

Cosmic-Ray Extremely Distributed Observatory: a tool to explore uncharted realm of science

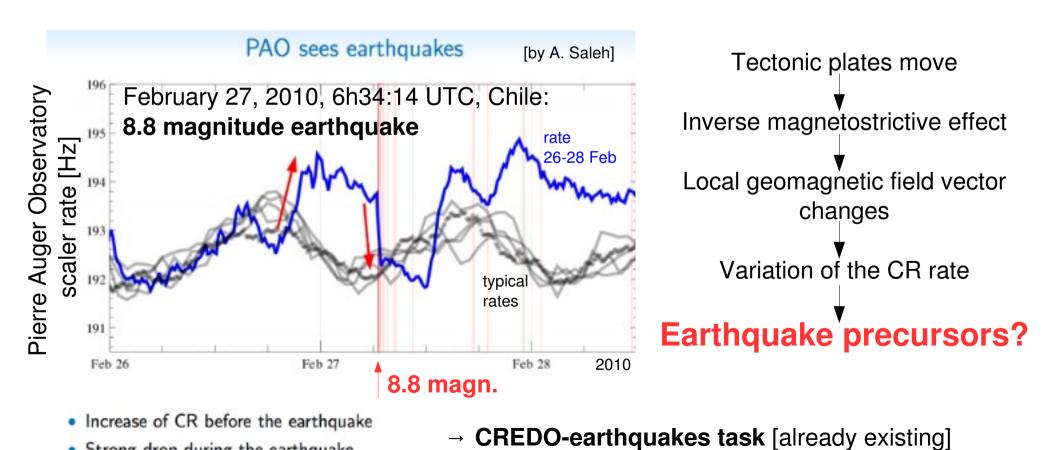
Piotr Homola INP PAS

Go global, cosmic-ray people!

- Global cosmic-ray intitiative: outreach is a margin!
- Strong science motivation: ASTRO / GEO / BIO / FISHING [not only GZ! A lot more...]
- Citizen science (OUTREACH 2.0 + REAL SCIENCE)
 - talk by Paweł Jagoda, Sławomir Stuglik, Mateusz Sułek
- We are all CREDO: Cosmic-Ray Extremely Distributed Observatory (biggest + "high schools" + desktop + smartphone clouds)
- "Just" think of technicalities:
 - get a powerful computing center involved (talk by Marek Magryś)
 - agree on data format (proposal by Krzysztof Woźniak)



Scientific diversity: GEO



Strong drop during the earthquake



Scientific diversity: BIO



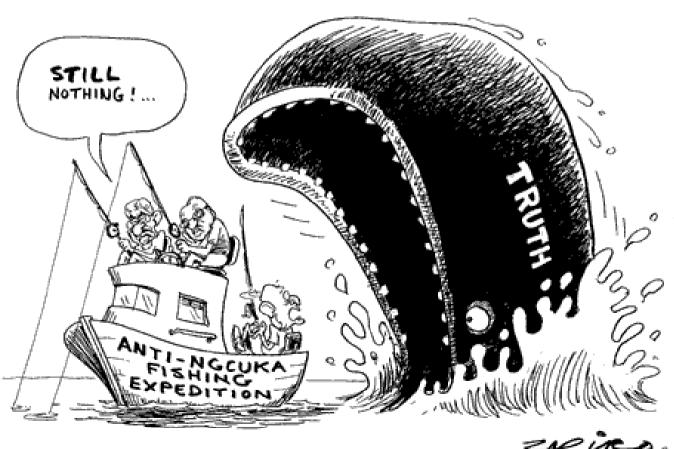
[Livescience.com, October 11, 2016]
On a Long Trip to Mars, Cosmic
Radiation May Damage Astronauts'
Brains

... and how can cosmic rays affect us on Earth?

Imagine a global network of cosmic ray detectors and global data on EEG...



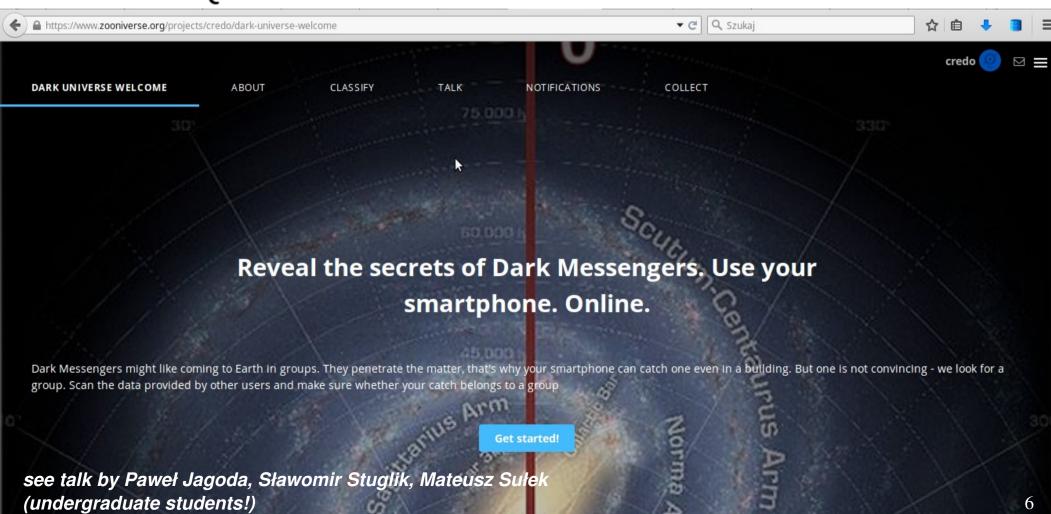
Scientific diversity: FISHING



Just cast the (global) cosmic-ray Net and see which **truth** gets in...

The citizen science potential of





Citizen Science: Science must be real

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]



New affiliation type: "amateur"

Mon. Not. R. Astron. Soc. 000, 000–000 (0000) Printed 26 January 2016 (MN LATEX style file v2.2)

Planet Hunters X. KIC 8462852 – Where's the flux? *†

T. S. Boyajian¹, D. M. LaCourse², S. A. Rappaport³,

D. Fabrycky⁴, D. A. Fischer¹, D. Gandolfi^{5,6}, G. M. Kennedy⁷, H. Korhonen^{8,9}, M. C. Liu¹⁰, A. Moor¹¹, K. Olah¹¹, K. Vida¹¹, M. C. Wyatt⁷, W. M. J. Best¹⁰, J. Brewer¹, F. Ciesla¹², B. Csák¹³, H. J. Deeg^{14,15}, T. J. Dupuy¹⁶, G. Handler¹⁷, K. Heng¹⁸, S. B. Howell¹⁹, S. T. Ishikawa²⁰, J. Kovács¹³, T. Kozakis²¹, L. Kriskovics¹¹, J. Lehtinen²², C. Lintott²³, S. Lynn²⁴, D. Nespral^{14,15}, S. Nikbakhsh^{22,25}, K. Schawinski²⁶, J. R. Schmitt¹, A. M. Smith²⁷, Gy. Szabo^{11,13,28}, R. Szabo¹¹, J. Viuho²², J. Wang^{1,29}, A. Weiksnar²⁰, M. Bosch², J. L. Connors², S. Goodman², G. Green², A. J. Hoekstra², T. Jebson², K. J. Jek², M. R. Omohundro², H. M. Schwengeler², A. Szewczyk²

¹Department of Astronomy, Yale University, New Haven, CT 06511, USA

²Amateur Astronomer

³Department of Physics, and Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

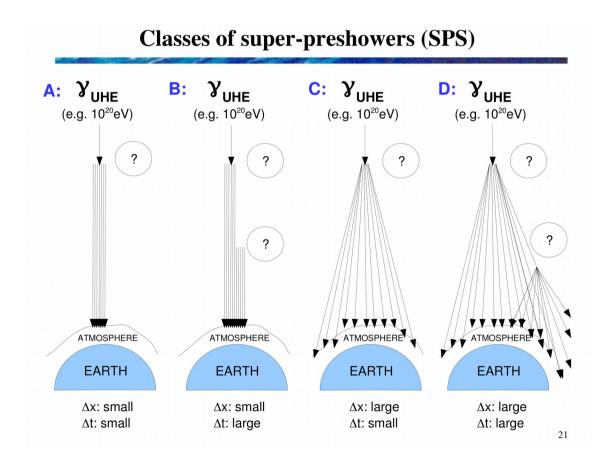
⁴Department of Astronomy and Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA

⁵Dipartimento di Fisica, Universitá di Torino, via P. Giuria 1, I-10125, Torino, Italy

⁶Landessternwarte Königstuhl, Zentrum für Astronomie der Universität Heidelberg, Königstuhl 12, D-69117 Heidelberg, Germany



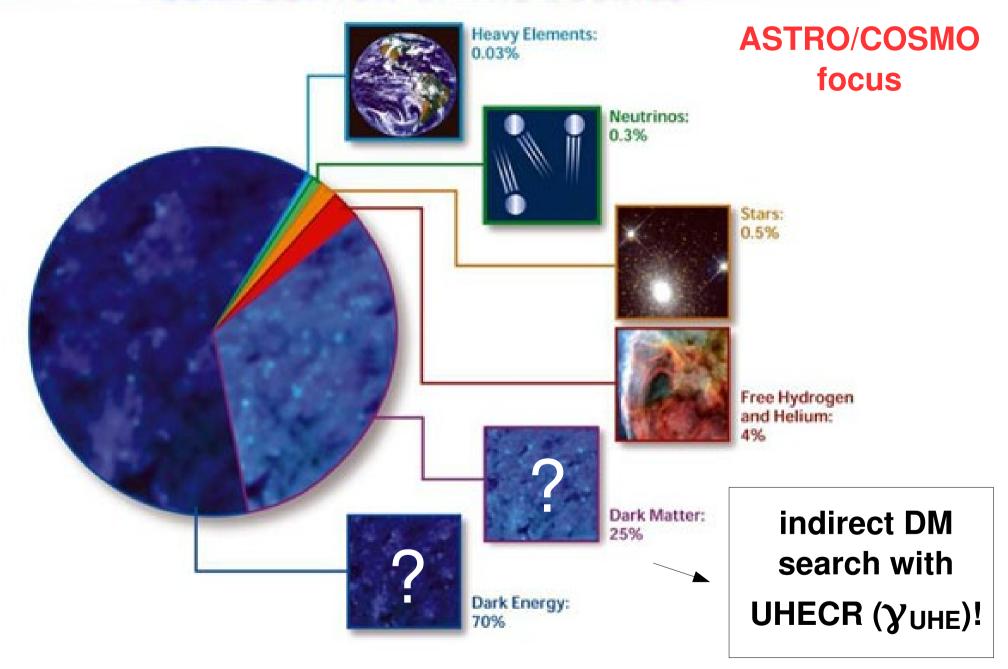
Scientific diversity: ASTRO/COSMO



→ millions of photons at E>TeV, arriving simultaneously at the top of the atmosphere, spread worldwide!

Let us hunt for coincidences!

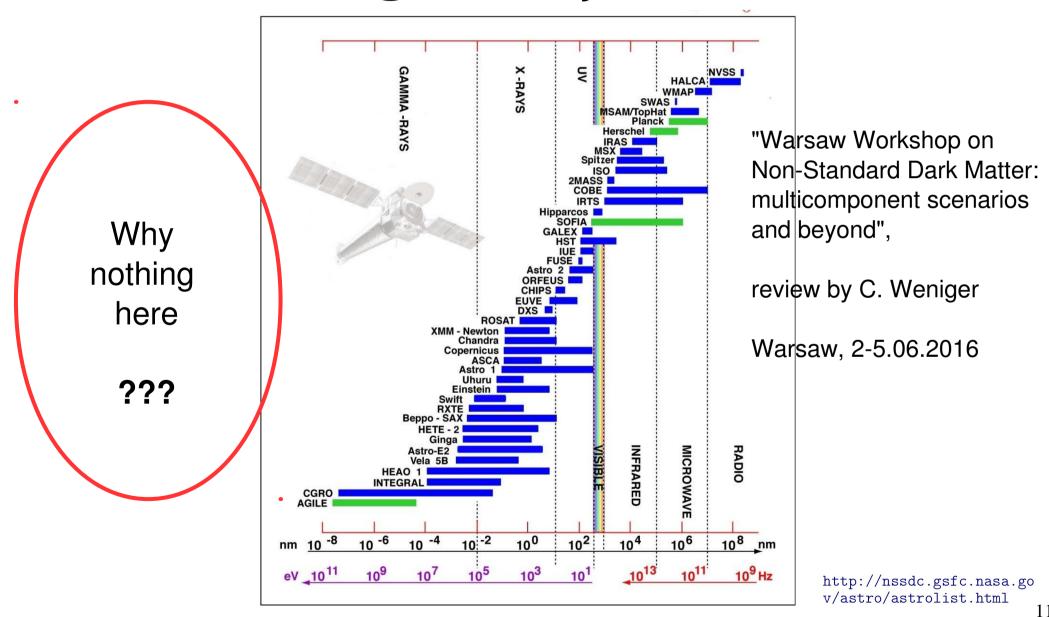
COMPOSITION OF THE COSMOS



http://certificate.ulo.ucl.ac.uk/modules/year one/NASA cosmology/goals5.html

gamma ray X-ray ultraviolet visible infrared microwave radio

From gamma rays to radio



Photons as UHECR: testing astrophysical scenarios

Bottom → **Up**: 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

Top → **Down:** Exotic scenarios (particle physics)

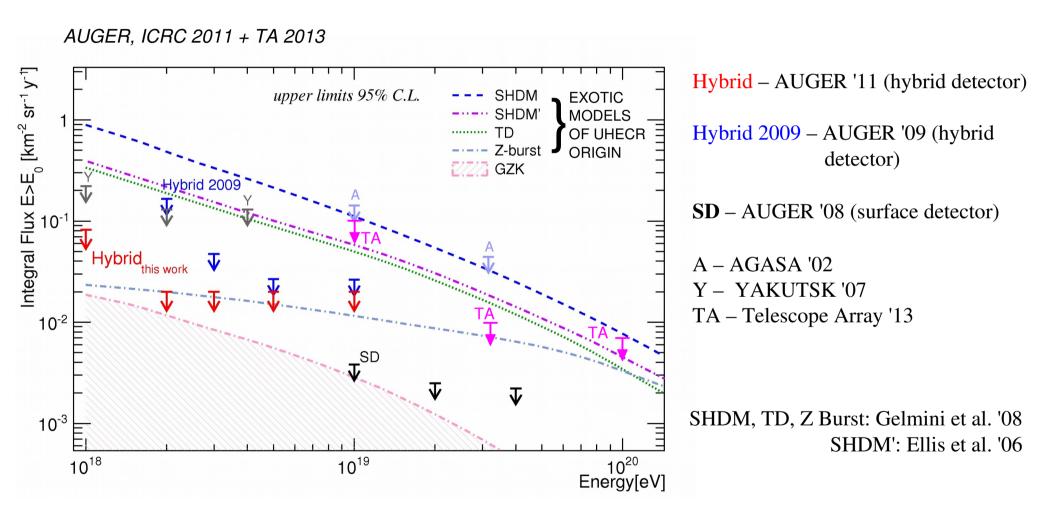
Decay or annihilation the early Universe relics

- \rightarrow hypothetic supermassive particles of energies $\sim 10^{23} \text{ eV}$
- → decay to quarks and leptons → hadronization (mainly pions)
- large fraction of photons and neutrinos in UHCER flux

DARK MATTER!

UHECR composition paradigm: "no photons"

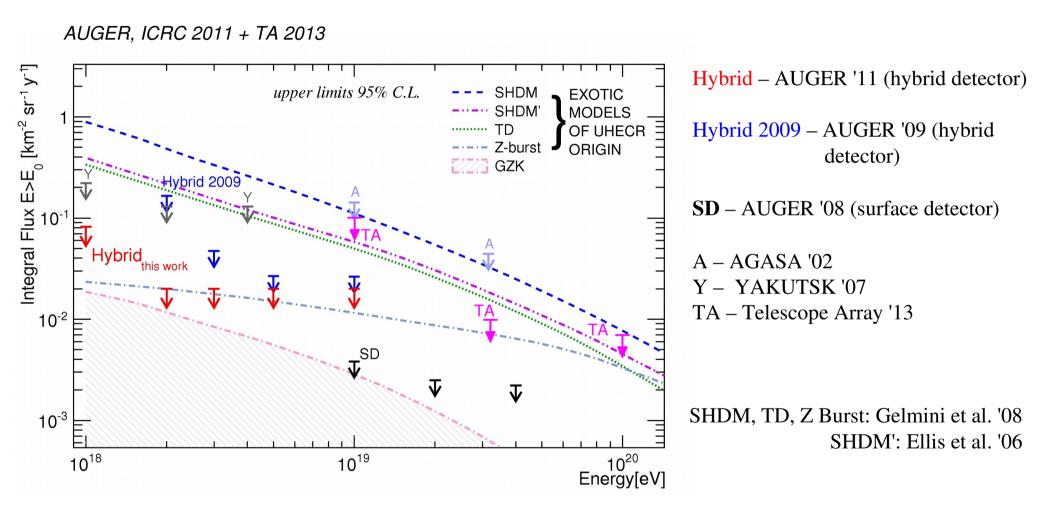
At the highest energies photon fractions < 1%



→ exotic (Dark Matter) scenarios severely constrained!

UHECR composition paradigm: ,,no photons"

At the highest energies photon fractions < 1%



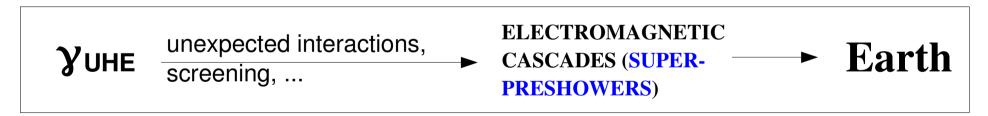
→ exotic (Dark Matter) scenarios severely constrained! *)

*) **Understand well**: limits apply to single photons, **assume no screening** eg. within exotic models of interactions, structure of a photon and the spacetime structure that could manifets at UHE...

Experimental evidence about γ_{UHE}

γυнε no interactions / screening Earth

NOT OBSERVED



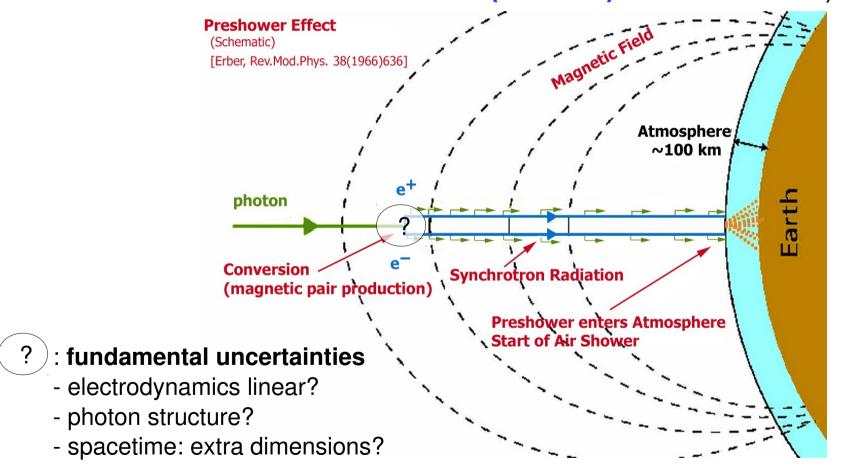
NOT TRIED SO FAR...



(Super-)preshowers: a must to study UHE photons

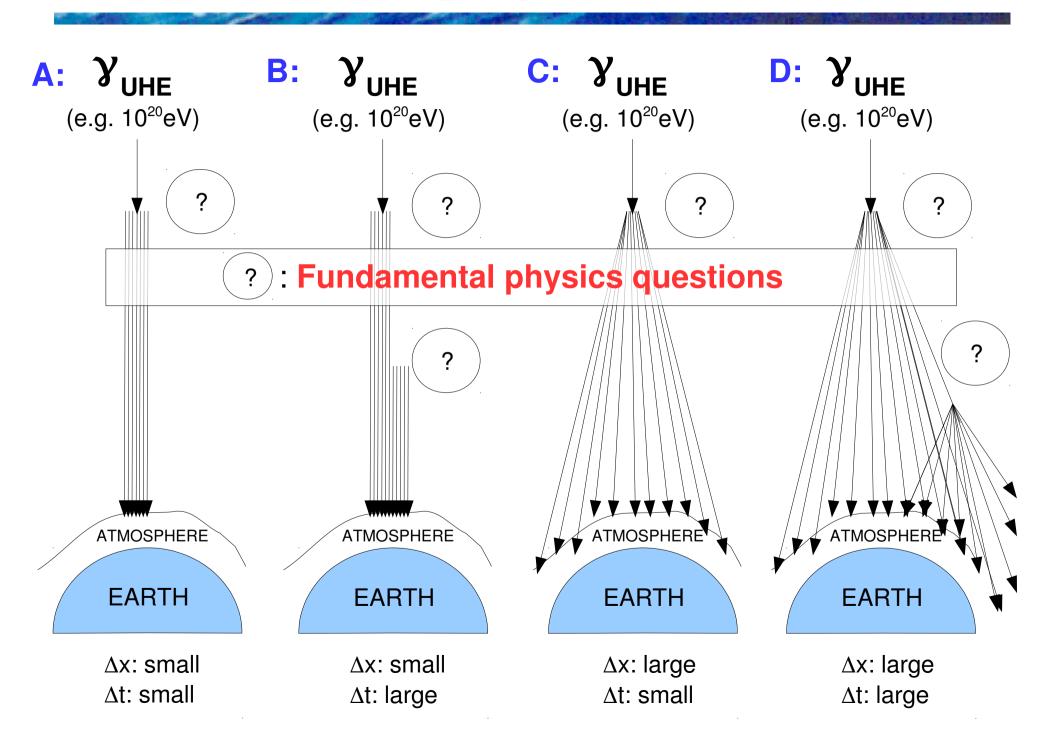
(super-)preshower:

- → contains typically (>1000) 100 particles
- → created at around (>10000) 1000 km a.s.l.)

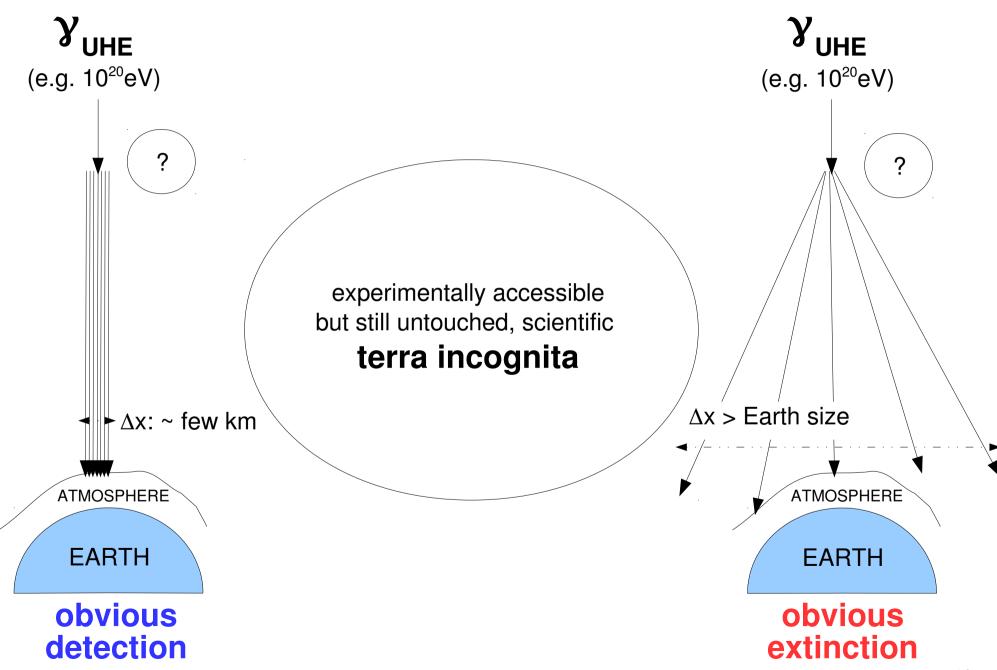


 \rightarrow dependence on E and B_{\(\perp}} (to be seen in data?)

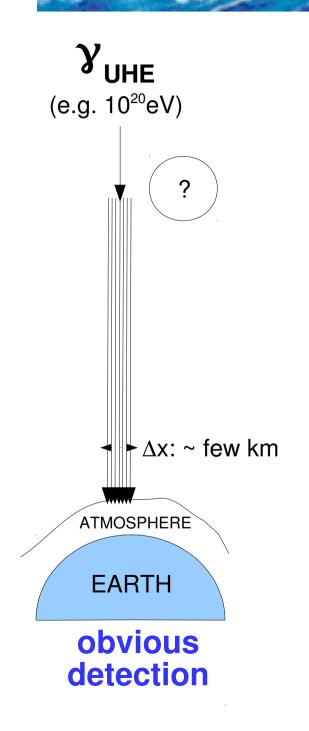
Classes of super-preshowers (SPS)

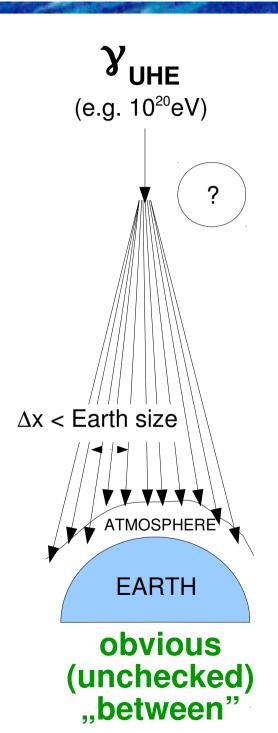


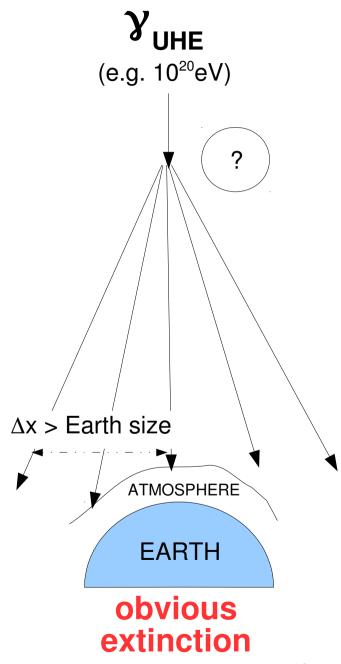
Super-preshowers on Earth: untouched ground



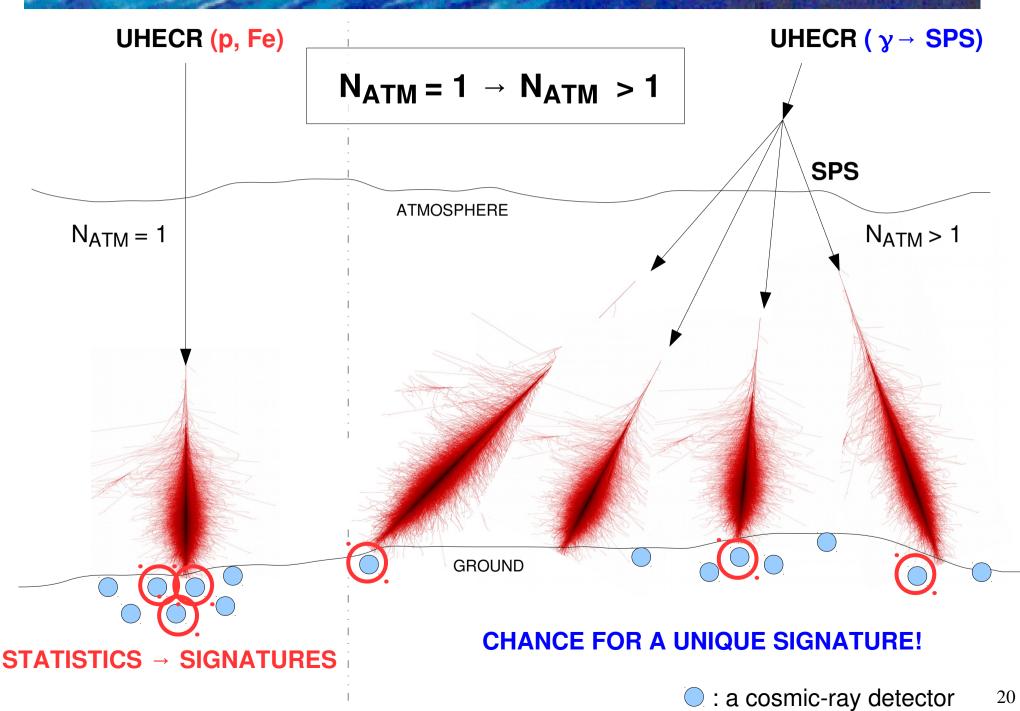
Super-preshowers on Earth: untouched ground







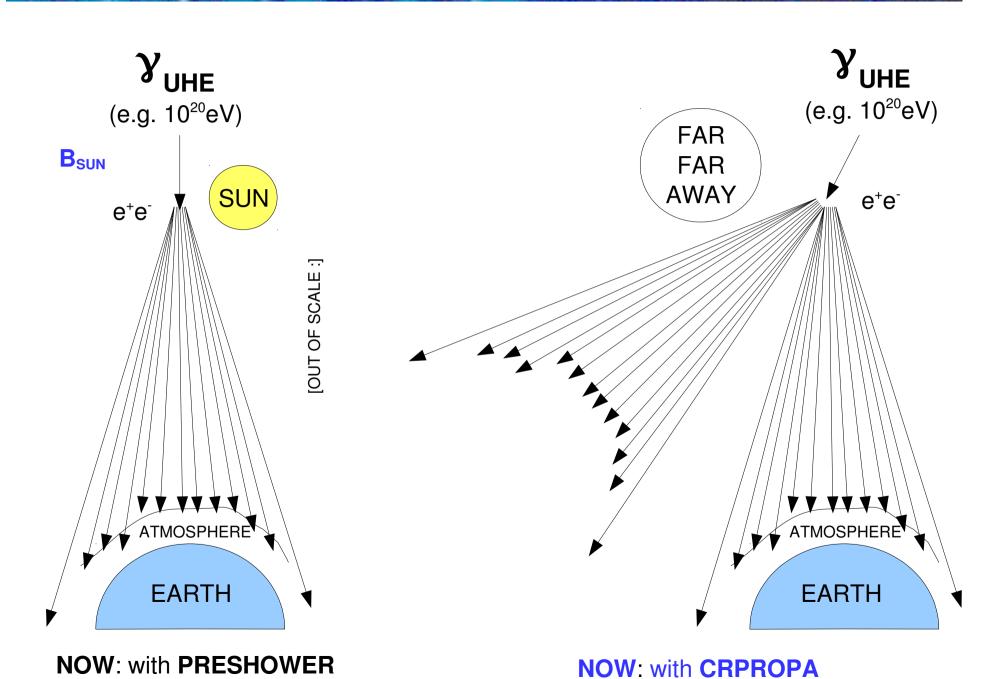
Generalization of UHECR research



Super-preshowers road map

Theoretical review (ongoing) non-exotic / exotic SPS standalone simulations → particle distributions at the top of the atmosphere (ongoing) Air shower simulations Detector response observation / upper limits

Non-exotic examples of "obvious" SPS between



22

MMMMultraviolet visible infrared microwave radio X-ray

PH:

Even more ways for indirect DM search:

gamma ray

ultra-high energy photons

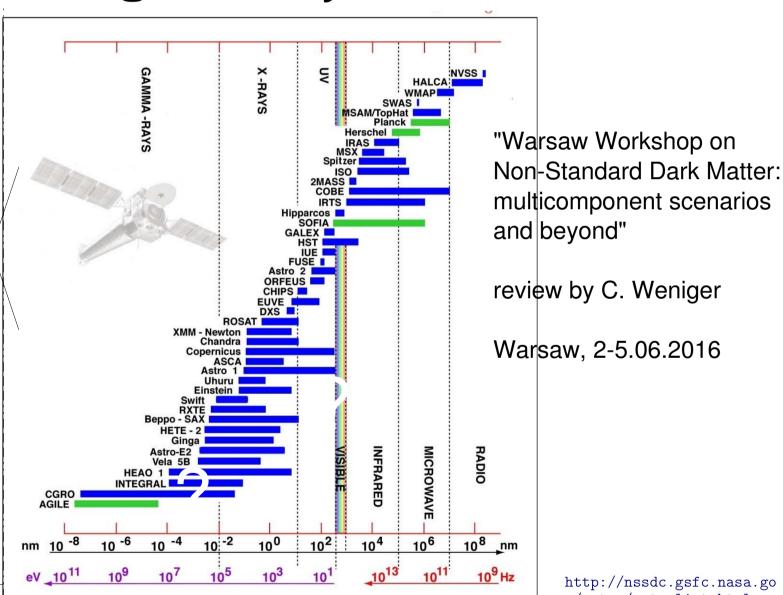
observation borde

SUPER PRESHOWERS?

- Pierre Auger **Observatory**
- **Telescope Array**

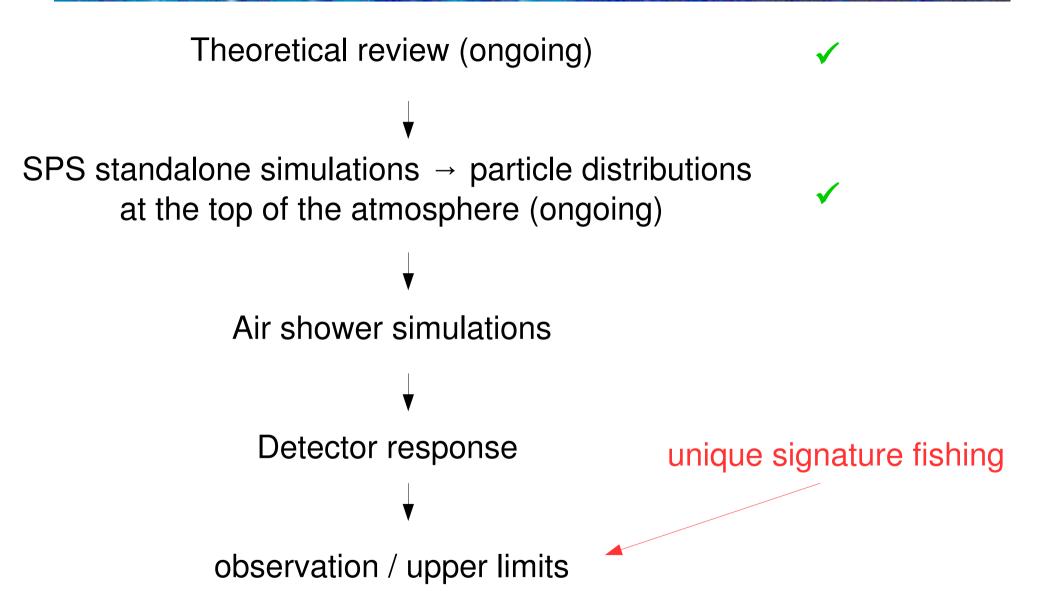
>10¹⁹

From gamma rays to radio

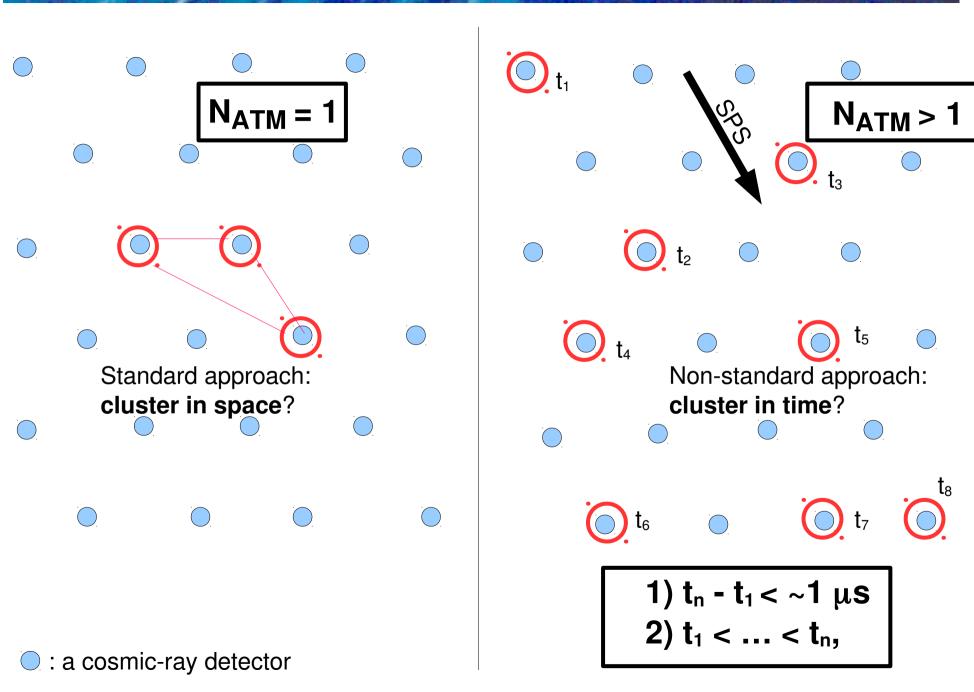


http://nssdc.gsfc.nasa.go v/astro/astrolist.html

Super-preshowers shortcut road map



A chance for a unique super-preshower signature



Super-preshowers 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

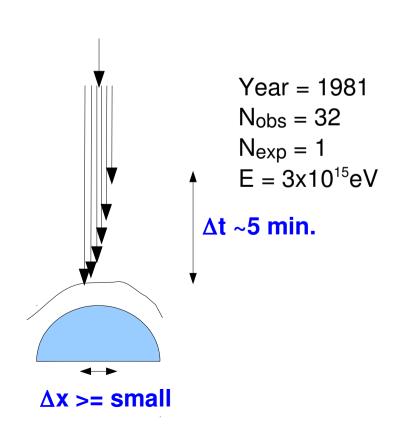
Physics Department, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

(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, 94.40.Rc, 95.30.-k

PH: Super-preshower class B?



Super-preshowers: motivated by data! (2)

VOLUME 51, NUMBER 25

PHYSICAL REVIEW LETTERS

19 DECEMBER 1983

Observation of a Burst of Cosmic Rays at Energies above 7×1013 eV

D. J. Fegan and B. McBreen

Physics Department, University College Dublin, Dublin 4, Ireland

and

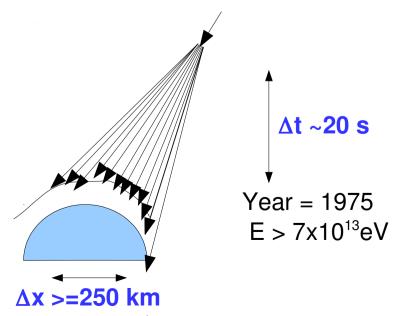
C. O'Sullivan

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

PH: Super-preshower class D?



CREDO Inauguration Meeting, 30.08.2016, INP PAS



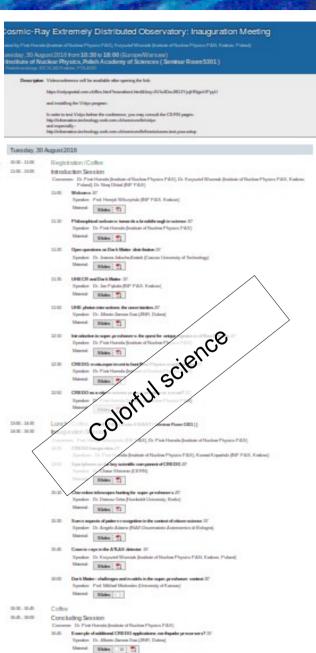
Cosmic-Ray Extremely Distributed Observatory: Inauguration Meeting

30 August 2016 Institute of Nuclear Physics, Polish Academy of Sciences.

Countes
Towards
Programme
In Registeries
United Inspiration
United Inspiration
Versus and Associations
Total



FredDisc Dales HURRAL

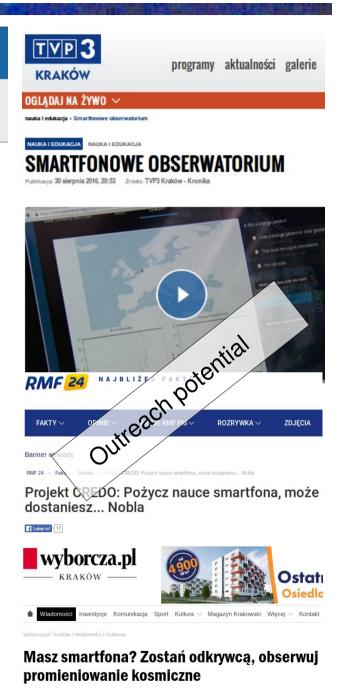


2500 CMEDO de simplesi rales el a collaboration 37

Material States (1)

21.25 Exercise y and Discounter-Di-

Named on Dr. Pint Horsels Stratists of Nuclear Physics PANS



Ada Chojnowska 05.09.2016 09:00

Data Acquisition Interfaces

CREDO SCHEMATIC 16.12.2016

Data Access and RT Alert Interface

CREDO Computing Infrastructure

Data Export Interface (experiment specific, common protocol)

For Data

Storage and Processing

3 5

Sensor Networks



aggregated
 Data Analysis

→ Science (or Nature :)

Pierre Auger Observatory Baikal-GVD Atlas CERN MAGIC/CTA,

CREDO letters of intent (Feb 2017)

Alan Watson



From Professor A. A. Watson, FRS a.a.watson@leeds.ac.uk tel: +44 (0)113 343 3888

Dr Piotr Homola Department of Cosmic Ray Research The H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences ul. Radzikowskiego 152, 31-342 Kraków, Poland

6 February 2017

Dear Piotr

Proposal ERC COG 2017

"Indirect search for non-standard Dark Matter with Ultra-High Energy Cosmic Rays" (SPS)

Your proposal (ERC_COG_2017) to develop an international network of cosmic-ray detectors by combining conventional devices, such as the Auger Observatory, with school shower-arrays and possibly mobile phones, both intrigues and interests me. The search for high-energy photons is crying out for new and more sensitive methods. It would be very easy for you to have joined one of the subgroups within the Auger Collaboration and have an easy life following some well-trodden path with higher statistical-precision but you are being much more imaginative and I applaud this. I very much hope that your bid for funding is successful.

Unfortunately I'm at a stage of my career when it is not realistic for me to commit much time to any new project, in addition to those that I'm presently involved with (collaborations with Auger colleagues in Granada and Santiago de Compostela) but perhaps my 50+ years of experience of working in this field could be of some help, maybe as a sort of unpaid consultant. In this spirit, I offer a couple of ideas that would extend the scientific reach of CREDO beyond the very important search for photons that is

The first is an idea that was suggested by Gerasimova and Zatsepin in the 1950s. If a cosmic-ray nucleus passes close to the Sun then there is a reasonable probability of the nucleus undergoing photodisintegration with the resulting two fragments proceeding towards earth where they would produce widely-separated air-showers. This is a beautiful idea and in the first analysis Gerasimova and Zatsepin estimated that the separation would be only a few hundred metres. However, they later realised that they had over-looked the interplanetary magnetic field. The deflections in this field mean that the showers would be separated by many kilometres. In 1999 Medina Tanco and I looked at this problem again (Astroparticle Physics 10 157 1999). Unfortunately, using modern data on the interplanetary field, it turns out that the separation for Fe-nuclei (where the fragments would usually be Fe55 and a neutron) is ~ 500 - 1000 km. It's a bit smaller of course for helium. Even with the Auger Observatory this separation is too great for a detection in a reasonable time, but your approach may offer a way

forward. It is a bit of a long shot but the Gerasimova-Zatsepin effect does point to a unique way of finding the mass of primary particles (from the ratio of the sizes of the showers) without invoking assumptions about hadronic interactions at energies beyond the LHC. This would be a major discovery.

The second idea is one deriving from a suggestion made privately to me by Bernard Peters (Danish Space Research Institute) in the late 1960s or early 1970s. Bernard did not believe that particles of 10¹¹ eV existed and he pointed out, correctly, that those of us measuring the energies did not know the distribution of particles close to the shower axis, where most of them lie, and so could be grossly overestimating the energies involved. He postulated that this region was flat and could be created by several overlapping low-energy showers created by interactions of a cosmic-ray with a rock on the lunar surface. It was easy to rule out this hypothesis as the high-energy events had no lunar association but it seems to me that it would be worth re-examining this idea within the prospects offered by the CREDO network. Neither Peters nor I thought about deflections in the magnetic fields.

I certainly support your proposal very strongly and I hope that I have a chance to interact with you

Professor Alan Watson, FRS Emeritus Professor, University of Leeds Emeritus Spokesperson, Pierre Auger Observatory

Mikhail Medvedev



7 February 2017

Dr Piotr Homola Department of Cosmic Ray Research The H. Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences ul. Radzikowskiego 152, 31-342 Kraków, Poland

Dear Piotr.

I find your proposal ERC COG 2017 titled "Indirect search for non-standard Dark Matter with Ultra-High Energy Cosmic Rays" (SPS) to be very interesting. I'm sure it fulfills well the ERC criteria and you will be granted the funding. The novel approach to detect cosmic rays you propose, namely to use existing infrastructure and data to explore our Universe from a completely new information channel is truly remarkable. This is a one-of-a-kind opportunity that should not be missed.

Your work plan looks scientifically sound and realistic. Obviously, this proposal is of rare "high reward, low risk" type. If super-preshowers are observed, that'll be a major breakthrough in astrophysics and maybe in fundamental physics. On the other hand, if one detects nothing in the new channel you open, it will be a meaningful observation as well, because it will constrain current models describing propagation and cascading of ultra-high energy cosmic rays.

Taking into account my field - Dark Matter - it is particularly interesting to realize that the cosmic-ray research you are planning might shed light on Dark Matter mystery, e.g., in the range of super heavy masses. Thus, I'm happy to offer you help, particularly my expertise in theoretical dark matter modeling. I'm sure it will be a fruitful scientific collaboration of mutual benefit for both of us and for the entire

I hereby declare the intention of cooperation with you and your group in the exploration of the super-spreshower channel.

I wish you success with your application and I'm looking forward to our scientific interactions.

Best regards

Department of Physics and Astronomy, University of Kansas 1251 Wescoe Hall Drive, Malott Hall #1082

University of Kansas, Department of Physics and Astronomy, Lawrence, KS 66045, USA Phone: +1-(785)-864-1225, Fax: +1-(785)-864-5262

ASTERICS (J. Jarvis, S. Serjeant)

School of Physical Sciences

The Open University

Walton Hall

Milton Keynes United Kingdom MK7 6AA http://stem.open.ac.uk/



The Open University

The Henryk Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences ul. Radzikowskiego 152

31-342 Kraków Poland Wednesday 8th February 2017

Dear Dr Piotr Homola,

As representatives of the DECS (Dissemination, Engagement and Citizen Science) work package within the ASTERICS (Astronomy ESERI & Research Infrastructure Cluster) project we write to express our support of the 'Indirect search for non-standard Dark Matter with Ultra- High Energy Cosmic Rays' proposal, incorporating the work of the CREDO (Cosmic-Ray Extremely Distributed Observatory) project, made to the ERC Consolidator Grant 2017.

ASTERICS, a €15million Research Infrastructure Cluster funded under Horizon 2020 INFRADEV aims to address the cross-cutting synergies and common challenges shared by the various Astronomy ESFRI facilities (SKA, CTA, KM3Net & E-ELT). It brings together for the first time, the astronomy, astrophysics and particle astrophysics communities, in addition to other related research infrastructures. Through an active dissemination programme, including direct engagement with all relevant stakeholders, and via the development of citizen scientist mass participation experiments ASTERICS has the ambition to be a flagship for the scientific, industrial and societal impact ESFRI

The work proposed in this application probes a scientific area of significant relevance to the ASTERICS project given its relationship with ESFRI astro-particle facilities and specifically the citizen science objectives of the DECS work package, DECS has already committed to developing educational resources for CREDO, supporting its Zooniverse application and will be promoting the resulting citizen science experiment and educational resources though press releases and social

The substantial and global approach to cosmic ray detection proposed here has a great deal of potential for public engagement in science and specifically the application of a citizen science based approach to particle physics and cosmology. As such we believe that project will further both the goals of the astro-particle community from a scientific perspective and the ASTERICS project from a

We would like to thank you for your ongoing engagement with the ASTERICS project and the effort put into assembling this excellent proposal. We look forward to future cooperation and to the common utilisation of the growing field of citizen science.

Your sincerely

Professor Stephen Serjeant (DECS PI) & Dr Johanna F Jarvis

The Open University is incorporated by Royal Charter (RC 000391), an exempt charity in England & Wales and a

... and yours?

Summary

Cosmic-Ray Extremely Distributed Observatory: a tool to explore uncharted realm of science?

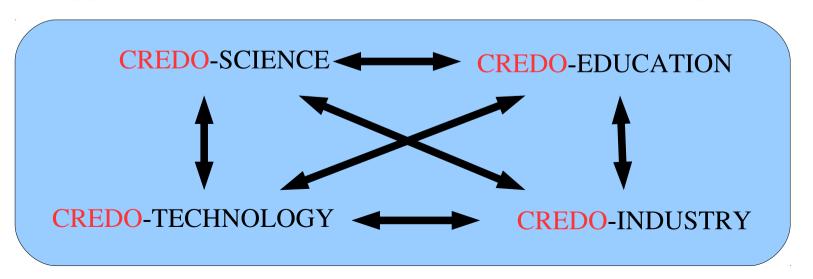
"I do think CREDO has a unique capability of entering in and exploring a completely uncharted realm of science."

Mikhail V. Medvedev, (2cDM author, now involved in CREDO tasks: organization, theory, publications)

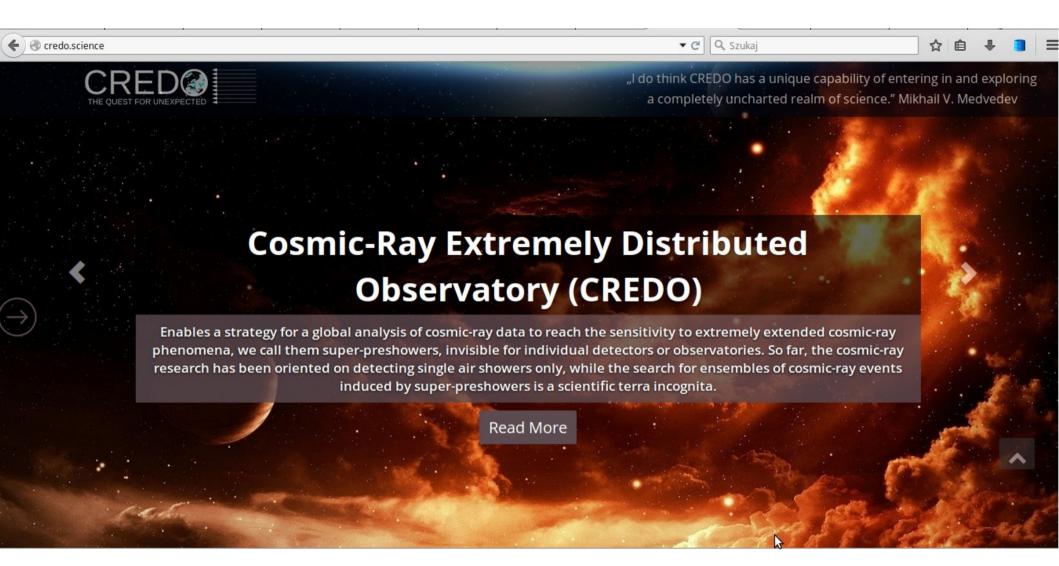
"Yes, but": Terra incognita might turn out to be a desert...

CREDO guarantee of success:

ocean of opportunities / synergy generator under one roof (project)



Visit credo.science...



... and contribute to CREDO science.

CREDO - data format

Search of pre-showers in CREDO - minimal information:

- particles detected at large distances POSITION
- measurements correlated in time TIME
- particles are approximately parallel DIRECTION (if available)

Identification of measurements:

- experiment identification EXPID
- detector (station) identification DETID
- detector type DETTYPE (not for all experiments necessary)

Detector activity information (in a header) - STARTTIME + ENDTIME

- for proper likelihood estimations (5 hits in 10 stations may mean more than 10 hits in 1000 stations)
- for background estimation
- for data quality (idenfification of incorrectly working stations)

This list is not exhaustive, full common format has to be open to extensions



CREDO - data format

Accuracy of the values

- POSITION GPS position accuracy is sufficient
- TIME GPS time accuracy is sufficient, but some experiments may provide more precise timing
- DIRECTION 1 degree should be sufficient

For simplicity integer values are preferable

File format

- pure text file (readable by any tool, no extension possible)
- json, xml (readable using appropriate libraries, easy extension)
- ROOT (most suitable for analysis, extension may be problematic)

json or xml seems to be most useful for common full data format ROOT (or text) can be used for actual analysis or shortened data



Lorentz invariance violation and super-preshowers

Isotropic, nonbirefringent LV



 κ endows the vacuum with an effective index of refraction, leading to a modification of the photon dispersion relation

$$\omega(q) = \frac{1}{n_{\text{eff}}} \, q = \sqrt{\frac{1 - \kappa}{1 + \kappa}} \, q$$

- This modification allows for processes which are kinematically forbidden in the conventional Lorentz-invariant theory
 - $\kappa > 0$: vacuum Cherenkov radiation possible above a threshold $E_{\rm thr}(\kappa)$

$$f \to f + \tilde{\gamma}$$

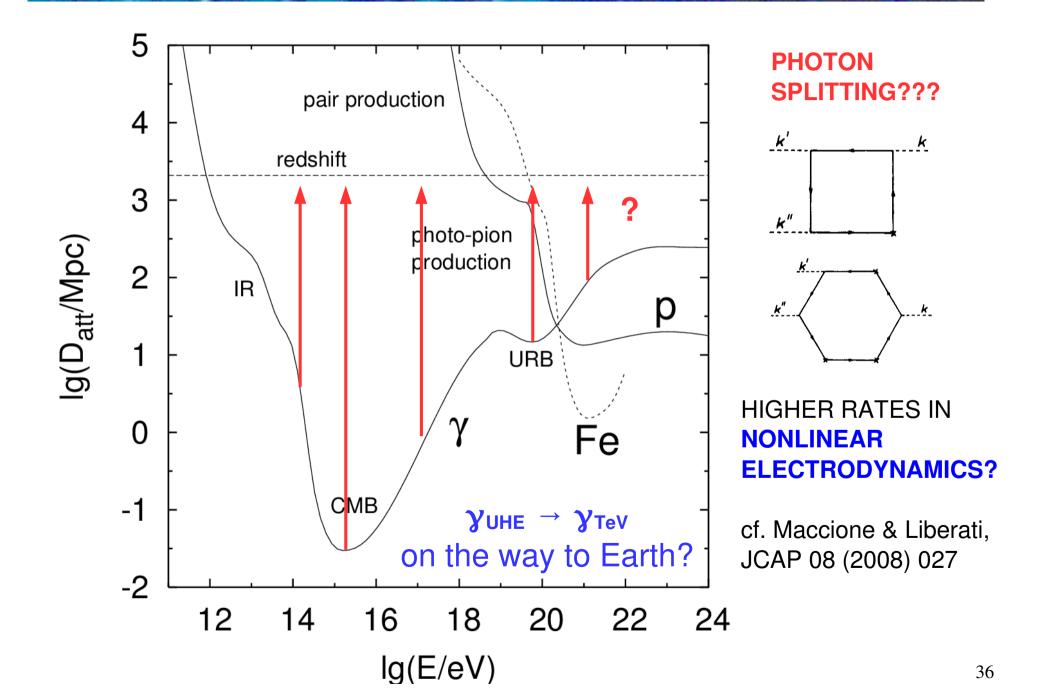
efficient energy loss mechanism for charged particles, current constraints ($K < 6 \times 10^{-20}$ at 98% C.L.) derived from observations of UHECRs [Klinkhamer & Risse 2008] [Klinkhamer & Schreck 2008]

• κ < 0: photon becomes unstable above a threshold $\omega_{thr}(\kappa)$

$$\tilde{\gamma} \to e^+ + e^-$$

ALL UHE photons

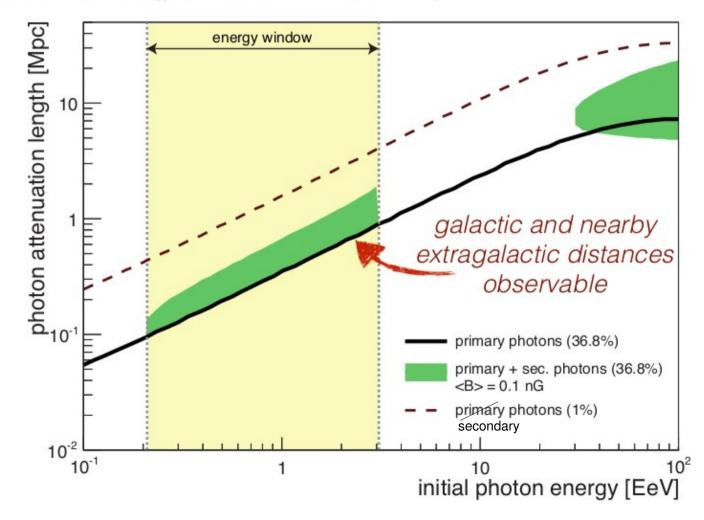
γ_{UHE} travelling through the Universe: exotic example



Non-exotic examples of "obvious" SPS between

Photon horizon

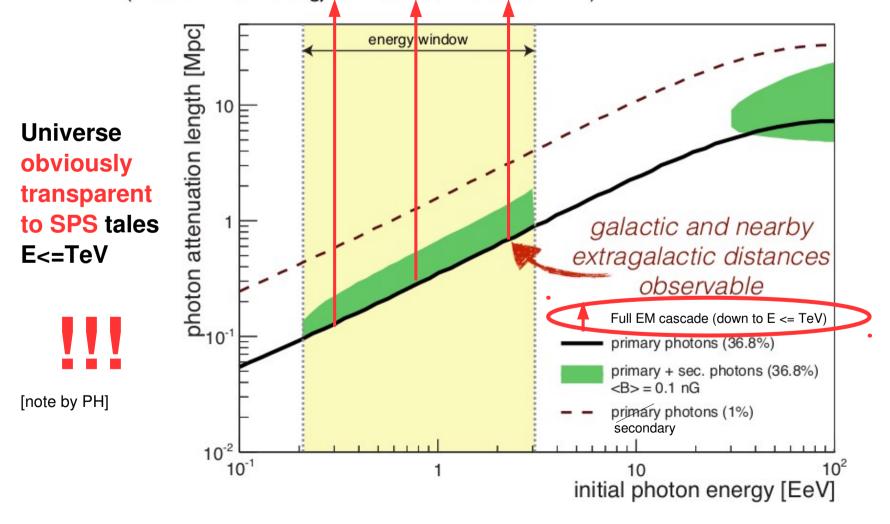
- CRPropa 3 simulation. Differentiate between
 - ▶ Primary photons: Photons from the source propagating without an interaction to observer
 - Secondary photons: At least one iteration from EM cascade process (must be in our energy window with deflection < 1°)



Non-exotic examples of "obvious" SPS between

Photon horizon

- CRPropa 3 simulation. Differentiate between
 - Primary photons: Photons from the source propagating without an interaction to observer
 - Secondary photons: At least one iteration from EM cascade process (must be in our energy window with deflection < 1°)</p>

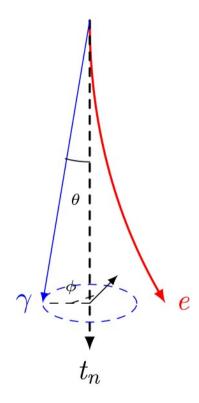


Sun super-preshowers: the opening angle

Opening Angle dependence on Energy

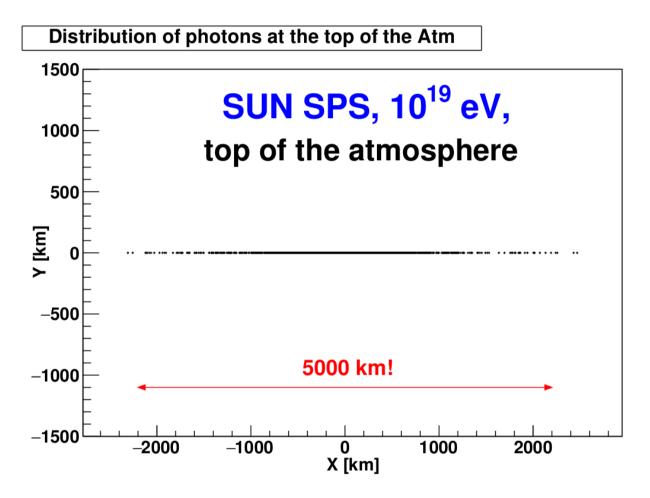
$$\theta = \frac{m_{\rm e}}{E}, \qquad \phi = \mathcal{U}(0, 2\pi)$$

⇒ Larger deflections for smaller energies, and vice-versa.



Schematic of deflection of emitted γ s

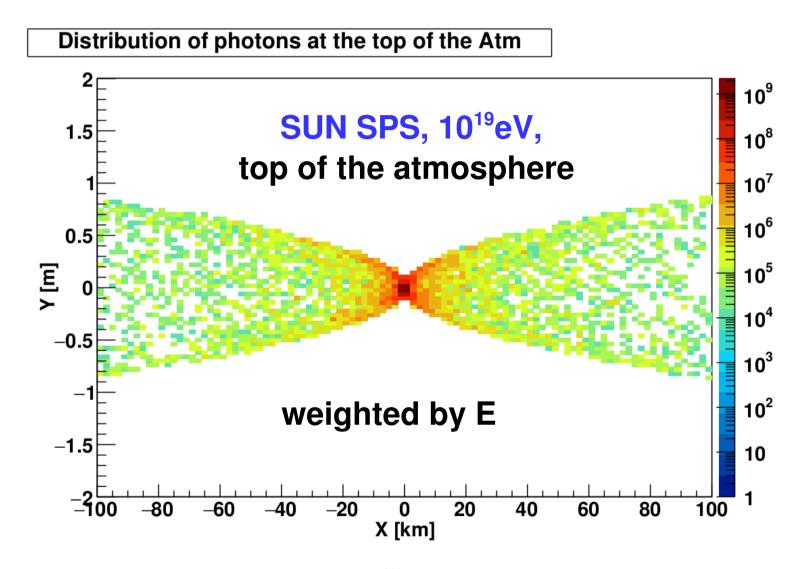
Sun super-preshowers at Auger? Simulations



Distribution of photons ($E>10^{13}$ eV) at the top of the atmosphere. $E_{\gamma}=$ 10 EeV, Impact parameter $=2.5R_{\rm S}.$

Sun super-preshowers: colorful air shower physics?

Distribution of photons weighted by their energies.

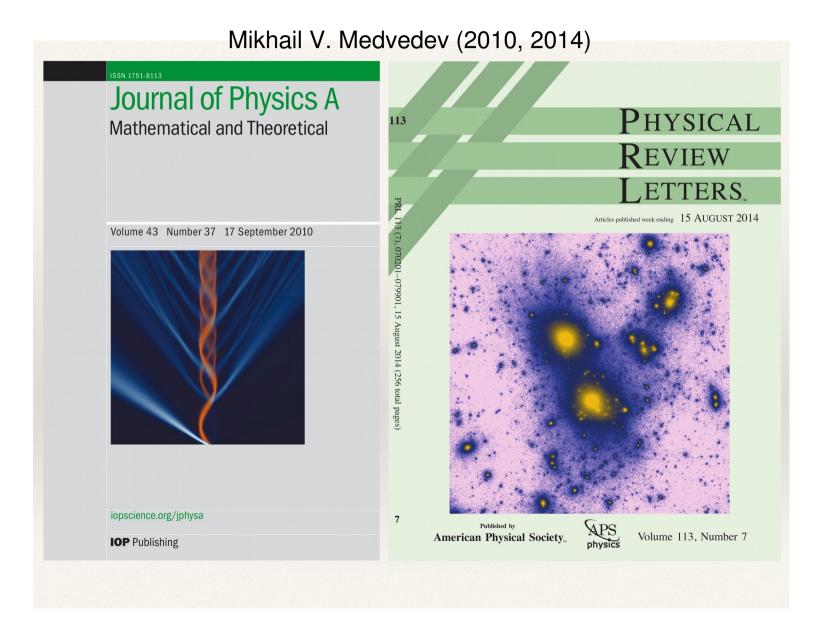


Distribution of photons $(E>10^{15}~{\rm eV})$ at the top of the atmosphere. $E_{\gamma}=$ 10 EeV, Impact parameter $=2.5R_{\rm S}.$

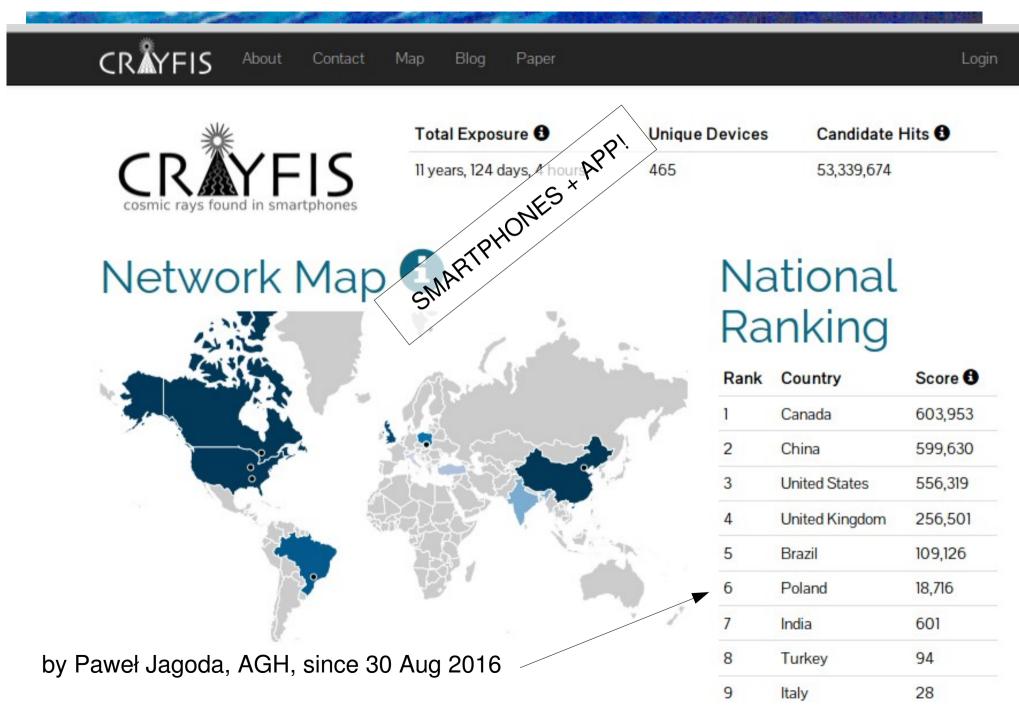
Let's test the hottest DM scenario!

2-component flavor-mixed DM (2cDM), $\Delta m=10^{-8}$

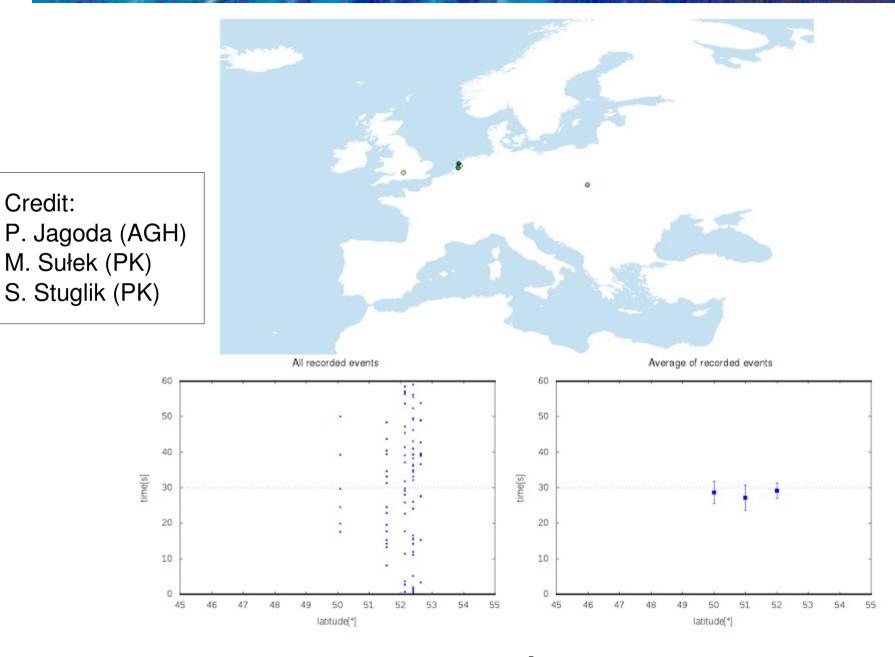
neutralinos, sterile neutrinos, photon and axion, ..., monopoles, super-heavies



Examples of CREDO players: CRAYFIS



CREDO: the first real data classification



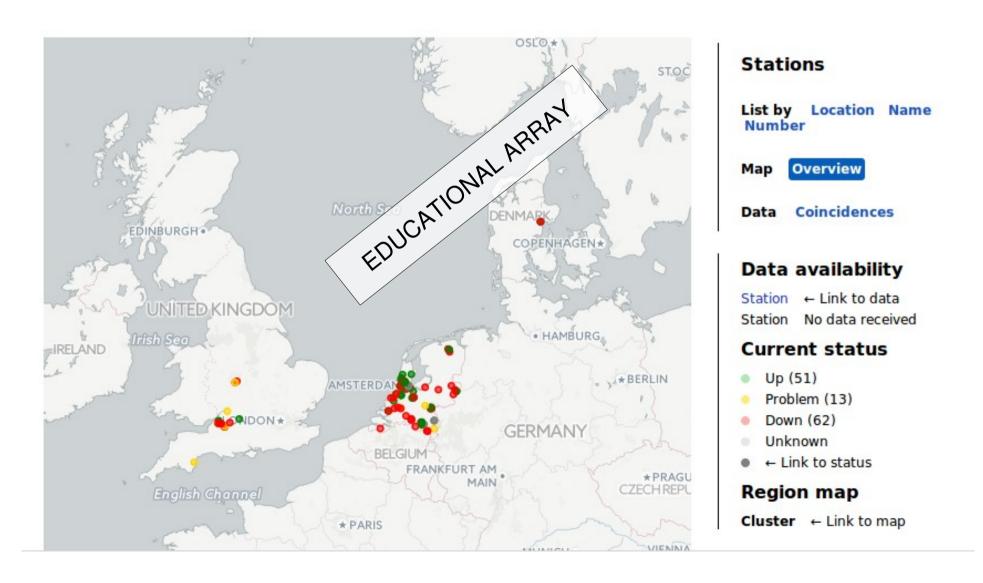
Credit:

→ random...

Examples of CREDO players: HiSPARC



Map of HiSPARC stations



Examples of CREDO players: DECO



DATA



CONTACT

FAQ

Examples of CREDO players: JINR

Manual

About site

Contacts

Shower of knowledge EDUCATIONAL ARRAY

Setup-

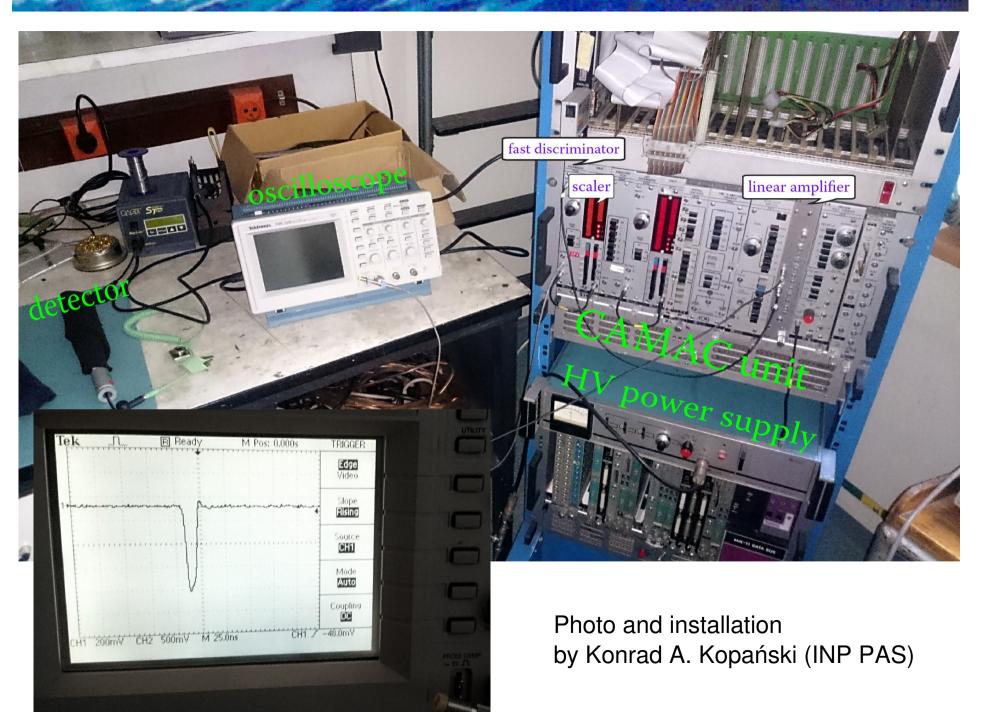
News

Project-

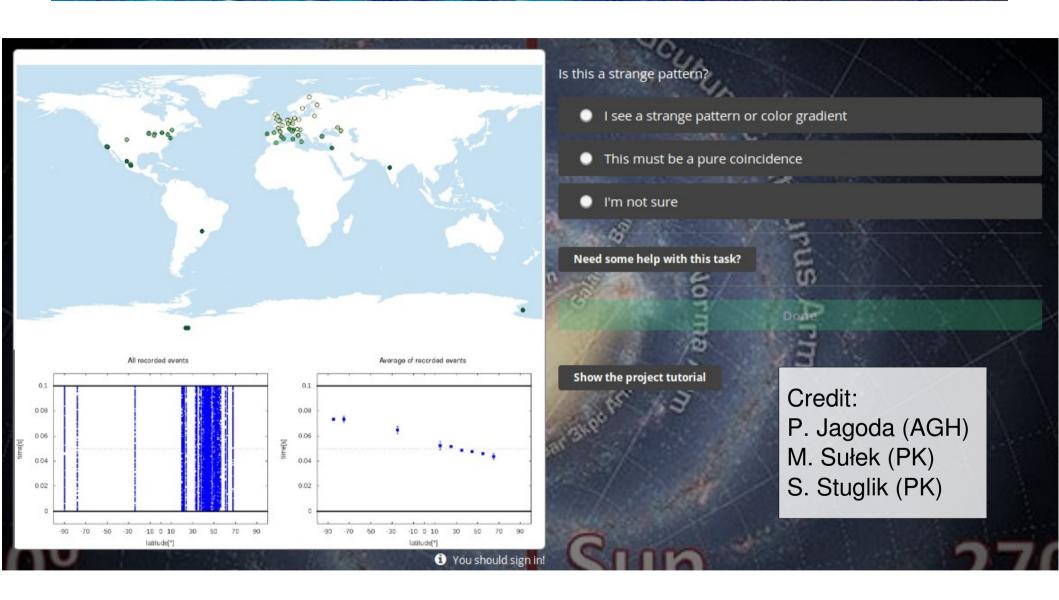
Welcome, dear Guest!

We are glad to see you in our laboratory of cosmic rays. We suggest you to start from surfing through the available sections and try to make the simplest analysis of real experimental data, which our station provides continuously. We hope that it will entice you and you will become a permanent and full-fledged member of our international laboratory.

Examples of CREDO players: INP PAS, Krakow



CREDO citizen science: Dark Universe Welcome



What is your vote? [a child can do this...]

the simplest CREDO anaylsis: "SIGNAL" simulation

