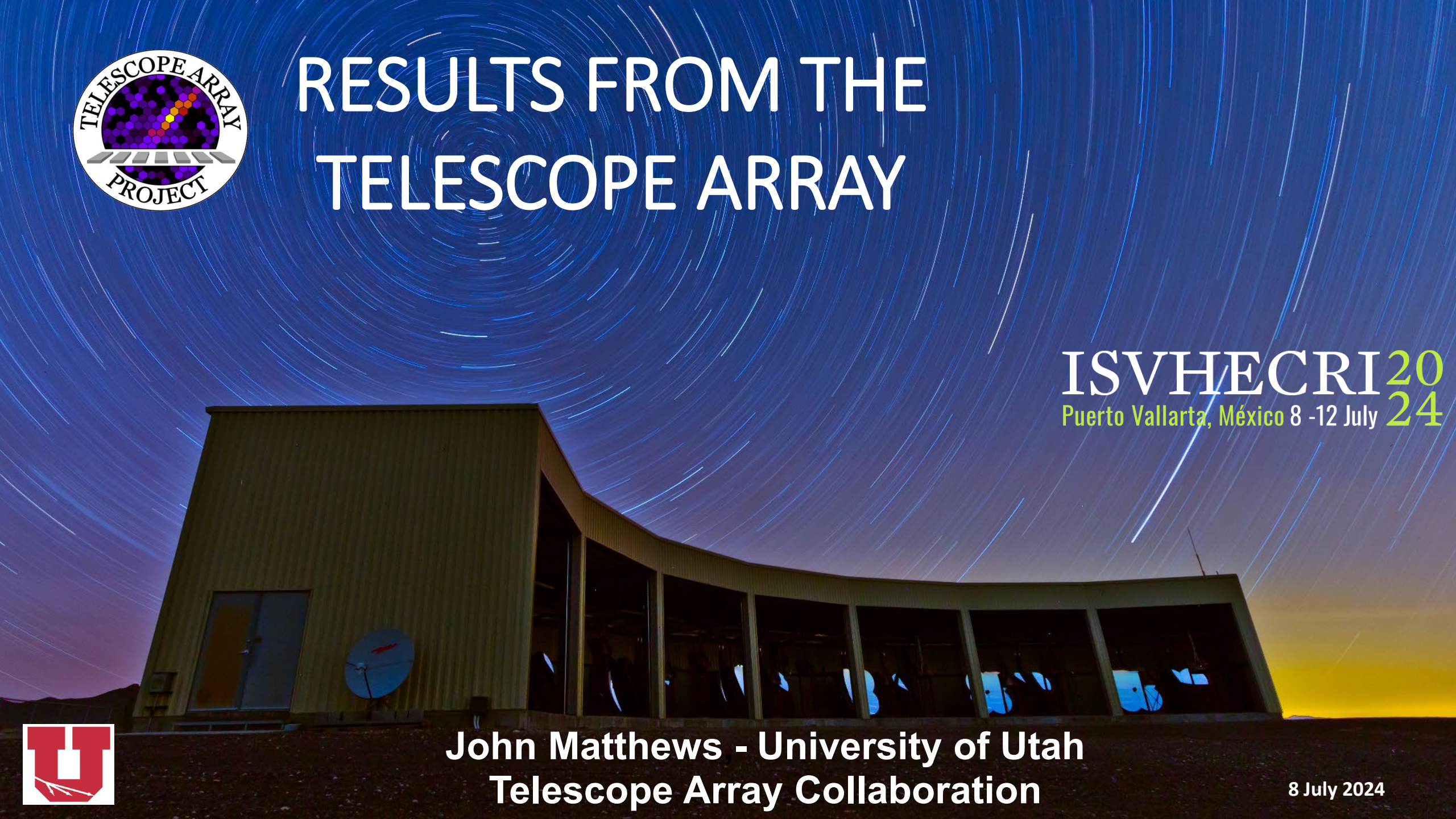


RESULTS FROM THE TELESCOPE ARRAY

ISVHECRI 2024
Puerto Vallarta, México 8 -12 July

John Matthews - University of Utah
Telescope Array Collaboration

8 July 2024

OUTLINE

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

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

TELESCOPE ARRAY

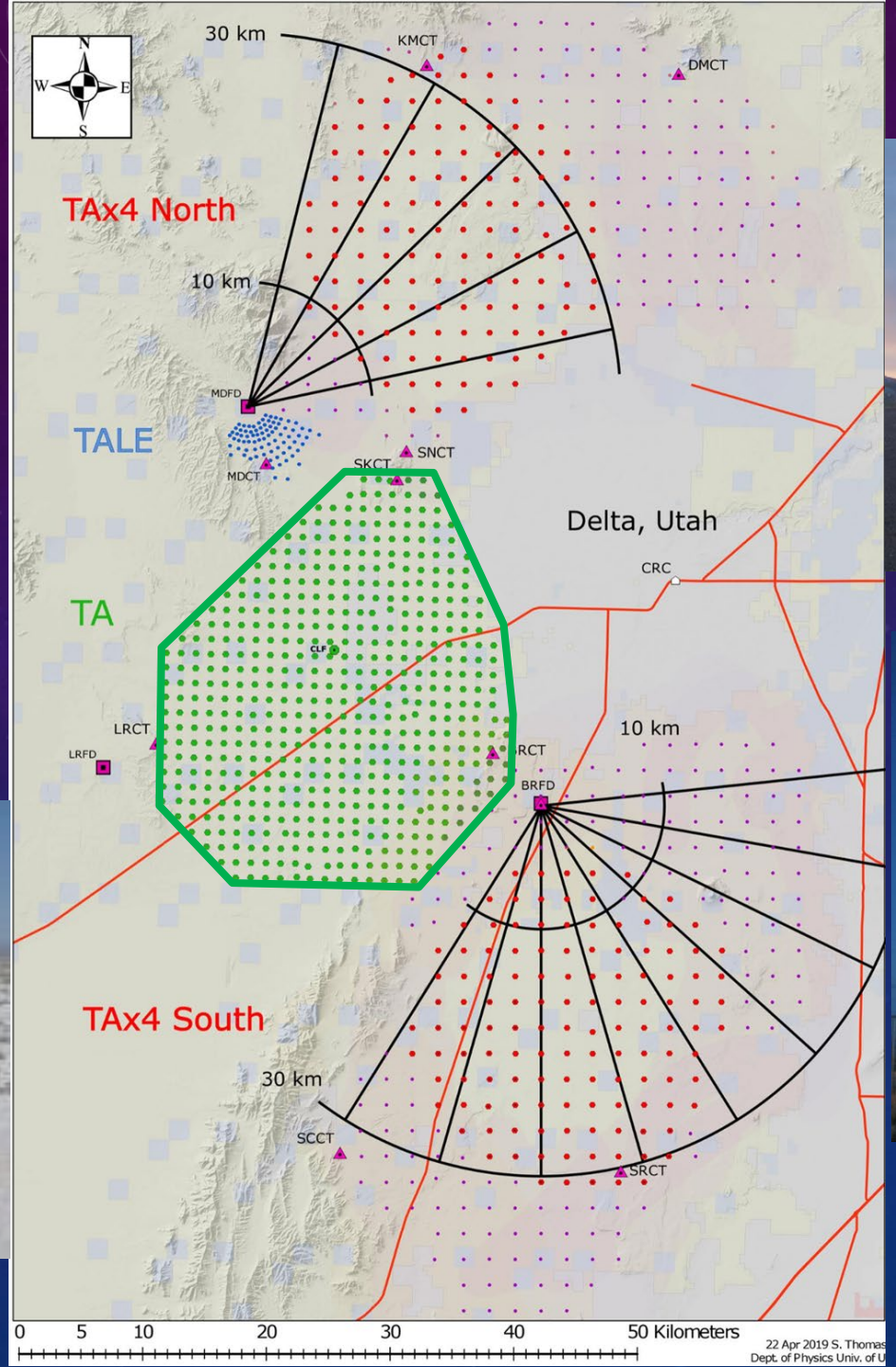
Telescope Array Detectors

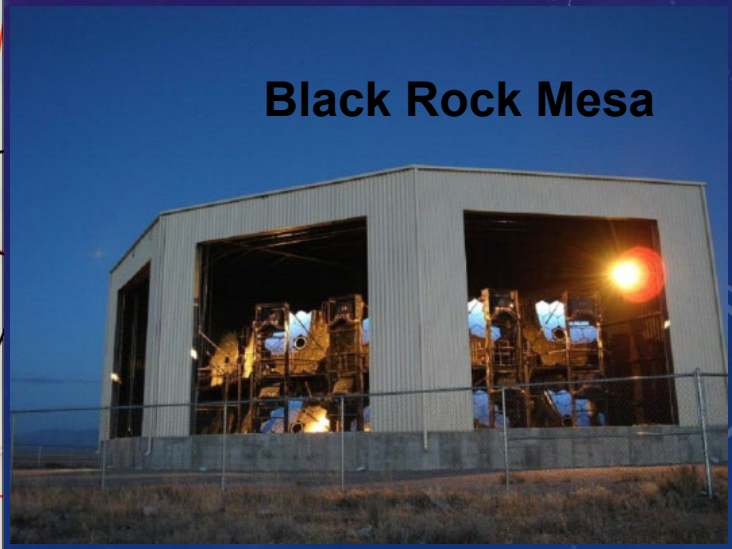
Surface Detector Array (3/2008)

- 507 Scintillator Counters
- 3 m^2 area
- 1.2 km spacing
- ~700 km^2

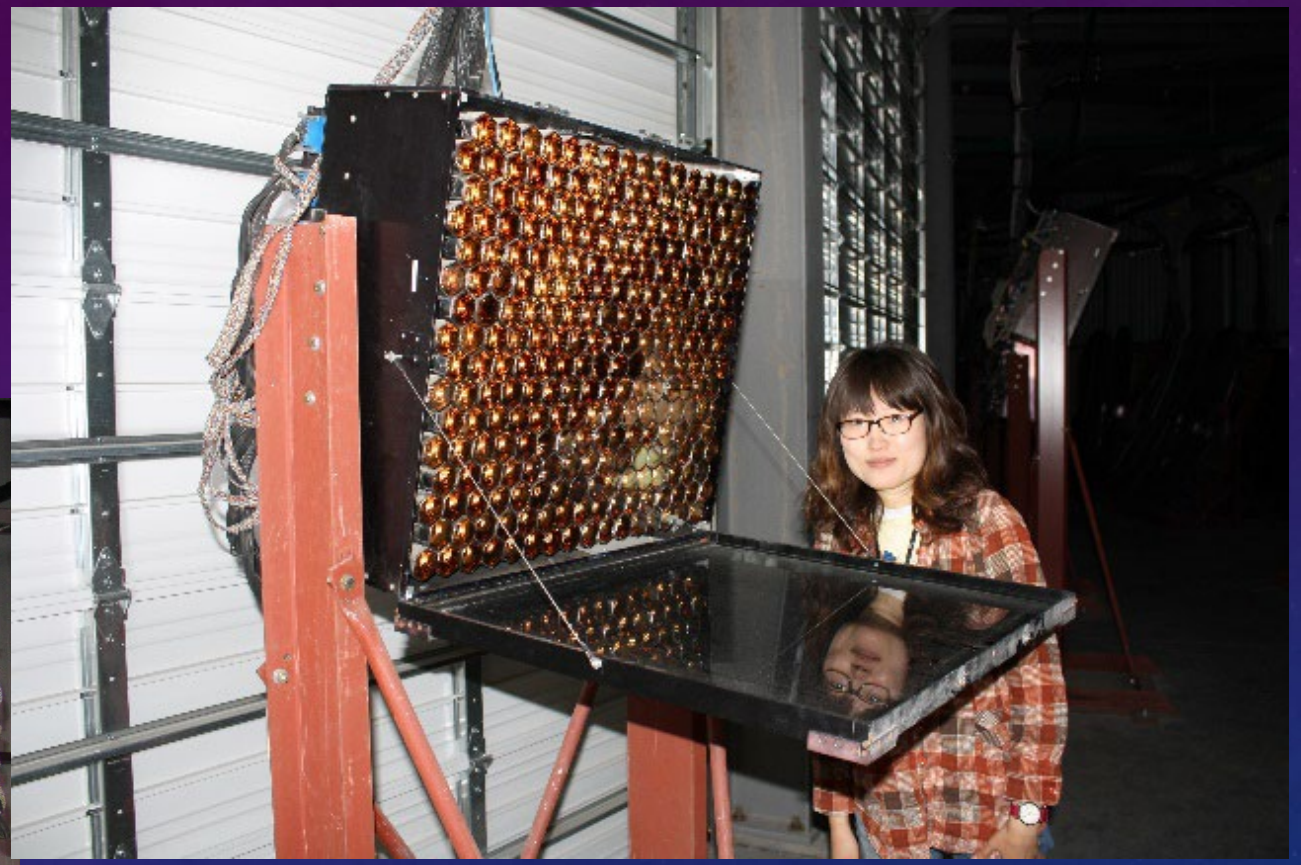
Fluorescence Telescopes (2007)

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





TELESCOPES

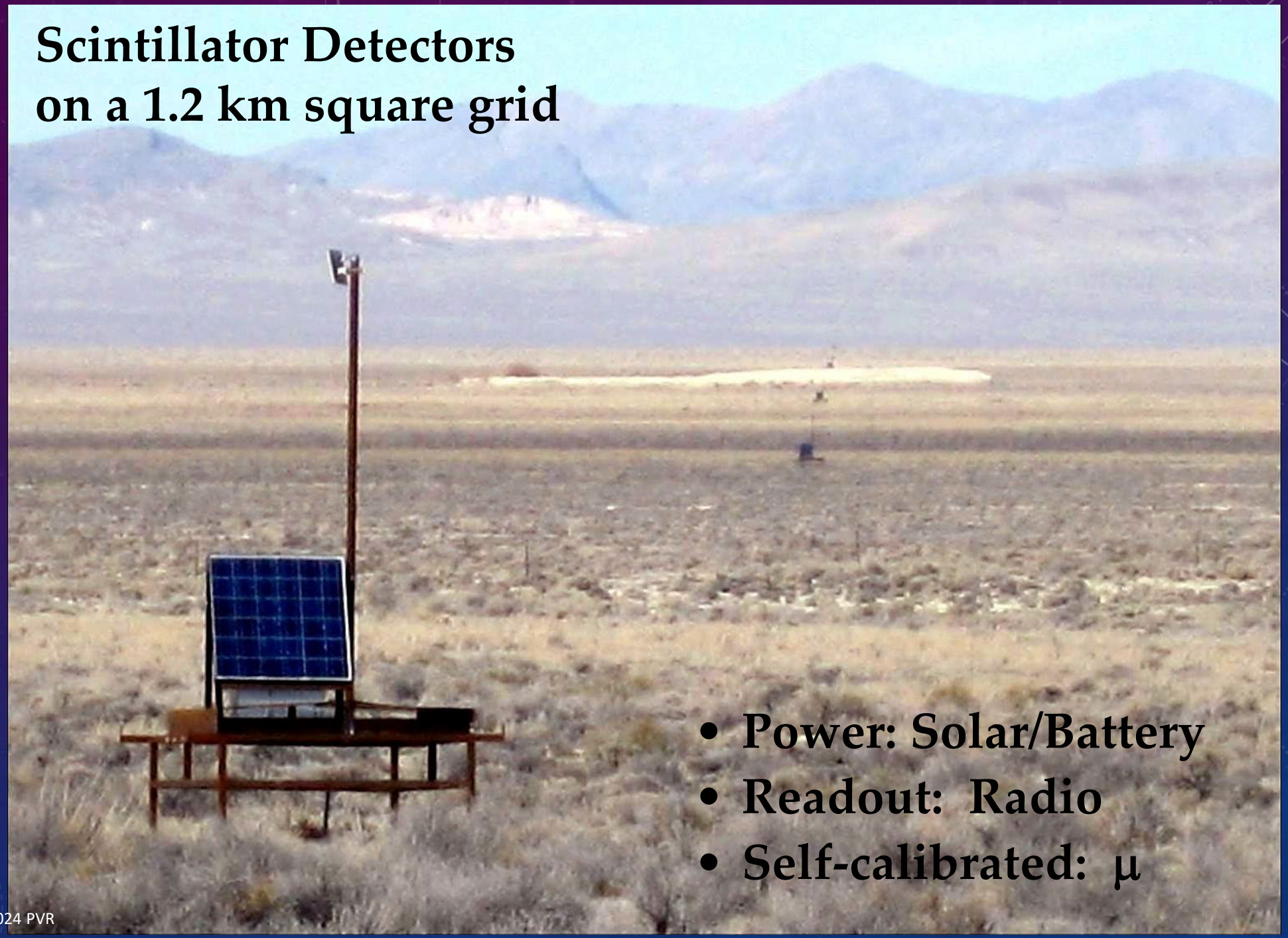


- Segmented mirrors
- 256 hexagonal PMTs/camera
- pixel views ~1° of sky
- UV band-pass filter

SCINTILLATOR SURFACE DETECTORS

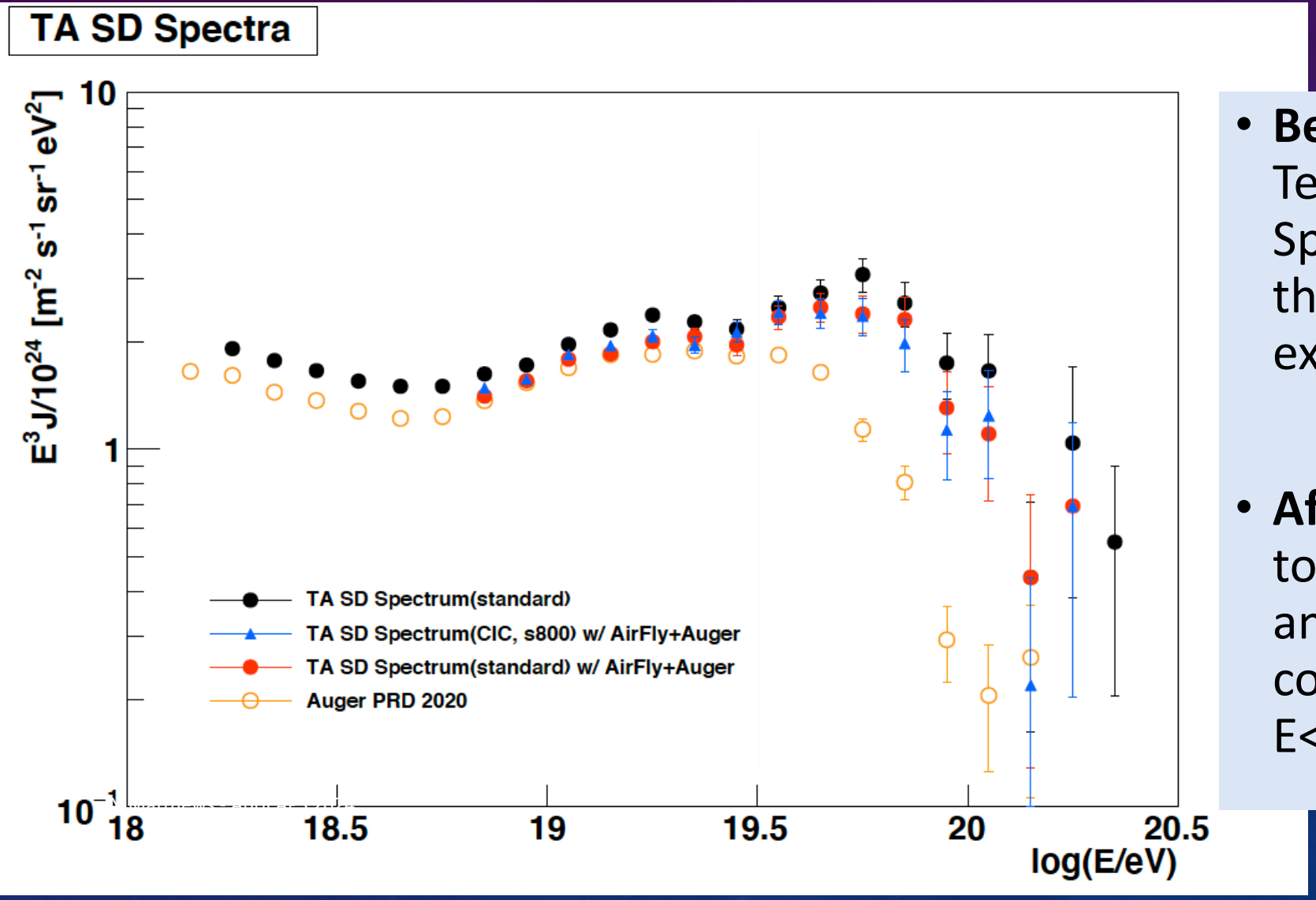
- 2 layers scintillator
- 1.25 cm thick, 3m^2 area
- WS Optical fibers to PMTs

Scintillator Detectors on a 1.2 km square grid



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

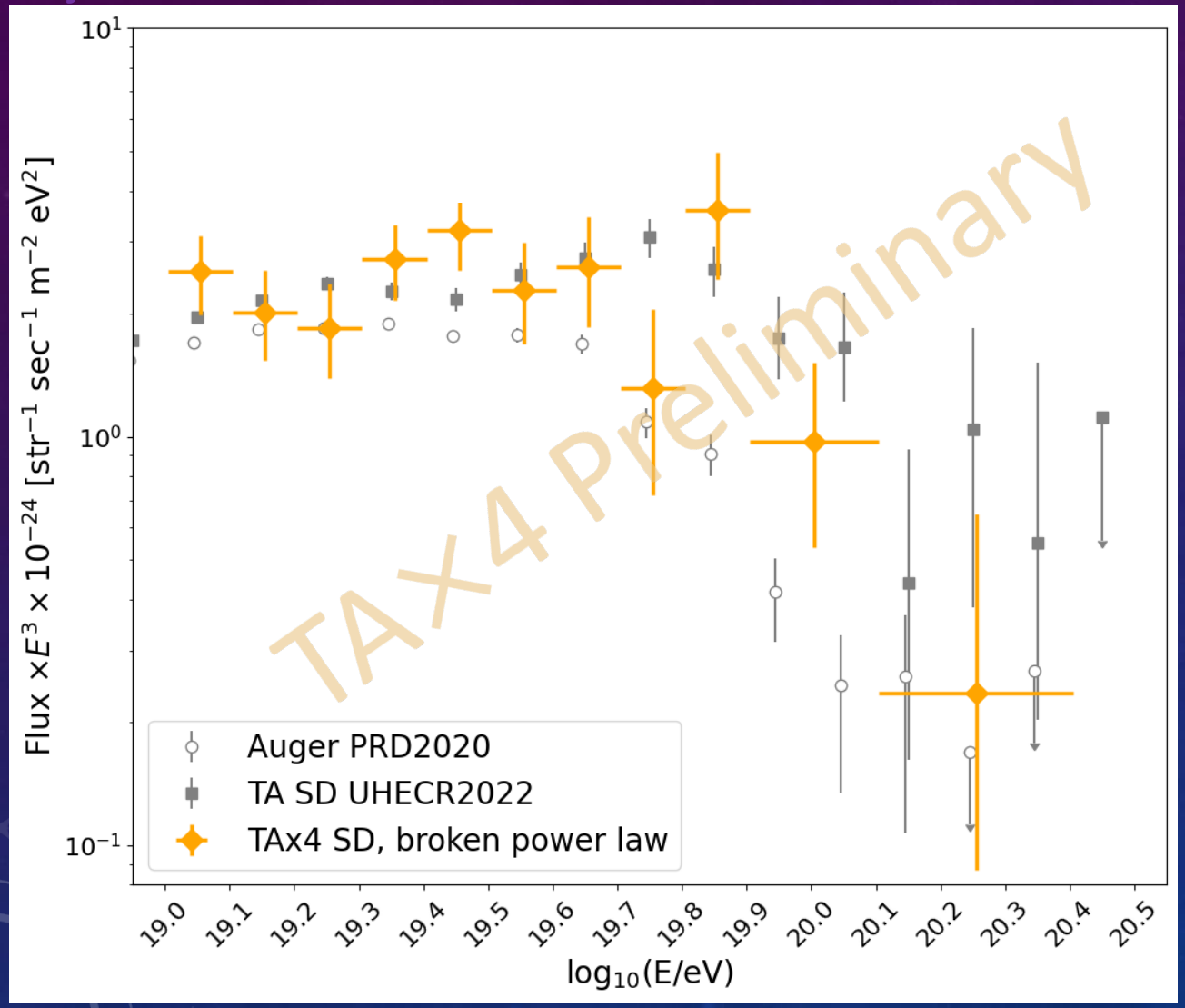
TELESCOPE ARRAY WITH AIRFLY YIELD & AUGER MISSING ENERGY



- **Before**: difference between Telescope Array and Auger Spectra was ~9%, well within the uncertainty of either experiment
- **After** modifying Telescope Array to use AirFly fluorescence yield and Auger missing energy correction, agree ~1%, for E<10^19.5 eV

TA×4 SD ENERGY SPECTRUM

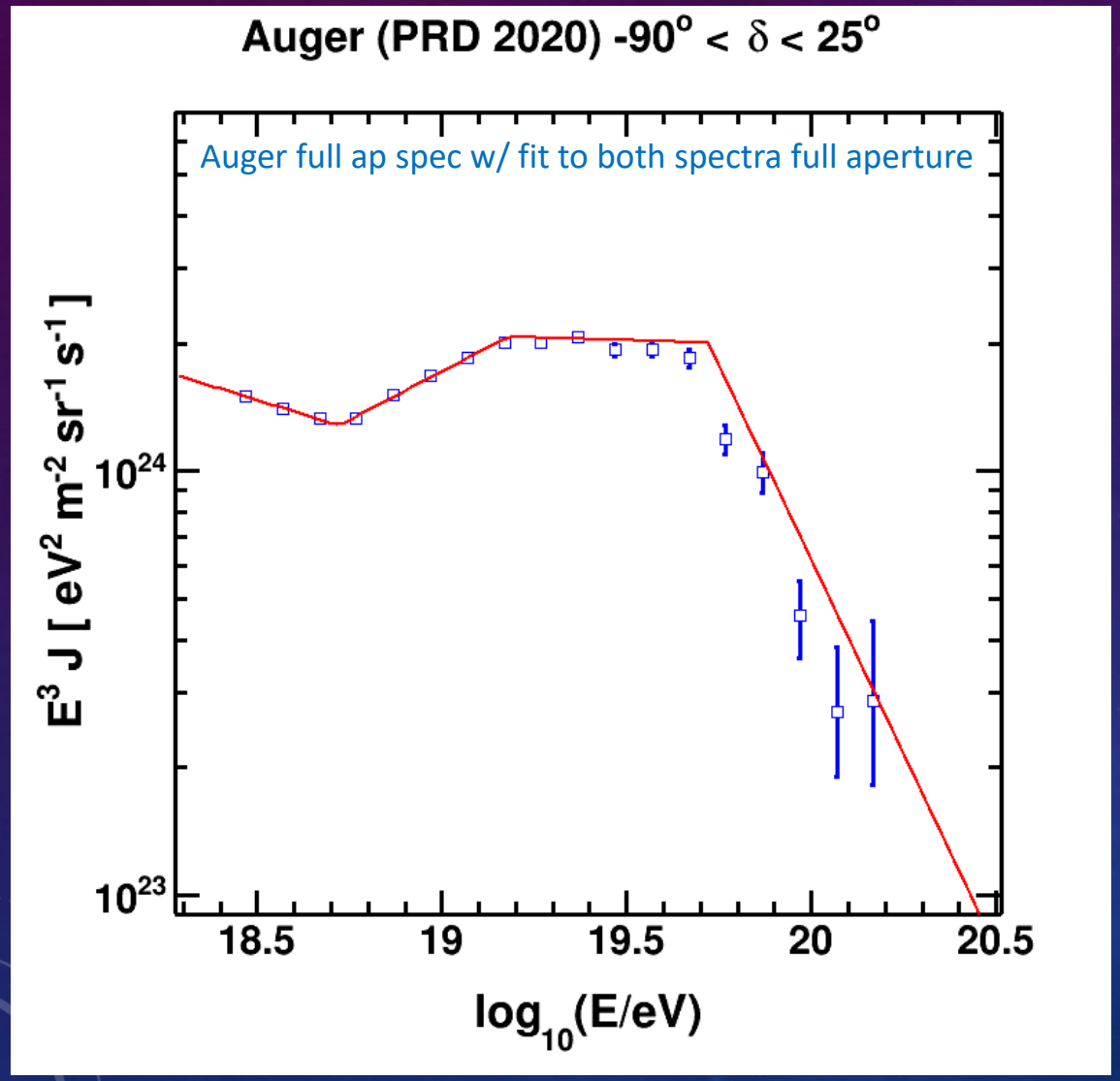
K. Fujisue

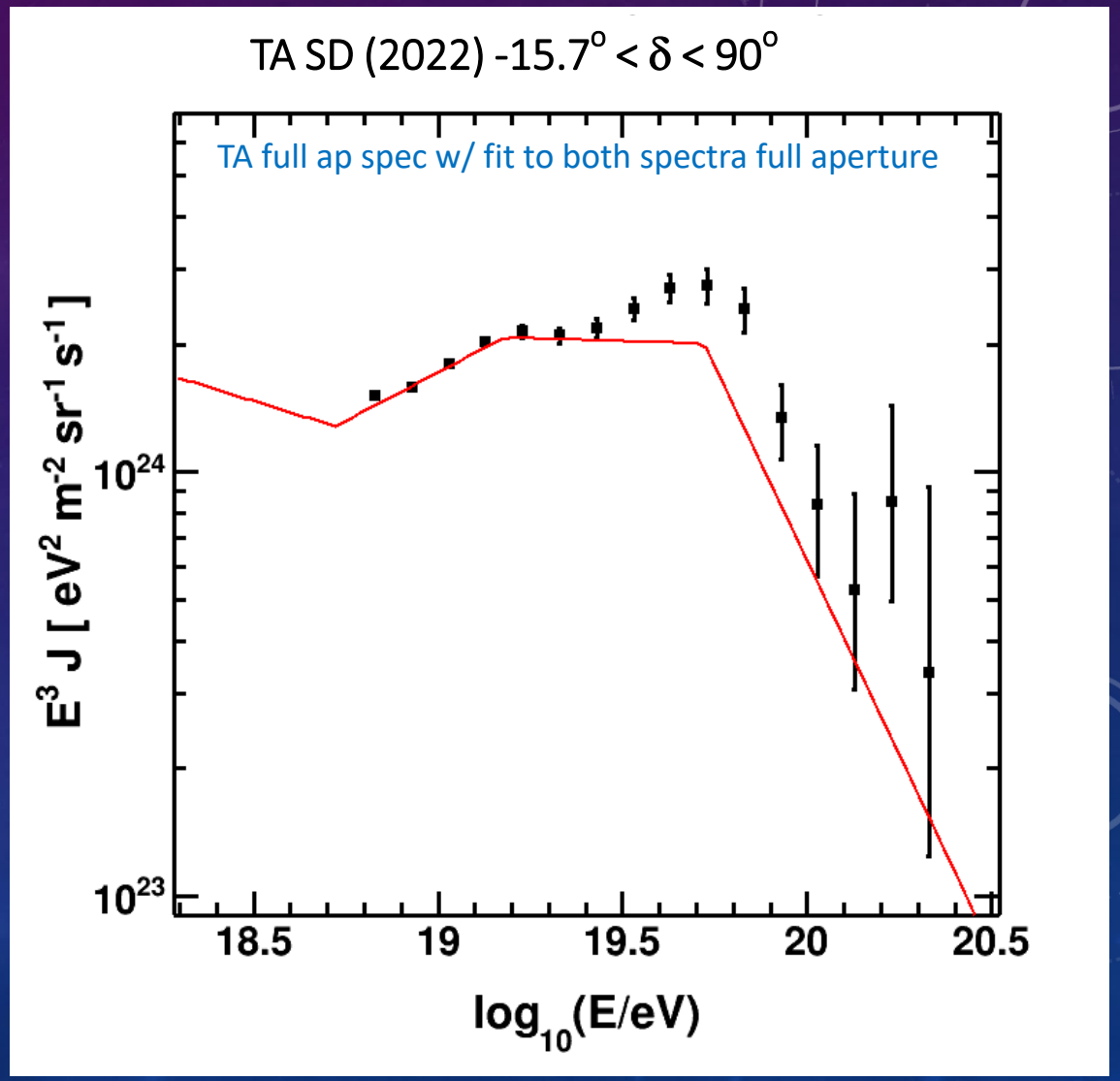


- The energy spectrum was measured by the TA×4 SD using data (3 years: Oct. 2019–Sep. 2022).
- Limited statistics in TAx4 SD start-up due to the absence of the inter-tower trigger system in this period.
- Consistent with the energy spectrum measured by the TA SD array.

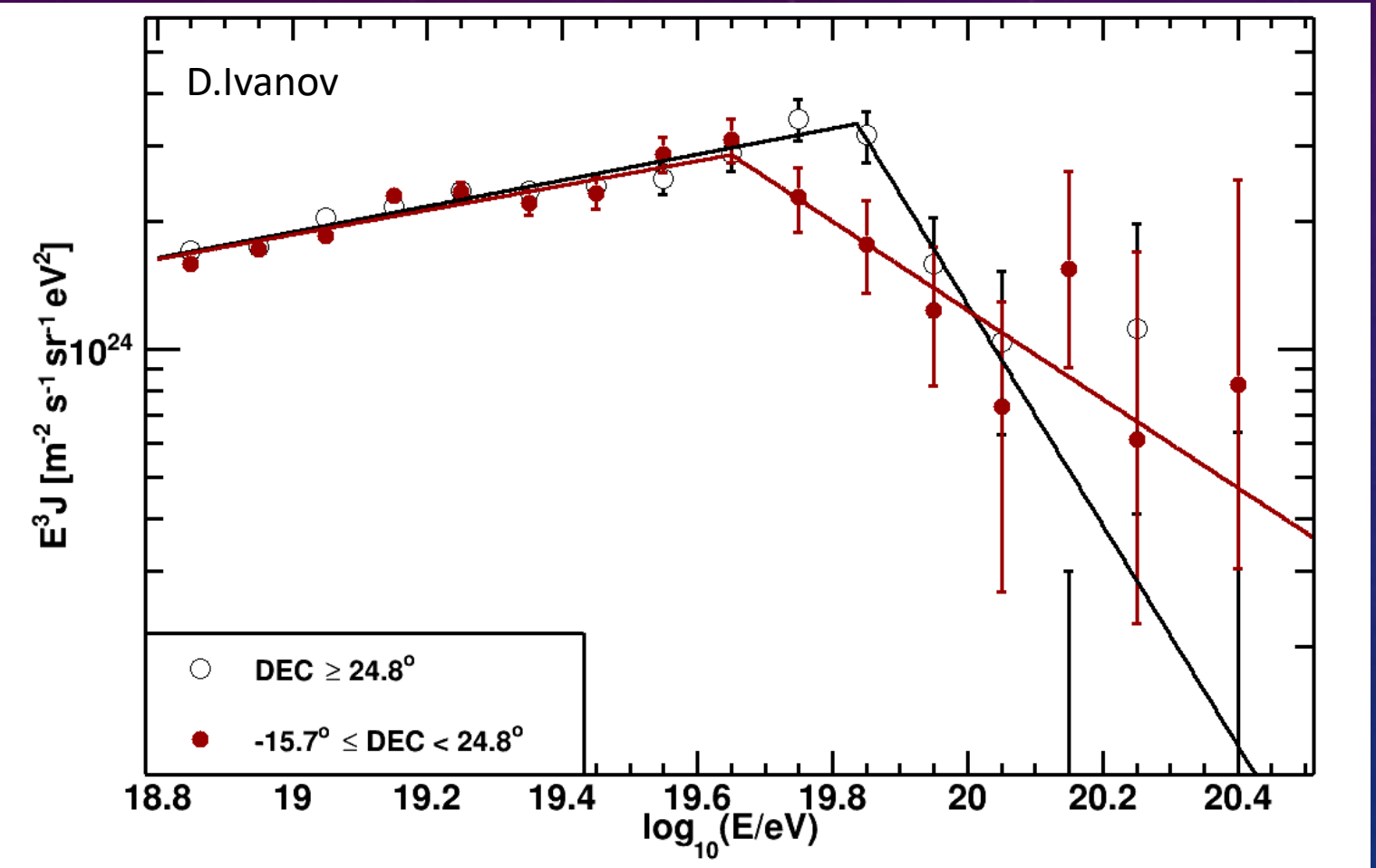
The red line is the same fit function.

FITTING BOTH SPECTRA IN THEIR FULL APERTURES: 8.0σ DIFFERENCE



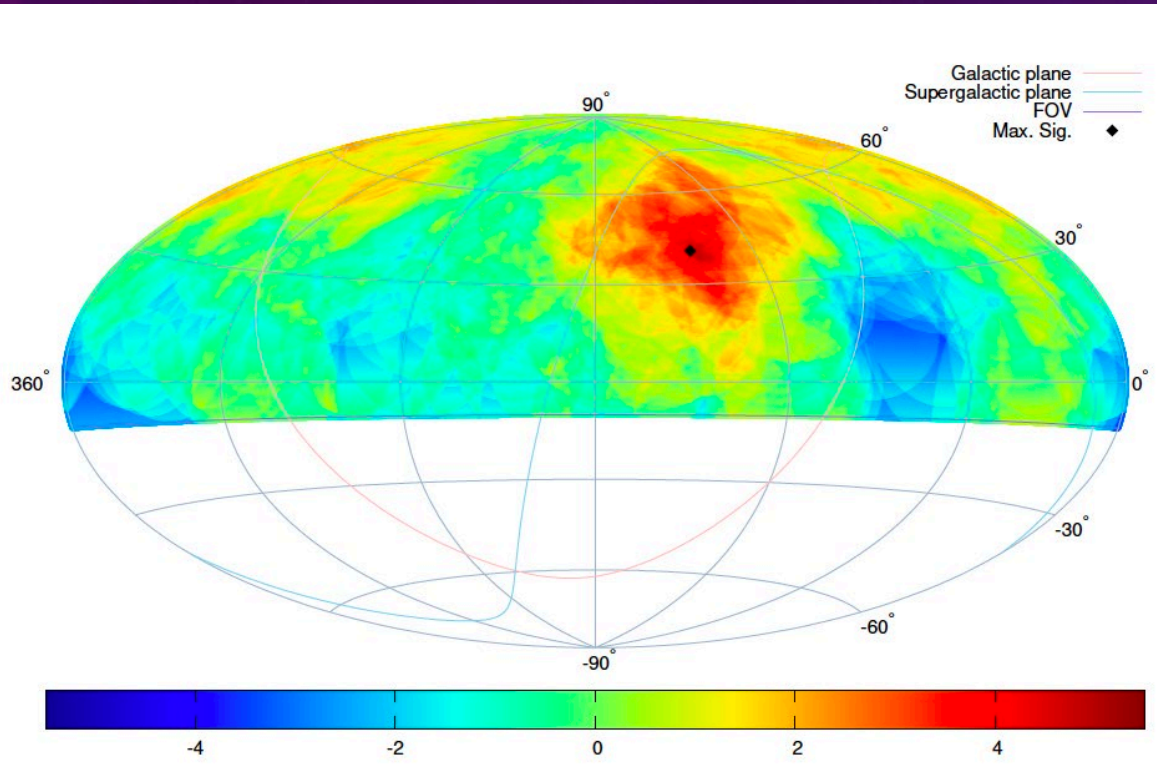


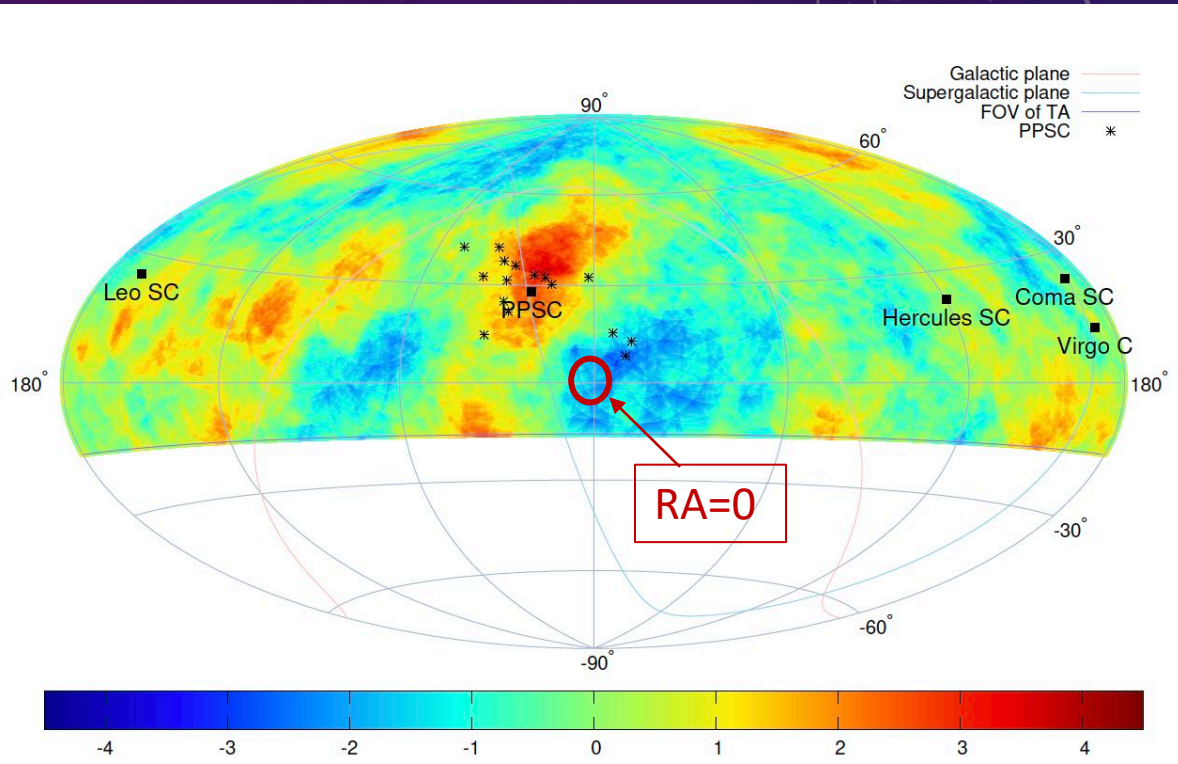
DECLINATION DEPENDENCE IN THE TA SD SPECTRUM



- Differences in the cutoff energies
  - $\log(E/eV)=\mathbf{19.84 \pm 0.02}$ for higher declination (24.8°–90°)
  - $\log(E/eV)=\mathbf{19.65 \pm 0.03}$ for lower declination (-16°–24.8°)
- The local significance is **4.8σ.**
- The global significance of the difference is estimated to be **4.4σ.**
- No instrumental causes were found.

ANISOTROPY SIGNAL/EXCESS REGIONS IN TELESCOPE ARRAY DATA (14 YRS)





J.H.Kim

TA Hotspot

$E > 10^{19.75}$ eV

3.2σ post-trial

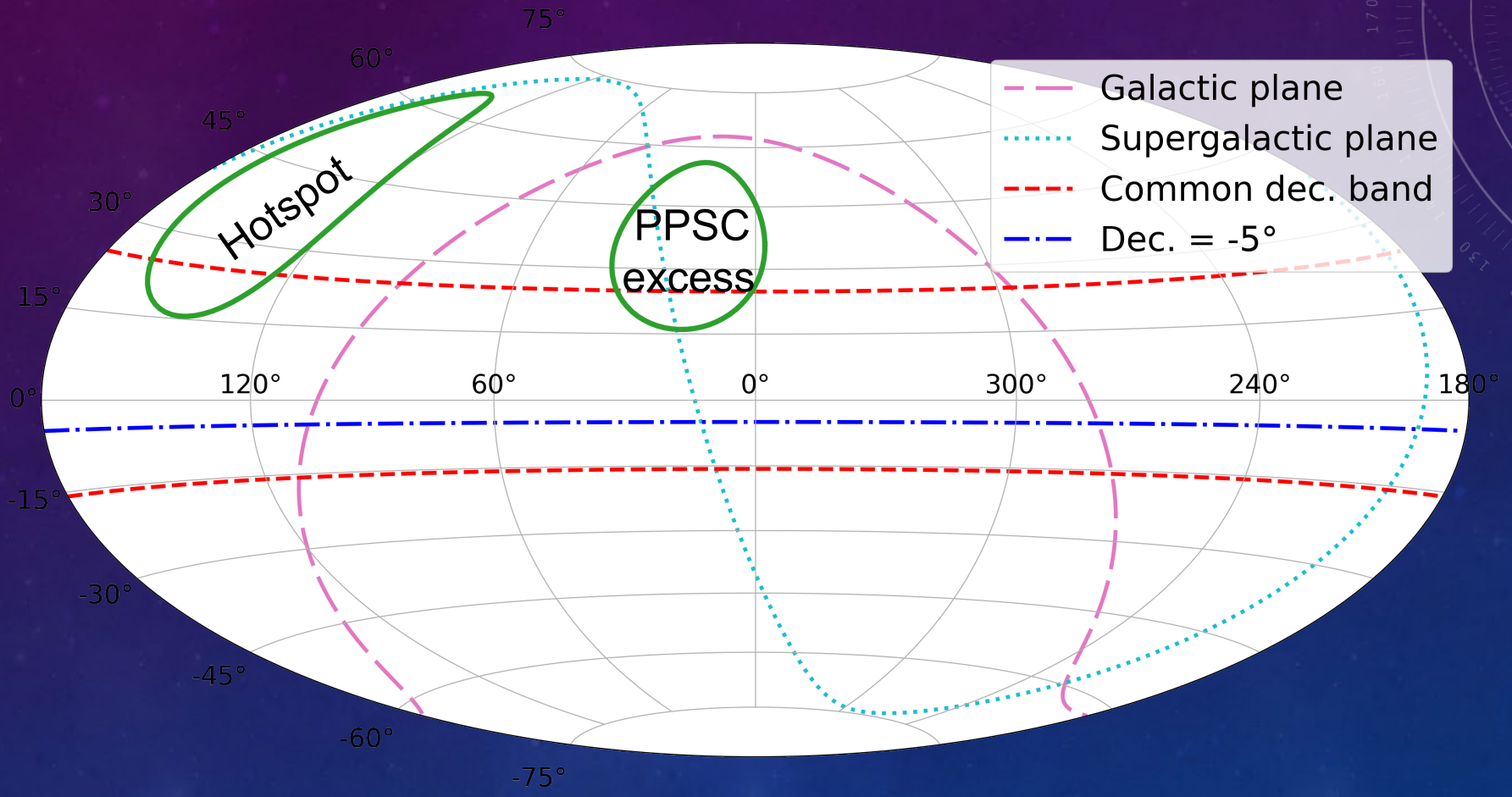
(brightness not sustained recently)

Perseus-Pisces SC

$E > 10^{19.4}$ eV

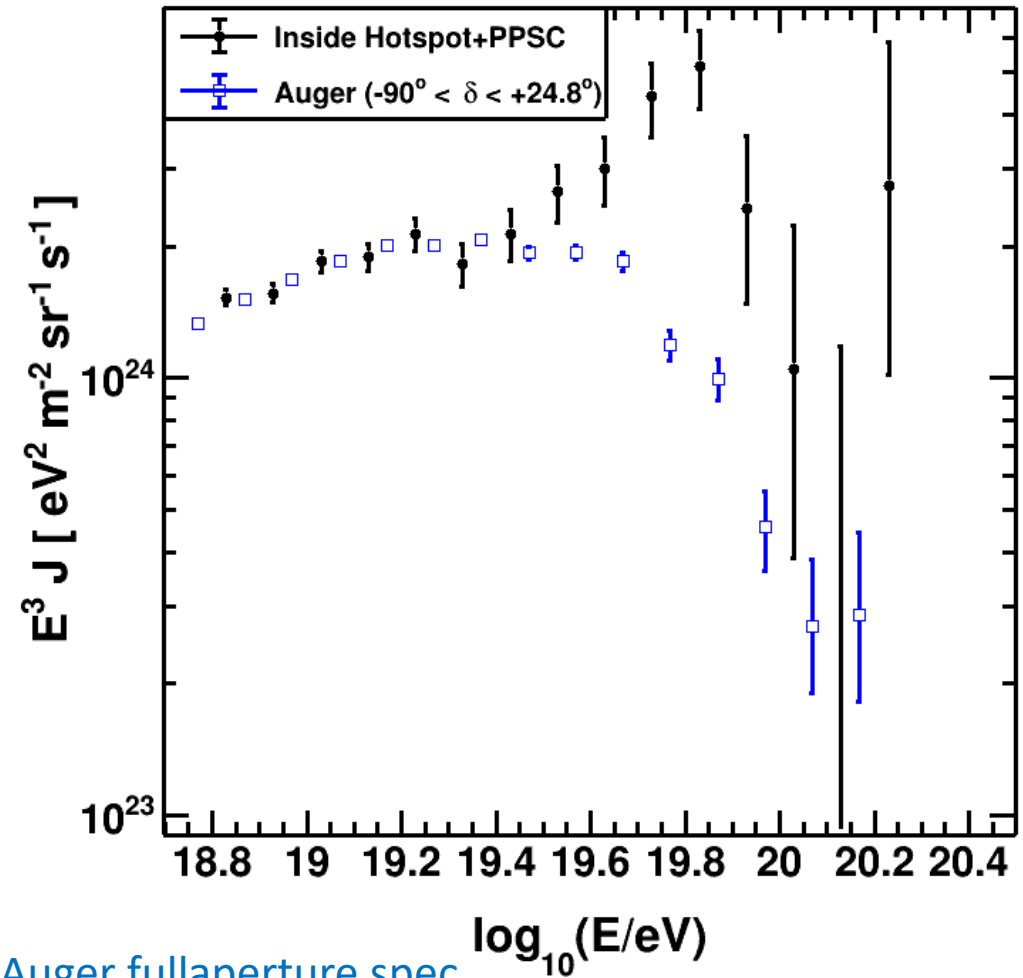
4.0σ local

FIGURE 4: SKY MAP IN EQUATORIAL COORDINATES



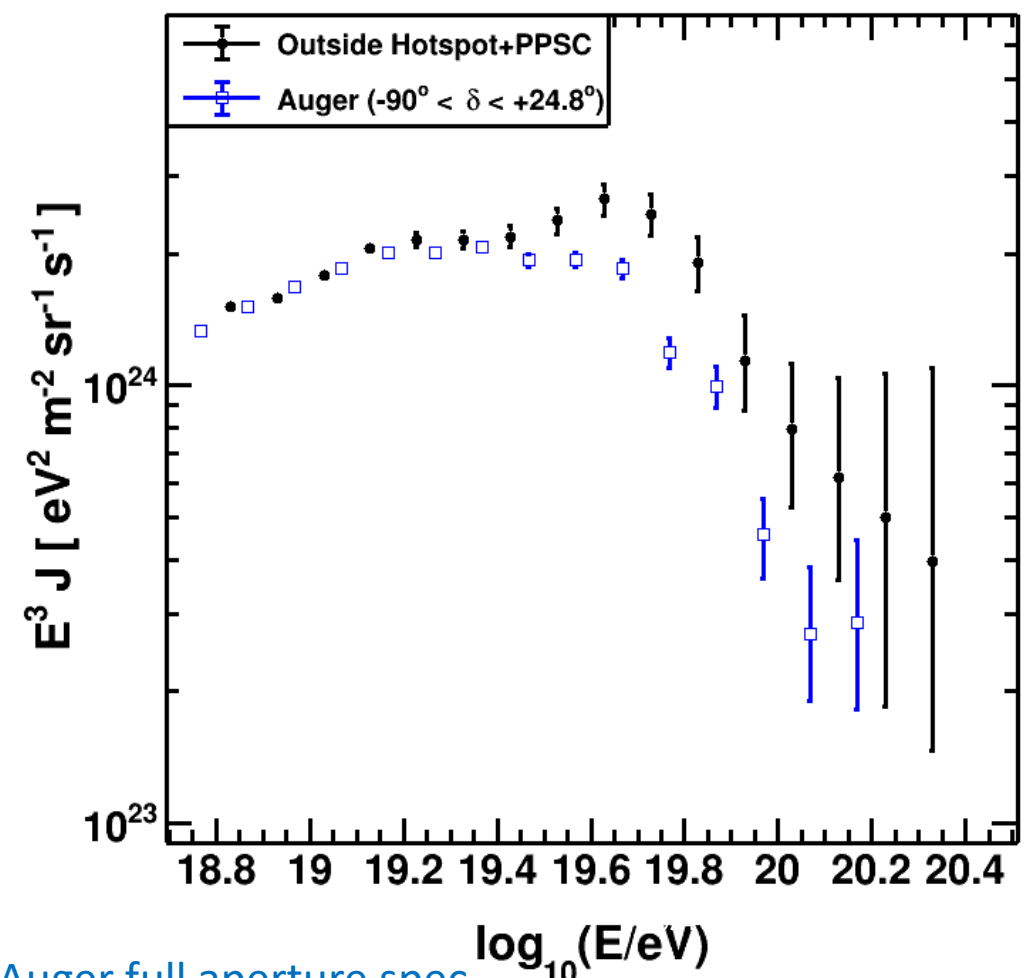
TA INSIDE/OUTSIDE HOTSPOT+PPSC

Telescope Array INSIDE the Excesses



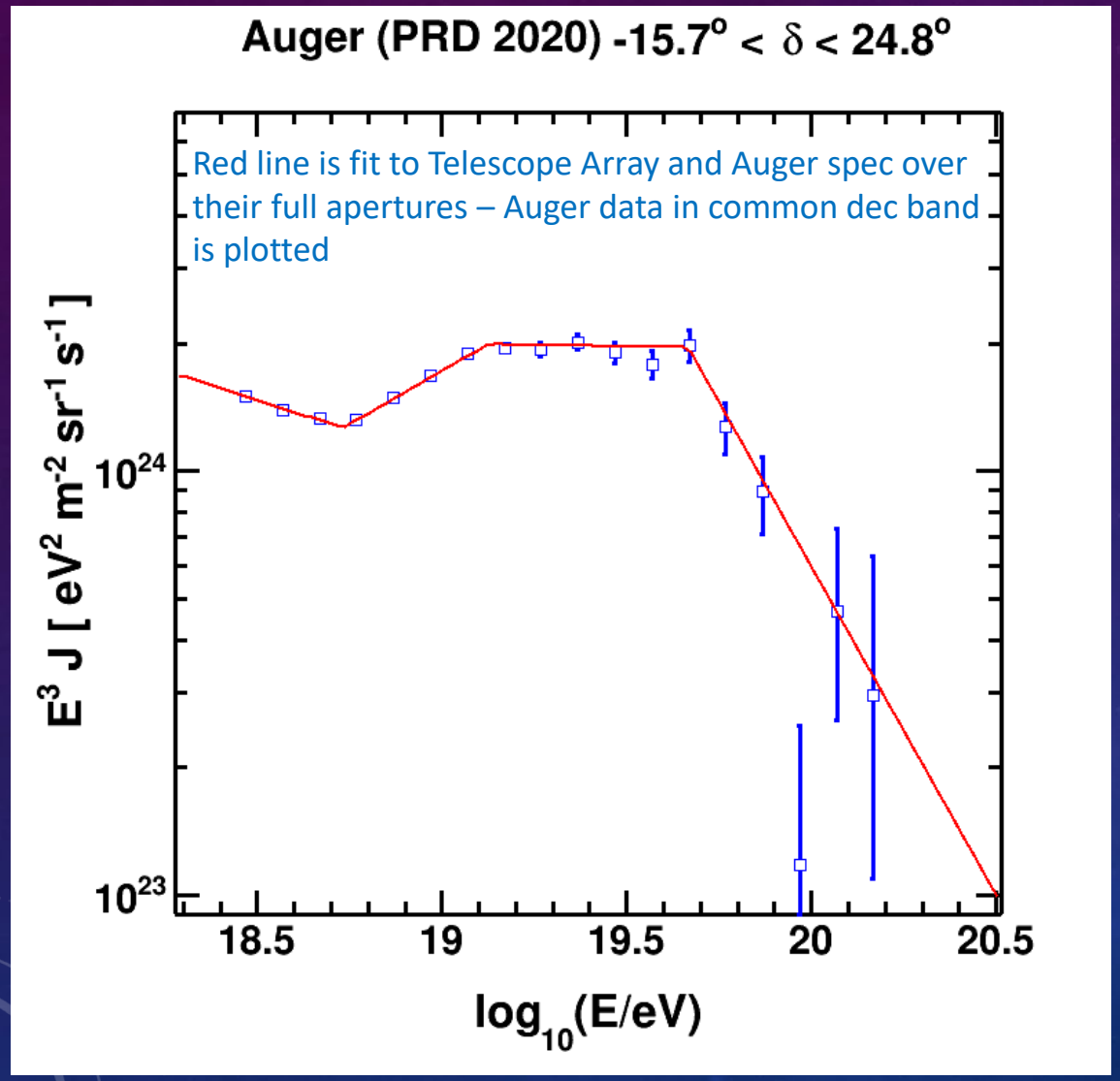
Auger fullaperture spec

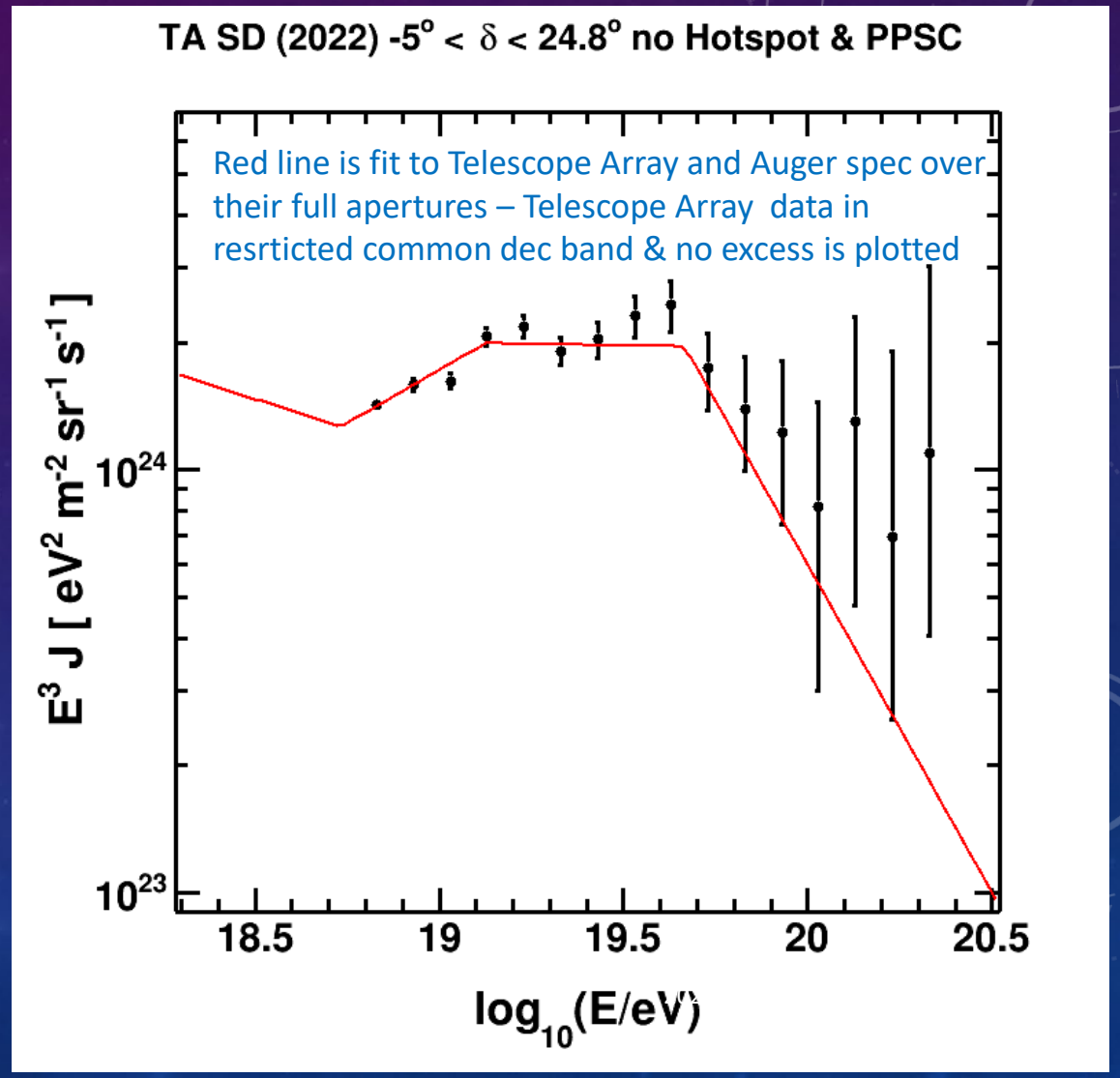
Telescope Array OUTSIDE the Excesses



Auger full aperture spec

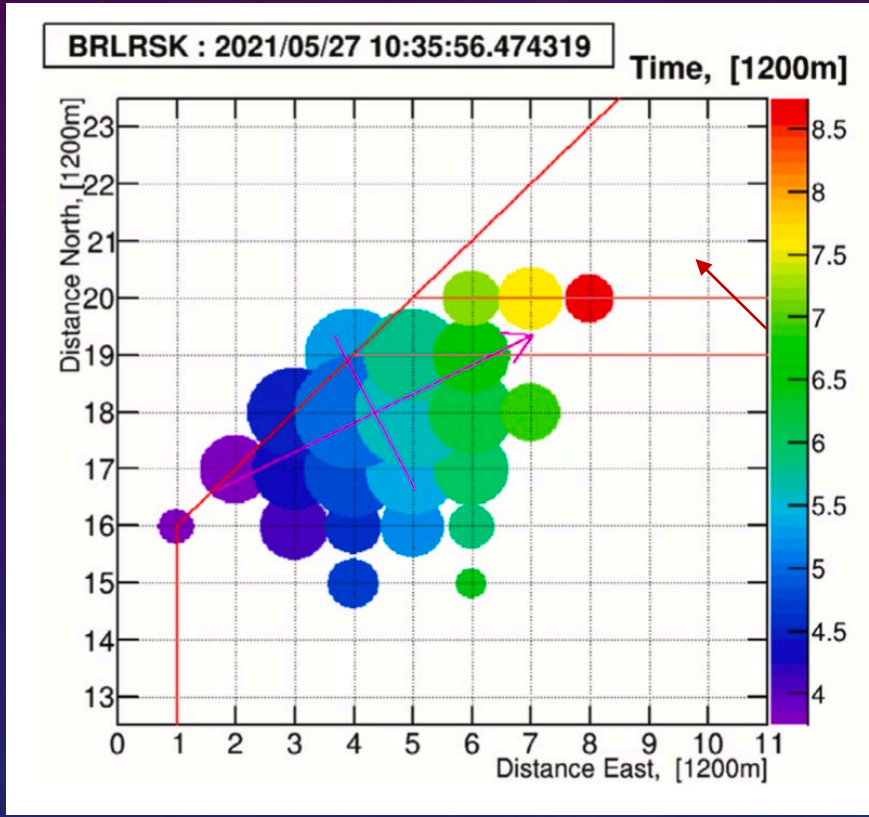
FITTING BOTH SPECTRA, TA -5°≤δ<24.8° & EXCL. HOTSPOT + PPSC: **1.8σ**

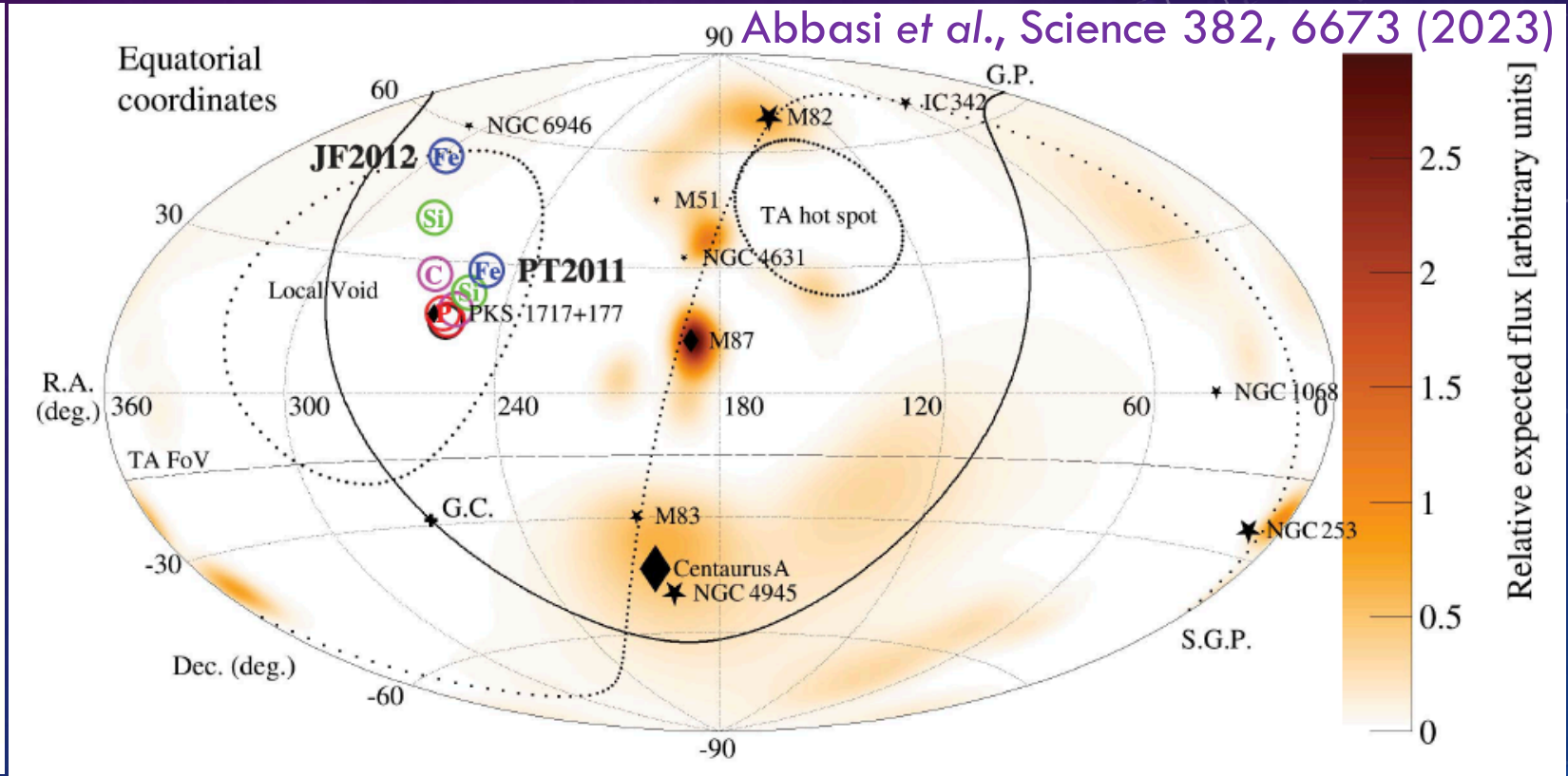




EXTREMELY ENERGETIC COSMIC RAY OBSERVED BY TA

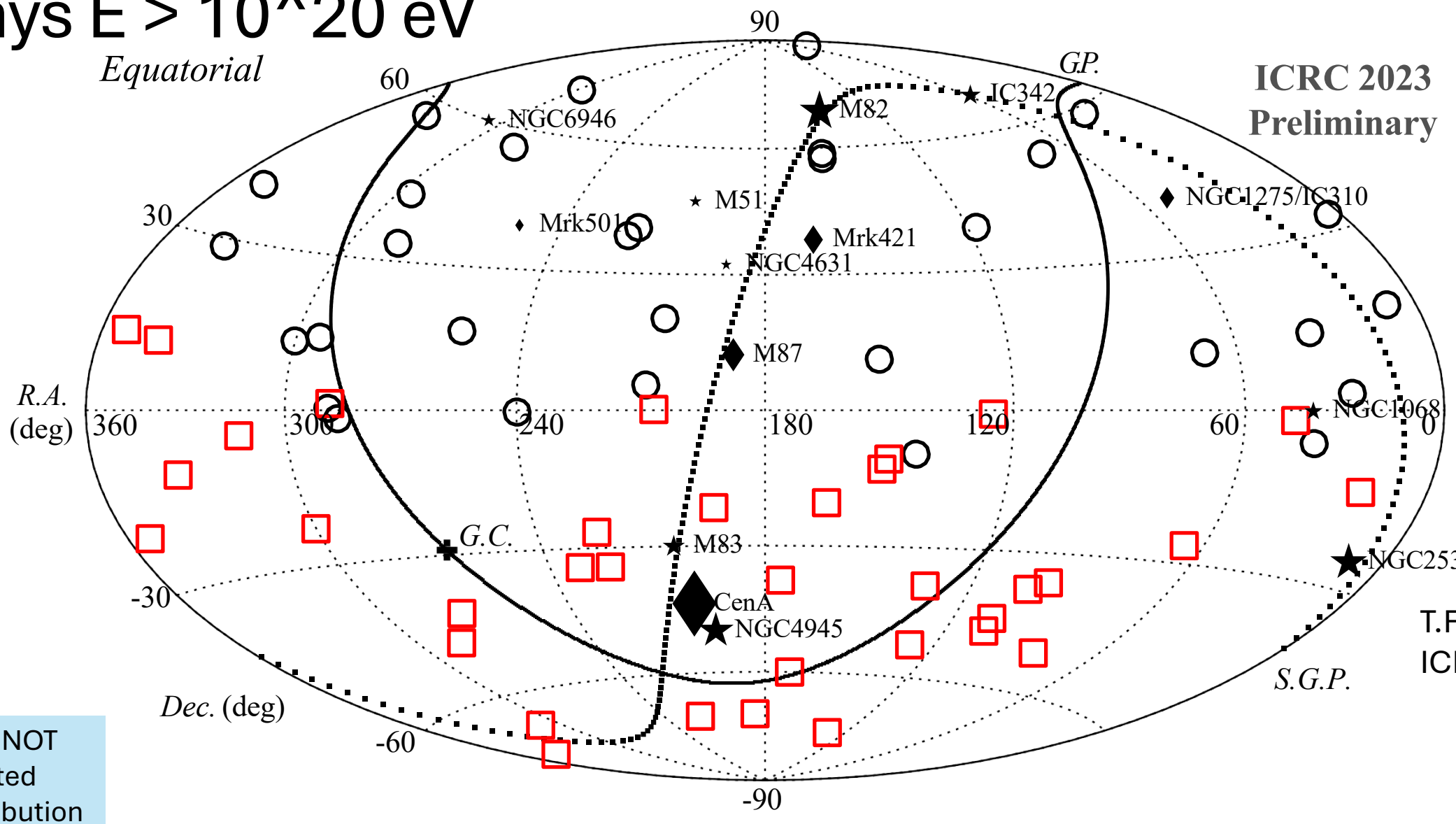
- 2021-05-27 10:35:56 UTC, No FD observation
- E = 244±29 EeV in the direction of (255.9°,16.1°) in the equatorial coordinates





Ultra-high energy cosmic rays E > 10^20 eV

No Obvious Sources



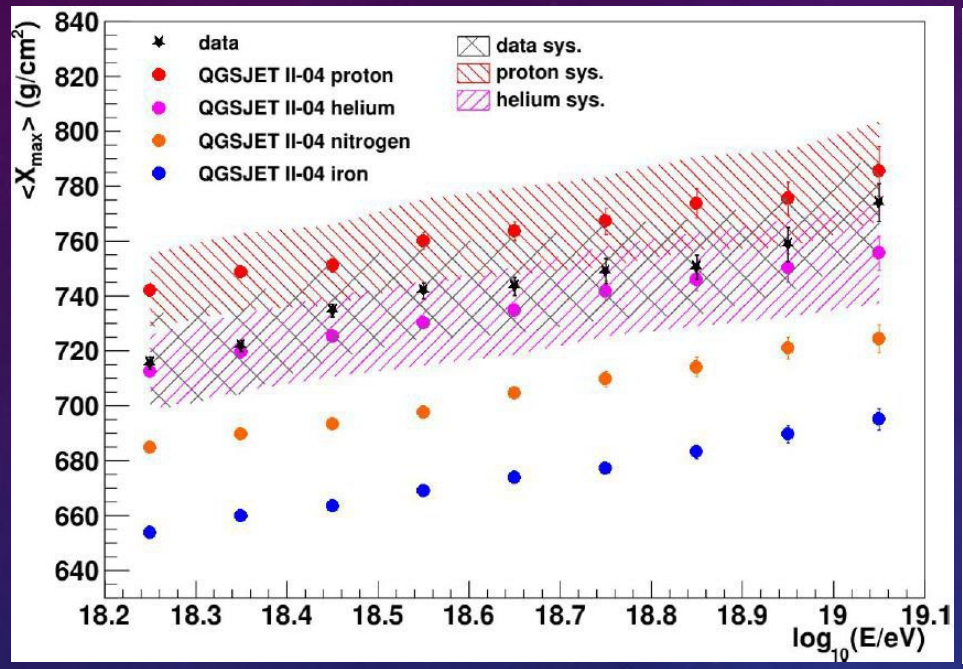
T.Fujii, ICRC2023

HE events do NOT seem correlated with the distribution of matter

TA 15-years (ICRC2023 Preliminary), Auger 17-years (ApJ 935 170 (2022))

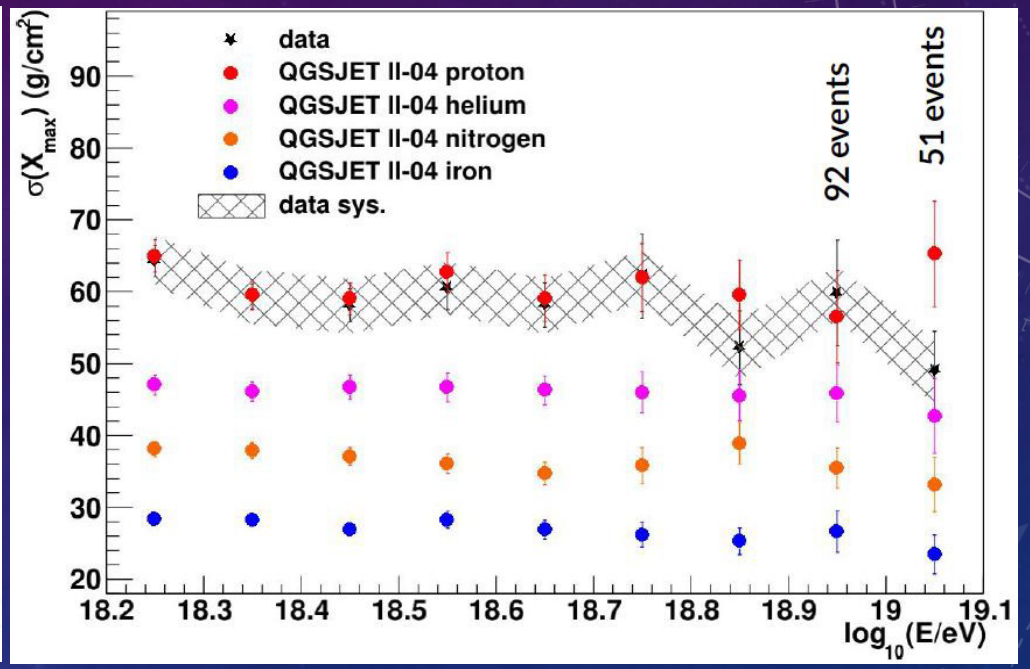
COMPOSITION ANALYSIS WITH TA HYBRID XMAX

Mean Xmax



10 years SD and FD hybrid data

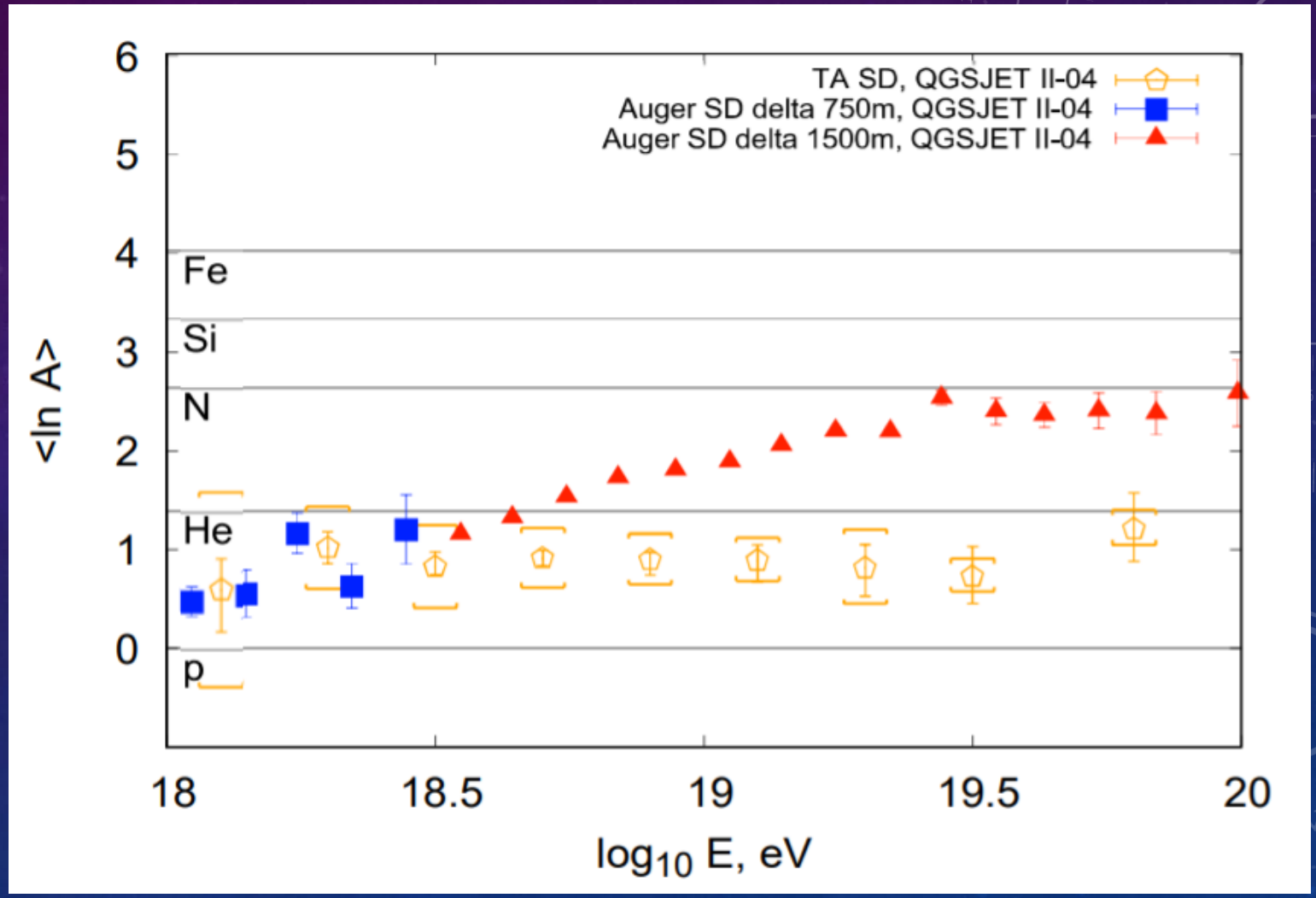
σ (Xmax)



- Energy Range: $10^{18.2}$ eV – $10^{19.1}$ eV
- 3560 events after the quality cuts
- Systematic uncertainty of <Xmax>: ± 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
- Also working on more models

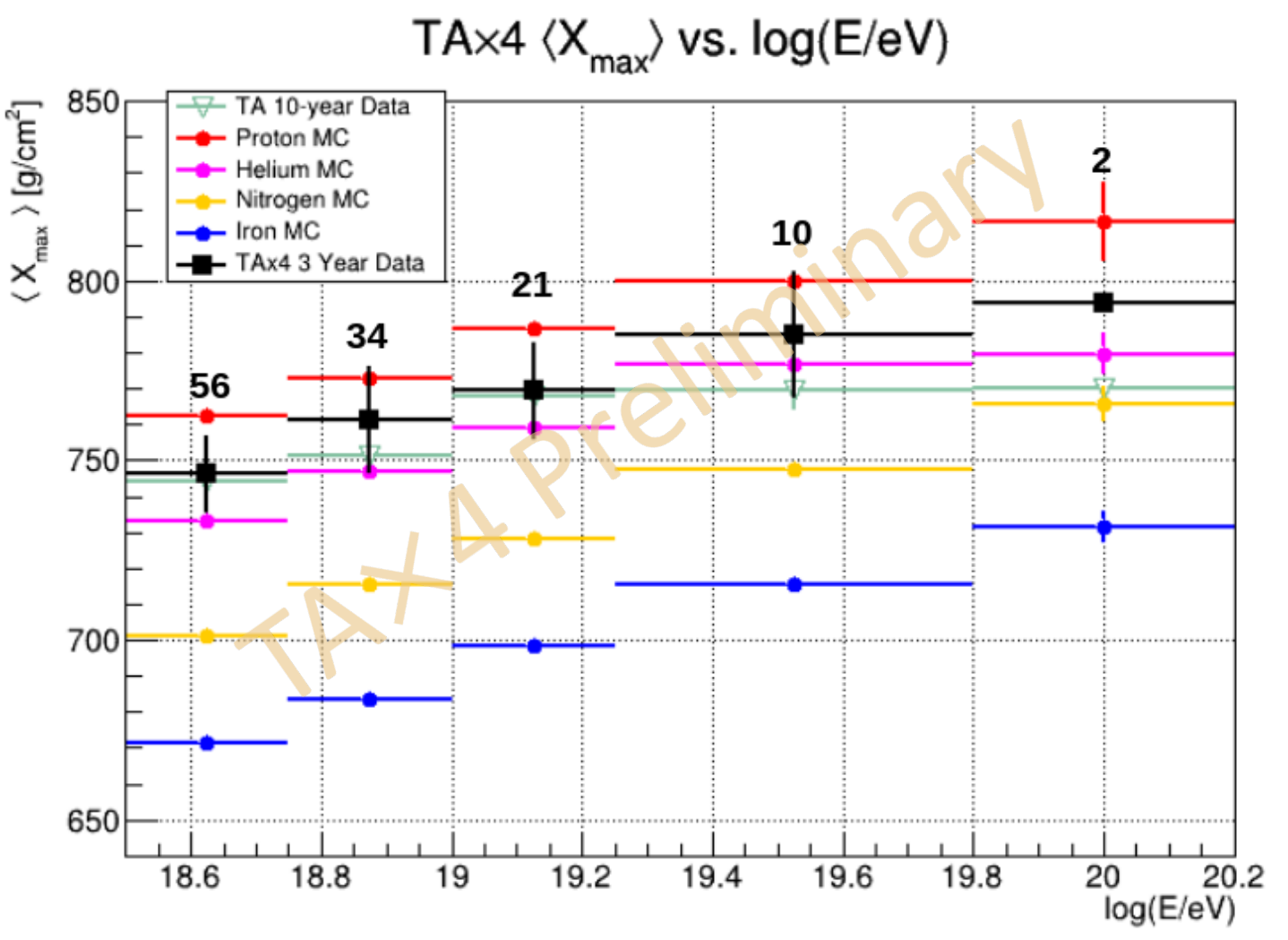
COMPOSITION

- 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



TA×4 HYBRID 3 YEARS OF DATA (NOVEMBER 2020–DECEMBER 2023)

Z. Gerber, APS April 2024

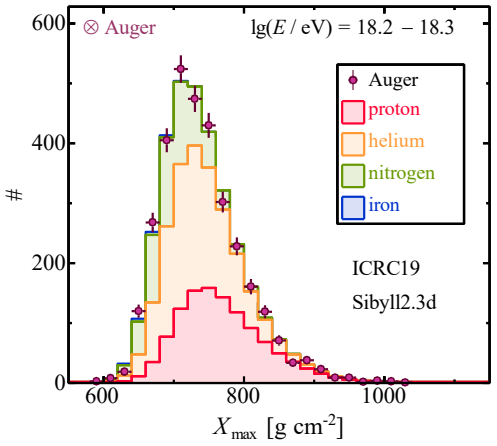


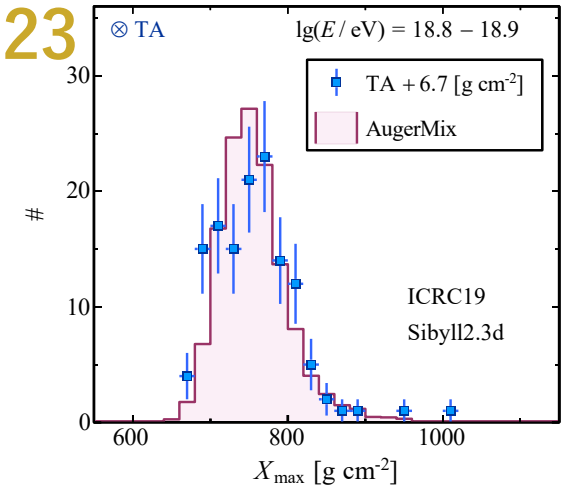
- $\langle X_{max} \rangle$ values vs energy for ~3 years data
- Compared to QGSJET II-04 Monte Carlo simulation distributions
- Point to a composition that is light and unchanging $10^{18.6}$ to 10^{20} eV
- Consistent with previous TA and HiRes results

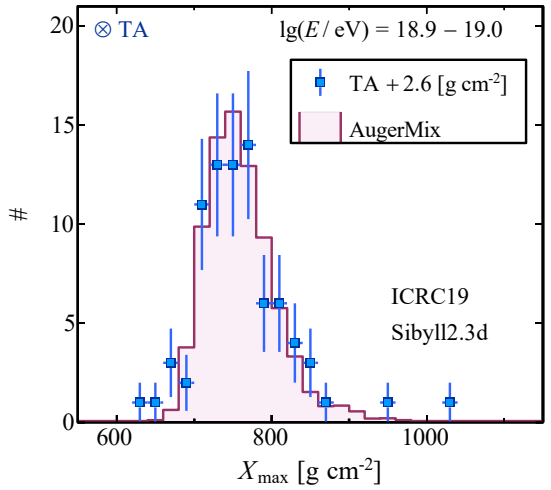
Auger-TA composition WG

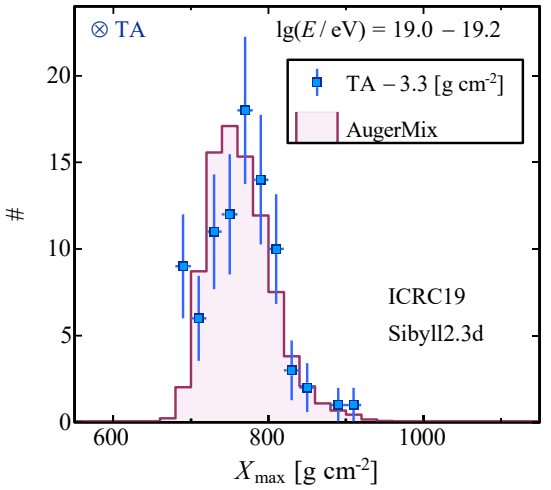
A. Yushkov ICRC2023

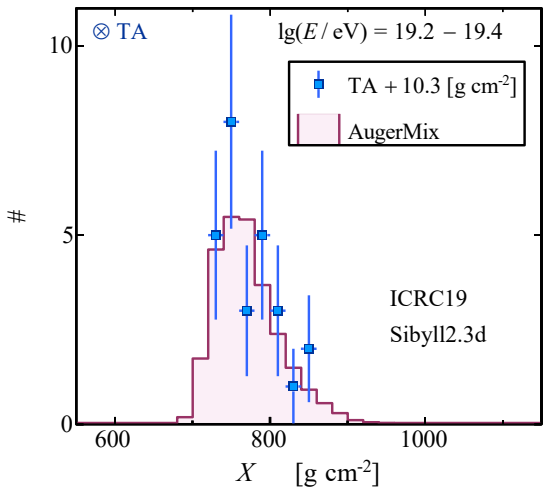
Combine (p, He, N, Fe) of Sibyll 2.3d to fit Auger X_{max} distributions

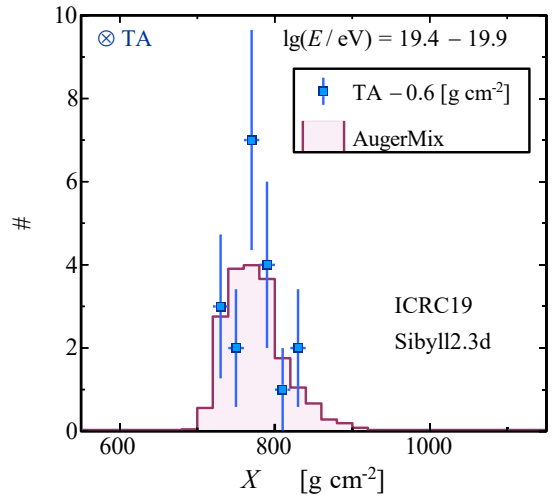


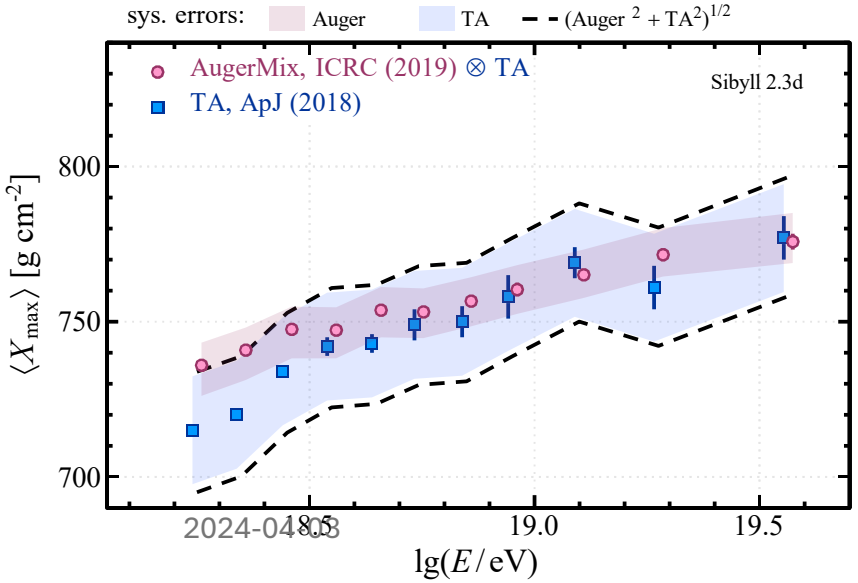








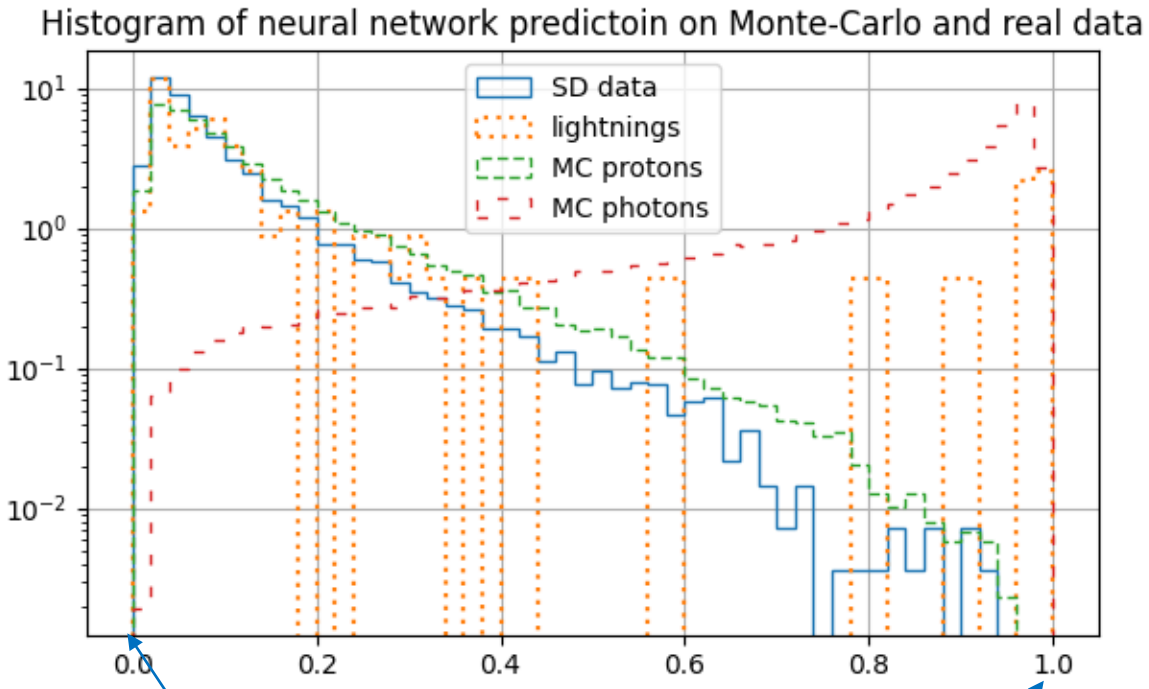


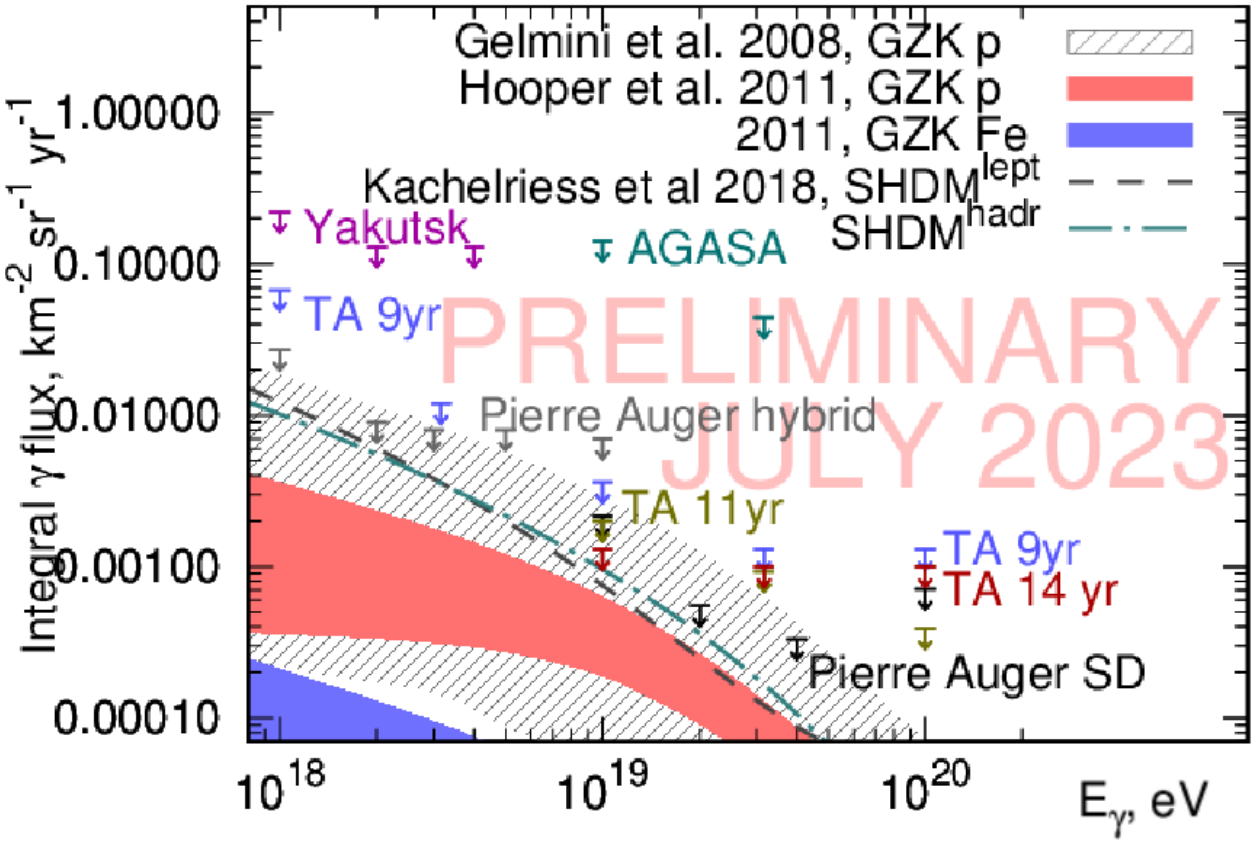


Auger and Telescope Array measurements are compatible at the current level of statistics and understanding of systematics

Telescope Array SD UHE Photon Search

- Neural network trained to classify protons and photons



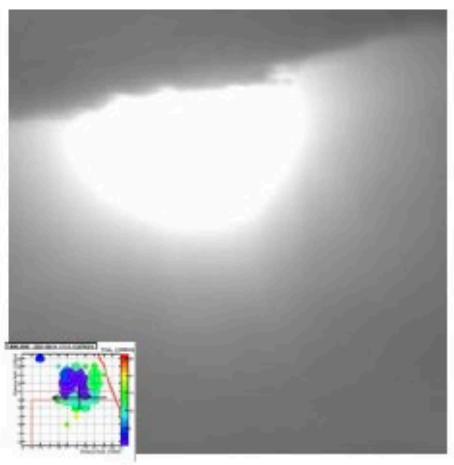


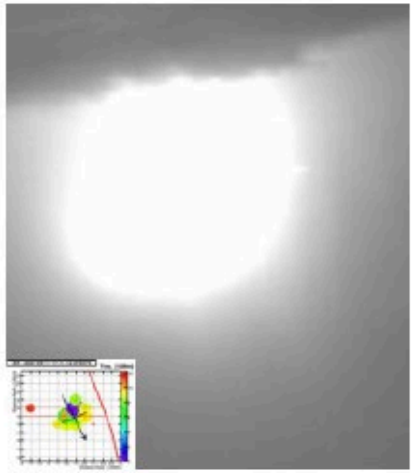
Estimation of the photon flux

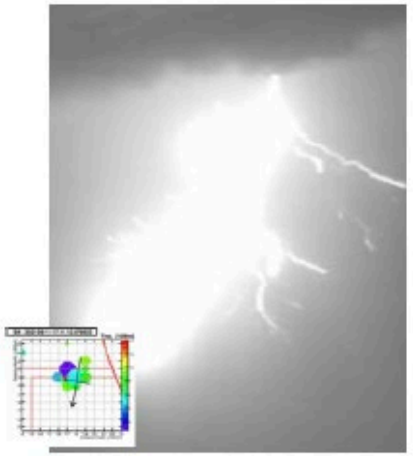
Telescope Array and Auger have searched for photons and neutrinos in their data and observed neither – setting limits

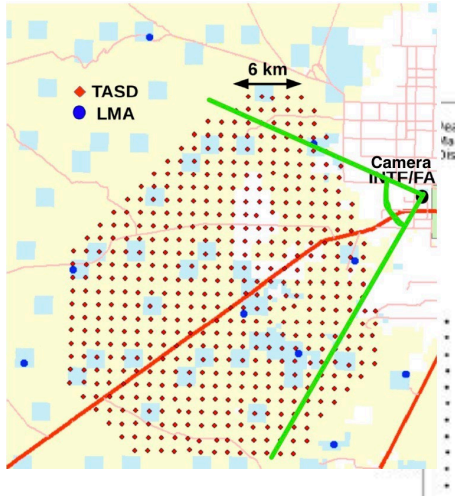
Observation and study of Terrestrial Gamma-Ray Flashes with Telescope Array SD

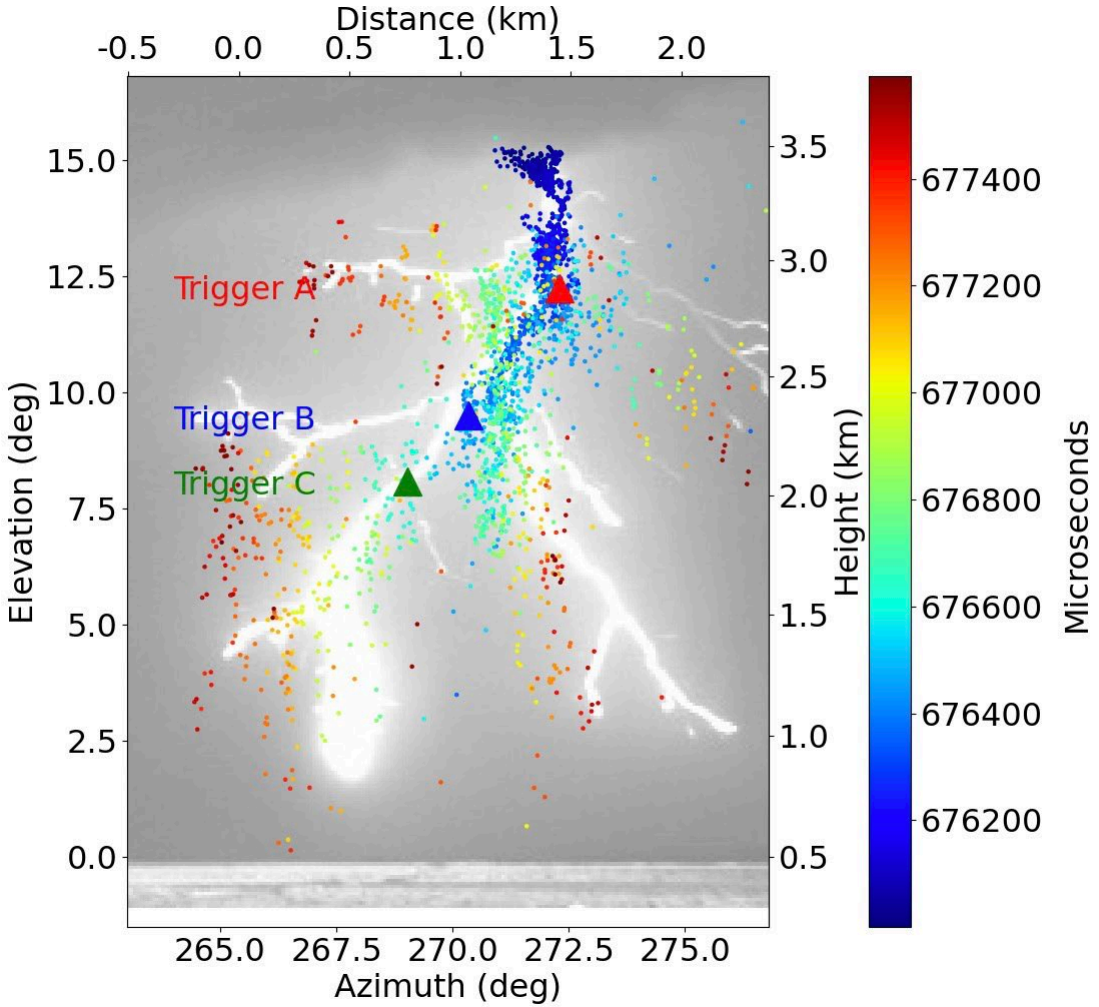
Rasha Abbasi, ICRC2023











SUMMARY – RESULTS FROM TELESCOPE ARRAY

Spectrum

- Spectrum measurements over >5 orders-of-magnitude in energy
- TA finds a significant difference in its own HE suppression **above and below 25˚ declination** (agreement with Auger in overlapping region) > 4σ
- > 8σ difference HE spectrum between TA and Auger in the full field of view
- Difference within common band can be reduced to 1.8σ by cutting excesses and exposure edge

Anisotropy

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

Composition

- Appears Light and Steady for E> 10^{18} eV
- But a Sibyll generated/reconstructed Auger mix similar in sky

High Energy Event Observed

- High Energy event: 2.4×10^{20} eV
- Approaching Fly's Eye (1991 OMG) particle energy: 3.2×10^{20} eV
- Events > 10^{20} eV appear isotropic…..

Future

- TAx4 to Improve statistics especially for Anisotropy and Composition measurements

Telescope Array Collaboration

R.U. Abbasi[1], Y. Abe[2], T. Abu-Zayyad[1,3], M. Allen[3], E. Barcikowski[3], J.W. Belz[3], D.R. Bergman[3], S.A. Blake[3], I. Buckland[3], W. Campbell[3], B.G. Cheon[4], M. Chikawa[5], K. Endo[6], A. Fedynitch[5,7], T. Fujii[6,8], K. Fujisue[5], K. Fujita[5], M. Fukushima[5], G. Furlich[3], Z. Gerber[3], N. Globus*[9], W. Hanlon[3], N. Hayashida[10], H. He[9], R. Hibi[2], K. Hibino[10], R. Higuchi[9], K. Honda[11], D. Ikeda[10], N. Inoue[12], T. Ishii[11], H. Ito[9], D. Ivanov[3], H.M. Jeong[13], S. Jeong[13], C.C.H. Jui[3], K. Kadota[14], F. Kakimoto[10], O. Kalashev[15], K. Kasahara[16], S. Kasami[17], Y. Kawachi[6], S. Kawakami[6], K. Kawata[5], I. Kharuk[15], E. Kido[9], H.B. Kim[4], J.H. Kim[3], J.H. Kim†[3], S.W. Kim[13], Y. Kimura[6], R. Kobo[6], I. Komae[6], K. Komori[17], Y. Kusumori[17], M. Kuznetsov[15,18], Y.J. Kwon[19], K.H. Lee[4], M.J. Lee[13], B. Lubsandorzhiev[15], J.P. Lundquist[3,20], T. Matsuyama[6], J.A. Matthews[3], J.N. Matthews[3], R. Mayta[6], K. Miyashita[2], K. Mizuno[2], M. Mori[17], M. Murakami[17], I. Myers[3], S. Nagataki[9], M. Nakahara[6], K. Nakai[6], T. Nakamura[21], E. Nishio[17], T. Nonaka[5], S. Ogio[5], H. Ohoka[5], N. Okazaki[5], Y. Oku[17], T. Okuda[22], Y. Omura[6], M. Onishi[5], M. Ono[9], A. Oshima[23], H. Oshima[5], S. Ozawa[24], I.H. Park[13], K.Y. Park[4], M. Potts[3], M. Przybylak‡[25], M.S. Pshirkov[15,26], J. Remington[3], D.C. Rodriguez[3], C. Rott[3,13], G.I. Rubtsov[15], D. Ryu[27], H. Sagawa[5], R. Saito[2], N. Sakaki[5], T. Sako[5], S. Sakurai[17], D. Sato[2], S. Sato[17], K. Sekino[5], P.D. Shah[3], N. Shibata[17], T. Shibata[5], J. Shikita[6], H. Shimodaira[5], B.K. Shin[27], H.S. Shin[6,8], K. Shinozaki[25], D. Shinto[17], J.D. Smith[3], P. Sokolsky[3], B.T. Stokes[3], T.A. Stroman[3], Y. Takagi[17], K. Takahashi[5], M. Takamura[28], M. Takeda[5], R. Takeishi[5], A. Taketa[29], M. Takita[5], Y. Tameda[17], K. Tanaka[30], M. Tanaka[31], S.B. Thomas[3], G.B. Thomson[3], P. Tinyakov[15,18], I. Tkachev[15], H. Tokuno[32], T. Tomida[2], S. Troitsky[15], Y. Tsunesada[6,8], S. Udo[10], F. Urban[33], I.A. Vaiman[15], M. Vrábel[25], D. Warren[9], T. Wong[3], K. Yamazaki[23], K. Yashiro[28], F. Yoshida[17], Y. Zhezher[5,15], Z. Zundel[3], and J. Zvirzdin[3]

[1] *Department of Physics, Loyola University Chicago, Chicago, Illinois 60660, USA*
[2] *Academic Assembly School of Science and Technology Institute of Engineering, Shinshu University, Nagano, Nagano 380-8554, Japan*
[3] *High Energy Astrophysics Institute and Department of Physics and Astronomy, University of Utah, Salt Lake City, Utah 84112-0830, USA*
[4] *Graduate School of Science, Osaka Metropolitan University, Sugimoto, Sumiyoshi, Osaka 558-8585, Japan*
[5] *Department of Physics and The Research Institute of Natural Science, Hanyang University, Seongdong-gu, Seoul 426-791, Korea*
[6] *Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[7] *Institute of Physics, Academia Sinica, Taipei City 115201, Taiwan*
[8] *Nambu Yoichiro Institute of Theoretical and Experimental Physics, Osaka Metropolitan University, Sugimoto, Sumiyoshi, Osaka 558-8585, Japan*
[9] *Astrophysical Big Bang Laboratory, RIKEN, Wako, Saitama 351-0198, Japan*
[10] *Faculty of Engineering, Kanagawa University, Yokohama, Kanagawa 221-8686, Japan*
[11] *Interdisciplinary Graduate School of Medicine and Engineering, University of Yamanashi, Kofu, Yamanashi 400-8511, Japan*
[12] *The Graduate School of Science and Engineering, Saitama University, Saitama, Saitama 338-8570, Japan*
[13] *Department of Physics, Sungkyunkwan University, Jang-an-gu, Suwon 16419, Korea*
[14] *Department of Physics, Tokyo City University, Setagaya-ku, Tokyo 158-8557, Japan*
[15] *Institute for Nuclear Research of the Russian Academy of Sciences, Moscow 117312, Russia*
[16] *Faculty of Systems Engineering and Science, Shibaura Institute of Technology, Minato-ku, Tokyo 337-8570, Japan*
[17] *Graduate School of Engineering, Osaka Electro-Communication University, Neyagawa-shi, Osaka 572-8530, Japan*
[18] *Department of Physics, Yonsei University, Seodaemun-gu, Seoul 120-749, Korea*
[19] *Center for Astrophysics and Cosmology, University of Nova Gorica, Nova Gorica 5297, Slovenia*
[20] *Faculty of Science, Kochi University, Kochi, Kochi 780-8520, Japan*
[21] *Department of Physical Sciences, Ritsumeikan University, Kusatsu, Shiga 525-8577, Japan*
[22] *College of Science and Engineering, Chubu University, Kasugai, Aichi 487-8501, Japan*
[23] *Quantum ICT Advanced Development Center, National Institute for Information and Communications Technology, Koganei, Tokyo 184-8795, Japan*
[24] *Astrophysics Division, National Centre for Nuclear Research, Warsaw 02-093, Poland*
[25] *Sternberg Astronomical Institute, Moscow M.V. Lomonosov State University, Moscow 119991, Russia*
[26] *Department of Physics, School of Natural Sciences, Ulsan National Institute of Science and Technology, UNIST-gil, Ulsan 689-798, Korea*
[27] *Department of Physics, Tokyo University of Science, Noda, Chiba 162-8601, Japan*
[28] *Earthquake Research Institute, University of Tokyo, Bunkyo-ku, Tokyo 277-8582, Japan*
[29] *Graduate School of Information Sciences, Hiroshima City University, Hiroshima, Hiroshima 731-3194, Japan*
[30] *Institute of Particle and Nuclear Studies, KEK, Tsukuba, Ibaraki 305-0801, Japan*
[31] *Service de Physique Théorique, Université Libre de Bruxelles, Brussels 1050, Belgium*
[32] *Graduate School of Science and Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8550, Japan*
[33] *CEICO, Institute of Physics, Czech Academy of Sciences, Prague 182 21, Czech Republic*

148 members, 33 institutes, 7 countries

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