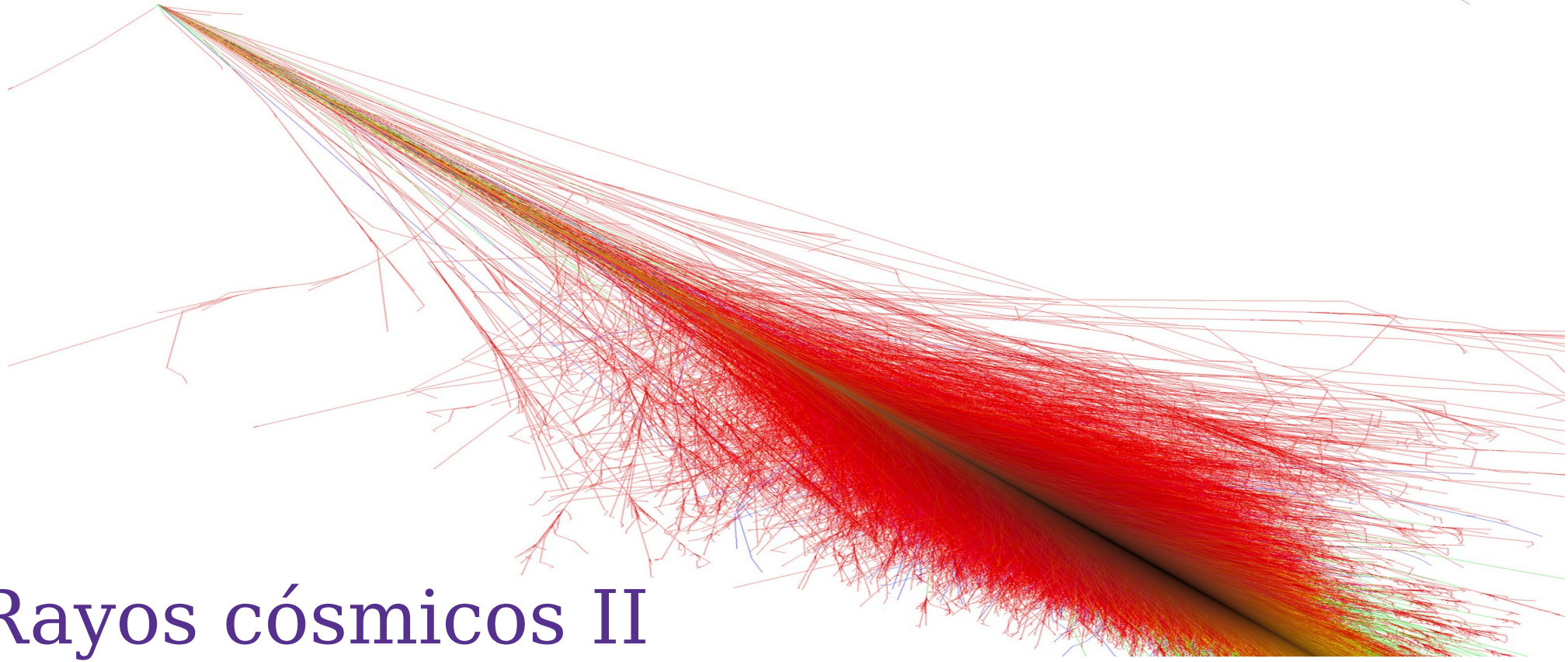
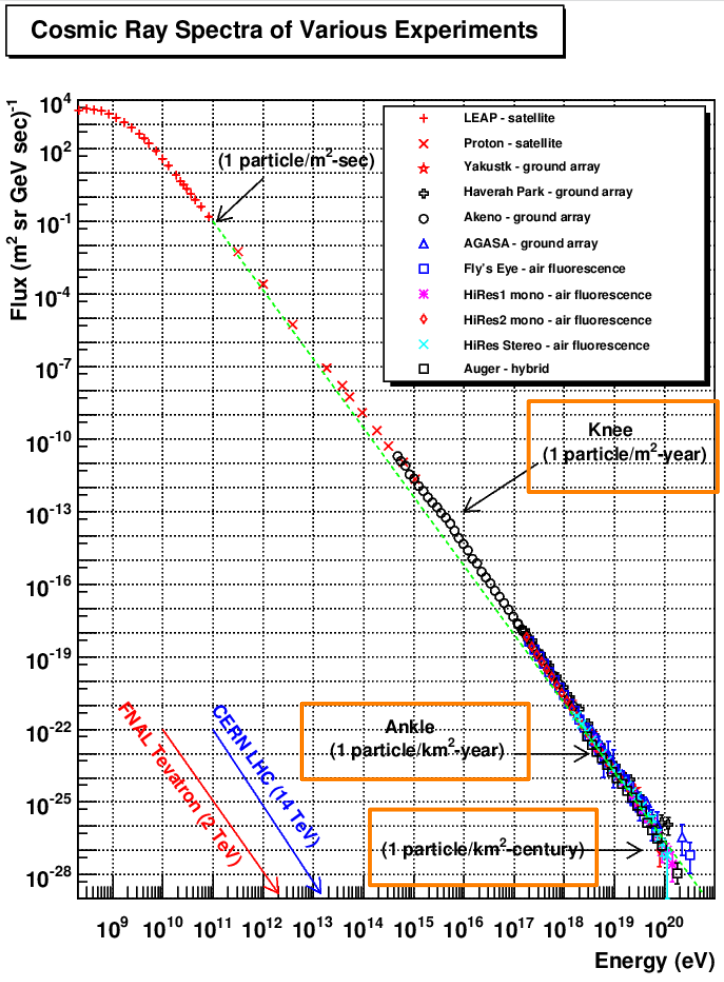


Rayos cósmicos II

Curso: Astronomía general
Profesor: Christian Sarmiento Cano
Escuela de Física, Universidad Industrial de Santander

Espectro de rayos cósmicos primarios



$$j(E)=\frac{\mathrm{d}N}{\mathrm{d}t\ \mathrm{d}A\ \mathrm{d}\Omega\ \mathrm{d}E}$$

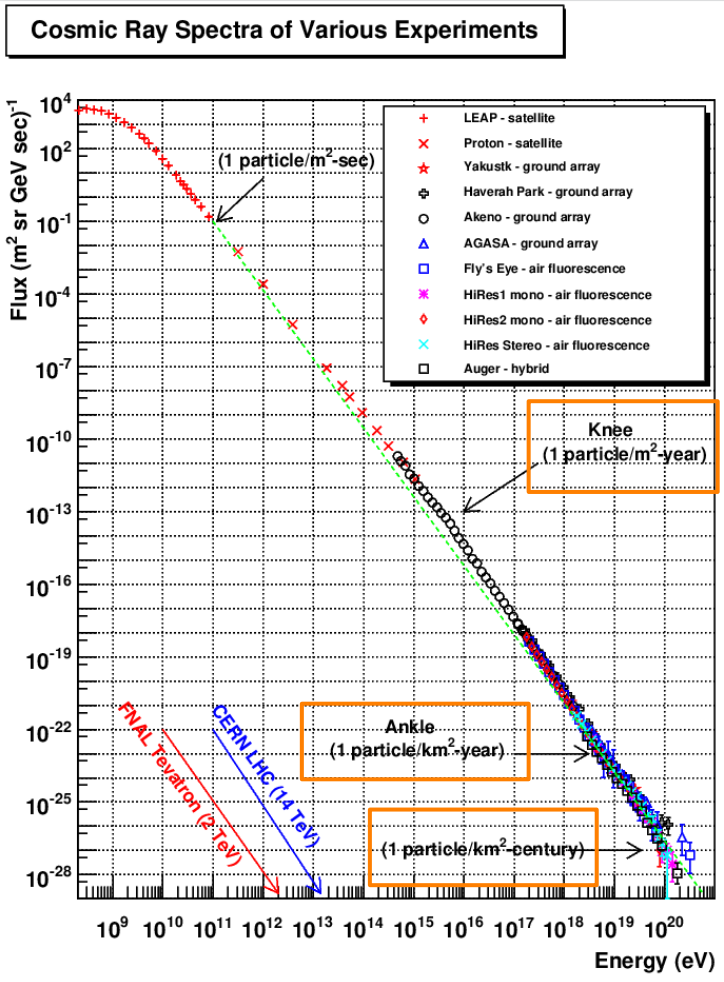
- Unidades

$$[j(E)]=\frac{1}{\mathrm{m}^2\ \mathrm{s}\ \mathrm{sr}\ \mathrm{eV}}$$

- En general:

$$j(E)=j_0 E^{\alpha},\ \alpha\simeq -3$$

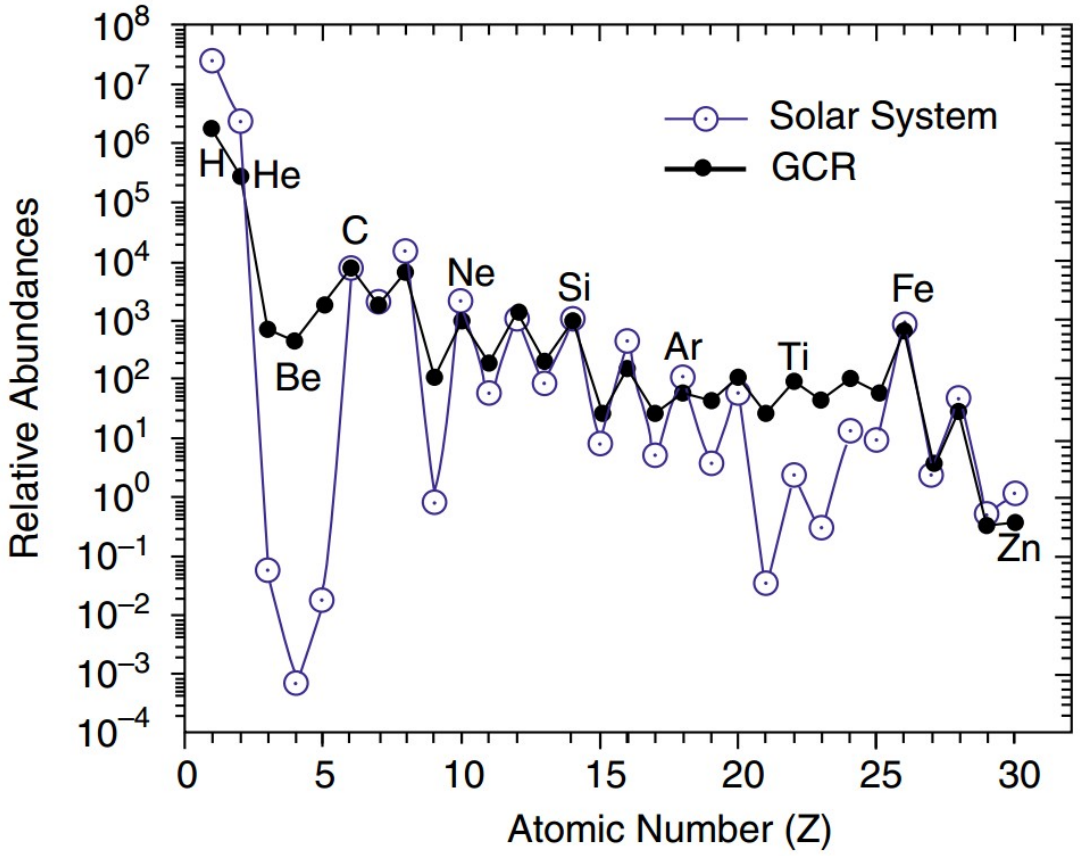
Espectro de rayos cósmicos primarios



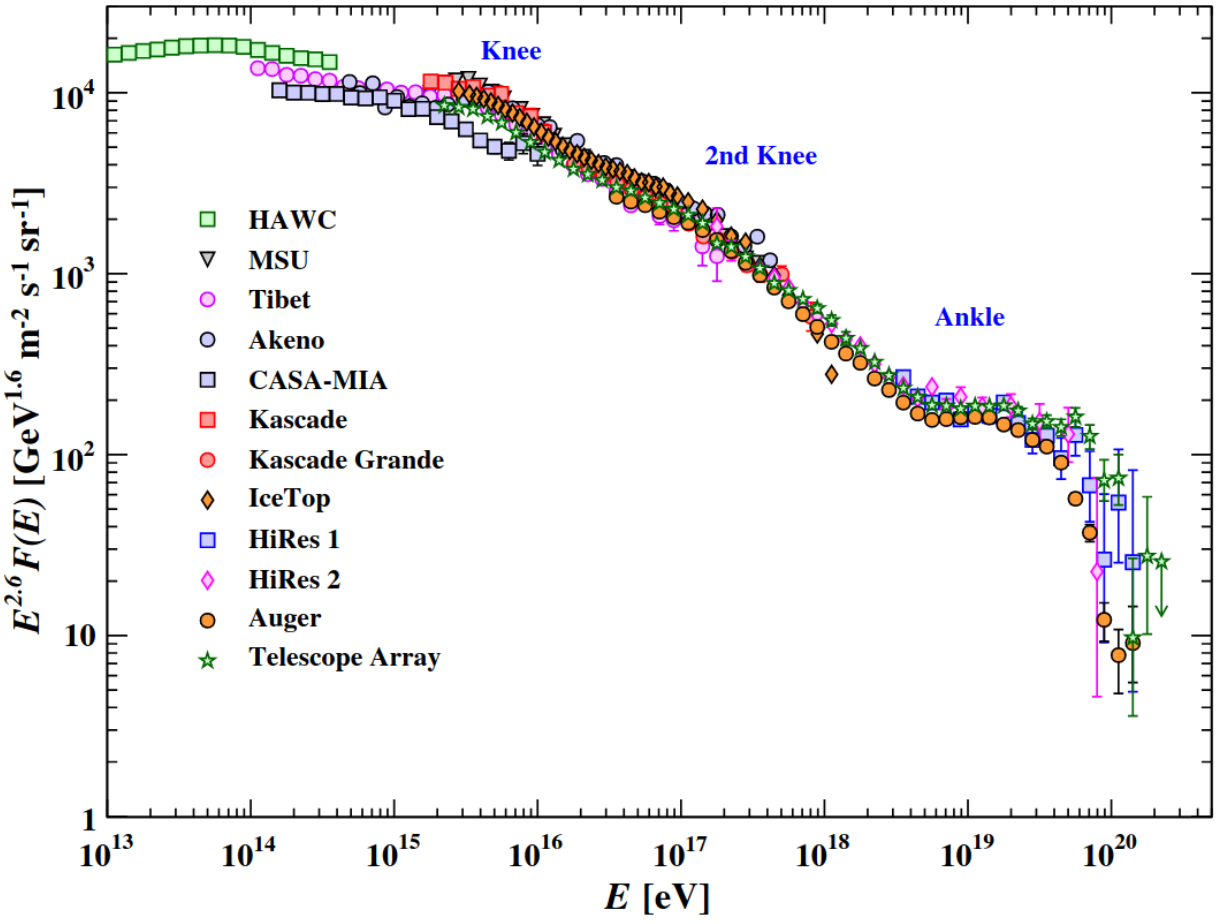
Cambios en la pendiente espectral:

- Viento Solar → 10^{9} eV
- 1ra rodilla → $10^{15.5}$ eV
- 2da rodilla → ~10^{17} eV
- Tobillo → $10^{18.61}$ eV
- Supresión → ~$10^{19.46}$ eV

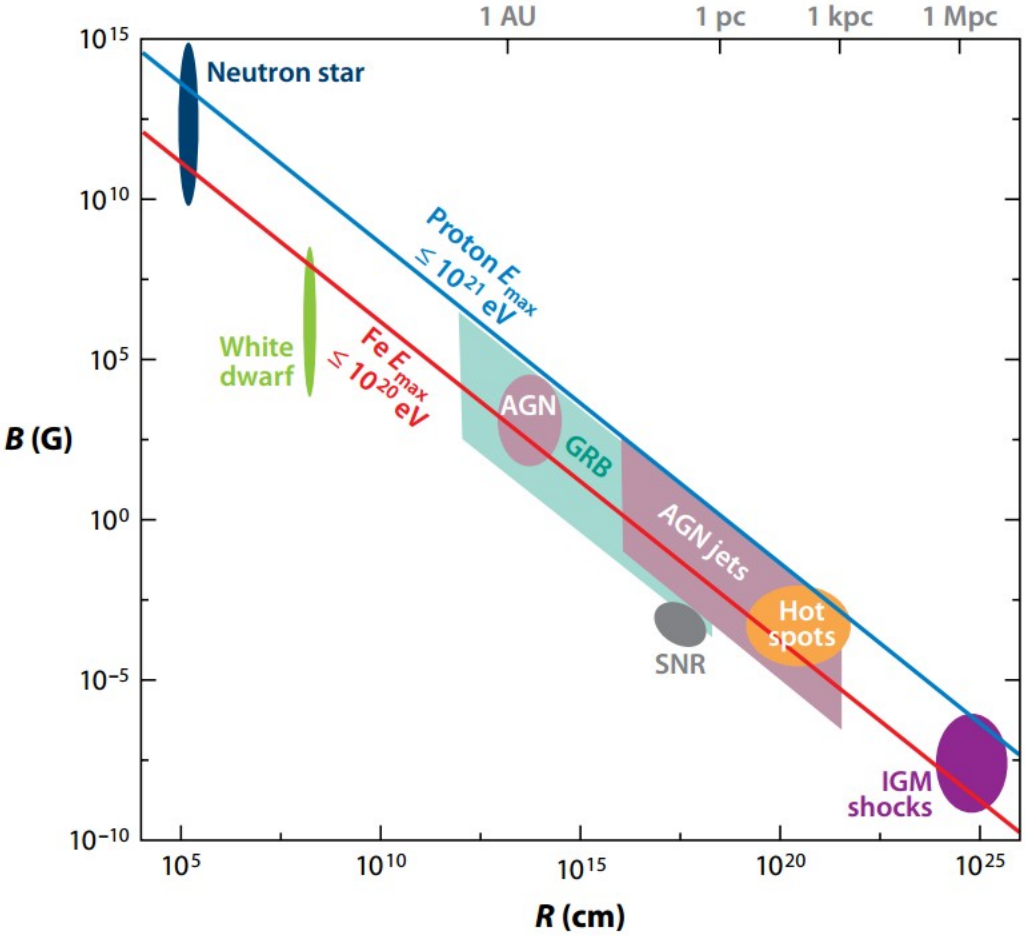
Espectro de rayos cósmicos primarios



Espectro de rayos cósmicos primarios



Fuentes de astropartículas



$$E_{max} \simeq \varepsilon E \frac{R}{r_L},$$

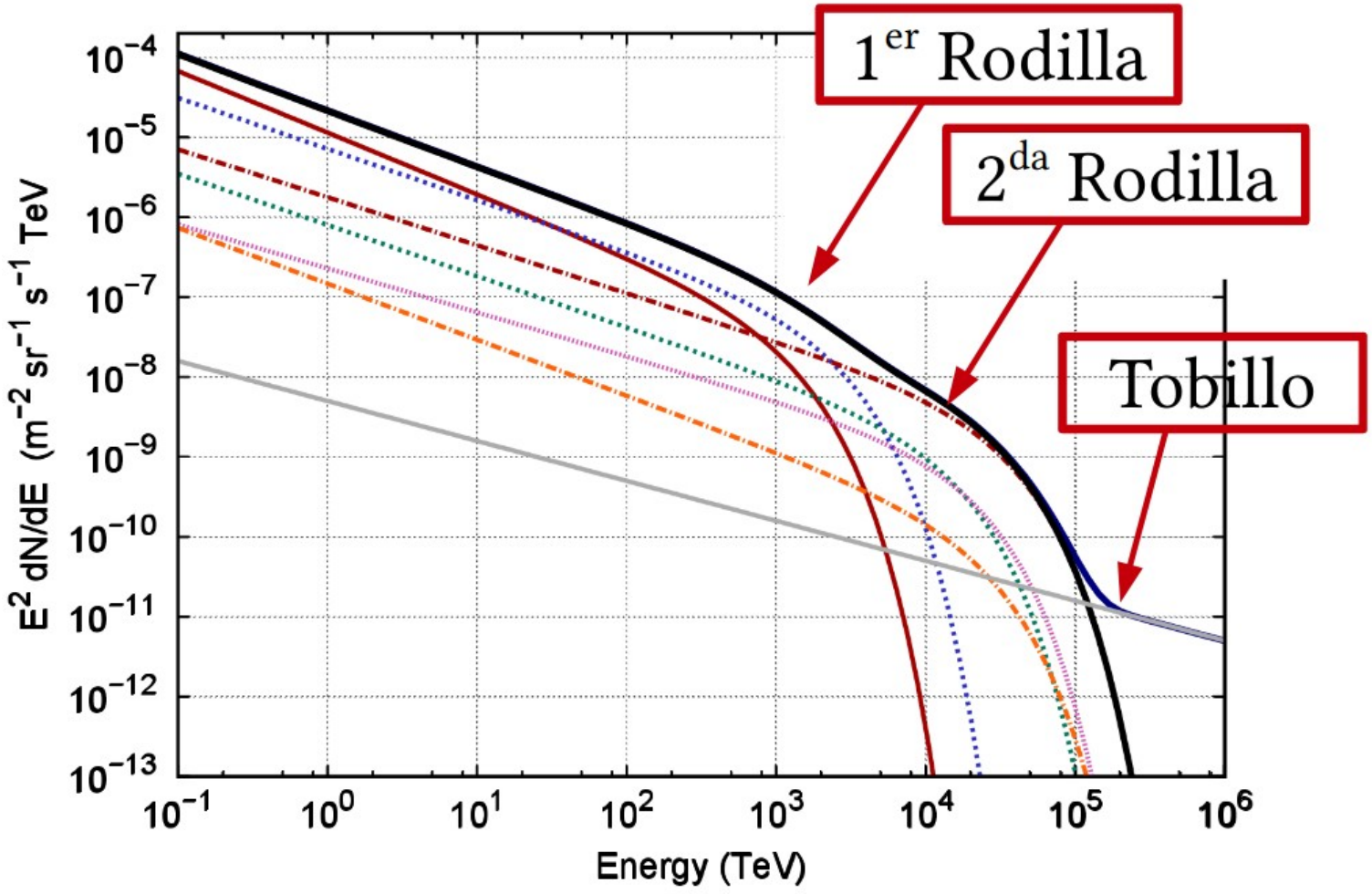
Donde,

$$r_L = \frac{E}{ZB},$$

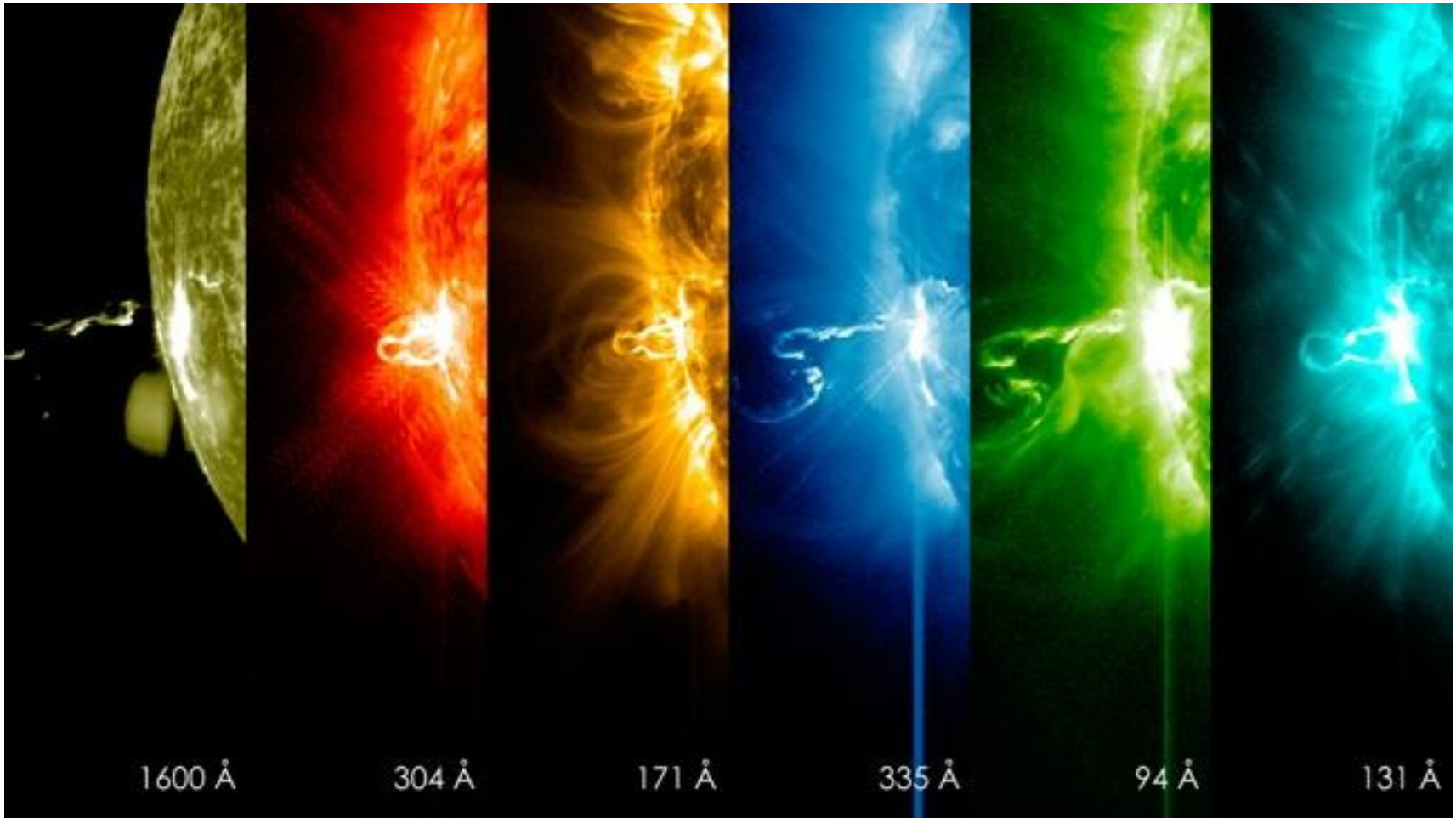
Entonces,

$$E_{max} \simeq \varepsilon ZBR.$$

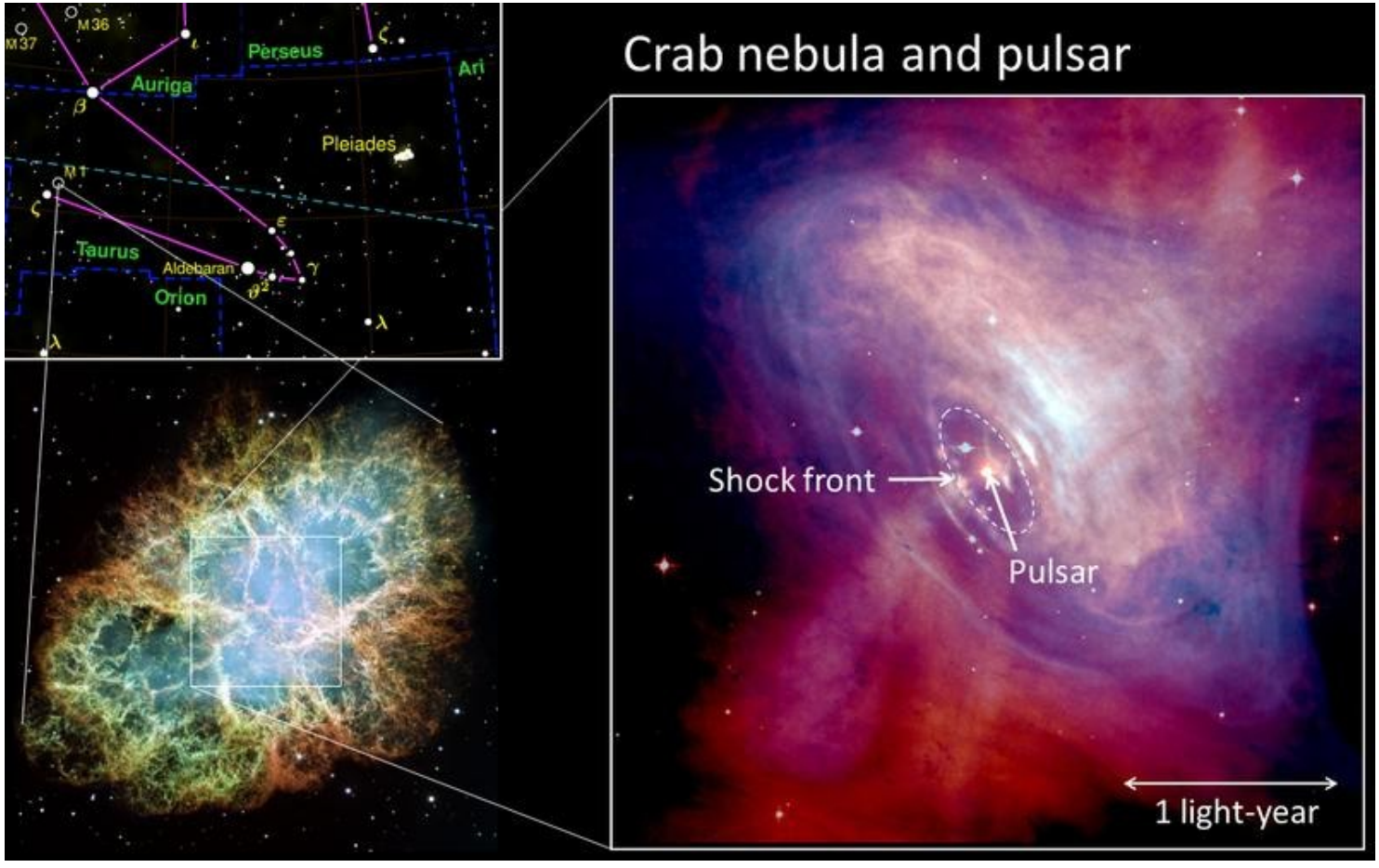
Cambios en la pendiente del espectro



El Sol



Remanentes de Supernova

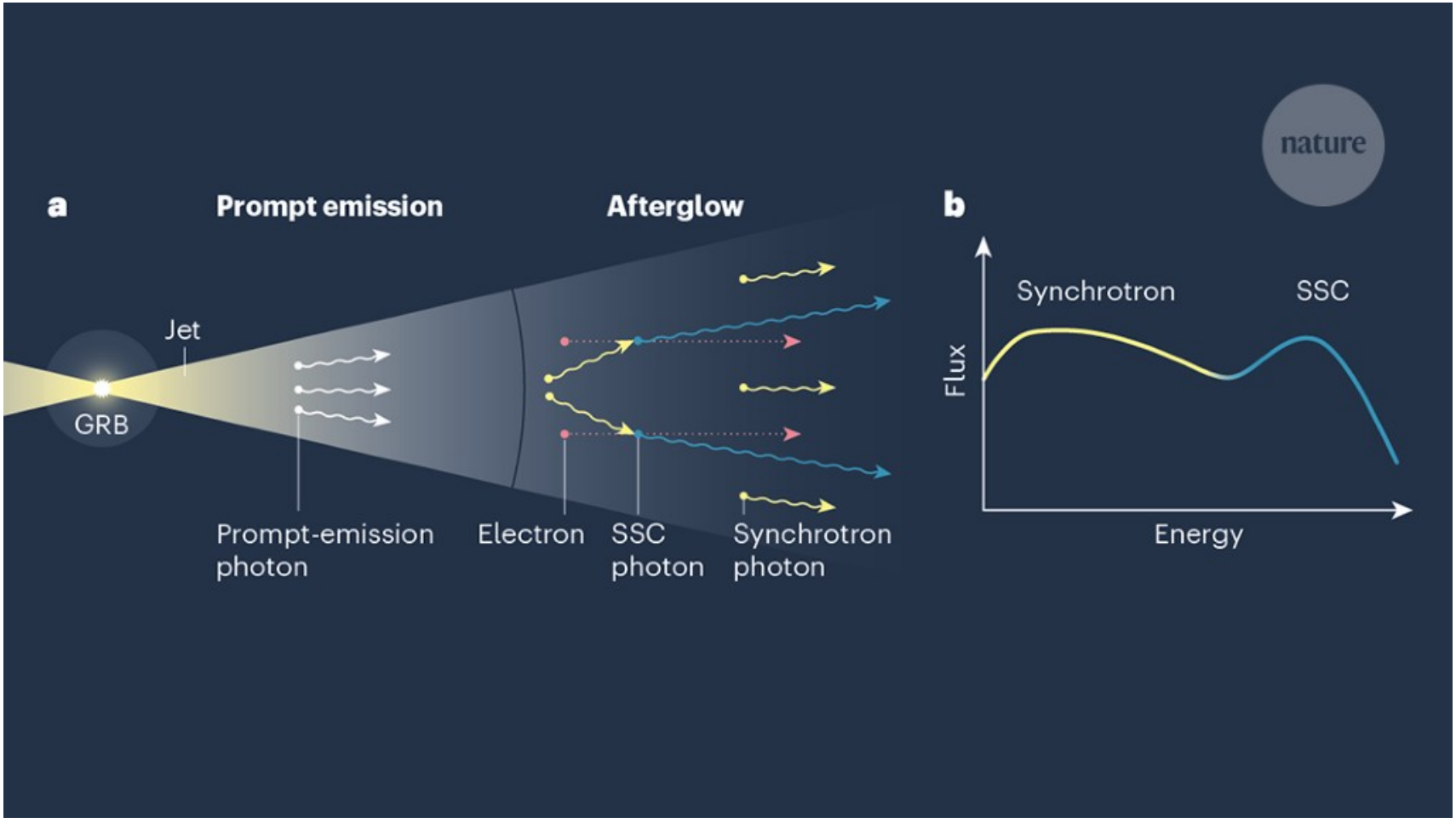


Emite partículas en el rango del KeV-GeV.

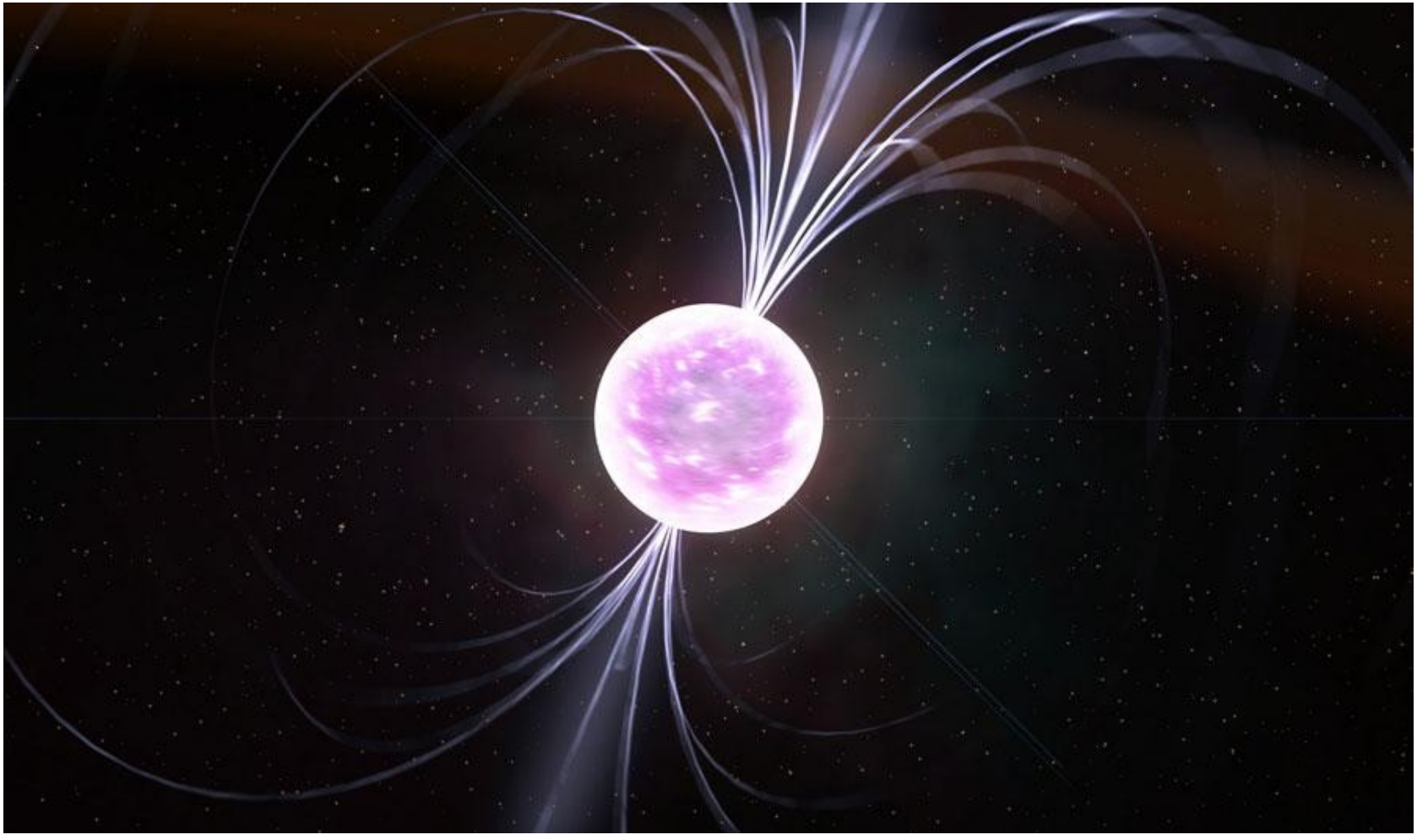
Se han corroborado detecciones tanto satelitales como en observatorios en Tierra.

¡Es una fuente de fotones gamma!

Destellos de rayos gamma

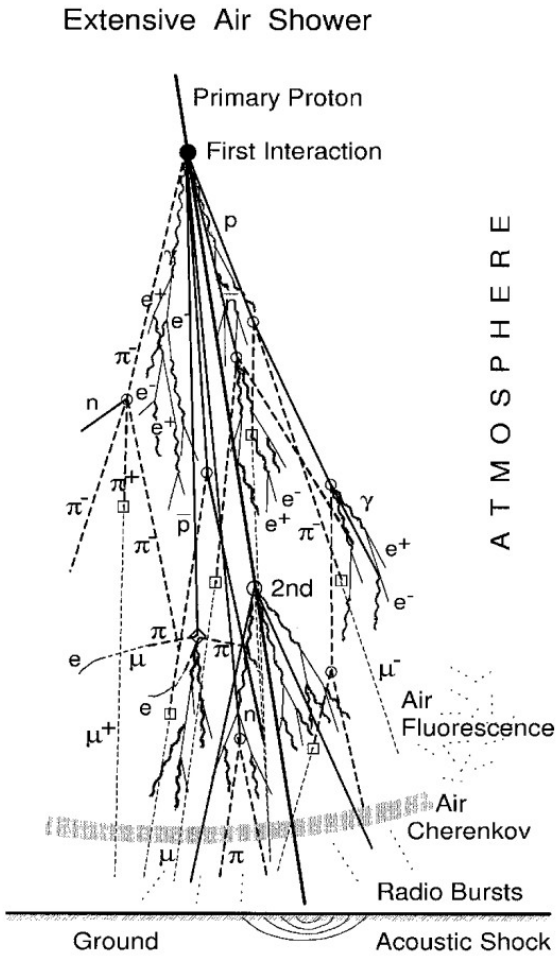


Estrellas de neutrones

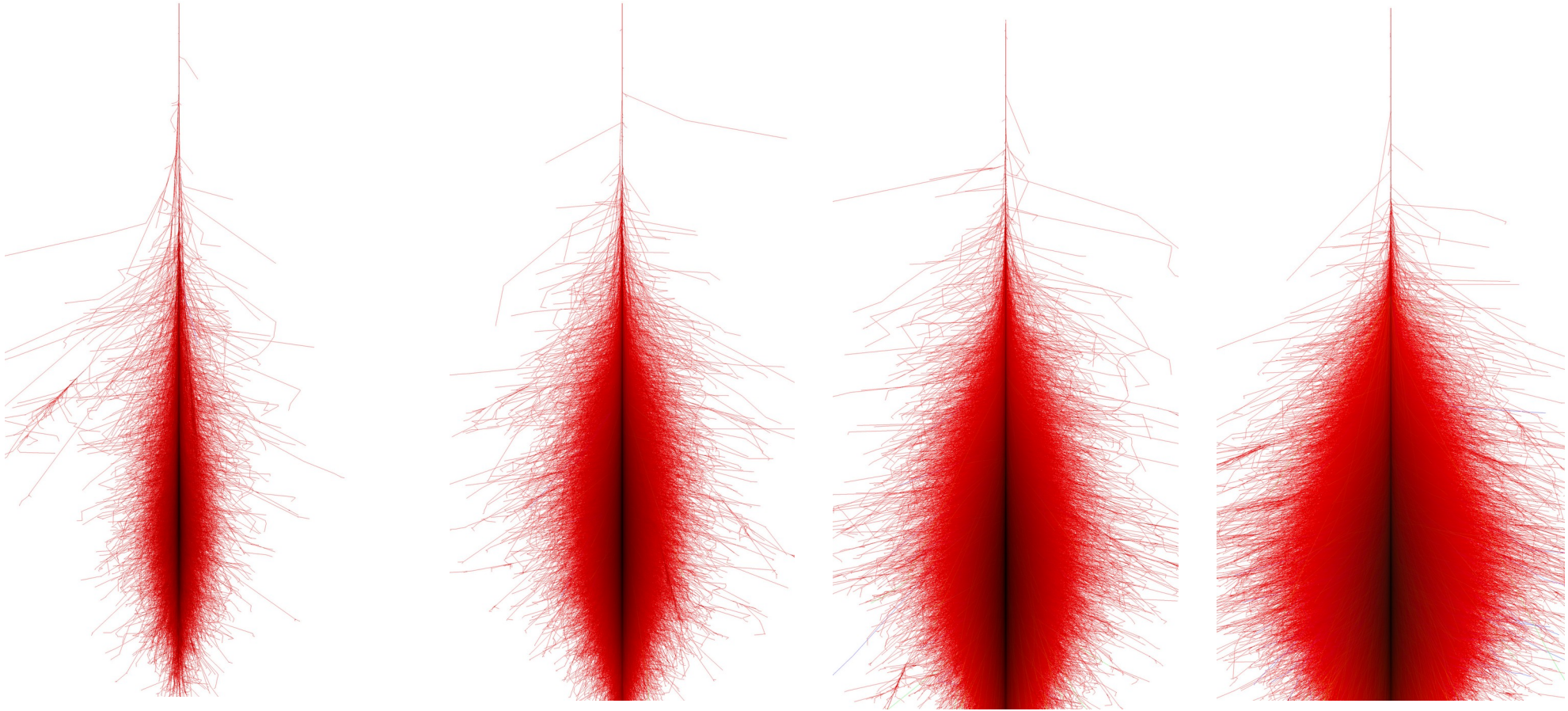


Núcleos activos de galaxias

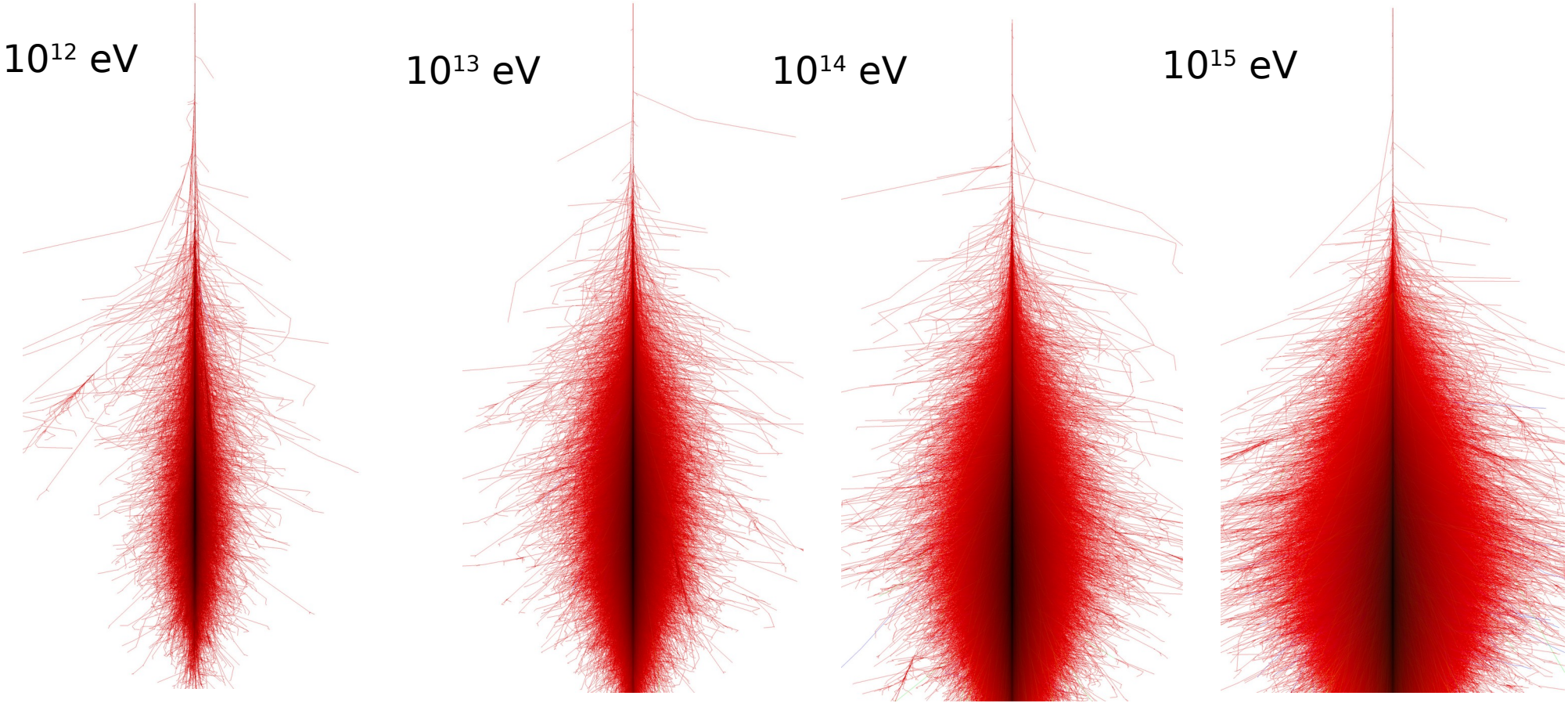
Lluvias de partículas secundarias (EAS)



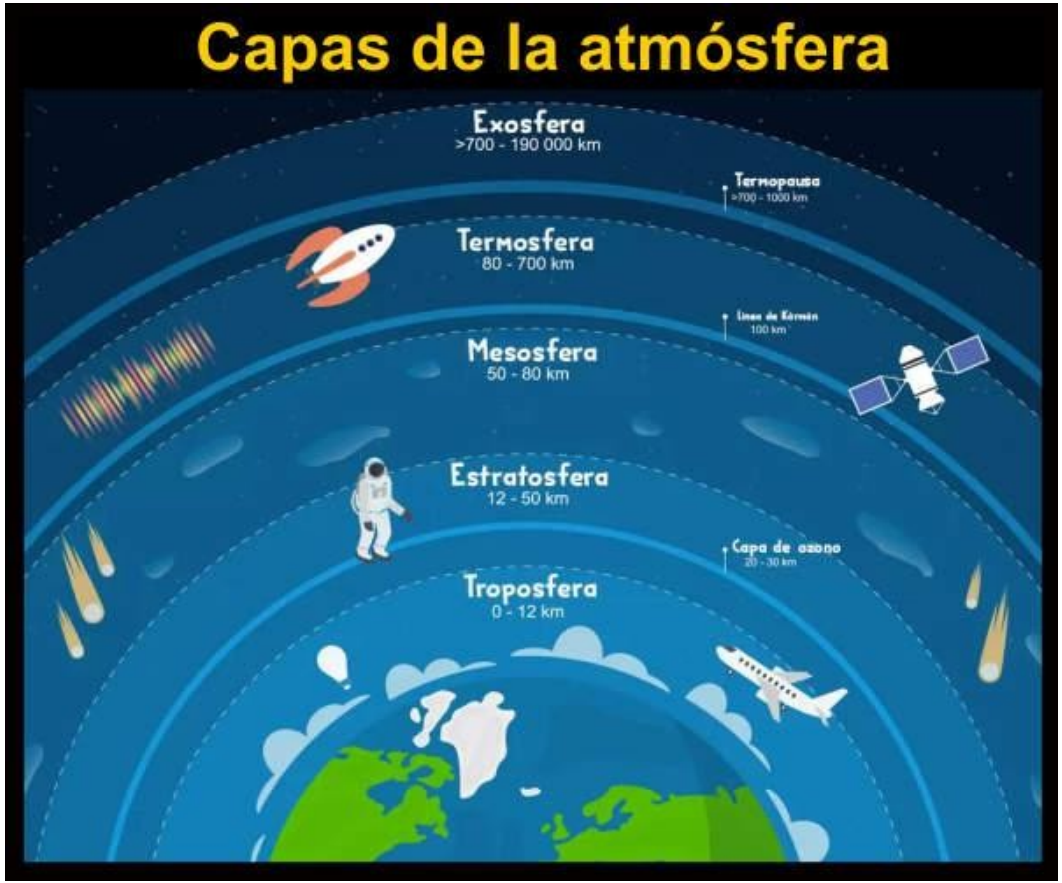
Lluvias de partículas secundarias



Lluvias de partículas secundarias



Profundidad atmosférica

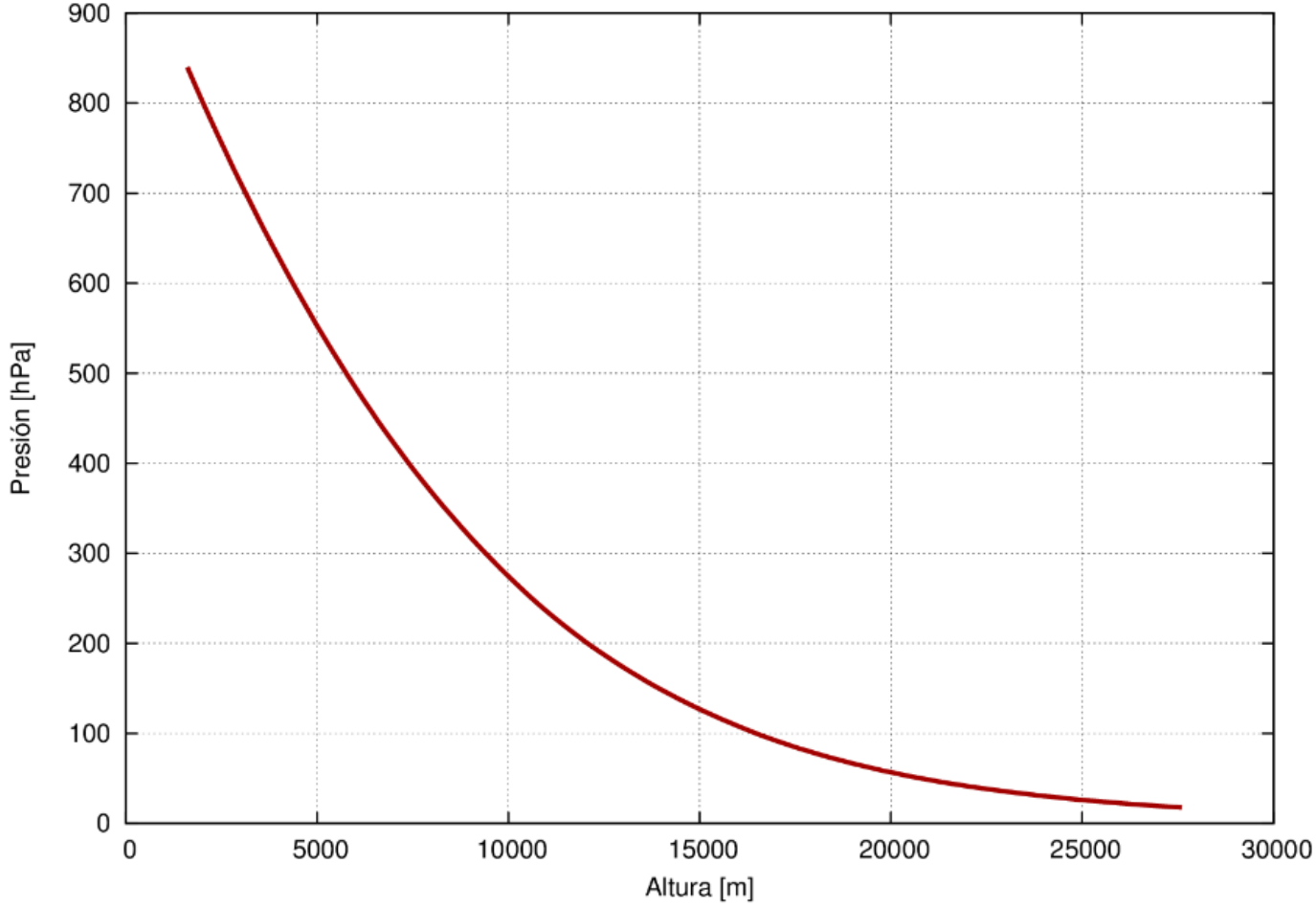


1 atm = 1033 g/cm2 = 91 cm Pb

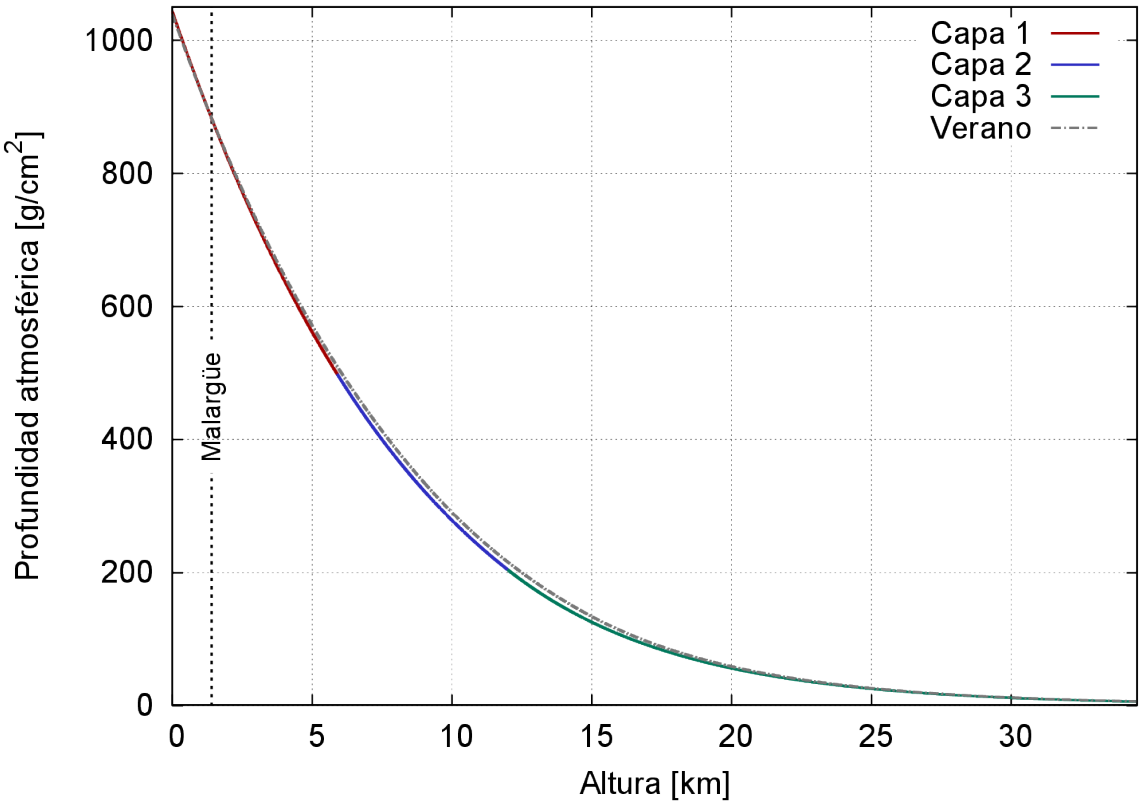
Profundidad atmosférica X: Cantidad de masa atravezada en la dirección transversal para una partícula entrando a la atm.

$$X(l) = \int_{l}^{\infty} \rho(l')\,\mathrm{d}\,l'$$

Presión vs Altura



Modelo atmosférico de Linsley



$$X_i(h) = a_i + b_i \exp\left(-\frac{h}{c_i}\right)$$

$$X_5(h) = a_5 + b_5\left(\frac{h}{c_5}\right)$$

Divide la atmósfera en cinco capas. Los coeficientes a_i, b_i y c_i y los límites entre capas se obtienen de mediciones en globo o datos satelitales (GDAS).

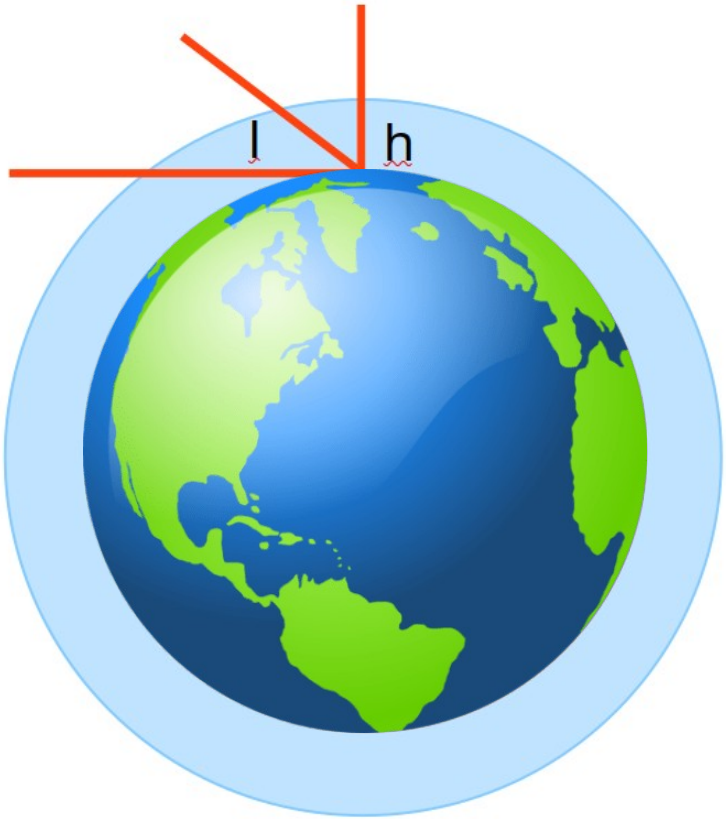
https://arxiv.org/pdf/2006.01224.pdf

Modelos MODTRAN

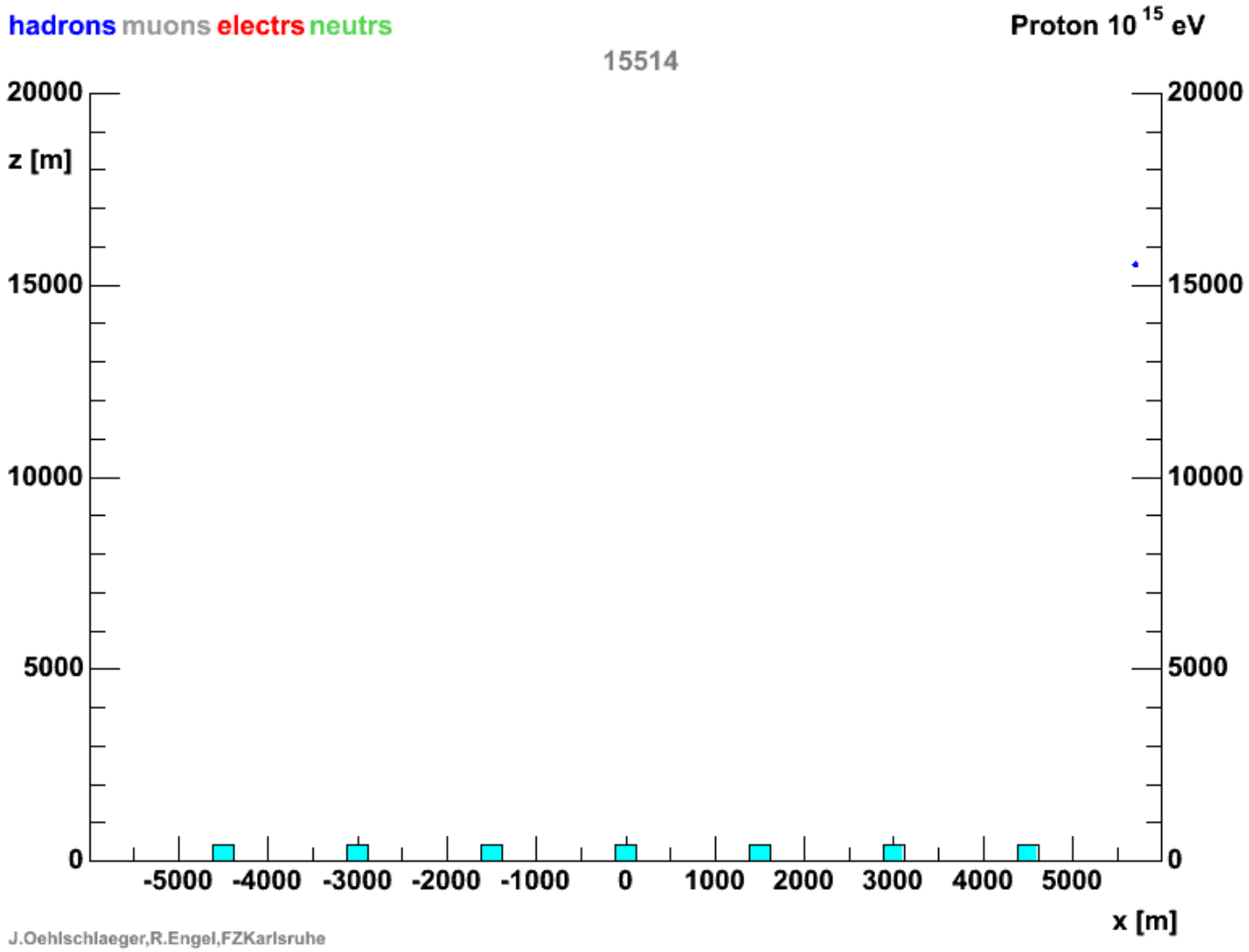
La Tierra es curva

La cantidad de aire recorrida depende de la dirección de movimiento (ángulo cenital) del rayo cósmico primario.

$$h(l) \simeq l\cos(\theta) + \frac{1}{2}\frac{l^2}{R_E}\sin^2(\theta)$$



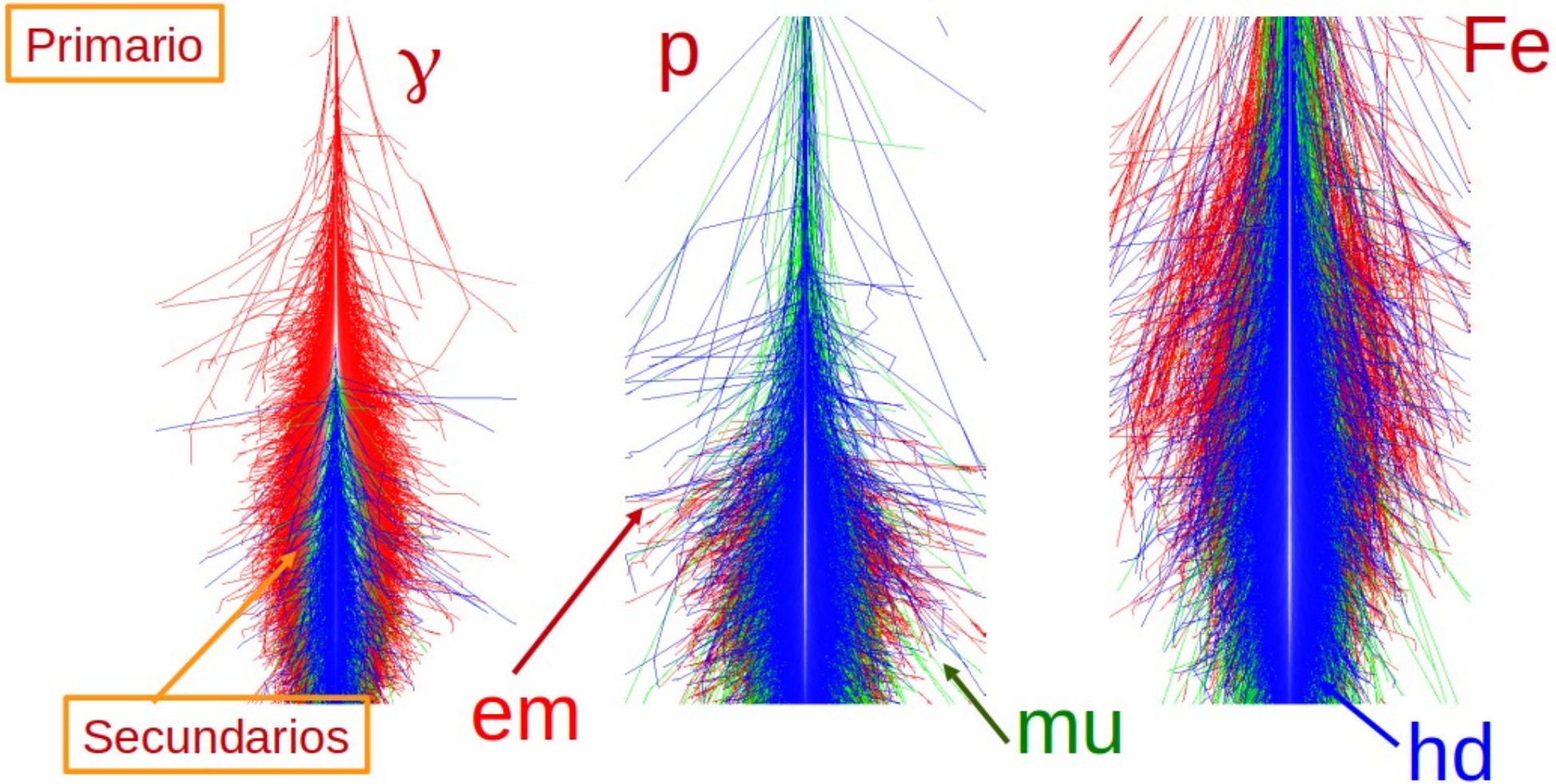
La cantidad de aire atravesada para una partícula con θ=90º es ~ 40 atmósferas.


hadrons muons electrs neutrs
Proton 10 15 eV
15514
20000
z [m]
15000
10000
5000
0
-5000 -4000 -3000 -2000 -1000 0 1000 2000 3000 4000 5000
x [m]
J.Oehlschlaeger,R.Engel,FZKarlsruhe

Animaciones de dos EAS

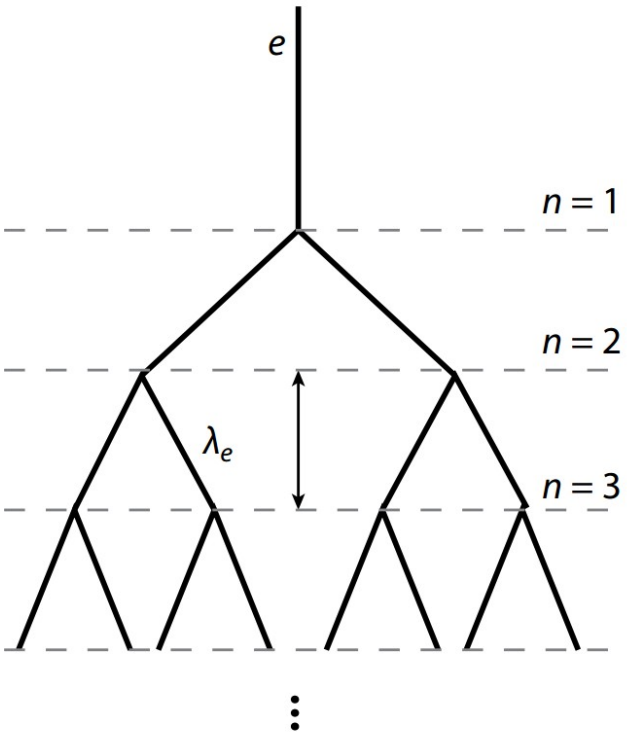
https://www.youtube.com/watch?v=xchtgvzzc5M

https://www.youtube.com/watch?v=WgzAwKe5aTQ

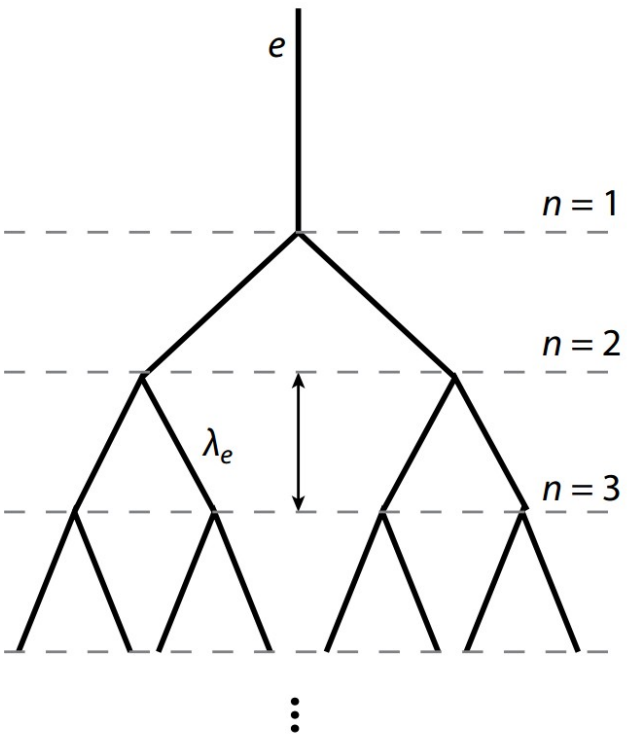


Desarrollo dependiente de la composición del primario

Modelo de Heitler



Modelo de Heitler



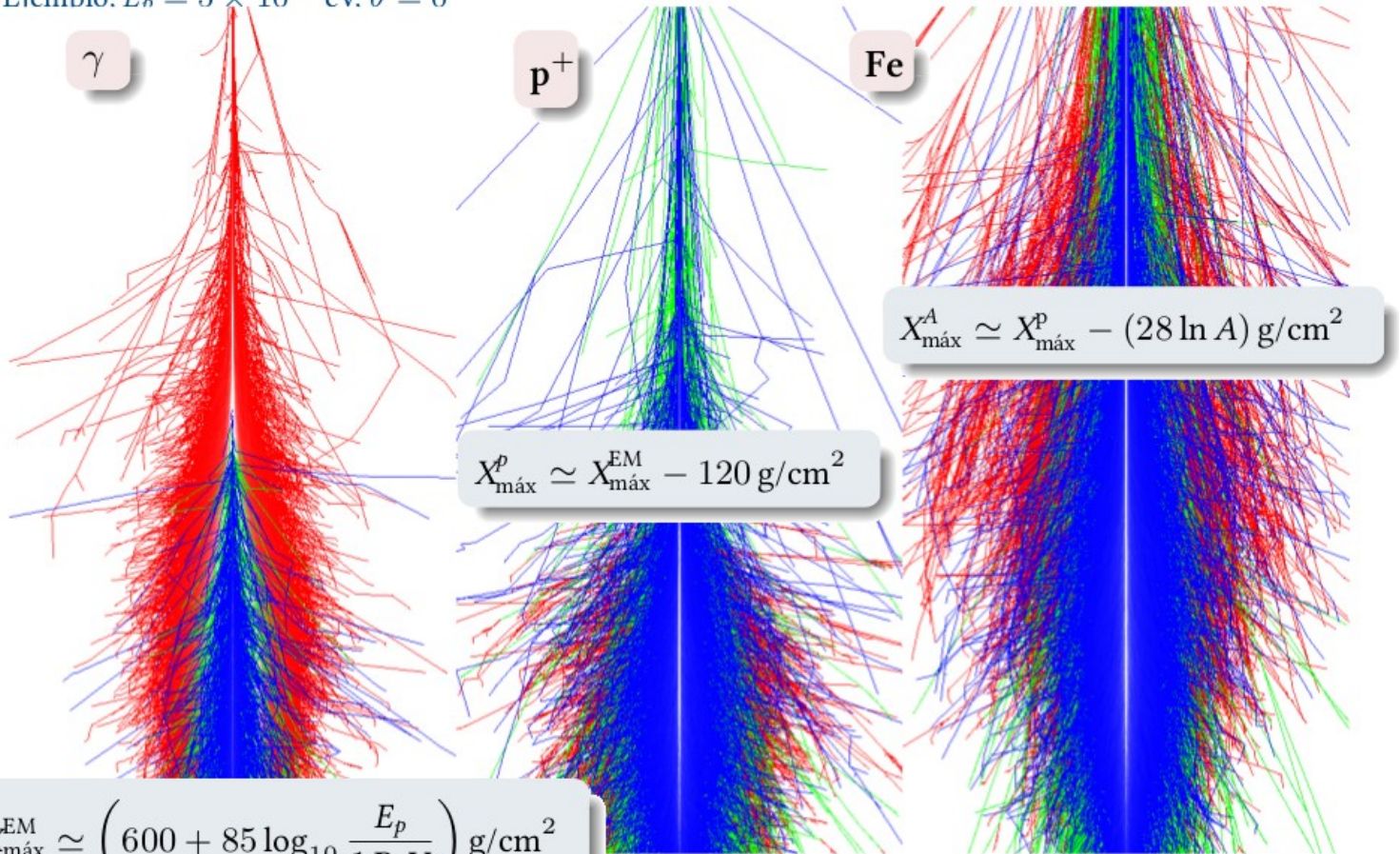
- Recorrida una distancia $\lambda_{EM} = X_{EM} / \ln 2$, una partícula produce 2 partículas con $E_{n+1}=E_n/2$
- El número de partículas: $N \sim 2^n$: $N(X) = 2^{X/\lambda_{EM}}$
- Luego, la energía media: $\langle E \rangle = E_p / N(X) = E_p / 2^{X/\lambda_{EM}}$
- Ahora, si $\langle E \rangle = E_c \rightarrow$ Se detiene la producción.

$$N_{\text{máx}} \sim \frac{E_p}{E_c}$$

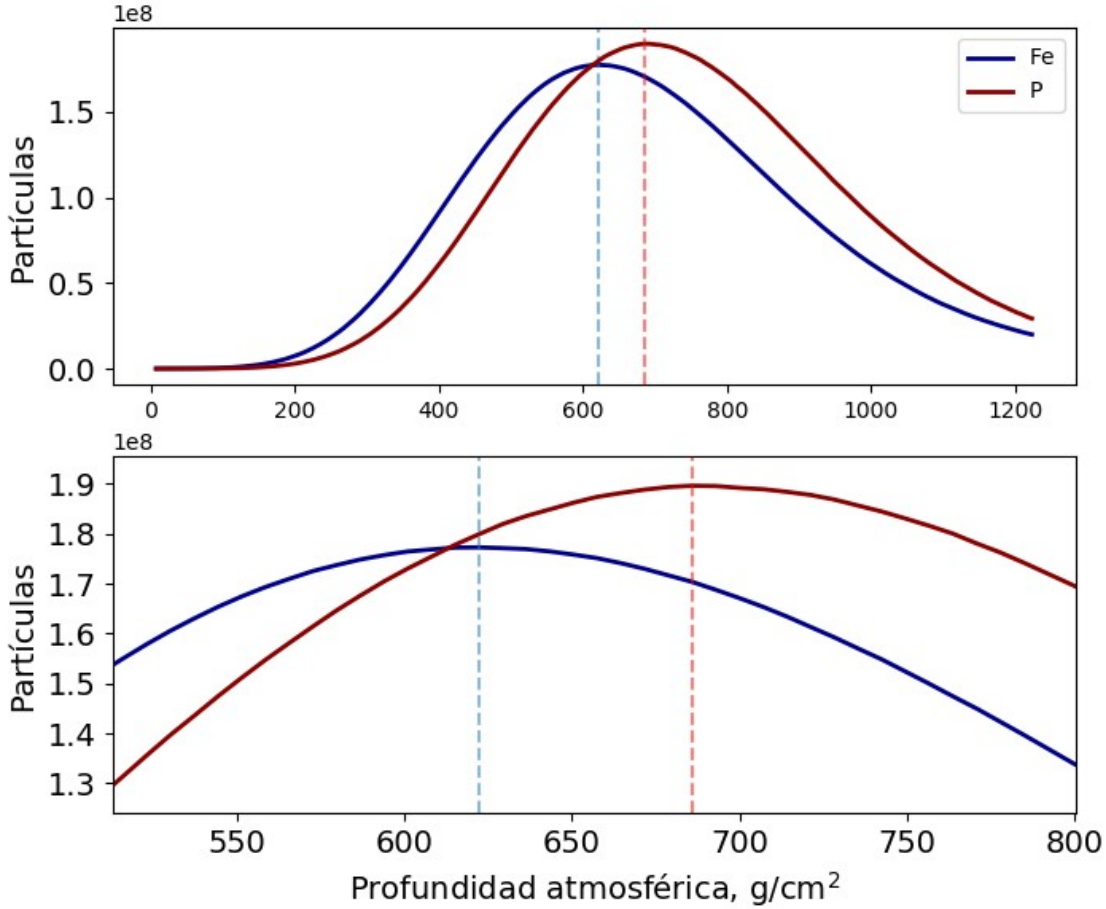
$$X_{\text{máx}} \sim \log\left(\frac{E_p}{E_c}\right)$$

Cascadas atmosféricas

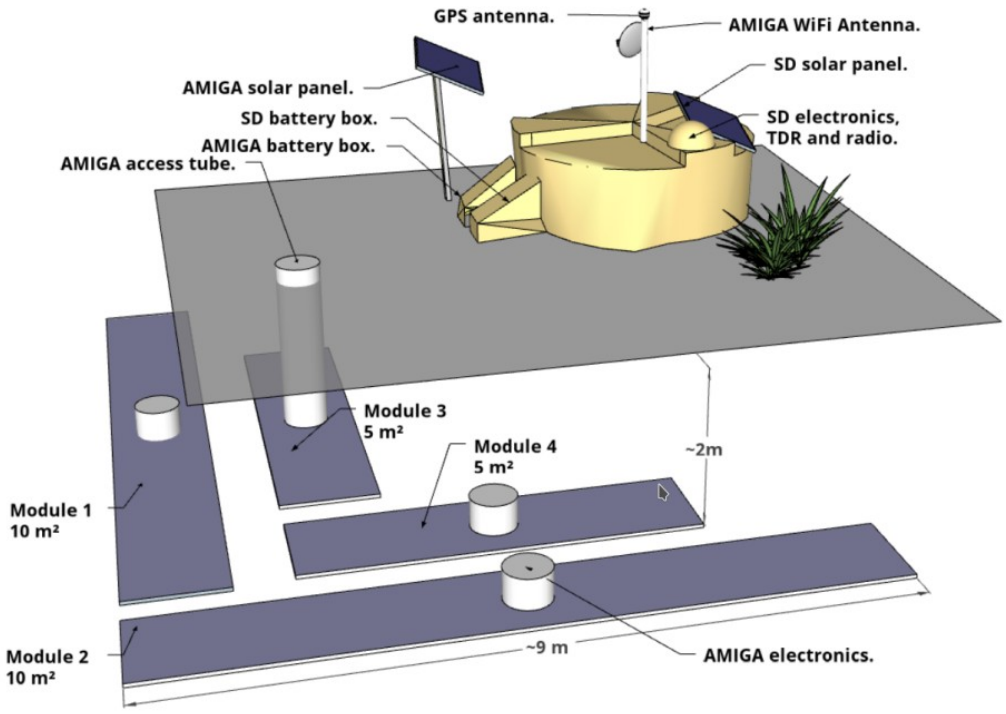
Ejemplo. $E_p = 5 \times 10^{14}$ eV, $\theta = 0^o$



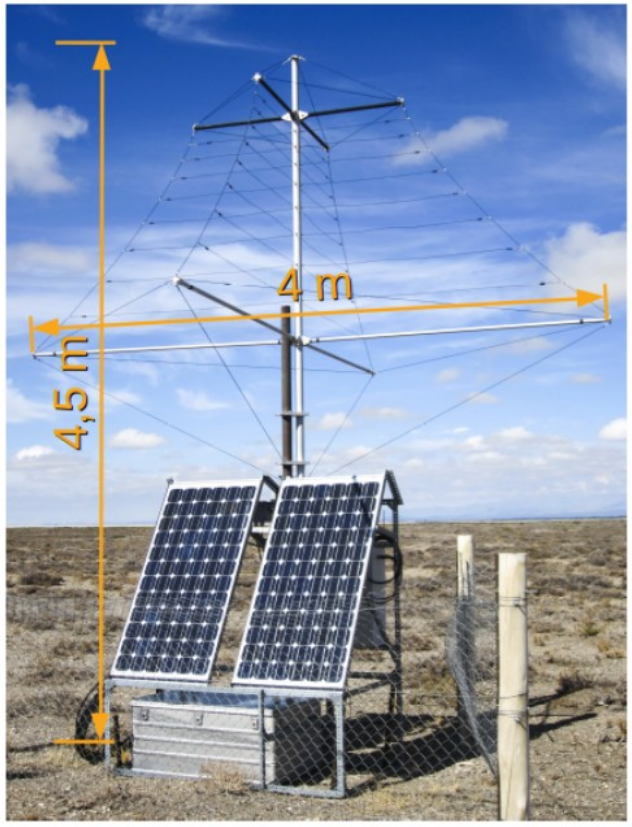
Distribución longitudinal del Fe y P



Separación hierro-protón

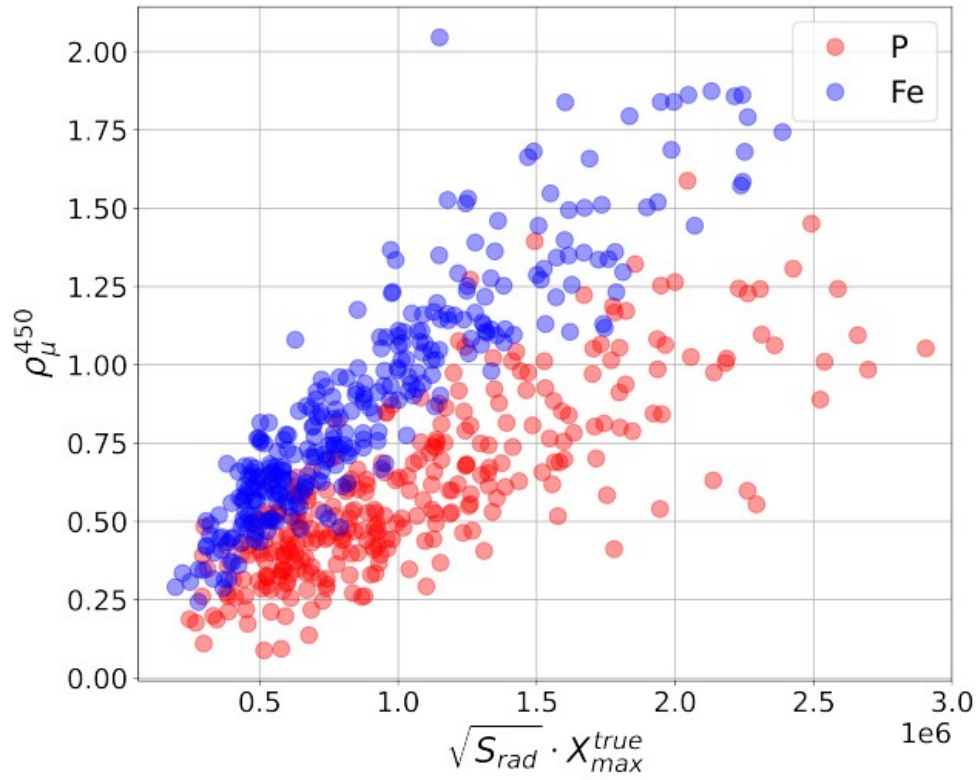


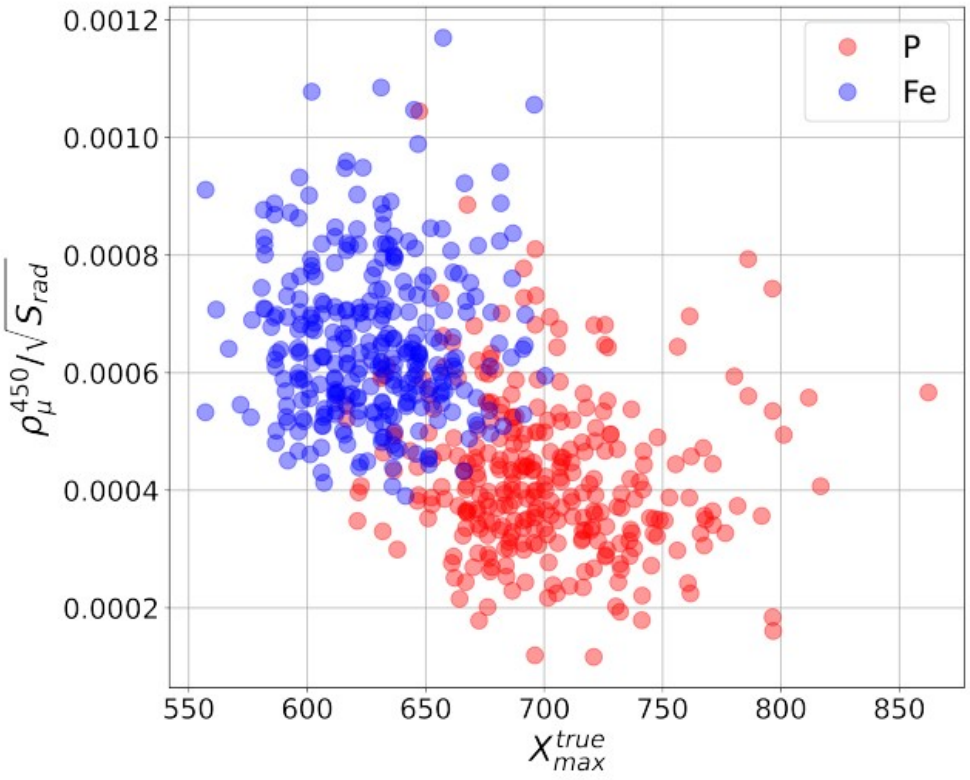
Componente muonica



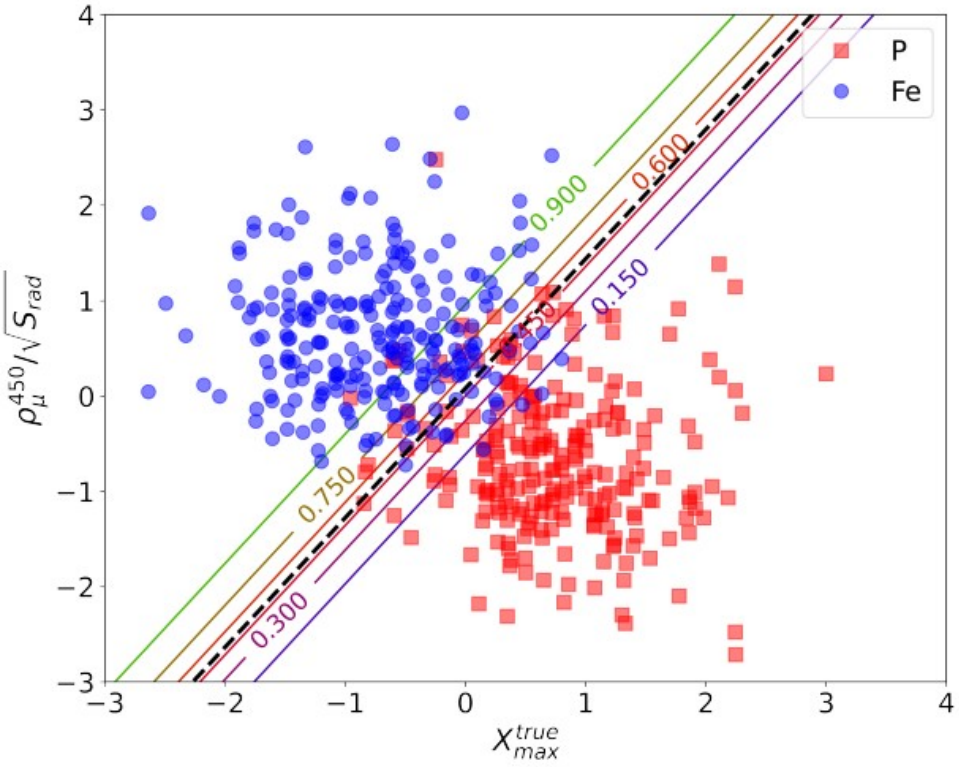
Componente electromagnética

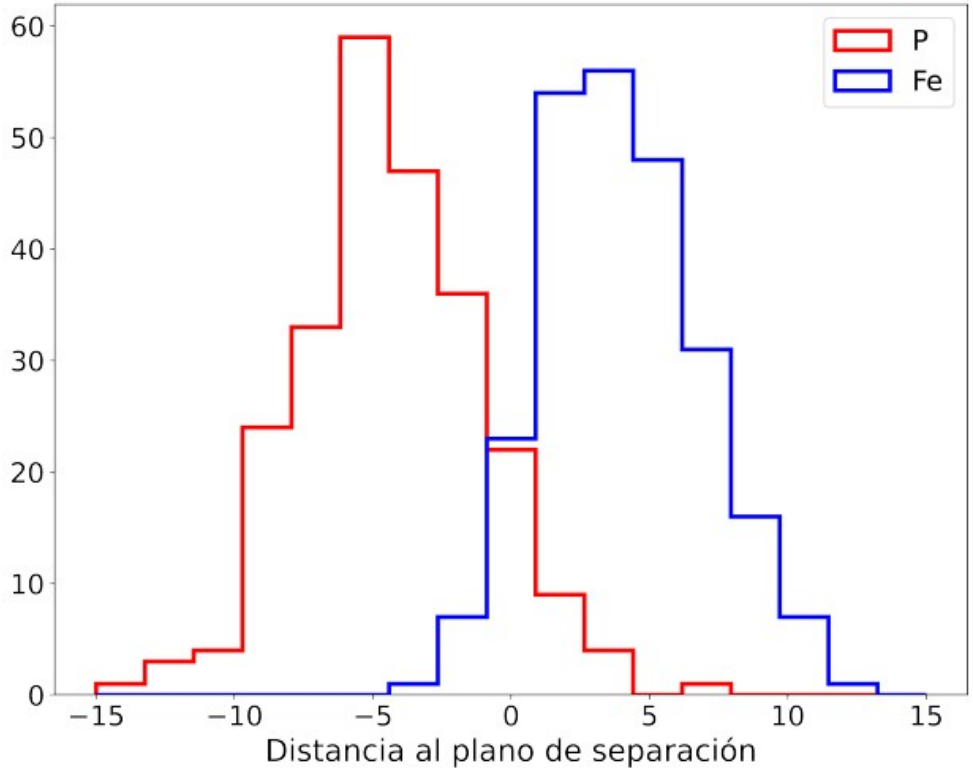
Separación hierro-protón





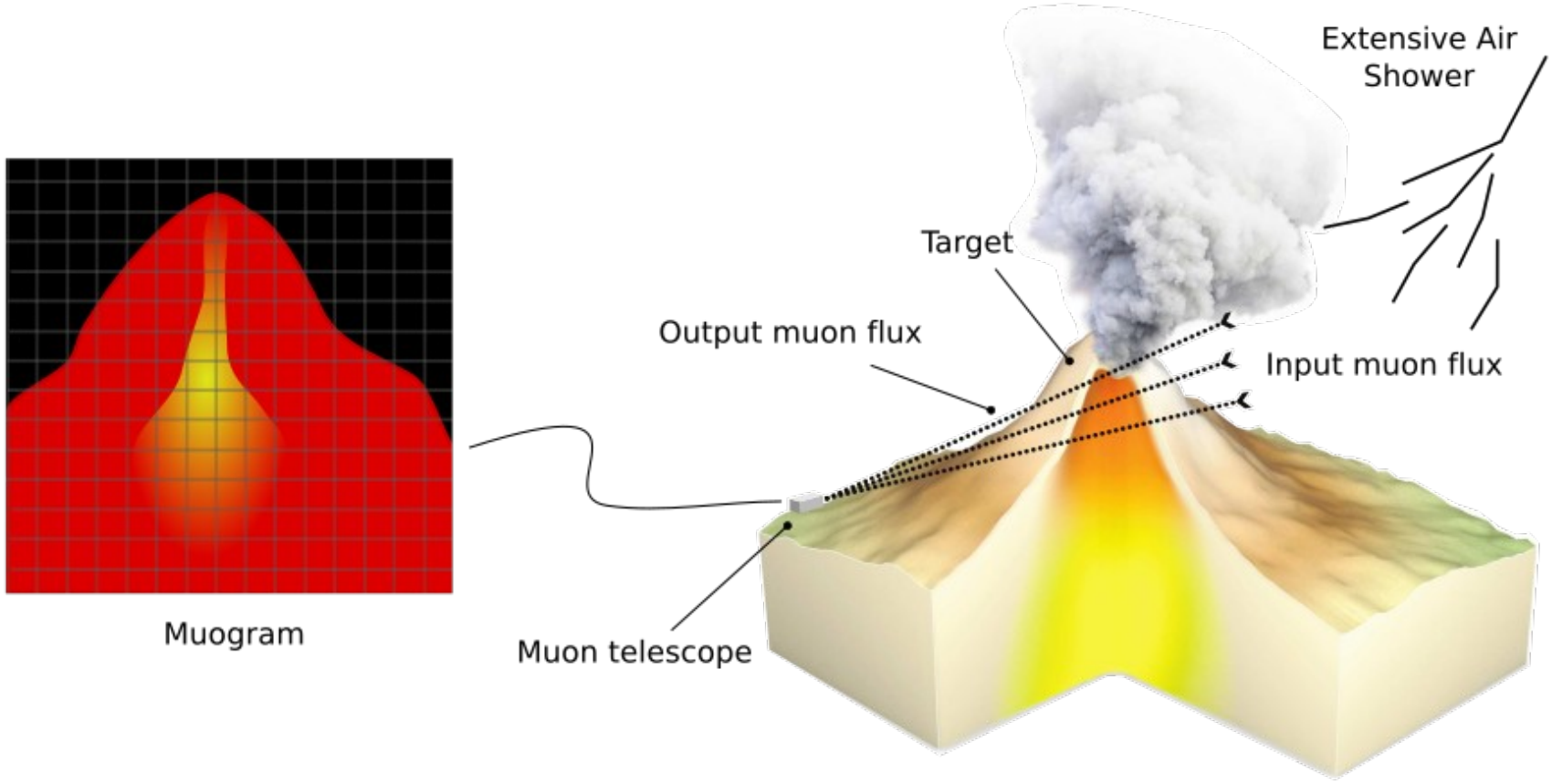
Separación hierro-protón



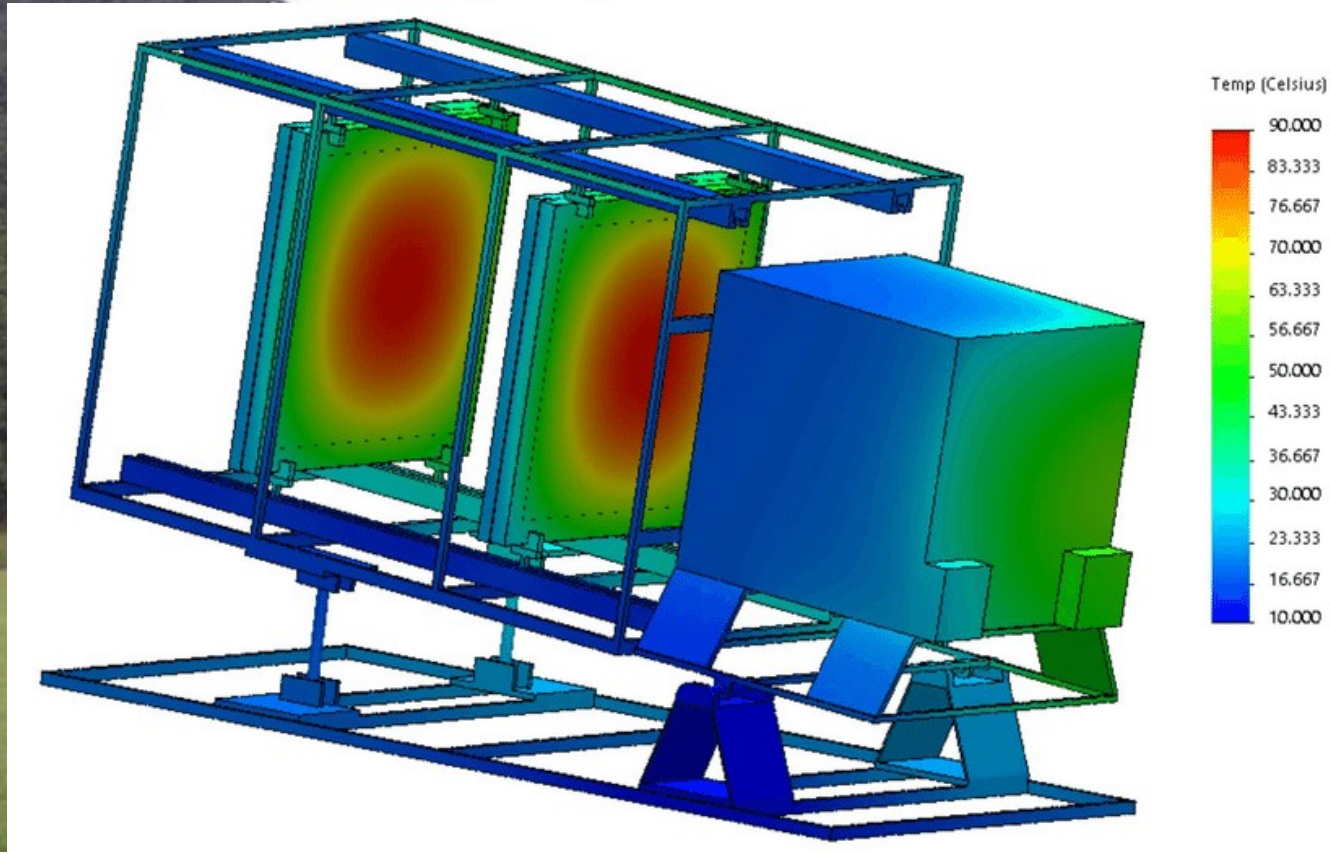


Aplicaciones de los rayos cósmicos

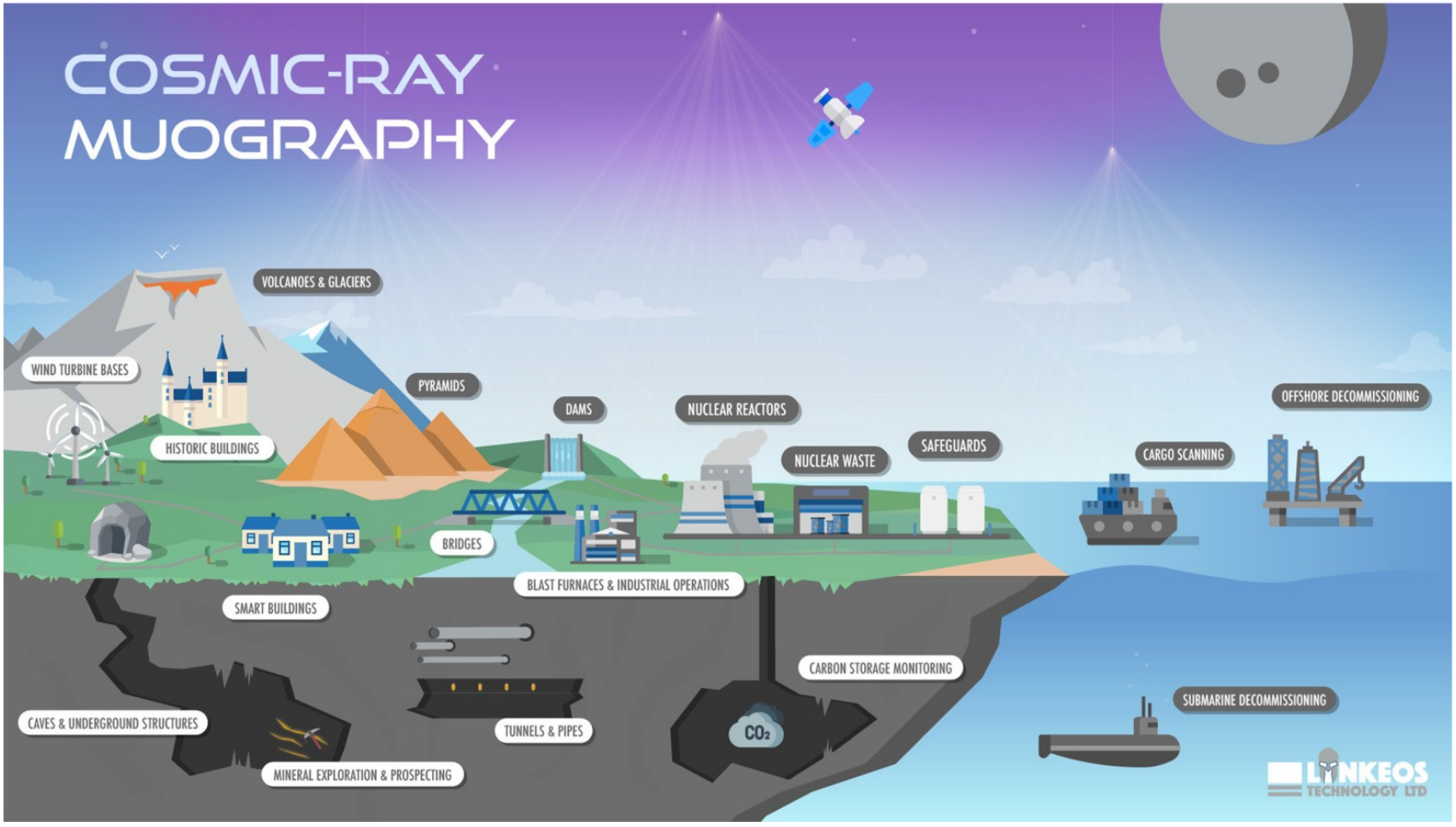
Muografia


Extensive Air
Shower
Target
Output muon flux
Input muon flux
Muon telescope
Muogram

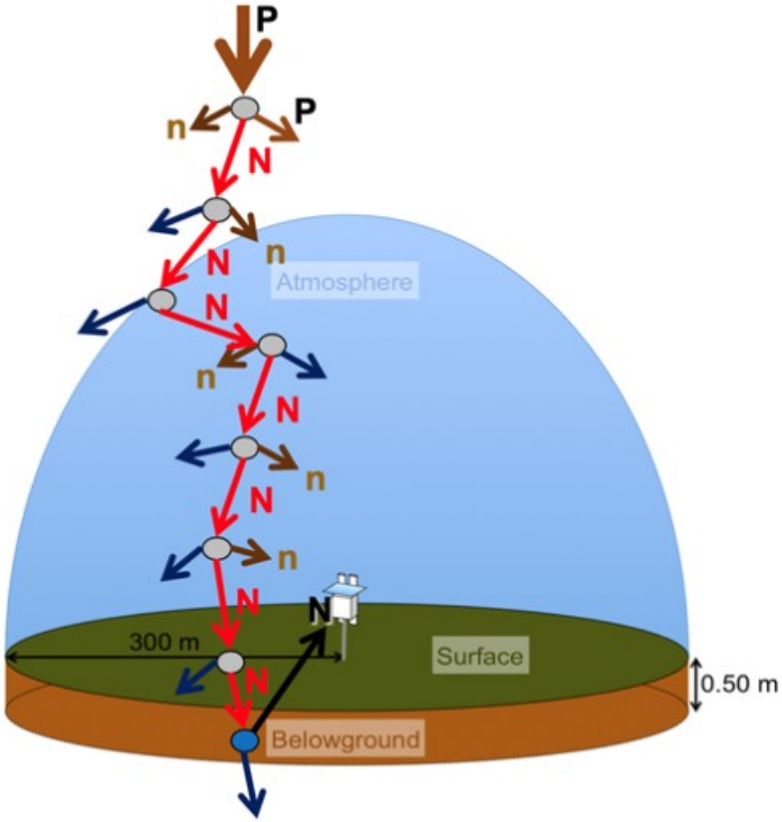
Muografia

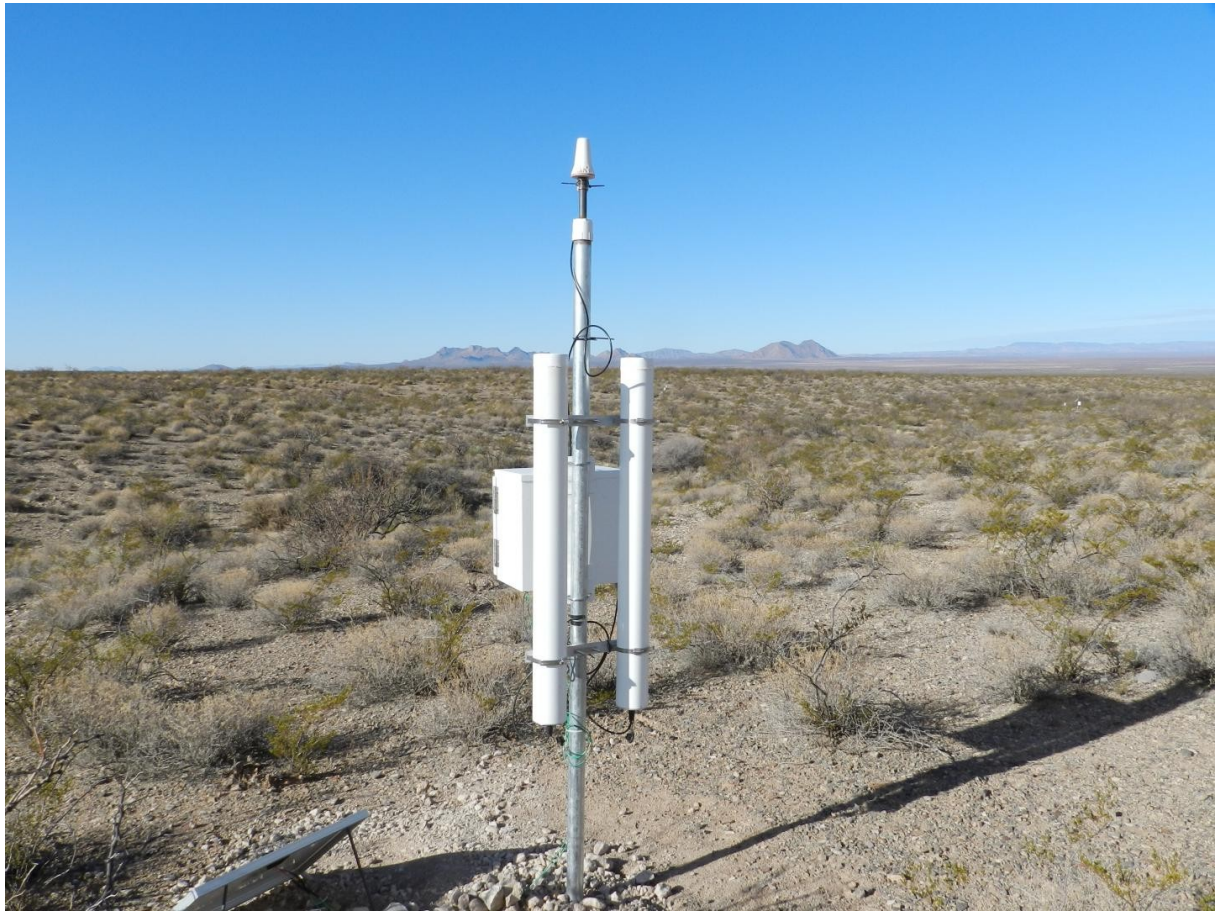

Temp (Celsius)
90.000
83.333
76.667
70.000
63.333
56.667
50.000
43.333
36.667
30.000
23.333
16.667
10.000

Muografia


COSMIC-RAY
MUOGRAPHY
VOLCANOES & GLACIERS
WIND TURBINE BASES
PYRAMIDS
DAMS
NUCLEAR REACTORS
OFFSHORE DECOMMISSIONING
HISTORIC BUILDINGS
NUCLEAR WASTE
SAFEGUARDS
CARGO SCANNING
BRIDGES
BLAST FURNACES & INDUSTRIAL OPERATIONS
SMART BUILDINGS
CARBON STORAGE MONITORING
SUBMARINE DECOMMISSIONING
CAVES & UNDERGROUND STRUCTURES
TUNNELS & PIPES
CO2
MINERAL EXPLORATION & PROSPECTING
LINKEOS
TECHNOLOGY LTD

Neutrones para la agricultura





Neutrones para la agricultura