



RESULTS FROM THE TELESCOPE ARRAY



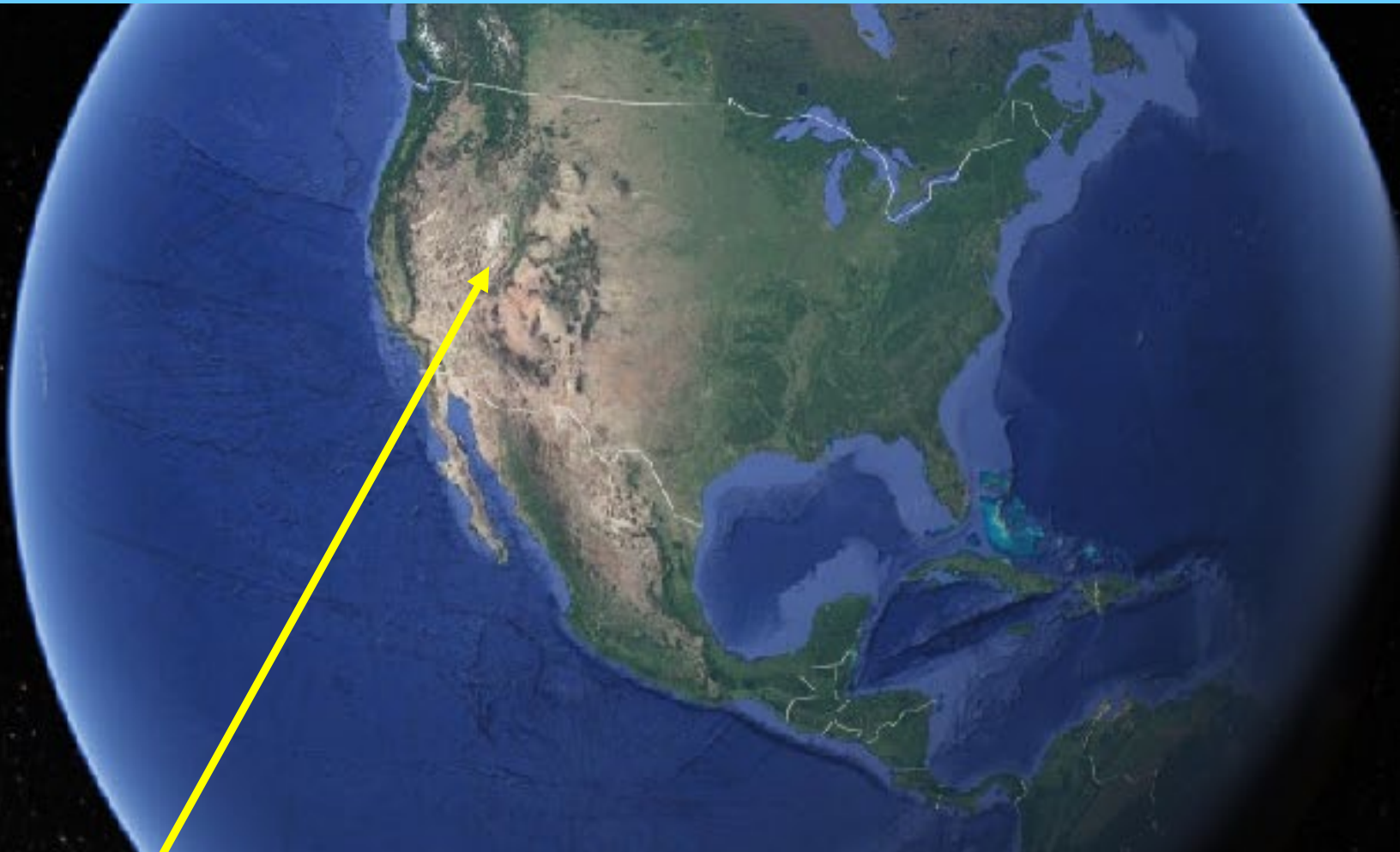
**John Matthews - University of Utah
Telescope Array Collaboration**

30 August 2023

OUTLINE

- Introduction
- Main Topics in UHECR
 - Energy Spectrum and Features
 - Chemical Composition
 - Anisotropy and Sources
- Conclusions

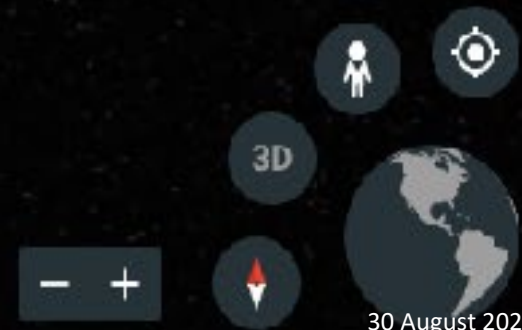
TELESCOPE ARRAY: THE LARGEST COSMIC RAY OBSERVATORY IN THE NORTHERN HEMISPHERE



Telescope Array

Delta, Utah, USA. ~ 39° N, 113° W 1400m a.s.l.

Collaborators from HiRes, AGASA joined by other institutes



30 August 2023

TELESCOPE ARRAY

Telescope Array Detectors

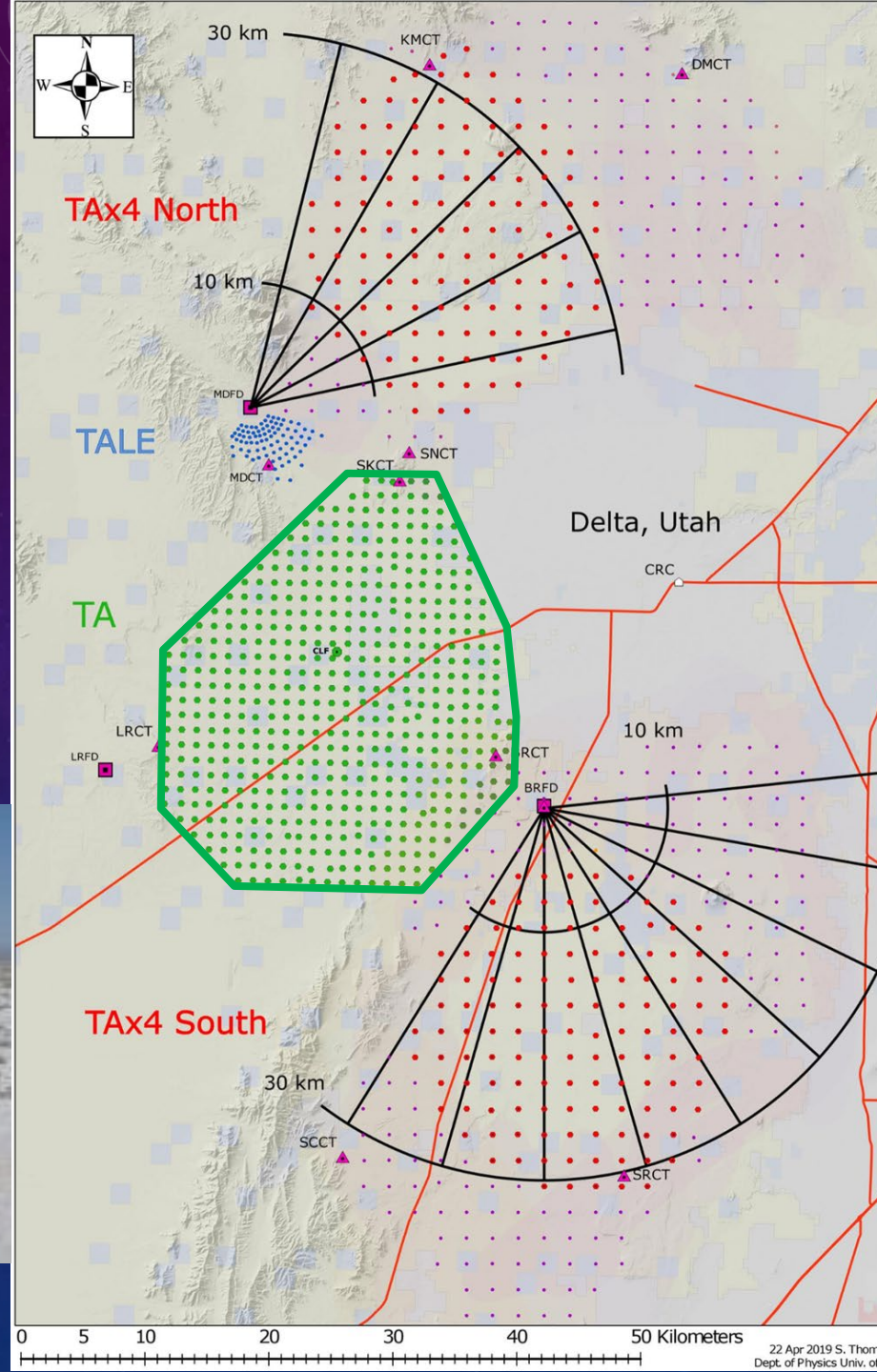
Surface Detector Array (3/2008)

- 507 Scintillator Counters
- 3 m² area
- 1.2 km spacing
- ~700 km²

Fluorescence Telescopes (2007)

- 3 Stations
- 12–14 Telescopes ea
- 3°–31° elevation
- Above SD Array

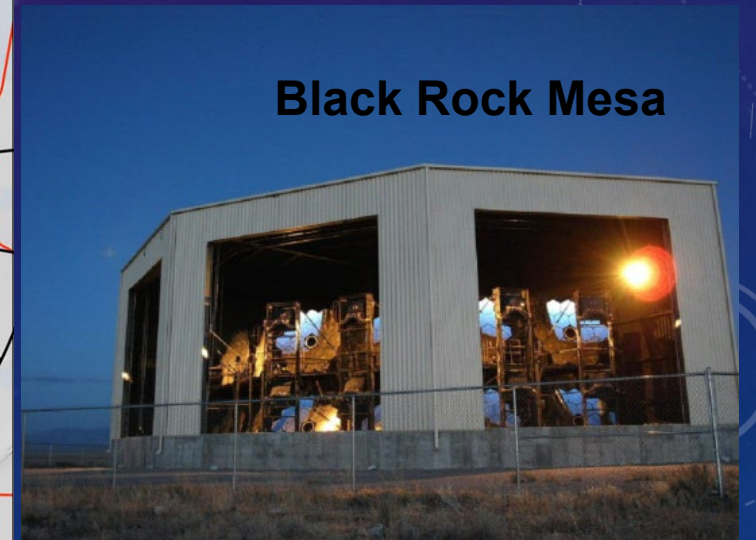
Scintillator Detector



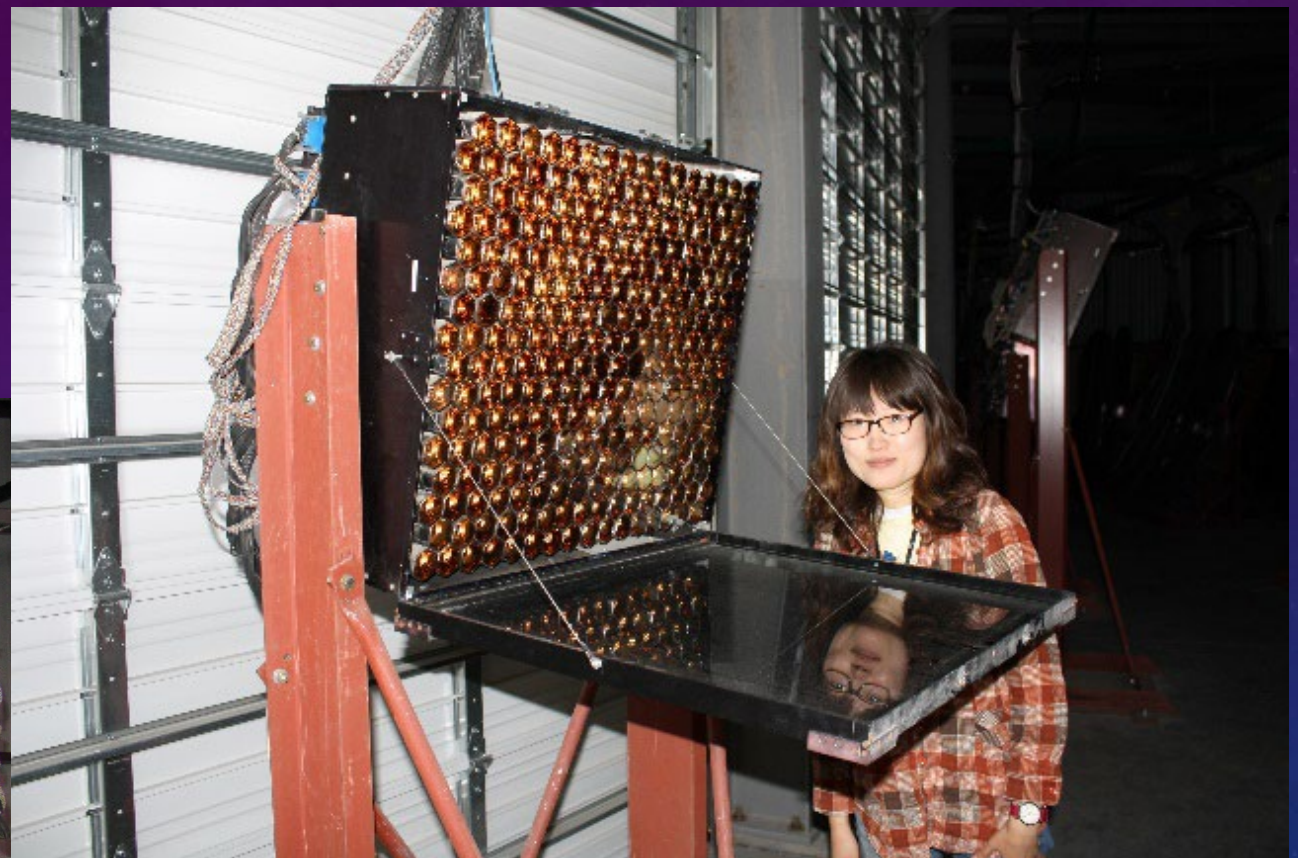
Middle Drum



Black Rock Mesa



TELESCOPES



- Segmented mirrors
- 256 hexagonal PMTs/camera
- 1 pixel views $\sim 1^\circ$ of sky
- UV band-pass filter

SCINTILLATOR SURFACE DETECTORS



- 2 layers scintillator
- 1.25 cm thick, 3m² area
- WS Optical fibers to PMTs

Scintillator Detectors on a 1.2 km square grid



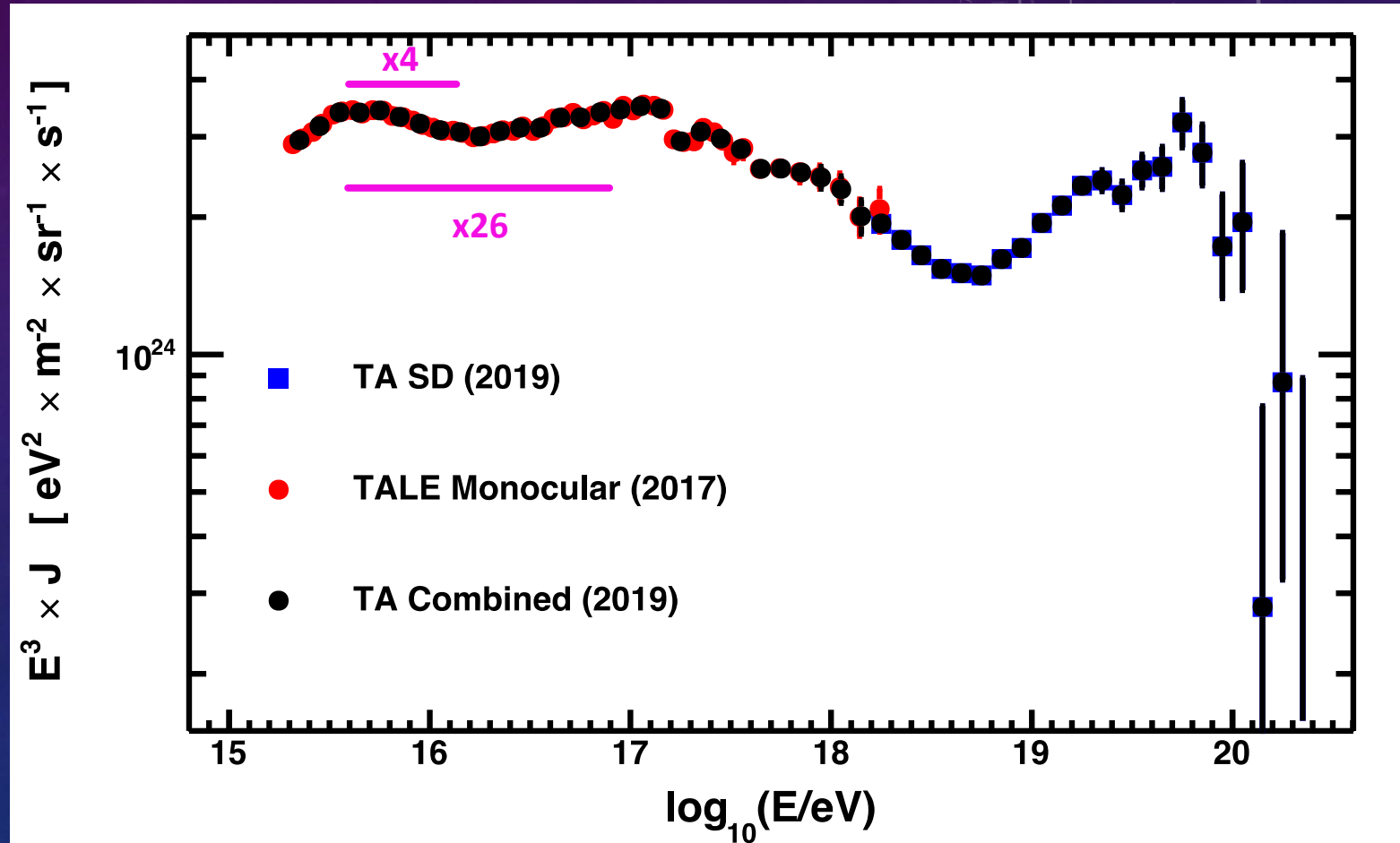
- Power: Solar/Battery
- Readout: Radio
- Self-calibrated: μ

ENERGY SPECTRUM

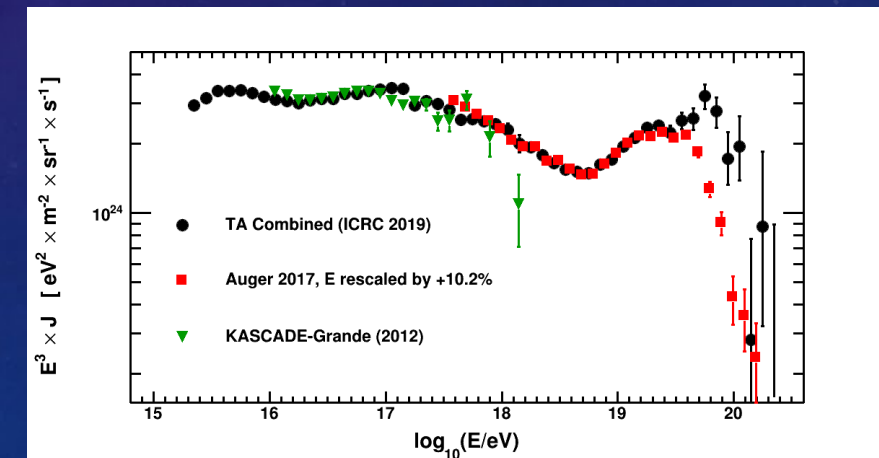
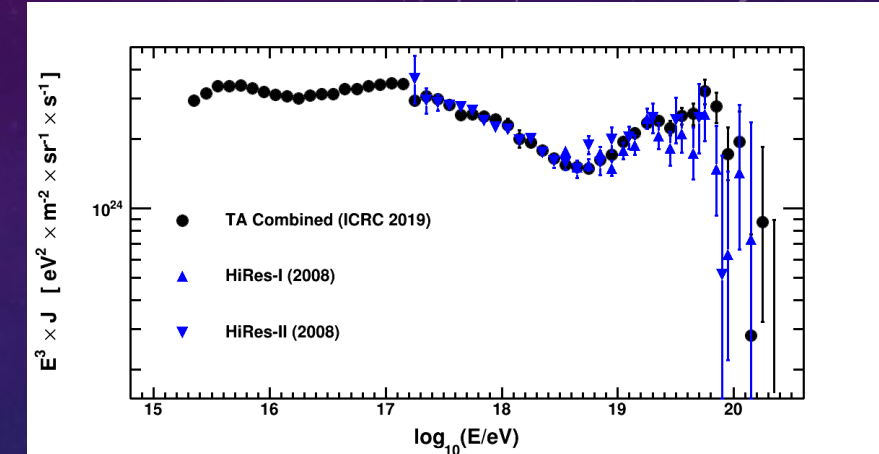
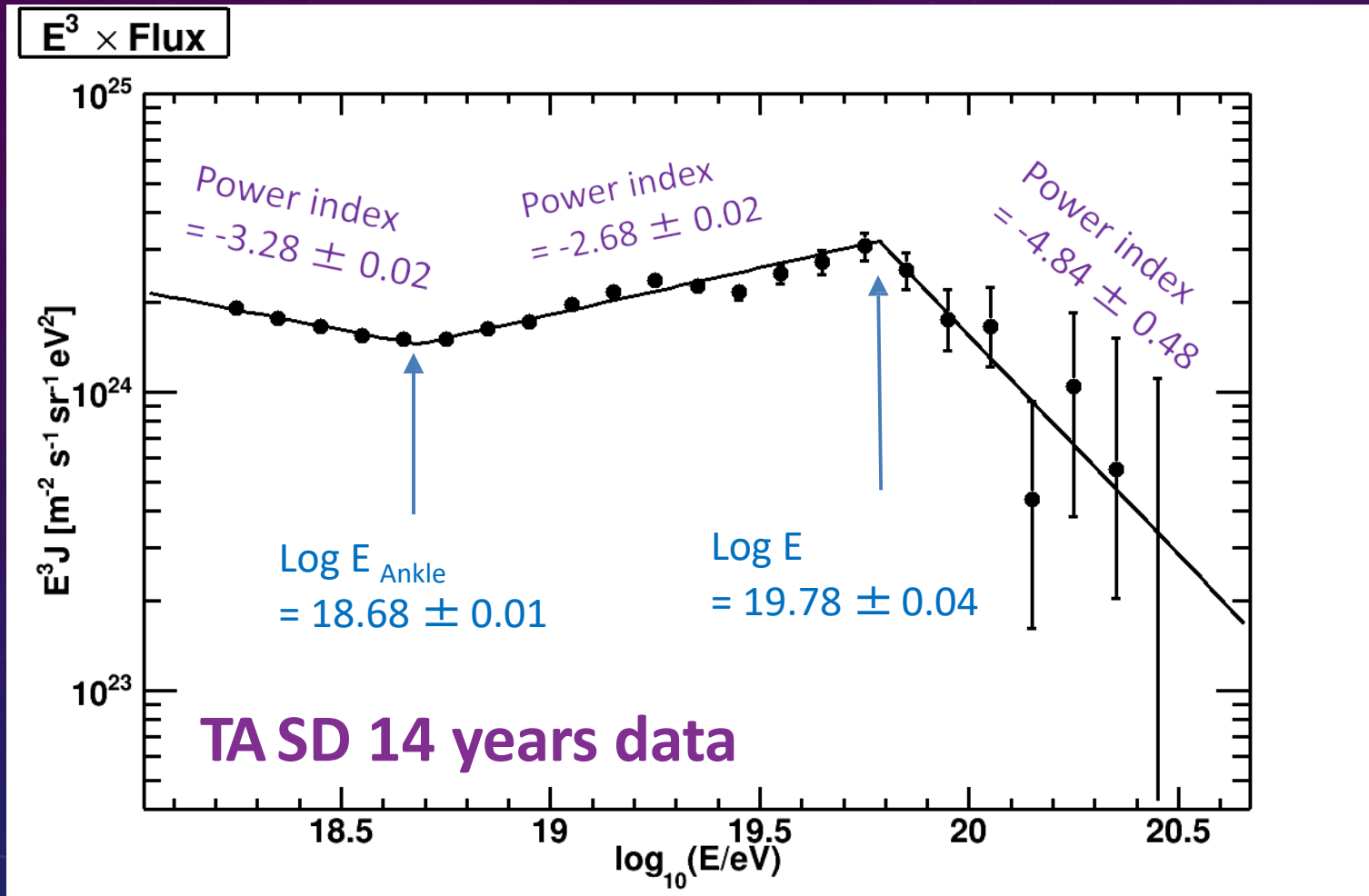
Combine TA SD spectrum (11 years)
with TALE FD monocular (22 months)
to get CR spectrum covering 5 orders-
of-magnitude

- Knee: $\log_{10}(E/\text{eV}) \sim 15.5$
- LE ankle: $\log_{10}(E/\text{eV}) = 16.22(2)$
- 2nd Knee: $\log_{10}(E/\text{eV}) = 17.04(4)$
- Ankle: $\log_{10}(E/\text{eV}) = 18.68(1)$
- Cutoff: $\log_{10}(E/\text{eV}) = 19.78(3)$

Peter's Cycle? : $10^{15.6} - 10^{17.1}$ eV



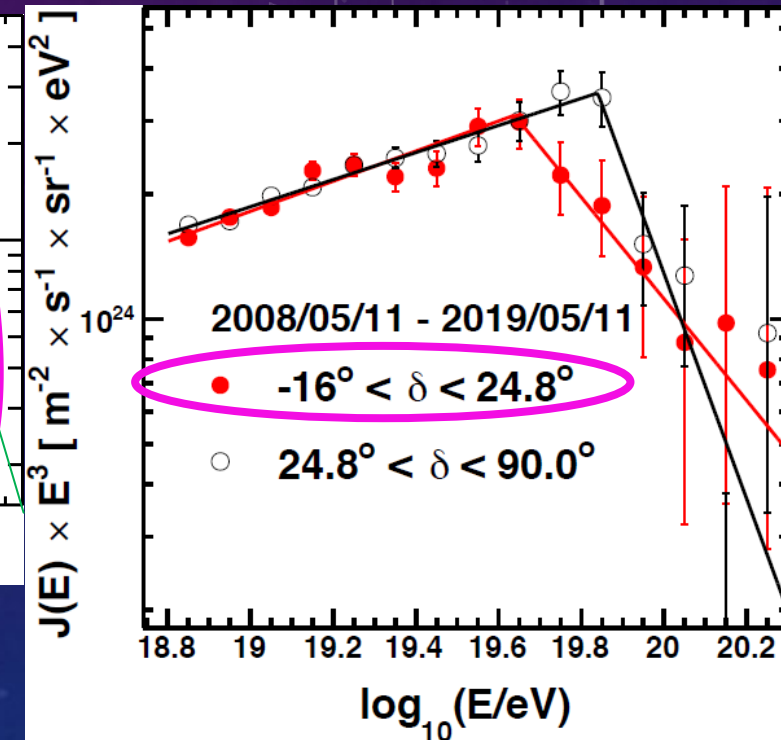
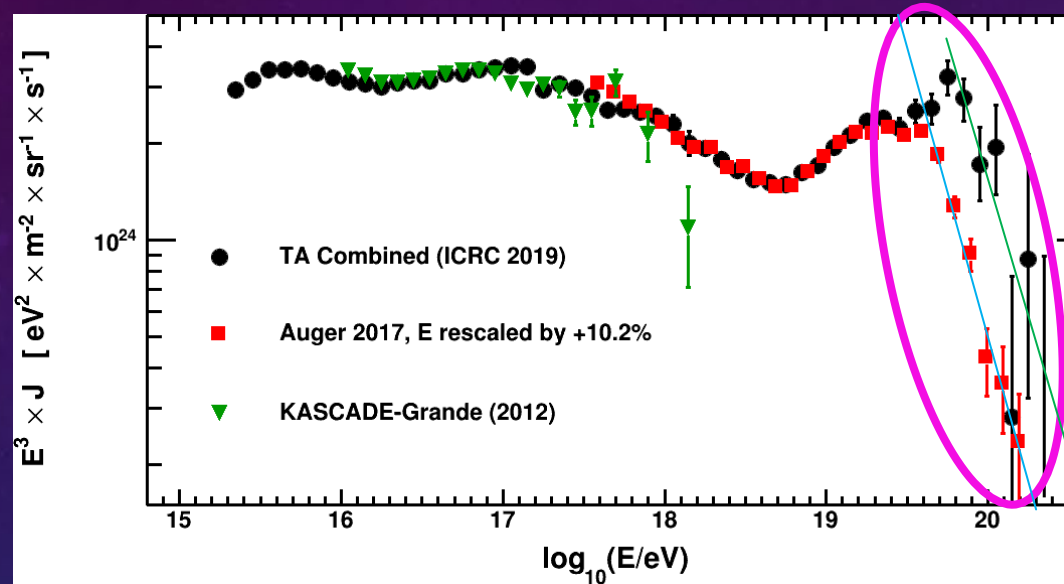
ENERGY SPECTRUM



ENERGY SPECTRUM

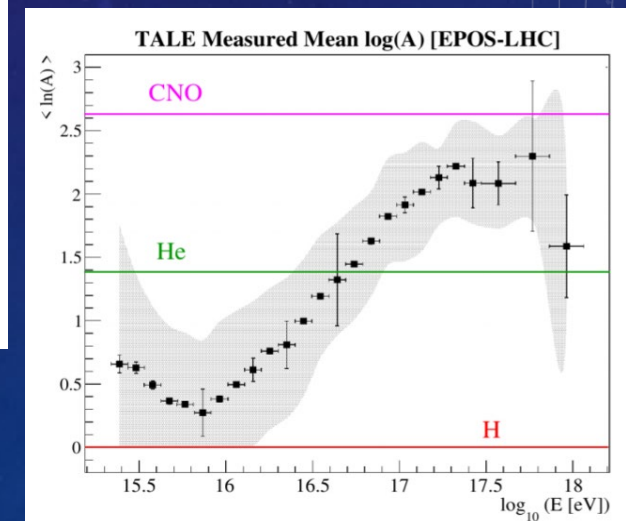
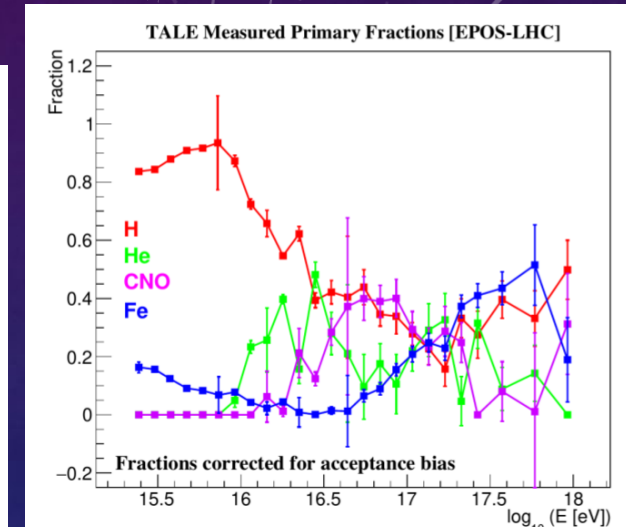
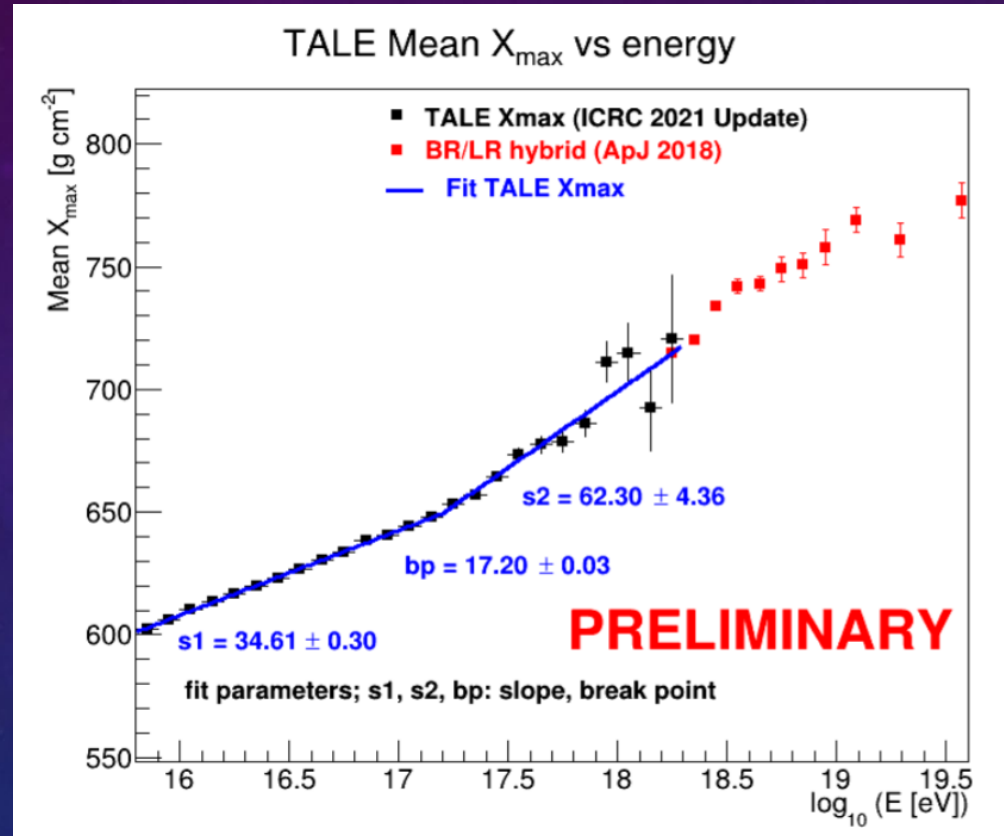
Declination dependence in the TA SD spectrum

- Difference of the cutoff of energy spectra
 - $\log(E/\text{eV}) = 19.64 \pm 0.04$ for lower dec. band (-16° – 24.8°)
 - $\log(E/\text{eV}) = 19.84 \pm 0.02$ for higher dec. band (24.8° – 90°)
- The global significance of the difference is estimated to be 4.3σ



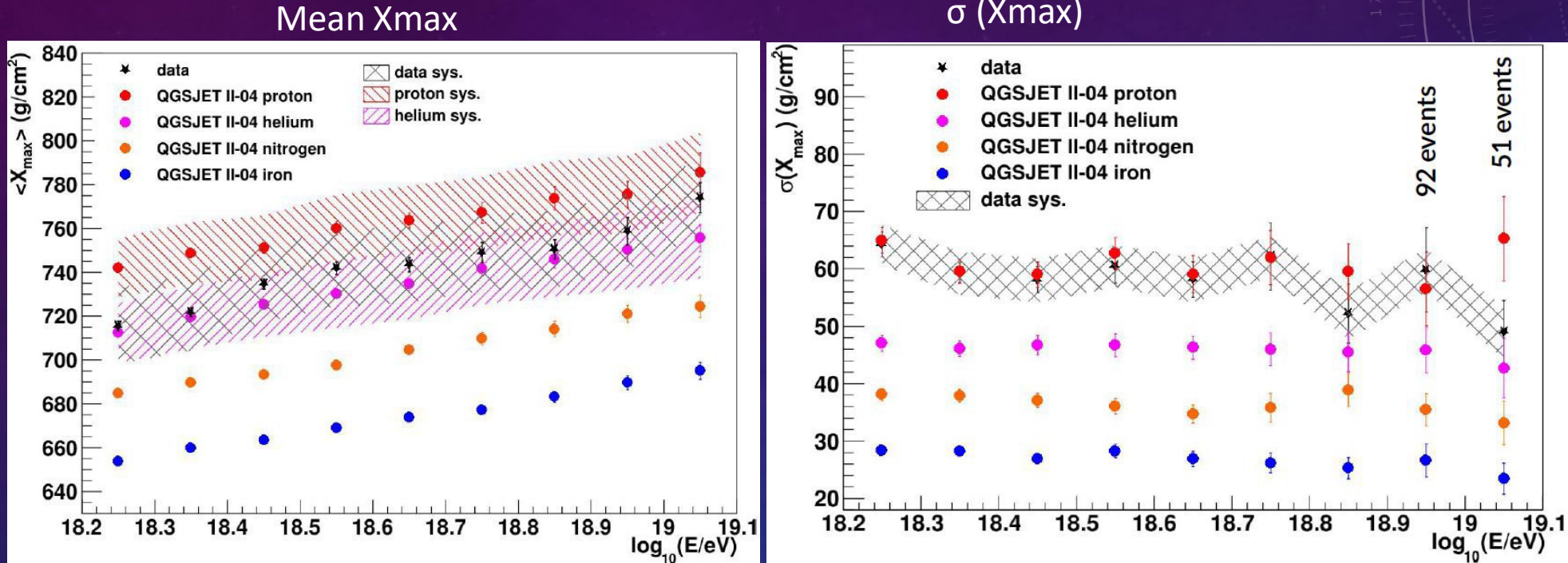
LOW ENERGY COMPOSITION

- TALE utilizing Cherenkov-light dominated events
- Detailed measurement of composition from 2 PeV to 2 EeV
 - ApJ 909 (2021)178
- Fit to four species
 - Reduction in protons above the Knee
 - Getting heavier to 2nd / iron knee
- Elongation rate fit
 - Break at 160 PeV at the 2nd Knee
 - Getting lighter above that



COMPOSITION ANALYSIS WITH TA HYBRID XMAX

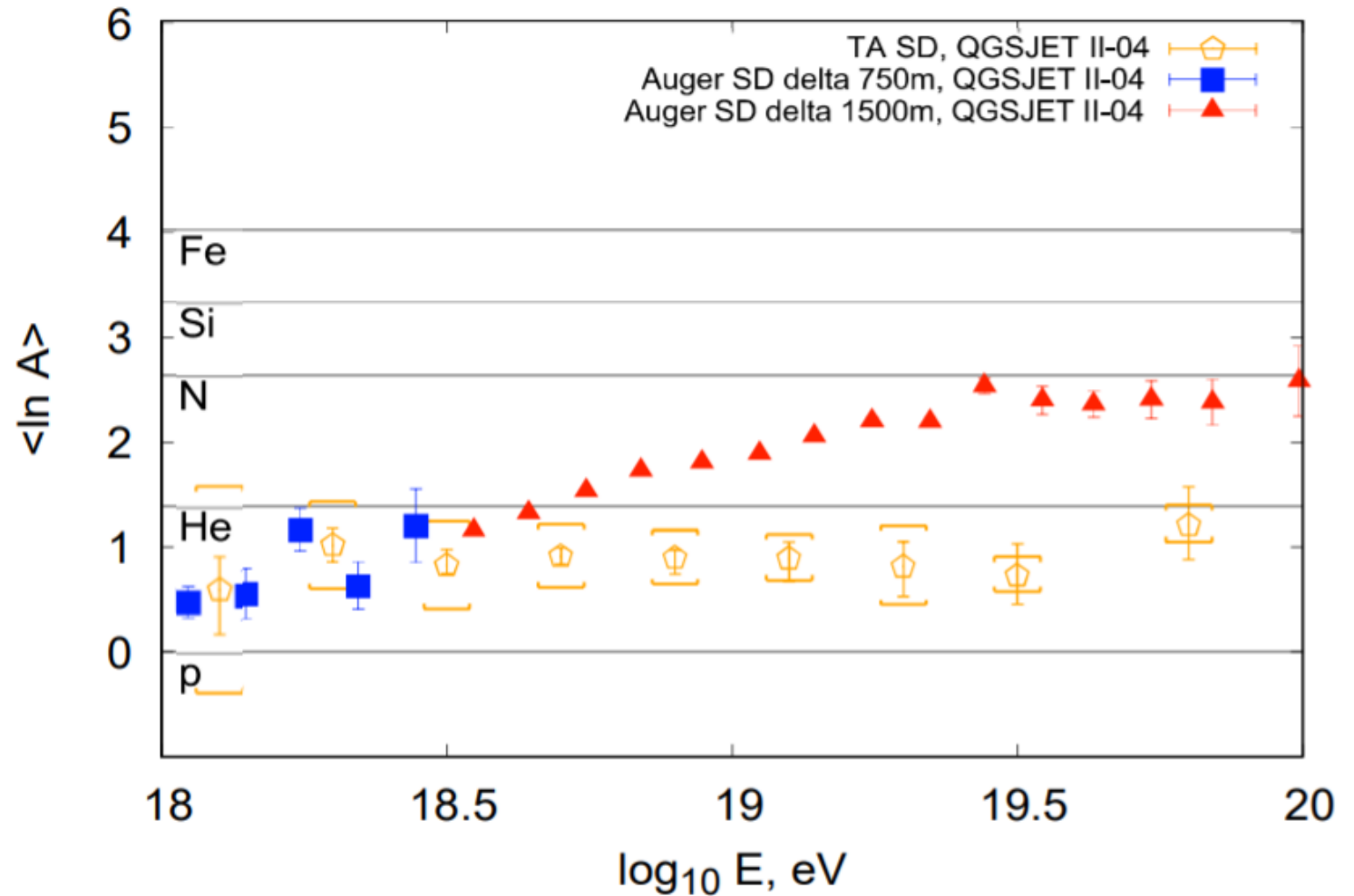
10 years SD and FD hybrid data
 $\sigma(X_{\max})$



- Energy Range: $10^{18.2} \text{ eV} - 10^{19.1} \text{ eV}$
- 3560 events after the quality cuts
- Systematic uncertainty of $\langle X_{\max} \rangle$: $\pm 17 \text{ g/cm}^2$
- QGSjetII-04 interaction model was compared with the data
→ agreement with light composition
- More events are needed to study highest energies
- Also working on more models

COMPOSITION

- TA SD composition: BDT analysis using 16 composition sensitive signals (12 years: 2008–2020)
 - Find light, unchanging composition above 1 EeV, with two different high-energy interaction models



ANISOTROPY

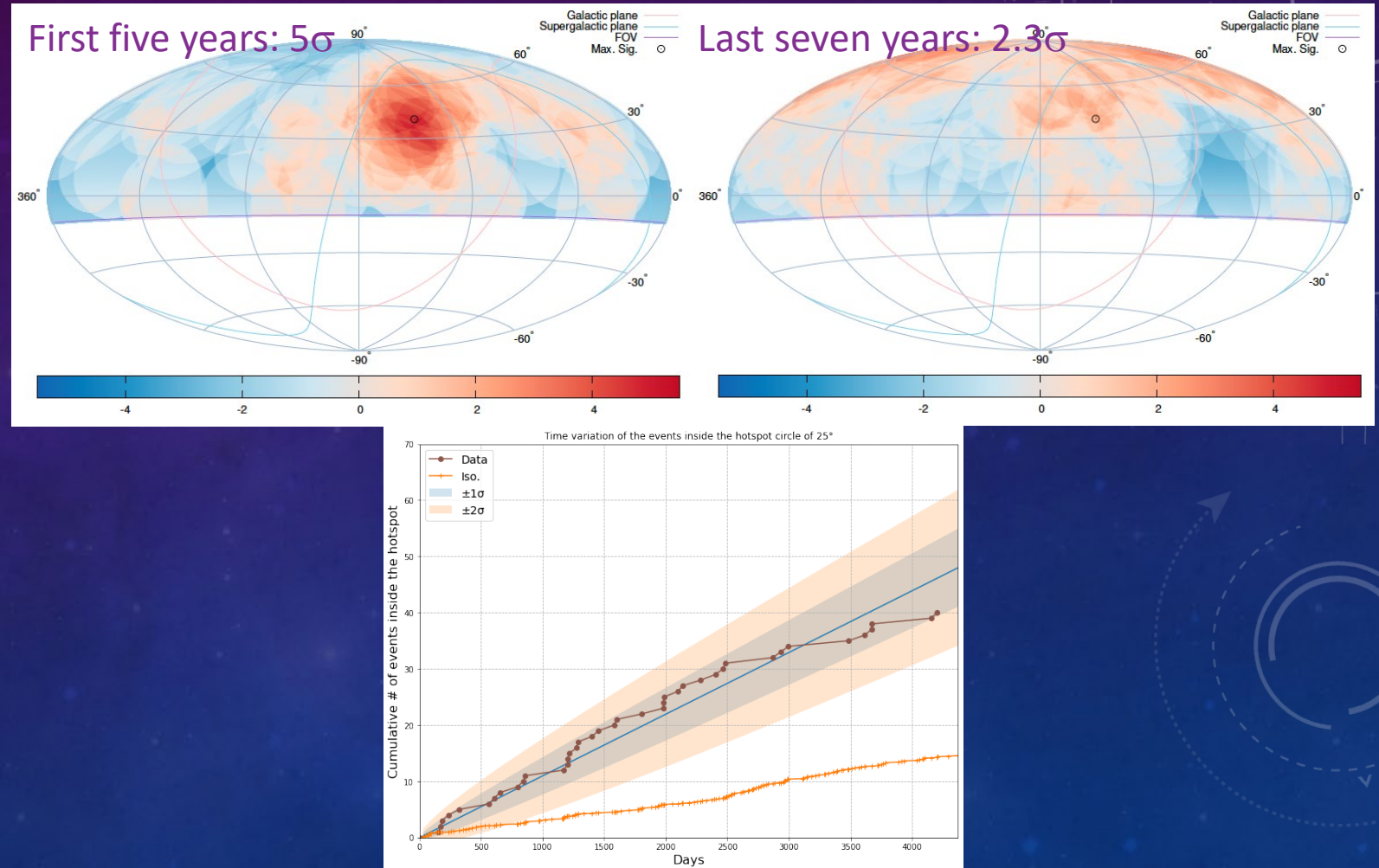
TA Hot Spot announced 2014 in data $E > 57$ EeV (ApJ **790** (2014) L21)

Now with 12 years of data

- 179 events with $E > 57$ EeV
- 40 events in hot-spot, 25° circle, local 4.5σ significance, 3.2σ global

The original brightness seems to not be sustained

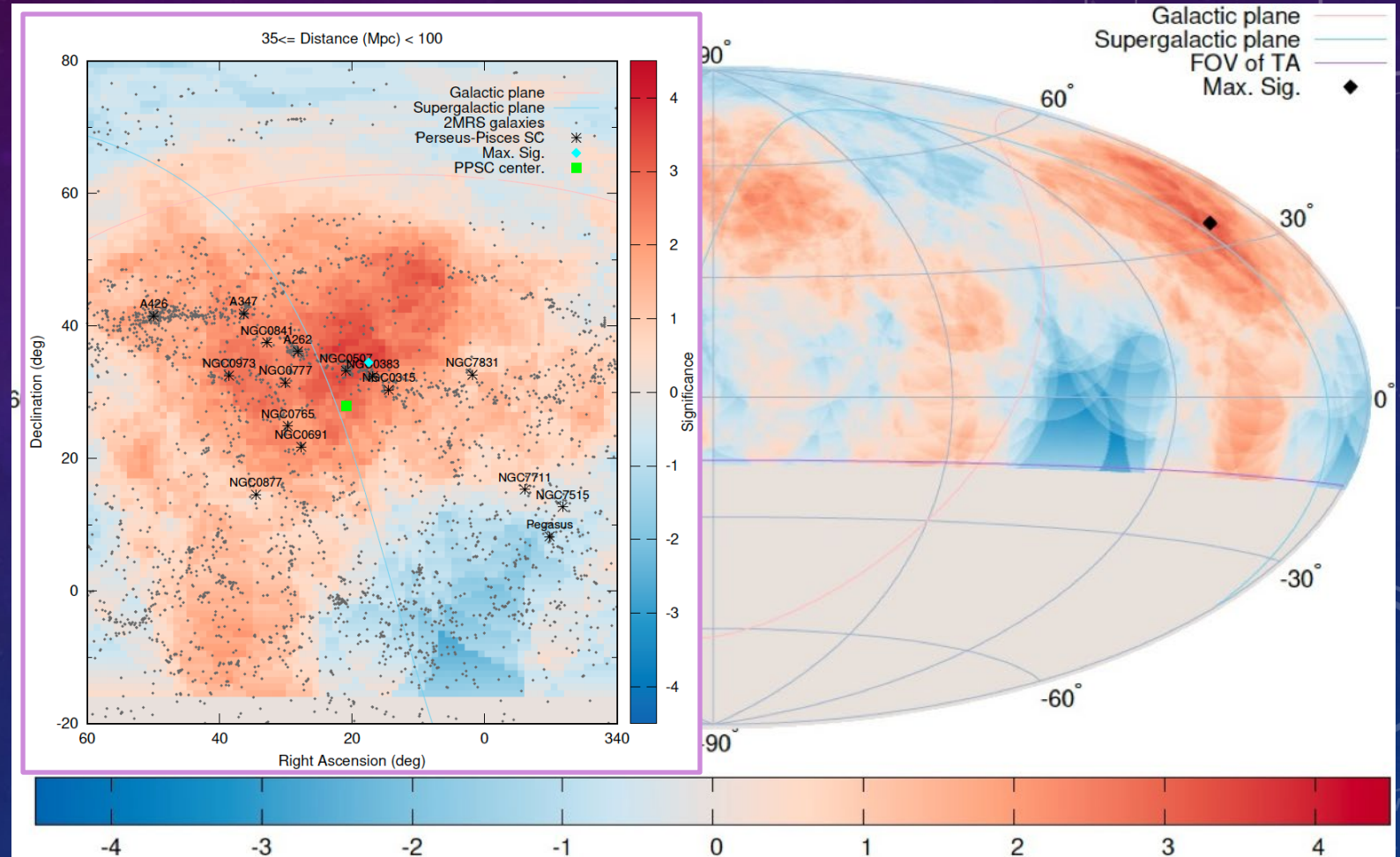
- Still significantly higher than background
- Growth rate consistent with linear



ANISOTROPY

At slightly lower energies ($E > 10^{19.4}$ eV)
see a new excess

- In the direction of the Perseus-Pisces Supercluster
- The chance probability of having an excess as close to the PPSC as the data is estimated:
- $(S_{mc} \geq 4.0\sigma) \text{ \& } (\theta_{mc} \leq 7.7^\circ) \rightarrow 3.3\sigma$.



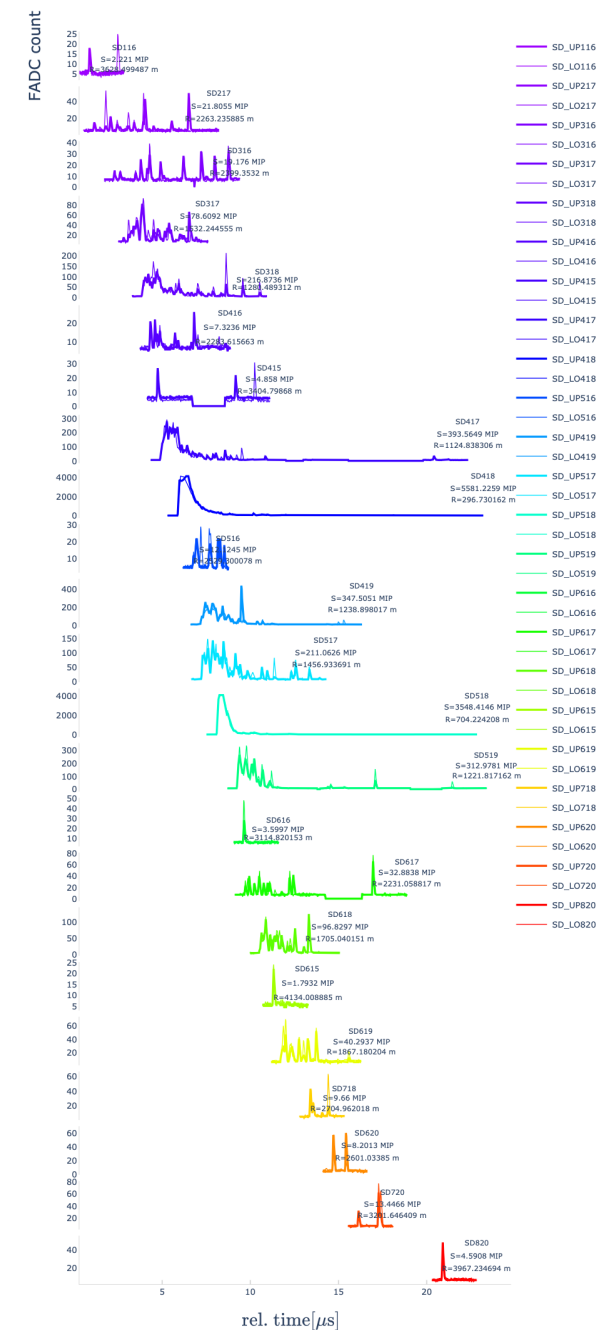
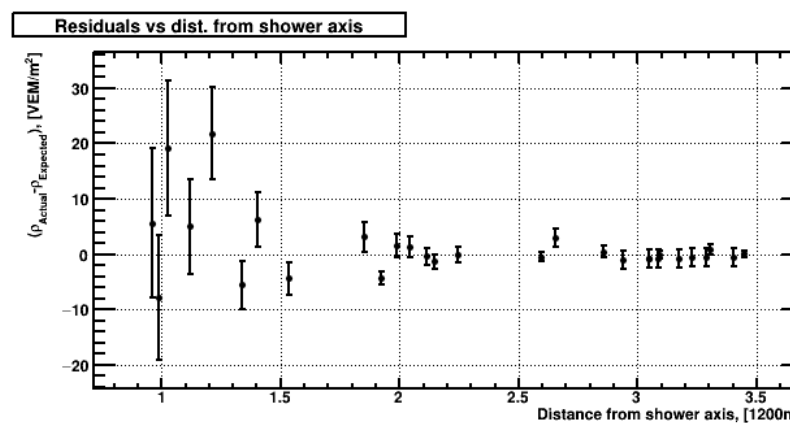
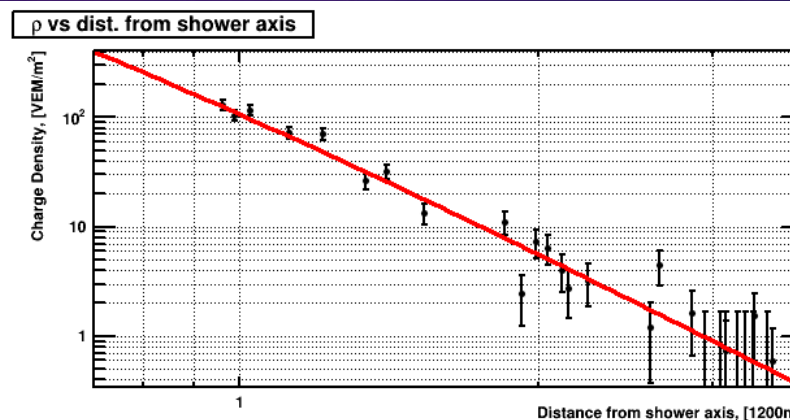
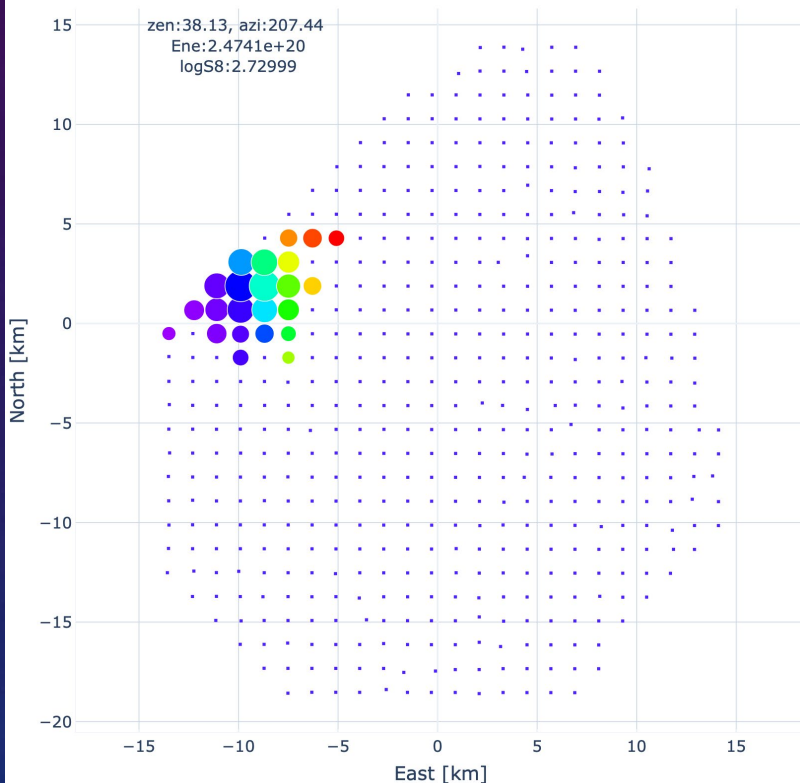
NEW HIGHEST EVENT DETECTED BY TA

2021/05/27 10:35:56.47, No FD observation

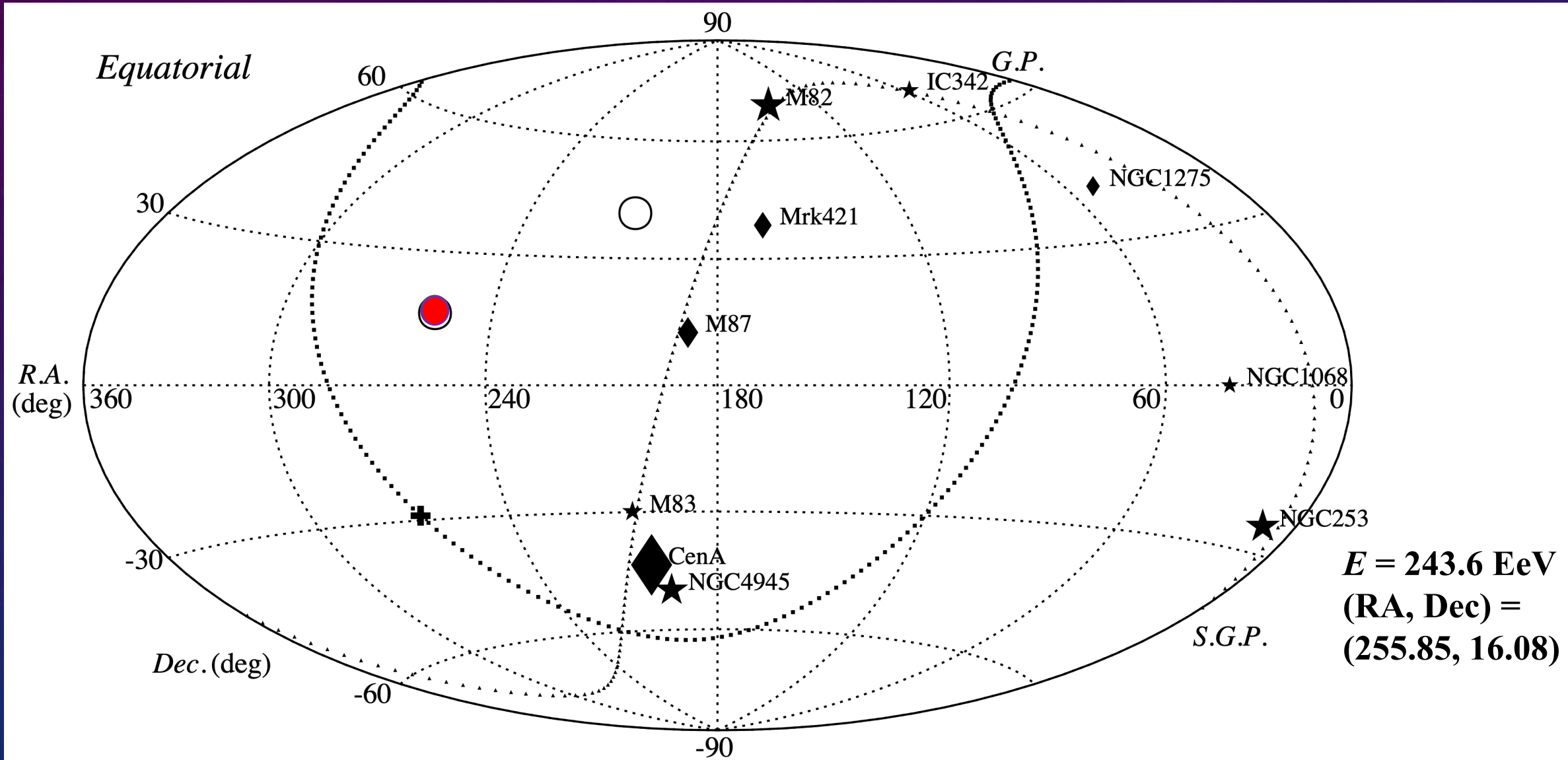
$E = 243.6 \pm 10.7 \text{ EeV}$, $\theta = 38.6^\circ$, $\varphi = 206.8^\circ$ - **Preliminary**

($E = 242.8 \text{ EeV}$ with the atmospheric energy correction) - **Preliminary**

TA SD map: data event



DIRECTION IN THE SKY-MAP



SUMMARY – RESULTS FROM TELESCOPE ARRAY

Spectrum

- Spectrum measurements over >5 orders-of-magnitude in energy
- Spectral features measured
- TA finds a significant difference in its own HE suppression **above and below 25° declination** (agreement with Auger in overlapping region)

Composition

- Light-heavy-light pattern in $10^{15} - 10^{18}$ eV energy range using TALE (Cherenkov)
- Appears Light and Steady for $E > 10^{18}$ eV

Anisotropy

- Hotspot persists, but significance not increasing very quickly
- New significant excess at slightly lower energy in conjunction with the Perseus-Pisces Supercluster

High Energy Event Observed

- New high energy event: 2.4×10^{20} eV
- Approaching Fly's Eye (1991 OMG) particle energy: 3.2×10^{20} eV

Future

- Need to Improve statistics especially for Anisotropy and Composition measurements
- Complete TAx4 and take more data!!



TELESCOPE ARRAY COLLABORATION

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