Cosmic-Ray Extremely Distributed Observatory: nowe możliwości badawcze w astrofizyce

Piotr Homola
IFJ PAN

AGH, Kraków, 28.10.2016

Outline

1. Motivation
→ a bit of philosophy: thinking top → down
→ (only) big questions

2. Ultra-High Energy Cosmic Rays (UHECR)
→ photons and super-preshowers

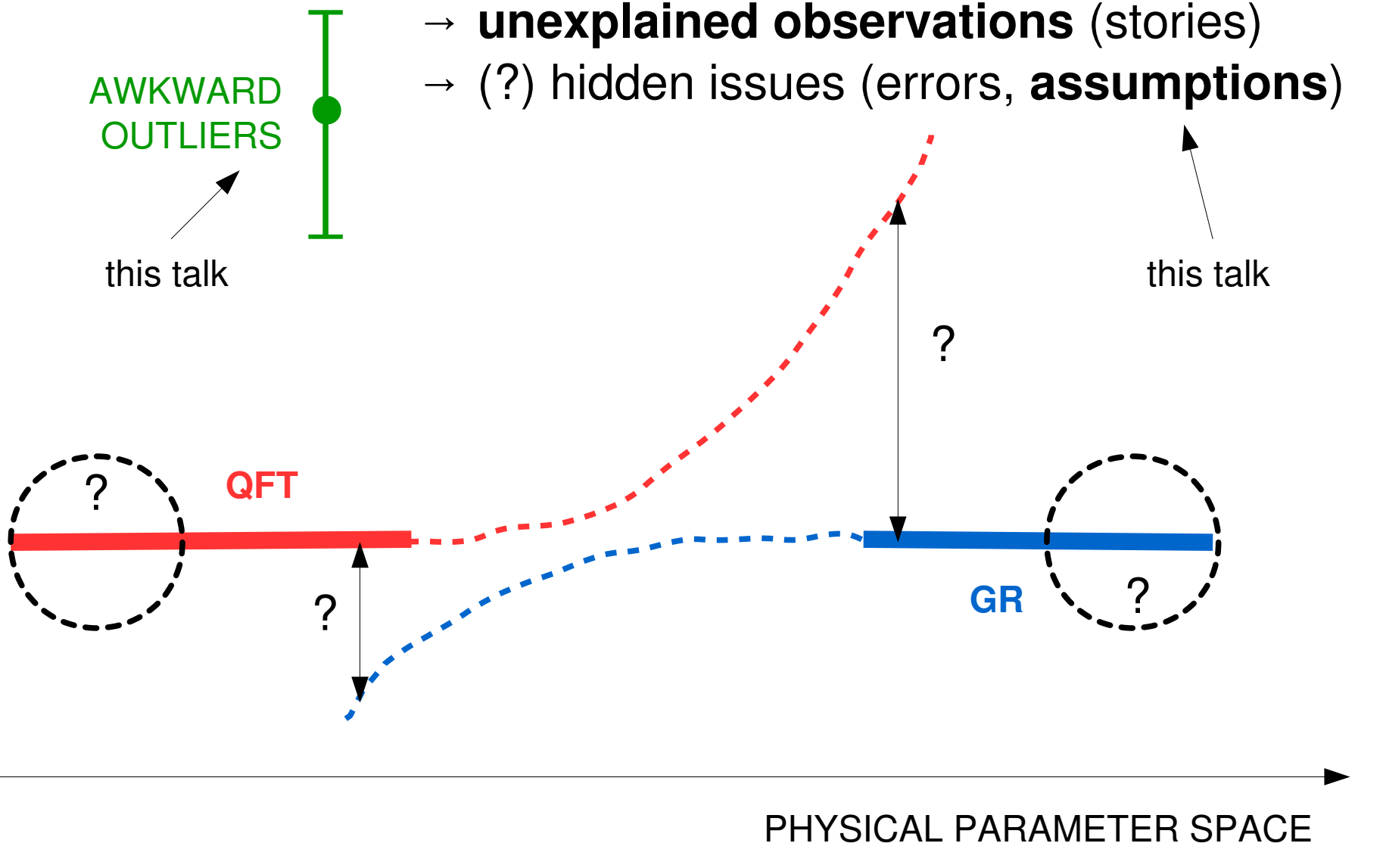
3. Generalizing UHECR detection strategy

4. Cosmic-Ray Extremely Distributed Observatory

5. Uncharted realm and/or ocean of opportunities?

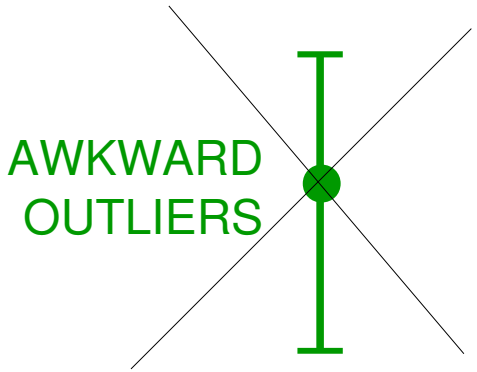
Understanding the Universe

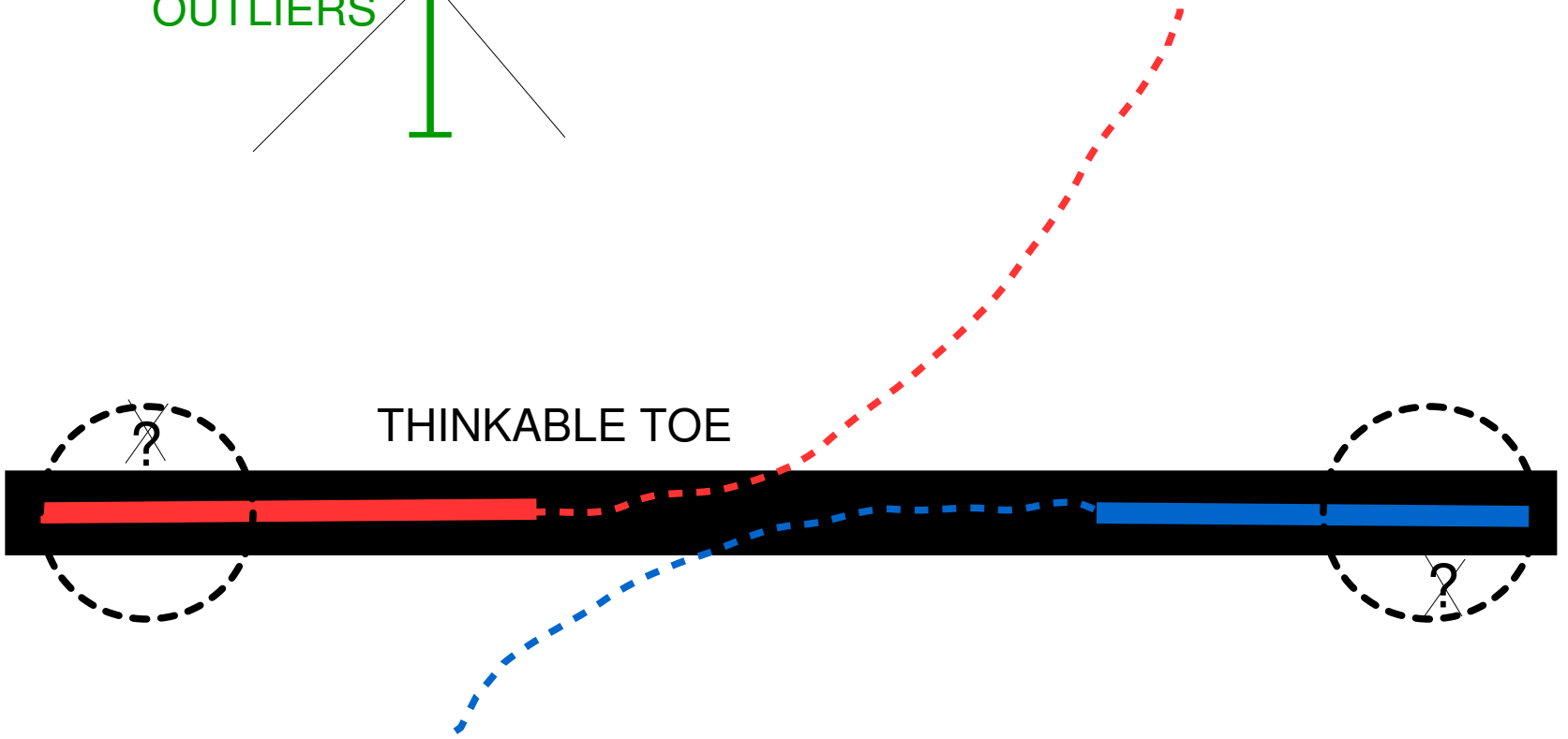
→ key theories disagree
→ **unexplained observations** (stories)
→ (?) hidden issues (errors, **assumptions**)



Ways towards a unifying theory (TOE): bottom → up

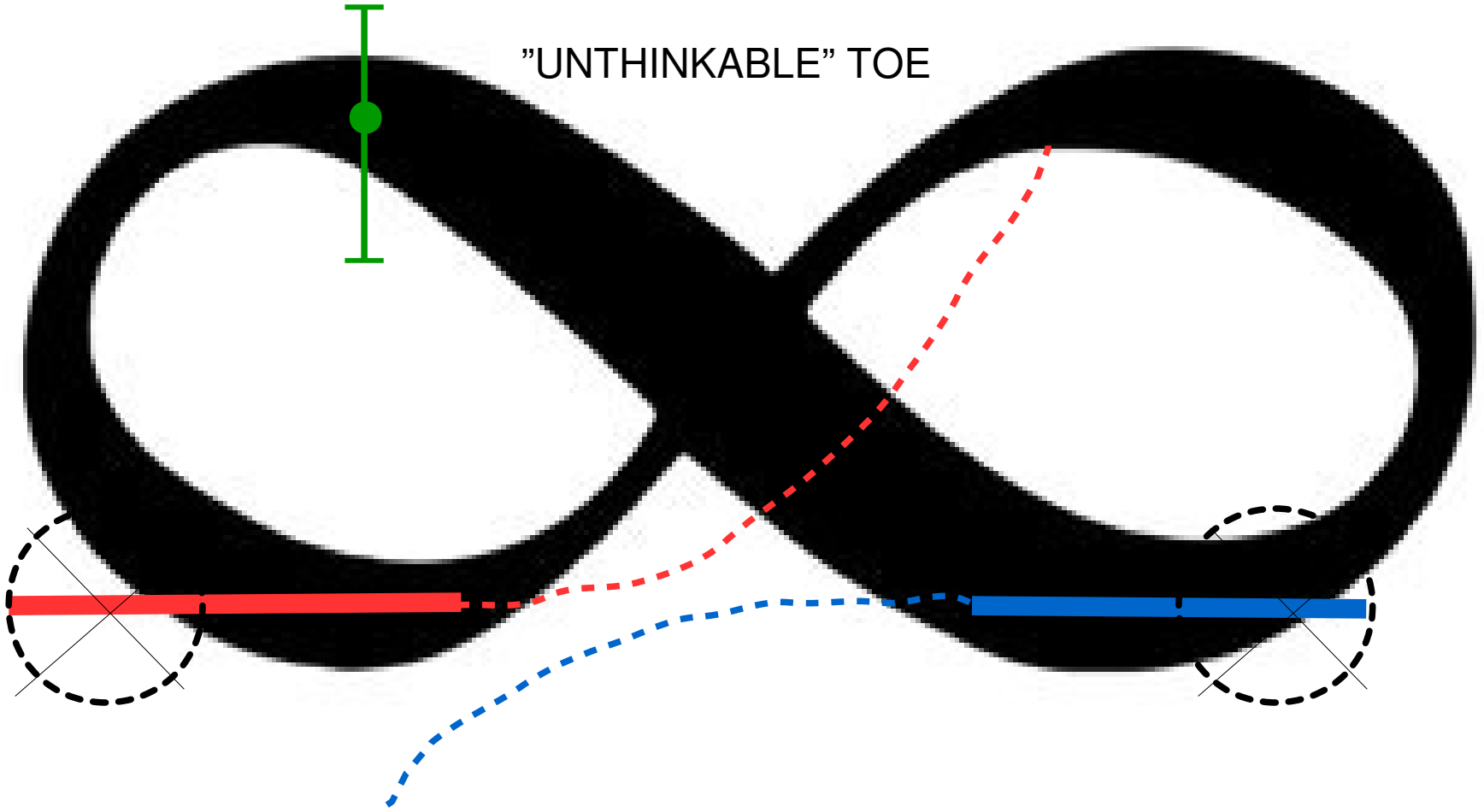
Thinking **bottom → up**:
understanding a bigger picture based on the known ingredients



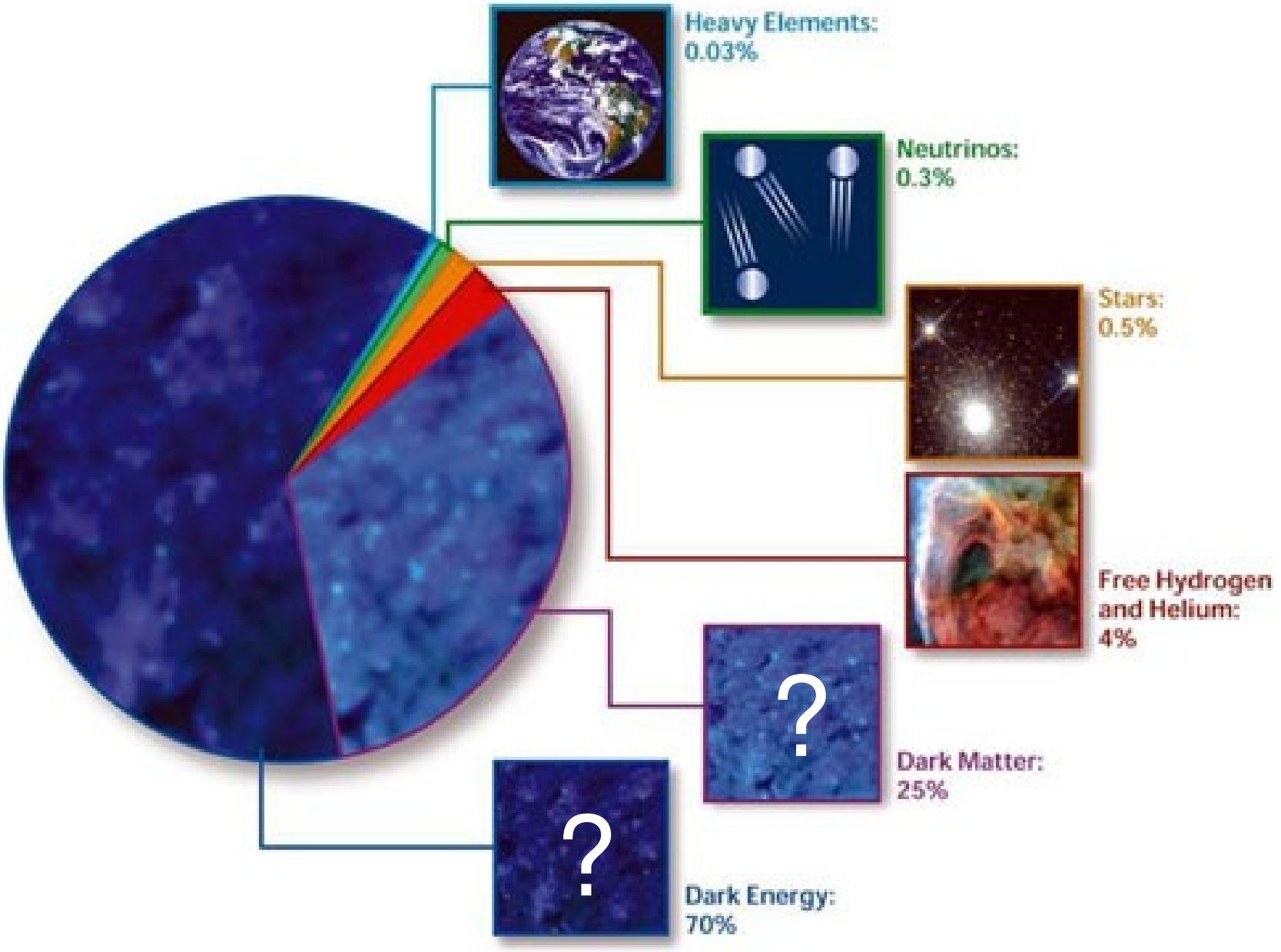


Ways towards a unifying theory (TOE): top → down

Thinking **top → down**:
understnad a bigger picture assuming hypothetic objects/laws

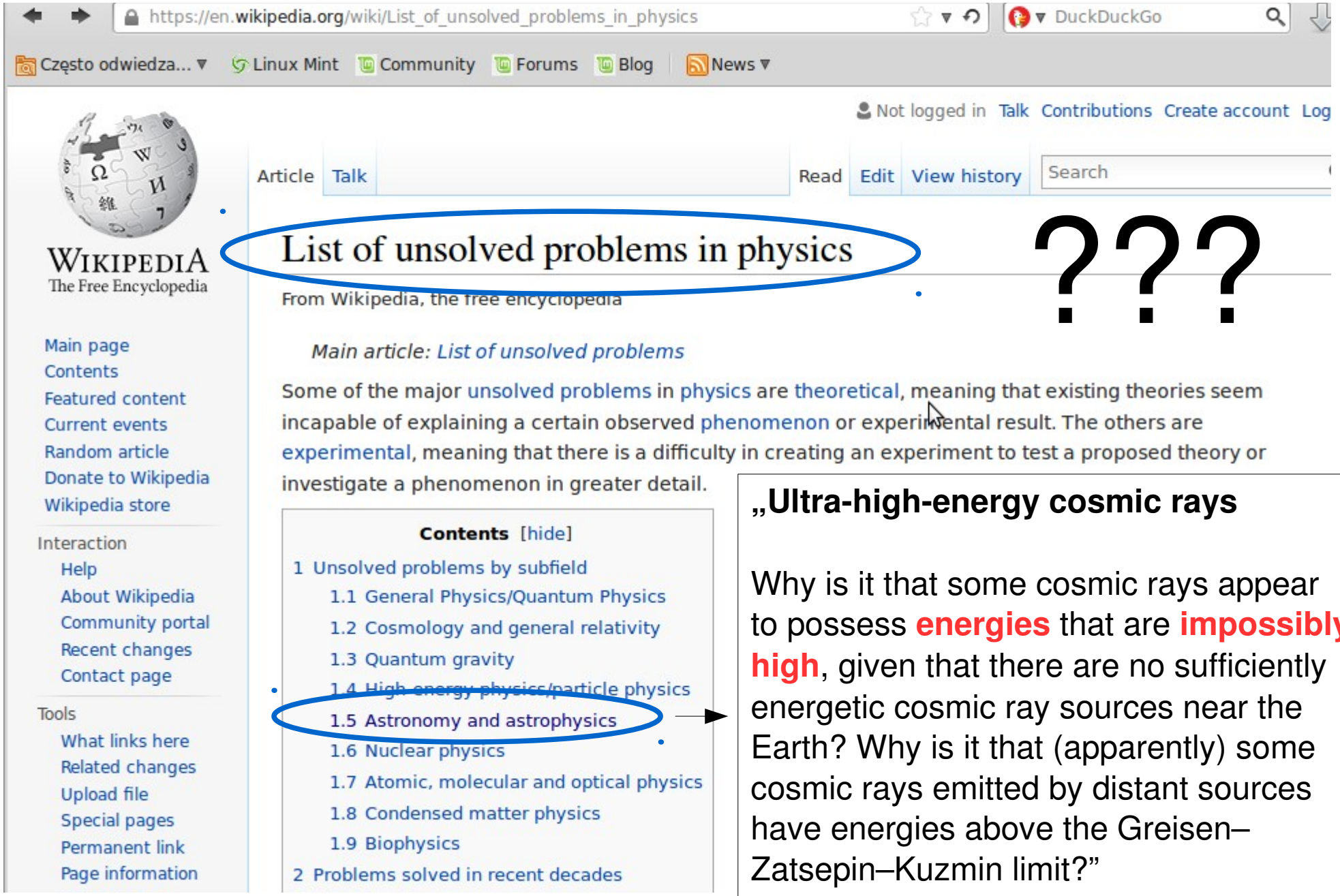


COMPOSITION OF THE COSMOS



http://certificate.ulo.ucl.ac.uk/modules/year_one/NASA_cosmology/goals5.html

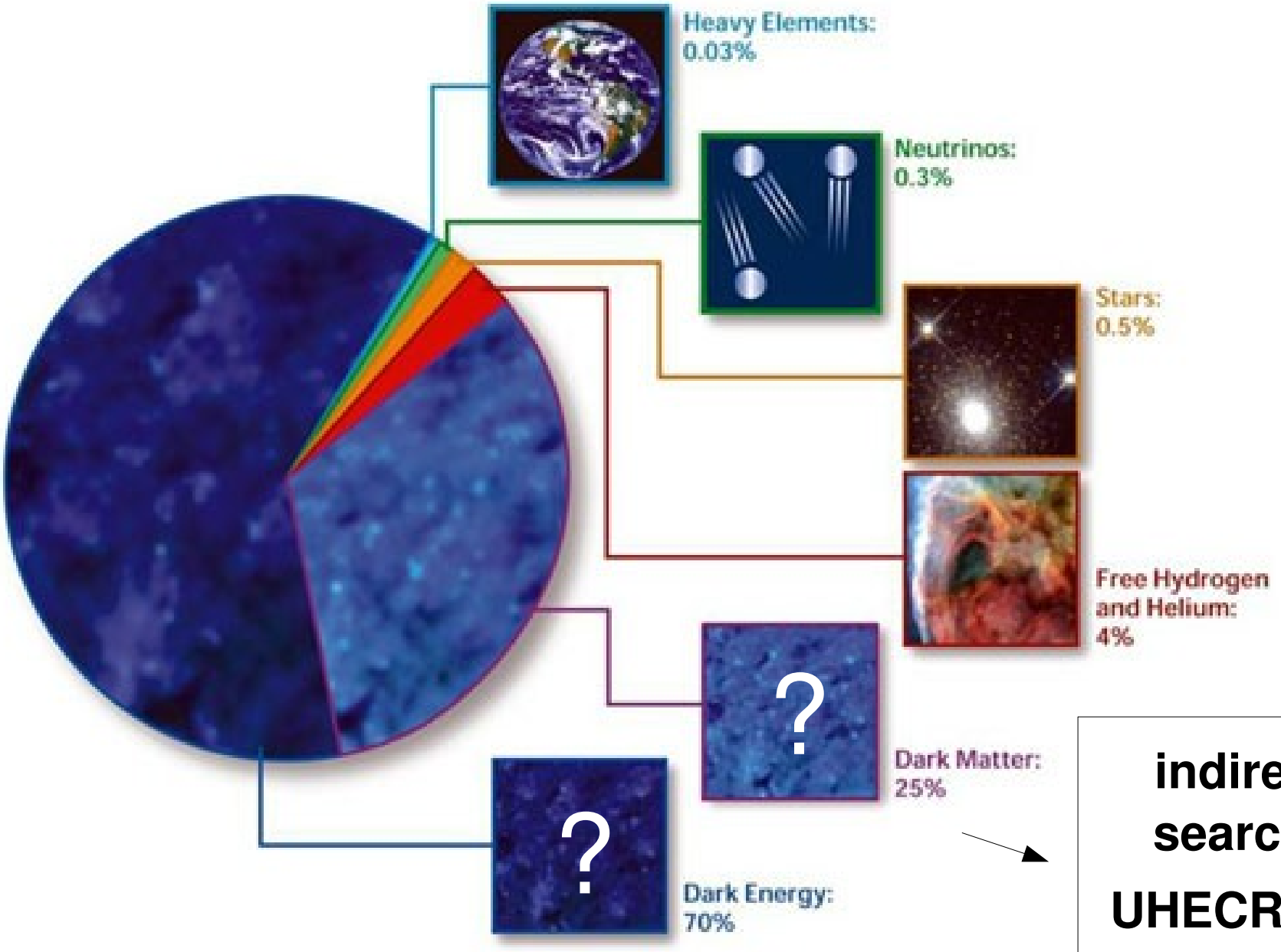
UHECR - one mystery more



„Ultra-high-energy cosmic rays

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

COMPOSITION OF THE COSMOS



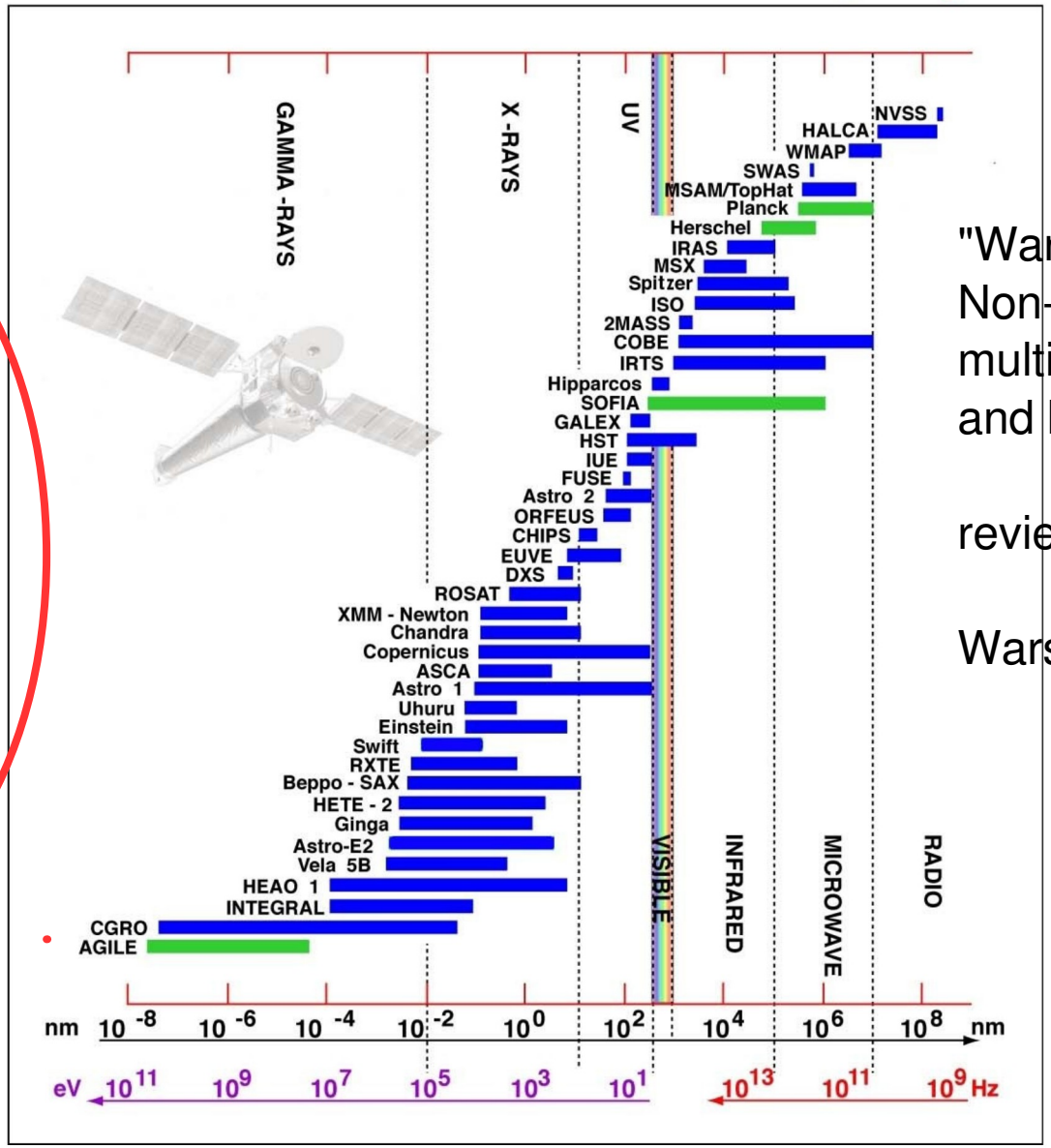
indirect DM search with UHECR (γ_{UHE})!

http://certificate.ulo.ucl.ac.uk/modules/year_one/NASA_cosmology/goals5.html

From gamma rays to radio

Why nothing here

???



"Warsaw Workshop on Non-Standard Dark Matter: multicomponent scenarios and beyond",

review by C. Weniger

Warsaw, 2-5.06.2016

http://nssdc.gsfc.nasa.gov/astro/astrolist.html

9

Short history of ultra-high energy cosmic rays (UHECR)

Particles coming to Earth from Space

1912. Electroscopes discharge faster with increasing altitude → rays of extraterrestrial origin: V. Hess (Nobel prize 1936).

1932. Discovery of antimatter (positron): C. Anderson (Nobel prize 1936).

1937. Discovery of muons: S. Neddermeyer and C. Anderson → particle physics begins.

1938. Extensive air showers (EAS) → $E > 10^{15}$ eV: P. Auger

1962. First EAS at 10^{20} eV: J. Linsley
→ what and why can have so huge energies???

.... high time for a next breakthrough?

Energy spectrum of cosmic rays

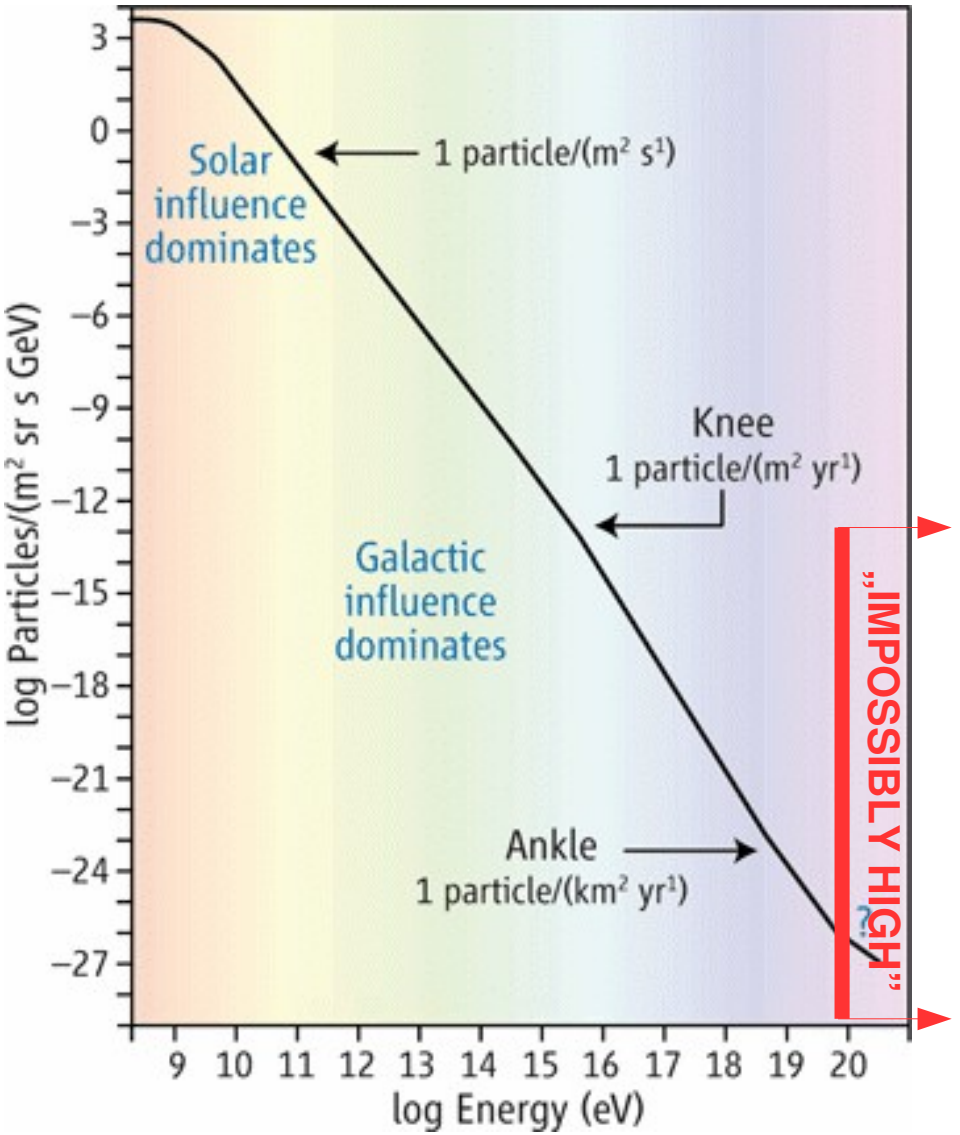
Ranges:
energy: > 10 orders of magnitude
flux: > 30 orders of magnitude
→ diverse physics (sources)
→ diverse detection techniques

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 UHECR? Where they come from?
How do they propagate?

Do photons contribute to the UHECR flux?



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
→ 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

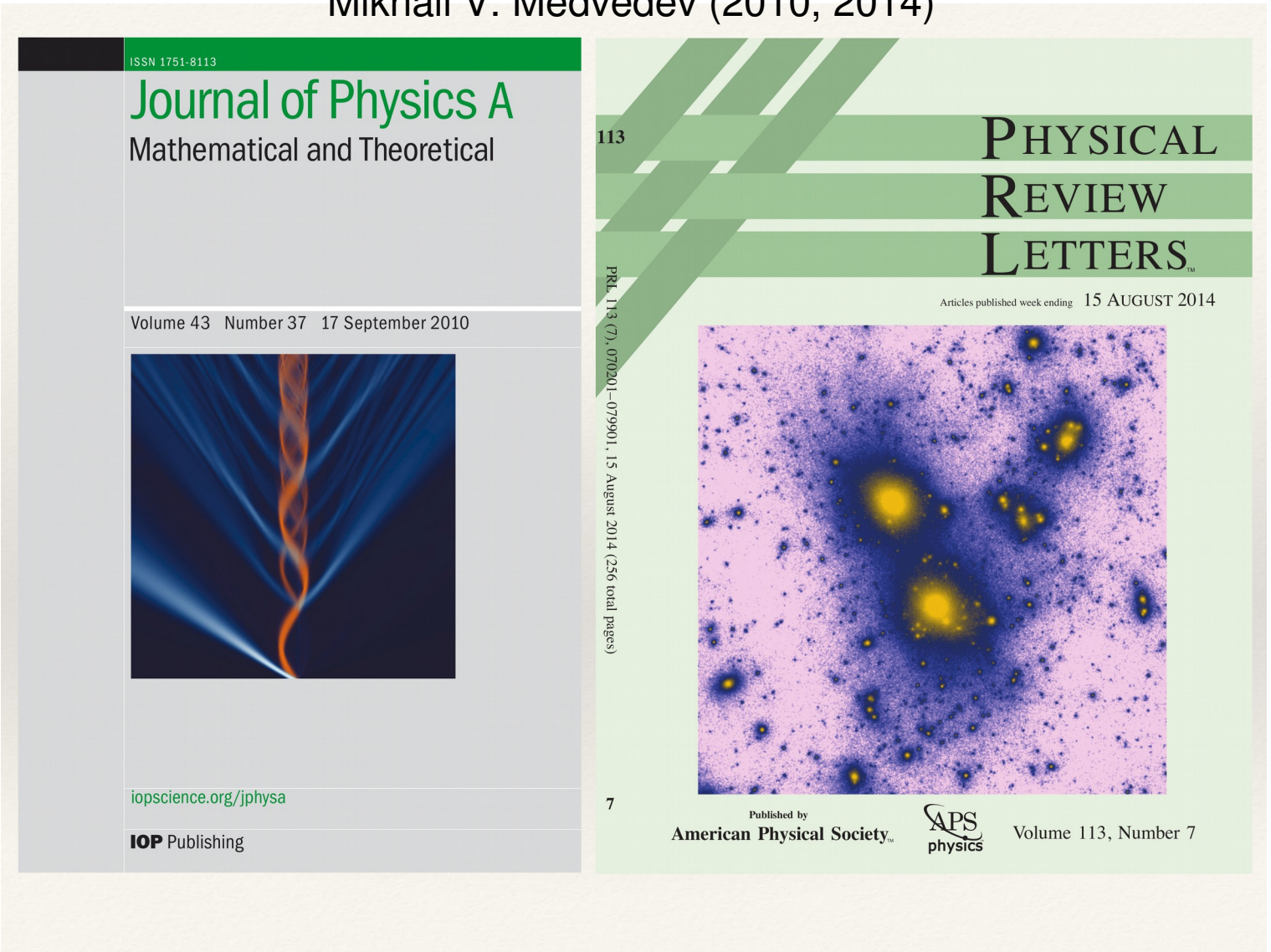
DARK MATTER!

Let's test the hottest DM scenario!

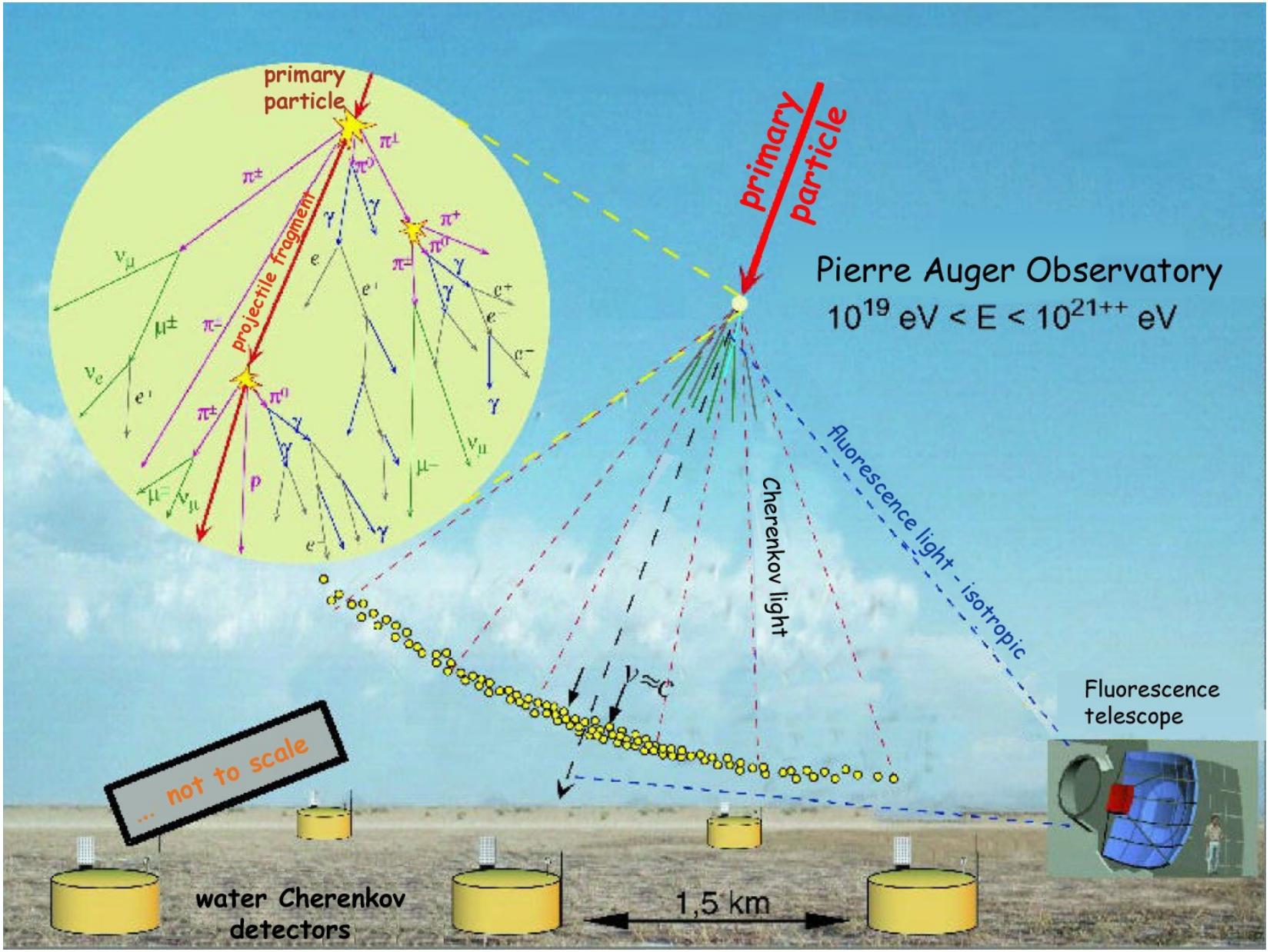
2-component flavor-mixed DM (2cDM), $\Delta m=10^{-8}$

neutralinos, **sterile neutrinos**, photon and axion, …, **monopoles**, **super-heavies**

Mikhail V. Medvedev (2010, 2014)



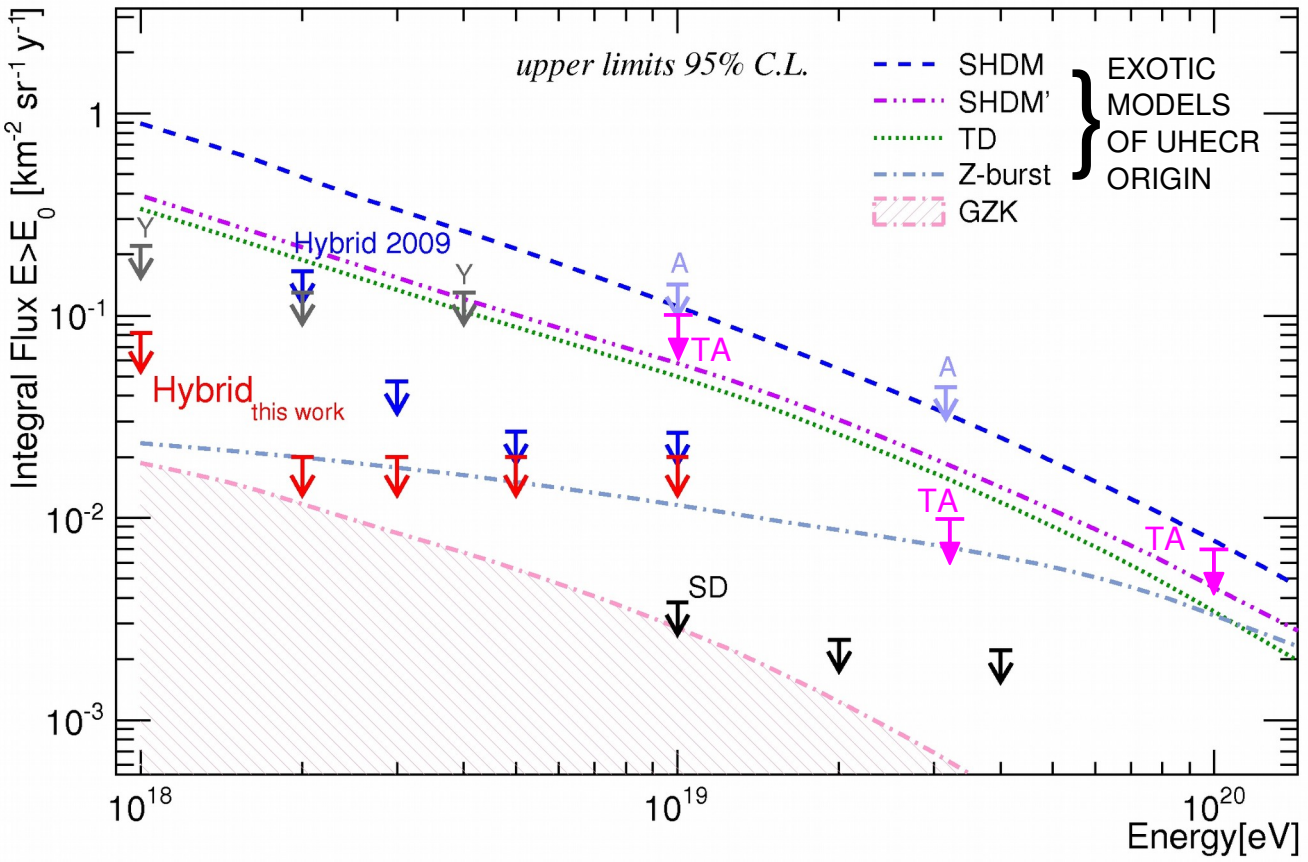
Detection of UHECR at the Pierre Auger Observatory



UHECR composition paradigm: „no photons”

At the highest energies photon fractions < 1%

AUGER, ICRC 2011 + TA 2013



Hybrid – AUGER '11 (hybrid detector)

Hybrid 2009 – AUGER '09 (hybrid detector)

SD – AUGER '08 (surface detector)

A – AGASA '02
Y – YAKUTSK '07
TA – Telescope Array '13

SHDM, TD, Z Burst: Gelmini et al. '08
SHDM': Ellis et al. '06

→ exotic (Dark Matter) scenarios severely constrained!

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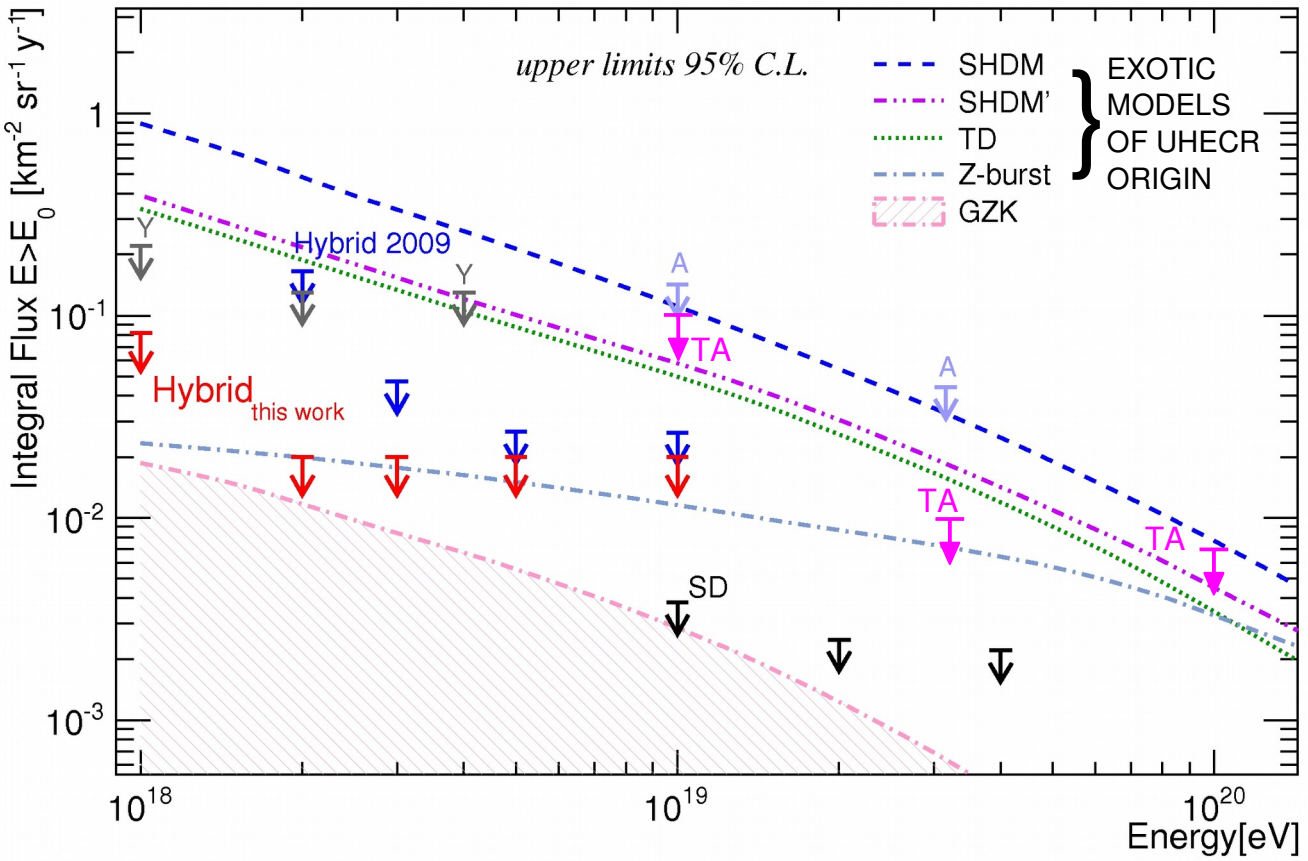

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→ exotic (Dark Matter) scenarios severely constrained! *)

*) **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}

γ_{UHE} —no interactions / screening→ **Earth**

NOT OBSERVED

γ_{UHE} —unexpected interactions, screening, ...→ **ELECTROMAGNETIC CASCADES (SUPER-PRESHOWERS)** → **Earth**

NOT TRIED SO FAR...

↓

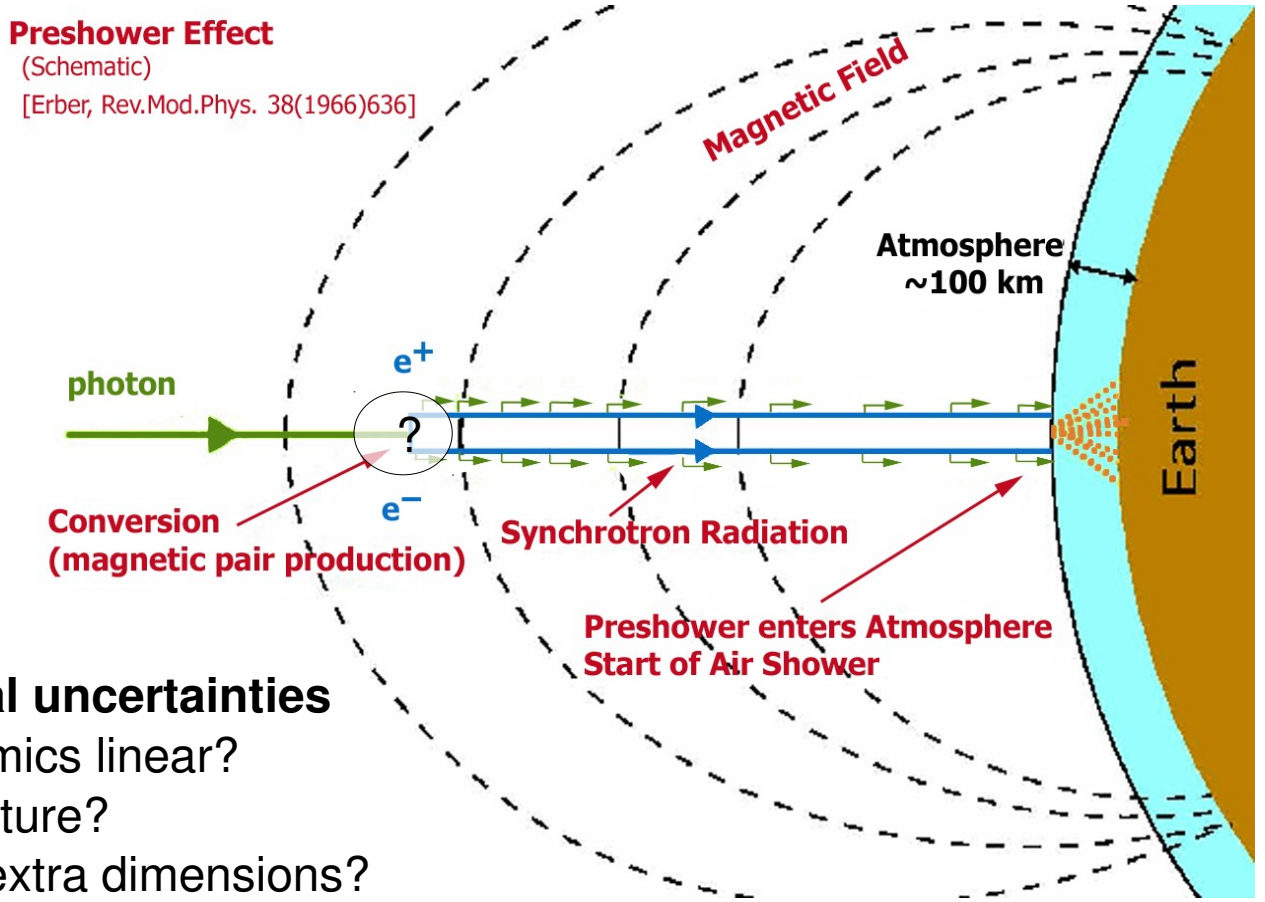
CREDO!

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

(super-)preshower:

→ contains typically **(>1000)** 100 particles

→ created at around **(>10000)** 1000 km a.s.l.)



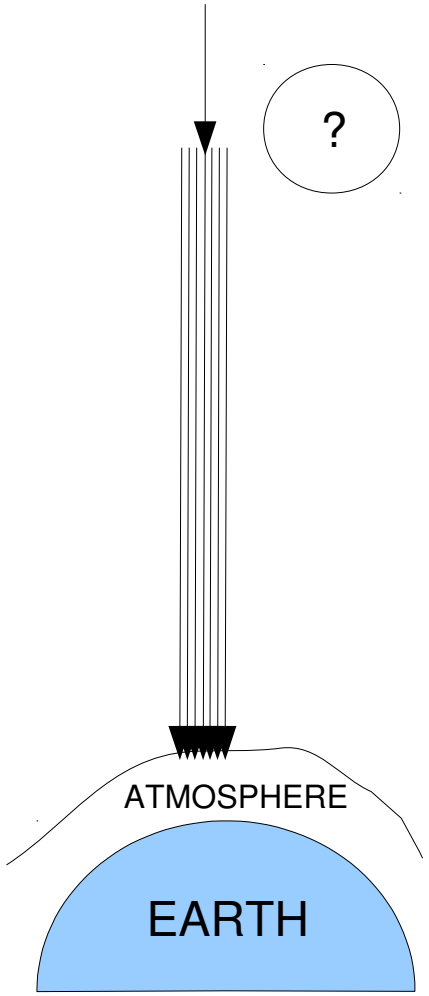
? : **fundamental uncertainties**

- electrodynamics linear?
- photon structure?
- spacetime: extra dimensions?

→ dependence on E and $B_\perp$ (to be seen in data?)

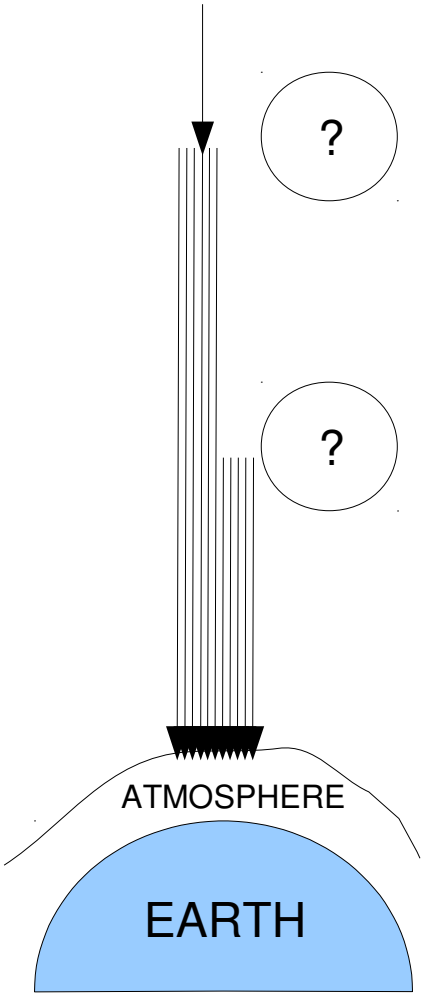
Classes of super-preshowers (SPS)

A: γ_{UHE} (e.g. 10^{20}eV)



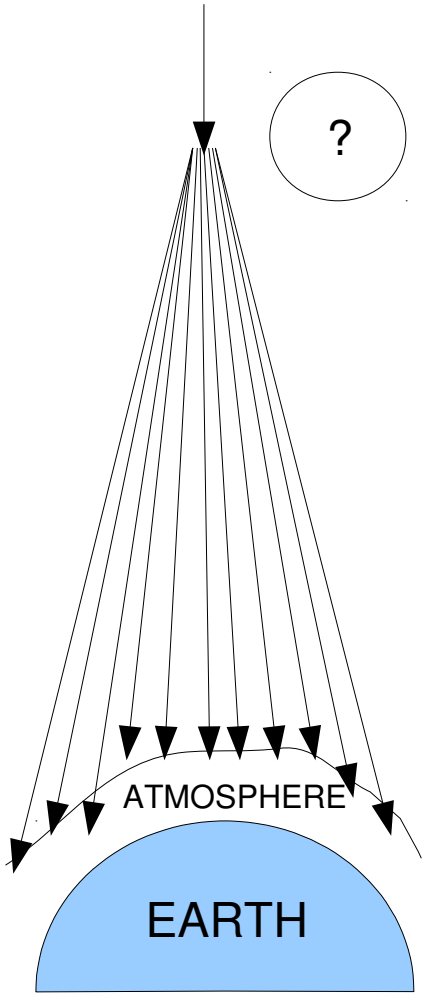
Δx: small
Δt: small

B: γ_{UHE} (e.g. 10^{20}eV)



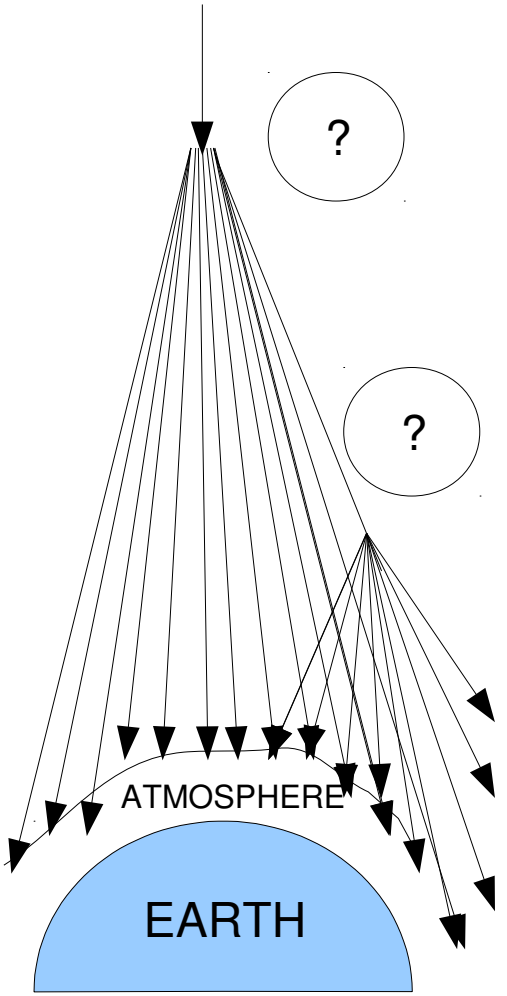
Δx: small
Δt: large

C: γ_{UHE} (e.g. 10^{20}eV)



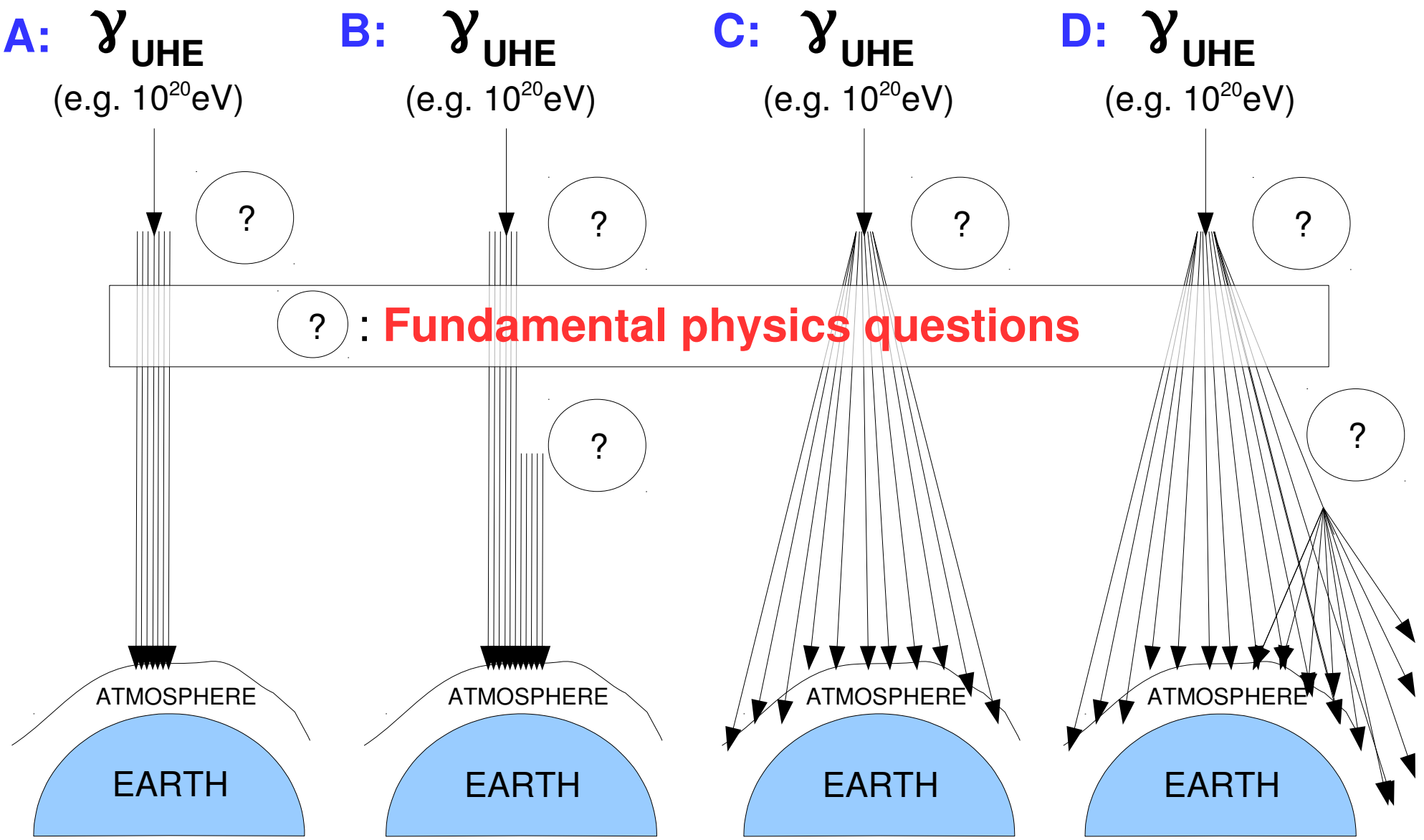
Δx: large
Δt: small

D: γ_{UHE} (e.g. 10^{20}eV)



Δx: large
Δt: large

Classes of super-preshowers



Super-preshowers motivated by data! (1)

$\ln A$ derivative with $\log E$? It has been recently observed (in data which are public!!!) that the electromagnetic observables have a consistently differe
behavior from the hadronic ob
and tend to diverge as
energy.

ACCESS RESTRICTED!

Super-preshowers motivated by data! (2)

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

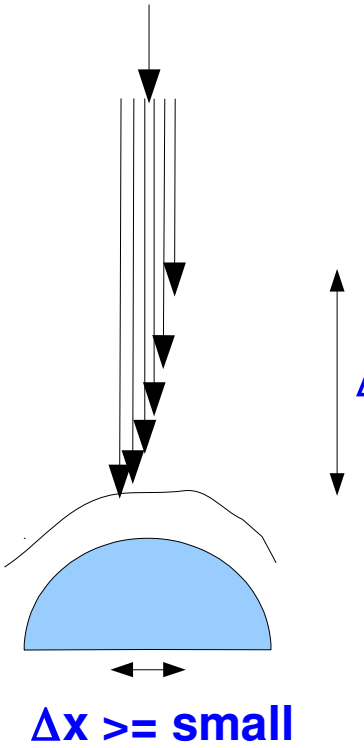
Gary R. Smith, M. Ogmen, E. Buller, and S. Standil
Physics Department, University of Manitoba, Winnipeg, Manitoba R3T 2N2, Canada

(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?



Year = 1981
N_{obs} = 32
N_{exp} = 1
E = 3×10^{15}eV

Super-preshowers: motivated by data! (3)

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

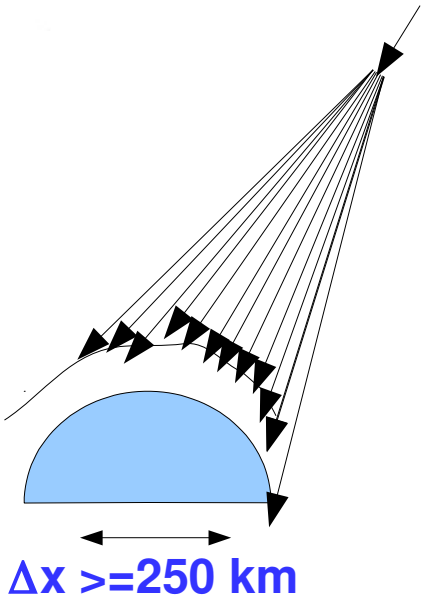
C. O'Sullivan
Physics Department, University College Cork, Cork, Ireland

(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.

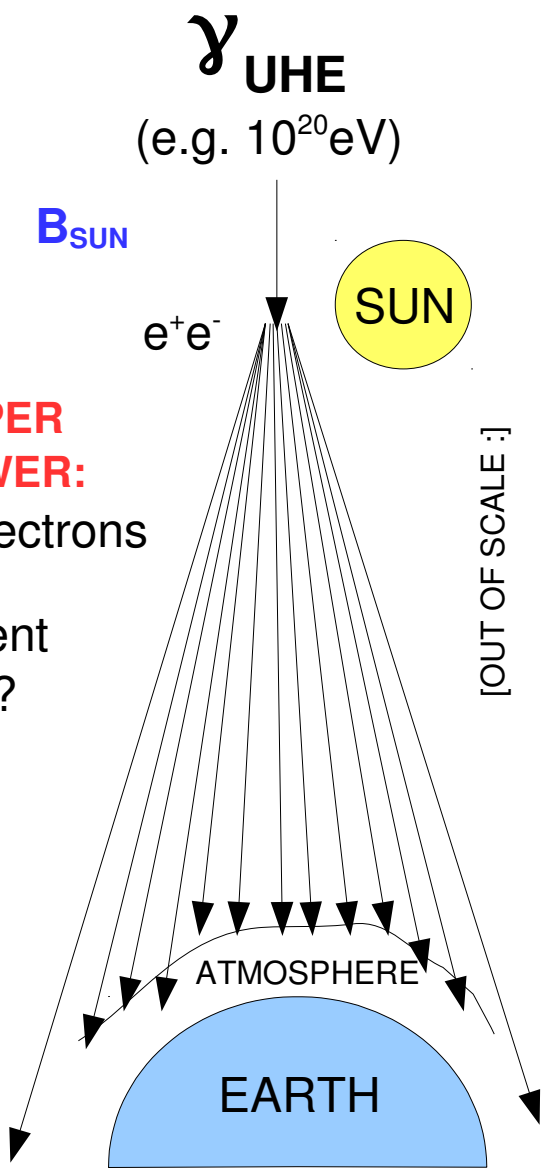
PACS numbers: 94.40.Pa, 95.85.Qx, 97.80.Jp

PH: Super-preshower class D?

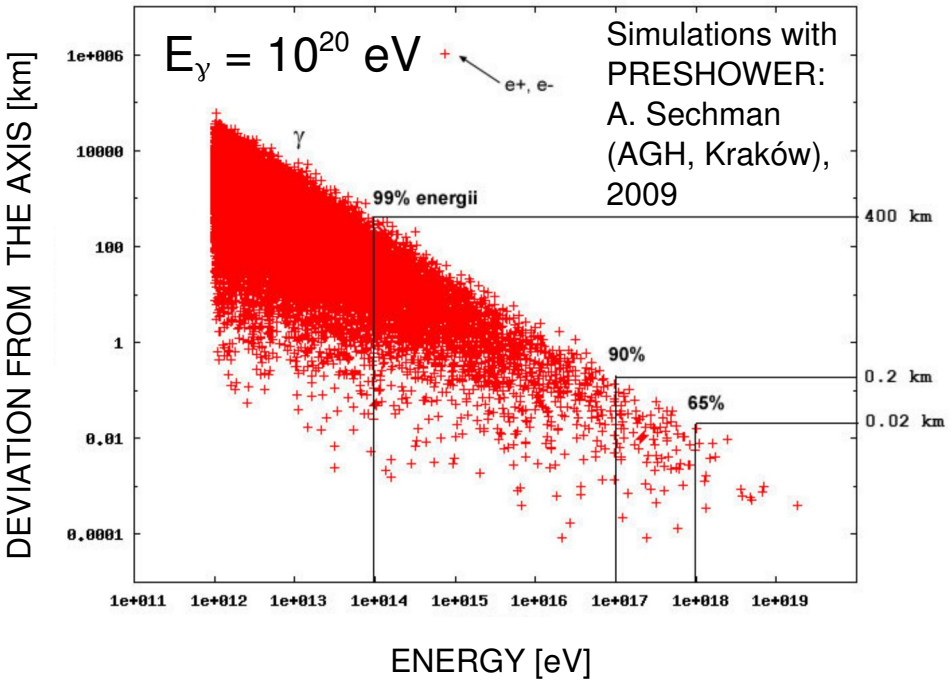


"Classical" super-preshowers: vicinity of the Sun

C & D:

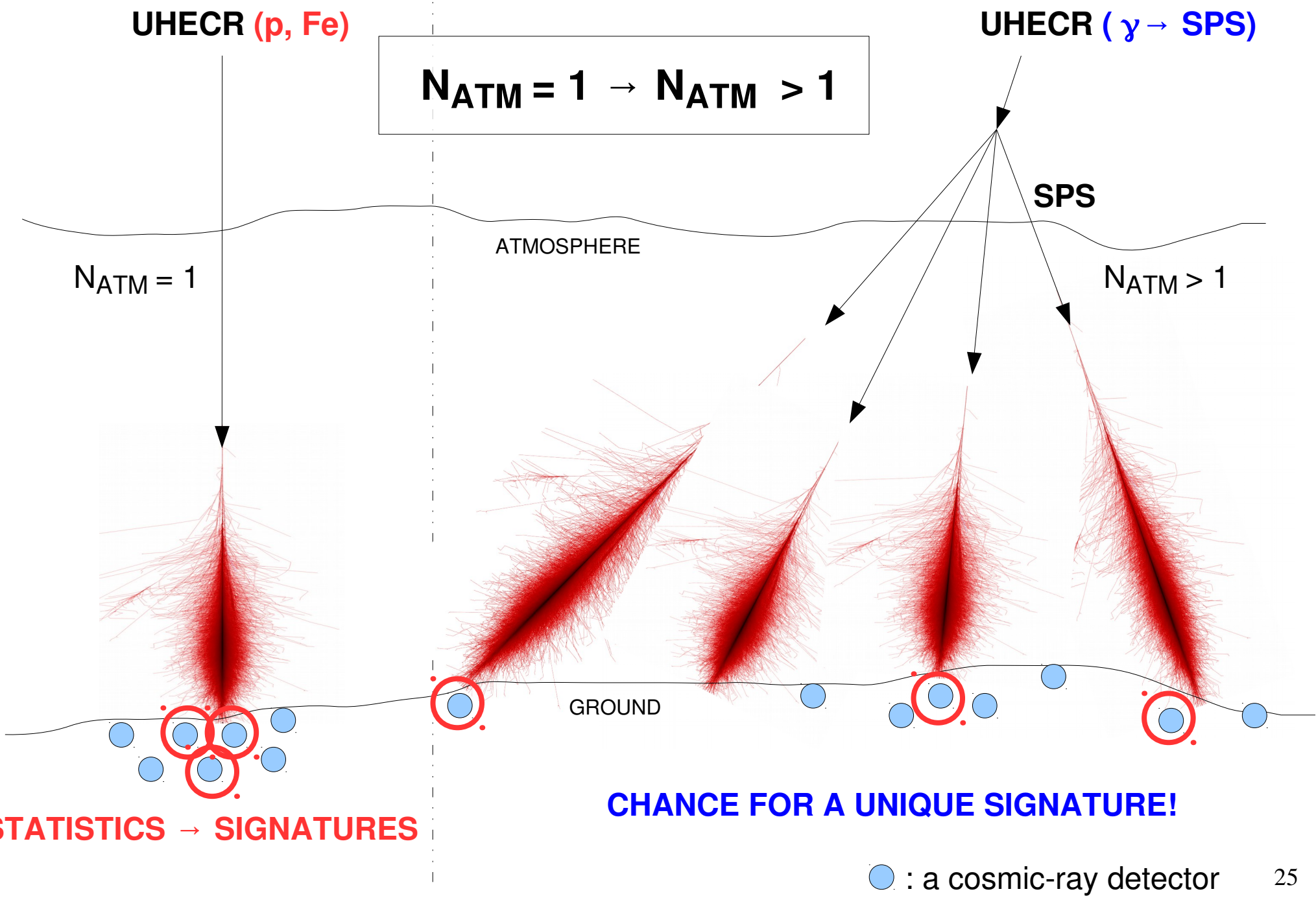


→ First calculations: W. Bednarek 1999
(low energies not treated → extent ~ tens of km)

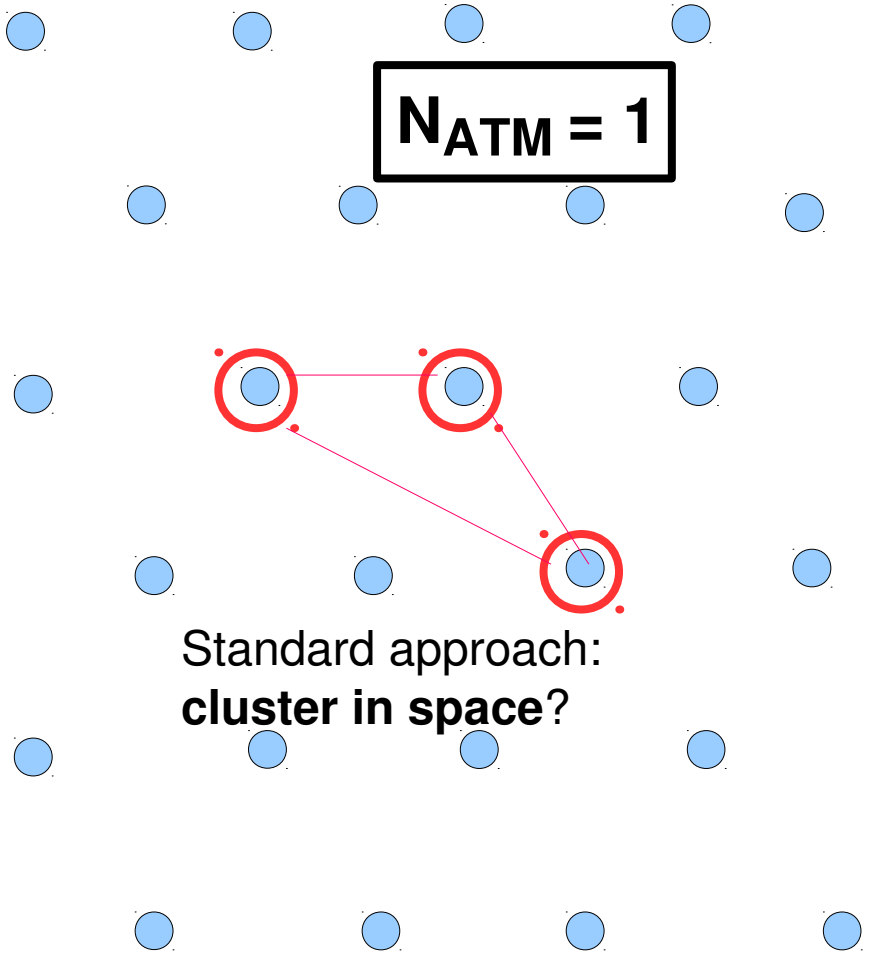


→ front 10000 km wide?
→ (over)compensates smaller solid angle?
→ particle density on ground?
→ **n isolated, time-ordered triggers?**

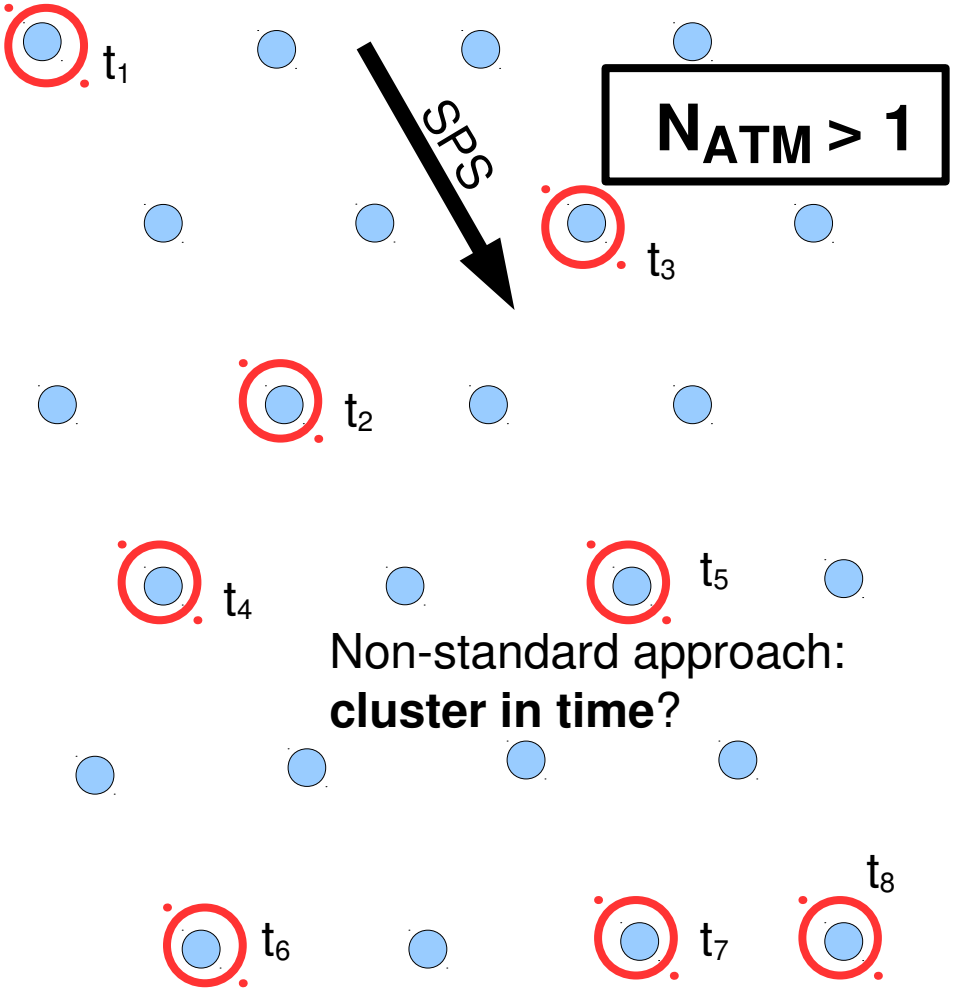
Generalization of UHECR research



A chance for a unique super-preshower signature



Standard approach:
cluster in space?

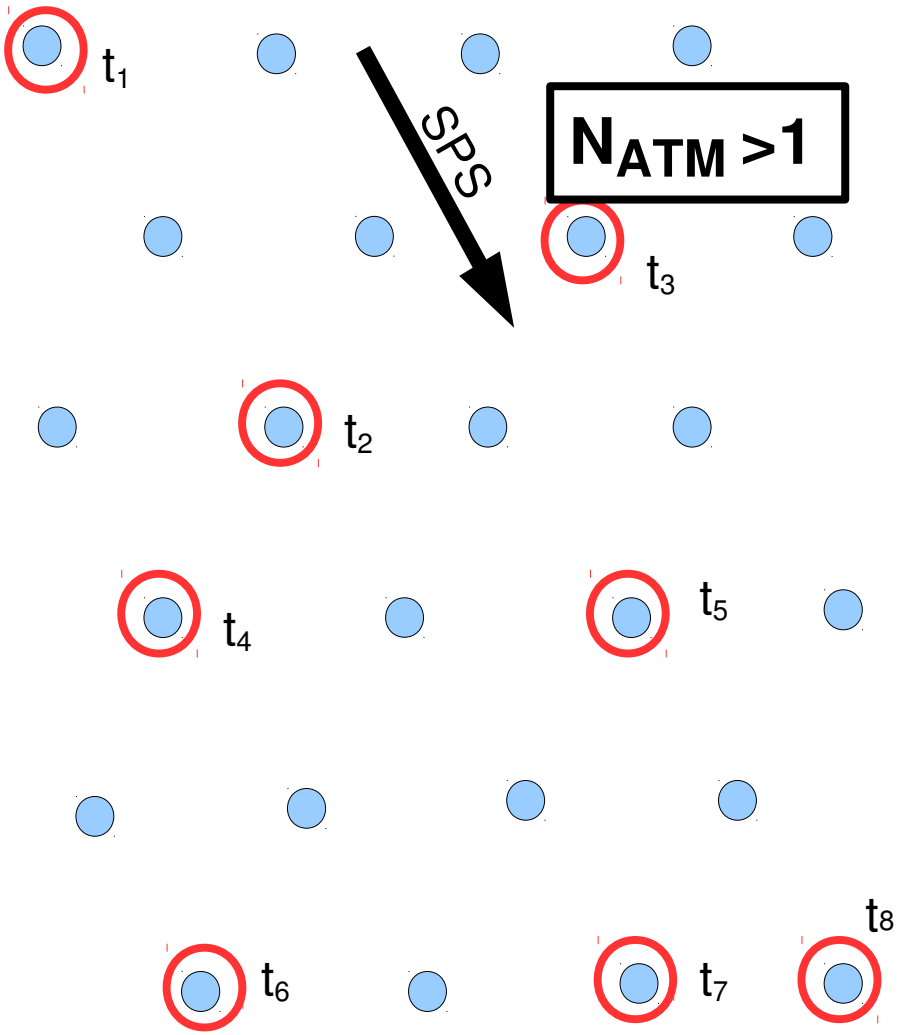


Non-standard approach:
cluster in time?

1) $t_n - t_1 <$ ~1 μs
2) $t_1 < \ldots < t_n$,

: a cosmic-ray detector

A chance for a unique super-preshower signature



1) $t_n - t_1 < \sim 1\mu s$
2) $t_1 < \ldots < t_n$,

Chance for a statistical coincidence for n=30, assuming Auger trigger rate 100 Hz:

$P_{acc} = \sim 10/30! * 0.16^{30} =$ ridiculously small chance

sensitivity to $n_{LOW} < n < 30$

$n_{LOW} = ?$

NEW TRIGGER: easy implementation, no hardware manipulation, no risk, ...

→ **why not?**

→ **unique signature**

(of New Physics?)

CREDO: mission organized for super-preshowers

Cosmic-Ray Extremely Distributed Observatory

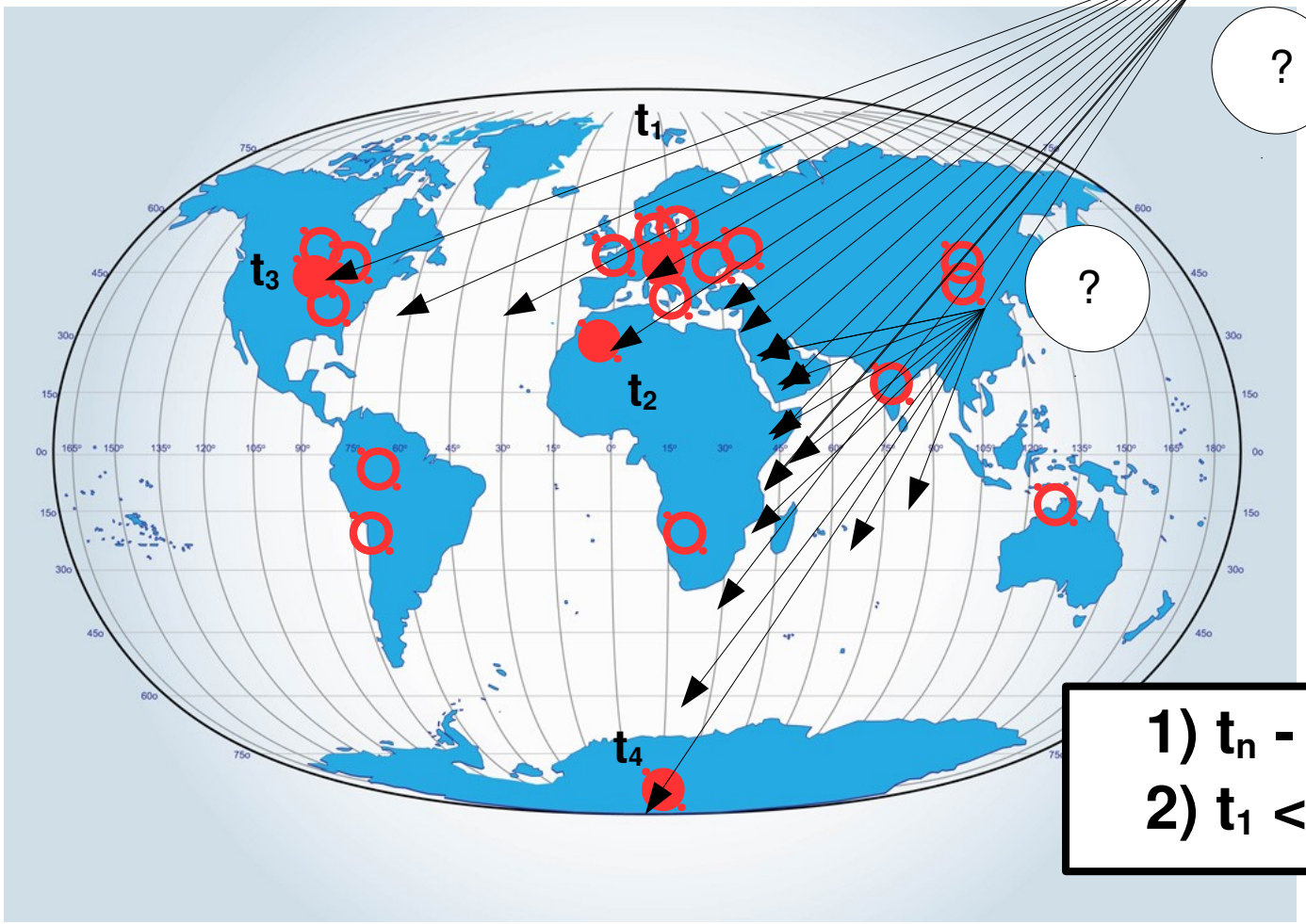
Status March 2016: „an idea”

Central database/interface: access to everything for everybody

CREDO

THE QUEST FOR UNEXPECTED

Citizens strenghten trigger capabilities of the educational arrays with **smartphone networks**



Citizens browse the data looking for „improbable" **time-space coincidences**

1) $t_n - t_1 < \sim 1\ \mu s$
2) $t_1 < \ldots < t_n$,

→ **indirect search for New Physics manifestations!**

→ **verification of „classic" QED predictions (preshower @ Sun)**

CREDO Inauguration Meeting, 30.08.2016, INP PAS

CREDO
THE QUEST FOR UNEXPECTED

Cosmic-Ray Extremely Distributed Observatory: Inauguration Meeting

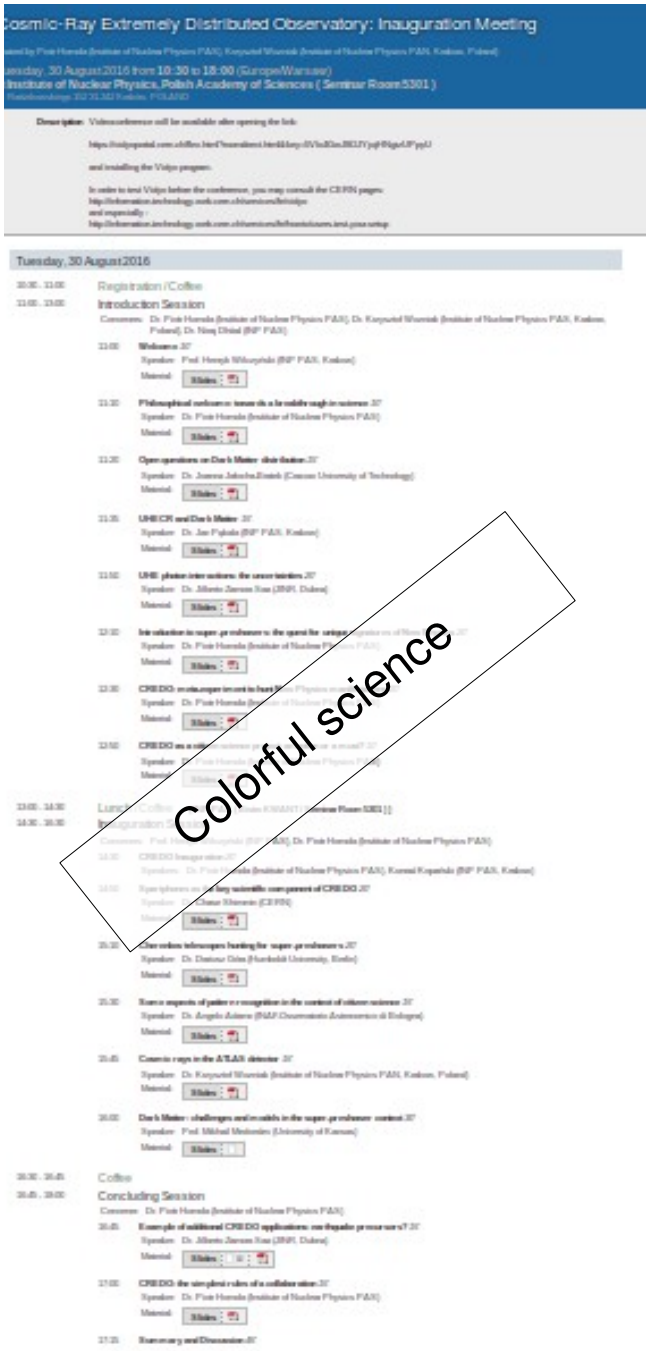
30 August 2016
Institute of Nuclear Physics, Polish Academy of Sciences

[47 registrants]

Diversified community (AGH: 6.3%)

Colorful science

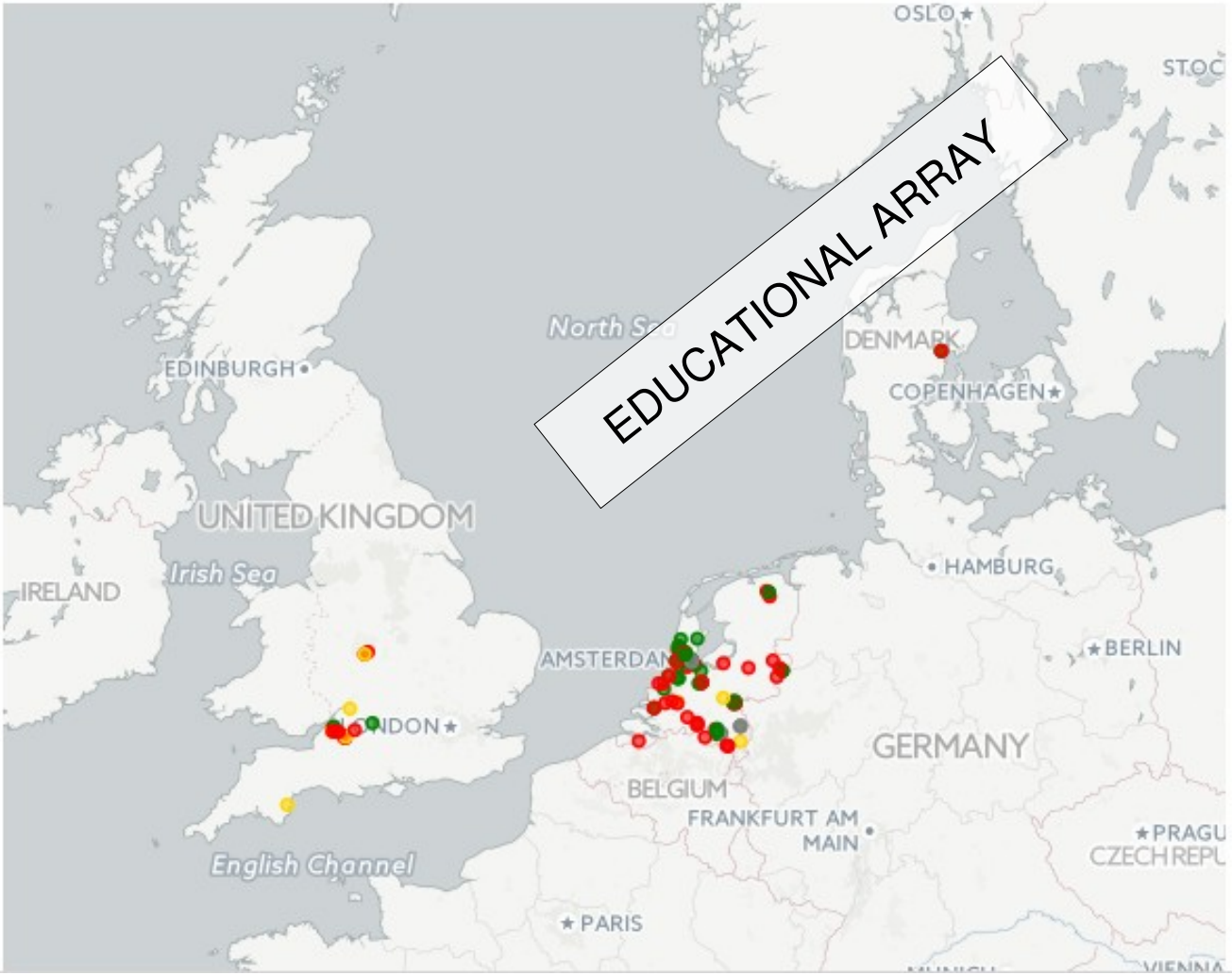
Outreach potential



Examples of CREDO players: HiSPARC

HiSPARC

Map of HiSPARC stations



Stations

List by Location Name Number

Map **Overview**

Data Coincidences

Data availability

Station ← Link to data

Station No data received

Current status

- Up (51)
- Problem (13)
- Down (62)
- Unknown
- ← Link to status

Region map

Cluster ← Link to map

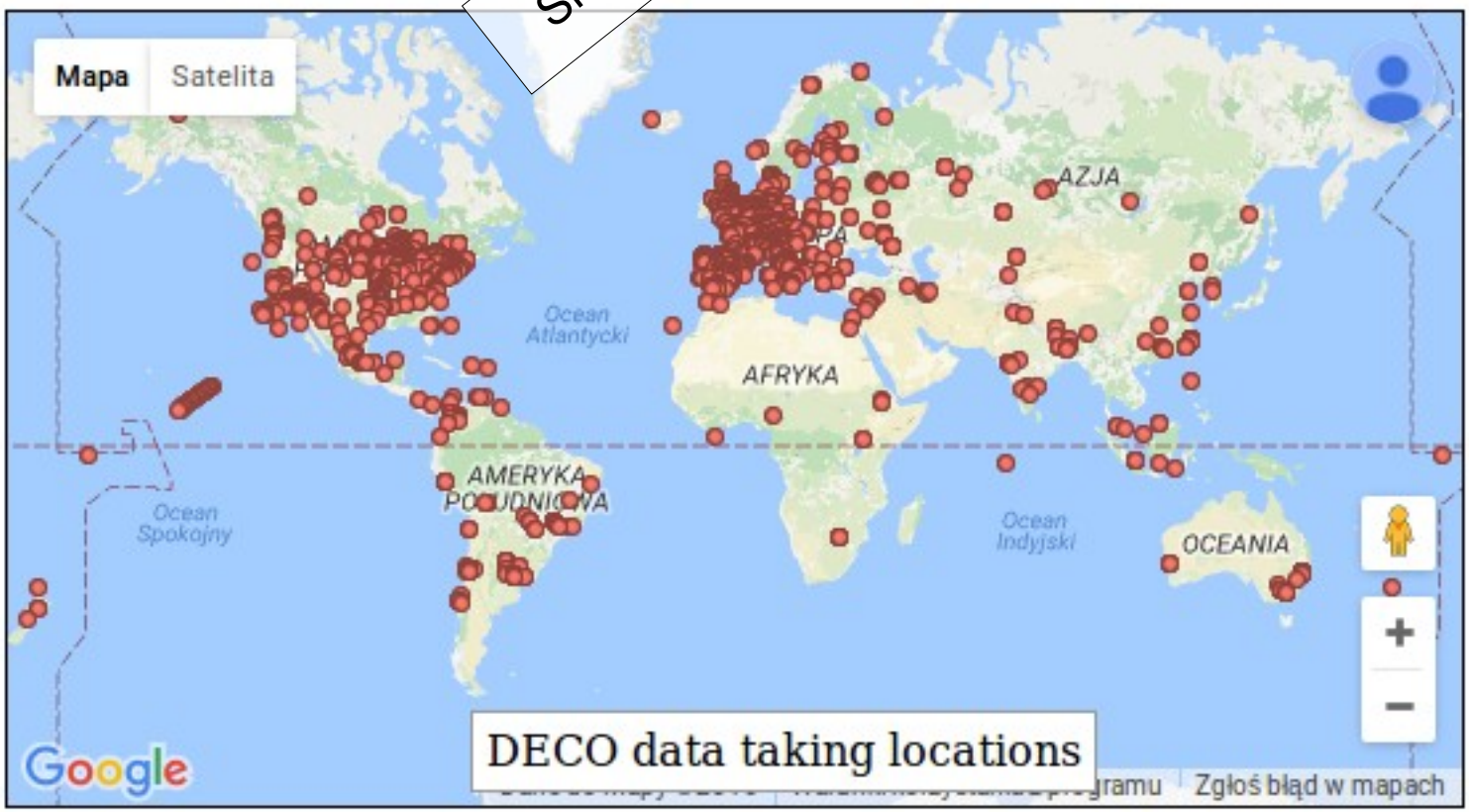
Examples of CREDO players: DECO

DECO
Distributed Electronic Cosmic-ray Observatory

HOME PROJECT APP DATA EDUCATION RESEARCH FAQ CONTACT

SMARTPHONES + APP!

DATA



DECO data taking locations

Examples of CREDO players: CRAYFIS

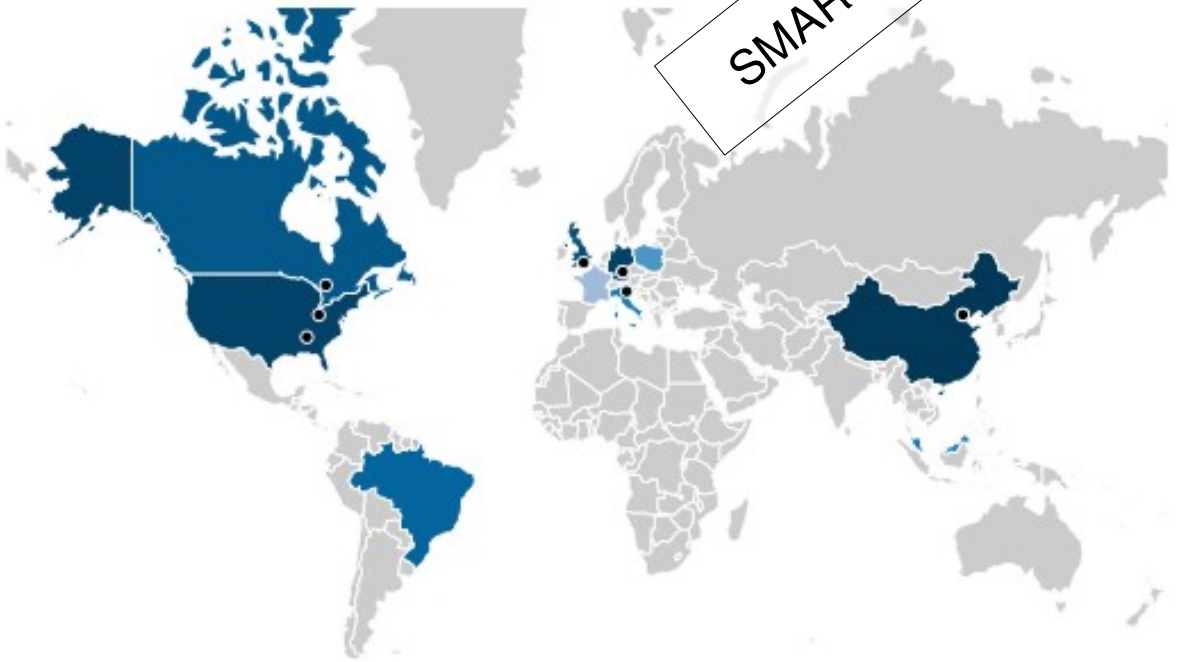
CRAYFIS About Contact Map Blog Paper Login

CRAYFIS
cosmic rays found in smartphones

Total Exposure	Unique Devices	Candidate Hits
10 years, 155 days, 8 hours	413	48,495,266

SMARTPHONES + APP!

Network Map



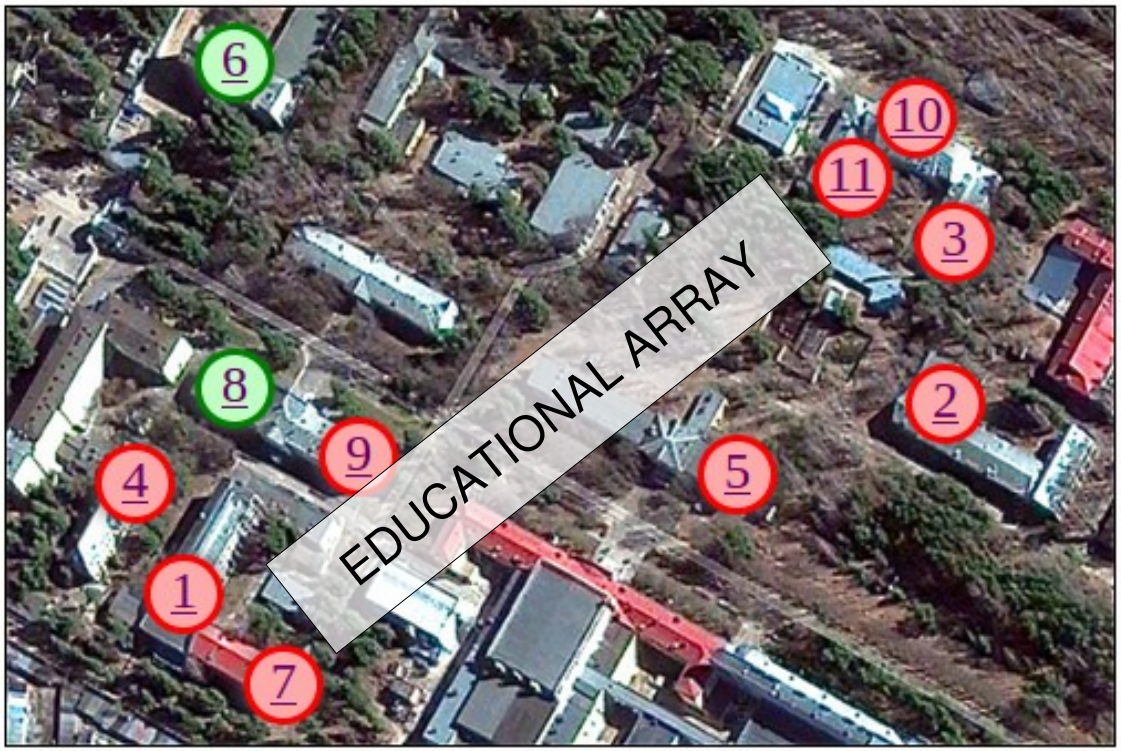
National Ranking

Rank	Country	Score
1	China	2,042,569
2	Germany	1,153,009
3	United States	1,141,242
4	United Kingdom	603,228
5	Canada	351,886
6	Brazil	129,957
7	Italy	28,007
8	Malaysia	27,862
9	Poland	5,265
10	France	279

by Paweł Jagoda, AGH, since 30 Aug 2016 →

Examples of CREDO players: JINR

Shower of knowledge News Project Setup Manual About site Contacts



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

Photo and installation
by Konrad A. Kopański (INP PAS)

Large Experiments and CREDO

On the formal way to contribute:

- Pierre Auger Observatory (cosmic rays)
- Baikal-GVD (neutrinos)
- MAGIC (gamma rays)

About initiating a formal way:

- ATLAS

EVERY cosmic ray detector can contribute to CREDO
CREDO can provide alerts to EVERYBODY

PH:

Even more ways for indirect DM search:

ultra-high energy photons

+

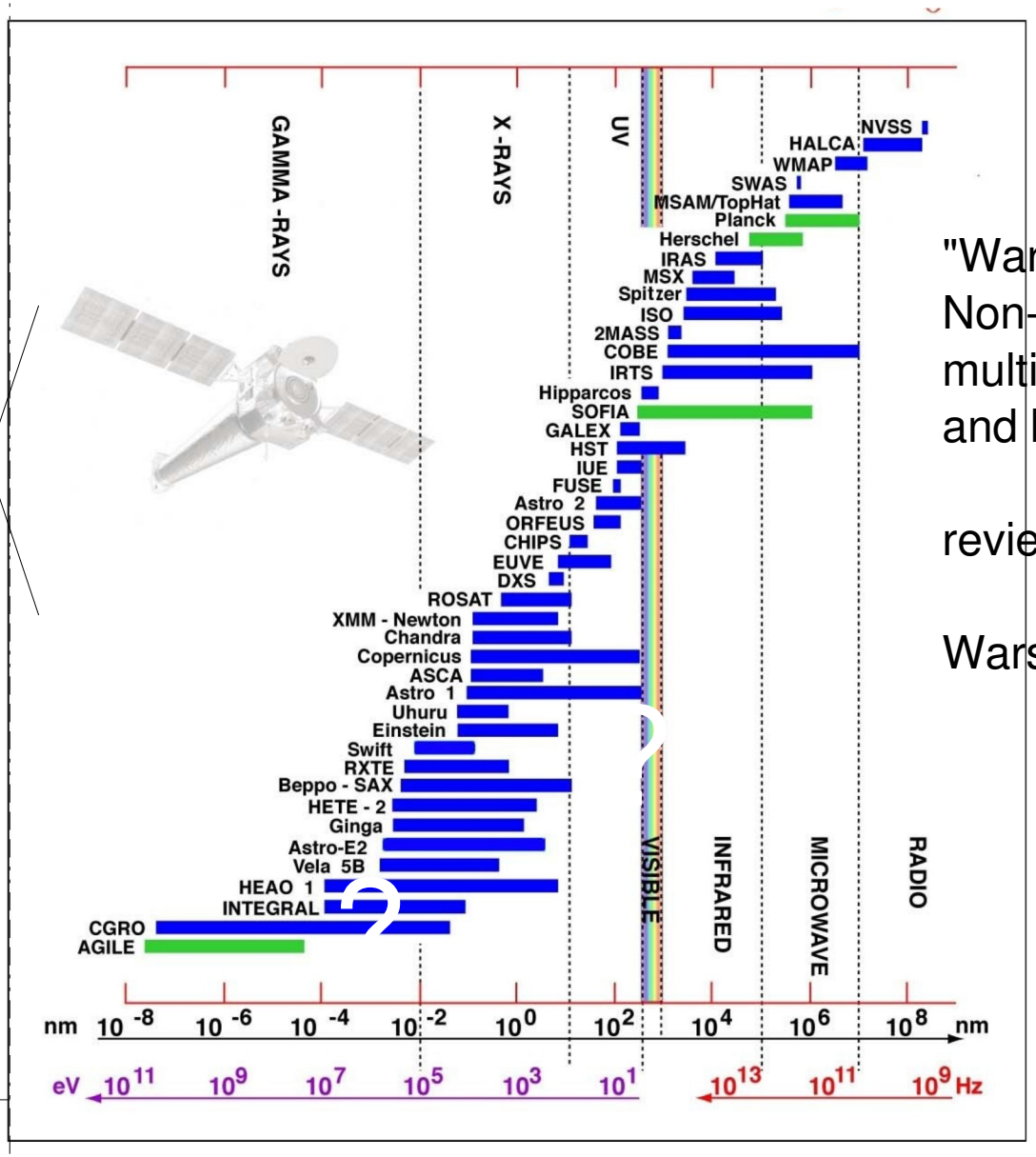
SUPER PRESHOWERS?

- Pierre Auger Observatory
- Telescope Array
- CREDO

...

$>10^{19}$ ...

From gamma rays to radio



"Warsaw Workshop on Non-Standard Dark Matter: multicomponent scenarios and beyond"

review by C. Weniger

Warsaw, 2-5.06.2016

http://nssdc.gsfc.nasa.gov/astro/astrolist.html

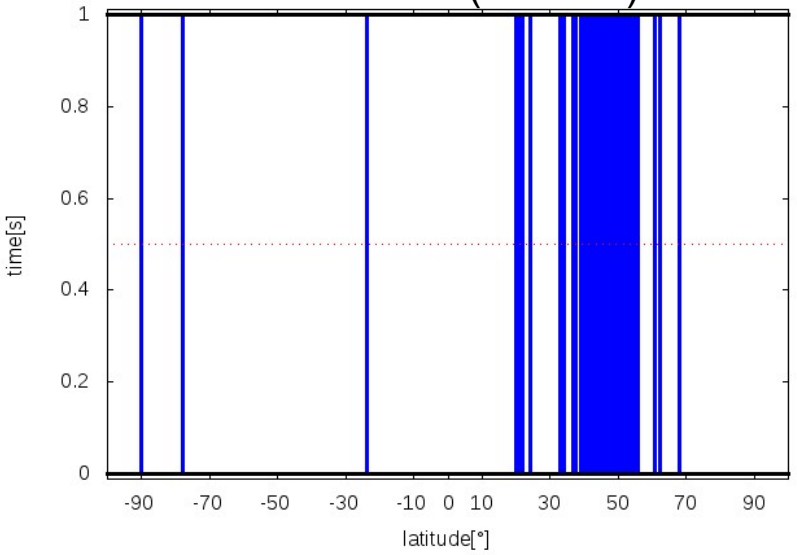
37

the simplest CREDO anaylsis: "NO SIGNAL" simulation

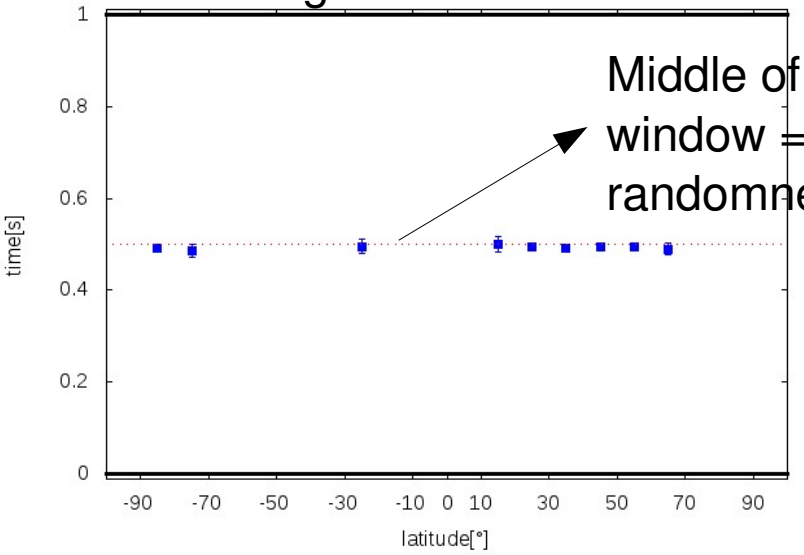
INP PAS Kraków CREDO station

Credit:
P. Jagoda (AGH)
M. Sułek (PK)
S. Stuglik (PK)

all events (scatter)

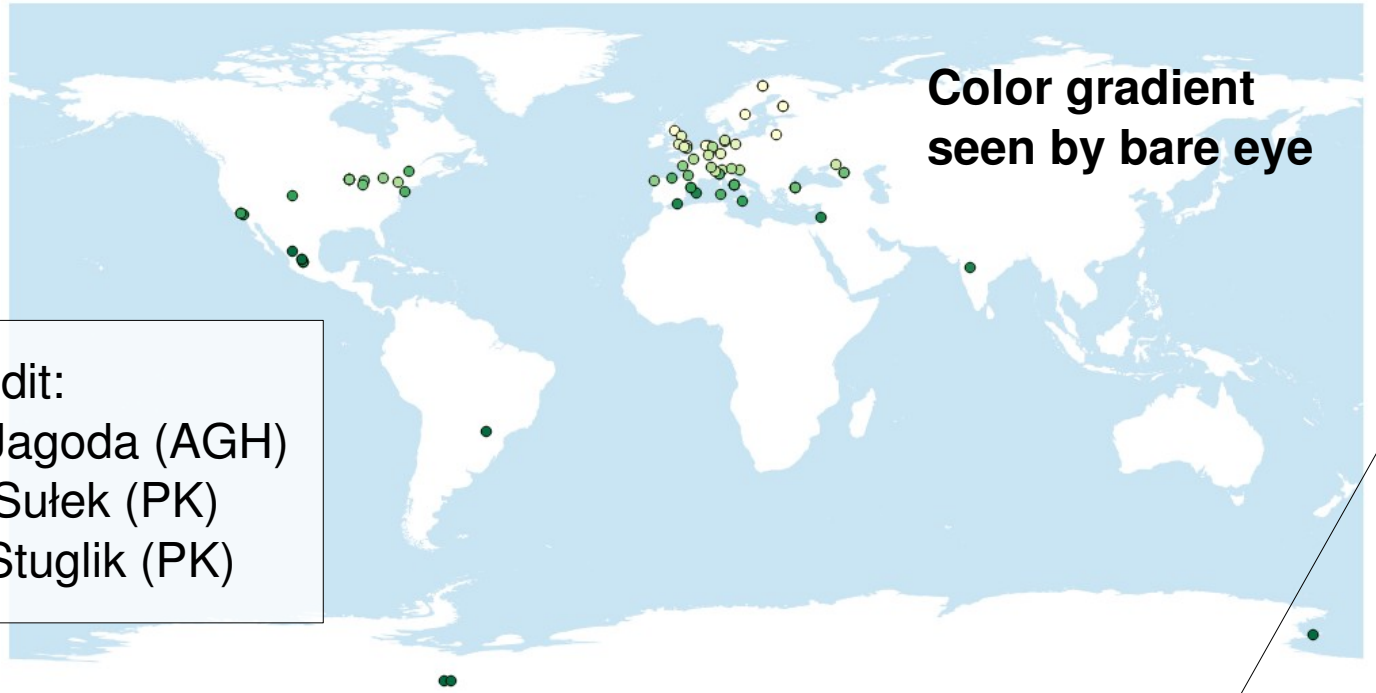


average in latitude bins



Middle of time window = randomness line

the simplest CREDO anaylsis: "SIGNAL" simulation



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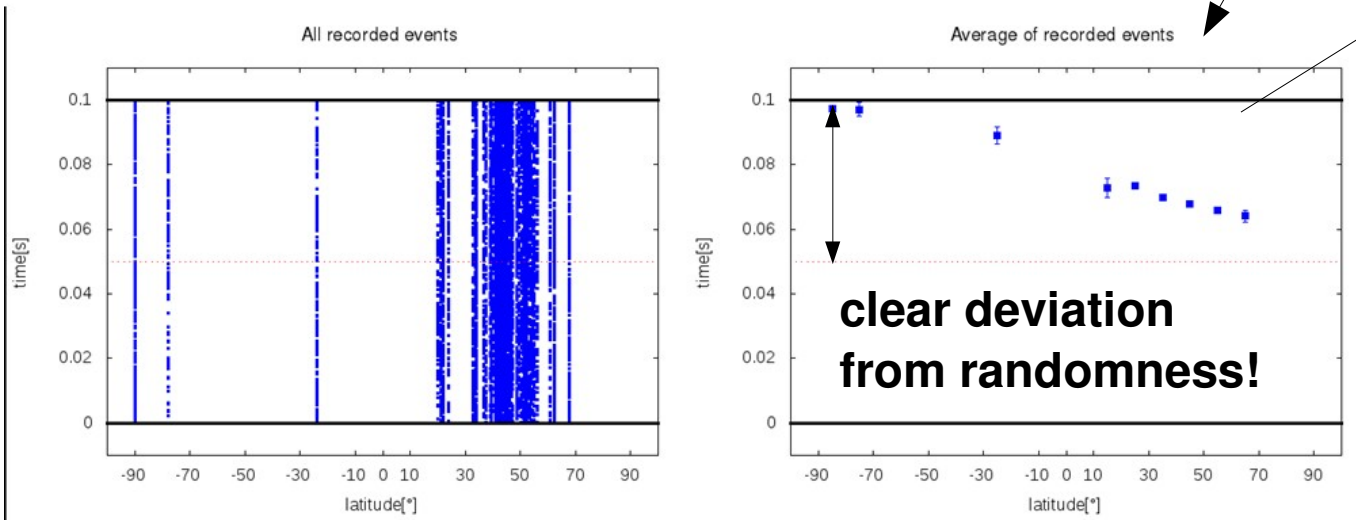
alerting potential

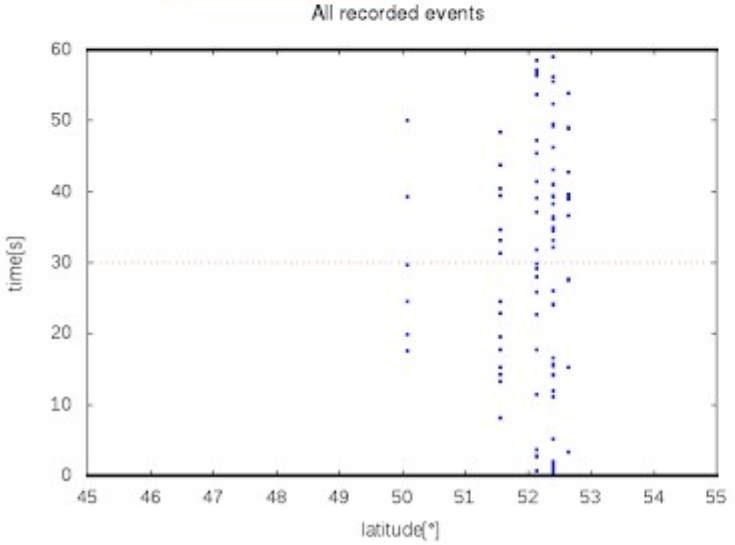


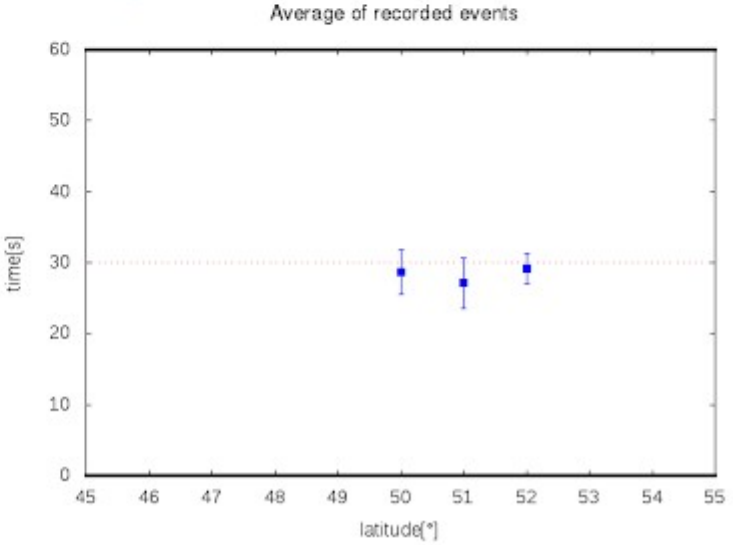
Good candidate for **unique super-preshower signature**

Middle of time window = randomness line

CREDO: the first real data classification

Credit:
P. Jagoda (AGH)
M. Sułek (PK)
S. Stuglik (PK)



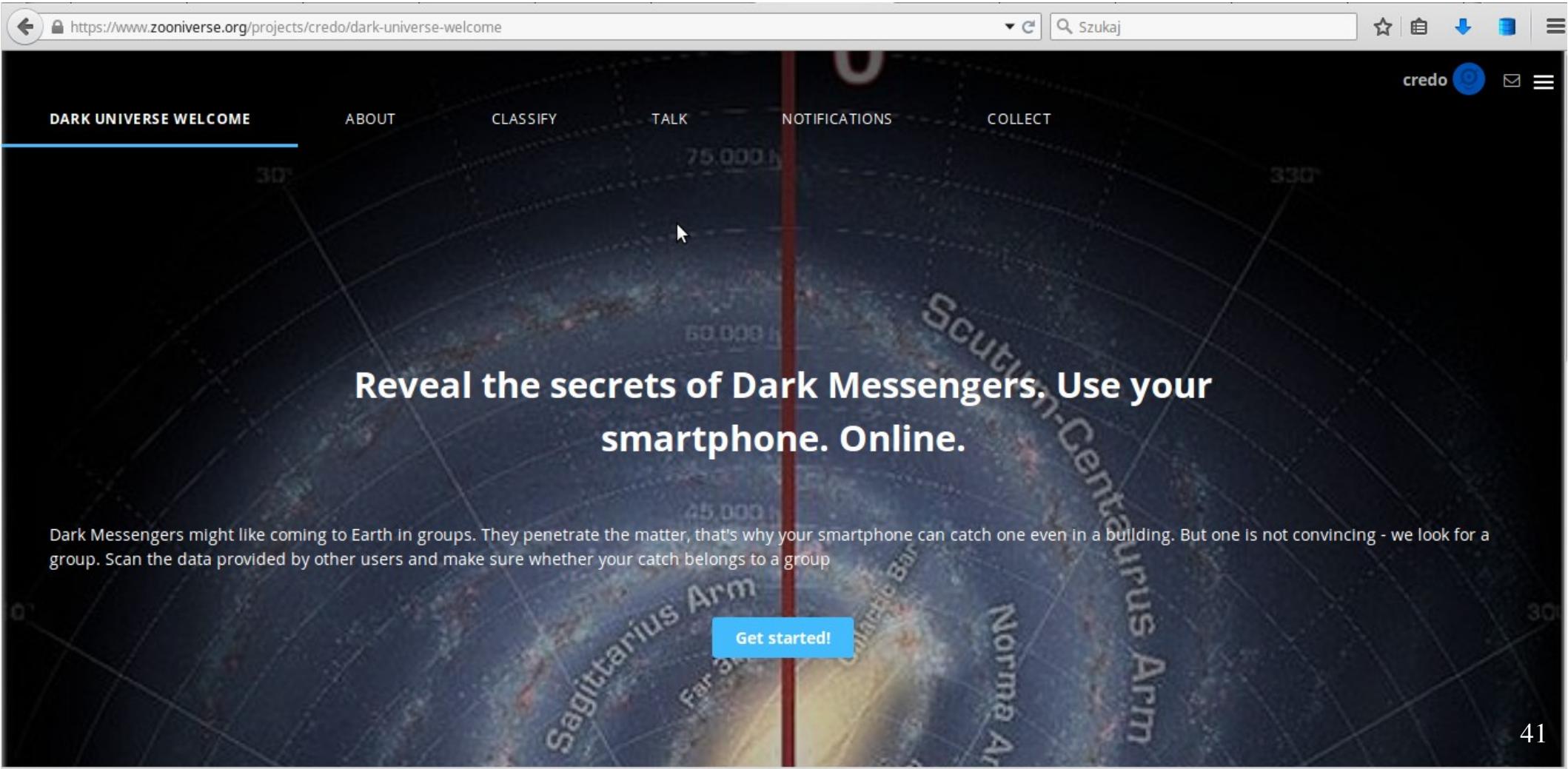


→ **random...**

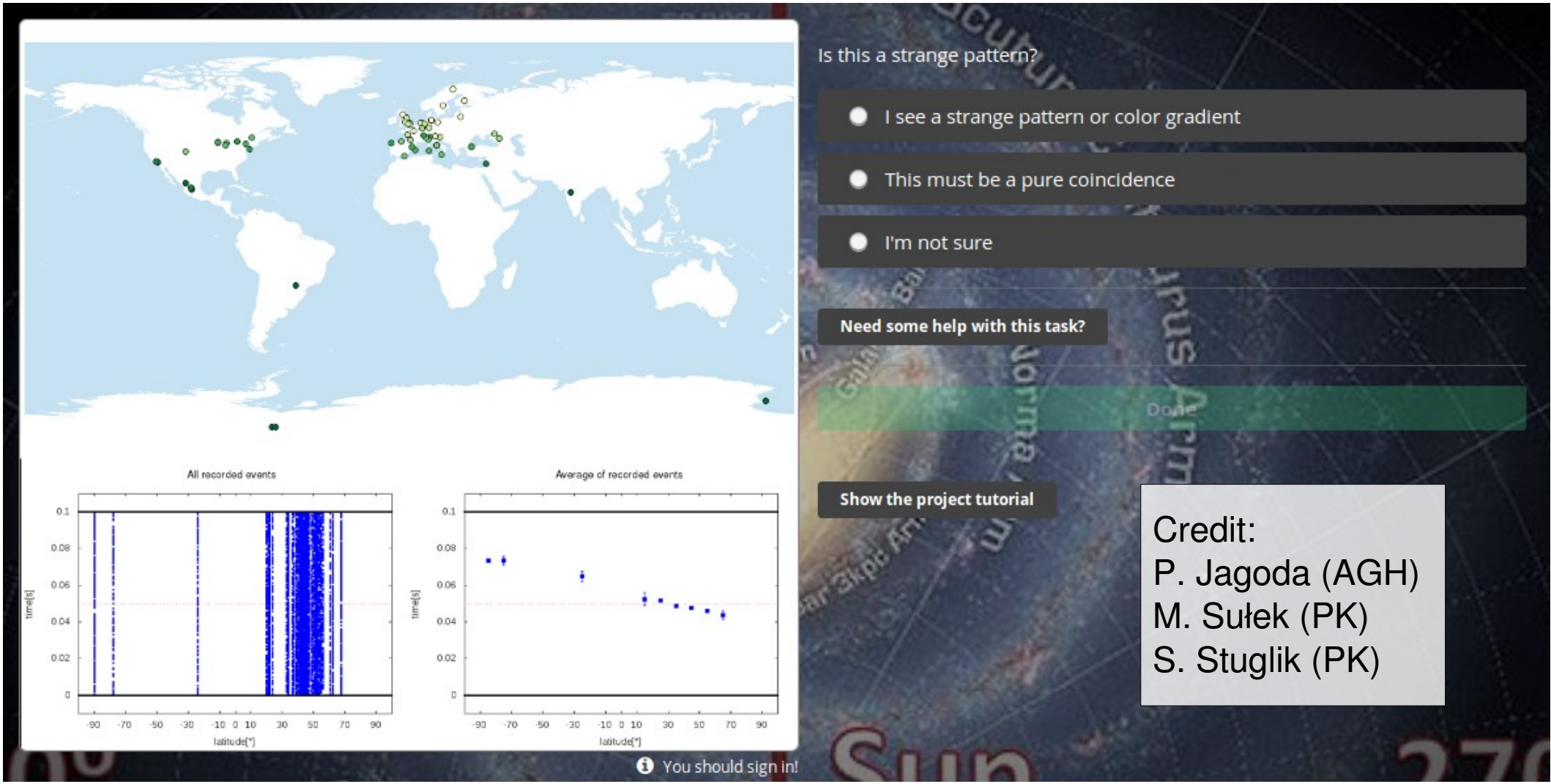
The citizen science potential of

CREDO

THE QUEST FOR UNEXPECTED



CREDO citizen science: Dark Universe Welcome



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

CREDO *by definition*: **the larger the better**

CREDO to be successful **needs as many people as possible**:
→ **for devices**
→ **for crowdsourcing**

Citizen science for CREDO: not an option, **a must!**

Positive side effects of citizen science

Summer practice 2016 in NZ15:
4 students working on CREDO citizen science interface

After summer practice 2016 in NZ15 (**no obligation to work**):
9 ~~students~~ colleagues continue or ready to join CREDO

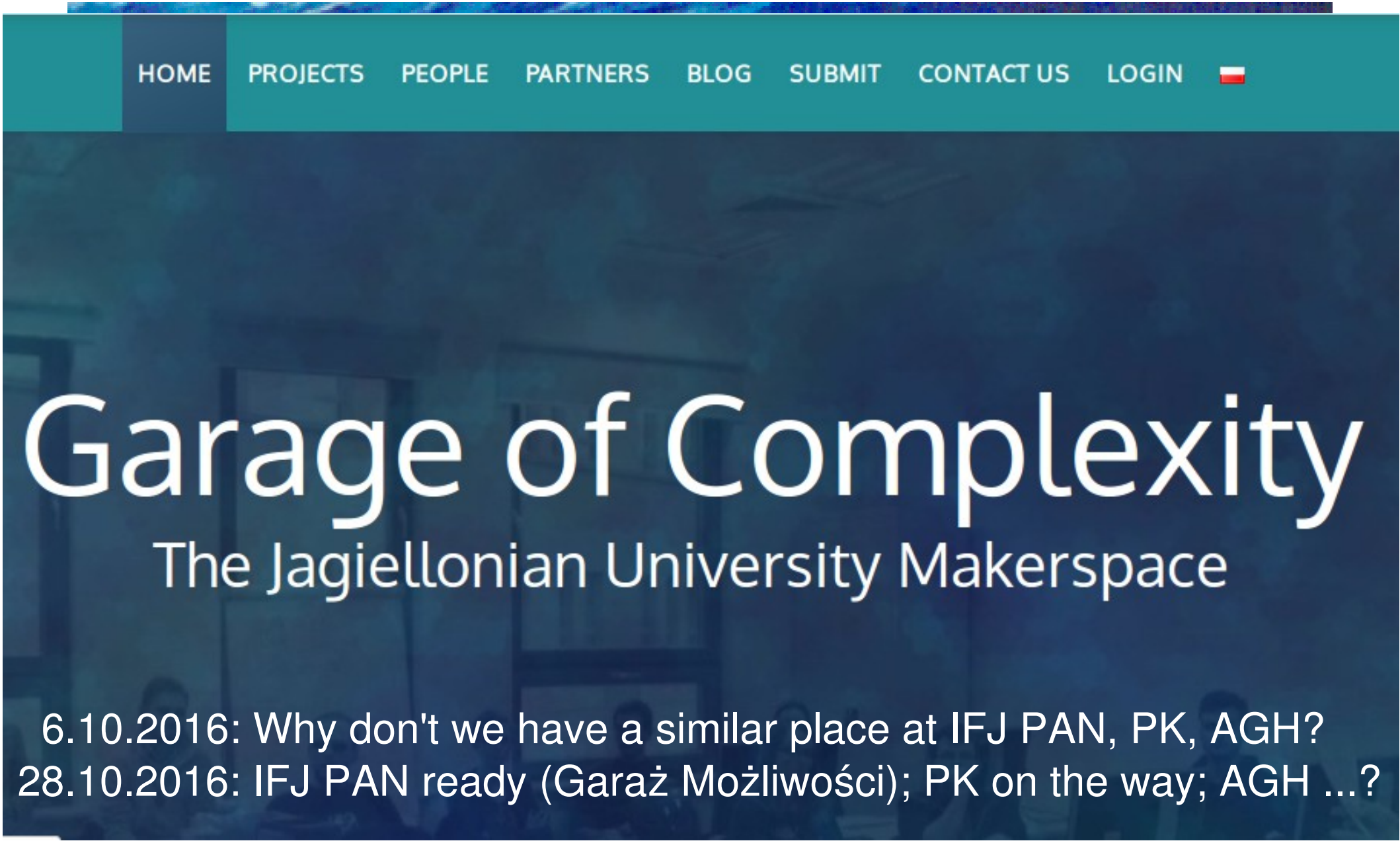
4 → 9 = 225% effect :)

Why?

Student = scientific partner?
Visible importance of work (TV)?
Ambitious scientific perspective given?

How to cultivate such an enthusiasm for science?

More sites like this + a system



System prototype: Cracow Incubator of Scientific Discoveries (KION)

An ocean of opportunities:

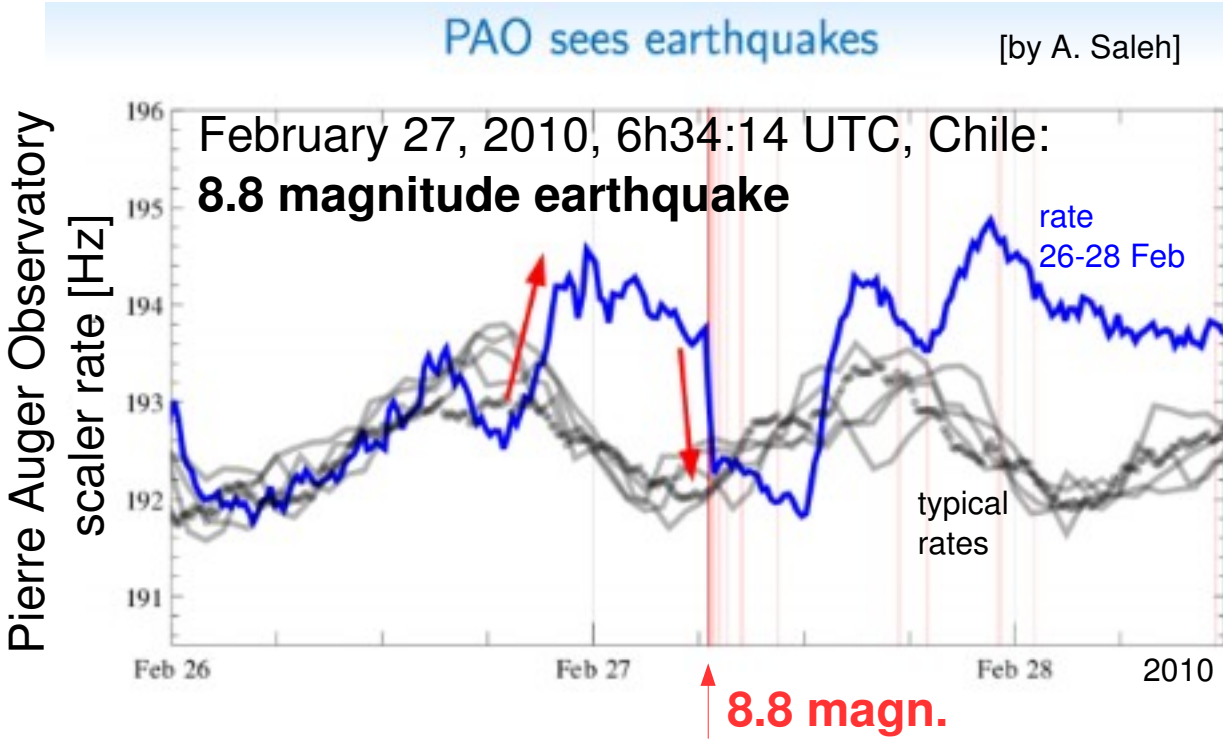
→ **fundamental science through astroparticle physics**
→ **geophysics through cosmic-rays**
→ space weather / solar activity
→ diversified engineering (wide range of cosmic-ray energies)
→ connections to industry
→ advanced/novel computing solutions required (cloud)
→ all level education/training
→ **citizen science** (people help science – science help people)
→ **outreach** (popularization)

→ **synergy generator**
at INP PAS: colleagues from 5 departments / 2 divisions involved;
joint efforts with Politechnika Krakowska WFiIS and IF UJ, AGH (yet unofficial);
everybody welcome!

CREDO

THE QUEST FOR UNEXPECTED

Scientific diversity example:



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

Tectonic plates move

↓

Inverse magnetostrictive effect

↓

Local geomagnetic field vector changes

↓

Variation of the CR rate

↓

Earthquake precursors?

→ **CREDO-earthquakes task** [already existing]

Summary

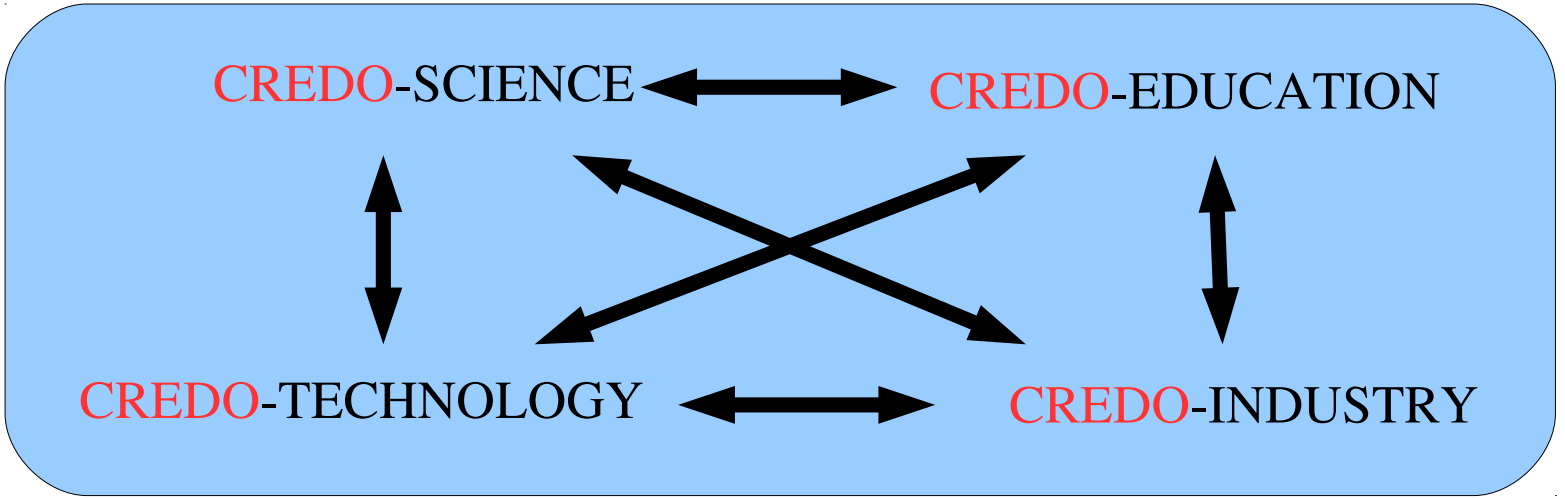
Cosmic-Ray Extremely Distributed Observatory:
a tool to explore **uncharted realm of science**?

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

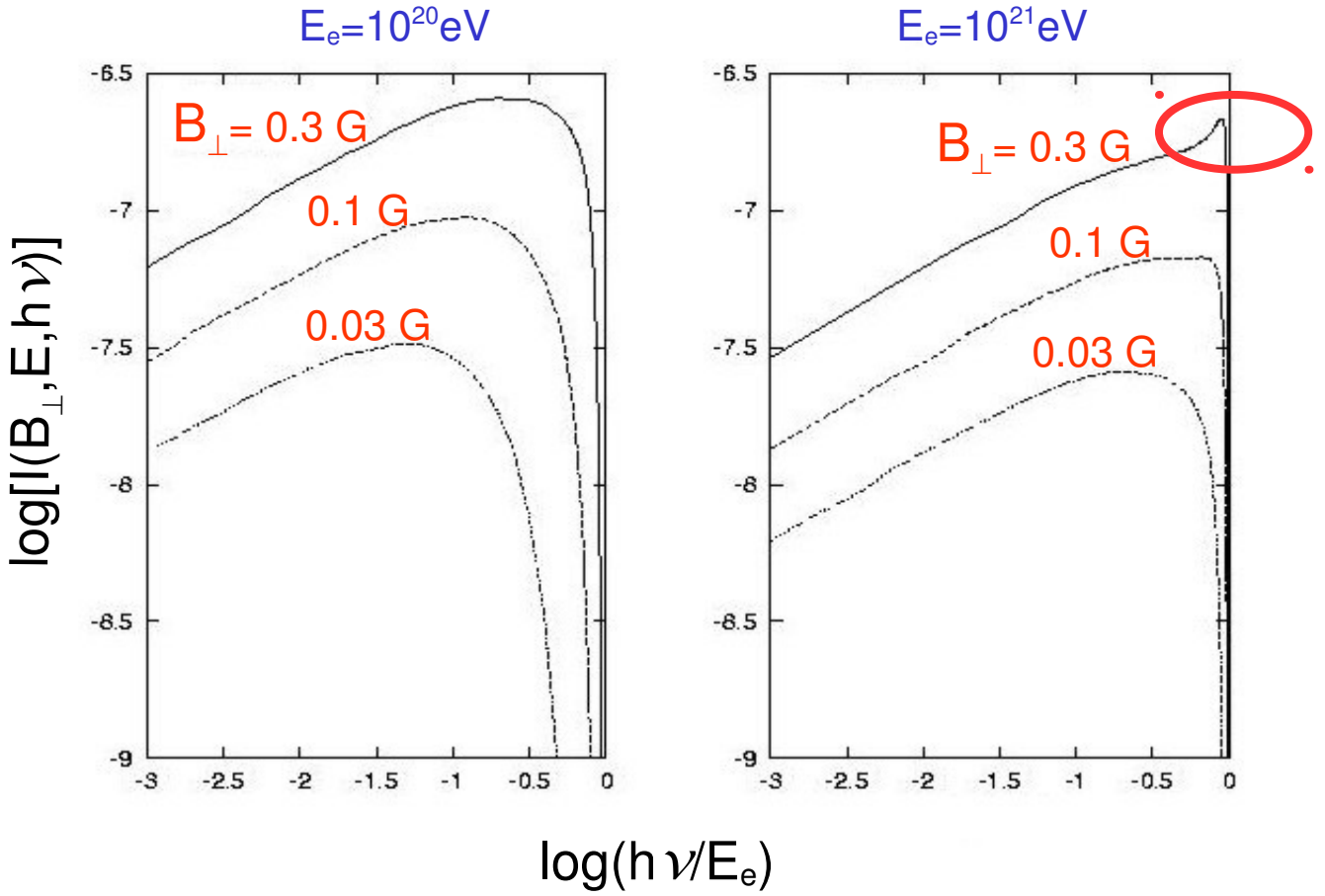
Mikhail V. Medvedev, (2cDM author, now involved in CREDO tasks: organization, theory, publications)

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

CREDO guarantee of success:
ocean of opportunities / synergy generator under one roof (project)



Magnetic bremsstrahlung of ultrarelativistic electrons



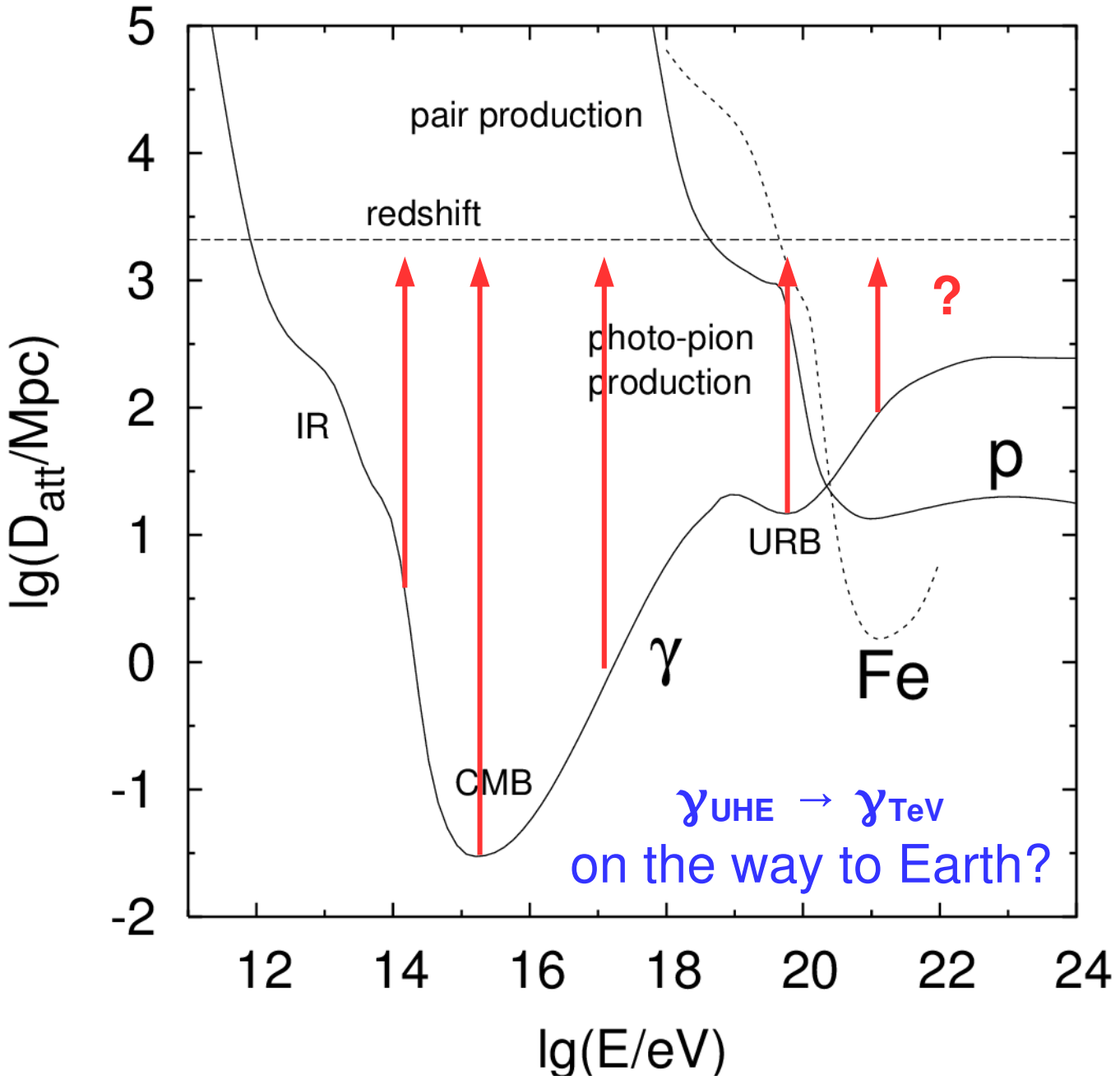
Catastrophic emission:

$E_{h\nu} \sim E_e$

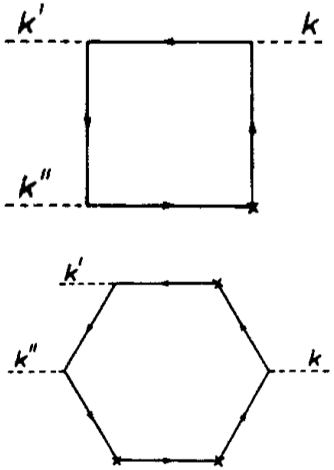
→ **probability of catastrophic emission increases with E**

→ **similarly for monopoles?** [question relevant for the Auger paper on monopoles]

γ_{UHE} travelling through the Universe: exotic example



PHOTON SPLITTING???



HIGHER RATES IN **NONLINEAR ELECTRODYNAMICS?**

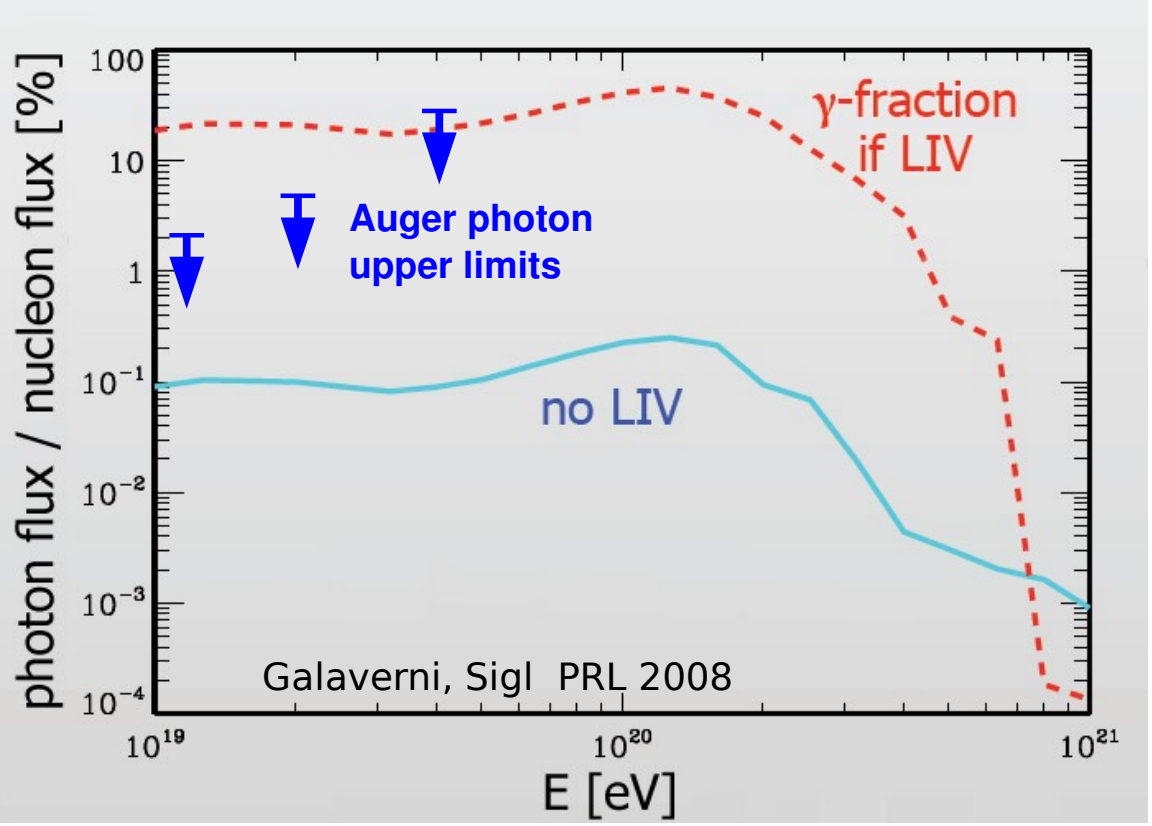
cf. Maccione & Liberati, JCAP 08 (2008) 027

Probing fundamental physics: example

Testing Lorentz Invariance Violation (LIV) → photon dispersion relation modified?

$\omega^2 = k^2 + \xi_n k^2 (k/M_{Pl})^n$ → e^+e^- production threshold modified

e.g. $\pi^0 \rightarrow \gamma\gamma$ $\quad \gamma \not\rightarrow e^+e^-$ cascading of photons supressed



If LIV:

$\xi_1, \xi_2 > 0$

Upper limits based on UHECR observations:

$\xi_1 < 2.4 \times 10^{-15}$

$\xi_2 < 2.4 \times 10^{-7}$

Naukowy Kapitał Entuzjazmu

Krajowy (Europejski) program na rzecz poprawienia konkurencyjności nauki polskiej (europejskiej) poprzez pełne wykorzystanie entuzjazmu naukowego, ambicji, dociekliwości i kreatywności ludzi młodych (przed uzyskaniem tytułu magistra)

„szkic szkicu" projektu, Kraków, 20.09.2016
autor: Piotr Homola, IFJ PAN

Mini-diagnoza przyczyn ograniczonej dynamiki wzrostu w polskiej nauce:

Młodzi, zdolni, ambitni ludzie zafascynowani nauką nie podążają scieżką kariery naukowej, tzn.
1) nie wybierają kierunków przyrodniczych;
2) nie kontynuują kariery naukowej po studiach;
3) rozoczynają / kontynuują karierę naukową zagranicą, bez planów powrotu

Niniejszy projekt dotyczy praktycznych rozwiązań w zakresie punktów 1) i 2) z perspektywami na zmiany odnośnie p. 3

I. Motto projektu (propozycja)**:**
„Ścieżka Twojej kariery naukowej zaczyna się od postawienia pierwszego pytania bez odpowiedzi"

Sports analogy: enable opportunities to develop a scientific career early

Naukowy Kapitał Entuzjazmu: pilotage in Krakow

Cracow Incubator for Scientific Discoveries
[Krakowski Inkubator Odkryć Naukowych]

Scientific Patrons (4):
IFJ PAN, UJ, POLITECHNIKA, AGH(?)

Supervisors (14): Ł. Bratek, N. Dhital, P. Homola, K. A. Kopański, K. Woźniak, B. Żabiński (all IFJ PAN), P. Warchoł, J. Mielczarek (both UJ), D. Duraj, J. Jałocha-Bratek, S. Kubis, Z. Tabor (all Politechnika), K. Niedźwiedzki (?), M. Nocuń (?) (both AGH)

PhD students (3): K. Cheminant, O. Sushchov (both IFJ PAN), M. Michałek (Politechnika)

Students (8): M. Sułek, S. Stuglik, M. Czyżowski, R. Goryl, ..., … (all Politechnika), M. Karpiel, P. Jagoda (both AGH)

Projects (4): CREDO-drones, CREDO-earthquakes, CREDO-array, CREDO-DUW

Sites (1): Complexity Garage (IF UJ)

Missing: Funding, business patrons, more sites (Garage at IFJ PAN?), more people, non-CREDO projects :)

Please join / help!