Beyond the DM paradigm: an experimental example from the ultra-high energy cosmic-ray physics

Piotr Homola

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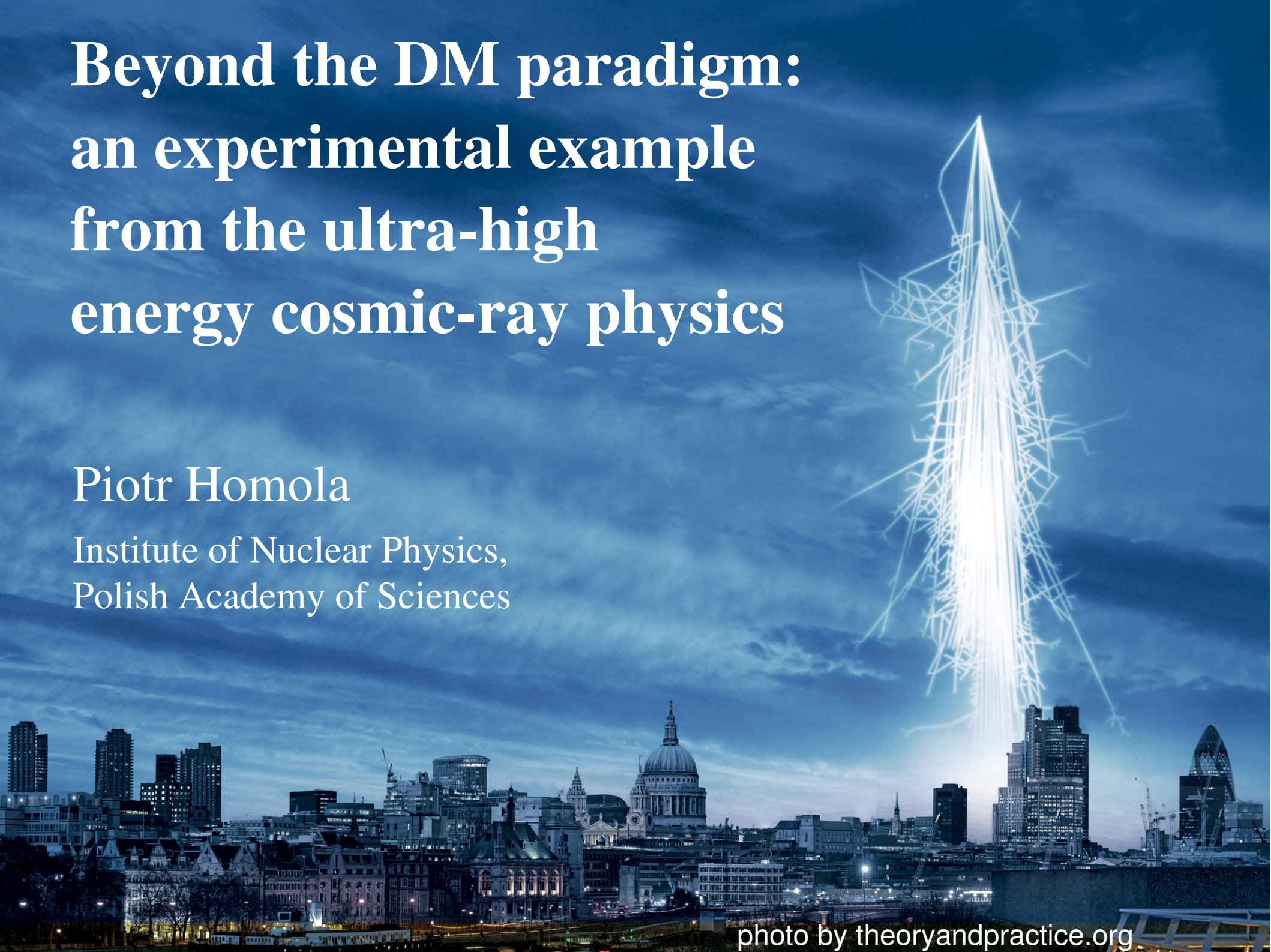
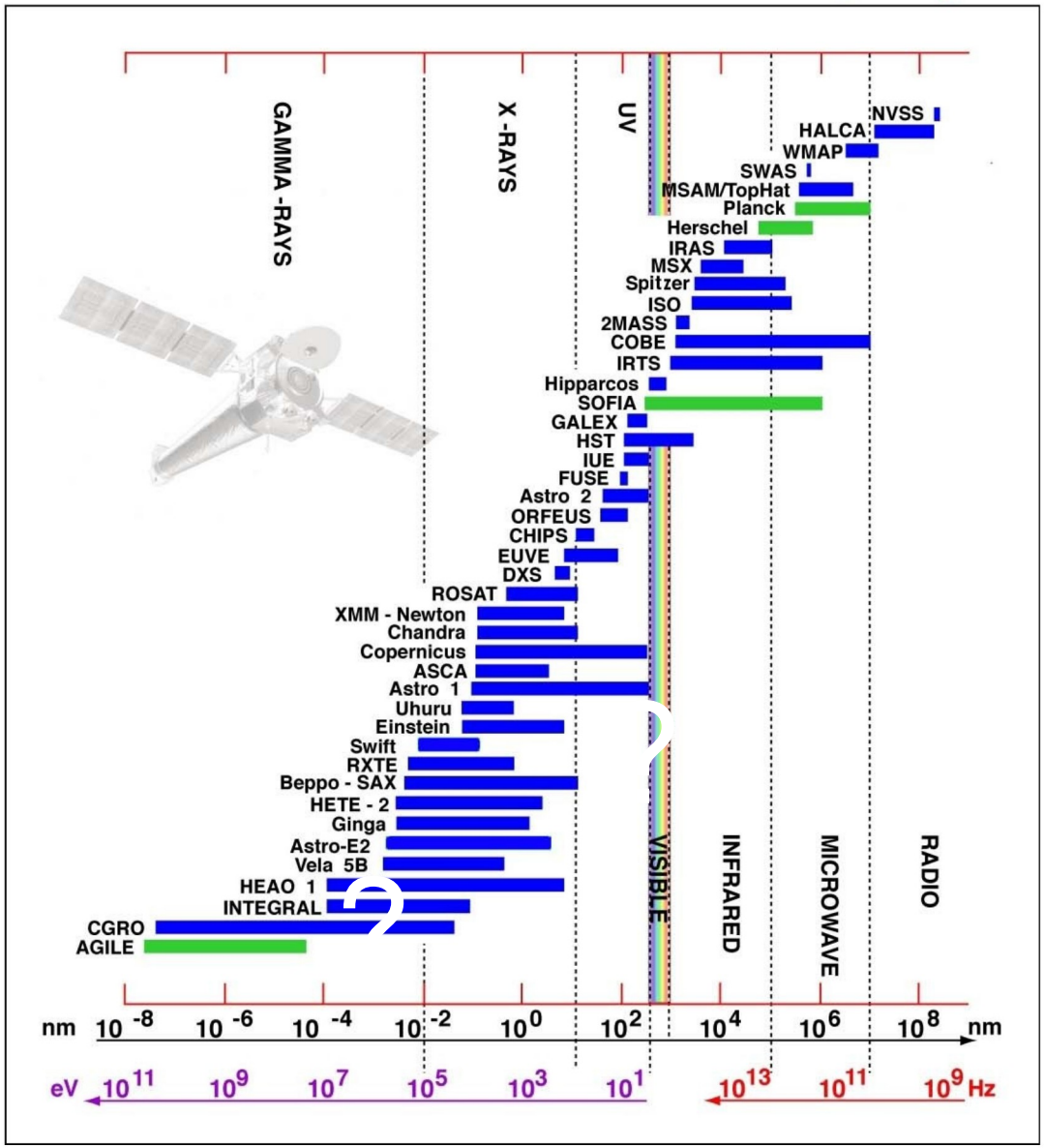


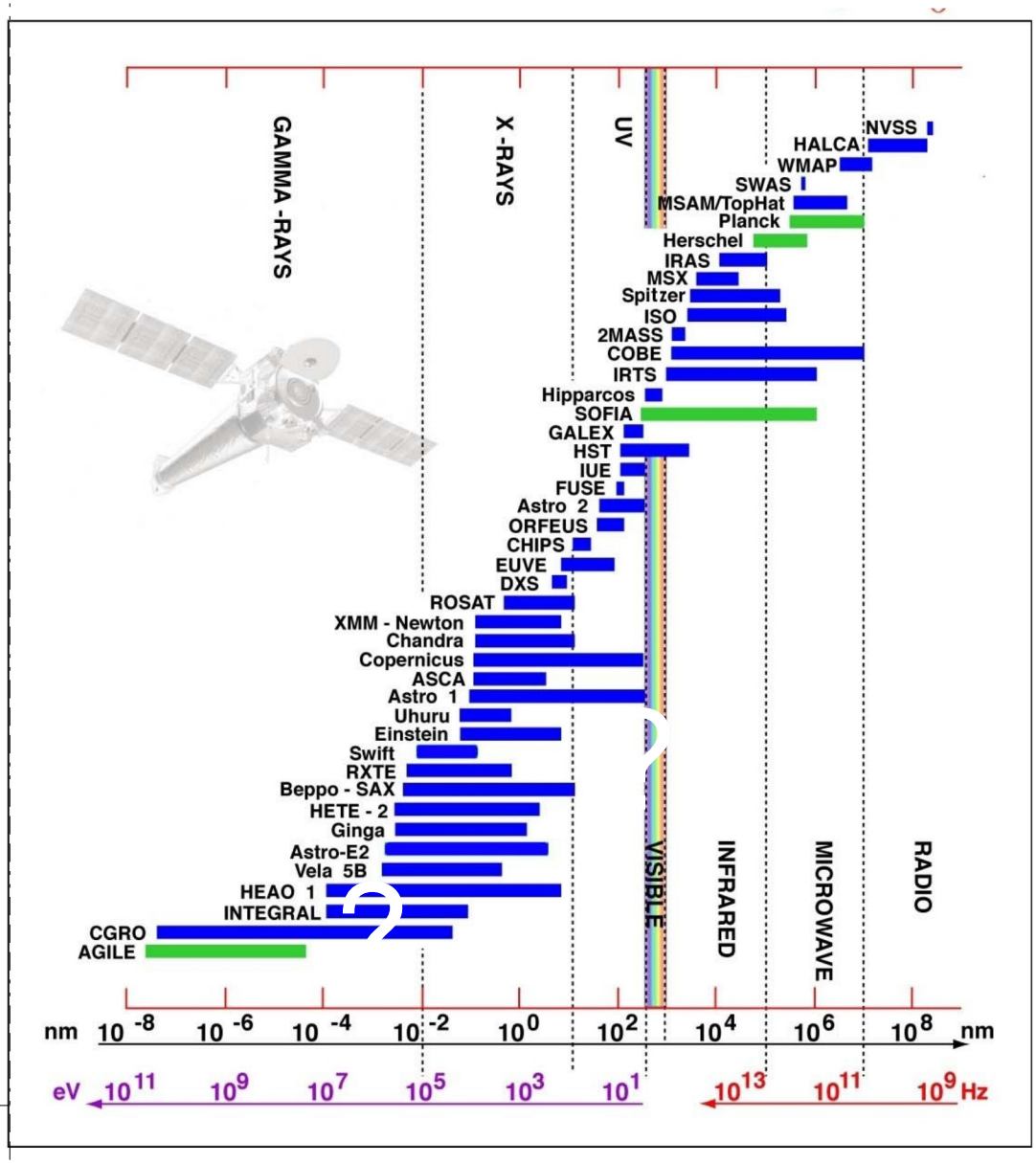
From gamma rays to radio



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

2

From gamma rays to radio



observation border

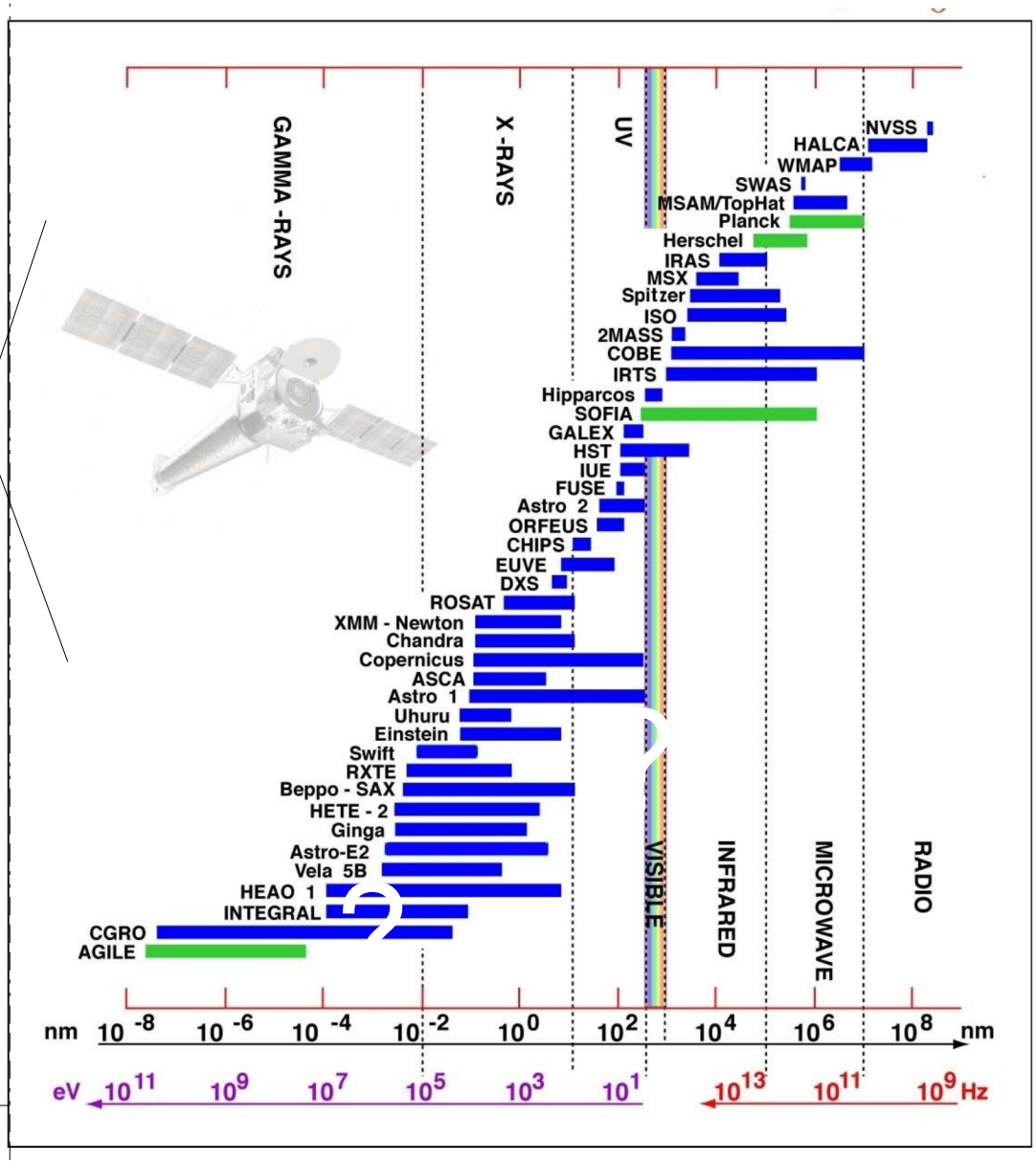
no ultra-high energy photons :(

$>10^{19}$ ...

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

3

From gamma rays to radio



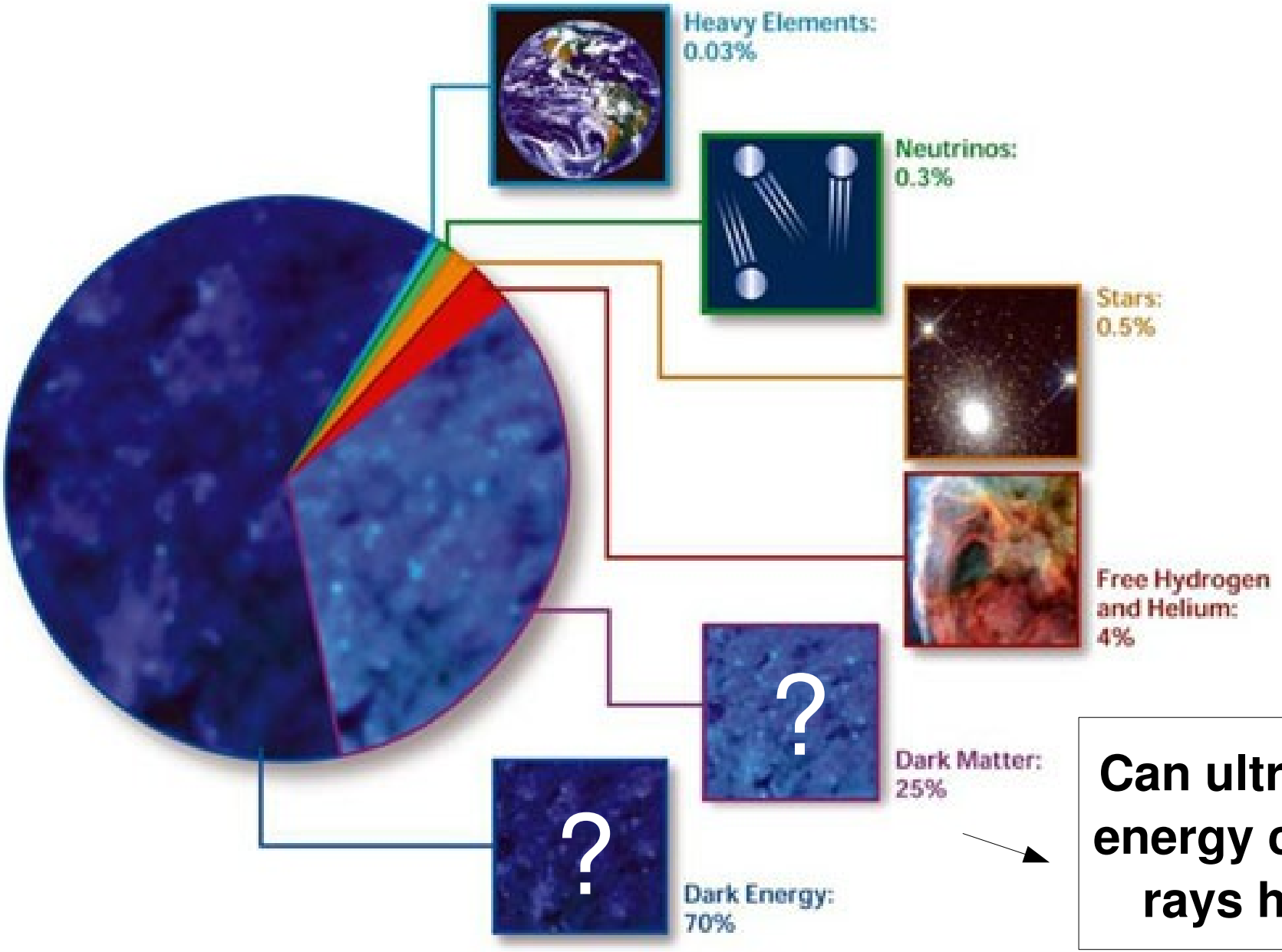
observation border

ultra-high energy photons?

>10^{19} ...

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

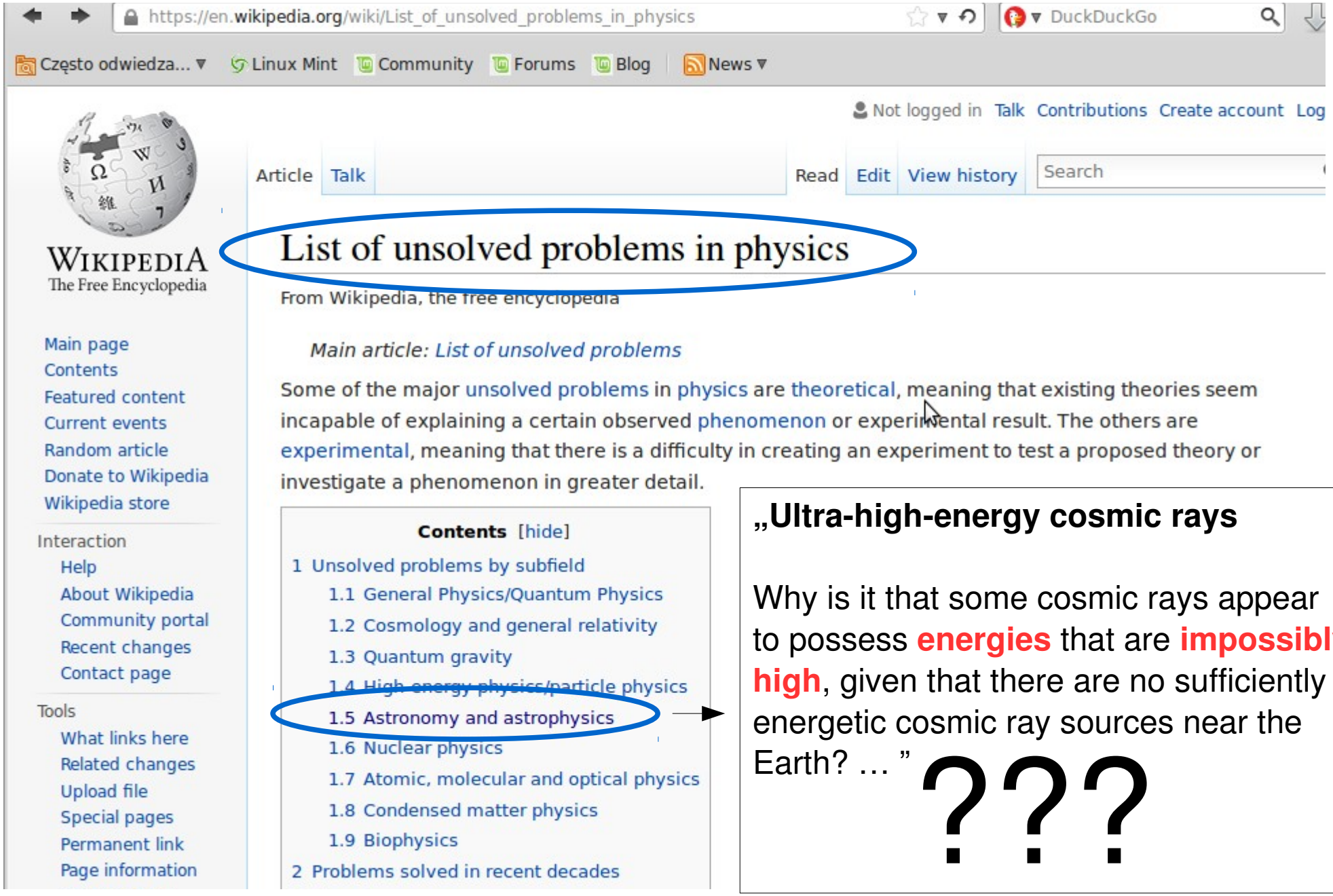
COMPOSITION OF THE COSMOS



Can ultra-high energy cosmic rays help?

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

The ultra-high energy cosmic rays (UHECR) puzzle



„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? … ”

???

Energy spectrum of cosmic rays

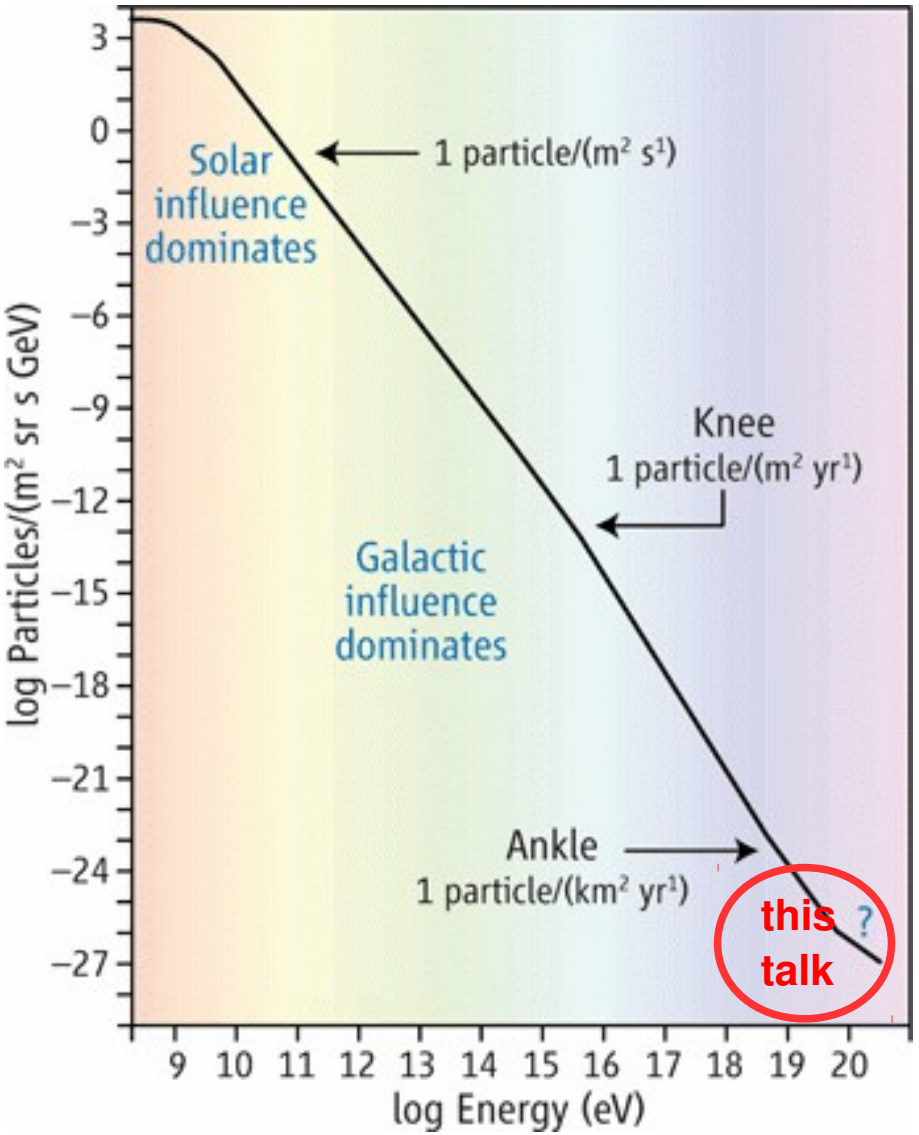
Ranges:
energy: > 10 orders of magnitude
flux: > 30 orders of magnitude
→ diverse physics (sources)
→ diverse detection techniques

Flux rapidly decreases with energy (~E^{-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

Astrophysical scenarios

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

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

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

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

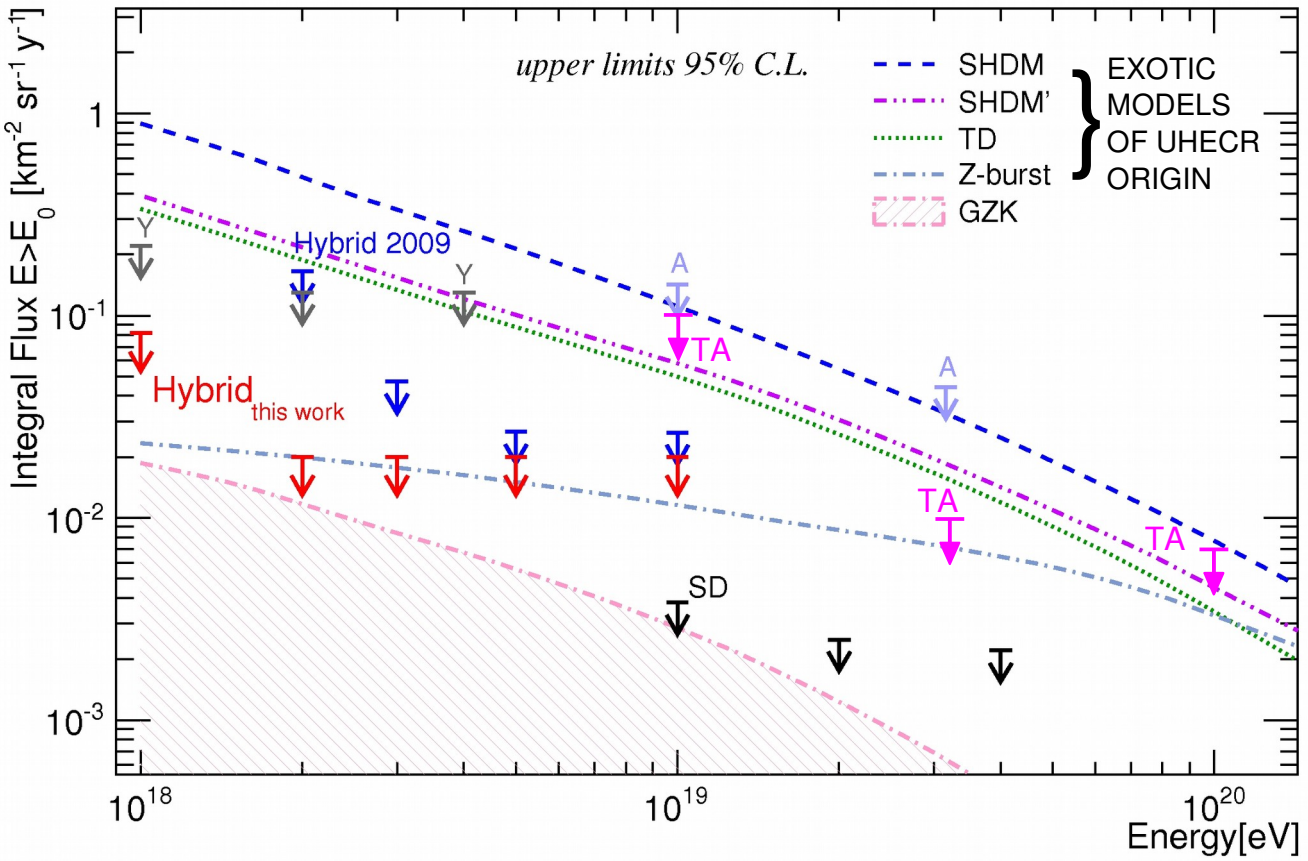
- large fraction of photons and neutrinos in UHCER flux

DARK MATTER!

UHECR composition paradigm: „no photons”

At the highest energies photon fractions < 1%

AUGER, ICRC 2011 + TA 2013



Hybrid – AUGER '11 (hybrid detector)

Hybrid 2009 – AUGER '09 (hybrid detector)

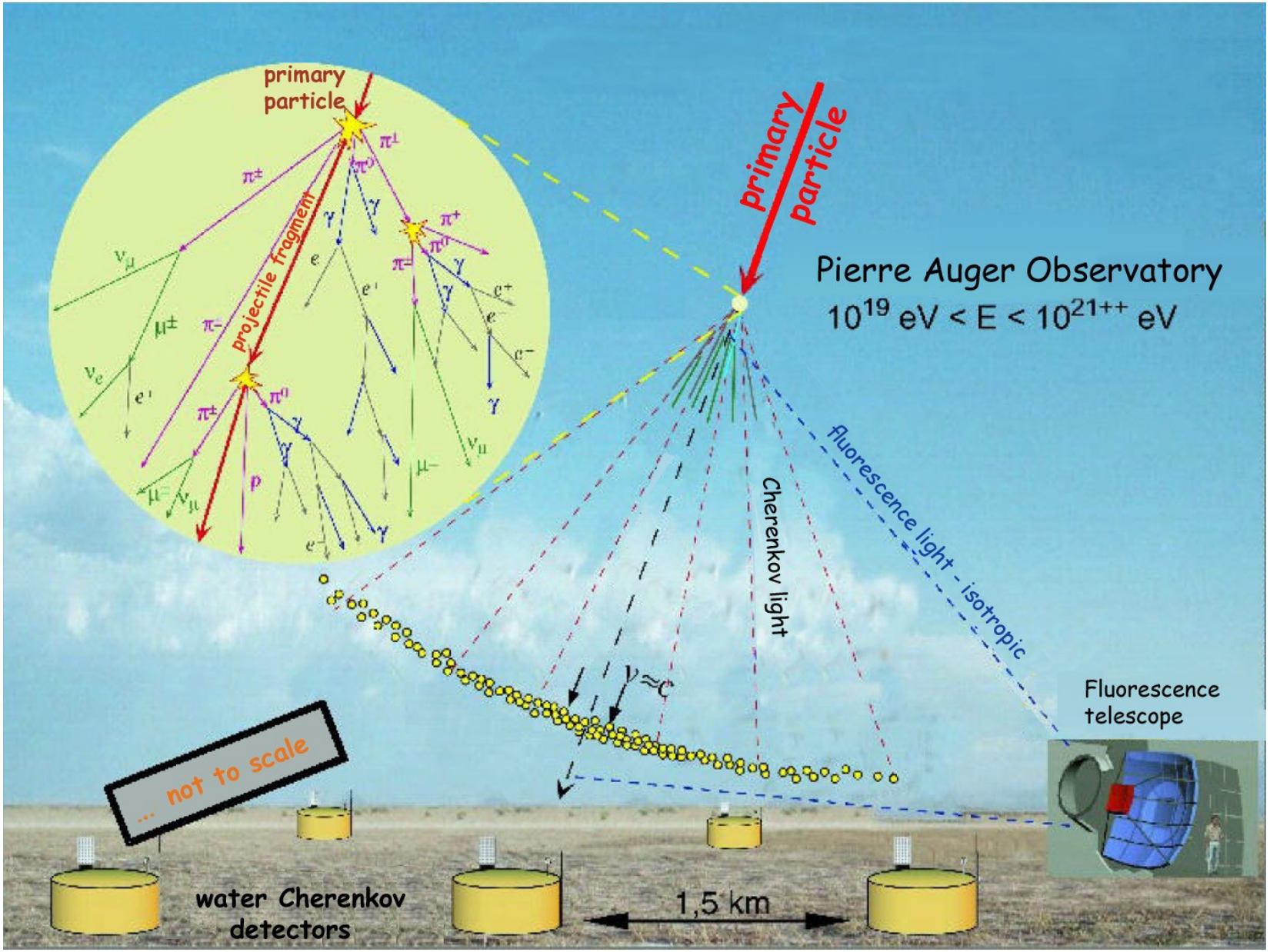
SD – AUGER '08 (surface detector)

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

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

→ severe limitations for exotic (Dark Matter) scenarios!

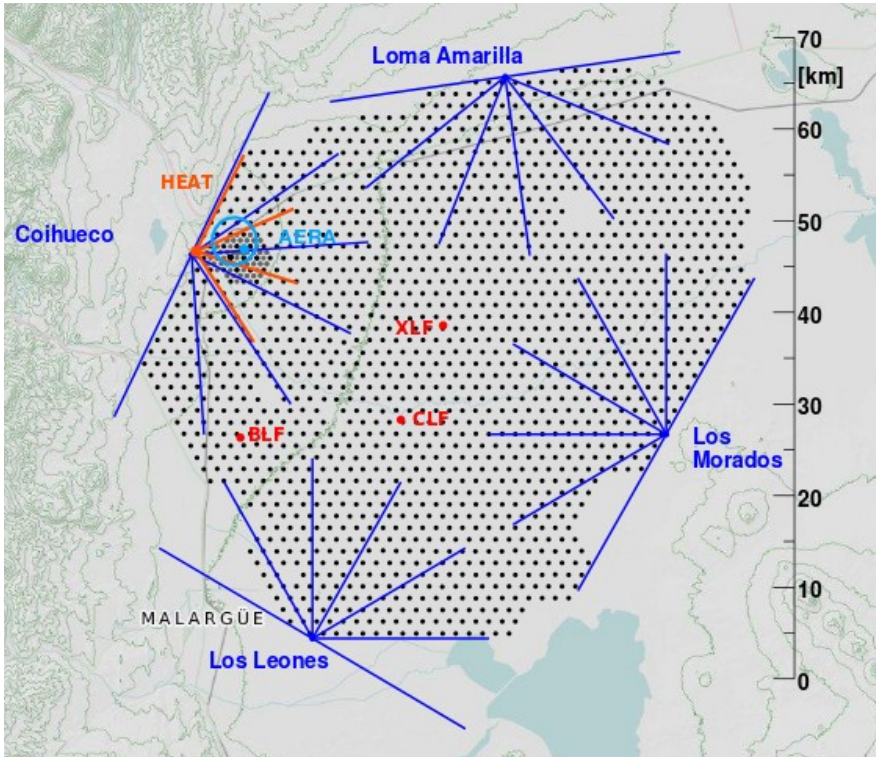
Detection of UHECR at the Pierre Auger Observatory



PIERRE AUGER OBSERVATORY

Malargüe, Argentina

www.auger.org



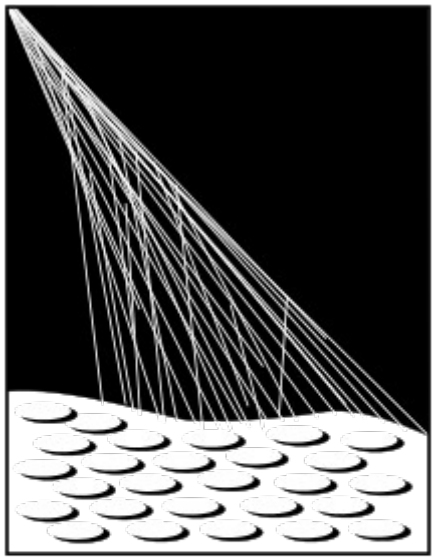
Surface Detector:

→ 1600 stations (3000 km^2)

+

Fluorescence Telescopes:

→ 4 stations



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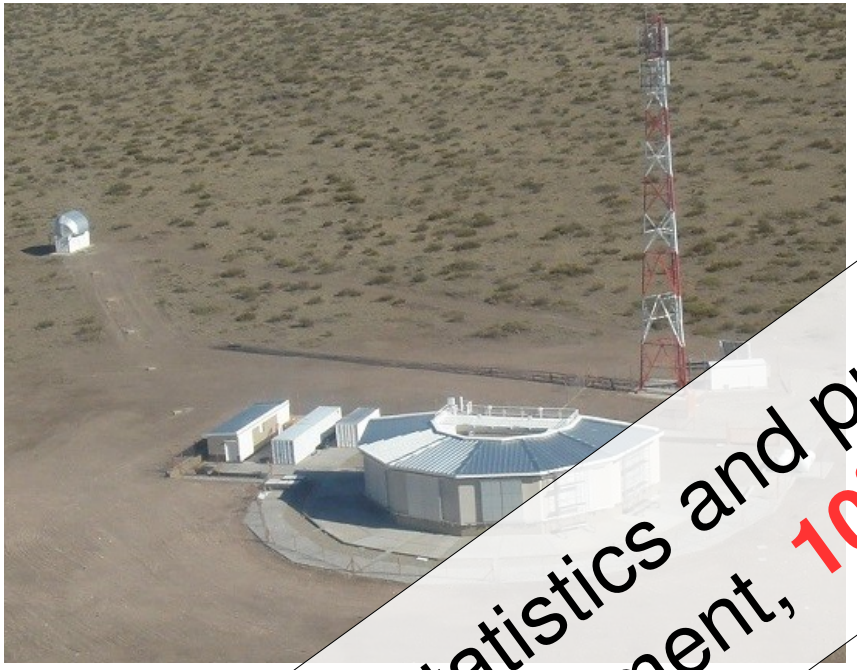
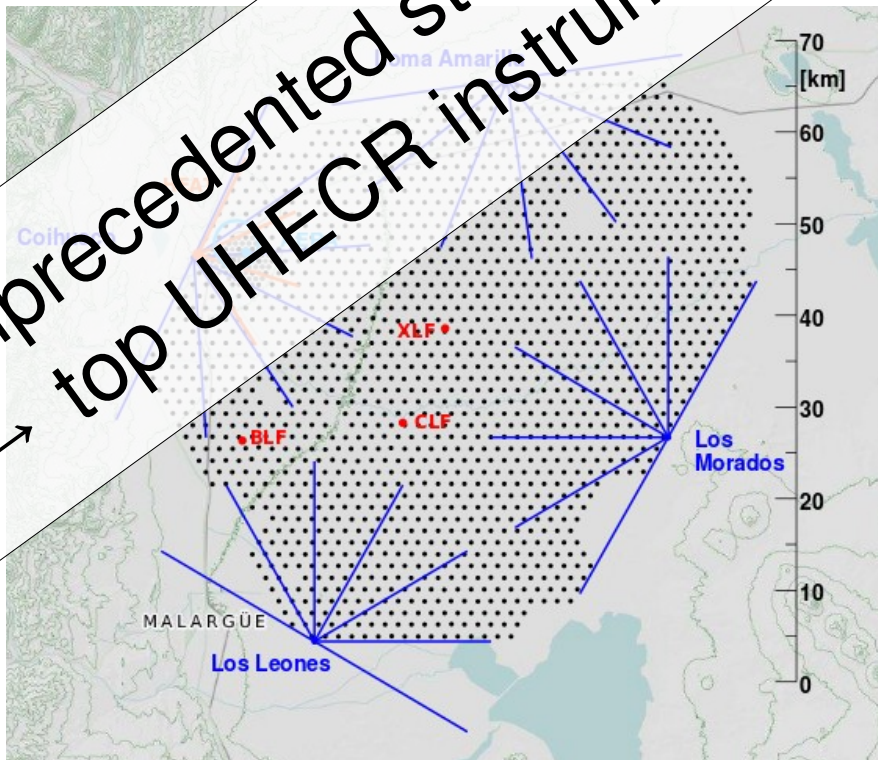


Unprecedented statistics and precision
→ top UHECR instrument, 10^{20} eV!!!



Surface Detector:

→ 1600 stations (3000 km^2)

+

Fluorescence Telescopes:

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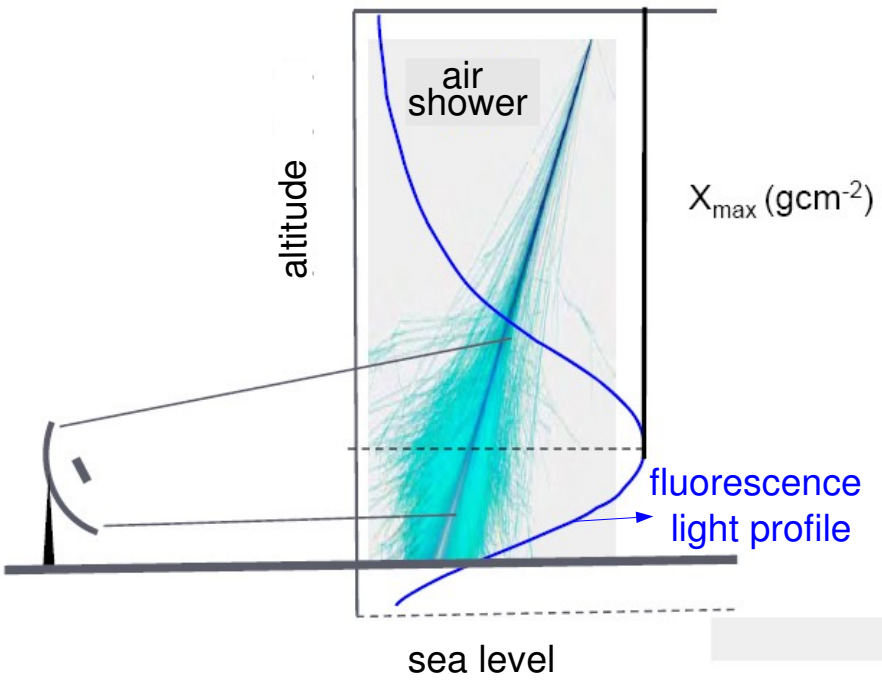
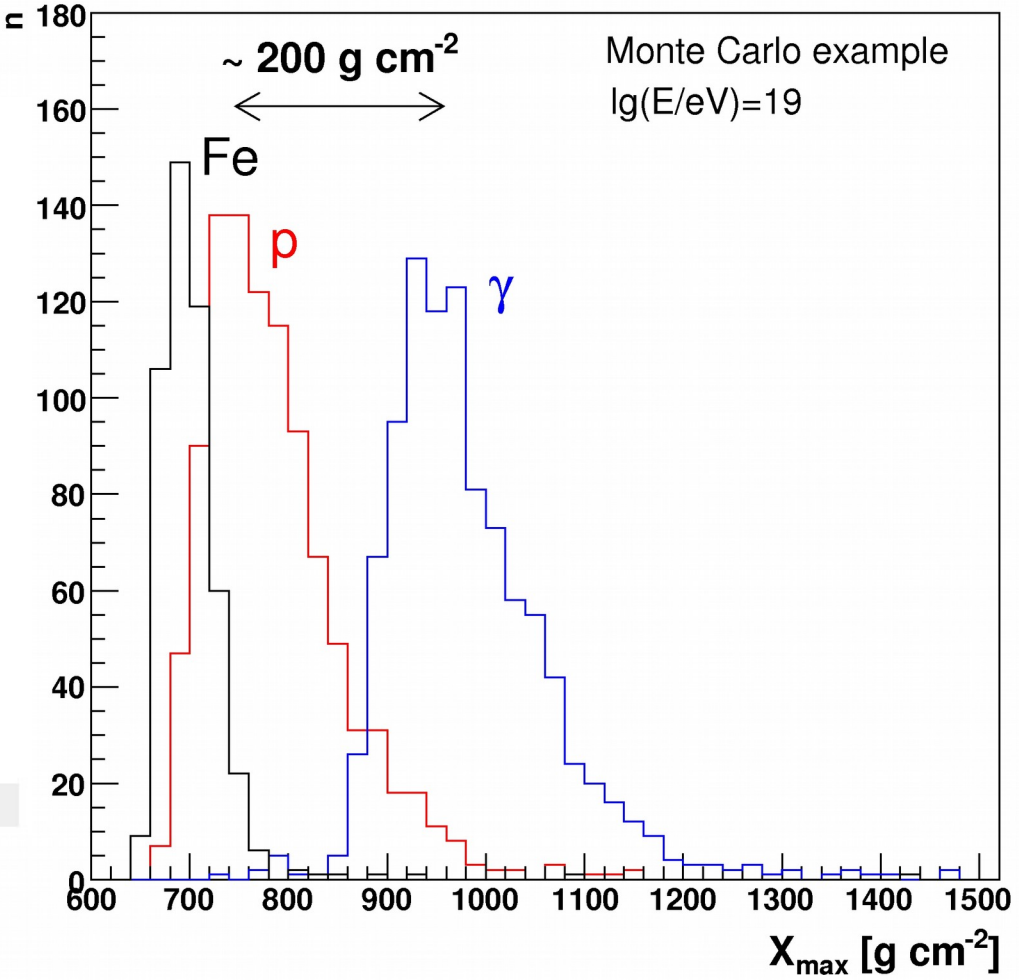
UHECR identification: X_{max}





X_{max}: atmospheric depth of shower maximum development

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

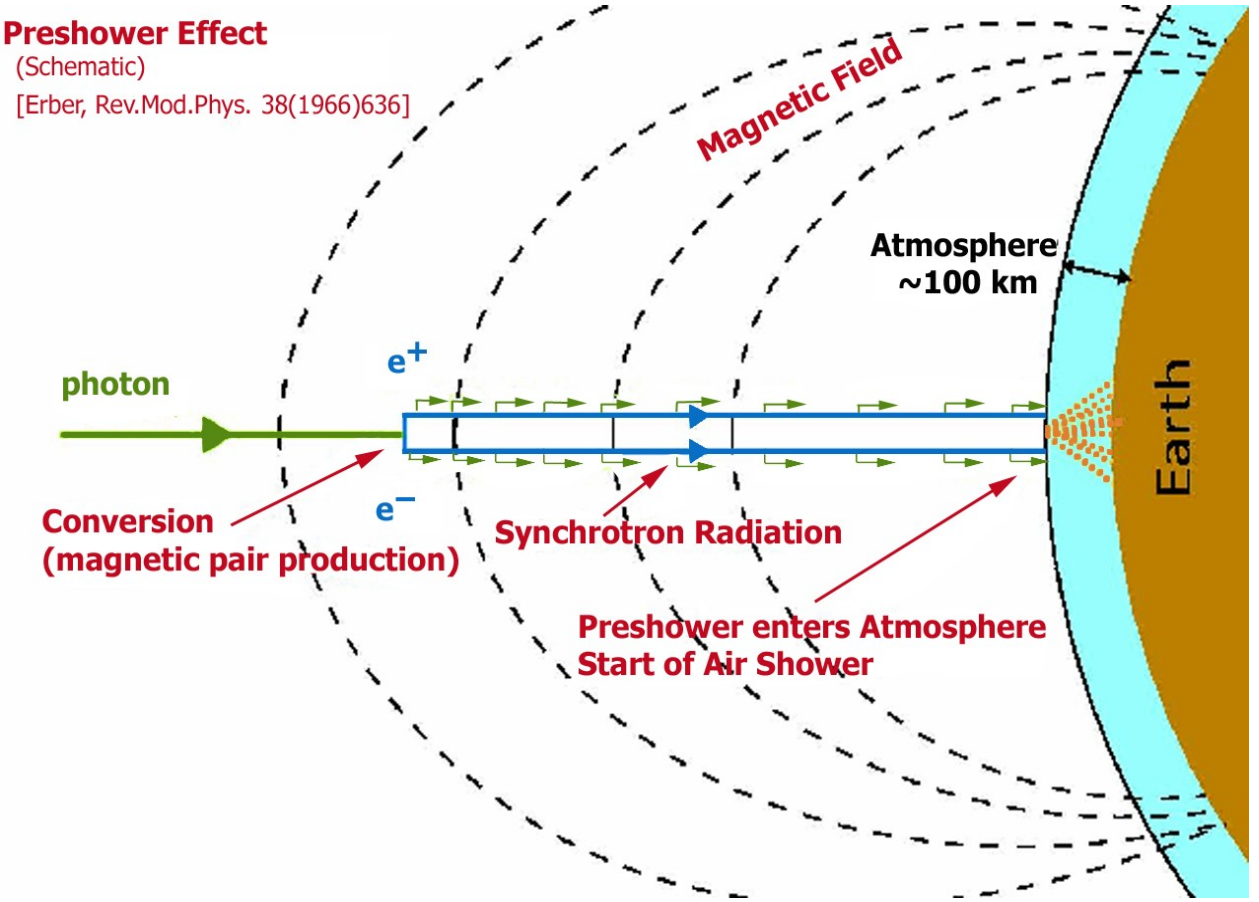
→ RMS[X_{max}(Fe)] < RMS[X_{max}(p)]

Preshowers: a must to study UHE photons

preshower:

→ contains typically 100 particles

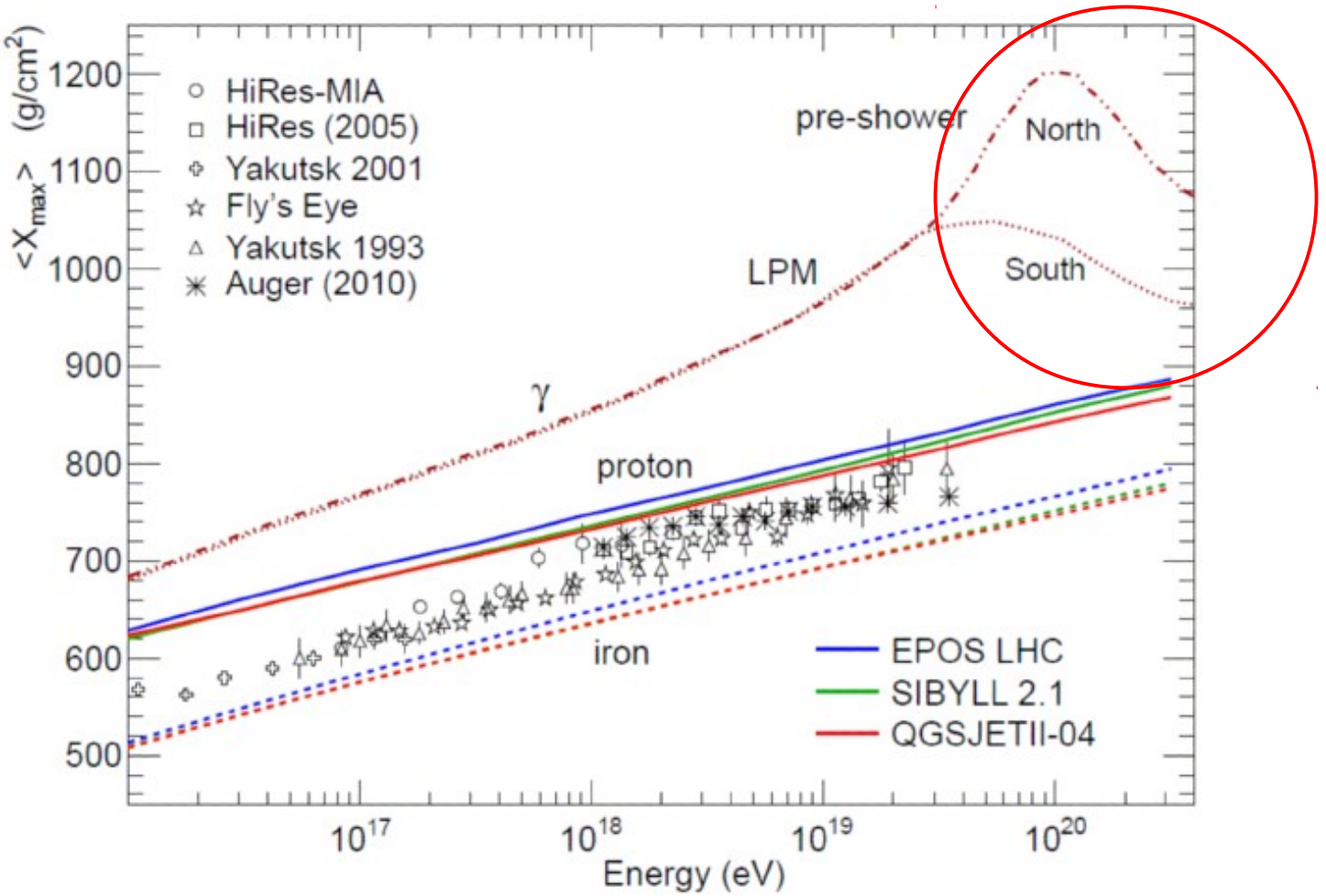
(created at around 1000 km a.s.l.)



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

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

„no photons" result mainly based on „no deep X_{max}"



Preshower effect:

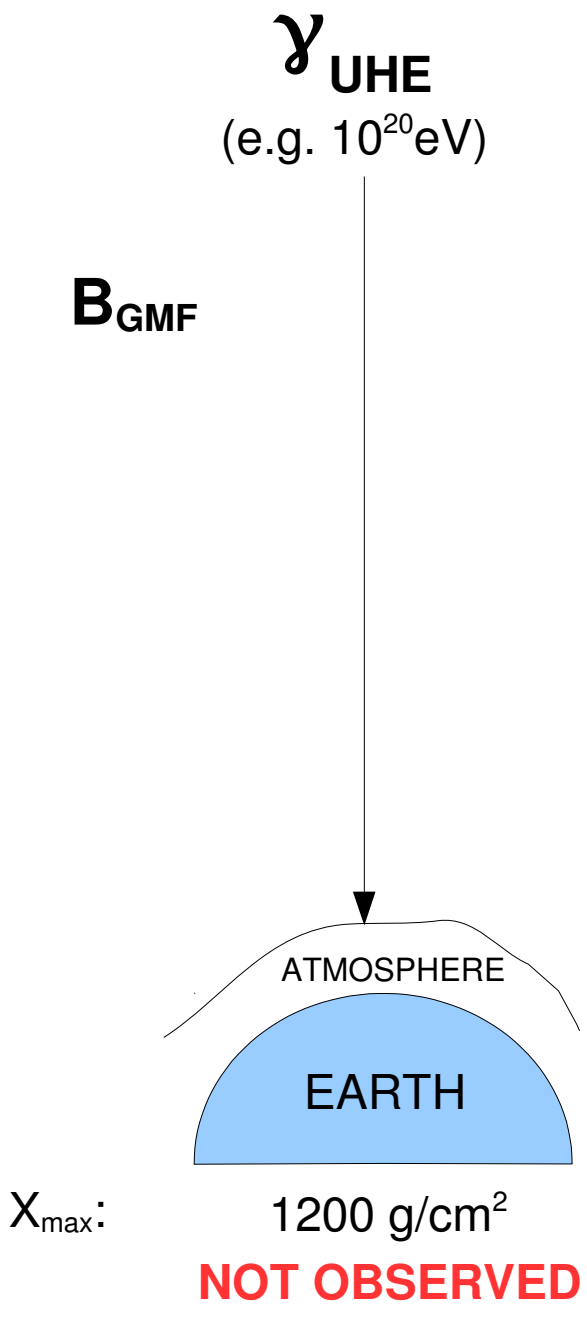
→ **negative** elongation rate!

→ dependence on arrival direction

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

→ no X_{max} values typical for preshowers → limits to UHE photons

SUPER-preshowers (SPS): new type “primary”?

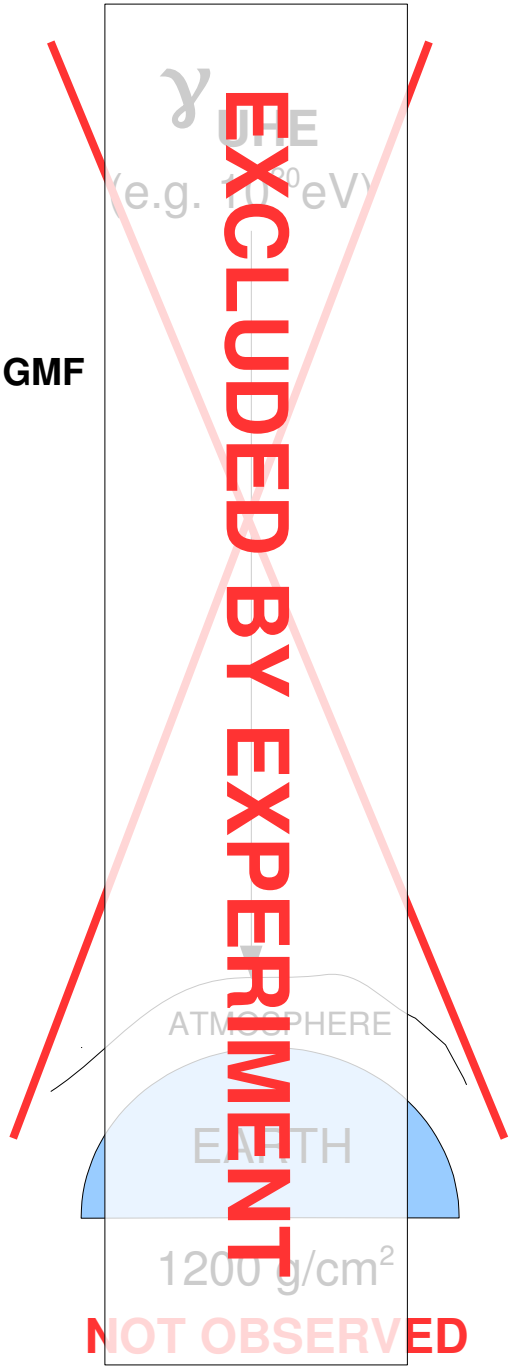


X_{max}: 1200 g/cm^2

NOT OBSERVED

THE PARADIGM LAND

SUPER-preshowers (SPS): new type “primary”?



B_{GMF}

X_{max}:

THE PARADIGM LAND

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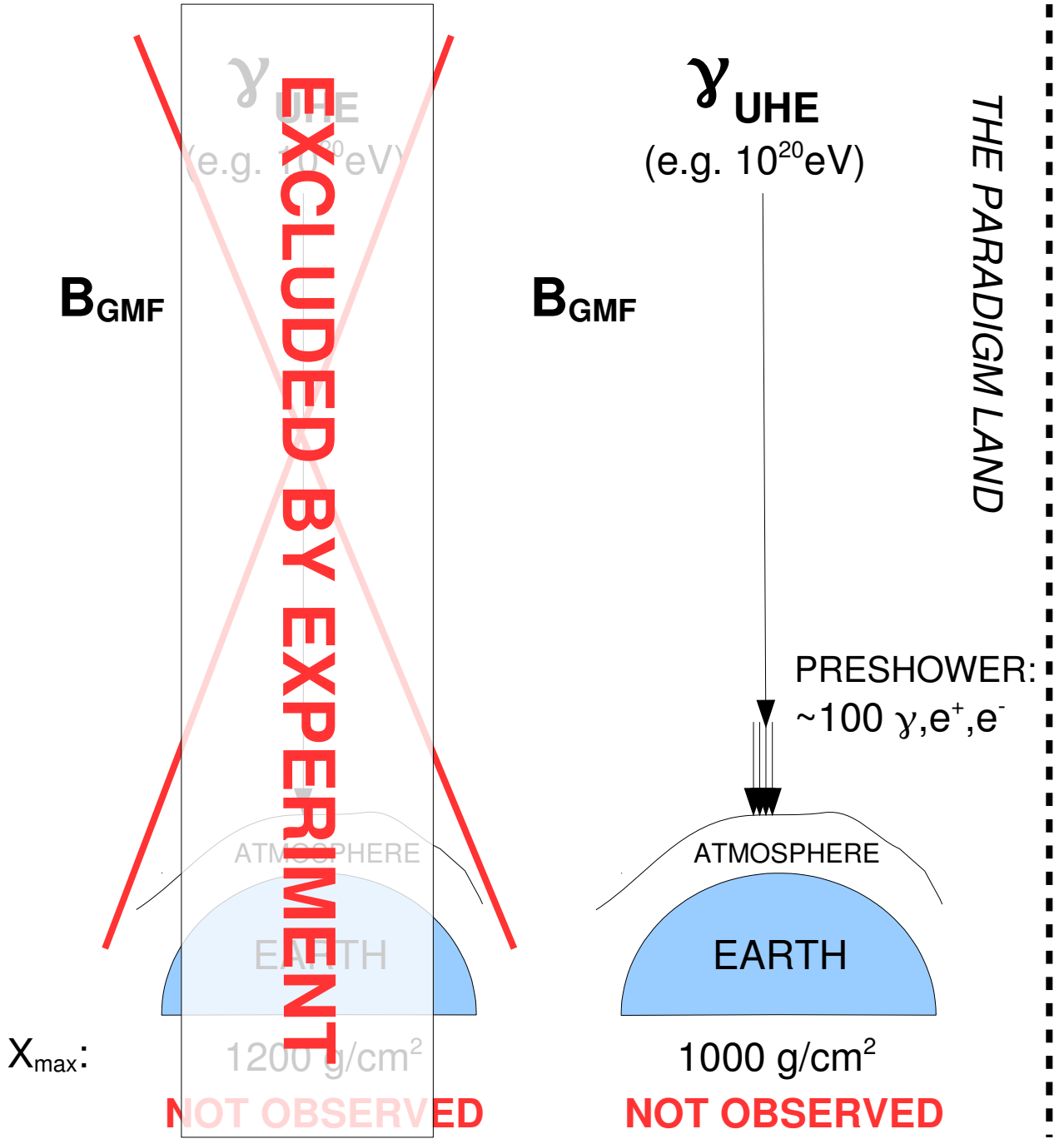

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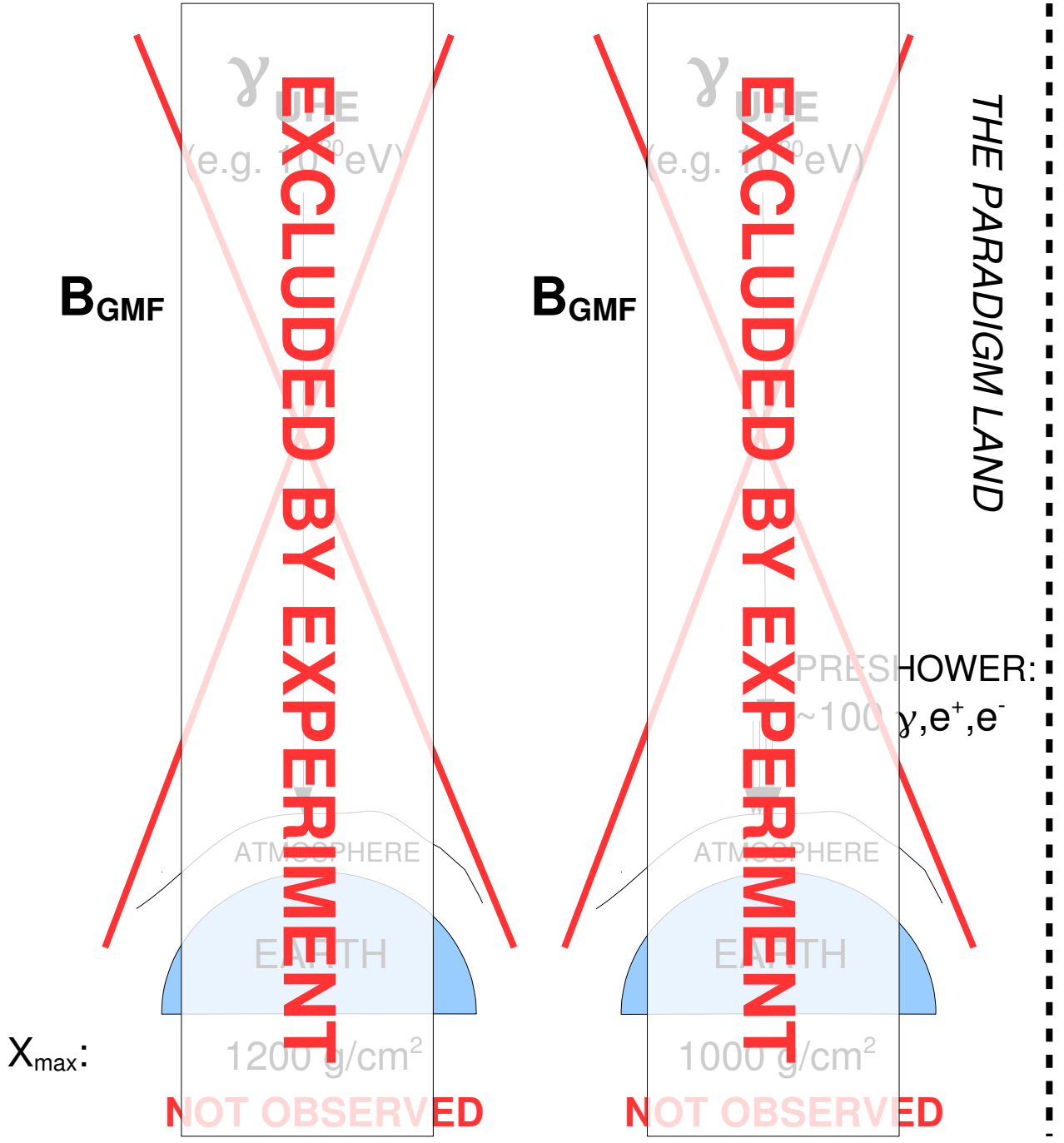

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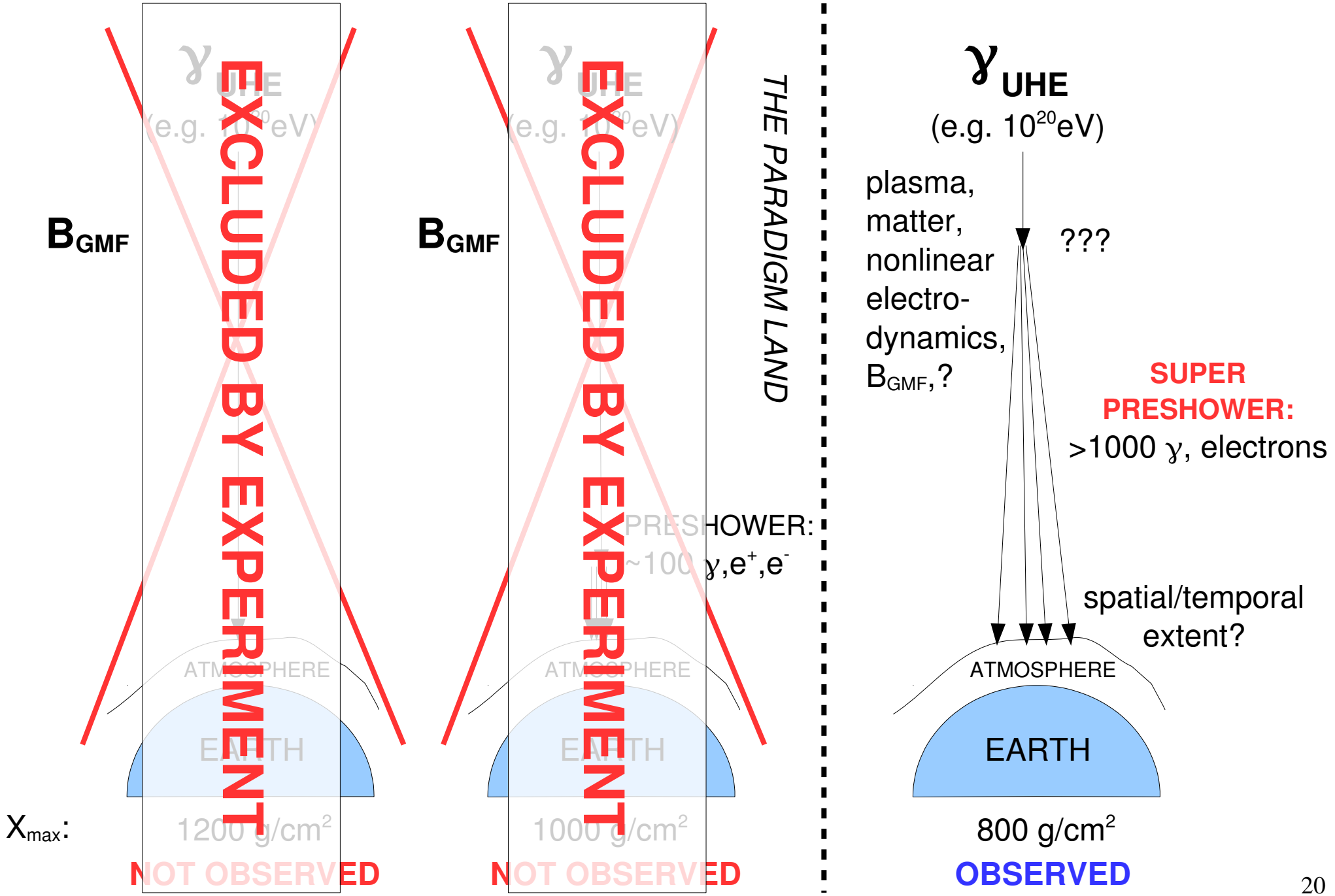

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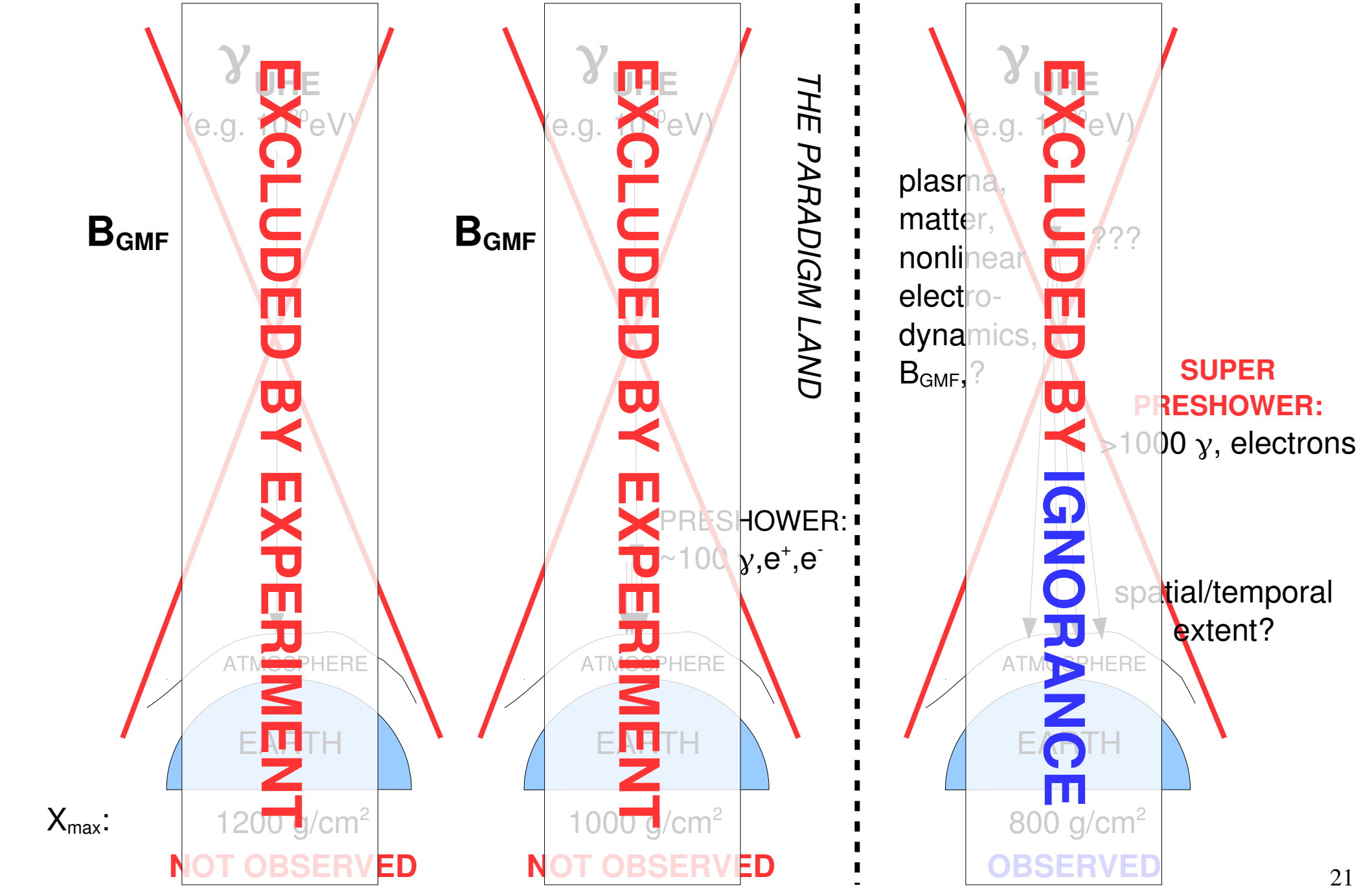

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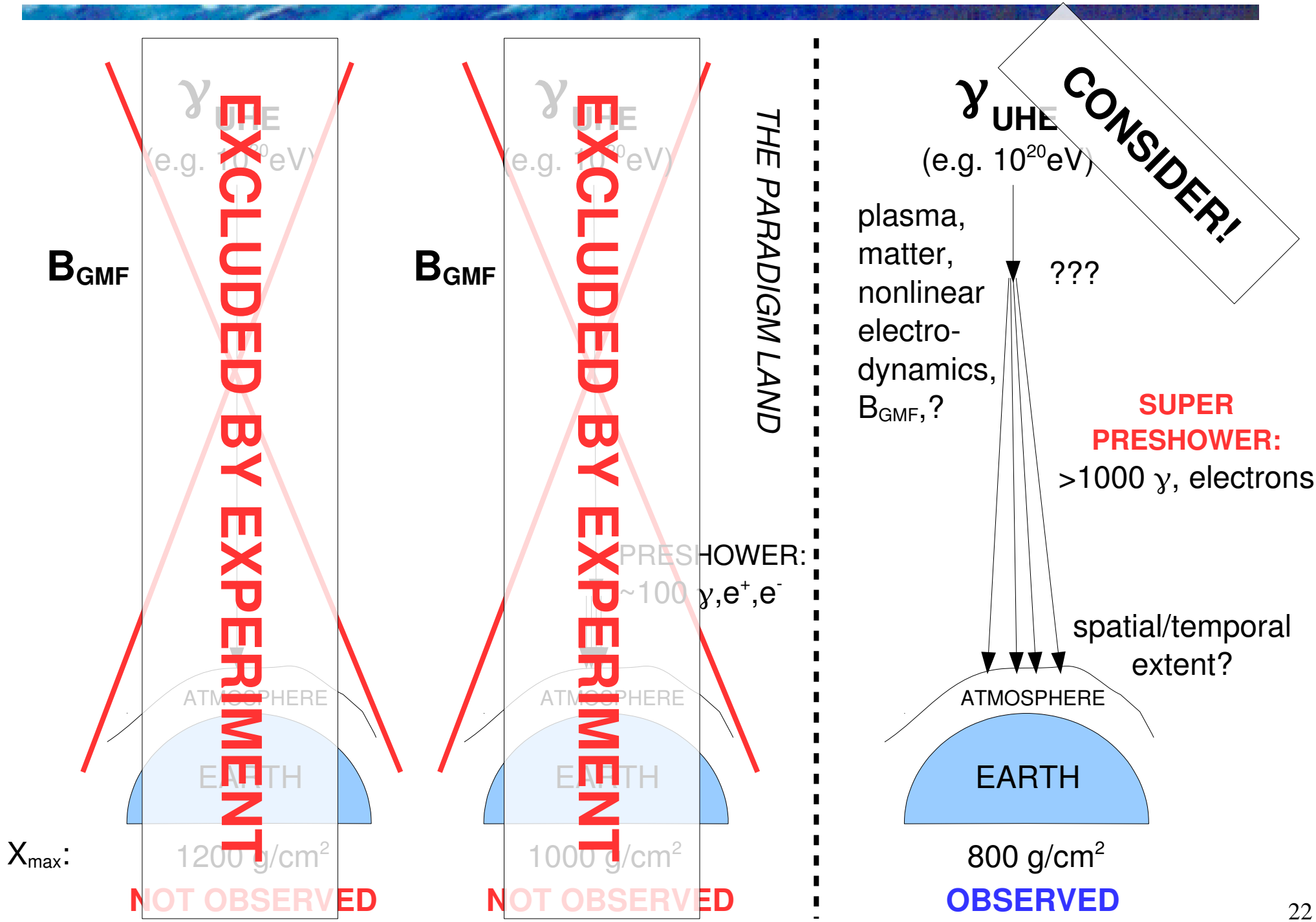
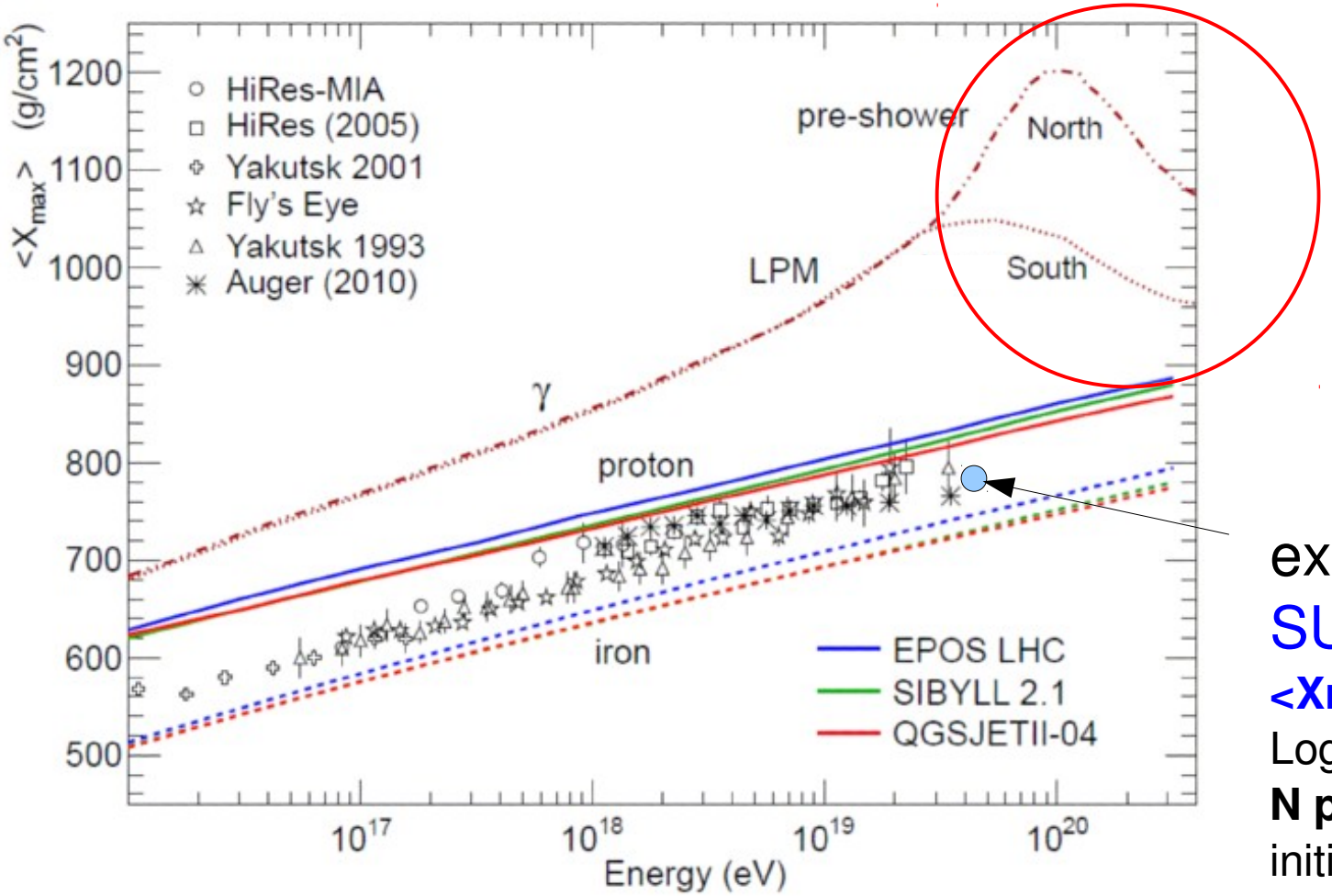


Identification of photon-induced air showers: X_{max} vs. E_γ

„no photons” result based on „no deep Xmax”



Preshower effect:

→ **negative** elongation rate!

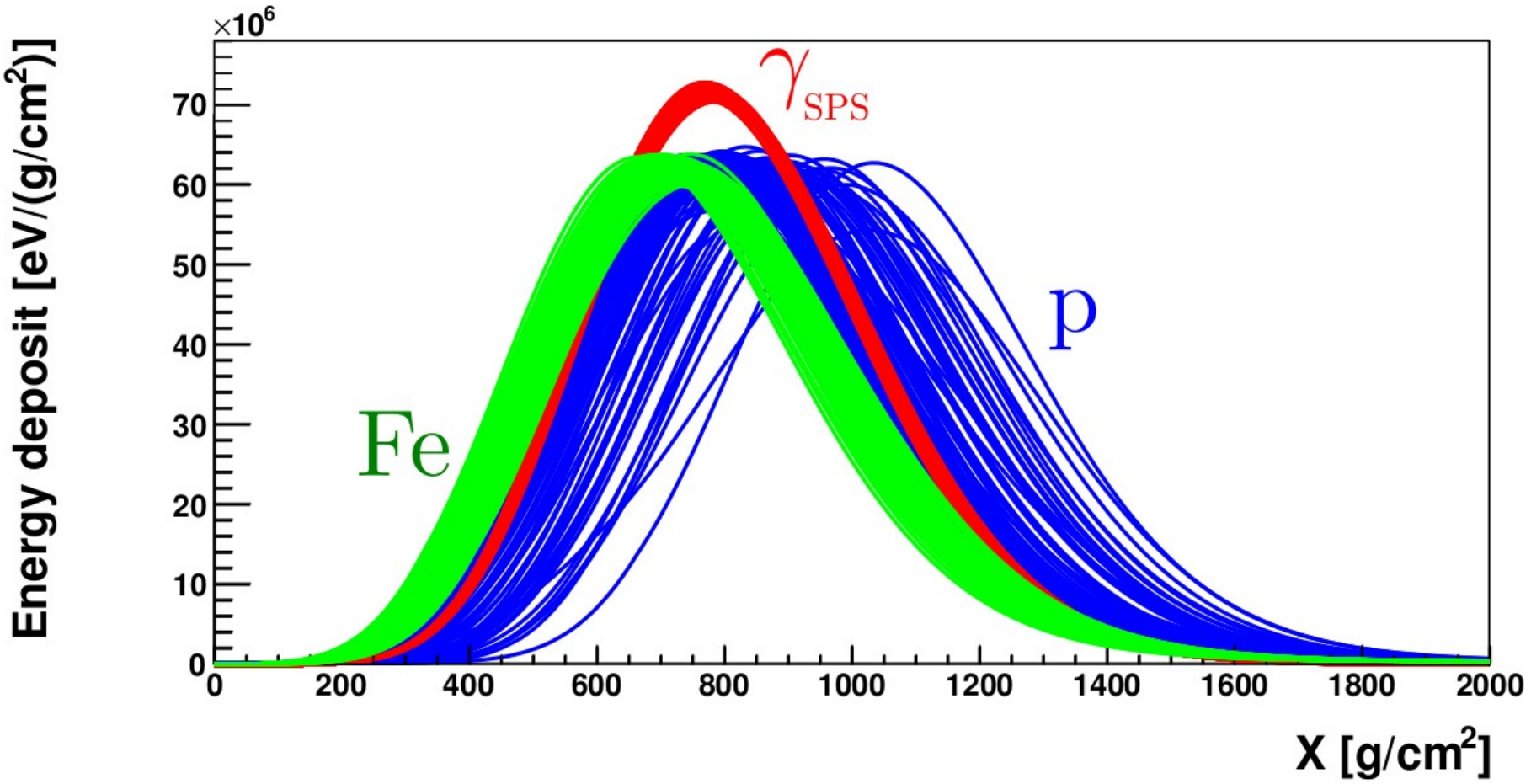
→ dependence on arrival direction

example SUPER-preshower:
<Xmax>=783±3g/cm²
LogE=19.6
N particles =1500
initiated at 17000 km a.s.l.

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

→ SUPER-preshowers (SPS) not (yet) considered!

Super Preshowers: longitudinal profile

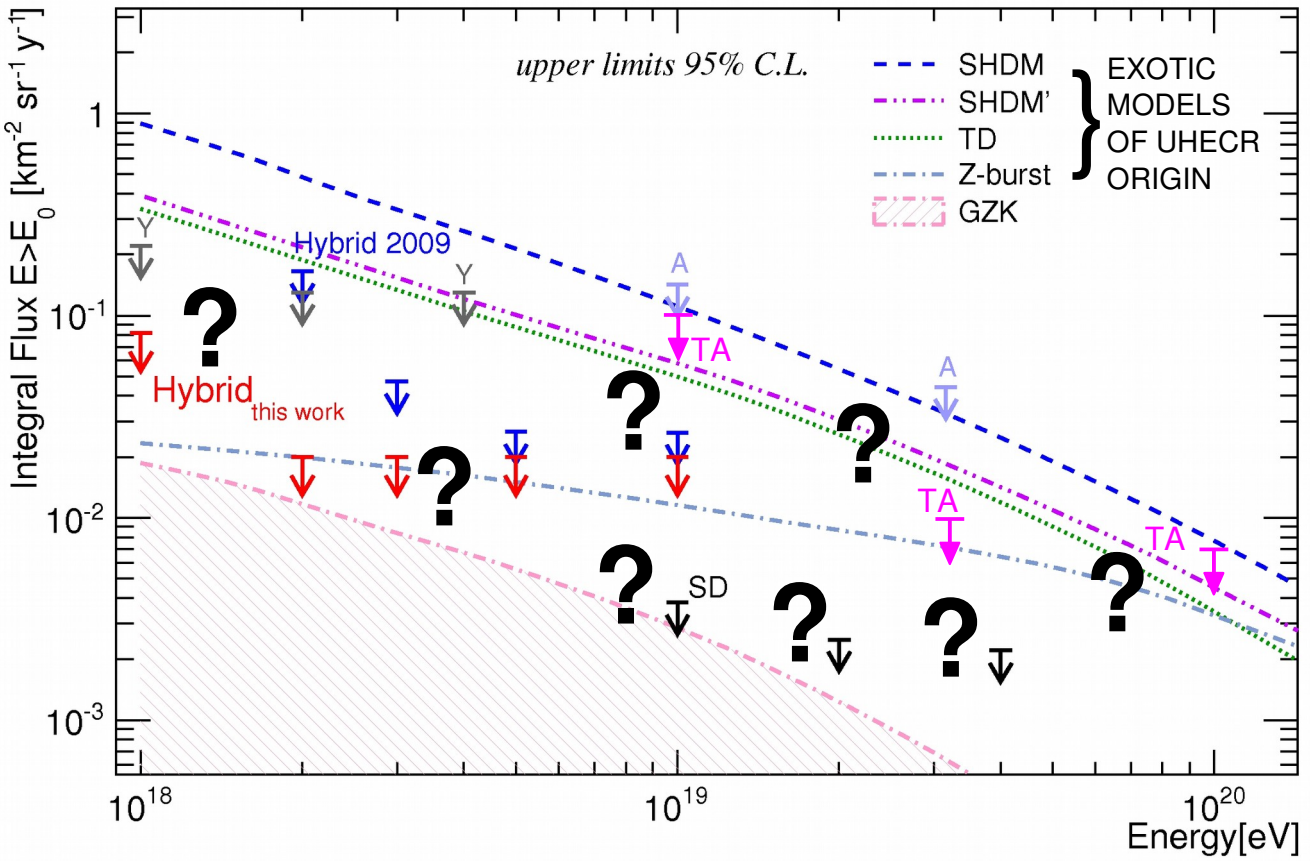


→ shape similar to hadron-induced showers,
smaller shower-to-shower fluctuations

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

→ **severe limitations for exotic (Dark Matter) scenarios!**

Let's study super-preshowers!

Super-preshowers:

- can induce air showers that **mimic hadronic showers**
- **not studied** before
- **POTENTIAL TO SHIFT THE UHECR/DM PARADIGM**

Scientific program:

- theory: propose super-preshower **scenarios**
- simulation: find super-preshower **sigantures** observable with the current / future infrastructure
- data: **identify or exclude** the super-preshower classes

→ **NEW SENSITIVITY TO NEW PHYSICS!**

From gamma rays to radio

Even more ways for indirect DM search:

ultra-high energy photons

+

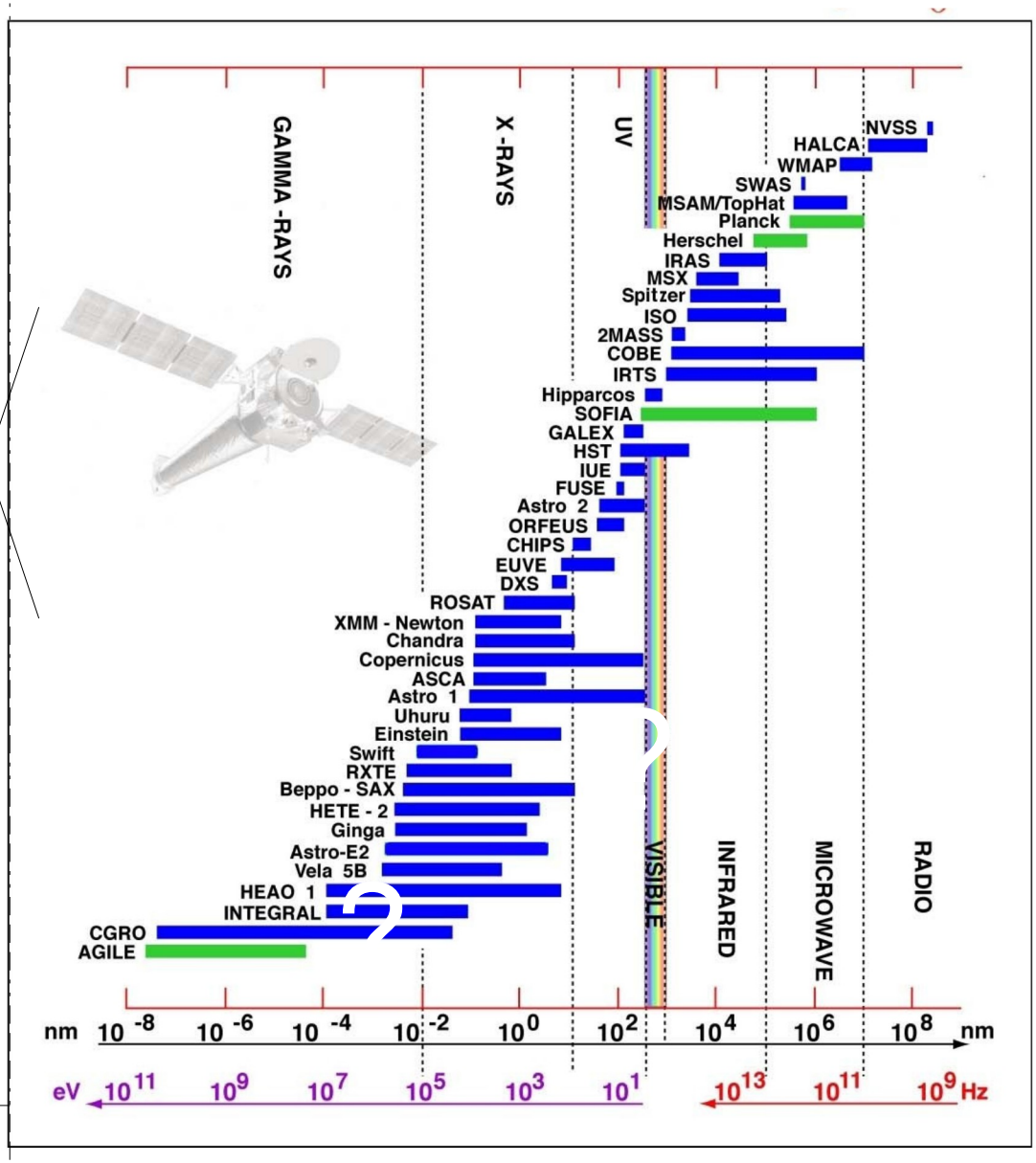
SUPER PRESHOWERS?

- Pierre Auger Observatory
- Telescope Array
- CREDO

...

$>10^{19}$ ...

observation border



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

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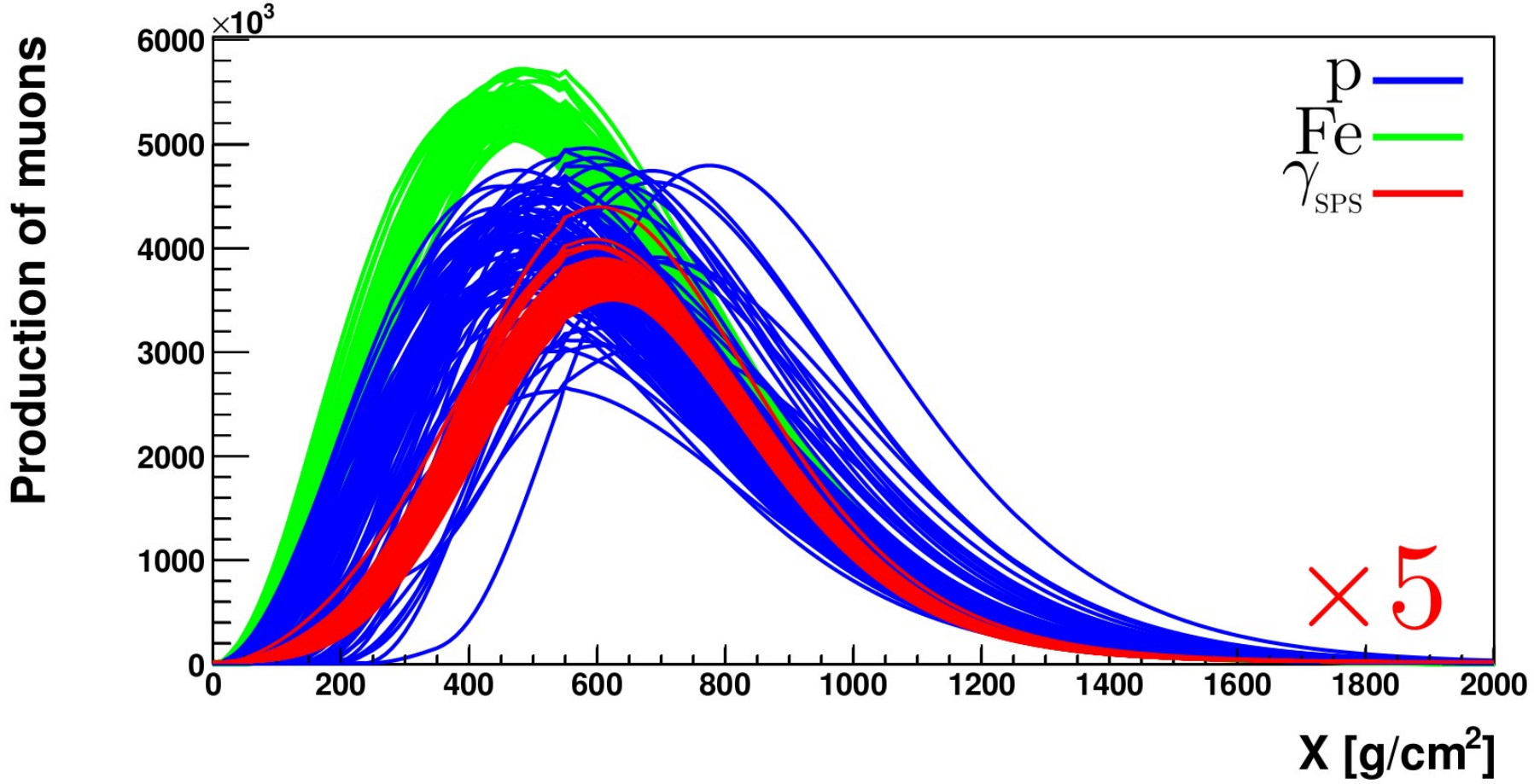
backup

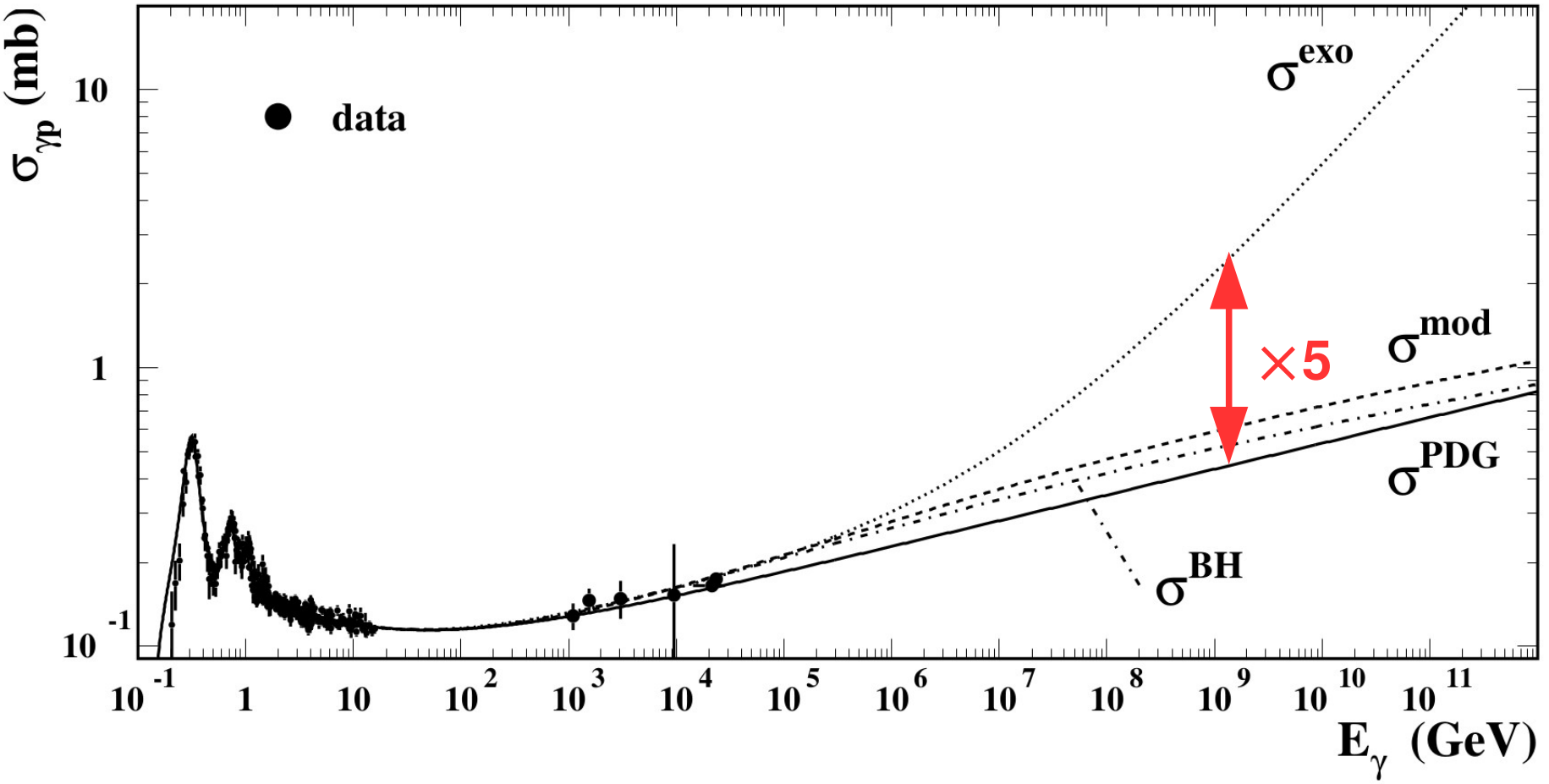
Super Preshowers: dN_μ/dX vs. X



→ shape similar, height 5-8 × lower

Super Preshowers: too low N_μ?

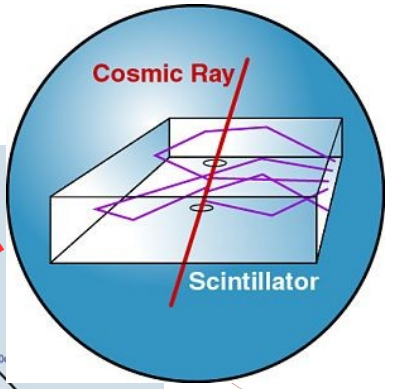
Risse et al., 2006



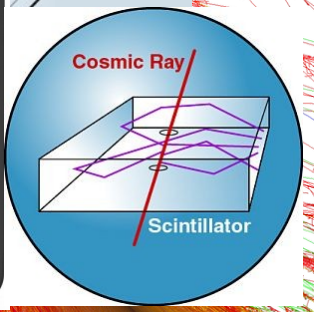
→ keeping in mind uncertainty about $\sigma_{\gamma p}$

Cosmic-Ray Extremely Distributed Observatory

distributed, open and diversified cosmic-ray detector



DATABASE/
INTERFACE



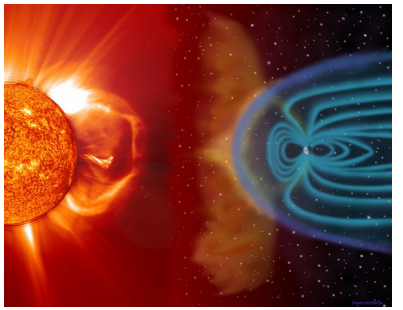
Cosmic-Ray Extremely Distributed Observatory

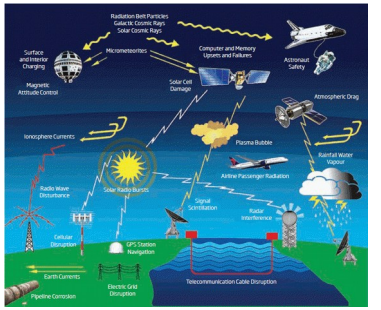
Generate enthusiasm about and attract enthusiasts only possible with an **attractive science case**!

(consider good examples: SETI@home, Planet Hunters,...)

→ Guaranteed science:

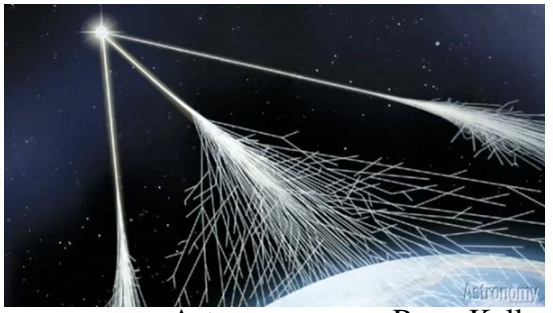
- space weather
- ....





→ **Unexpected but possible science:**

- large distance correlations in time (GW follow up: arXiv/1602.04735v2, arXiv/1602.06961; Smith et al. 1983, Fegan et al. 1983,...)???
- **SUPER-PRESHOWERS**?, ...



Astronomy.com, Roen Kelly

→ **Best comes unexpected:**

- on the edge of the energy scale expect ….**discoveries**!

Time to shift the paradigm? Let's work together!

If shifting the physics paradigm is really needed to move on towards TOE, it might be very difficult an isolated effort.
Let's consider this direction together!

@ IFJ PAN, ZAKŁAD PROMIENI KOSMICZNYCH:

→ PIERRE AUGER OBSERVATORY (3000 km^2 in Argentina, near Andes)
→ BAIKAL GIGATON VOLUME DETECTOR (1km^3 of water, lake Baikal, Russia)
→ CREDO (limited by world size)

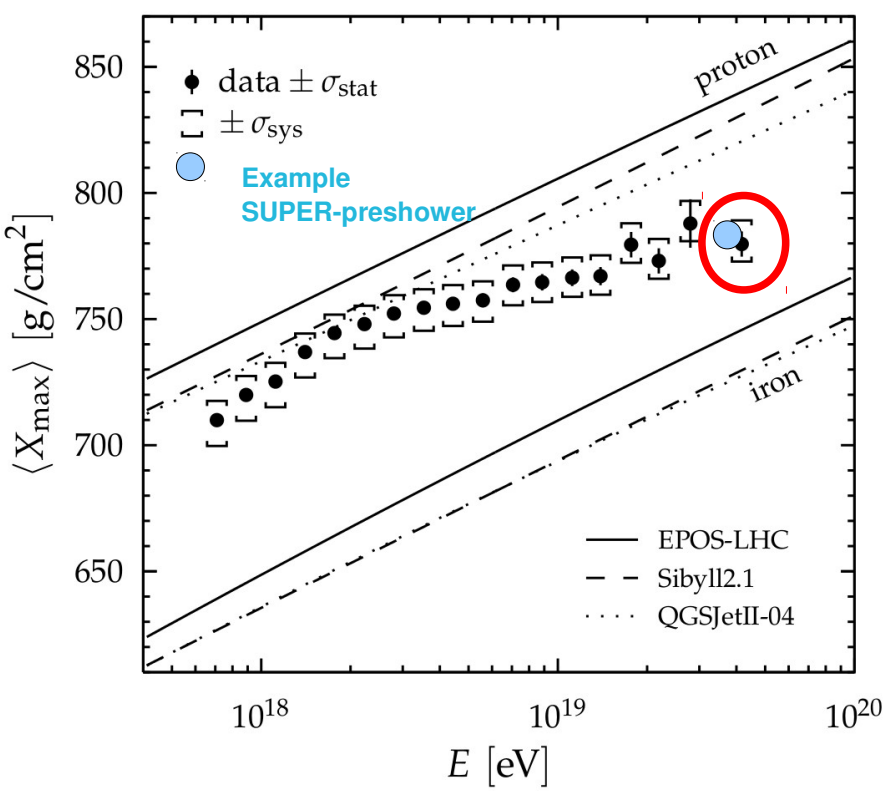
ALL LEVEL EXCITING PROJECTS AVAILABLE:

→ BSc, MSc, PhD topics + student practices + **mini-jobs for students (!)**
→ **JOB OFFERS** (Baikal-GVD: physicist, electronics engineer)
→ student's practice & lab (Baikal, CREDO)
→ ERASMUS: Wuppertal, Siegen, Lecce (Pierre Auger Observatory)
→ senior scientists: new ideas / mutual inspiration
… see more: **auger.ifj.edu.pl**

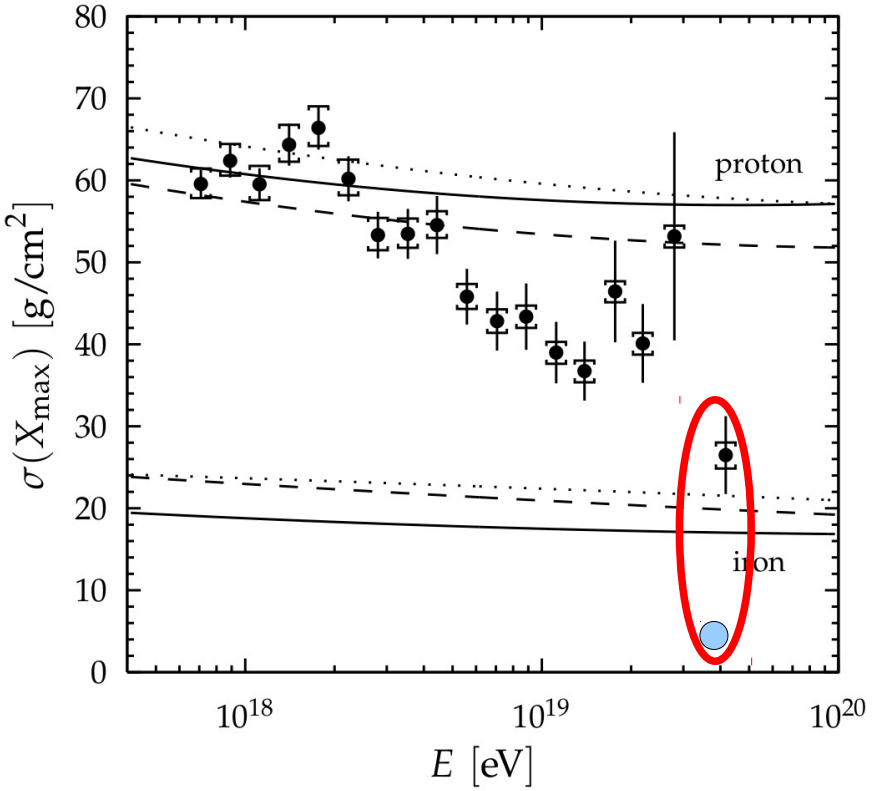
Please contact: Piotr.Homola@ifj.edu.pl

Mass composition challenge: p, Fe, mixed or … SUPER-preshowers?

AUGER, 2014



mixed composition?

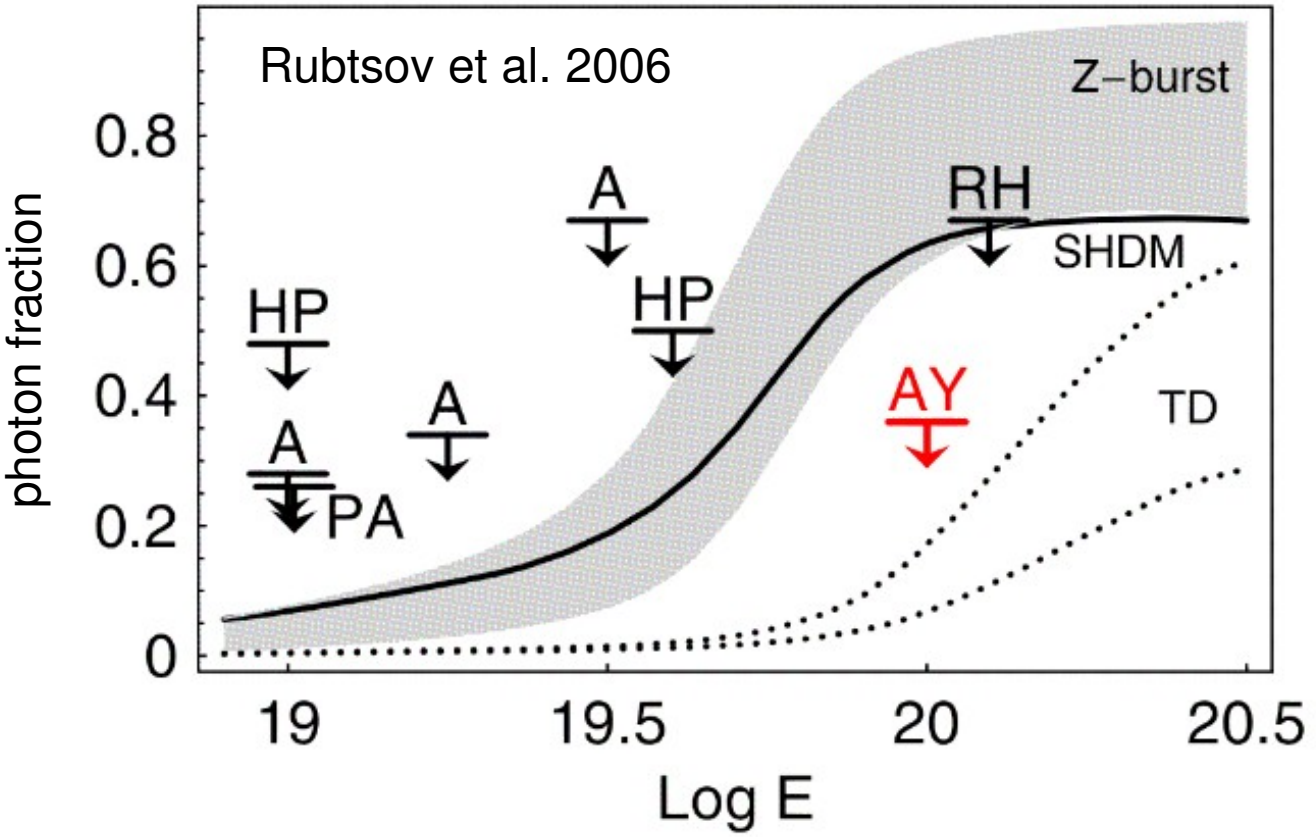


heavy nuclei?

50% SUPER-preshowers + **50% protons** (roughly)
can explain both X_{max} and RMS(X_{max}) at highest energies

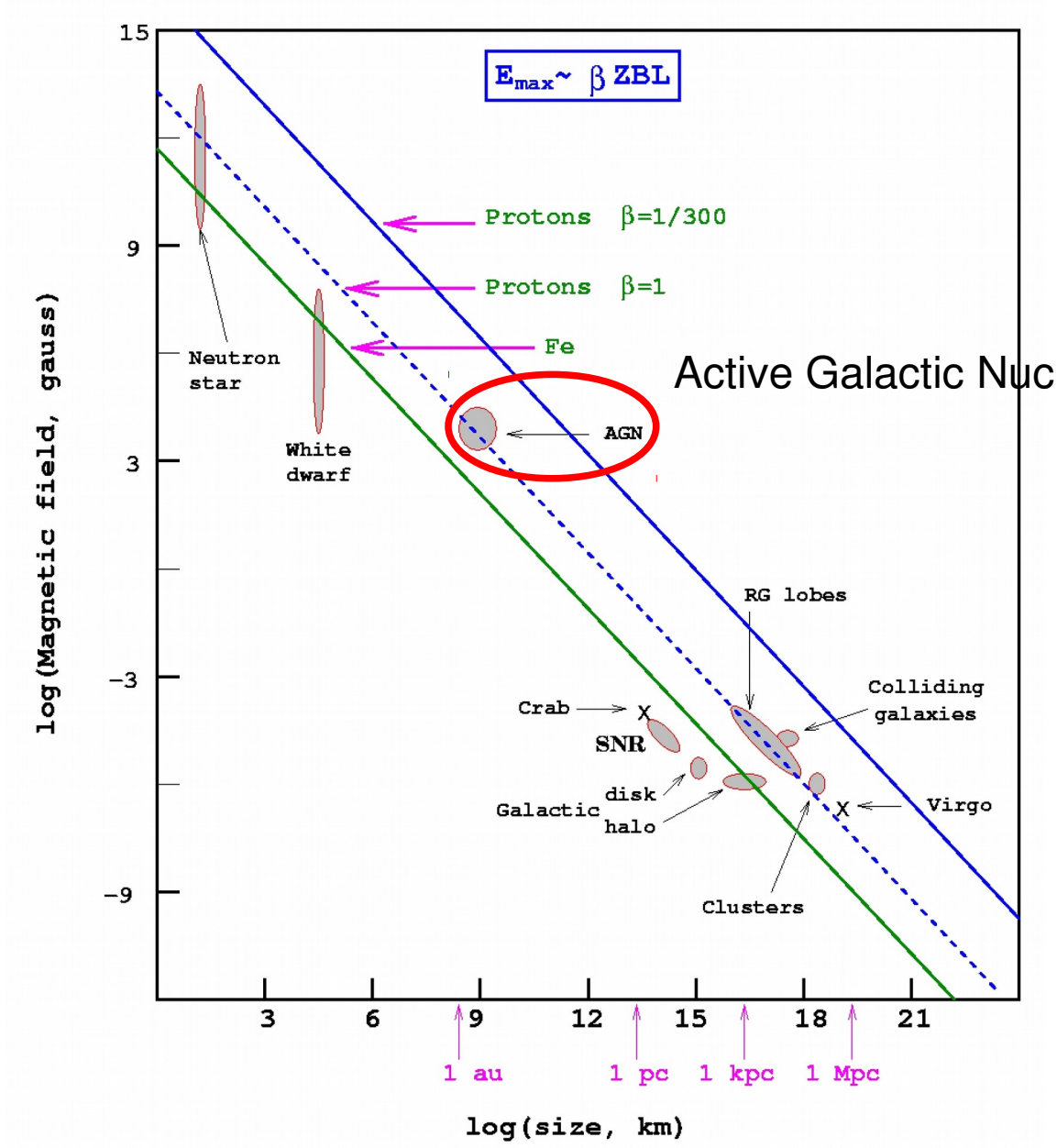
Limits to UHE photon fractions & exotic models

Limits to UHECR photon fractions at $E > 10^{19}$eV



Exotic models: photon **fraction increases** with E

UHECR sources

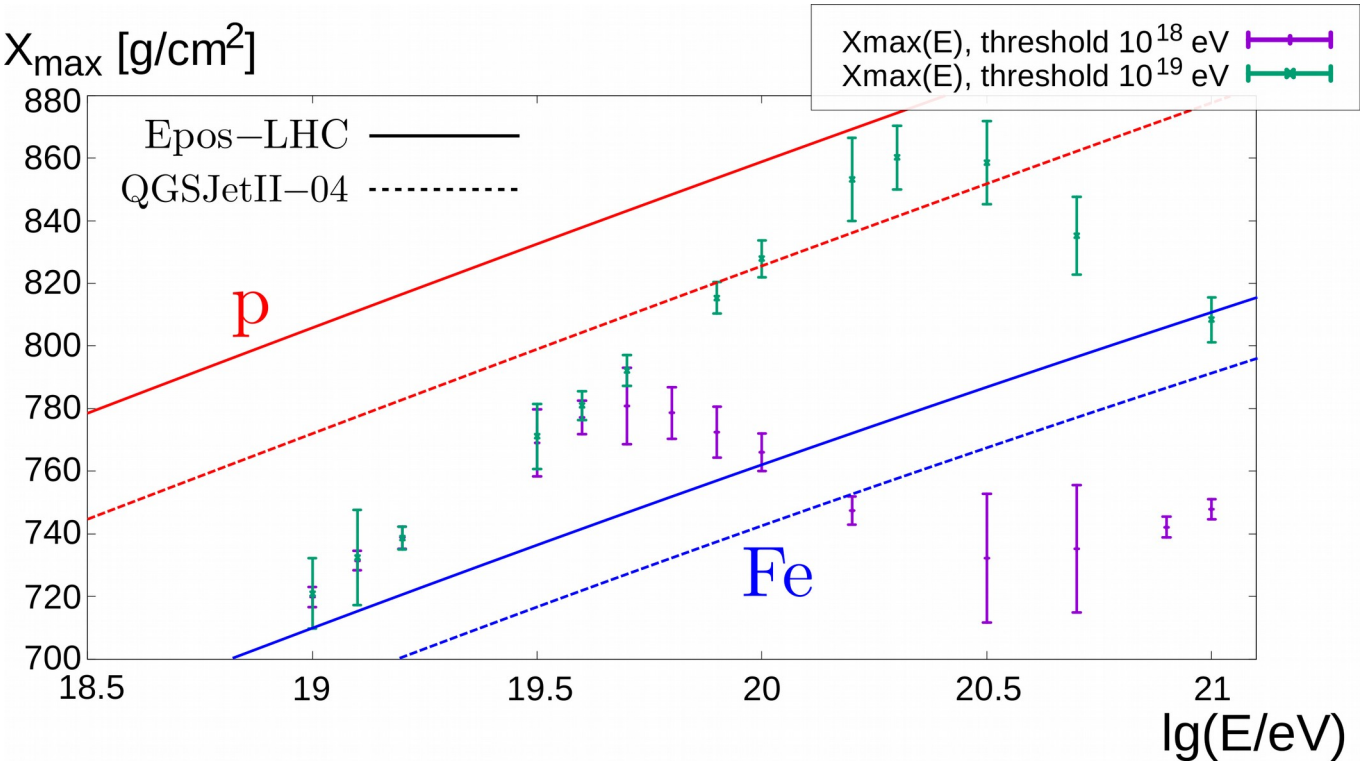


Active Galactic Nuclei (AGN)

Sufficiently efficient source difficult to find!

Super Preshowers: first simulations

→ Example arrival direction
→ Fixed altitude of conversion: 25000 km a.s.l.
→ vary primary photon energies
→ check different pair production threshold



→ negative elongation rate visible in the hadronic range!

Super-preshowers: example of unchecked scenarios

Credit to Łukasz Bratek (IFJ PAN)

Born Infeld theory (example of nonlinear electrodynamics)

- photonics processes with alternative properties
- Magnetic pair production or photon splitting: likely at lower E?
Then all UHE photons could produce super-preshowers above Earth...

→ connection to TOE from Wikipedia:

„Born-Infeld theory ... found in some limits of string theory”