The FAST Project
-Next Generation UHECR Observatory-

Fluorescence detector Array of Single-pixel Telescopes
http://www.fast-project.org

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Highlights on UHECR

Spectrum discrepancy at suppression

No anisotropy seen


Intermediate composition or models, no information above $10^{19.7}$ eV


Hotspot/Warmpspot

K. Kawata et al, ICRC 2015
Highlights on UHE Photon/Neutrino

Top-down model disfavored, close to GZK photon/neutrino

Photon limits 95% C.L.

Neutrino single flavour limits (90% C.L.)

Cosmogenic ν models
- p, Fermi-LAT best-fit (Ahlers '10)
- p, Fermi-LAT 99% CL band (Ahlers '10)
- p, FRII & SFR (Kampert '12)
- Fe, FRII & SFR (Kampert '12)
- p or mixed, SFR & GRB (Kotera '10)
- Waxman-Bahcall '01
On-going Upgrade: TA×4

Detailed measurement on Hotspot
Enlarge the fourfold coverage to TA×4 = Auger, 3,000 km²

Expected in 2020 (Simulation)

Transport
- First 12 TAx4 SDs have shipped from Japan on last Monday
- Expected arrival to TA site is middle of Mar.
- Unpack and final assembly to the frame.
- If condition is fine, remaining 90 SDs will be shipped quickly.

~200 kg /1SD
~2400 kg /stack
Stackable flame up to 10-12 SDs

On-going Upgrade: AugerPrime

Install 4 m² Scintillator to measure the mass composition by SD.

- Improve electromagnetic/muon separation of SD to measure the mass composition above $10^{19.7}$ eV.
- Boost in statistics by a factor of ~ 10 compared to FD $X_{\text{max}}$ analysis.
- Small PMT in the water tank, FD operation during moon night.
- Origin of flux suppression, proton contribution above $10^{19.7}$ eV, new particle physics beyond the human-made accelerator.
JEM-EUSO
Extreme Universe Space Observatory onboard Japanese Experiment Module

Pioneer detection of UHECRs from space

A. Olinto, ICRC2015
Physics Goal and Future Prospects

Origin and Nature of Ultra-high Energy Cosmic Rays and Particle Interactions at the Highest Energies

Exposure and Full Sky Coverage
TA×4 + Auger
JEM-EUSO: pioneer detection from space and sizable increase of exposure

5 - 10 years

Detector R&D
Radio, SiPM, Low-cost Detectors

“Precision” Measurements
AugerPrime
Low energy enhancement (Auger infill+HEAT+AMIGA, TALE+TA-muon+NICHE)

10 - 20 years

Next Generation Observatories
In space (100×exposure): EUSO-NEXT
Ground (10×exposure with high quality events): Giant Ground Array, FAST
Target: $> 10^{19.5}$ eV, ultra-high energy cosmic rays (UHECR) and neutral particles

Huge target volume $\Rightarrow$ Fluorescence detector array

- Fine pixelated camera
- Too expensive to cover a huge area
- Single or few pixels and smaller optics
- Low-cost and simplified/optimized FD

Segmented mirror telescope

Variable angles of elevation – steps.

Joint Laboratory of Optics Olomouc – March 2014
Fluorescence detector Array of Single-pixel Telescopes

- Each telescope: 4 PMTs, $30^\circ \times 30^\circ$ field of view (FoV).
- Reference design: 1 m$^2$ aperture, $15^\circ \times 15^\circ$ FoV per PMT
- Each station: 12 telescopes, 48 PMTs, $30^\circ \times 360^\circ$ FoV.
- Deploy on a triangle grid with 20 km spacing, like “Surface Detector Array”.
- If 500 stations are installed, a ground coverage is $\sim 150,000$ km$^2$.
- Geometry: Radio, SD, coincidence of three stations being investigated.
Conventional operation of FD under 10~15% duty cycle

Target: $>10^{19.5}$ eV

Observation in moon night to achieve 25% duty cycle,

Target: $>10^{19.8}$ eV = Super GZK events (Hotspot/Warmspot)

Test operation in moon night with Auger FD (R. Smida)

Ground area of 150,000 km$^2$ with 25% duty cycle = 37,500 km$^2$

(12×Auger, cost ~50 MUSD)
GZK Recovery

First detection of UHE photons and neutrinos

V. Berezinsky et al., (2001)

Physics Target

UHECR Anisotropy

with ~10x statistics

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First detection of UHE photons and neutrinos

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V. Berezinsky et al., (2001)
Window of Opportunity at EUSO-TA

- Temporally use the EUSO-TA optics at the TA site.
  - Two Fresnel lenses (+ 1 UV acrylic plate in front for protection)
  - 1 m² aperture, 14°×14° FoV ≈ FAST reference design.
- Install FAST camera and DAQ system at EUSO-TA telescope.
- Milestones: Stable observation under large night sky backgrounds, UHECR detection with external trigger from TAFD.

- 8 inch PMT (R5912-03, Hamamatsu)
- PMT base (E7694-01, Hamamatsu)
- Ultra-violet band pass filter (MUG6, Schott)
FAST DAQ System

TAFD external trigger, 3~5 Hz

Anode & dynode
Signal

Amplifiers
R979 CAEN
Signal × 10

Portable VME Electronics
- Struck FADC 50 MHz sampling, SIS3350
- GPS board, HYTEC GPS2092

Amplifiers
SIS3350
Signal × 10

15 MHz low pass filter

777, Phillips scientific
Signal × 50

High Voltage power supply, N1470 CAEN

All modules are remotely controlled through wireless network.
Results on the First Field Observation

✦ Data set: April and June 2014 observation, 19 days, 83 hours
✦ Very stable observation under large night sky backgrounds
✦ Laser detection to confirm a performance of the prototype
✦ UHECR search: 16 candidates coincidence with TA-FD
✦ Very successful example among Telescope Array, JEM-EUSO, Pierre Auger Collaborations.

Figure 14: Distribution of the impact parameter as a function of the primary energy reconstructed by TA for shower candidates detected by the FAST prototype. The line indicates the maximum detectable distance by the FAST prototype (not fitted).
Full-scale FAST Prototype

✧ Confirmed milestones by EUSO-TA Telescope
  ✧ Stable operation under high night sky backgrounds.
  ✧ UHECR detection.

✧ Next milestones by new full-scale FAST prototype
  ✧ Establish the FAST sensitivity.
  ✧ Detect a shower profile including $X_{\text{max}}$ with FAST

FAST meeting in December 2015 (Olomouc, Czech Republic)
Full-scale FAST Prototype

- 1m² aperture
- FOV = 25° x 25°

- UV Plexiglass
- 8 inch PMT camera (2 x 2)
- Segmented primary mirror

Joint Laboratory of Optics in Olomouc, Czech Republic
Robust Design of Telescope

- Robust design for maintenance free and stand-alone observation.
- Adjustable elevation 15° or 45° to enlarge the FoV of the current FD.

- FAST components
- UV PMMA "window" in octagonal aperture
- 4 PMTs camera 8 inch
- UV filter glass
- cabling
- electronics

- Building - ground plan – required dimensions
  - Cca 3000 mm
  - Cca 3500 mm
  - 600 mm

- FOV Cca 3000 mm

- Building height – elevation 15° required dimensions
  - Cca 1000 mm

- Robust design for maintenance free and stand-alone observation.
- Adjustable elevation 15° or 45° to enlarge the FoV of the current FD.
Full-scale FAST Prototype

- 8 inch PMT Hamamatsu (R5912-03)
- Commercial electronics
  - VME Crate (CAEN, VME8008B)
  - Single board PC (V7768-330000, GE)
  - GPS module (GPS2092, Hytec)
  - 16 ch, 14-bit Digitizer (SIS3316-250-14, Struck Innovative Systeme)
- NIM crate (CAEN, NIM8301)
- HV power supply (CAEN, N1470)
- 8 ch fast amplifier (Phillips Scientific 777)
Concrete pad and hut being constructed

Telescope Array experiment, Black Rock Mesa site

We will plan to install the full-scale FAST telescope in September 2016
Possible Application of the FAST Prototype

- Install FAST at Auger and TA for a cross calibration.
- Profile reconstruction with geometry given by SD (smearing gaussian width of 1° in direction, 100 m in core location).
- Energy: 10%, $X_{\text{max}}$ : 35 g/cm$^2$ at $10^{19.5}$ eV
- Independent cross-check of Energy and $X_{\text{max}}$ scale between Auger and TA

![Energy Resolution vs. log(E(eV))](image)

![$X_{\text{max}}$ Resolution vs. log(E(eV))](image)

**Preliminary**

Flux $\times E^{1.124} (\text{eV}^2 \text{m}^{-2} \text{sr}^{-1} \text{s}^{-1})$

- $10^{17.5}$
- $10^{18}$
- $10^{18.5}$
- $10^{19}$
- $10^{19.5}$
- $10^{20}$
- $10^{20.5}$

- TA ICRC 2015
- Auger ICRC 2015

**Identical simplified FD**

Pierre Auger Observatory

Pierre Auger Collaboration, NIM-A (2010)

Telescope Array Experiment

Telescope Array Collaboration NIM-A (2012)
Summary and Future Plans

- **Fluorescence detector Array of Single-pixel Telescopes (FAST)**
  - Deploy the economical fluorescence detector array.
  - Detect UHECRs and neutral particles with $>10 \times$ Auger effective area.

- This concept of single-pixel telescope was confirmed by the field measurements using the EUSO-TA optics.
  - Published in Astroparticle Physics 74 (2016) 64-72

- The full-scale FAST prototype is being constructed, and almost ready to install to Utah.
  - We plan to install in September 2016 to observe $X_{\text{max}}$

- New collaborators are welcome.
Our Challenges

http://www.fast-project.org