

# Kozmični žarki

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# Povzetek

- Delci
- Odkritje
- Lastnosti
- Izvor, nastanek, pospeševanje
- Moderni detektorji
- Zaključek

# Delci

- Nabiti delci (ionizirana atomska jedra, elektroni, pozitroni, anti-protoni, ...)

- $m_p = 1,67 * 10^{-27} \text{ kg}$

- Hitrosti blizu  $c$

- $E = 10^{10} - 10^{20} \text{ eV}$

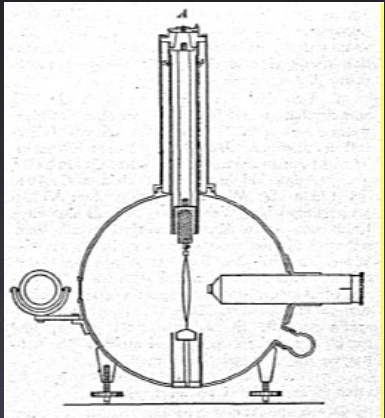
- $E_{\text{max}} = 3 * 10^{20} \text{ eV} = 50 \text{ J}$



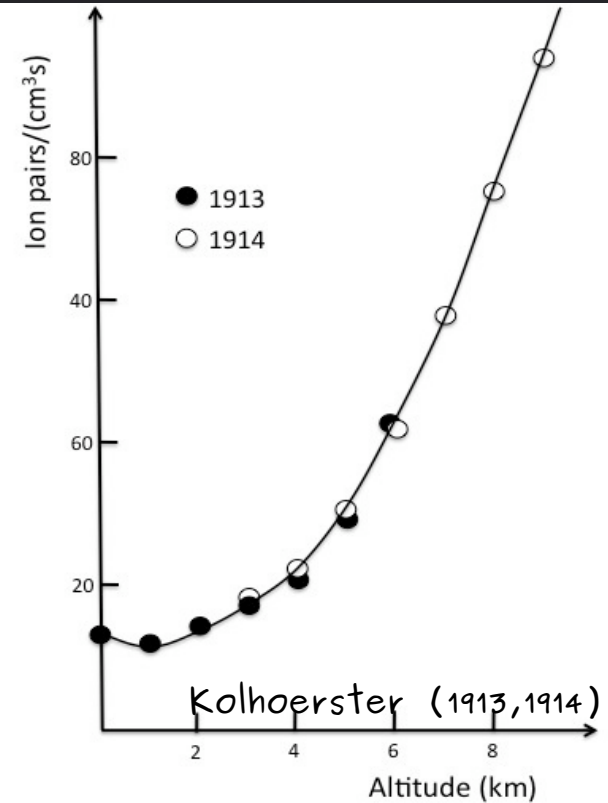
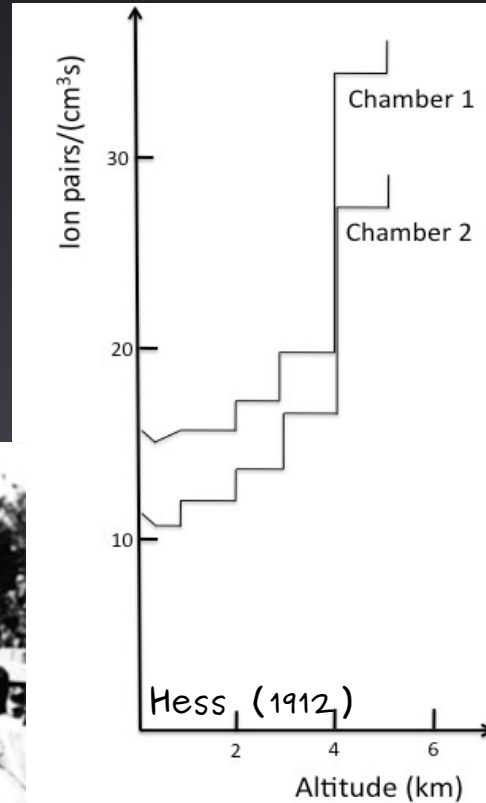
$\rightarrow 150 \text{ km/h} \rightarrow mv^2/2 \approx 50 \text{ J}$

# Kratka zgodovina

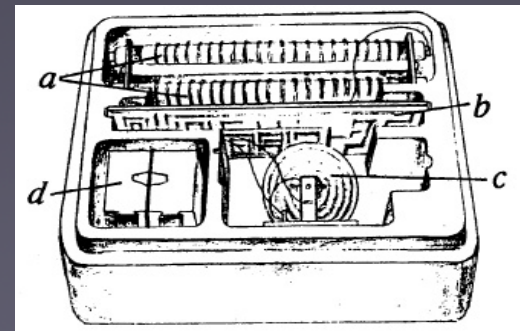
- Odkritje: Victor Hess, 1912 (NN 1936)



Wulf-ov  
elektrometer



Shema radio  
sonde za  
detekcijo KŽ



# Pomembni mejniki

- $e^+$ : Carl Anderson (1932, NN 1936)
- $\mu^-$ : Anderson & Neddermeyer (1936 – 1937)
- Sekundarni KŽ: Pierre Auger (1937)
- Fermi: mehanizem pospeševanja na udarnih valovih (1949)
- Odkritje KŽ z  $E_{\max} = 3 * 10^{20}$  eV (1991)
- 1995: Projekt Pierre Auger (SLO, UNI NG)

# Klasifikacija KŽ

- Sončevi

- maksimum pri sončevih izbruhih, pri izmetu sončeve mase
- tipične energije:  $E < 1 \text{ GeV}$

- Galaktični

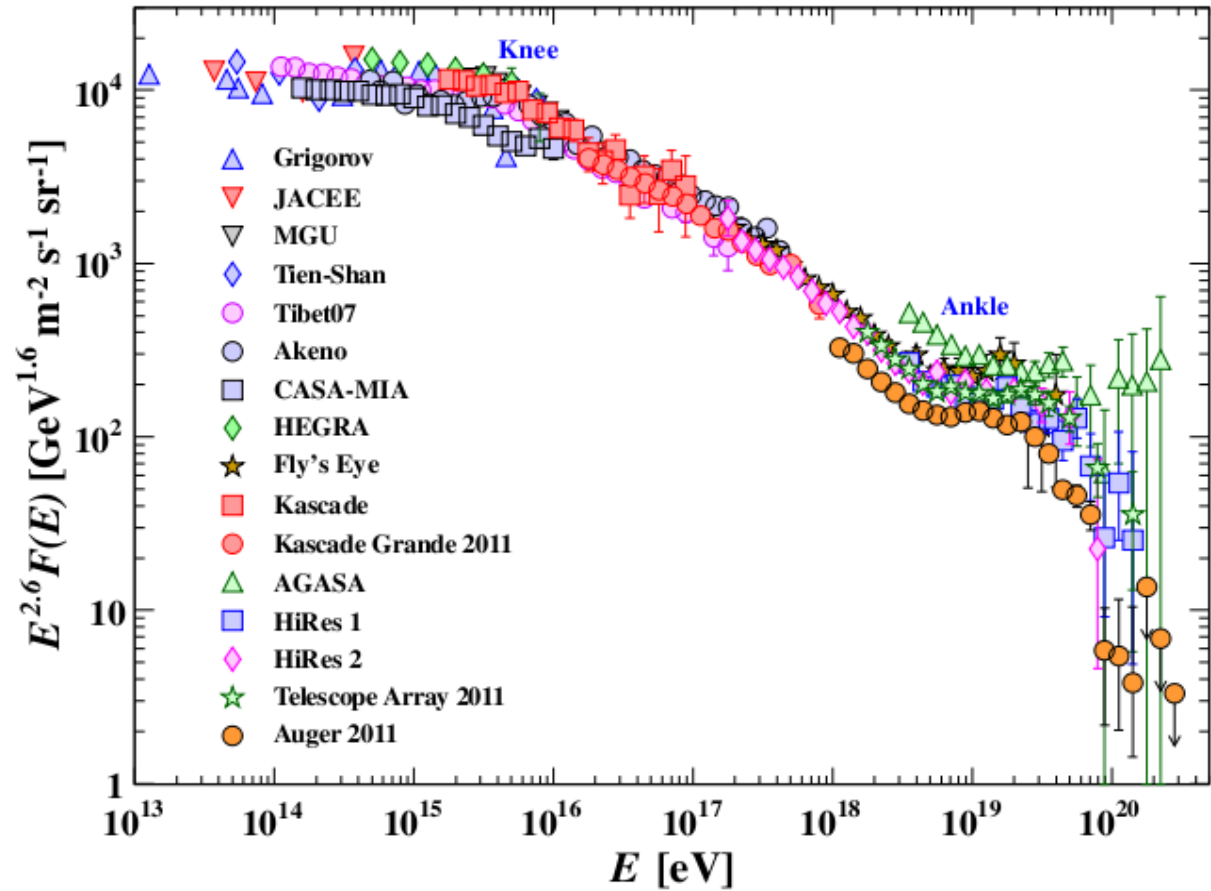
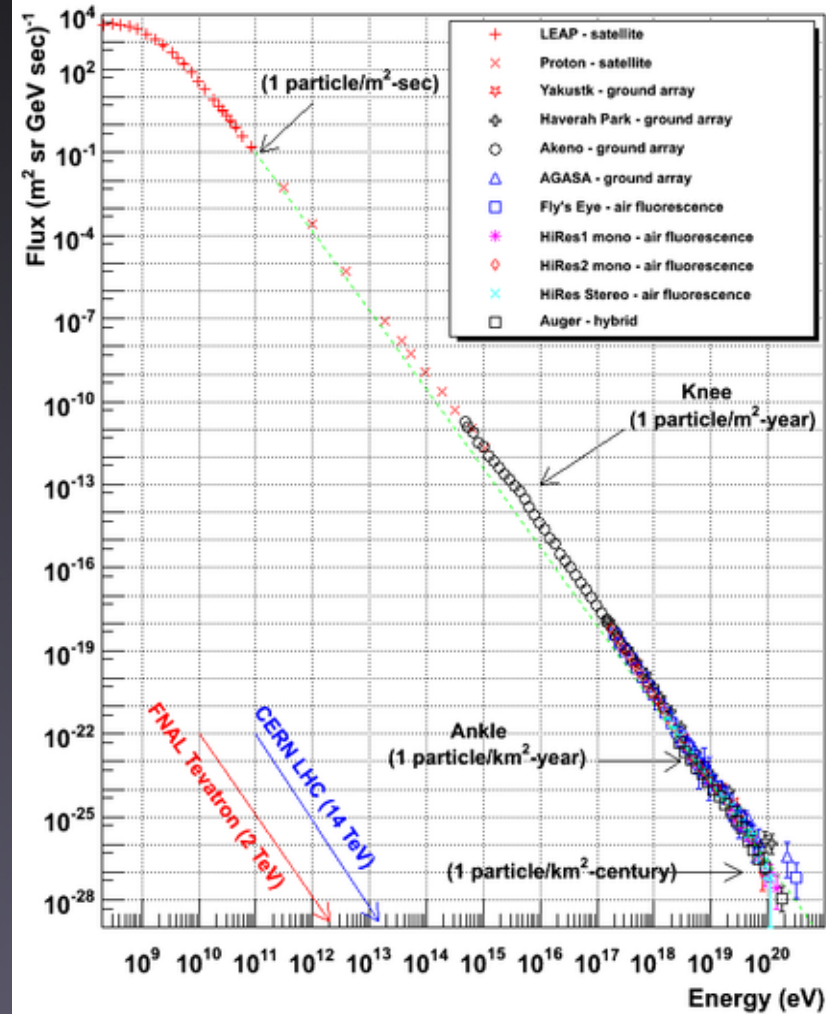
- daleč od sončevega sistema, v naši galaksiji
- zelo energetski
- potenčni spekter, največ med 100 MeV in 10 GeV, koleno:  $10^{16} \text{ eV}$
- večino protoni (H jedra), okrog 10% He jedra ( $\alpha$ ), 1% težjih jeder

- Ekstragalaktični

- izvor izven naše Galaksije, vendar zelo majhen fluks
- UHECR (ultra visoko-energetski), do  $E = 10^{20} \text{ eV}$

# Spekter KŽ

Cosmic Ray Spectra of Various Experiments



Beatty & Matthews (2011)

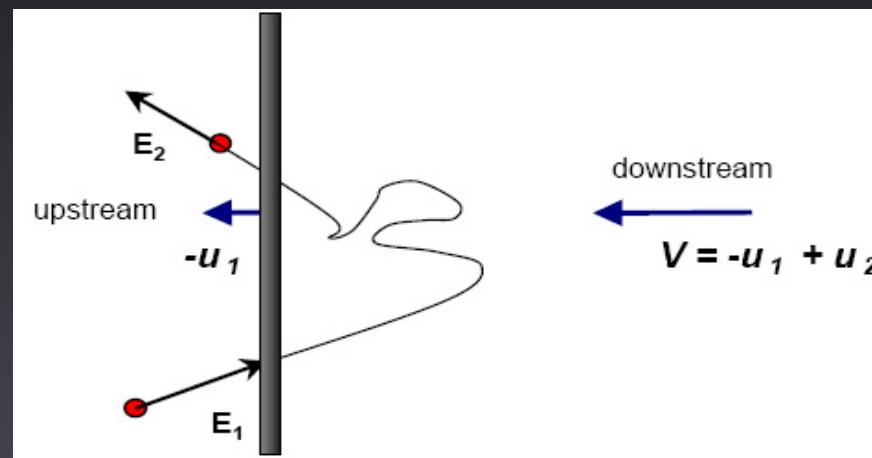
- Potenčni spekter
- "Koleni", "gleženj"
- GZK padeč pri  $6 \cdot 10^{19}$  eV (150M LY)  
(Greisen ter Zatsepin & Kuzmin, 1966)

Hanlon (2013)

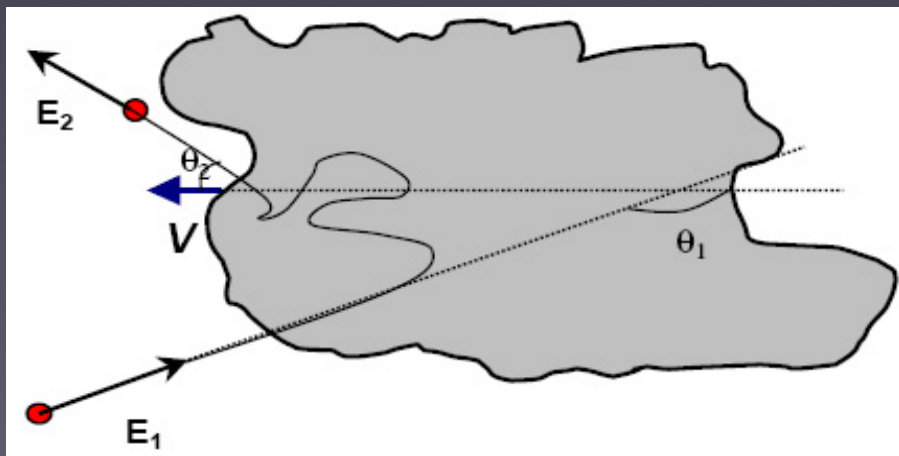
# Pospeševanje KŽ

- Fermi-jevo pospeševanje I in II reda
  - I: pospeševanje na udarnih valovih (npr. v ostankih supernov)

$$dE/E \approx (4/3) V/c$$
$$V \ll c$$



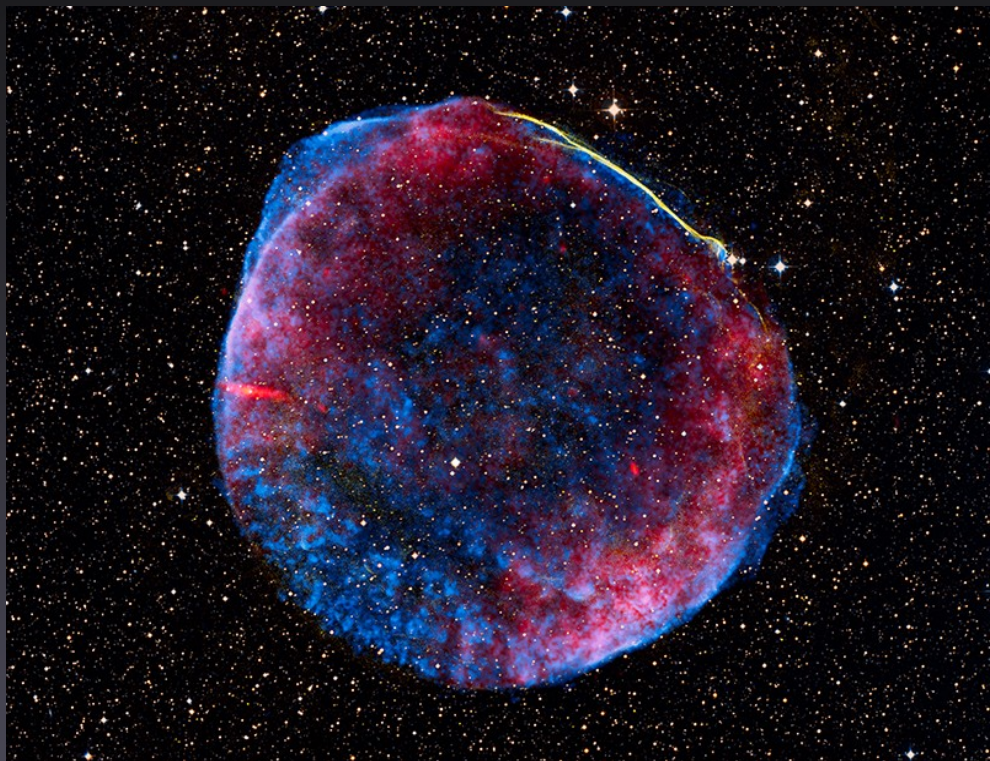
- II: pospeševanje v močnih magnetnih poljih ("magnetno zrcalo")



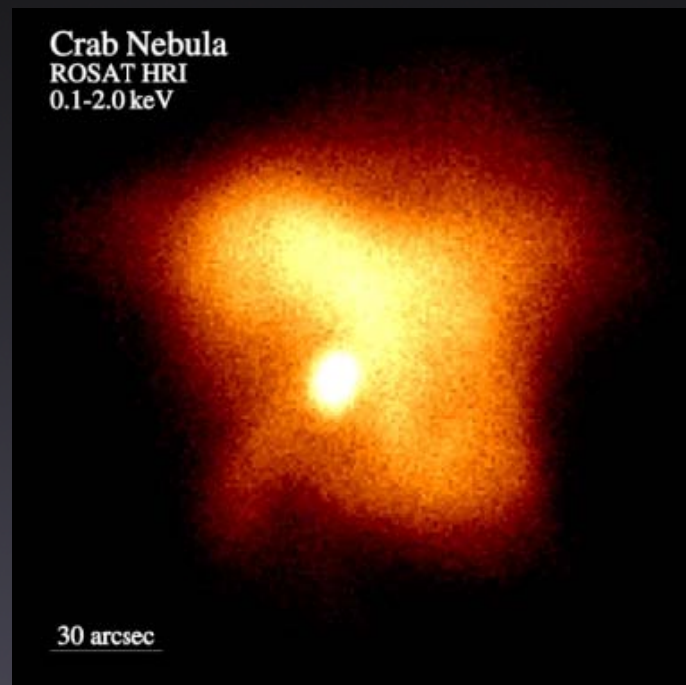
$$dE/E \propto (V/c)^2$$



# Izvori KŽ



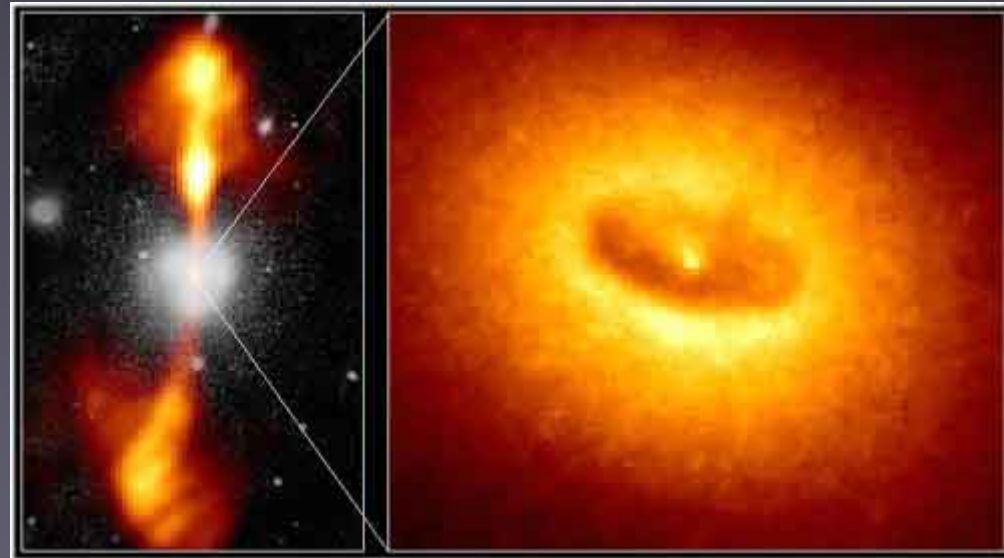
OstaneK SN 1006  
(radio: rdeče, rentgensko: modro)



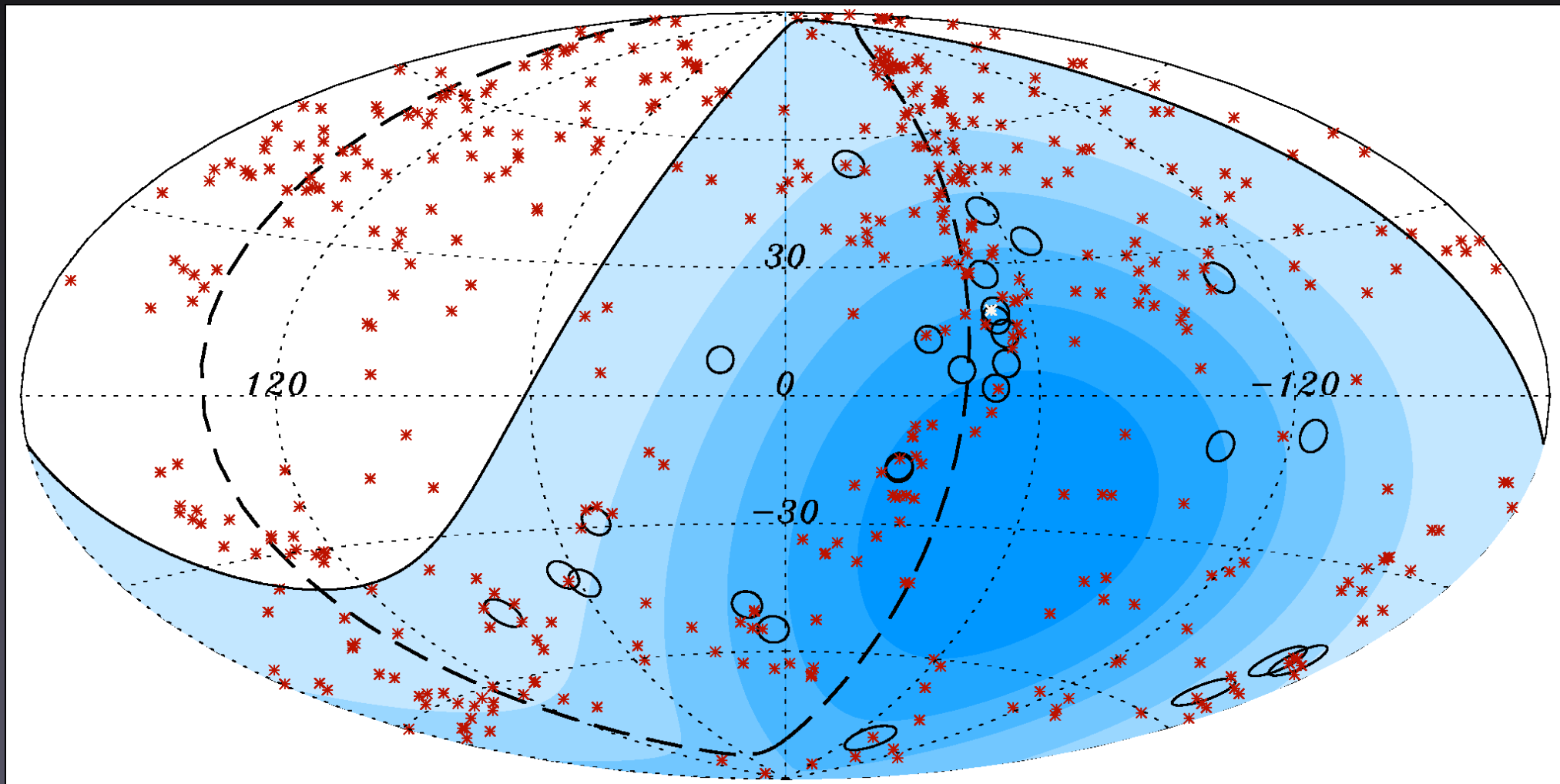
Meglica Rakovica; rentgensko

NGC 4261, AGN

Levo: radijski curki; desno: vidno



# Izvori KŽ

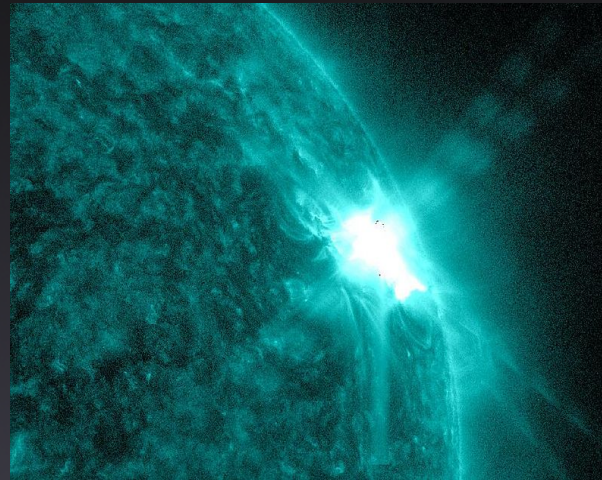


Pierre Auger, 2007, KŽ  $z E > 5.7 \cdot 10^{19}$  eV (črne elipse) naj bi prihajali iz AGN (rdeči križci so AGN do 75 Mpc, bel križec je najbližji Centaurus A)

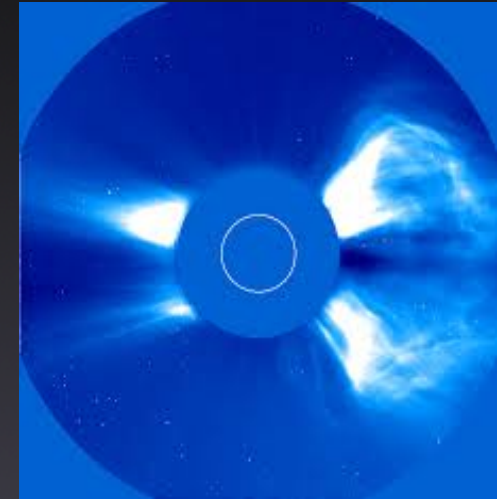
# Pospeševanje KŽ

## • Za Sonce:

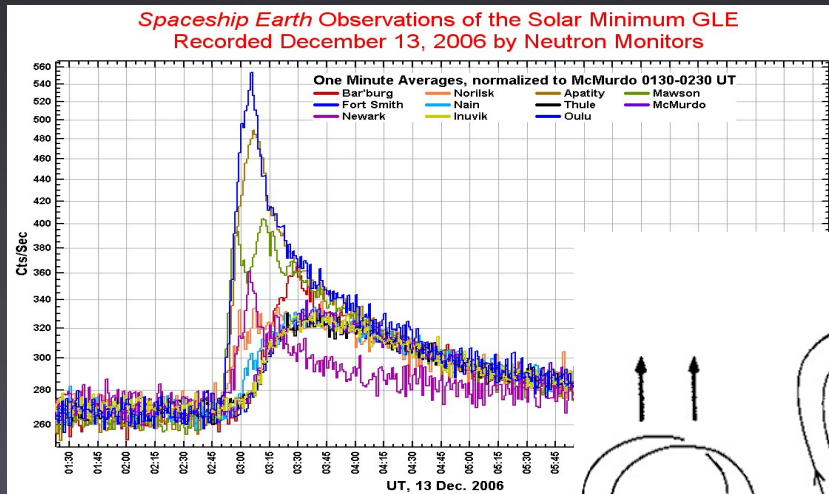
- Sončevi izbruhi s koronalnimi izmeti mase (CME)
- GLE: povišan fluks KŽ sonca



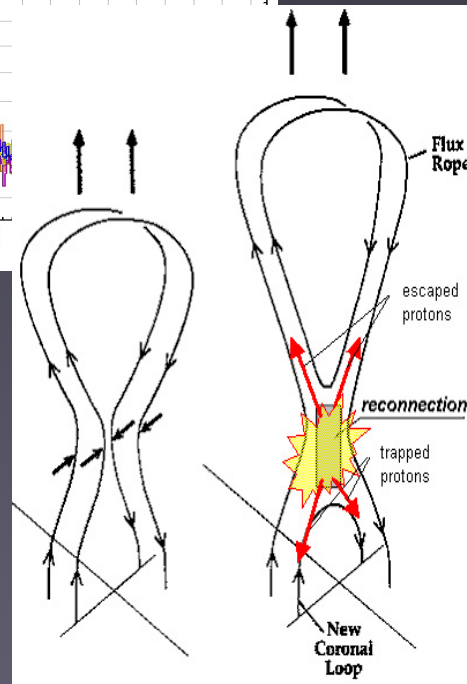
Sončev izbruh (2012)



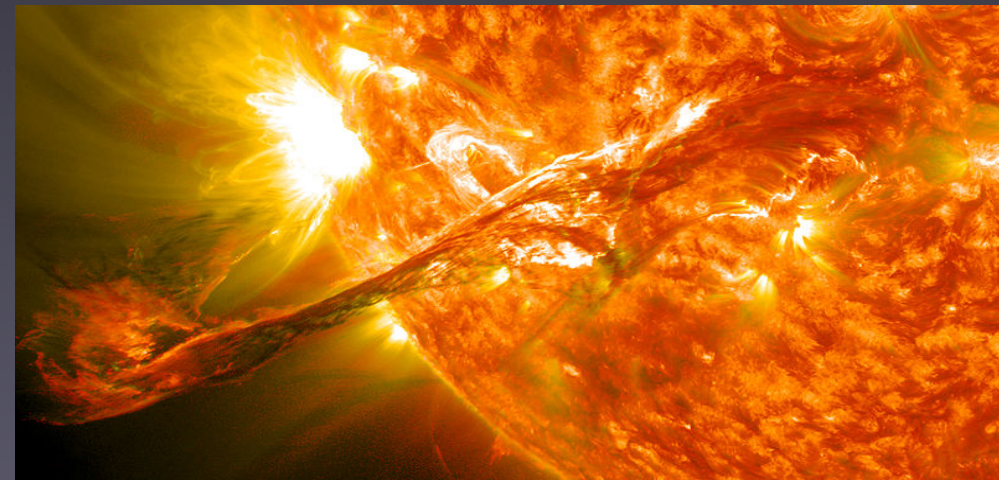
SOHO CME (1997)



GLE 13.12.2006



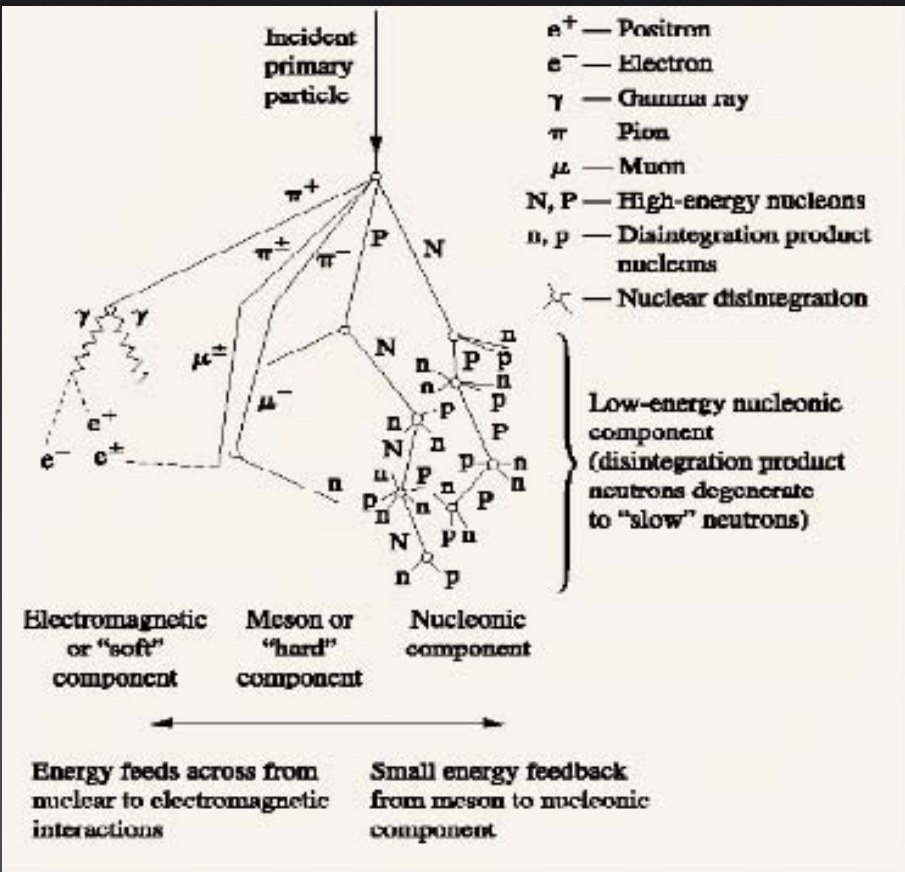
Magnetna sklopitev



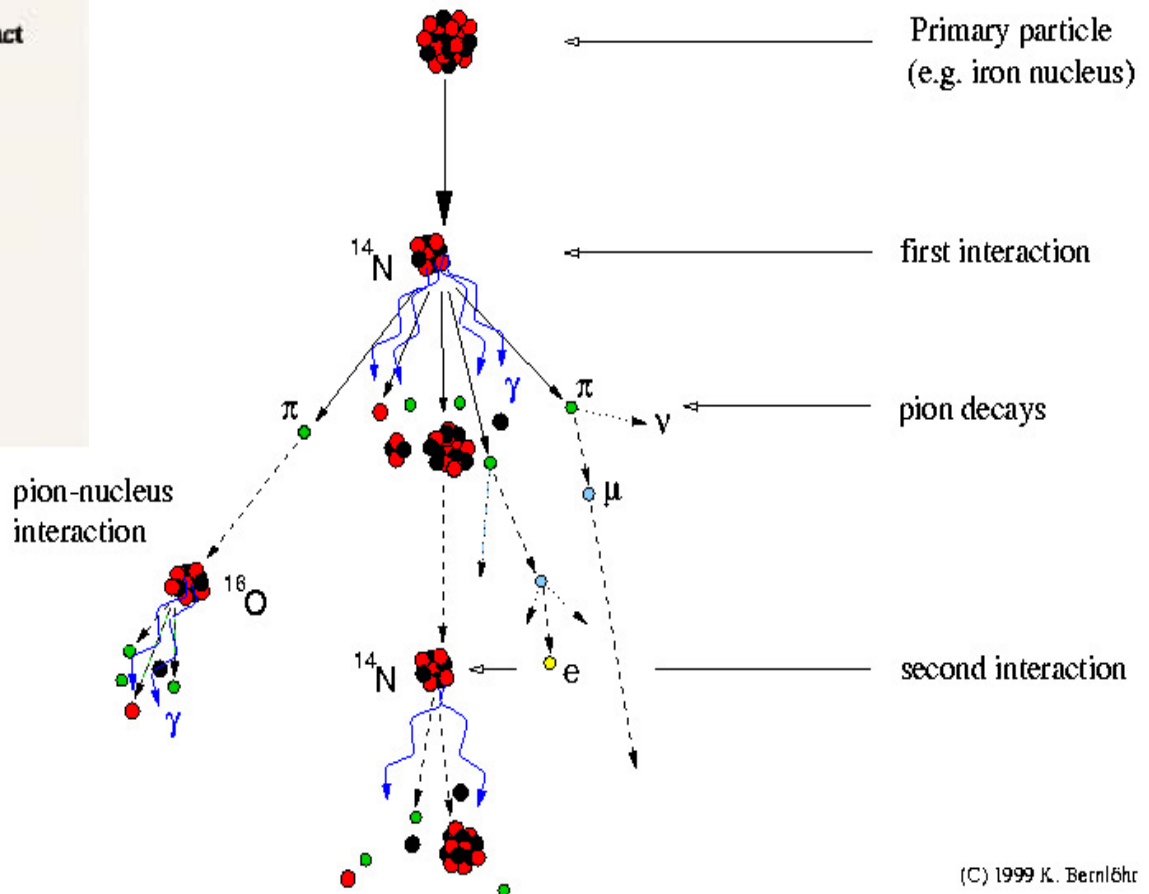
Koronalni izmet mase (2012)

# Nalivi KŽ (showers)

- V atmosferi nastane kaskada sekundarnih KŽ



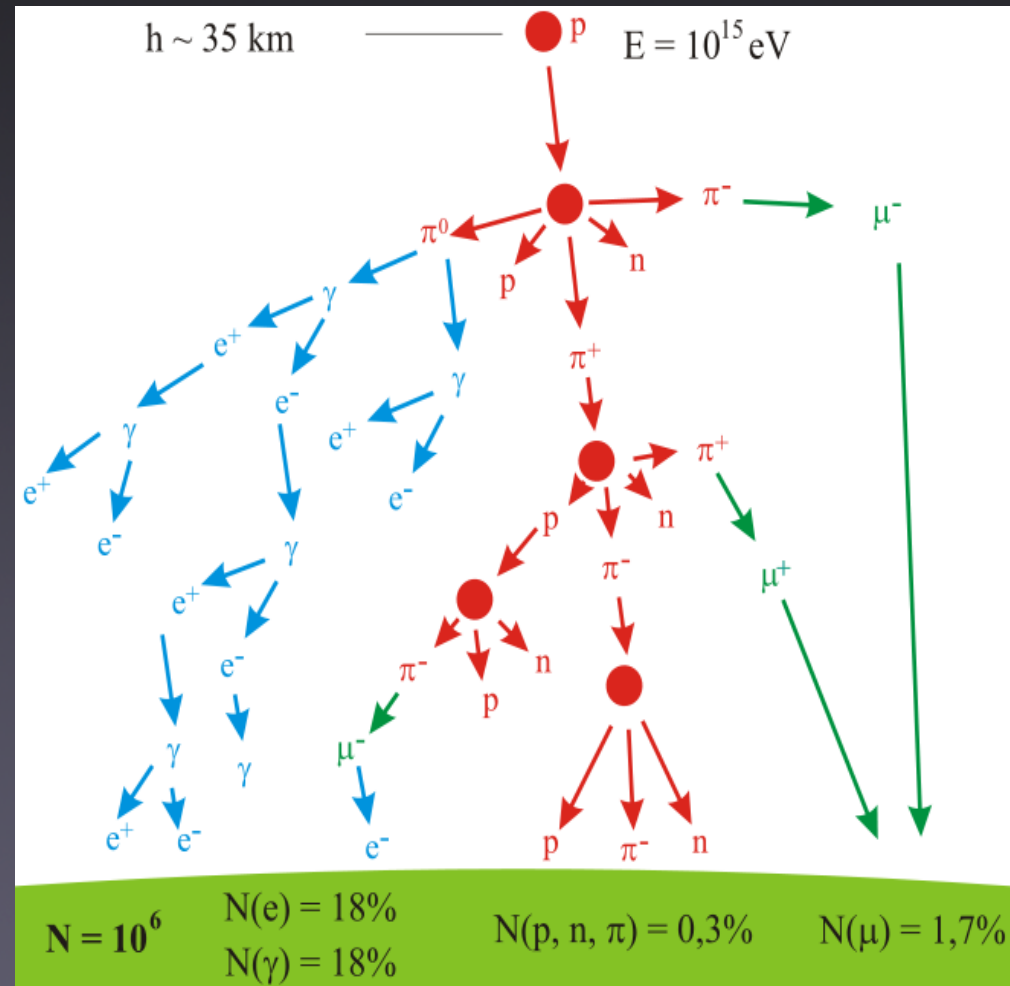
Development of cosmic-ray air showers



PP protona je mnogo manjša od gostote atmosfere

# Nalivi KŽ (showers)

- Mehka komponenta ( $e^-$ ,  $e^+$ , gama)
- Trda komponenta (mioni, nevtrini)
- Jedrska komponenta (p, n)

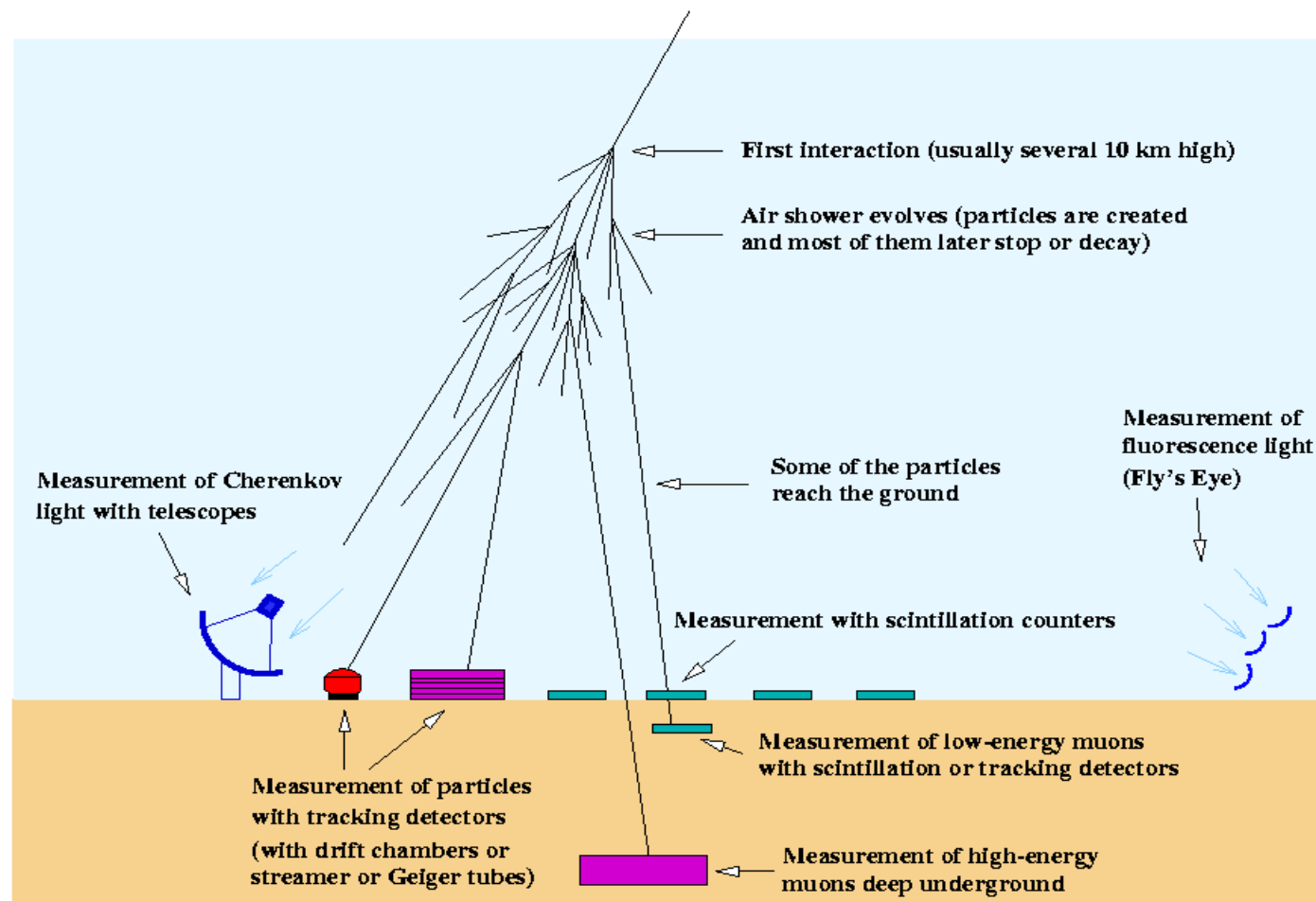


Particle	Interaction			mass (MeV)	lifetime	Atmospher. absorb.length ( $g/cm^2$ )
	electromagn.	strong	weak			
Pion	x	x		$\approx 134$	$\approx 26$ ns	$\approx 115$
Muon	x		x	$\approx 106$	$\approx 2$ $\mu$ s	$\approx 260$
Neutron		x		932	12 min	$\approx 140$
Proton	x	x		938	stable	$\approx 110$
Electron	x			0.511	stable	$\approx 100$
Photon	x				stable	

# Detekcija KŽ

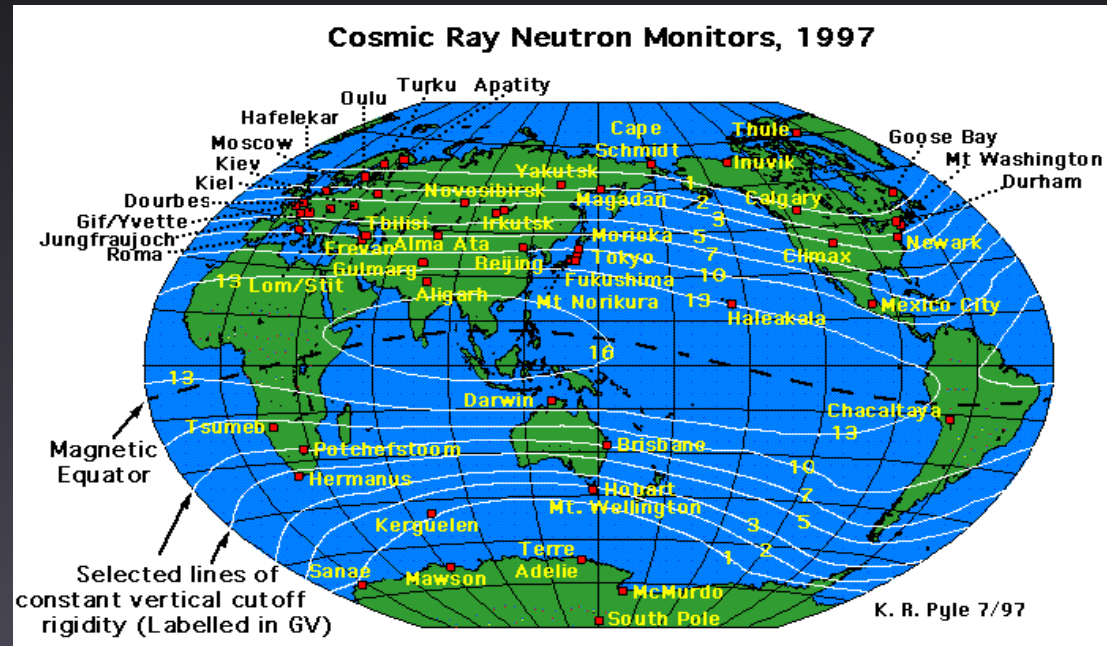
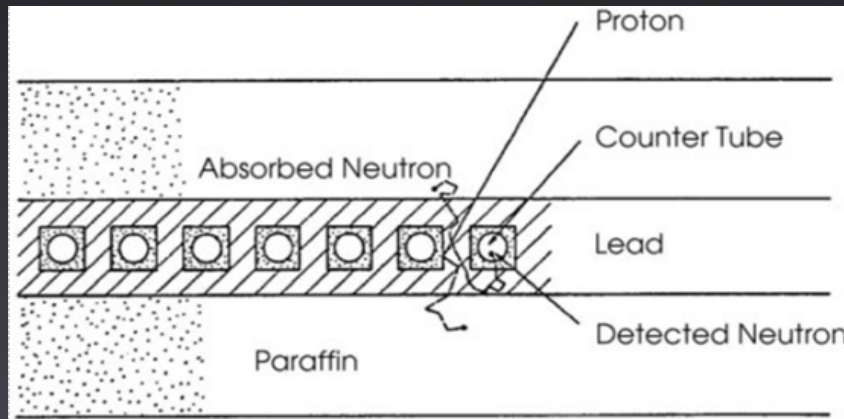
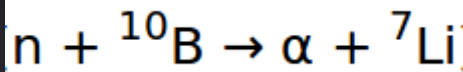
- Pod Zemljo, na Zemlji, v zraku in v vesolju (do roba sončevega sistema)

## Measuring cosmic-ray and gamma-ray air showers

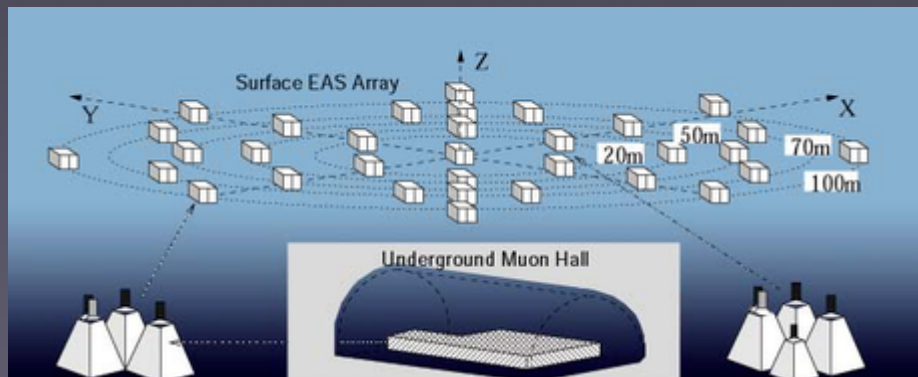


# Na zemlji in pod zemljo

- Nevtronski monitorji: merjenje jedrske komponente



- Mionski detektorji: pod zemljo ( $E > 5\text{GeV}$  mioni)

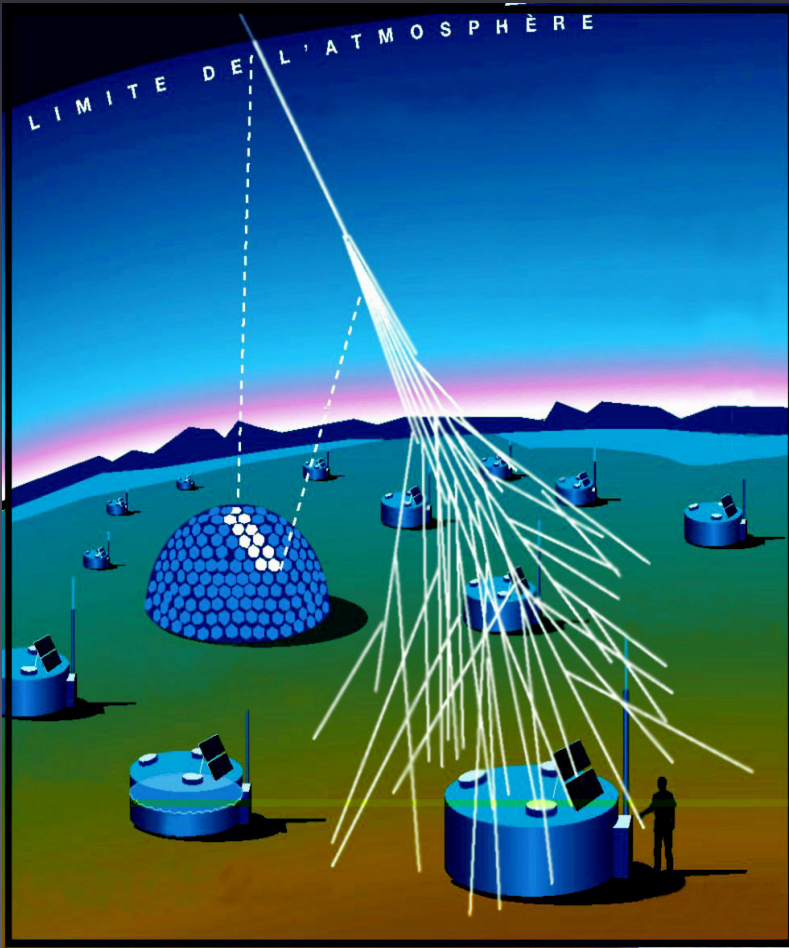


GAMMA eksperiment v Armeniji na 3200m n.v.

Scintilatorji

# Na zemlji in pod zemljo

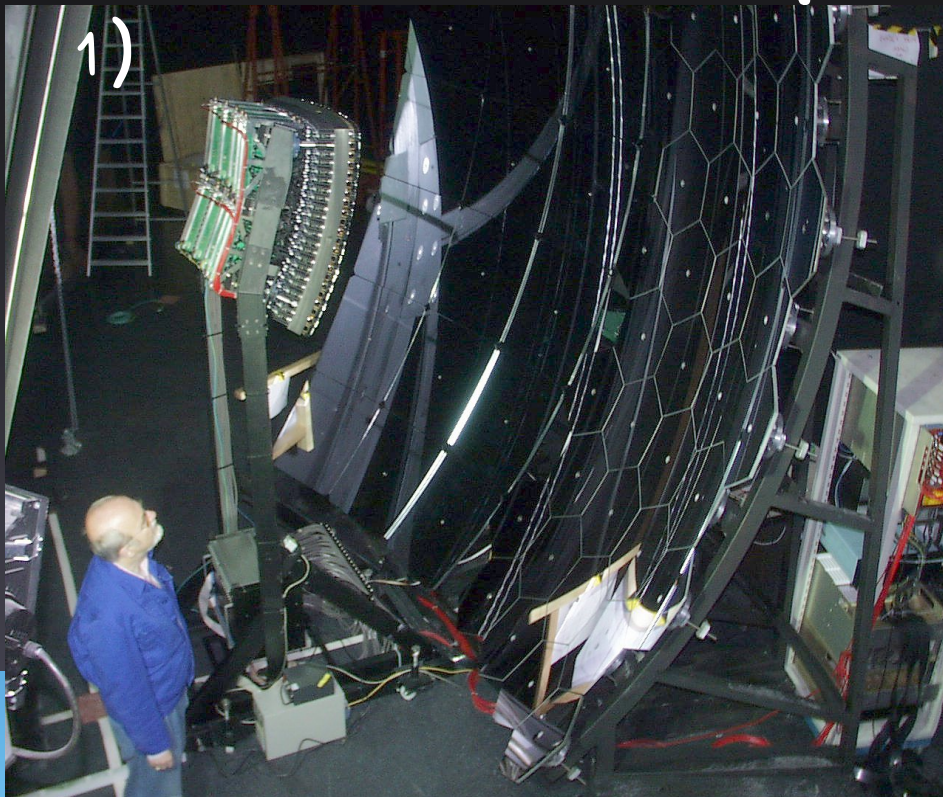
- Čerenkovo sevanje: MAGIC, VERITAS, Pierre Auger
- Atmosferska fluorescenca: Fly's Eye, Pierre Auger
- Nevtrini: IceCube



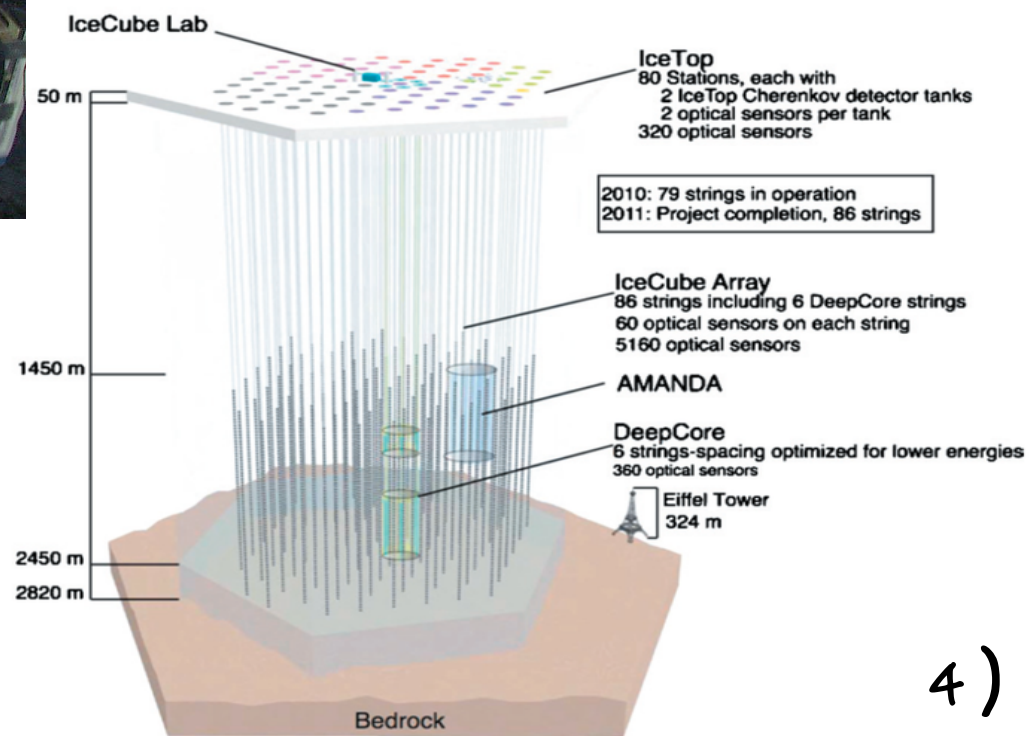
Pierre Auger: Argentina, 1600 vodnih tankov preko 3000 km<sup>2</sup>, 4 fluorescentni teleskopi



# Na in pod zemljo



- 1) Pierre Auger
- 2) HiRes - Fly's Eye
- 3) MAGIC (17 m)
- 4) IceCube



4)

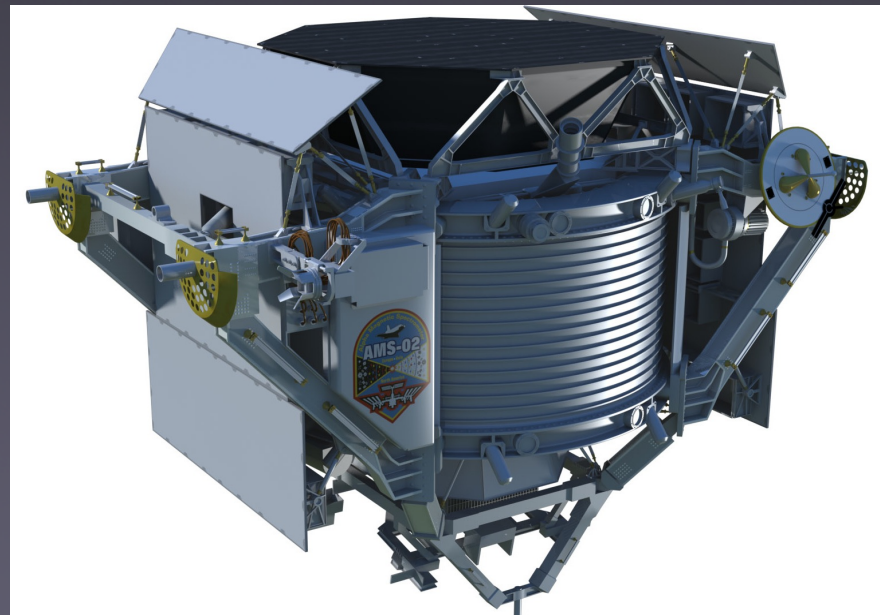
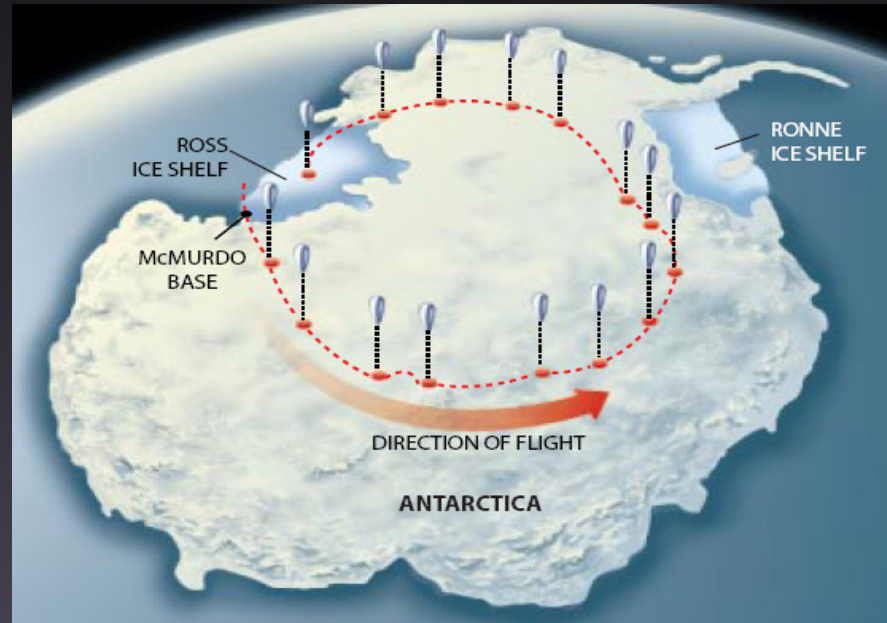
# V zraku in v vesolju

- Balonski eksperimenti



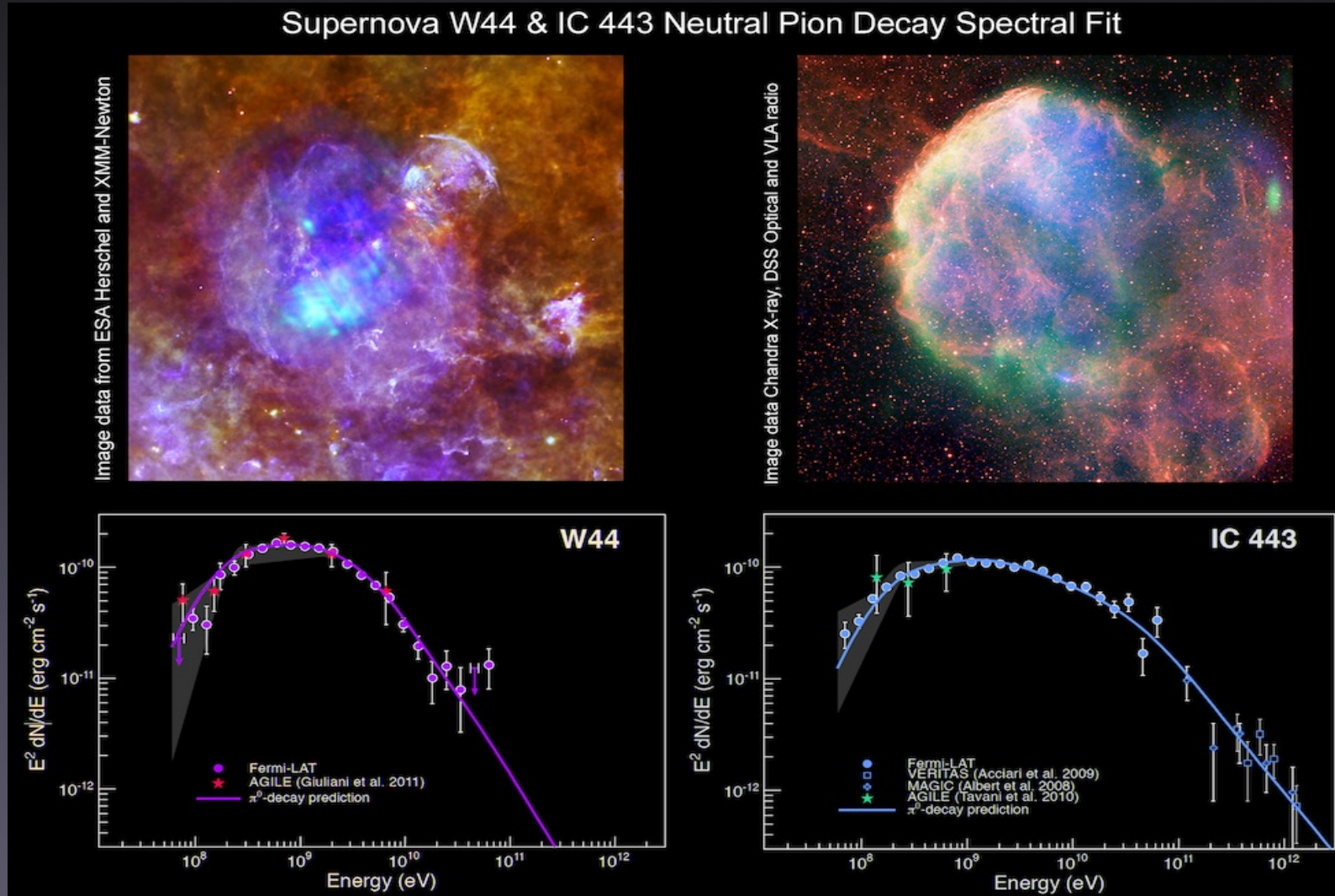
$h = 40-70\text{km}$

- Sateliti in instrumenti na vesoljskih misijah:
  - AMS-02
  - Fermi
  - Voyager 1 & 2



# Zadnji rezultati: Fermi (2013)

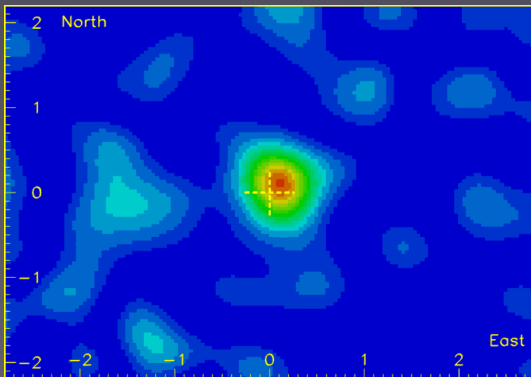
- Ostanke SN: gama žarki iz energetskih protonov



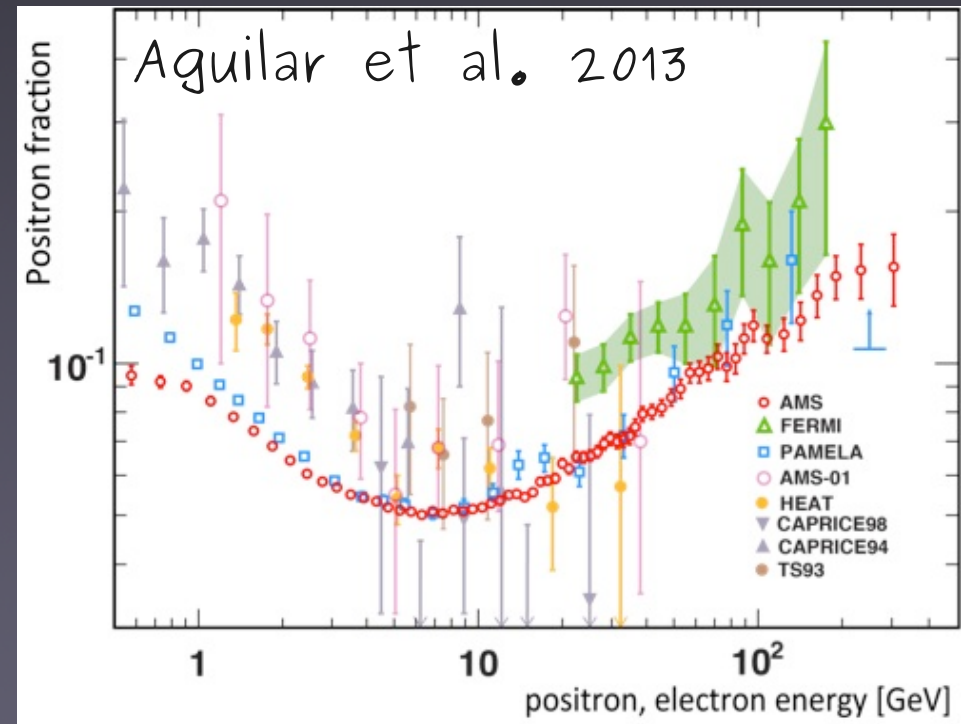
- Video: <https://www.youtube.com/watch?v=C3ue7cEocvI>

# Zanimivosti:

- KŽ imajo vpliv na elektronske naprave, sploh v vesolju in visoko v atmosferi
- KŽ (relativistični elektroni) povzročajo strele, saj je prav energetski  $e^-$  potreben za začetek procesa
- Raziskave antimaterije in temne snovi:
  - iskanje nevtralinov z detekcijo  $e^+$  z AMS-02
- Senca Lune:



Mionski detektor  
Soudan 2



# Zanimivosti: doza sevanja

