The Cosmic Ray Extremely Distributed Observatory

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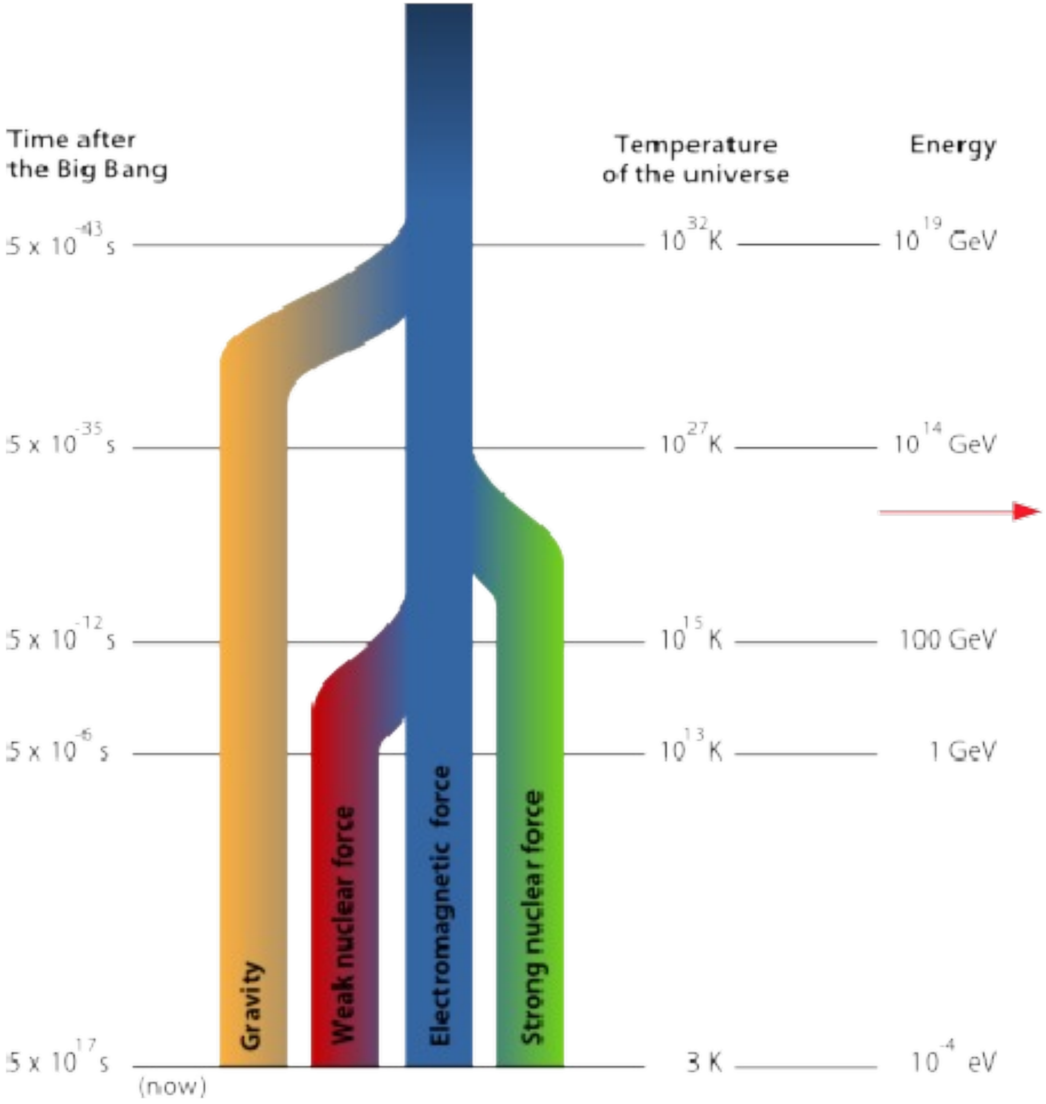
Outline

- Introduction to detection of cosmic rays: CREDO.
- Invitation to participate in CREDO
- Introduction to high energy cosmic rays ensembles and theoretical scenarios for production.
- Cosmic ray ensembles as probes of fundamental physics.
- Cosmic rays signatures as possible precursors of Earthquakes
- Outlook

Energy: the higher the better?

Theory of „Everything" (Qunatum Gravity)?

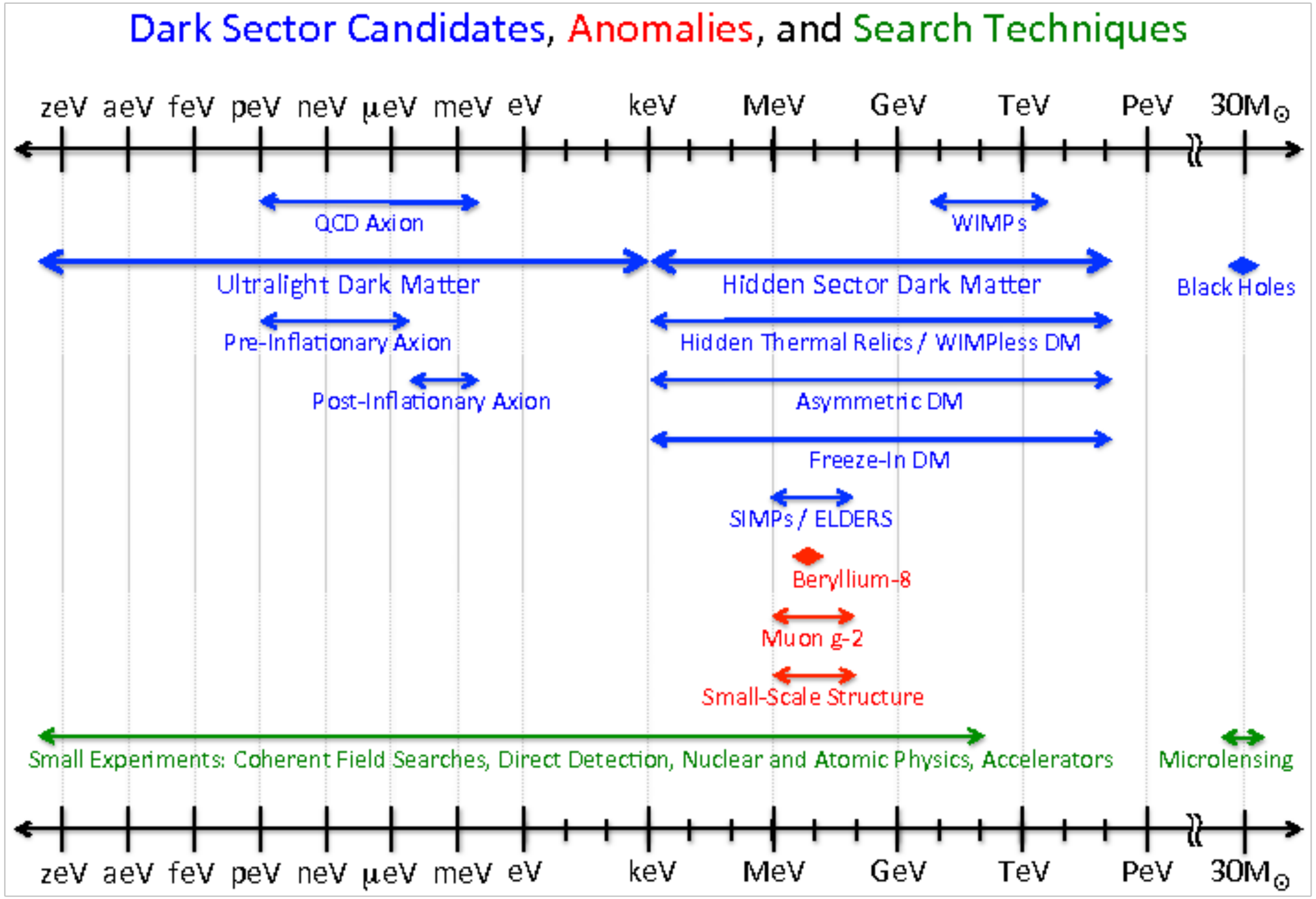
Grand Unified Theory?



Planck scale

Ultra-high energies (10^{20} eV)

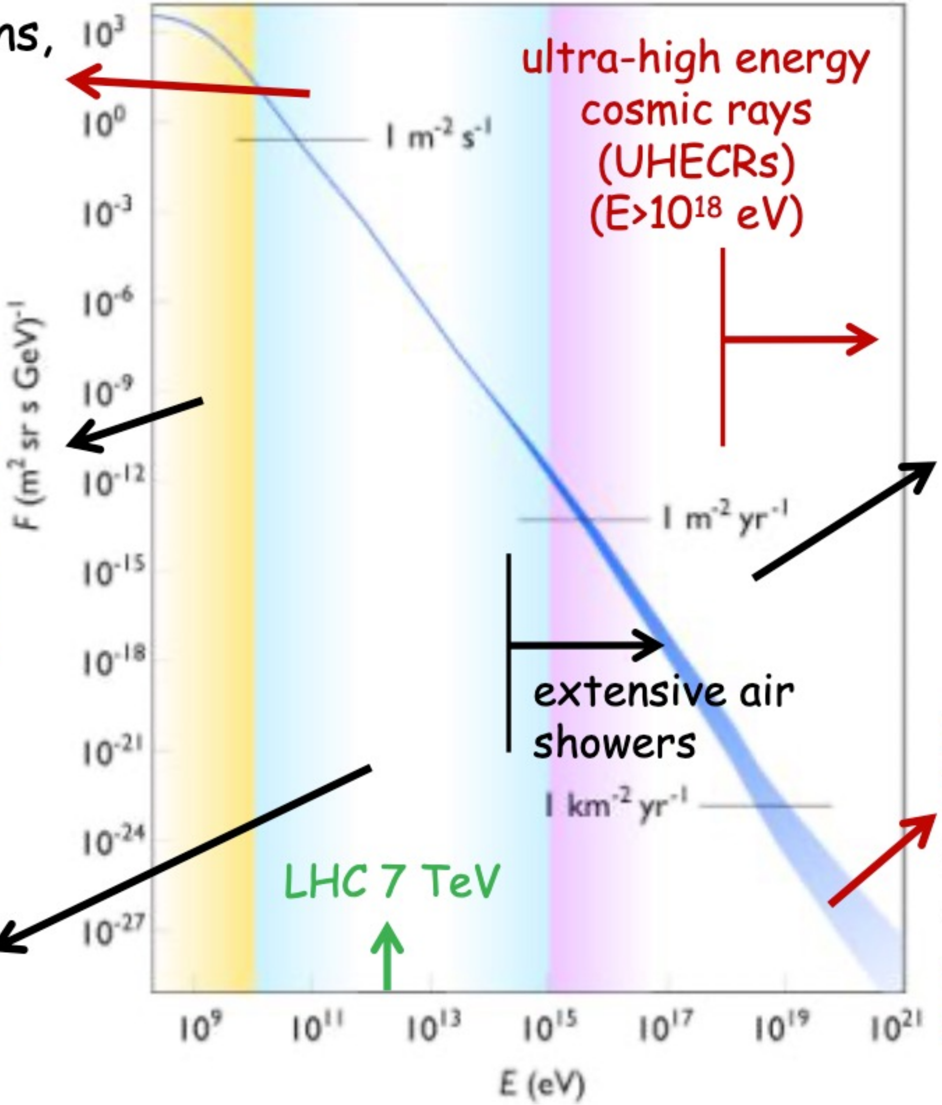
Dark Matter Candidates and Searches



US Cosmic Visions: New Ideas in Dark Matter 2017: Community Report - Battaglieri, Marco et al.
arXiv:1707.04591FERMILAB-CONF-17-282-AE-PPD-T

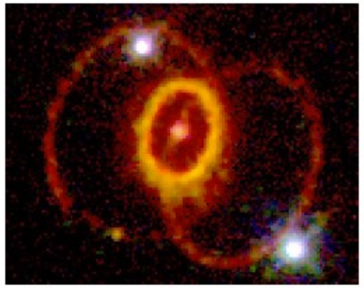
Cosmic rays (CRs) – high-energy particles coming from space
(protons, nuclei, neutrinos, photons, electrons,...)

direct observations, satellites, balloon-borne experiments

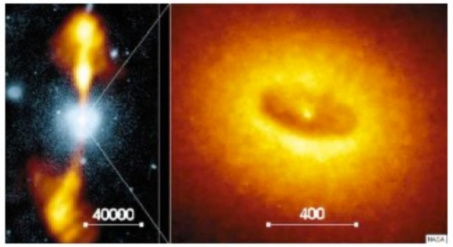


Sun

Supernovae, pulsars



Sources unknown! star burst galaxies, active galactic nuclei (AGNs) ???



$E>10^{20}$ eV, very low flux: 1 particle/km^2/1000 yr (indirect observations, extensive air showers, detector arrays covering large area)

10^{20} eV in LHC technology ⟶ accelerator size of Mercury orbit

(Underexplored) Cosmic Rays!

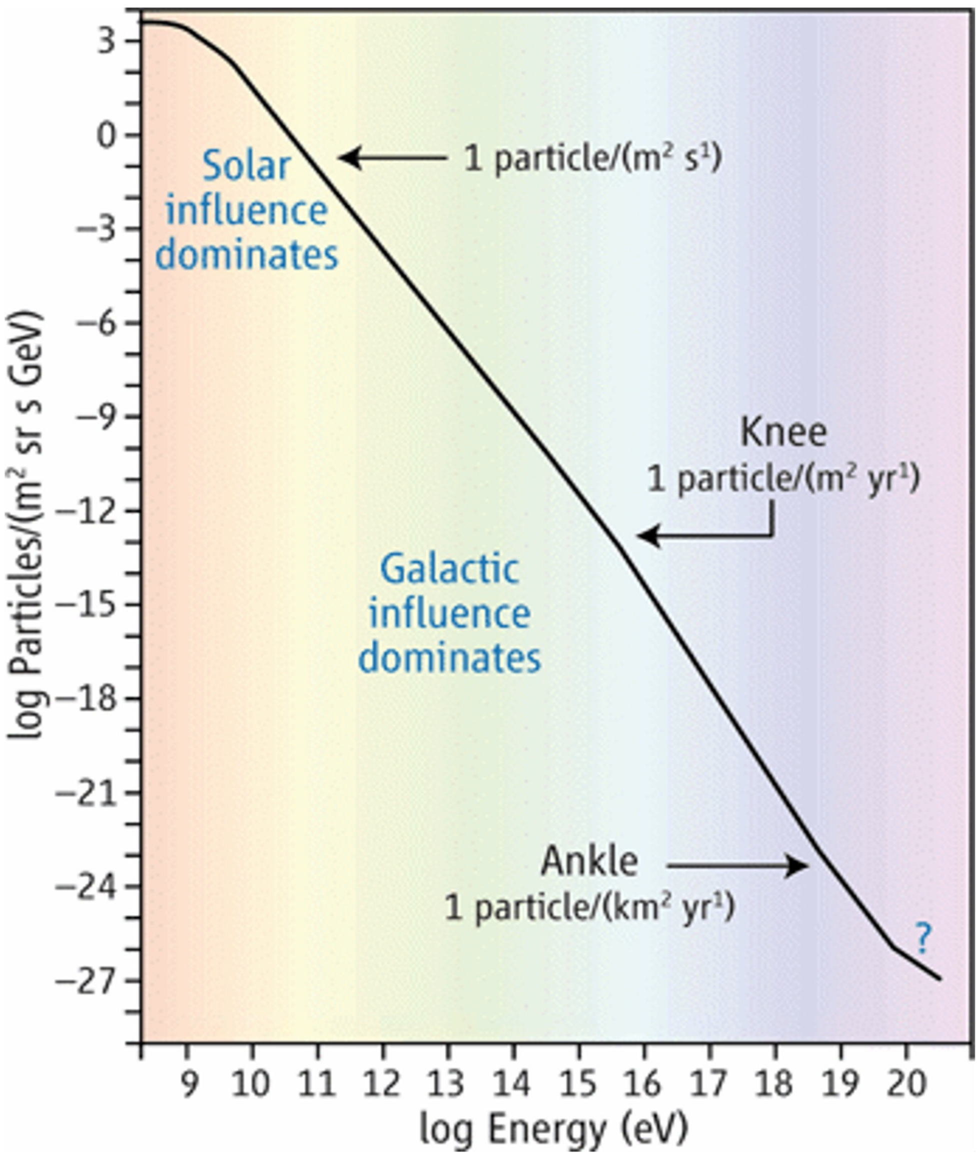
Ranges:

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

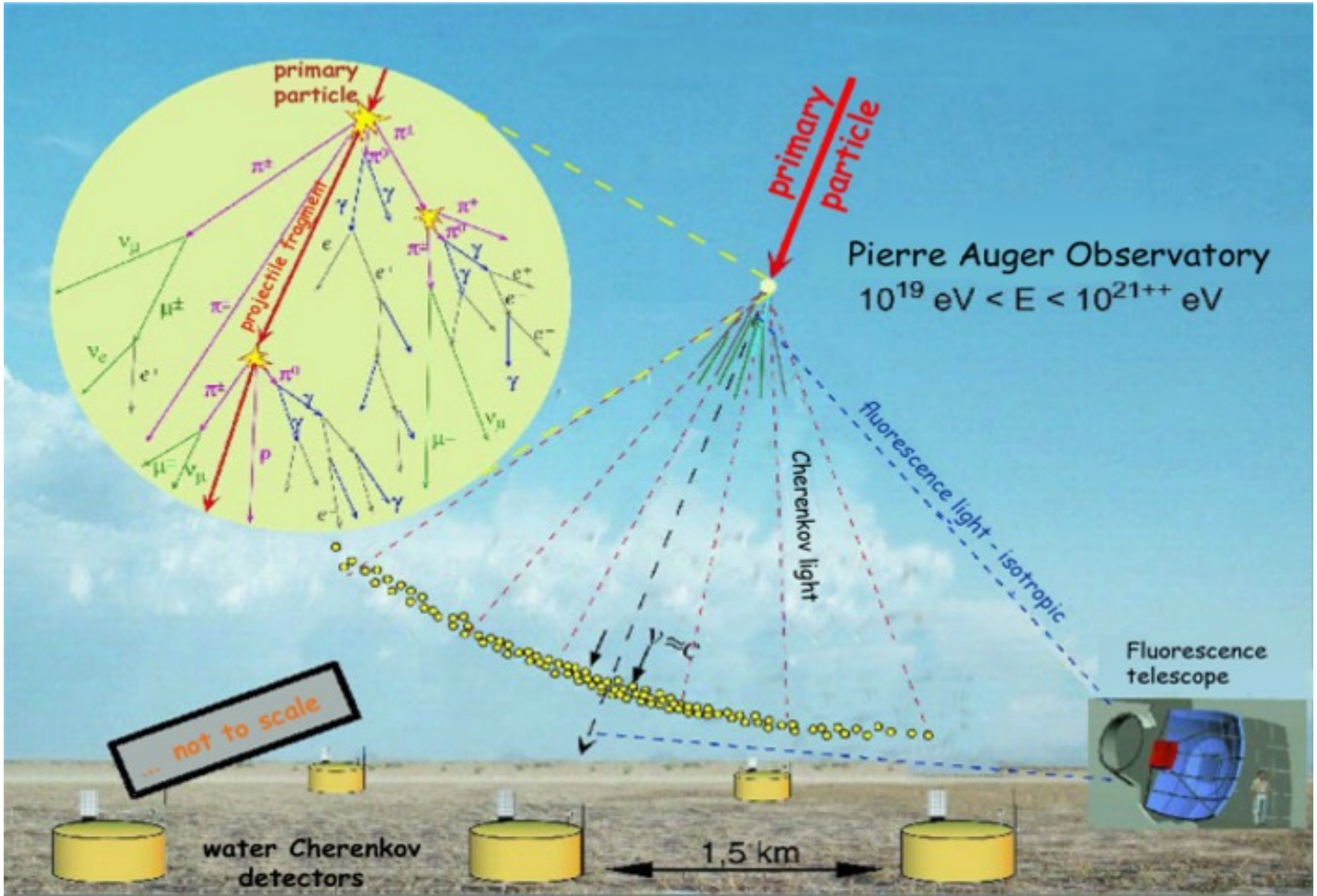
Flux rapidly decreases with energy (~10^{-3}),
Highest energies → the most demanding challenges:

→ 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?



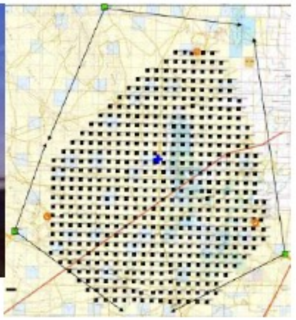
State-of-the art detection of cosmic rays: $N_{ATM}=1$

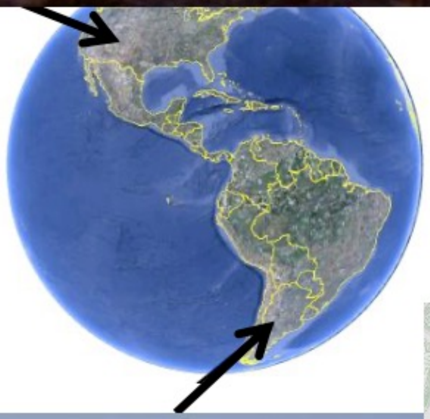


The largest UHECRs observatories

Northern hemisphere

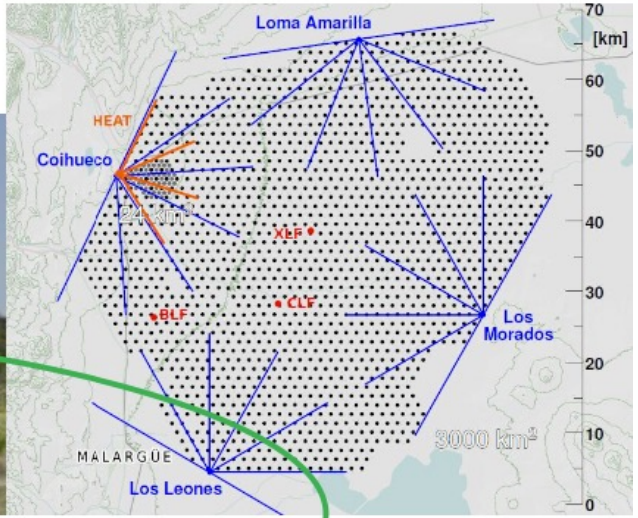
Telescope Array (TA)
Location: USA
507 SD stations, area 680 km^2
36 FD telescopes overlooking the surface detector





Southern hemisphere

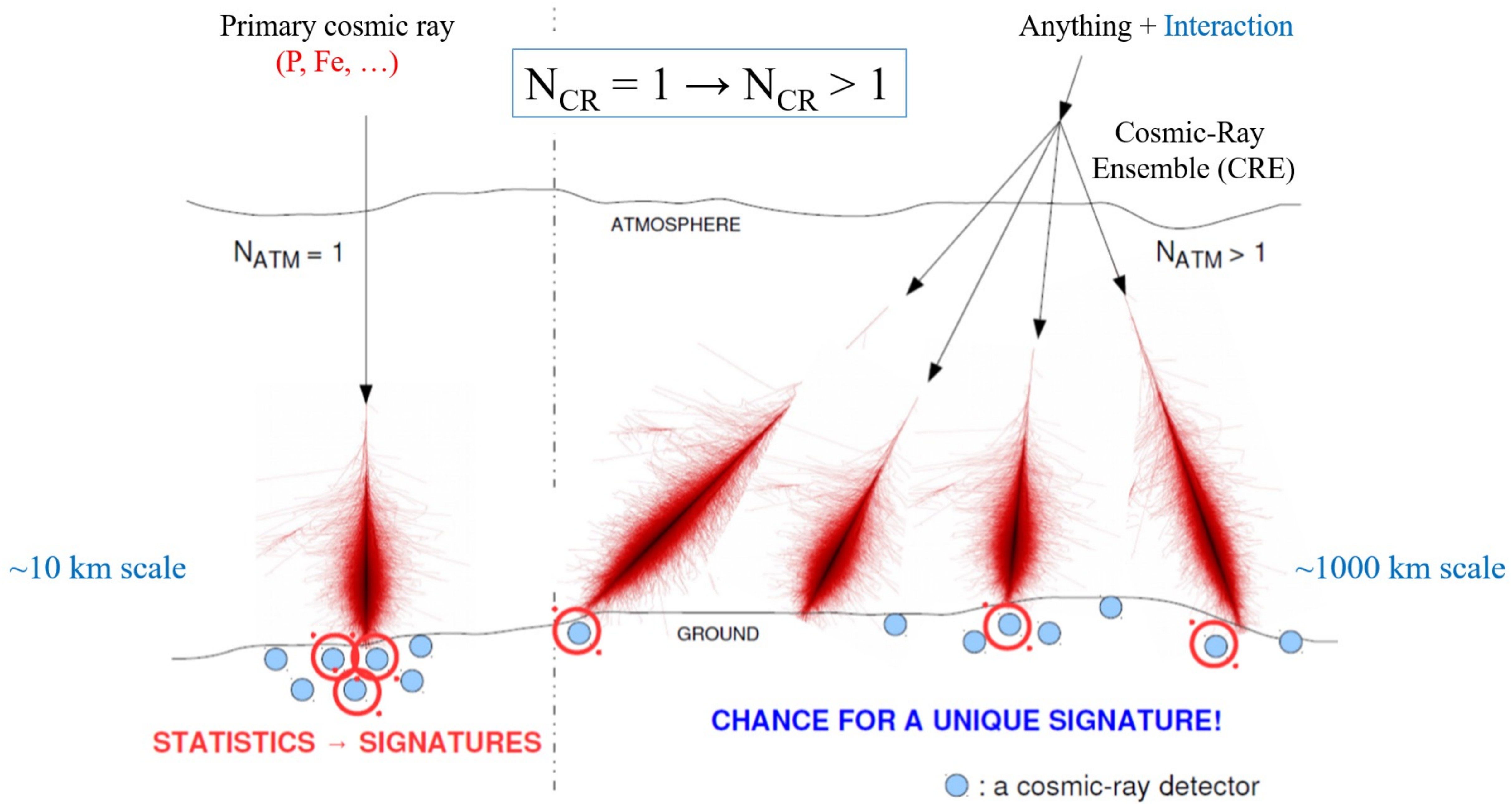
Pierre Auger Observatory (Auger)
Location: Argentina
1660 SD stations, area 3000 km^2
27 FD telescopes



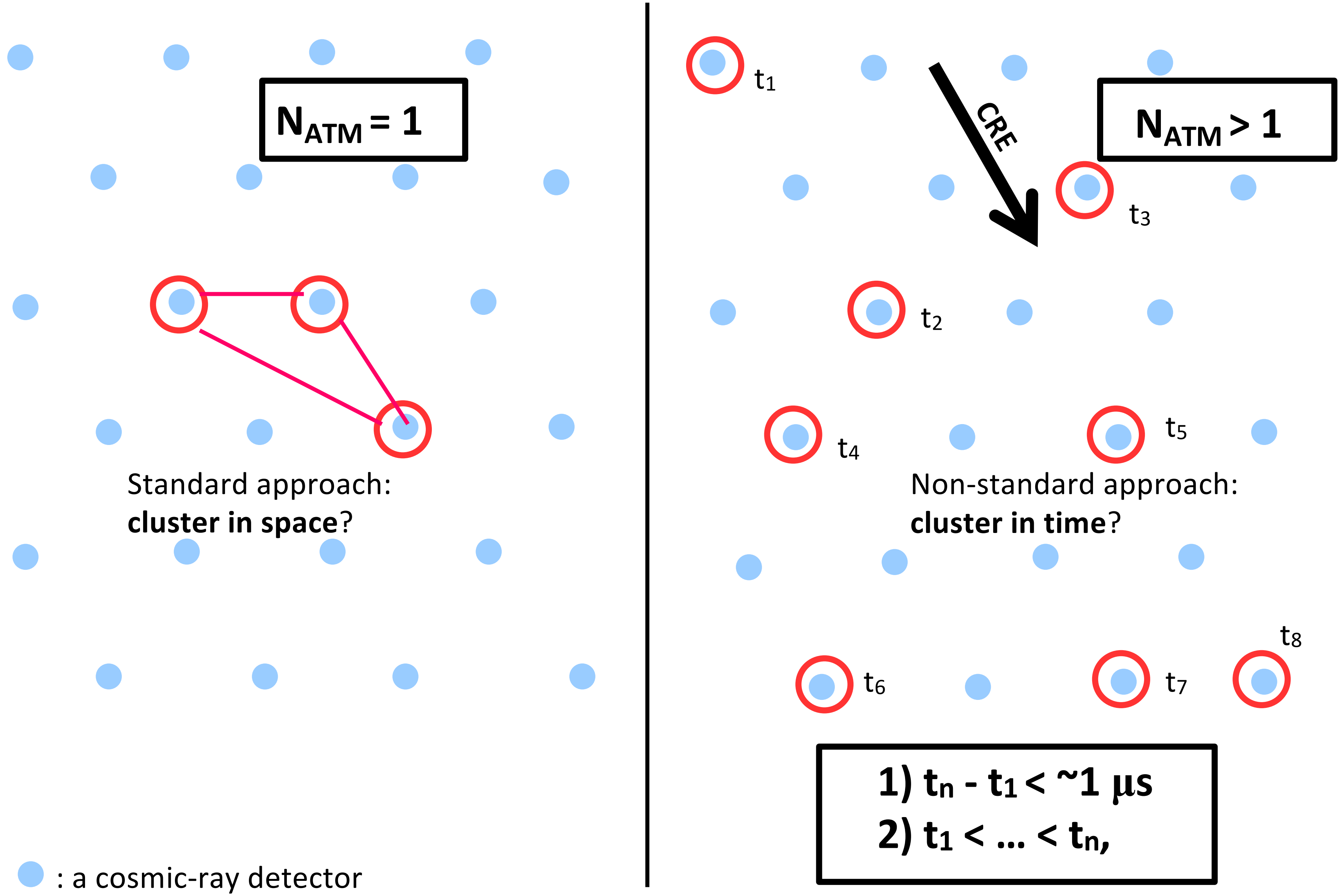
Key questions:

- Origin?
- Mass composition?
- Acceleration process?
- Is there an upper limit to the UHECRs energies?

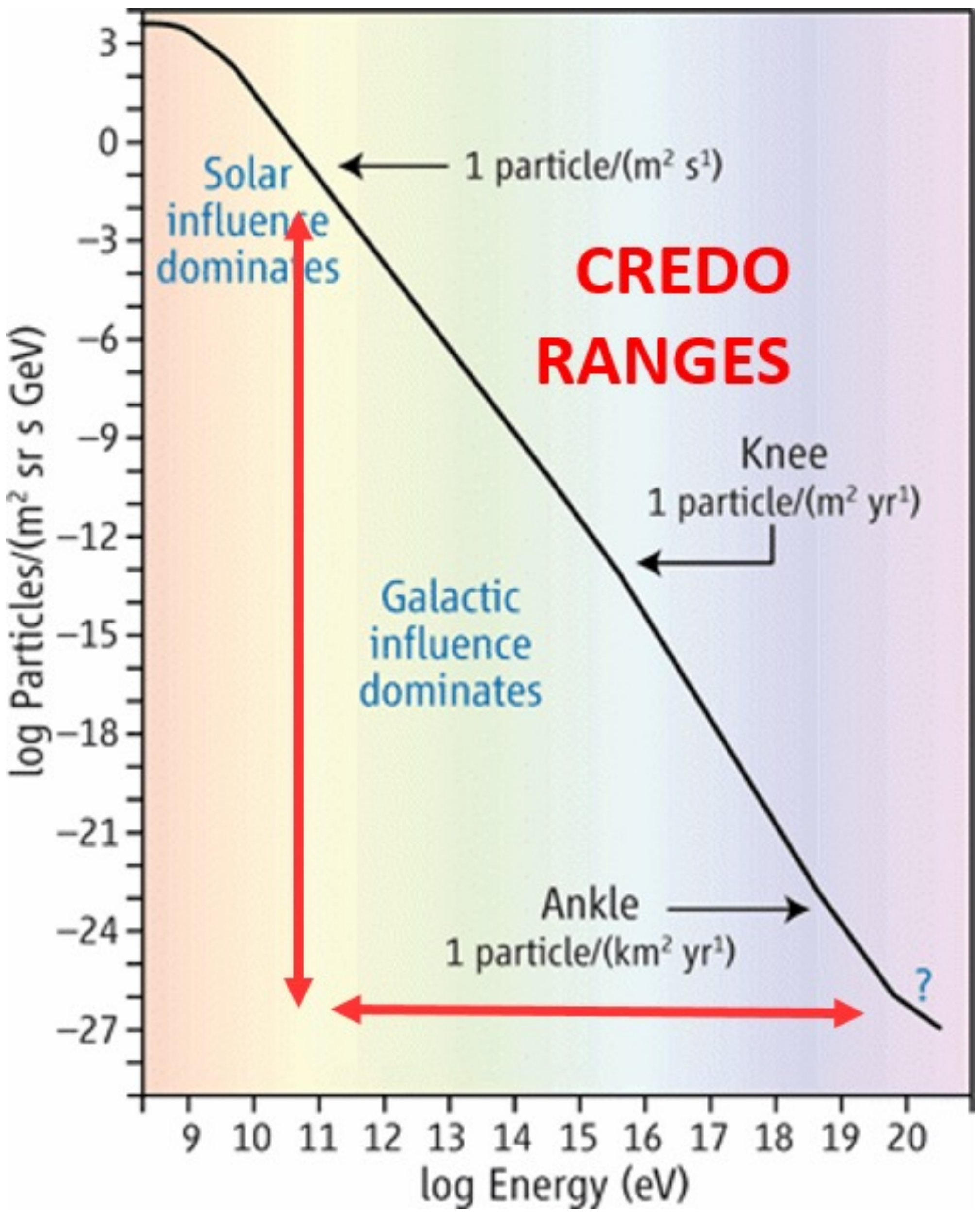
What about large scale correlation of cosmic rays?



A chance for a unique CRE signature



Cosmic Ray Ensembles (CRE)! Full energy spectrum!



Novel global concept: cloud of clouds

Invitation to the Cosmic Ray Extremely Distributed Observatory

CREDO
THE QUEST FOR THE UNEXPECTED

+ you = stronger together

CREDO
JOURNEY

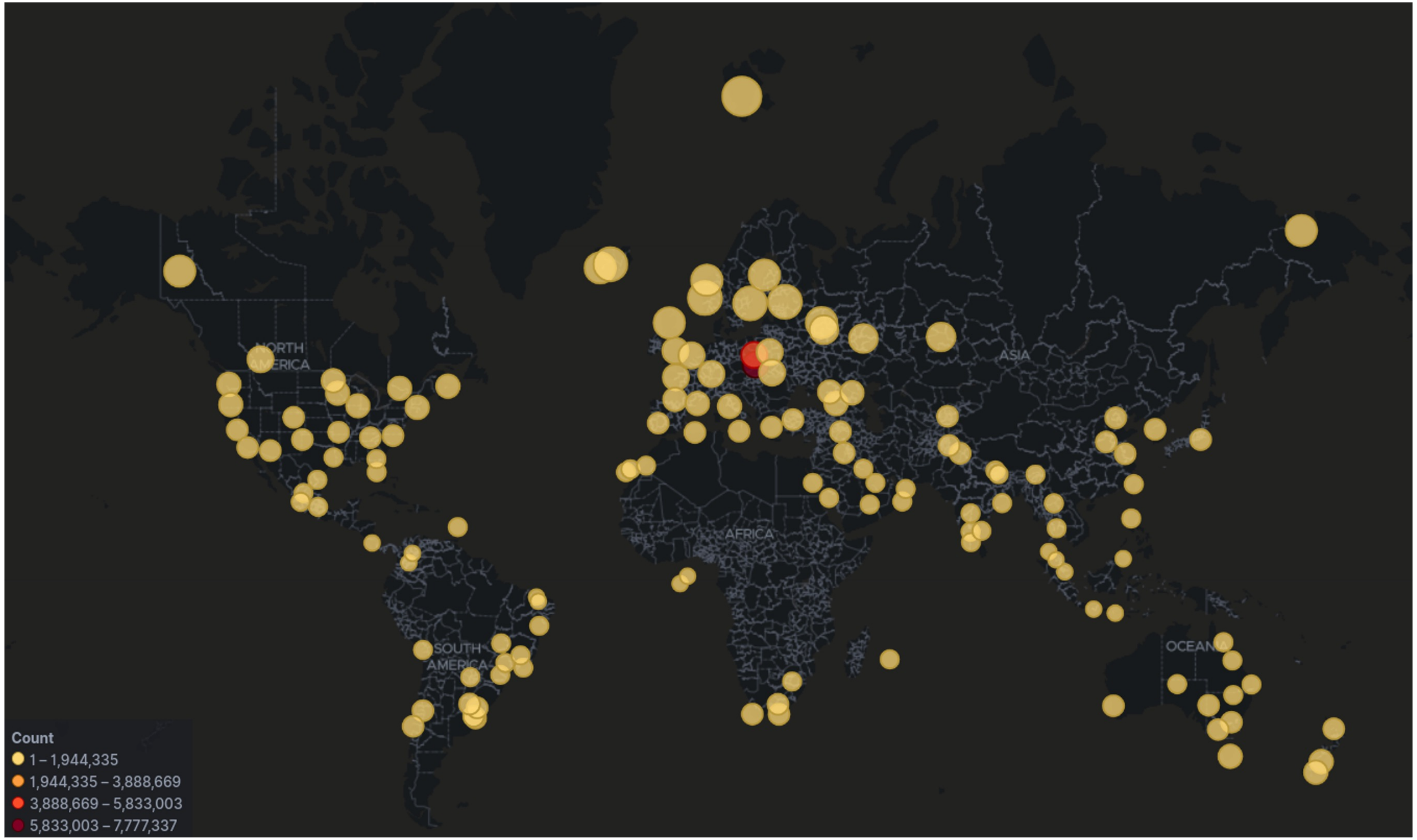
CREDO Science Potential

astro/cosmo/geo/bio/eco/hi-tech/…
infrastructure

CREDO

THE QUEST FOR THE UNEXPECTED

CREDO: already global



48 institutions / 20 countries / 5 continents / ~ 16 700 users / ~ 12 700 teams / > 12 500 000 smartphone detections / > 1200 smartphone work years

CREDO Memorandum of Understanding

Cosmic Ray Extremely Distributed Observatory (CREDO)

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 institutional members (11.10.2021):

- Australia (2)
- Canada (2)
- Chile (1)
- Czech Republic (3)
- Estonia (1)
- Georgia (1)
- Hungary (1)
- India (2)
- Italy (1)
- Mexico (1)
- Nepal (1)
- Poland (16)
- Portugal (1)
- Russia (1)
- Slovakia (1)
- Spain (2)
- Thailand (1)
- Ukraine (3)
- Uruguay (2)
- USA (3)

(46 institutions, 20 countries)

CREDO Detector: what do we see?

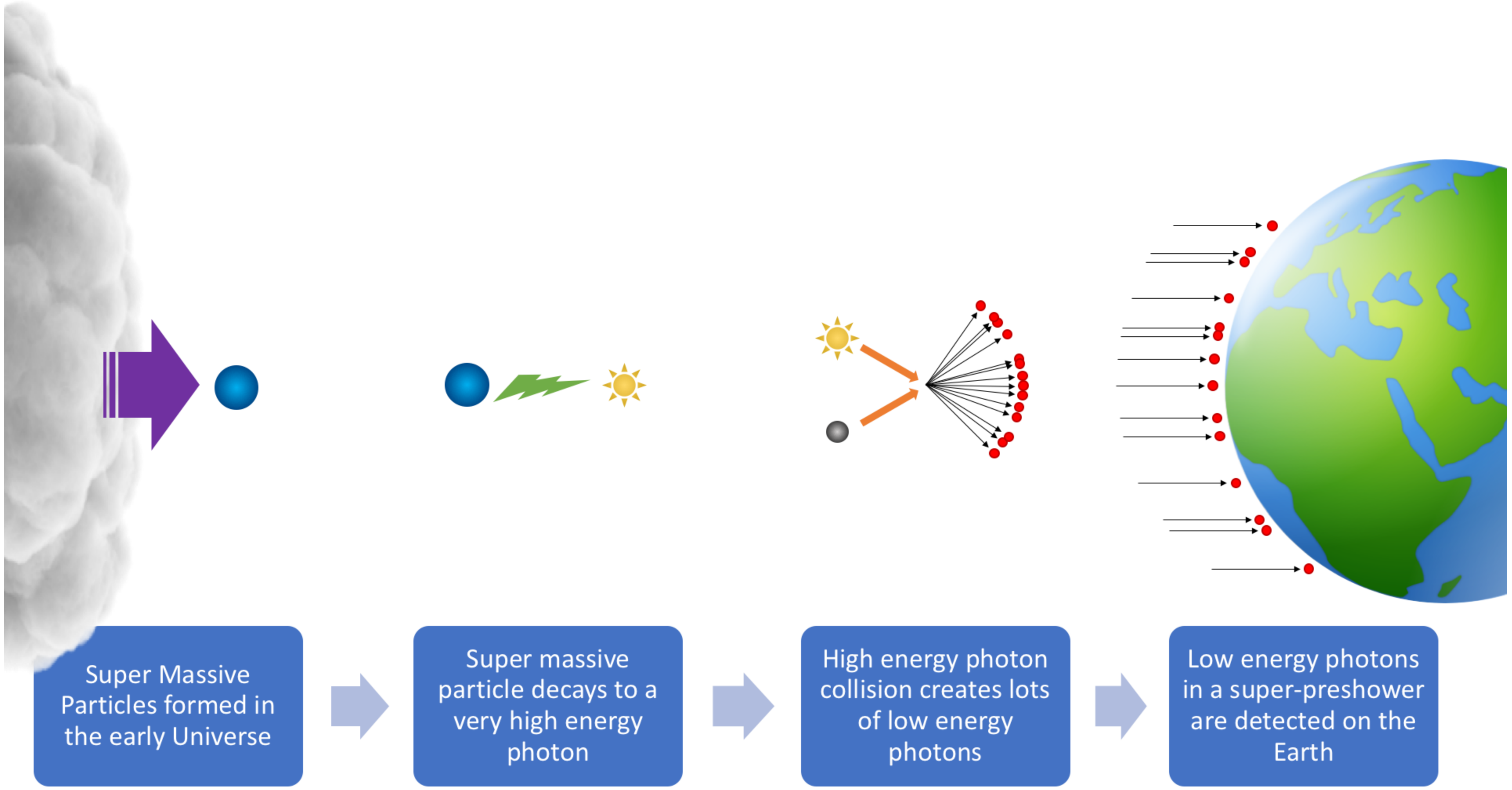
[work in progress, e.g. at IFJ PAN]

scenarios!

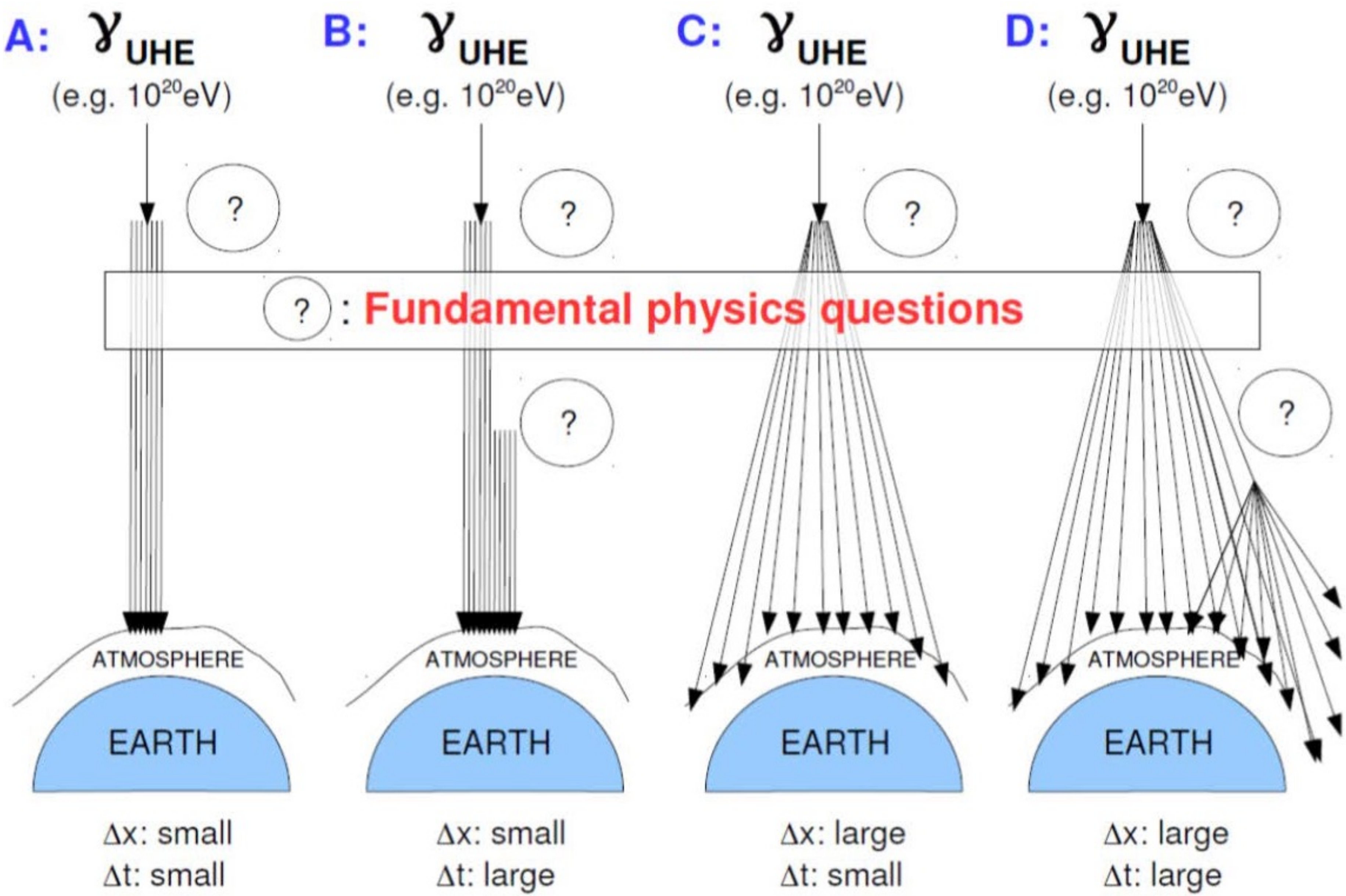
muons?

air showers ?

CRE?


Super Massive Particles formed in the early Universe
Super massive particle decays to a very high energy photon
High energy photon collision creates lots of low energy photons
Low energy photons in a super-preshower are detected on the Earth

Classes of 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)

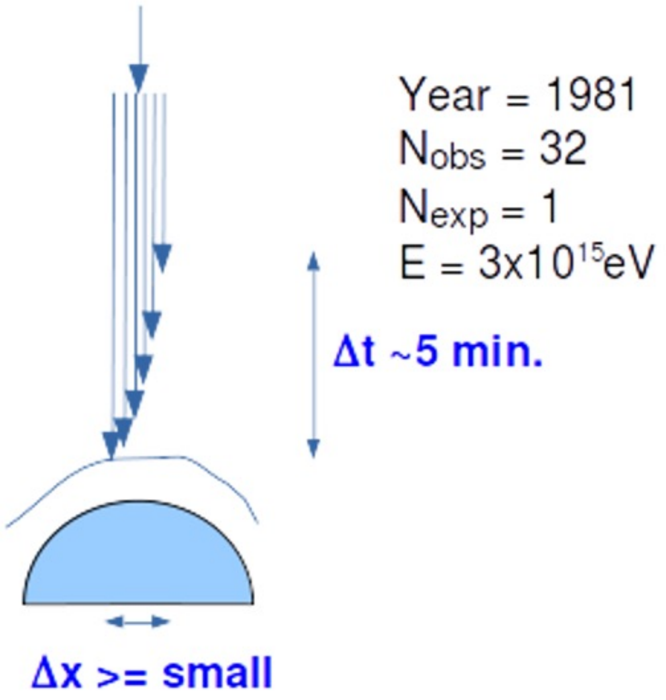
A series or burst of 32 extensive air showers of estimated mean energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9:55 A.M. (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in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

PACS numbers: 94.40.Pa, [illegible], 95.30.-k

Forgotten (!) treasure (?) no. 1

Correlated cosmic rays?

$N_{ATM} > 1$?



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)

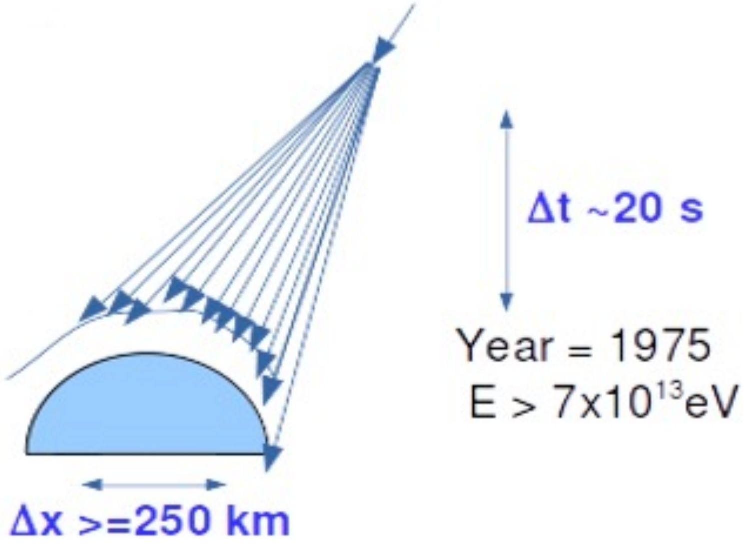
Forgotten (!) treasure (?) no. 2

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

Correlated cosmic rays?

N_{ATM} > 1?



Cosmic-Ray Ensembles: 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

Photons as UHECR: astrophysical scenarios

Astrophysical scenarios

acceleration of nuclei (e.g. by shock waves)
+ „conventional interactions", e.g. with CMBR

- sufficently efficent astrophysical objects difficult to find
- small fractions of photons and neutrinos – mainly nuclei expected

??? Exotic scenarios (particle physics) ???

Decay or annihilation the early Universe relics
→ hypothetic supermassive particles of energies $\sim 10^{23}$ eV
→ decay to quarks and leptons → hadronization (mainly pions)

- large fraction of photons and neutrinos in UHCER flux

↓

not the case?

UHE photons: expected, but not identified yet

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

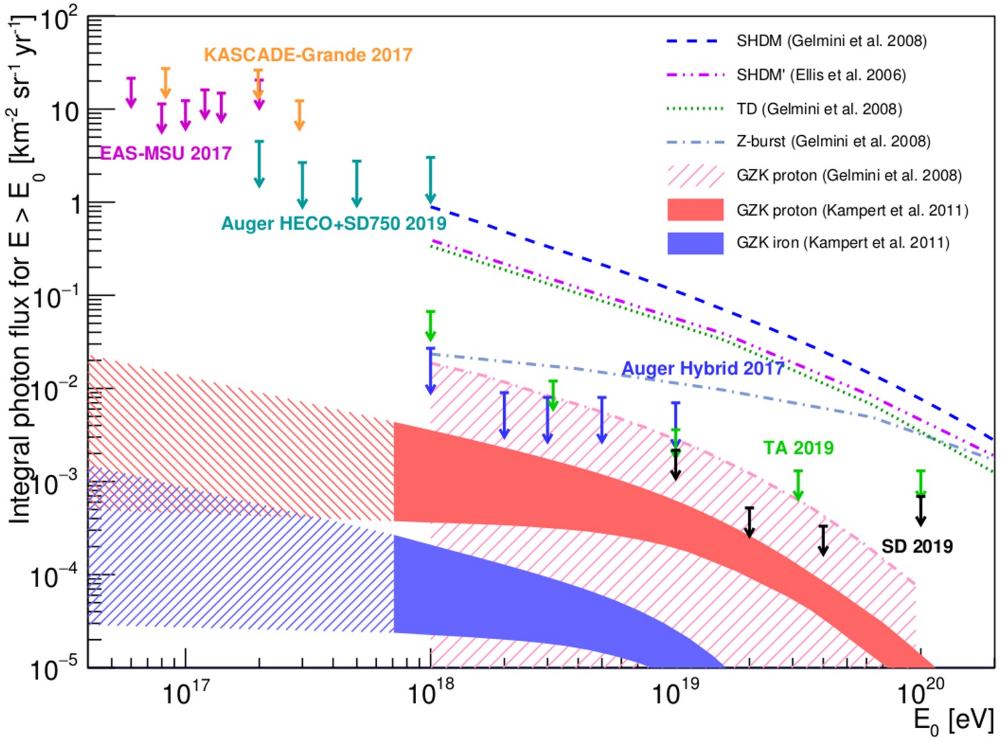


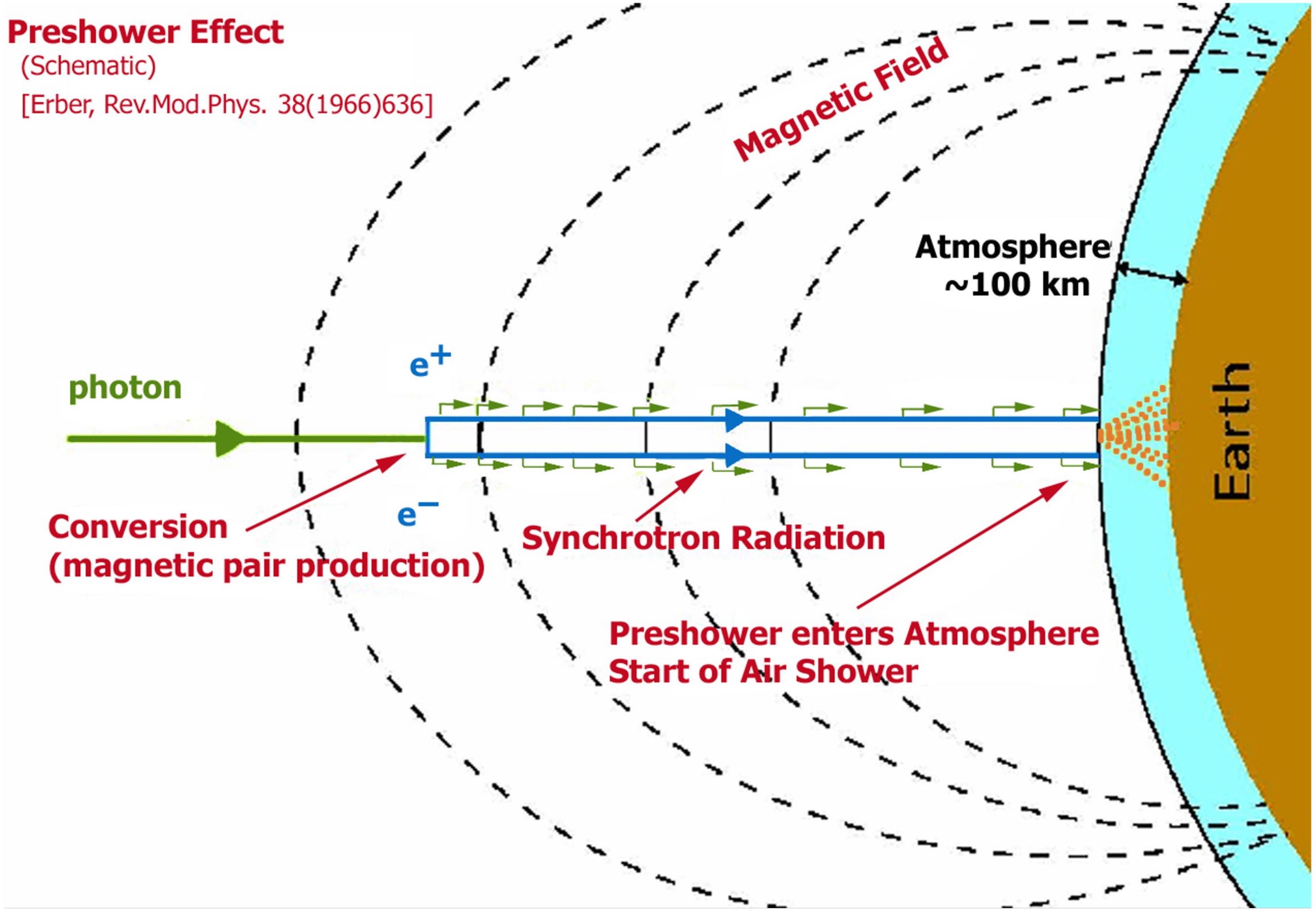
Figure 7: Photon flux limits at 95% C.L. for the different analysis of the Pierre Auger Observatory, compared to model predictions [14, 15, 16] and other experimental limits at 95% C.L. [17], as well as at 90% C.L. [18, 19].

Example non-exotic scenario: preshowers

Preshower (important for E > 10^{19} eV):

→ contains typically 100 particles

(created at around 1000 km a.s.l.)



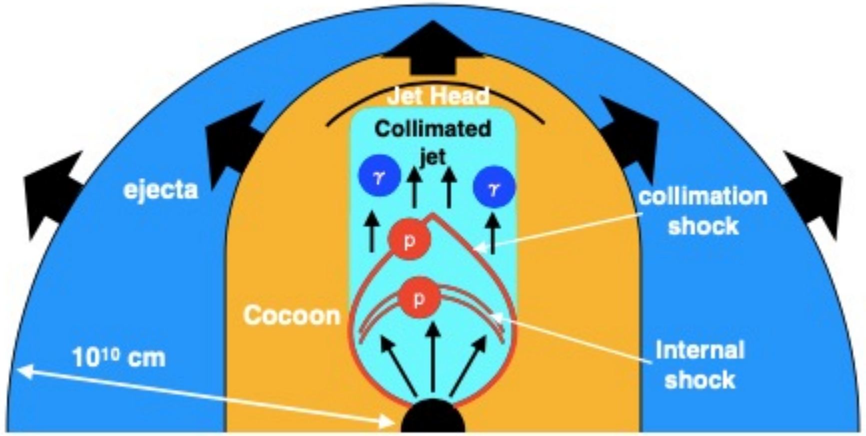
Neutron star mergers

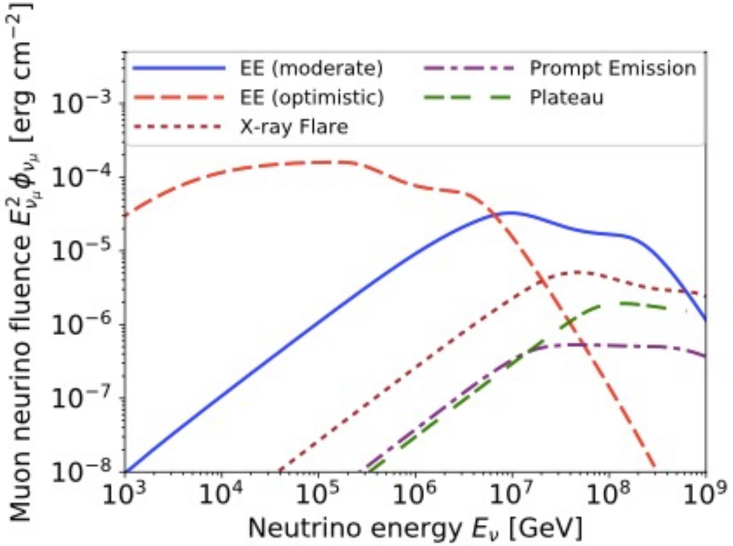
High-energy emissions from neutron star mergers

Shigeo S. Kimura[1,2,3,*]

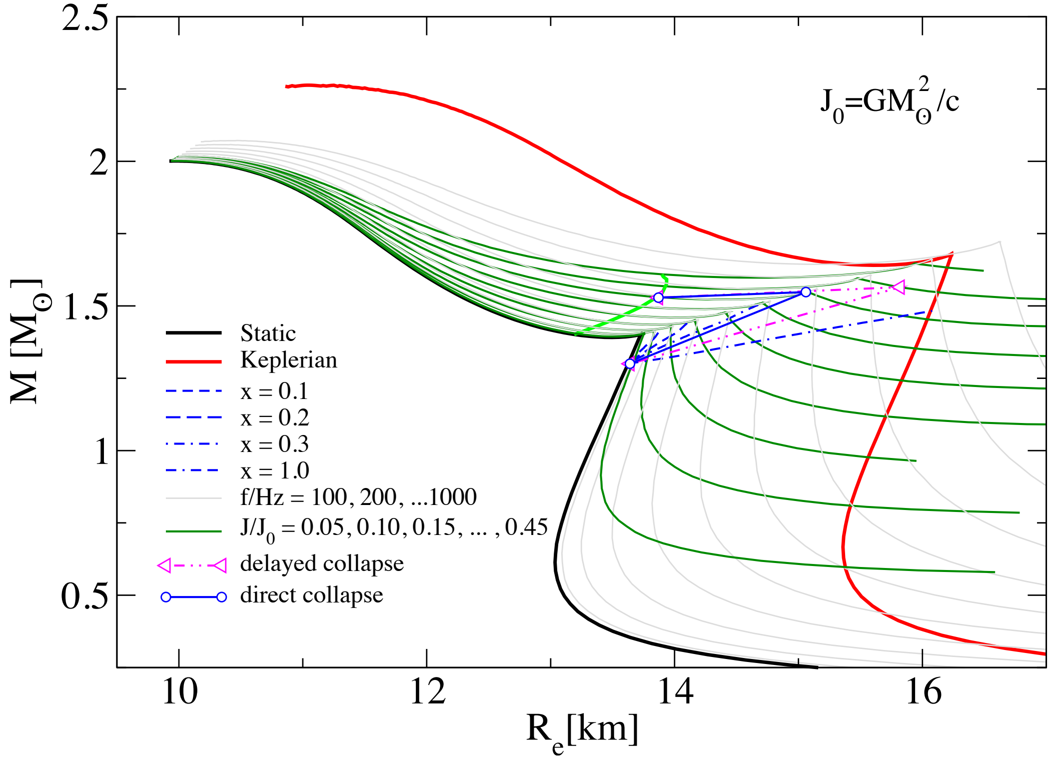
[1]Department of Physics, Pennsylvania State University, University Park, Pennsylvania, 16802, USA
[2]Center for Particle and Gravitational Astrophysics, Pennsylvania State University, University Park, Pennsylvania, 16802, USA
[3]Department of Astronomy & Astrophysics, Pennsylvania State University, University Park, Pennsylvania, 16802, USA

Abstract. In 2017, LIGO-Virgo collaborations reported detection of the first neutron star merger event, GW170817, which is accompanied by electromagnetic counterparts from radio to gamma rays. Although high-energy neutrinos were not detected from this event, mergers of neutron stars are expected to produce such high-energy particles. Relativistic jets are launched when neutron stars merge. If the jets contain protons, they can emit high-energy neutrinos through photomeson production. In addition, neutron star mergers produce massive and fast ejecta, which can be a source of Galactic high-energy cosmic rays above the knee. We briefly review what we learned from the multi-messenger event, GW170817, and discuss prospects for multi-messenger detections and hadronic cosmic-ray production related to the neutron star mergers.





Spin frequency vs gravitational mass of the hybrid star at birth



$$ds^2 = -e^{\nu}\left[1+2(h_0+h_2P_2)\right]dt^2 + e^{\lambda}\left[1+\frac{2(m_0+m_2P_2)}{r-2M}\right]dr^2$$
$$+r^2\left[1+2(v_2-h_2)P_2\right]\left[d\theta^2+\sin^2(d\phi-\omega dt)^2\right]+O(\Omega^3),$$

$$\frac{dJ}{dM_b} = l_{\rm tot} = \kappa l(r_0) - l_m,$$

$$l_m = \frac{\mu^2}{9r_0^3\dot{M}_b}\left(3-2\sqrt{\frac{r_c^3}{r_0^3}}\right)$$

$$\frac{1}{\Omega r}\frac{dl}{dr} = \frac{1}{2}f_{ms}(r_0) = \left(\frac{r_m}{r_0}\right)^{7/2}\left(\sqrt{\frac{r_c^3}{r_0^3}}-1\right),$$

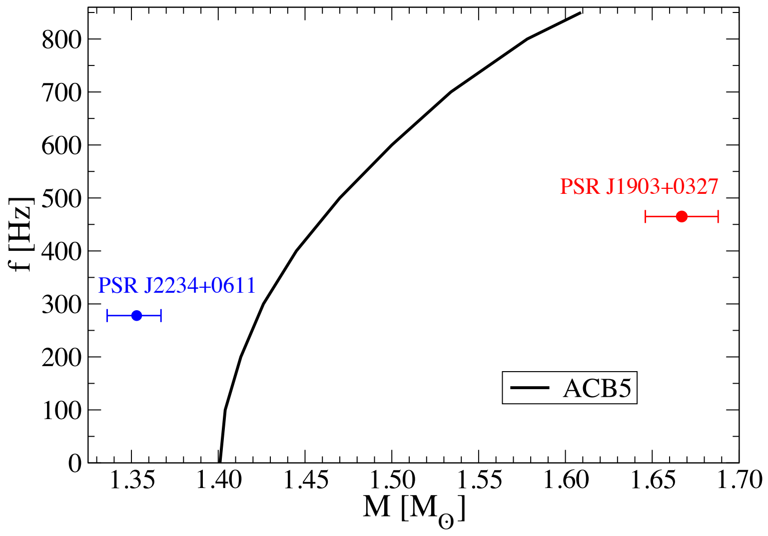
$$r_m = \frac{\mu^{\frac{4}{7}}}{(GM)^{\frac{1}{7}}\dot{M}_b^{\frac{2}{7}}},$$

$$r_c = \left(\frac{GM}{\Omega^2}\right)^{1/3},$$

$$0 = f_{ms}(r_{ms}).$$

$$B(M_{acc}) = \frac{B_i}{1+M_{acc}/m_B}.$$

$$\dot{M}_b \cong 10^{-9}M_\odot,\quad B_i \cong 10^8\ \mathrm{G}.$$



DAC et al. - Astron. Nachr. 2019;340:878-884. Eprint: arXiv: 1912.08782

Accretion-induced collapse to third family compact stars as trigger for eccentric orbits of millisecond pulsars in binaries

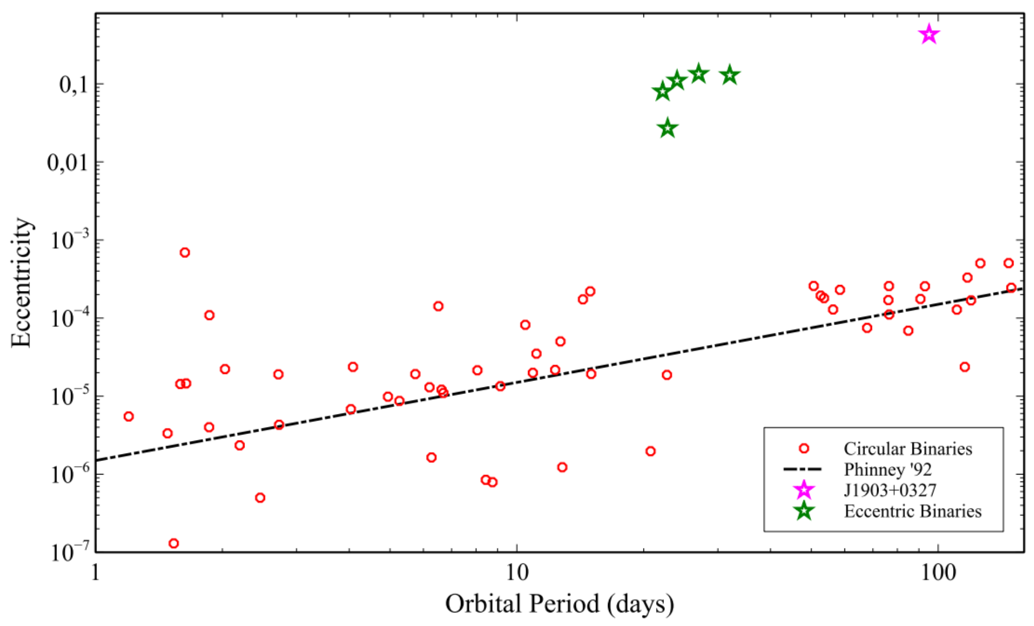
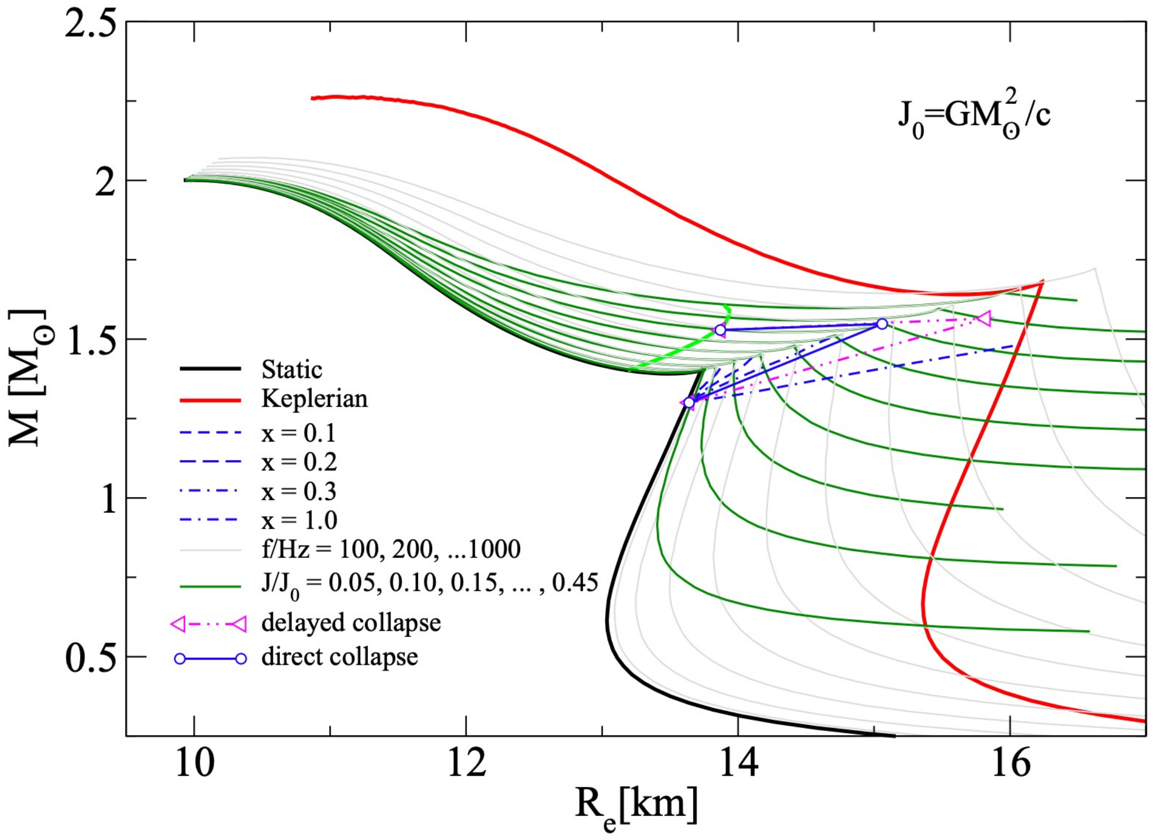
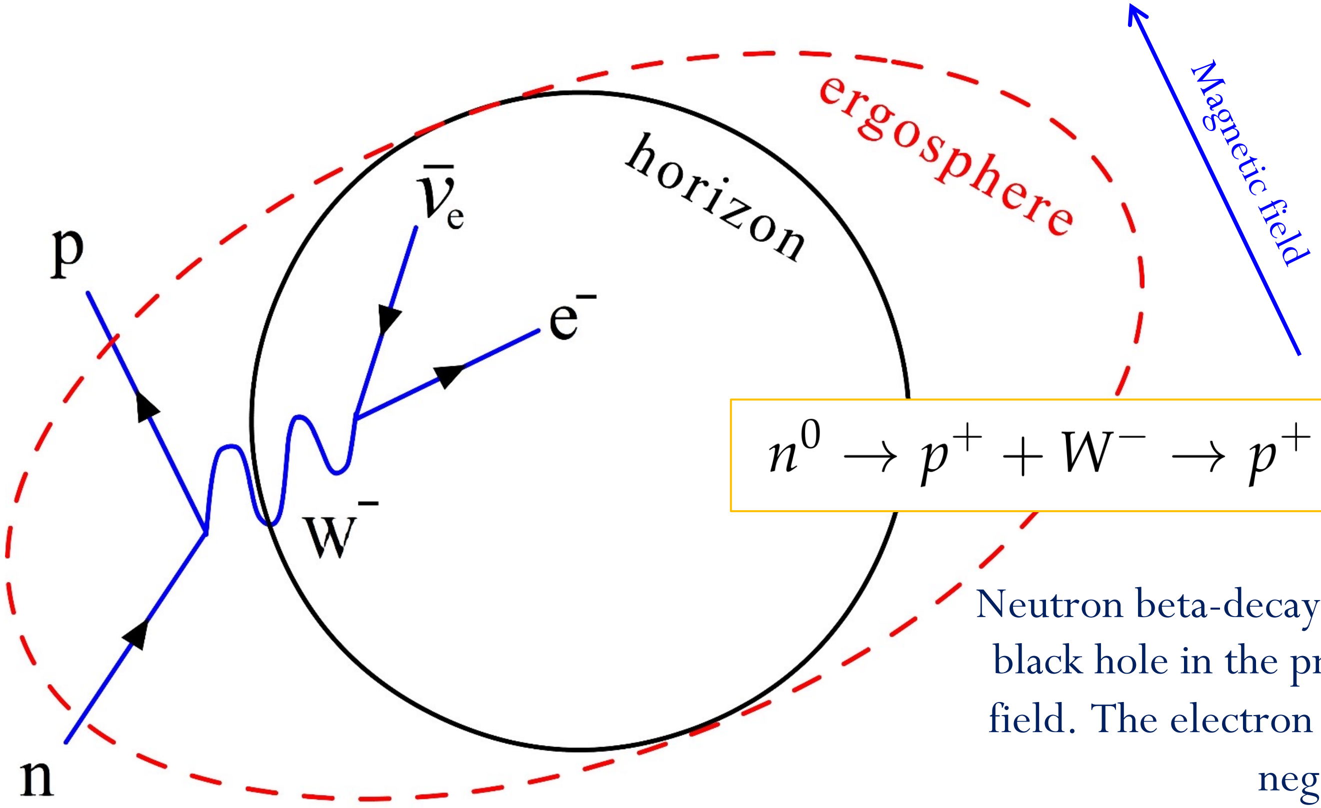


FIGURE 1 Eccentricity vs. orbital period for millisecond pulsars in binaries with white dwarf companions, see (J. Antoniadis, 2014; Stovall, 2019).



DAC et al. - Astron. Nachr. 2019;340:878-884. Eprint: arXiv: 1912.08782

Beta-decay in ergosphere



$$n^0 \rightarrow p^+ + W^- \rightarrow p^+ + e^- + \bar{\nu}_e,$$

Neutron beta-decay in the ergosphere of rotating black hole in the presence of external magnetic field. The electron falls into black hole with the negative energy.

In the hot and dense torus, with temperature of $\sim 10^{11}$ K and density $>10^{10}$ g·cm^{-3}, neutrinos are efficiently produced. The main reactions that lead to their emission are the electron/positron capture on nucleons, as well as the neutron decay. Their nuclear equilibrium is described by the following reactions:

$$p + e^- \rightarrow n + \nu_e$$
$$p + \bar{\nu}_e \rightarrow n + e^+$$
$$p + e^- + \bar{\nu}_e \rightarrow n$$

A. Janiuk et al, Galaxies 5, 15 (2017)

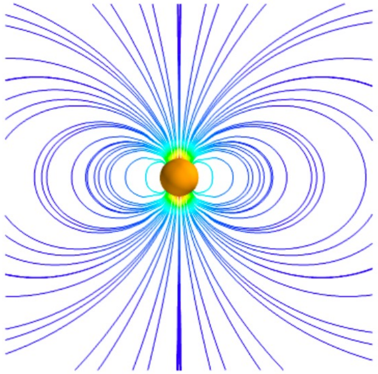
Credit: Arman Tursonov

Simulations of SPS at the vicinity of the Sun

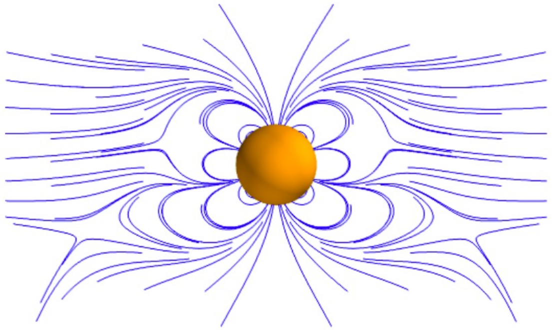
Two approaches to the description of the magnetic field of the Sun:

- Dipole field approximation[1] considering the magnetic moment of the Sun as $M_S = 6.87 \times 10^{32}\ \mathrm{G \cdot cm^3}$.

- Dipole – quadrupole– current sheet[2] (DQCS) which is more realistic than the dipole model even at larger distances from the Sun. It provides a more accurate tracking of electron-positron pairs on their way towards the Earth, and a better treatment of the magnetic Bremsstrahlung process.



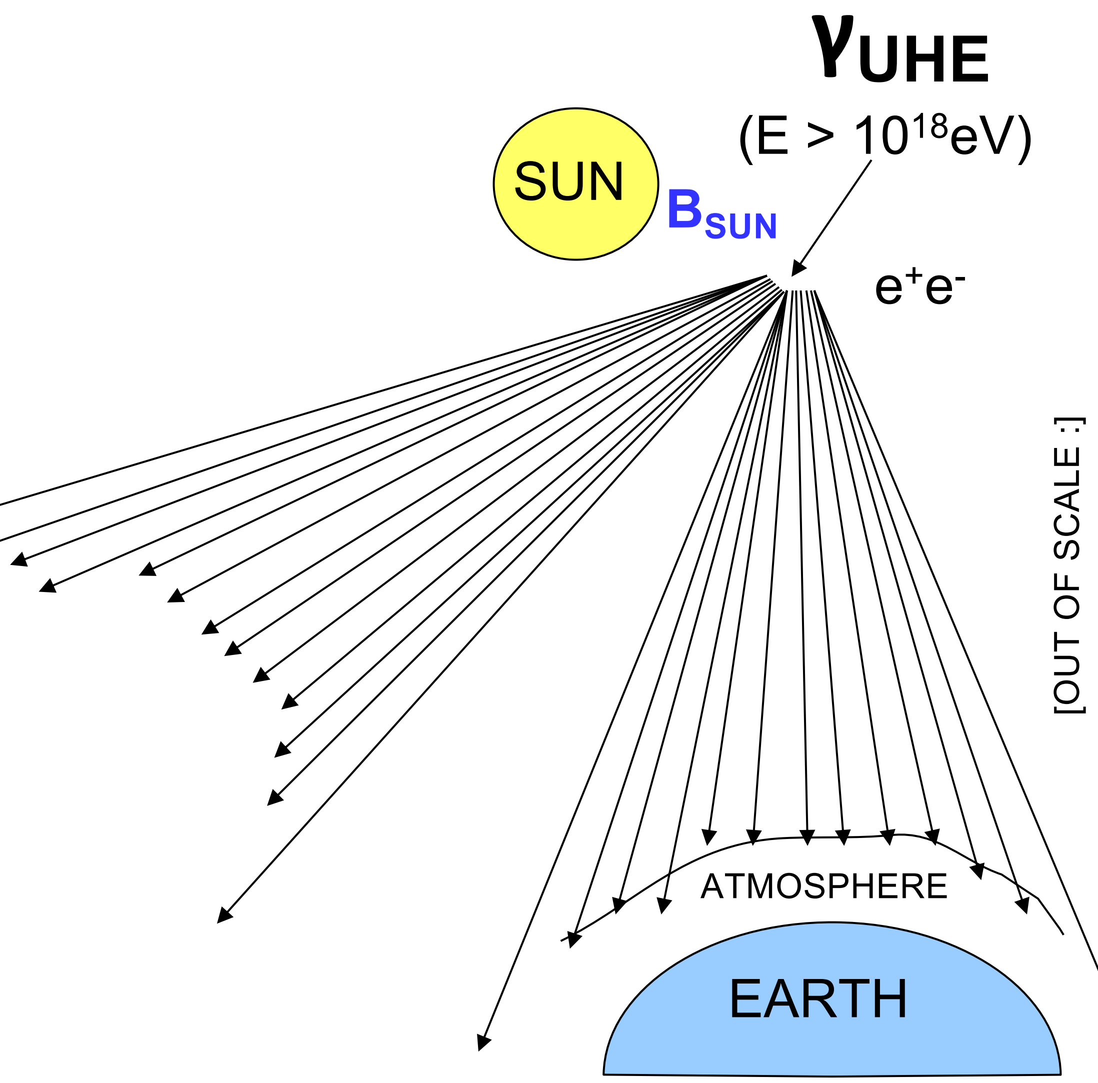
Dipole model

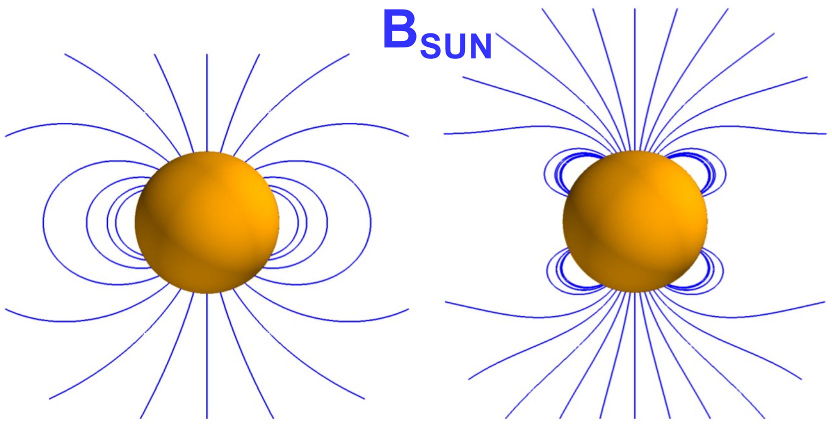


DQCS model

[1]W. Bednarek 1999, arXiv:astro-ph/9911266
[2]Banaszkiewicz et al. 1998, A&A

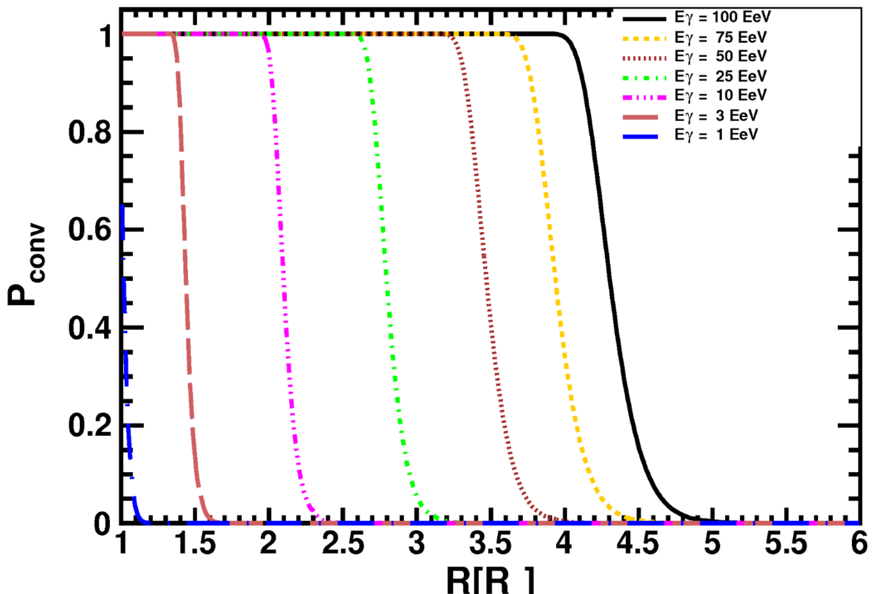
>=EeV photons nearby the Sun→ big CRE





(a) Dipole field (b) DQCS field

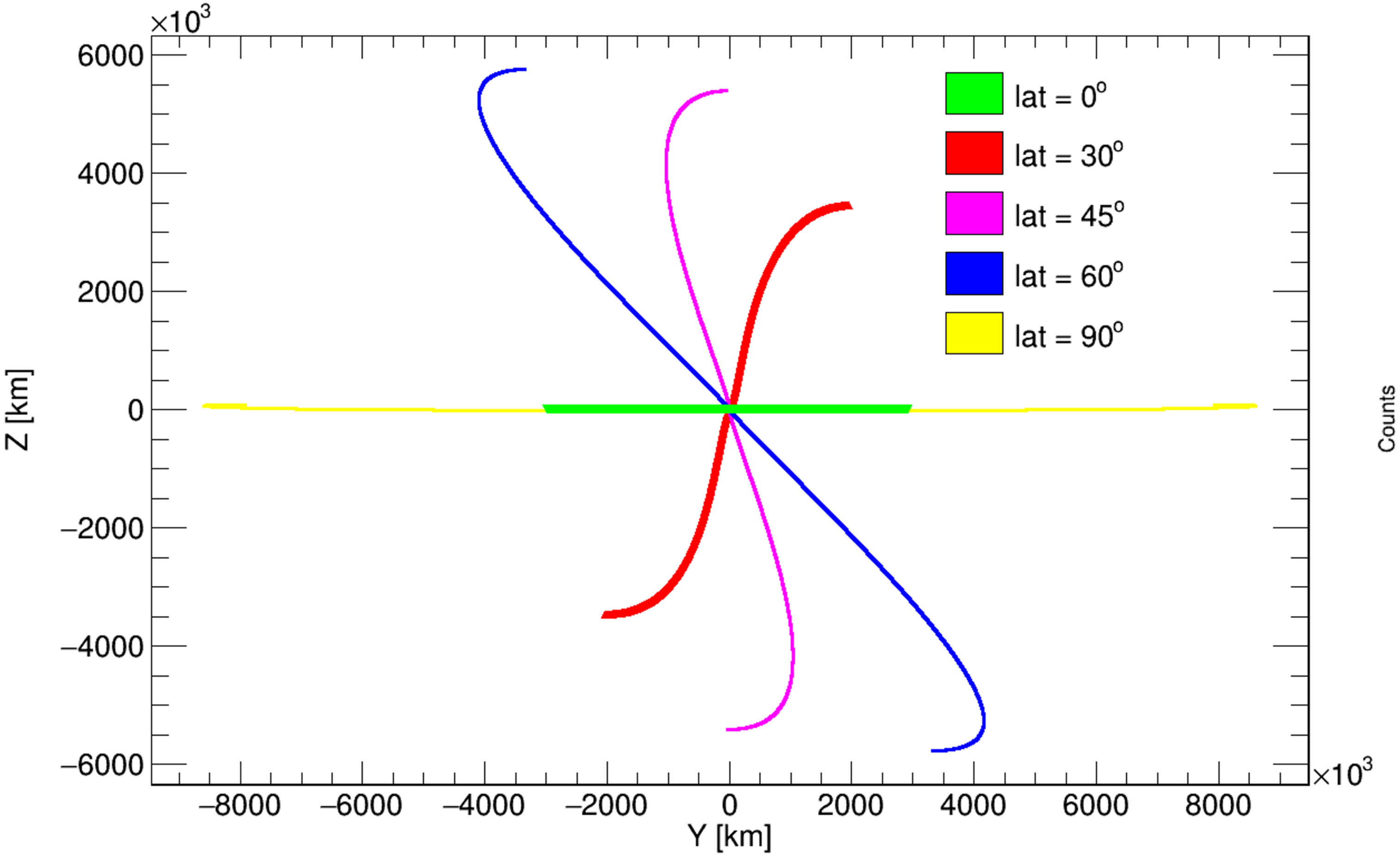
The Sun-preshower effect starts at 1 EeV



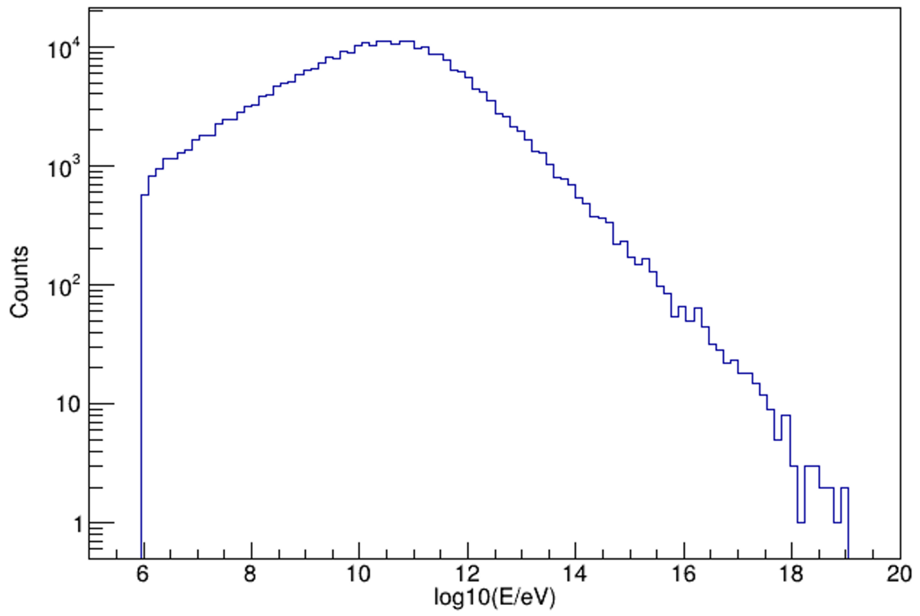
Primary gamma conversion probability vs. impact parameter, polar incidence

Sun-CRE: footprints up to 1 AU, all photon energies

Footprints very thin, up to 1 AU long, non-trivial shapes, dependent on incidence angle and impact parameter

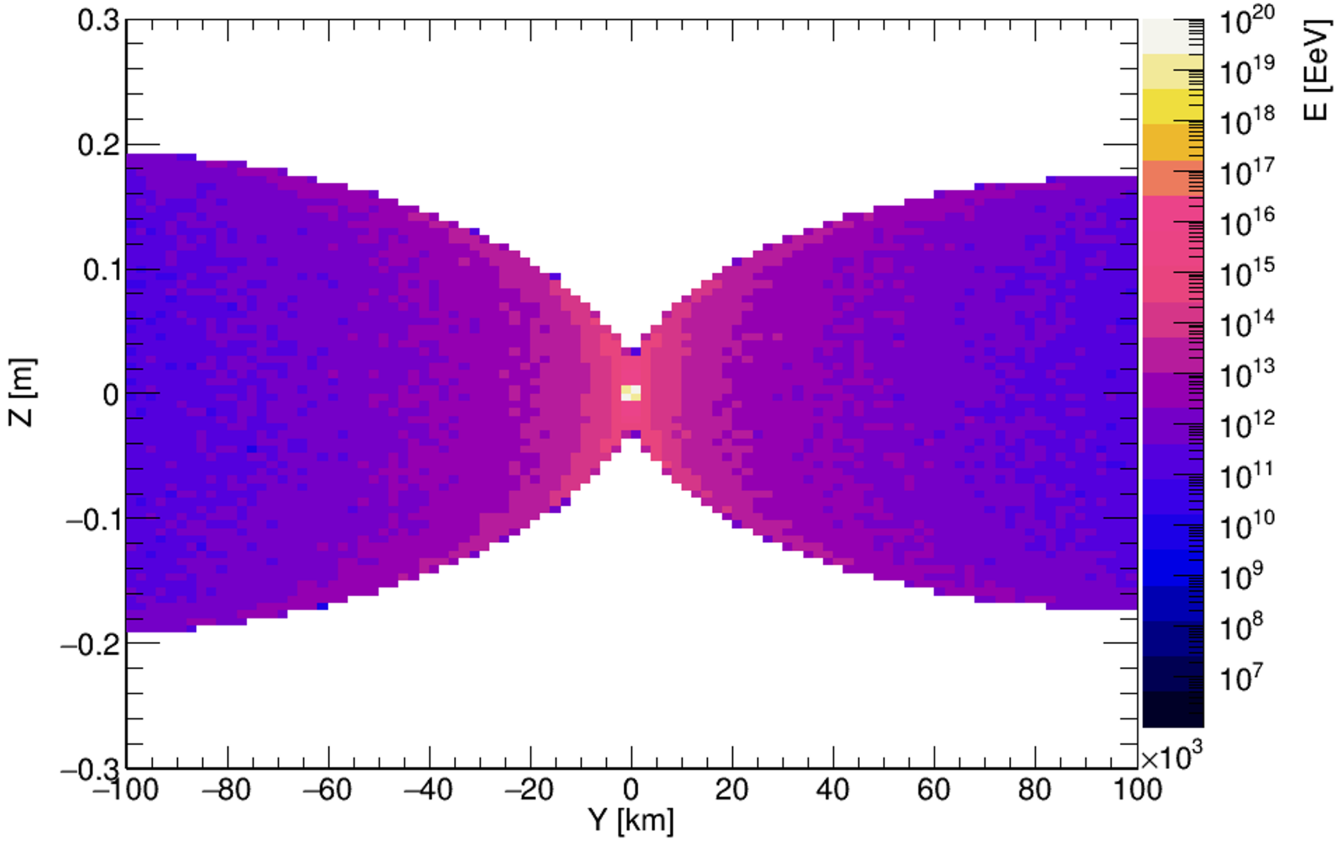


Entire photon spectrum engaged

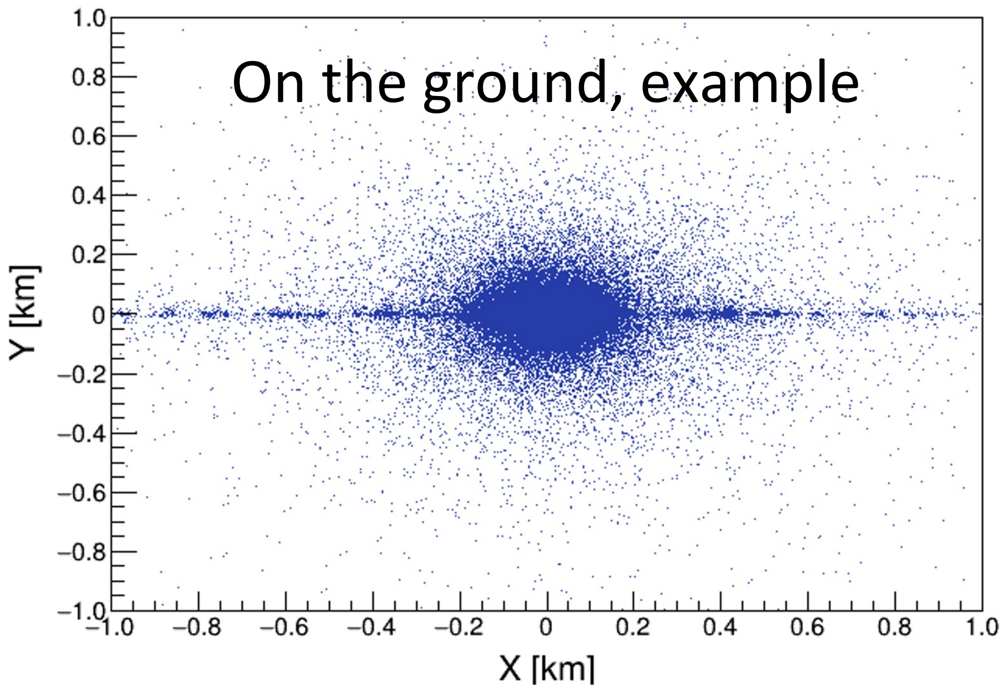


The Sun-CRE footprints

On top of the atmosphere, example

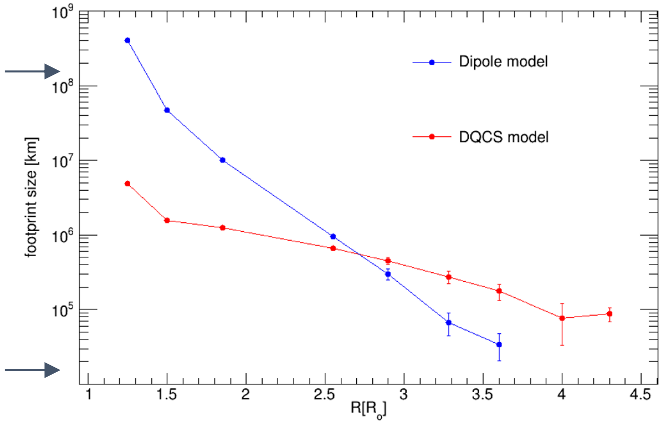


On the ground, example



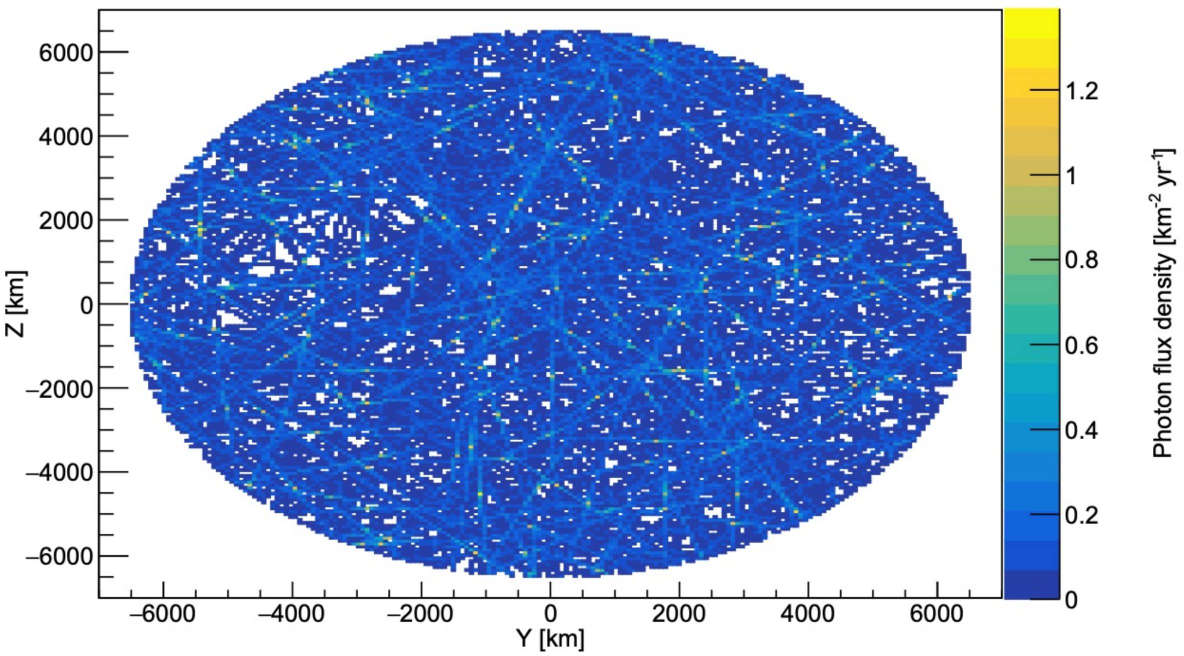
Size vs. impact parameter, on top of the atmosphere

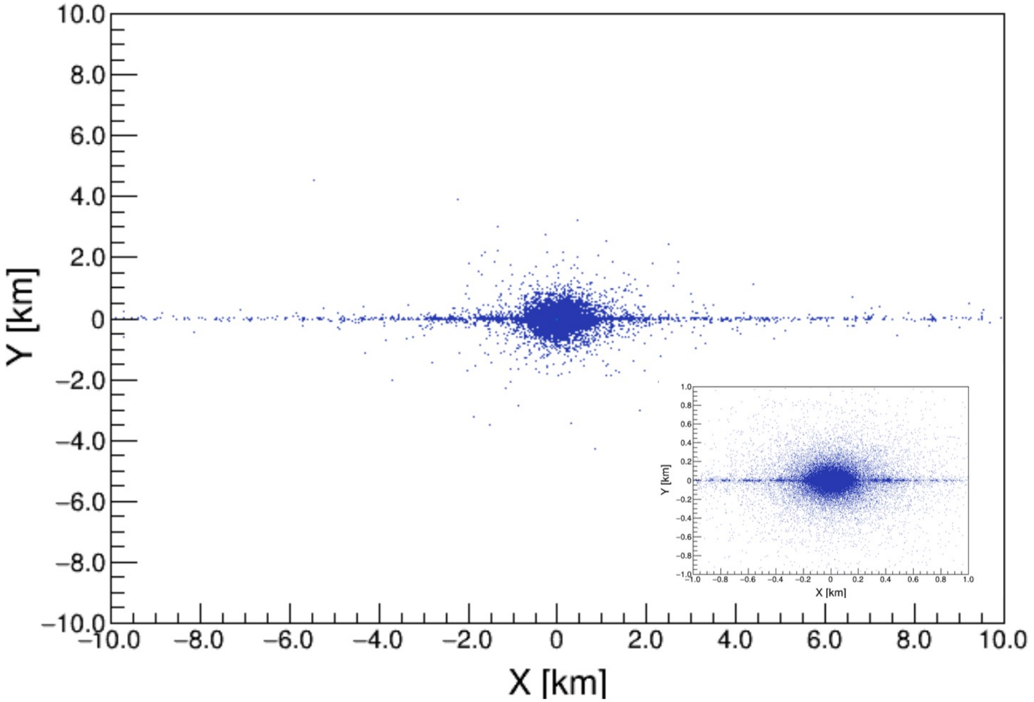
1 A.U.



Earth

Simulations of SPS at the vicinity of the Sun

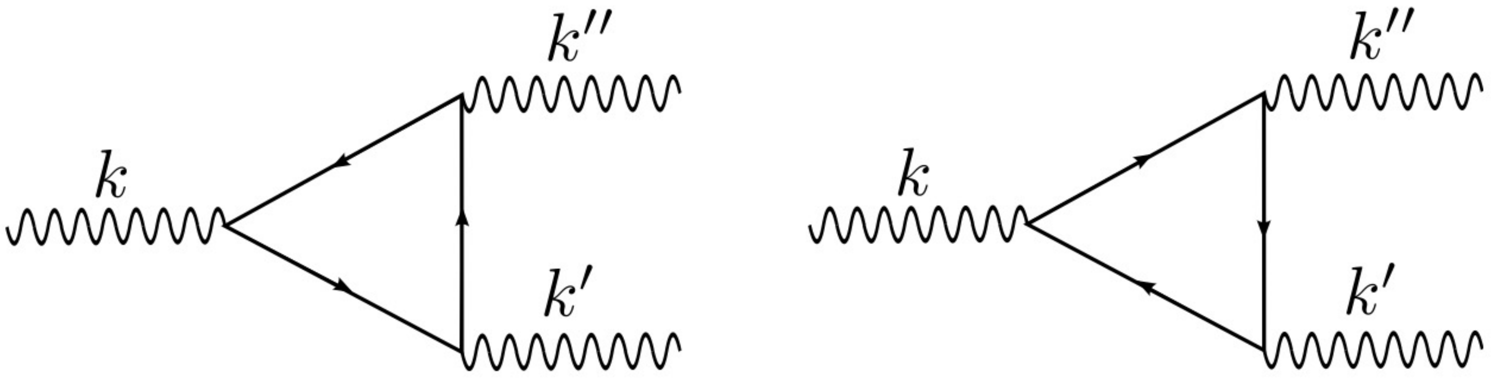




Left: The cumulative spatial distribution of secondary photons at the top of the atmosphere, for the primary photons energy 100 EeV. *Right*: Shower footprint derived from the CORSIKA simulation program for particles that are tracked through the atmosphere that eventually react with air nuclei. The inset displays the core of the footprint in a smaller area.

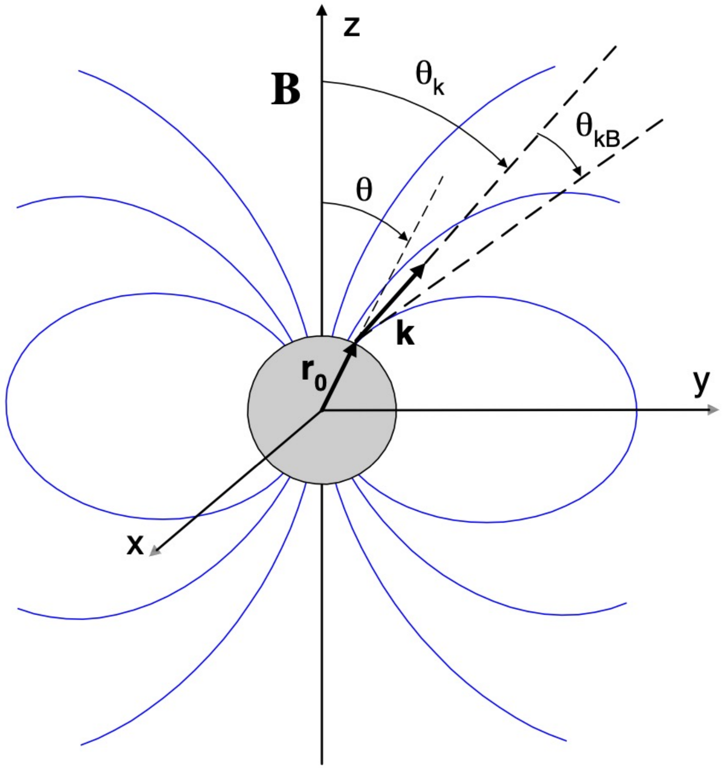
N. Dhital, P. Homola, D. Alvarez-Castillo et al., arXiv:1811.10334
B. Poncyljusz, T. Bulik, N. Dhital et al., arXiv:2205.14266

Photon Splitting around compact objects



Alice K. Harding, Matthew G. Baring, and Peter L. Gonthier - ApJ 476 246 (1997)

Photon Splitting around compact objects



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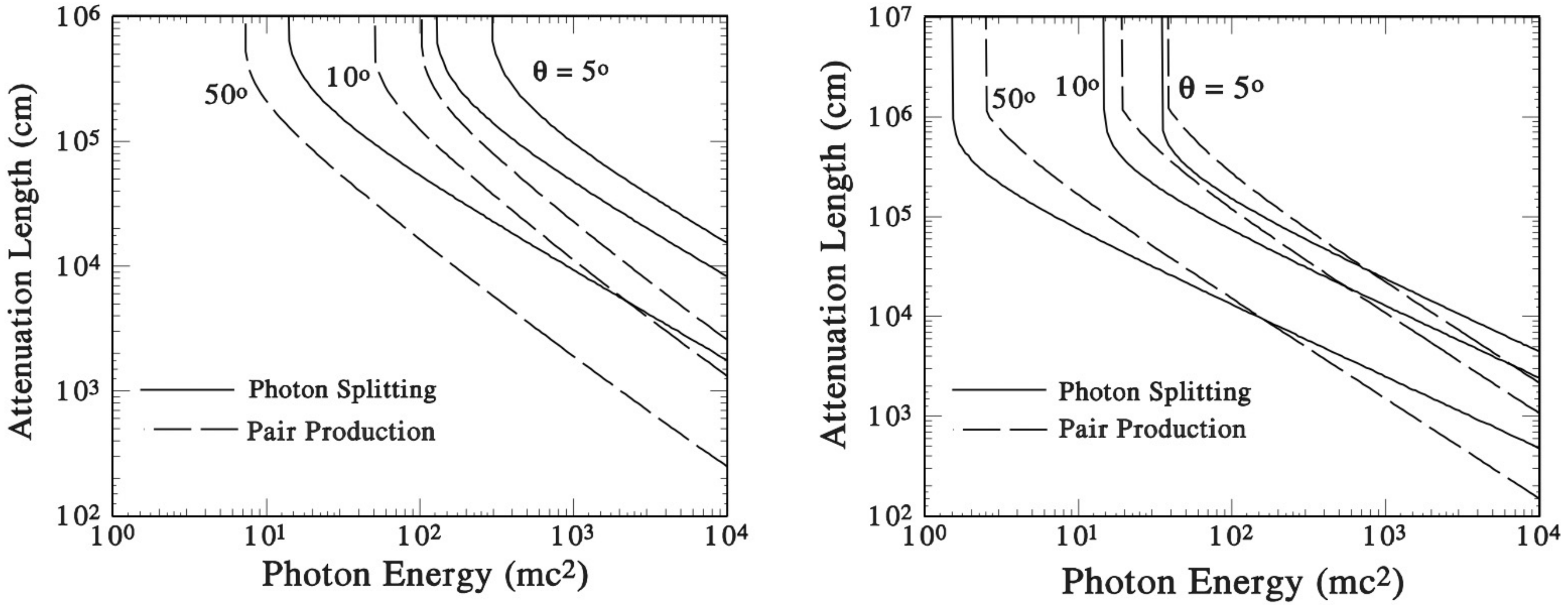
Photon Splitting around compact objects



Alice K. Harding, Matthew G. Baring, and Peter L. Gonthier - ApJ 476 246 (1997)

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A New Method of Simulation of Cosmic-ray Ensembles Initiated by Synchrotron Radiation

by Oleksandr Sushchov [1,*], Piotr Homola [1], Marcin Piekarczyk [2], Ophir Ruimi [3], Kévin Almeida Cheminant [1], Olaf Bar [2], Łukasz Bibrzycki [2], Bohdan Hnatyk [4], Péter Kovács [5], Bartosz Łozowski [6], Michał Niedźwiecki [7], Sławomir Stuglik [1], Arman Tursunov [8] and Tadeusz Wibig [9]

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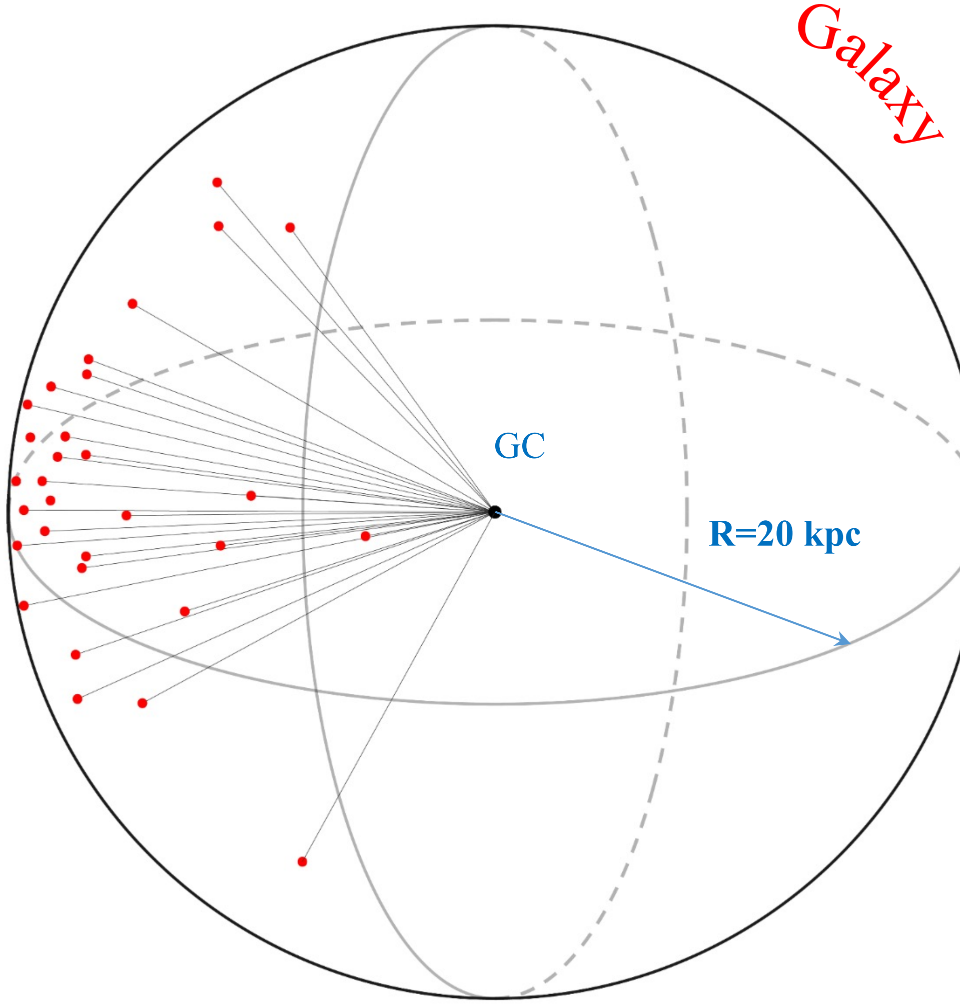
(This article belongs to the Special Issue **Symmetry in Cosmic Ray Detections**)

Astrophysics scenarios. Galactic center (GC) model

Simulation parameters

- The primary electron starting energy (21 values in total): $10^{17} \leq \log(E_0/eV) \leq 10^{19}$ with the step $\Delta(\log(E_0/eV))$=0.1
- The initial position: GC
- The minimum energy threshold: E_{br}=10 PeV
- The initial directions: 11 randomly chosen
- The Galactic magnetic field described by the JF12 model
- The synchrotron radiation threshold: E_{synch} = 1 GeV
- The propagation module (PropagationCK, 10^{-4}, 10^{-5} pc, 10^{-2} pc)
- 10 runs in every energy/direction combination
- 2310 runs overall

Setup scheme



Studying the Variation of Fundamental Constants at The Cosmic Ray Extremely Distributed Observatory

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[b] Institute of Nuclear Physics PAN, Cracow 31-342, Poland

The Study of the Variation of Fundamental Constants through time or in localized regions of space is one of the goals of the The Cosmic Ray Extremely Distributed Observatory which consists of multiple detectors over the Earth. In this letter, the various effects which can be potentially identified through cosmic rays detections by CREDO are presented.

PACS: 06.20.Jr; 96.50.S−; 04.60.−m; 11.30.Cp

Phys.Part.Nucl. 53 (2022) 4, 825-828. Eprint: arXiv: 2208.09391

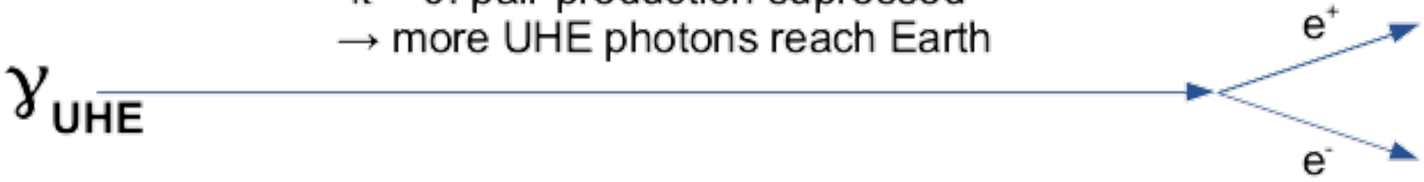
CRE and Lorentz Invariance Violation

Modified dispersion relation of a photon:

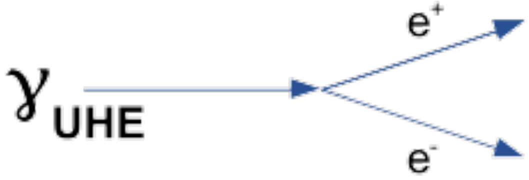
$$E_\gamma(\vec{k}) = \sqrt{\frac{(1-\kappa)}{(1+\kappa)}}|\vec{k}|$$

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

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



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

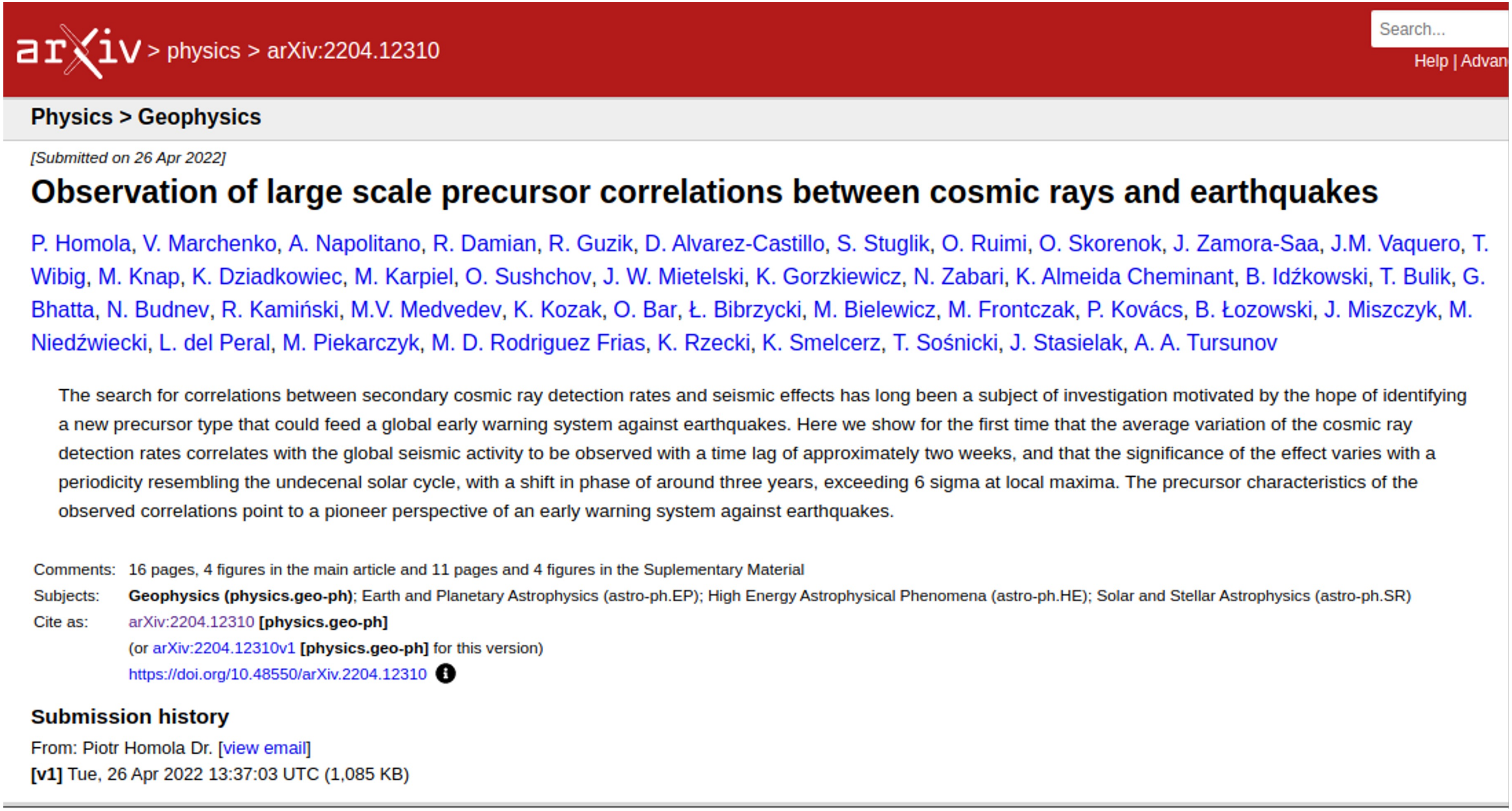


$\kappa < 0$: pair production enhanced
(photon lifetime ~ 1 sec.!)
→ no UHE photons reach Earth

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

Jacobson T., Liberati S., Mattingly D. Annals Phys. (2006) V. 321. P. 150 196 arXiv:astro-ph/0505267.

Interdisciplinary potential: contribution to earthquake early warning system?



27/02/2010 earthquake in Chile
Magnitude 8.8

On the Magnetic Precursor of the Chilean Earthquake of February 27, 2010

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Received March 24, 2014; in final form, June 19, 2014

Abstract—Some recent publications reported on an anomalous geomagnetic disturbance that was observed three days before the strongest Chilean earthquake on February 27, 2010. The present paper analyzes in detail the data from magnetic station, photometers, and riometers in Canada, Chile, and Antarctica. The analysis unambiguously shows that the supposedly anomalous geomagnetic disturbance was not related to seismic activity and was caused by a standard isolated substorm.

DOI: 10.1134/S0016793215010107

INTRODUCTION

Recent publications by Shestopalov et al. (2011a, 2011b, 2013) reported on a series of anomalous geophysical phenomena prior to the Chilean earthquake of February 27, 2010. In particular, it was reported that a significant geomagnetic disturbance had been observed three days before the event for about an hour long at different magnetic stations of the INTERMAGNET network. The authors thought it was endogenous disturbance (Belov, Shestopalov, and Kharin, 2009; Belov et al., 2010), because no magnetic storms took place that time.

However, an absence of magnetic storms in the analyzed period does not exclude effects from such natural geomagnetic disturbances as substorms, which are constantly observed in auroral zones in the absence of magnetic storms. The natural problem is whether the phenomenon analyzed in (Shestopalov et al., 2013) an anomalous disturbance or a common substorm. To solve this problem, we will consider a broader set of geophysical data.

ANALYSIS OF GEOMAGNETIC ACTIVITY PRIOR TO THE EARTHQUAKE

The strongest M 8.8 Chilean earthquake occurred on February 27, 2010 in 0634 UT at a depth of H = 35 km (the geographic coordinates of the epicenter are 35.93° S, 72.78° W). According to (Shestopalov et al., 2013), the magnetic precursor of this event was revealed on February 24, 2010, at different magnetic stations.

Let us consider the magnetograms of February 24, 2010, obtained at stations of the SAMBA (Chile) and CARISMA (Canada) networks (Mann et al., 2008), which form a latitudinal profile along the zero mag-

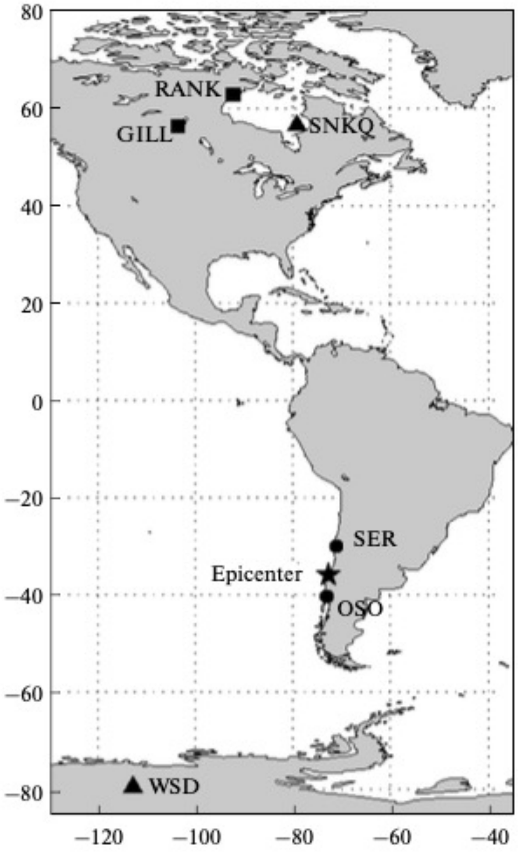


Fig. 1. Map of positions of the chosen stations and the earthquake epicenter.

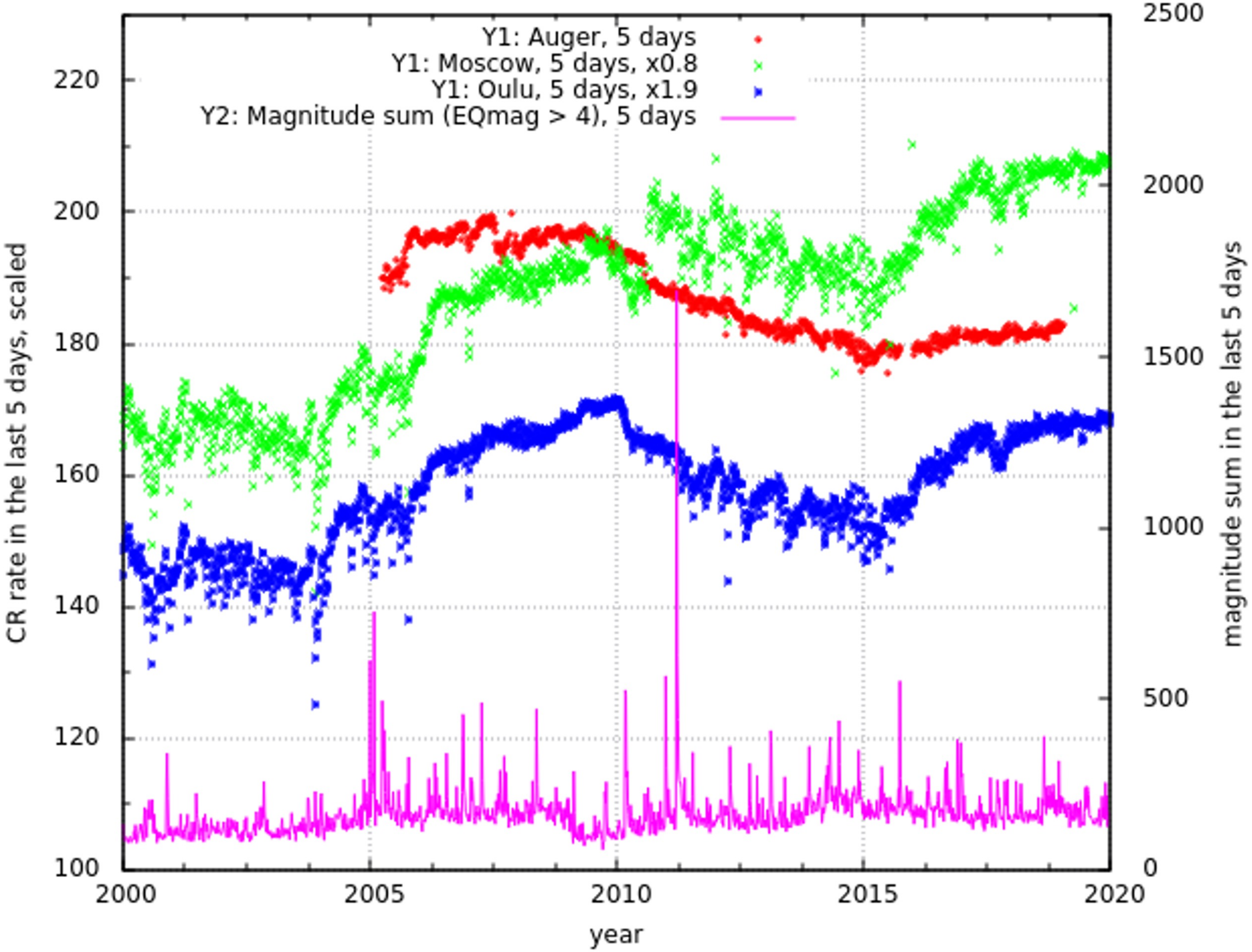
Chile 2010 earthquake & DEMETER satellite:

Statistical study of the ionospheric density variation related to the 2010 Chile earthquake and measured by the DEMETER satellite D. Pısa, O. Santolik Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic. M. Parrot LPC2E/CNRS, Orl´eans, France.

Statistical Study of the Ionospheric Density Variation Related to the 2010 Chile Earthquake and Measured by the DEMETER Satellite

-> Unexplained anomaly in particle density in the ionosphere 10-20 days before the EQ

The data



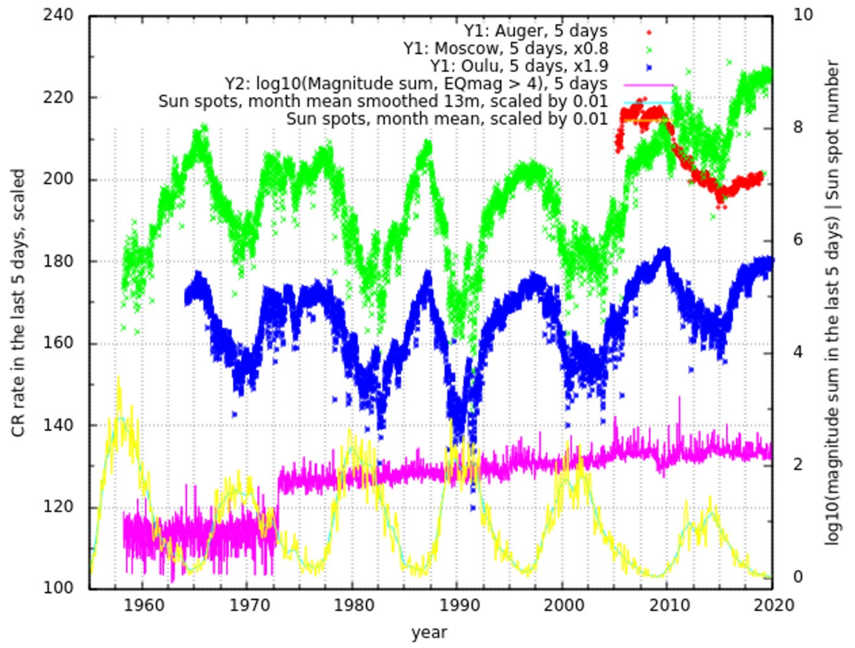
public resources of:

[Pierre Auger Observatory scaler data]()

[Neutron Monitor Database]()

[U.S. Geological Survey]()

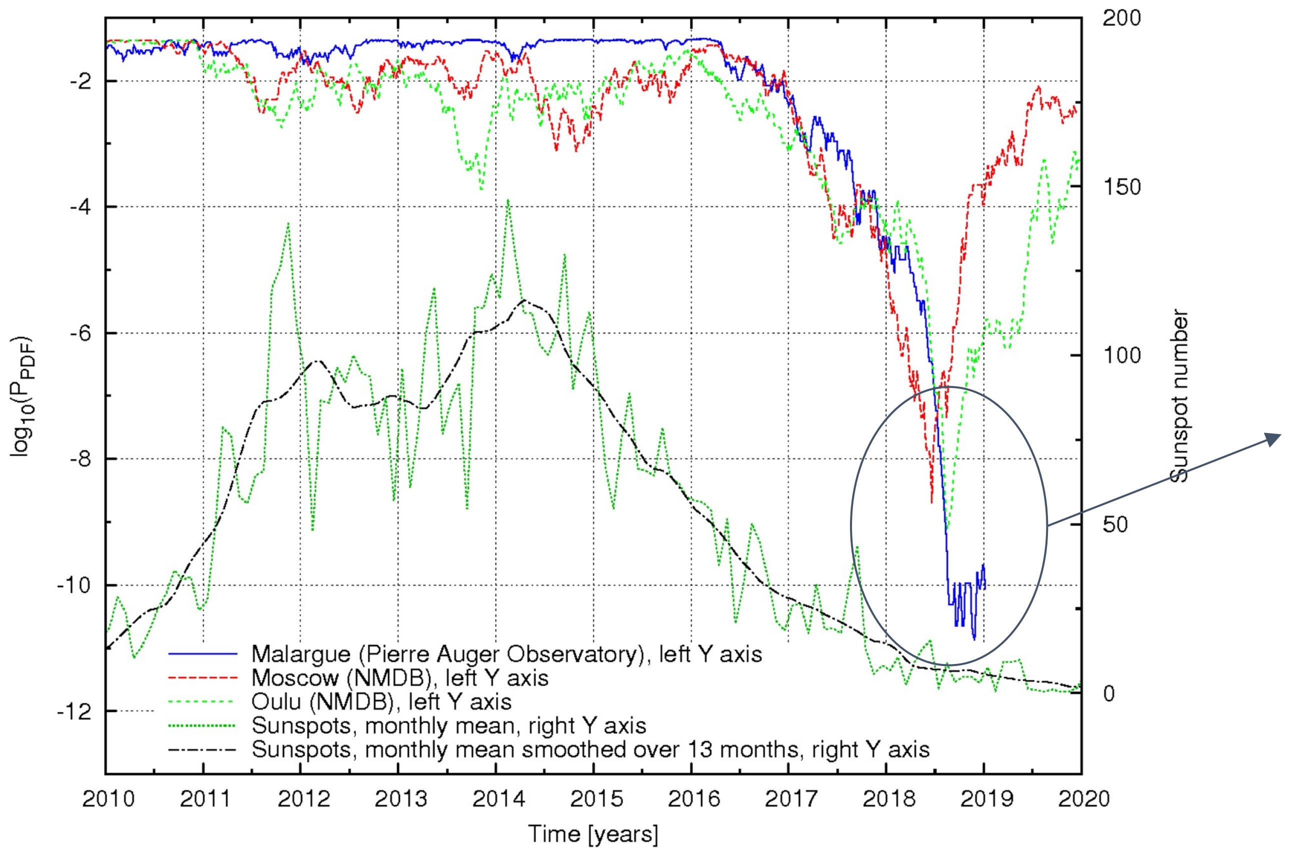
[Solar Influences Data analysis Center]()



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?

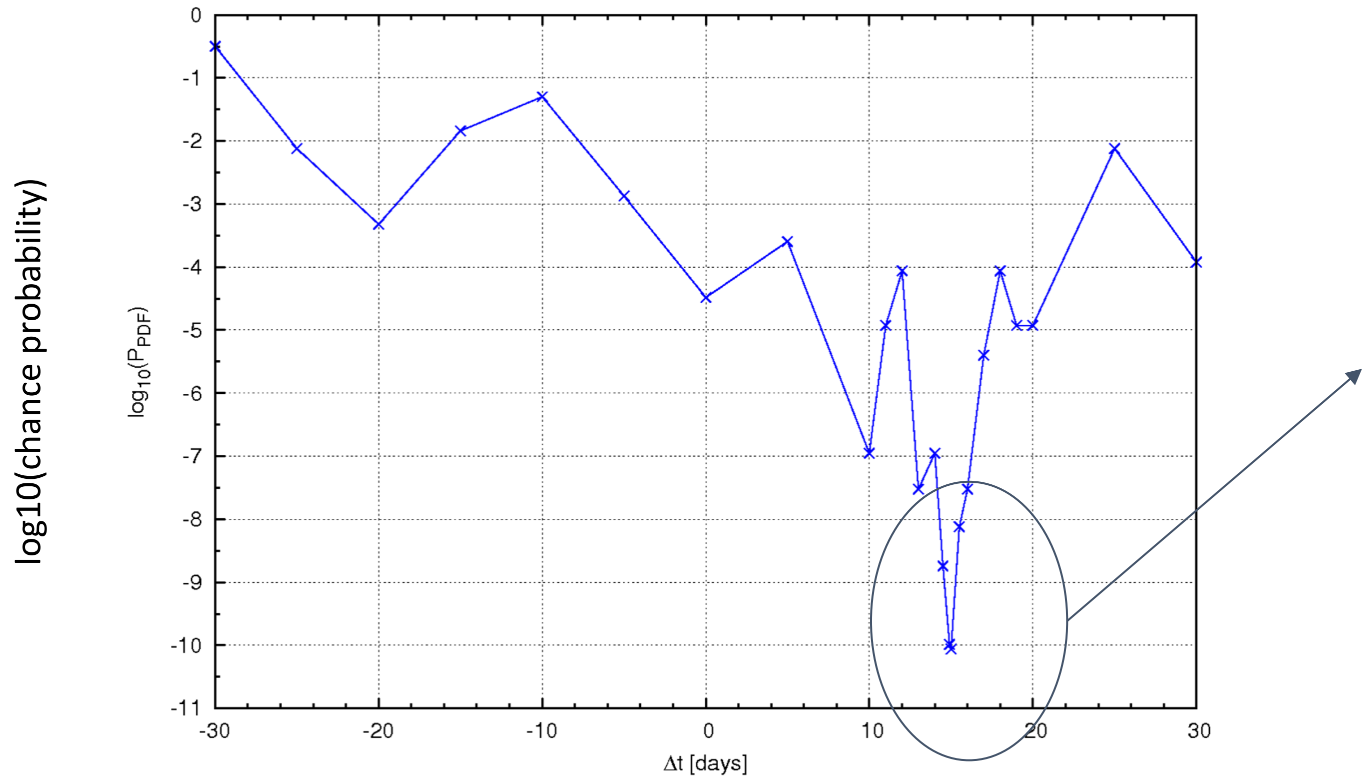
log10(chance probability)



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

~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.

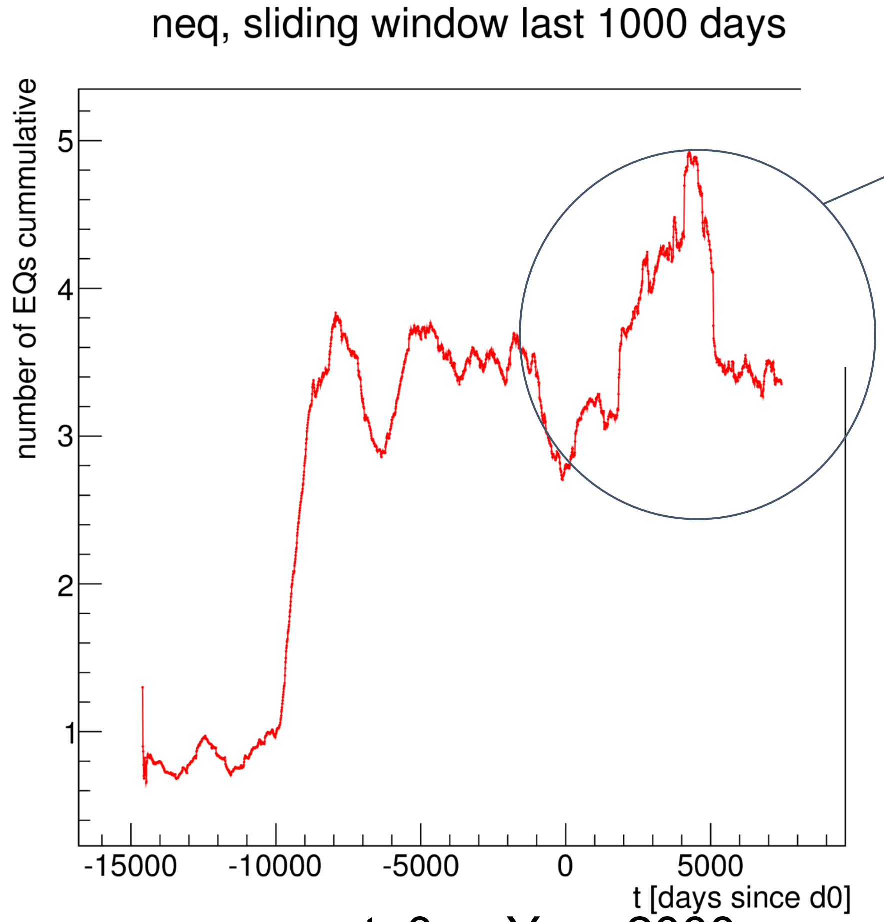
Cosmic ray variation 15 days before the corresponding change in seismic activity!

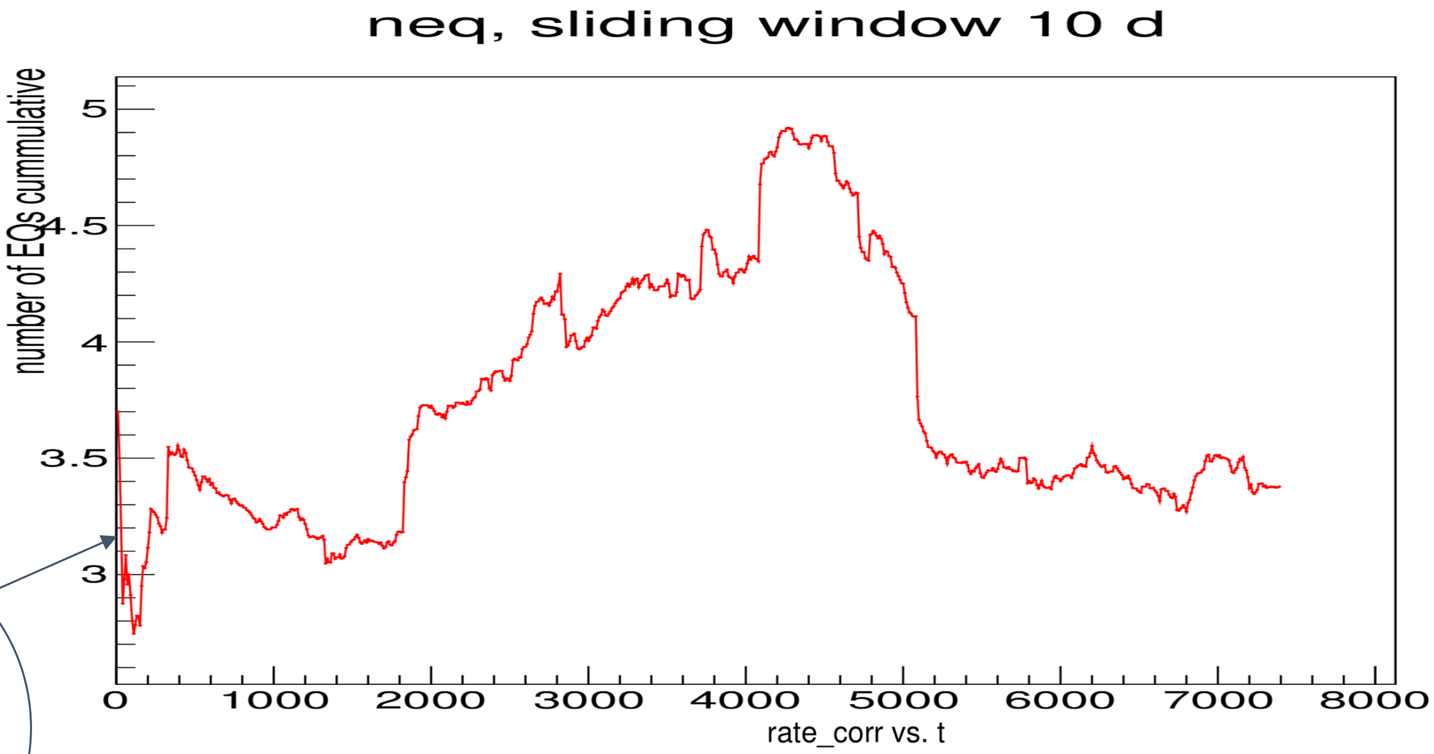


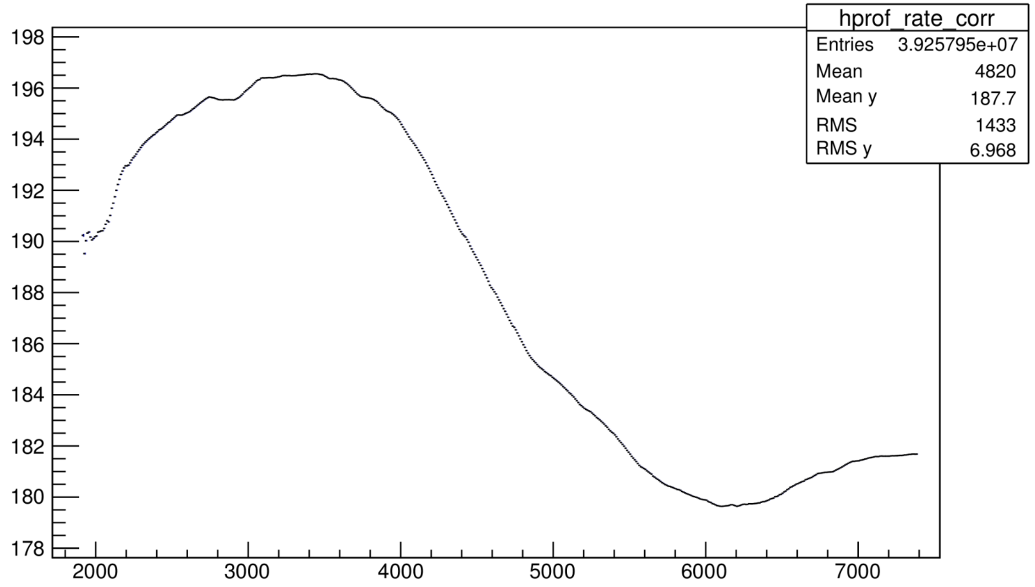
New perspective for an early warning system against earthquakes?

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.

Super large scale EC CR behavior







t=0 -> Year 2000

Bayesian Analysis/Inference

Bayesian analysis is a statistical paradigm that shows the most expected hypotheses using probability statements and current knowledge.
One of the most frequent case is analysis of probable values of model parameters.

Bayes' theorem:

$$\underbrace{p(H_1 \mid D, I)}_{\text{Posterior}} = \frac{\overbrace{p(D \mid H_1, I)}^{\text{Likelihood}}\,\overbrace{p(H_1 \mid I)}^{\text{Prior}}}{\underbrace{p(D \mid I)}_{\text{Evidence}}}$$

Prior: knowledge before experiment (logically)
Likelihood: Probability for data if the hypothesis was true
Posterior: Probability that the hypothesis is true given the data
Evidence: normalization; important for model comparison

Generally, maximum likelihood (parameters which maximize the probability for data) **does not** give the most likely parameters!!!

Bayesian Analysis

Formulation of set of models (set of hypothesis):

π_i here $i = 0..N-1$

↓

Finding the *a priori* probabilities of the models:

$$P(\pi_i) = 1/N \quad \text{for} \quad \forall i = 0..N-1$$

↓

Calculating the coditional probabilities of the events:

$$P(E\,|\,\vec{\pi}_i) = \prod_\alpha P(E_\alpha\,|\,\vec{\pi}_i),$$

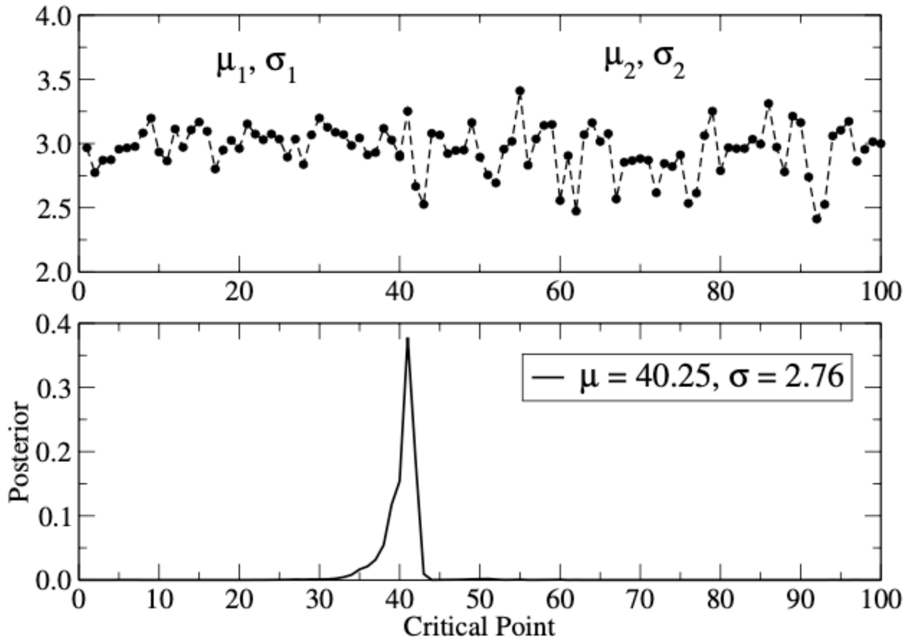
where α is the index of the observational constraints.

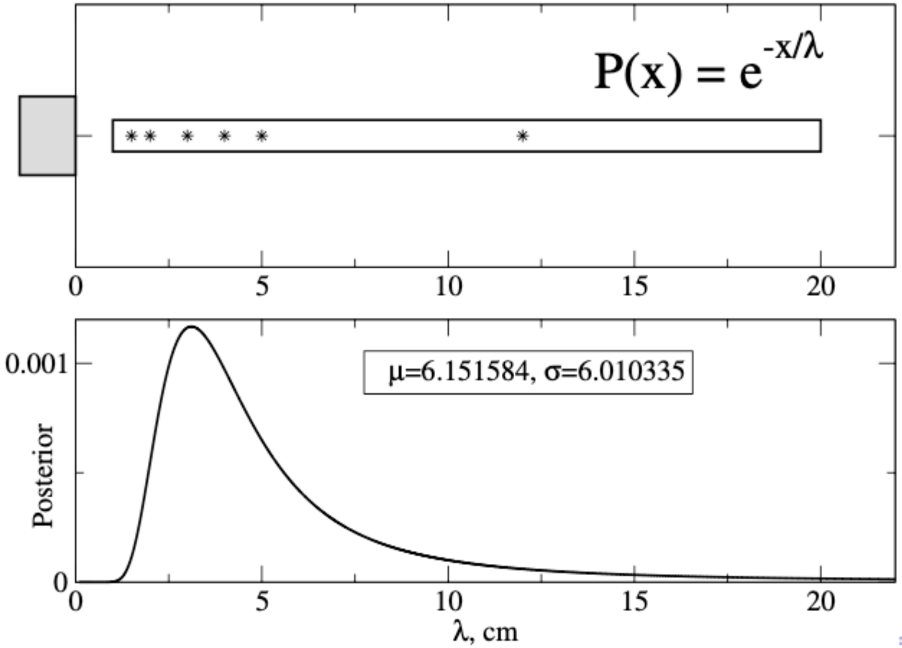
↓

Calculating the *a posteriori* probabilities of the models:

$$P(\vec{\pi}_i\,|\,E) = \frac{P(E|\vec{\pi}_i)P(\vec{\pi}_i)}{\sum_{j=0}^{N-1} P(E|\vec{\pi}_j)P(\vec{\pi}_j)}$$

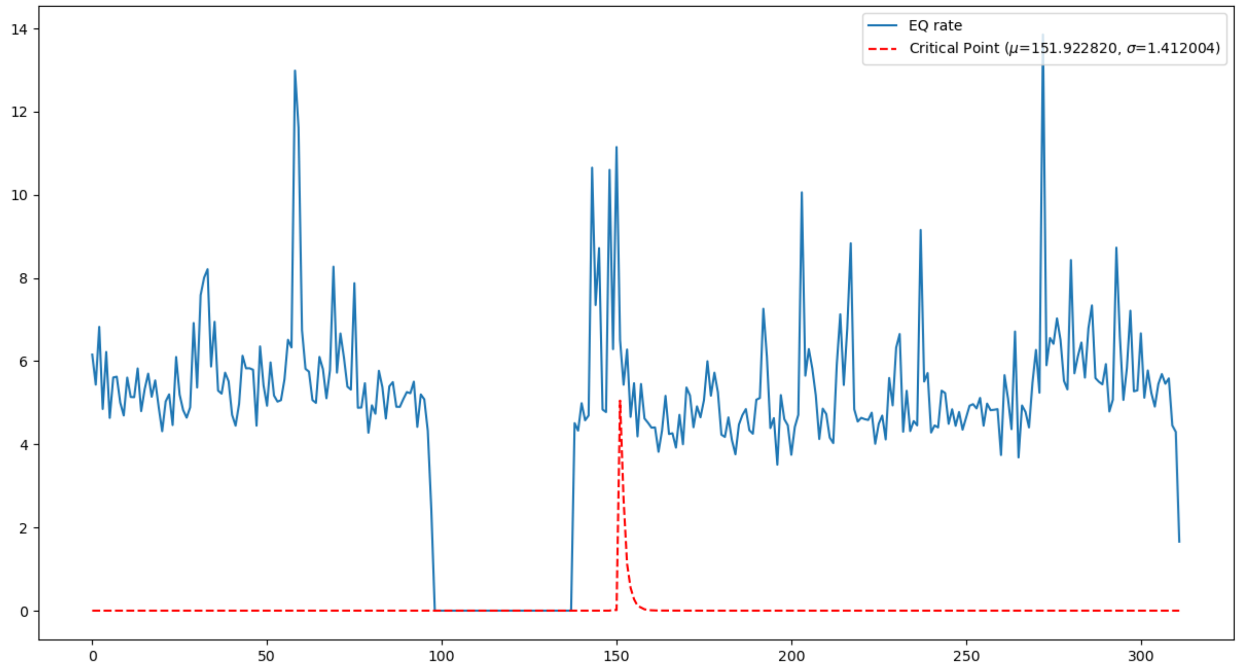
Bayesian Analysis

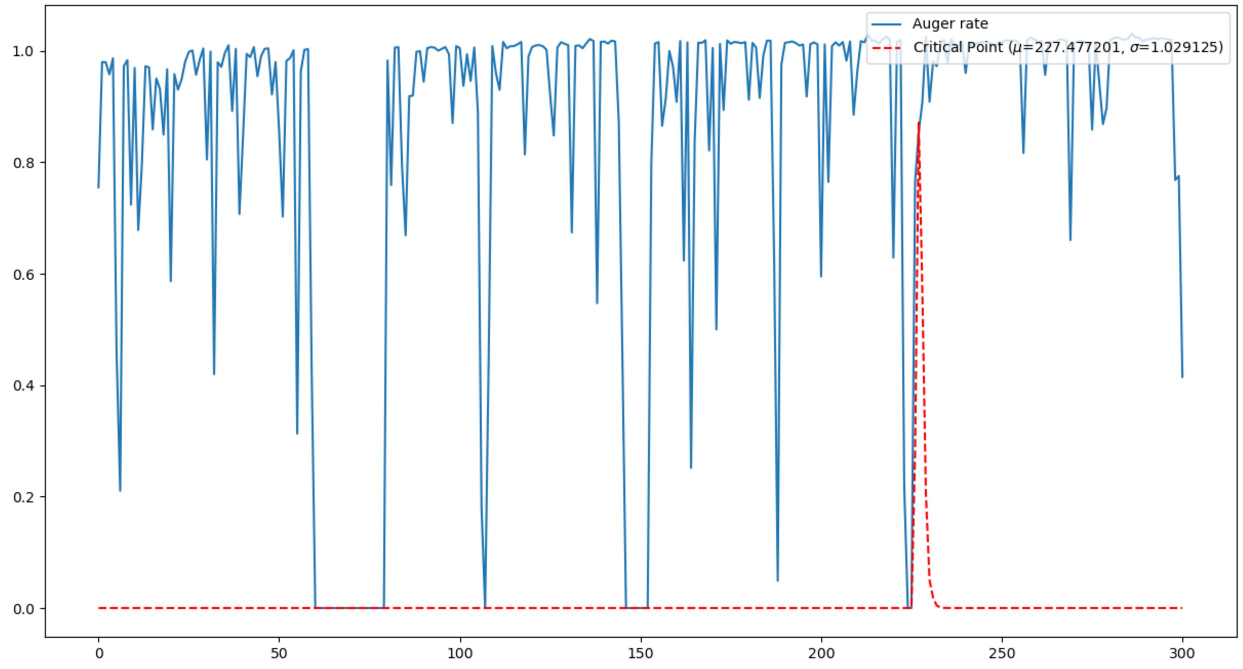




Results

Detected changepoints for EQ rate (left) and Auger rate (right)





CREDO detectors today

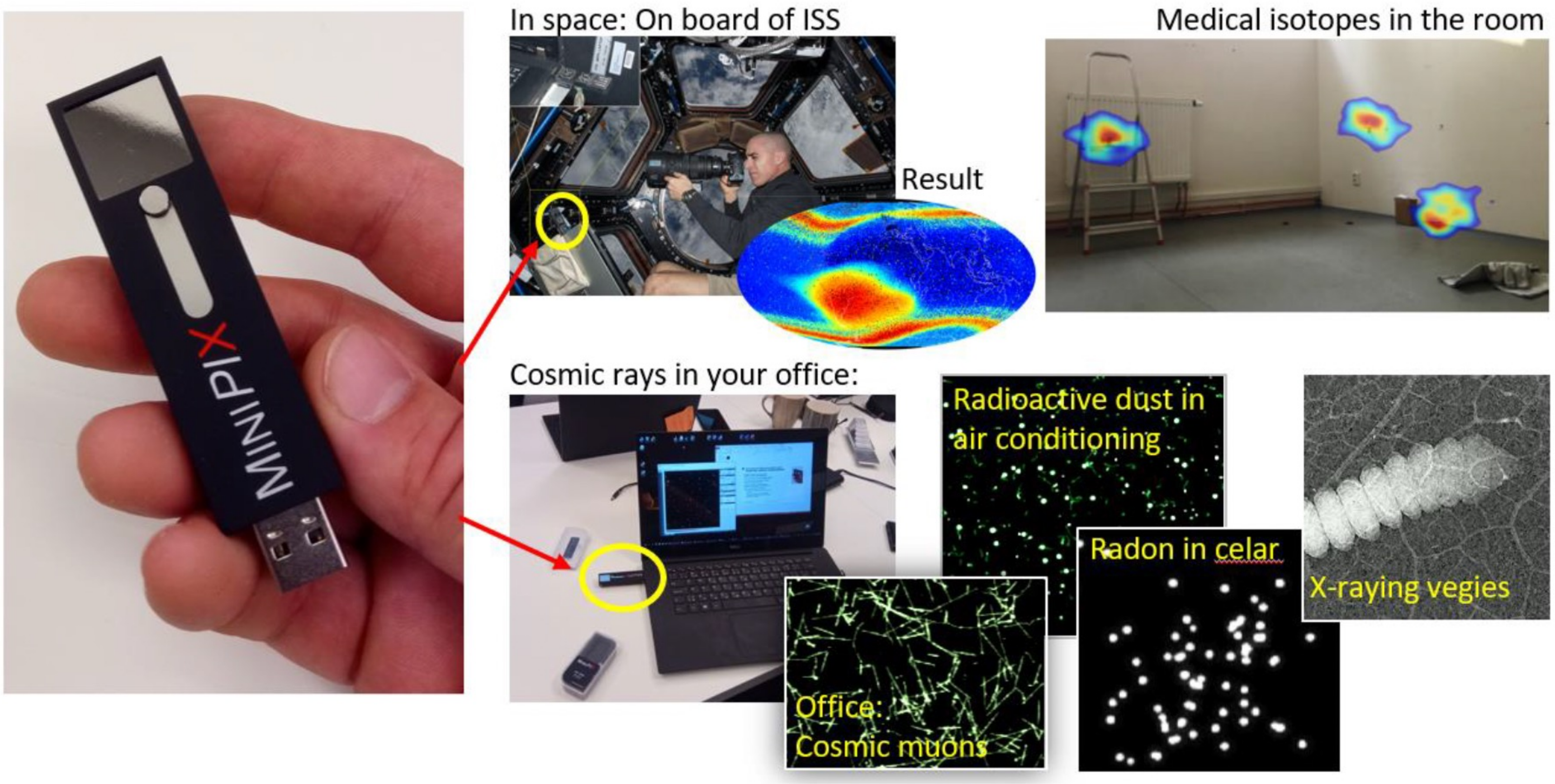
- CREDO Detector (Android app, ~2M track candidates, origin: IFJ PAN, Kraków)
- cosmicrayapp.com (iOS, ~7M track candidates, origin: Canada)
- CREDO Web Detector (Chrome, in tests, origin: Kraków)
- HEAMS - High Energy Astrophysics Muon System (8 x 1m^2 scintillator detectors, ~300k ~0.1 PeV air showers,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

Public resources:

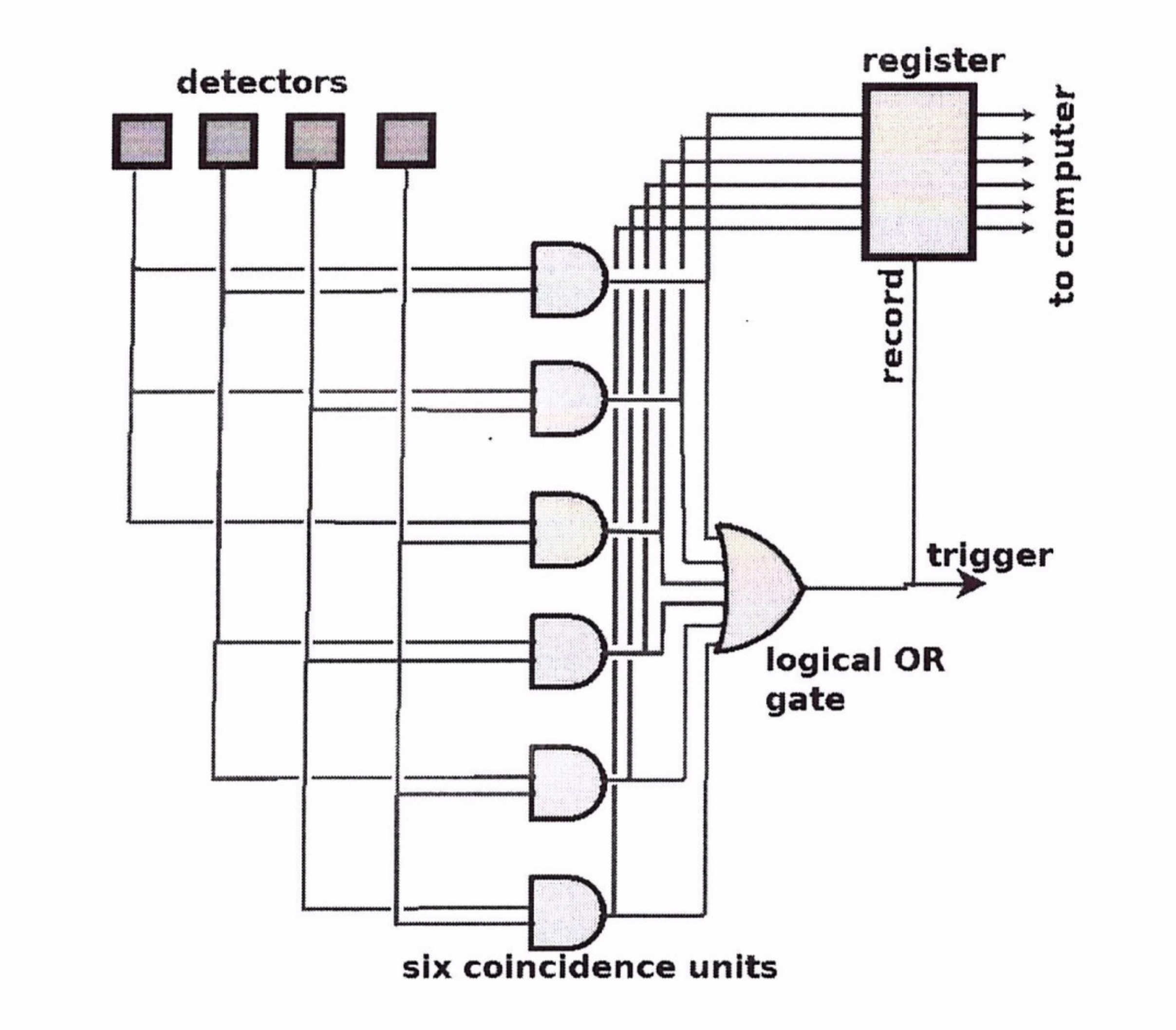
Pierre Auger Observatory scaler data, Neutron Monitor Database

Short term perspective: GELATICA, CZELTA, other public resources

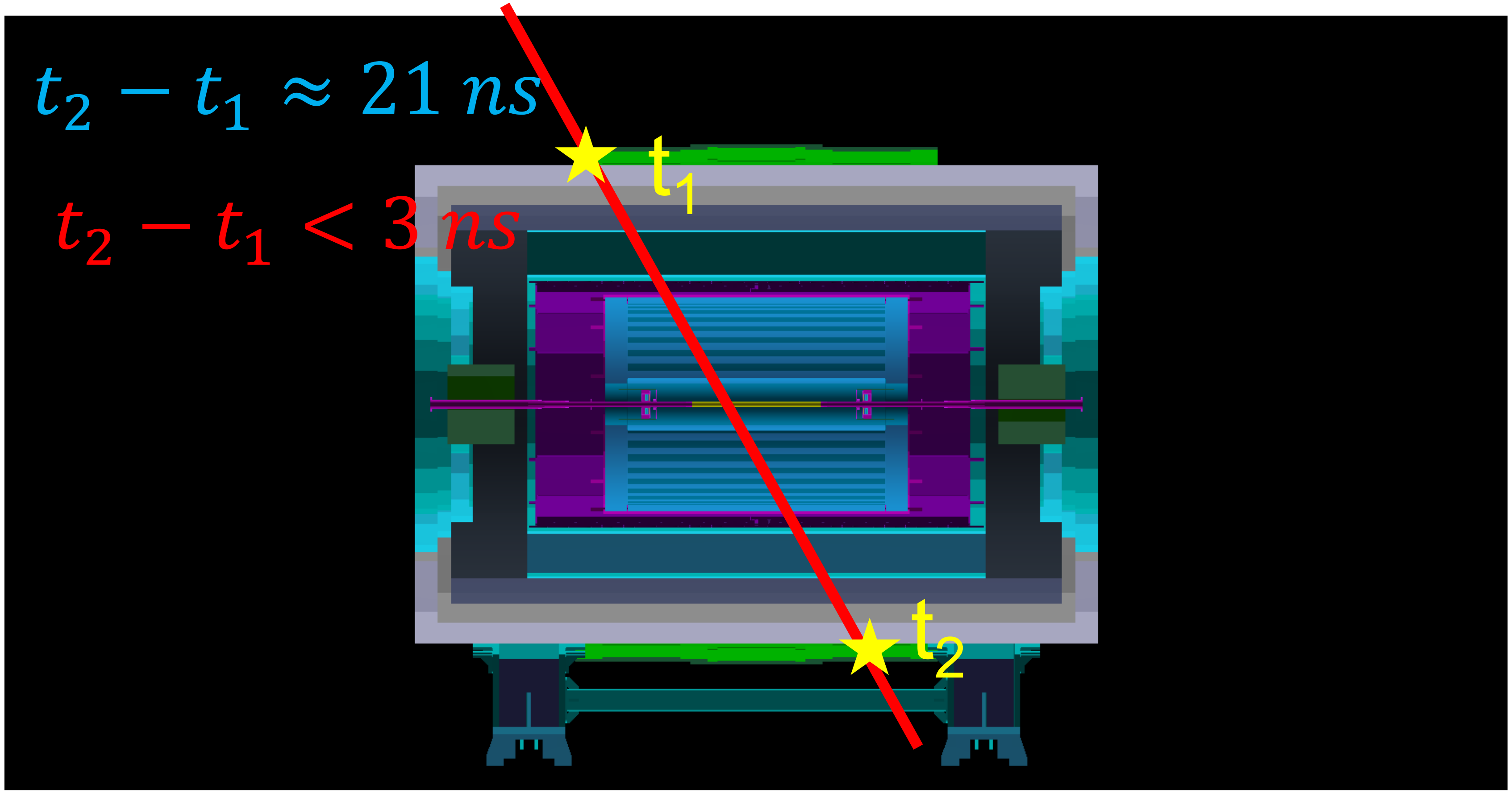
ADVACAM MiniPix



CREDO-MAZE Detector



Time of flight in colliders



THE IDEA

Astrotectonic will enable to obtain early signal notifications for upcoming earthquakes in the threatened area. Essence of the idea lies in multi-channel approach. We develop unified system which allows to manage various earthquake precursors within single platform.

INNOVATION

- Astrotectonic is opening an information channel - **cosmic particles registration**.
- Multichannel approach unifies the data of different nature.
- Astrotectonic introduces recent advances in **deep learning** to find and define anomalies in data that appear prior shakes (multimodal Neural Network).

HARDWARE & SOFTWARE

Astrotectonic is a hardware-software solution. Hardware is remote, compact, easy to use cosmic ray detector. Whereas software is a dedicated system for data analysis and visualization. Astrotectonic will install several detectors to provide a continuous accurate data feed and a live visualization of earthquake chance probability.

Citizen science motivation

Citizen science

From Wikipedia, the free encyclopedia

Citizen science (**CS**) (also known as **crowd science**, **crowd-sourced science**, **civic science**, **volunteer monitoring** or **networked science**) is scientific research conducted, in whole or in part, by amateur or nonprofessional scientists. Citizen science is sometimes described as "public participation in scientific research", participatory monitoring and participatory action research.[1]

Mutual benefit resulting from synergy!

Participants get opportunities:

- To educate themselves
- To do real science
- To feed their curiosity
- To become co-authors of a scientific paper

CREDO gets:

- Manpower
- Geographical expansion
- Popularization of its ideas and PR

Sustainability? Fun -> gamification!

https://credo.science/particle_hunters/

Predicting earthquakes?? Probing DM streams??? Testing Quantum Gravity scenarios??? With smartphones????

-> possible ultimate ambition: **cosmic ray station in every school and BTS station + citizen science**

-> organizational concept: e.g. **Open Multi Messenger Organization** (OMMO)

The breakthrough in science might come from citizen science…

→ large geographical spread

→ inter-collaboration cooperation

→ **massive public engagement**

↓

citizen science might be an invaluable scientific tool!

More about CREDO

https://credo.science

Personal contact:

Piotr Homola / CREDO Project Coordinator /
Piotr.Homola@credo.science / +48 502 294 333

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