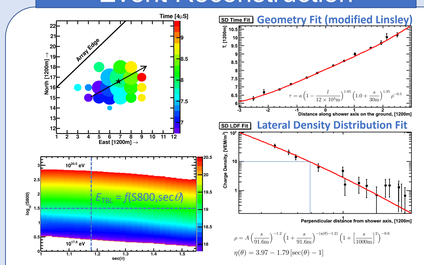
- 3 stations
- 12–14 telescopes
- 256 hexagonal PMTs per camera
- 3˚–31˚ elevation
- Look over the SD array for hybrid observation

Surface Detectors

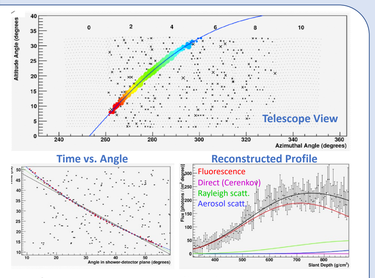


- 507 plastic scintillation counters
- 2 layers, 1.2 cm thick, 3 m² area
- 1.2 km square grid spacing covering ~700 km²

Event Reconstruction



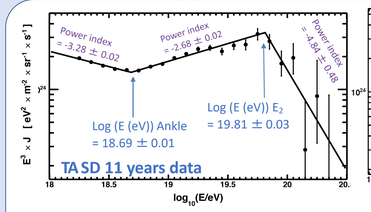
- Use counter location and timing to locate shower core and arrival direction
- Fit counter signal size to find lateral distribution
- Signal size at 800 m, S800, is the energy indicator
- Use reconstructed S800 and zenith angle to look up energy (from CORSIKA-produced table)
- Hybrid fluorescence provides an energy scale:
  $E_{final} = E_{TBL}/1.27$

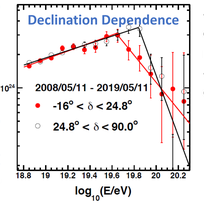


- In fluorescence, we see the shower sweep across the mirror
- Reconstruct Shower-Detector Plane
- Fit time-vs-angle to get geometry (For hybrid, add in SD times, giving much greater lever arm for fit)
- Reconstruct the size of the shower vs. depth – mass composition

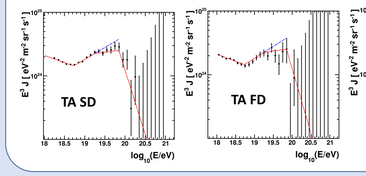
Recent Results from Telescope Array

Energy Spectrum



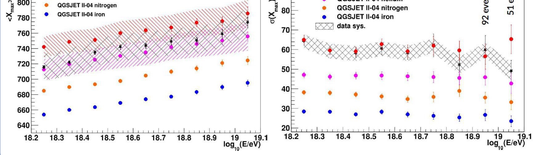


- Spectral shape is indicative of collisions of the UHECR en route to us at Earth
- Differences in the cutoff energies of energy spectra
  - log(E/eV) = **19.64 ±0.04** for lower dec. band (-16°–24.8°)
  - log(E/eV) = **19.84 ±0.02** for higher dec. band (24.8°–90°)
  - The global significance of the difference is estimated to be **4.3σ**.



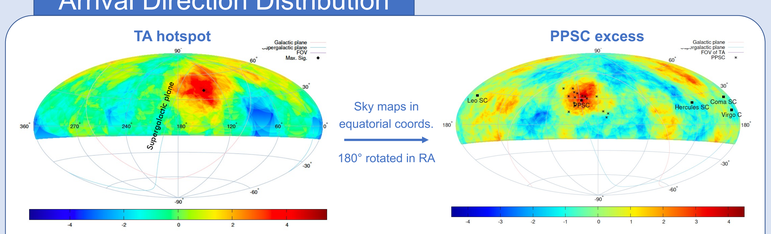
- **New feature** (Hardening, Instep) in 10^{19}–$10^{19.5}$ eV range
- Combining TA SD, TA FD, and HiRes FD data, we observe the Instep feature in the northern hemisphere at **$10^{19.25\pm0.03}$ eV** with a **5.3σ** significance.

Mass Composition



- Energy Range: $10^{18.2}$–$10^{19.1}$ eV
- 3560 events after the quality cuts
- Systematic uncertainty of <Xmax>: ± 17 g/cm2
- QGSjetII-04 interaction model was compared with the data
  → agreement with the light composition
- More events are needed to study the highest energies

Arrival Direction Distribution



- 179 events with E > 5.7×10^{19} eV (12-year SD data)
- Maximum local Li-Ma sig.: 5.1σ at (144.0°, 40.5°)
  Observed: 40 events
  Expected from iso.: 14.6 events
  } ~170% excess
- **Post-trial probability:**
  $P(S_{MC} > 5.1\sigma) = 6.8\times10^{-4}$ → 3.2σ

- 864 events with E ≥ $10^{19.4}$ eV (11-year SD data)
- Maximum local Li-Ma sig.: 4.4σ at (17.4°, 36.0°)
  Observed: 85 events
  Expected from iso.: 49.5 events
  } ~72% excess
- **Post-trial probability:**
  $P(S_{MC}\geq4.4\sigma)\&(\theta_{MC}\leq8.6°)) = 1.6\times10^{-4}$ → 3.6σ

Summary

- **Energy Spectrum**
  Find a significant difference in the spectra above and below ~25˚ in declination
  Observe the "instep" feature
- **Mass Composition**: Appears light and steady for E>10^{18} eV
- **Arrival Direction Distribution**
  Hotspot persists, but significance does not increase very quickly
  New significant excess at a slightly lower energy in conjunction with the Perseus-Pisces supercluster
- Need more data to improve statistics, especially for anisotropy and mass composition measurement
- Plan to complete the extension of the Telescope Array, the TA×4 project, and take more data!!