Vysokoenergetické častice z vesmíru

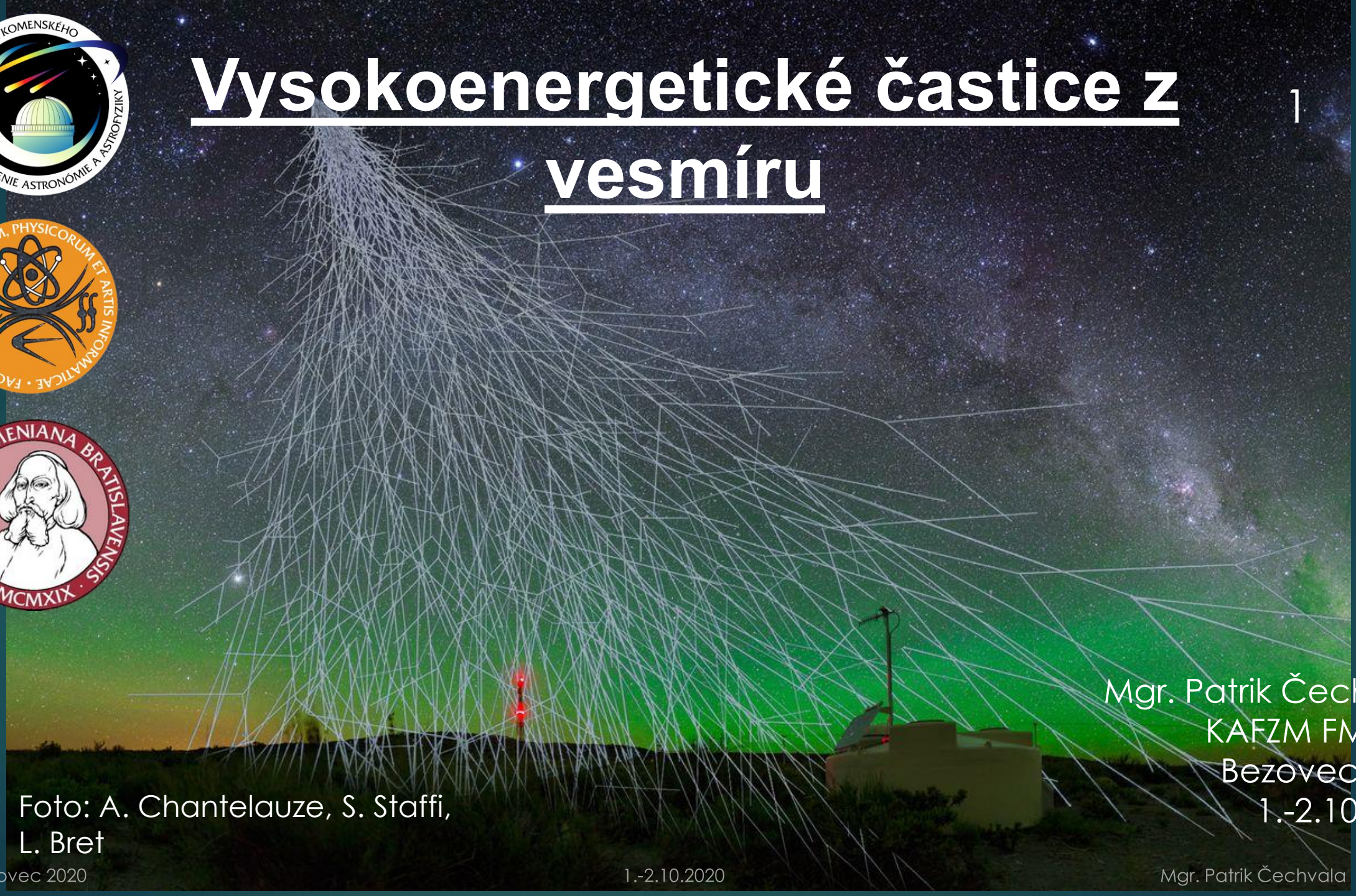


Foto: A. Chantelauze, S. Staffi, L. Bret

Mgr. Patrik Čechvala
KAFZM FMFI UK
Bezovec 2020
1.-2.10.2020

Content

- Základné charakteristiky kozmického žiarenia a gama žiarenia
- Propagácia častíc od zdroja k Zemi
- Detekčné techniky
- Citizen Science projekty

Victor Franz Hess

(* 24.6. 1883 - † 17.12. 1964)

- Rakúsky fyzik
- 1911 – nemohol by sa zdroj skôr nachádzať na oblohe?
- Využil pri tom svoje hobby

Vzduchoplavba

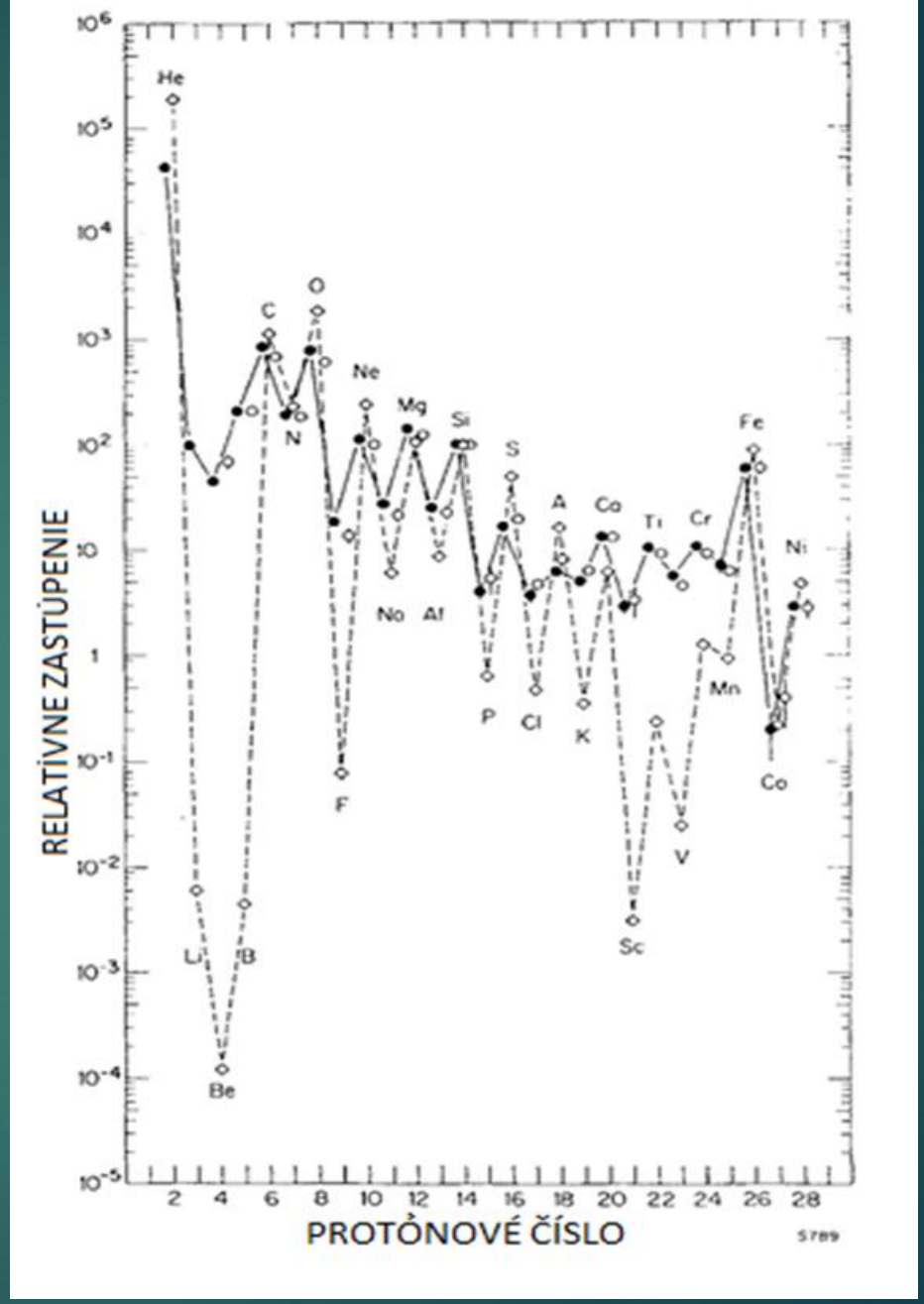
- V rozdedzí rokov 1911 – 1913 realizoval sériu 10 výstupov teplovzdušným balónom
- 1911 – 2
- 1912 – 7 – ***7.8.1912***
- 1913 – 1

- Predpokladal, že gama lúče výhradne z pôdy by mali byť úplne absorbované vo výške 500 m

Zdroj: Wikipedia

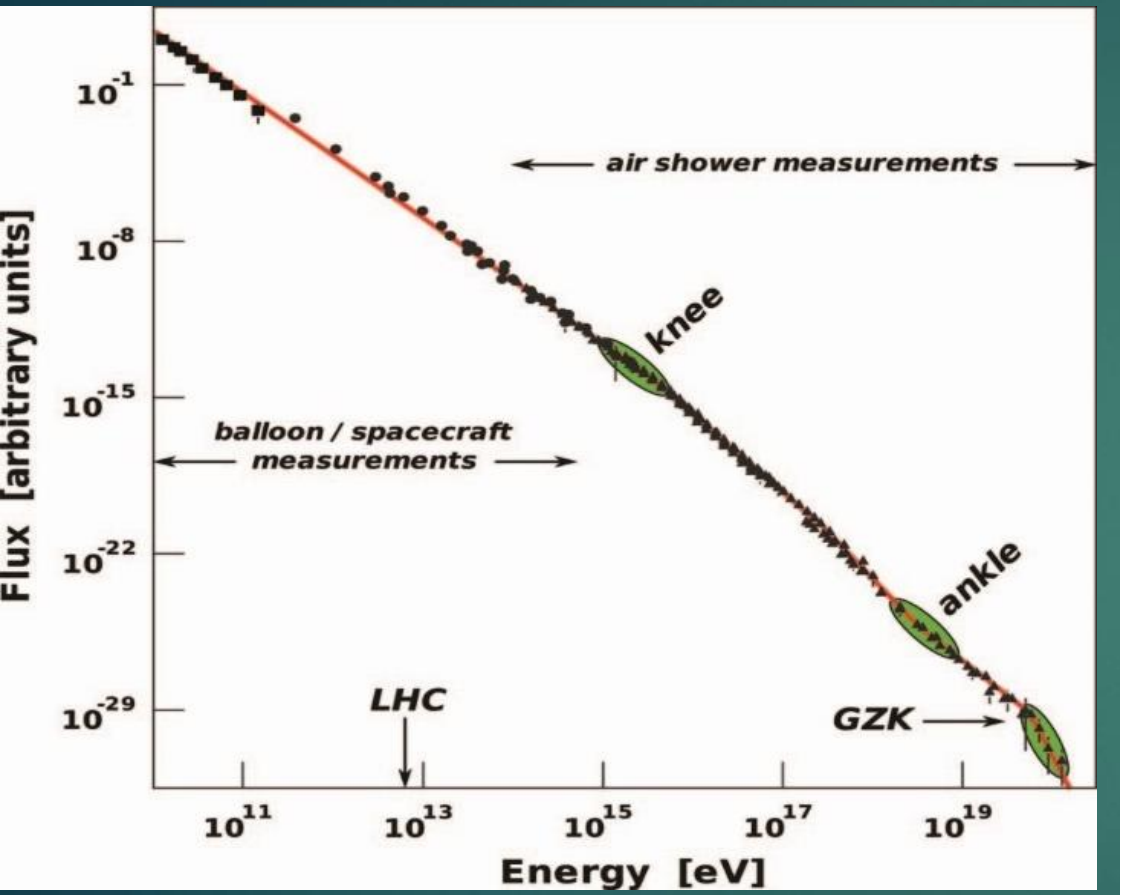
- protóny (Z = 1)
- a častice – jadrá hélia (Z = 2)
- ľahké jadrá L – Li, Be, B ($3 \leq Z \leq 5$)
- stredne ťažké jadrá M – C, N, O, F ($6 \leq Z \leq 9$)
- ťažké jadrá H – Ne až K ($10 \leq Z \leq 19$)
- veľmi ťažké jadrá VH – Ca až vyššie ($20 \leq Z$)

- Približne 90% tvoria protóny, 9% jadrá hélia, zbytok približne 1% ostatné ťažšie jadrá

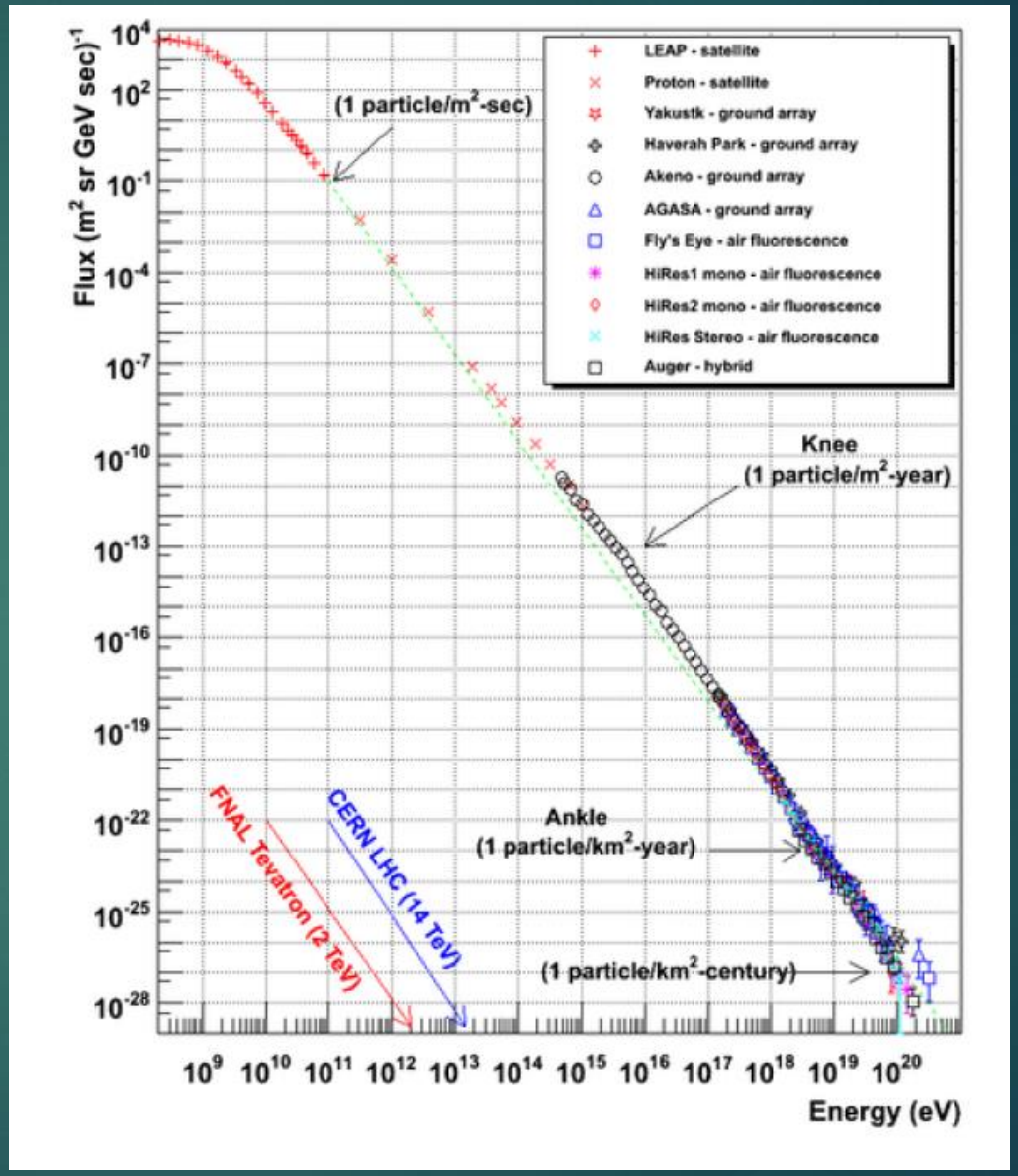


(L. O´C. Drury, 1994)

Energetické spektrum



(Zavrtanik, 2010)



Zdroj: https://www.physics.utah.edu/~whanlon/spectrum.html

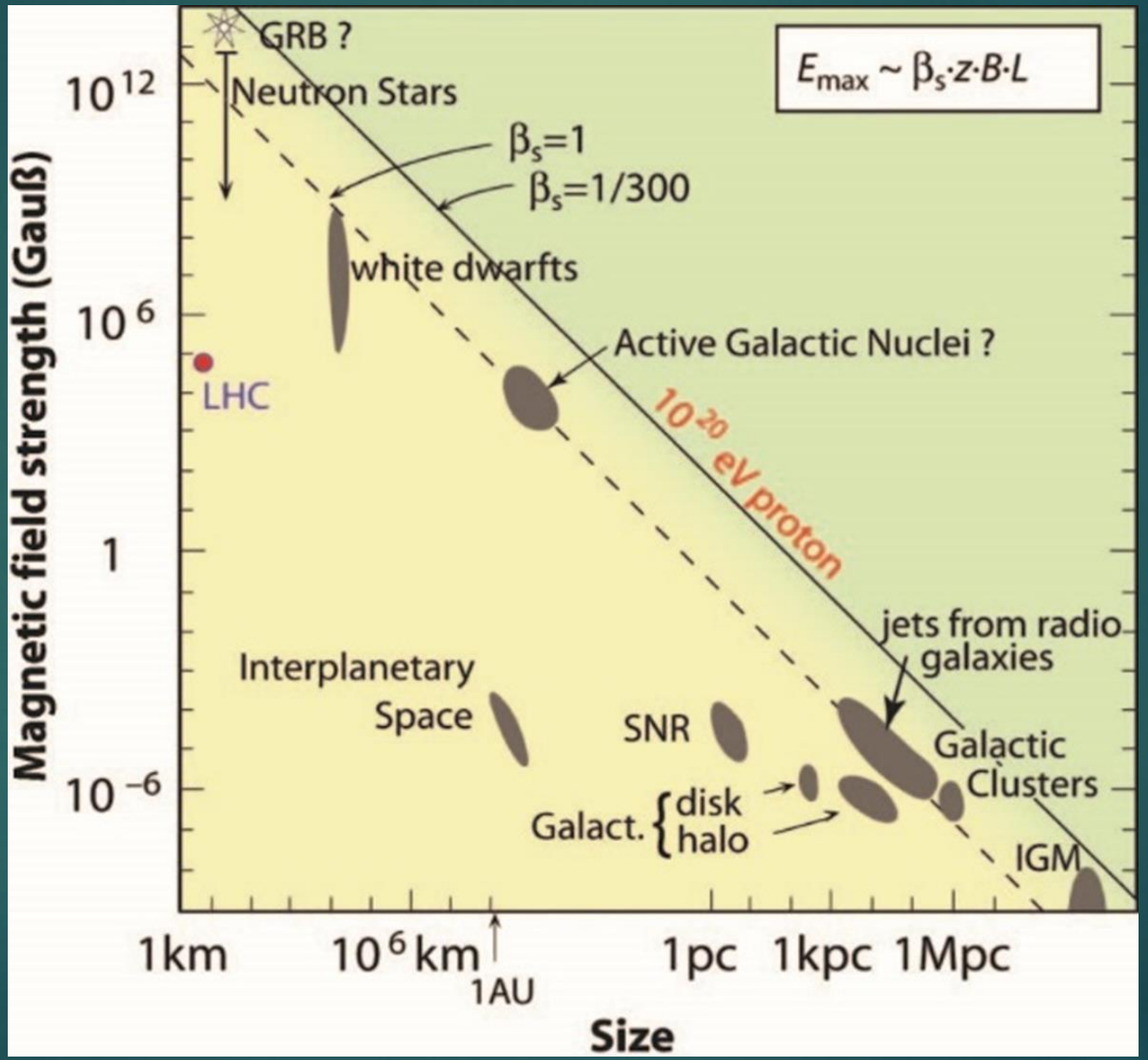
$1\ eV = 1{,}6.10^{-19}\ C.V = 1{,}6.10^{-19}\ J$

$10^{20}\ eV \approx 16\ J$

K porovnaniu – tenisová loptička m = 56 g s kinetickou energiou E = 16 J

$$E_k = \frac{1}{2}mv^2 \qquad v = \sqrt{\frac{2E_k}{m}} \longrightarrow v = 23{,}9\ m.s^{-1} = 86{,}04\ km.h^{-1}$$

Odkiaľ sa takéto častice berú pri najvyšších energiách?



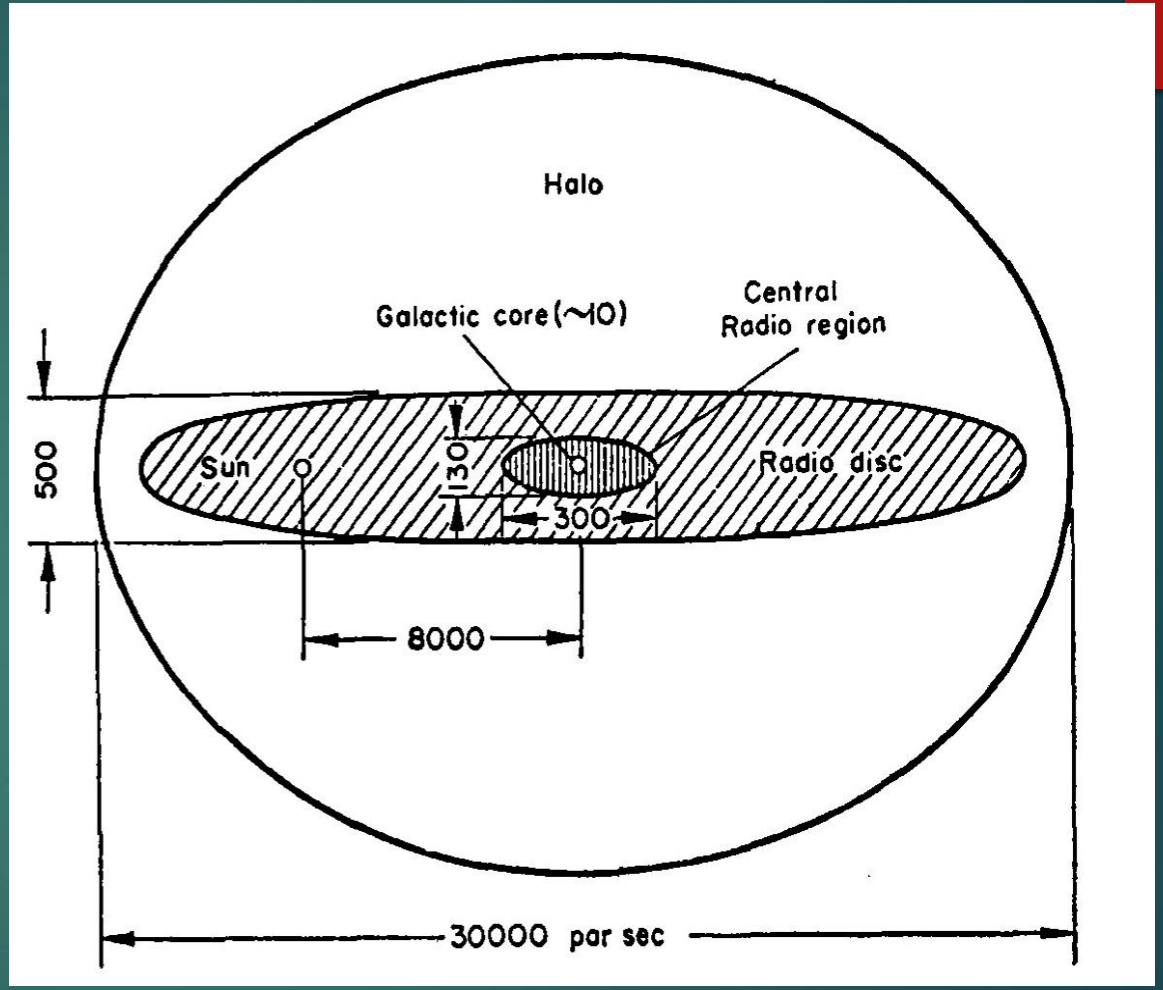
(Zavrtanik, 2010)

$$r_L = 1.08 \frac{E}{Z \cdot B} \quad [\mathrm{pc}] .$$

E = 10 000 PeV
B = rádovo 1 μG
Z = 1 (uvažujeme protóny)

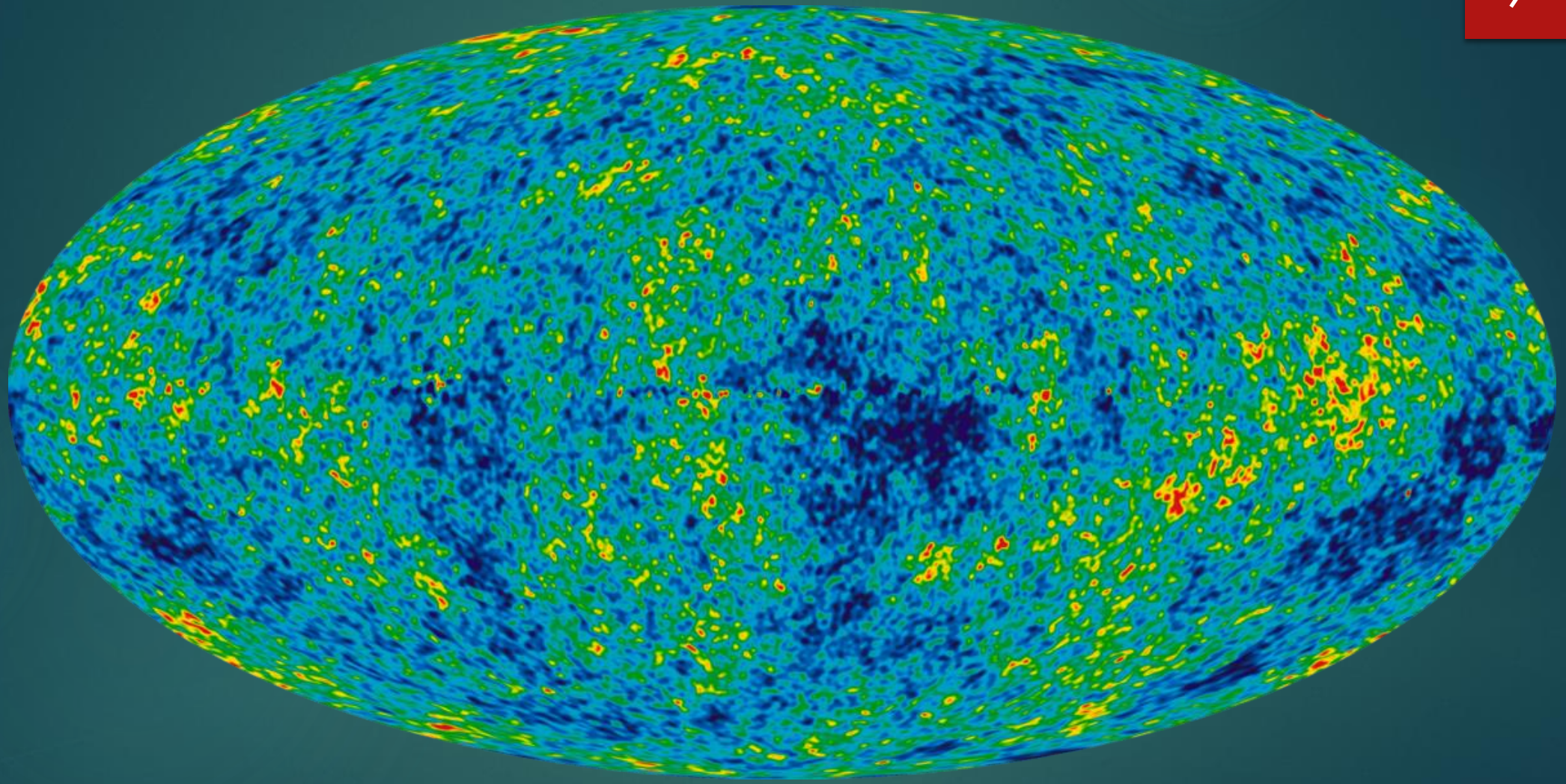
$$r_L = 108\,000\ pc$$

Viac ako rozmery Galaxie – častica sa v nej neudrží!!!



(D. Ter Haar, 1965)

Potreba modelovania interakcie častíc s mikrovĺnnym pozadím



Zdroj: Wikipedia

T_0 = 2,7 K
E = 10^{-3} eV

Procesy, s ktorými treba počítať

- Tvorba párov

$$ {}^{A}_{Z}X + \gamma \longrightarrow {}^{A}_{Z}X + e^{+} + e^{-} $$

- Fotodezintegrácia

$$ {}^{A}Z + \gamma \rightarrow {}^{A-1}Z + \mathrm{n}, \qquad {}^{A}Z + \gamma \rightarrow {}^{A-1}(Z-1) + \mathrm{p} $$
$$ {}^{A}Z + \gamma \rightarrow {}^{A-4}(Z-2) + {}^{4}\mathrm{He}, \qquad \text{etc.} $$

- Foto-piónová produkcia

$$ \mathrm{p} + \gamma \rightarrow \mathrm{p} + \pi^{0}, \qquad \mathrm{n} + \gamma \rightarrow \mathrm{n} + \pi^{0} $$
$$ \mathrm{p} + \gamma \rightarrow \mathrm{n} + \pi^{+}, \quad \text{and} \quad \mathrm{n} + \gamma \rightarrow \mathrm{p} + \pi^{-} $$

- Straty energie z dôvodu rozpínania vesmíru

$$ \left(-\frac{1}{E}\frac{\mathrm{d}E}{\mathrm{d}t}\right)_{\mathrm{ad}} = H(t) = H_0\sqrt{(1+z)^3\Omega_{\mathrm{m}} + \Omega_{\Lambda}} $$

(Aloisio et al., 2016)

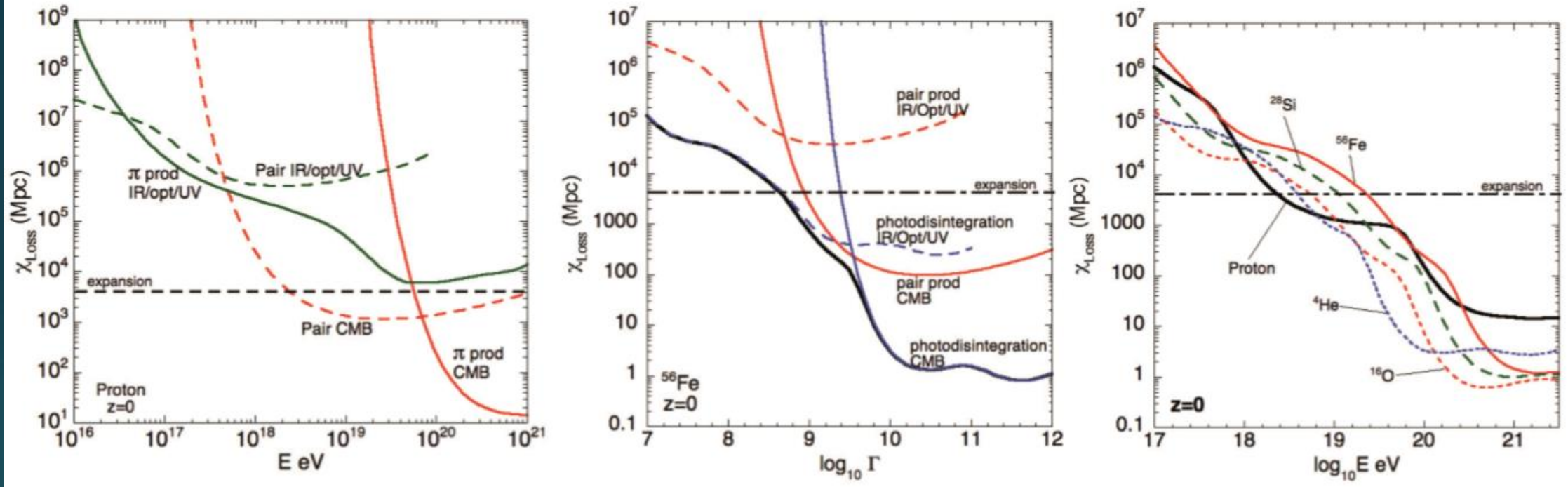
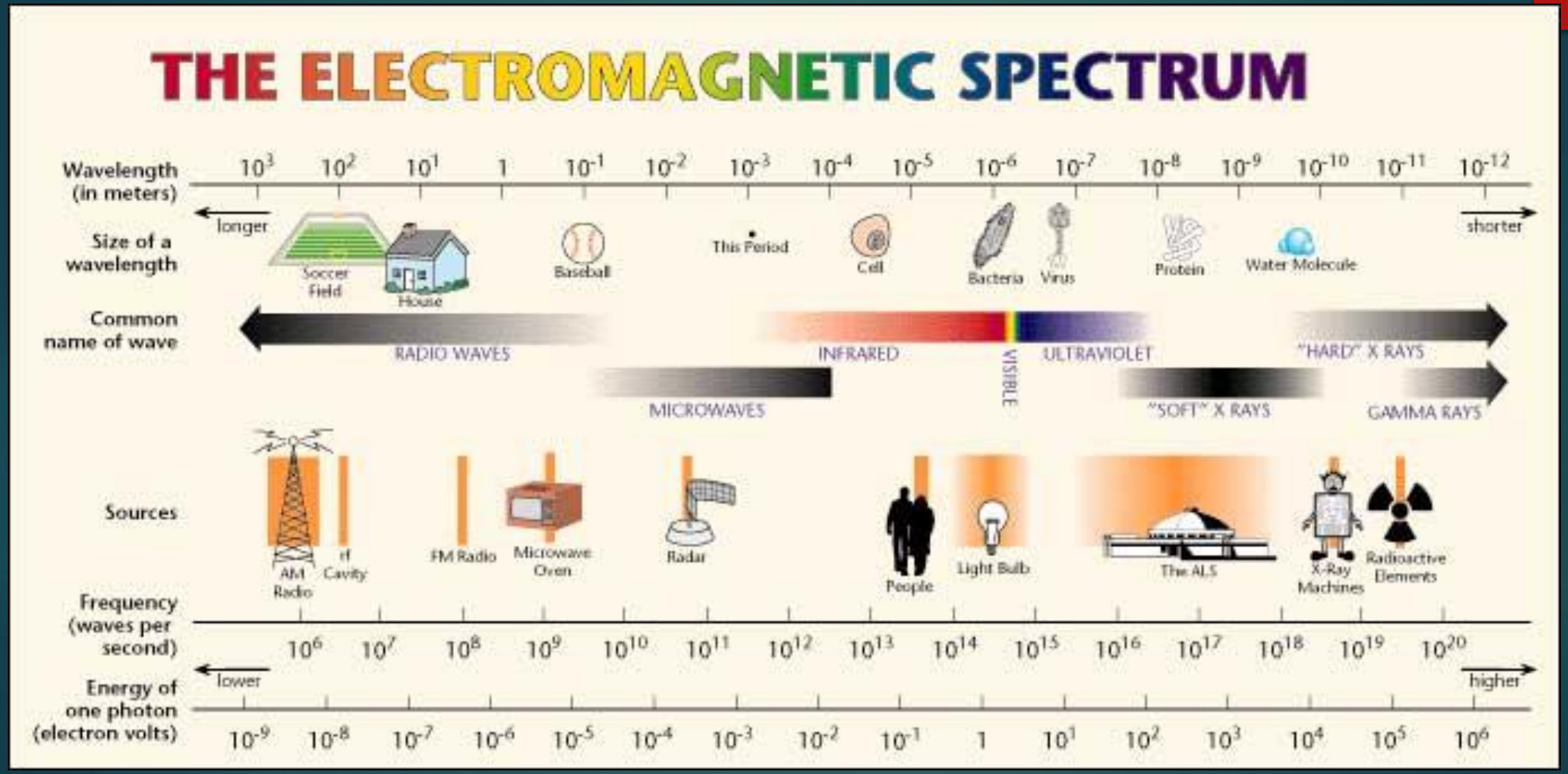


Figure 2 – Left: Energy loss length $\chi_{Loss} = \left(\frac{E}{-dE/dx}\right)$ for primary protons as a function of energy. Different energy-loss processes on various photon backgrounds (CMB, infrared, optical and ultra-violet) are indicated. Center: Energy loss length for iron as a function of the Lorentz factor Γ. Different contributions of pair production and photodisintegration on various backgrounds are indicated. Right: Energy loss length for different nuclei as a function of energy. In all three figures, the effect of adiabatic expansion of the universe is indicated by a horizontal dashed line. (From [9])

Vesmír je nepriehľadný pre takéto častice – musia pochádzať z blízkeho okolia do 100 Mpc

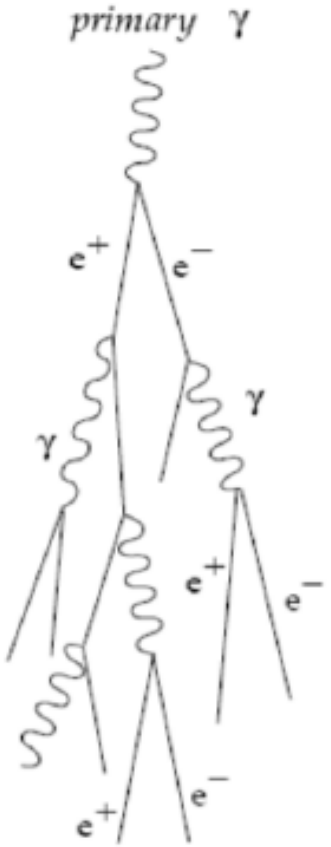
(Kuempel, 2014)

Zdroj: NASA

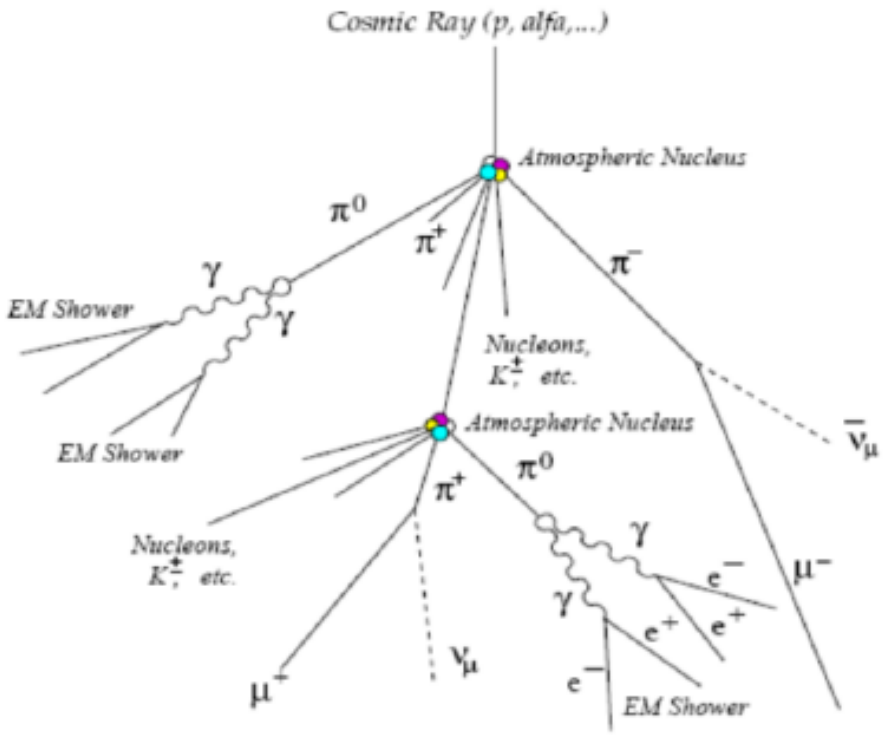


- Enegie od 100 keV až do rádovo 100 TeV

Electromagnetic Shower (γ, e^-)

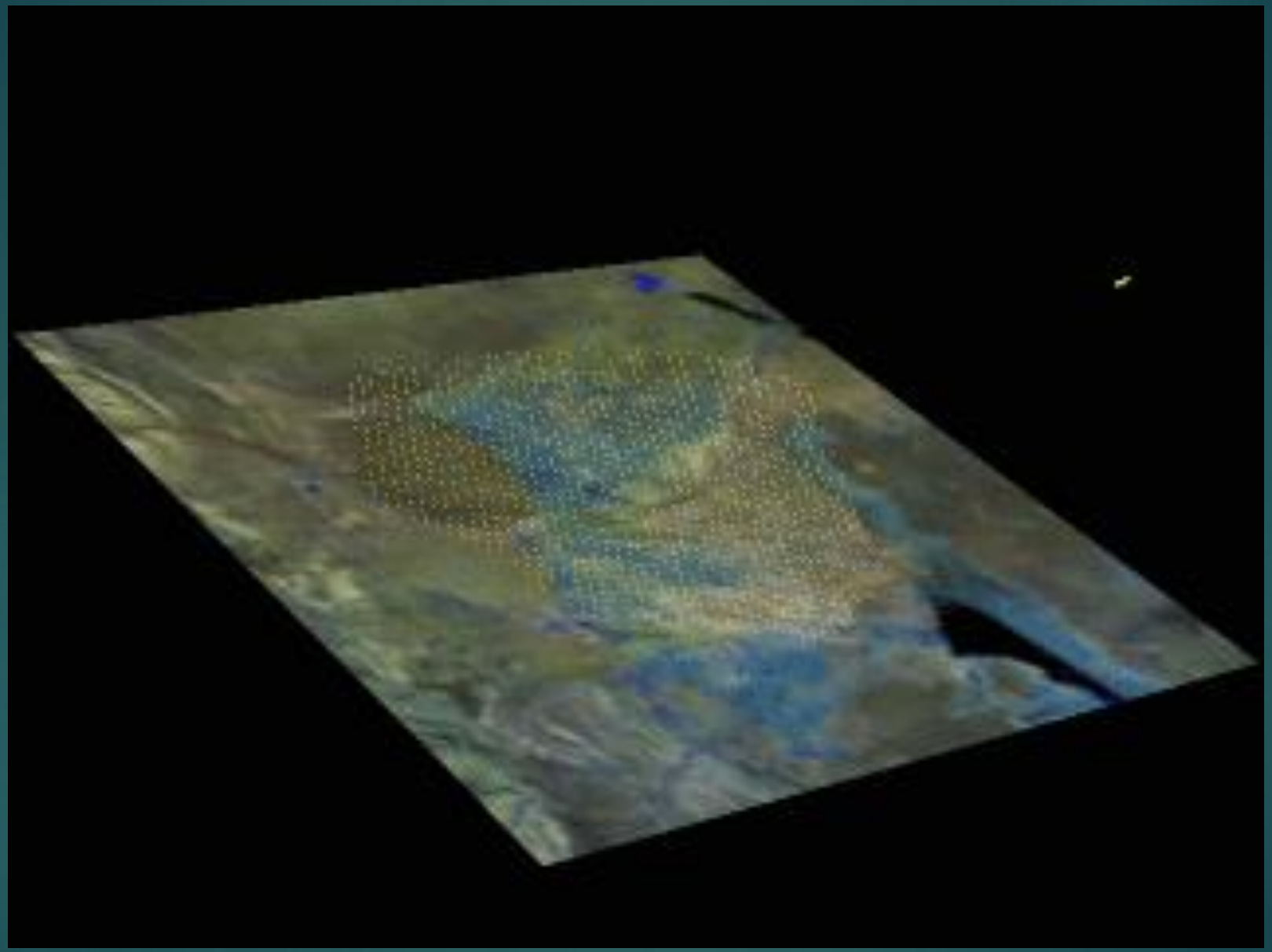


Hadronic Shower



e^- Shower

(Otero Santos, 2018)



Zdroj: https://www.auger.org/index.php/cosmic-rays/shower-simulations

Detekčné techniky

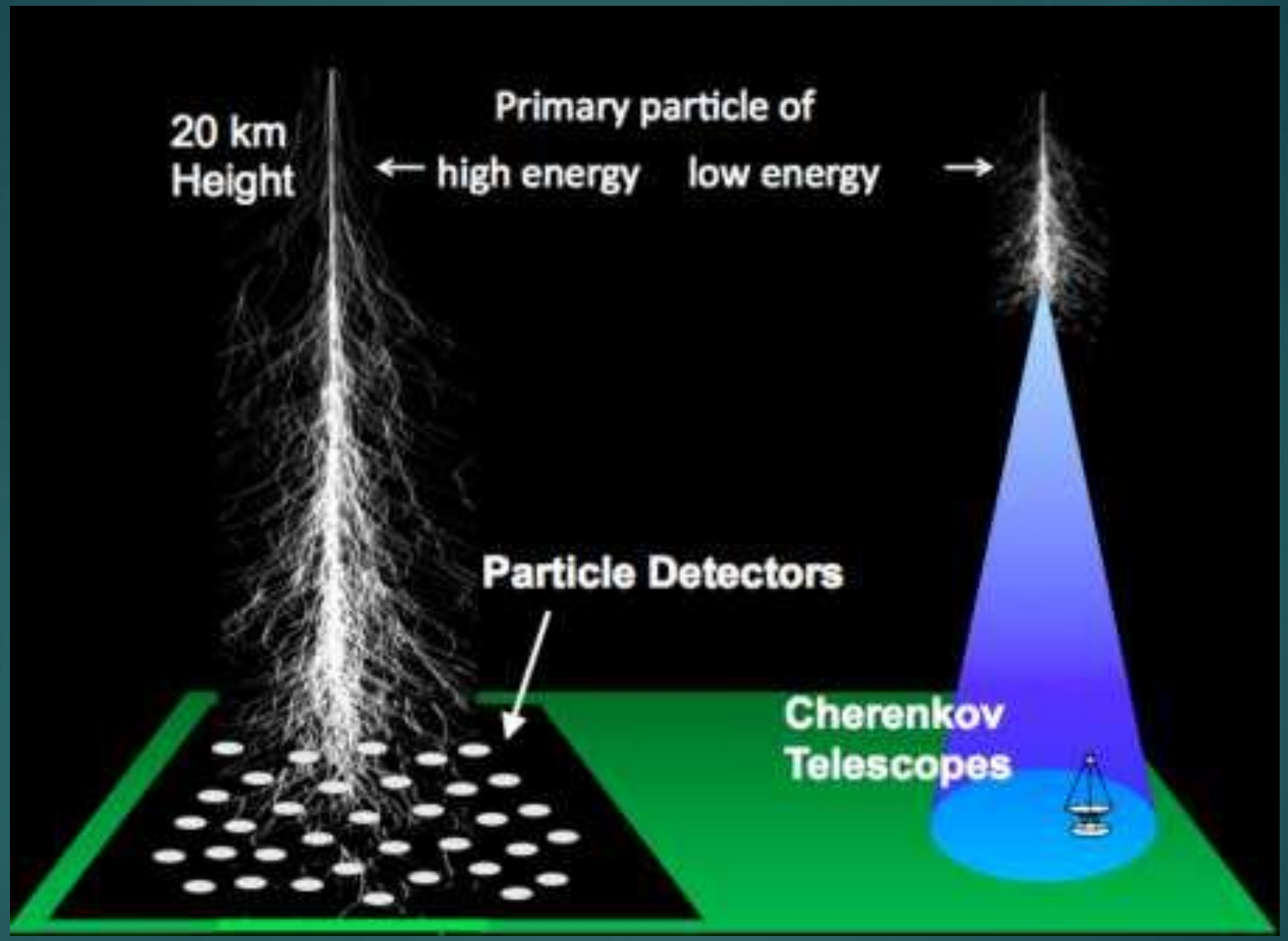
- Priame – účinné pre nižšie energie, detektory na satelitoch (Fermi)

Zdoj: NASA

- Nepriame – detekcia sekundárnych častíc v sprškach
  - **Imaging Atmospheric Cherenkov Telescopes (IACT)** – MAGIC, Veritas, H.E.S.S., CTA
  - **Extensive Air Showers** (EAS) – HAWC, PAO

(Degrange et al., 2015)

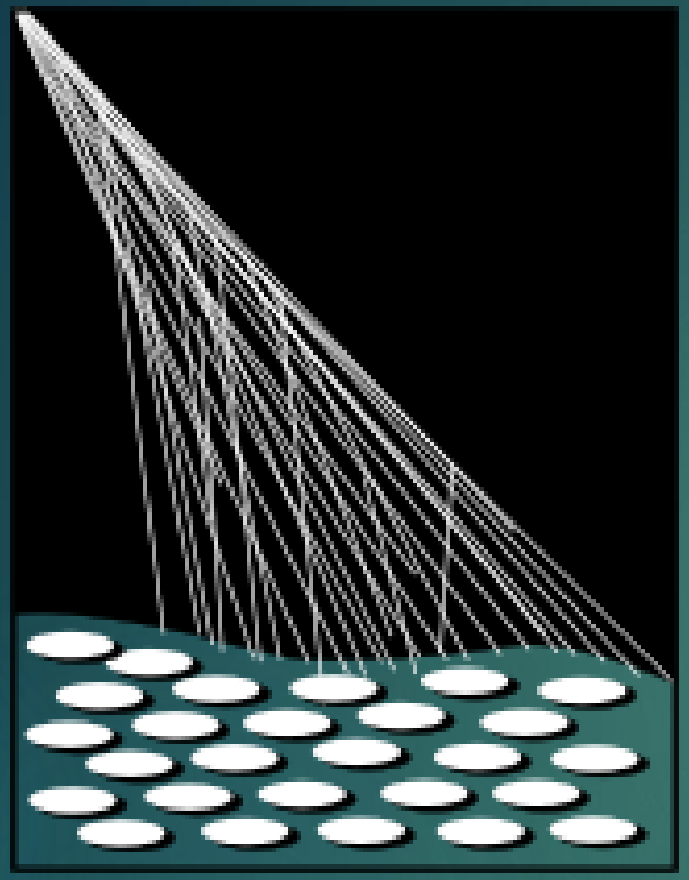
Zdroj: https://www.hawc-observatory.org/



Zdroj: https://inspirehep.net/record/1123761/plots

Quantity	*Fermi*	IACTs	EAS
Energy range	20 MeV–200 GeV	100 GeV–50 TeV	400 GeV–100 TeV
Energy res.	5–10 %	15–20 %	$\sim$ 50 %
Duty cycle	80 %	15 %	$>$ 90 %
FoV	$4\pi/5$	5 deg $\times$ 5 deg	$4\pi/6$
PSF (deg)	0.1	0.07	0.5
Sensitivity	1 % Crab (1 GeV)	1 % Crab (0.5 TeV)	0.5 Crab (5 TeV)

Table 1. A comparison of the characteristics of Fermi, the IACTs and of the Extensive Air Showers (EAS) particle detector arrays. Sensitivity computed over one year for Fermi and the EAS, and over 50h for the IACTs.



PIERRE AUGER OBSERVATORY

Pierre Auger Observatory

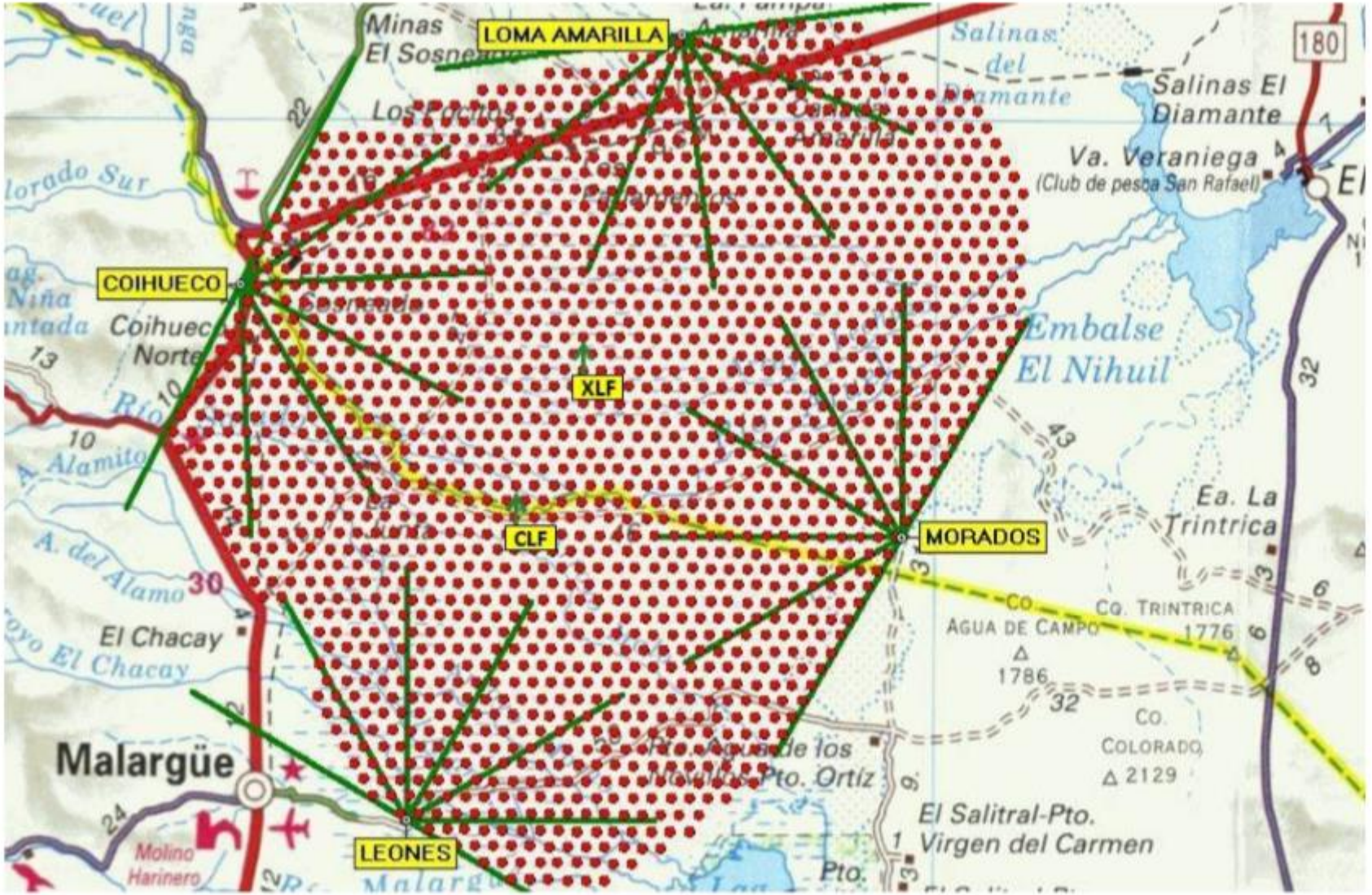
- Najväčšie svetové observatórium pre štúdium tzv. UHECRs
- Medzinárodná spolupráca 18 krajín
- Situované v Argentíne
- Štúdium spŕšok kozmického žiarenia
- Určovanie energií, zloženia a smer príchodu vysokoenergetických častíc
- Dokončenie v roku 2008

Location of Pierre Auger Observatory in Argentina.

- Šírka 35,0° - 35,3° S
- Dĺžka 69,0° - 69,4° W
- Stredná nadmorská výška 1400 m
- Medzi 1340 m – 1610 m

Zdroj: Wikipedia

Zdroj: https://www.auger.org/index.php/about-us/institutions



(The Pierre Auger Collaboration, 2015)

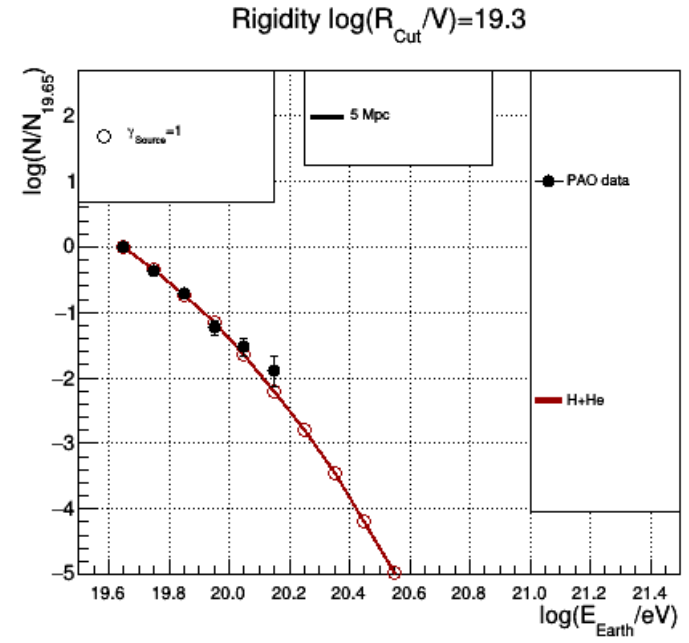
Akademie věd České republiky

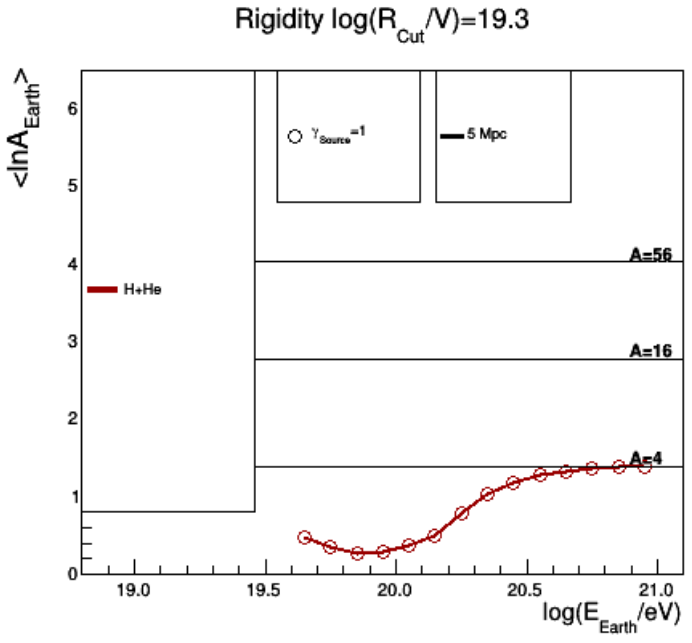
Diplomová práca

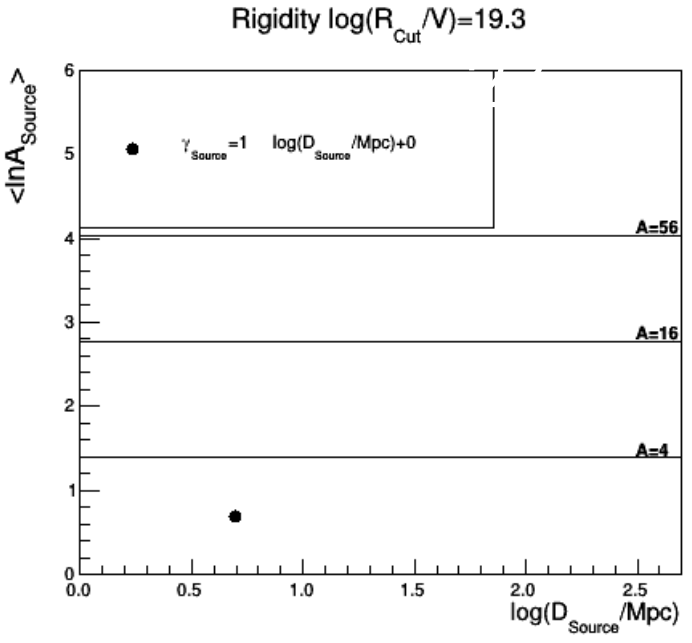
Sources, mass composition and energy spectrum of ultra-high energy cosmic rays

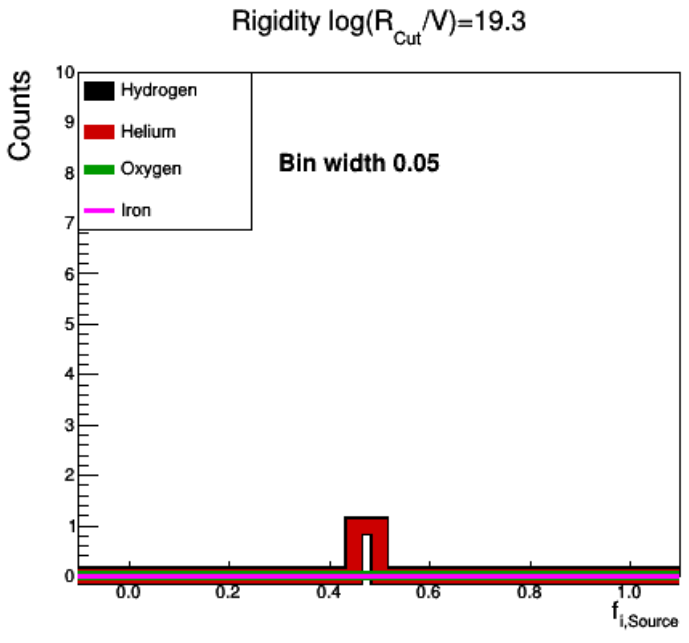
Author: Mgr. Patrik Čechvala
Supervisor: Ing. Jakub Vícha, PhD.°
Consultant: RNDr. Petr Trávniček, PhD. °

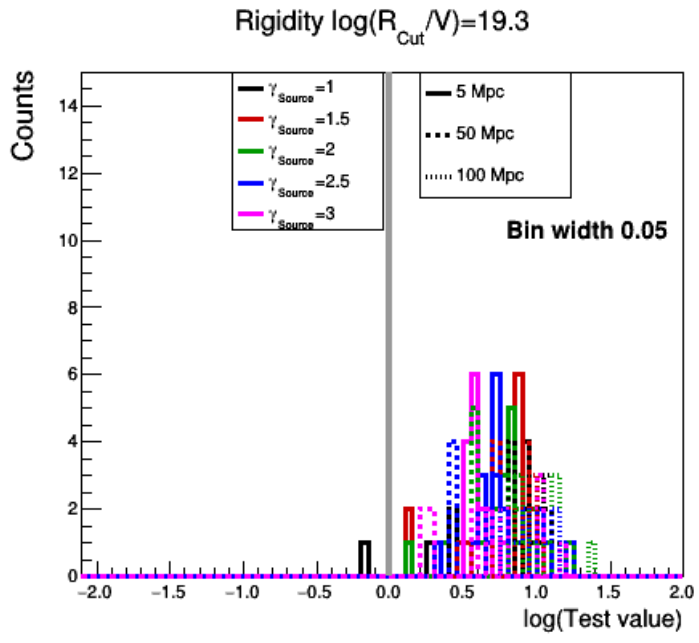
° Institute of Physics, Czech Academy of Sciences

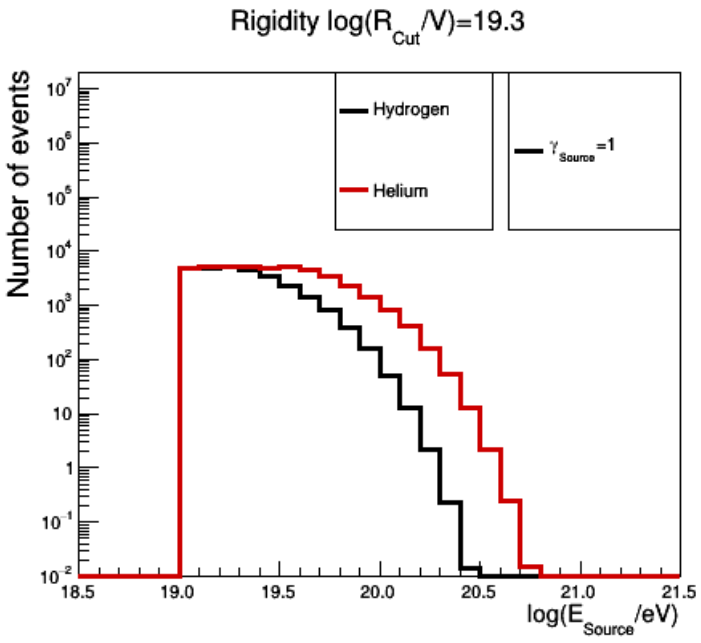

Rigidity log(R_Cut/V)=19.3
log(N/N_19.65)
γ_Source=1
5 Mpc
PAO data
H+He
log(E_Earth/eV)


Rigidity log(R_Cut/V)=19.3
<lnA_Earth>
γ_Source=1
5 Mpc
H+He
A=56
A=16
A=4
log(E_Earth/eV)


Rigidity log(R_Cut/V)=19.3
<lnA_Source>
γ_Source=1
log(D_Source/Mpc)+0
A=56
A=16
A=4
log(D_Source/Mpc)


Rigidity log(R_Cut/V)=19.3
Counts
Hydrogen
Helium
Oxygen
Iron
Bin width 0.05
f_i,Source


Rigidity log(R_Cut/V)=19.3
Counts
γ_Source=1
γ_Source=1.5
γ_Source=2
γ_Source=2.5
γ_Source=3
5 Mpc
50 Mpc
100 Mpc
Bin width 0.05
log(Test value)


Rigidity log(R_Cut/V)=19.3
Number of events
Hydrogen
Helium
γ_Source=1
log(E_Source/eV)

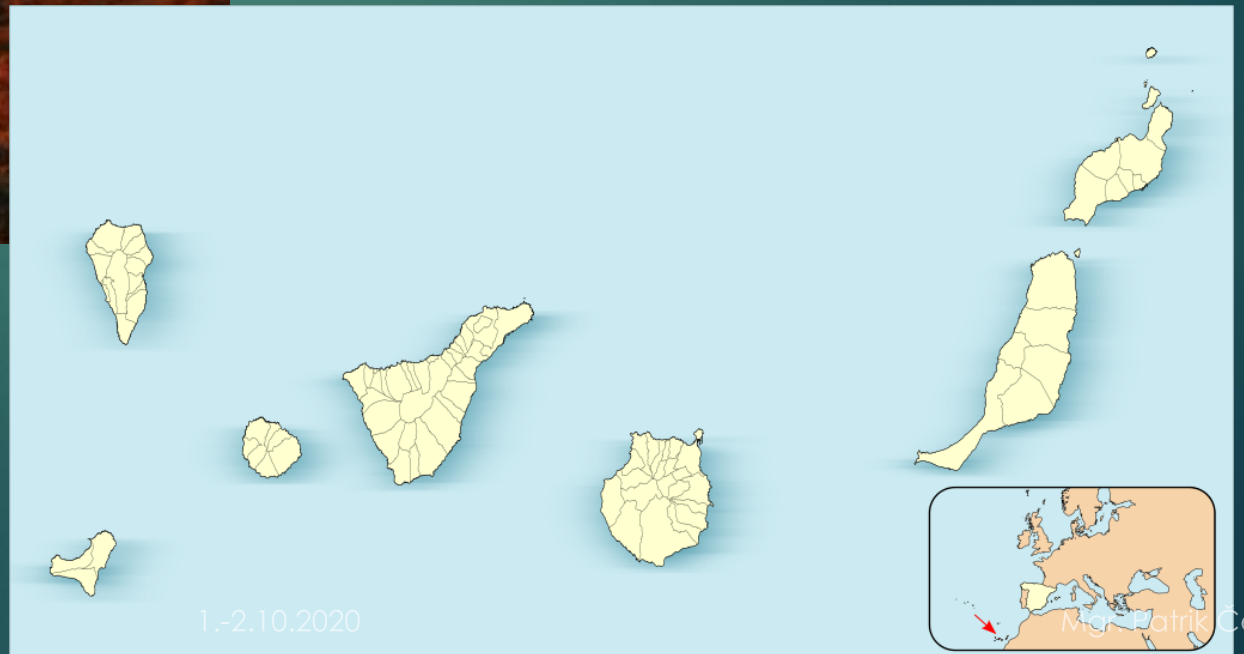
MAGIC Telescopes

Major Atmospheric Gamma Imaging Cherenkov Telescopes

- 17 m reflektory

Kanárske ostrovy

Zdroj: http://www.magic.iac.es/



MAGIC telescopes

- Major Atmospheric Gamma Imaging Cherenkov Telescopes
- Citlivosť – 50 GeV – 30 TeV
- Roque de Los Muchachos Observatory, La Palma
- 17 m priemer
- Kamera – 1039 fotonásobičov (PMTs)
- FoV – 3.5°

Foto: Daniel López, IAC

Project – Study of the gamma source 2FHL J1839.5-0705 using archival data taken by MAGIC telescopes

Supervisor – Alicia López Oramas (IAC)

- Idea projektu – spracovanie archívnych dát

Unidentified Fermi Source (UFO) in an active galactic region

Diploma thesis

Author: Jorge Otero Santos

Supervisor: Alicia López Oramas

Ramón García López

2018

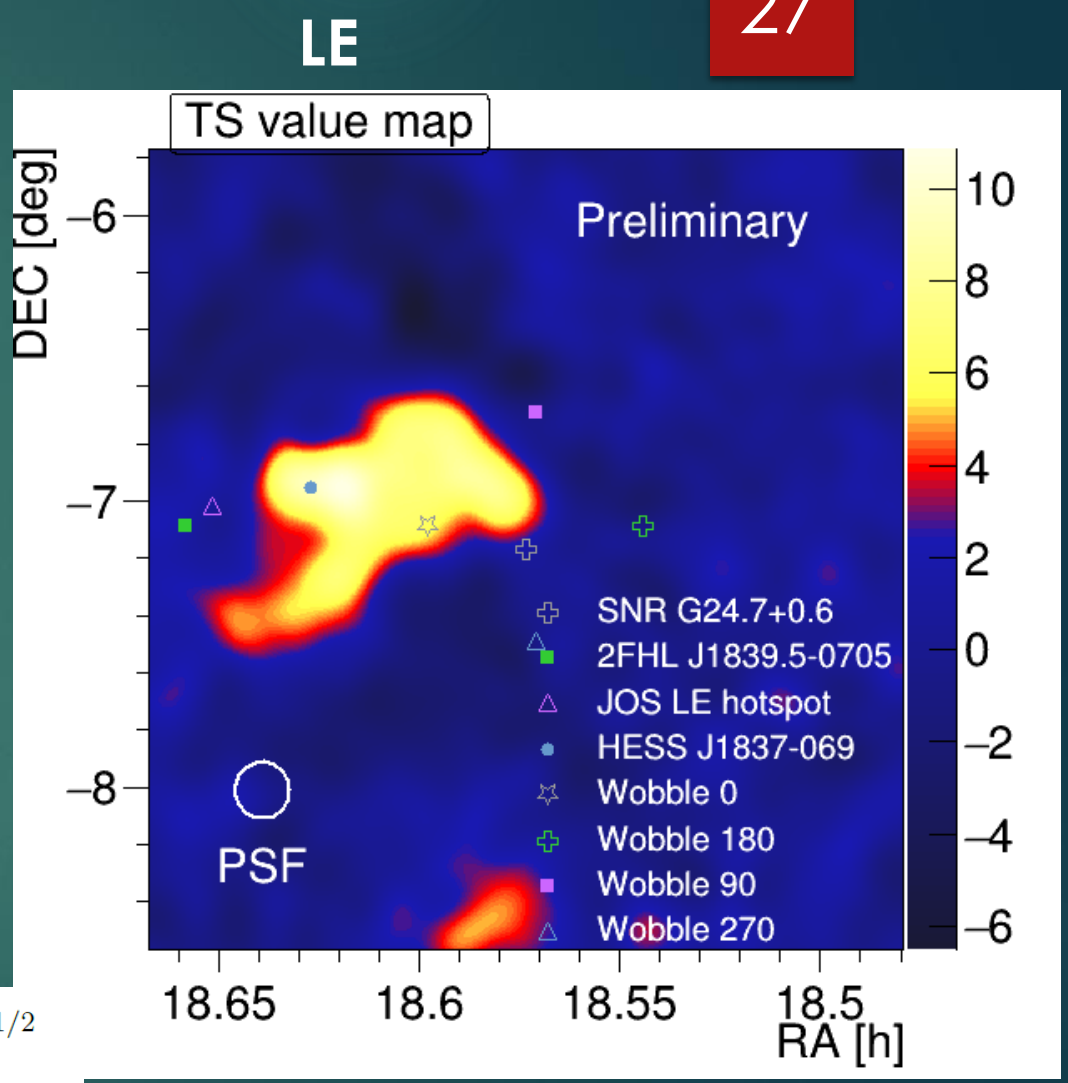
Analýza a prvotné výsledky

- Study of the source in 3 energy intervals

- **Low energy – LE, *E* > 100 GeV**
- **Full range – FR, *E* > 250 GeV**
- **High energy – HE, *E* > 1 TeV**

- Generation of the skymap – Caspar routine
- TS value – corresponds to Li & Ma (1983) significance given by formula

$$\sigma = \sqrt{2}\left\{ N_{on} \log\left[(\tau+1)\left(\frac{N_{on}}{N_{on}+N_{off}}\right)\right] + N_{off}\log\left[\left(\frac{1+\tau}{\tau}\right)\left(\frac{N_{off}}{N_{on}+N_{off}}\right)\right]\right\}^{1/2}$$




tu

Cherenkov Telescope Array

- Small – Sized Telescope (SST) – 70 teleskopov so 4 m piemerom zrkadla
- Medium – Sized Telescope (MST) – 40 teleskopov s 12 m priemerom zrkadla
- Large – Sized Telescope (LST) – 8 teleskopov s 23 m priemerom zrkadla

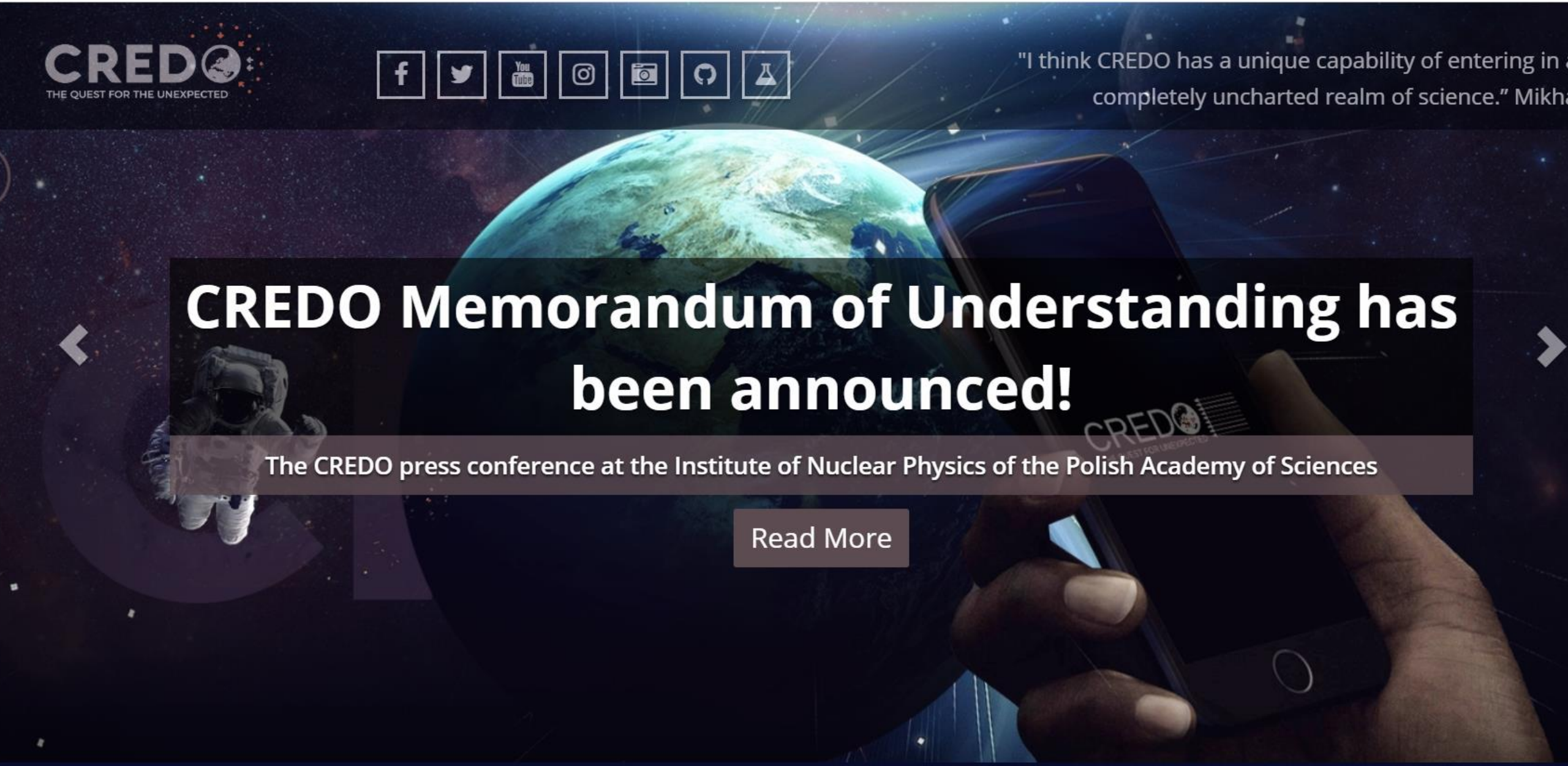
Zdroj: https://www.cta-observatory.org/

Ako sa môžu zapojiť do výskumu laici?

credo.science

CREDO
THE QUEST FOR THE UNEXPECTED

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



CREDO Memorandum of Understanding has been announced!

The CREDO press conference at the Institute of Nuclear Physics of the Polish Academy of Sciences

Read More

zooniverse.org/projects/zooniverse/muon-hunter-classic

PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS SIGN IN

Muon Hunter Classic

ABOUT CLASSIFY TALK COL

Great work! Looks like this project is out of data at the moment!
See the results or dismiss this message

Help astronomers to find elusive muons disguised as gamma rays!

Learn more

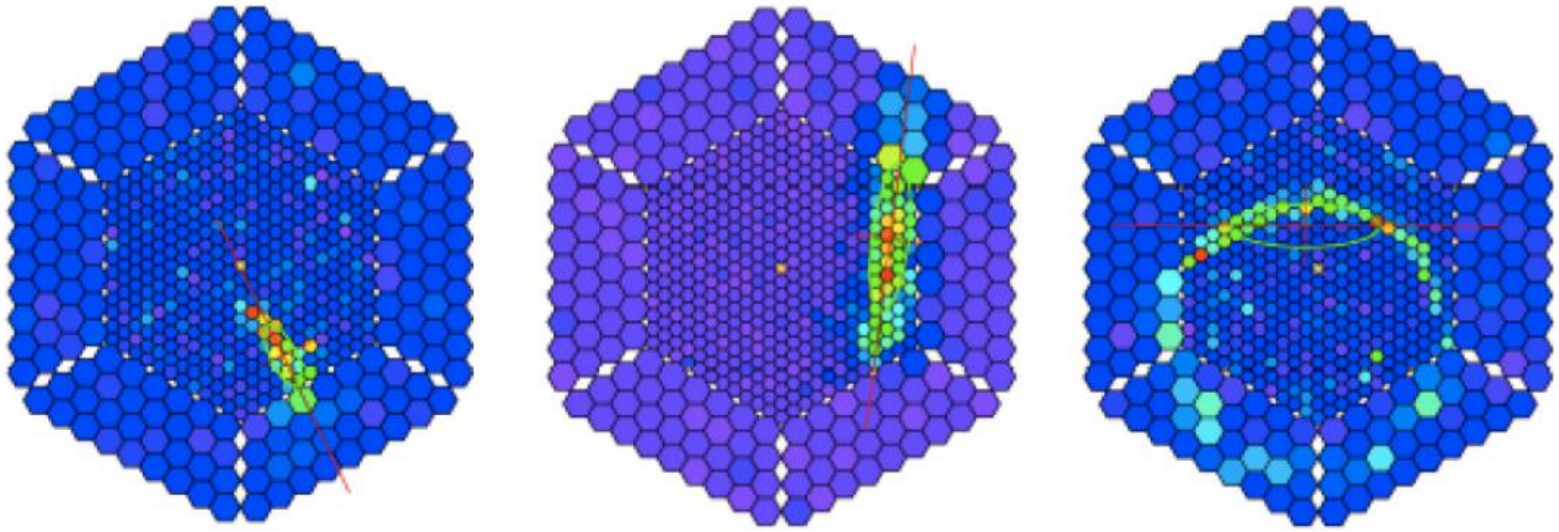


Figure 3: *Left*: Example of an image of an electromagnetic shower, with a compact and elliptical shape. *Center*: Example of an image formed by a hadronic shower, broader than the γ-ray cascade. *Right*: Characteristic ring shape image of a muon detection. *Credit: MAGIC Collaboration.*

(Otero Santos, 2018)

Poďakovanie

Práca bola podporená grantom pre doktorandov a mladých vedeckých pracovníkov Univerzity Komenského s číslom UK/363/2020.

Ďakujem za pozornosť