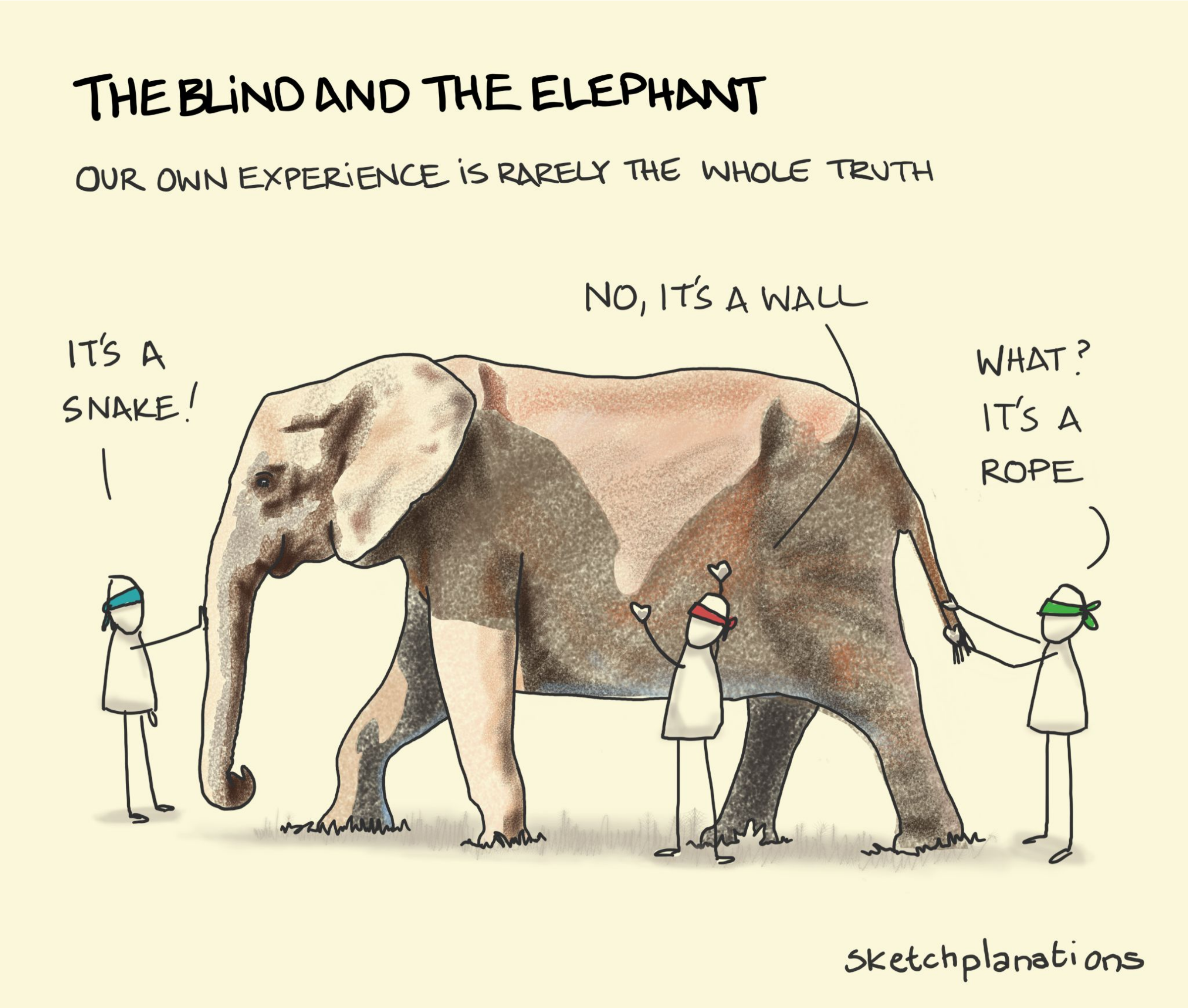
Detektory promieniowania kosmicznego nowej generacji – od pomiarów precyzyjnych do odkryć

Piotr Homola

Instytut Fizyki Jądrowej PAN

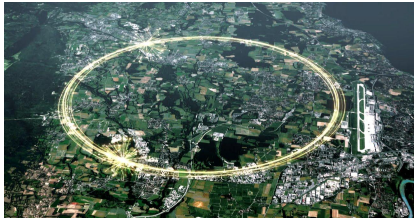
49. Zjazd Fizyków Polskich, Katowice 2025

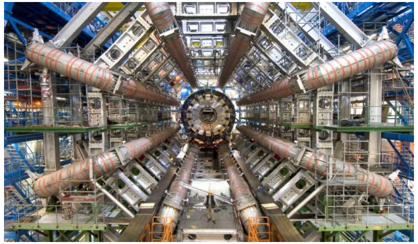

THE BLIND AND THE ELEPHANT
OUR OWN EXPERIENCE IS RARELY THE WHOLE TRUTH
IT'S A SNAKE!
NO, IT'S A WALL
WHAT? IT'S A ROPE
sketchplanations

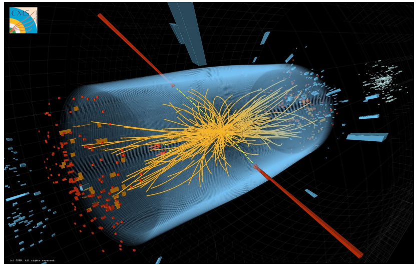
Zrozumieć Wszechświat przez cząstki

produkcja → przyspieszanie → interakcja → zespół cząstek → wnioski

Laboratoryjne
przyśpieszacze i zderzacze







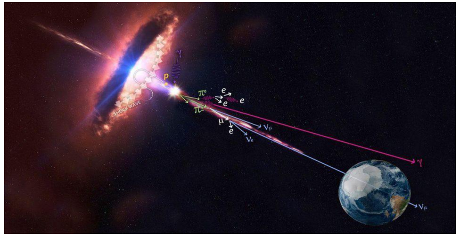
Koszt:
~100 mld $ ~0 $

Energie
<= 10^{12} eV <= 10^{20} eV

Dostępność:
zamożne kraje kto chce

Liczba zdarzeń:
ogromna mała

Kosmos jako
przyśpieszacz i zderzacz



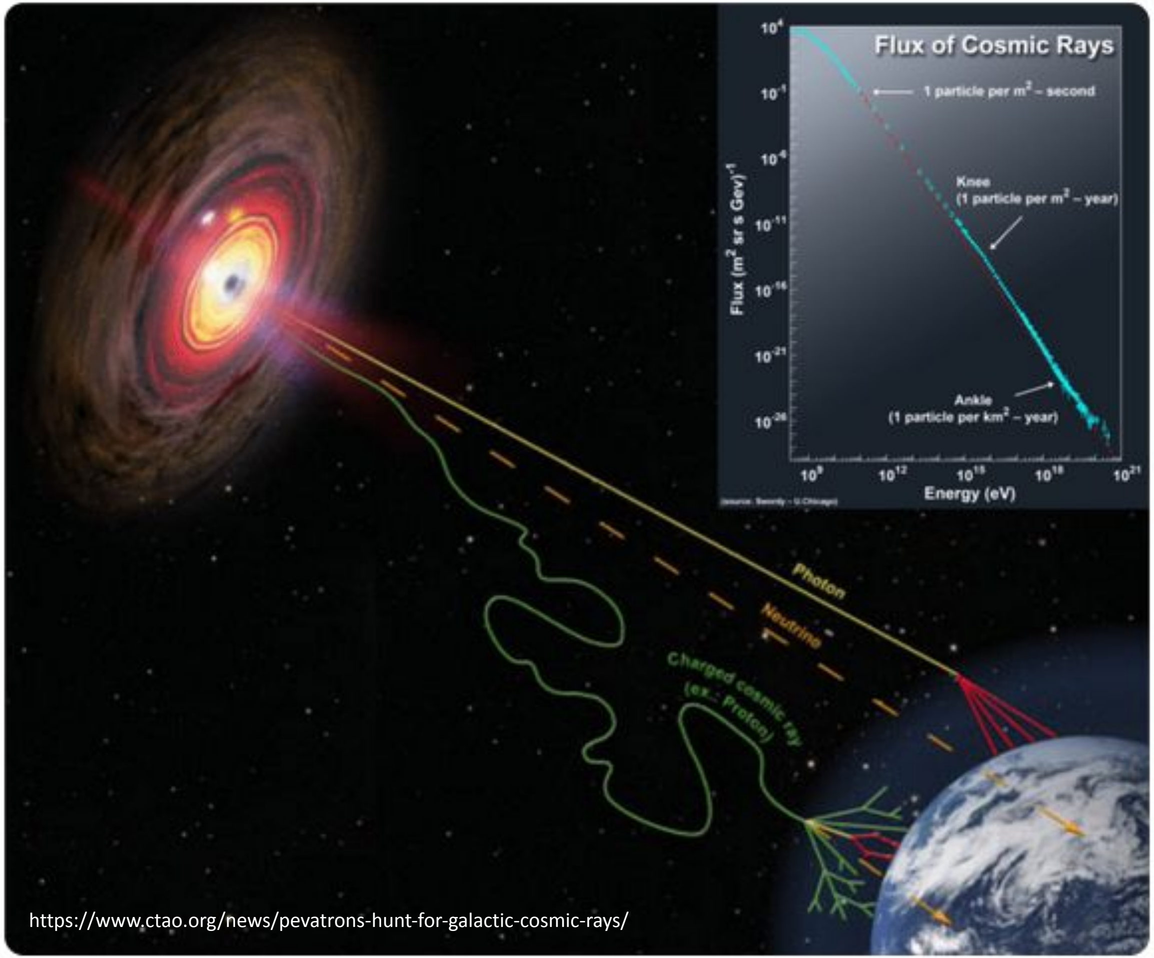


Figure 1: The origin of cosmic rays is explored with neutral messengers, such as gamma rays. The inset shows the cosmic-ray energy spectrum observed from Earth with the main spectral features. Credit: HAP/A. Chantelauze

Cosmic Ray Physics:
astrophysical sources
+ particle interactions

The strategies

The "Snowmass process" (2021-2022) -> community input to provide recommendations to the [Particle Physics Project Prioritization Panel (P5)]() -> strategy for U.S. particle physics, including astrophysics (2023)

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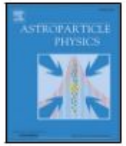
journal homepage: www.elsevier.com/locate/astropartphys



Check for updates

Ultra high energy cosmic rays
The intersection of the Cosmic and Energy Frontiers☆

A. Coleman [1,a], J. Eser [2,a], E. Mayotte [3,a], F. Sarazin [3,a,*], F.G. Schröder [1,4,a,*], D. Soldin [1,5,a], T.M. Venters [6,a,*], R. Aloisio [7,b], J. Alvarez-Muñiz [8,b], R. Alves Batista [9,b], D. Bergman [10,b], M. Bertaina [11,b], L. Caccianiga [12,b], O. Deligny [13,b], H.P. Dembinski [14,b], P.B. Denton [15,b], A. di Matteo [16,b], N. Globus [17,18,b], J. Glombitza [19,b], G. Golup [20,b], A. Haungs [4,b], J.R. Hörandel [21,b], T.R. Jaffe [22,b], J.L. Kelley [23,b], J.F. Krizmanic [6,b], L. Lu [23,b], J.N. Matthews [10,b], I. Mariş [24,b], R. Mussa [16,b], F. Oikonomou [25,b], T. Pierog [4,b], E. Santos [26,b], P. Tinyakov [24,b], Y. Tsunesada [27,28,b], M. Unger [4,b], A. Yushkov [26,b], M.G. Albrow [29,c], L.A. Anchordoqui [30,c], K. Andeen [31,c], E. Arnone [11,16,c], D. Barghini [11,16,c], E. Bechtol [23,c], J.A. Bellido [32,c], M. Casolino [33,34,c], A. Castellina [16,35,c], L. Cazon [8,c], R. Conceição [36,c], R. Cremonini [37,c], H. Dujmovic [4,c], R. Engel [4,5,c], G. Farrar [38,c], F. Fenu [11,16,c], S. Ferrarese [11,c], T. Fujii [39,c], D. Gardiol [16,35,c], M. Gritsevich [40,41,c], P. Homola [42,c], T. Huege [4,43,c], K.-H. Kampert [44,c], D. Kang [4,c], E. Kido [45,c], P. Klimov [46,c], K. Kotera [43,47,c], B. Kozelov [48,c], A. Leszczyńska [1,5,c], J. Madsen [23,c], L. Marcelli [34,c], M. Marisaldi [49,c], O. Martineau-Huynh [50,c], S. Mayotte [3,c], K. Mulrey [21,c], K. Murase [51,52,c], M.S. Muzio [51,c], S. Ogio [28,c], A.V. Olinto [2,c], Y. Onel [53,c], T. Paul [30,c], L. Piotrowski [54,c], M. Plum [55,c], B. Pont [21,c], M. Reininghaus [4,c], B. Riedel [23,c], F. Riehn [36,c], M. Roth [4,c], T. Sako [56,c], F. Schlüter [4,57,c], D.H. Shoemaker [58,c], J. Sidhu [59,c], I. Sidelnik [20,c], C. Timmermans [21,60,c], O. Tkachenko [4,c], D. Veberic [4,c], S. Verpoest [61,c], V. Verzi [34,c], J. Vícha [26,c], D. Winn [53,c], E. Zas [8,c], M. Zotov [46,c]

[DOI: https://doi.org/10.1016/j.astropartphys.2022.102794]()

The APPEC strategy: the Astroparticle Physics European Consortium's strategic roadmap for the future of astroparticle physics research in Europe, which establishes priority research directions and encourages coordination and collaboration

Now being created:
the strategy for 2027-2036
- open for discussions!

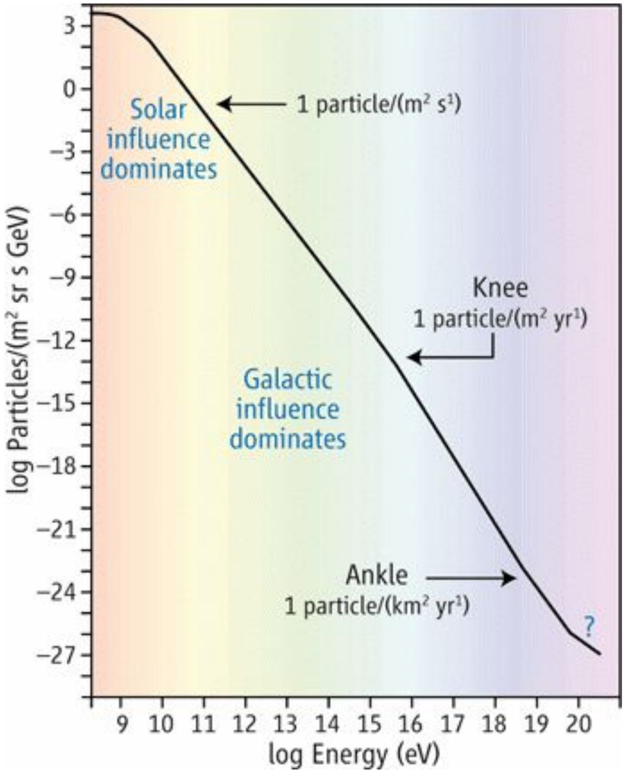
Promienie kosmiczne!

Ranges:
energy: > 10 orders of magnitude
flux: > 30 orders of magnitude
→ diverse physics (sources)
→ diverse detection techniques

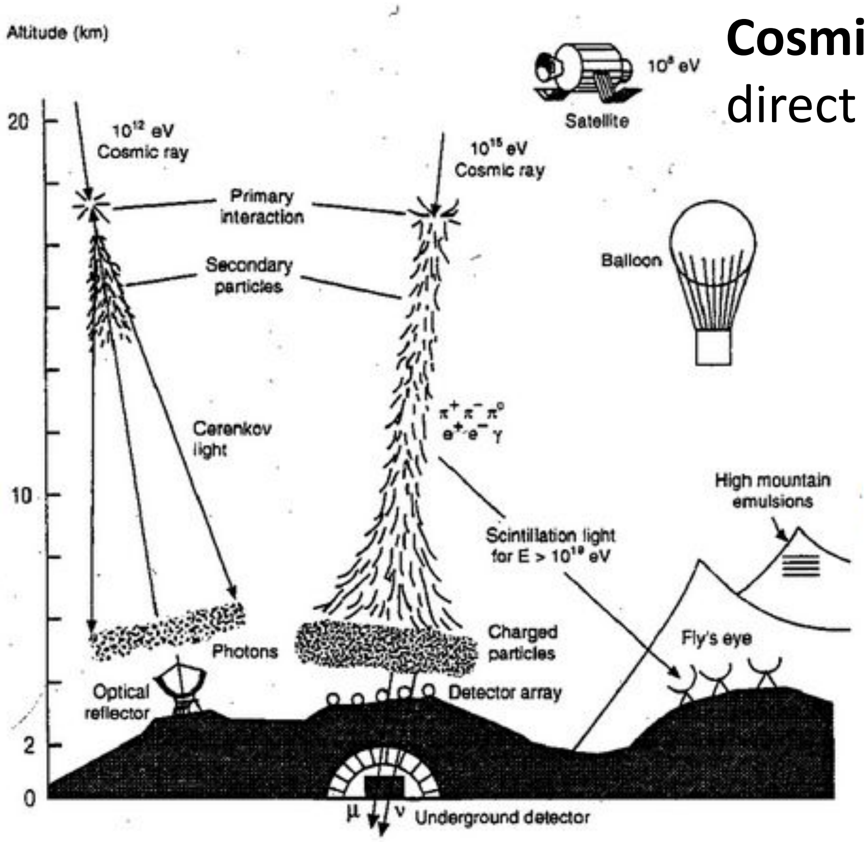
Flux rapidly decreases with energy (~10^{-3}),
Highest energies → the most demanding challenges:

→ technical:
extremely low flux (at $E=10^{20}$eV
1 particle / km^2 / millenium), but now:
the Pierre Auger Observatory (~3000 km^2)

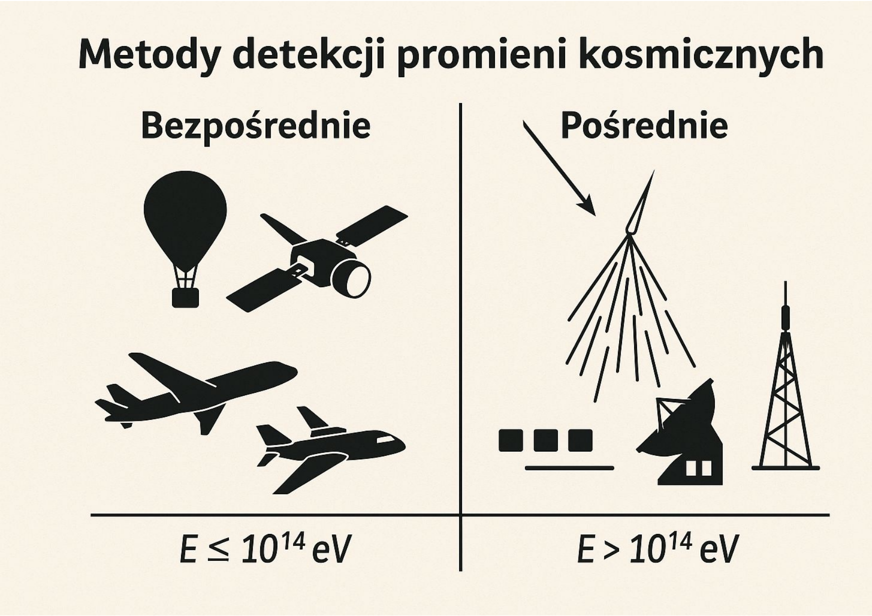
→ scientific:
What are Ultra-High Energy Cosmic Rays (UHECR)?
Where they come from?
How do they propagate?
Do we (have a chance to) see UHE photons?



Cosmic ray detection:
direct (small energies) vs. indirect (high energies)



Hadron flux:	1 particle/m²/s	@ TeV	10^{12} eV
	1 particle/m²/day	@ PeV	10^{15} eV
	1 particle/km²/day	@ EeV	10^{18} eV
	1 particle/km²/century	@	10^{20} eV



graphics credit: ChatGPT

[left] Spiro, M., Aubourg, É., & Palanque-Delabrouille, N. (2000). Review on experimental particle astrophysics. *Surveys in High Energy Physics*, *15*(1–3), 1–36. https://doi.org/10.1080/01422410008229138

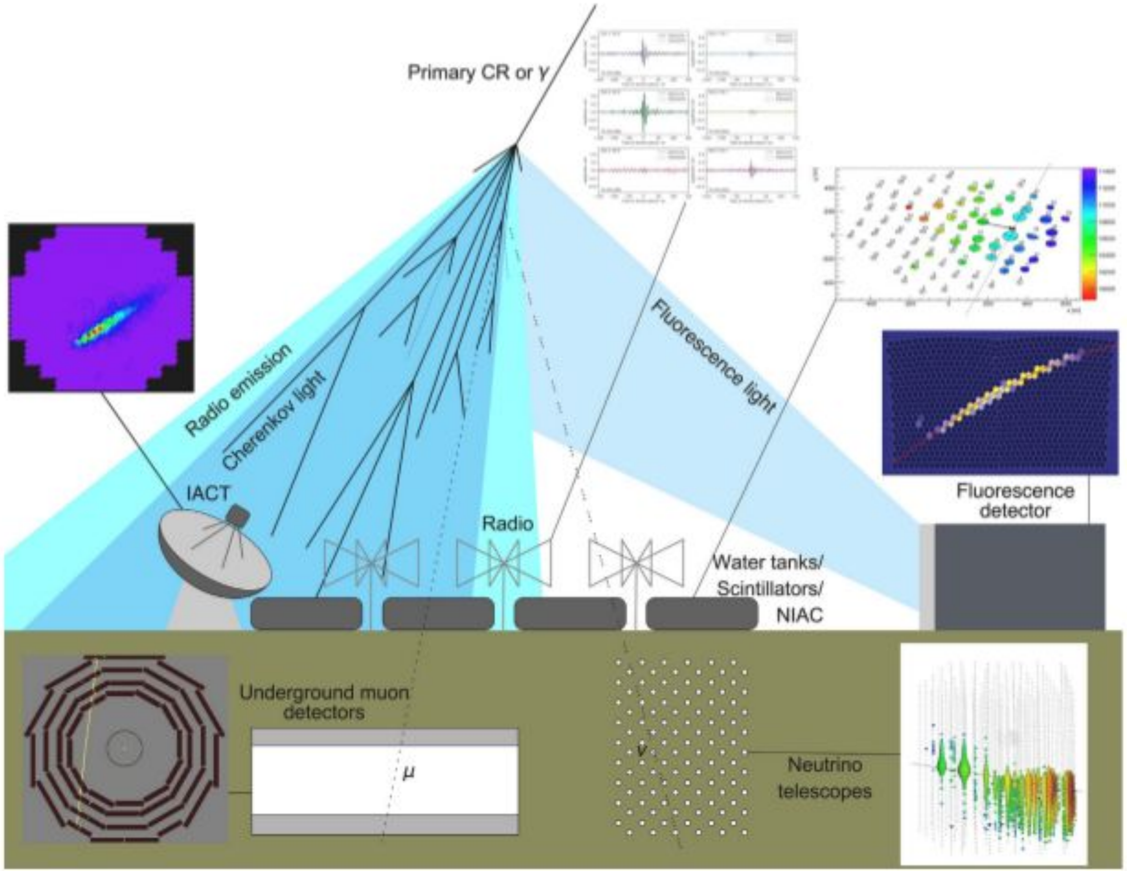


Fig. 57. Schematic of indirect CR detection methods for EAS. Surface and underground particle detectors measure electromagnetic particles and muons. Imaging (IACT) and non-imaging (NIAC) air-Cherenkov detectors as well as radio antennas provide a measurement of the electromagnetic shower component when located in the footprint of the shower, while fluorescence light detectors can observe the shower development from the side.
Source: Pictures from Refs. [106,777–781].

indirect cosmic ray detection methods: extensive air showers as **individual events**

The UHECR landscape

UHECR:
Ultra High Energy
Cosmic Rays:
E > ~10^{18} eV

E_{record} = 3.2 x 10^{20} eV
(Fly's Eye, 1991)

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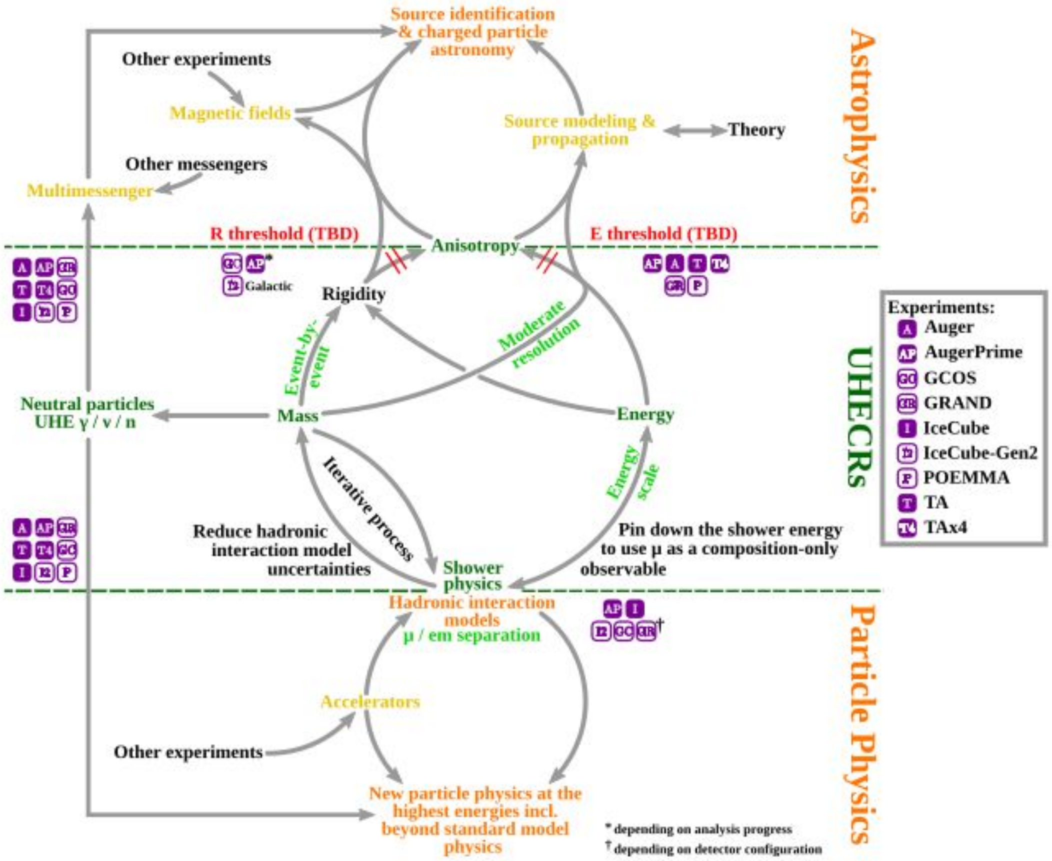
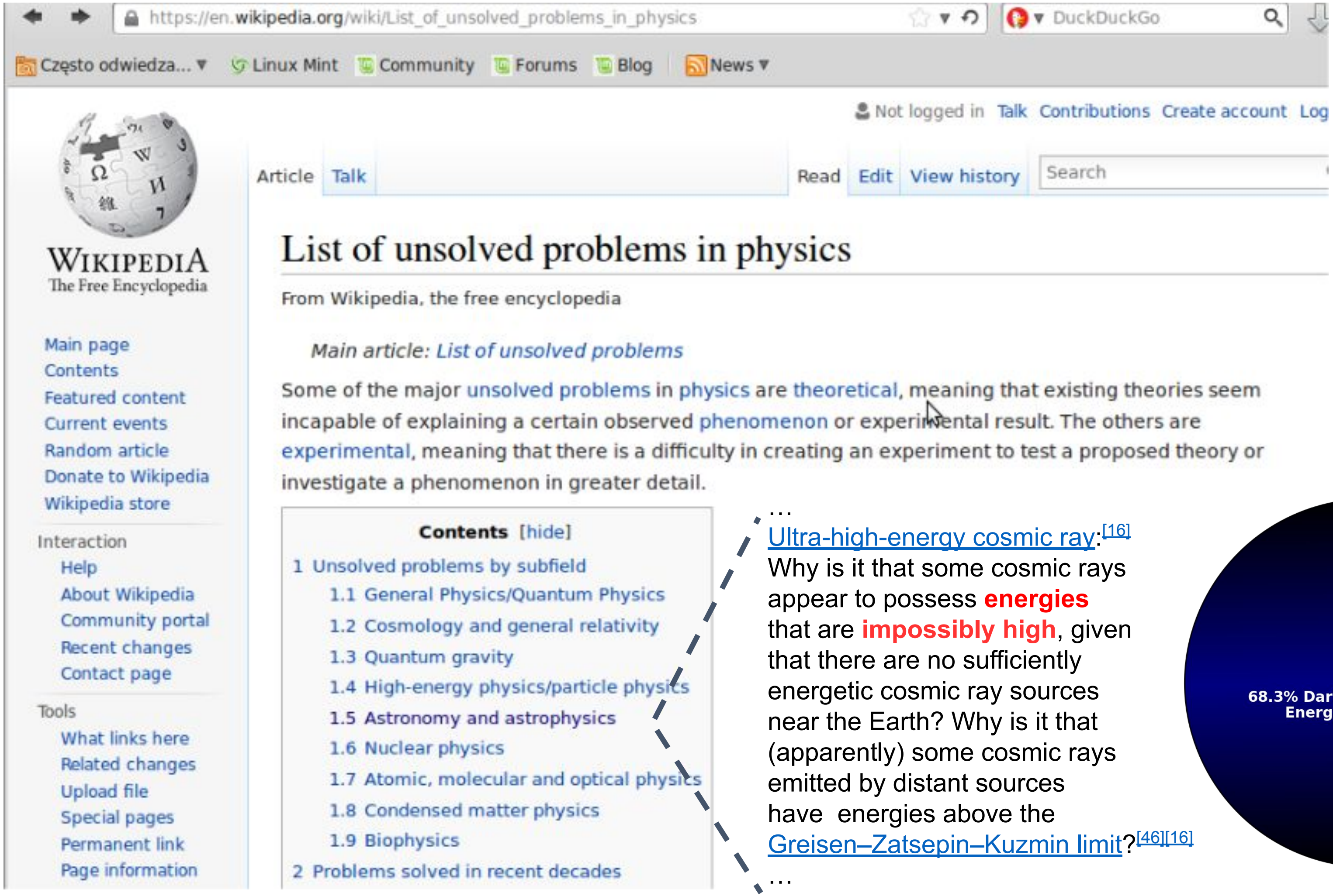


Fig. 1. Diagram summarizing the strong connections of UHECRs with particle physics and astrophysics, the fundamental objectives of the field (in orange) for the next two decades, and the complementarity of current and next-generation experiments in addressing them.


https://en.wikipedia.org/wiki/List_of_unsolved_problems_in_physics

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List of unsolved problems in physics

From Wikipedia, the free encyclopedia

Main article: List of unsolved problems

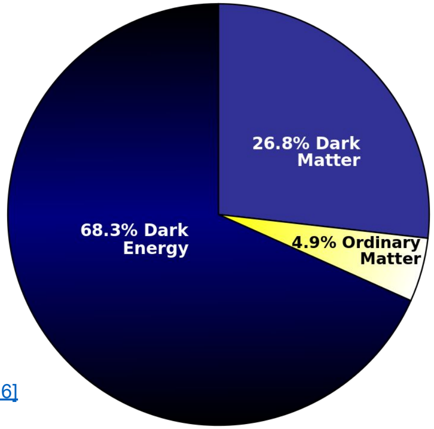
Some of the major unsolved problems in physics are theoretical, meaning that existing theories seem incapable of explaining a certain observed phenomenon or experimental result. The others are experimental, meaning that there is a difficulty in creating an experiment to test a proposed theory or investigate a phenomenon in greater detail.

Contents [hide]

…

Ultra-high-energy cosmic ray:[16]
Why is it that some cosmic rays appear to possess **energies** that are **impossibly high**, given that there are no sufficiently energetic cosmic ray sources near the Earth? Why is it that (apparently) some cosmic rays emitted by distant sources have energies above the Greisen–Zatsepin–Kuzmin limit?[46][16]

…



The mystery of ultra-high energy cosmic rays (UHECR)

from: https://www.auger.org/outreach/cosmic-rays/cosmic-ray-mystery

Cosmologists, who study the structure and dynamics of the universe, offer another possible explanation for the mysterious source of the **highest-energy cosmic rays**. Cosmologists postulate a universe filled with relics left over from the Big Bang icon info - hypothetical objects, called topological defects, with names like "cosmic strings," "**domain walls**," and "monopoles." Although these strange objects figure prominently in theories of the evolution of the universe, we have no experimental evidence to show that they really exist. However, if they did exist, and if they sometimes collapsed, their collapse could produce enough energy to create very high-energy cosmic rays. If we could make the connection between high-energy cosmic rays and the collapse of topological defects, it would provide experimental evidence for these topological defects and a great step forward in understanding the early universe.

UHECR <-> collapse of topological defects ???

The tension in the UHECR energy spectrum

From: Deligny, O.; for the Pierre Auger and Telescope Array Collaborations. The energy spectrum of ultra-high energy cosmic rays measured at the Pierre Auger Observatory and at the Telescope Array. *PoS* **2020**, *ICRC2019*, 234.

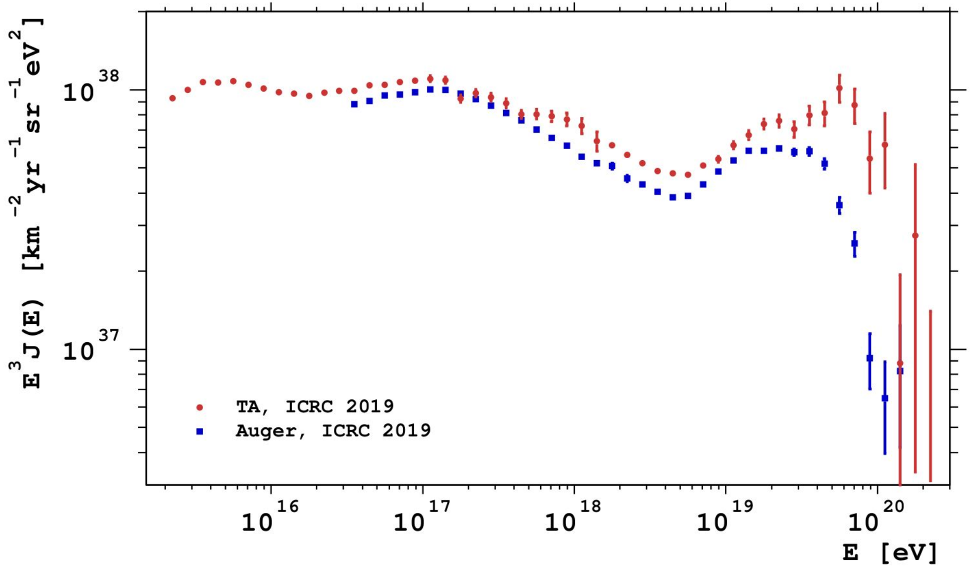
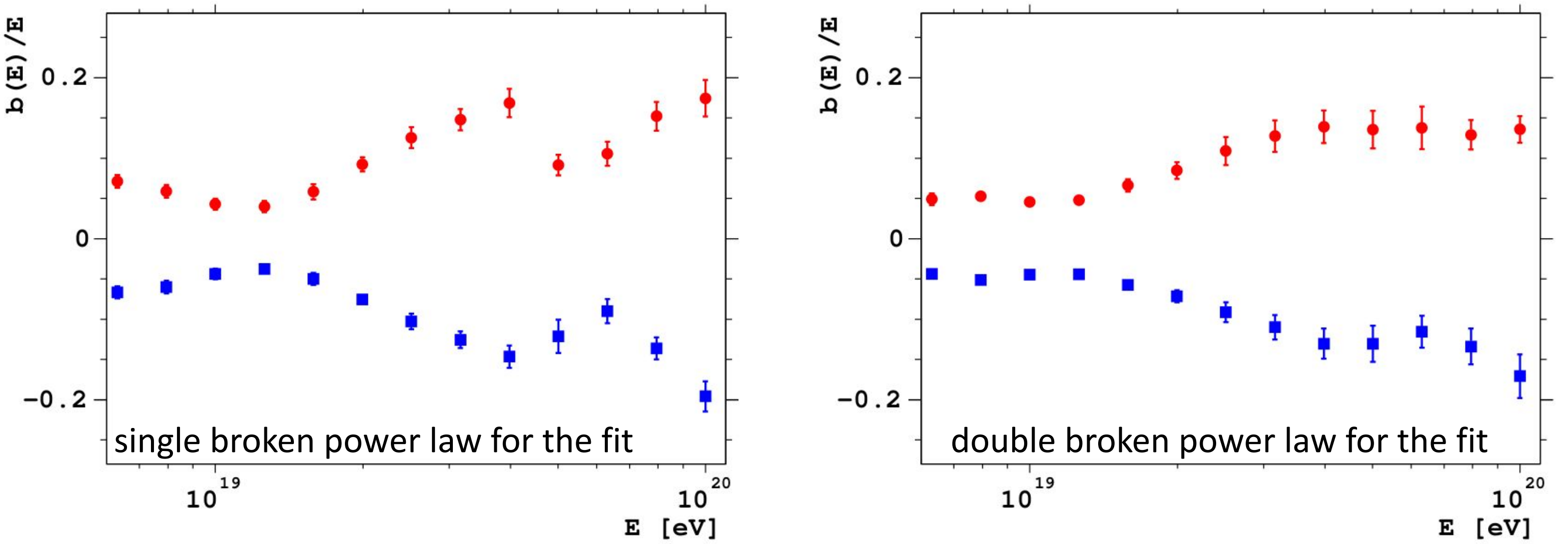


Figure 1: ICRC 2019 energy spectra of the Pierre Auger Observatory and the Telescope Array scaled by E^3. In each experiment, data of different detection techniques are combined to obtain the spectrum over a wide energy range.

The tension: energy dependent reconciliation

Energy shift term needed to bring the fitted differential spectra in agreement, common declination ranges.



"On top of a global rescaling of energies, a **non-linearity is needed** to bring spectra in agreement in the **range of common declinations** … The **sources** of the non-linearity **have not been identified**, yet."

From: Deligny, O.; for the Pierre Auger and Telescope Array Collaborations. The energy spectrum of ultra-high energy cosmic rays measured at the Pierre Auger Observatory and at the Telescope Array. *PoS* **2020**, *ICRC2019*, 234.

Ideas: technology, mistakes, or physics?

14

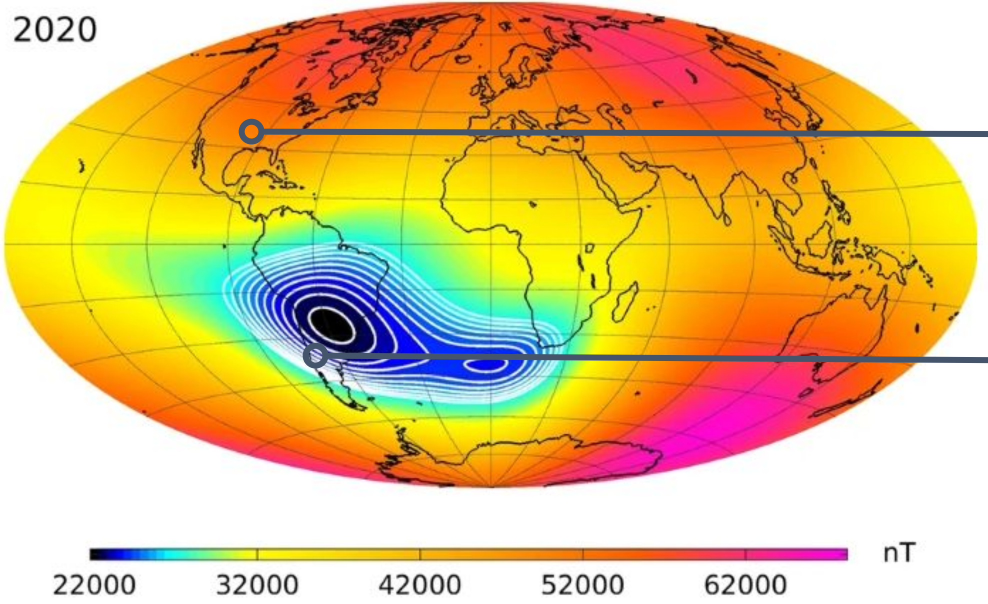


Image by Christopher C. Finlay, Clemens Kloss, Nils Olsen, Magnus D. Hammer, Lars Tøffner-Clausen, Alexander Grayver; Alexey Kuvshinov - The CHAOS-7 geomagnetic field model and observed changes in the South Atlantic Anomaly, Earth, Planets and Space, Volume 72, Article number 156 (2020), https://earth-planets-space.springeropen.com/articles/10.1186/s40623-020-01252-9, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=99760567

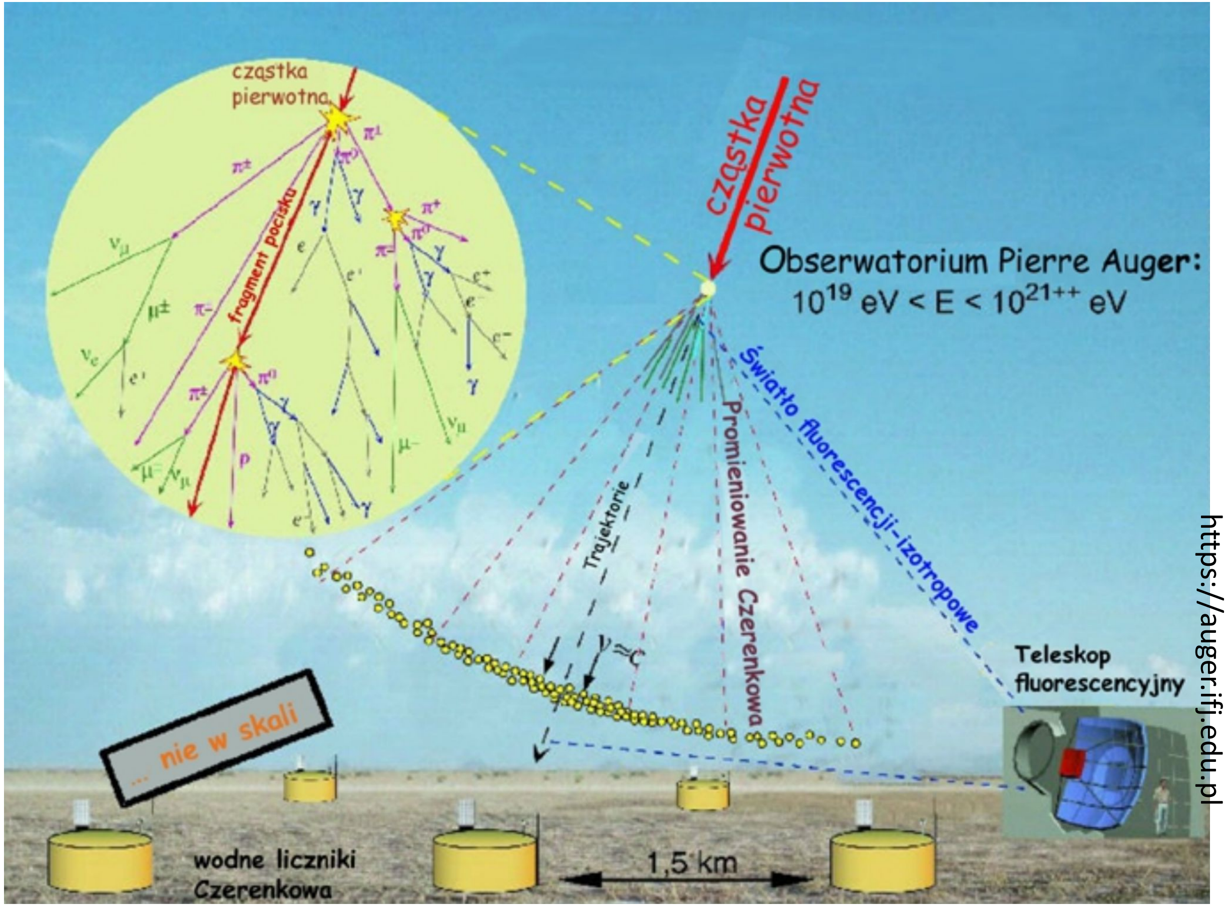
If physics:

Telescope Array:
$|\vec{B}| \sim 55\,\mu T$

Pierre Auger Observatory:
$|\vec{B}| \sim 25\,\mu T$

Factor ~2 difference in the strength of the geomagnetic field

Wielkie pęki atmosferyczne jako pojedyncze zdarzenia



źródło: https://auger.ifj.edu.pl

The AugerPrime upgrade of the Pierre Auger Observatory: 24/7 event-by-event mass sensitivity

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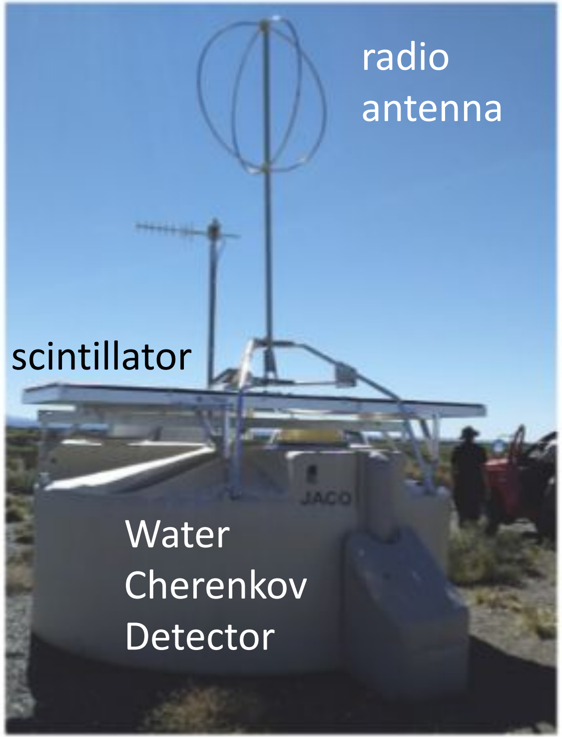
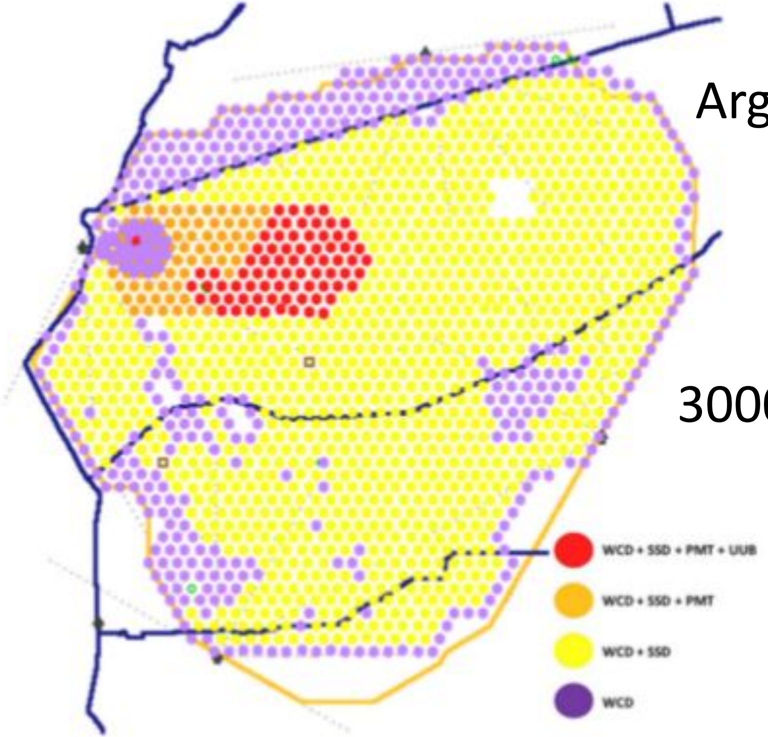
znaczący wkład IFJ PAN





Argentina

3000 km^2

Fig. 42. Left: one of the AugerPrime SD stations. From top to bottom, the RD antenna, communication antenna, scintillation detector, and water-Cherenkov detector can be seen. Right: deployment status of the AugerPrime SD array as of June 10, 2021 (see the text for details).

in operation until > 2032

The Global Cosmic Ray Observatory (GCOS)

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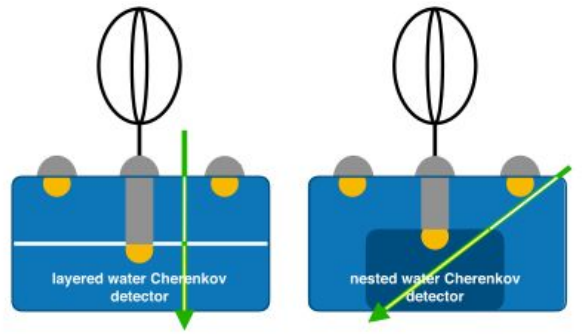
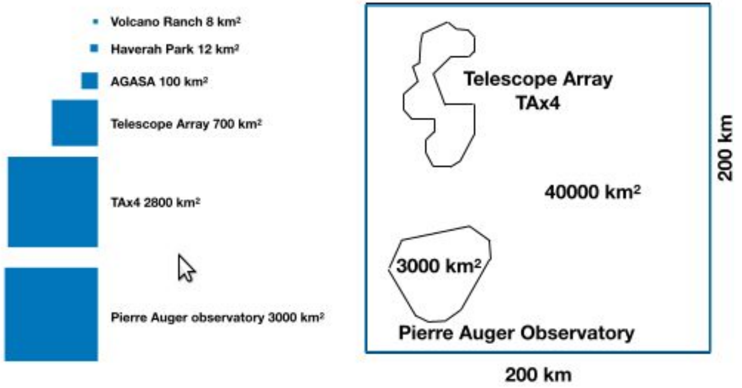


Fig. 77. Detection concepts, using a layered (left) and a nested (right) water Cherenkov detector with a radio antenna on top.



accuracy for ultra-high-energy cosmic rays

-> radio + Water Cherenkov Detectors; 40 000 km^2 at least two locations

multi-site Giant Radio Array for Neutrino Detection (GRAND)

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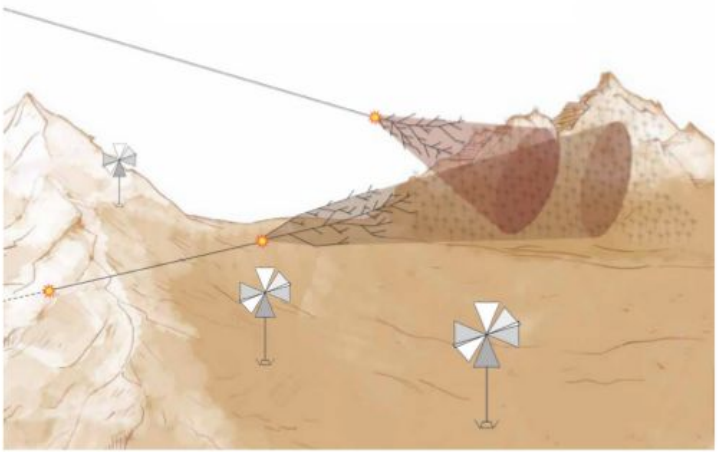

Fig. 74. A schematic of the GRAND design [26]. Arrays of radio antennae on the side of mountains can detect inclined extensive air showers from Earth-skimming and mountain passing tau neutrinos (lower trajectory) and inclined UHECR events (higher trajectory).

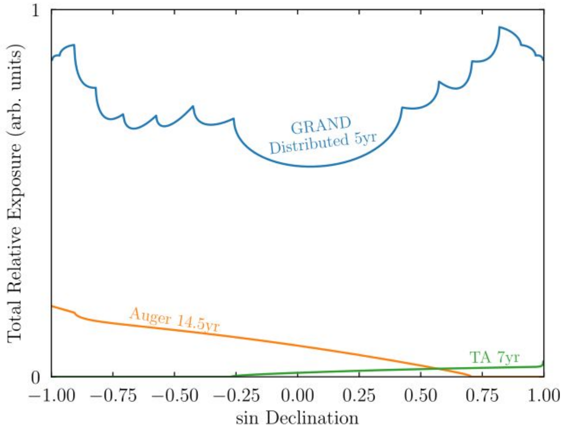

Fig. 75. The relative integrated exposure as a function of declination for Auger, TA, and a distributed GRAND array [906].

“highest exposure from ground by a huge distributed array”

10-20 sites x 10 000 - 20 000 km^2 -> **up to 400 000 km^2**

Probe of MultiMessenger Astrophysics (POEMMA)

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"highest exposure enabled from space"

1 000 000 km^2

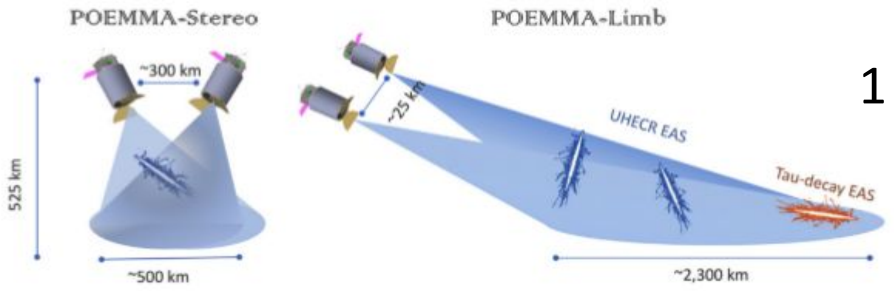


Fig. 68. The POEMMA science modes. Left: POEMMA-Stereo where the spacecraft are separated and viewing a common atmospheric volume to measure the fluorescence emission from EAS. Right: POEMMA-Limb where the instruments are tilted to view near and below the limb of the Earth for optical Cherenkov light from upward-moving EAS induced by tau neutrino events in the Earth.
Source: From Ref. [25].

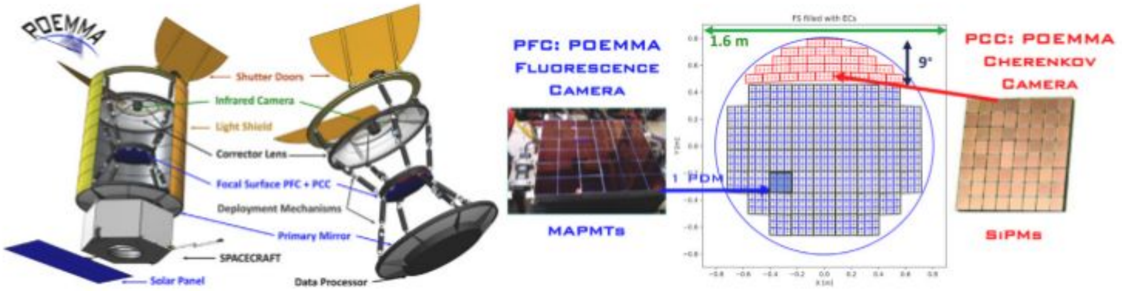
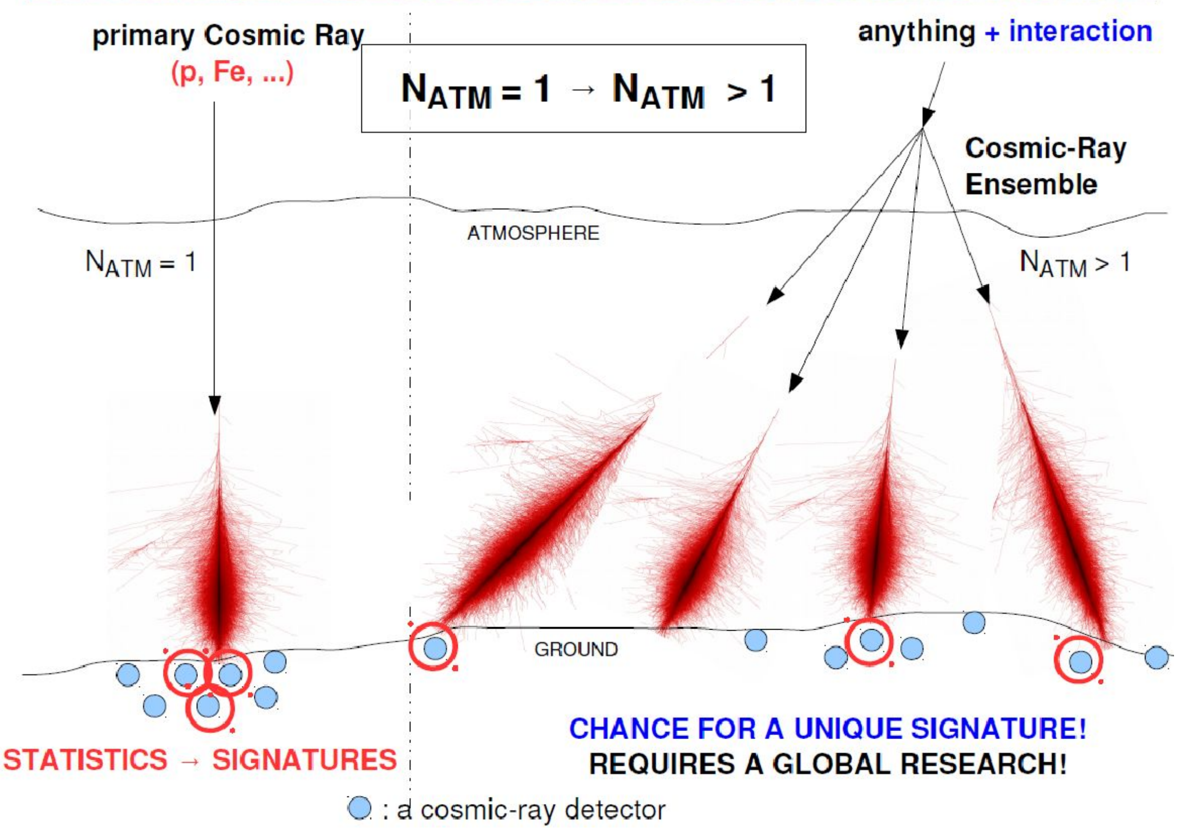


Fig. 69. Left: Schematics of a POEMMA satellite and the Schmidt telescope consisting of a 4-m diameter primary mirror, 3.3-m diameter corrector plate, and 1.6-m diameter focal surface comprised of 126,720 pixels in the PFC and 15,360 pixels in the PCC Several components are detailed in the schematic including infrared cameras which will measure cloud cover within the 45° full FoV of each telescope during science observations. Right: The layout of the hybrid focal plane of a POEMMA Schmidt telescope. The majority of the area is comprised of PFC MAPMT modules with a UV filter to record the 300-–500 nm air fluorescence light in 1 μs snapshots. The PCC is comprised of SiPM pixels whose 300-–1000 nm wavelength response is well-matched to that from the EAS optical Cherenkov signals and are recorded with 10 ns cadence.
Source: From Ref. [25].

Out of the box?

Wielkoskalowe korelacje w promieniowaniu kosmicznym: **zespoły promieni kosmicznych** (Cosmic Ray Ensembles)



$N_{ATM} > 1$ motivated by data! (1)

VOLUME 50, NUMBER 26 PHYSICAL REVIEW LETTERS 27 JUNE 1983

Possible Observation of a Burst of Cosmic-Ray Events in the Form of Extensive Air Showers

Gary R. Smith, M. Ogmen, E. Buller, and S. Standil
Physics Department, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

(Received 7 April 1983)

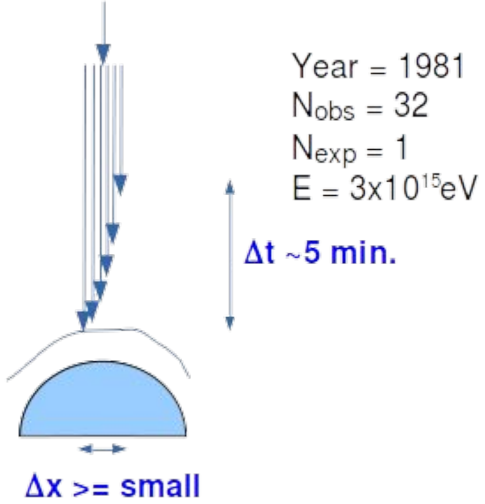
A series or burst of 32 extensive air showers of estimated primary energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9:55 A.M. (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in a period of 18 months between October 1980 and April 1982.

PACS numbers: 94.40.Pa, 96.40.Re, 95.30.-k

Forgotten (!) treasure (?) no. 1

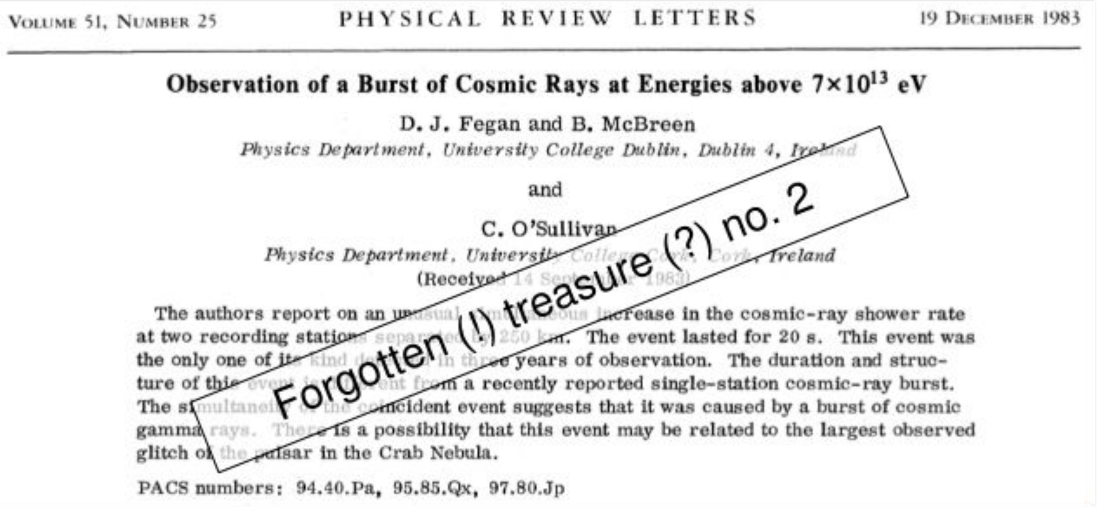
PH: Correlated cosmic rays?

$N_{ATM} > 1$?



-> "Pay attention to data"!

$N_{ATM} > 1$ motivated by data! (2)


VOLUME 51, NUMBER 25 PHYSICAL REVIEW LETTERS 19 DECEMBER 1983

Observation of a Burst of Cosmic Rays at Energies above 7×10^{13} eV

D. J. Fegan and B. McBreen
Physics Department, University College Dublin, Dublin 4, Ireland

and

C. O'Sullivan
Physics Department, University College Cork, Cork, Ireland
(Received 14 September 1983)

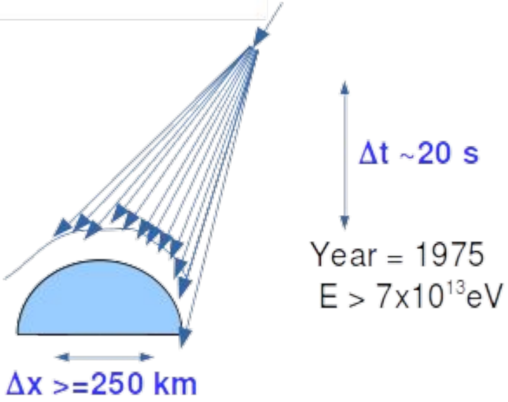
The authors report on an unusual simultaneous increase in the cosmic-ray shower rate at two recording stations separated by 250 km. The event lasted for 20 s. This event was the only one of its kind detected in three years of observation. The duration and structure of this event is different from a recently reported single-station cosmic-ray burst. The simultaneity of the coincident event suggests that it was caused by a burst of cosmic gamma rays. There is a possibility that this event may be related to the largest observed glitch of the pulsar in the Crab Nebula.

PACS numbers: 94.40.Pa, 95.85.Qx, 97.80.Jp

Forgotten (!) treasure (?) no. 2

PH: Correlated cosmic rays?

$N_{ATM} > 1$?



-> "Pay attention to data"!

symmetry

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A Search for Cosmic Ray Bursts at 0.1 PeV with a Small Air Shower Array

by Roger Clay [1,*], Jassimar Singh [1], Piotr Homola [2], Olaf Bar [3], Dmitry Beznosko [4], Apoorva Bhatt [2], Gopal Bhatta [5], Łukasz Bibrzycki [3], Nikolay Budnev [6], David E. Alvarez-Castillo [2,7], Niraj Dhital [8], Alan R. Duffy [9], Michał Frontczak [3], Dariusz Góra [2], Alok C. Gupta [10], Bartosz Łozowski [11], Mikhail V. Medvedev [12,13], Justyna Mędrala [14], Justyna Miszczyk [2], Michał Niedźwiecki [15], Marcin Piekarczyk [3], Krzysztof Rzecki [14], Jilberto Zamora-Saa [16], Katarzyna Smelcerz [15], Karel Smolek [17], Tomasz Sośnicki [14], Jaroslaw Stasielak [2], Sławomir Stuglik [2], Oleksandr Sushchov [2], Arman Tursunov [18] and Tadeusz Wibig [19] – Hide full author list

1 School of Physical Sciences, University of Adelaide, North Terrace, Adelaide 5005, Australia
2 Institute of Nuclear Physics Polish Academy of Sciences, 31-342 Krakow, Poland
3 Institute of Computer Science, Pedagogical University of Krakow, 30-084 Krakow, Poland
4 Department of Chemistry and Physics, Clayton State University, Morrow, GA 30260, USA
5 Astronomical Observatory, Jagiellonian University, 30-244 Krakow, Poland
6 Faculty of Physics, Irkutsk State University, 664003 Irkutsk, Russia
7 Joint Institute for Nuclear Research, Joliot-Curie Street 6, 141980 Dubna, Russia
8 Central Department of Physics, Tribhuvan University, Kirtipur 44613, Nepal
9 Centre for Astrophysics and Supercomputing, Swinburne University of Technology, Melbourne 3122, Australia
10 Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital 263001, India

+ Show full affiliation list

* Author to whom correspondence should be addressed.

Academic Editor: Davide Pagano

Symmetry **2022**, *14*(3), 501; https://doi.org/10.3390/sym14030501

Received: 28 January 2022 / Revised: 14 February 2022 / Accepted: 25 February 2022 / Published: 1 March 2022

- **4 bursts, total chance probability: 4σ**
- **additional properties:**
  - **clustering directions in 3 bursts**
  - **increasing time between events in bursts**

and: R. Clay, J. Singh, for the CREDO Collaboration, PoS(ICRC2021)298, https://pos.sissa.it/395/298/pdf;

The search for air shower clusters: Adelaide

R. Clay, J. Singh, for the CREDO Collaboration, PoS(ICRC2021)298, https://pos.sissa.it/395/298/pdf
(a conference report at the 37th International Cosmic Ray Conference 2021)

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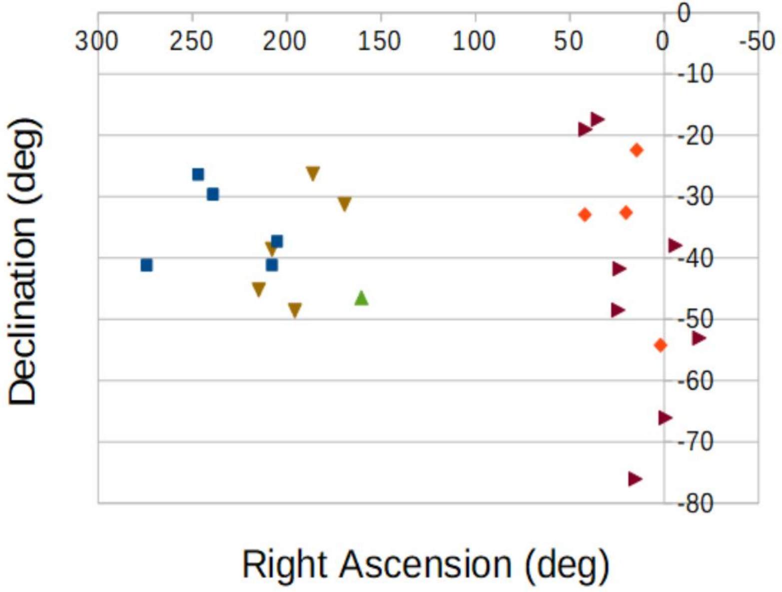


Figure 6. Scatter diagram of burst event arrival directions from five bursts.

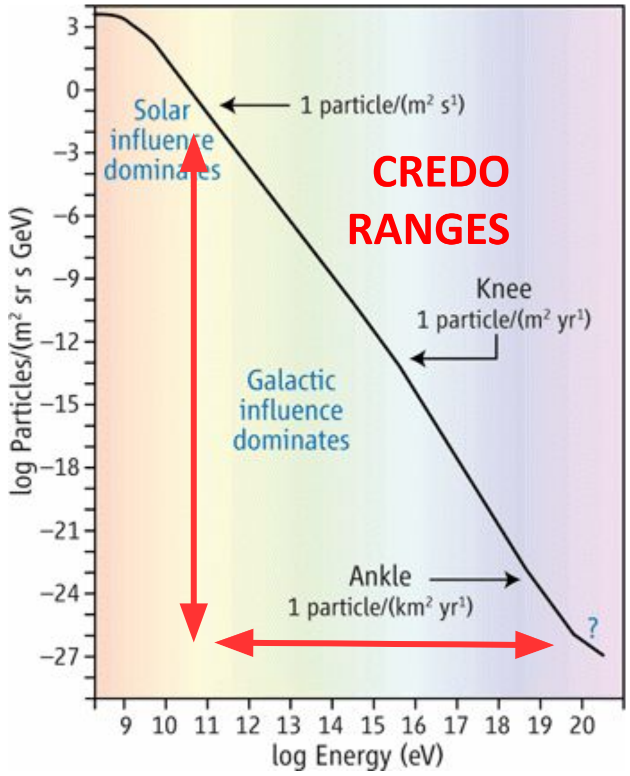
Purple: 2019/07/19 Green: 2019/06/18

Blue: 2017/10/29 Red: 2017/10/10

Brown: 2017/10/08

Ultimate statistical significance? Work in progress!

Cosmic Ray Ensembles (CRE)! Full energy spectrum!

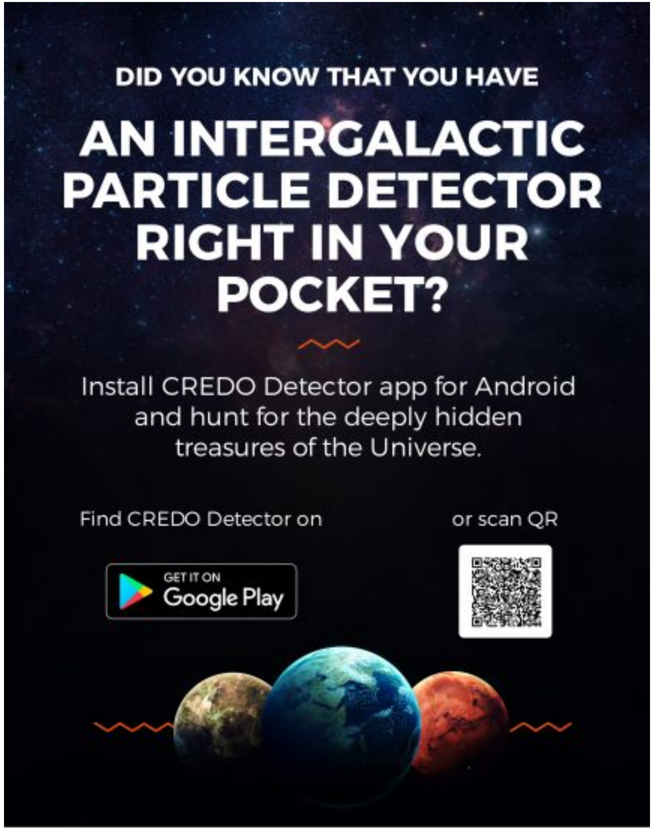


CREDO
THE QUEST FOR THE UNEXPECTED

->

Cosmic Ray Extremely Distributed Observatory

Novel global concept: **cloud of clouds**

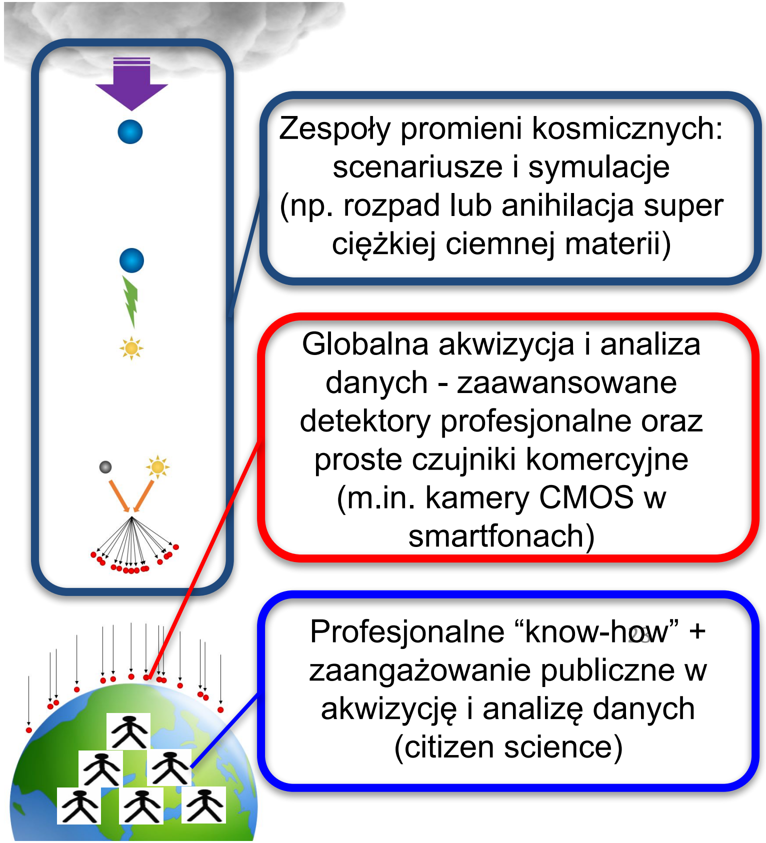


Cosmic Ray Extremely Distributed Observatory

CREDO
THE QUEST FOR THE UNEXPECTED

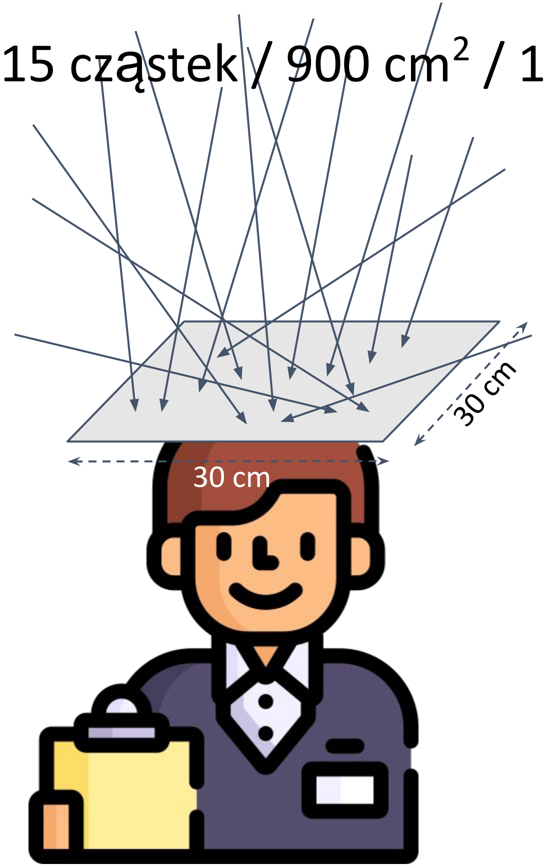
badanie korelacji promieniowania kosmicznego w skali globalnej: poszukiwanie zespołów promieni kosmicznych

- **Międzynarodowa współpraca**: 50 instytucji z 20 krajów na 5-ciu kontynentach
- **Wiodąca rola IFJ PAN**: założyciel i lider
- **Otwarte obserwatorium:** analizy łączące dane ze zróżnicowanych technologicznie urządzeń →objęcie badaniami **całego spektrum energii** promieniowania kosmicznego
- Największe osiągnięcie: **obserwacja korelacji kosmiczno-sejsmicznych - odkrycie > 6σ** : *J. Atmos. Sol. Terr. Phys.* 247 (2023) 106068 DOI:10.1016/j.jastp.2023.106068.

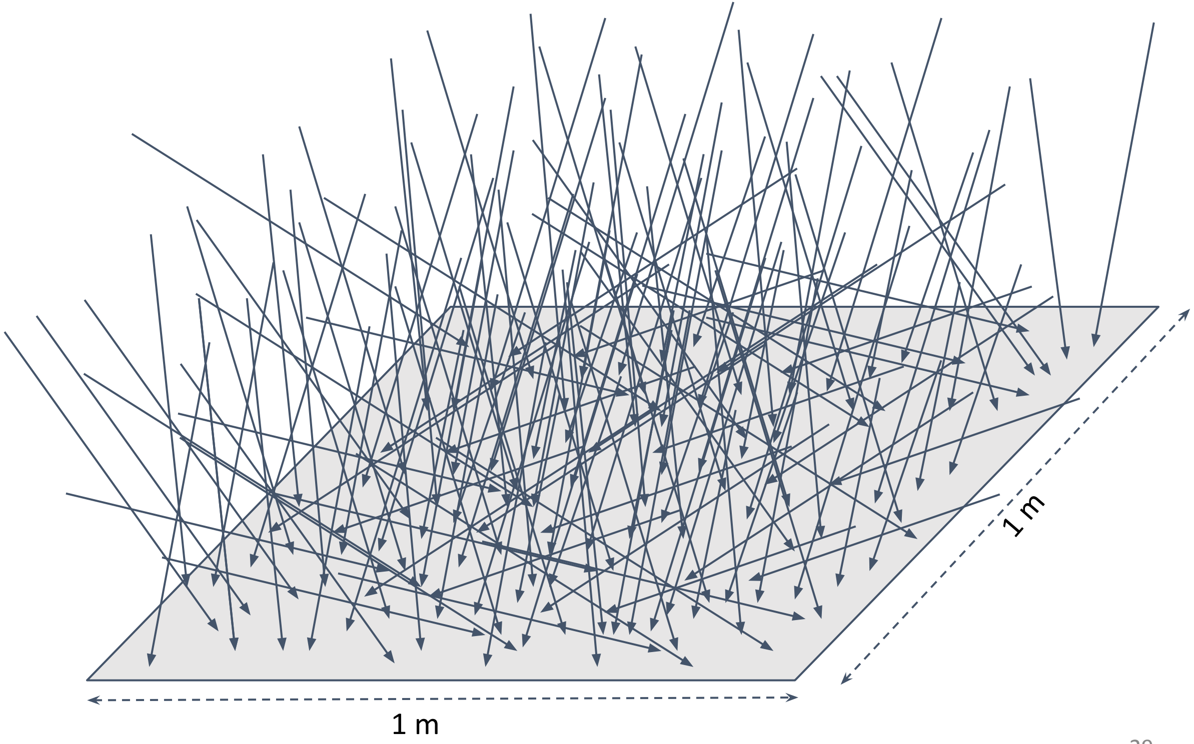


Ocean wtórnego promieniowania kosmicznego

~15 cząstek / 900 cm^2 / 1 sekundę



~150 cząstek / 1 m^2 / 1 sekundę



Journal of Atmospheric and Solar–Terrestrial Physics 247 (2023) 106068

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

Research Paper

Observation of large scale precursor correlations between cosmic rays and earthquakes with a periodicity similar to the solar cycle

P. Homola[a,*], V. Marchenko[x], A. Napolitano[q], R. Damian[j], R. Guzik[j], D. Alvarez-Castillo[a], S. Stuglik[a], O. Ruimi[b], O. Skorenok[i], J. Zamora-Saa[c,d], J.M. Vaquero[g], T. Wibig[p], M. Knap[s], K. Dziadkowiec[j], M. Karpiel[f], O. Sushchov[a], J.W. Mietelski[a], K. Gorzkiewicz[a], N. Zabari[e], K. Almeida Cheminant[a], B. Idźkowski[h,z], T. Bulik[h,k], G. Bhatta[a], N. Budnev[r], R. Kamiński[a], M.V. Medvedev[t,u], K. Kozak[a], O. Bar[y], Ł. Bibrzycki[j], M. Bielewicz[w], M. Frontczak[l], P. Kovács[o], B. Łozowski[v], J. Miszczyk[a], M. Niedźwiecki[y], L. del Peral[n], M. Piekarczyk[j], M.D. Rodriguez Frias[n], K. Rzecki[j], K. Smelcerz[y], T. Sośnicki[j], J. Stasielak[a], A.A. Tursunov[m]

[a] Institute of Nuclear Physics Polish Academy of Sciences, 31-342, Kraków, Poland
[b] Racah Institute of Physics, Hebrew University of Jerusalem, Jerusalem, IL, 91904, Israel
[c] Departamento de Ciencias Físicas, Universidad Andres Bello, Fernández Concha 700, Las Condes, Santiago, Chile
[d] Millennium Institute for Subatomic Physics at High Energy Frontier - SAPHIR, Fernández Concha 700, Las Condes, Santiago, Chile
[e] AstroTectonic Ltd., Juliusza Słowackiego 24, 35-069, Rzeszów, Poland
[f] Astroparticle Physics Amateur, 34-500, Zakopane, Poland
[g] Departamento de Física, Universidad de Extremadura, Avda. de Elvas s/n, 06006, Badajoz, Spain
[h] Astronomical Observatory University of Warsaw, Al. Ujazdowskie 4, 00-478, Warsaw, Poland
[i] Taras Shevchenko National University of Kyiv, 01601, Kyiv, Ukraine
[j] AGH University of Krakow, al. Mickiewicza 30, 30-059, Kraków, Poland
[k] Astrocent, Nicolaus Copernicus Astronomical Center, Rektorska 4, 00-614, Warsaw, Poland
[l] Pedagogical University of Krakow, Podchorążych 2, 30-084, Kraków, Poland
[m] Institute of Physics, Silesian University in Opava, Bezručovo nám. 13, CZ-74601, Opava, Czech Republic
[n] Space and Astroparticle Group, University of Alcalá; Ctra. Madrid-Barcelona, Km. 33.7, E-28871, Madrid, Spain
[o] Wigner Research Centre for Physics, Konkoly-Thege Miklós út 29-33, H-1121 Budapest, Hungary
[p] Department of Theoretical Physics, Faculty of Physics and Applied Informatics, University of Lodz, Pomorska 149/153, PL-90-236, Lodz, Poland
[q] University of Napoli "Parthenope", Department of Engineering, Centro Direzionale, Isola C4, 80143, Napoli, Italy
[r] Irkutsk State University, Physical Department, K.Marx str., 1, Irkutsk, 664003, Russia
[s] Astroparticle Physics Amateur, 58-170, Dobromierz, Poland
[t] Department of Physics and Astronomy, University of Kansas, Lawrence, KS, 66045, USA
[u] Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, MA, 02139, USA
[v] Faculty of Natural Sciences, University of Silesia in Katowice, Bankowa 9, 40-007, Katowice, Poland
[w] National Centre for Nuclear Research (NCBJ), Soltana Str. 7, 05-400, Otwock, Swierk, Poland
[x] Astronomical Observatory, Jagiellonian University, Orla Str. 171, 30-244, Kraków, Poland
[y] Department of Computer Science, Cracow University of Technology, 31-155, Kraków, Poland
[z] SKA Observatory Jodrell Bank, Lower Withington, Macclesfield Cheshire, SK11 9FT, UK

ARTICLE INFO

Handling Editor: Dora Pancheva

ABSTRACT

The search for correlations between secondary cosmic ray detection rates and seismic effects has long been a subject of investigation motivated by the hope of identifying a new precursor type that could feed a global early warning system against earthquakes. Here we show for the first time that the average variation of the cosmic ray detection rates correlates with the global seismic activity to be observed with a time lag of approximately two weeks, and that the significance of the effect varies with a periodicity resembling the undecenal solar cycle, with a shift in phase of around three years, exceeding 6 σ at local maxima. The precursor characteristics of the observed correlations point to a pioneer perspective of an early warning system against earthquakes.

* Corresponding author.
E-mail address: Piotr.Homola@ifj.edu.pl (P. Homola).

https://doi.org/10.1016/j.jastp.2023.106068
Received 12 September 2022; Received in revised form 24 February 2023; Accepted 6 April 2023
Available online 13 April 2023
1364-6826/

J. Atmos. Sol. Terr. Phys. **247** (2023) 106068
DOI:10.1016/j.jastp.2023.106068

Obserwacja globalnych korelacji kosmiczno-sejsmicznych: odkrycie > 6 σ!

"Astroparticle Physics Amateur"!

Intrygująca korelacja między trzęsieniami ziemi a promieniowaniem kosmicznym

?

CREDO
THE QUEST FOR THE UNEXPECTED

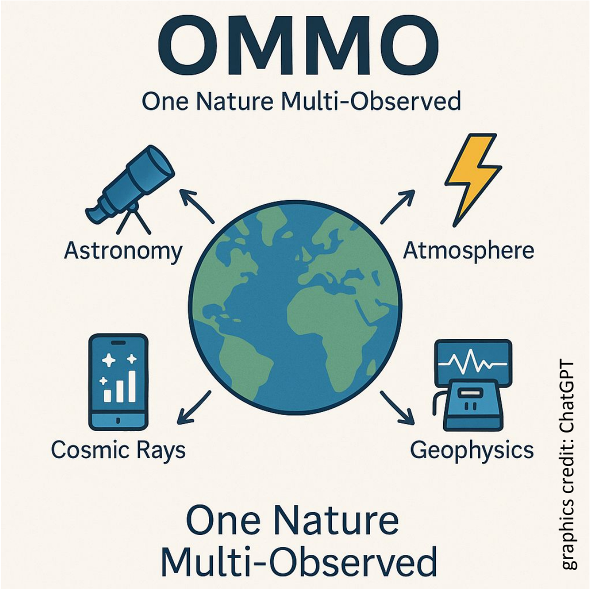
J. Atmos. Sol. Terr. Phys. **247** (2023) 106068
DOI:10.1016/j.jastp.2023.106068

Graphics source: IFJ PAN / NASA / JSC


DEMOTYWATORY.PL
Korelacja nie oznacza przyczynowości

A Flagship Proposal – OMMO

- OMMO: Open Multi-Messenger Organisation – a global cross-domain initiative
- Combines data from cosmic rays, seismic signals, electromagnetic fields and more
- Enables a systems-science approach to Nature as a sensing network
- Supports anomaly detection and interdisciplinary discovery
- APPEC can lead in framing and launching OMMO as a community-driven process
  - *"We propose a flagship initiative: the Open Multi-Messenger Organisation (OMMO)... a global open system to cross-link signals from multiple domains. (ID 187)"*
  - *"From a discovery perspective, we should treat Nature as one system with many complementary sensors. (paraphrased from ID 187)"*



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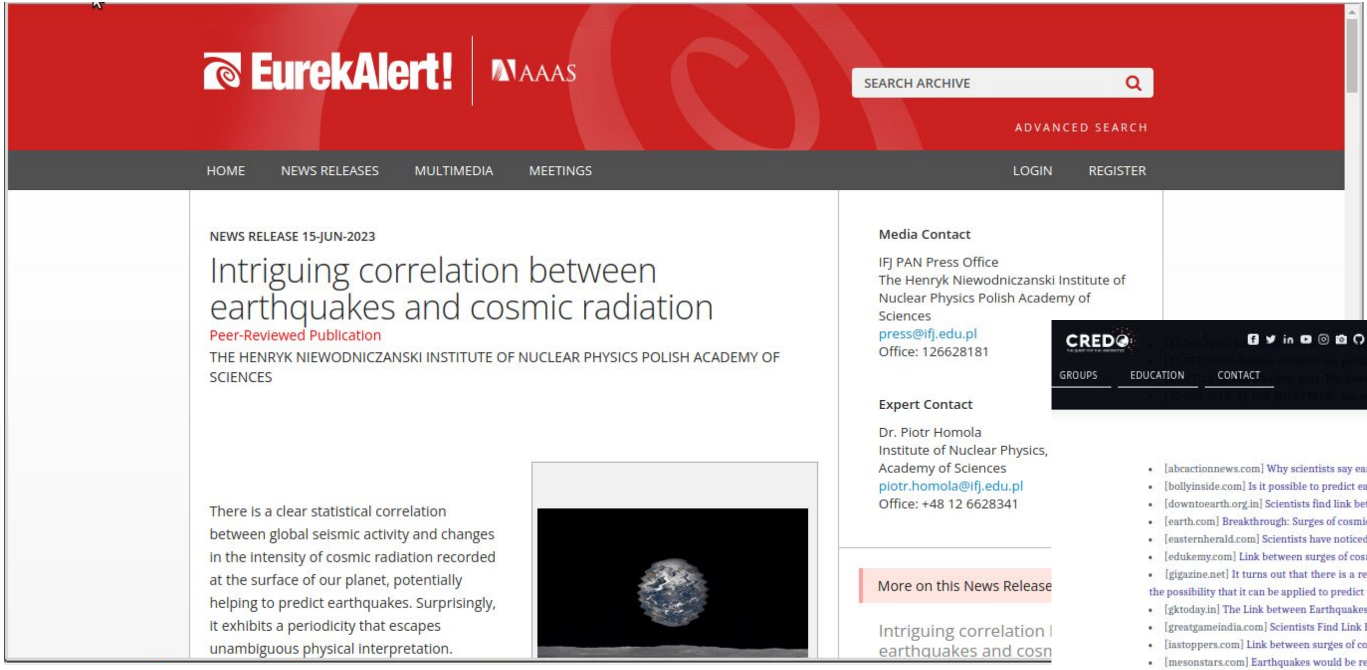
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NEWS RELEASE 15-JUN-2023

Intriguing correlation between earthquakes and cosmic radiation

Peer-Reviewed Publication

THE HENRYK NIEWODNICZANSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

There is a clear statistical correlation between global seismic activity and changes in the intensity of cosmic radiation recorded at the surface of our planet, potentially helping to predict earthquakes. Surprisingly, it exhibits a periodicity that escapes unambiguous physical interpretation.

Media Contact

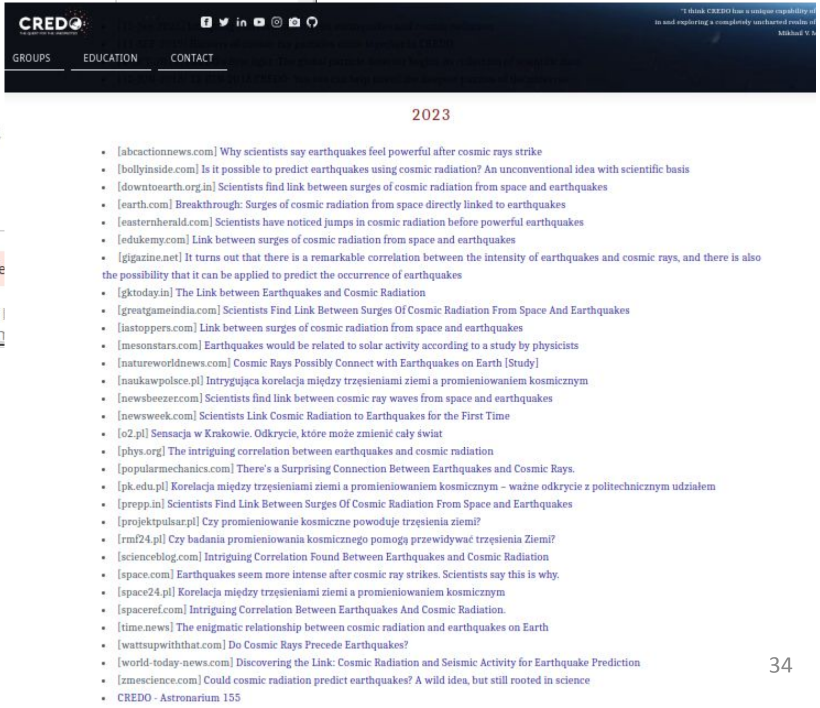
IFJ PAN Press Office
The Henryk Niewodniczanski Institute of Nuclear Physics Polish Academy of Sciences
press@ifj.edu.pl
Office: 126628181

Expert Contact

Dr. Piotr Homola
Institute of Nuclear Physics, Academy of Sciences
piotr.homola@ifj.edu.pl
Office: +48 12 6628341

More on this News Release

Intriguing correlation earthquakes and cosn


CREDO

GROUPS EDUCATION CONTACT

2023

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- CREDO - Astronarium 155

duży odzew mediów!

Breakthrough: Surges of cosmi ×

earth.com/news/breakthrough-surges-of-cosmic-radiation-from-space-directly-linked-to-earthquakes/

earth.com
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o2.pl/technologia/sensacja-w-krakowie-odkrycie-ktore-moze-zmienic-caly-swiat-6912196023569056a

Warszawa 8° cały dzień bez opadów

enhanced by Google

POCZTA

23.06.2023 21:27, aktualizacja 23.06.2023 22:00

Sensacja w Krakowie. Odkrycie, które może zmienić cały świat

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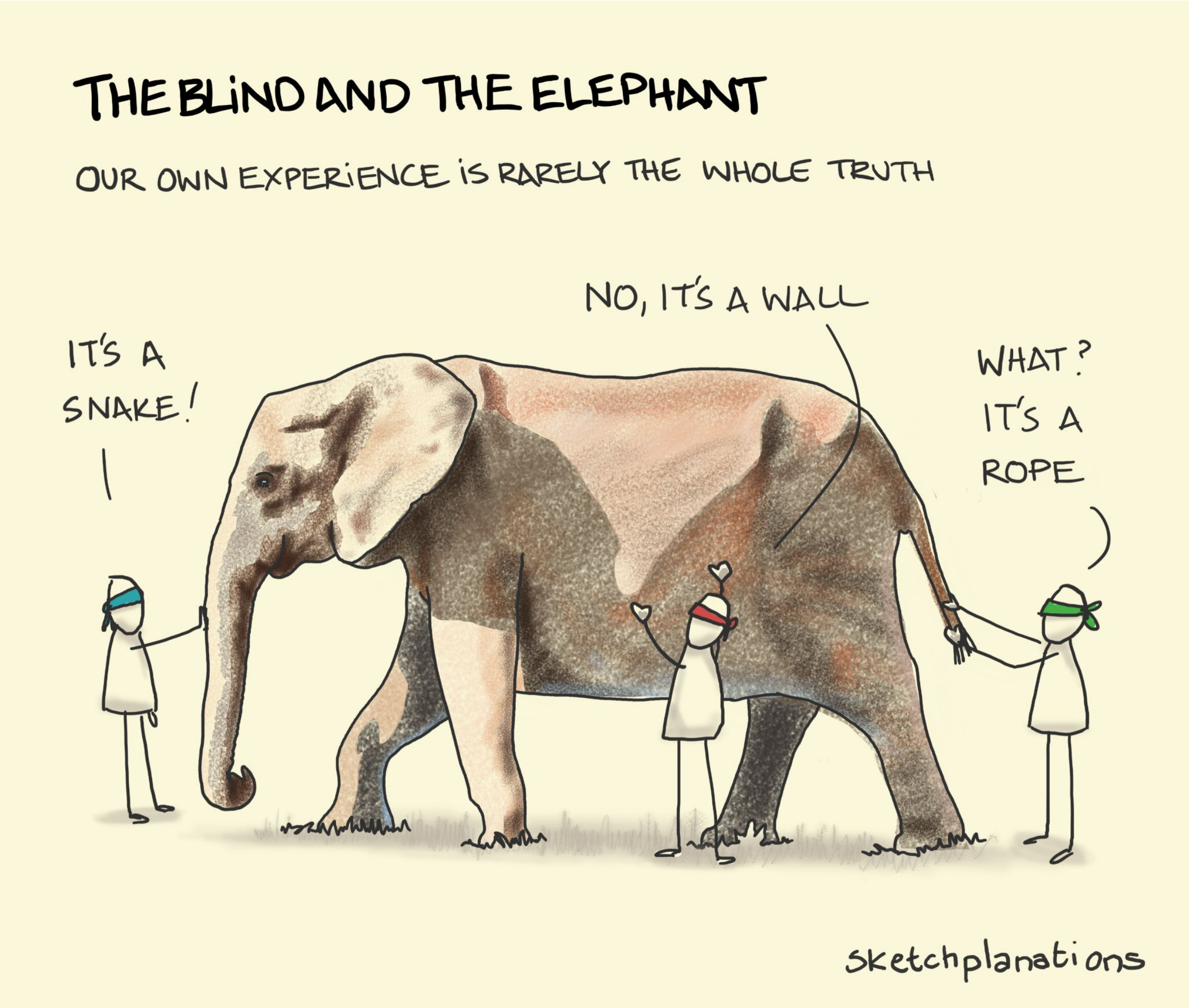
Naukowcy odkryli związek między promieniowaniem kosmicznym a trzęsieniami ziemi. Projekt CREDO, zainicjowany w 2016 r. przez Instytut Fizyki Jądrowej Polskiej Akademii Nauk (IFJ PAN) w Krakowie, ma na celu analizę możliwości przewidywania trzęsień ziemi na podstawie pomiarów promieniowania kosmicznego.

Naukowcy odkryli niezwykłą zależność. (PIXABAY)

06-15-2023

Breakthrough: Surges of cosmic radiation from space directly linked to earthquakes


THE BLIND AND THE ELEPHANT
OUR OWN EXPERIENCE IS RARELY THE WHOLE TRUTH
IT'S A SNAKE!
NO, IT'S A WALL
WHAT? IT'S A ROPE
sketchplanations


STILL NOTHING! ...
ANTI-NGCUKA FISHING EXPEDITION
TRUTH
ZAPIRO

BACKUP

graphics credit: ChatGPT

Exposures

A. Coleman et al. Astroparticle Physics 149 (2023) 102819

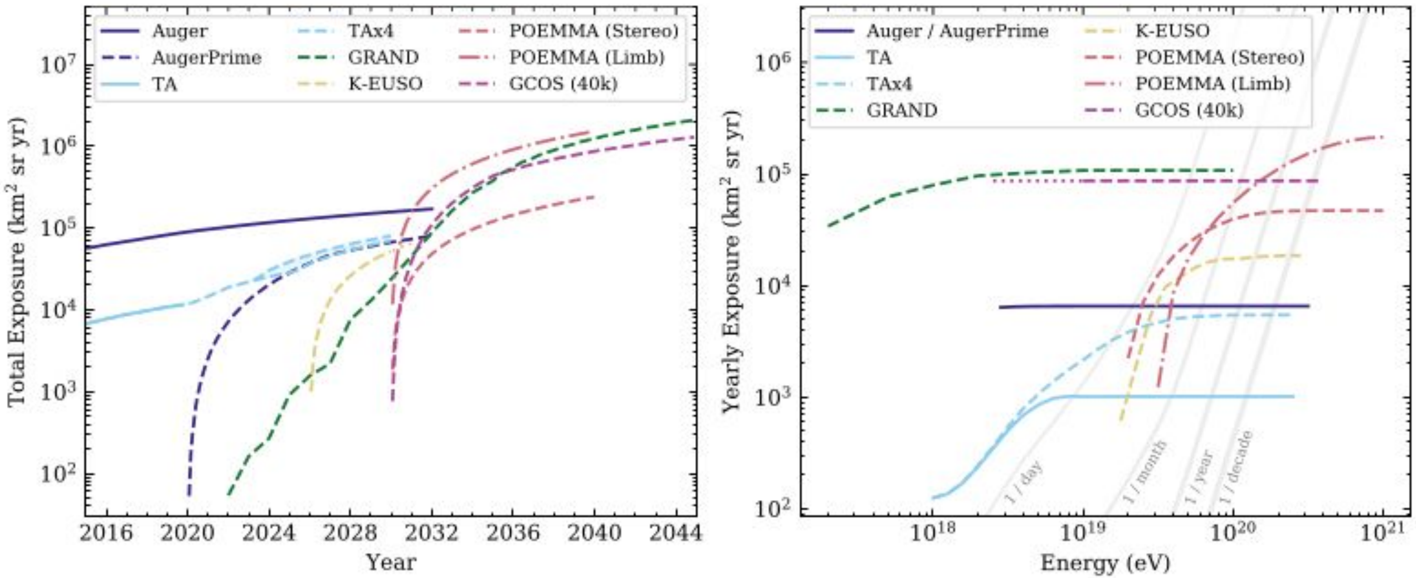
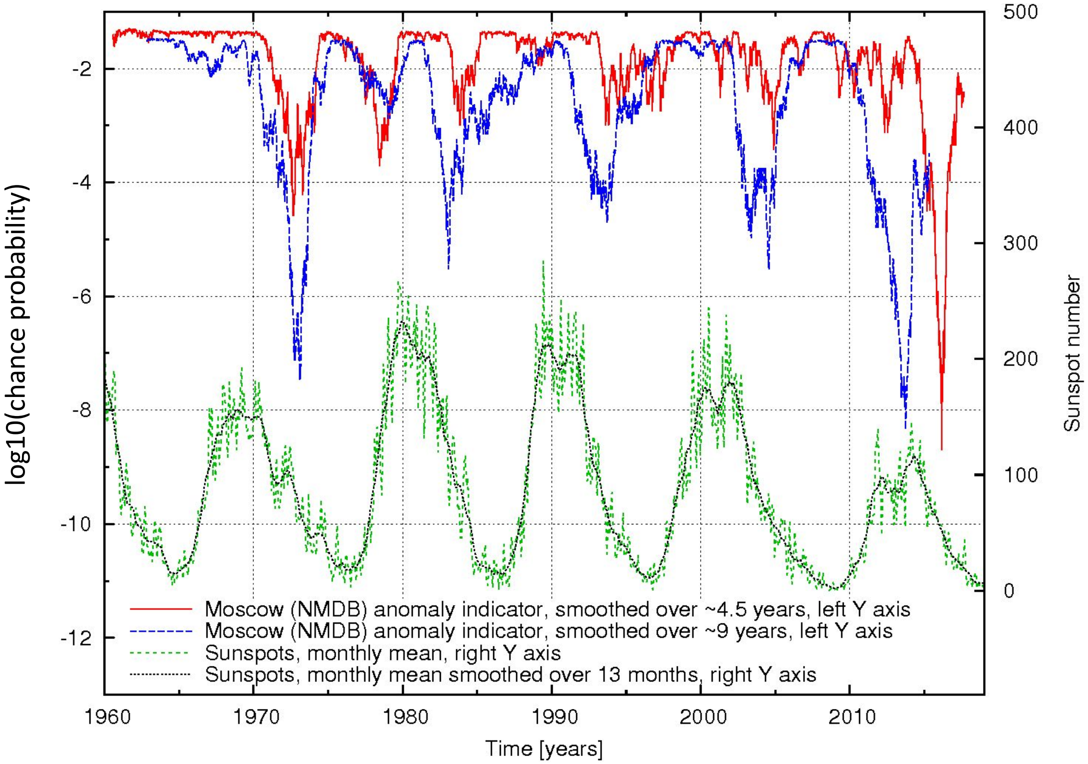


Fig. 79. Left: The exposure to cosmic rays near the suppression region (50 EeV) is shown as a function of time for Auger & Auger-Prime (SD-1500), TA & TA×4, GRAND, K-EUSO [949], POEMMA in stereo-mode, and GCOS. The exposure for POEMMA in limb-mode is shown for 300 EeV. A band is shown to indicate the exposure for various deployment schedules for TA×4. Right: The effective aperture of the experiments are shown as a function of energy. The gray lines indicate the yearly exposure that is required for an experiment to observe the indicated event rate, according to the flux model given in Ref. [67]. In both panels, currently operating experiments are shown in solid lines and future experiments/upgrades are shown in dashed lines.

Interpretation: Role of the Sun or….?

P. Homola et al., 2022: https://arxiv.org/abs/2204.12310



The anomaly indicator in the Moscow NMDB data set compared to the sunspot number. Each point on the correlation significance curves corresponds to the effect found over the smoothing window length of **~4.5 years (1675 days, in red)** and ~9 years (3350 days, in blue), with the curve points located at the centers of the windows.

Cosmic ray variation 15 days before the corresponding change in seismic activity!

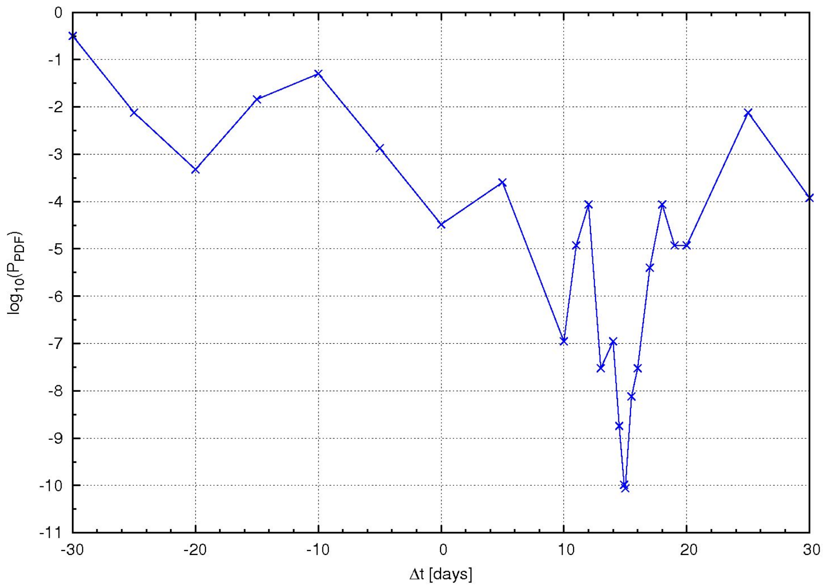
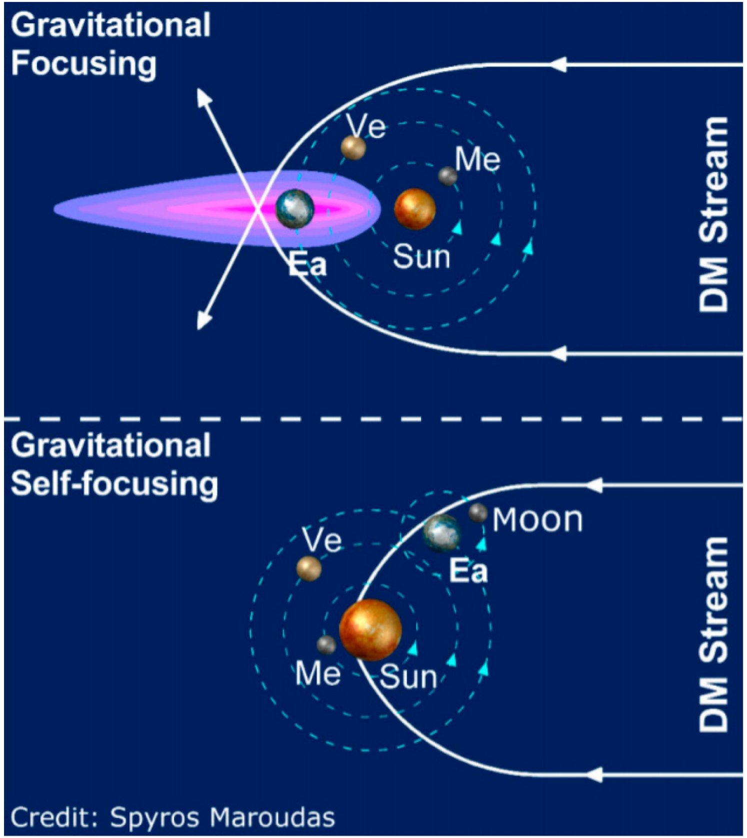


Fig. 3: The dependence of the significance of the *cosmo-seismic* correlations on the time shift t of the EQ data with respect to the Auger CR data, for the optimum free parameter set defined in Eq. 1. The positive or negative values of t correspond to the situations in which one compares the secondary cosmic ray data in a given time interval to the seismic data recorded in time intervals in the future or in the past, respectively.

Interpretation: role of the Sun, or … Dark Matter stream?

K. Zioutas et al., 2021
Phys. Sci. Forum **2021**, 2(1), 10; https://doi.org/10.3390/ECU2021-09313



PH: **(SH)DM overdensities:**
-> periodic (yearly?) CR variations?
-> delayed gravitational shocks?

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Szkoła z Charakterem

im. Edith Stein

rozmowy o możliwych obszarach współpracy
i podpisanie CREDO Memorandum of Understanding

budowa grupy badawczo-analitycznej i popularyzatorskiej (uczniowie, absolwenci, zainteresowani dorośli)

próba nawiązania współpracy z placówkami zagranicznymi

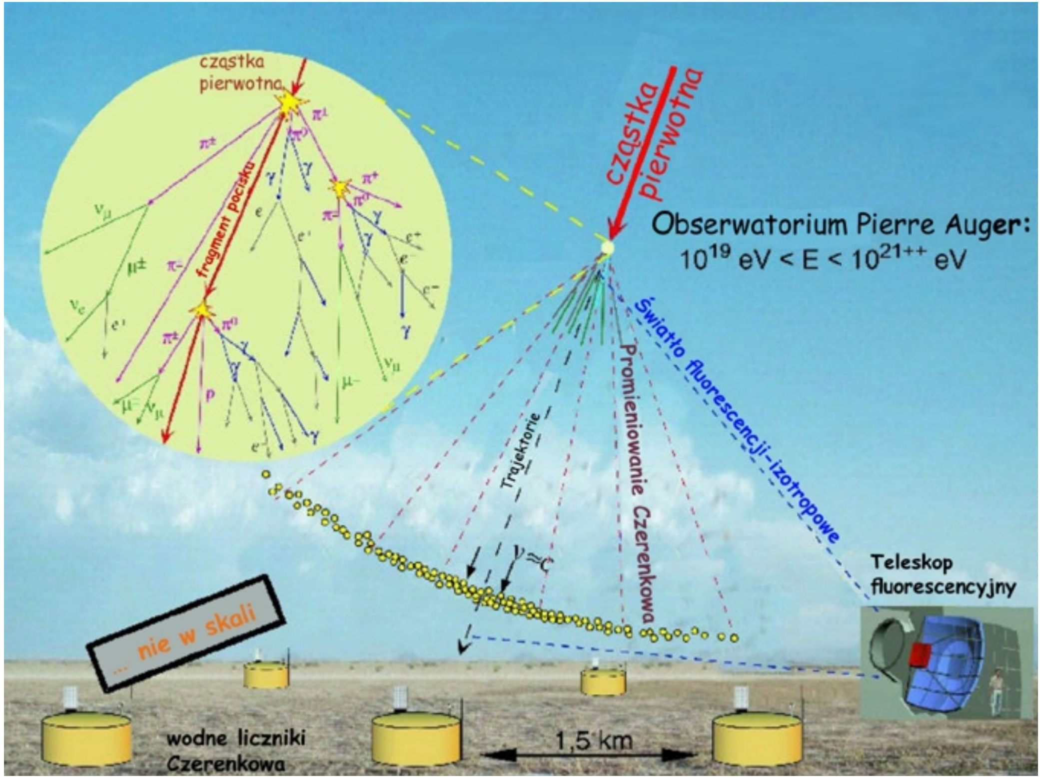
wniosek o dofinansowanie "stanowiska do badań promieniowania kosmicznego i edukacji astrofizycznej"

regularna działalność jest planowana od września 2023 r.

www.szkolazcharakterem.gliwice.pl
KATOLICKIE SZKOŁY Z CHARAKTEREM im. EDITH STEIN
Gliwice, ul. Bałtycka 8 tel. 32 335 30 64

autor slajdu: dr Bronisław Psiuk, nauczyciel fizyki w Szkole z Charakterem, przedstawiciel Szkoły w CREDO

Obserwatorium Pierre Auger i wielkie pęki atmosferyczne



źródło:
https://auger.ifj.edu.pl

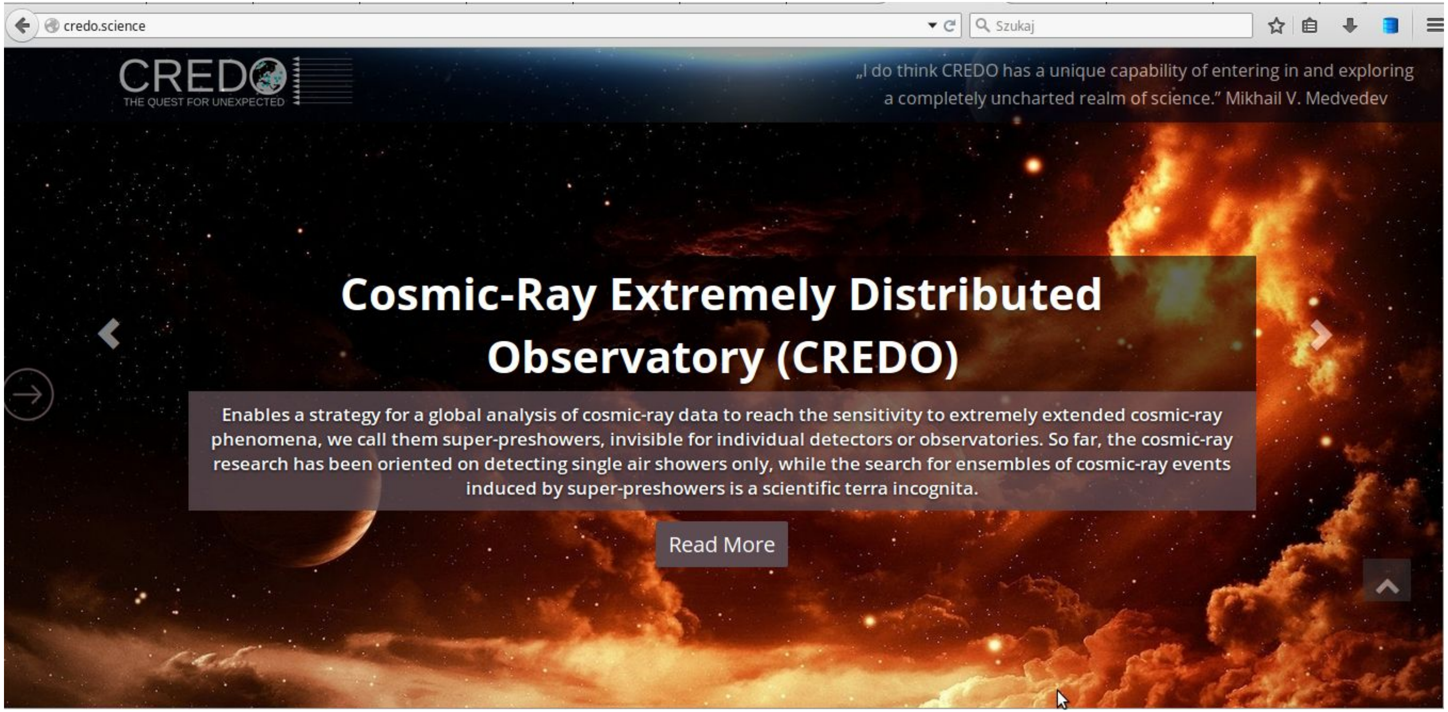
położenie: **Argentyna**

(m.in.) liczniki cząstek:
1600 detektorów

powierzchnia jednego detektora: **10 m^2**

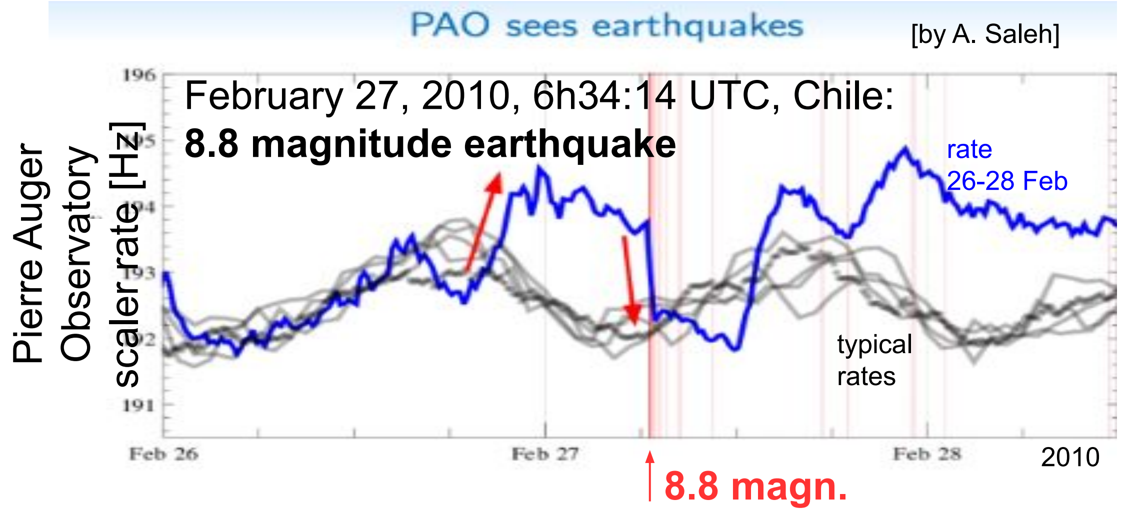
całkowita powierzchnia Obserwatorium: **3000 km^2**

Odwiedź credo.science...



… i włącz się.

The seismic precursor in cosmic rays: inspiration from the Pierre Auger Observatory



- Increase of CR before the earthquake
- Strong drop during the earthquake

→ **CREDO-earthquakes task**

Inhabitants of territories threatened by earthquakes [= potential CREDO public engagement target]:

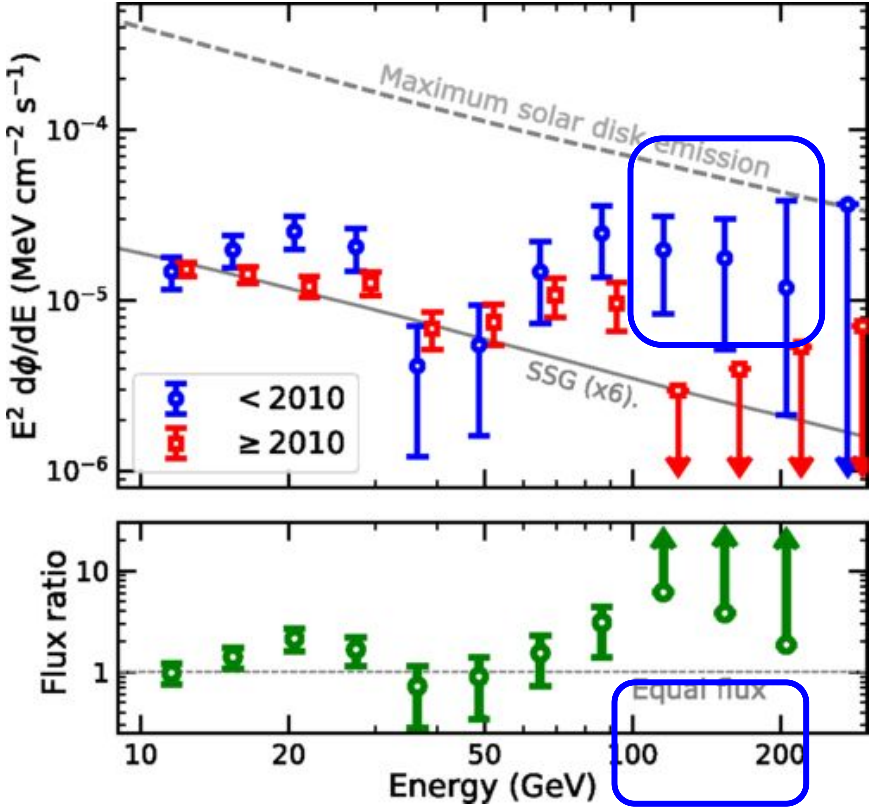
2,7 billion people

Science as a service to the human community?

Even the smallest chance to save lives

= **a must check!**

Fermi-LAT: “a New Component of High-Energy Solar Gamma-Ray Production”, observed only during the solar minimum



(Top panel) The solar disk γ-ray spectrum during solar minimum (**before January 1, 2010; blue circles**) and after it (red squares). Small shifts along the x axis improve readability. The gray lines show the SSG model renormalized by a factor of 6 to fit the lowest-energy data point (solid line), and the maximum γ-ray flux that could be produced by hadronic cosmic rays (dashed line). (Bottom panel) The ratio of the γ-ray flux observed during and after solar minimum. All upper and lower limits are based on 2σ Poisson fluctuations in the photon count.

“These **observations** provide important new clues about the mechanisms behind solar disk γ-ray emission, which **remains mysterious**.”

[T. Linden, et al., Phys. Rev. Lett. 121, 131103, https://doi.org/10.1103/PhysRevLett.121.131103]

Journal of Cosmology and Astroparticle Physics

PAPER

Cosmic ray ensembles as signatures of ultra-high energy photons interacting with the solar magnetic field

The CREDO collaboration, N. Dhital[1,2], P. Homola[2], D. Alvarez-Castillo[2,3], D. Góra[2], H. Wilczyński[2], K. Almeida Cheminant[2], B. Poncyljusz[4], J. Mędrala[5], G. Opiła[5], A. Bhatt[1], B. Łozowski[6], G. Bhatta[2], Ł. Bibrzycki[7], T. Bretz[8], A. Ćwikła[9], L. Del Peral[10], A.R. Duffy[11], A.C. Gupta[12], B. Hnatyk[13], P. Jagoda[5,2], M. Kasztelan[14], K. Kopański[2], P. Kovacs[15], M. Krupinski[2], M. Medvedev[16,17], V. Nazari[3], M. Niedźwiecki[18], D. Ostrogórski[5], M. Piekarczyk[7], M.D. Rodríguez Frías[10], K. Rzecki[5], K. Smelcerz[9], K. Smolek[19], J. Stasielak[2], O. Sushchov[2], T. Wibig[20], K. Wozniak[2], J. Zamora-Saa[21,22], Z. Zimborás[15] and A. Tursunov[23] − Hide full author list

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Journal of Cosmology and Astroparticle Physics, Volume 2022, March 2022

universe

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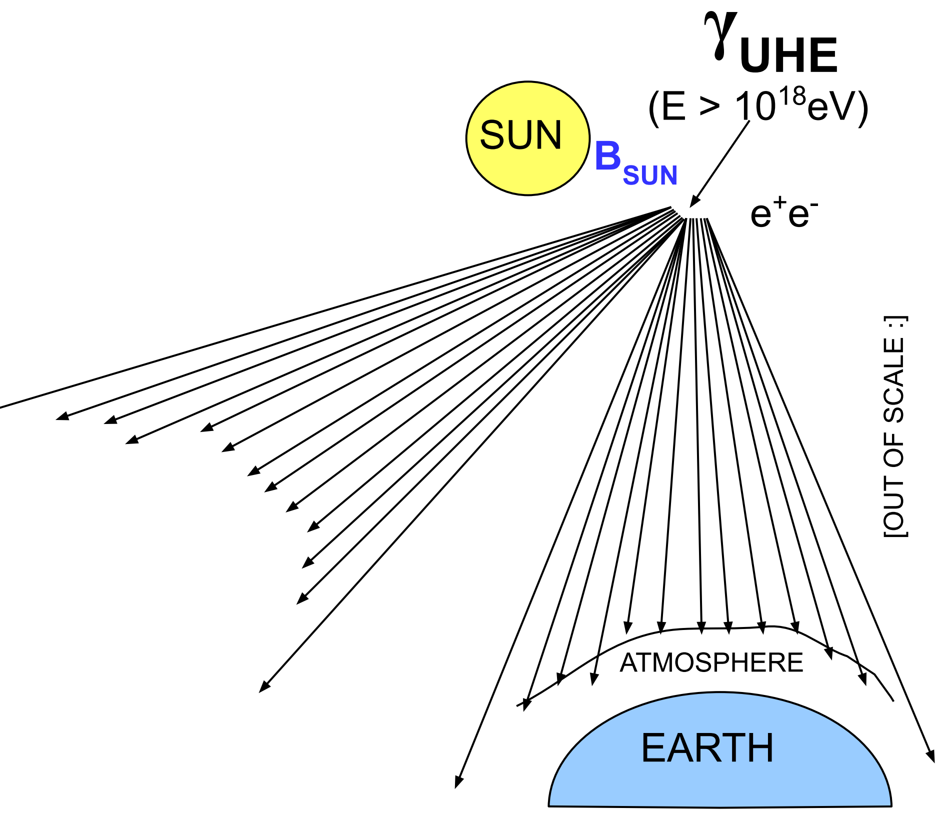
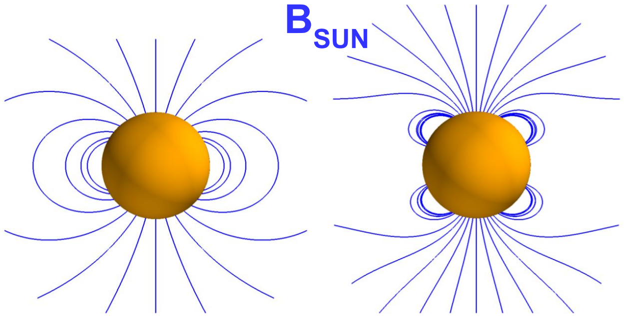
Simulation of the Isotropic Ultra-High Energy Photon Flux in the Solar Magnetic Field

by Bożena Poncyljusz[1,*], Tomasz Bulik[1], Niraj Dhital[2], Oleksandr Sushchov[3], Sławomir Stuglik[3], Piotr Homola[3], David Alvarez-Castillo[3], Marcin Piekarczyk[4], Tadeusz Wibig[5], Jaroslaw Stasielak[3], Péter Kovács[6], Katarzyna Smelcerz[7], Maria Dolores Rodriguez Frias[8], Michał Niedźwiecki[9], Justyna Miszczyk[3], Tomasz Sośnicki[10], Łukasz Bibrzycki[4], Arman Tursunov[11], Luis Del Peral[8] and Krzysztof Rzecki[10]

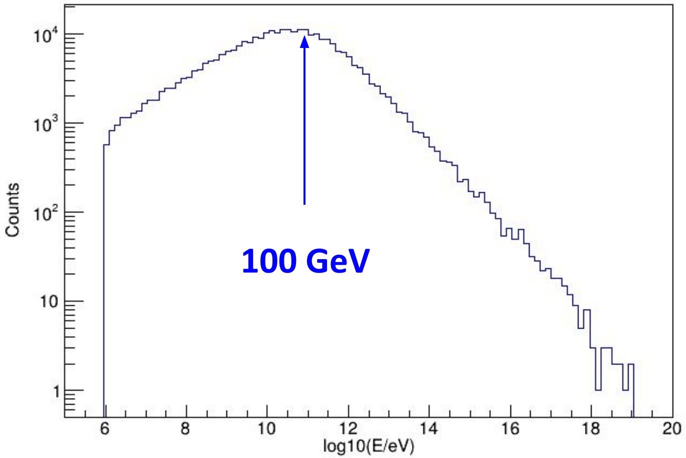
>=EeV photons nearby the Sun⟶ air shower walls



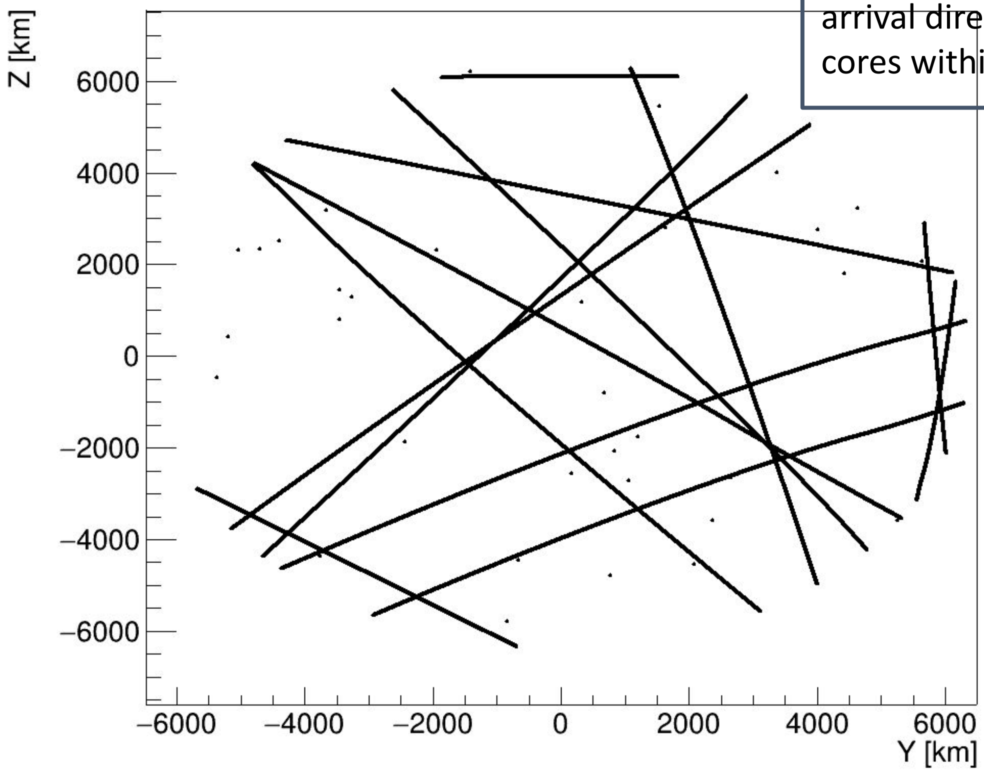


(a) Dipole field (b) DQCS field

entire photon spectrum engaged



Air shower walls & new astrophysical constraints



Air shower walls simulations: Eγ=10^{20} eV, 100 random arrival directions passing near the Sun, CRE footprint cores within 10,000 km from the Earth center

(!) Comparable with the existing observations of the Sun in gamma rays, e.g. Fermi-LAT [T. Linden, et al., Phys. Rev. Lett. 121, 131103; 10.1103/PhysRevLett.121.131103], HAWC [A. Albert et al. (HAWC Collaboration), Phys. Rev. D 98, 123011 (2018); 10.1103/PhysRevD.98.123011

->

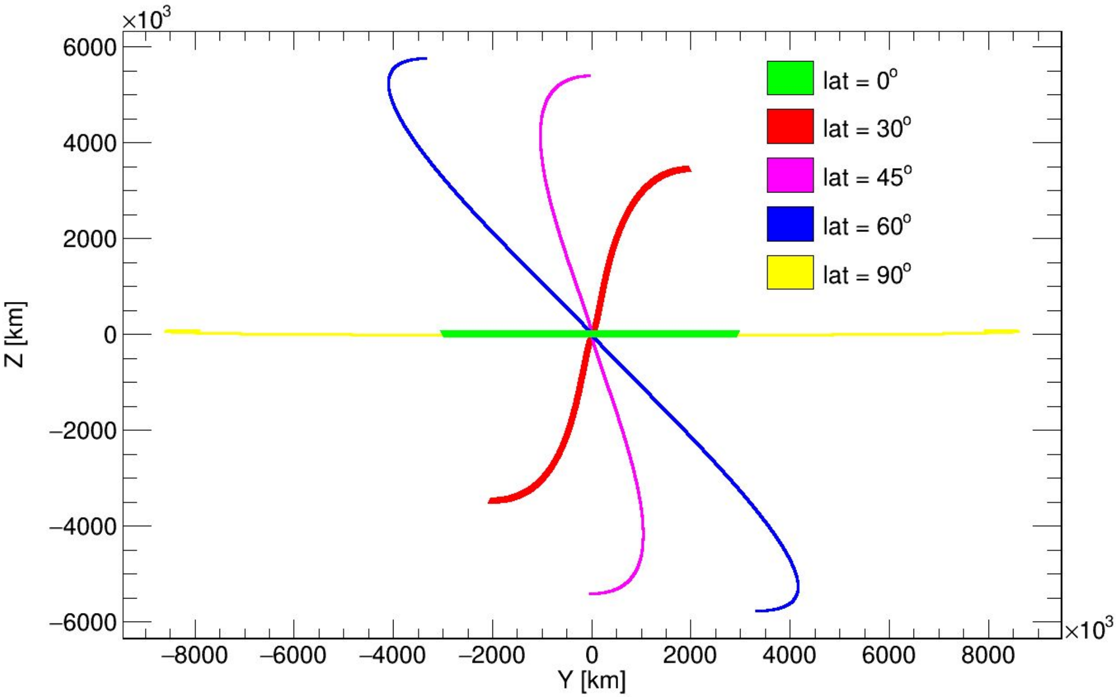
B. Poncyljusz et al. (CREDO Collaboration), *Universe* **2022**, *8*(10), 498; https://doi.org/10.3390/universe8100498

+ work in progress

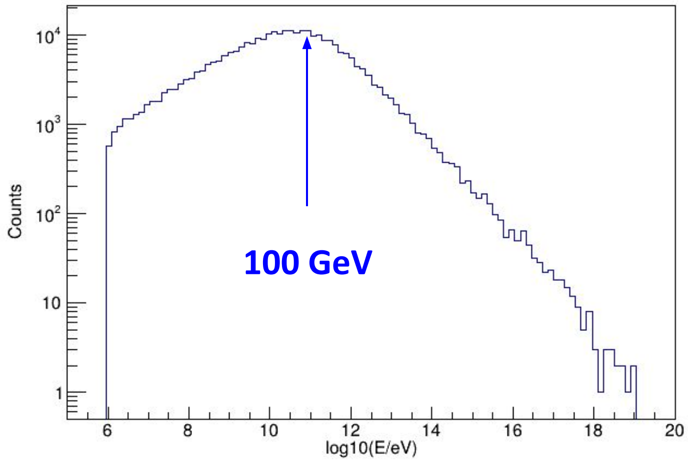
From: BSc project of B. Poncyljusz (UW) with PH and Tomasz Bulik (UW) as supervisors, 2021

Air shower walls: footprints up to 1AU, all photon energies

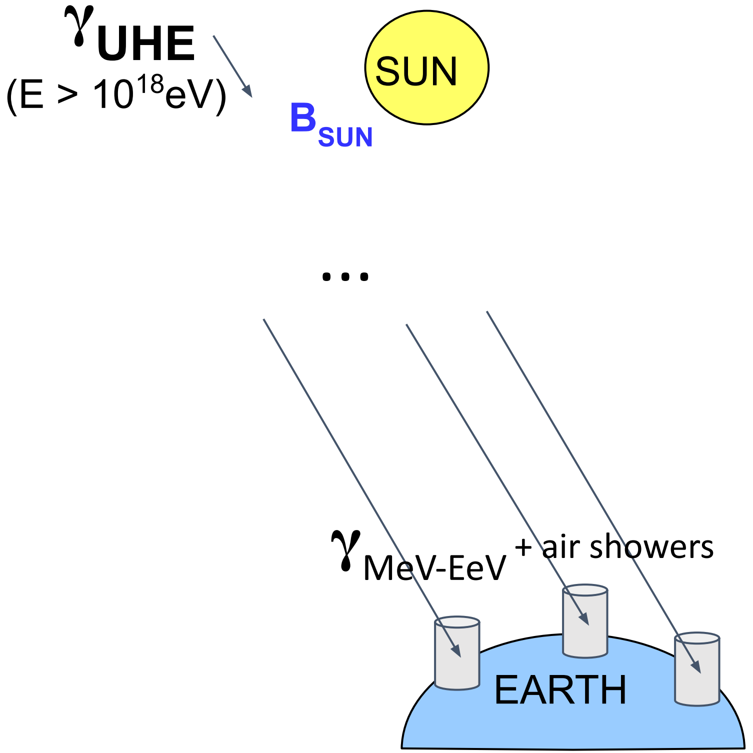
footprints very thin (~1m), up to 1 AU long, non-trivial shapes, dependent on incidence angle and impact parameter



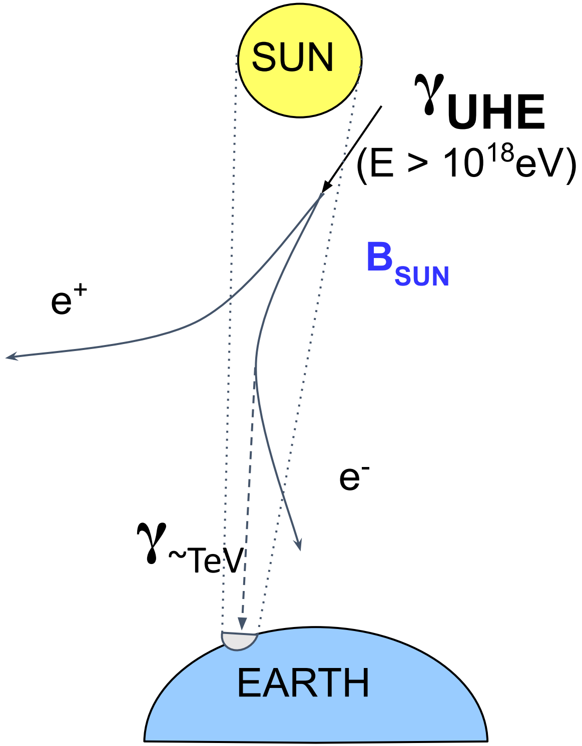
entire photon spectrum engaged



Air shower walls: observe or constrain UHE photons

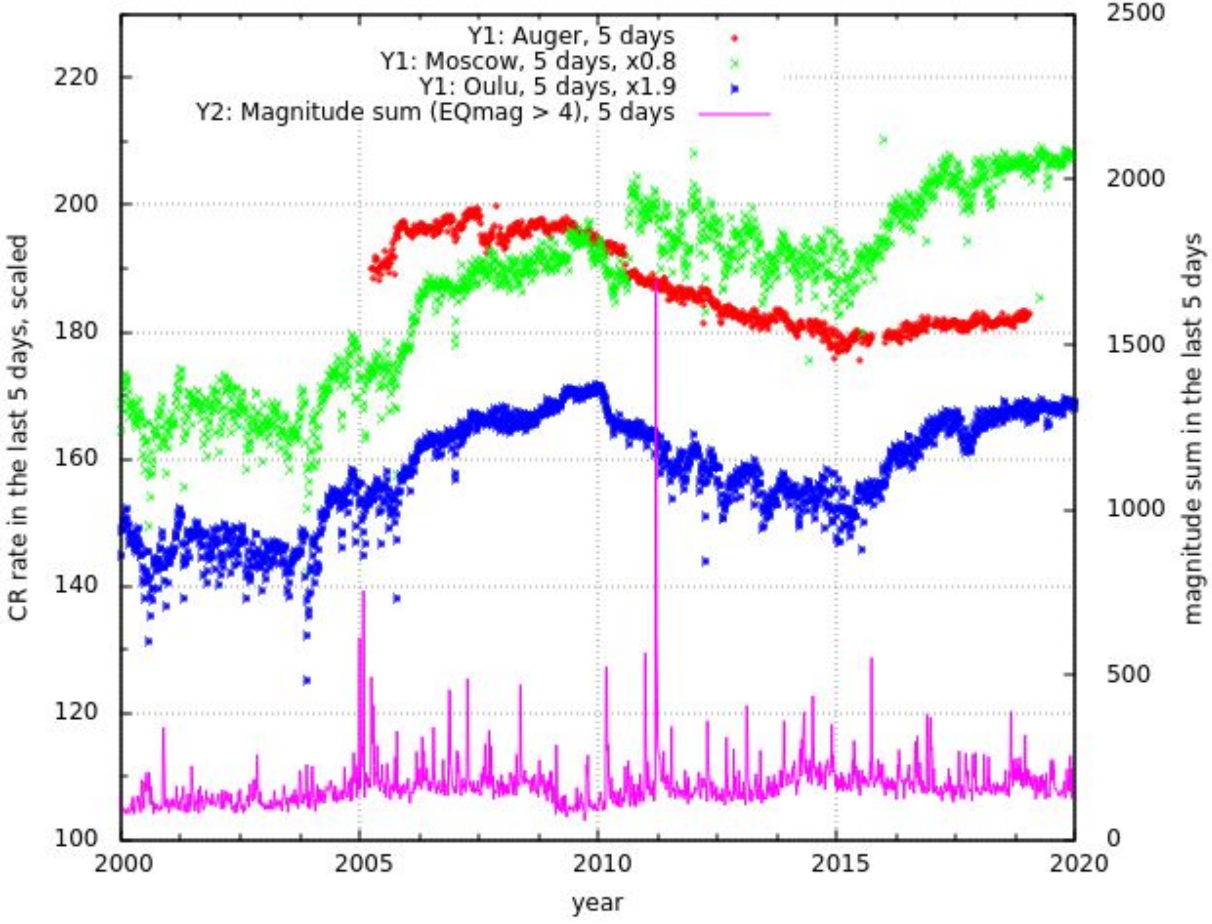


- displacement > ~100 km
- similar arrival directions
- consistent timing



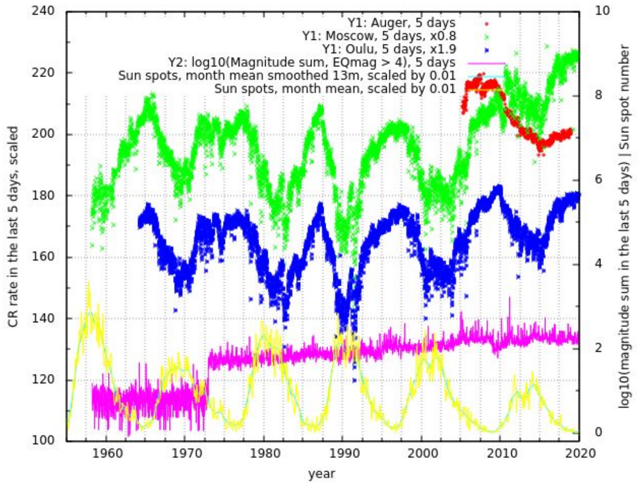
- γ_{TeV} from the direction of the Sun
- characteristic E spectrum excess towards TeV

The data



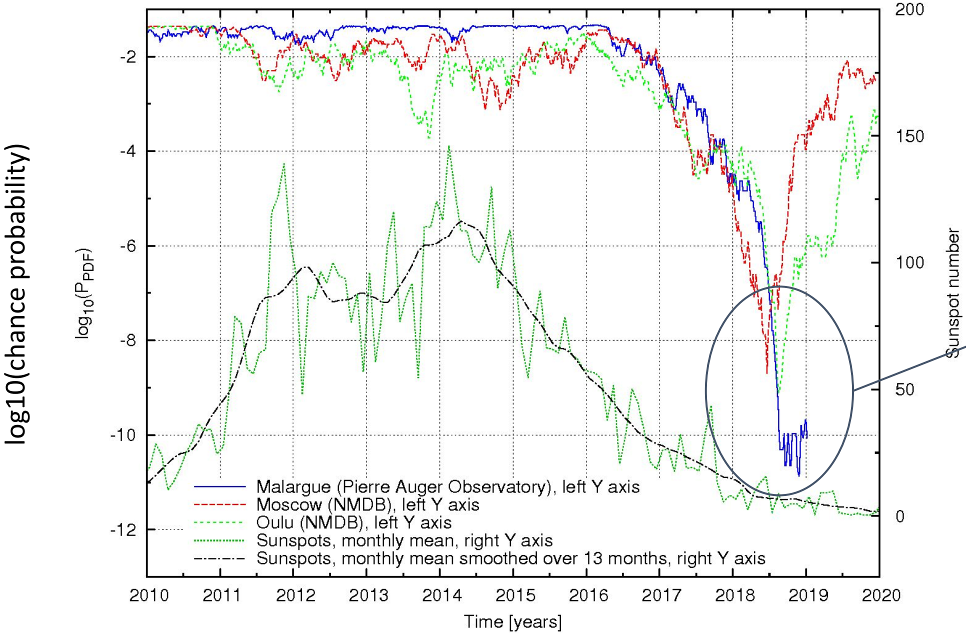
public resources of:

[Pierre Auger Observatory scaler data]
[Neutron Monitor Database]
[U.S. Geological Survey]
[Solar Influences Data analysis Center]



Checking for a correlation **$|dN_{CR}|$ vs. Σmagnitude$_{EQ}$** using **5-day bins** over ~**4.5 yr windows**

Local cosmic dynamics vs. global seismicity: dependence on geographical location?

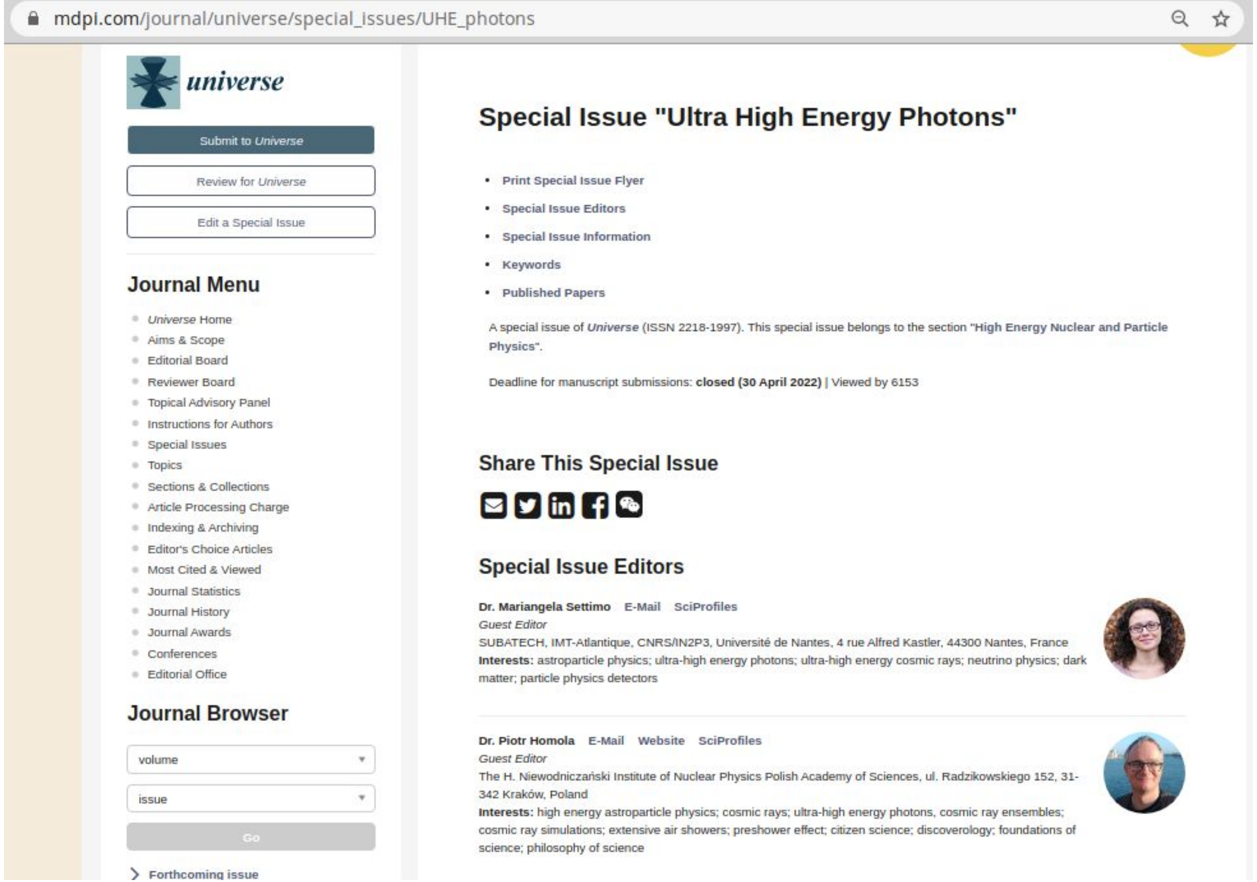


different cosmic ray sites see the **dichotomic** correlation effect differently? Need for more detectors?

55

~6 σ significance of the effect in three technically independent CR data sets collected by the Moscow and Oulu NMDB stations, and by the Pierre Auger Observatory, compared to sunspot numbers. **Each point** illustrates the correlation effect during **the last ~4.5 years** (335 **five-day intervals**). All the significance curves were obtained after fine tuning of the parameter t_0 performed by applying 20 small shifts in time between 0 and 5 days.

Universe - the Special Issue on UHE Photons: Nov 2022



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Special Issue "Ultra High Energy Photons"

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A special issue of *Universe* (ISSN 2218-1997). This special issue belongs to the section "High Energy Nuclear and Particle Physics".

Deadline for manuscript submissions: **closed (30 April 2022)** | Viewed by 6153

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Special Issue Editors

Dr. Mariangela Settimo E-Mail SciProfiles
Guest Editor
SUBATECH, IMT-Atlantique, CNRS/IN2P3, Université de Nantes, 4 rue Alfred Kastler, 44300 Nantes, France
Interests: astroparticle physics; ultra-high energy photons; ultra-high energy cosmic rays; neutrino physics; dark matter; particle physics detectors

Dr. Piotr Homola E-Mail Website SciProfiles
Guest Editor
The H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences, ul. Radzikowskiego 152, 31-342 Kraków, Poland
Interests: high energy astroparticle physics; cosmic rays; ultra-high energy photons, cosmic ray ensembles; cosmic ray simulations; extensive air showers; preshower effect; citizen science; discoverology; foundations of science; philosophy of science

11 articles
(7 research + 4 review):

G. Gelmini
D. Semikoz
O. Kalashev
V. de Souza
B. Qiang-Ma
Y. Jack Ng
E. Perlman
T. Bulik
T. Wibig
S. Casanova
G. Bhatta
Ł. Bratek
M. Biesiada
The Pierre Auger Collaboration
…

CREDO Memorandum of Understanding

Cosmic Ray Extremely Distributed Observatory (CREDO)

CREDO
THE QUEST FOR THE UNEXPECTED

since 2.10.2018

This multi-beneficiary Memorandum of Understanding (MoU) is made

BETWEEN:

the Institutions named in Section 8: Signatories, henceforth referred to as "Parties", with the Effective Date being the date of signing by each of the Parties,

in relation to the Project entitled

COSMIC RAY EXTREMELY DISTRIBUTED OBSERVATORY (CREDO), henceforth referred to as "Project".

THEREFORE, IT IS AGREED THAT:

Section 1: Background

The Parties agree to cooperate in exploring the multidisciplinary potential of a widely distributed network of cosmic ray detectors, under the name of the Cosmic Ray Extremely Distributed Observatory (CREDO). As an initiative of the Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences the CREDO concept has been under development since 30th August 2016.

Section 2: Purpose

The purpose of this MoU is to stipulate, in the context of the Project, the relationship between the Parties. In particular, this concerns the distribution of work between the Parties, the management of the Project and the rights and obligations of the Parties.

CREDO Memorandum of Understanding

CREDO institutional members (10.11.2022):

- Australia (2)
- Canada (2)
- Chile (1)
- Czech Republic (3)
- Estonia (1)
- Georgia (1)
- Hungary (1)
- India (2)
- Italy (1)
- Mexico (1)
- Nepal (1)
- Poland (18)
- Portugal (1)
- Russia (1)
- Slovakia (1)
- Spain (2)
- Thailand (1)
- Ukraine (3)
- Uruguay (2)
- USA (3)

(48 institutions, 20 countries)

How can the geomagnetic field affect UHECR?

The preshower effect: a strong dependence of extensive air shower development on the geomagnetic field component transverse to the primary trajectory (**$B_\perp$**), and on **E_γ**.

From: **"Search for ultra-high energy photons through preshower effect with gamma-ray telescopes: Study of CTA-North efficiency",** K. A. Cheminant, et al. (CREDO Collab.), Astroparticle Physics, 123, 102489, December 2020. [DOI: 10.1016/j.astropartphys.2020.102489].

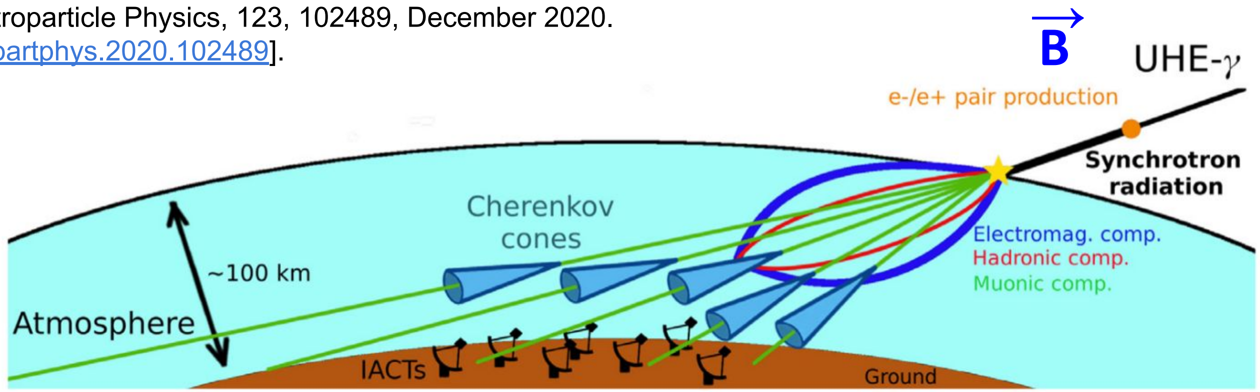
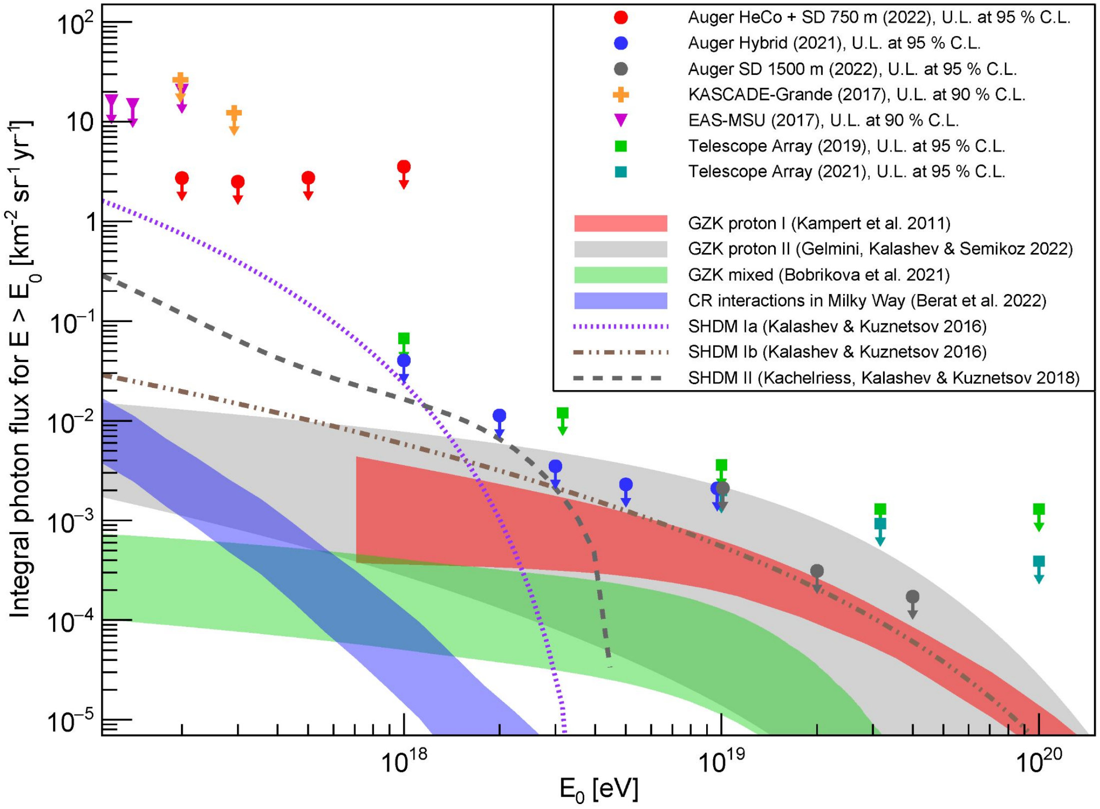


Fig. 1. A ultra-high energy photon interacting with the transverse component of the geomagnetic field produces an e^+/e^- pair ~ 1000 km above sea level which emits bremsstrahlung photons. As such process can repeat itself for some of these photons, a collection of particles (mainly photons and a few e^+ and e^-) reaches the top of the atmosphere. Consequently, atmospheric air showers are produced and in the case of nearly horizontal showers, only the muonic component reaches the Imaging Atmospheric Cherenkov Telescopess (IACTs) on the ground, which detect the Cherenkov emission of this component.

UHE photons: expected but not seen?



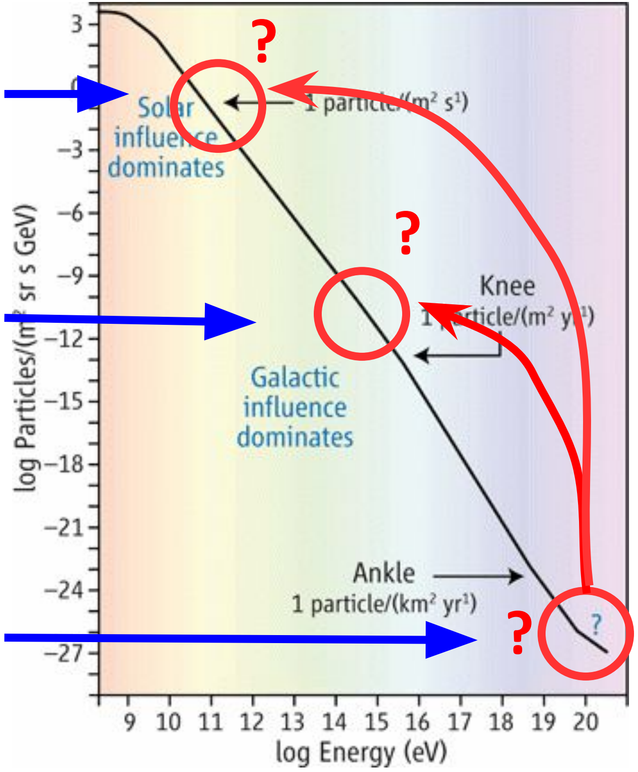
… the assumptions!

- physics understood?
- models correct?
- mean free paths?
- distribution of sources?
- …?

Pierre Auger Collaboration, *Universe* **2022**, *8*(11), 579;
https://doi.org/10.3390/universe8110579

Three unexplained observations

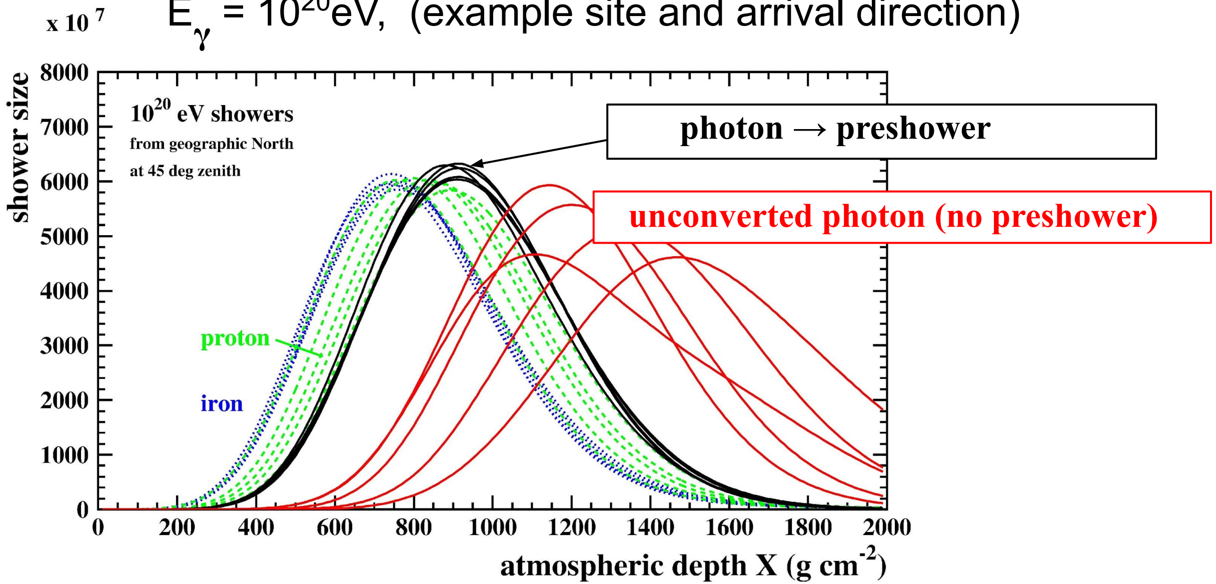
1. Cosmo-seismic precursor-like correlations with periodicity similar to the solar cycle (CREDO)
2. Hard gamma emission from the solar disk seen only during the solar minimum (Fermi-LAT)
3. Tension in the UHECR high-end energy spectrum (Pierre Auger Observatory & Telescope Array)



Can **UHE photons** be considered as a common explanation?

Preshowers and air shower development

$E_\gamma = 10^{20}$eV, (example site and arrival direction)



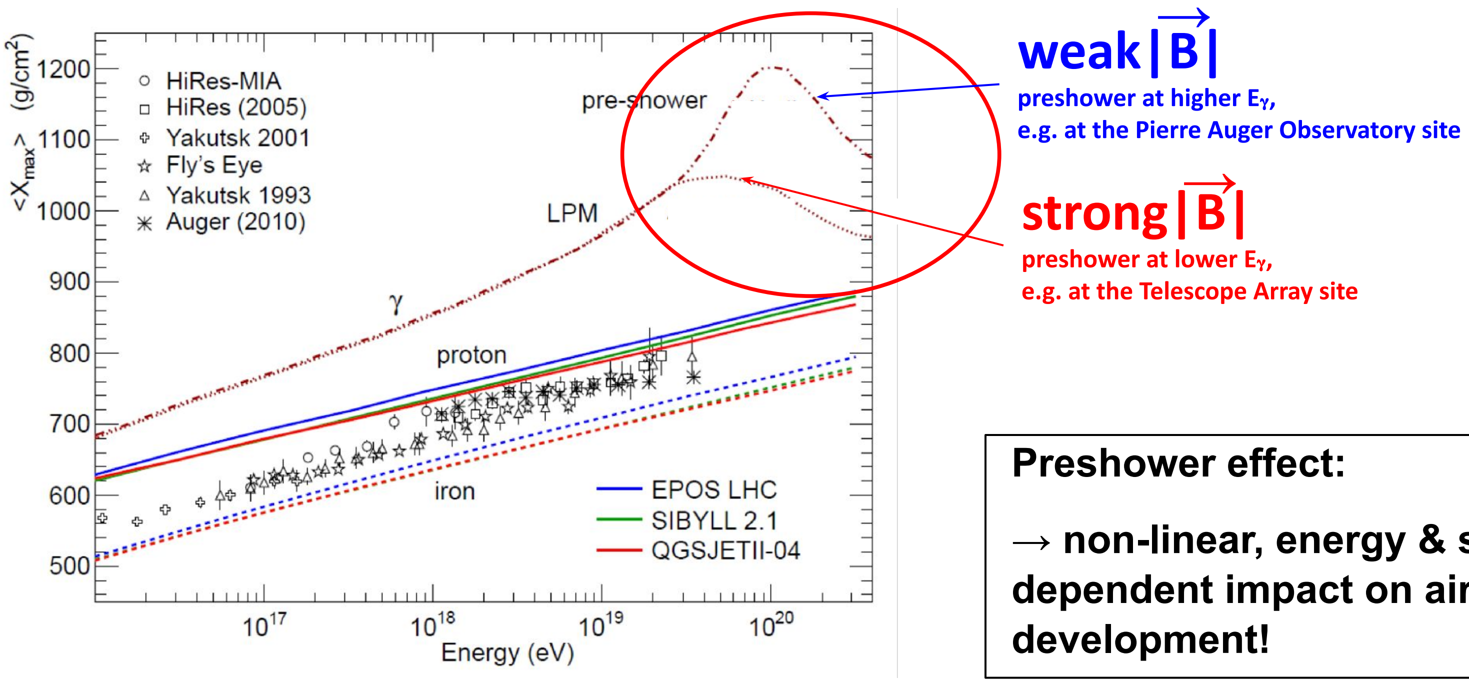
LPM (in top layers of atmosphere is important for $E_\gamma > 10^{19}$ eV):

→ **deep** X_{max}, **large** fluctuations of X_{max}

PRESHOWER (primary E_γ split into preshower particles):

→ **shallow** X_{max}, **small** fluctuations of X_{max}

UHE photon-induced air showers: X_{max} vs. E_γ



M. Settimo for the Pierre Auger Collaboration,
Proceedings of Photon 2013 Conference

Preshower effect:

→ non-linear, energy & site dependent impact on air shower development!

But... what if the physics extrapolations by many orders of magnitude are slightly wrong?

From: Yushkov, A.; for the Pierre Auger Collaboration. Mass composition of cosmic rays with energies above $10^{17.2}$ eV from the hybrid data of the Pierre Auger Observatory, [PoS 2020, ICRC2019, 482](#).

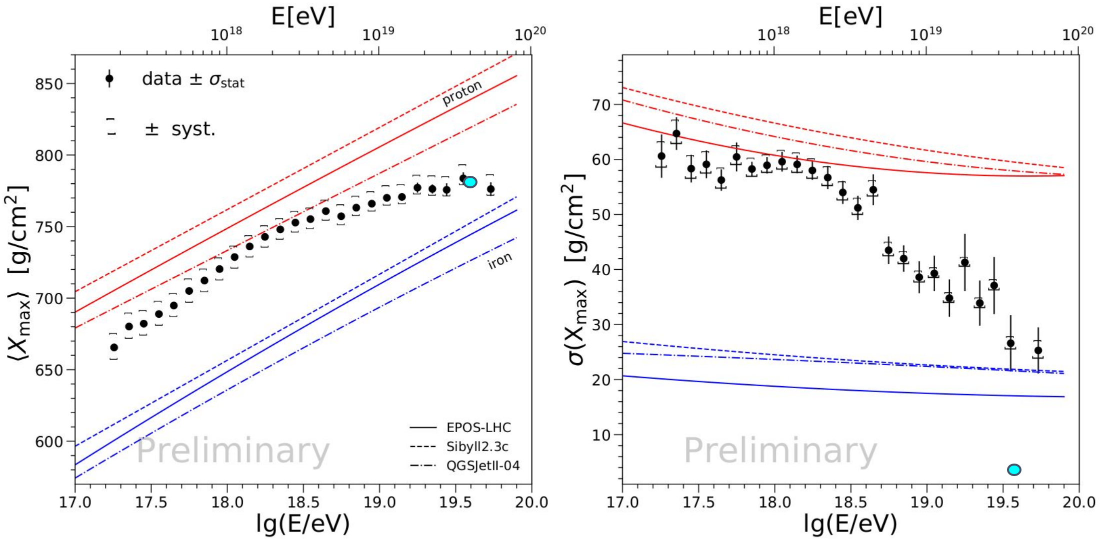
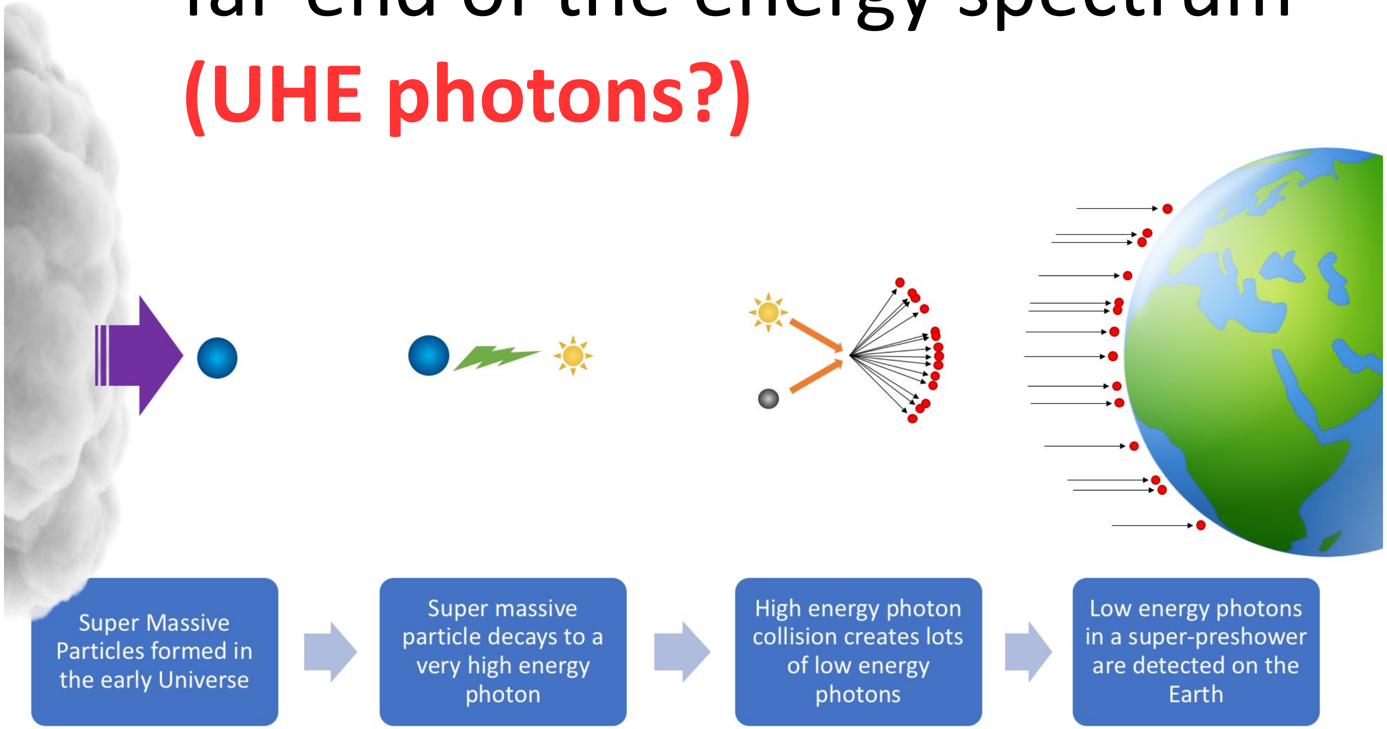


Figure 1: Measurements of $\langle X_{\text{max}} \rangle$ (left) and $\sigma(X_{\text{max}})$ (right) at the Pierre Auger Observatory compared to the predictions for proton and iron nuclei of the hadronic models EPOS-LHC, Sibyll 2.3c and QGSJetII-04.

[added by PH]:
example primary preshower
$\langle X_{max} \rangle = 783 \pm 3$ g/cm^2
Log(E/eV)=19.6
N particles = 1500
forced initiation at 17000 km a.s.l.
[typical initiation: 100-200 km a.s.l.]

Physics at the highest energies uncertain -> more uncertainty in X_{max} likely?

a. UHECR / Dark Matter (exotic) puzzle (puzzles) and the challenge in the far-end of the energy spectrum (UHE photons?)



UHE photons expected, not yet seen (identified)

From: Rautenberg, J.; for the Pierre Auger Collaboration. Limits on ultra-high energy photons with the Pierre Auger Observatory, *PoS* **2020**, *ICRC2019*, 398.

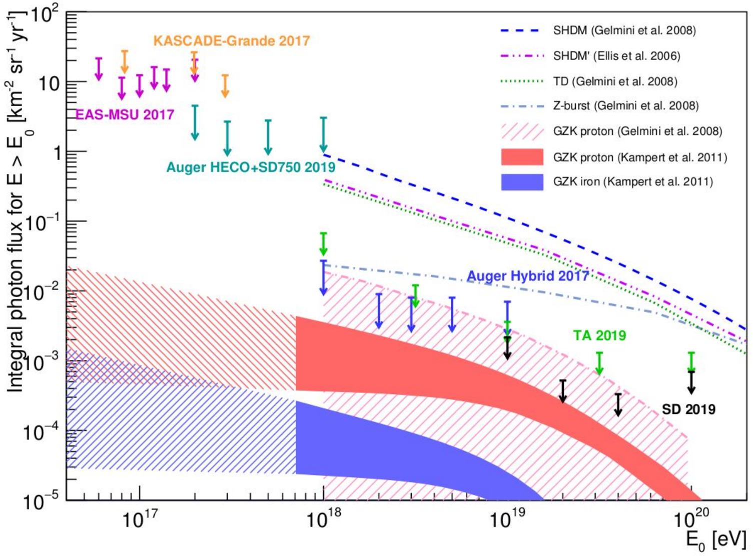


Figure 7: Photon flux limits at 95% C.L. for the different analysis of the Pierre Auger Observatory, compared to model predictions [14, 15, 16] and other experimental limits at 95% C.L. [17], as well as at 90% C.L. [18, 19].

But... what if the physics extrapolations by many orders of magnitude are slightly wrong (2)?

Muon “puzzles” in the news!

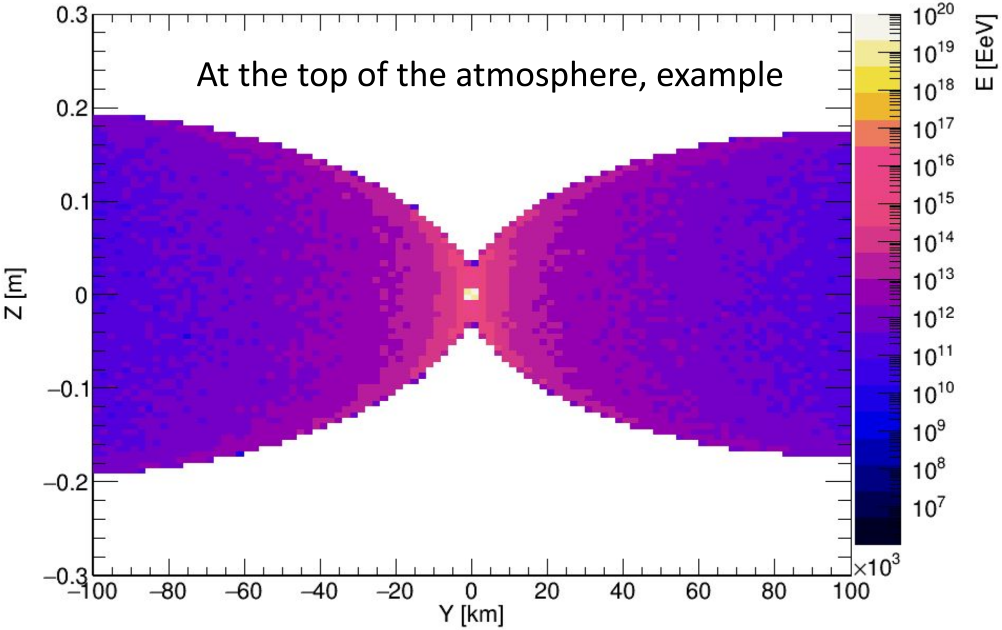
- muon excess in air showers; see popular article
- muon deficit in B meson decays (R_K flavour anomaly); see popular article
- muon g-2 anomaly (?); popular article

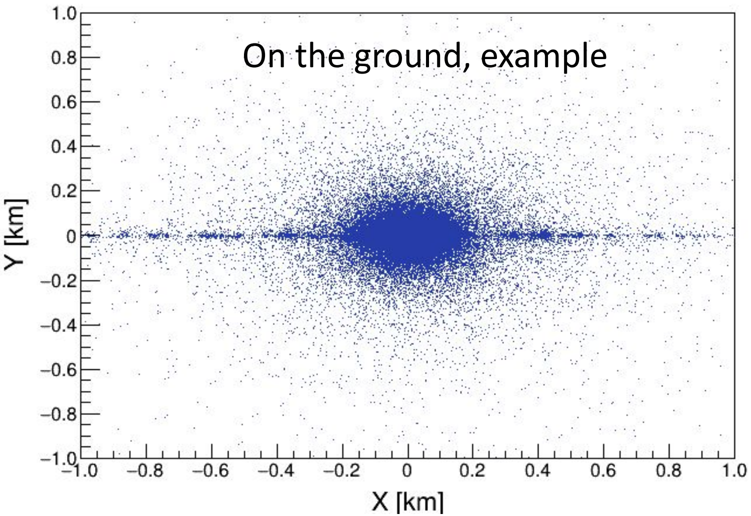
-> more uncertainty in hadronic interactions likely!

-> do not give up UHE photons as a potential explanation of the observed tension in the UHECR energy spectrum?

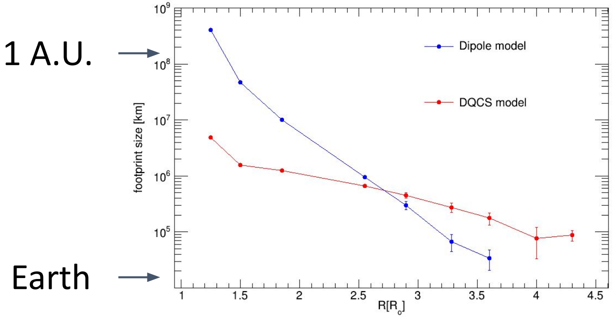
-> how can CREDO help? **Alternative check for UHE photon flux** (no dependence on hadronic interactions)

The Sun-CRE footprints





Sizes vs. impact parameter, on top of the atmosphere



CREDO detectors today

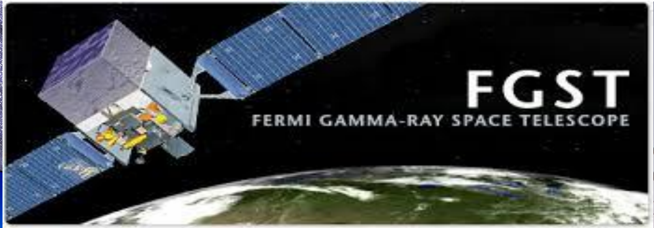
- CREDO Detector (Android app, ~2M track candidates, origin: IFJ PAN)
- cosmicrayapp.com (iOS, ~7M track candidates, origin: Canada)
- CREDO Web Detector (Chrome, in tests, origin: Kraków)
- HEAMS - High Energy Astrophysics Muon System (8 x 1m^2 scintillator detectors, ~300k ~0.1 PeV air showers, location: Adelaide)
- IFJ PAN Gamma Spectrometer: *Appl. Sci.* **2021**, *11*(17), 7916; https://doi.org/10.3390/app11177916

public resources:

Pierre Auger Observatory scaler data, Neutron Monitor Database

short term perspective: GELATICA, CZELTA, other public resources

Spacetime structure and gamma astronomy



→ **maximum photon energies < ~10^{12} eV**

→ **testable scale of the spacetime „grain" ("foaminess") < 10^{-18} m** (see e.g. E. S. Perlman *et al* 2015 *ApJ* 805 10)

CREDO
THE QUEST FOR THE UNEXPECTED

→ **maximum photon energies in CRE (ensembles) < 10^{20} eV +**

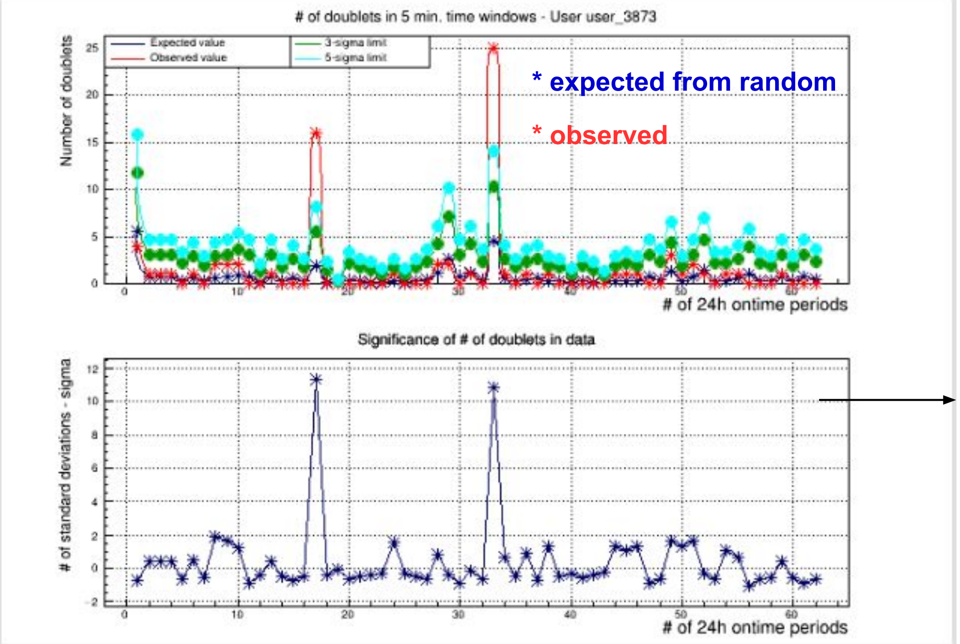
→ **Potential sensitivity to the spacetime „grain" < 10^{-26} m**

Quantum Gravity Previewer: online experiment!

Cumulative number of hit pairs („doublets") within 5 min, in a single smartphone

by Kevin Almeida Cheminant, for the CREDO Collaboration

Number of doublets (two cosmic ray detections in an interval of 5 minutes) found in data (red) in every 24 hour period versus the expected value obtained from background simulations(dark blue). Number of doublets needed to obtain a 3 or 5 sigma effect are also given (green and light blue, respectively).



Significance of number of doublets (two cosmic ray detections in an interval of 5 minutes) found in data in every 24 hour period.

10σ

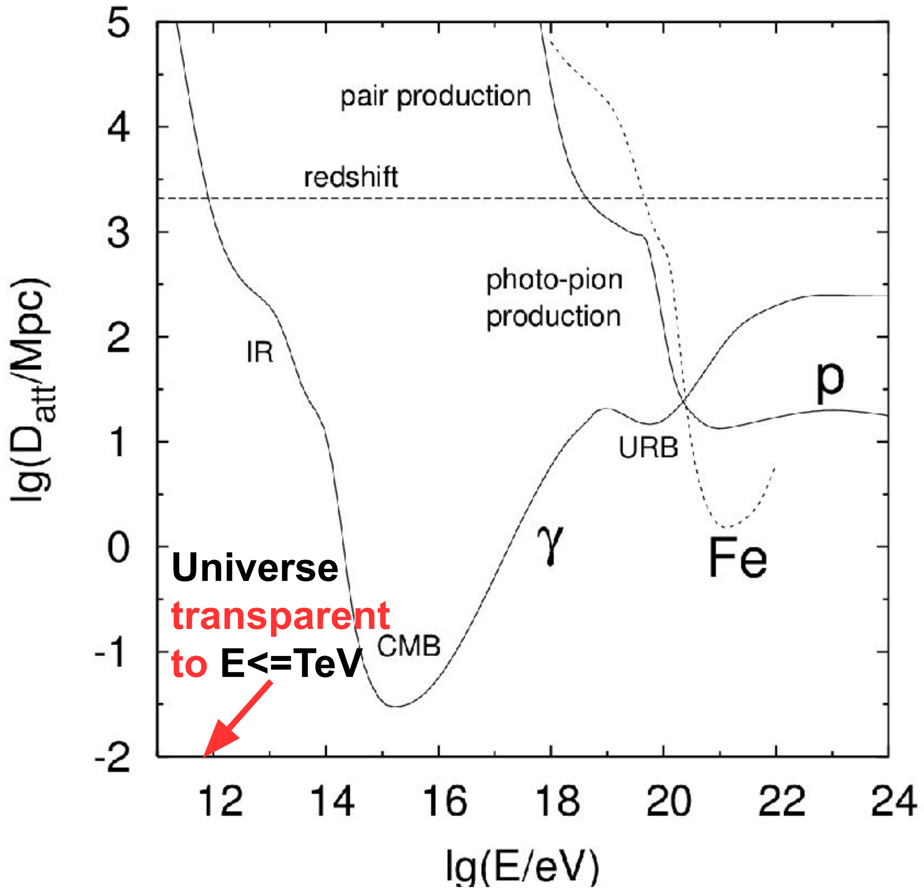
(significance)

See also the IFJ PAN / CREDO public release in EurekAlert! [HERE]

https://youtu.be/6rHnW--PZQk


Pay attention
to data!
Give me
more new data!
PRACTICE
THEORY

CR propagation → interactions → products!



c. Earthquakes: early warning system with help of a global network of cosmic ray sensors?

The existing astro-geo effort

https://indico.in2p3.fr/event/18287/

Workshop on Observatory Synergies for Astroparticle physics and Geoscience

11-12 February 2019
IPGP
Europe/Paris timezone

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Timetable

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09:00	**Speed-of-light Seismology and Earthquake Early Warning Systems** *Amphithéâtre, IPGP*	*J-P Montagner et al.* 09:00 - 09:20
	Time and frequency transfer over telecommunication fiber networks: a new research infrastructure for geoscience and astroparticle physics?	*P-E Pottie*
	Geophysical noise in the Virgo gravitational wave antenna *Amphithéâtre, IPGP*	*Irene Fiori* 09:40 - 09:55
10:00	**Seismic characterization of GW detector sites using an array of wireless geophones** *Amphithéâtre, IPGP*	*Soumen Koley* 09:55 - 10:10

other channels, example:

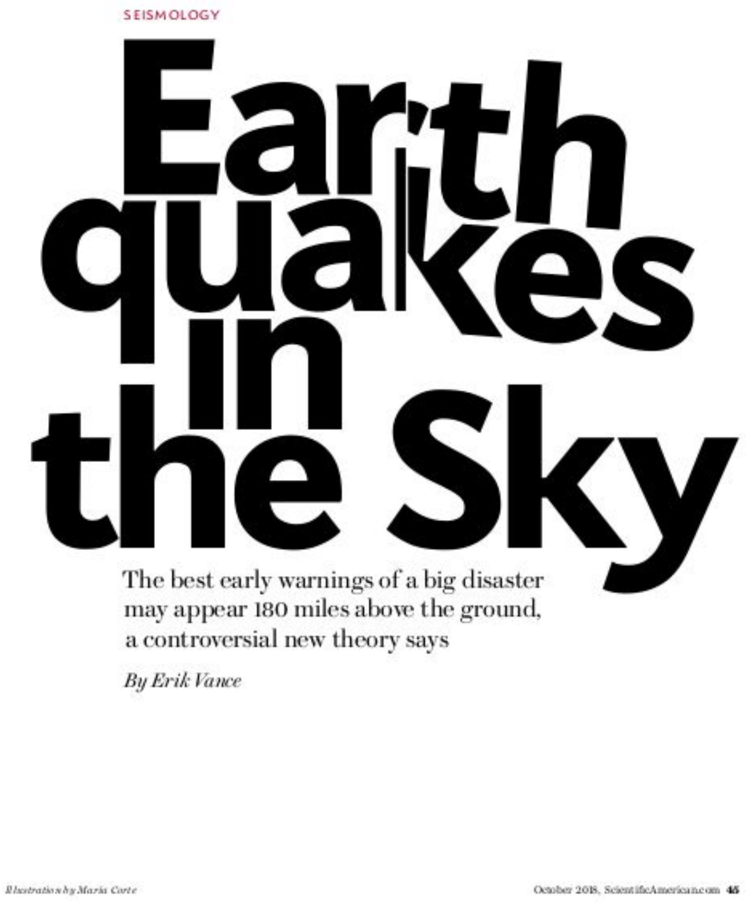

OCTOBER 2018

VOLUME 319, NUMBER 4

SCIENTIFIC AMERICAN

ON THE COVER
Three mathematicians spent several years and 146 pages proving that the "spectral gap" problem—the question of whether materials have a gap between their lowest energy level and first excited state—is undecidable. To reach this conclusion, the researchers investigated the computer science of Turing machines, the mathematics of bathroom floor tiles and the foundations of quantum physics.
Illustration by Mark Ross Studios.

SCIENTIFIC AMERICAN THE UNSOLVABLE PROBLEM


SEISMOLOGY

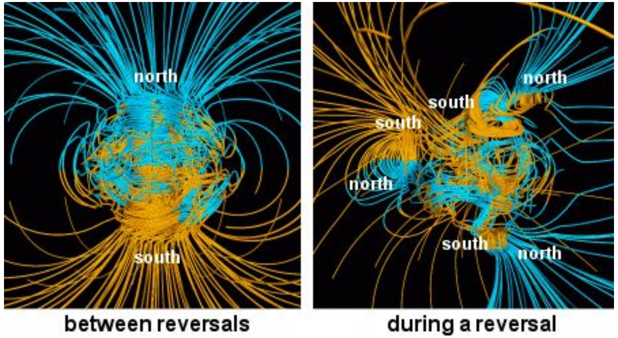
Earthquakes in the Sky

The best early warnings of a big disaster may appear 180 miles above the ground, a controversial new theory says

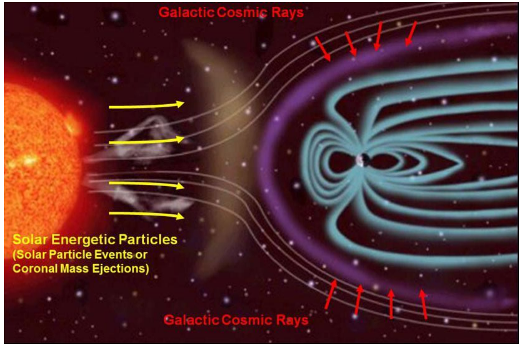
By Erik Vance

Illustration by Maria Corte

the COSMO-GEO precursor concept



Source: Wikipedia / „Geomagnetic reversal"



Source: Wikipedia / „Health threat from cosmic rays"

Earth outer core: Liquid (molten iron)
→ geomagnetism

↓

Impulse (tidal forces)
→ hydrodynamics: waves

↓

→ Mechanical wave upwards (slow, hours?)
→ Electromagnetic wave („instant", ms)

↓

Local/global geomagnetic field vector changes
AND seismic effect might occur!

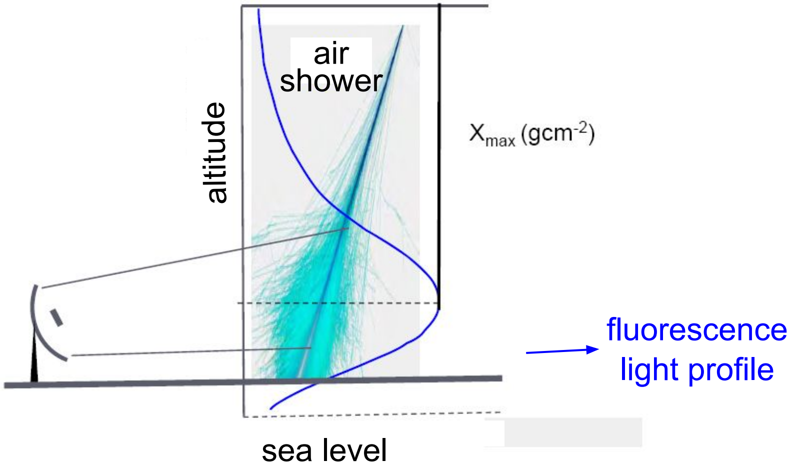
↓

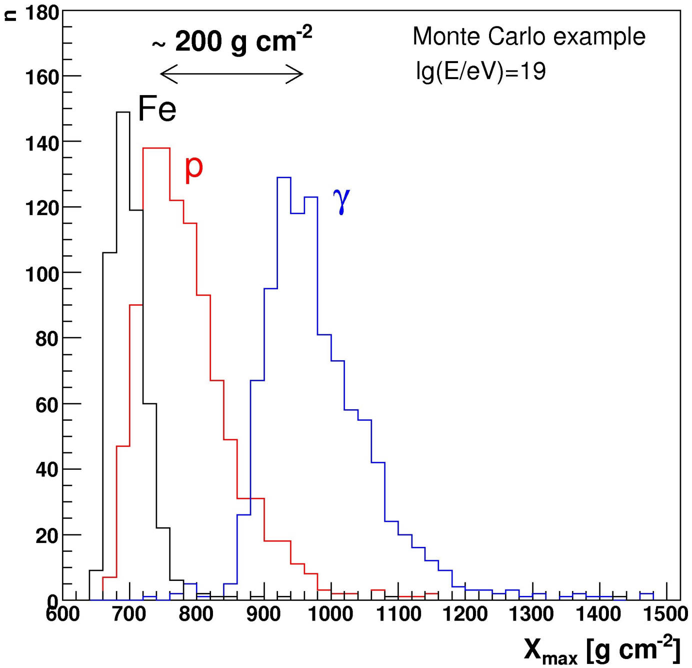
Variation of the CR rate!

↓

Earthquake precursors?

UHECR identification: X_{max}





X_{max}: atmospheric depth of shower maximum development

$\rightarrow \langle X_{max}(Fe)\rangle < \langle X_{max}(p)\rangle < \langle X_{max}(\gamma)\rangle$

$\rightarrow$ RMS[X_{max}(Fe)] < RMS[X_{max}(p)]

Landau-Pomeranchuk-Migdal (LPM) effect I

LPM effect:
Pair prodution formation length ⩾ mean free path → destructive interference from several scattering centers: $\gamma \not\rightarrow e^+e^-$

Bremsstrahlung supressed as well. Confirmed by experiments.

Formation lenght: the lenght of the photon trajectory over which pair production happens
Pair production formation length icreases with photon energy $\mathbf{E_\gamma}$
Photon mean free path decreases with medium density ϱ

→ the **Bethe-Heitler cross-section** for pair production by photons, σ_{BH} (in air $\sigma_{BH} \approx 0.51$ b), can be **reduced** when $\mathbf{E_\gamma}$ and/or medium density ϱ **high**

$\kappa = E_\gamma E_{LPM}/[E_e(E_\gamma - E_e)]$, $E_{LPM} = m_e^2 c^3 \alpha X_0/(4\pi\hbar\varrho) \approx (7.7 \text{ TeV/cm}) \times X_0/\varrho$, $X_0 \sim 37 \text{ g cm}^{-2}$
E_γ - photon energy, E_e - electron energy, ϱ - medium density, X_0 - radiation length

Approximation for $\kappa<1$: $\boldsymbol{\sigma_{LPM} = \sigma_{BH}\, \kappa^{1/2} \propto (\varrho\, E_\gamma)^{-1/2}}$
→ σ_{BH}/σ_{LPM} largest for a symmetric energy partition in the electron pair, $E_e \approx E_\gamma/2$

Landau-Pomeranchuk-Migdal (LPM) effect II

The LPM effect delays the development of an air shower initiated by a single UHE photon!

→ deep X_{max}

For atmospheric depths $X_2 > X_1$: $\sigma_{LPM}(X_2) < \sigma_{LPM}(X_1)$.

The deeper photon goes the smaller pair production probability!

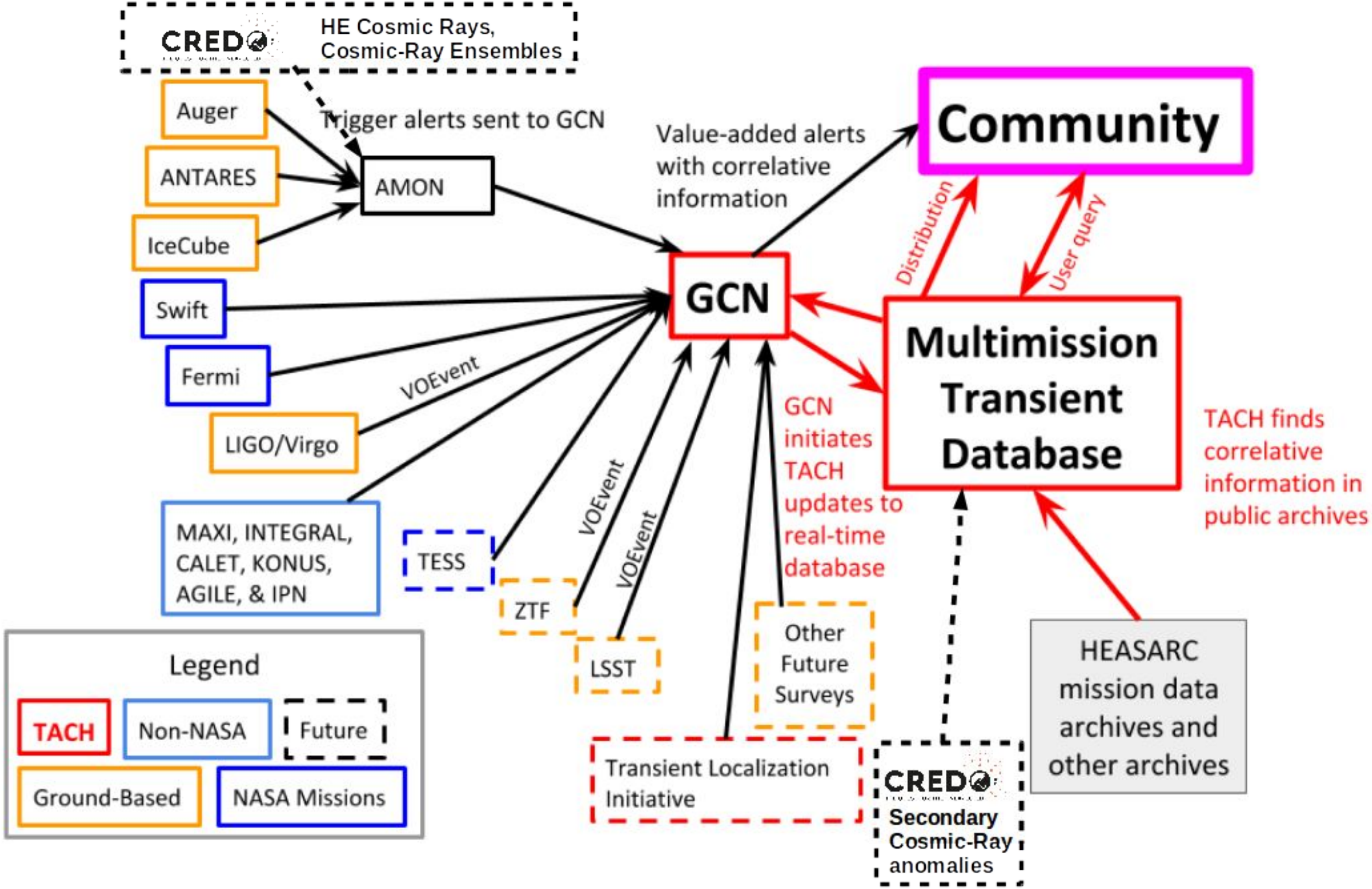
→ very large X_{max} fluctuations

Both deep X_{max} and very large X_{max} fluctuations are **good photon signatures!**

The LPM effect is accounted for in CORSIKA.

More:
PDG review and the references therein:
K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014)

the CREDO potential/ambition



The CREDO potential contributions to the Time Domain Astronomy Coordination Hub (TACH), a new NASA initiative (the CREDO logo has been positioned in two distinct places on top of the slide by Judith Racusin, NASA, from her invited talk at the New Era of Multi-Messenger Astrophysics Conference, Groningen, March 2019).

Cosmic-Ray Ensembles (CRE): road map

Theoretical scenarios (ongoing) ✓
non-exotic / exotic

↓

CRE standalone simulations → particle distributions at the top of the atmosphere (ongoing) ✓

↓

Air shower simulations (ongoing) ✓

↓

Detector response (ongoing) ✓

↓

observation / upper limits

scenarios!

Cosmic-Ray Ensembles (CRE): shortcut road map

quest (fishing) for the unexpected

Theoretical review (ongoing) ✓

↓

CRE standalone simulations → particle distributions at the top of the atmosphere (ongoing) ✓

↓

Air shower simulations (ongoing) ✓

↓

Detector response (ongoing) ✓

↓

observation / upper limits ← unique signature **fishing (ongoing)** ✓

CRE and Experimental Quantum Gravity

T. Jacobson, S. Liberati, and D. Mattingly, Annals Phys. 321 (2006) 150

Lorentz violation at high energy: concepts, phenomena and astrophysical constraints

Ted Jacobson [a], Stefano Liberati [b], David Mattingly [c]

[a] *Department of Physics, University of Maryland, USA*

[b] *International School for Advanced Studies and INFN, Trieste, Italy*

[c] *Department of Physics, University of California at Davis, USA*

extensive review). A partial list of such "windows on quantum gravity" is

- sidereal variation of LV couplings as the lab moves with respect to a preferred frame or directions
- cosmological variation of couplings
- cumulative effects: long baseline dispersion and vacuum birefringence (e.g. of signals from gamma ray bursts, active galactic nuclei, pulsars, galaxies)
- new threshold reactions (e.g. photon decay, vacuum Čerenkov effect)
- shifted existing threshold reactions (e.g. photon annihilation from blazars, GZK reaction)
- LV induced decays not characterized by a threshold (e.g. decay of a particle from one helicity to the other or photon splitting)
- maximum velocity (e.g. synchrotron peak from supernova remnants)
- dynamical effects of LV background fields (e.g. gravitational coupling and additional wave modes)

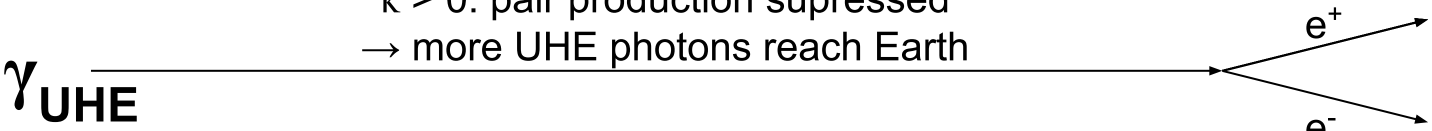
CRE and Lorentz Invariance Violation

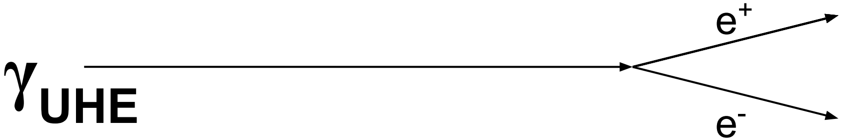
Modified dispersion relation of a photon:

$$E_\gamma(\vec{k}) = \sqrt{\frac{(1-\kappa)}{(1+\kappa)}}|\vec{k}|$$

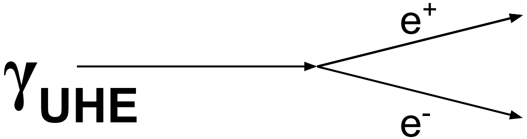
limits from gamma-ray astronomy,
98% C.L. (Klinkhamer & Schreck, 2008):
$6 \times 10^{-20} > \kappa > -9 \times 10^{-16}$

$\kappa > 0$: pair production supresed
→ more UHE photons reach Earth





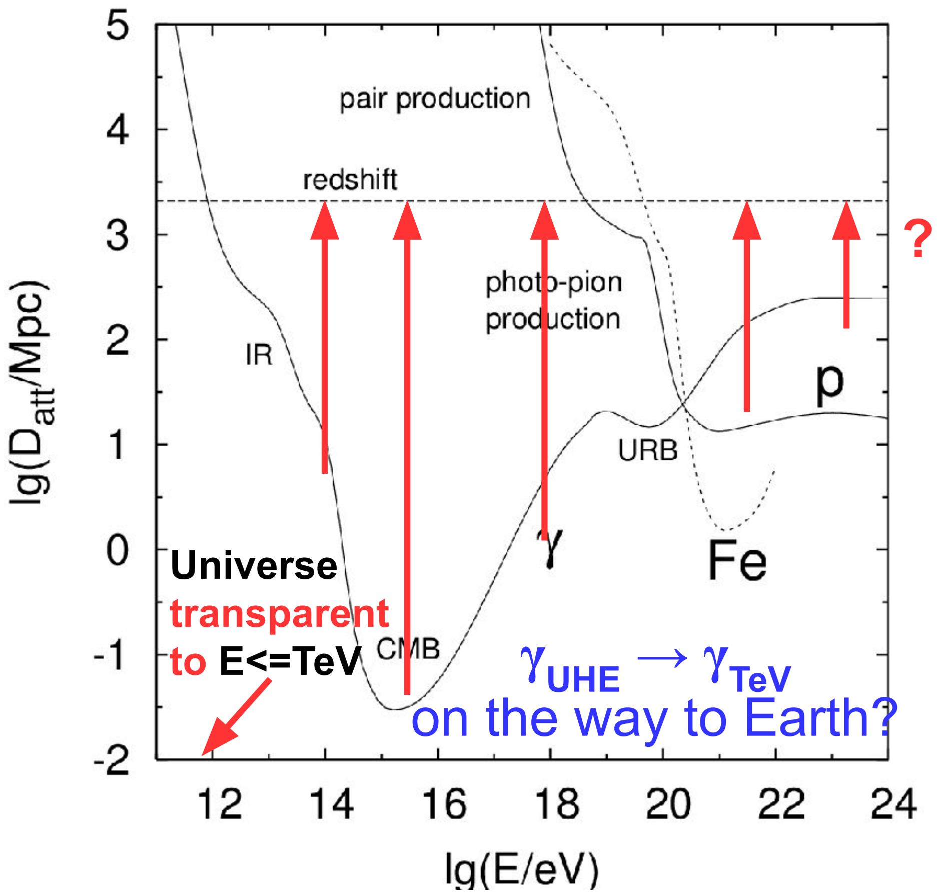
$\kappa = 0$: „normal” pair production



$\kappa < 0$: pair production enhanced
(photon lifetime ~ 1 sec.!)
→ no UHE photons reach Earth

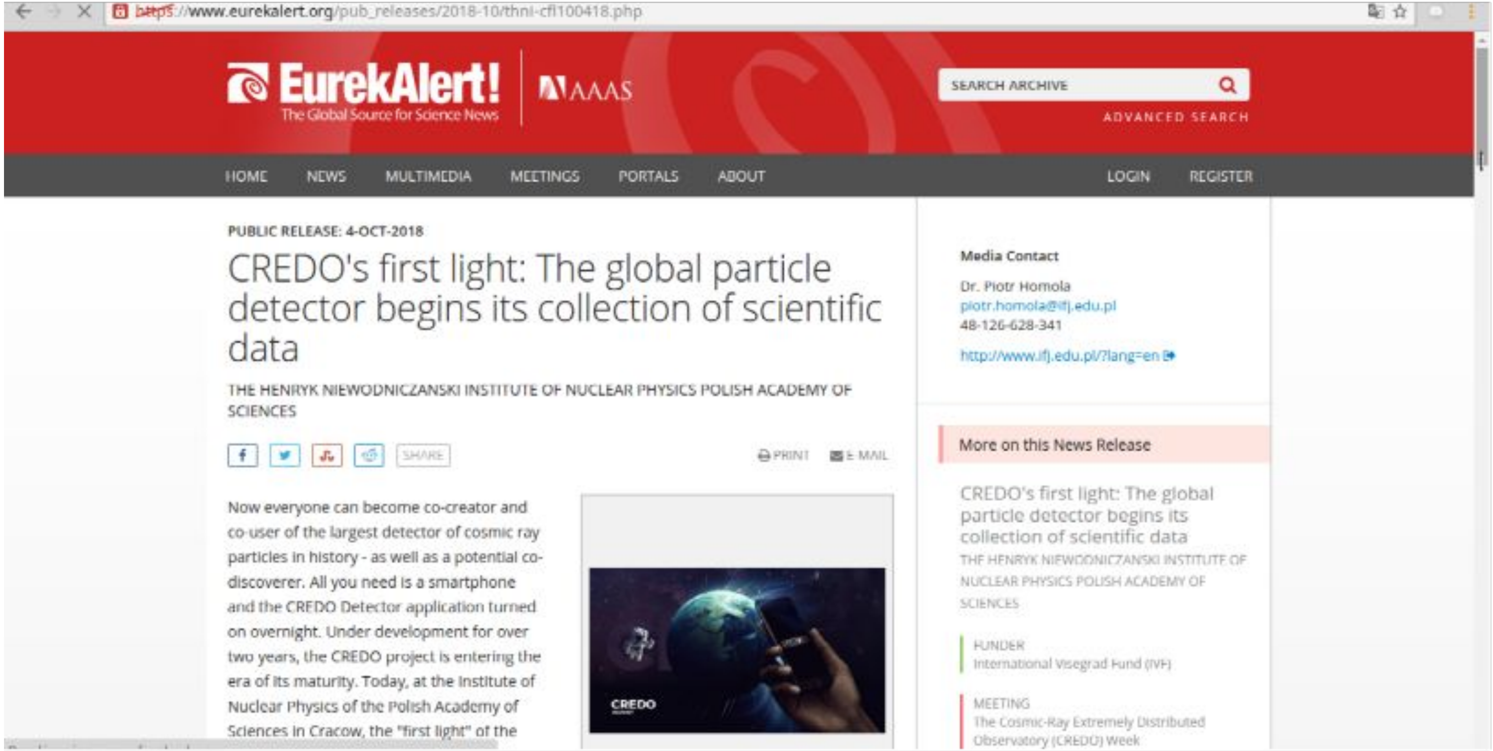
→ critical importance for the UHE photon search!
Observation of **photon cascades** would point to $\kappa < 0$!

γ_{HE} travelling through the Universe: photon decay?



4 October 2018: CREDO's first light!

quest (fishing) for the unexpected



https://www.eurekalert.org/pub_releases/2018-10/thni-cfl100418.php

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PUBLIC RELEASE: 4-OCT-2018

CREDO's first light: The global particle detector begins its collection of scientific data

THE HENRYK NIEWODNICZANSKI INSTITUTE OF NUCLEAR PHYSICS POLISH ACADEMY OF SCIENCES

SHARE PRINT E-MAIL

Now everyone can become co-creator and co-user of the largest detector of cosmic ray particles in history - as well as a potential co-discoverer. All you need is a smartphone and the CREDO Detector application turned on overnight. Under development for over two years, the CREDO project is entering the era of its maturity. Today, at the Institute of Nuclear Physics of the Polish Academy of Sciences in Cracow, the "first light" of the

CREDO

Media Contact

Dr. Piotr Homola
piotr.homola@ifj.edu.pl
48-126-628-341
http://www.ifj.edu.pl/?lang=en

More on this News Release

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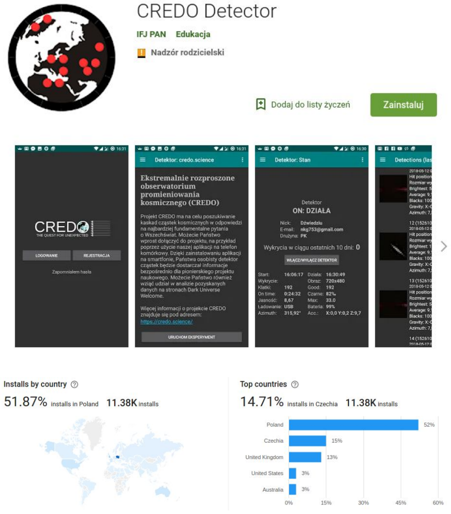
FUNDER
International Visegrad Fund (IVF)

MEETING
The Cosmic-Ray Extremely Distributed Observatory (CREDO) Week

Achievement (4.10.2018): signal from the first automatized, mass participation scientific experiment on the CREDO infrastructure

CREDO
THE QUEST FOR THE UNEXPECTED

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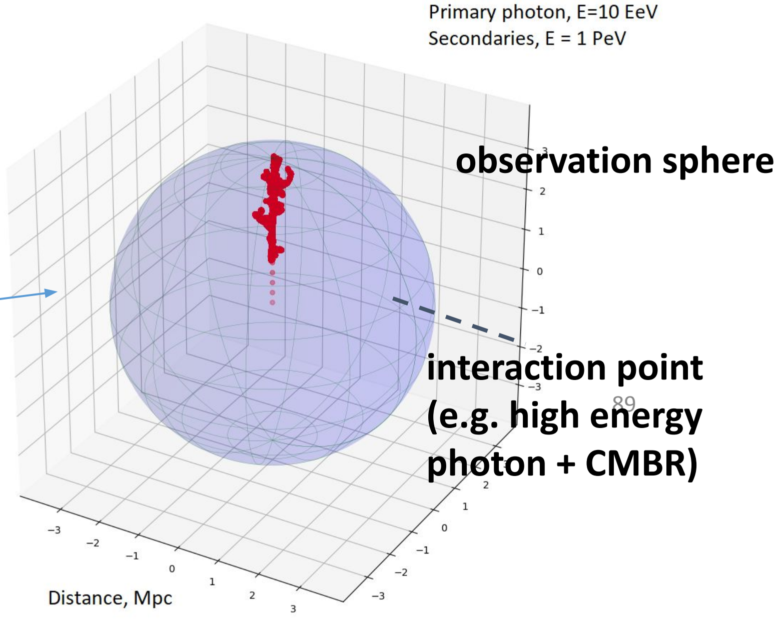
mobile app → data → scaling up → first results → dissemination

CRE exist! Simulations with CRPropa

CRPropa3 [https://github.com/CRPropa/CRPropa3, https://arxiv.org/abs/1603.07142]

3D simulations of a photon primary propagation

1. Simplest case – { GMF (JF12) + } EGMF
2. Accounting for synchrotron radiation (computational issues)
3. Specific cases (e.g. neuron star environment)
4. Making use of [Kobzar O., Hnatyk B., Marchenko V., Sushchov O. MNRAS, Vol. 484, Issue 2, pp. 1790-1799, DOI: 10.1093/mnras/stz094].



scenarios!

credit: A. Sushchov, IFJ PAN

CREDO Detector: what do we see?

[work in progress, e.g. at IFJ PAN]

scenarios!

muons?

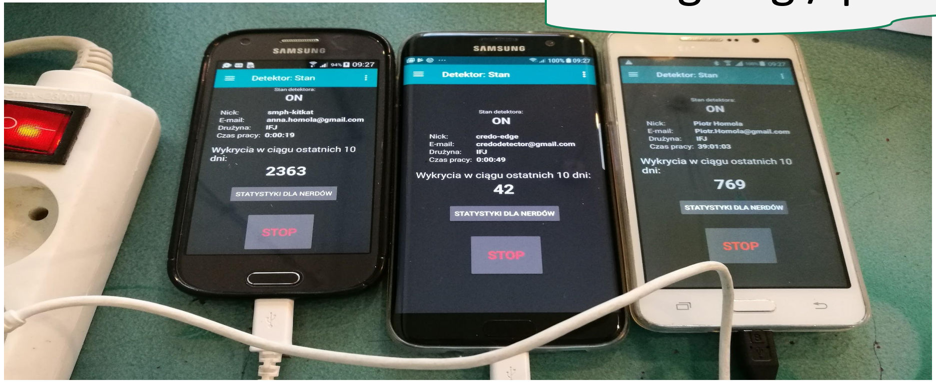
air showers ?

CRE?

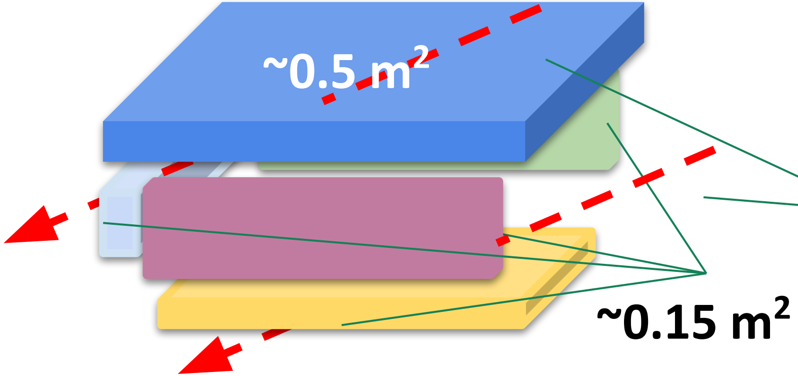
Smartphone detections: calibration for air showers and muons with scintillator plates

work at IFJ PAN,
credit Krzysztof Gorzkiewicz, PH

ongoing / preliminary



CANBERRA BEGe BE5030(Broad Energy Germanium) + 5 plastic scintillation detectors type EJ-200 by Scionix (2 horizontal and 3 vertical) + Digitizer CAEN DT5725

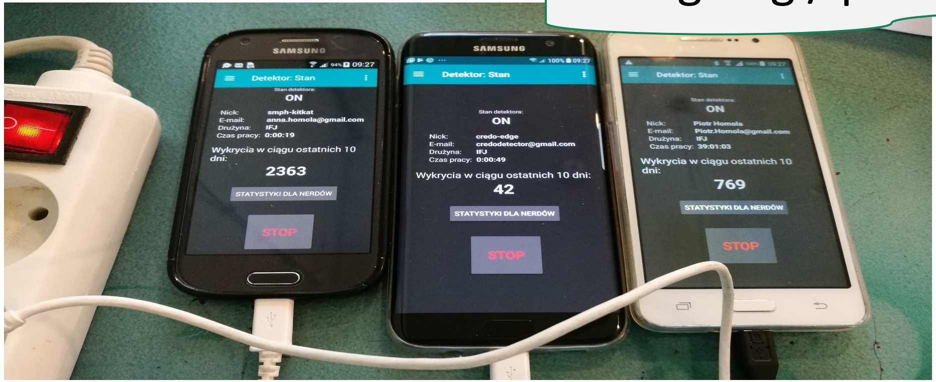


Events registered simultaneously in at least 3 different detectors
= air showers (N_{muon}>1)
observed ~15000 / day
(cf. c.a. 10000 10^{12} eV air showers expected per m^2 per day, verifying with simulations in progress)

Smartphone detections: calibration for air showers and muons with scintillator plates

work at IFJ PAN,
credit Krzysztof Gorzkiewicz, PH

ongoing / preliminary



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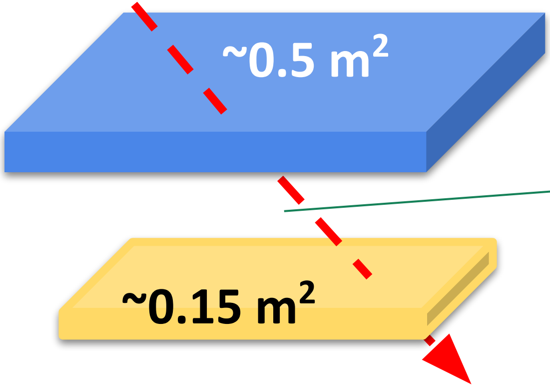


Events registered simultaneously in the top and bottom detectors = air shower muons

observed ~400,000 / day

(compatible with background vertical muons expected per 0.15 m^2 per day, data)

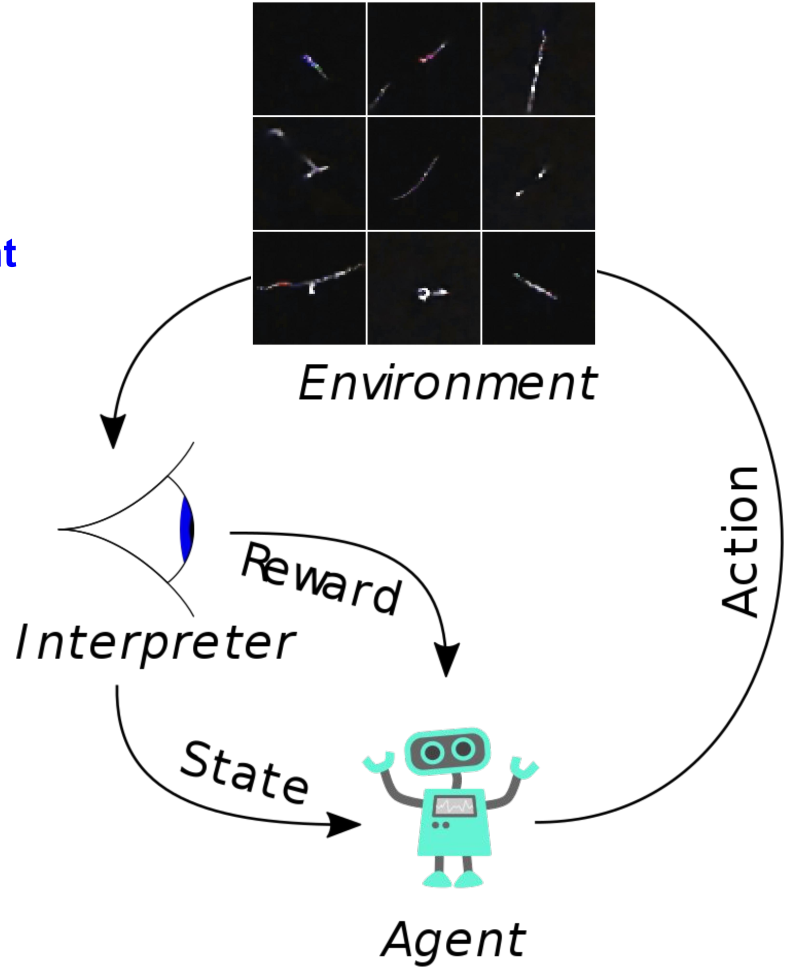
CREDO
THE QUEST FOR THE UNEXPECTED

"Citizen science support for reinforcement learning - a case of CREDO experiment"

Michał Niedźwiecki (PK) - PhD topic
Robert Kamiński (IFJ PAN) - supervisor
Krzysztof Rzecki (PK) - assistant supervisor

PhD/publication perspective: 24 months

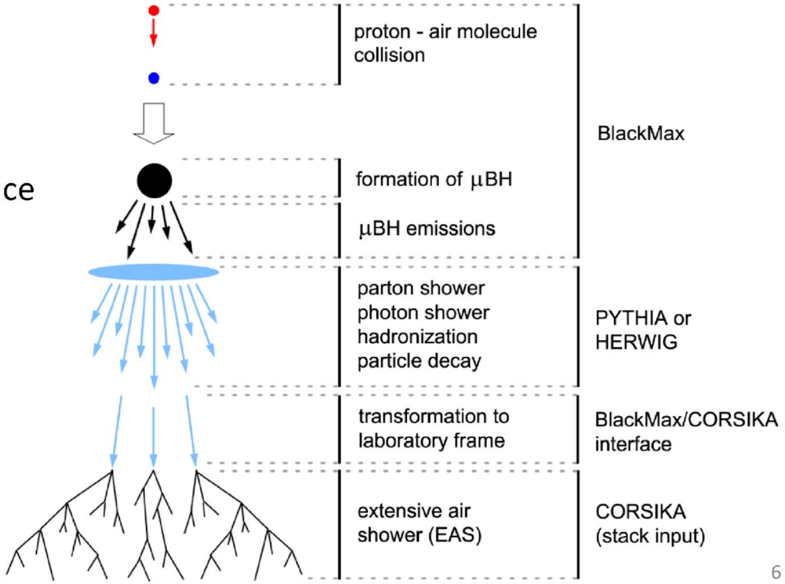
Wikipedia:
machine learning paradigms:
- supervised learning
- unsupervised learning
- **reinforcement learning**



Wikipedia / CREDO

Detection of μBHs at the PAO

- Main research idea: Prepare an interface between two Monte Carlo simulators and check, if μBH induced extensive air showers (EAS) can be separated from normal cosmic ray EAS
- Simulators used: BlackMax (μBH evaporation) and CORSIKA (development of EAS)
- Formation of μBHs assumes existence of extra dimensions
- Use longitudinal development of an EAS and X^{μ}_{max} as a separation indicator



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Credit: Gasper Kukec, University Nova Gorica, Slovenia

CREDO Theatre!

https://www.youtube.com/watch?v=TaKB2zhZ8j4

Trailer, Part I, Part II: CREDO YouTube