TA2/GCOS
(Global Cosmic Ray Observatory)

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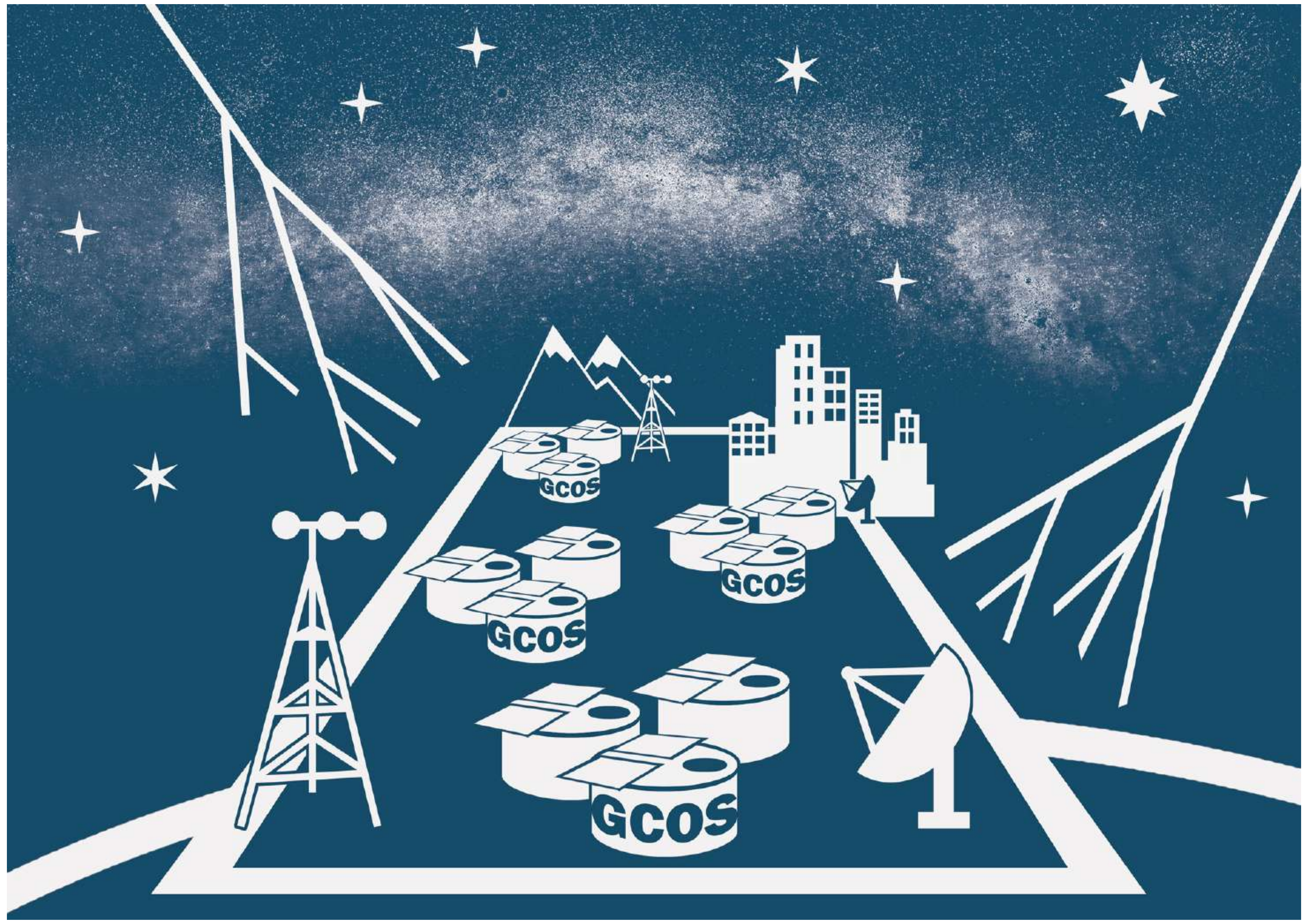
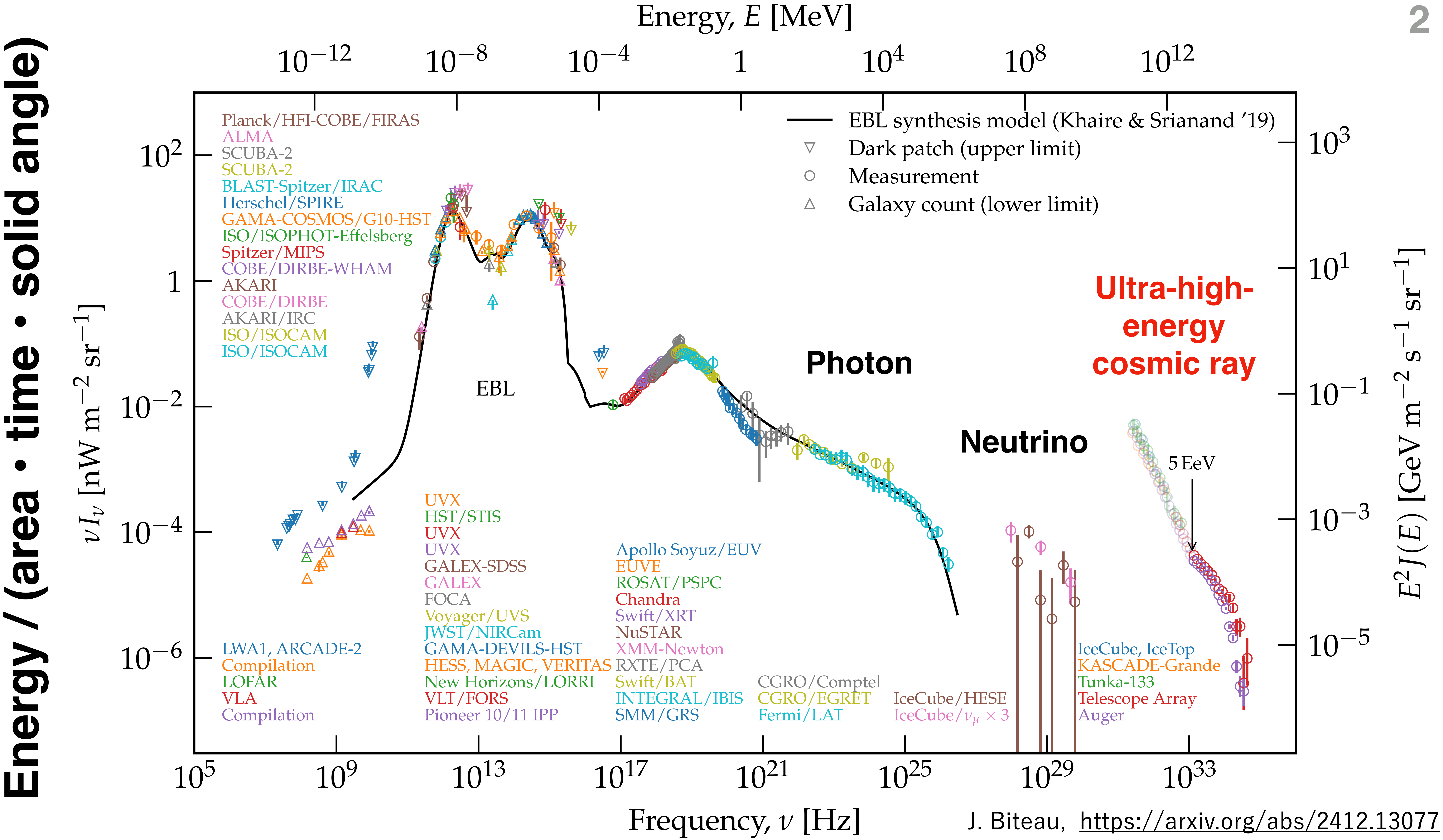
March 11, 2025
CRC town meeting



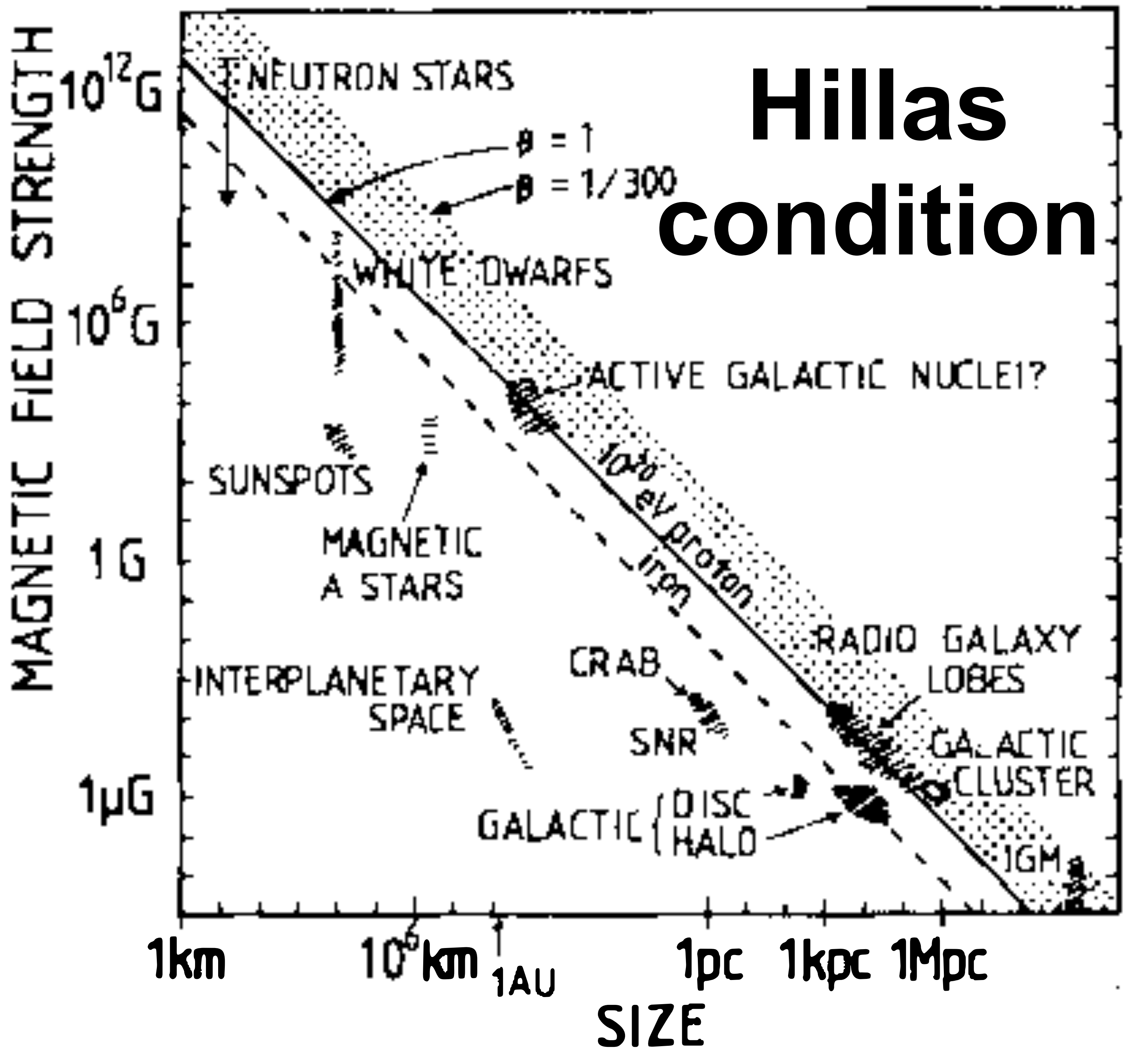
Ideas and Requirements for the Global Cosmic-Ray Observatory (GCOS)
https://arxiv.org/abs/2502.05657



Energy, E [MeV]
10^{-12}
10^{-8}
10^{-4}
1
10^{4}
10^{8}
10^{12}
Energy / (area • time • solid angle)
νI_ν [nW m^{-2} sr^{-1}]
10^{2}
1
10^{-2}
10^{-4}
10^{-6}
$E^2 J(E)$ [GeV m^{-2} s^{-1} sr^{-1}]
10^{3}
10^{1}
10^{-1}
10^{-3}
10^{-5}
Planck/HFI-COBE/FIRAS
ALMA
SCUBA-2
SCUBA-2
BLAST-Spitzer/IRAC
Herschel/SPIRE
GAMA-COSMOS/G10-HST
ISO/ISOPHOT-Effelsberg
Spitzer/MIPS
COBE/DIRBE-WHAM
AKARI
COBE/DIRBE
AKARI/IRC
ISO/ISOCAM
ISO/ISOCAM
EBL synthesis model (Khaire & Srianand '19)
Dark patch (upper limit)
Measurement
Galaxy count (lower limit)
EBL
Photon
Neutrino
Ultra-high-energy cosmic ray
5 EeV
UVX
HST/STIS
UVX
UVX
GALEX-SDSS
GALEX
FOCA
Voyager/UVS
JWST/NIRCam
GAMA-DEVILS-HST
HESS, MAGIC, VERITAS
New Horizons/LORRI
VLT/FORS
Pioneer 10/11 IPP
Apollo Soyuz/EUV
EUVE
ROSAT/PSPC
Chandra
Swift/XRT
NuSTAR
XMM-Newton
RXTE/PCA
Swift/BAT
INTEGRAL/IBIS
SMM/GRS
CGRO/Comptel
CGRO/EGRET
Fermi/LAT
IceCube/HESE
IceCube/$\nu_\mu \times 3$
LWA1, ARCADE-2
Compilation
LOFAR
VLA
Compilation
IceCube, IceTop
KASCADE-Grande
Tunka-133
Telescope Array
Auger
10^{5}
10^{9}
10^{13}
10^{17}
10^{21}
10^{25}
10^{29}
10^{33}
Frequency, ν [Hz]
J. Biteau, https://arxiv.org/abs/2412.13077


2021 May 27, 04:35:56 AM
Detection of **"Amaterasu particle"**
2.44×10^{20} eV = 244 exa-electron volts (EeV)
Telescope Array Collaboration, Science 382, 903 (2023)

Source candidates and next-generation astronomy



Hillas condition

A. M. Hillas, Astron. Astrophys., 22, 425 (1984)

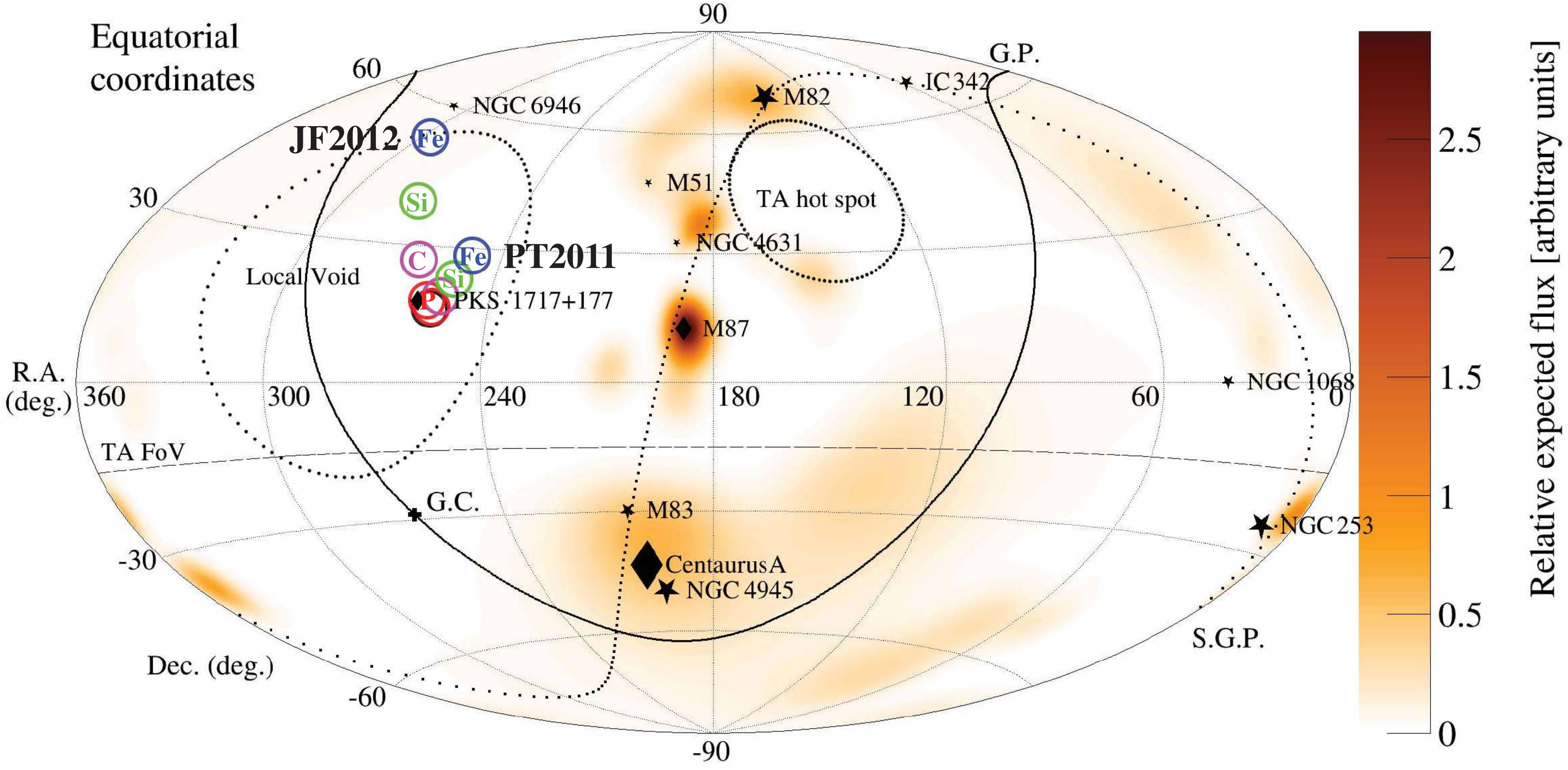
or "New physics"

$$\left(\frac{E_{\max}}{100\,\mathrm{EeV}}\right) \leq Z\left(\frac{B}{10\,\mu\mathrm{G}}\right)\left(\frac{R}{10\,\mathrm{kpc}}\right) = Z\left(\frac{B}{100\,\mathrm{mG}}\right)\left(\frac{R}{1\,\mathrm{pc}}\right)$$

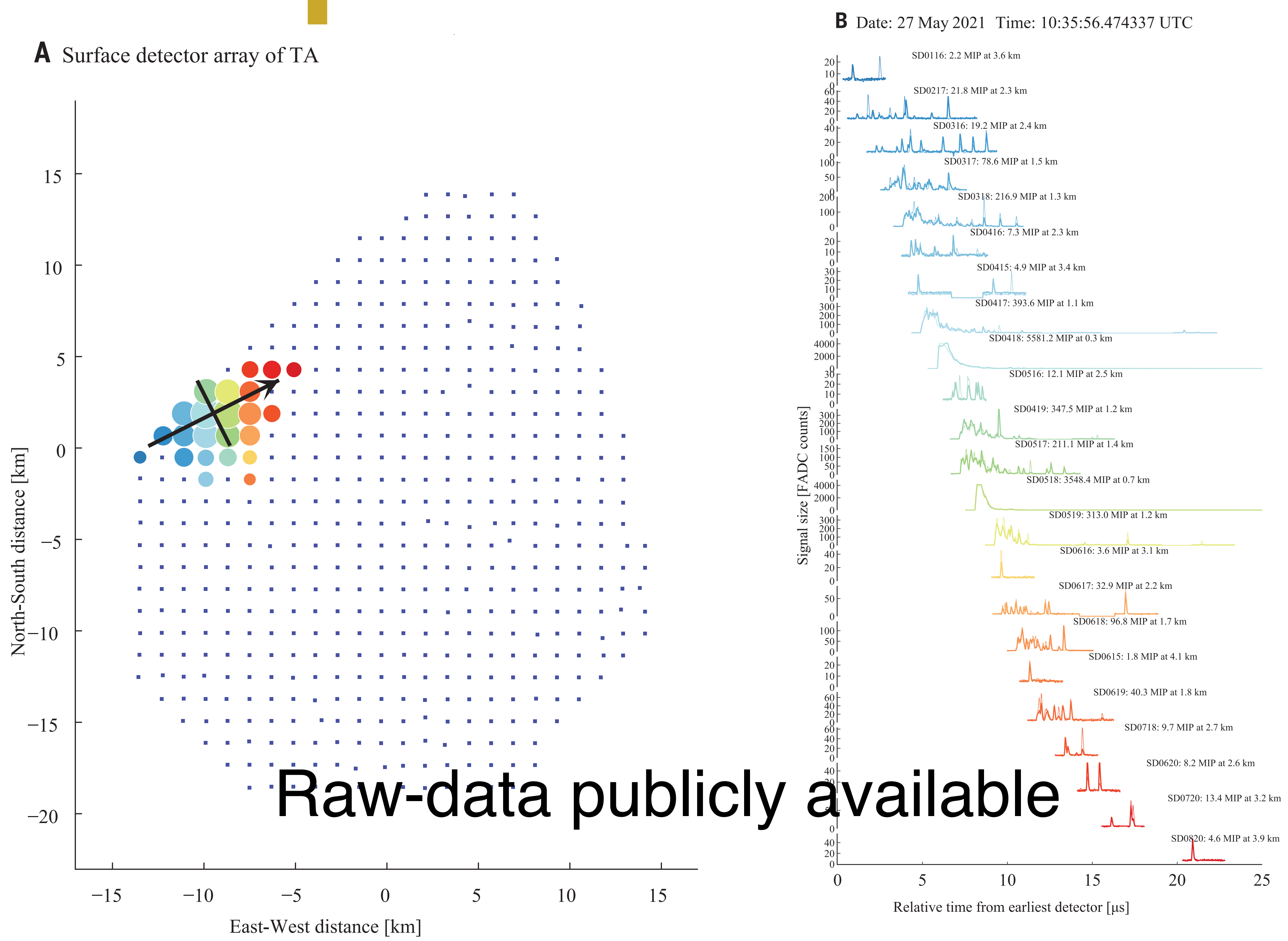
- **Limitation of nearby sources** due to "GZK cutoff"
- **Less deflections** of Galactic/extragalactic magnetic fields
  - Directionally correlations between **UHECRs** and nearby **inhomogeneous sources** to identify their origins
- **A next-generation "astronomy" using charged particles**

Arrival direction of Amaterasu particle

- E = 244 ± 29 (stat.) +51,-76 (syst.) EeV
  - **Unexpectedly, come from the Local Void**
  - No promising astronomical source candidates



Telescope Array Collaboration, Science 382, 903 (2023)

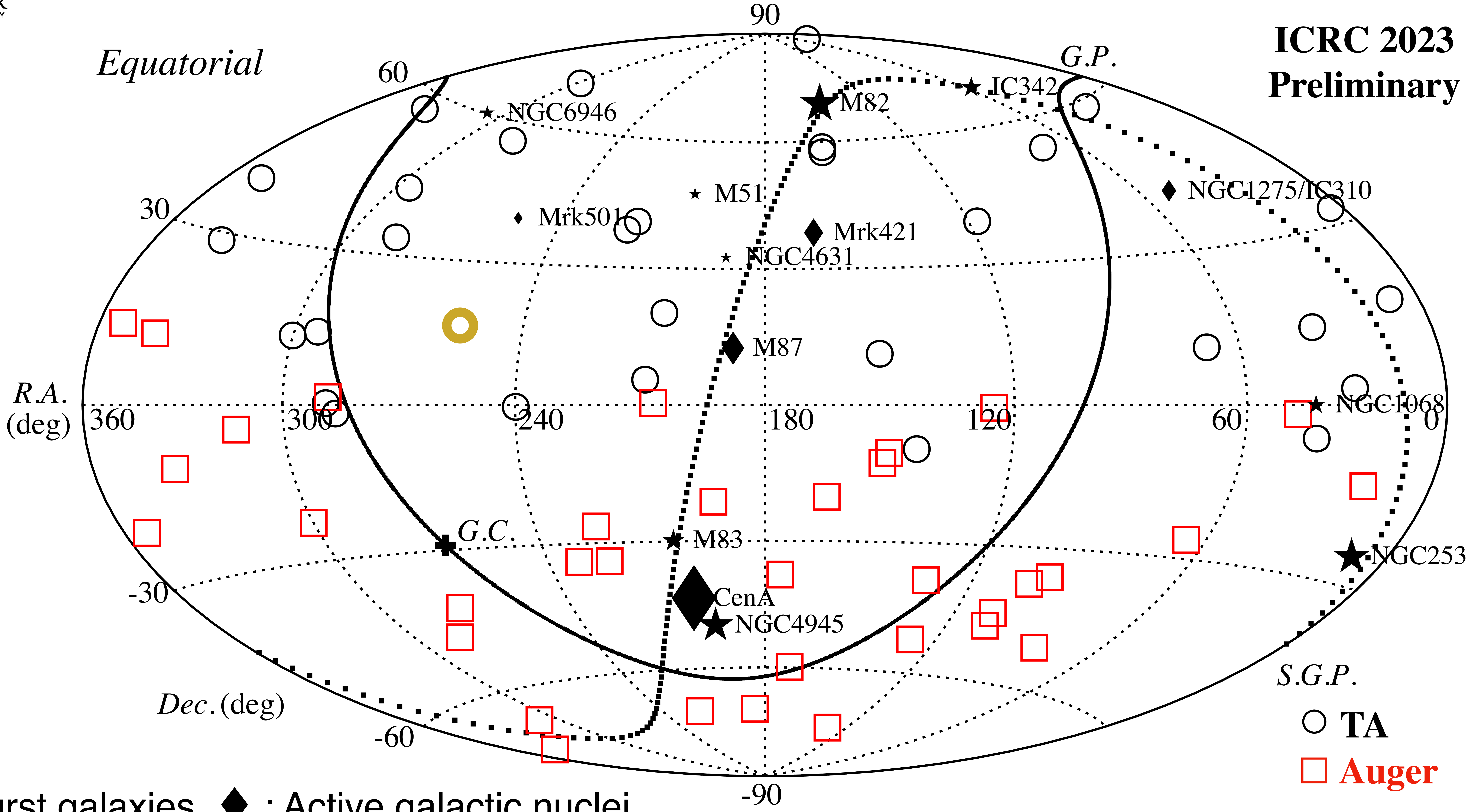


Raw-data publicly available

- **Possible source region** [Unger and Farrar, ApJL 962 L5 (2024)]
- **Magnetic monopole** [Frampton, Phys.Lett.B 855, 138777 (2024)]
- **Ultra-heavy composition** like Te or Pt [Zhang, Murase+, arXiv:2405.17409]
- **Binary neutron star merger** [Farrar, PRL 134, 081003 (2025)]
- **Bursting magnetar** [Shimoda and Wada, arXiv:2409.19915]

>100 EeV skymap

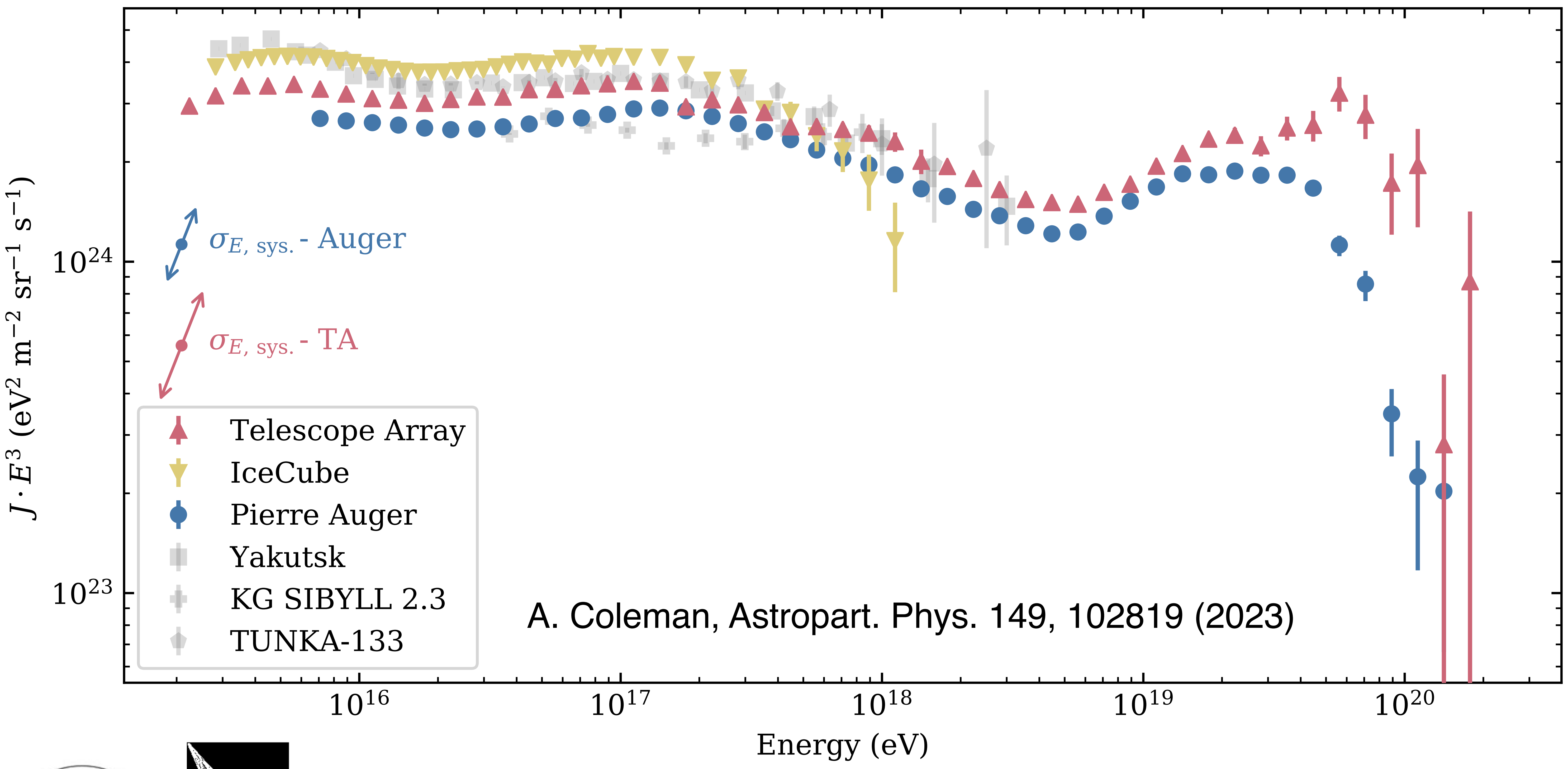
T. Fujii, PoS (ICRC2023) 031 (2023)

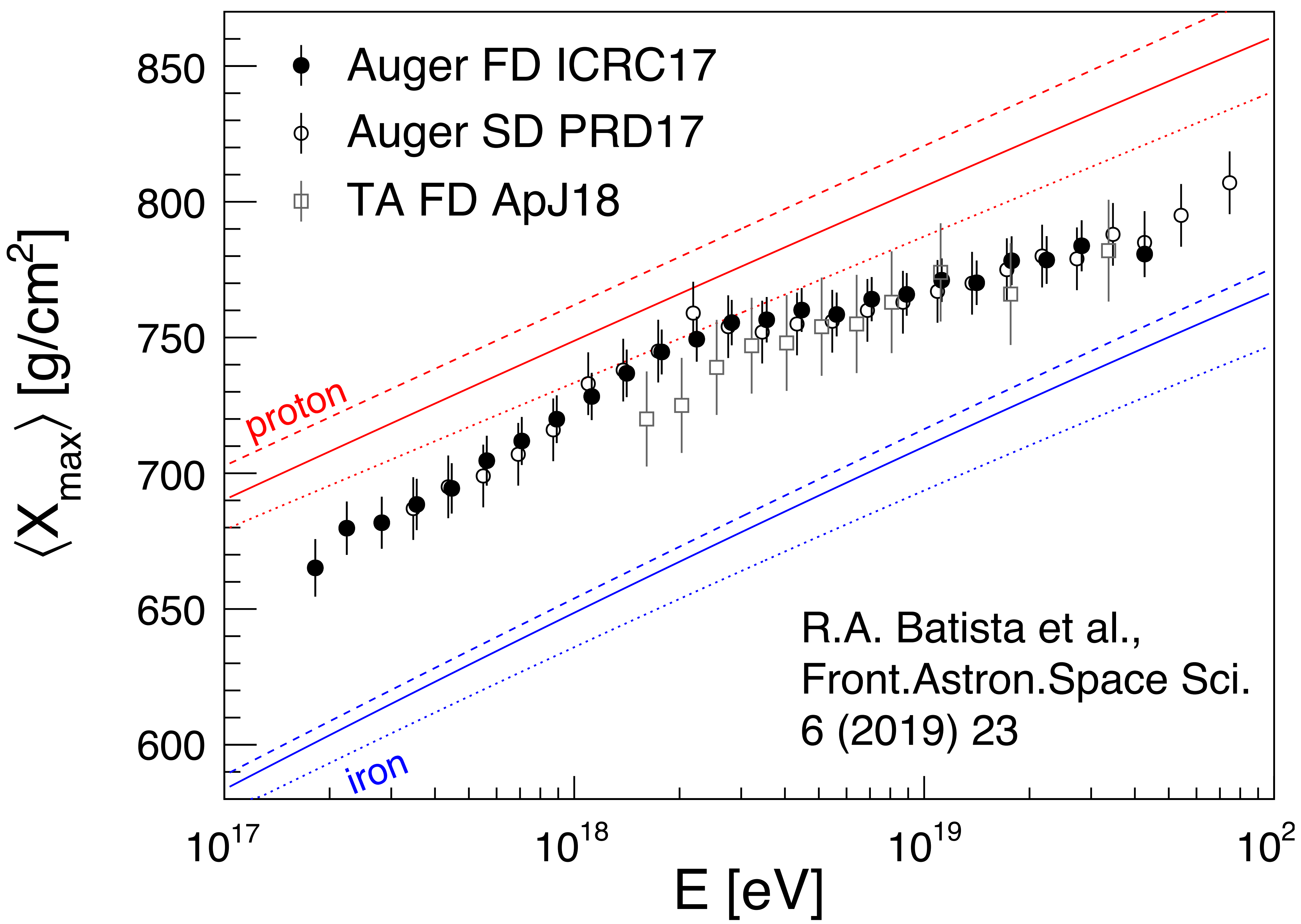


★ : Starburst galaxies ♦ : Active galactic nuclei

>100 EeV of TA 15-years and Auger 17-years

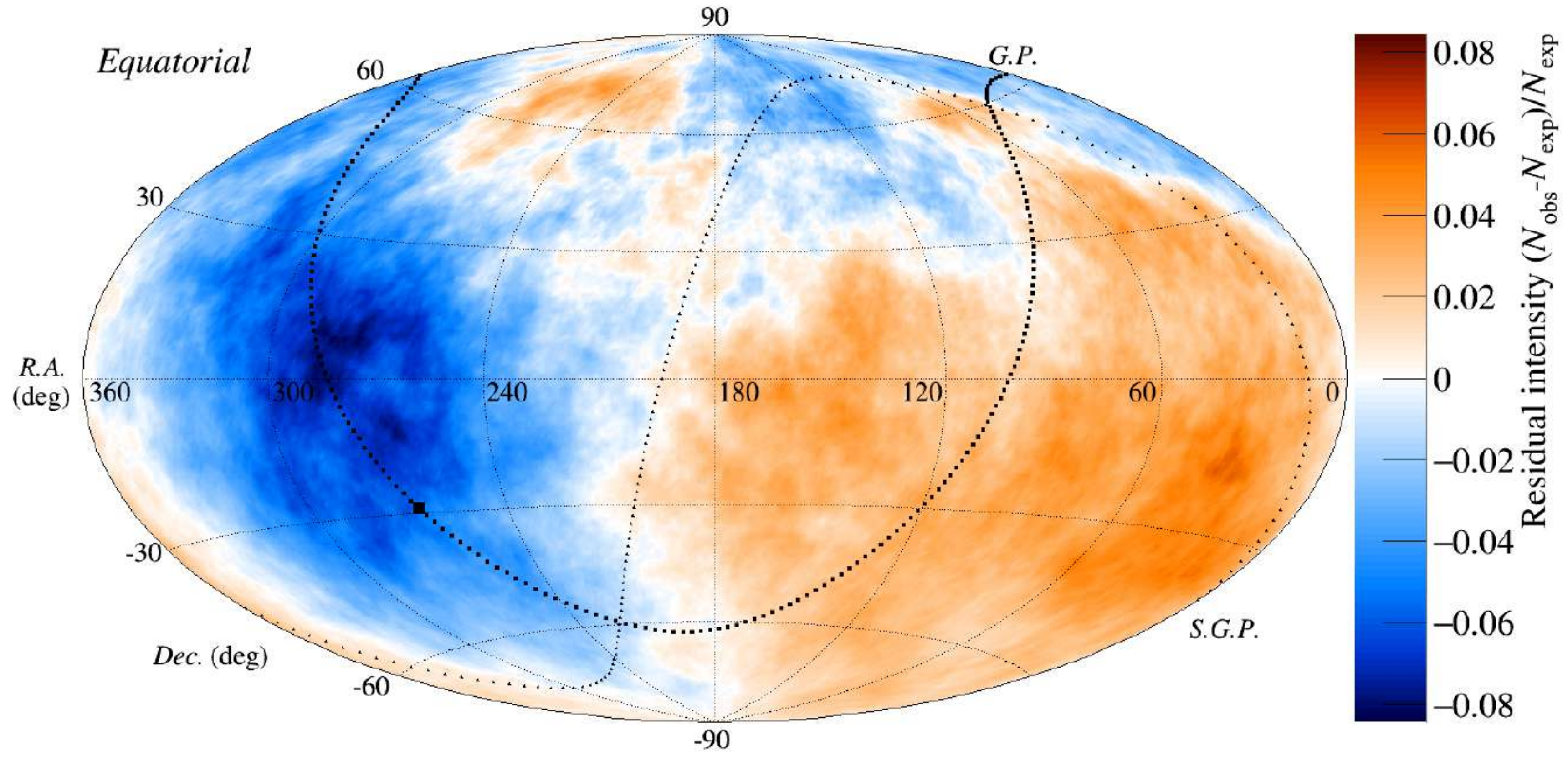
No obvious clustering appeared



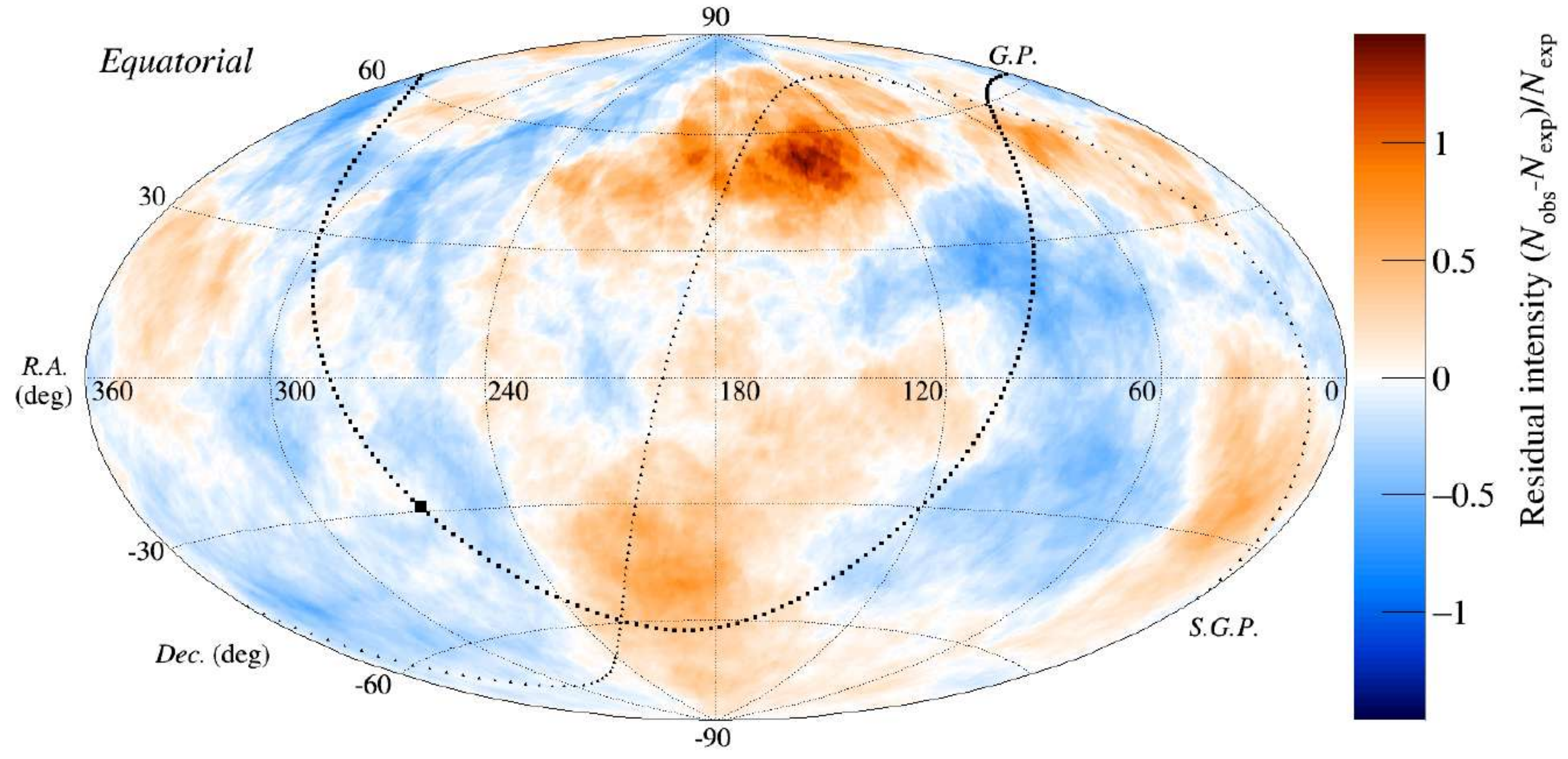


Latest results

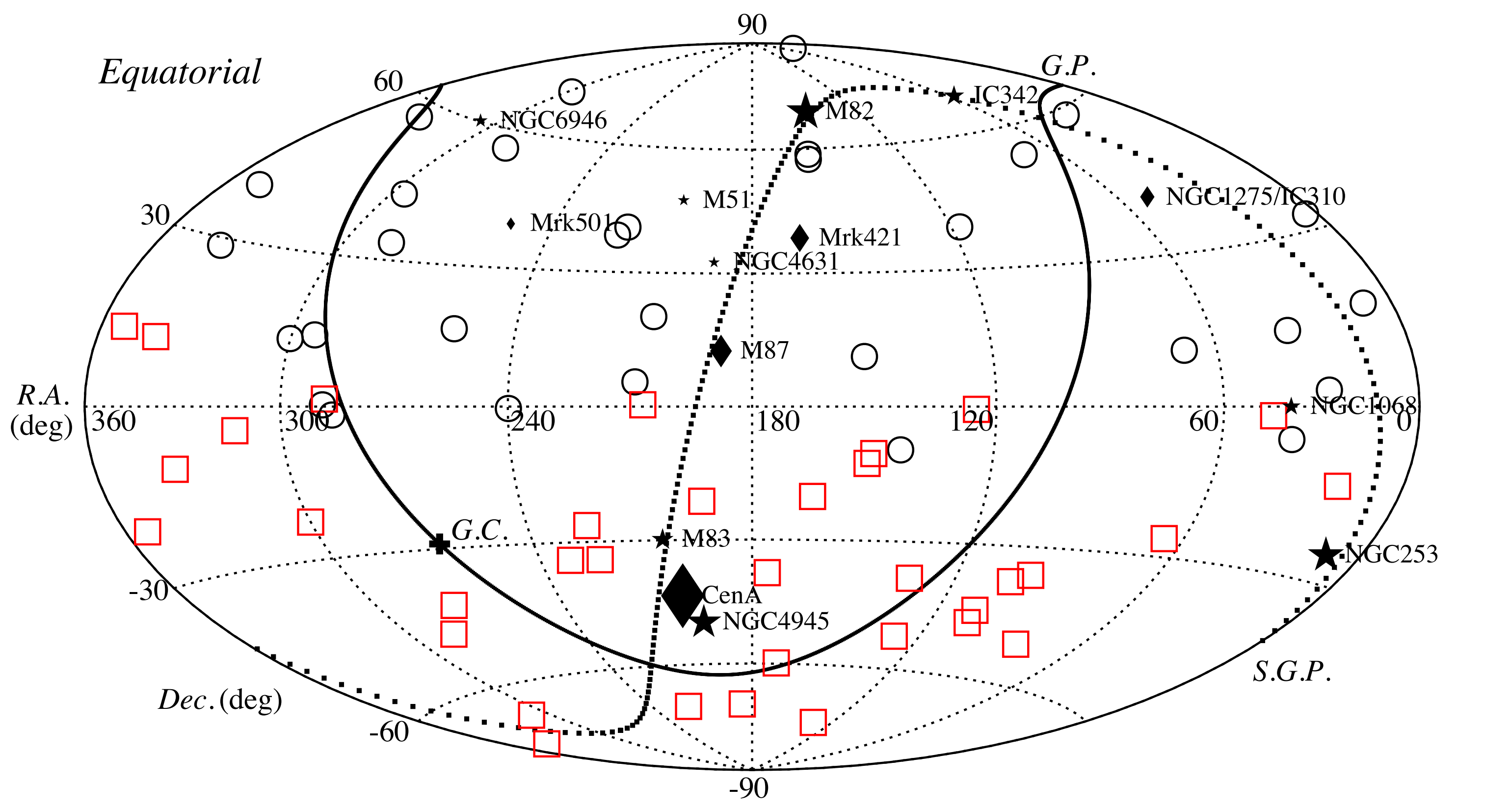
$$\theta \sim 10^\circ Z \left(\frac{E}{10\,\text{EeV}} \right)^{-1} \qquad t_{\text{delay}} \sim 100\, Z^2 \left(\frac{E}{10\,\text{EeV}} \right)^{-2} \text{yr}$$



Ankle ($E > 10$ EeV)



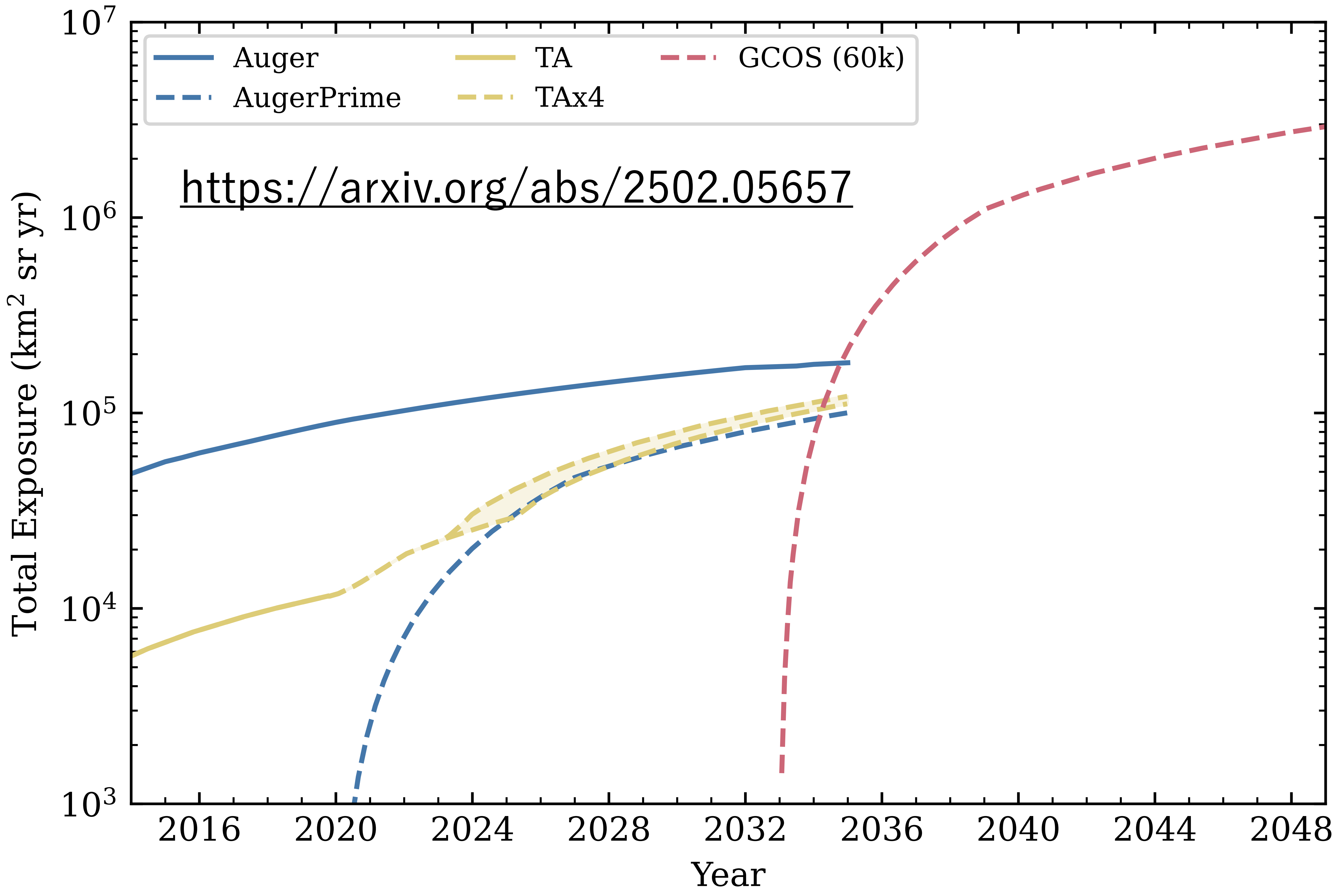
Cutoff ($E > 50$ EeV)

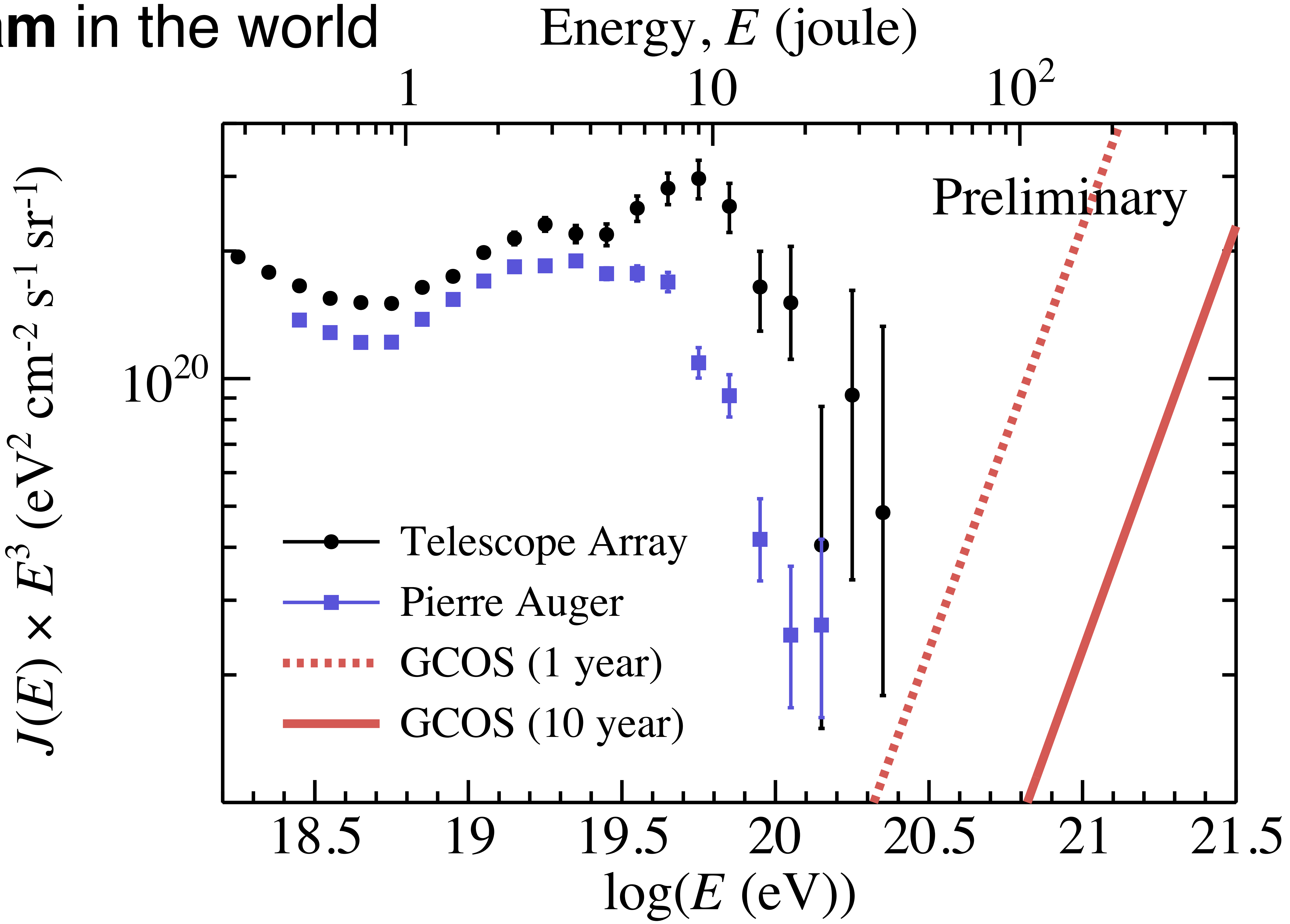


Beyond-cutoff ($E > 100$ EeV)

Science of the Global Cosmic Ray Observatory (GCOS)

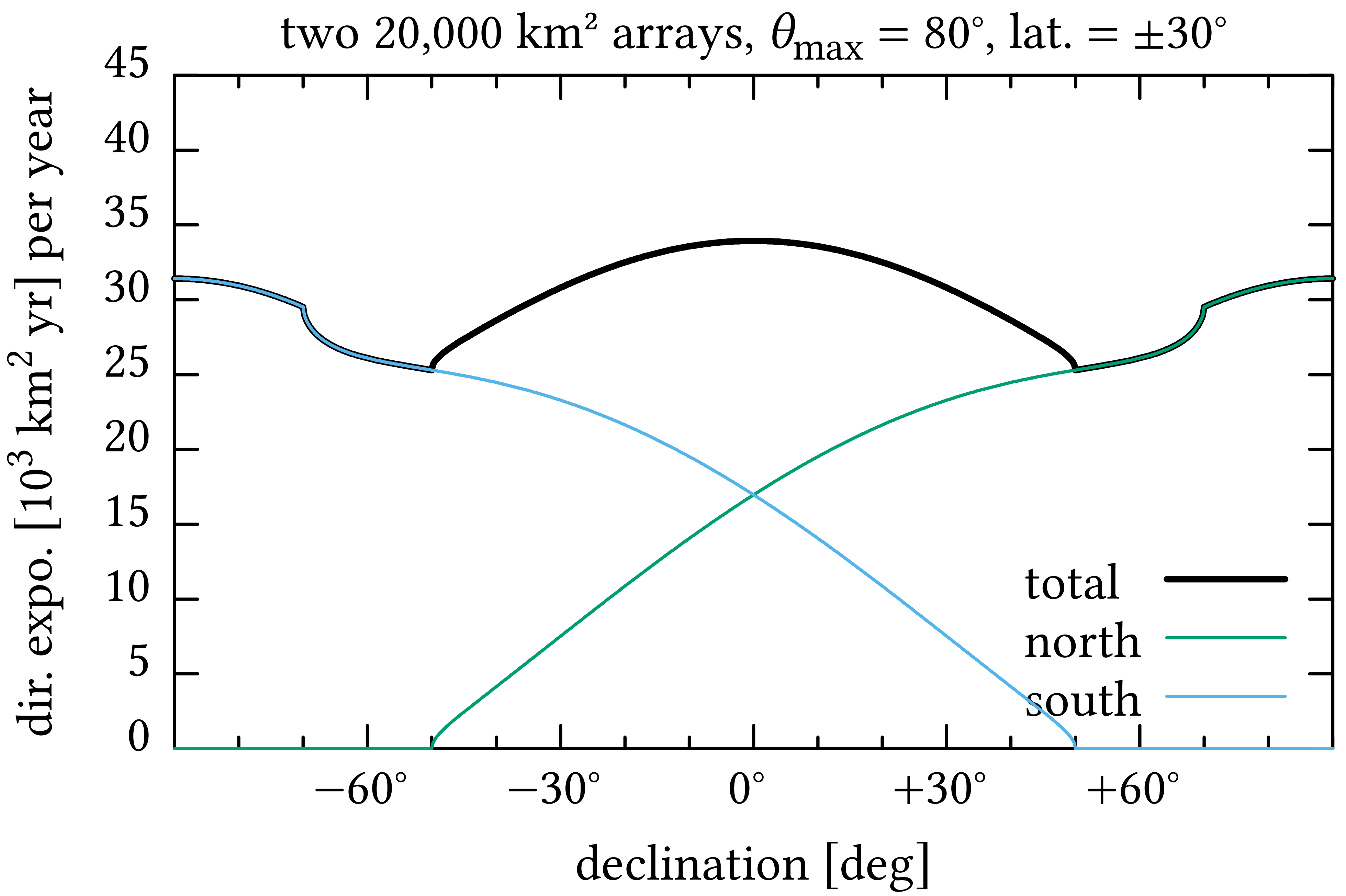
- **Charged-particle astronomy to clarify the origin and nature of the most energetic particles in the universe**
- **Unprecedented effective area, 60,000 km²** and **mass identification capabilities**
- Begin operations after 2030s, **One team** in the world





Detector of the Global Cosmic Ray Observatory (GCOS)

- **Number of sites ≧ 2**, Trigger energy threshold: **10 EeV**
  - Energy resolution: **10%**, mass resolution: **ln(*A*) ~ 1**, arrival direction: **1 degree**
- Under considerations about detector design and possible installation sites



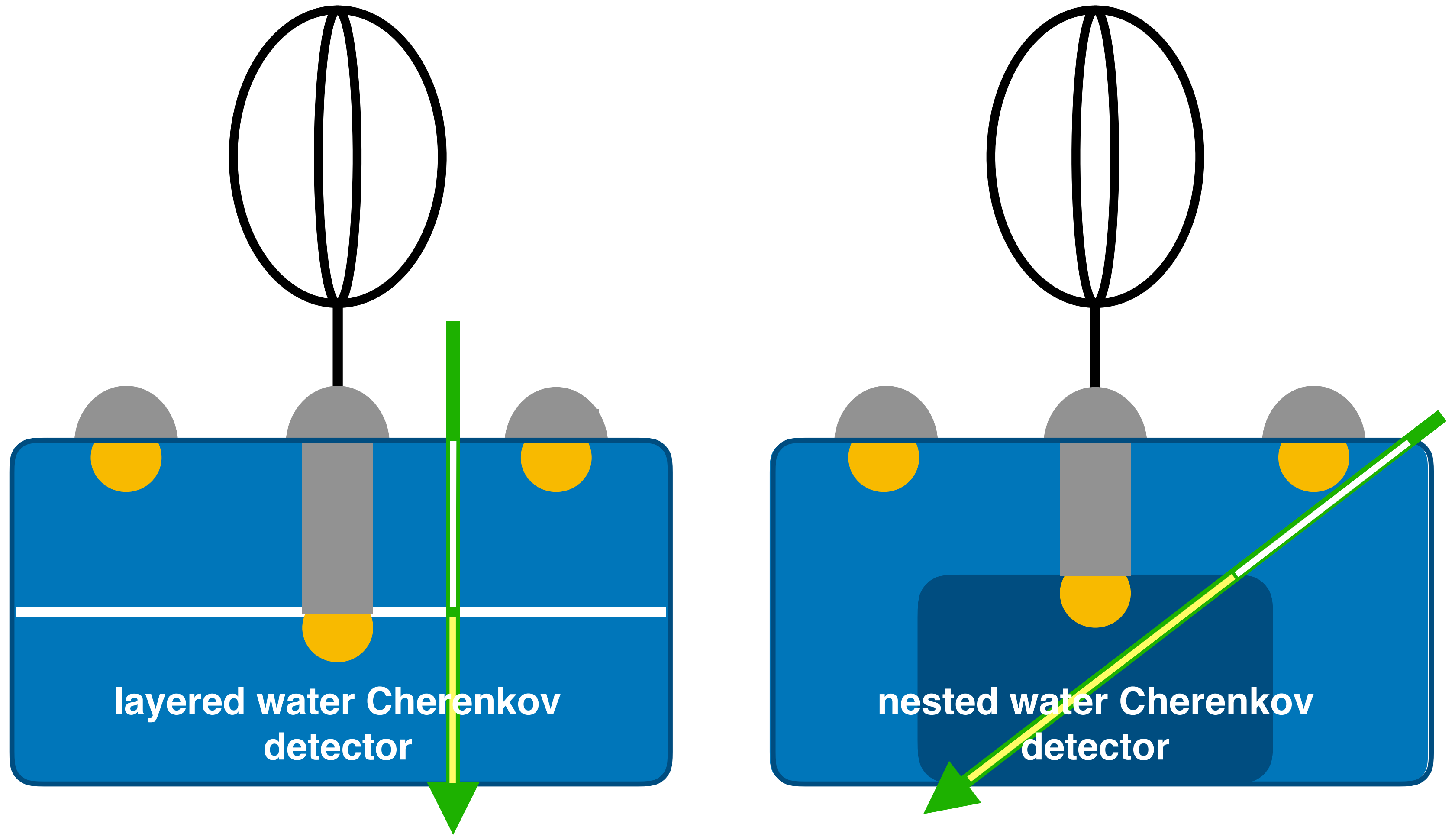


Figure 6: Detection concepts, using a layered (left) and a nested (right) water Cherenkov detector with a radio antenna on top.

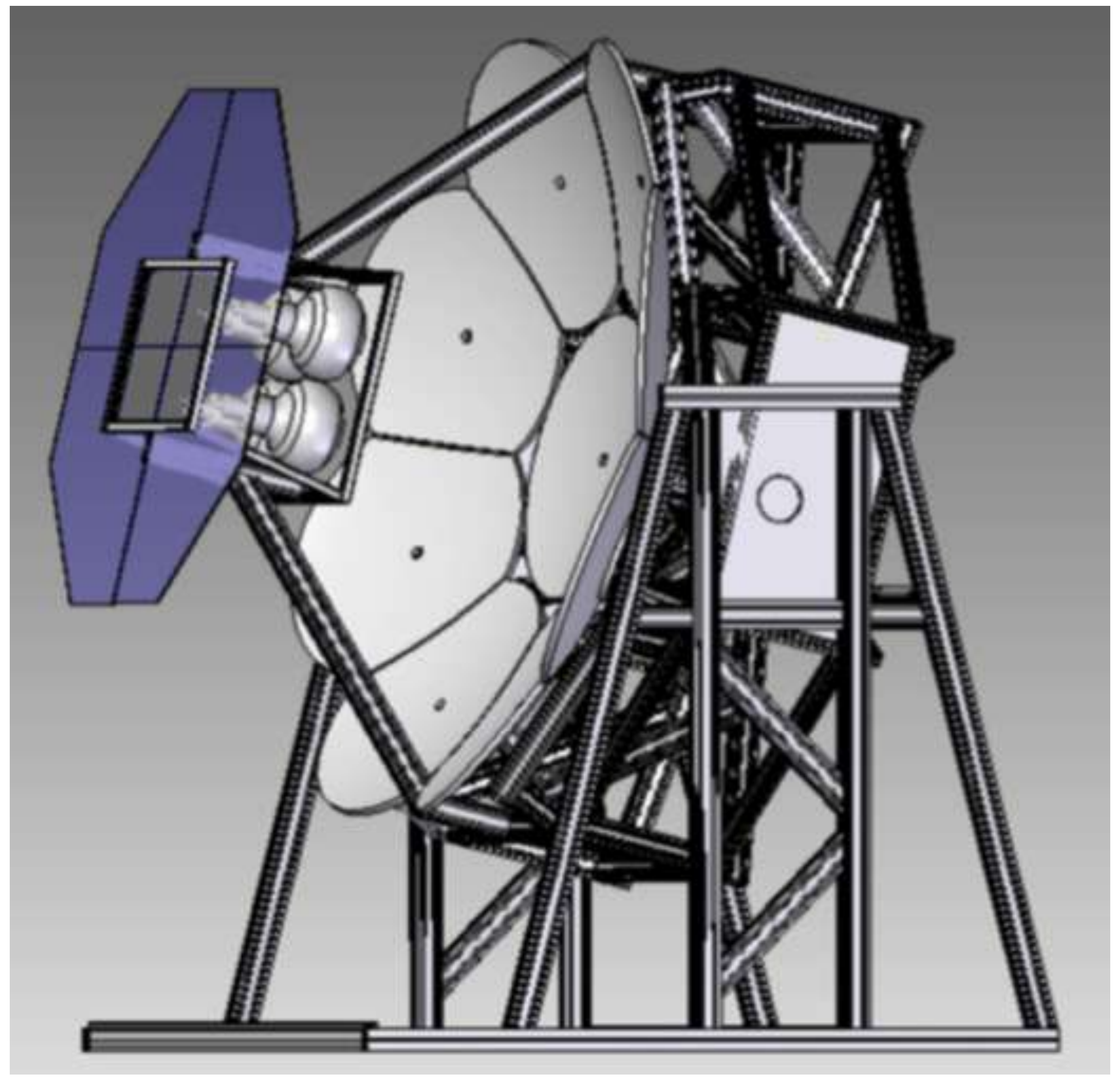


Figure 7: A FAST telescope frame, showing four PMTs at the focus of a 1.6 m diameter segmented mirror. The support structure is made from aluminium profiles. The UV band-pass filter can be seen attached to the periphery of the camera box [100, 101].

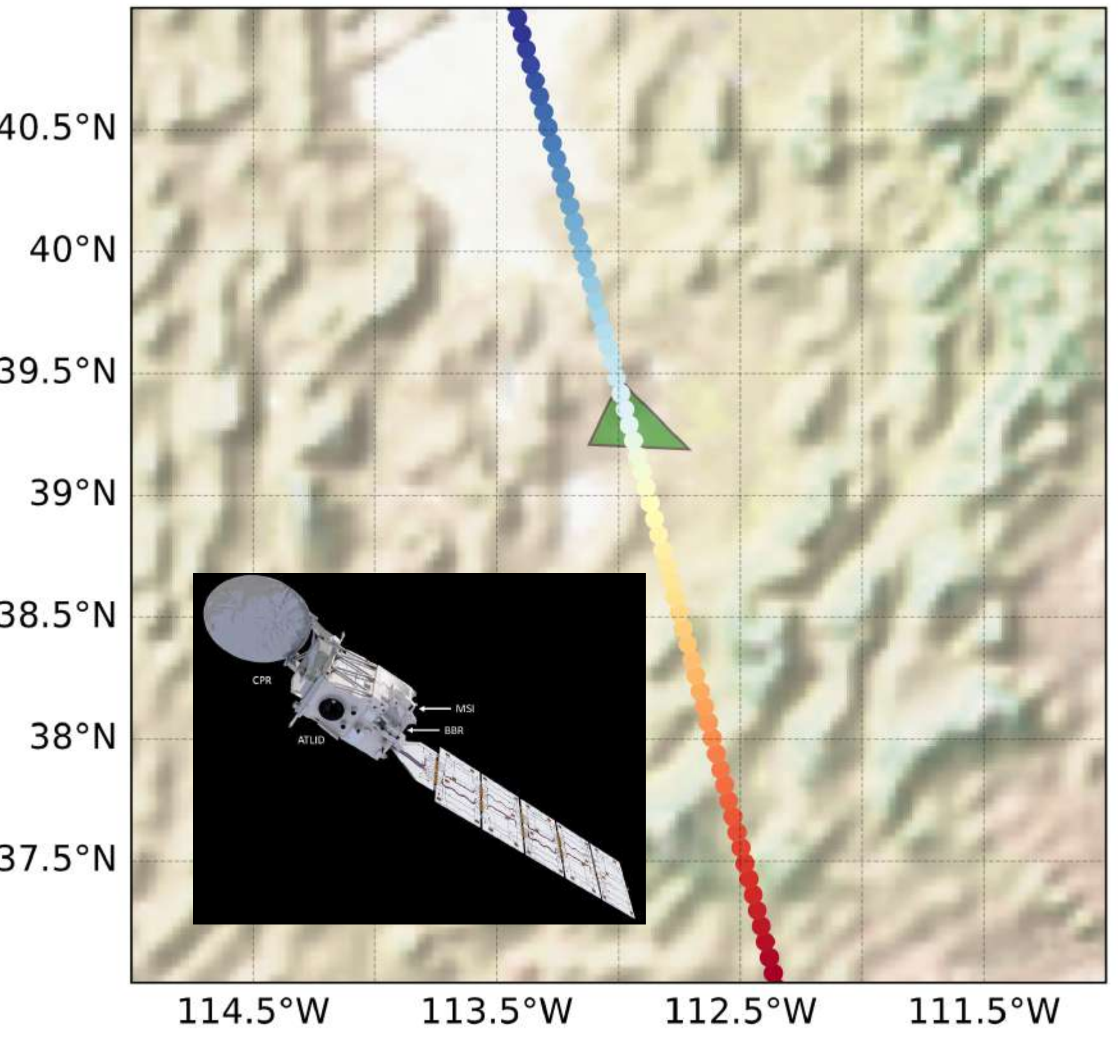
J.R. Horandel et al. PoS (ICRC 2021)

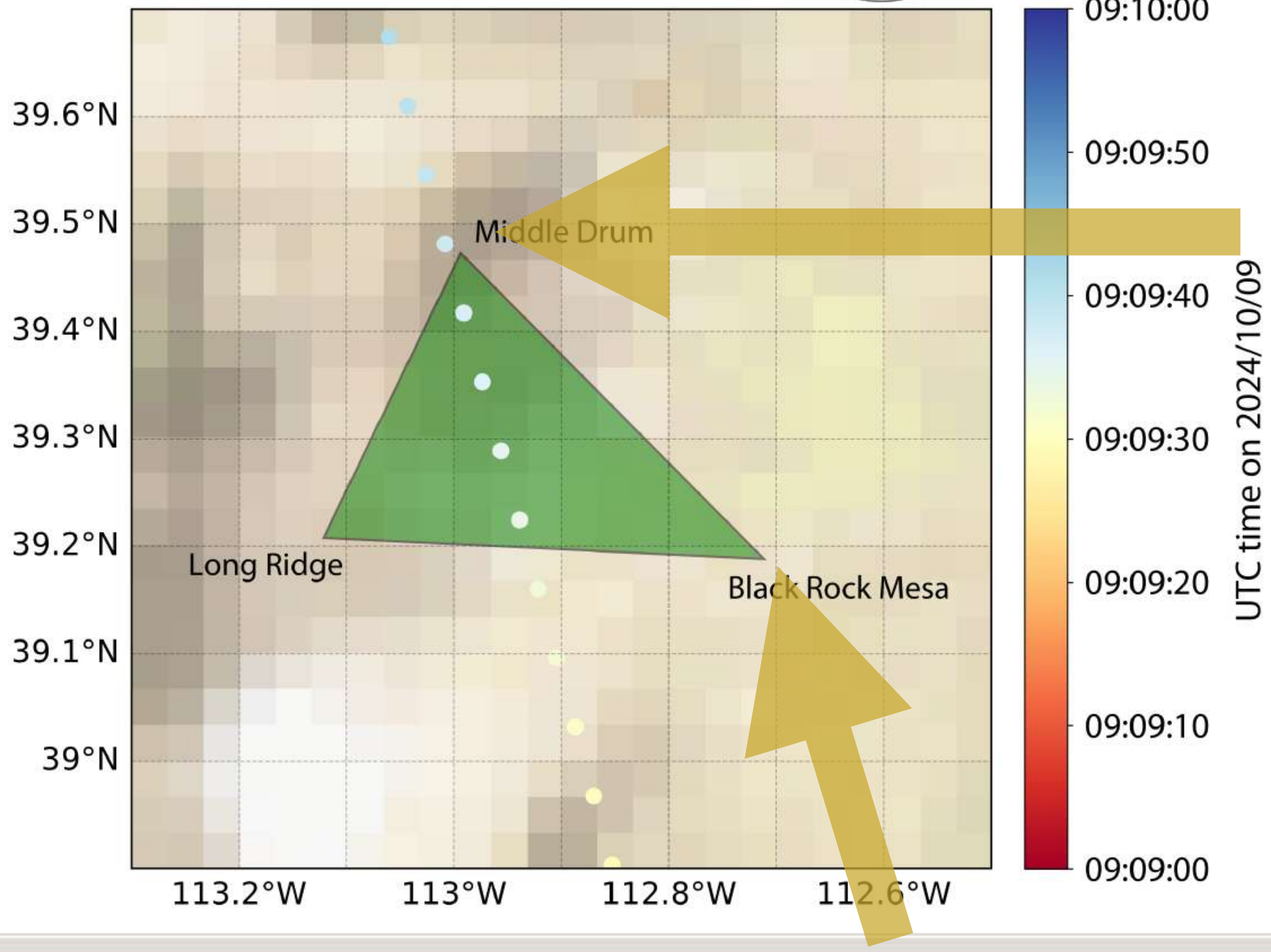
Cosmic-ray observatories on ground

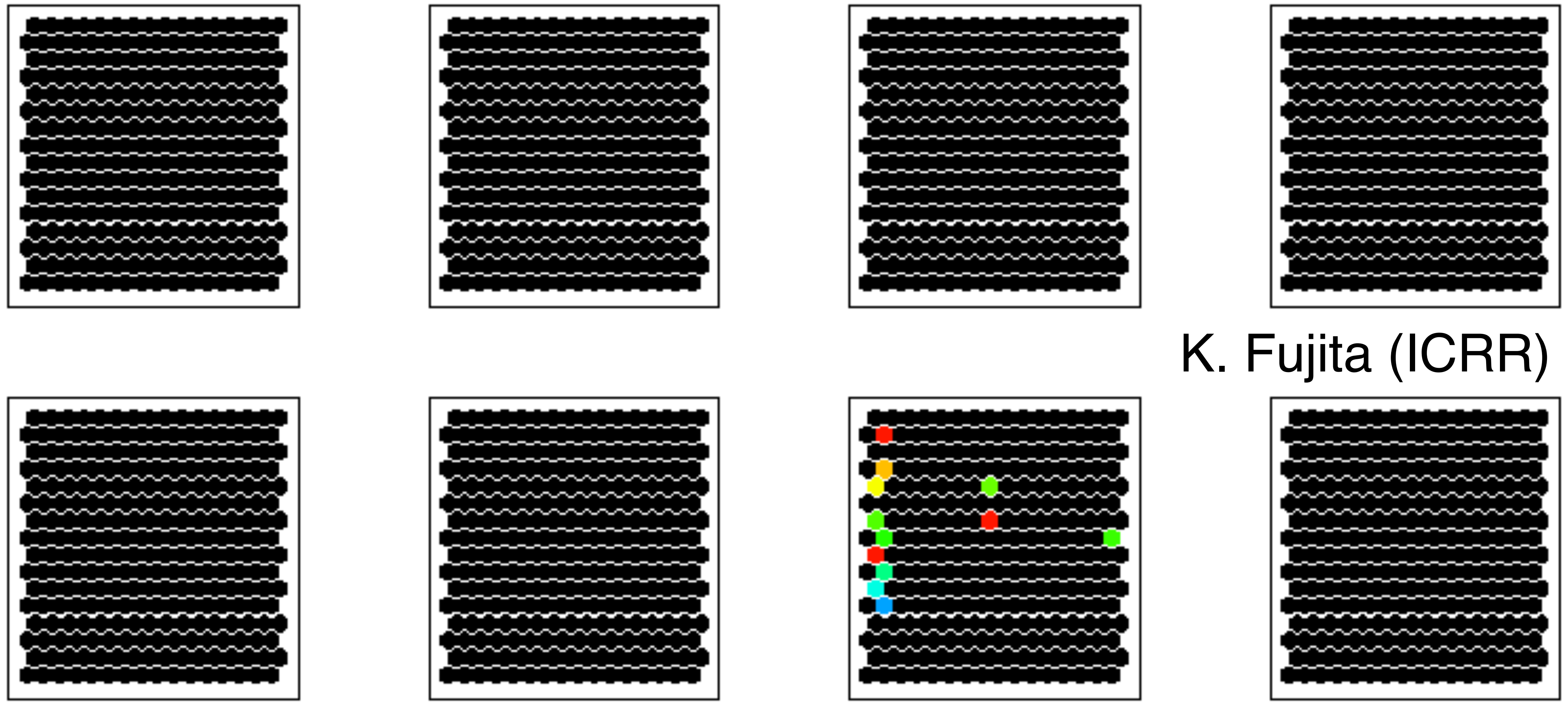
T. Fujii, PoS (ICRC2023) 031 (2023)

Intersection with Earth science as "global light source"

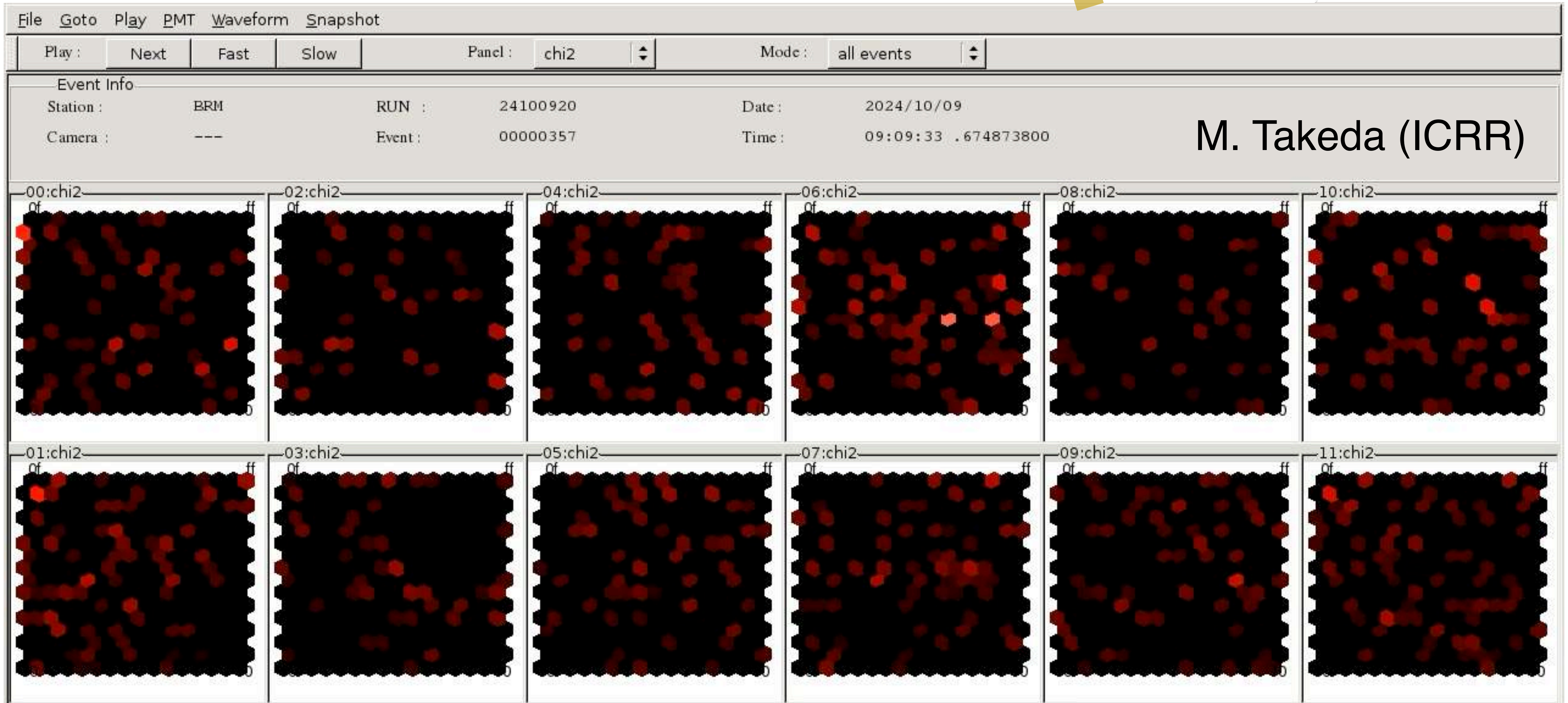
TA overpass on 9 October 2024







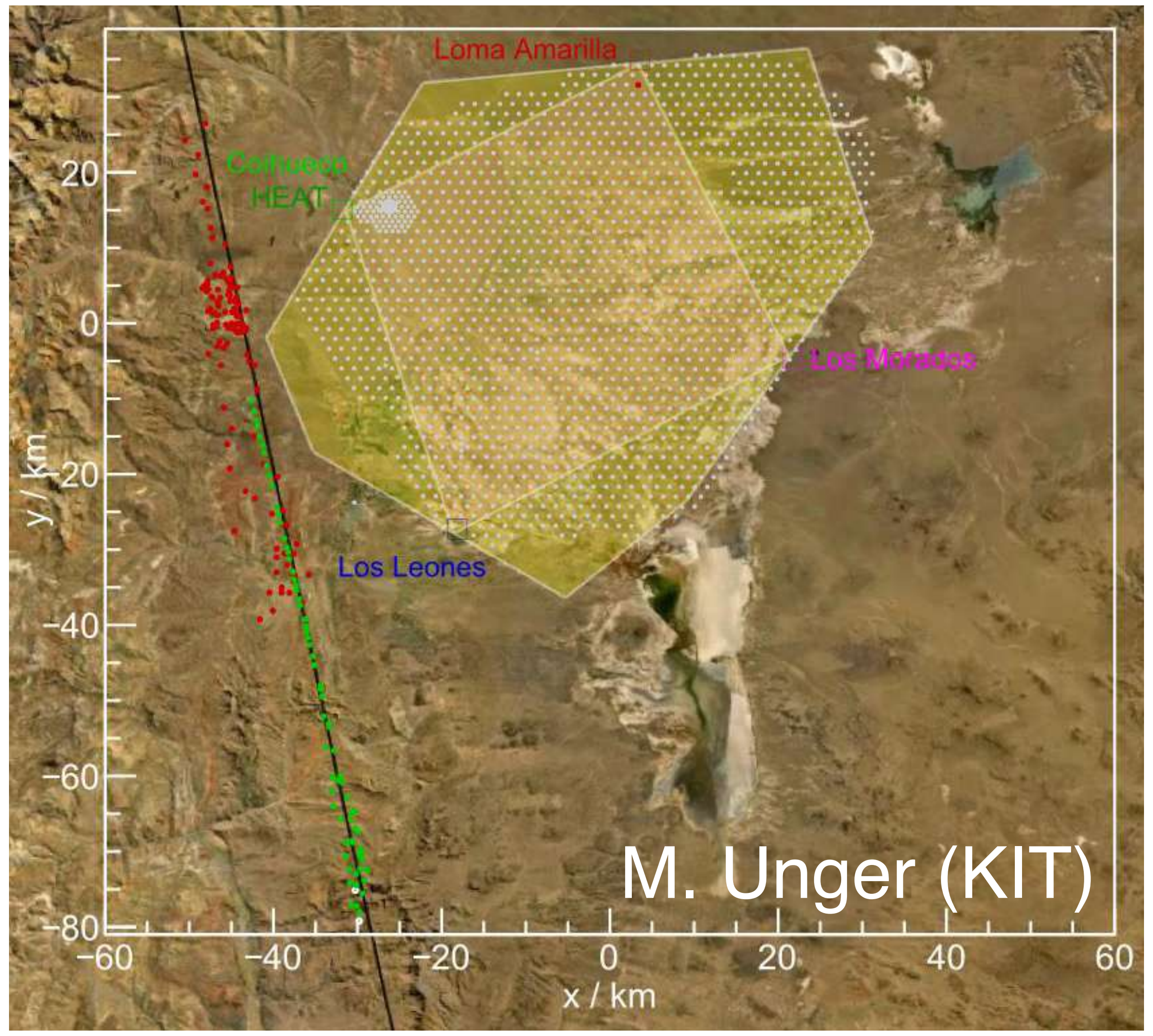
K. Fujita (ICRR)



M. Takeda (ICRR)

Auger overpass on 29 October 2024

PIERRE AUGER OBSERVATORY



M. Unger (KIT)

EarthCARE team: O. Lux and O. Reitebuch (DLR)

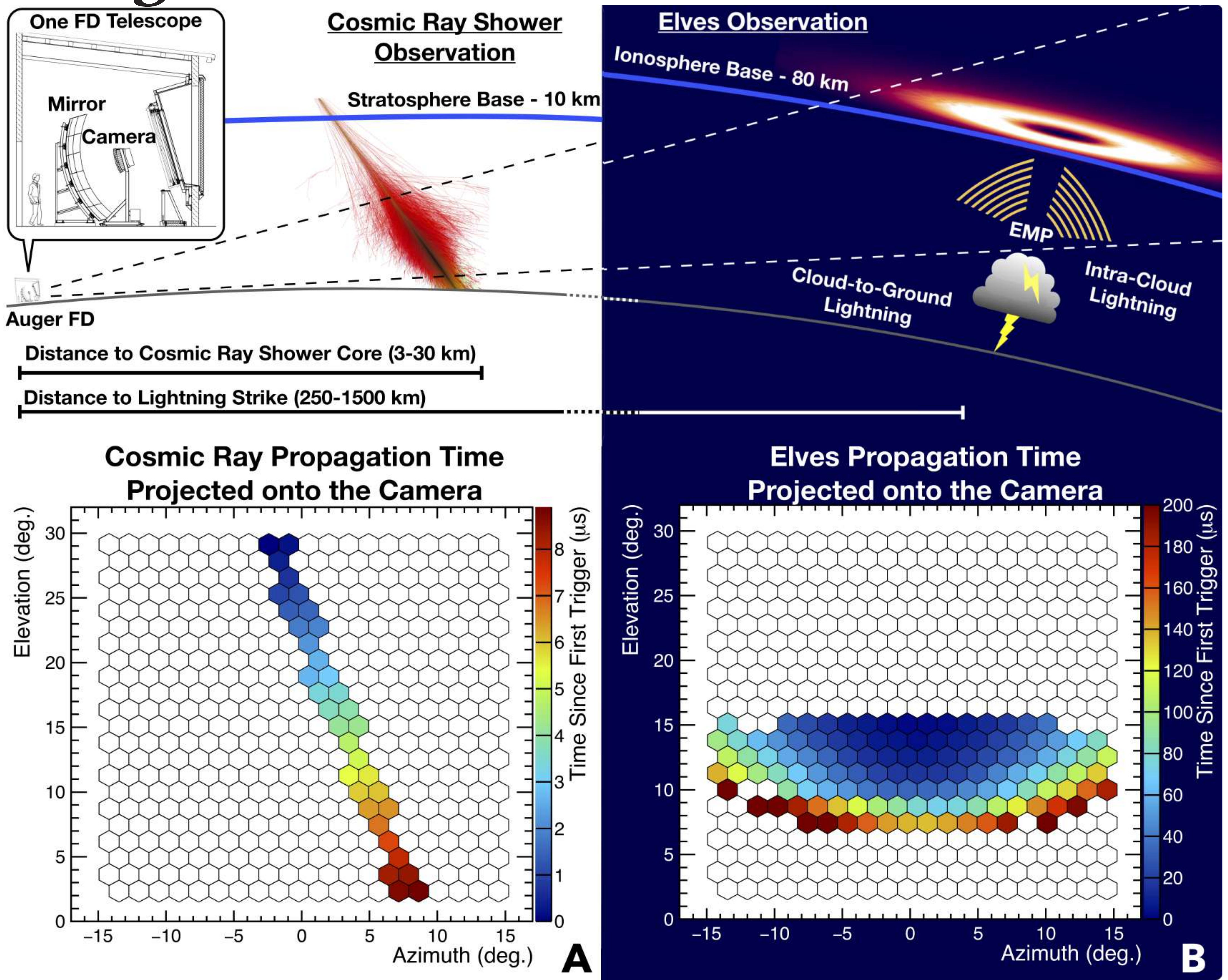
Intersection with Earth science

Towering thunderstorms regularly roll over central Argentina.

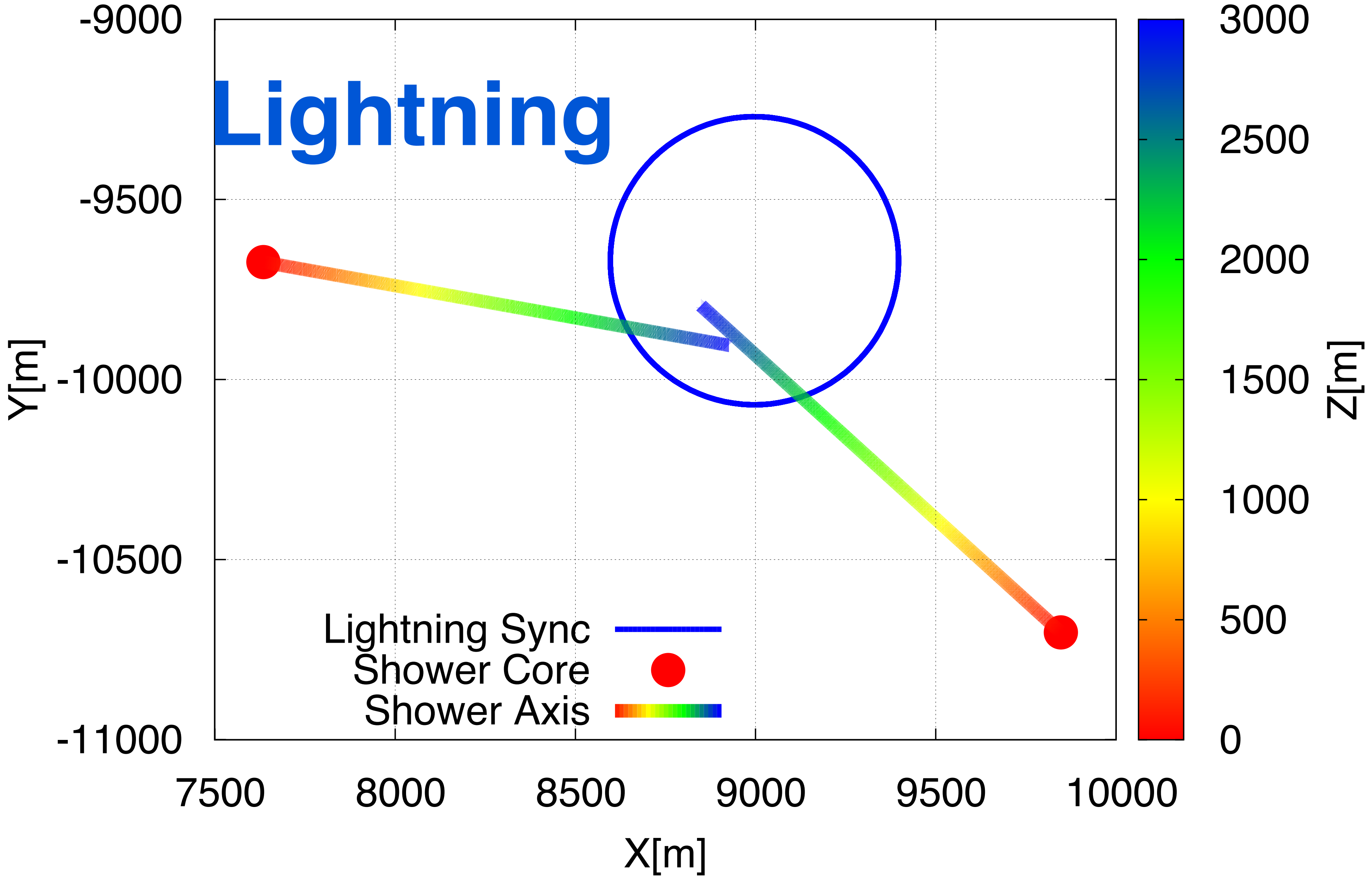
ATMOSPHERIC SCIENCE

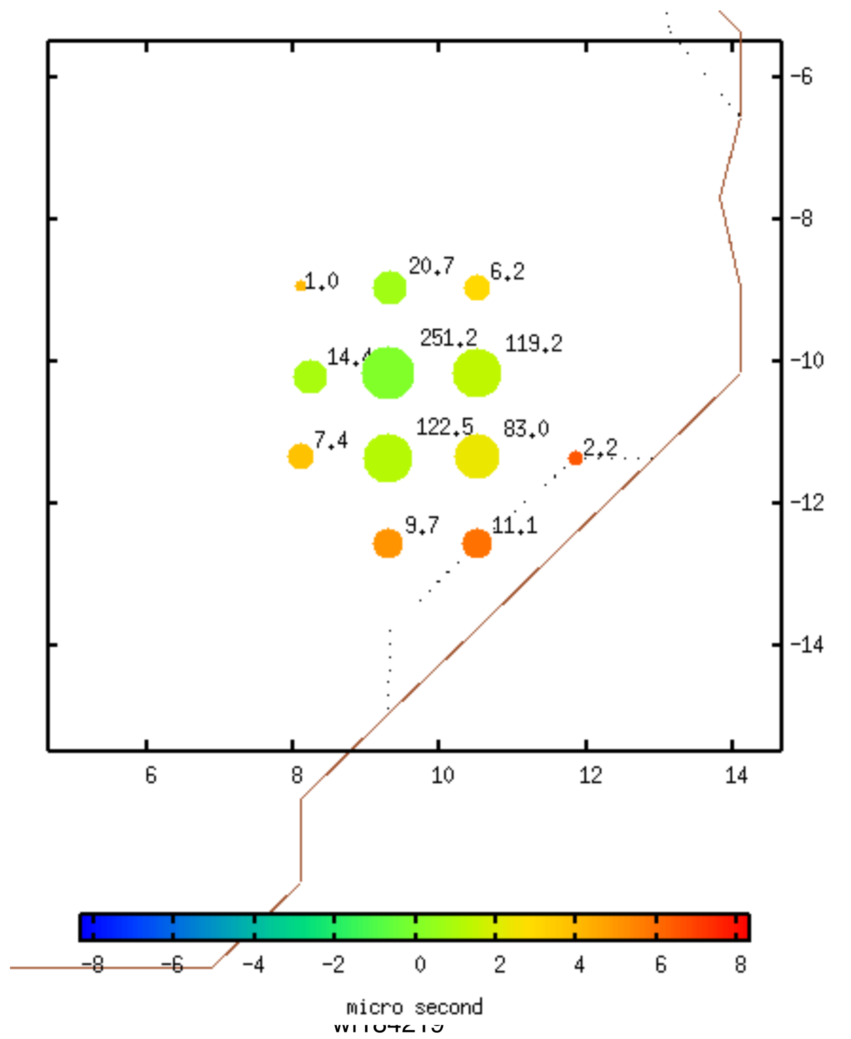
Inside Argentina's mega-storms

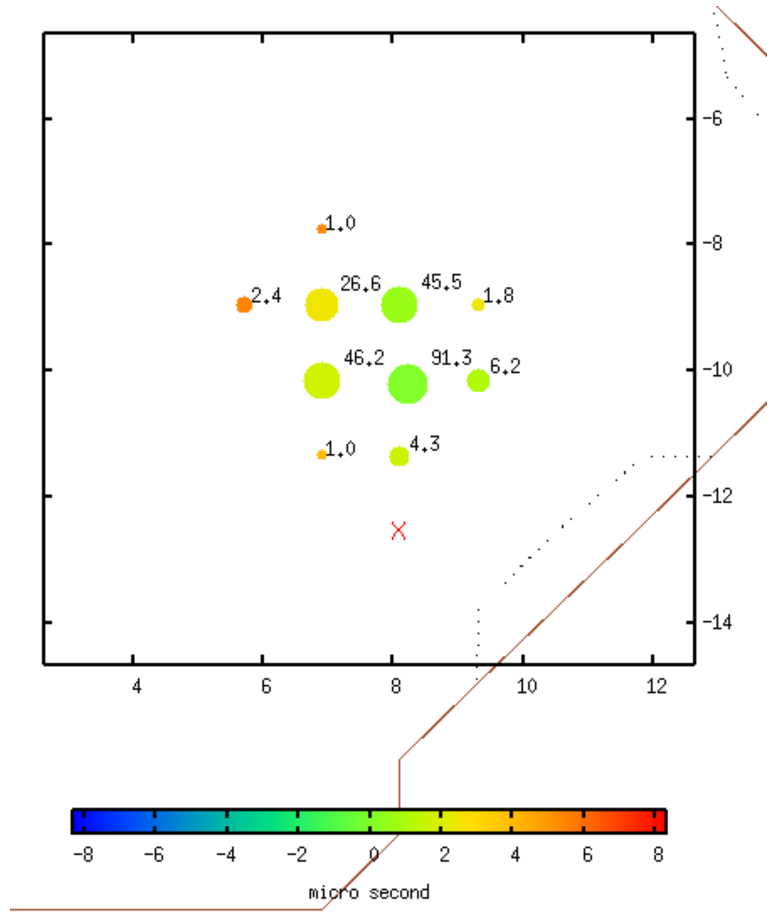
Pierre Auger Collaboration (2020) https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2019EA000582

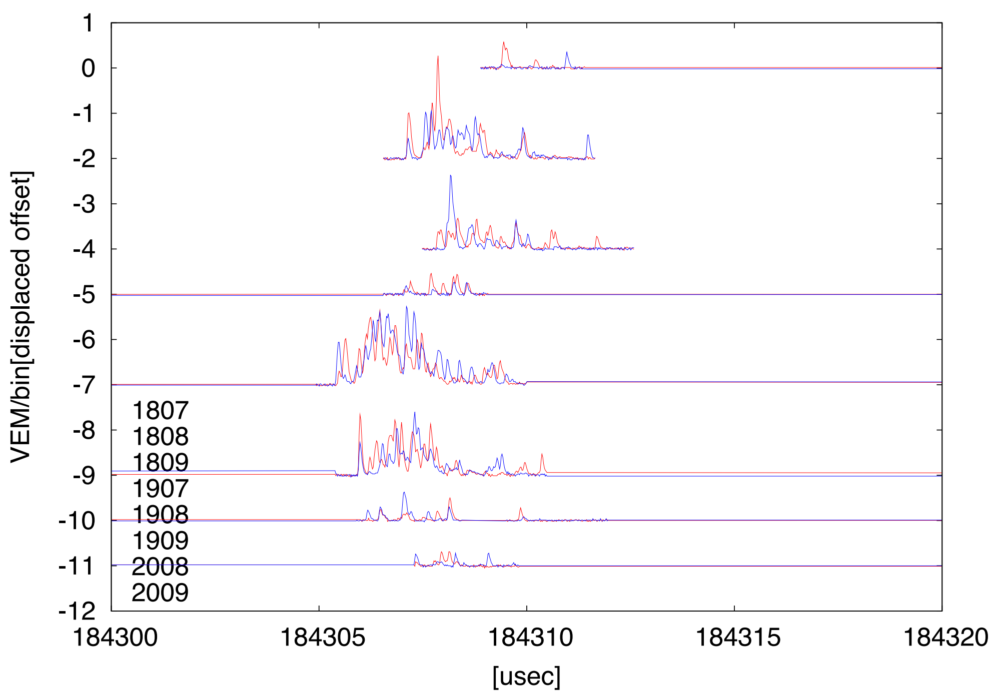


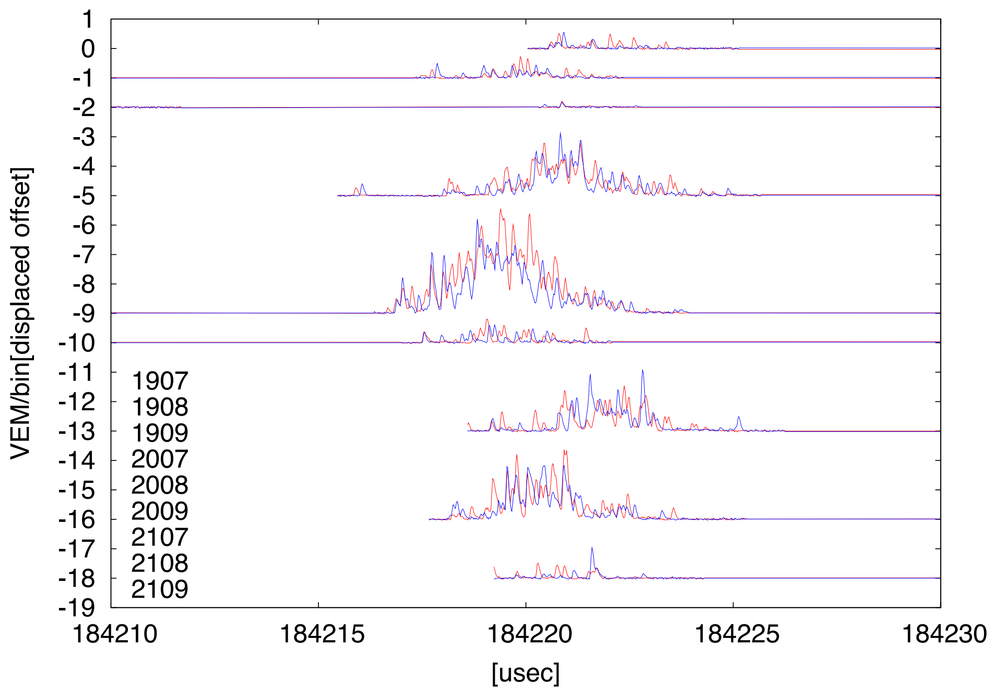
bursts of shower correlating with lightnings











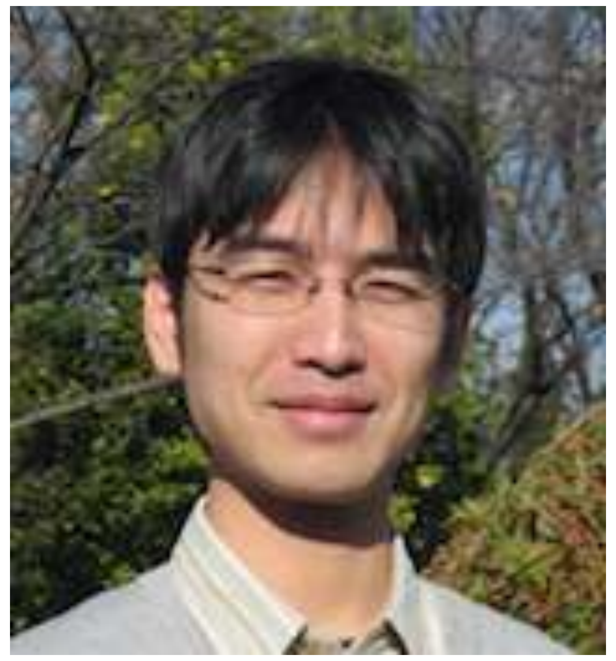
Telescope Array collaboration,
Physics Letters A 381 (2017) pp. 2565-2572

GCOS-Japan consortium のタスクリーダー

地表粒子検出器：
木戸 英治（東京大学宇宙線研究所、理化学研究所）
タスク：地表粒子検出器の検討・開発・最適化・試験観測など

起源・加速・伝搬の理論：
大平 豊（東京大学理学系研究科）
タスク：宇宙線の発生源・加速メカニズムや伝搬過程を中心とした理論研究など

大気蛍光望遠鏡：
多米田 裕一郎（大阪電気通信大学）
タスク：大気蛍光望遠鏡の検討・開発・最適化・試験観測など

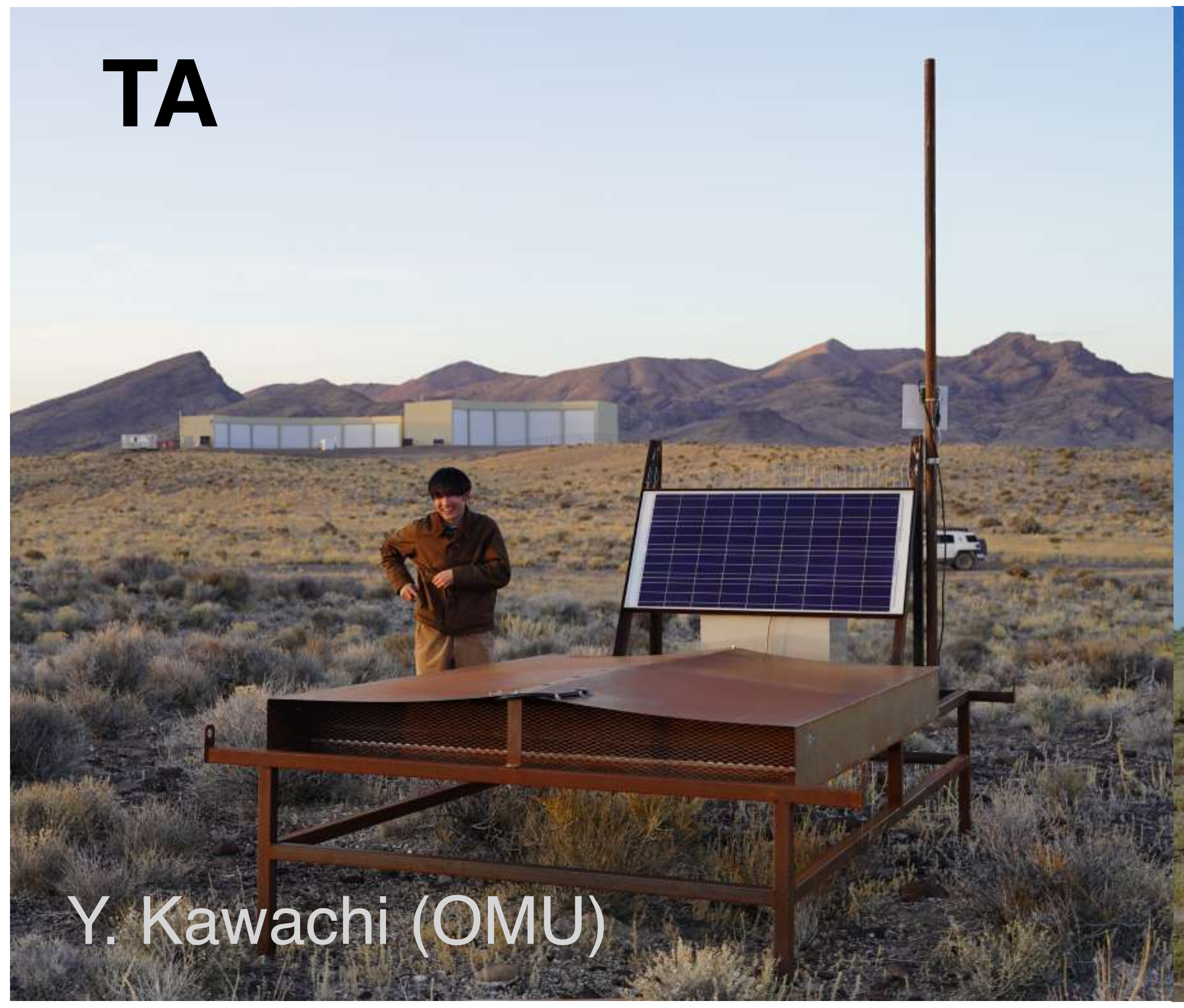


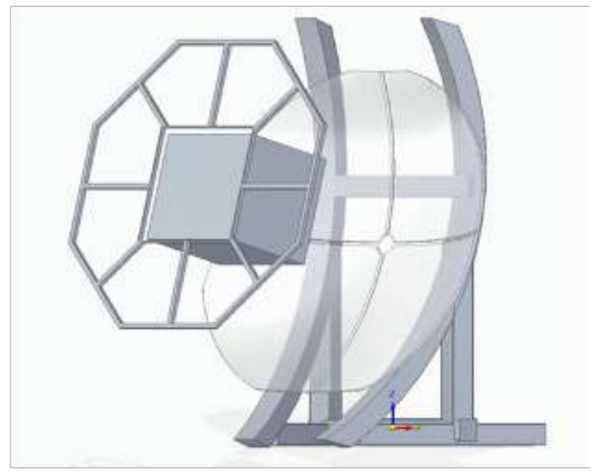
ハドロン相互作用：
毛受 弘彰（名古屋大学ISEE）
タスク：ハドロン相互作用モデルの最適化や、加速器実験との連携など

アウトリーチ・教育：
一方井 祐子（金沢大学）
タスク：宇宙線の魅力の発信、アウトリーチ推進、次世代研究者の育成など

ロードマップ2026へ向けて、日本語文章を作成予定

GCOSの早期実現にむけた開発研究





- **検出器案の最適化**（シンチレーター、水チェレンコフ検出器、電波検出器）
    - 鉛・コンクリートシールド、二層式水チェレンコフ検出器
- **機械学習**による粒子識別能力の評価・検証

- **低コスト化、量産体制**の確立
- 大気蛍光望遠鏡の**完全自立稼働**による宇宙線の**長期安定観測**の実現
- **多地点観測**による再構成精度の実験的検証
- TAとAugerのエネルギー・Xmaxの**相互較正**

【過去の大型研究、コミュニティの合意状況】

未来の学術振興構想（2023年度版）へのGCOSの提案書より

- GCOSは、2011年に“TA2”という名称で提案され、宇宙線研究者会議（CRC）から展望を持って進めるべき計画として推進されている。以後、CRCタウンミーティングで提案と計画のアップデートを報告し続けている。2015年には、テレスコープアレイ実験の拡張計画であるTAx4実験をその前段階として提案し、科研費特別推進研究により予算化された。2022年現在、テレスコープアレイ実験の2.5倍の1800平方キロメートルの有効検出面積まで拡張が進み定常観測を実施している。

- GCOSは、東京大学宇宙線研究所の将来計画検討委員会の報告書にも取り上げられ、テレスコープアレイ実験のこれまでの成果とともに、宇宙線研究の重要な研究課題として評価されている。**GCOSは、TA2の提案時に課題として挙げられていたピエールオージェ観測所との共同研究体制を構築した、新たな国際共同研究組織**となっている。

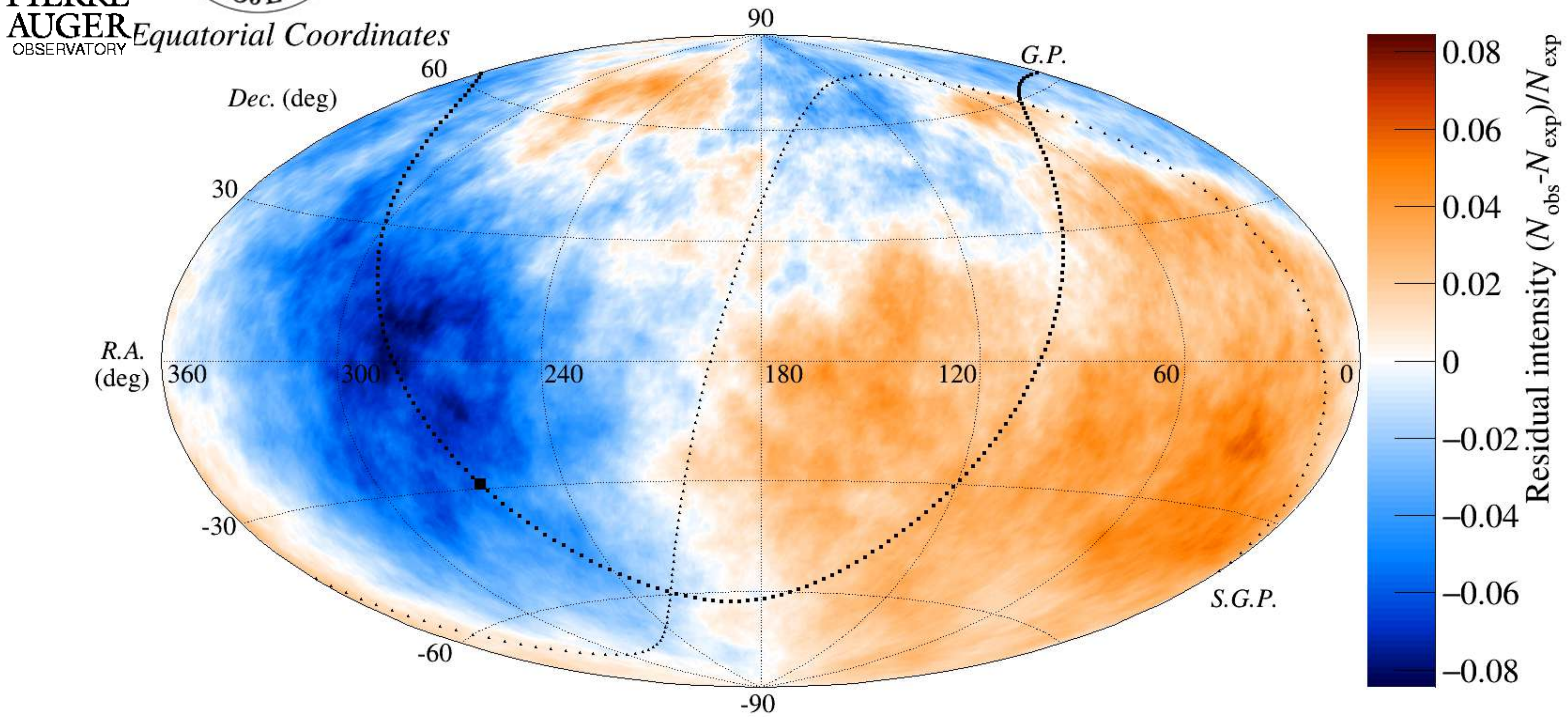
まとめと今後

- GCOS：次世代の天文学である**荷電粒子天文学を開拓し、極限宇宙物理現象を解明する**
- 日本国内の連携強化のため、**GCOS-Japan consortiumを結成**
  - **ロードマップ2026へ向けて日本語文章を作成予定**
  - 開発の最新状況は3月19日の日本物理学会のGCOS連続講演にて
- 研究会開催：**September 9 - 11, 2025**, "Workshop for The Global Cosmic Ray Observatory -- Challenging next-generation multi-messenger astronomy with interdisciplinary research", @Koshiba Hall, Hongo Campus, University of Tokyo

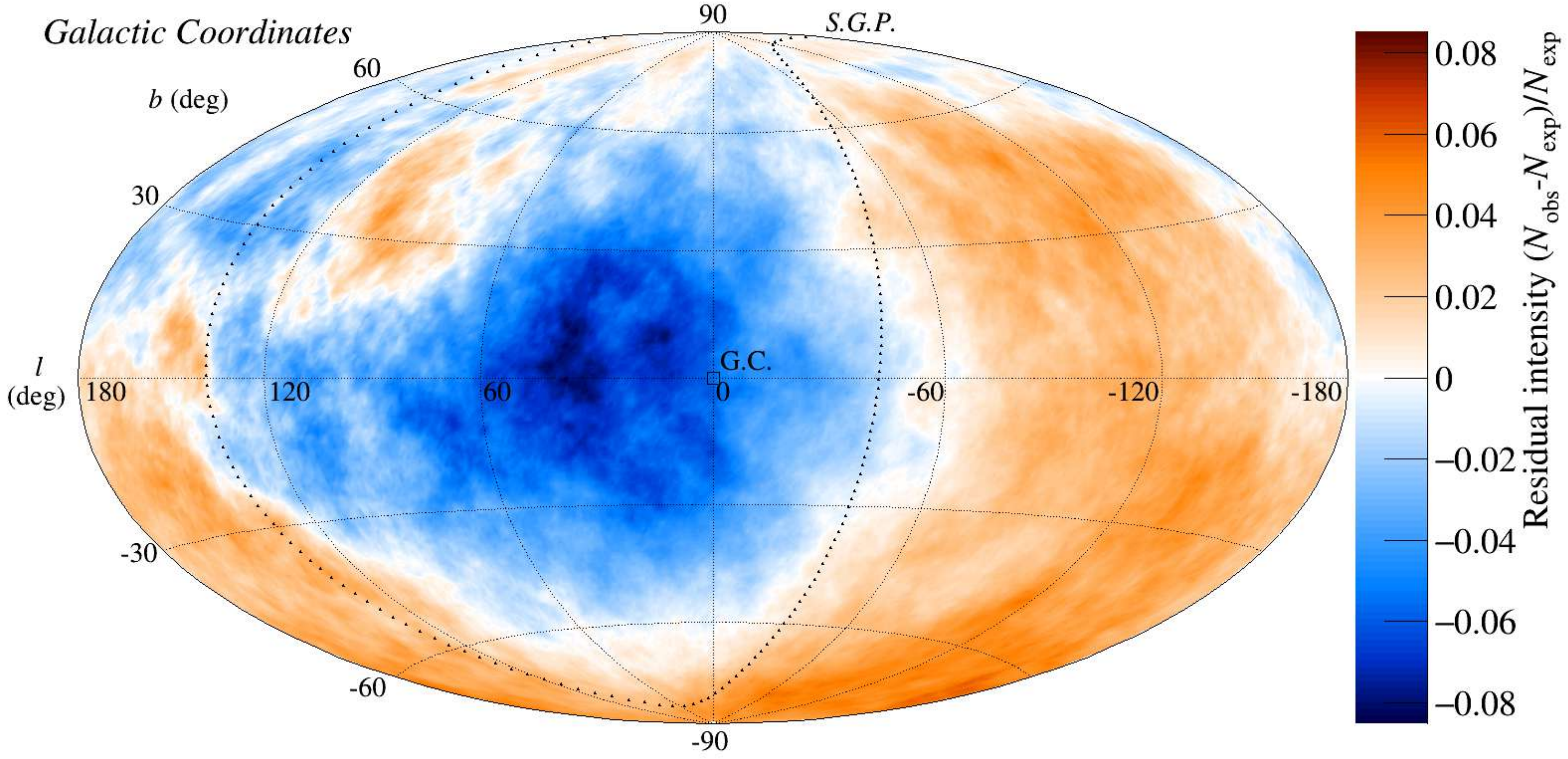
「未来の学術振興構想（2023年度版）」グランドビジョン18，No.167

Backup

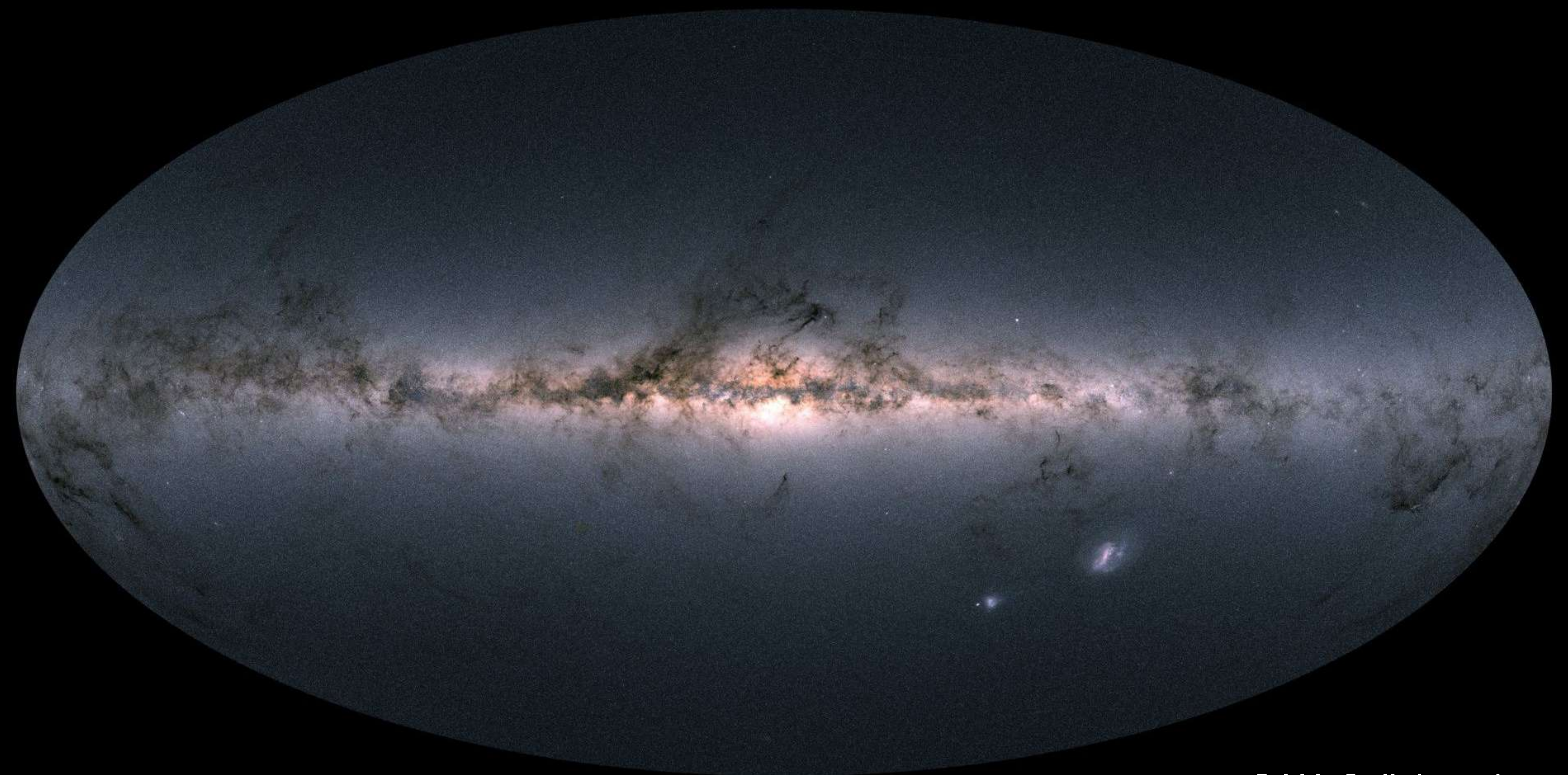
10 EeV skymap



Converted to **Galactic coordinates**



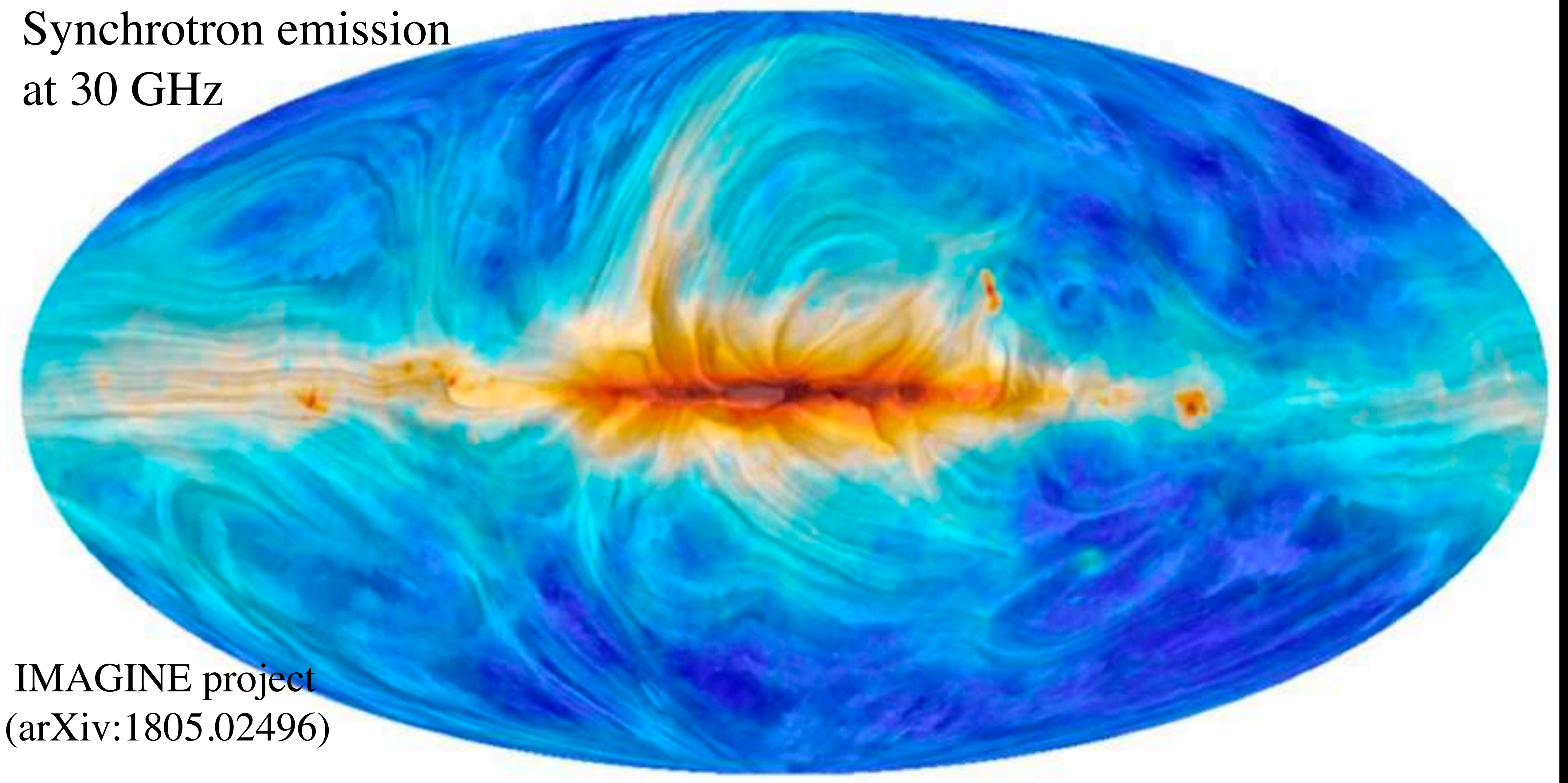
T. Fujii, PoS (ICRC2021) 402 (2021)



GAIA Collaboration

"Deciphering" magnetic fields

Synchrotron emission at 30 GHz



IMAGINE project (arXiv:1805.02496)

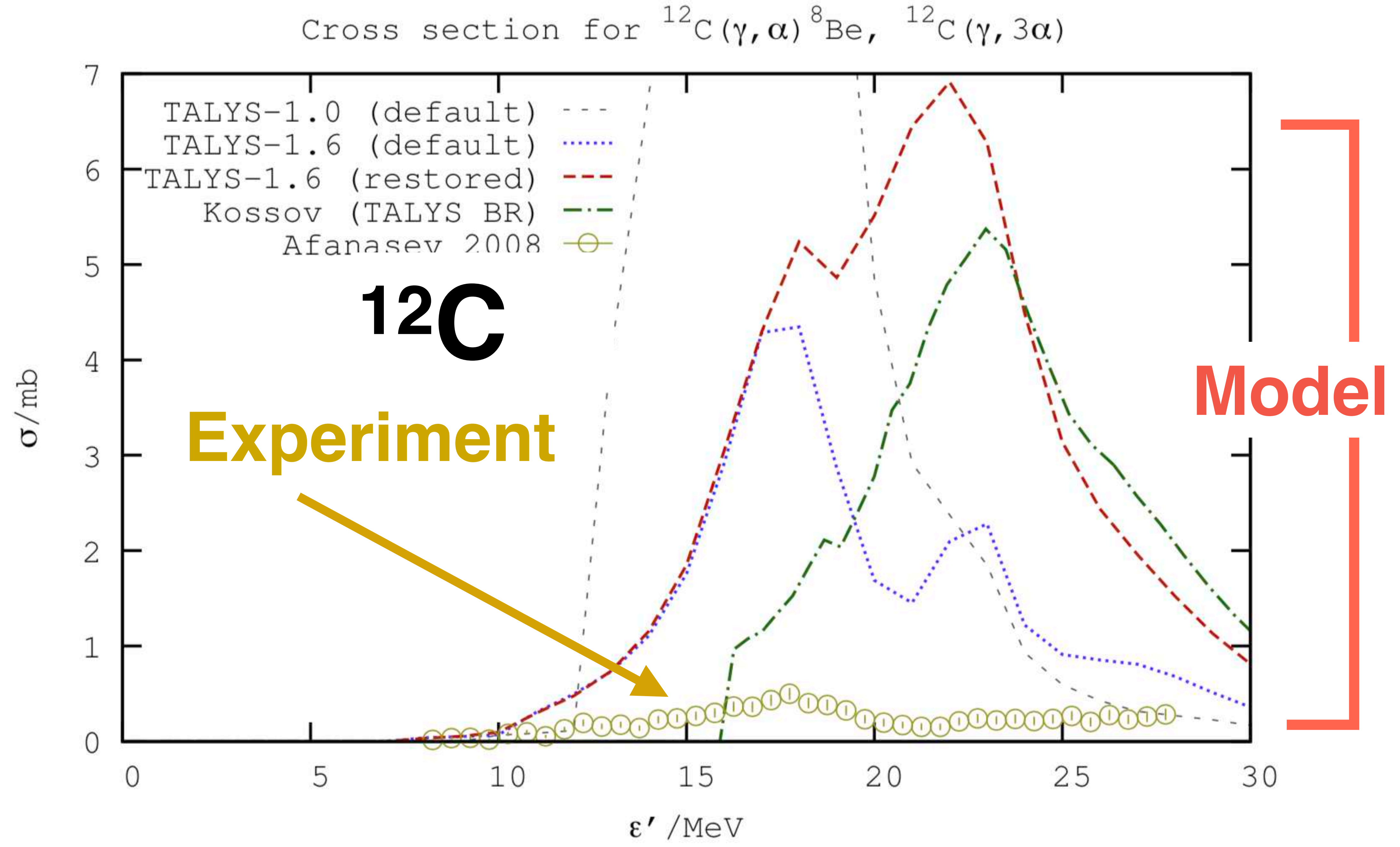
Nuclear Physics meets UHECRs (PANDORA project)

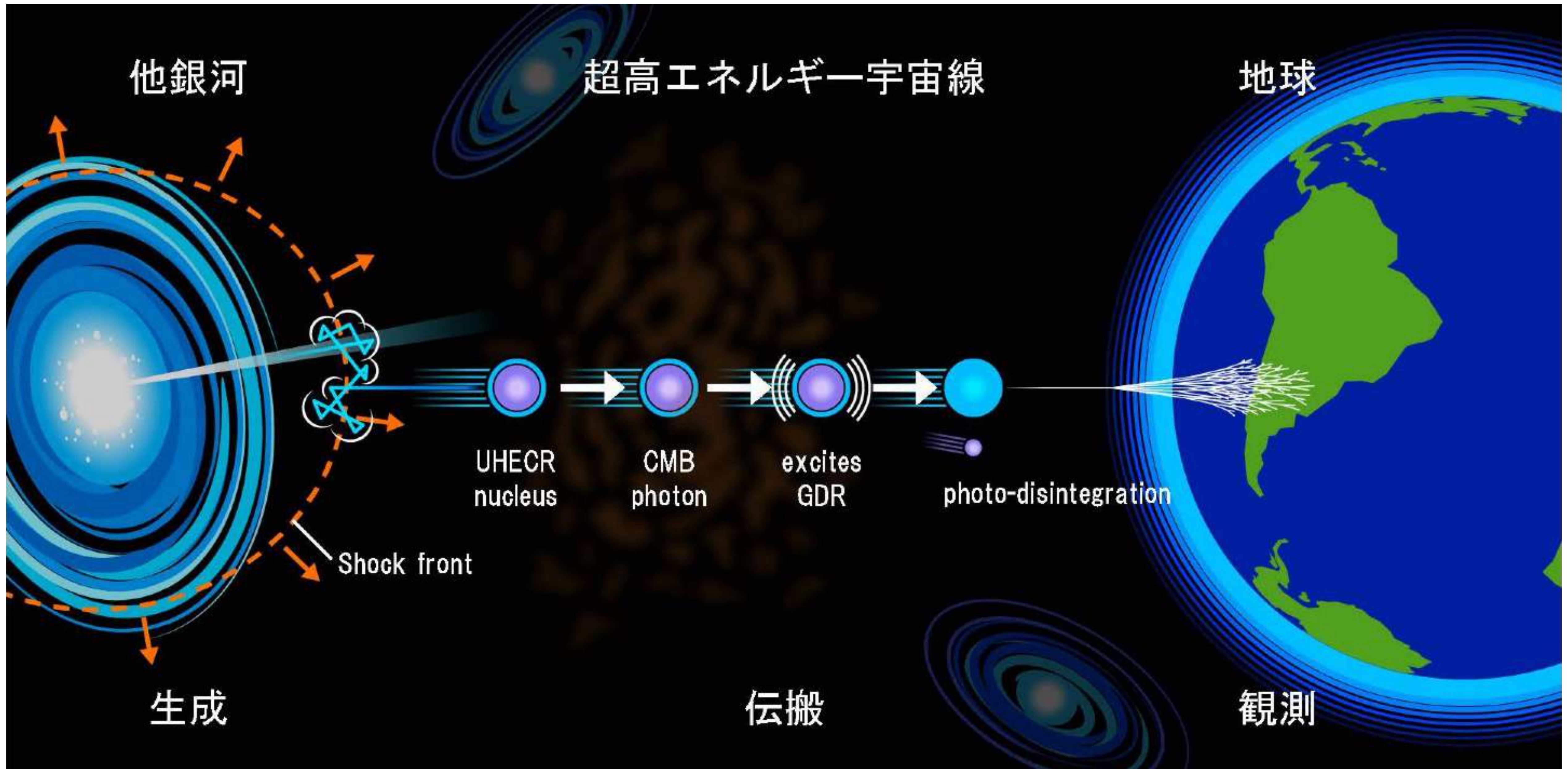
$$ {}^{A}_{Z}N + \gamma_{\mathrm{CMB}} \rightarrow {}^{A-1}_{Z-1}N' + p $$

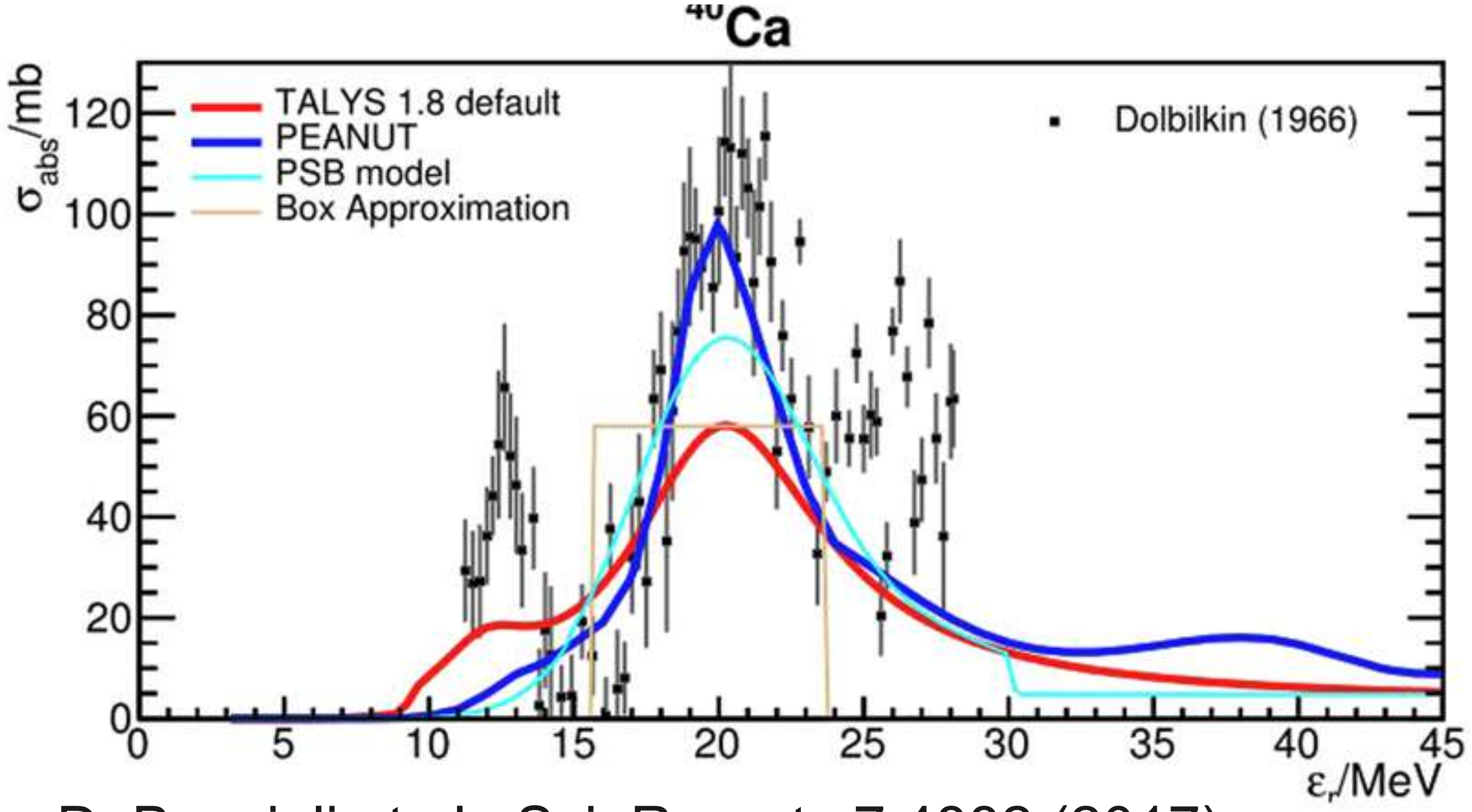
- Large uncertainty of the cross section from the giant dipole resonants for A < 60 nuclei
- Multidisciplinary research among nuclear physics, UHECR and CMB

A. Tamii, E. Kido et., Eur. Phys. J. A 59, 208 (2023)

E. Kido et al., *Astropart.Phys.* 152 (2023) 102866







D. Boncioli et al., Sci. Reports 7:4882 (2017)

Muon puzzle

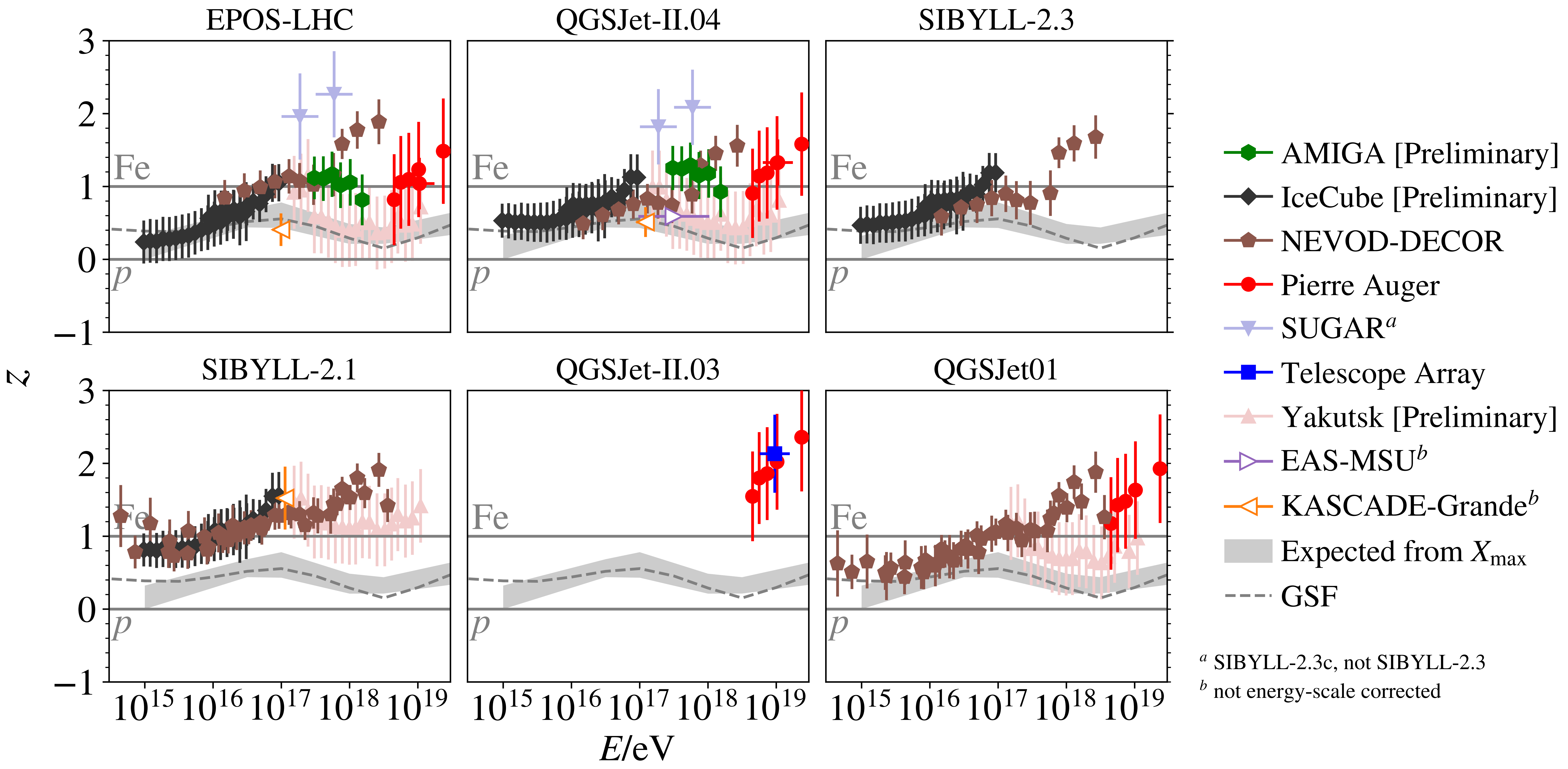
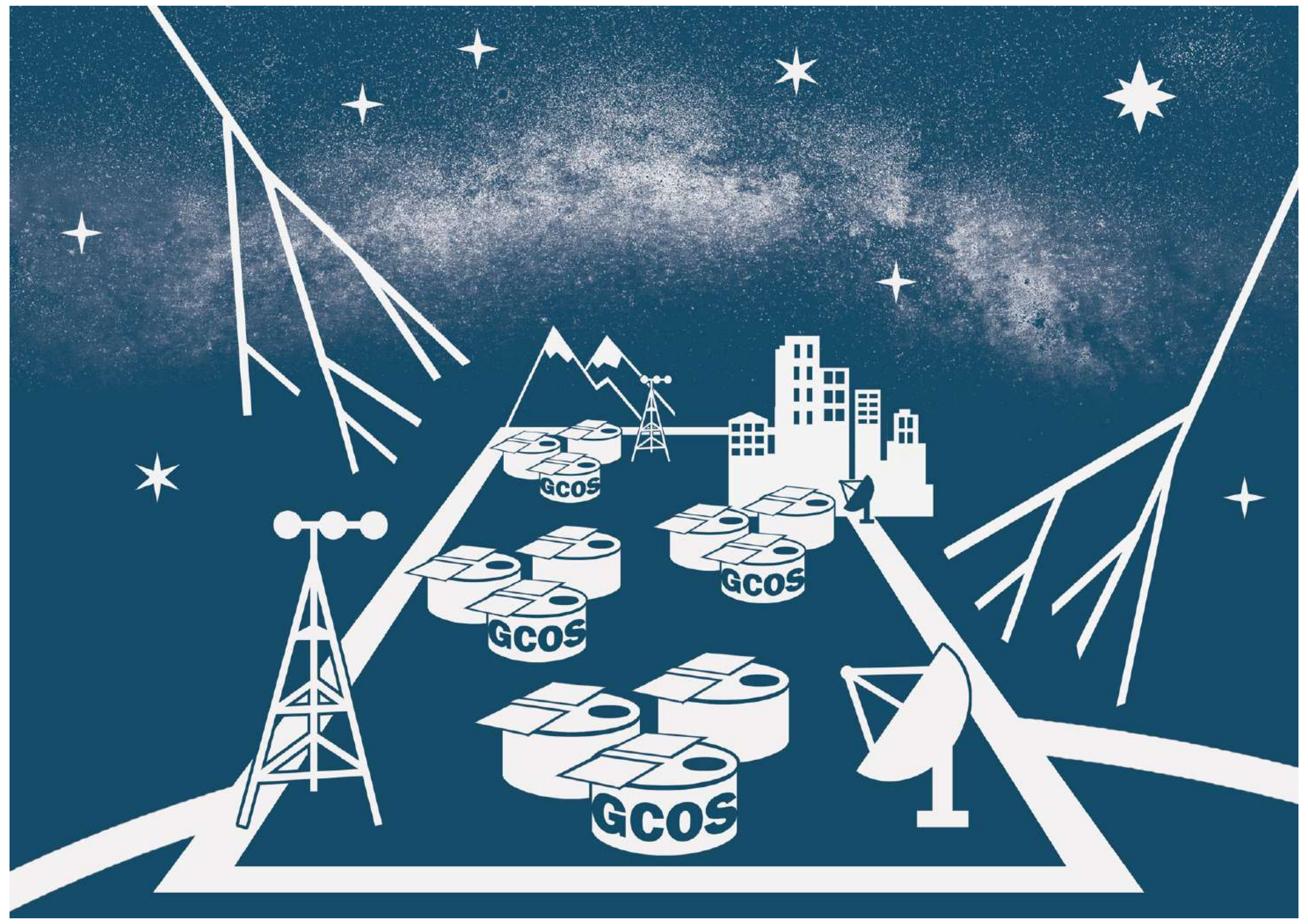


Fig. 3 Compilation of muon measurements converted to the abstract z-scale and after cross-calibrating the energy scales of the experiments as described in the text (image from Dembinski et al. (2019)). Shown for comparison are predicted z_{mass}-values based on air shower simulations and X_{max}-measurements (grey band). The prediction from the GSF model (Dembinski et al. 2018) for z_{mass} is also shown (dashed line).

J. Albrecht et al., arXiv:2105.06138 (2021)

Workshop for the Global Cosmic Ray Observatory

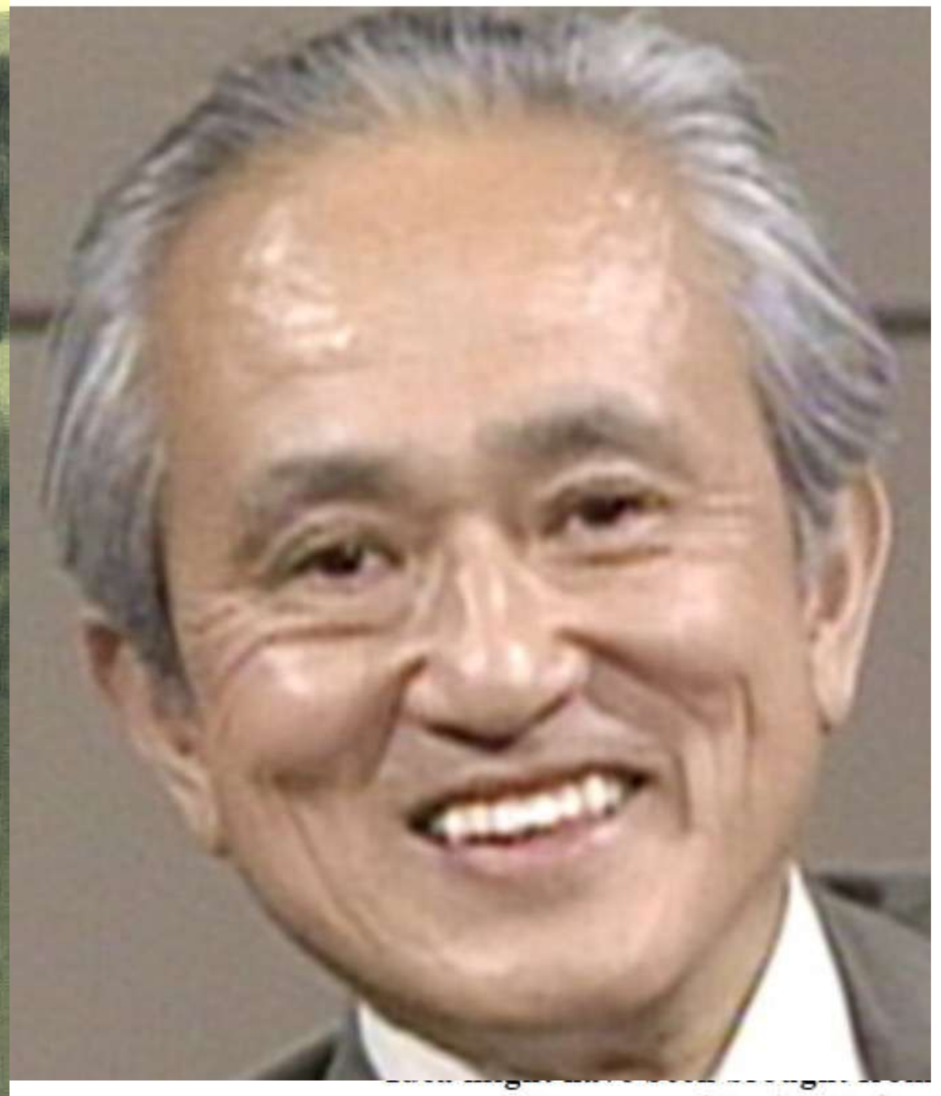


- 1st GCOS workshop 2021 online
  - https://agenda.astro.ru.nl/event/18/
- 2nd GCOS workshop 2022 Wuppertal
  - https://agenda.astro.ru.nl/event/21/
- 3rd GCOS workshop 2023 Brussels (June 10 - 11, 2023)
  - https://indico.iihe.ac.be/event/1729/
- **4th GCOS workshop 2025 (September 9 - 11, 2025)**
  - **Workshop for The Global Cosmic Ray Observatory -- Challenging next-generation multi-messenger astronomy with interdisciplinary research**
  - **Koshiba hall, Hongo Campus, University of Tokyo**

Global Cosmic Ray Observatory (GCOS)

Fathers of Fluorescence: Oda, Suga, Chudakov and Greisen

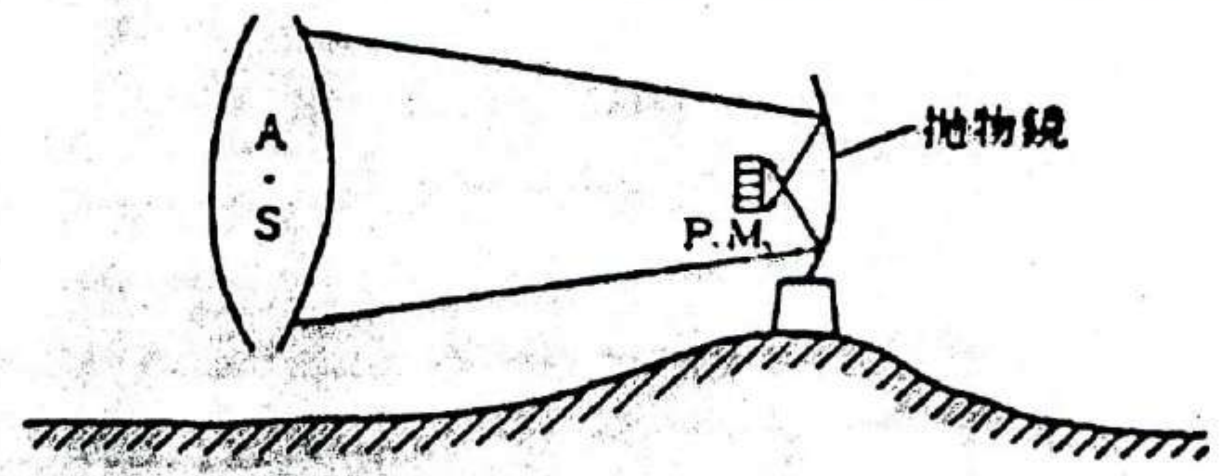
Suga



Oda

ALEKSANDR EVGENIEVICH CHUDAKOV

Greisen



第3図　1958年乗鞍シンポジウムで話されたシャワー・カーブ測定の提案

P. Sokolsky (UHECR 2022)

Greisen, Chudakov, Oda, Suga → Wow, GCOS!!

Possible extension at Auger site, ~10000 km²

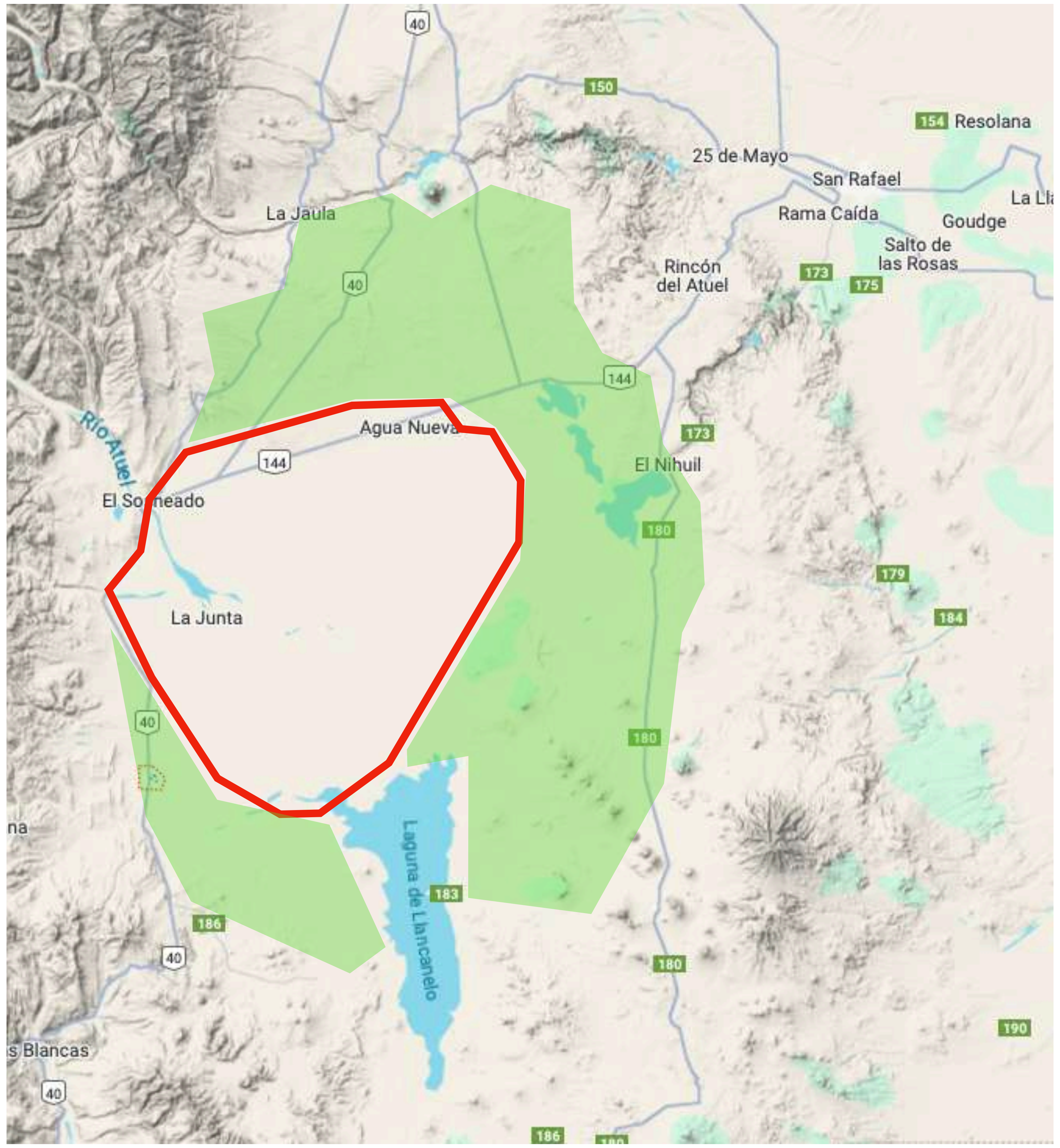


Figure 2: Illustration of a potential extension of the Pierre Auger Observatory.

Ideas and Requirements for the Global Cosmic-Ray Observatory (GCOS)
https://arxiv.org/abs/2502.05657