Telescope Array Experiment

BK Shin on behalf TA collaboration

Osaka City University

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• Introduce of Telescope Array Experiment.
  • Fluorescence Detector, Surface detector Array
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Cosmic Rays

Air Shower
E > 10^{15} eV

Ultra High Energy CR
E > 10^{18} eV

Huge Air Shower Observatory

1 Particle/km^2 Century

Fluorescence

Number of Particles

Air Shower: CR interaction with air

Cosmic Ray Spectra of Various Experiments

BK Shin, Osaka City Univ.  CHEF2017, Lyon, France
Overview of TA Experiment

- Physics goal: Research for UHECR
  - Precise Measurement: Energy spectrum, Mass composition, Anisotropy
  - International collaboration: 5 countries, Japan, USA, Korea, Russia, Belgium
- Hybrid Observatory: 3 FD stations, an array with 507 SDs to cover 700 km² Aperture
- Site: Utah, USA
- Operated from 2008
Fluorescence Detectors (FDs)

The TA has 3 stations of FD
AS Longitudinal property
Operation in Moonless night: 12% of duty

A PMT with a UV filter

A 16 × 16 PMT Camera

A Telescope: Camera & mirror

12 (BR, LR) or 14 (MD) Telescopes in a station
1 station cover 3°~33° in elev, 108° in azi

A Station
Surface Detector (SD) Array

507 of SDs with 1.2 km spacing.
AS Lateral property on the ground.
Environment independent: Operation (Full time).

Consists PMT & Scintillation
Calibration Facilities
**Calib: Laser Facilities**

**CLF:** Position at centre position in TA site
- Measurement of air transmittance.
- Cross calibration between stations
- 2 LIDARs: Measurement of air density

**LIDAR Laser**
- 355nm ～4 mJ

**CLFLaser**
- 355 nm 2~4mJ
- Scatter photons => Air transmittance

**LIDAR@BRM**
- Back Scatter
- => Air density

**CLF**
- Observe backscatter photon

**LIDAR@CLF**
- Telescope with PMT

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*Calibration: Laser Facilities*

- Laser transmittance measurement
- Cross calibration between stations
- 2 LIDARs for air density measurement

*Images: Laser equipment setup and calibration areas.*

*Source:* BK Shin, Osaka City Univ. | CHEF2017, Lyon, France
Calib: Electron Light Source

Energy calibration using electron linear accelerator
Developed from KEK.

- Energy: 40 MeV/e-
- Charge: up to 180 pC
- 0.5 Hz shooting

Preliminary result

\[ \text{DATA/MC} = \sim 1.2 \]
ELS Applications

Detector R&D group test/calibrate their detector with ELS
- 4 of Radio type UHECR detector
- 2 FD type

EUSO-TA, FAST Telescope can be seen ELS beam.

Scatter Radiowave

Askaryan wave Detector

Askaryan effect in ice
Analysis & Result
Observation Analysis

Longitudinal Property (FD)

Higher accuracy Small statistics

G-H Formula

Energy X_{max}

Cross Check

Lateral Property (SD)

Less accuracy Higher statistics

LDF

Energy

X_{max} : Air Depth of maximum N particle => Composition

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$X_{\text{max}}$: Composition Study

E$<10^{19.6}$: Tendency of composition is close to proton
Agreement between results from data
Anisotropy

Event $E > 10^{19.7}$ eV


New 2-year data (37 events) — Updated

Max significance $5.1\sigma$ ($N_{SIG} = 24$, $N_{BG} = 6.88$) for 7 years

Centered at $R.A = 148.4^\circ$, $Dec. = 44.5^\circ$ (shifted from SGP by $17^\circ$)

Global Excess Chance Probability: $3.7 \times 10^{-4}$ : $3.4\sigma$ (~ same as first 5 years)

What is property energy spectrum and composition?

UHECR source ?
Ursa ~30 Mpc
TA×4 Project

Target > $10^{19}$ eV
Aperture 700 km² → 3000 km²

500 SDs
-2.1 km spacing
-First stage 173 SDs were prepared
Start to deploy from next winter

2 FD stations:
12 telescopes
North (MD) Station under construction.
TA Branches

• TALE: Lower Energy Extension.
  • Additional SD: 400m, 800m, 1200m spacing grid
  • A station of FD Looking 30~60°
  • $E > 10^{16} \text{eV}$

• TARA: Radio antenna array
  • Radio echo from UHECR

• NICHE: Cherenkov Detector Array
  • Cherenkov detector: 70m, 100m, 200m spacing grid
  • $E > 10^{15} \text{eV}$
Summary

• Telescope Array Experiments
  • UHECR: energy, composition, anisotropy
  • 3 stations of FD, an Array with 507 SDs

• Result:
  • Composition by Xmax: near proton (E<10^{19.6} eV)
  • Spectrum: cut off E~10^{19.7} eV
  • Anisotropy: ~5 sigma near Ursa cluster evidence of UHECR source (E>10^{19.7} eV)

• TA×4 = Extension of Aperture 700 km^2 -> 3000 km^2
Backup
**Observation & Axis Analysis**

**FD Observation**

**FD Shower Geometry Analysis**

- **Monocular: Timing**
  - Res: ~10°
  - Resolution ~10°

- **Stereo (2more FDs): intersection**
  - Res: ~10°
  - Resolution ~1°

**SD Observation**

**Hybrid: Timing with SD Geometry**

- Resolution: 2°
- Resolution 1°
Analysis

FD/Hybrid Shower profile Recon.
G-H Formula

SD Energy estimation

Shower Profile

- Signal
- MC Fit
- Scin
- Rayl
- Aero
- Cher

Fluorescence Contribution

Cherenkov Contribution

Shower Profile

Signal (pe) vs. Slant Depth (g/cm²)

- Signal
- MC Fit
- Scin
- Rayl
- Aero
- Cher

Fluorescence Contribution

Cherenkov Contribution

$X_{\text{max}} \Rightarrow$ Composition
$N_{\text{max}} \Rightarrow$ Energy
Shower axis $\Rightarrow$ Arrival direction

$\log_{10}(E) = 20.12$
$X_{\text{Max}} = 764.10$
$N_{\text{Max}} = 8.44e+10$

Lateral Distribution Function

VEM / m² vs. Lateral distance [m]
TA Low energy Extension

- $E > 10^{16}\text{eV}$
- 1 station of FD: 30° ~ and 60° elev.
- 400m, 800m, 1.2 km grid array

Same Type of TA SD and FD
NICHE: Cherenkov Detection.
Energy: $>10^{15.5}$ eV
Sensitivity to composition

Now under construction.
TARA

TA Radio Array
- Radio echo from air shower
- Low cost detector Array
Log-periodic antenna

TX
RX

LR
BRM

-50 km

TX
RX

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Energy Limit of UHECR

Greisen, Zatsepin and Kuzmin suggested the limit of CR energy by photo-meson process (1966)

Hillas suggested energy limit by acceleration by magnet of astronomic objects (1984)

Bethe-Heitler process
\[ P + \gamma \rightarrow P + 2e \]

\[ E_{\text{max}} = \gamma e Z B R \]

UHECR >10^{20} eV: Unknown Object and Placed in 100Mpc
Origin of Source??, Composition of UHECR??
Design of the TAx4 SD array

- E > 57 EeV: reconstruction efficiency > 95%
- Angular resolution: 2.2°
- Energy resolution: ~25%
Extensive Air Shower

EAS: Primary Cosmic-Rays interaction with air molecule

Gaisser-Hillas (G-H) formula

\[ N(X) = N_{\text{max}} \left( \frac{X - X_0}{X_{\text{max}} - X_0} \right)^\frac{X_{\text{max}} - X_0}{\lambda} \exp \left( \frac{X_{\text{max}} - X}{\lambda} \right) \]

- \( N_{\text{max}} \): Energy estimation
- \( X_{\text{max}} \): composition estimation

Observation methods
- Ground Array: Lateral properties
- Fluorescence telescope: Longitudinal properties