The Fluorescence detector Array of Single-pixel Telescopes: The next-generation cosmic ray observatory

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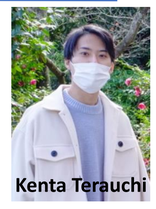
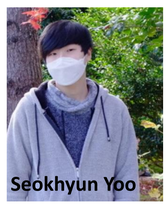
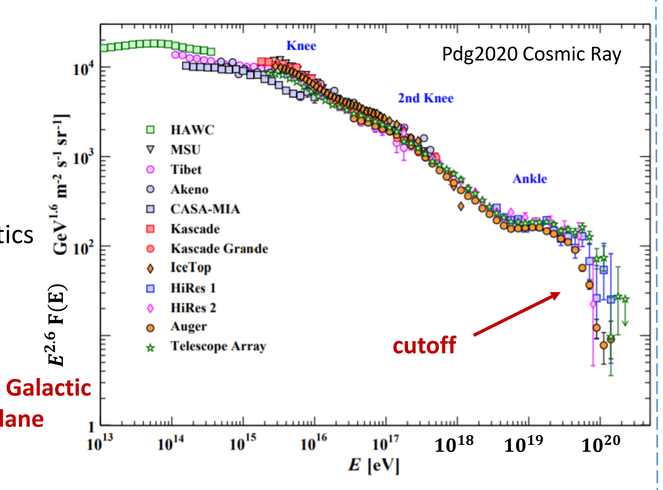

Kenta Terauchi


Seokhyun Yoo

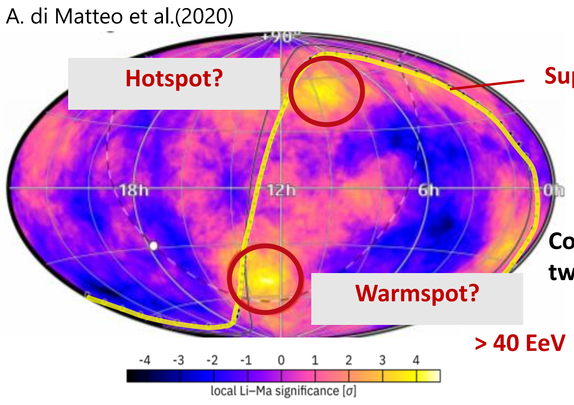
The origin and nature of ultra-high energy cosmic rays (UHECRs) are hot topics in the astroparticle physics community. The Fluorescence detector Array of Single-pixel Telescopes (FAST) is a design for a next-generation ground-based UHECR observatory, addressing the requirements for a large-area, low-cost detector suitable for measuring the properties of the highest energy cosmic rays with an unprecedented aperture. We have developed a full-scale prototype consisting of four 200 mm photomultiplier tubes at the focus of a segmented mirror of 1.6 m in diameter. Over the last four years, we have installed three prototypes at the Telescope Array Experiment in Utah, USA and one at the Pierre Auge Observatory in Argentina. These telescopes have been steadily taking data since installation. We report on preliminary results of the full-scale FAST prototypes and discuss the installation of an additional identical FAST prototype at the Pierre Auger Observatory in Argentina. Possible benefits to the Telescope Array Experiment and the Pierre Auger Observatory include a comparison of the transparency of the atmosphere above both experiments, a study of the systematic uncertainty associated with their existing fluorescence detectors, and a cross-calibration of their energy and Xmax scales.

1. Ultra-High Energy Cosmic Rays (UHECRs)

- ✓ Cosmic ray with energy over 10^{18} eV
- ✓ Less likely to be bent by magnetic field
  - ⇒ Origin of UHECRs (~1 deg for 10^{20} eV proton)
- ✓ Arrival rate:
  - one particle per 100 km^2 per 1 yr (@10^{20} eV)
  - ⇒ Need for larger effective area to increase statistics
- ✓ What is the maximum acceleration energy?

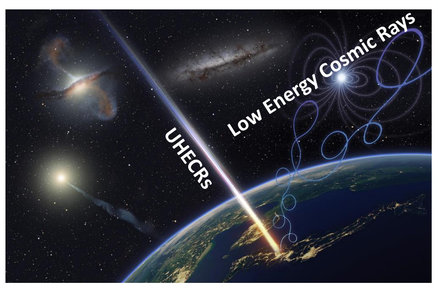


A. di Matteo et al.(2020)



> 40 EeV

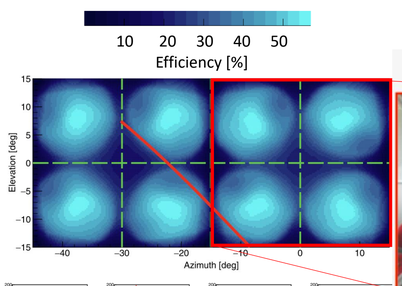
Correlation between two spots and SG Plane?

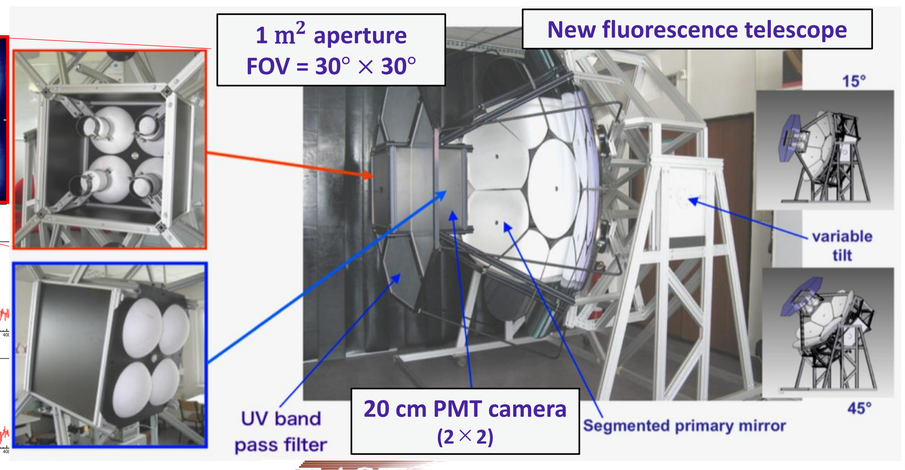


2. FAST Experiment

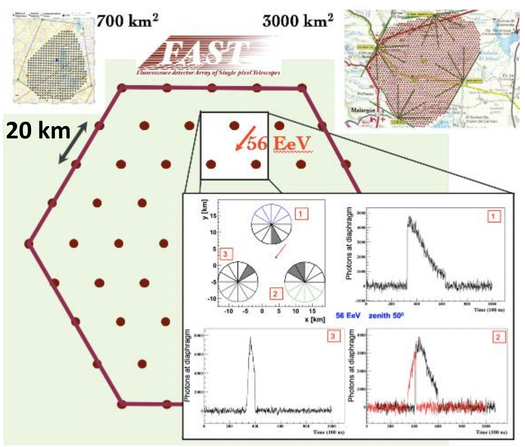
2.1 New Fluorescence Telescope

Small-sized low cost Fluorescence telescopes ▶ Array of fluorescence telescopes ▶ Large effective area! (~ 30,000 km^2)





TA site



Auger site

FAST

20 cm PMT × **4**
1.6 m mirror
Lower cost

Others

5 cm PMT × few hundred
3.4 m mirror

3 telescopes at TA site:
Installed in 2016, 2017, 2018

1 telescope at Auger site:
Installed in 2019

⇨Second telescope will be installed in 2021

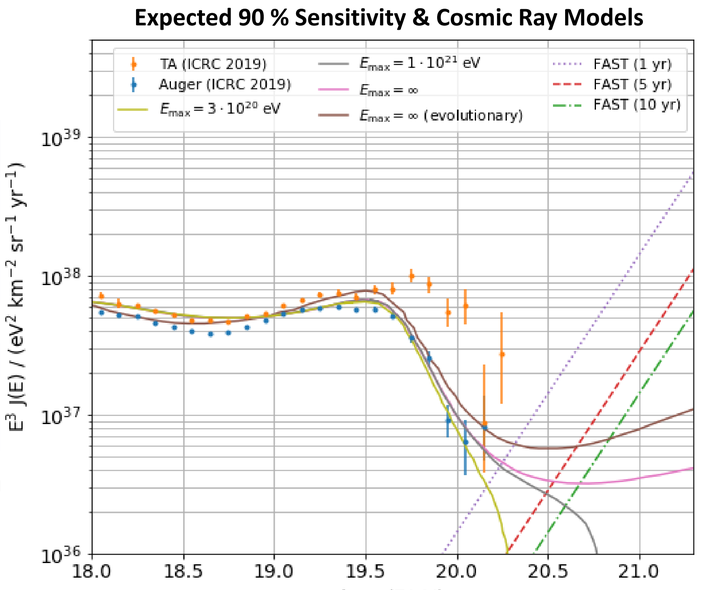
2.2 Expected Sensitivity

Assumption for sensitivity calculation:
- 30,000 km^2 effective area
- No backgrounds

log(Emax)	20.5	21.0	∞	∞ (evolutionary)
$\log_{10}$(E/eV)	Number of Events			
20.0 - 20.1	135	166	166	213
20.1 - 20.2	50	65	65	88
20.2 - 20.3	17	30	30	41
20.3 - 20.4	6	14	15	21
20.4 - 20.5		7	8	12
20.5 - 20.6		4	4	7

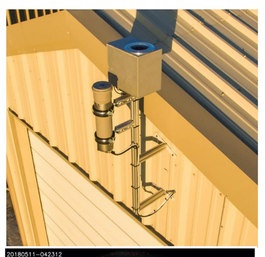
10 years of FAST observation can distinguish the theoretical models
⇒ It will be clear whether the flux of UHECRs recovers or not

Expected 90 % Sensitivity & Cosmic Ray Models



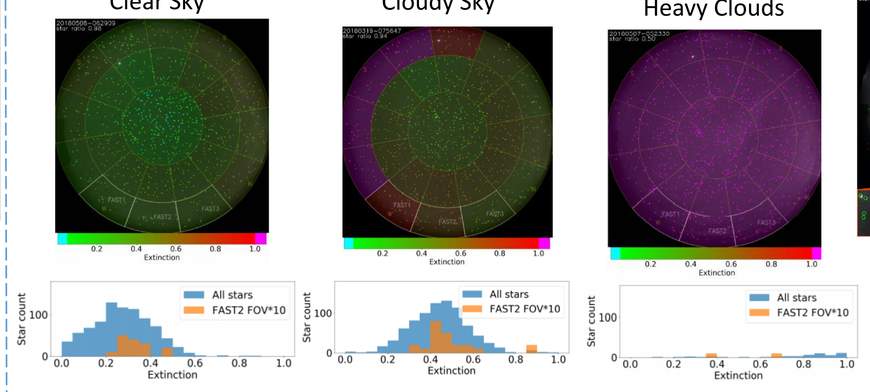
2.3 FAST All-Sky Camera (FASCam)

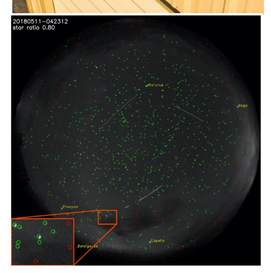
- ✓ Measure number and brightness of detectable stars
  - ⇒ Estimate cloudiness and transparency of observatory sky
- ✓ FOV: 360° × 90°



FASCam @TA site

Clear Sky / Cloudy Sky / Heavy Clouds





Night sky images @TA site

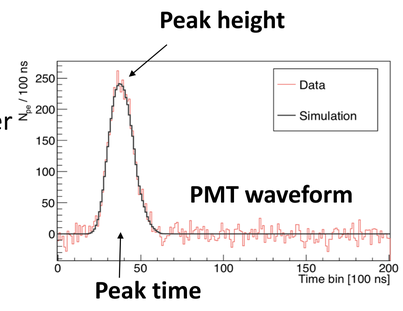
- ○ Detectable
- ○ Exists but undetectable

Extinction maps

2.4 Reconstruction Methods and Results

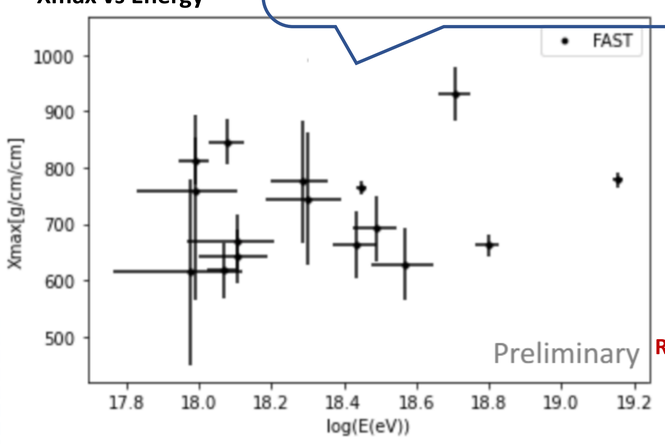
Top Down Reconstruction
Compare between observation and simulation waveforms in every 100 ns, and maximize the likelihood to reconstruct the air shower

Initial Values
- ✓ Current
  Use TA results measured by fluorescence detector (FD)
- ✓ Developing
  Use neural network results
  3 input data for training: **Peak height, peak time, and total charge**

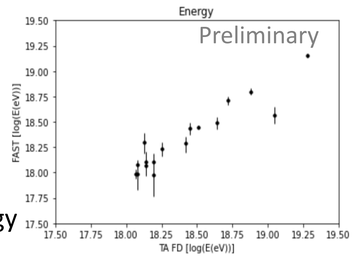


- ・Only used events with > 10^{18} eV (measured by TA FDs)
- ・Multi-hit events on PMTs
- ・Initial values from TA FDs

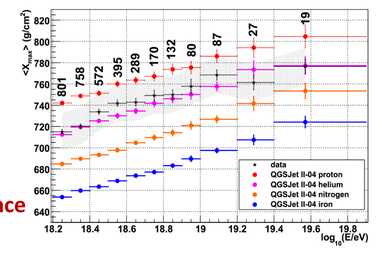
FAST Reconstructed Xmax vs Energy



TA FD vs FAST FD Reconstructed Energy



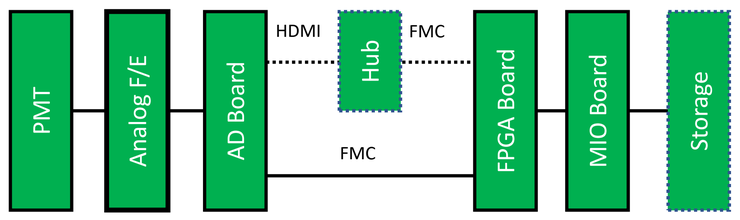
TA Data & Simulations



More statistics ▶ **Future goal**: **Reveal chemical abundance**

3. Electronics Development

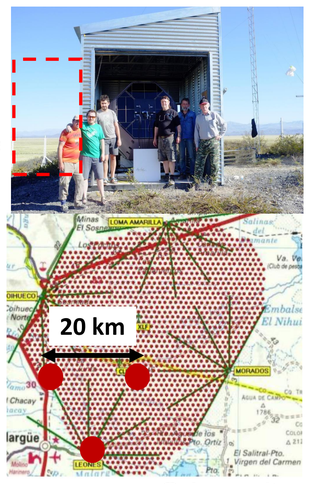
Goal
- ✓ Total power under 30 W / telescope (For solar battery application)
- ✓ Dynamic range: 3000 p.e.
- ✓ Lower cost
- ✓ Automatic observation



4. Future of FAST

- ✓Installation of second telescopes at Auger site in 2021
- ✓Installation of new electronics in 2021
- ✓New mirror design
- ✓Development of dedicated trigger for FAST (Right now, an external trigger from TA FD has been used)

2nd telescope @Auger site



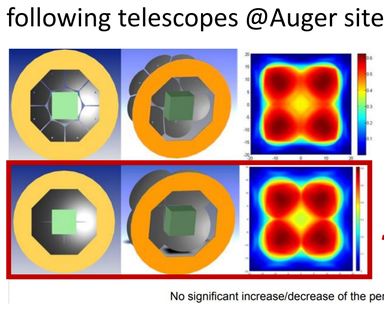
Planning to observe from 3 triangular spots

@ Auger site

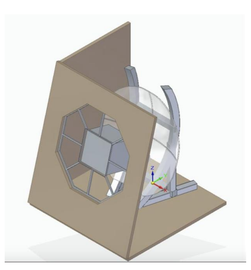
New mirror design for 3rd and following telescopes @Auger site

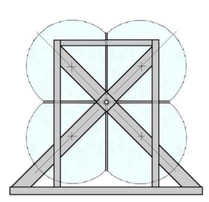
Current (9 mirrors)

New (**4** mirrors)



⇒ **lighter and fewer components**





https://www.fast-project.org