

Subaru Hyper Supreme-Cam Meets Cosmic Ray Showers

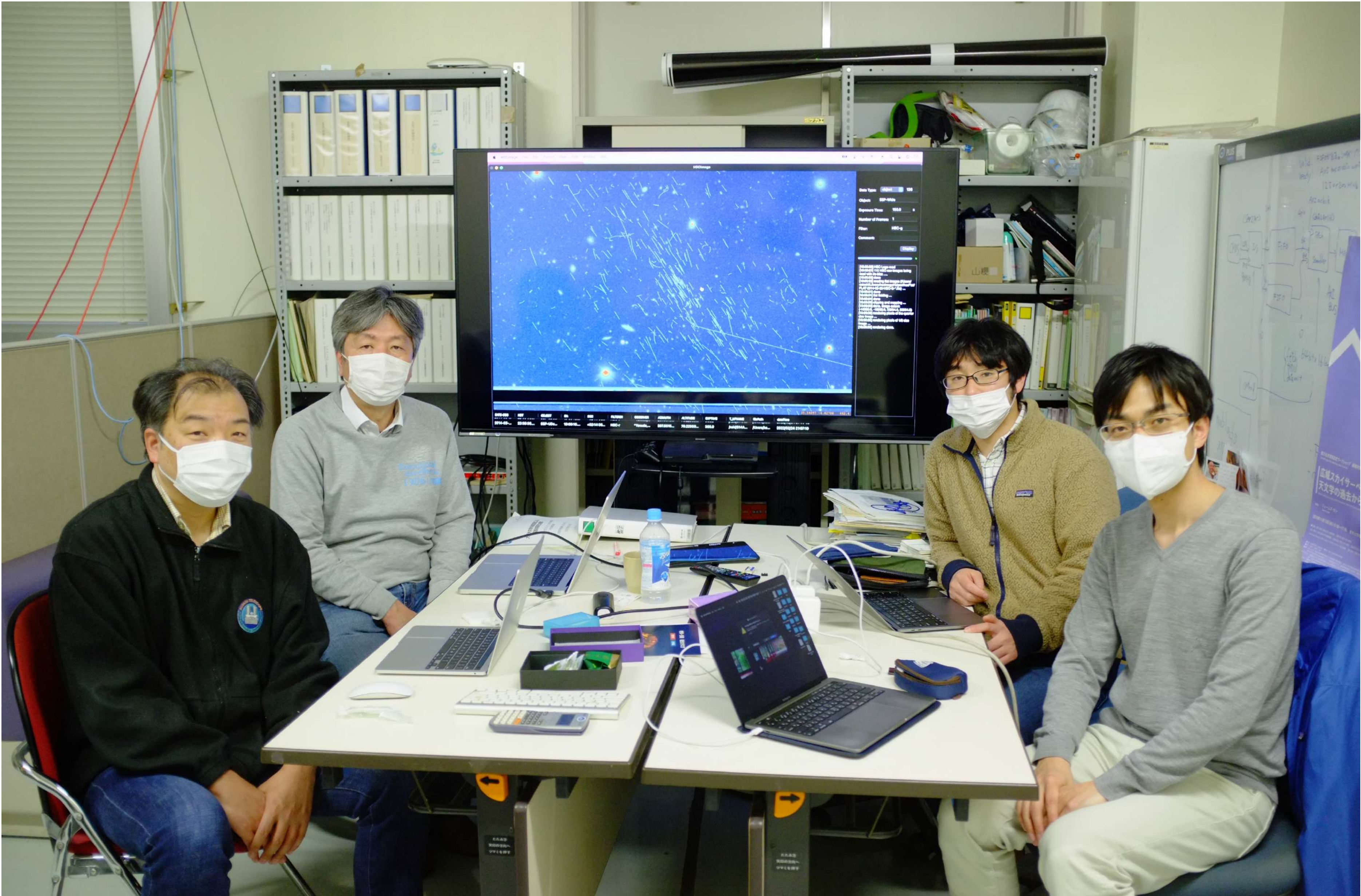
Paper being prepared under HSC project 433

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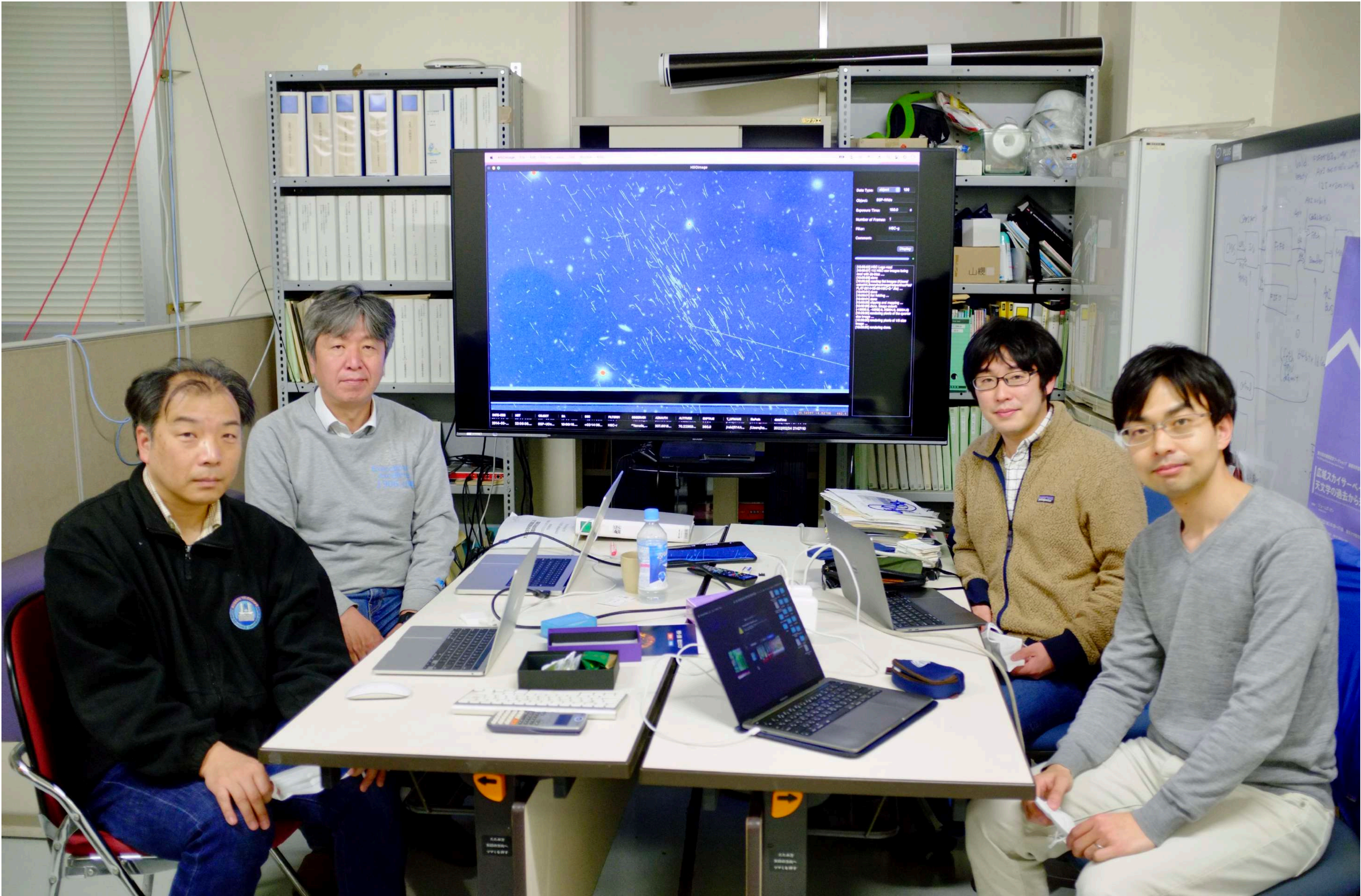
Recently joined: Masanori Iye, Tsuyoshi Terai (NAOJ)

2022 March 29th, "What is dark matter? - Comprehensive study of the huge discovery space in dark matter" Symposium

Subaru HSC researchers meet cosmic ray researcher.

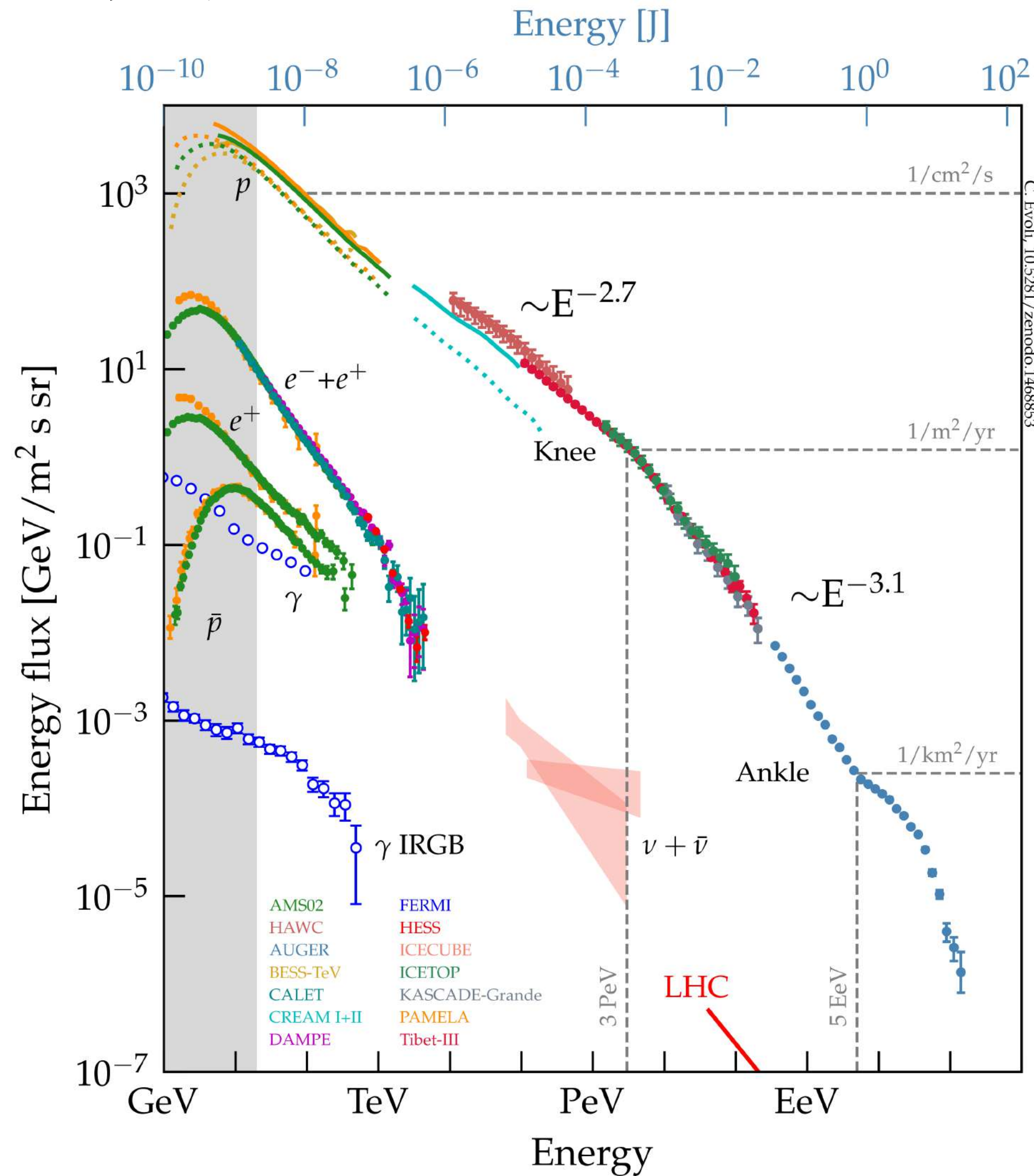


Subaru HSC researchers meet cosmic ray researcher.

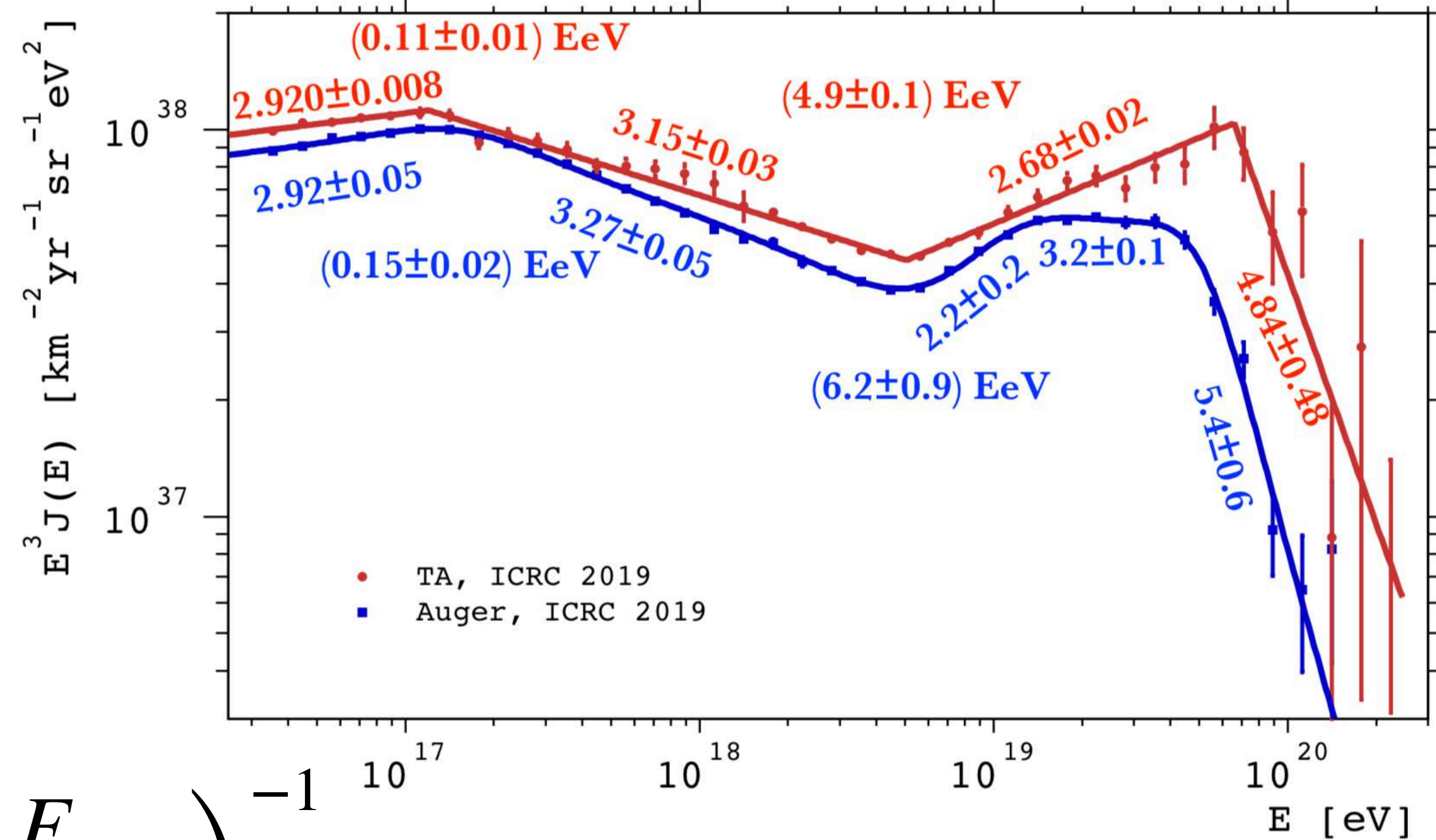


Energy spectrum of cosmic ray

$$J(E) \times E^2$$



$$J(E) \times E^3$$



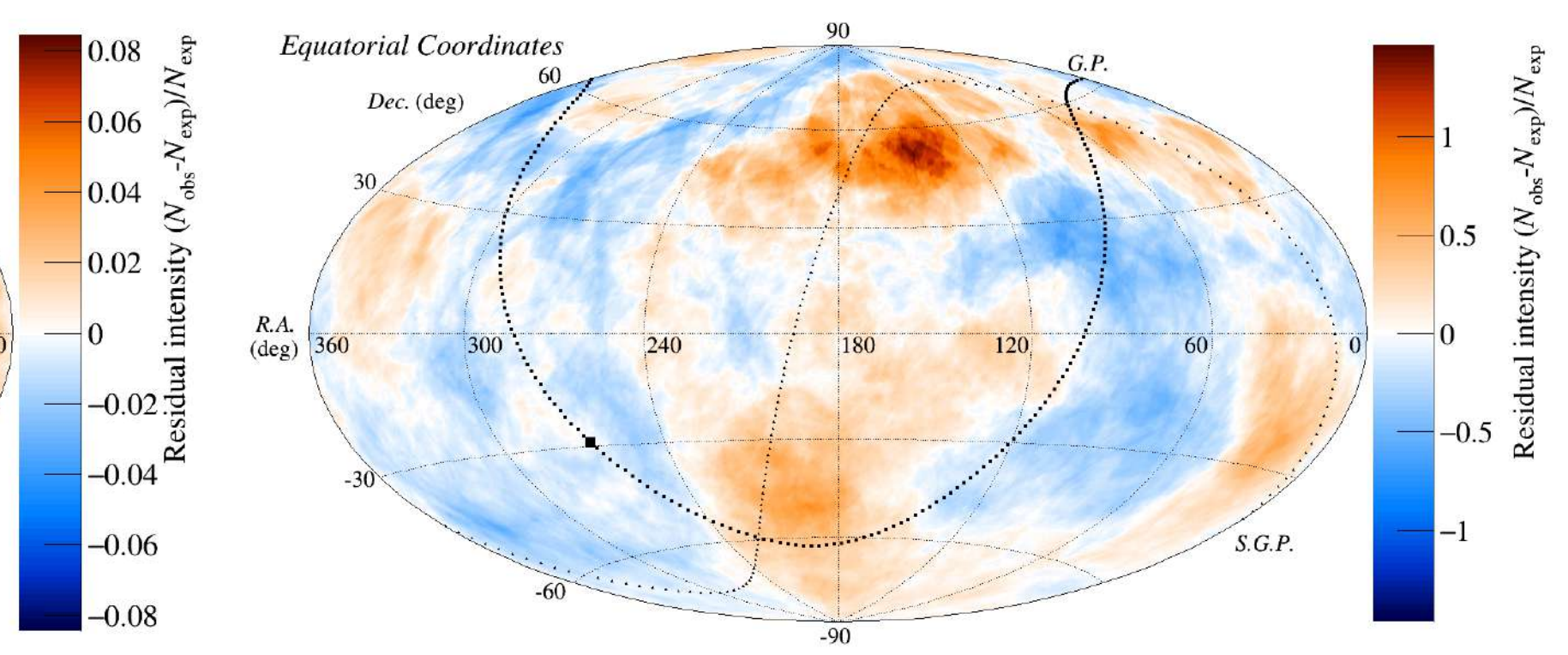
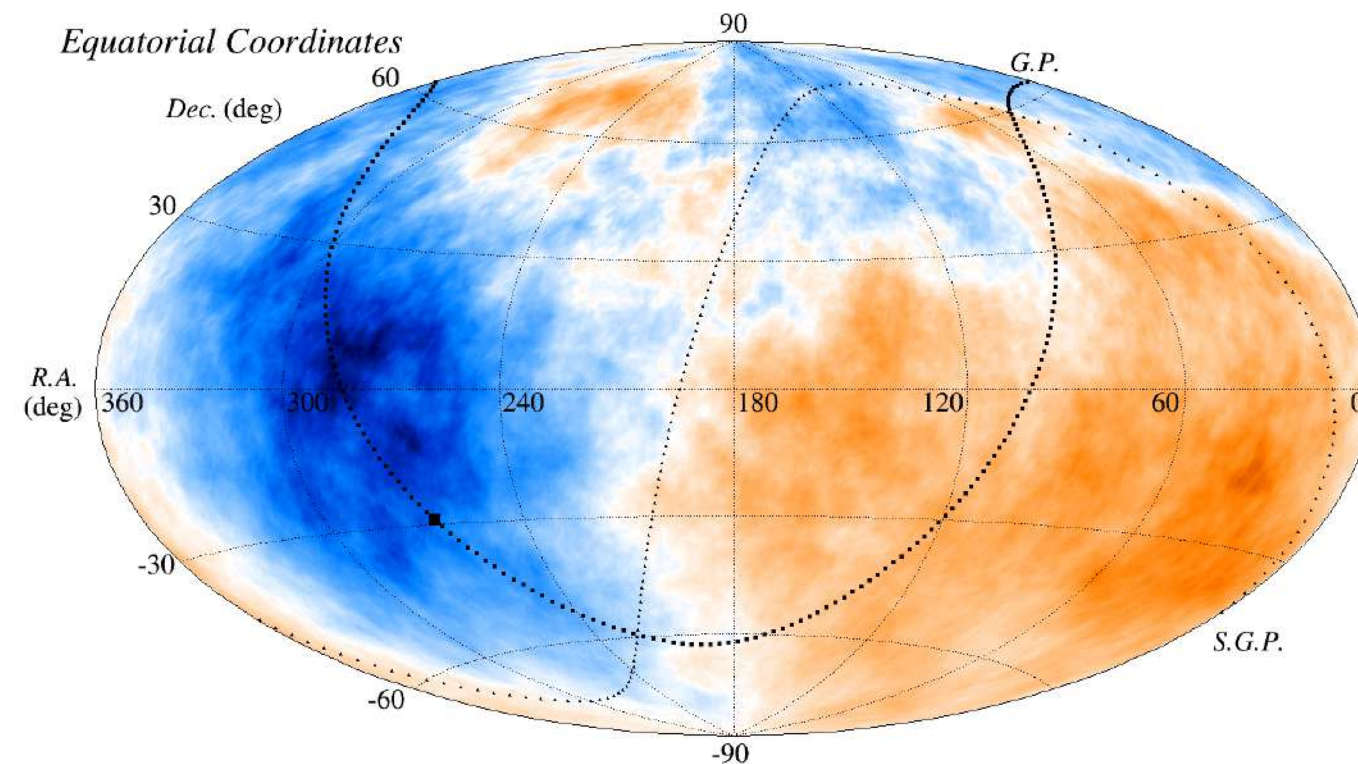
Deflection angle in our Galaxy

$$\theta \sim 10^\circ Z \left(\frac{E}{10 \text{ EeV}} \right)$$

Z : atomic number

E > ~10 EeV

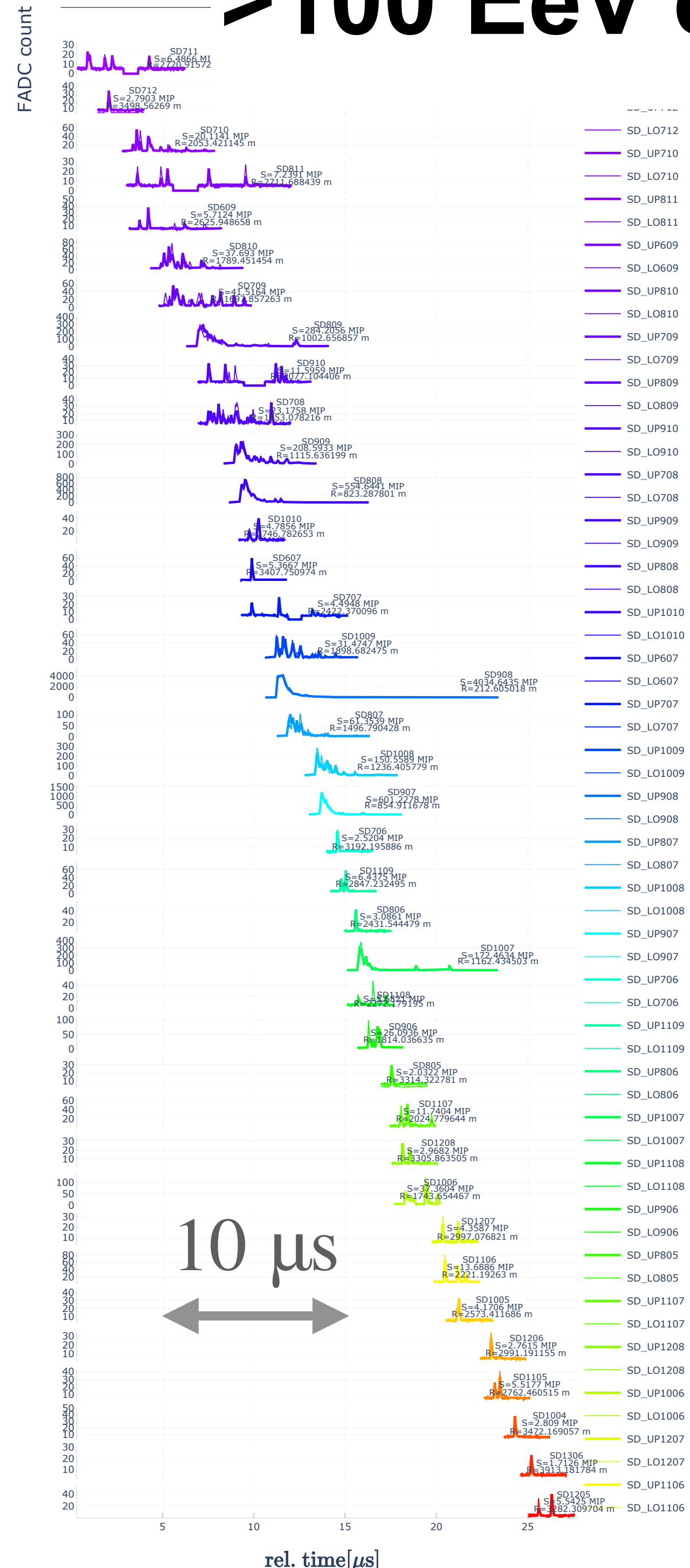
E > ~50 EeV T. Fujii et al., PoS (ICRC2021) 402



Cosmic Ray Extensive Air Showers

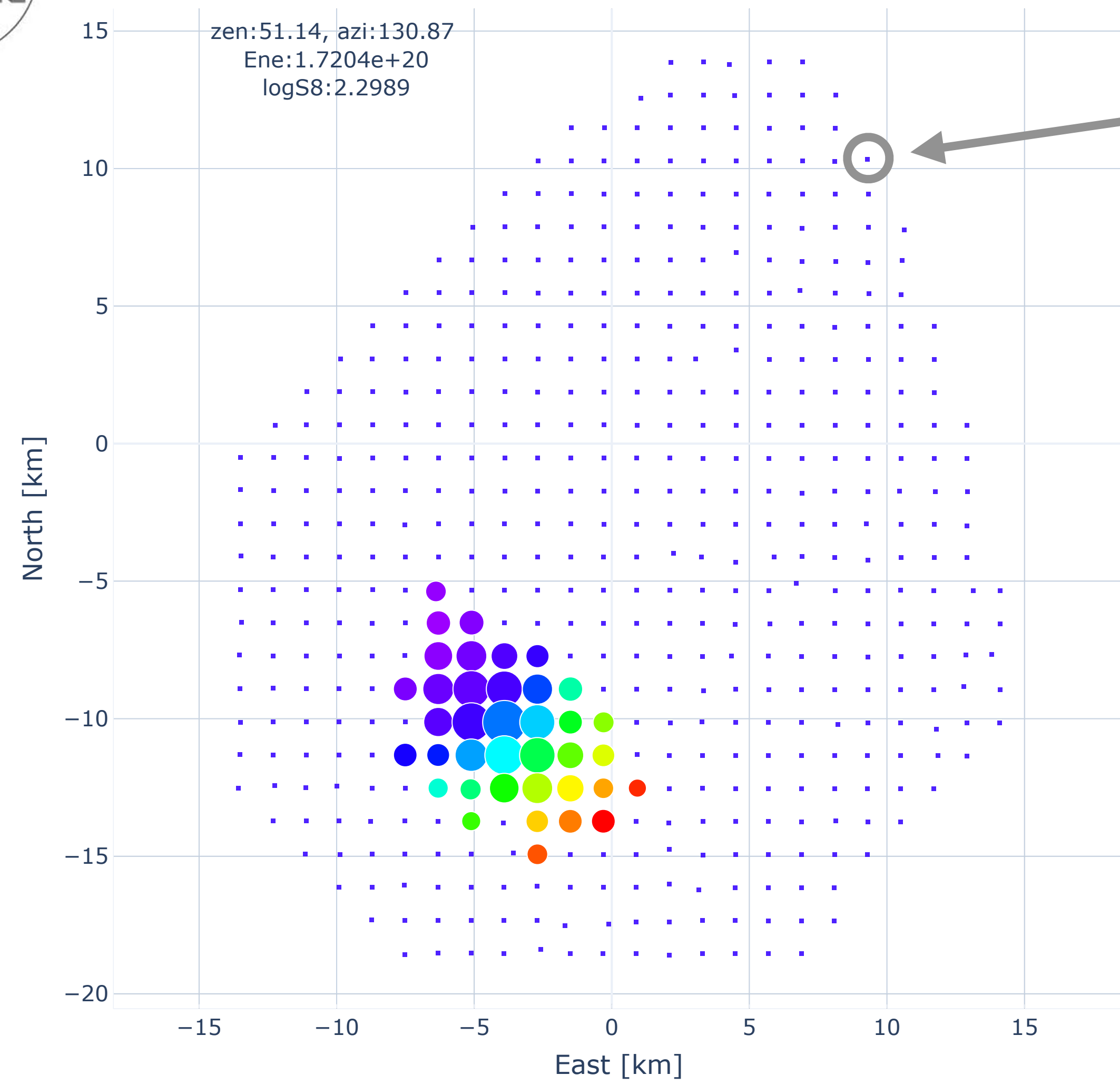


Hybrid SD event-> **>100 EeV event detected by Telescope Array Experiment**

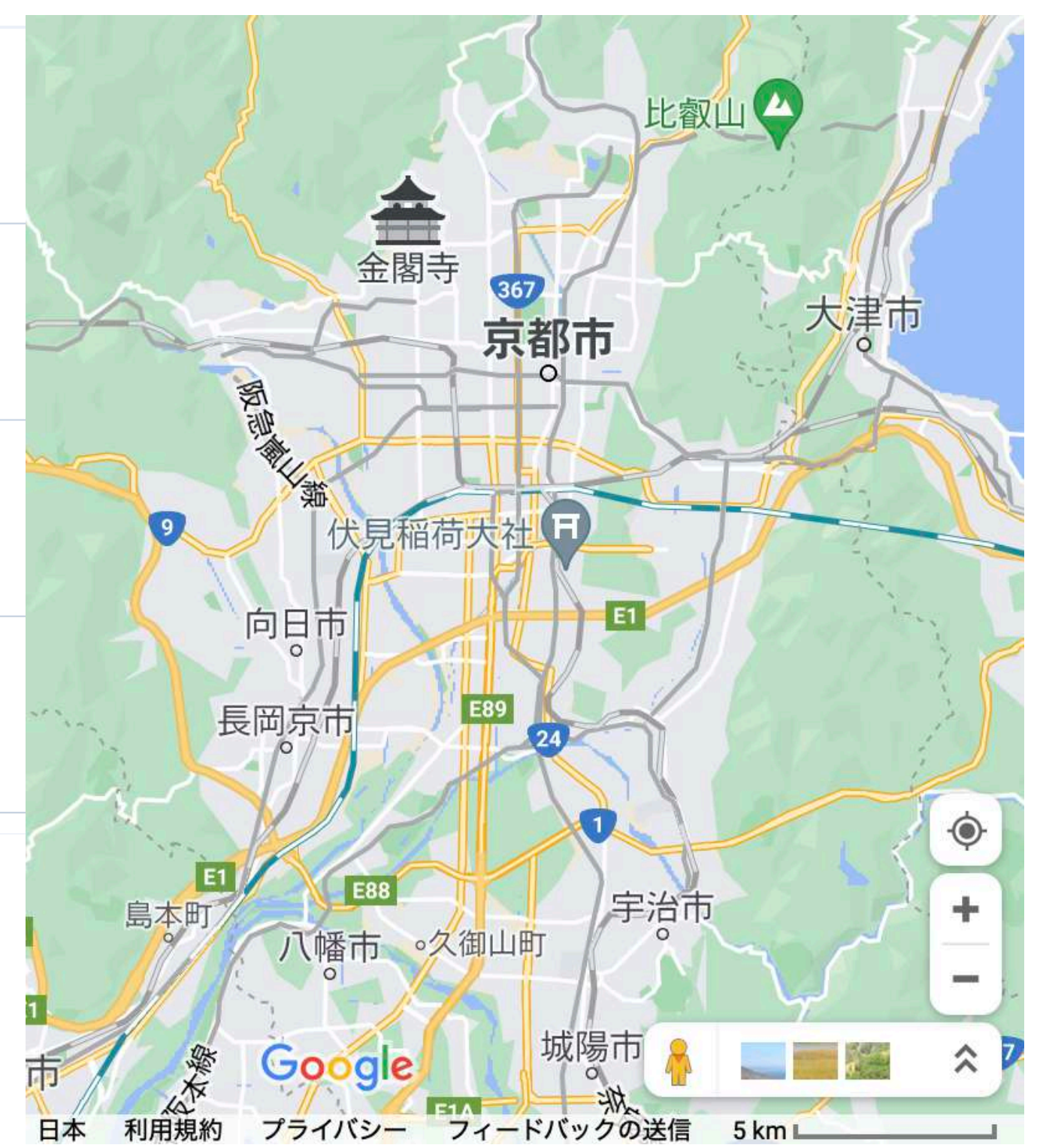


https://www.icrr.u-tokyo.ac.jp/ta/ta_public

TA SD map: data event



3 m² plastic scintillator

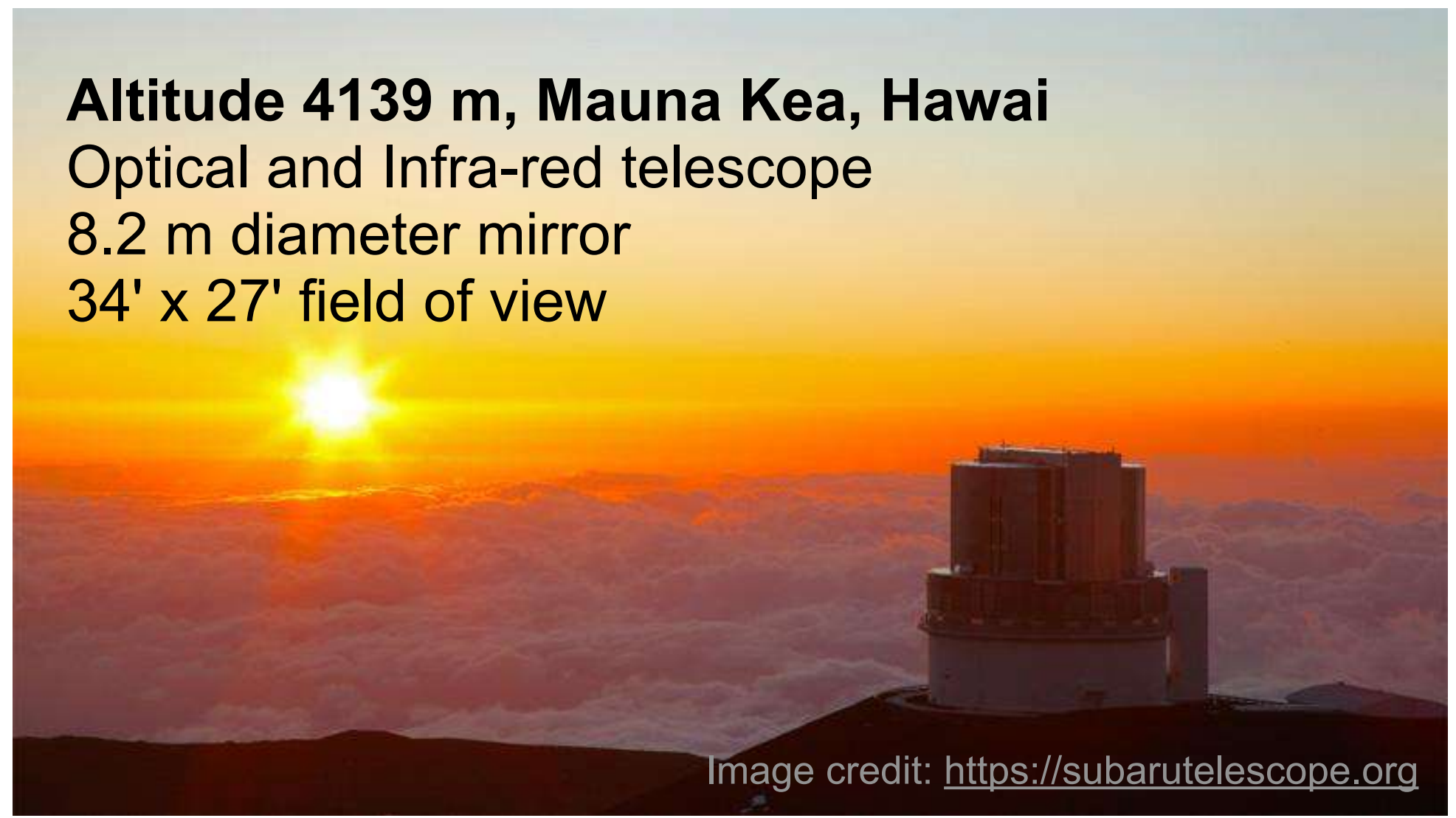


700 km² area in Utah, USA

Figure made by Rosa Mayta

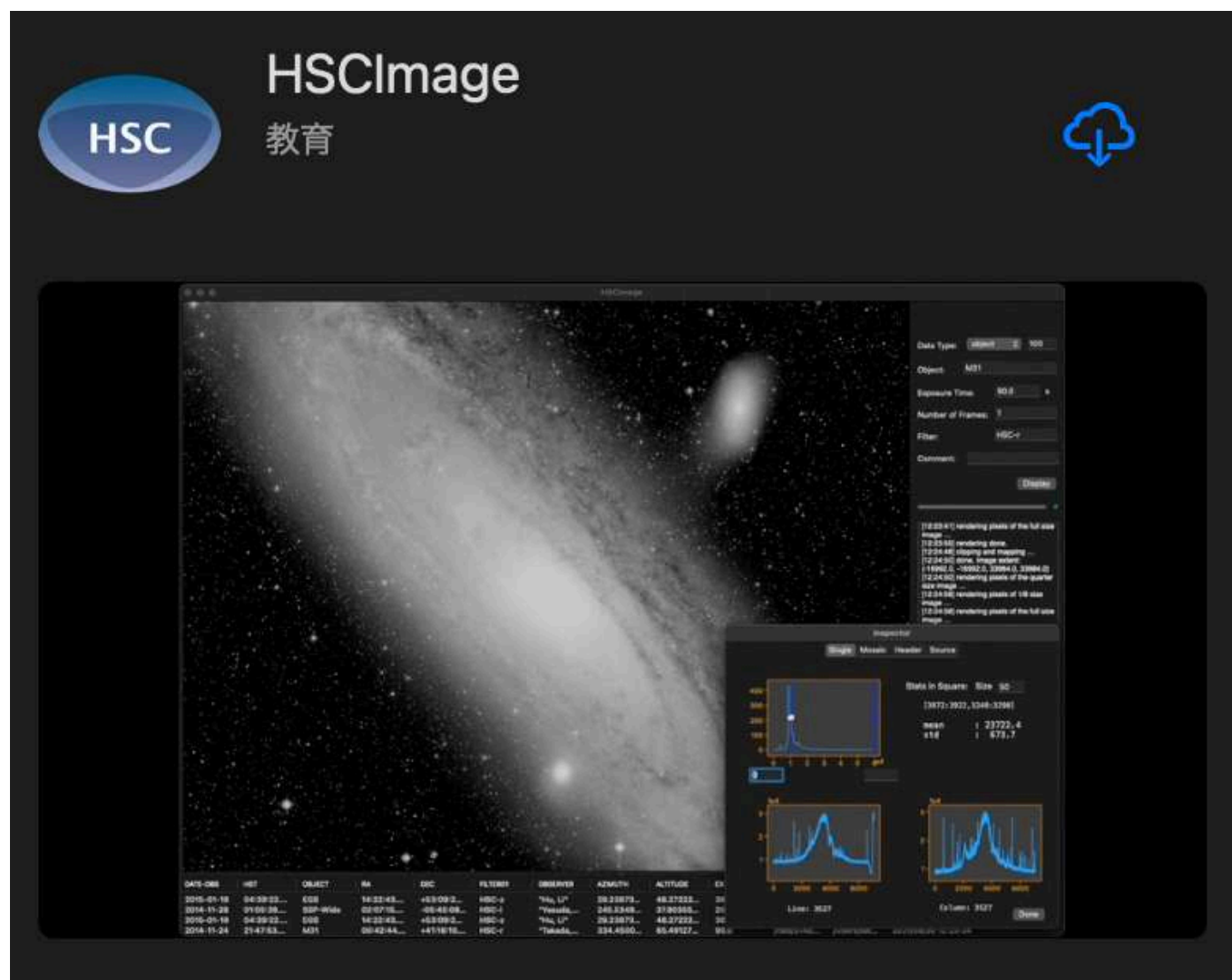
"Seeing" Cosmic Ray Extensive Air Showers

Direct detection of Subaru HSC CCDs

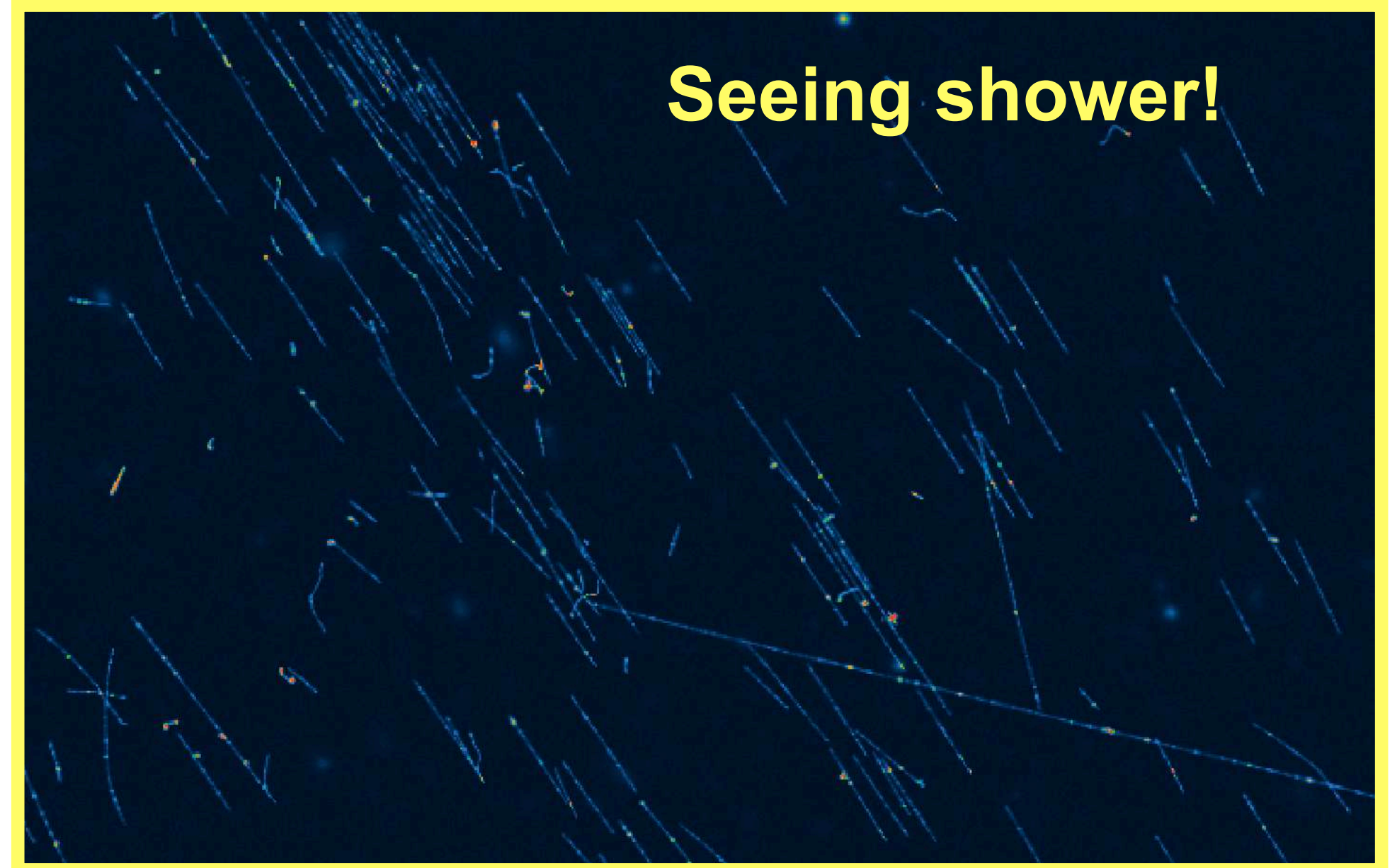
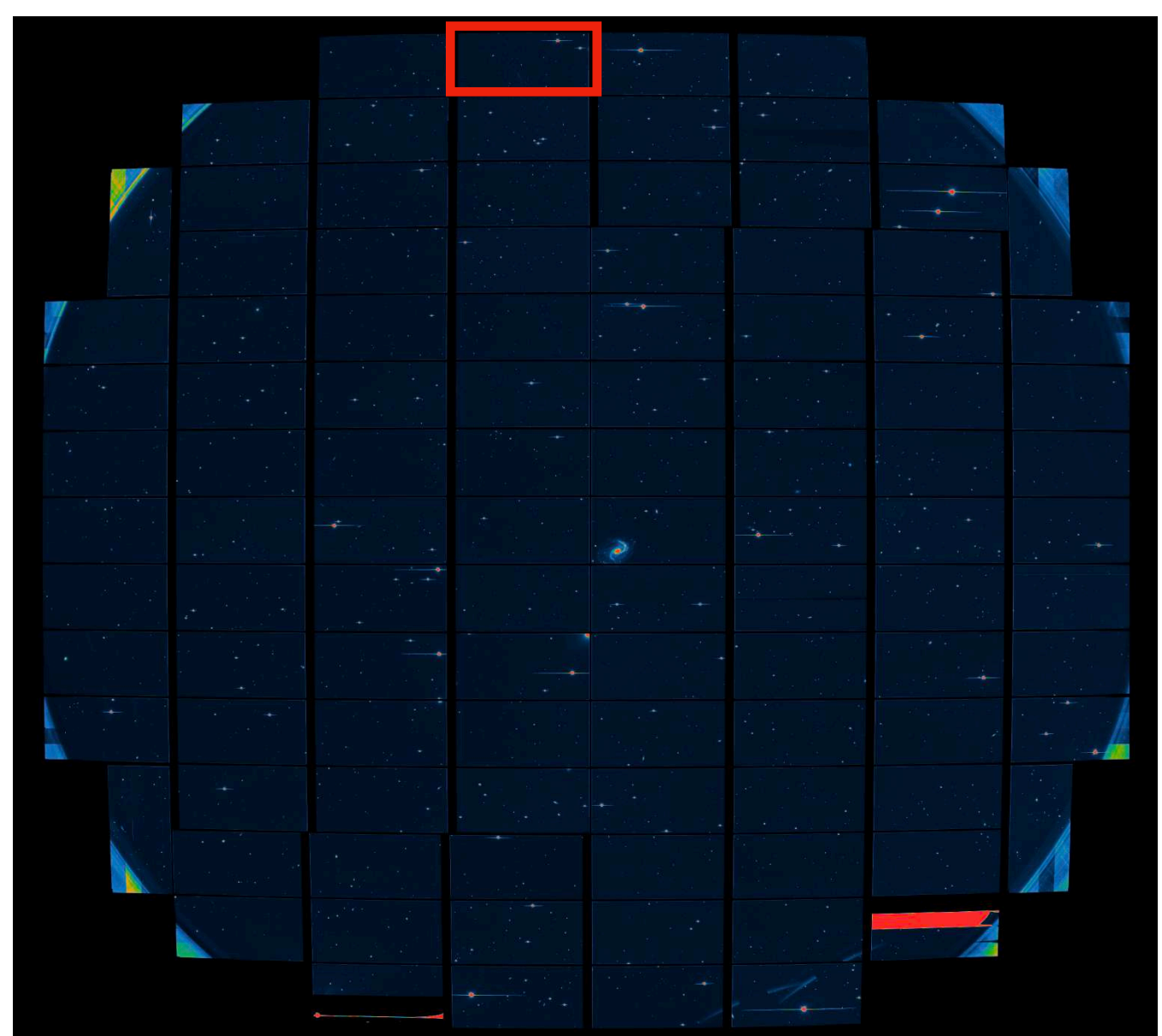


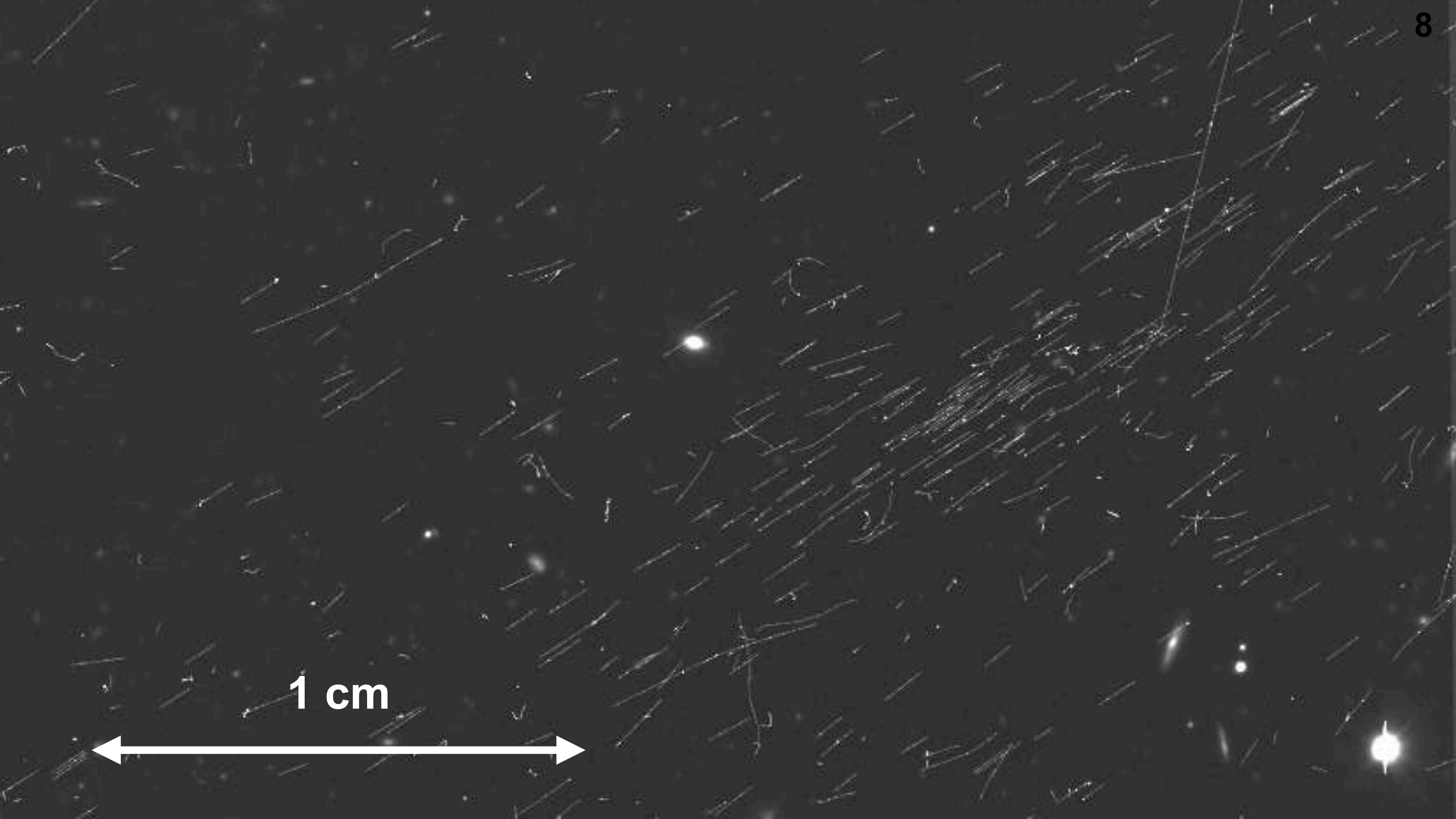
CCD size
 30 mm x 60 mm
 0.2 mm thickness
 150 sec. exposure

116 CCDs



App Store (Mac)

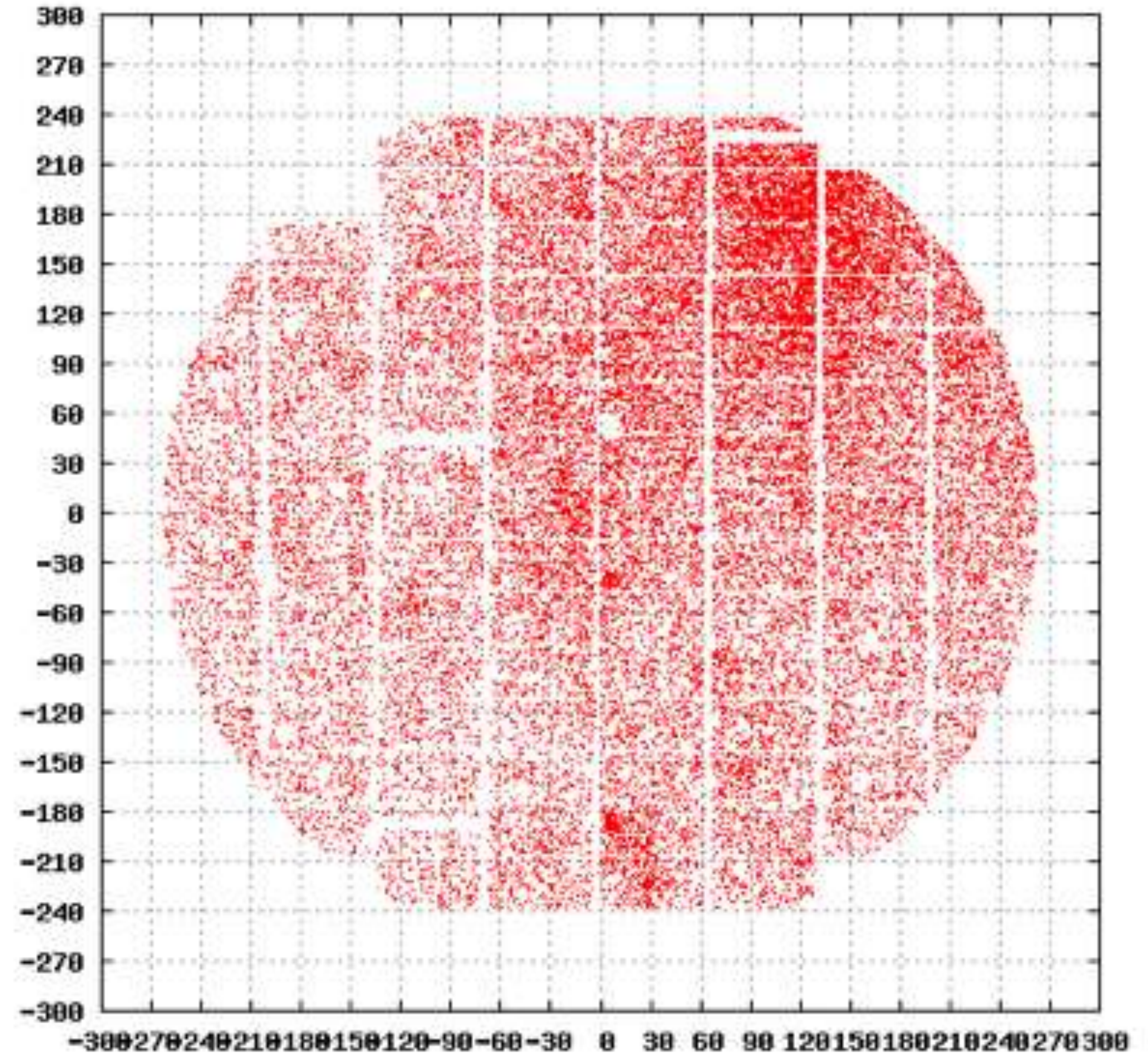
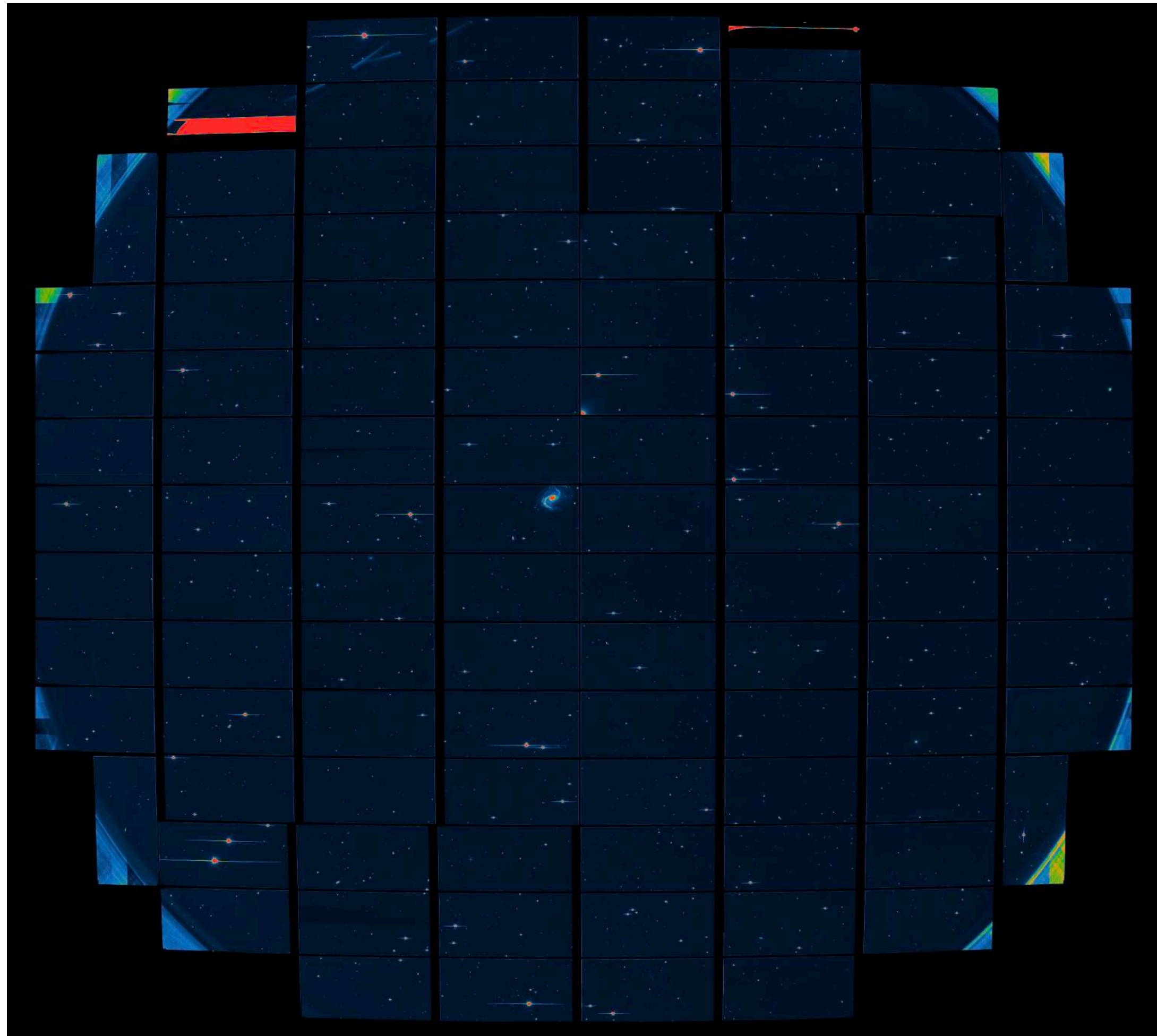




1 cm

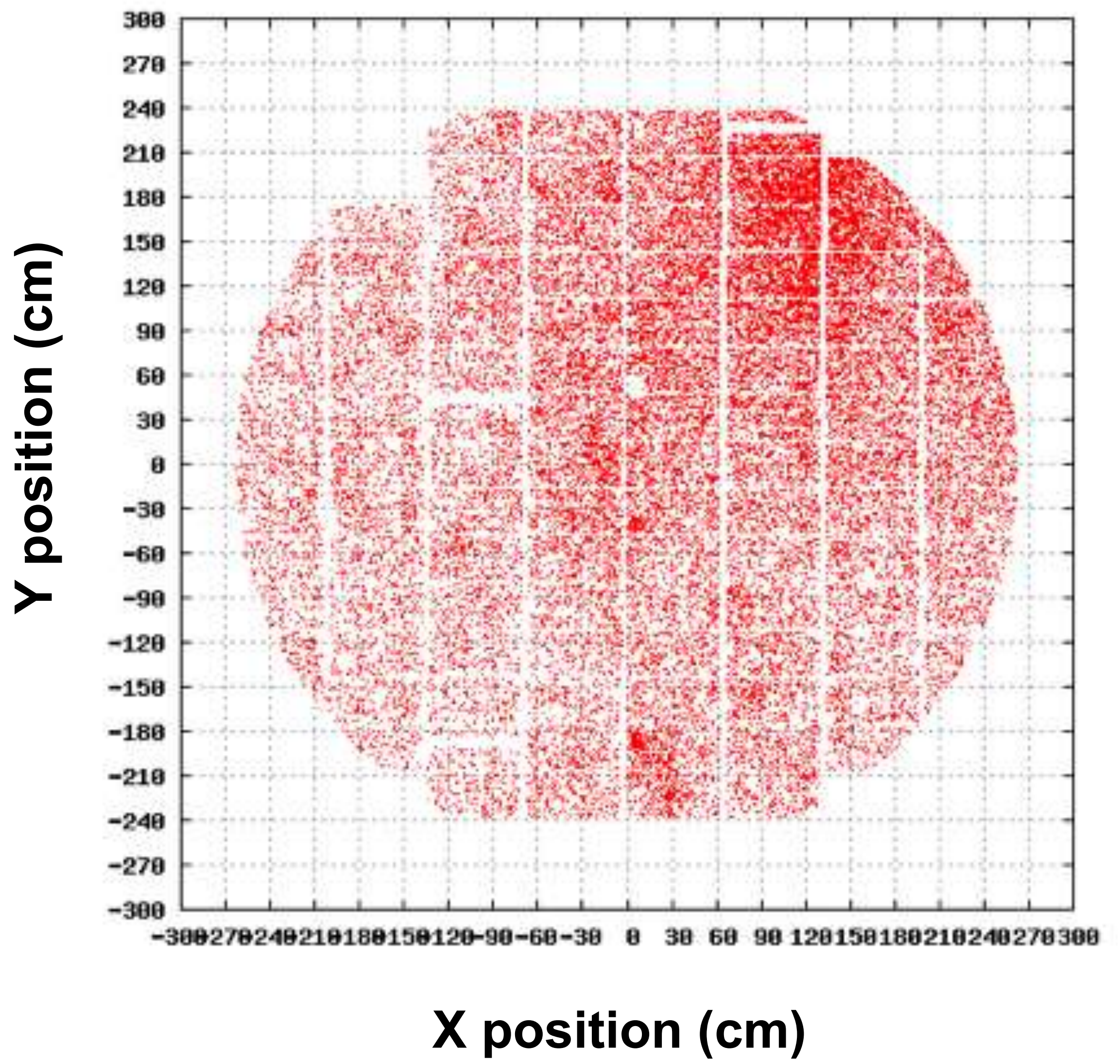


Position of cosmic ray particles in Subaru HSC

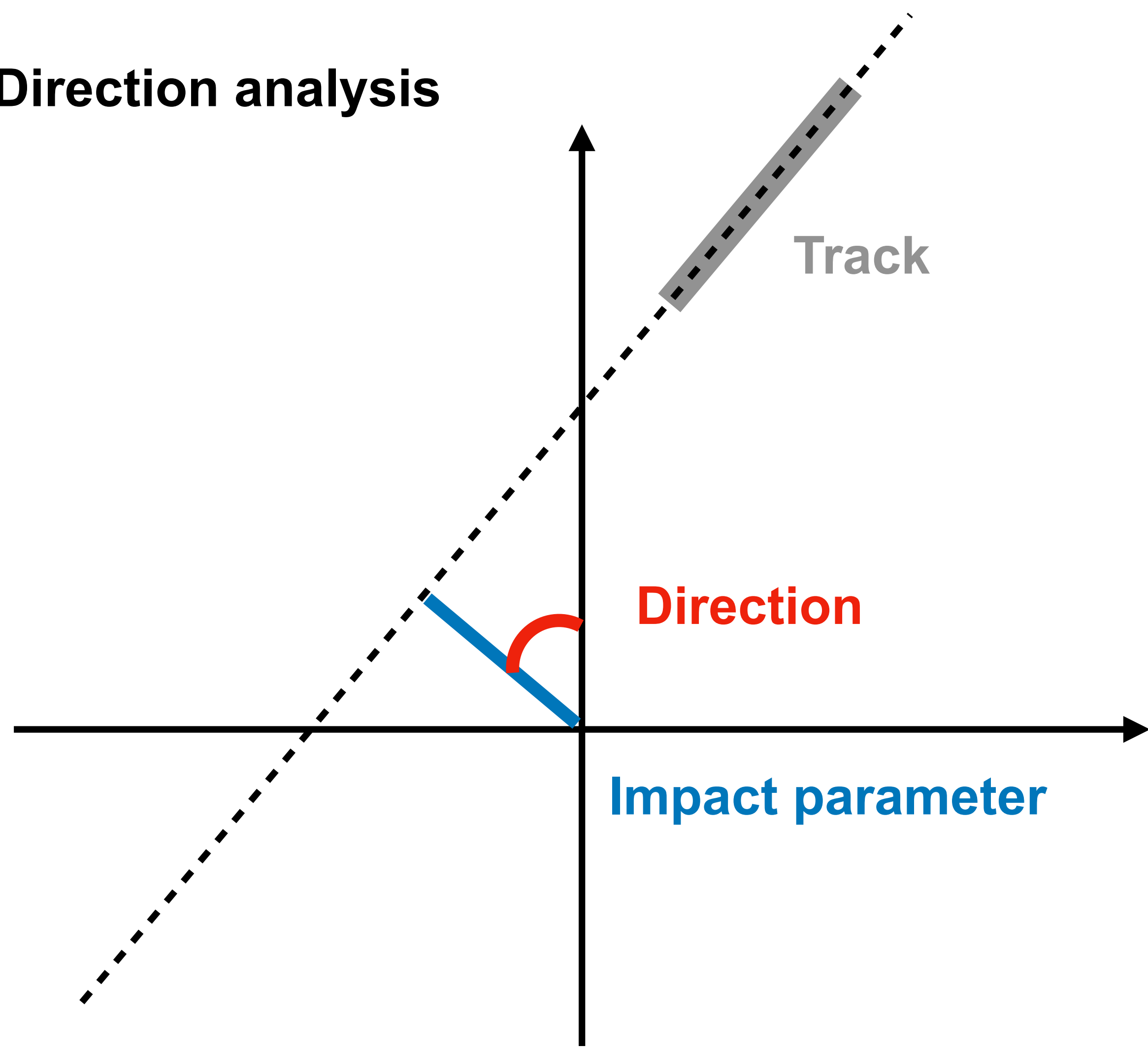


Directional analysis of cosmic-ray particles

Position of particles



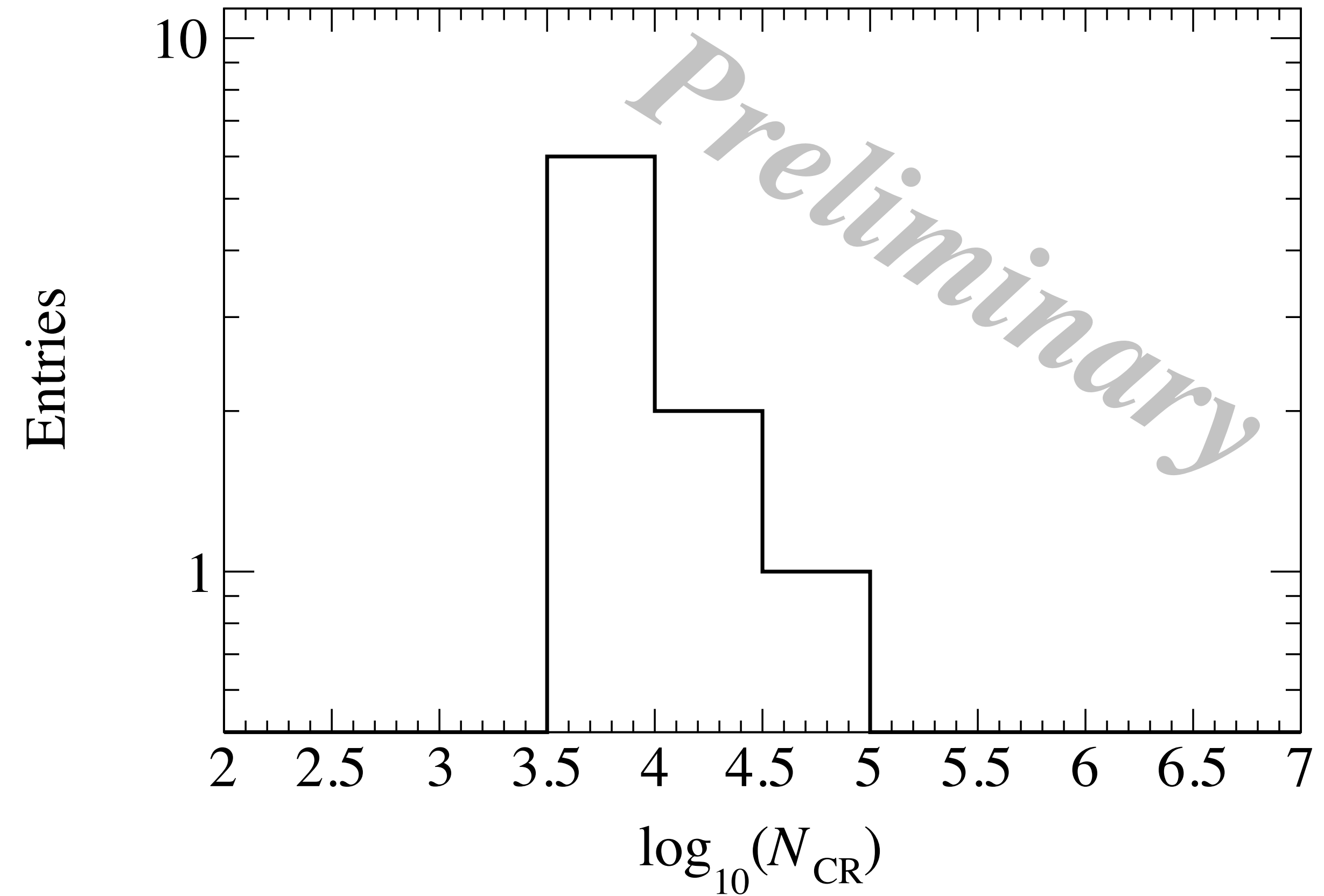
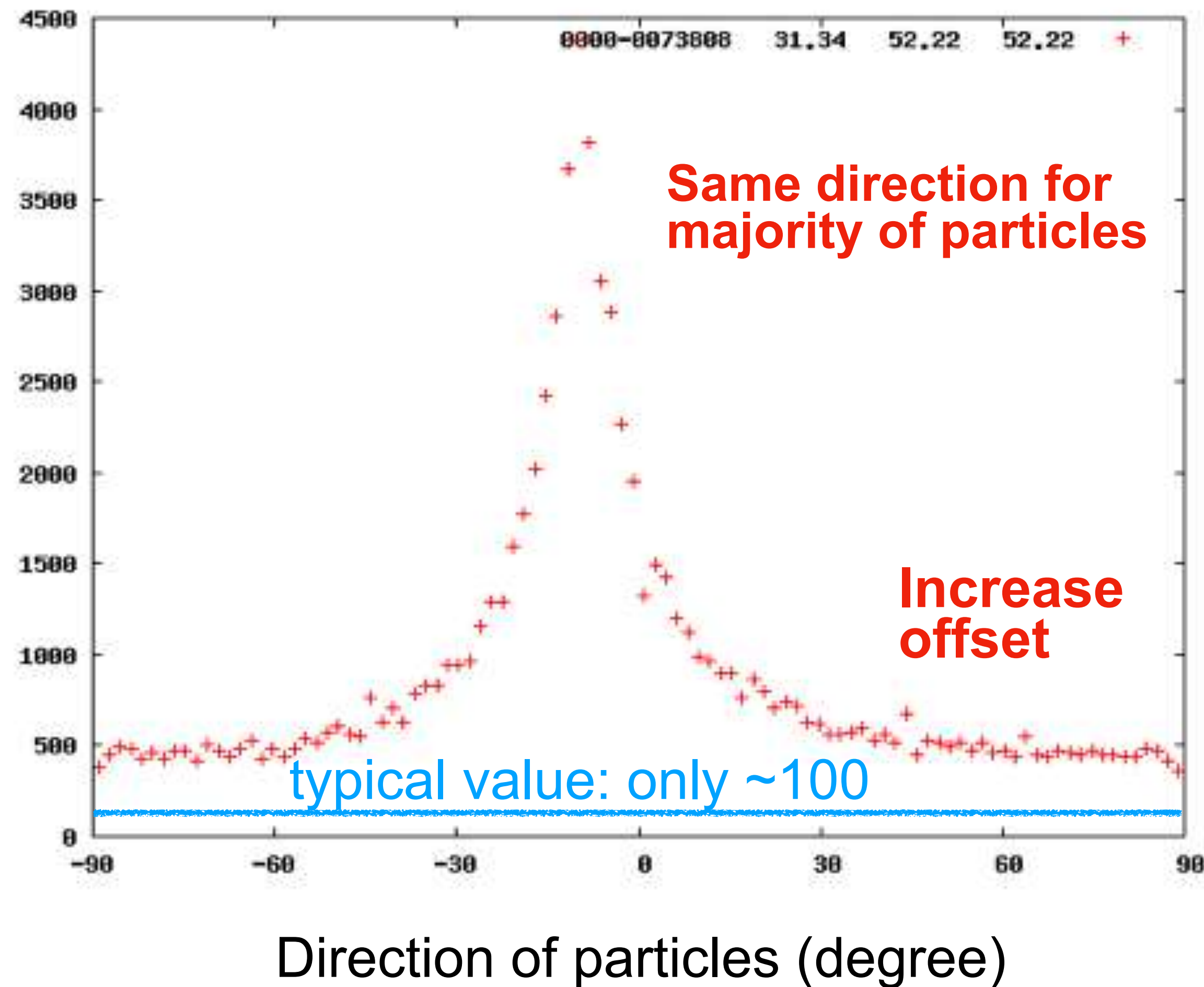
Direction analysis



Directional analysis of cosmic-ray shower particles

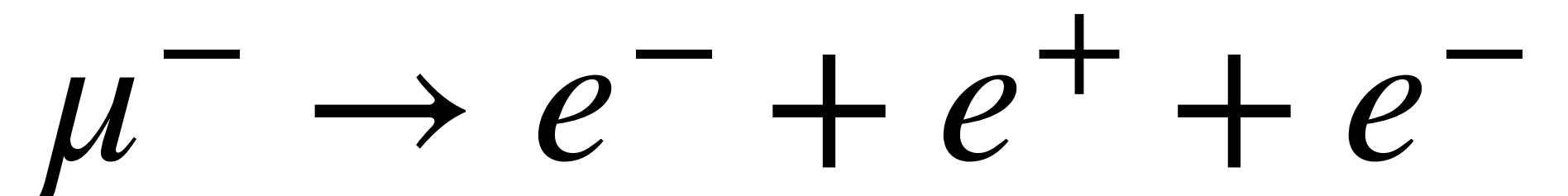
- Same direction of these particles
- Number of cosmic rays, $N_{cr} \sim 60,000$ particles

- Quick look on Subaru HSC data in 7 years
- Found 9 events, indicating a power-law distribution



Physics motivation

- 📌 Unprecedented detailed measurements for cosmic ray extensive air showers
- 📌 Possibility on proton, He, Li, Be Fe identification by separating electrons and muons
- 📌 Understanding air shower physics and hadron interactions models
- 📌 **Potential on new physics search?** (Discussed with M. Yamanaka @A02)
- 📌 Search for Lepton flavor violating decay?



μ^- DECAY MODES

μ^+ modes are charge conjugates of the modes below.

Mode	Fraction (Γ_i/Γ)	Confidence level
Γ_1 $e^- \bar{\nu}_e \nu_\mu$	$\approx 100\%$	
Γ_2 $e^- \bar{\nu}_e \nu_\mu \gamma$	[a] $(6.0 \pm 0.5) \times 10^{-8}$	
Γ_3 $e^- \bar{\nu}_e \nu_\mu e^+ e^-$	[b] $(3.4 \pm 0.4) \times 10^{-5}$	

Lepton Family number (LF) violating modes

Γ_4	$e^- \nu_e \bar{\nu}_\mu$	LF	[c] < 1.2	%	90%
Γ_5	$e^- \gamma$	LF	< 4.2	$\times 10^{-13}$	90%
Γ_6	$e^- e^+ e^-$	LF	< 1.0	$\times 10^{-12}$	90%
Γ_7	$e^- 2\gamma$	LF	< 7.2	$\times 10^{-11}$	90%

Summary and future plans

- 📌 Subaru Hyper Supreme-Cam Meets Cosmic Ray Showers
- 📌 **Unprecedented detailed measurements of cosmic ray showers**
- 📌 All data scan and analysis update are now in progress
- 📌 Preparing two papers : a discovery paper, energy spectrum measurement paper
- 📌 Brain storming of possible application
- 📌 **Serendipity of new synergy between A02 group (K. Murase) and B03 group (S. Miyazaki)**