Invitation to the Cosmic Ray Extremely Distributed Observatory

Piotr Homola on behalf of the CREDO Collaboration, ICRC 2021, 12-23.07.2021

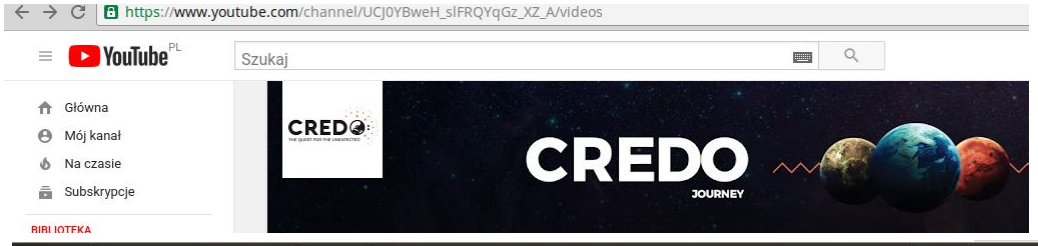
CREDO
THE QUEST FOR THE UNEXPECTED

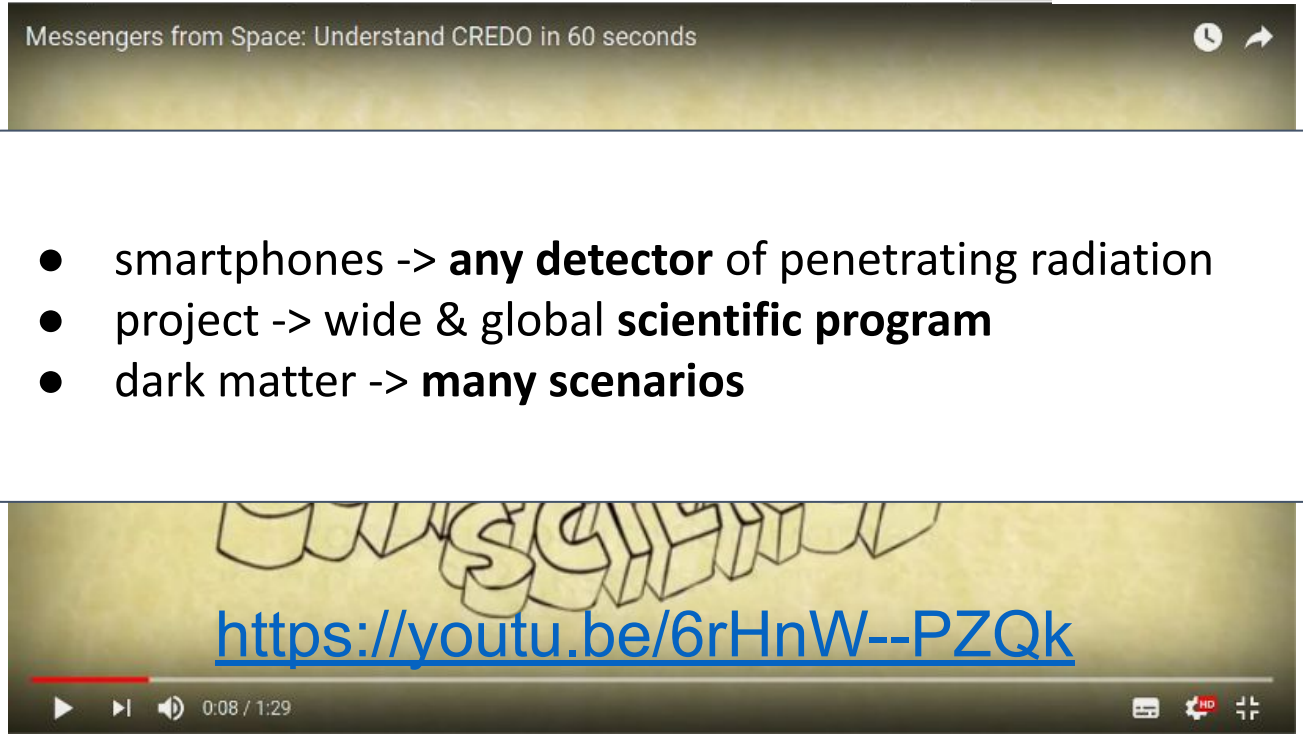
+ you = smarter together

CREDO
JOURNEY

key reference: *Symmetry* **2020**, *12*(11), 1835; **https://doi.org/10.3390/sym12111835**


https://www.youtube.com/channel/UCJ0YBweH_sIFRQYqGz_XZ_A/videos
YouTube PL
Szukaj
Główna
Mój kanał
Na czasie
Subskrypcje
CREDO
JOURNEY
Messengers from Space: Understand CREDO in 60 seconds
60 SECOND ADVENTURES IN COLLABORATIVE SCIENCE
https://youtu.be/6rHnW--PZQk
0:08 / 1:29





- smartphones -> **any detector** of penetrating radiation
- project -> wide & global **scientific program**
- dark matter -> **many scenarios**

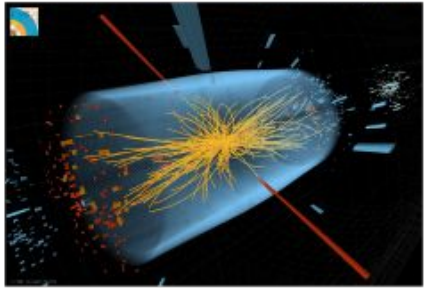
https://youtu.be/6rHnW--PZQk


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

Where to find new data? A biased view

production → (acceleration) → interactions → particle ensemble → conclusions

Laboratories (experiments)
accelerators & collinders



Investment:

~100 mld $ ~0 $

Energies

$<10^{12}$ eV $<10^{20}$ eV+

Availability:

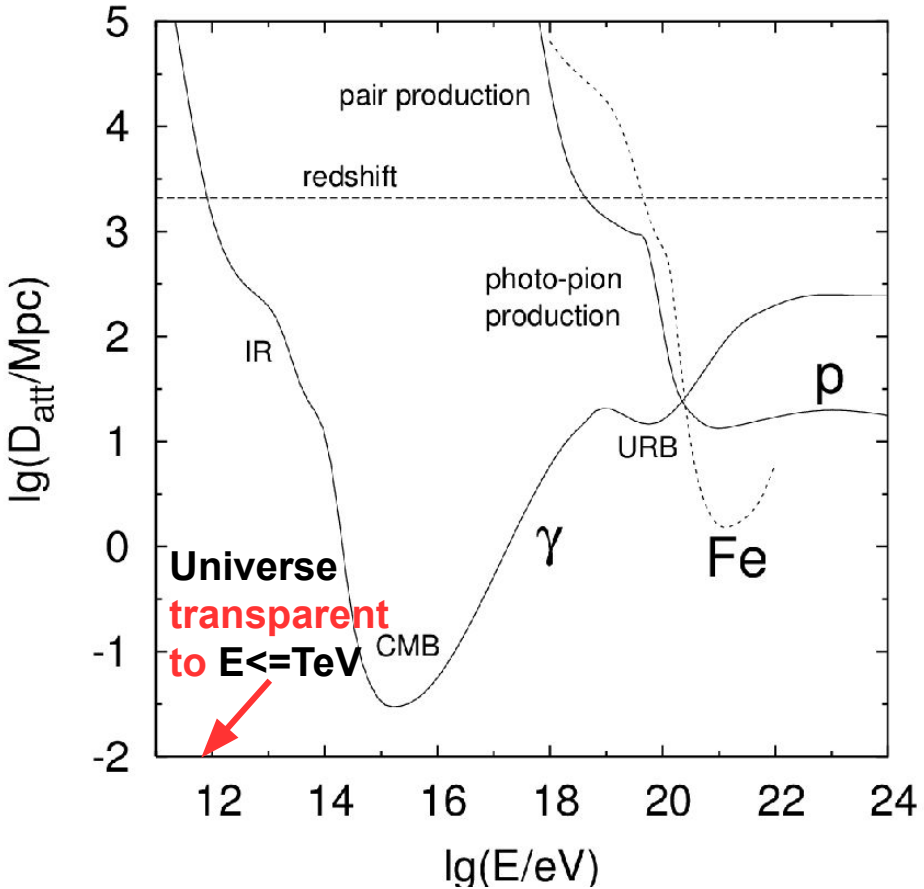
Rich countries Everybody

Data flux:

huge small

Cosmos (observations)
accelerator & collider

CR propagation → interactions → products!



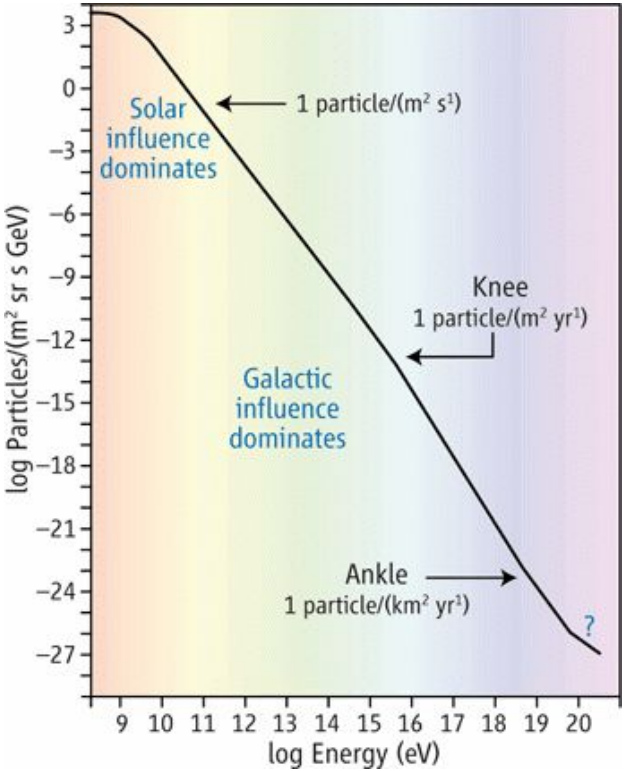
CR: under-explored field! Global search not yet tried!

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

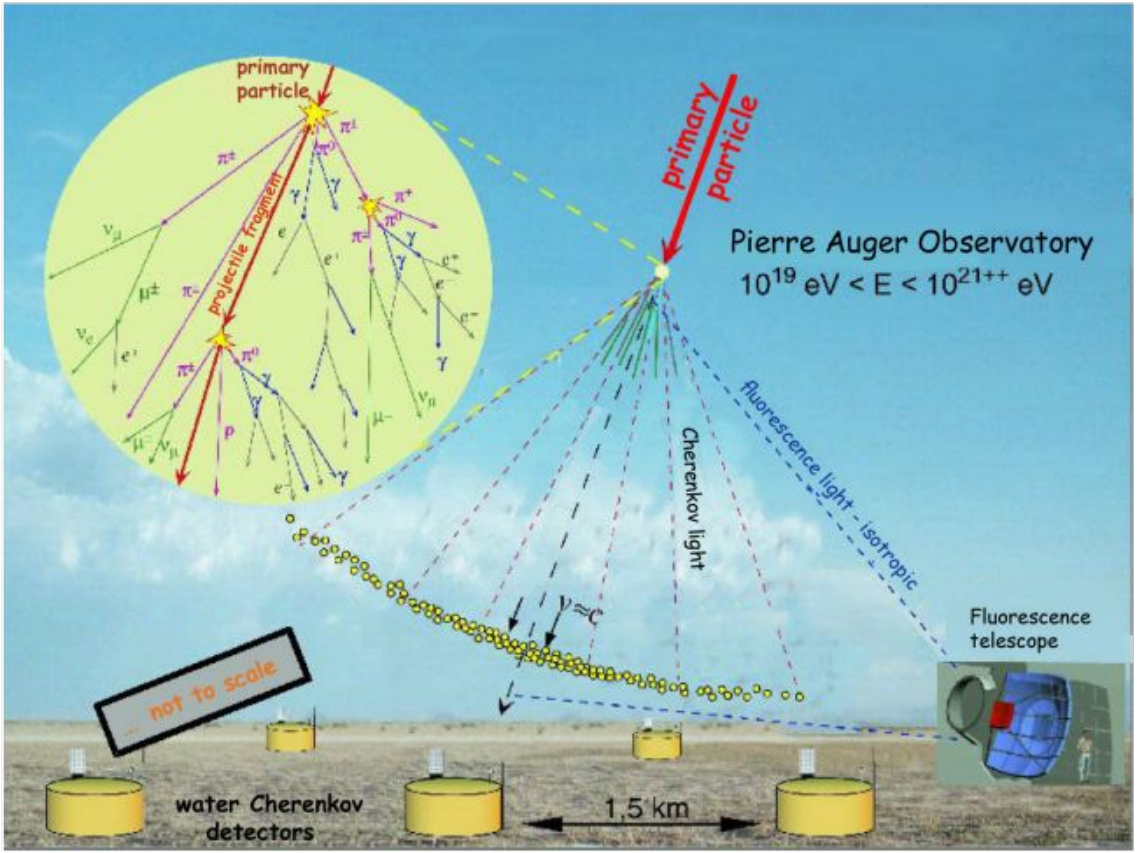
Flux rapidly decreases with energy (~10^{-3}),
Highest energies → the most demanding challenges:

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

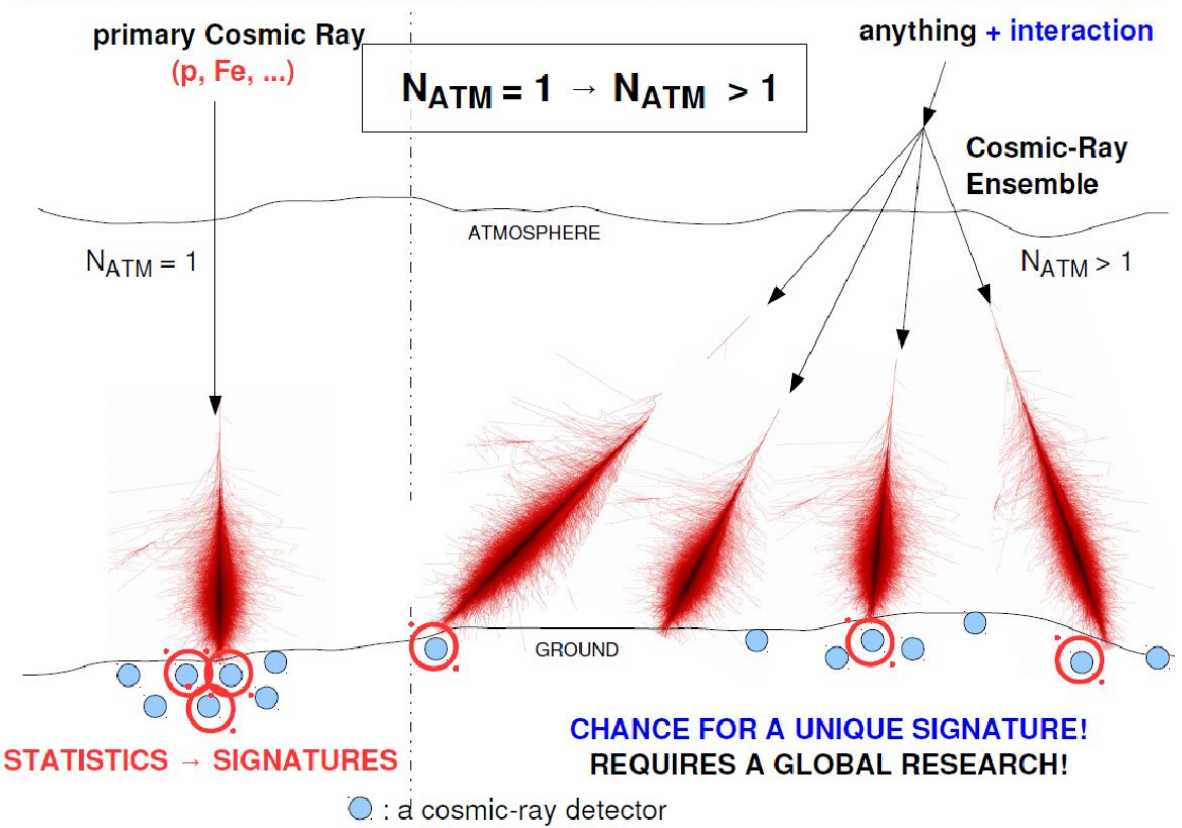
→ scientific:
What are Ultra-High Energy Cosmic Rays (UHECR)?
Where they come from?
How do they propagate?



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

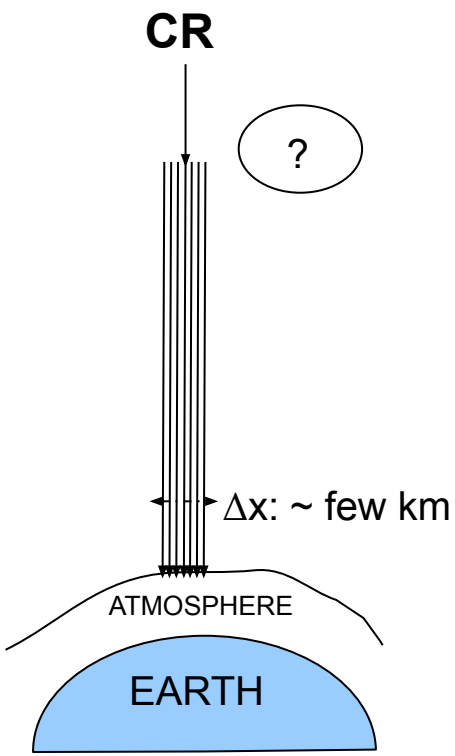


Novel science: cosmic ray large scale correlations

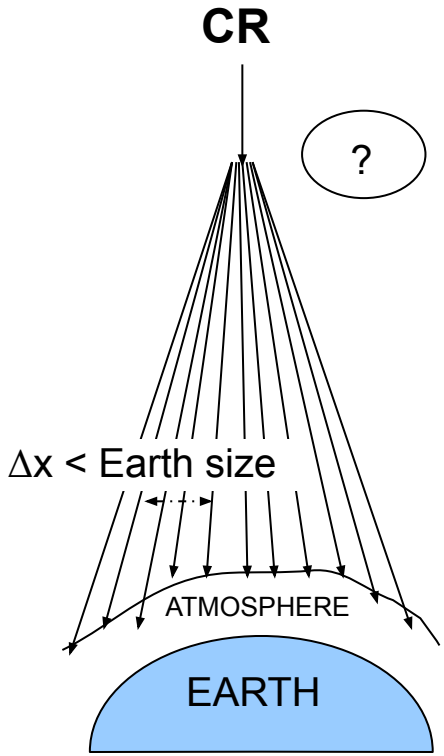


CREDO
THE QUEST FOR THE UNEXPECTED

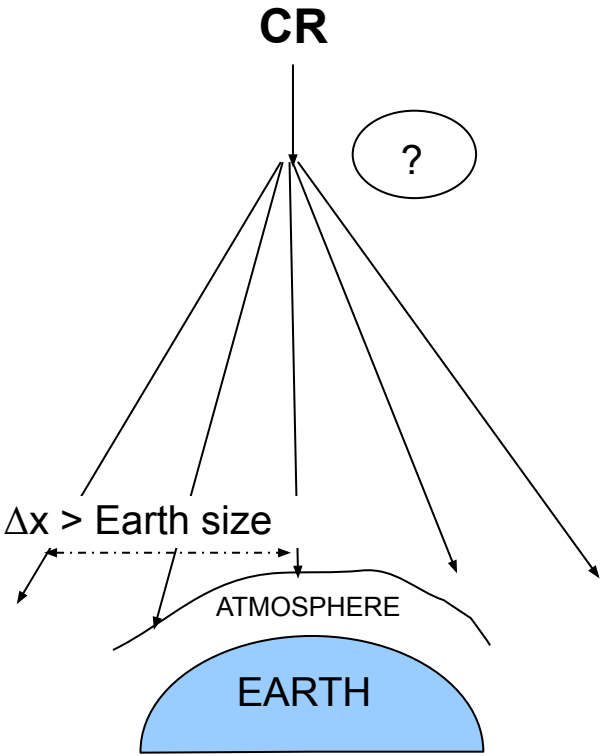
N_{ATM} >= 1: obvious, untouched ground



obvious detection



obvious (unchecked) „between"



obvious extinction

$N_{ATM} > 1$ 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)

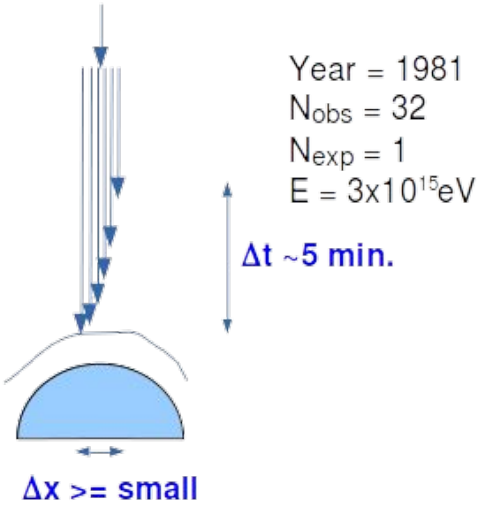
A series or burst of 32 extensive air showers of estimated energy 3×10^{15} eV was observed within a 5-min time interval beginning at 9.56 [illegible] (CST) on 20 January 1981 in Winnipeg, Canada. This observation was the only one of its kind during an experiment which recorded 150 000 such showers in a period of 18 months between October 1980 and April 1982.

PACS numbers: 94.40.Pa, 96.40.Ro, 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)

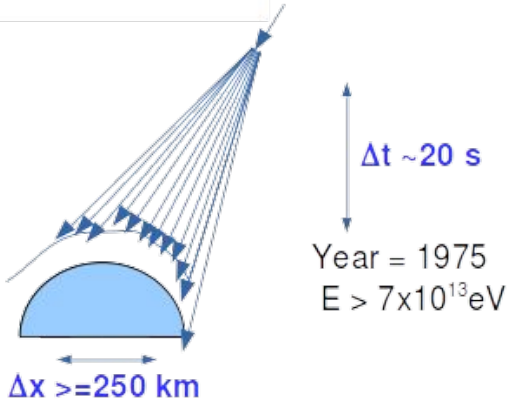
The authors report on an unusual simultaneous increase in the cosmic-ray shower rate at two recording stations separated by 250 km. The event lasted for 20 s. This event was the only one of its kind detected in three years of observation. The duration and structure of this event is different from a recently 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

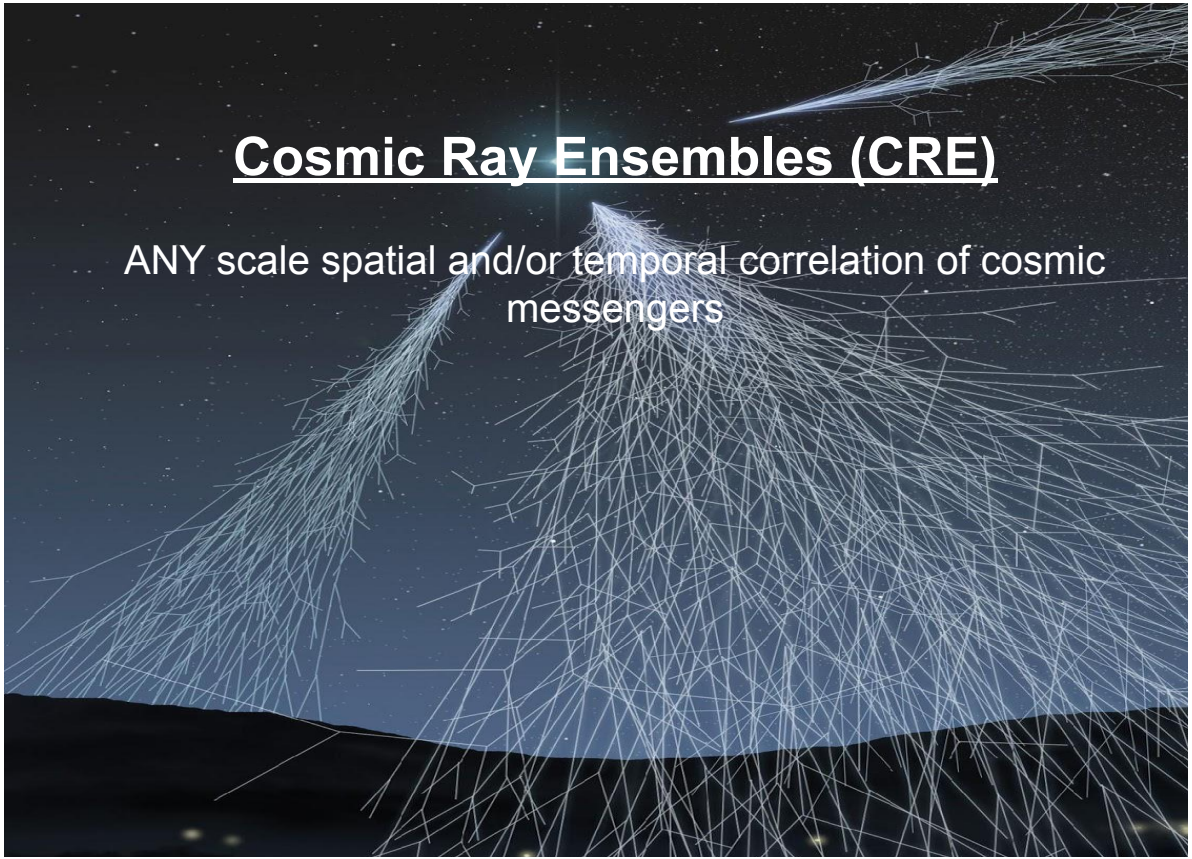
PH: Correlated cosmic rays?

$N_{ATM} > 1$?

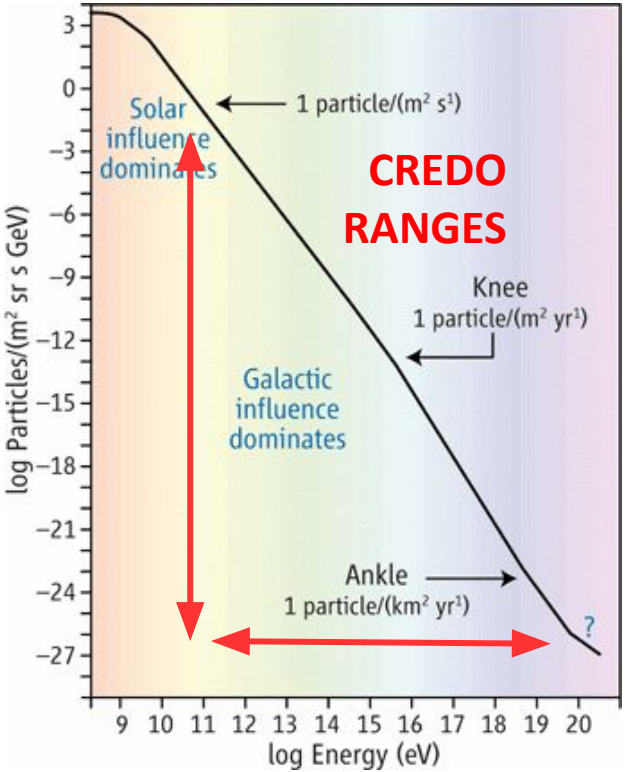


-> "Pay attention to data"!

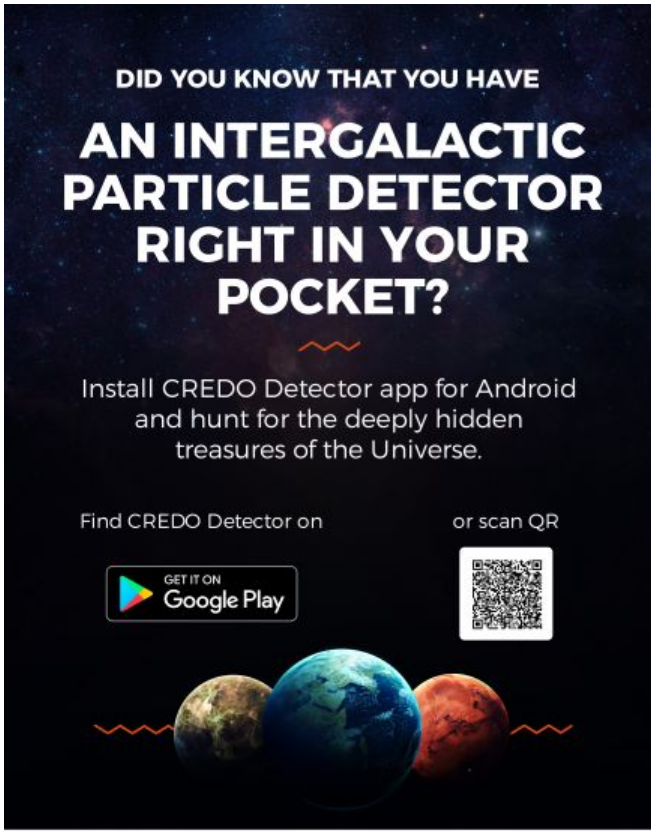
$N_{ATM} > 1$: new channel in multi-messenger astrophysics!



Cosmic Ray Ensembles (CRE)! Full energy spectrum!

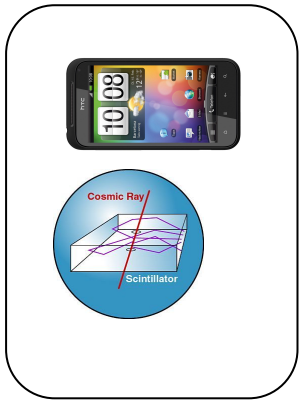


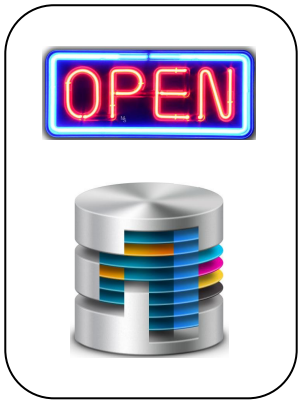
Novel Global Solution: **cloud of clouds**

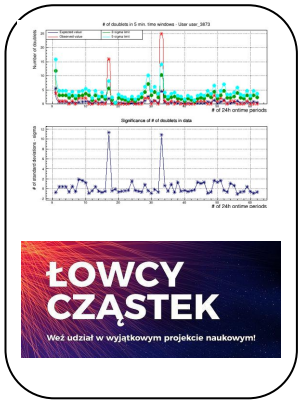


-> “new data”!

infrastructure: globally distributed network of technologically diverse particle sensors + central data processing and sharing





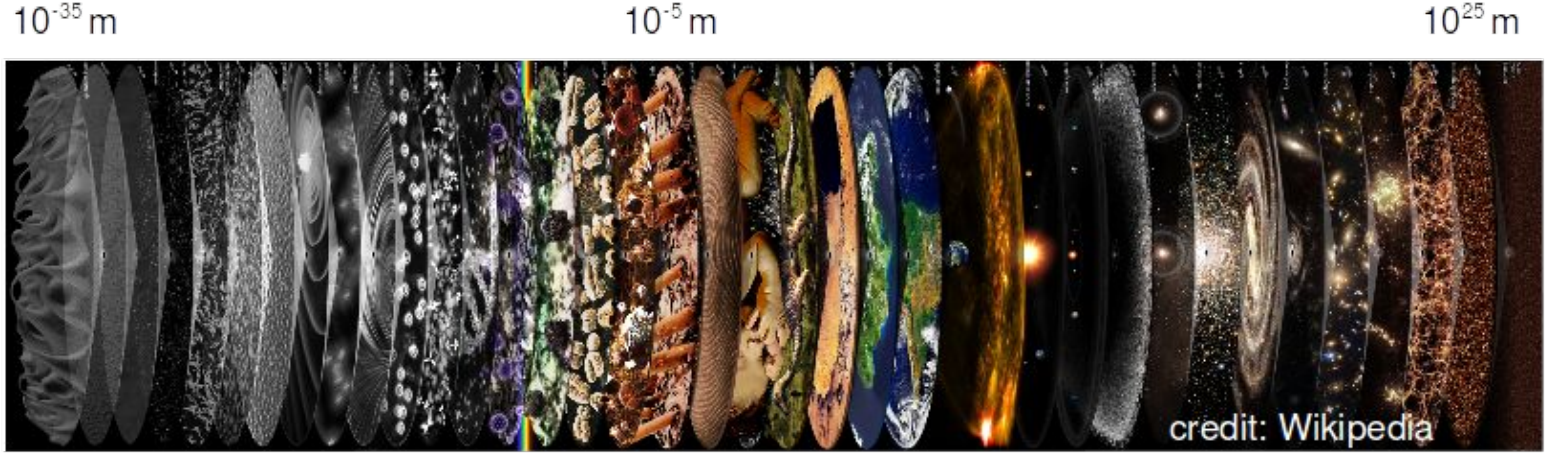


Distributed data acquisition (expert and non-expert)

Central database, processing, interfaces (Cyfronet AGH-UST)

Scientific and societal benefits (publications, education, engagement)

CREDO Science Potential

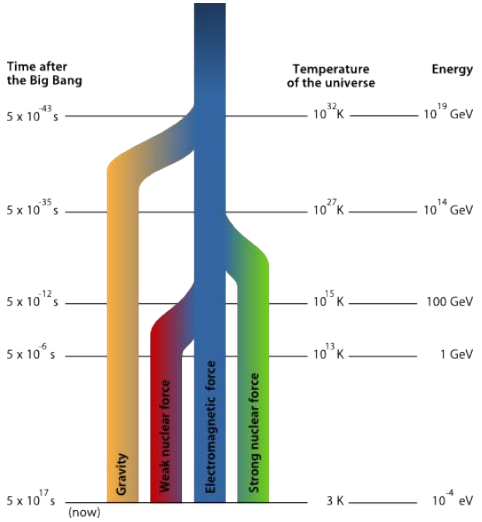


more (popular level): https://credo.science/education-materialyeng/podcast/ (EN) / https://credo.science/education-materialypl/podcast/ (PL)

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

N_{ATM} >= 1 mission (briefly)

Scenarios AND Fishing



CREDO: already global

42 institutions / 19 countries / 5 continents / ~ 11 900 users / ~ 4400 teams / > 10 000 000 smartphone detections / > 1100 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 (18.02.2021):

- Australia (2)
- Canada (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 (1)
- Thailand (1)
- Ukraine (3)
- Uruguay (1)
- USA (3)

(42 institutions, 19 countries)

CREDO

THE QUEST FOR THE UNEXPECTED

CREDO the 2nd Anniversary Symposium
IFJ PAN, Kraków, 4 October 2018

fot. Ireneusz Kochanek / FILMNET

Peer-reviewed publications “for the CREDO Collaboration”:

published:

1. **“Determination of Zenith Angle Dependence of Incoherent Cosmic Ray Muon Flux Using Smartphones of the CREDO Project”,** M. Karbowiak, T. Wibig, et al. (CREDO Collab.), *Appl. Sci.* 2021, *11*, 1185, January 2021. [DOI: 10.3390/app11031185].
2. **“Cosmic Ray Extremely Distributed Observatory”,** P. Homola, et al. (CREDO Collab.), Symmetry 2020, 12(11), 1835, 2020. [DOI: 10.3390/sym12111835].
3. **“Towards A Global Cosmic Ray Sensor Network: CREDO Detector as the First Open-Source Mobile Application Enabling Detection of Penetrating Radiation”,** Ł. Bibrzycki, et al. (CREDO Collab.), Symmetry, 12(11), 1802, 2020. [DOI: 10.3390/sym12111802].
4. **“The first CREDO registration of extensive air shower”,** M. Karbowiak, T. Wibig, et al. (CREDO Collab.), Physics Education, 55(5), July 2020.[DOI: 10.1088/1361-6552/ab9dbc].
5. **“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].

in preparation:

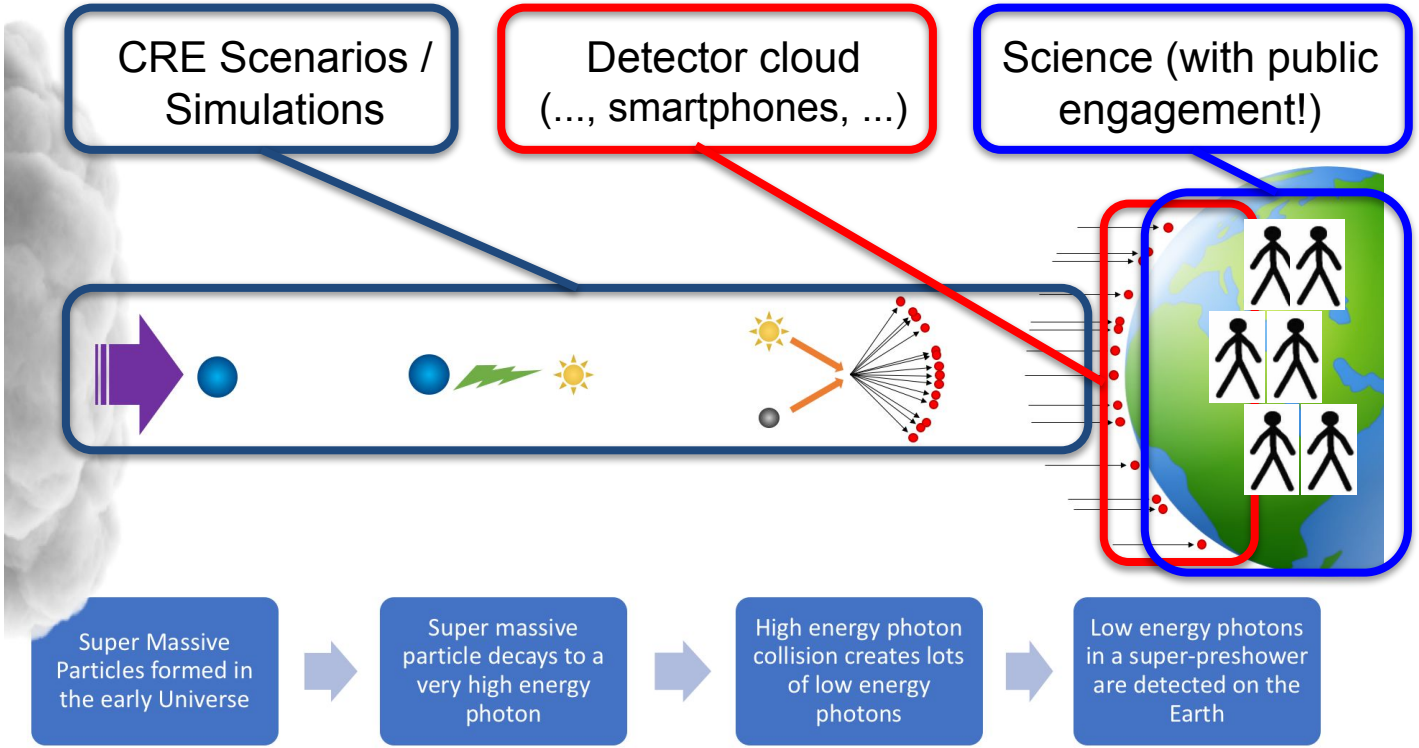
- **“Cosmic ray ensembles as signatures of ultra-high energy photons interacting with the solar magnetic field”**
- **“Observation of large scale precursor correlations between cosmic rays and earthquakes”**
- “On the method of ascertainment of the possible historical proximity of two extensive air showers”
- “A search for bursts at 0.1 PeV with a small air shower array”
- [The CREDO data ontology]
- [Machine learning for CREDO]

planned soon (selection):

- [UHE photon limit from CRE simulations & gamma astronomy]
- [CRE formation - simulations with CRPropa]
- [PRESHOWER 3.0 code]

CREDO
THE QUEST FOR THE UNEXPECTED

today: selected science highlights



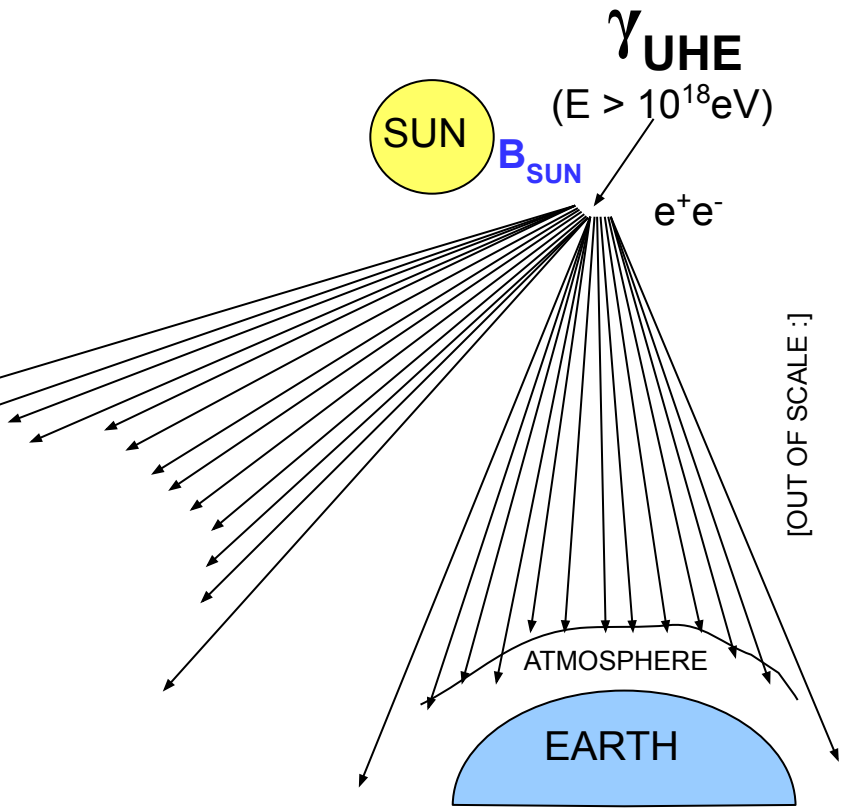
Prepared for submission to JCAP

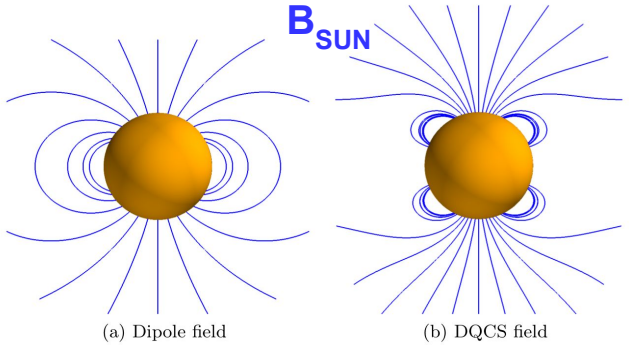
Cosmic ray ensembles as signatures of ultra-high energy photons interacting with the solar magnetic field

The CREDO Collaboration

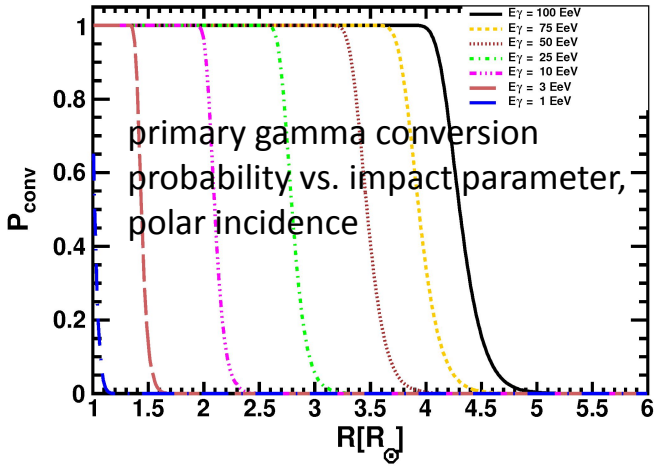
N. Dhital,[a] P. Homola,[a] D. Gora,[a] H. Wilczyński,[a] K. Almeida Cheminant,[a] D. Alvarez-Castillo,[a,d] G. Bhatta,[b] T. Bretz,[c] A. Ćwikła,[e] A.R. Duffy,[f] B. Hnatyk,[g] P. Jagoda,[h,a] M. Kasztelan,[i] K. Kopański,[a] P. Kovacs,[j] M. Krupinski,[a] V. Nazari,[d] M. Niedźwiecki,[k] D. Ostrogórski,[h] K.Smelcerz,[k] K. Smolek,[l] J. Stasielak,[a] O. Sushchov,[a] T. Wibig,[m] K. Wozniak,[a] J. Zamora-Saa[n] and Z. Zimborás[j]

>=EeV photons nearby the Sun→ big CRE



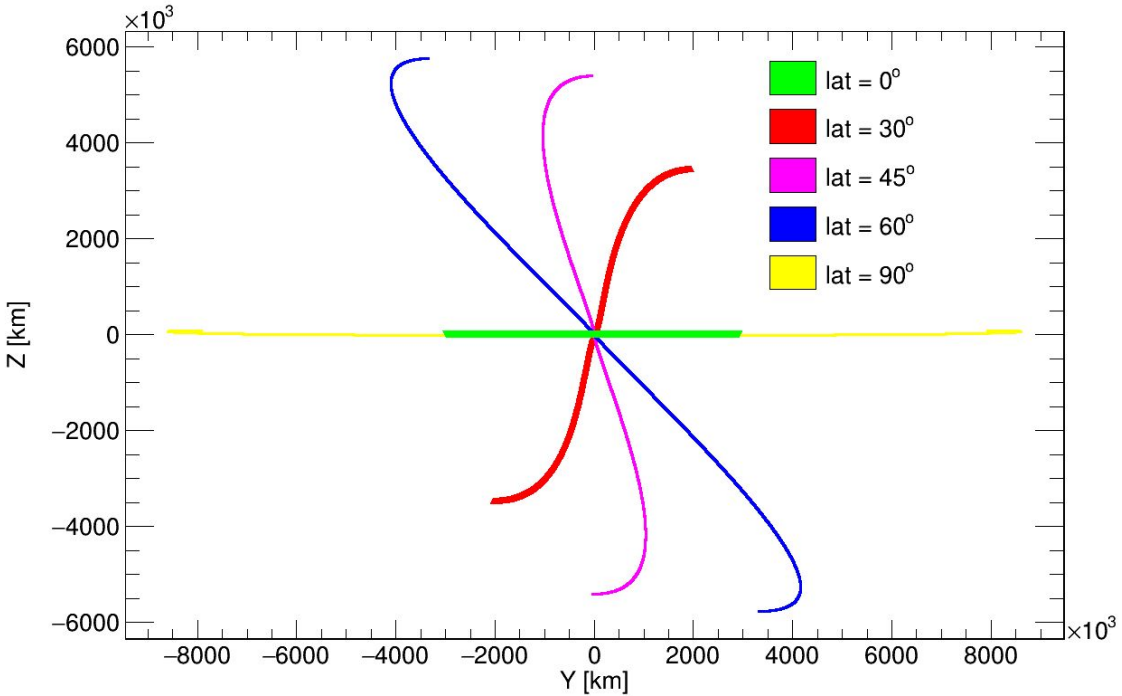


the Sun-preshower effect starts at 1 EeV

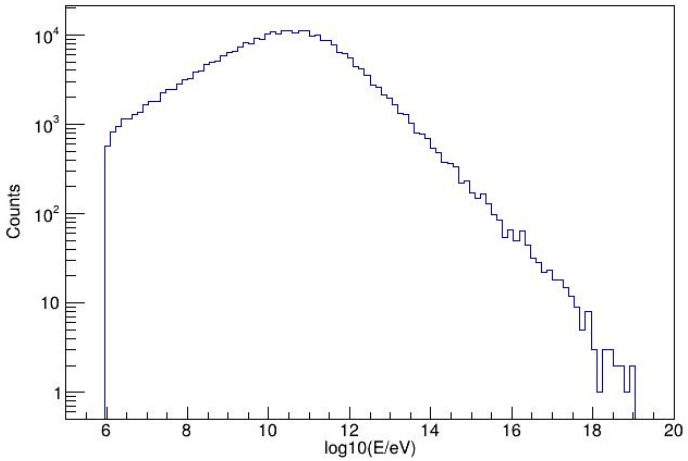


Sun-CRE: footprints up to 1AU, all photon energies

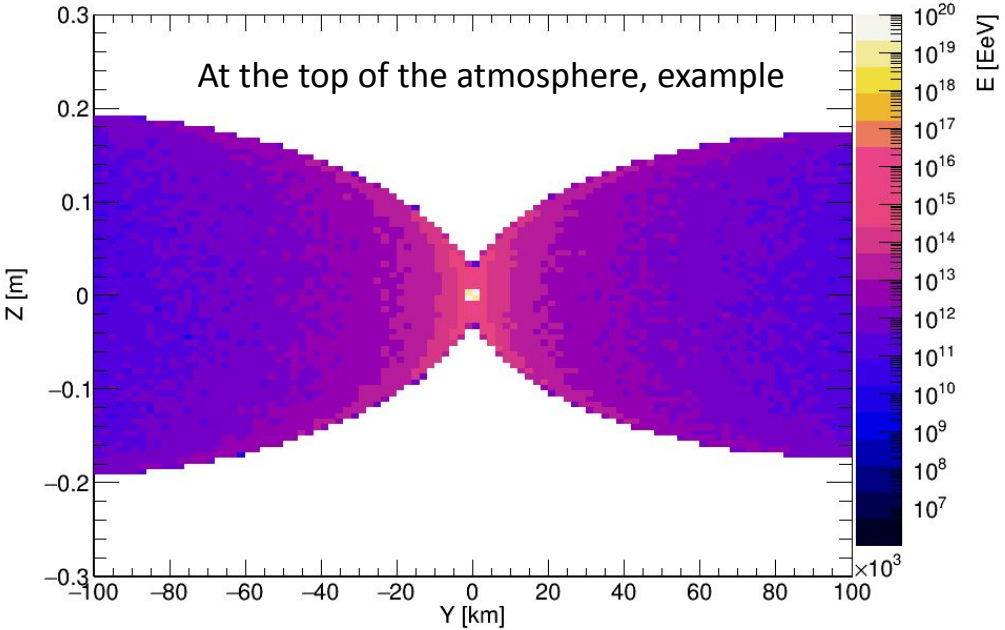
footprints very thin, up to 1 AU long, non-trivial shapes,
dependent on incidence angle and impact parameter

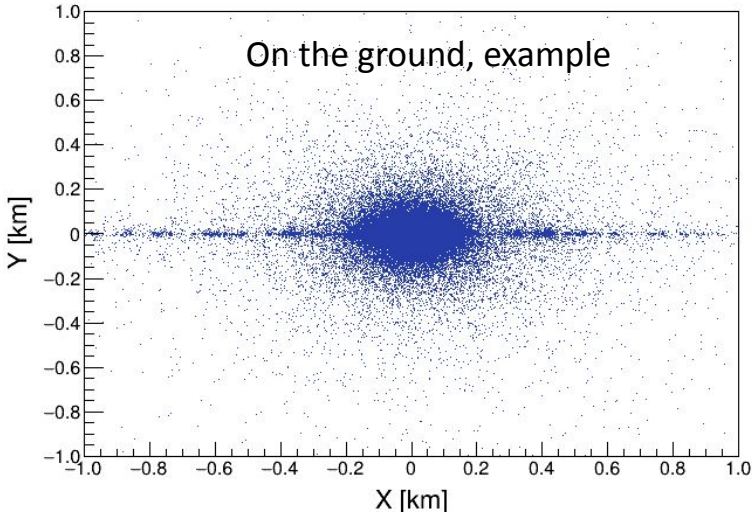


entire photon spectrum engaged



The Sun-CRE footprints

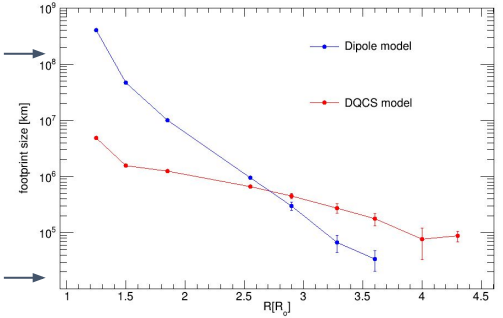




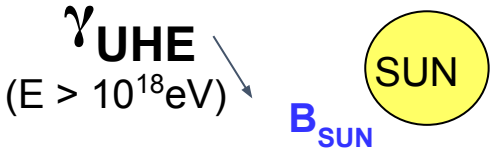
Sizes vs. impact parameter, on top of the atmosphere

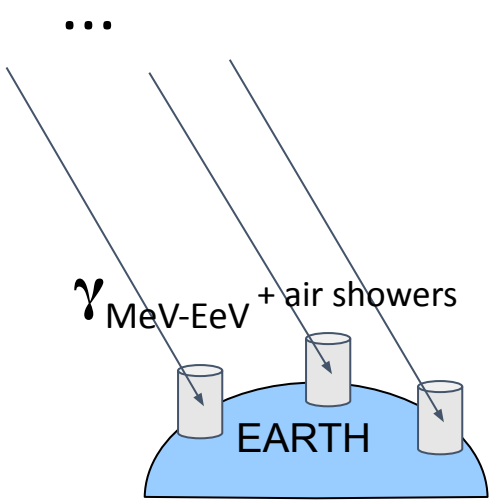
1 A.U. →

Earth →

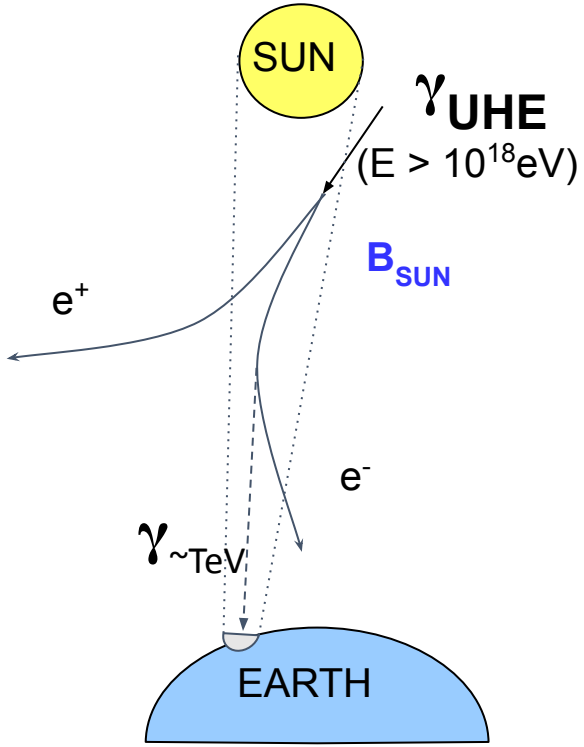


Sun-CRE: observe or constrain UHE photons



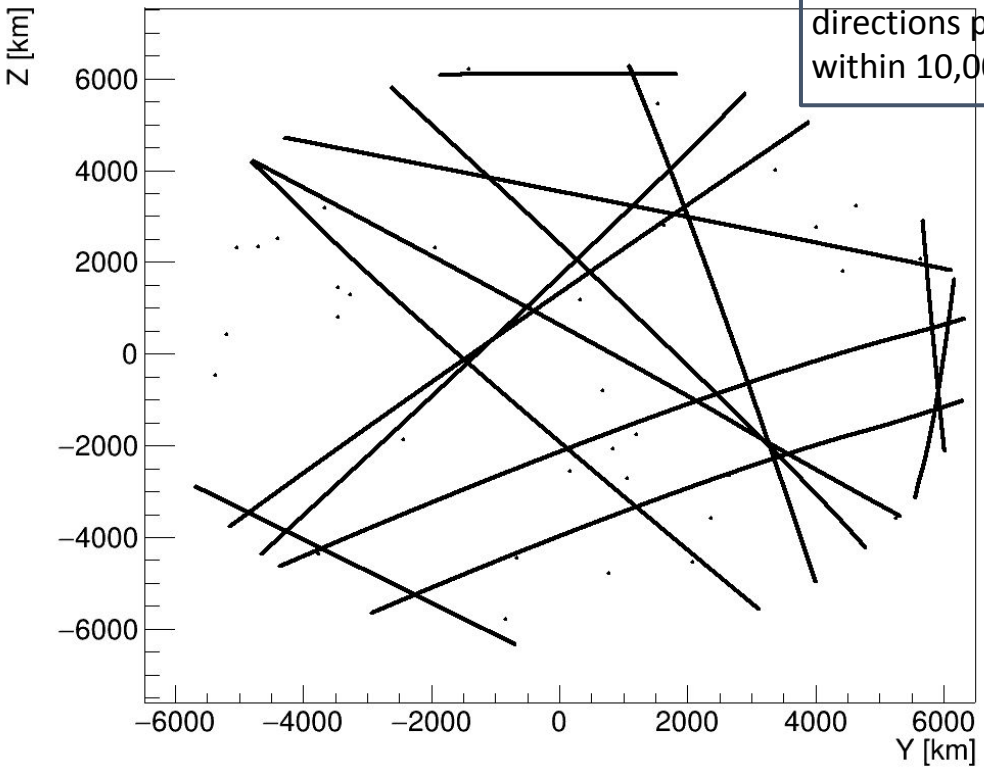


- displacement > ~100 km
- similar arrival directions
- consistent timing



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

Sun-CRE random footprints: new astrophysical constraints

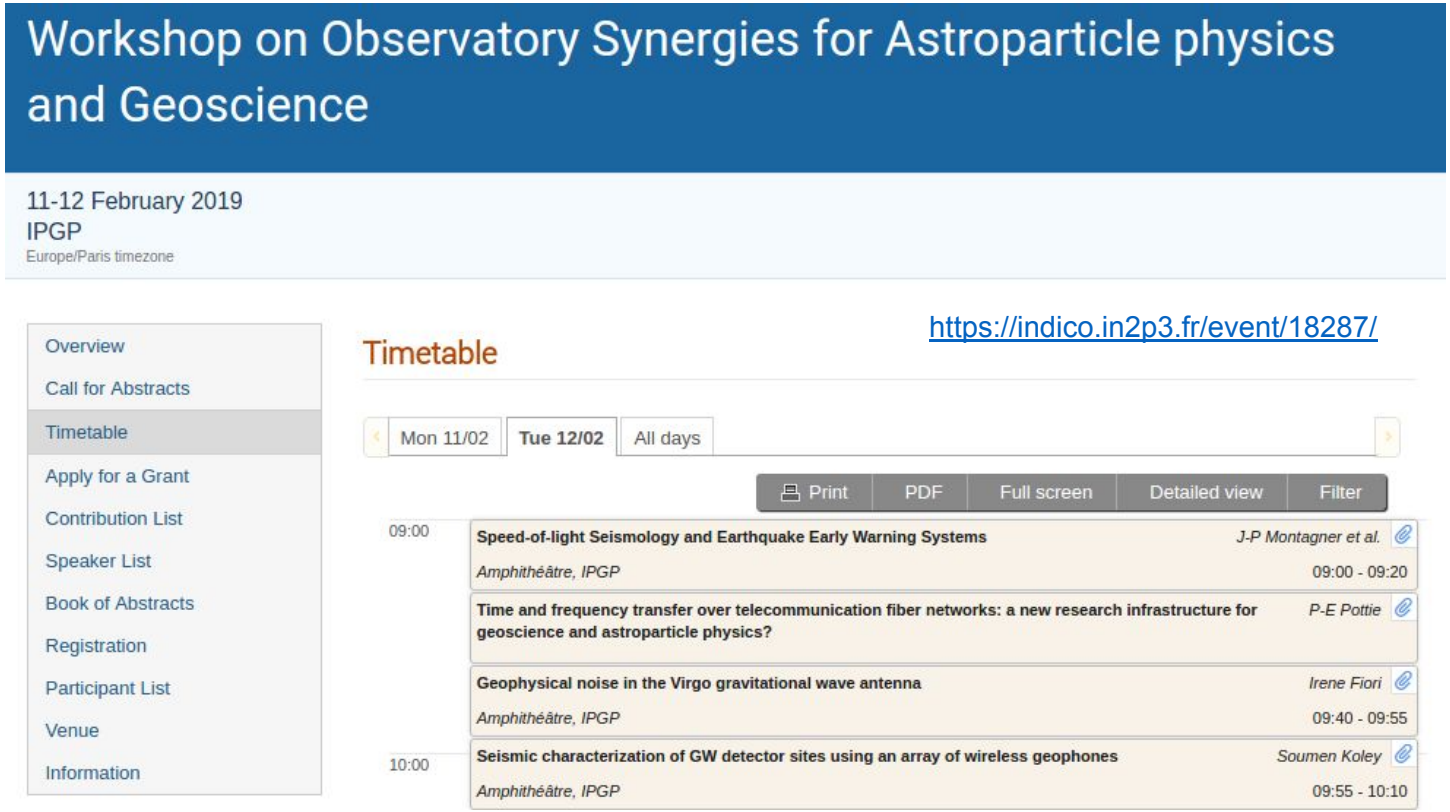


Sun CRE simulations: $E_\gamma=10^{20}$ eV, 100 random arrival directions passing near the Sun, CRE footprint cores within 10,000 km from the Earth center

(!) Comparable with the existing observations of the Sun in gamma rays, e.g. A. Albert et al. (HAWC Collaboration), "First HAWC Observations of the Sun Constrain Steady TeV Gamma-Ray Emission" Phys. Rev. D 98, 123011 (2018); DOI: 10.1103/PhysRevD.98.123011 [credit: S. Casanova]

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

The existing astro-geo effort / stayed tuned for the CREDO cosmo-seismic article!



CREDO: an astro/geo multi-messenger infrastructure!

Instead of Summary

ERC-2020-SyG (ERC Synergy Grant)
Acronym: **CREsearch**
Applicants: P….. H…… (corresponding PI); T…... W…..; M……. M…….
Title: **The search for New Physics phenomena manifesting in properties of Cosmic Ray Ensembles**
Amount Requested: 14 MEUR for 6 years
Final Panel Score: B (ranking range 66%-75%)

a sample review:

Ground-breaking nature and potential impact of the research project
The theoretical assumption is that there are families of cosmic particles that penetrate the atmosphere and generate cascades of showers, which the authors call cosmic-ray cascades. The idea is to observe them and to use them to understand their origin. Even the origin of single cosmic showers is not really understood, and this phenomenon sounds speculative, daring, exciting and promising. For me, **this is one of the strongest proposals I have read**. **If successful, the impact will be huge, and the consequences profound**. Being based on theoretical estimates there is a good chance that things turn out differently than anticipated, but I would not consider that a strong weakness, rather a mild inconvenience.

More about CREDO

https://credo.science

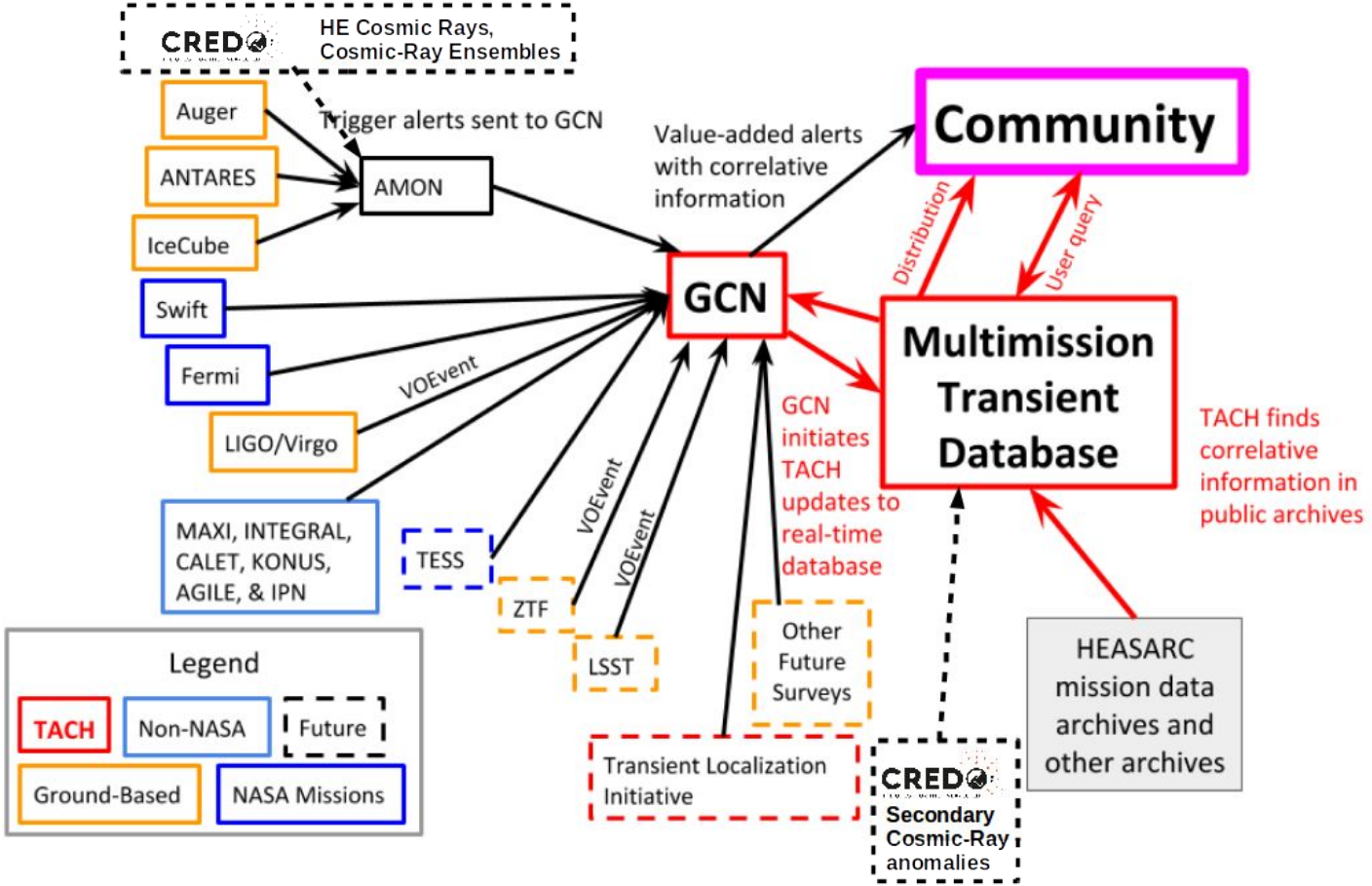
Topic examples (PH): https://credo.science/practices/

Personal contact:

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

Backup

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) ✓

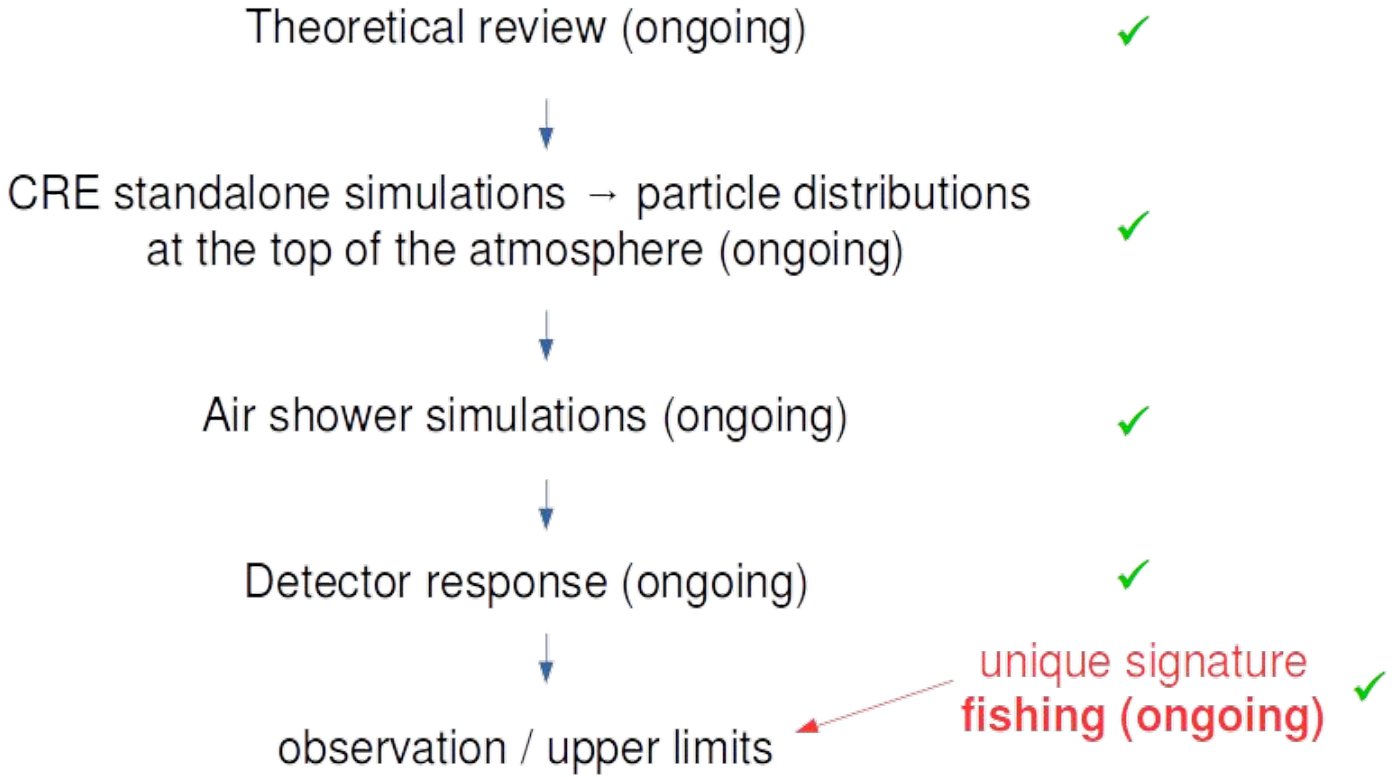
↓

observation / upper limits

scenarios!

Cosmic-Ray Ensembles (CRE): shortcut road map

quest (fishing) for the unexpected



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)

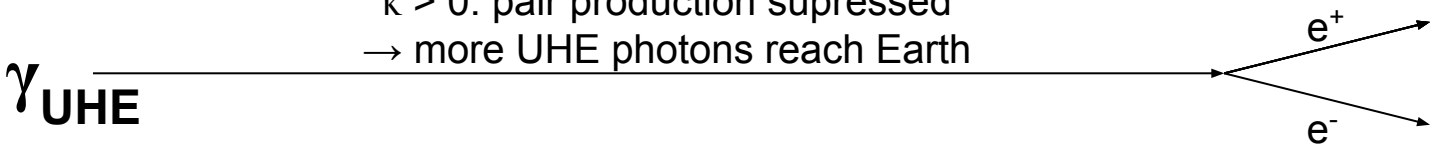
CRE and Lorentz Invariance Violation

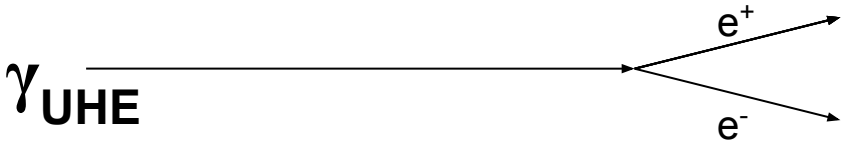
Modified dispersion relation of a photon:

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

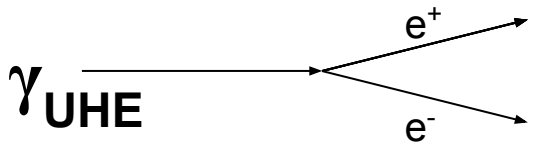
limits from gamma-ray astronomy,
98% C.L. (Klinkhamer & Schreck, 2008):
$6 \times 10^{-20} > \kappa > -9 \times 10^{-16}$

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





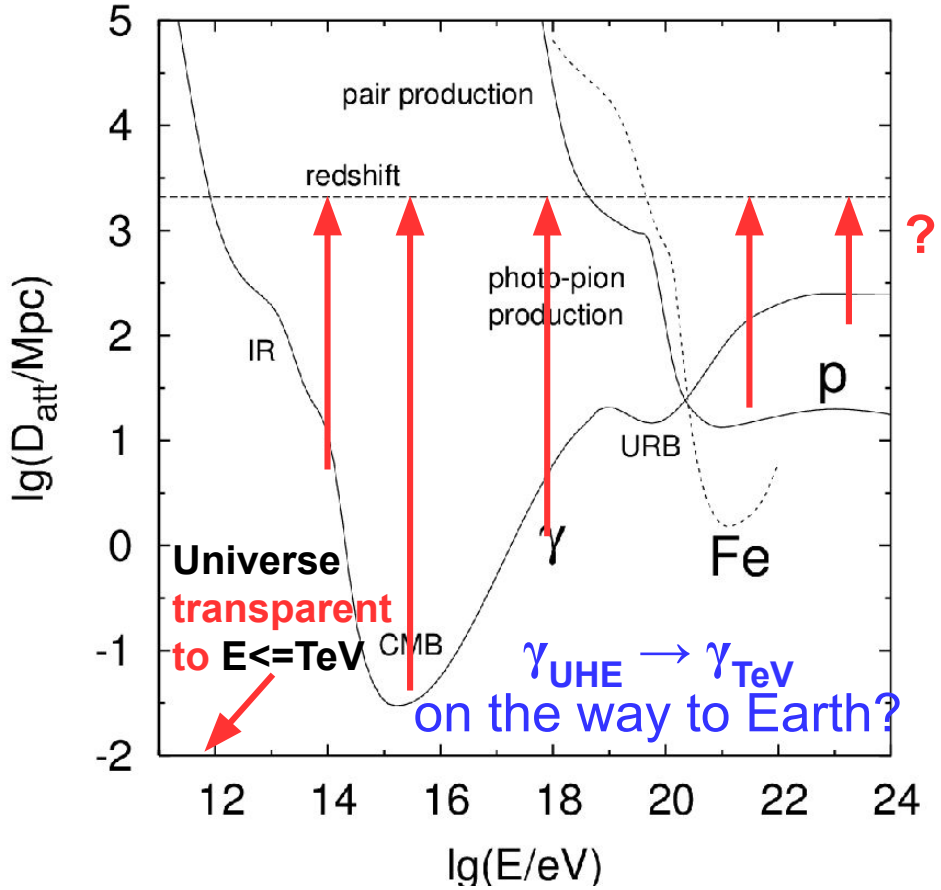
$\kappa = 0$: „normal" pair production



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

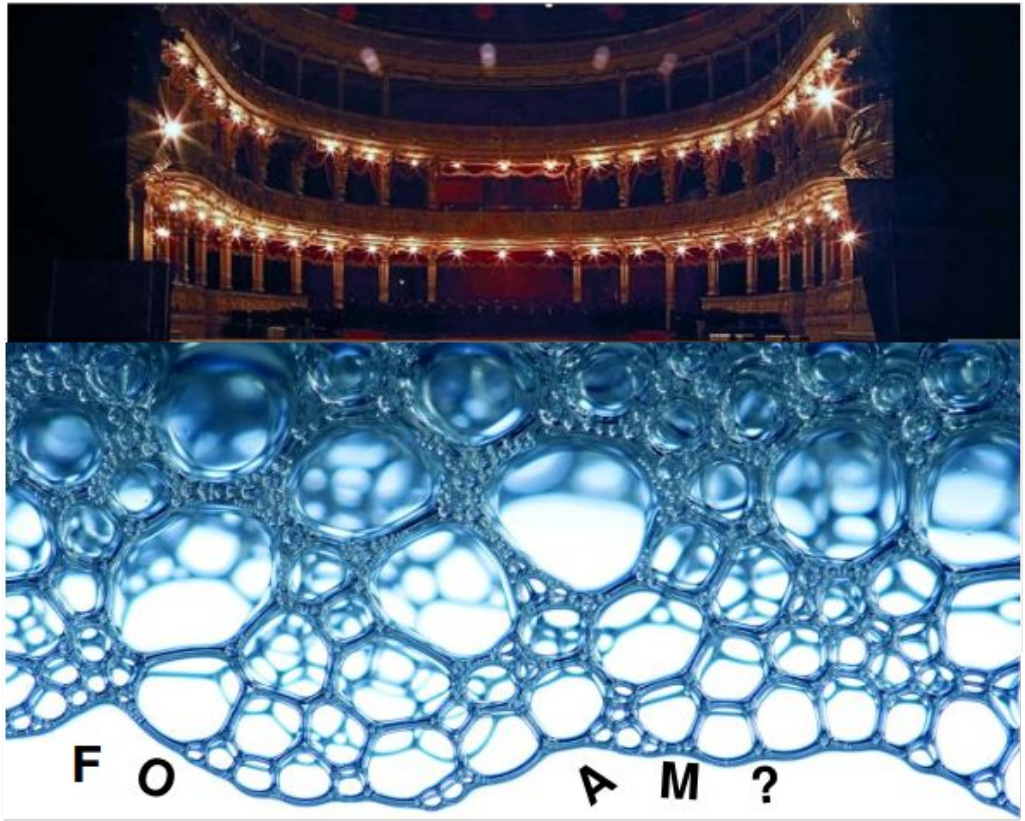
→ critical importance for the UHE photon search!
Observation of **photon cascades** would point to $\kappa < 0$!

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

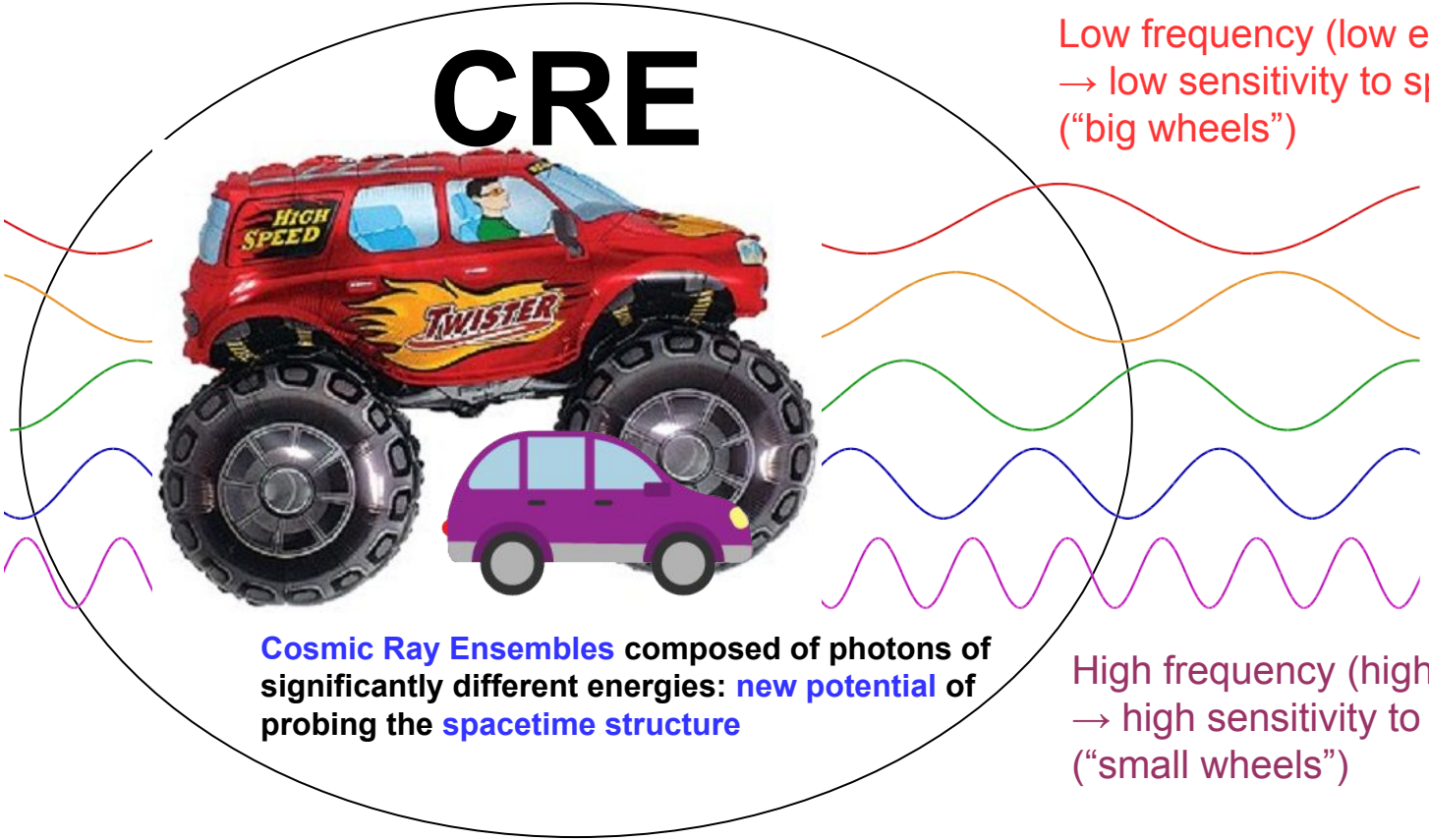


Foundation of foundations:
The spacetime

quest (fishing) for the unexpected



Cosmic Ray Ensembles as spacetime probes



Low frequency (low energy)
→ low sensitivity to spacetime structure
("big wheels")

Cosmic Ray Ensembles composed of photons of significantly different energies: new potential of probing the spacetime structure

High frequency (high energy)
→ high sensitivity to spacetime structure
("small wheels")

Astro-tests of the space-time structure

quest (fishing) for the unexpected

→ maximum photon energies < 10^{12} eV

→ testable scale of the space-time „grain" < 10^{-18} m

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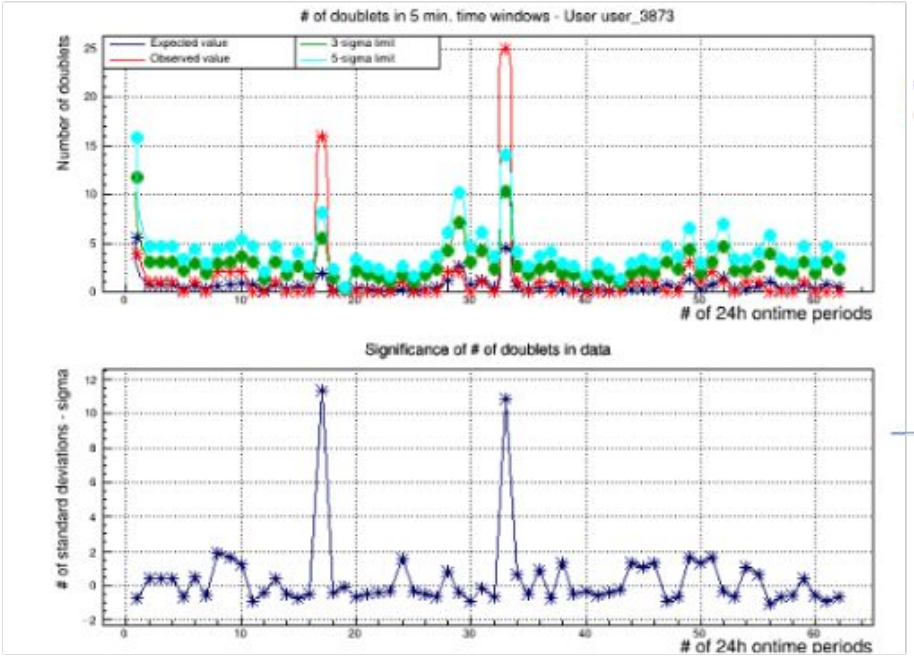
→ maximum photon energies in CRE (ensembles) < 10^{20} eV +

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

Quantum Gravity Previewer: online experiment!

quest (fishing) for the unexpected

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



by Kevin Almeida Cheminant, for the CREDO Collaboration

expected from random
observed

10σ
(significance)

Request zoom in, track back, investigate!
Privately, locally, and globally!
Get engaged!

4 October 2018: CREDO's first light!

quest (fishing) for the unexpected

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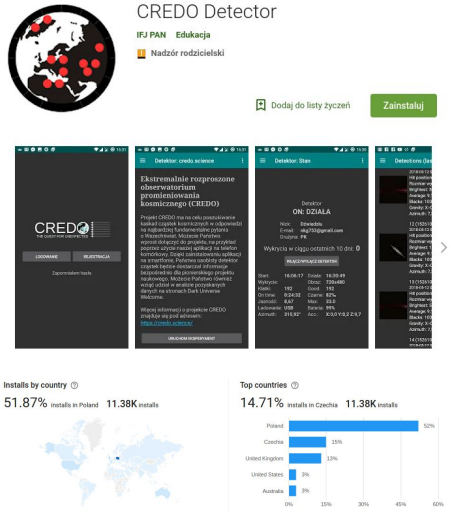
Achievement (4.10.2018):
signal from the first automatized, mass participation scientific experiment on the CREDO infrastructure



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

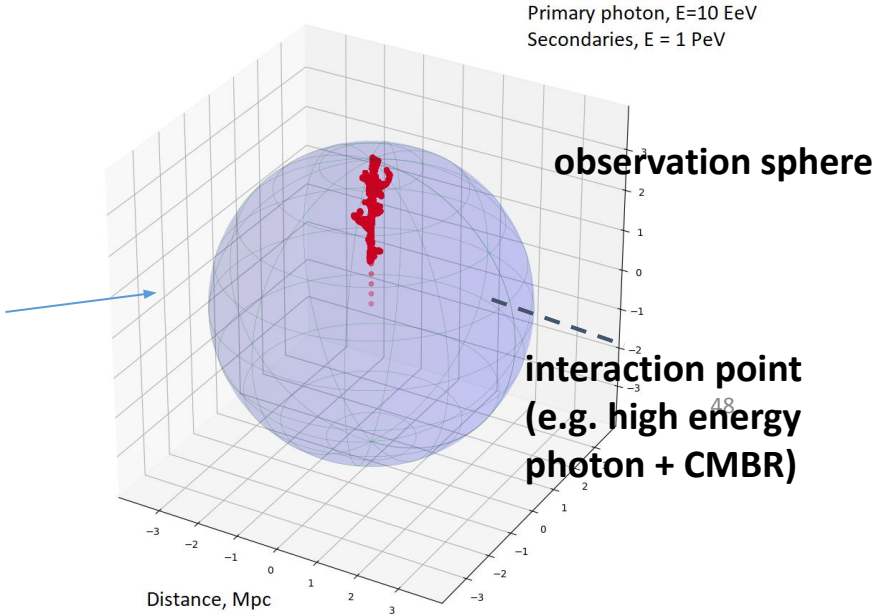
CRE exist! Simulations with CRPropa

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?

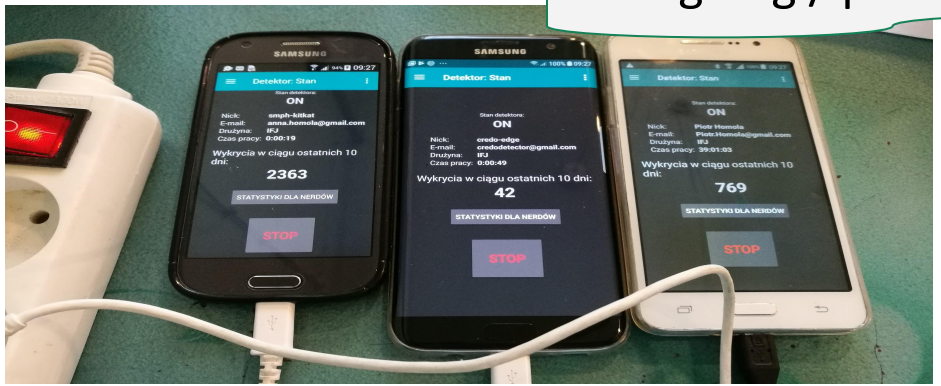
air showers ?

CRE?

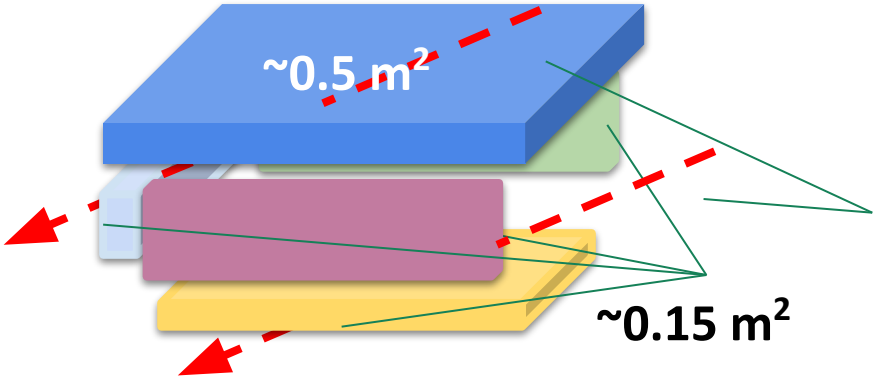
Smartphone detections: calibration for air showers and muons with scintillator plates

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

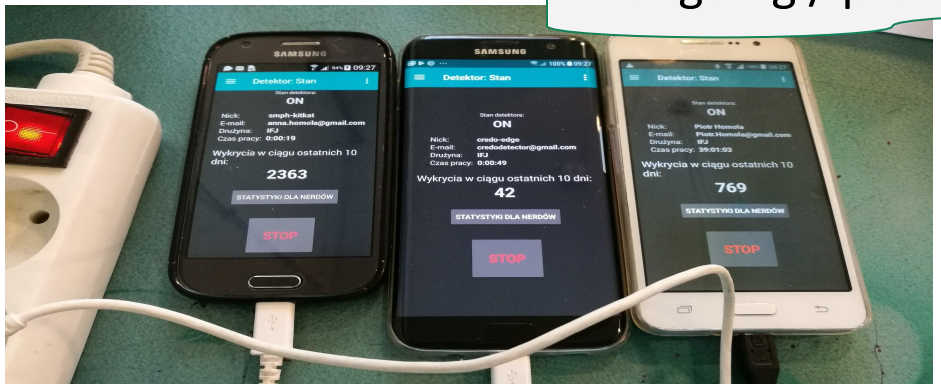


Events registered simultaneously in at least 3 different detectors
= air showers (N_{muon}>1)
observed ~15000 / day
(cf. c.a. 10000 10^{12} eV air showers expected per m^2 per day, verifying with simulations in progress)

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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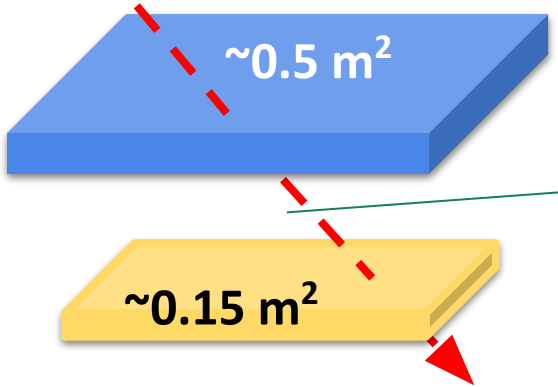

Events registered simultaneously in the top and bottom detectors
= air shower muons
observed ~400,000 / day
(compatible with background vertical muons expected per 0.15 m^2 per day, data)

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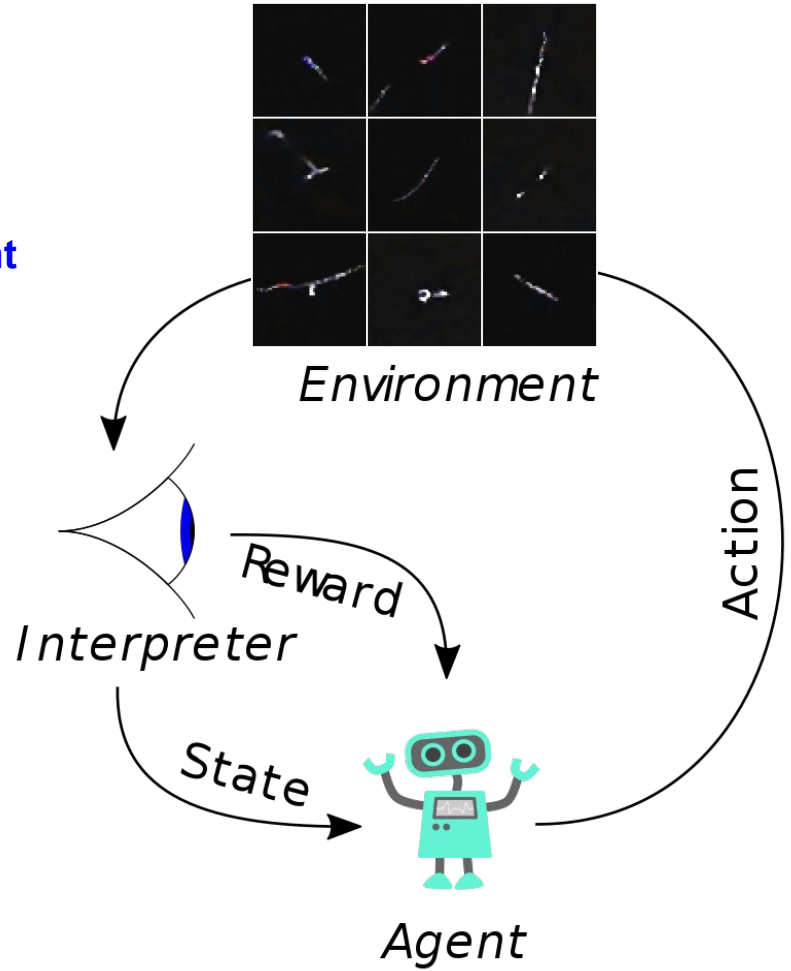
"Citizen science support for reinforcement learning - a case of CREDO experiment"

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

PhD/publication perspective: 24 months

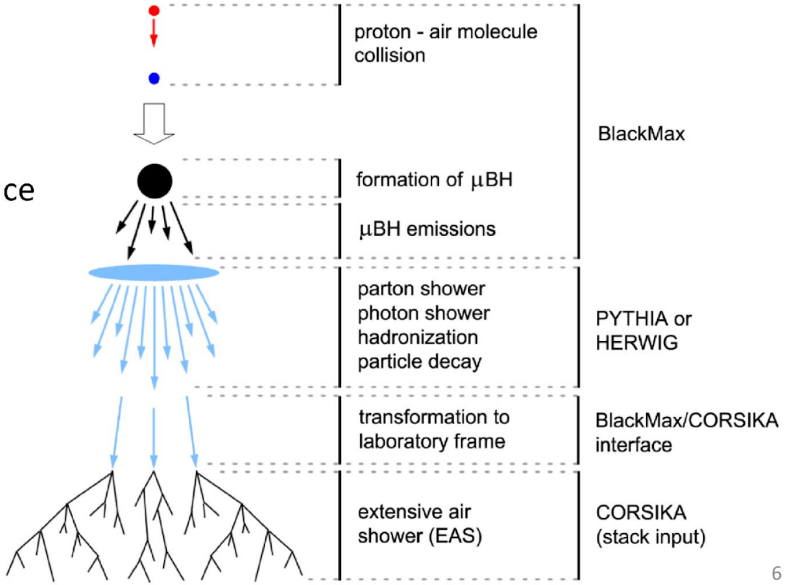
Wikipedia:
machine learning paradigms:
- supervised learning
- unsupervised learning
- **reinforcement learning**



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

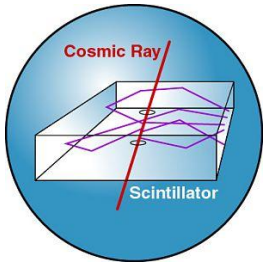


Credit: Gasper Kukec, University Nova Gorica, Slovenia

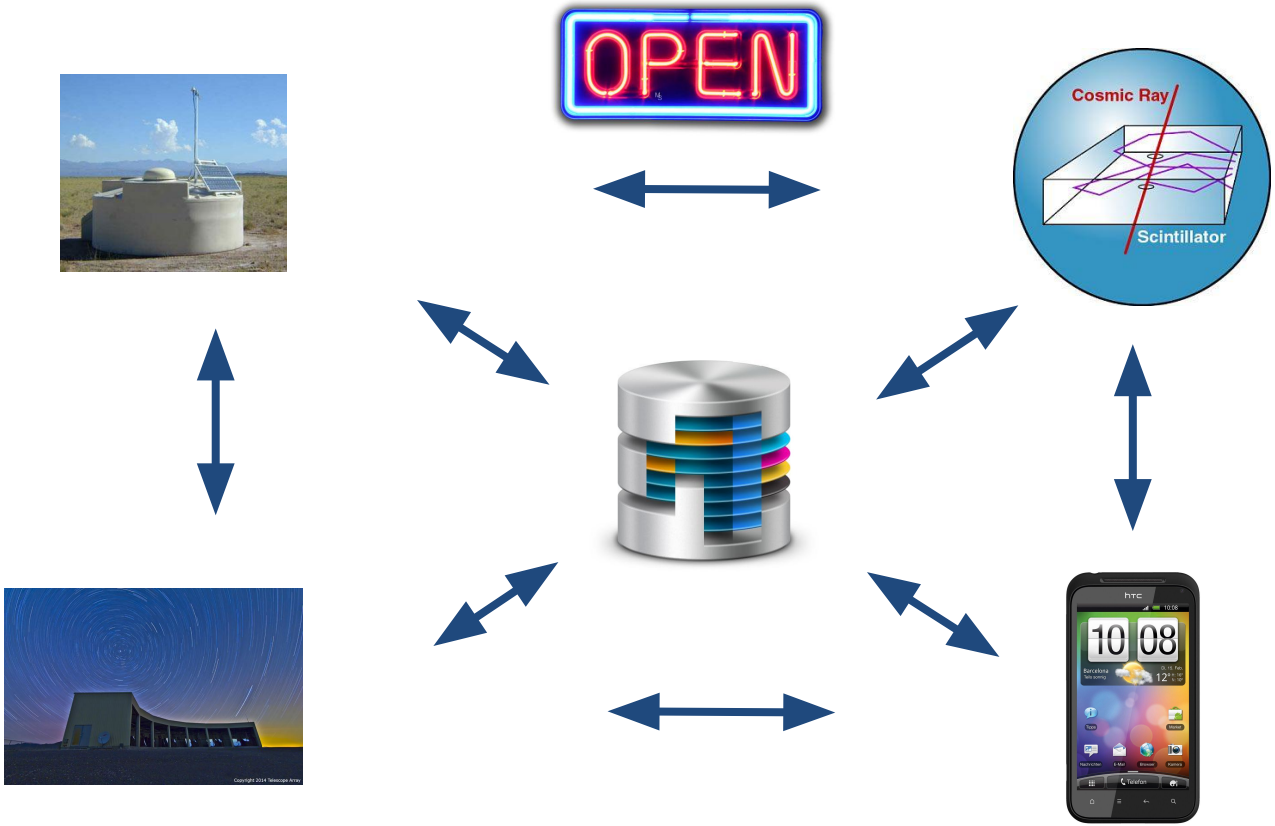
Cosmic-ray ensembles? **Massive participation: detectors & people!**
Also non experts: citizen science / public engagement → children?
Why not? Science Education By Doing Science And Having Fun!

Children like toys. Also educational toys.

Cosmic ray detection: today

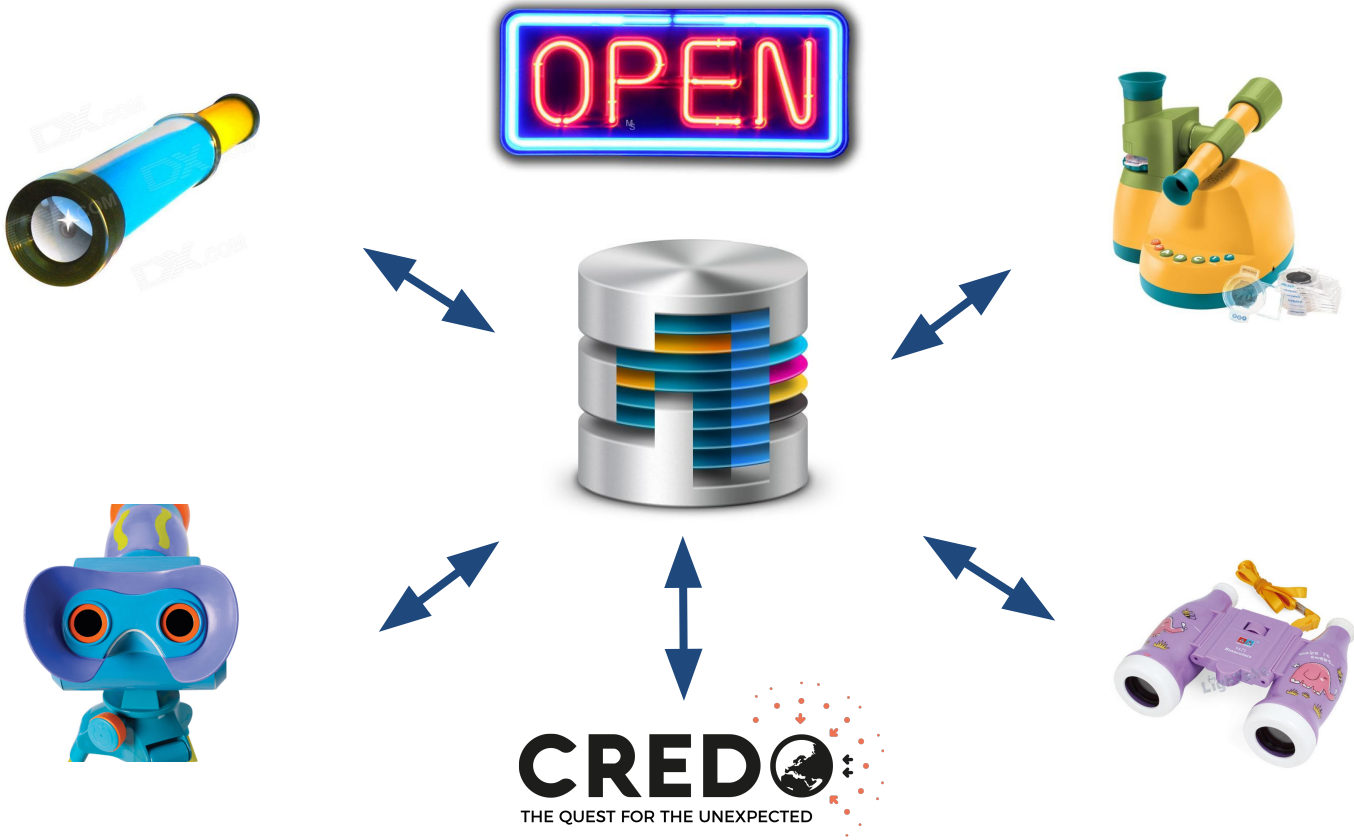


Cosmic ray detection: tomorrow



Educational toys: today

Educational toys: tomorrow



CREDO Theatre!

Trailer, Part I, Part II: CREDO YouTube