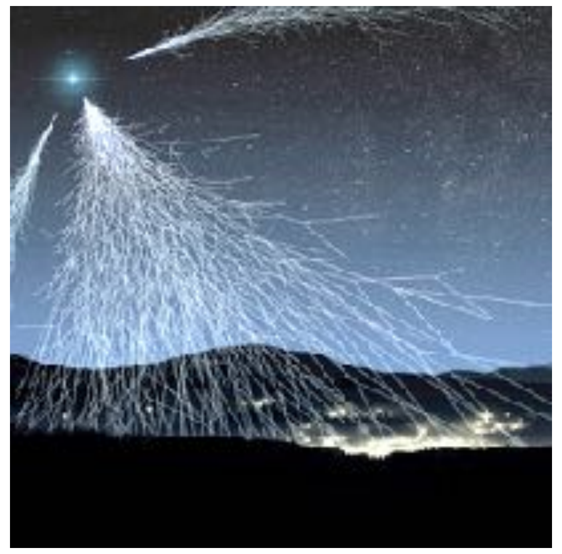
GCOS - The Global Cosmic Ray Observatory

Brainstorming workshop May 2021



Welcome!

Rafael Alves Batista, Antonella Castellina, Ralph Engel, Toshihiro Fujii, Jörg R. Hörandel, Charles Jui, Lu Lu, Ioana Maris, Shoichi Ogio, Takashi Sako, Fred Sarazin

GCOS homepage: http://particle.astro.ru.nl/gcos

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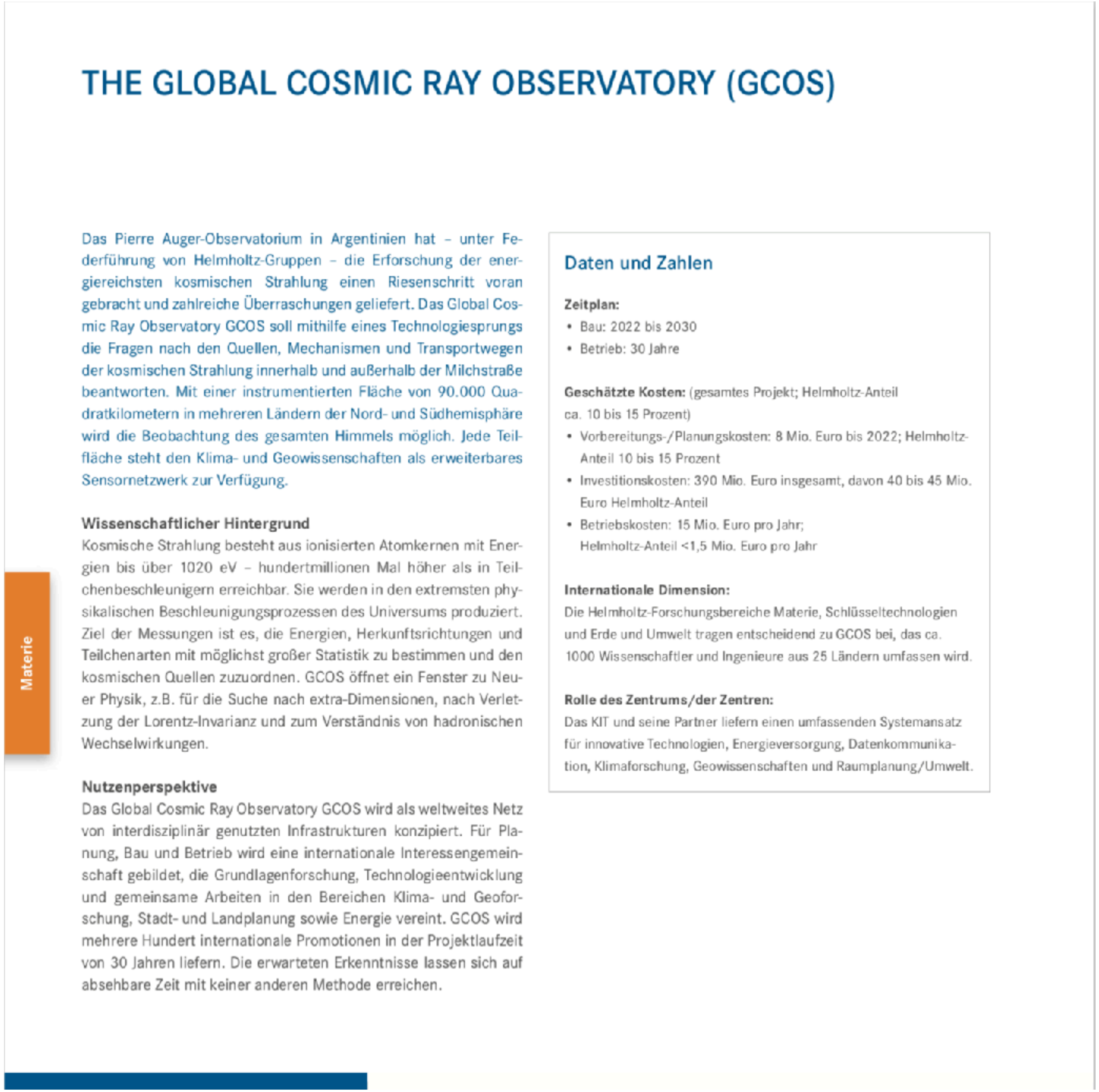
HELMHOLTZ-ROADMAP FÜR
FORSCHUNGSINFRASTRUKTUREN II
2015

HELMHOLTZ
GEMEINSCHAFT



THE GLOBAL COSMIC RAY OBSERVATORY (GCOS)

Materie

Das Pierre Auger-Observatorium in Argentinien hat – unter Federführung von Helmholtz-Gruppen – die Erforschung der energiereichsten kosmischen Strahlung einen Riesenschritt voran gebracht und zahlreiche Überraschungen geliefert. Das Global Cosmic Ray Observatory GCOS soll mithilfe eines Technologiesprungs die Fragen nach den Quellen, Mechanismen und Transportwegen der kosmischen Strahlung innerhalb und außerhalb der Milchstraße beantworten. Mit einer instrumentierten Fläche von 90.000 Quadratkilometern in mehreren Ländern der Nord- und Südhemisphäre wird die Beobachtung des gesamten Himmels möglich. Jede Teilfläche steht den Klima- und Geowissenschaften als erweiterbares Sensornetzwerk zur Verfügung.

Wissenschaftlicher Hintergrund

Kosmische Strahlung besteht aus ionisierten Atomkernen mit Energien bis über 1020 eV – hundertmillionen Mal höher als in Teilchenbeschleunigern erreichbar. Sie werden in den extremsten physikalischen Beschleunigungsprozessen des Universums produziert. Ziel der Messungen ist es, die Energien, Herkunftsrichtungen und Teilchenarten mit möglichst großer Statistik zu bestimmen und den kosmischen Quellen zuzuordnen. GCOS öffnet ein Fenster zu Neuer Physik, z.B. für die Suche nach extra-Dimensionen, nach Verletzung der Lorentz-Invarianz und zum Verständnis von hadronischen Wechselwirkungen.

Nutzenperspektive

Das Global Cosmic Ray Observatory GCOS wird als weltweites Netz von interdisziplinär genutzten Infrastrukturen konzipiert. Für Planung, Bau und Betrieb wird eine internationale Interessengemeinschaft gebildet, die Grundlagenforschung, Technologieentwicklung und gemeinsame Arbeiten in den Bereichen Klima- und Geoforschung, Stadt- und Landplanung sowie Energie vereint. GCOS wird mehrere Hundert internationale Promotionen in der Projektlaufzeit von 30 Jahren liefern. Die erwarteten Erkenntnisse lassen sich auf absehbare Zeit mit keiner anderen Methode erreichen.

Daten und Zahlen

Zeitplan:
- Bau: 2022 bis 2030
- Betrieb: 30 Jahre

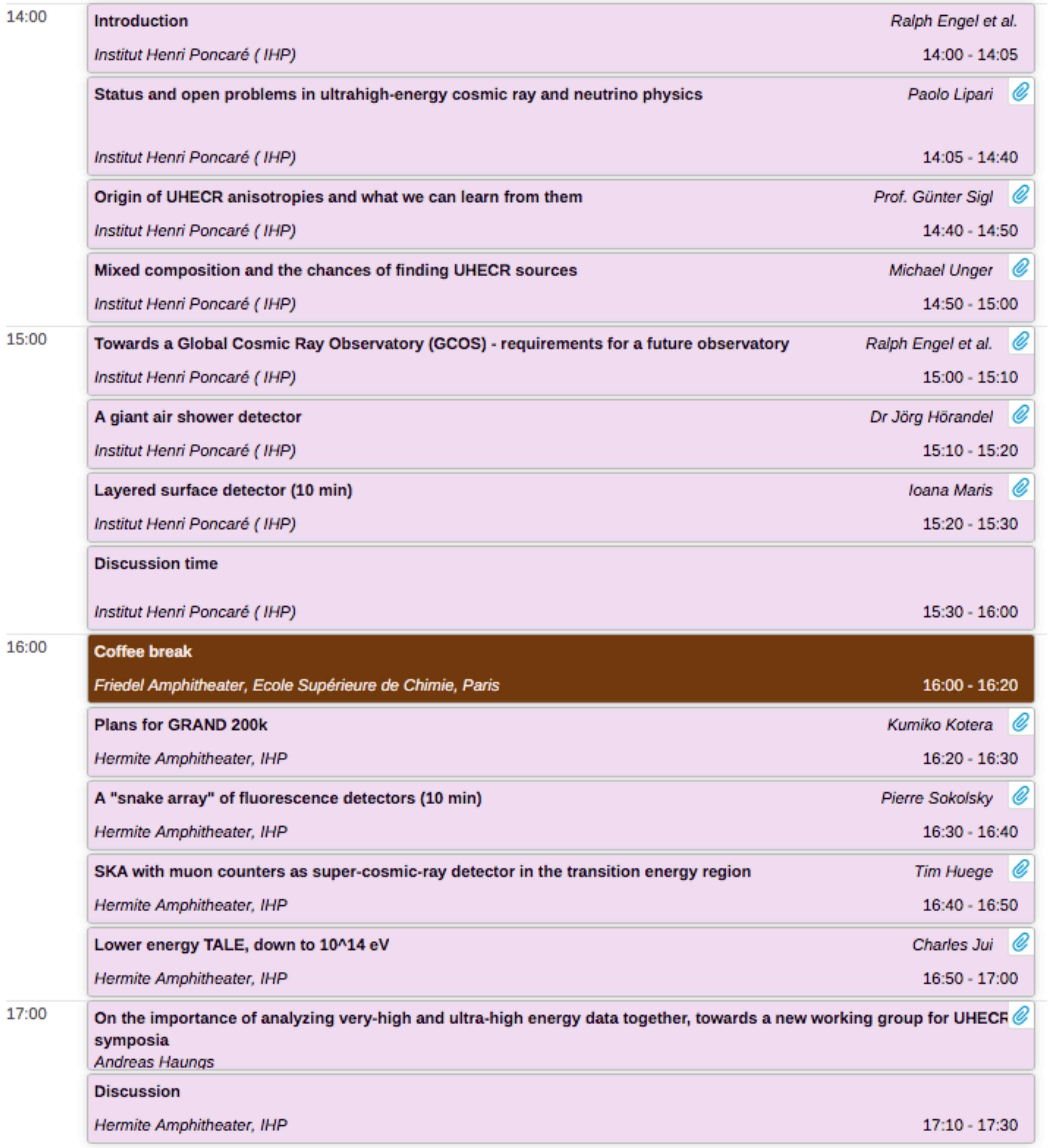
Geschätzte Kosten: (gesamtes Projekt; Helmholtz-Anteil ca. 10 bis 15 Prozent)
- Vorbereitungs-/Planungskosten: 8 Mio. Euro bis 2022; Helmholtz-Anteil 10 bis 15 Prozent
- Investitionskosten: 390 Mio. Euro insgesamt, davon 40 bis 45 Mio. Euro Helmholtz-Anteil
- Betriebskosten: 15 Mio. Euro pro Jahr; Helmholtz-Anteil <1,5 Mio. Euro pro Jahr

Internationale Dimension:
Die Helmholtz-Forschungsbereiche Materie, Schlüsseltechnologien und Erde und Umwelt tragen entscheidend zu GCOS bei, das ca. 1000 Wissenschaftler und Ingenieure aus 25 Ländern umfassen wird.

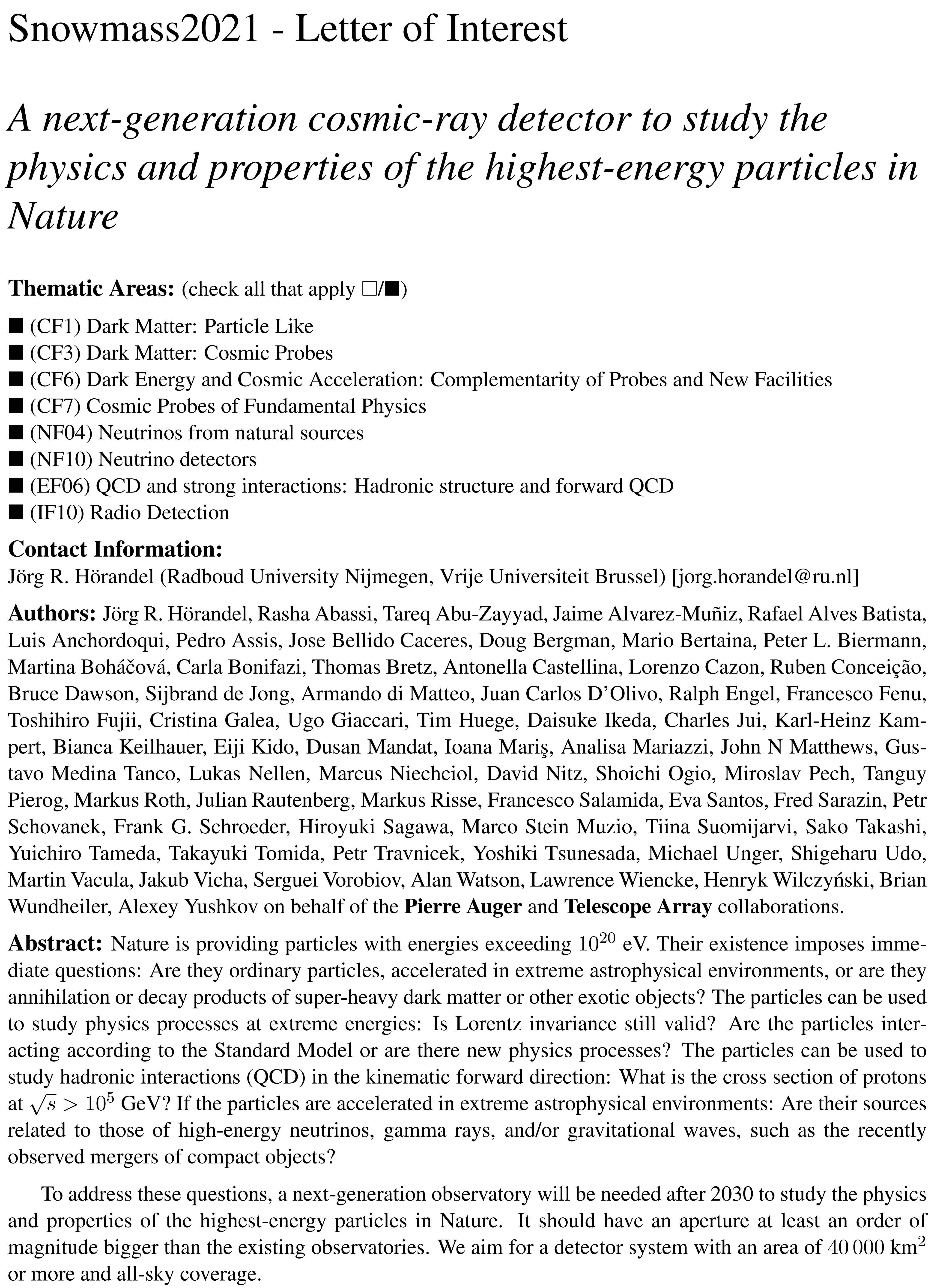
Rolle des Zentrums/der Zentren:
Das KIT und seine Partner liefern einen umfassenden Systemansatz für innovative Technologien, Energieversorgung, Datenkommunikation, Klimaforschung, Geowissenschaften und Raumplanung/Umwelt.

Ultra High Energy Cosmic Rays 2018

8-12 octobre 2018
Ecole Supérieure de Chimie, Paris



	Title	Speaker	Location	Time
14:00	**Introduction**	*Ralph Engel et al.*	*Institut Henri Poncaré (IHP)*	14:00 - 14:05
	Status and open problems in ultrahigh-energy cosmic ray and neutrino physics	*Paolo Lipari*	*Institut Henri Poncaré (IHP)*	14:05 - 14:40
	Origin of UHECR anisotropies and what we can learn from them	*Prof. Günter Sigl*	*Institut Henri Poncaré (IHP)*	14:40 - 14:50
	Mixed composition and the chances of finding UHECR sources	*Michael Unger*	*Institut Henri Poncaré (IHP)*	14:50 - 15:00
15:00	**Towards a Global Cosmic Ray Observatory (GCOS) - requirements for a future observatory**	*Ralph Engel et al.*	*Institut Henri Poncaré (IHP)*	15:00 - 15:10
	A giant air shower detector	*Dr Jörg Hörandel*	*Institut Henri Poncaré (IHP)*	15:10 - 15:20
	Layered surface detector (10 min)	*Ioana Maris*	*Institut Henri Poncaré (IHP)*	15:20 - 15:30
	Discussion time		*Institut Henri Poncaré (IHP)*	15:30 - 16:00
16:00	**Coffee break**		*Friedel Amphitheater, Ecole Supérieure de Chimie, Paris*	16:00 - 16:20
	Plans for GRAND 200k	*Kumiko Kotera*	*Hermite Amphitheater, IHP*	16:20 - 16:30
	A "snake array" of fluorescence detectors (10 min)	*Pierre Sokolsky*	*Hermite Amphitheater, IHP*	16:30 - 16:40
	SKA with muon counters as super-cosmic-ray detector in the transition energy region	*Tim Huege*	*Hermite Amphitheater, IHP*	16:40 - 16:50
	Lower energy TALE, down to 10^14 eV	*Charles Jui*	*Hermite Amphitheater, IHP*	16:50 - 17:00
17:00	**On the importance of analyzing very-high and ultra-high energy data together, towards a new working group for UHECR symposia**	*Andreas Haungs*		
	Discussion		*Hermite Amphitheater, IHP*	17:10 - 17:30



Snowmass2021 - Letter of Interest

A next-generation cosmic-ray detector to study the physics and properties of the highest-energy particles in Nature

Thematic Areas: (check all that apply □/■)

■ (CF1) Dark Matter: Particle Like
■ (CF3) Dark Matter: Cosmic Probes
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (CF7) Cosmic Probes of Fundamental Physics
■ (NF04) Neutrinos from natural sources
■ (NF10) Neutrino detectors
■ (EF06) QCD and strong interactions: Hadronic structure and forward QCD
■ (IF10) Radio Detection

Contact Information:
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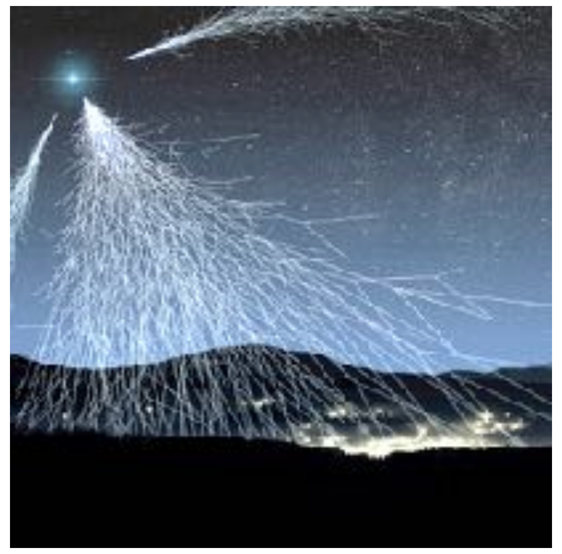
Authors: Jörg R. Hörandel, Rasha Abassi, Tareq Abu-Zayyad, Jaime Alvarez-Muñiz, Rafael Alves Batista, Luis Anchordoqui, Pedro Assis, Jose Bellido Caceres, Doug Bergman, Mario Bertaina, Peter L. Biermann, Martina Boháčová, Carla Bonifazi, Thomas Bretz, Antonella Castellina, Lorenzo Cazon, Ruben Conceição, Bruce Dawson, Sijbrand de Jong, Armando di Matteo, Juan Carlos D'Olivo, Ralph Engel, Francesco Fenu, Toshihiro Fujii, Cristina Galea, Ugo Giaccari, Tim Huege, Daisuke Ikeda, Charles Jui, Karl-Heinz Kampert, Bianca Keilhauer, Eiji Kido, Dusan Mandat, Ioana Mariş, Analisa Mariazzi, John N Matthews, Gustavo Medina Tanco, Lukas Nellen, Marcus Niechciol, David Nitz, Shoichi Ogio, Miroslav Pech, Tanguy Pierog, Markus Roth, Julian Rautenberg, Markus Risse, Francesco Salamida, Eva Santos, Fred Sarazin, Petr Schovanek, Frank G. Schroeder, Hiroyuki Sagawa, Marco Stein Muzio, Tiina Suomijarvi, Sako Takashi, Yuichiro Tameda, Takayuki Tomida, Petr Travnicek, Yoshiki Tsunesada, Michael Unger, Shigeharu Udo, Martin Vacula, Jakub Vicha, Serguei Vorobiov, Alan Watson, Lawrence Wiencke, Henryk Wilczyński, Brian Wundheiler, Alexey Yushkov on behalf of the **Pierre Auger** and **Telescope Array** collaborations.

Abstract: Nature is providing particles with energies exceeding 10^{20} eV. Their existence imposes immediate questions: Are they ordinary particles, accelerated in extreme astrophysical environments, or are they annihilation or decay products of super-heavy dark matter or other exotic objects? The particles can be used to study physics processes at extreme energies: Is Lorentz invariance still valid? Are the particles interacting according to the Standard Model or are there new physics processes? The particles can be used to study hadronic interactions (QCD) in the kinematic forward direction: What is the cross section of protons at $\sqrt{s} > 10^5$ GeV? If the particles are accelerated in extreme astrophysical environments: Are their sources related to those of high-energy neutrinos, gamma rays, and/or gravitational waves, such as the recently observed mergers of compact objects?

To address these questions, a next-generation observatory will be needed after 2030 to study the physics and properties of the highest-energy particles in Nature. It should have an aperture at least an order of magnitude bigger than the existing observatories. We aim for a detector system with an area of $40\,000$ km^2 or more and all-sky coverage.

GCOS - The Global Cosmic Ray Observatory
Brainstorming workshop May 2021



Scope of the workshop:

To discuss UHE multi-messenger astroparticle physics after 2030

- **What physics do we want to do with UHE particles* after 2030?**
  *** protons, nuclei, neutrinos, gamma rays**
- **What requirements follow from the physics case for an observatory?**
- **How and where would we want to build such an observatory?**

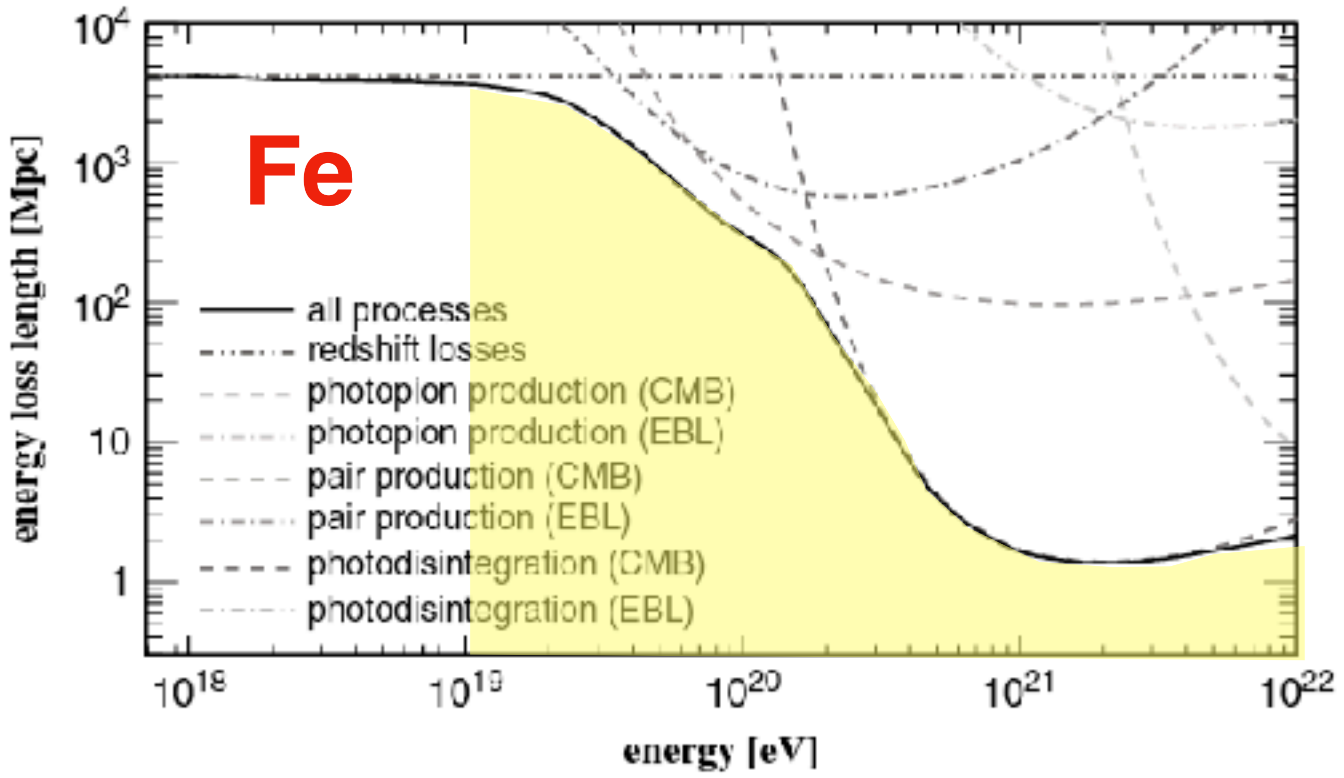


Figure 10.4 Energy loss length for iron nuclei calculated with CRPropa [316] using the model of Gilmore et al. [317] for the extragalactic background light (EBL). Shown are the contributions due to different interaction processes with CMB and EBL photons. From [185].

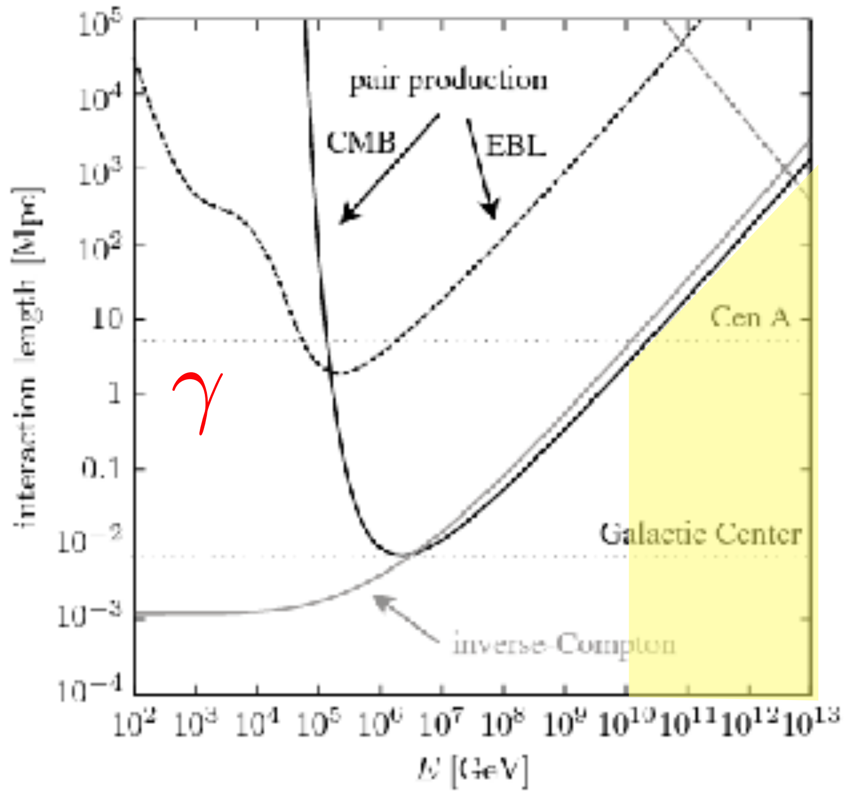


Figure 10.7 Length scales for $\gamma\gamma \rightarrow e^+e^-$ pair production and inverse-Compton scattering of photons with the CMB and EBL. The distances to the Galactic Center and the radio galaxy Cen A are marked for reference. From [324].

Physics and origin of the highest-energy particles in Nature

Nature is providing particles with energies exceeding 10^{20} eV.

Their existence imposes immediate questions:

- **Are they ordinary particles, accelerated in extreme astrophysical environments,**
- **or are they annihilation or decay products of super-heavy dark matter or other exotic objects?**

The particles can be used to study physics processes at extreme energies:

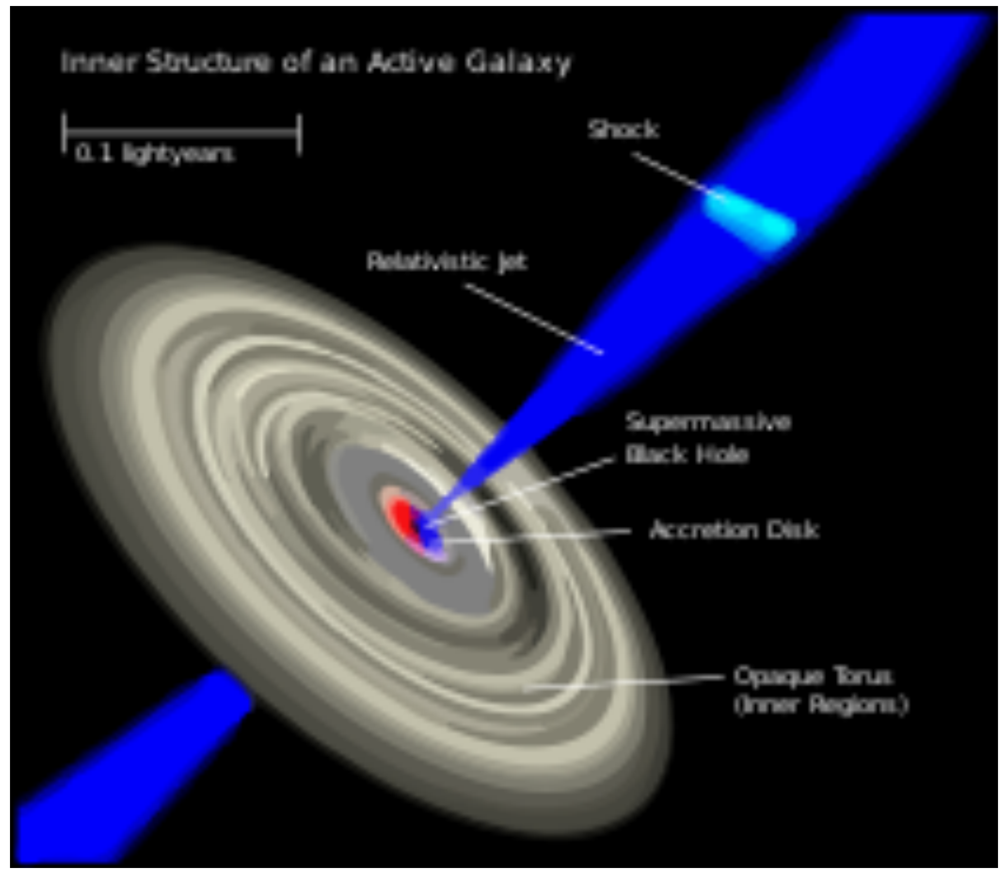
- **Is Lorentz invariance still valid?**
- **Are the particles interacting according to the Standard Model or are there new physics processes?**

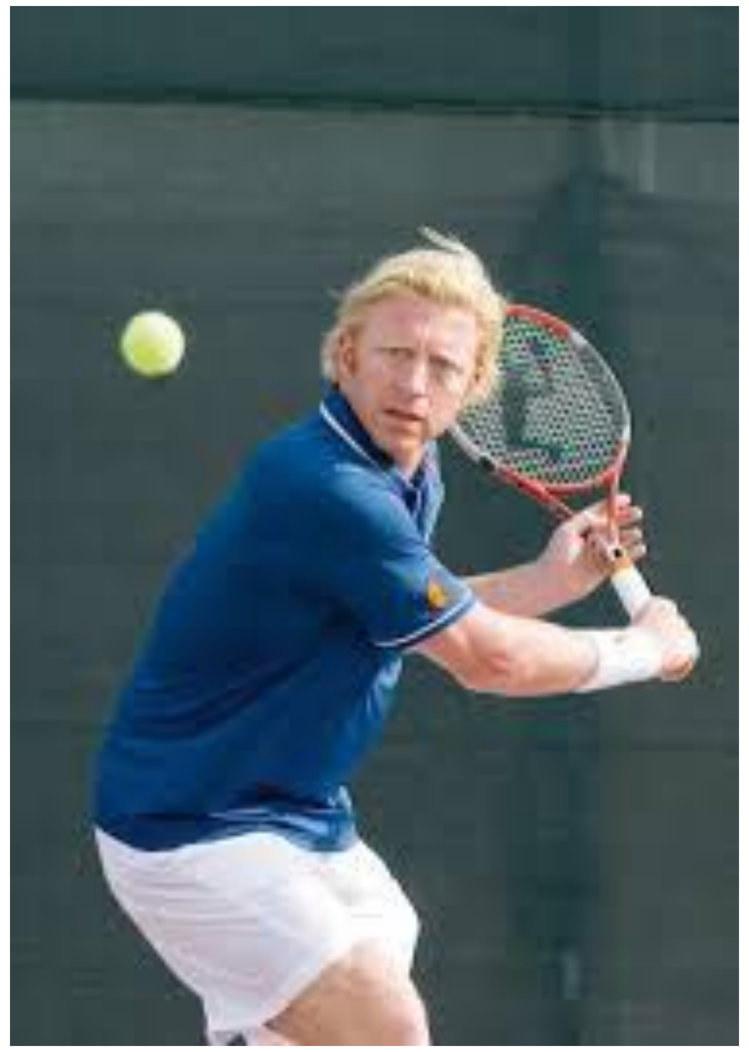
The particles can be used to study hadronic interactions (QCD) in the kinematic forward direction:

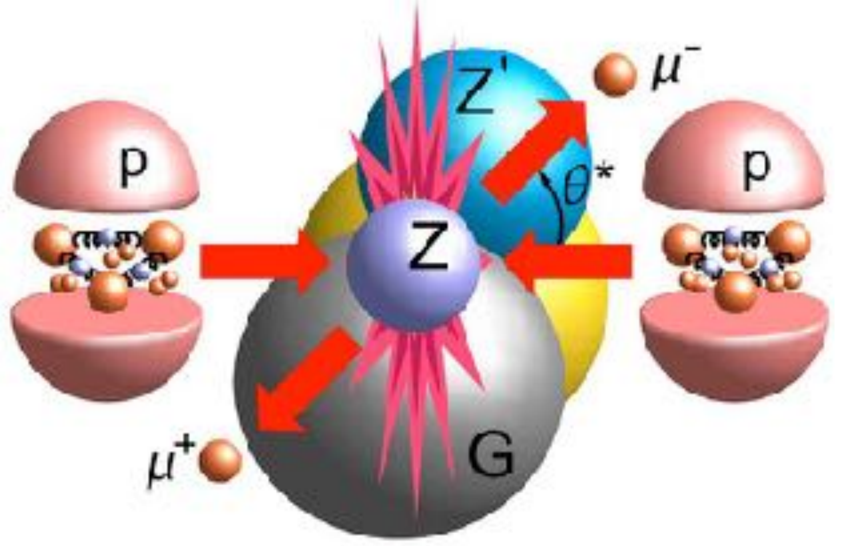
- **What is the cross section of protons at $\sqrt{s} > 10^5$ GeV?**

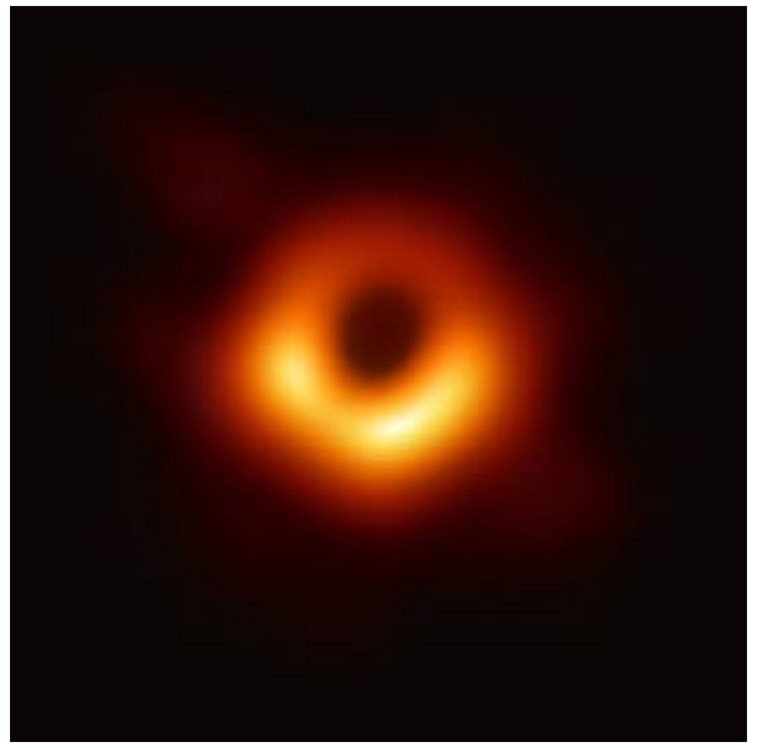
If the particles are accelerated in extreme astrophysical environments:

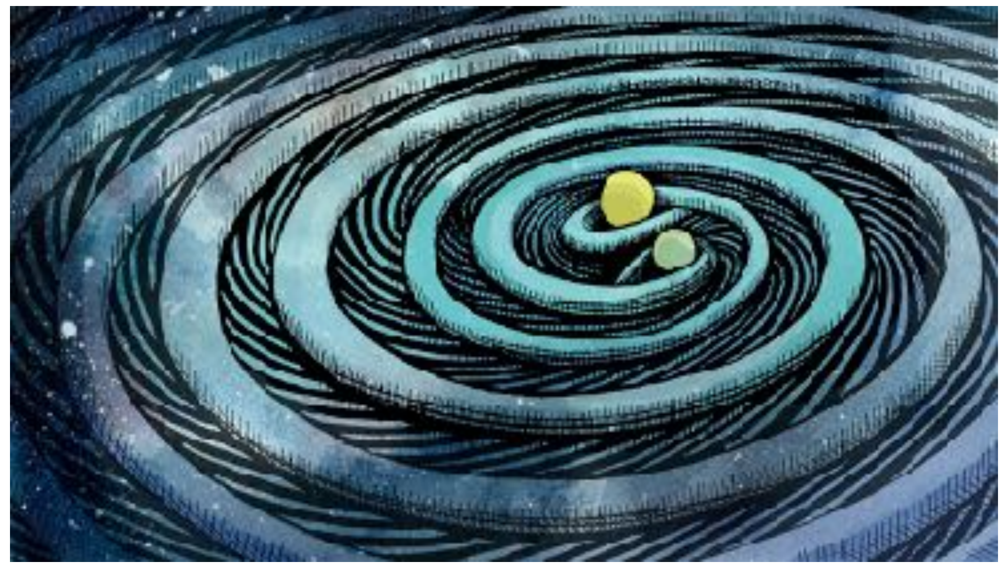
- **Are their sources related to those of high-energy neutrinos, gamma rays, and/or gravitational waves, such as the recently observed mergers of compact objects?**











Multi-messenger studies of (potential) sources

A&A 619, A71 (2018)
https://doi.org/10.1051/0004-6361/201832640

Astronomy & Astrophysics

The γ-ray spectrum of the core of Centaurus A as observed with H.E.S.S. and *Fermi*-LAT

ABSTRACT

Centaurus A (Cen A) is the nearest radio galaxy discovered as a very-high-energy (VHE; 100 GeV–100 TeV) γ-ray source by the High Energy Stereoscopic System (H.E.S.S.). It is a faint VHE γ-ray emitter, though its VHE flux exceeds both the extrapolation from early *Fermi*-LAT observations as well as expectations from a (misaligned) single-zone synchrotron-self Compton (SSC) description. The latter satisfactorily reproduces the emission from Cen A at lower energies up to a few GeV. New observations with H.E.S.S., comparable in exposure time to those previously reported, were performed and eight years of *Fermi*-LAT data were accumulated to clarify the spectral characteristics of the γ-ray emission from the core of Cen A. The results allow us for the first time to achieve the goal of constructing a representative, contemporaneous γ-ray core spectrum of Cen A over almost five orders of magnitude in energy. Advanced analysis methods, including the template fitting method, allow detection in the VHE range of the core with a statistical significance of 12σ on the basis of 213 hours of total exposure time. The spectrum in the energy range of 250 GeV–6 TeV is compatible with a power-law function with a photon index $\Gamma = 2.52 \pm 0.13_{\rm stat} \pm 0.20_{\rm sys}$. An updated *Fermi*-LAT analysis provides evidence for spectral hardening by $\Delta\Gamma \simeq 0.4 \pm 0.1$ at γ-ray energies above $2.8^{+1.0}_{-0.6}$ GeV at a level of 4.0σ. The fact that the spectrum hardens at GeV energies and extends into the VHE regime disfavour a single-zone SSC interpretation for the overall spectral energy distribution (SED) of the core and is suggestive of a new γ-ray emitting component connecting the high-energy emission above the break energy to the one observed at VHE energies. The absence of significant variability at both GeV and TeV energies does not yet allow disentanglement of the physical nature of this component, though a jet-related origin is possible and a simple two-zone SED model fit is provided to this end.

Key words. gamma rays: galaxies – radiation mechanisms: non-thermal

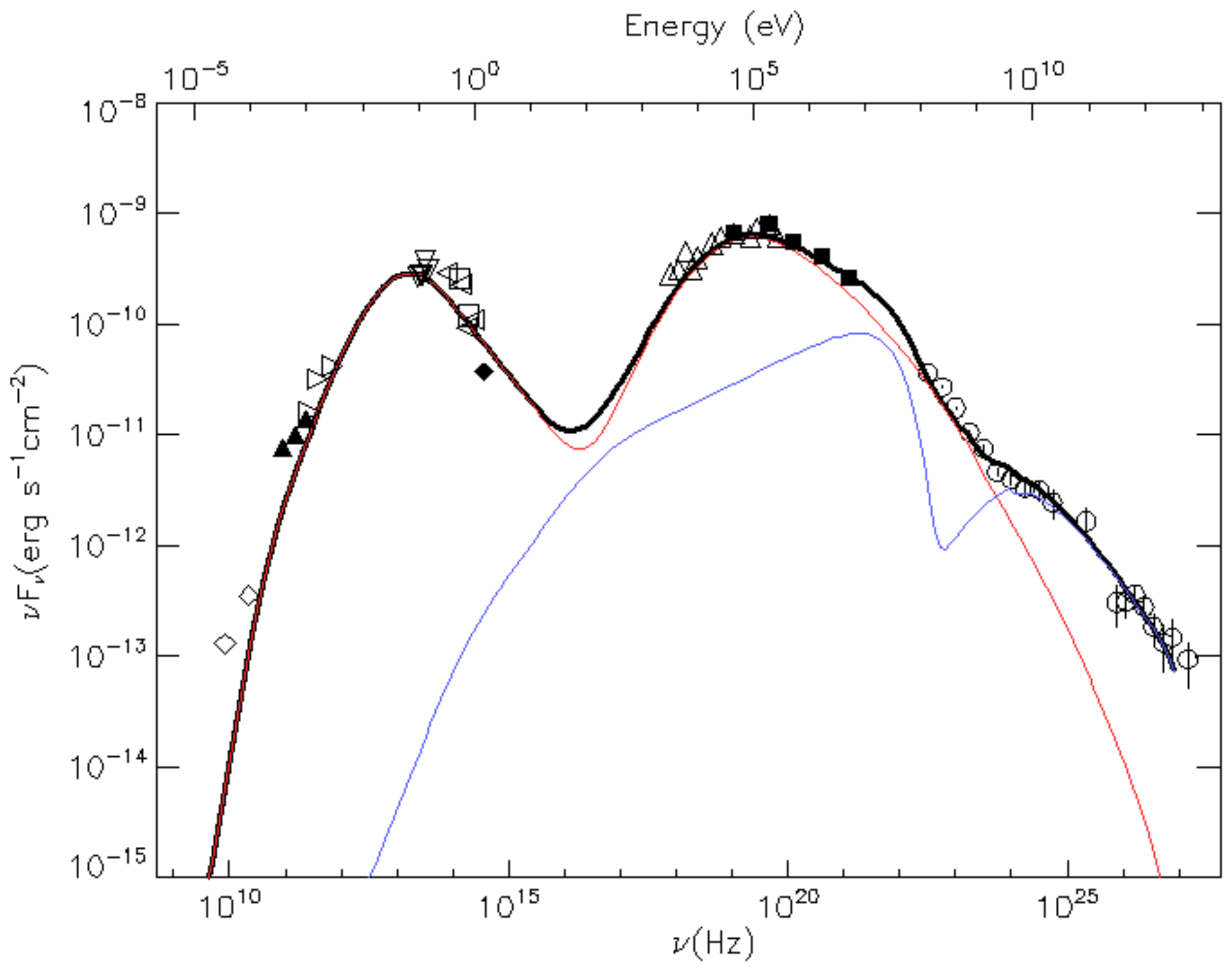
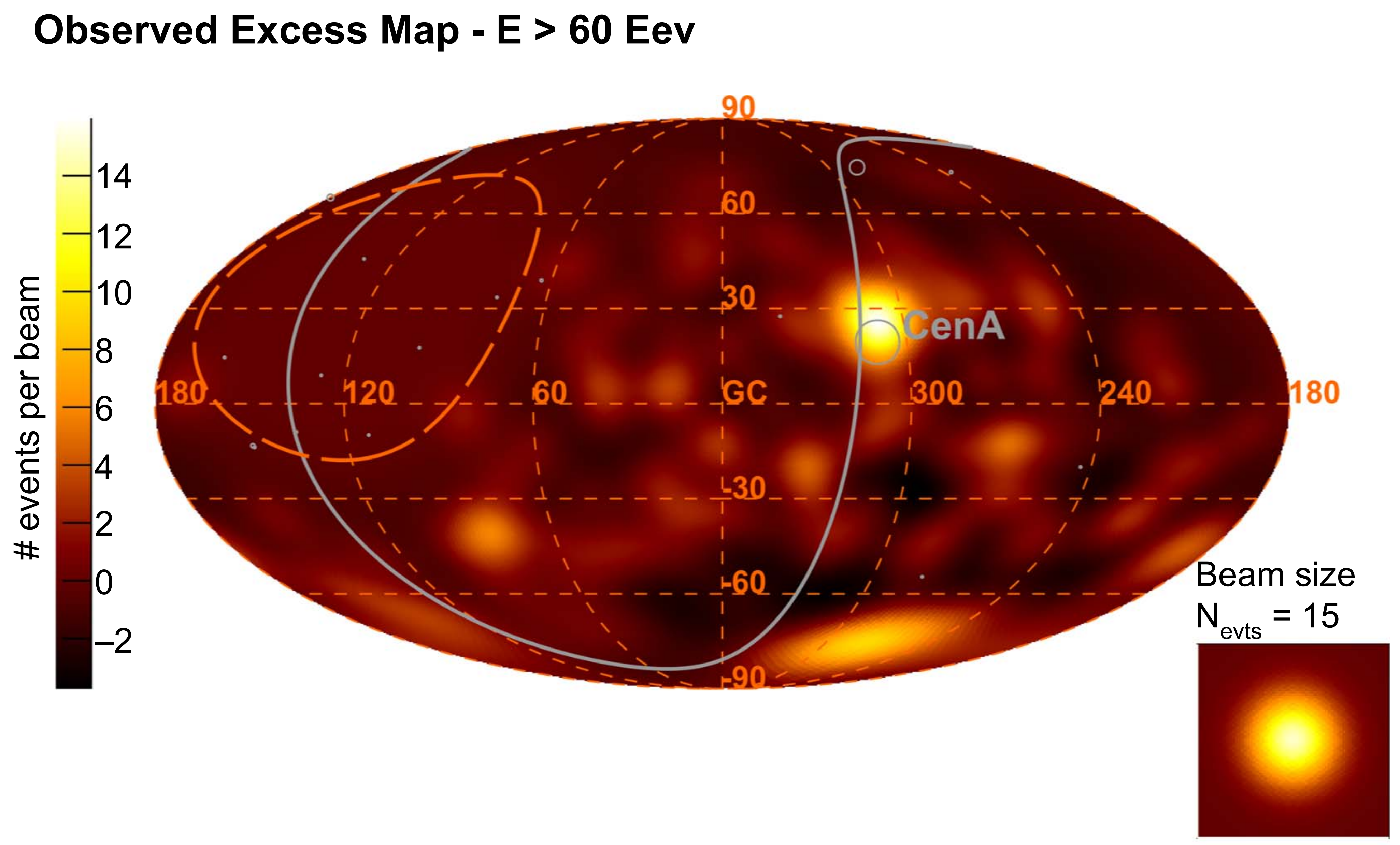


Fig. 3. SED of Cen A core with model fits as described in text. The red curve corresponds to an SSC component designed to fit the radio to sub-GeV data. The blue curve corresponds to a second SSC component added to account for the highest energy data. The black curve corresponds to the sum of the two components. SED points as derived from H.E.S.S. and *Fermi*-LAT data in this paper are shown with open circles. Observations from the radio band to the MeV γ-ray band are from TANAMI (◇), SEST (▲), JCMT (▷), MIDI (▽), NAOS/CONICA (◁), NICMOS (□), WFPC2 (♦), *Suzaku* (△), OSSE/COMPTEL (■). The acronyms are described in Appendix B.

The Astrophysical Journal Letters, 853:L29 (10pp), 2018 February 1
https://doi.org/10.3847/2041-8213/aaa66d

An Indication of Anisotropy in Arrival Directions of Ultra-high-energy Cosmic Rays through Comparison to the Flux Pattern of Extragalactic Gamma-Ray Sources*



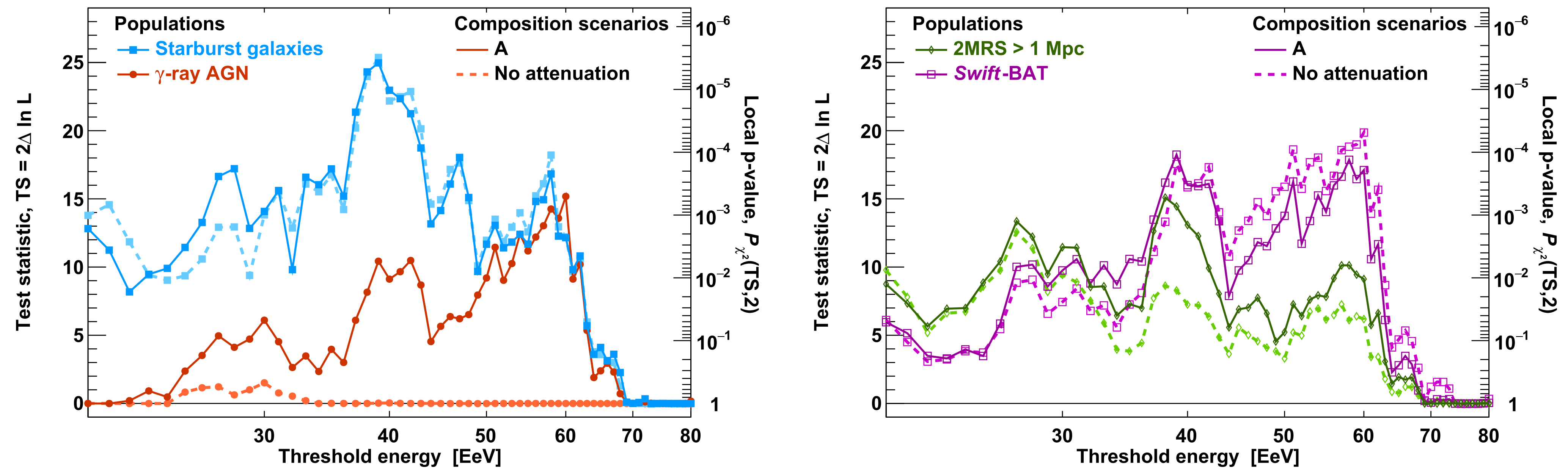


Figure 1. TS scan over the threshold energy for SBGs and AGNs (left) and *Swift*-BAT and 2MRS sources (right), including attenuation (lighter dashed lines) or not (darker solid lines).

Multi-messenger studies of (potential) sources

Influence of B-fields on charged particles

deflection

With $\theta_{\mathrm{RMS}} = \sqrt{\langle \Delta\theta^2 \rangle}$ we can write

$$\theta_{\mathrm{RMS}} \approx \underline{3.5^\circ} \left(\frac{Z\,B}{10^{-9}\,\mathrm{G}}\right) \left(\frac{10^{20}\,\mathrm{eV}}{E}\right) \left(\frac{d}{100\,\mathrm{Mpc}}\right)^{\frac{1}{2}} \left(\frac{l_{\mathrm{coh}}}{1\,\mathrm{Mpc}}\right)^{\frac{1}{2}} .$$

time delay

$$\langle t_{\mathrm{delay}} \rangle \approx \frac{l_{\mathrm{coh}}}{9c} \left(\frac{d}{R_L}\right)^2$$

$$\approx \underline{3.1 \times 10^5\,\mathrm{yr}} \left(\frac{Z\,B}{10^{-9}\,\mathrm{G}}\right)^2 \left(\frac{10^{20}\,\mathrm{eV}}{E}\right)^2 \left(\frac{d}{100\,\mathrm{Mpc}}\right)^2 \left(\frac{l_{\mathrm{coh}}}{1\,\mathrm{Mpc}}\right) .$$

T. Gaisser, R. Engel, E. Resconi

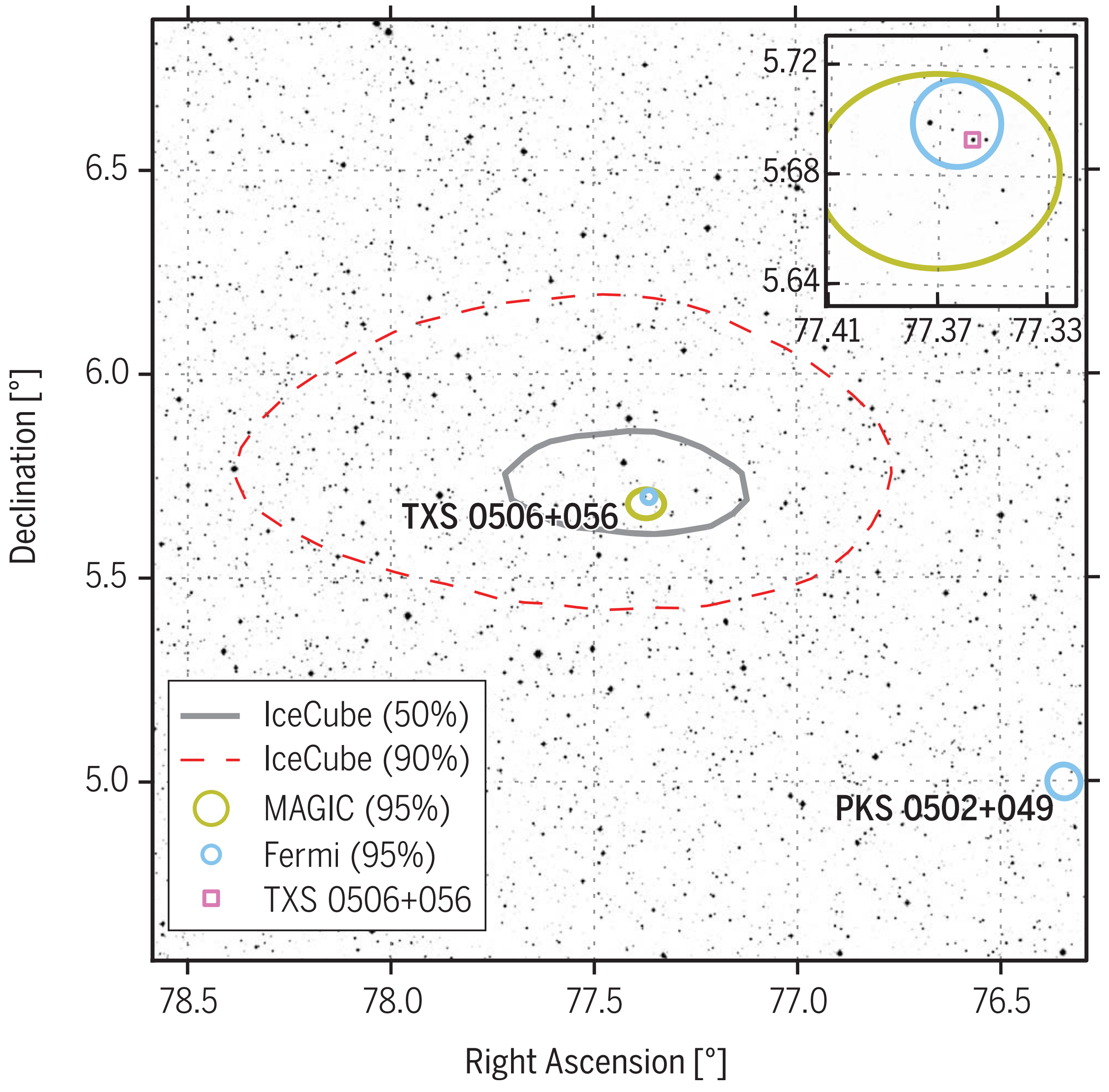
Multi-messenger studies of sources

RESEARCH ARTICLE SUMMARY

NEUTRINO ASTROPHYSICS

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†



Multimessenger observations of blazar TXS 0506+056. The 50% and 90% containment regions for the neutrino IceCube-170922A (dashed red and solid gray contours, respectively), overlain on a V-band optical image of the sky. Gamma-ray sources in this region previously detected with the *Fermi* spacecraft are shown as blue circles, with sizes representing their 95% positional uncertainty and labeled with the source names. The IceCube neutrino is coincident with the blazar TXS 0506+056, whose optical position is shown by the pink square. The yellow circle shows the 95% positional uncertainty of very-high-energy γ-rays detected by the MAGIC telescopes during the follow-up campaign. The inset shows a magnified view of the region around TXS 0506+056 on an R-band optical image of the sky.

The IceCube Collaboration *et al.*, *Science* **361**, 146 (2018) 13 July 2018

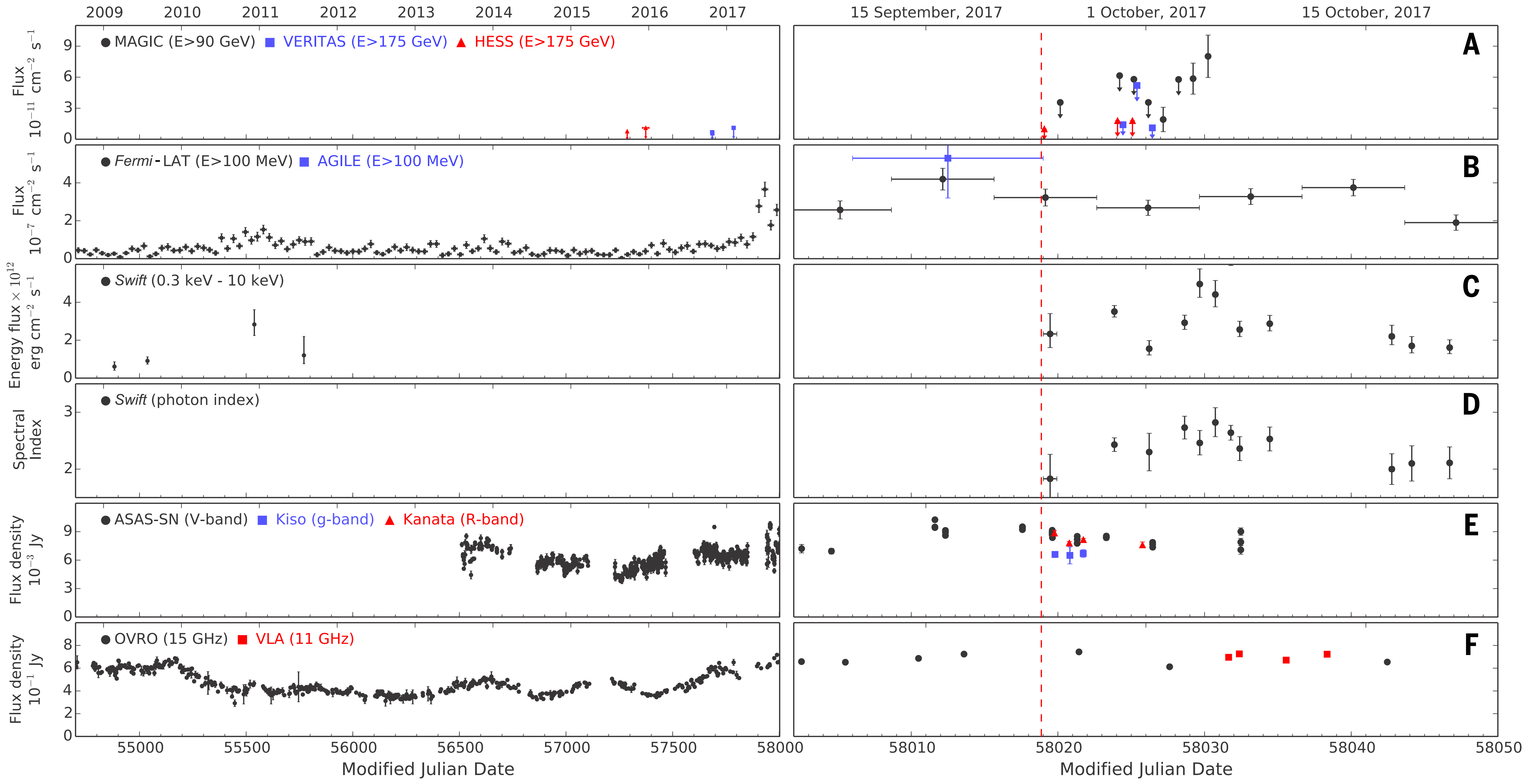
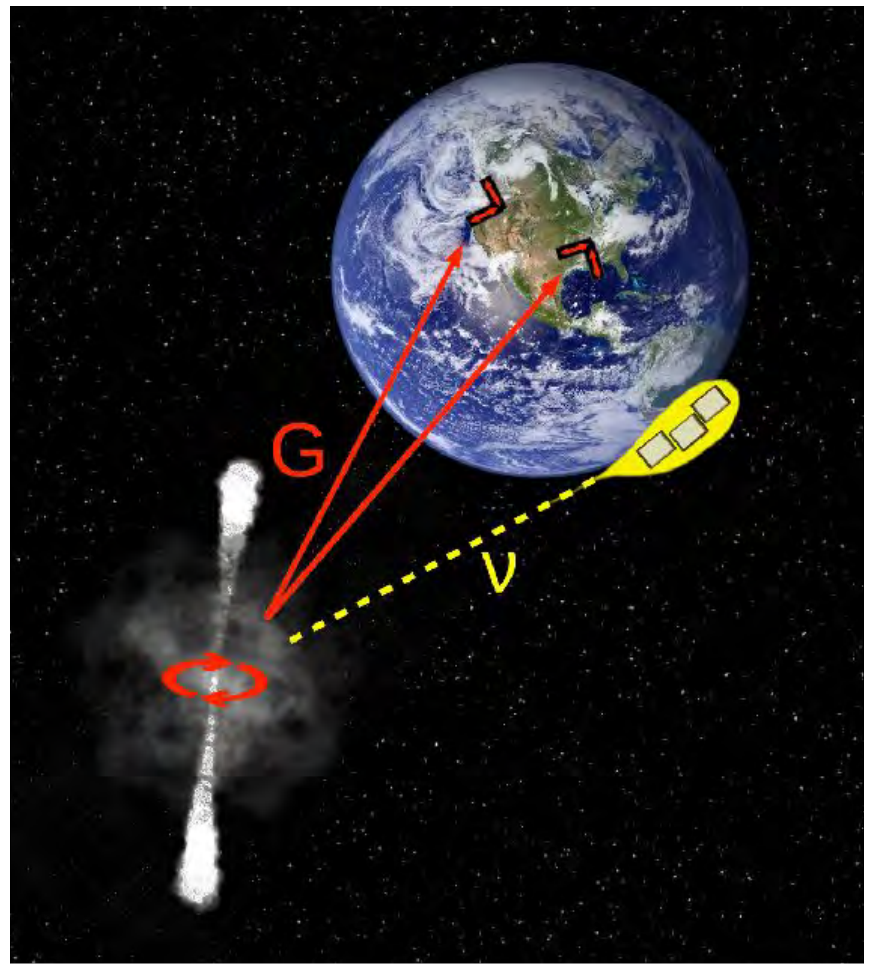
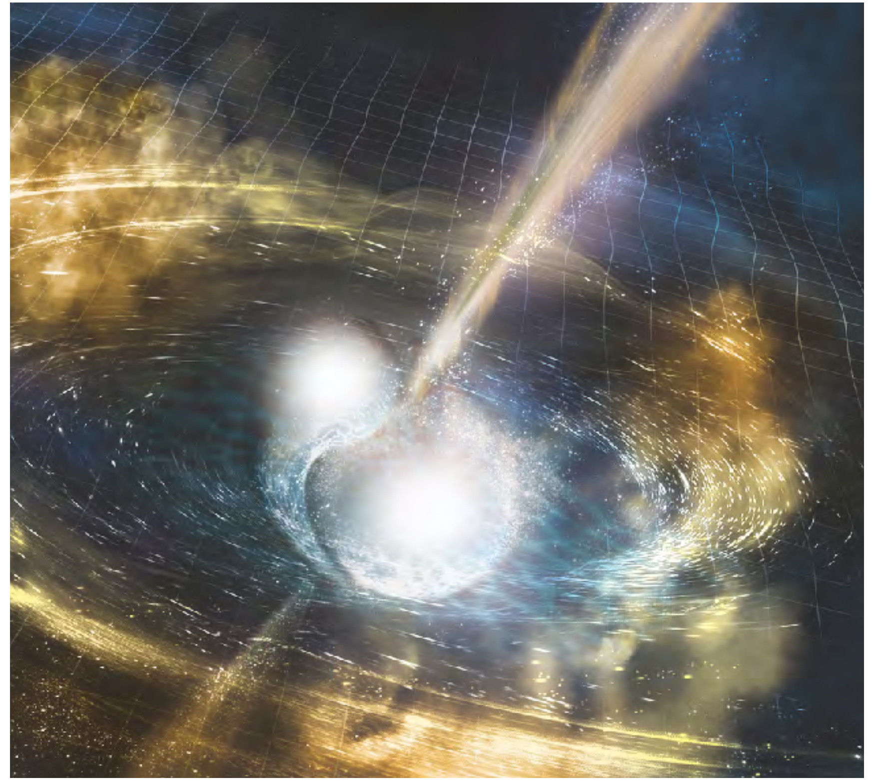
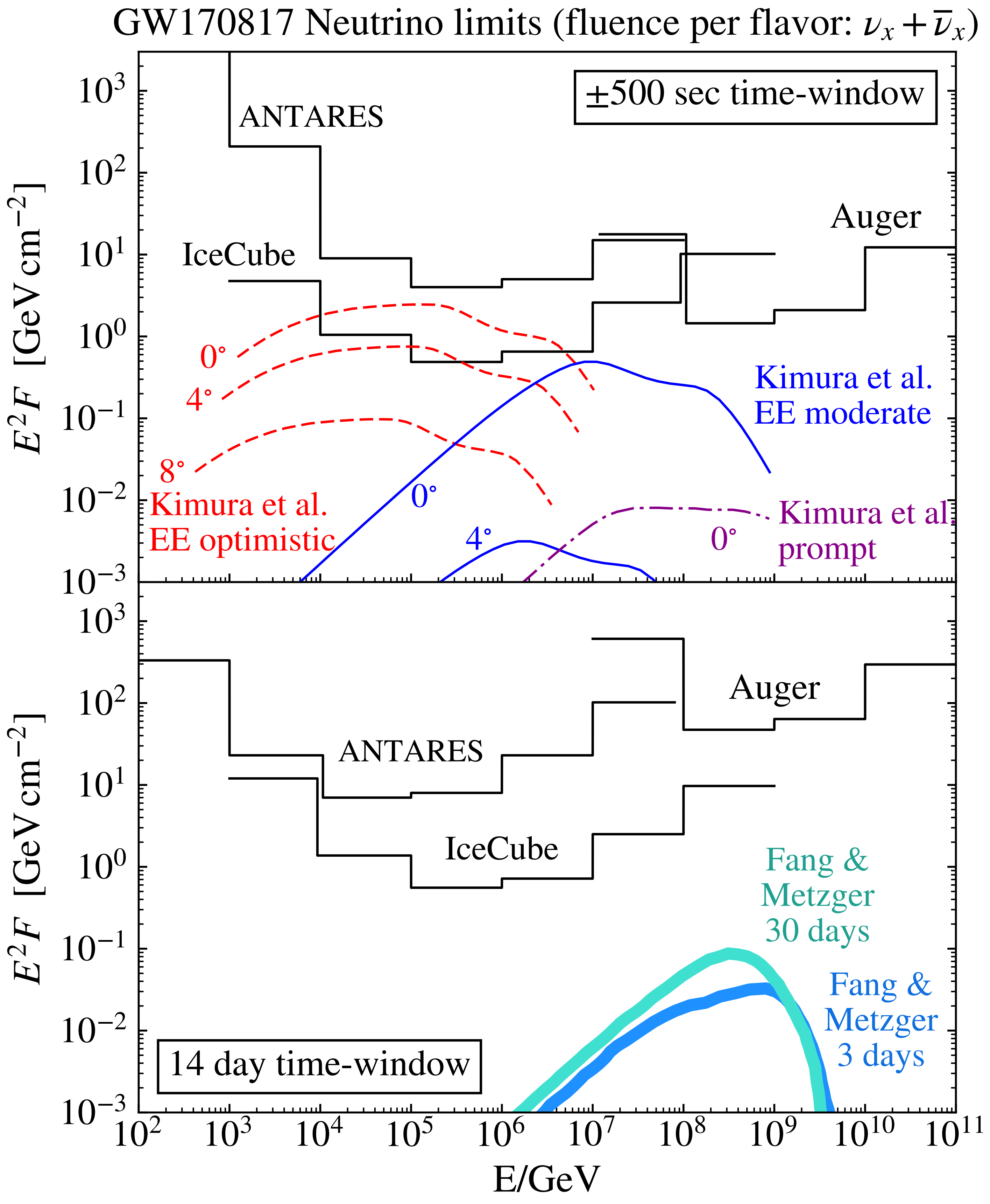


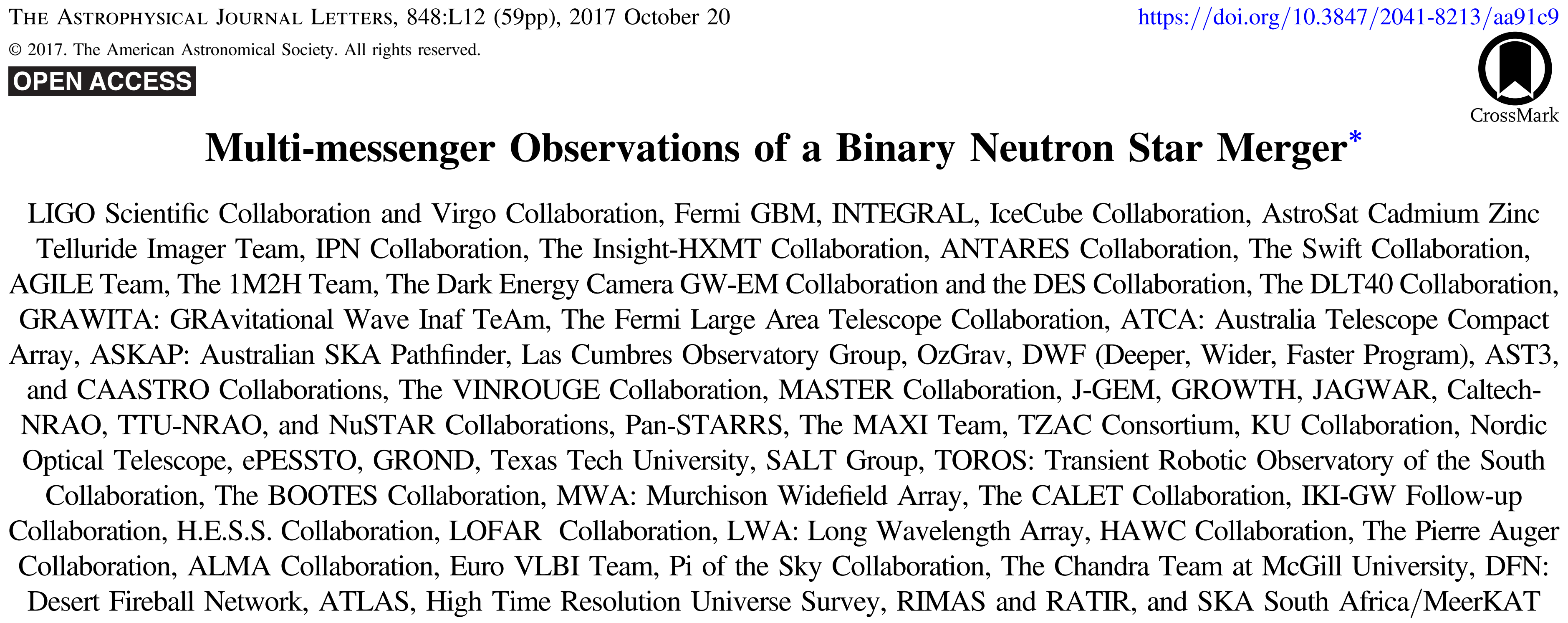
Fig. 3. Time-dependent multiwavelength observations of TXS 0506+056 before and after IceCube-170922A. Significant variability of the electromagnetic emission can be observed in all displayed energy bands, with the source being in a high-emission state around the time of the neutrino alert. From top to bottom: (**A**) VHE γ-ray observations by MAGIC, H.E.S.S., and VERITAS; (**B**) high-energy γ-ray observations by *Fermi*-LAT and *AGILE*; (**C** and **D**) x-ray observations by *Swift* XRT; (**E**) optical light curves from ASAS-SN, Kiso/KWFC, and Kanata/HONIR; and (**F**) radio observations by OVRO and VLA. The red dashed line marks the detection time of the neutrino IceCube-170922A. The left set of panels shows measurements between MJD 54700 (22 August 2008) and MJD 58002 (6 September 2017). The set of panels on the right shows an expanded scale for time range MJD 58002 to MJD 58050 (24 October 2017). The *Fermi*-LAT light curve is binned in 28-day bins on the left panel, while finer 7-day bins are used on the expanded panel. A VERITAS limit from MJD 58019.40 (23 September 2017) of 2.1×10^{-10} cm^{-2} s^{-1} is off the scale of the plot and not shown.

Follow-up of GW170817 with neutrinos







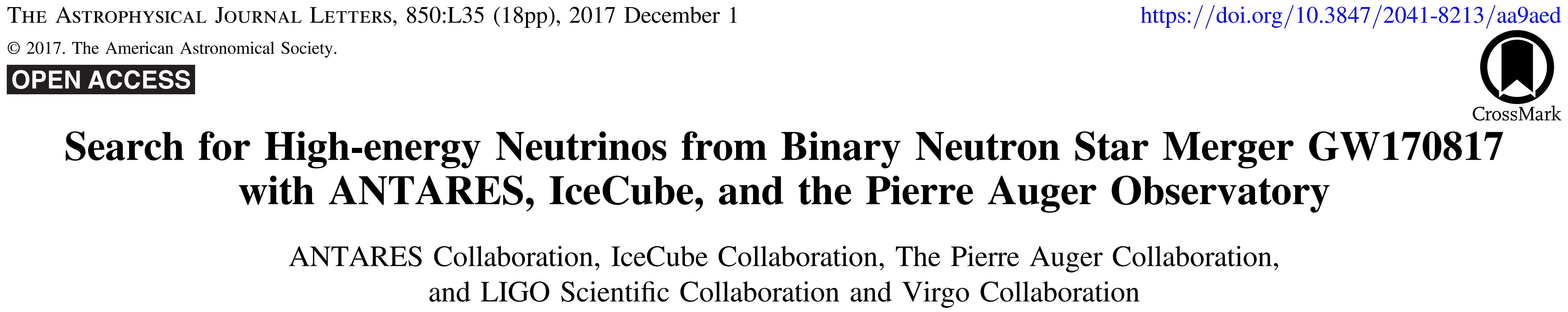


The Astrophysical Journal Letters, 848:L12 (59pp), 2017 October 20 https://doi.org/10.3847/2041-8213/aa91c9

OPEN ACCESS

Multi-messenger Observations of a Binary Neutron Star Merger*

LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-HXMT Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT

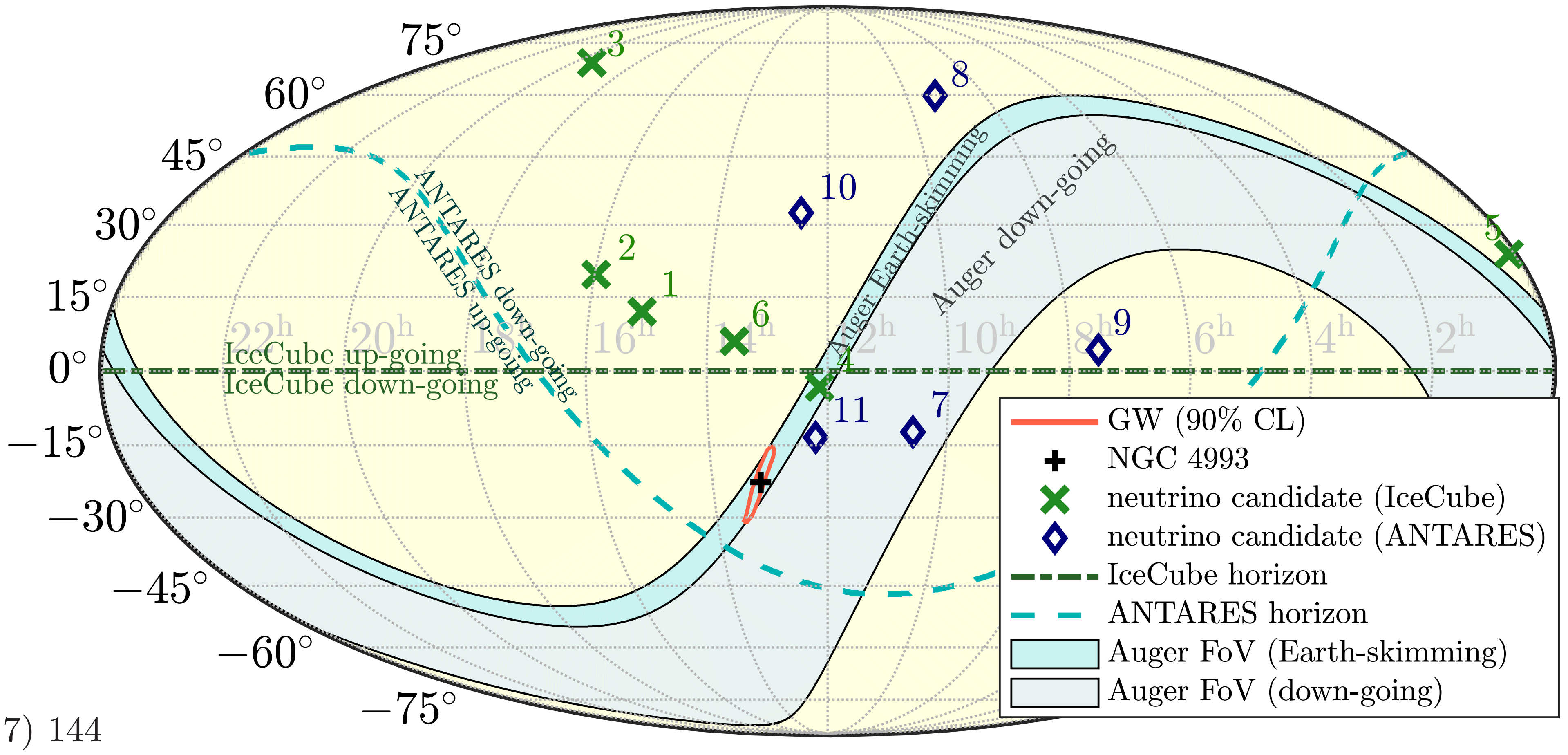


The Astrophysical Journal Letters, 850:L35 (18pp), 2017 December 1 https://doi.org/10.3847/2041-8213/aa9aed

OPEN ACCESS

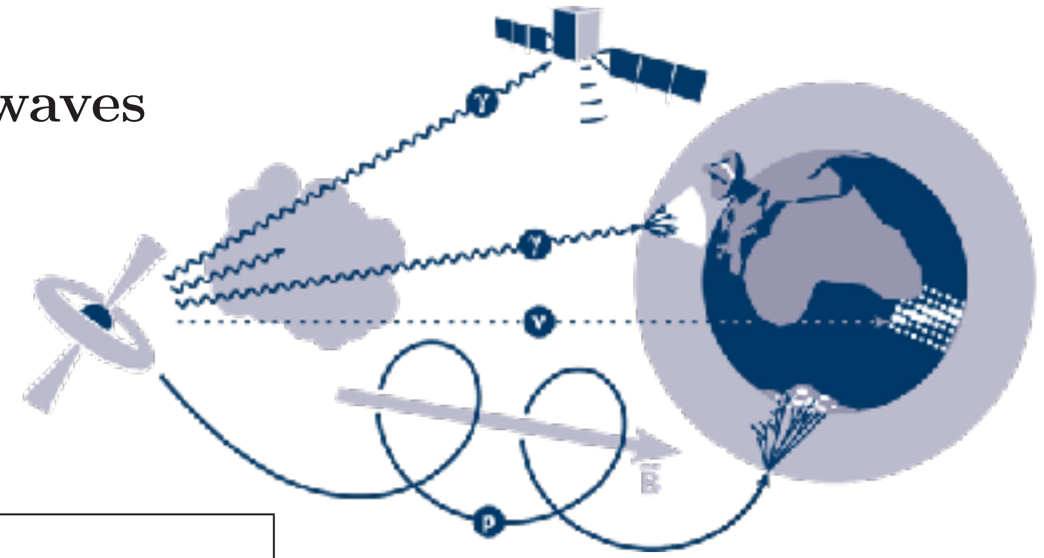
Search for High-energy Neutrinos from Binary Neutron Star Merger GW170817 with ANTARES, IceCube, and the Pierre Auger Observatory

ANTARES Collaboration, IceCube Collaboration, The Pierre Auger Collaboration,
and LIGO Scientific Collaboration and Virgo Collaboration



IL NUOVO CIMENTO **40 C** (2017) 144
DOI 10.1393/ncc/i2017-17144-0

Colloquia: SciNeGHE 2016



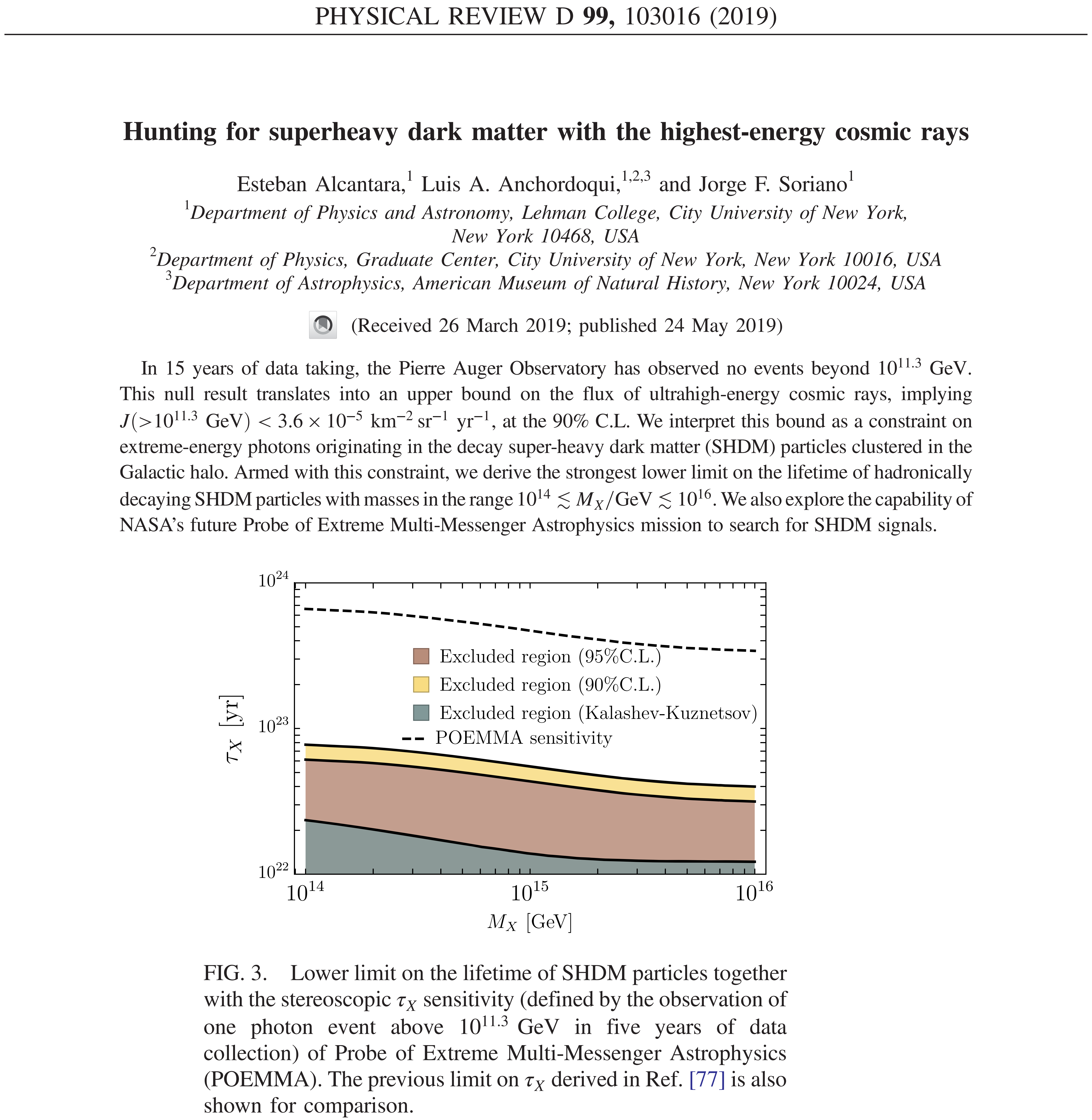
Cosmic rays, gamma rays, neutrinos and gravitational waves

Paolo Lipari
INFN, Sezione di Roma "Sapienza" - Roma, Italy

received 31 July 2017

Summary. — This paper discusses the relation between the study of the fluxes of cosmic rays, gamma rays and neutrinos, and the connection of these observations with the newly born field of gravitational wave astronomy.

Fundamental physics at extreme energies


PHYSICAL REVIEW D **99**, 103016 (2019)

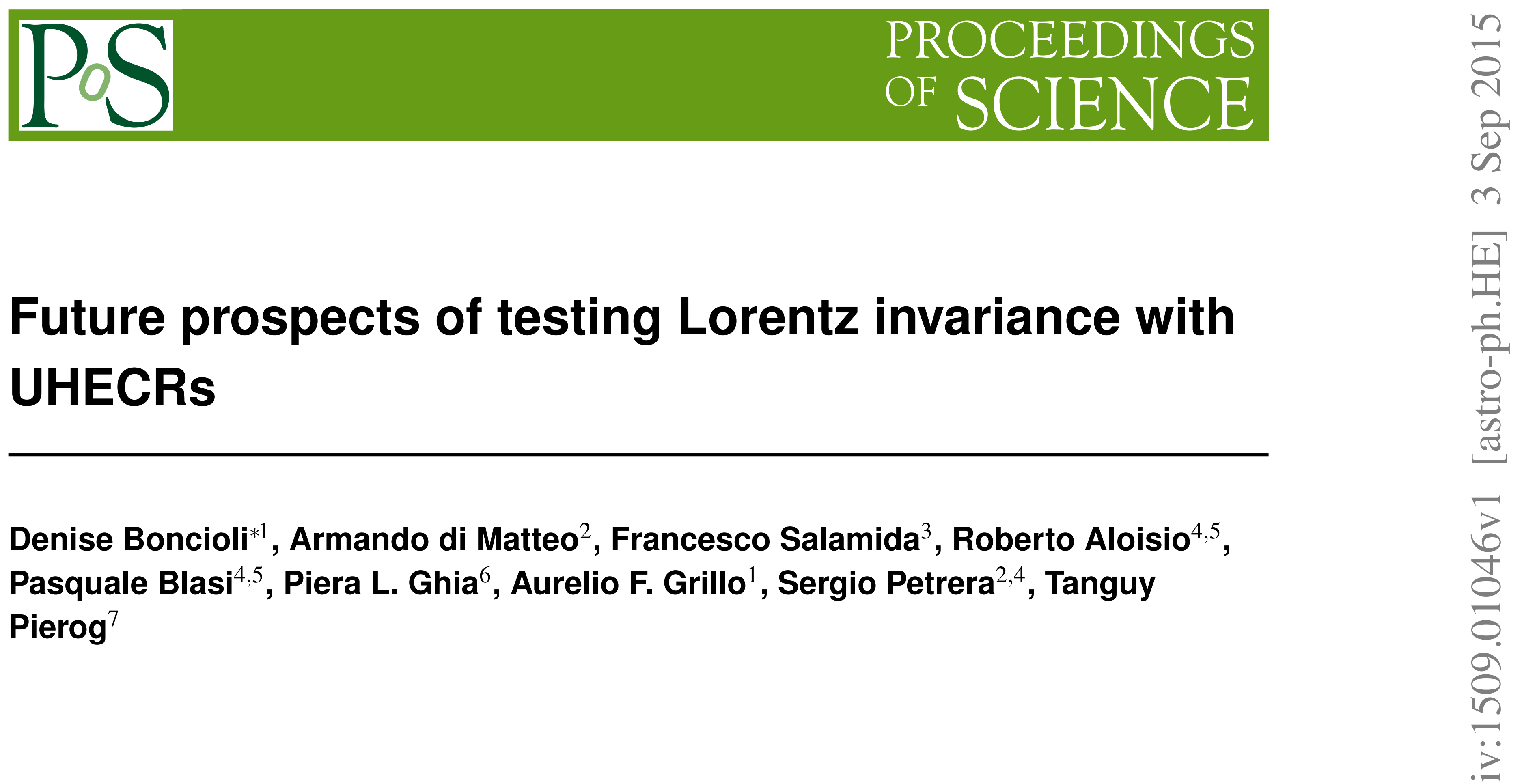
Hunting for superheavy dark matter with the highest-energy cosmic rays

Esteban Alcantara,[1] Luis A. Anchordoqui,[1,2,3] and Jorge F. Soriano[1]
[1]*Department of Physics and Astronomy, Lehman College, City University of New York, New York 10468, USA*
[2]*Department of Physics, Graduate Center, City University of New York, New York 10016, USA*
[3]*Department of Astrophysics, American Museum of Natural History, New York 10024, USA*

(Received 26 March 2019; published 24 May 2019)

In 15 years of data taking, the Pierre Auger Observatory has observed no events beyond $10^{11.3}$ GeV. This null result translates into an upper bound on the flux of ultrahigh-energy cosmic rays, implying $J(>10^{11.3}\ \mathrm{GeV}) < 3.6 \times 10^{-5}\ \mathrm{km^{-2}\ sr^{-1}\ yr^{-1}}$, at the 90% C.L. We interpret this bound as a constraint on extreme-energy photons originating in the decay super-heavy dark matter (SHDM) particles clustered in the Galactic halo. Armed with this constraint, we derive the strongest lower limit on the lifetime of hadronically decaying SHDM particles with masses in the range $10^{14} \lesssim M_X/\mathrm{GeV} \lesssim 10^{16}$. We also explore the capability of NASA's future Probe of Extreme Multi-Messenger Astrophysics mission to search for SHDM signals.

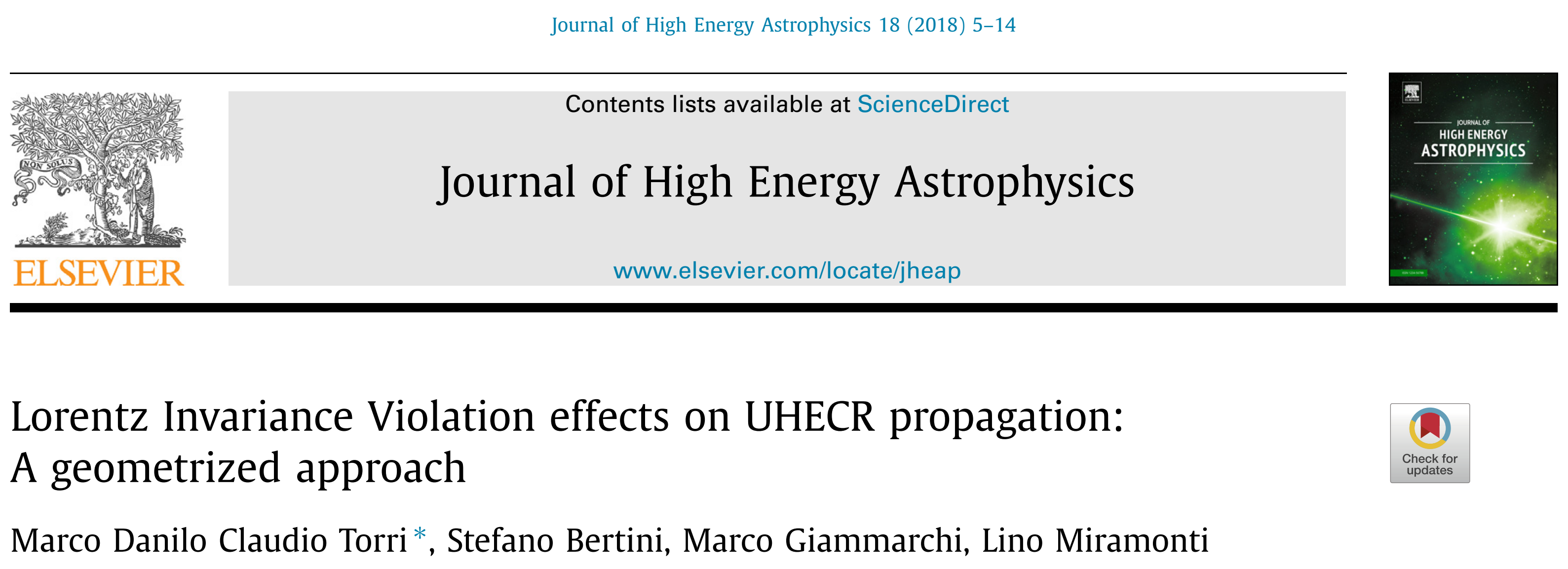
FIG. 3. Lower limit on the lifetime of SHDM particles together with the stereoscopic τ_X sensitivity (defined by the observation of one photon event above $10^{11.3}$ GeV in five years of data collection) of Probe of Extreme Multi-Messenger Astrophysics (POEMMA). The previous limit on τ_X derived in Ref. [77] is also shown for comparison.


PROCEEDINGS OF SCIENCE

Future prospects of testing Lorentz invariance with UHECRs

Denise Boncioli[*1], **Armando di Matteo**[2], **Francesco Salamida**[3], **Roberto Aloisio**[4,5], **Pasquale Blasi**[4,5], **Piera L. Ghia**[6], **Aurelio F. Grillo**[1], **Sergio Petrera**[2,4], **Tanguy Pierog**[7]

arXiv:1509.01046v1 [astro-ph.HE] 3 Sep 2015


Journal of High Energy Astrophysics 18 (2018) 5–14

Contents lists available at ScienceDirect

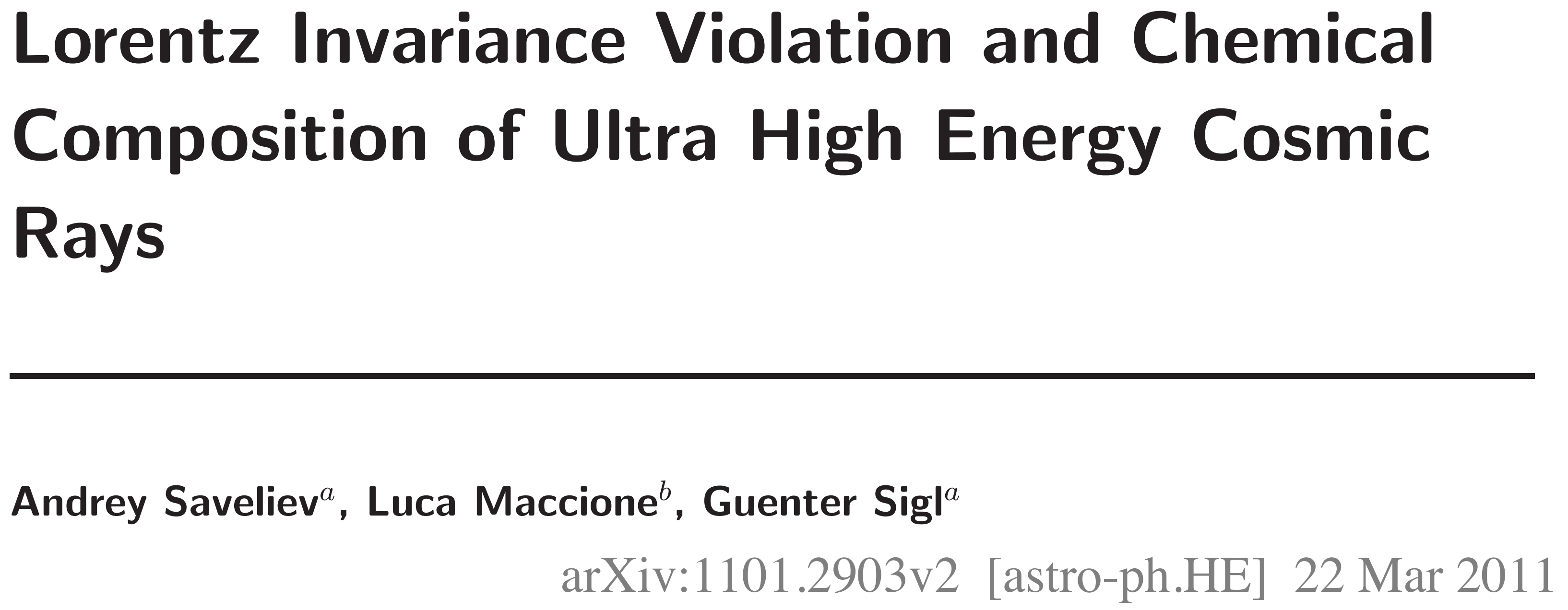
Journal of High Energy Astrophysics

www.elsevier.com/locate/jheap

ELSEVIER

Lorentz Invariance Violation effects on UHECR propagation: A geometrized approach

Marco Danilo Claudio Torri*, Stefano Bertini, Marco Giammarchi, Lino Miramonti

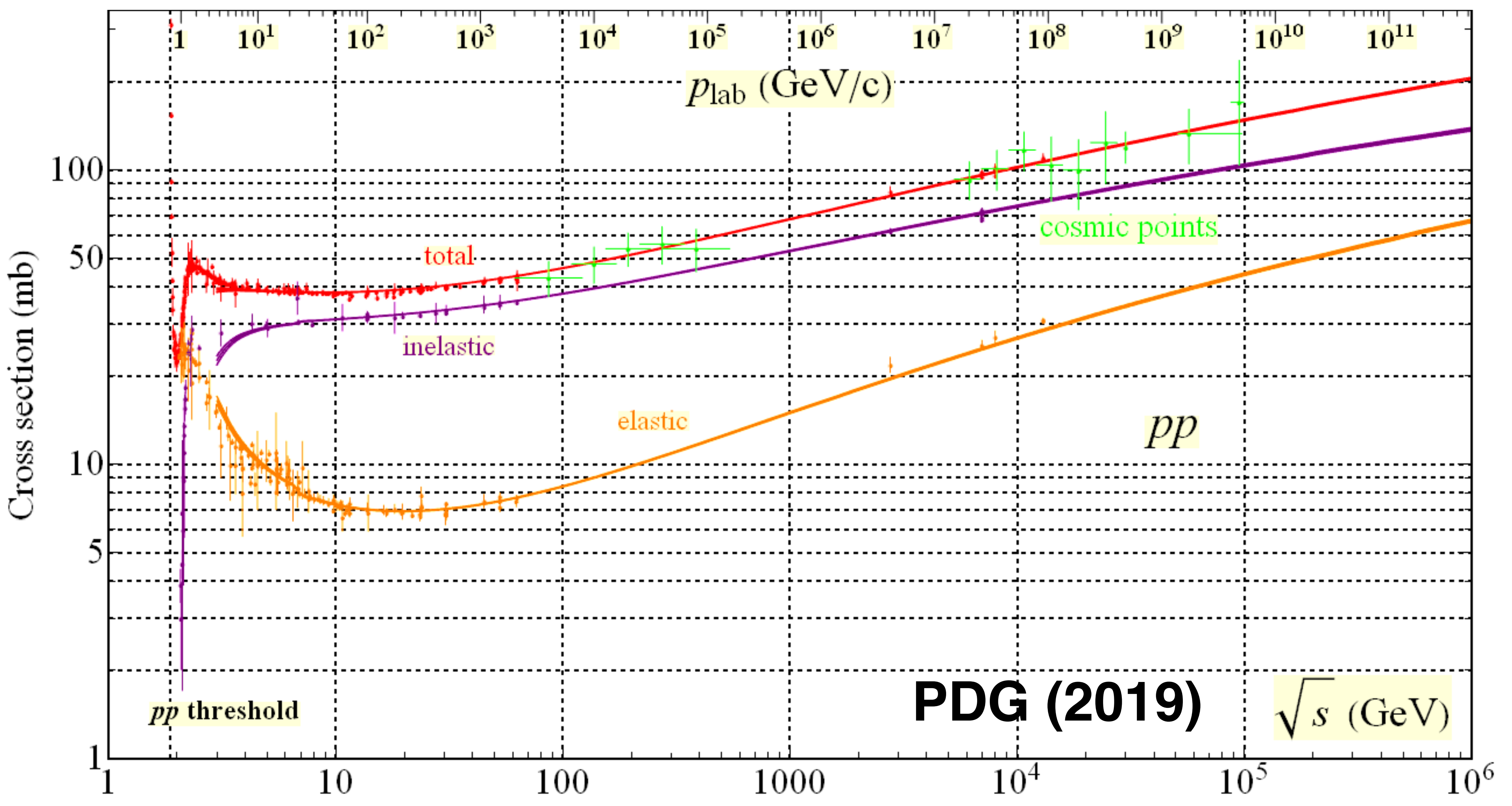

Lorentz Invariance Violation and Chemical Composition of Ultra High Energy Cosmic Rays

Andrey Saveliev[a], **Luca Maccione**[b], **Guenter Sigl**[a]

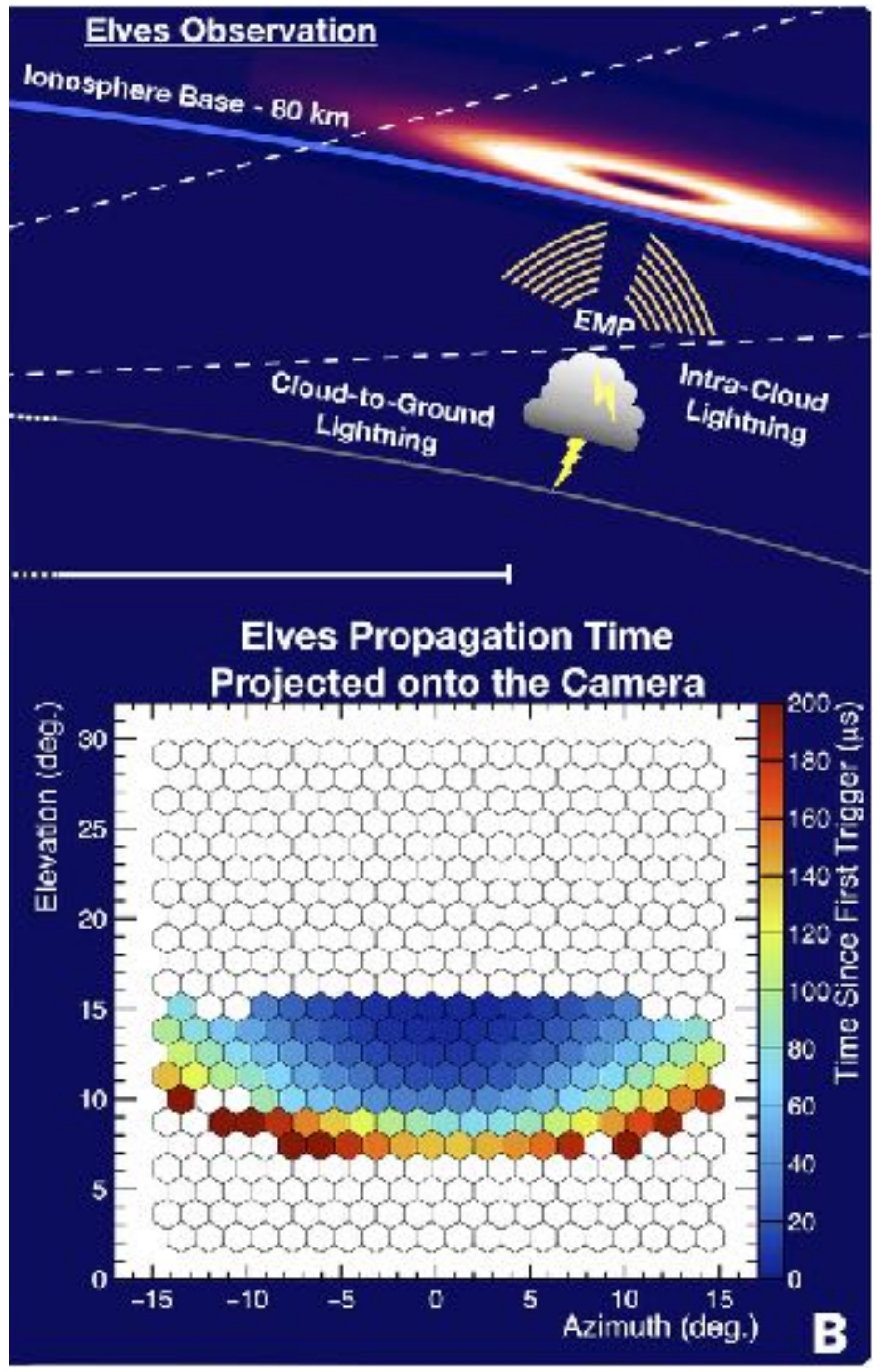
arXiv:1101.2903v2 [astro-ph.HE] 22 Mar 2011

Additional physics cases

- **(Hadronic) interactions/particle physics at extreme energies**
- **Geophysics, elves, atmospheric phenomena, …**
- **What else?**
  Think out of the box…
  E.g. LOFAR key science project Cosmic Rays —> detailed investigations of lightning



PDG (2019)



Auger (2020)

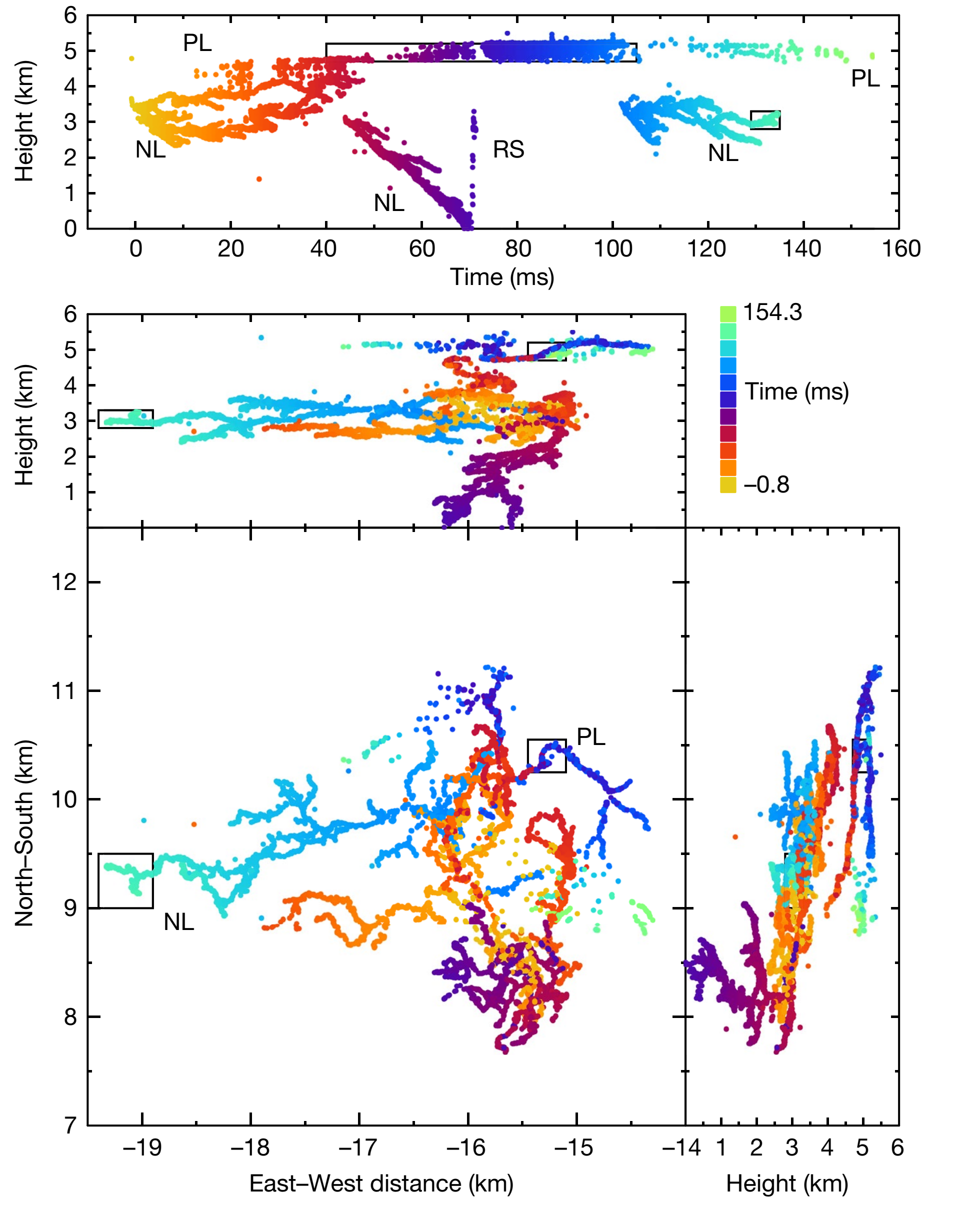


Fig. 1 | Map of the 2017 flash. Each dot is the location of a radio source. Sources from the positive leaders (PL) and negative leaders (NL) are shown. When the negative leader connects to ground, it creates a 'short' that propagates up the lightning channel called a return stroke (RS). The boxes indicate the areas that are shown in Fig. 2. Distances are relative to the LOFAR core.

LOFAR, Nature (2019)

CR anisotropy

The Astrophysical Journal, 862:91 (6pp), 2018 August 1 https://doi.org/10.3847/1538-4357/aac9c8

Evidence of Intermediate-scale Energy Spectrum Anisotropy of Cosmic Rays $E \geqslant 10^{19.2}$ eV with the Telescope Array Surface Detector

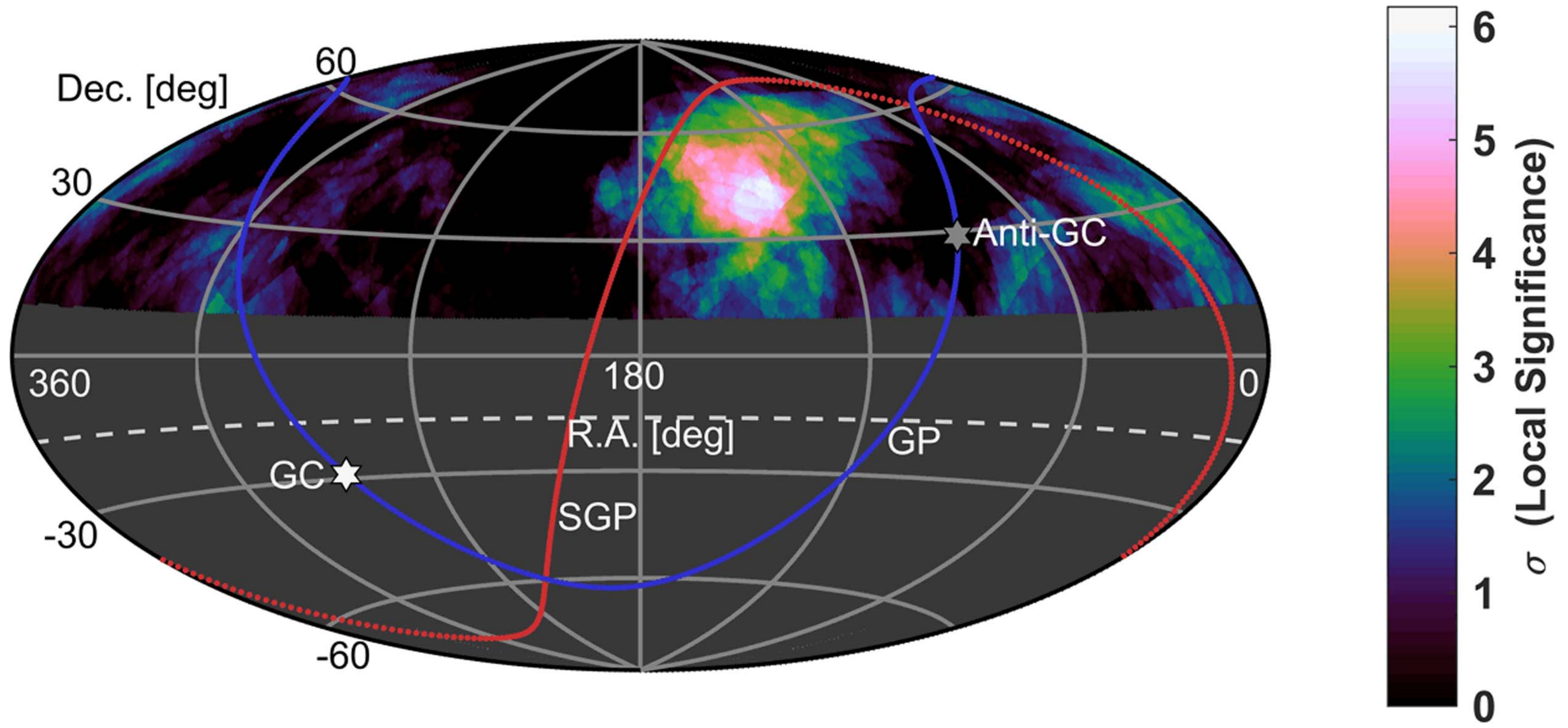


Figure 3. Projection of the energy spectrum anisotropy local pre-trial significance, for 14.03% equal exposure spherical cap bins ($E \geqslant 10^{19.2}$ eV). The maximum is $6.17\sigma_{\rm local}$ at $9^{\rm h}16^{\rm m}$, 45° and is 7° from the the Hotspot location of Abbasi et al. (2014a). The dashed curve at decl. $= -16°$ defines the FOV. Solid curves indicate the Galactic plane (GP) and supergalactic plane (SGP). White and gray hexagrams indicate the Galactic center (GC) and anti-galactic center (Anti-GC).

The Astrophysical Journal, 899:86 (13pp), 2020 August 10 https://doi.org/10.3847/1538-4357/aba26c

Evidence for a Supergalactic Structure of Magnetic Deflection Multiplets of Ultra-high-energy Cosmic Rays

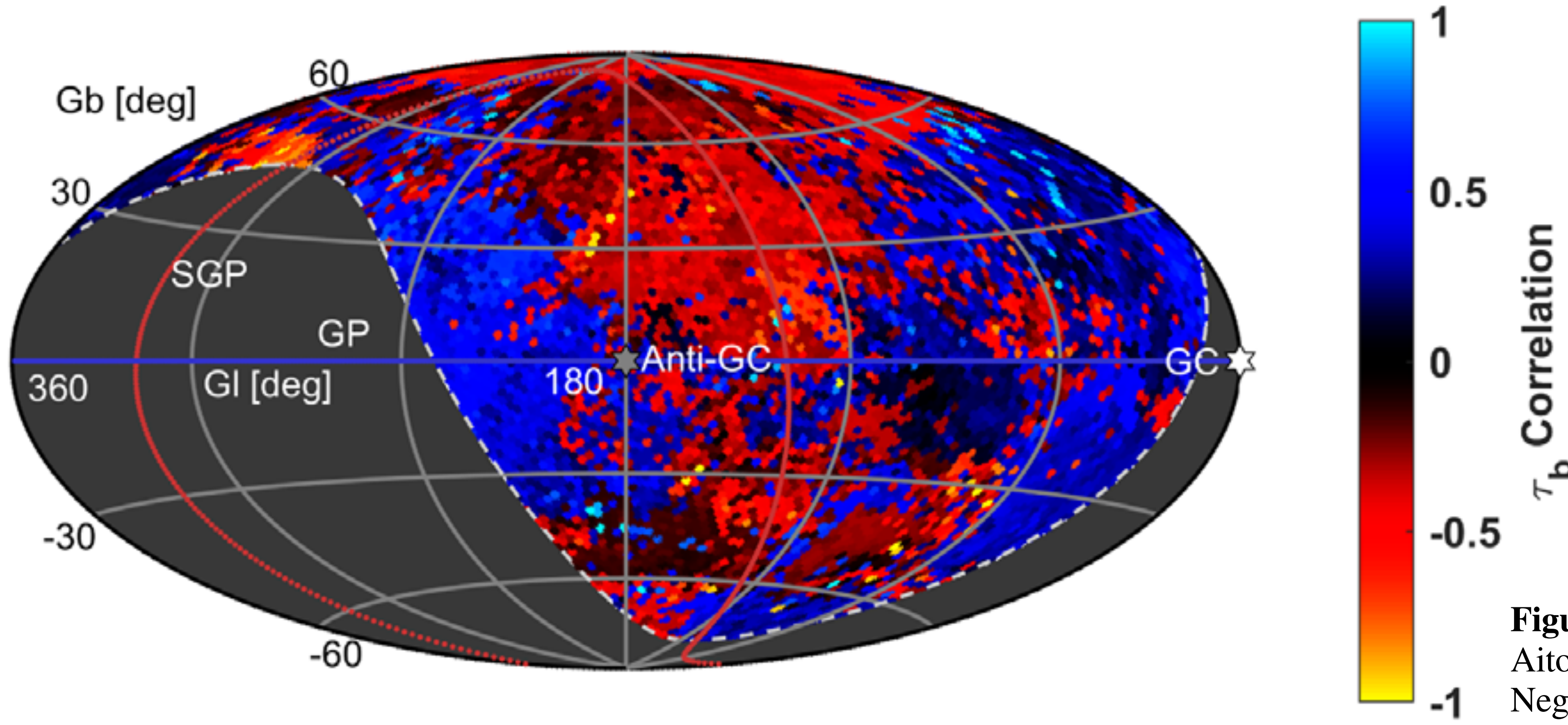


Figure 17. Ten years of data result shown in galactic coordinates. (a) Hammer–Aitoff galactic projection of the correlation strength τ for all grid points. Negative correlations expected for magnetic deflections are not apparent around the galactic plane.

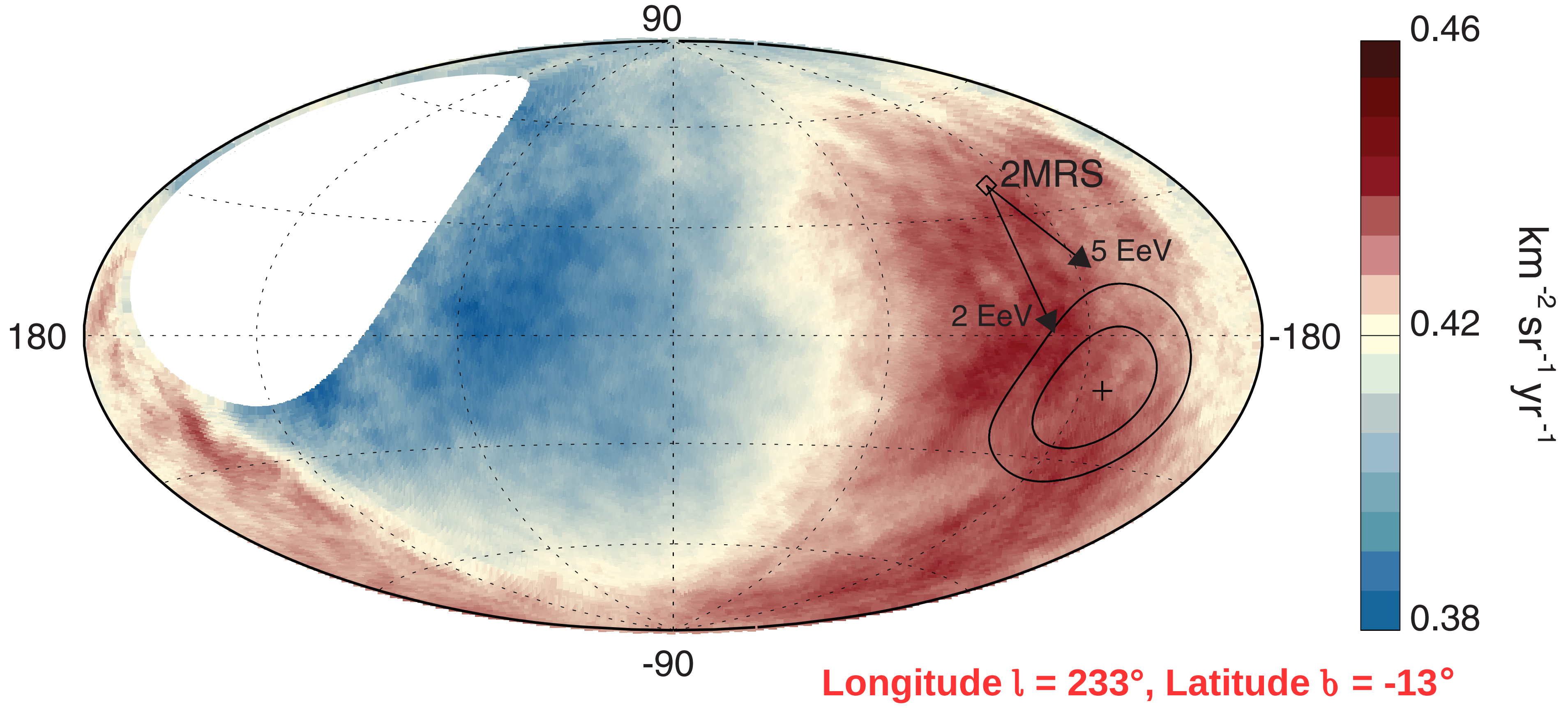
RESEARCH A. Aab et al., Science 357 (2017) 1266

COSMIC RAYS

Observation of a large-scale anisotropy in the arrival directions of cosmic rays above 8×10^{18} eV

The Pierre Auger Collaboration*†

$E>8*10^{18}$ eV $3*10^{4}$ CRs



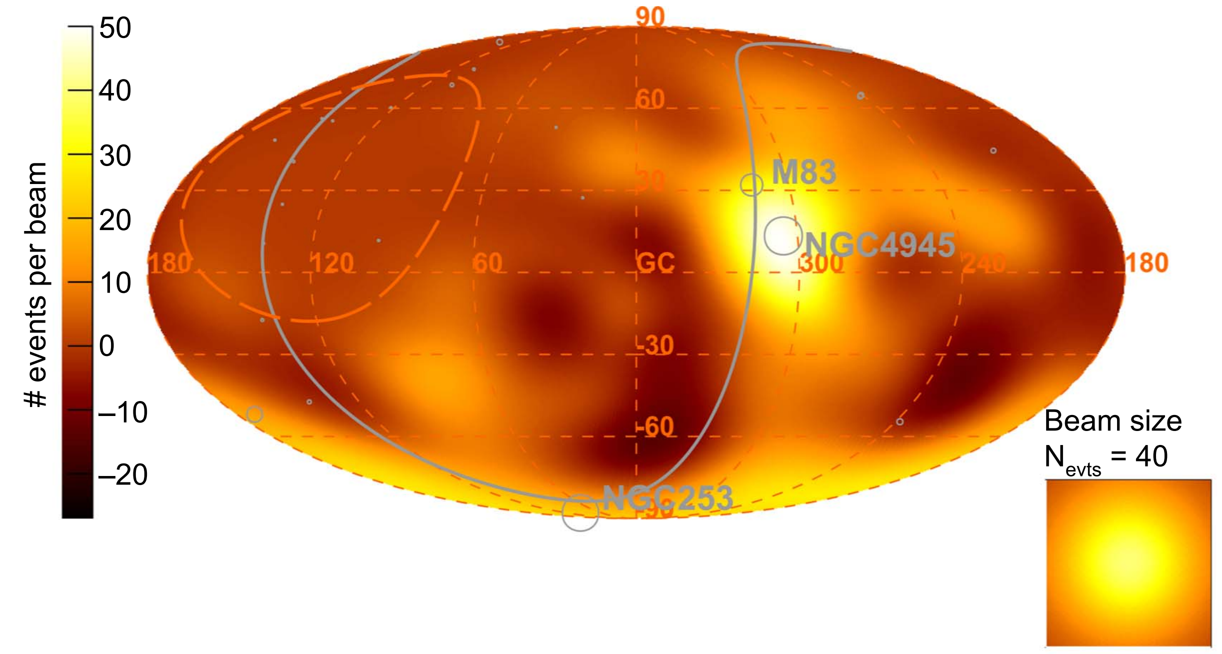
Longitude l = 233°, Latitude b = -13°

Fig. 3. Map showing the fluxes of particles in galactic coordinates. Sky map in galactic coordinates showing the cosmic-ray flux for $E \geq 8$ EeV smoothed with a 45° top-hat function. The galactic center is at the origin. The cross indicates the measured dipole direction; the contours denote the 68% and 95% confidence level regions. The dipole in the 2MRS galaxy distribution is indicated. Arrows show the deflections expected for a particular model of the galactic magnetic field (*8*) on particles with $E/Z = 5$ or 2 EeV.

The Astrophysical Journal Letters, 853:L29 (10pp), 2018 February 1 https://doi.org/10.3847/2041-8213/aaa66d

An Indication of Anisotropy in Arrival Directions of Ultra-high-energy Cosmic Rays through Comparison to the Flux Pattern of Extragalactic Gamma-Ray Sources*

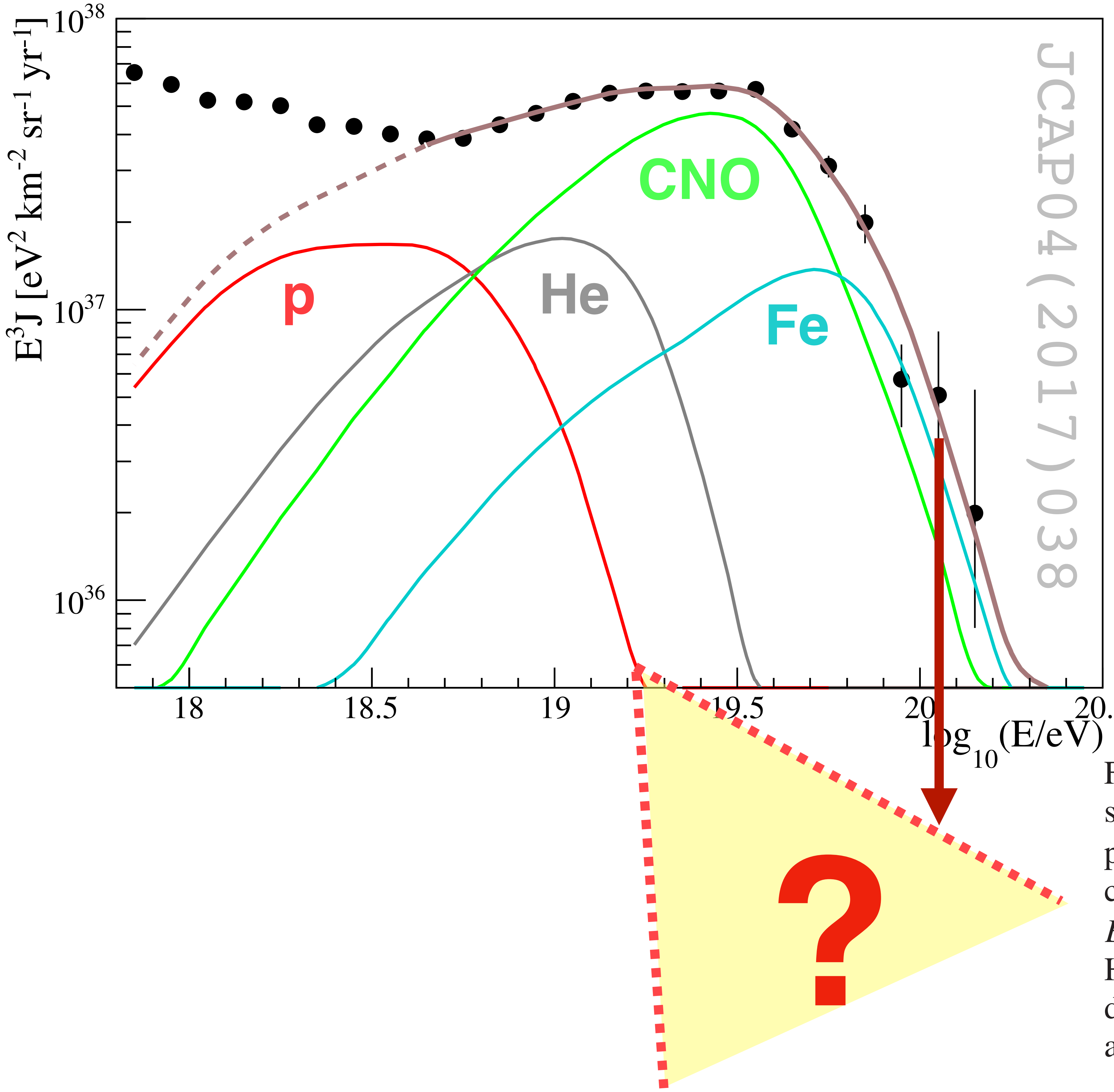
Observed Excess Map - E > 39 Eev



Light particles at highest E?

Combined fit of spectrum and composition data as measured by the Pierre Auger Observatory

The Pierre Auger collaboration



PHYSICAL REVIEW D **100,** 021302(R) (2019)

Rapid Communications

Determining the fraction of cosmic-ray protons at ultrahigh energies with cosmogenic neutrinos

Arjen van Vliet,[1,2,*] Rafael Alves Batista,[3] and Jörg R. Hörandel[1,4,5]

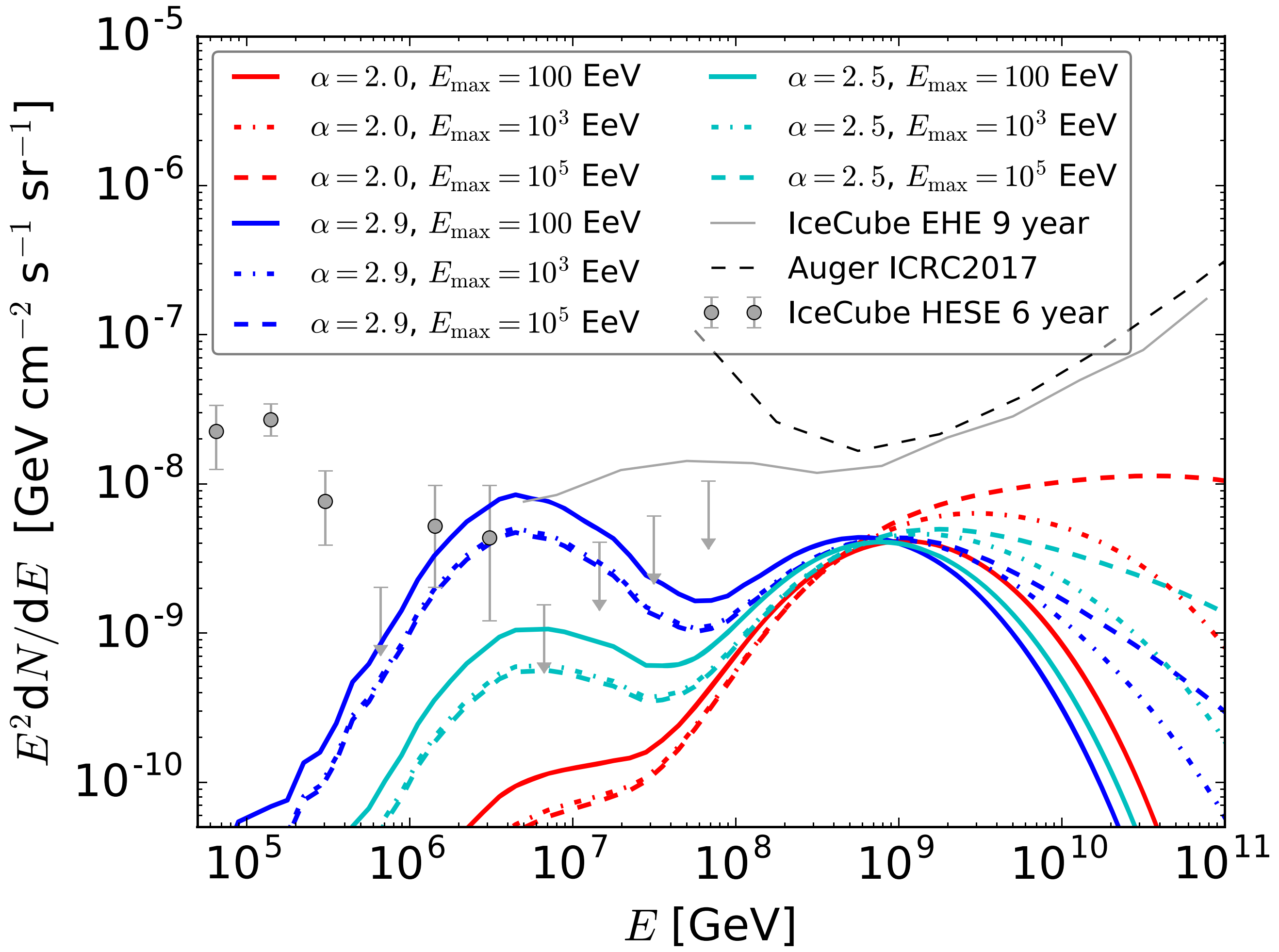


FIG. 1. Simulated single-flavor cosmogenic neutrino ($\nu + \bar{\nu}$) spectra [assuming a $(\nu_e : \nu_\mu : \nu_\tau) = (1:1:1)$ flavor ratio] for pure-proton scenarios with $m = 3.0$ and $f = 1.0$. The corresponding cosmic-ray curves are normalized to the Auger spectrum [43] at $E_0 = 10^{19.55}$ eV. For reference, we also show the IceCube 6-yr HESE data [44] and the Auger [45,46] and IceCube [47] differential 90% C.L. upper limits for single-flavor neutrinos and half-energy-decade fluxes.

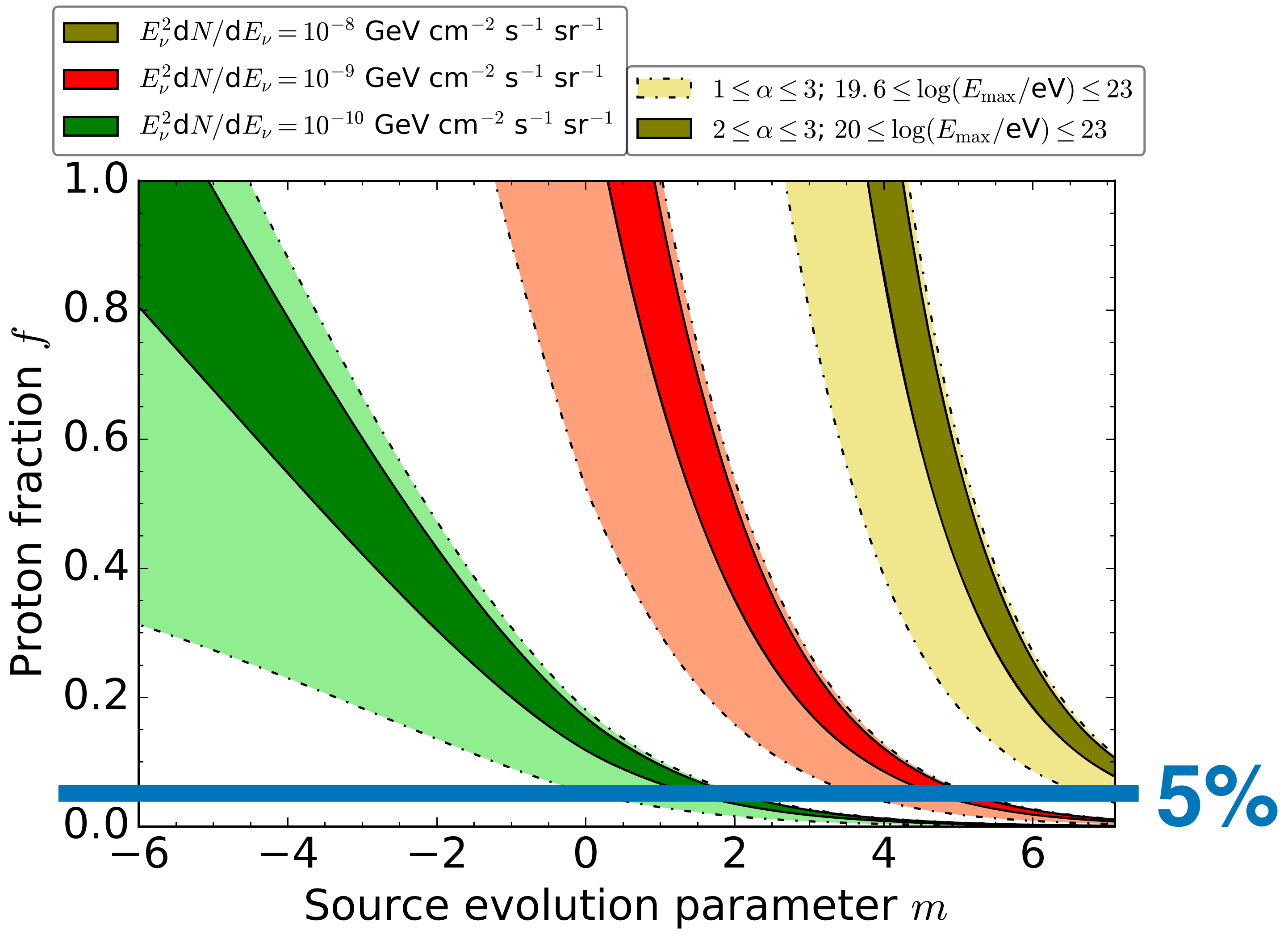


FIG. 2. Observable fraction of protons f at ultrahigh energies as a function of the source evolution parameter m. Three different single-flavor flux levels at a neutrino energy of $E_\nu = 1$ EeV are shown, corresponding roughly to the current sensitivity of IceCube and Auger (yellow), and upper (red) and lower (green) ranges for the expected sensitivity of ARA, ARIANNA and GRAND200k.

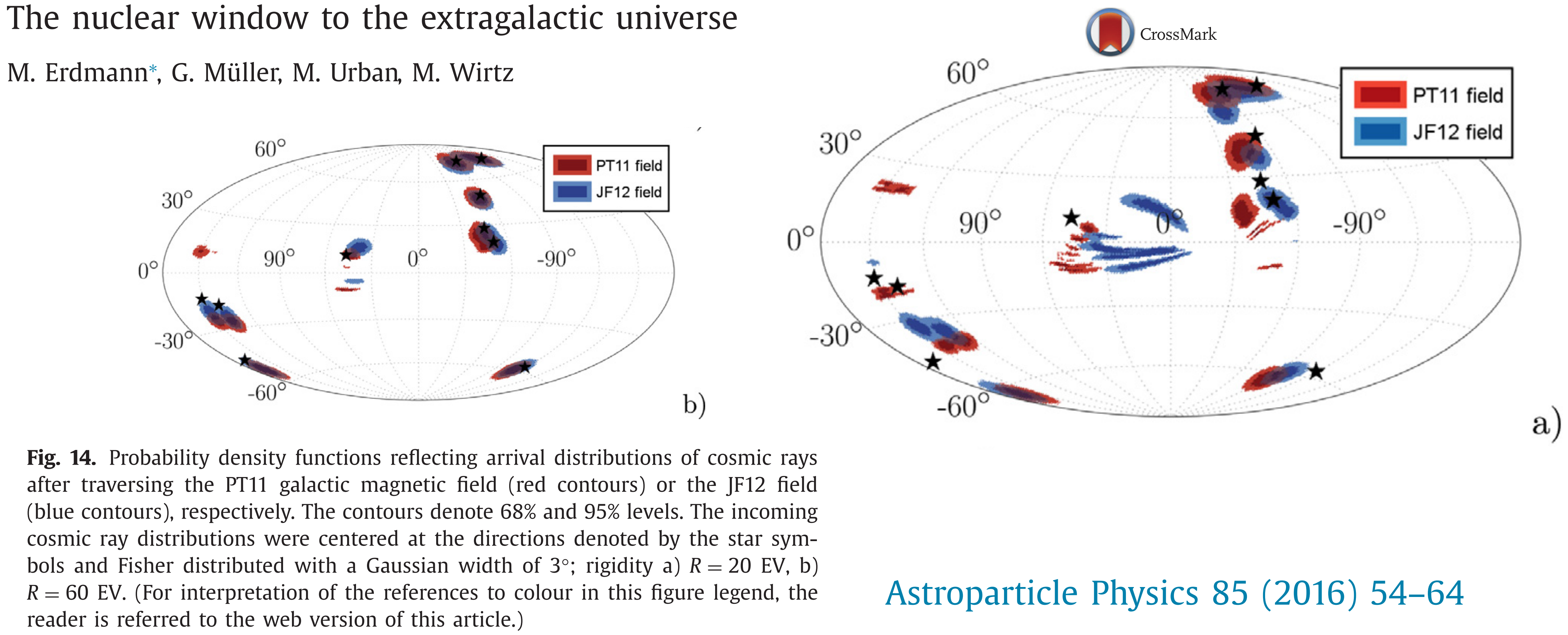
How big and where do we want to build GCOS?

Acceptance/exposure?
What statistics will we need?

$E > 10^{19.6}$ eV ~500 /yr (1000 km^2 and 2π)

- ~5% light particles
- ~50% efficiency
- 40000 km^2

—> 5000 light particles/decade ($E > 10^{19.6}$ eV)



The nuclear window to the extragalactic universe

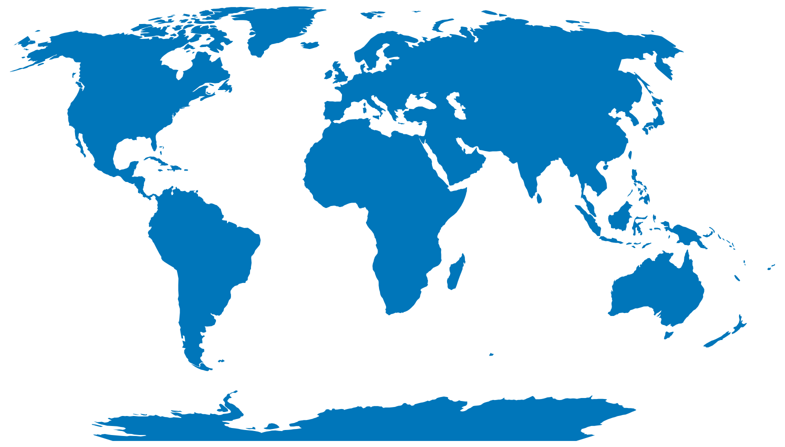
M. Erdmann*, G. Müller, M. Urban, M. Wirtz

Fig. 14. Probability density functions reflecting arrival distributions of cosmic rays after traversing the PT11 galactic magnetic field (red contours) or the JF12 field (blue contours), respectively. The contours denote 68% and 95% levels. The incoming cosmic ray distributions were centered at the directions denoted by the star symbols and Fisher distributed with a Gaussian width of 3°; rigidity a) $R = 20$ EV, b) $R = 60$ EV. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Astroparticle Physics 85 (2016) 54–64

Where: full sky coverage?

—> equator, several sites, …

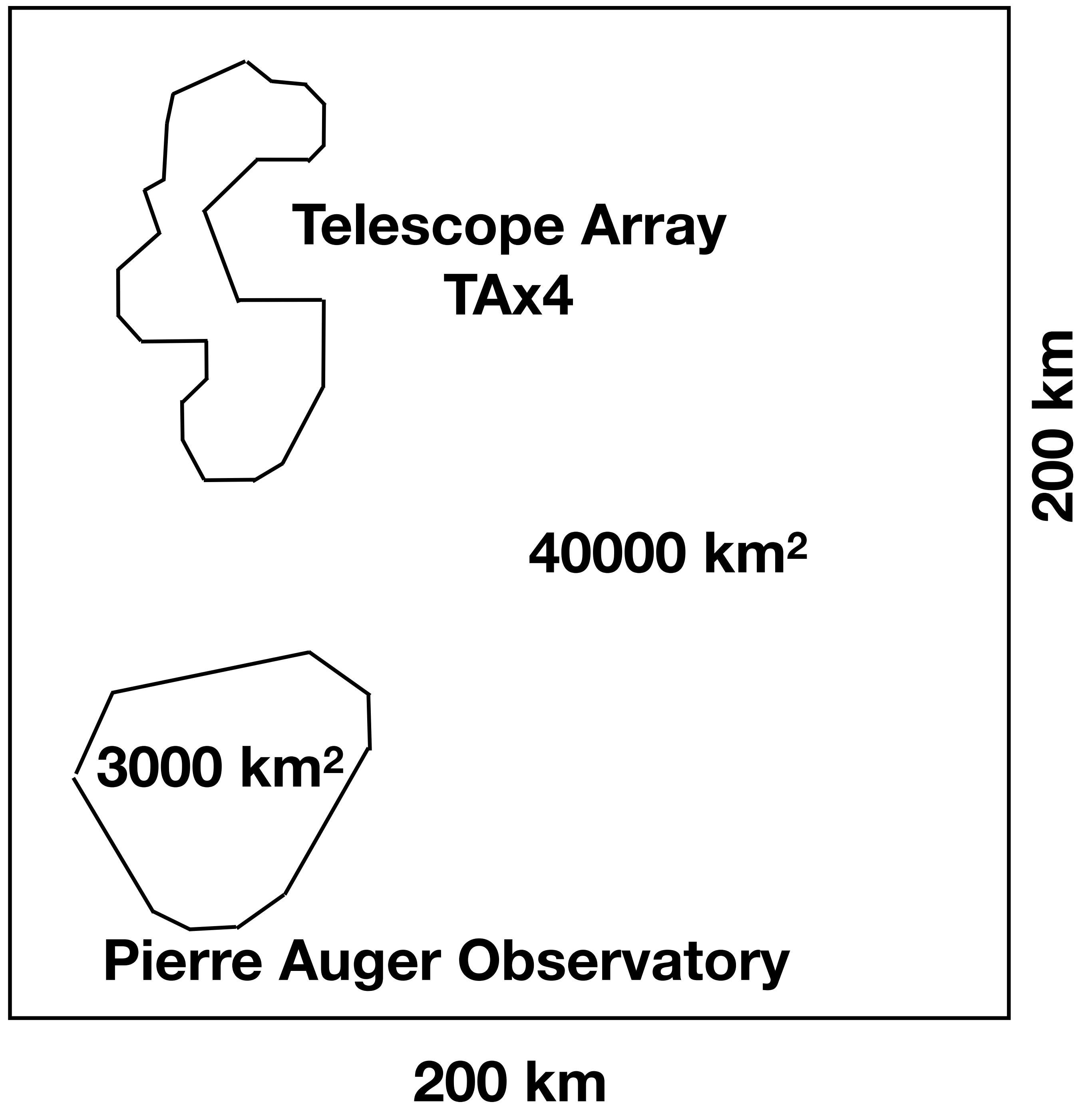


What is realistic in terms of area and number of detectors?

10x existing arrays? —> 40 000 - 50 000 km^2

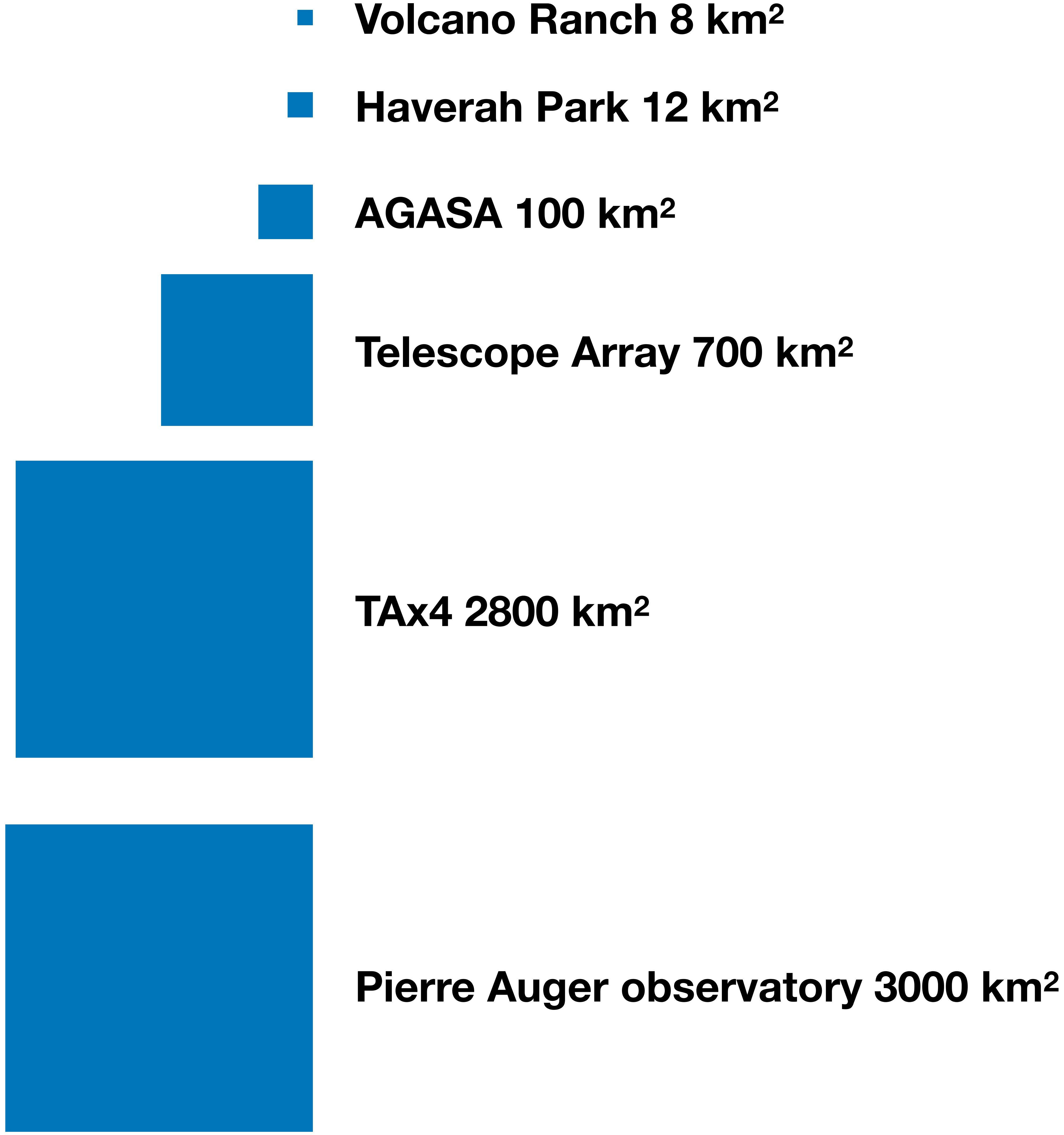
10x number of units? —> 10 000 - 20 000 detectors

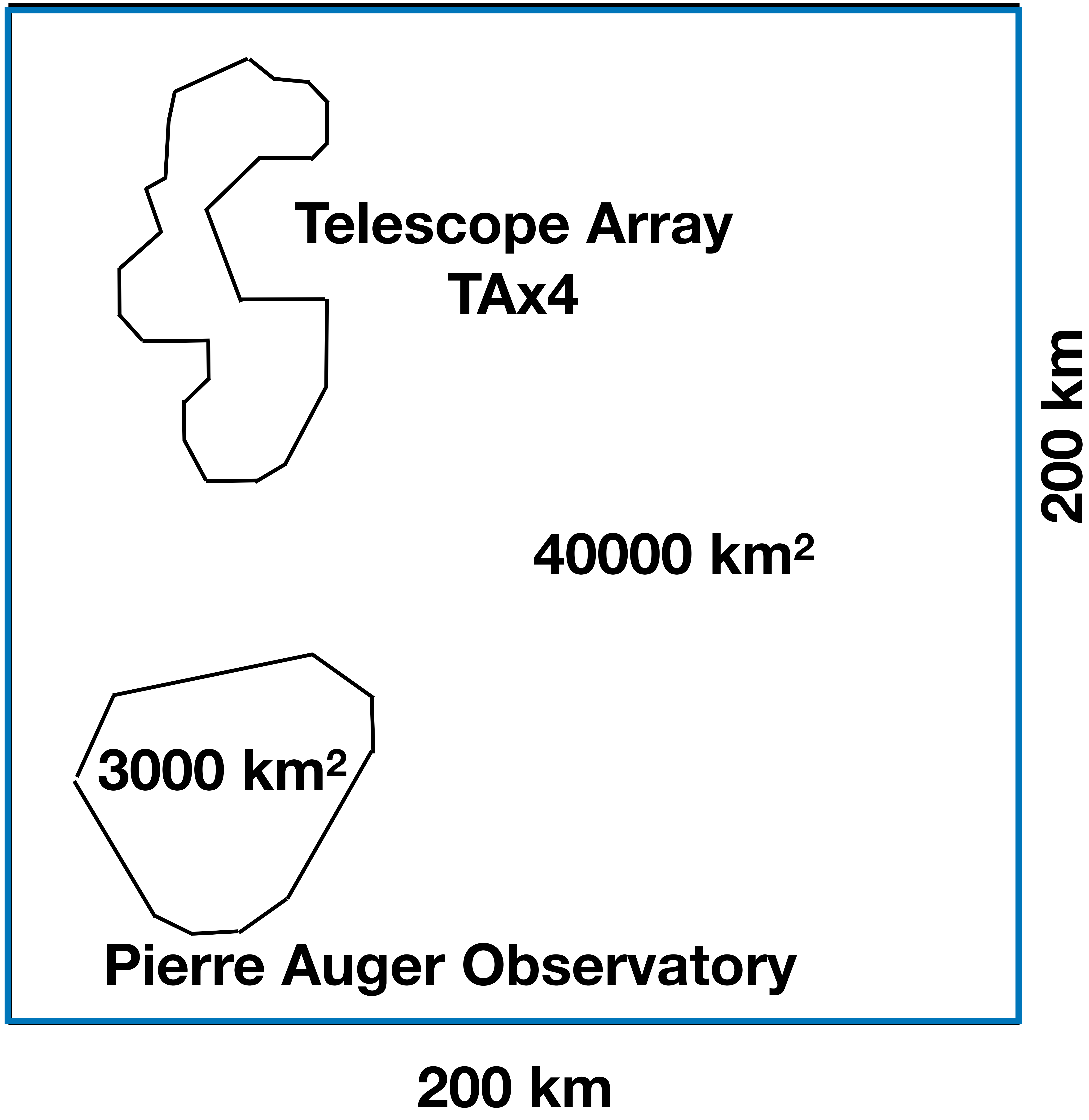
1.6 - 2 km spacing



see also K-H Kampert at High-Energy neutrino and cosmic-ray astrophysics, Weizmann Institute (2017)

How big and where do we want to build GCOS?





How would we build GCOS?

Detector array with mass sensitivity and ~100% duty cycle —> measurement of e/m and muonic component

water Cherenkov detector

* 3 dim —> 2π acceptance

* segmented/nested

—> e/m & mu separation

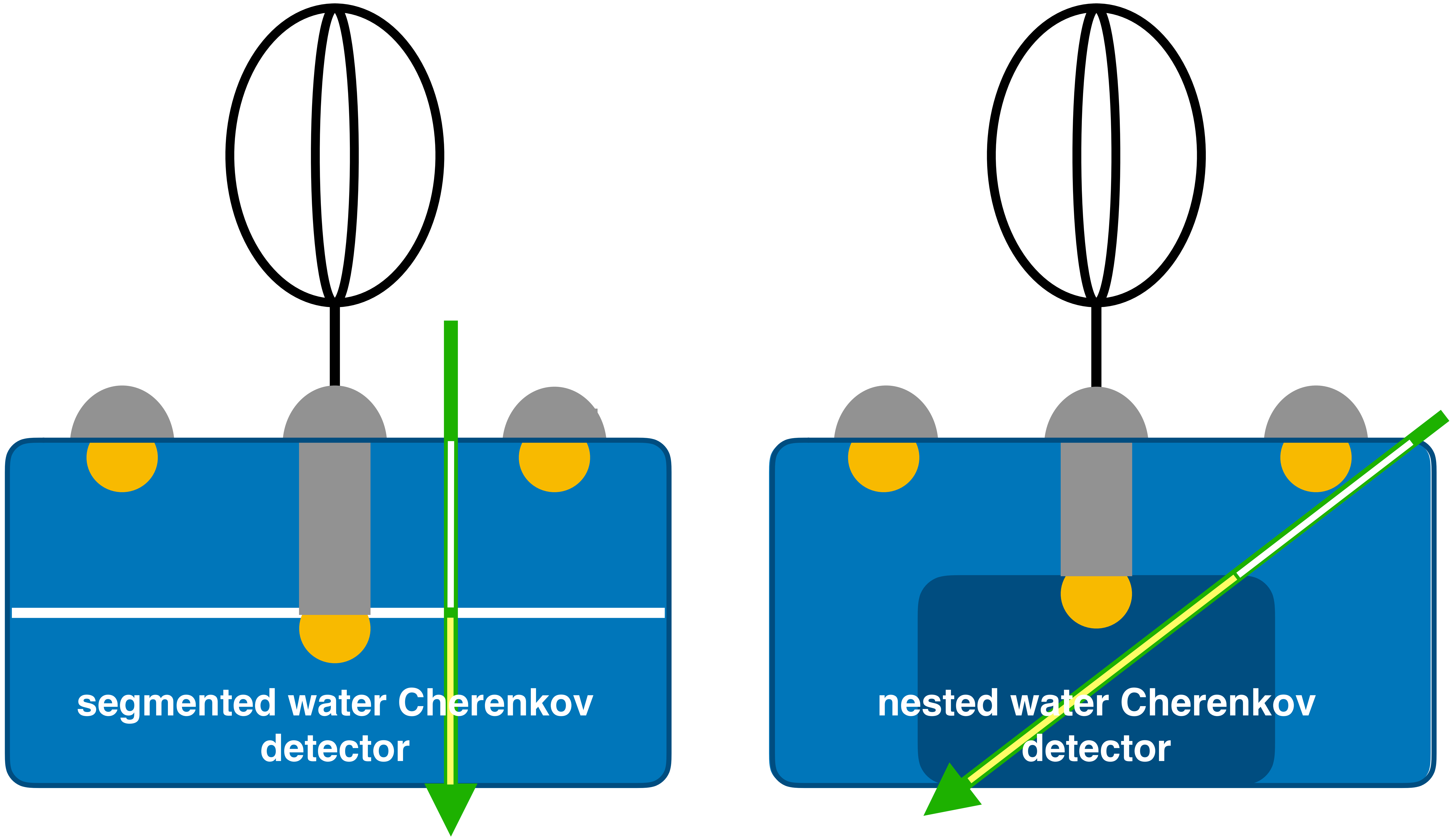
Antoine Letessier-Selvon et al., Nucl. Instr. Meth. A 767 (2014) 41–49

radio antenna

* e/m component

* absolute energy scale

JRH, EPJ Web of Conferences 216 (2019) 01003



see also I. Maris, JRH, R. Engel and others at UHECR2018, Paris (2018)

How would we build GCOS?

Detector array with mass sensitivity and ~100% dut cycle
—> measurement of e/m and muonic compo

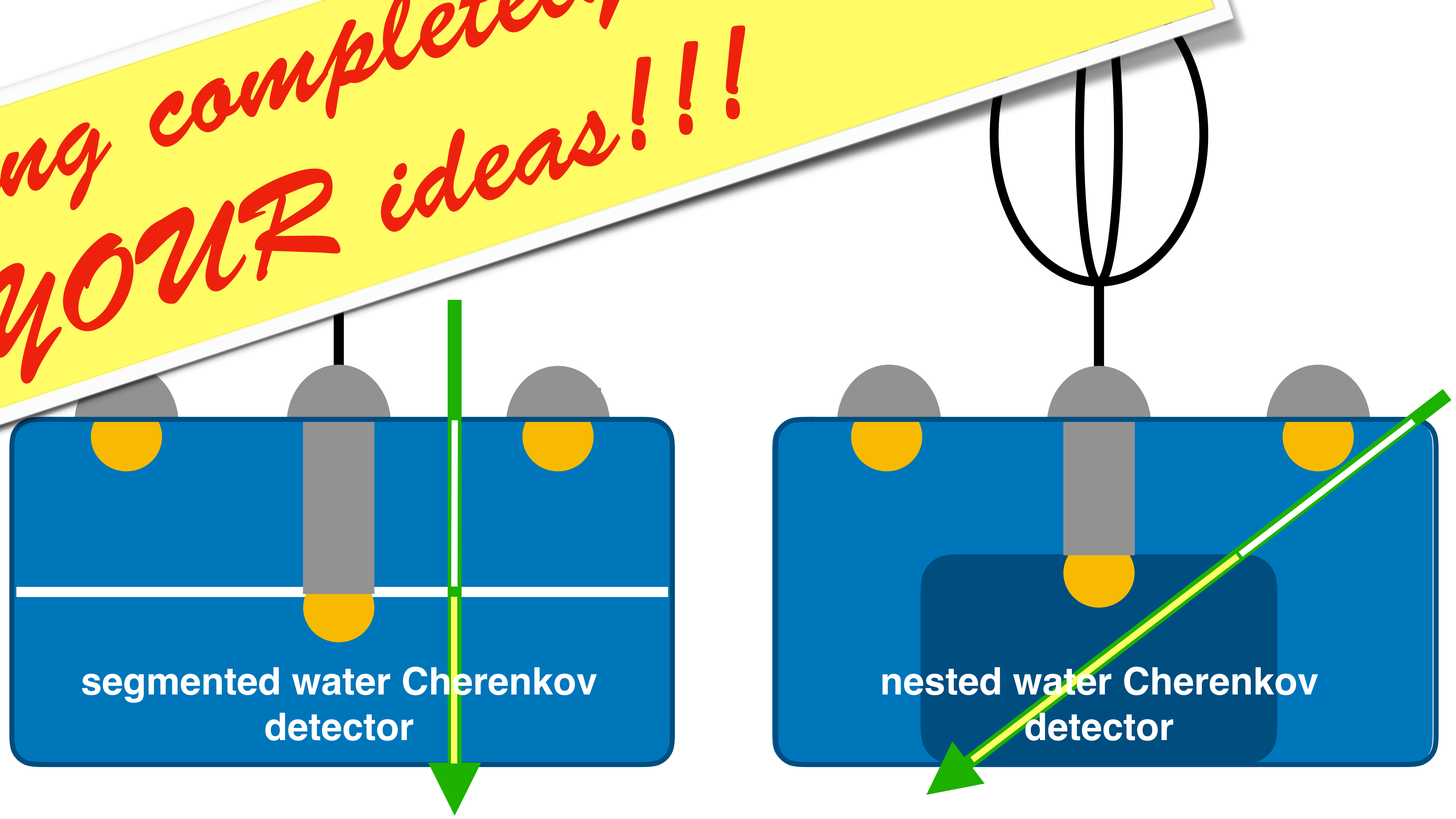
Maybe something completely different?
—> YOUR ideas!!!

water Cherenkov detector
- 3 dim —> 2π acceptance
- segmented/nested
    —> e/m & m

Antoine Letessier-Selv

radio
- e/m
- abso ergy scale

JRH, EPJ Web of Conferences 216 (2019) 01003



see also I. Maris, JRH, R. Engel and others at UHECR2018, Paris (2018)

What resolution(s) do we require for GCOS?

Mass (ln A) Simple Heitler model of (hadronic) showers

- **Average depth of shower maximum X_{max}**

$$X^A_{max} \sim \ln \frac{E_0}{A}$$

$$X^A_{max} = X^p_{max} - X_0 \ln A$$

$$X^{Fe}_{max} = X^p_{max} - 150\,\mathrm{g/cm^2}$$

$\Delta \ln A \sim 1$
→$\Delta X_{max} \sim 36$ g/cm²
→$\Delta (N_e/N_\mu) \sim 16\%$

- **N_e-N_μ ratio**

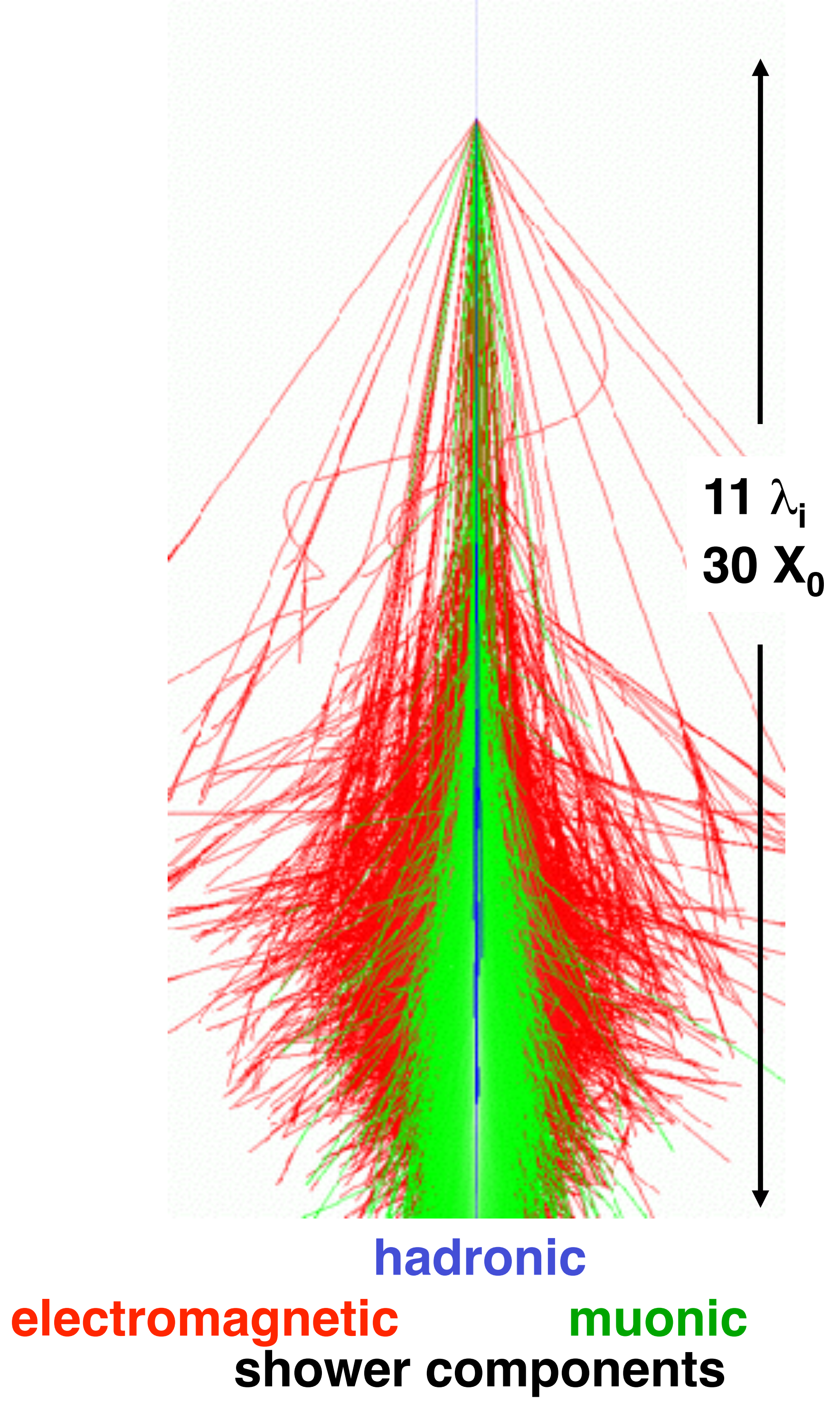
$$\frac{N_e}{N_\mu} \approx 35.1 \left(\frac{E_0}{A\ \mathrm{PeV}}\right)^{0.15} \quad \text{or} \quad \lg\left(\frac{N_e}{N_\mu}\right) = C - 0.065 \ln A$$

→ $\Delta \ln A \approx 0.8$

in „best“ experiments

→ **4-5 groups in ln A**

J. Matthews, Astropart. Phys. 22 (2005) 387
JRH, Mod. Phys. Lett. A 22 (2007) 1533
JRH, Nucl. Instr. and Meth. A 588 (2008) 181



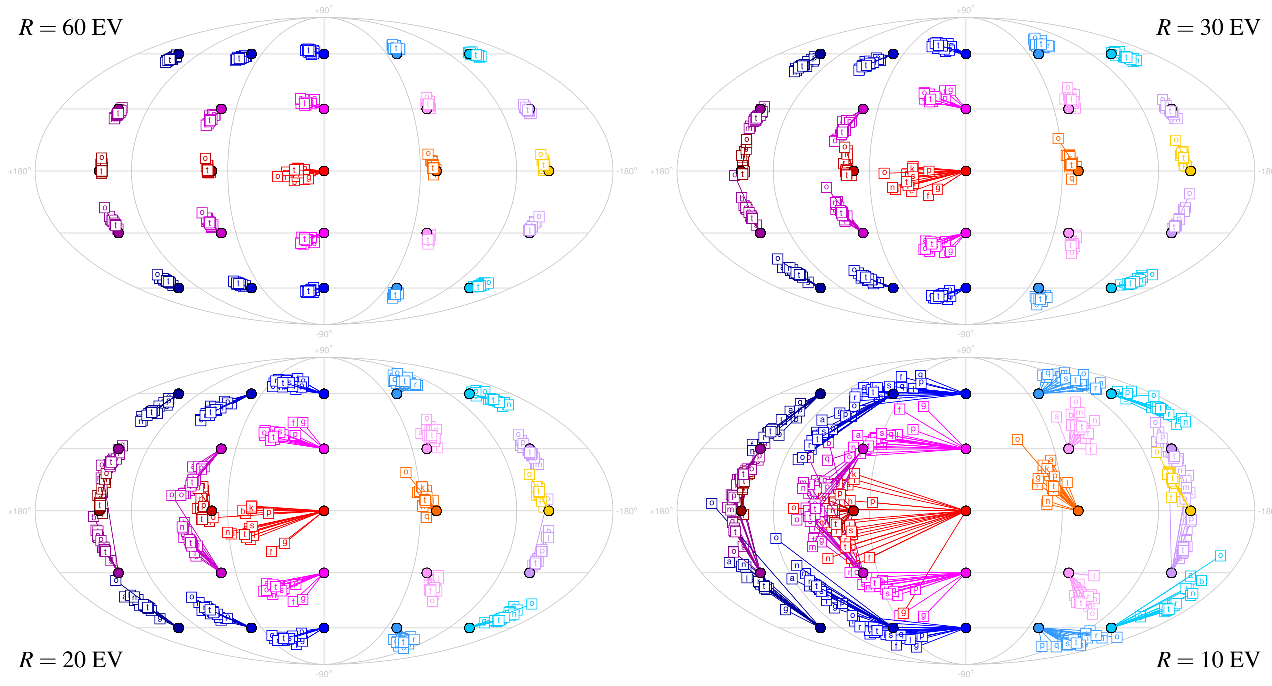


Figure 2: Backtracking of charged particles at different rigidities from a regular grid of initial directions (dots) through different models of the coherent GMF. The resulting directions outside of the Galaxy are denoted by squares and the letters correspond to the models listed in Table 1. The sky maps are in Galactic coordinates and the particle rigidities indicated in corners of each panel.

PoS(ICRC2017)558

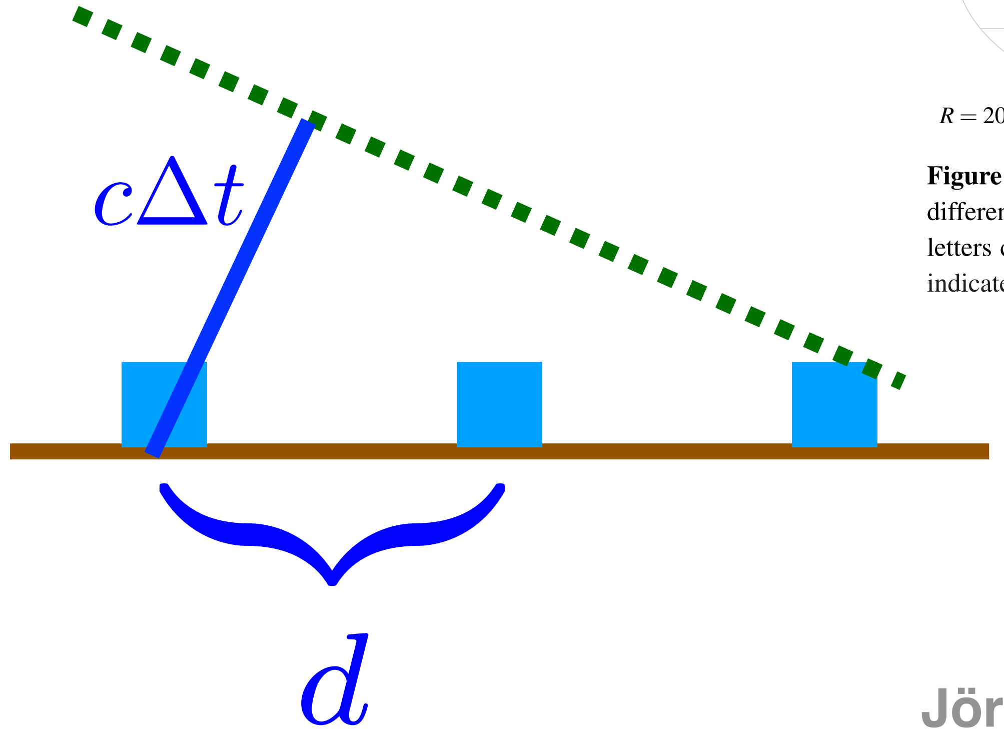
Rigidity $R = \frac{E}{Z} = \frac{E}{Z = f(\ln A)}$ $Z \approx \frac{A}{2}$

→ **R resolution** $\propto \ln$

Direction —> arrival time

spacing: $d \approx 2$ km
GPS accuracy (ionospheric distortions): $\sigma_{\Delta t} \approx 5 - 8$ ns

→ **angular resolution** $\sigma_\Theta < 1^\circ$



Workshop structure

Monday	* Lessons learned from existing observatories until 2030 TA, Pierre Auger observatory, multi-messenger/IceCube * Theory, source models/scenarios, propagation
Tuesday	* Magnetic fields and deflection of UHE particles * Multi-disciplinary science Geophysics, hadronic interactions, fundamental physics
Wednesday	* Discussion UHE physic case * Experimental techniques - R&D
Thursday	* Multi-messenger experimental techniques * Discussion ground arrays vs space observatories * Discussion what can we hope to learn from GCOS? * Next steps, white paper, follow up workshop, … * ICRC contribution and proceedings
Friday	* additional discussions as needed

Each presentation followed by discussion time!

14:00

Opening - scope of workshop — *Jörg Hörandel*
zoom 14:00 - 14:20

TA and TAx4 experiment summary. Status and results. — *Eiji Kido*
zoom 14:20 - 14:35

TA anisotropy results and interpretations — *Jihyun Kim*
zoom 14:35 - 14:50

discussion
zoom 14:50 - 15:00

15:00

Auger(Prime) charged CRs, neutrinos, gamma rays — *Ralph Engel*
zoom 15:00 - 15:30

discussion
zoom 15:30 - 15:40

UHE Universe in the multimessenger paradigm - lessons from neutrinos — *Markus Ahlers*
zoom 15:40 - 16:10

16:00

discussion
zoom 16:10 - 16:20

UHE acceleration, status theoretical understanding, open questions what observations does theory need from GCOS in order to move on? — *Kohta Murase*

discussion
zoom 16:50 - 17:00

17:00

Source model scenarios - starburst galaxies vs AGNs — *Luis Anchordoqui*
zoom 17:00 - 17:20

discussion
zoom 17:20 - 17:30

Magnetic fields and directional correlations of UHECRs with local galaxies — *Arjen van Vliet*
zoom 17:30 - 17:50

discussion
zoom 17:50 - 18:00

18:00

Relevance of photo-nuclear processes in UHECR interactions — *Denise Boncioli*
zoom 18:00 - 18:20

discussion
zoom 18:20 - 18:30

14:00

galactic and extragalactic magnetic fields and their relation to UHECR propagation
zoom 14:00 - 14:20

discussion
zoom 14:20 - 14:30

deflection of charged particles in B fields (--> particle astronomy?) — *Michael Unger*
zoom 14:30 - 14:50

discussion
zoom 14:50 - 15:00

15:00

influence of distribution of local matter density in Universe on arrival directions — *Glennys Farrar*
zoom 15:00 - 15:20

discussion
zoom 15:20 - 15:30

astronomy with charged particles, nu and GW — *Paolo Lipari*
zoom 15:30 - 15:50

discussion
zoom 15:50 - 16:00

16:00

Transient Luminous Events
zoom 16:30 - 16:45

discussion
zoom 16:45 - 16:50

TA, TGFs correlated with a signal in the SD — *Rasha Abbasi*
zoom 16:50 - 17:05

17:00

discussion
zoom 17:05 - 17:10

(hadronic) interactions at highest energies, including synergies with LHC p-O — *Tanguy Pierog*
zoom 17:10 - 17:25

discussion
zoom 17:25 - 17:30

test of hadronic interaction models with TeV-PeV muons, IceCube-IceTop — *Dennis Soldin*
zoom 17:30 - 17:45

discussion
zoom 17:45 - 17:50

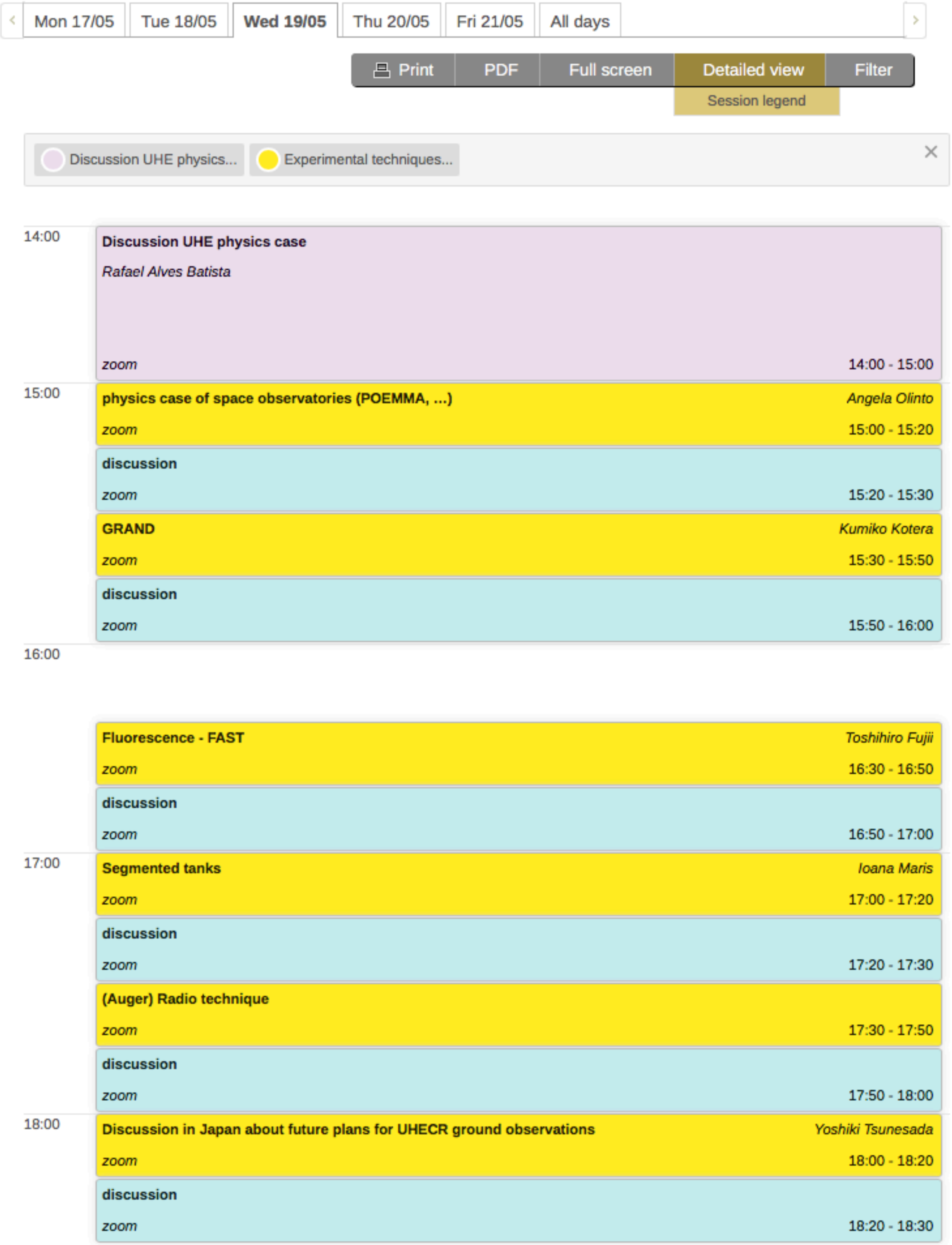
uh-DM annihilation — *Olivier Deligny*
zoom 17:50 - 18:05

18:00

discussion
zoom 18:05 - 18:10

Lorentz Invariacne — *Günter Sigl*
zoom 18:10 - 18:25

discussion
zoom 18:25 - 18:30



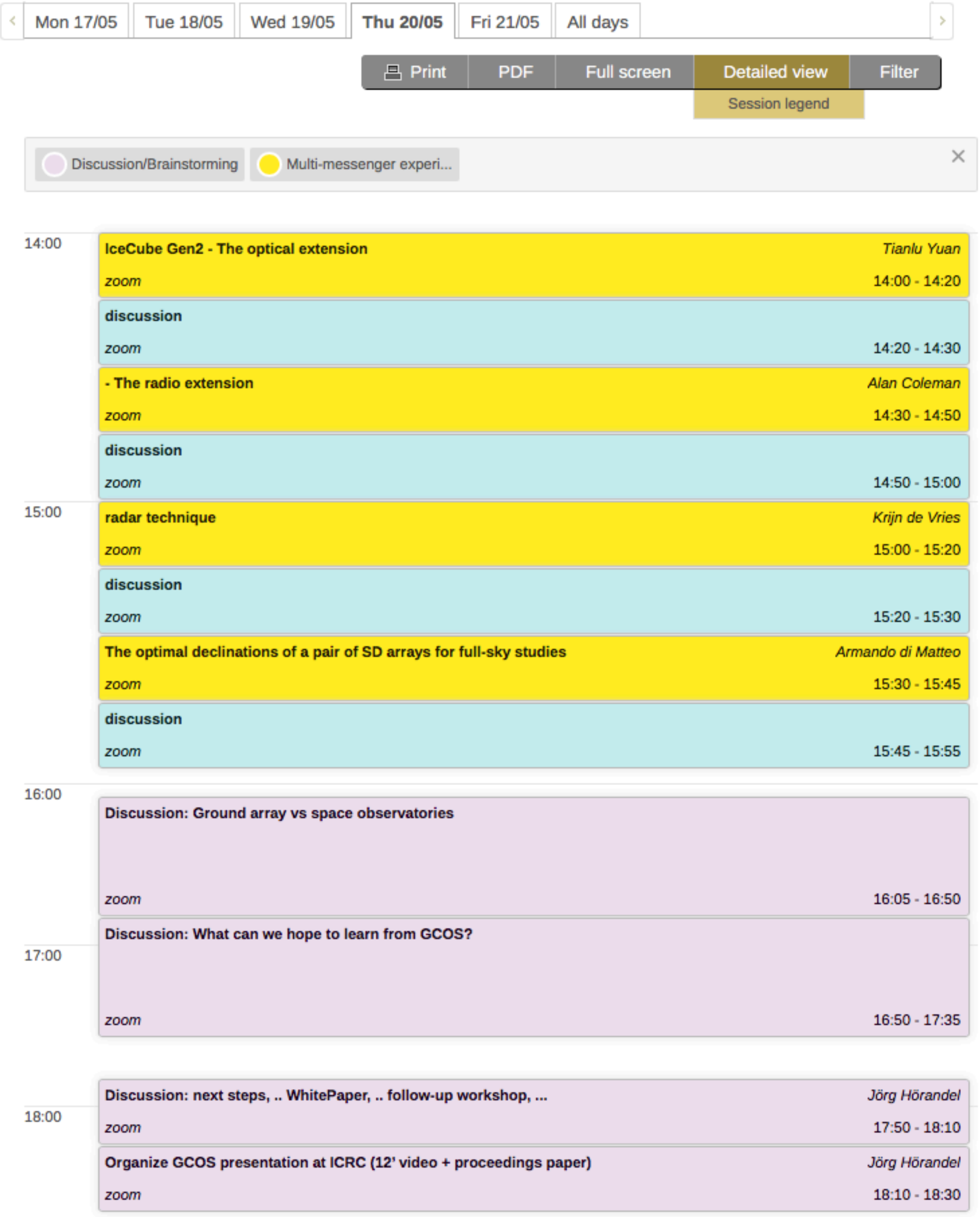
14:00
Discussion UHE physics case – *Rafael Alves Batista* – *zoom* – 14:00 - 15:00

15:00
physics case of space observatories (POEMMA, ...) – *Angela Olinto* – *zoom* – 15:00 - 15:20
discussion – *zoom* – 15:20 - 15:30
GRAND – *Kumiko Kotera* – *zoom* – 15:30 - 15:50
discussion – *zoom* – 15:50 - 16:00

16:00
Fluorescence - FAST – *Toshihiro Fujii* – *zoom* – 16:30 - 16:50
discussion – *zoom* – 16:50 - 17:00

17:00
Segmented tanks – *Ioana Maris* – *zoom* – 17:00 - 17:20
discussion – *zoom* – 17:20 - 17:30
(Auger) Radio technique – *zoom* – 17:30 - 17:50
discussion – *zoom* – 17:50 - 18:00

18:00
Discussion in Japan about future plans for UHECR ground observations – *Yoshiki Tsunesada* – *zoom* – 18:00 - 18:20
discussion – *zoom* – 18:20 - 18:30



14:00
IceCube Gen2 - The optical extension – *Tianlu Yuan* – *zoom* – 14:00 - 14:20
discussion – *zoom* – 14:20 - 14:30
- The radio extension – *Alan Coleman* – *zoom* – 14:30 - 14:50
discussion – *zoom* – 14:50 - 15:00

15:00
radar technique – *Krijn de Vries* – *zoom* – 15:00 - 15:20
discussion – *zoom* – 15:20 - 15:30
The optimal declinations of a pair of SD arrays for full-sky studies – *Armando di Matteo* – *zoom* – 15:30 - 15:45
discussion – *zoom* – 15:45 - 15:55

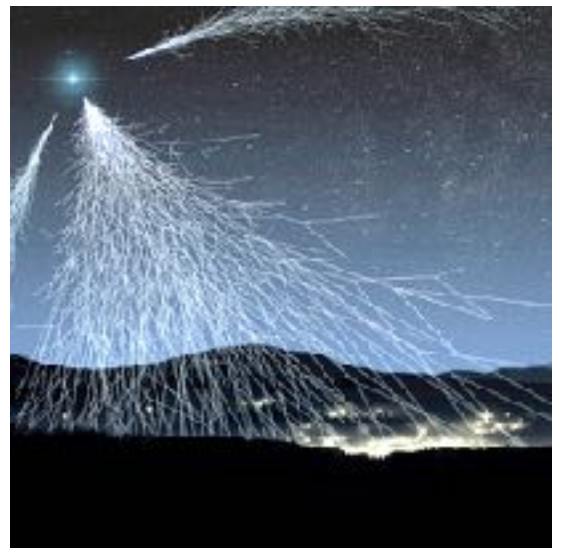
16:00
Discussion: Ground array vs space observatories – *zoom* – 16:05 - 16:50
Discussion: What can we hope to learn from GCOS? – *zoom* – 16:50 - 17:35

17:00

18:00
Discussion: next steps, .. WhitePaper, .. follow-up workshop, ... – *Jörg Hörandel* – *zoom* – 17:50 - 18:10
Organize GCOS presentation at ICRC (12' video + proceedings paper) – *Jörg Hörandel* – *zoom* – 18:10 - 18:30

GCOS - The Global Cosmic Ray Observatory

Brainstorming workshop May 2021



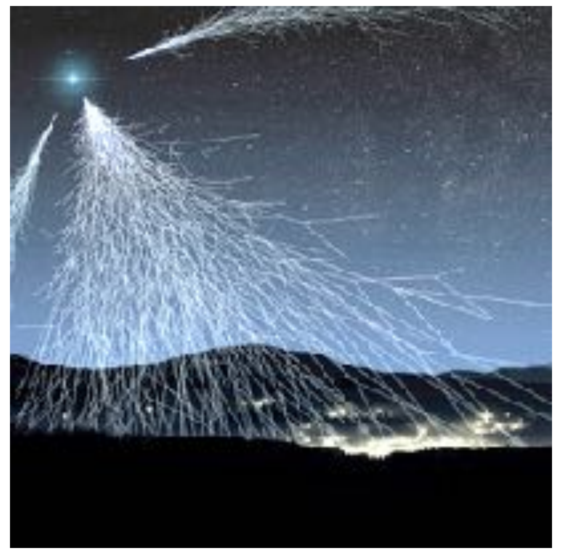
We would like to make the slides available on indico for future reference.

To all presenters:
There are two possibilities to upload your slides.

1. Make an indico account on our system and send me an email. I will assign the correct rights and you can upload the slides yourself.
2. Send me the slides as pdf and I will upload them.

GCOS - The Global Cosmic Ray Observatory

Brainstorming workshop May 2021

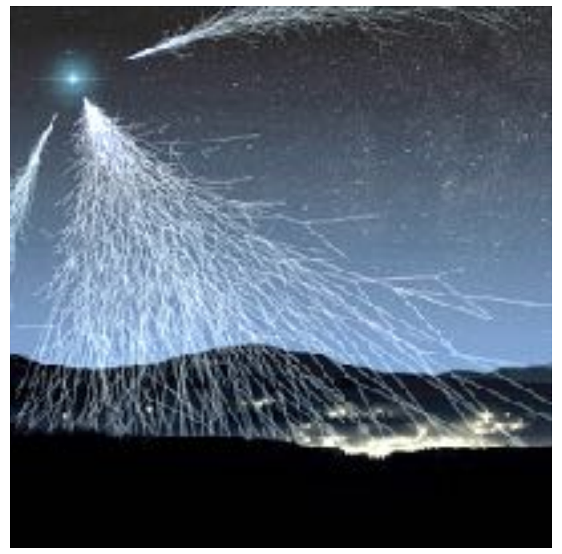


We are many colleagues here in the zoom room.
Please obey the following rules:

1. Please mute your microphone until the chair gives the floor to you.
2. The session chair will handle the Q&A after each talk in their session and keep the time.
3. Please raise your hand to ask a question and wait for the chair to give you the floor.
4. Once the speaker replies to your question, you will be allowed one immediate follow-up to foster the discussion as appropriate. The discussion can continue beyond that if there are no other hands raised.

GCOS - The Global Cosmic Ray Observatory

Brainstorming workshop May 2021



We wish you an interesting workshop with fruitful discussions!

Rafael Alves Batista, Antonella Castellina, Ralph Engel, Toshihiro Fujii,
Jörg R. Hörandel, Charles Jui, Lu Lu, Ioana Maris, Shoichi Ogio,
Takashi Sako, Fred Sarazin