Recent results and status of the Telescope Array Experiment

Eiji Kido for the Telescope Array Collaboration

Riken
Outline

• The Telescope Array (TA) Experiment
  • Detectors
  • Energy Spectrum
  • Anisotropy
  • Composition

• Extension of the TA Experiment
  • The TAx4 Experiment

• Summary
Telescope Array collaboration

147 collaborators from 36 institutes in 6 countries


(1) High Energy Astrophysics Institute and Department of Physics and Astronomy, University of Utah, Salt Lake City, Utah, USA, (2) The Graduate School of Science and Engineering, Saitama University, Saitama, Saitama, Japan, (3) Graduate School of Science and Engineering, Tokyo Institute of Technology, Meguro, Tokyo, Japan, (4) Department of Physics and Research Institute of Natural Science, Hanyang University, Seongdong-gu, Seoul, Korea, (5) Department of Physics, Tokyo University of Science, Noda, Chiba, Japan, (6) Department of Physics, Kinki University, Higashi-Osaka, Osaka, Japan, (7) Service de Physique Théorique, Université Libre de Bruxelles, Bruxelles, Belgium, (8) The Hakuai Center for Advanced Research and Graduate School of Science, Kyoto University, Kitashirakawa-Oiwakecho, Sakyo-ku, Kyoto, Japan, (9) Graduate School of Science, Osaka City University, Osaka, Japan, (10) Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba, Japan, (11) Kavli Institute for the Physics and Mathematics of the Universe (WPI), Todai Institutes for Advanced Study, University of Tokyo, Tokyo, Chiba, Japan, (12) Information Engineering School of Science and Technology, Shinshu University, Nagano, Nagano, Japan, (13) Faculty of Engineering, Kanagawa University, Yokohama, Kanagawa, Japan, (14) Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Kofu, Yamanashi, Japan, (15) Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo, Japan, (16) Academic Assembly School of Science and Technology Institute of Engineering, Shinshu University, Nagano, Nagano, Japan, (17) Astrophysical Big Bang Laboratory, RIKEN, Wako, Saitama, Japan, (18) Department of Physics, Sungkyunkwan University, Jang-an-gu, Suwon, Korea, (19) Department of Physics, Tokyo City University, Setagaya-ku, Tokyo, Japan, (20) Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia, (21) Advanced Research Institute for Science and Engineering, Waseda University, Shinjuku-ku, Tokyo, Japan, (22) Department of Engineering Science, Faculty of Engineering, Osaka Electro-Communication University, Neyagawa-shi, Osaka, Japan, (23) Department of Physics, China University of Science and Technology, Beijing, China, (24) Department of Physics, School of Natural Sciences, Ulsan National Institute of Science and Technology, Ulsan, Korea, (25) Department of Physics, Yonsei University, Seodaemun-gu, Seoul, Korea, (26) Faculty of Science, Kochi University, Kochi, Kochi, Japan, (27) National Research Institute of Theoretical and Experimental Physics, Osaka City University, Osaka, Osaka, Japan, (28) Department of Physical Sciences, Ritsumeikan University, Kusatsu, Shiga, Japan, (29) Sternberg Astronomical Institute, Moscow M.V. Lomonosov State University, Moscow, Russia, (30) Department of Physics and Astronomy, Rutgers University - The State University of New Jersey, Piscataway, New Jersey, USA, (31) Graduate School of Information Sciences, Hiroshima City University, Hiroshima, Hiroshima, Japan, (32) Institute of Particle and Nuclear Studies, KEK, Tsukuba, Ibaraki, Japan, (33) National Institute of Radiological Science, Chiba, Chiba, Japan, (34) CIAO, Institute of Physics, Czech Academy of Sciences, Prague, Czech Republic, (35) Department of Physics and Institute for the Early Universe, Ewha Womans University, Seodaemun-gu, Seoul, Korea, (36) Department of Physics, Ehime University, Matsuyama, Ehime, Japan)
The TA Detectors are a hybrid observation system consisting of Surface Detectors (SD) and Fluorescence Detectors (FD). The detectors are located in Utah, USA, at Latitude 39.30° N and Longitude 112.91° W, at an altitude of 1382 m. The system covers an area of approximately 700 km² with 1.2 km spacing between detectors. The TA Detectors include 507 Surface Detectors and 12 telescopes, making it the largest cosmic-ray observatory in the northern hemisphere. The full operation was initiated in May 2008.
TALE (TA Low-energy Extension) Detectors

TALE FD was installed in Nov. 2012

- Operation since Sep. 2013
- Hybrid trigger: Sep. 2018

400m spacing 40 SDs

600m spacing 40 SDs
Event Reconstructions with SDs

- Timing fit → Shower Geometry
- Lateral distribution fit → $S(800)$ → Energy from MC → rescale to calorimetrically measured $E_{FD}$ using SD and FD hybrid events

$S(800)$: energy depositions which are converted in VEM unit.
Event reconstruction

Stereo

Line intersection of shower detector planes

Hybrid

Shower axis

Comparing with MC → Xmax
Integration of signals → 1ry E
Energy Spectrum with TA SD

TA SD 11 years data

Fit to broken power law

Log (E (eV)) Ankle

Power index

$= -3.28 \pm 0.02$

Log (E (eV)) $E_2$

Power index

$= -2.68 \pm 0.02$

Power index

$= -4.84 \pm 0.48$

Log (E (eV)) Ankle

$= 18.69 \pm 0.01$

Log (E (eV)) $E_2$

$= 19.81 \pm 0.03$

$E^3 \times J \ [eV^2 \times m^{-2} \times sr^{-1} \times s^{-1}]$

Log$_{10}$ (E/eV)

$[18, 18.5, 19, 19.5, 20, 20.5]$
Combined Energy Spectrum with TALE FD Mono

Combined TA spectrum using 22 months TALE FD monocular data + 11 years TA SD data
Declination Dependence of Energy Spectrum

D. Ivanov, ICRC2019

- Difference of the cutoff energies of energy spectra
  - $\log(E/\text{eV}) = 19.64 \pm 0.04$ for lower dec. band ($-16^\circ$ - $24.8^\circ$)
  - $\log(E/\text{eV}) = 19.84 \pm 0.02$ for higher dec. band ($24.8^\circ$ - $90^\circ$)
- The global significance of the difference was estimated to be $4.3\sigma$
Hotspot: $E > 57$ EeV

Original hotspot reported in 2014, from 5 years of data
$E > 57$ EeV (Observed 72 events)
20° over-sampling circle
19 events fall in “Hotspot” centered at $(146.7°, 43.2°)$
(Expected $= 4.5$ events)
local significance $5.1\sigma$, post trial significance $3.4\sigma$

$E > 57$ EeV, in total 168 events
38 events fall in Hotspot ($\alpha=144.3°$, $\delta=40.3°$, 25° radius, 22° from SGP), expected=14.2 events
local significance $= 5.1 \sigma$, chance probability $\rightarrow 2.9 \sigma$
25° over-sampling radius shows the highest local significance (scanned 15° to 35° with 5° step)
The cumulative events inside the hotspot circle (25°-radius circle) defined by the 11-year. The increase rate of the events inside the hotspot circle:

**Consistent with the linear increase within ~1σ**
Energy spectrum anisotropy $E > 10^{19.2} \text{eV}$

@7° from hotspot, $\sim30$ deg. circle

post trial significance: $3.7\sigma$

$K.\ Kawata,\ ICRC2019$

Significance map from isotropy expectation

Energy Range: $10^{18.2}$ eV – $10^{19.1}$ eV
3560 events after the quality cuts
Systematic uncertainty of $<X_{\text{max}}>$: $\pm 17$ g/cm$^2$
QGSjetII-04 interaction model was compared with the data → agreement with light composition
More events are needed to study highest energies
Composition Analysis with TALE FD Mono Xmax

T. Abu-Zayyad, ICRC2019

- Energy Range: $10^{15.3}$ eV – $10^{18.3}$ eV
- Break point log (E/eV) = 17.23 ± 0.05
Photon Search

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M. Kuznetsov, ICRC2019

- **Left**: updated upper limit on GZK photons with 9 years TA SD data
  - Multivariable classifier is built on 16 reconstructed parameters
- **Right**: upper limit for directions in the field of view

\[ E > 1 \text{ EeV} \]
To study more about the highest energies and examine the implications obtained by TA

**500 new SDs with 2.08 km spacing**

E > 57 EeV:

- Reconstruction efficiency > 95%
- Angular resolution: 2.2°
- Energy resolution: ~25%

and TA SDs cover

**4 × TA SD detection area (~3000 km²)**

**2 new Fluorescence Detector (FD) stations**  
(4+8 HiRes Telescopes)
Deployment of Assembled SDs

Helicopter for the transportation of SDs
More than half of SDs (257 SDs) were deployed on 19 Feb. – 12 Mar. 2019.

Locations of SDs were decided to optimize hybrid events above 10 EeV and consider practical conditions of wireless communications.
Largest number of SDs were fired in this event

**DAQ of each sub-array was started** from the end of Apr. 2019 when the sub-array is ready.

Cosmic ray events are being collected.

$\sim 4 \times$ TA SD equivalent cosmic ray events are collected when the full operation is started.
Construction of FD Station

16th Feb. 2018 First light at the north FD station
22nd Oct. 2019 First light at the south FD station
Stable operation of north FD station was started from 8th June 2018.
Data analysis is ongoing.
Xmax: $\sim 3 \times$ TA SDFD equivalent events are collected at the highest energies when the full operation is started.
Summary

- **Energy Spectrum**
  - Combined spectrum of TA SD with TALE FD mono
  - Energy spectrum with $\log (E/eV) > 15.3$ was obtained.
  - Declination dependence of TA SD energy spectrum was implicated in $4.3\sigma$

- **Anisotropy**
  - Hotspot ($> 57 \text{ EeV}$): $\sim 3 \sigma$ global significance was obtained from 11 years TA SD data

- **Composition**
  - TA SD and FD hybrid: consistent with light composition with $\log (E/eV) > 18.2$ and $\log (E/eV) < 19.1$
  - TALE FD mono: preliminary $X_{\text{max}}$ results were obtained with $\log (E/eV) > 15.3$

- **Photon limit** was updated with 9 years TA SD data and the dependence of the arrival directions was also obtained.

- Implications on anisotropy were obtained by the TA experiment.

  $\rightarrow$ TAx4 experiment is **in operation**

- **TAx4 detectors**:
  - 500 new SDs with $2.08 \text{ km}$ spacing + TA SDs $\rightarrow$ Coverage of $4 \times \text{TA SDs} \sim 3000 \text{ km}^2$
  - 2 new Fluorescence Detector (FD) stations (4+8 Telescopes)

- More than half of TAx4 SDs were deployed, and 2 TAx4 FD stations were constructed.

- Data acquisition was started. SD: from **Apr. 2019**, FD: from **Jun. 2018**. Cosmic ray events are being collected.

- **Prospects**
  - $\sim 4 \times \text{TA SD}$ equivalent cosmic ray events with $E > 57 \text{ EeV}$ will be collected when the full operation is started.
  - $\sim 3 \times \text{TA SDFD}$ equivalent hybrid events will be collected especially for $X_{\text{max}}$ at the highest energies when the full operation is started.
Backup