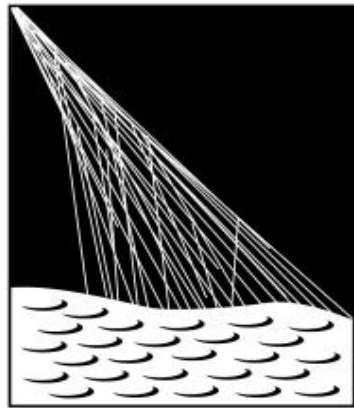


Astrofísica de Partículas



PIERRE
AUGER
OBSERVATORY



Vitor de Souza
vitor@ifsc.usp.br

www.astro.ifsc.usp.br

Programa do dia:

Introdução histórica

Apresentação do problema em astrofísica

Experimentos: Pierre Auger e CTA

Estudos fenomenológicos

Perspectivas futuras

Mensagem pra levar pra casa:

- Astrofísica de partículas é uma área com grande potencial de descobertas fundamentais e propícia para a inovação tecnológica
- A comunidade brasileira ocupa uma posição de destaque no cenário internacional
- Observatório Pierre Auger:
 - Resultados históricos já publicados
 - Ainda tem muito a produzir na próxima década
- Cherenkov Telescope Array (CTA)
 - O próximo experimento em Astrofísica de Partículas

Em 1900 ...

Eletromagnetismo recém apresentado
como uma teoria completa

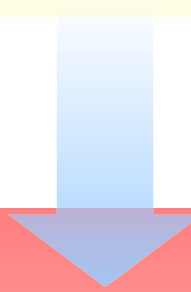
Primeiras pesquisas com “radiação” estão sendo
realizadas: raios-X e tubos de raios catódicos

Desenvolvem-se detectores de radiação:

- Câmara de núvens
- Filmes
- Contador Geiger

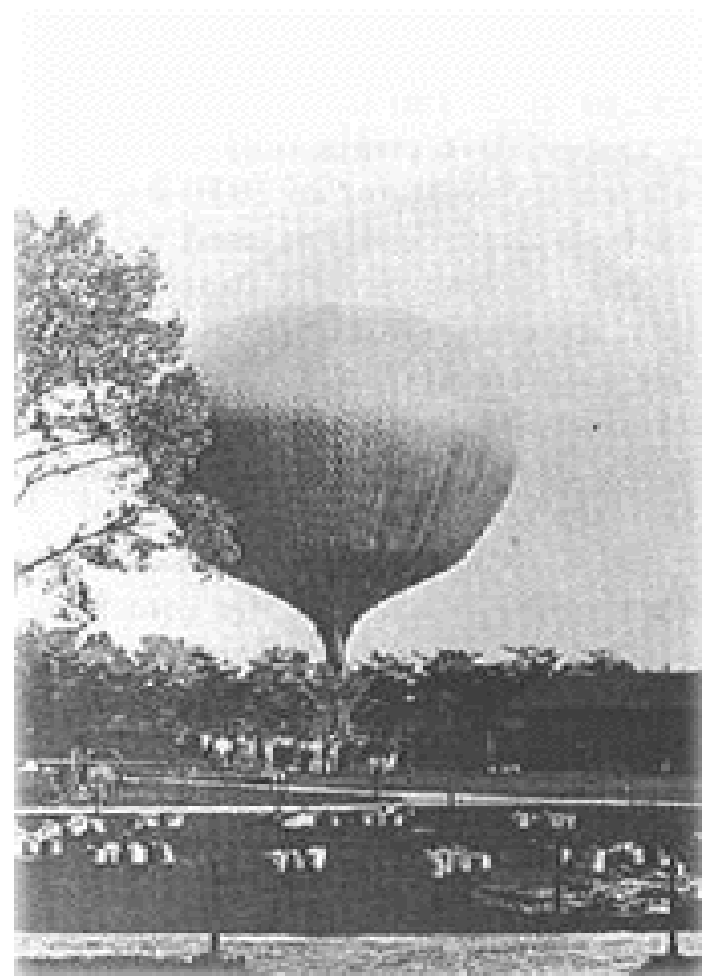
Radiação Natural

No nível do solo mede-se uma radiação
que deve ser gerada por
material radiativo no solo

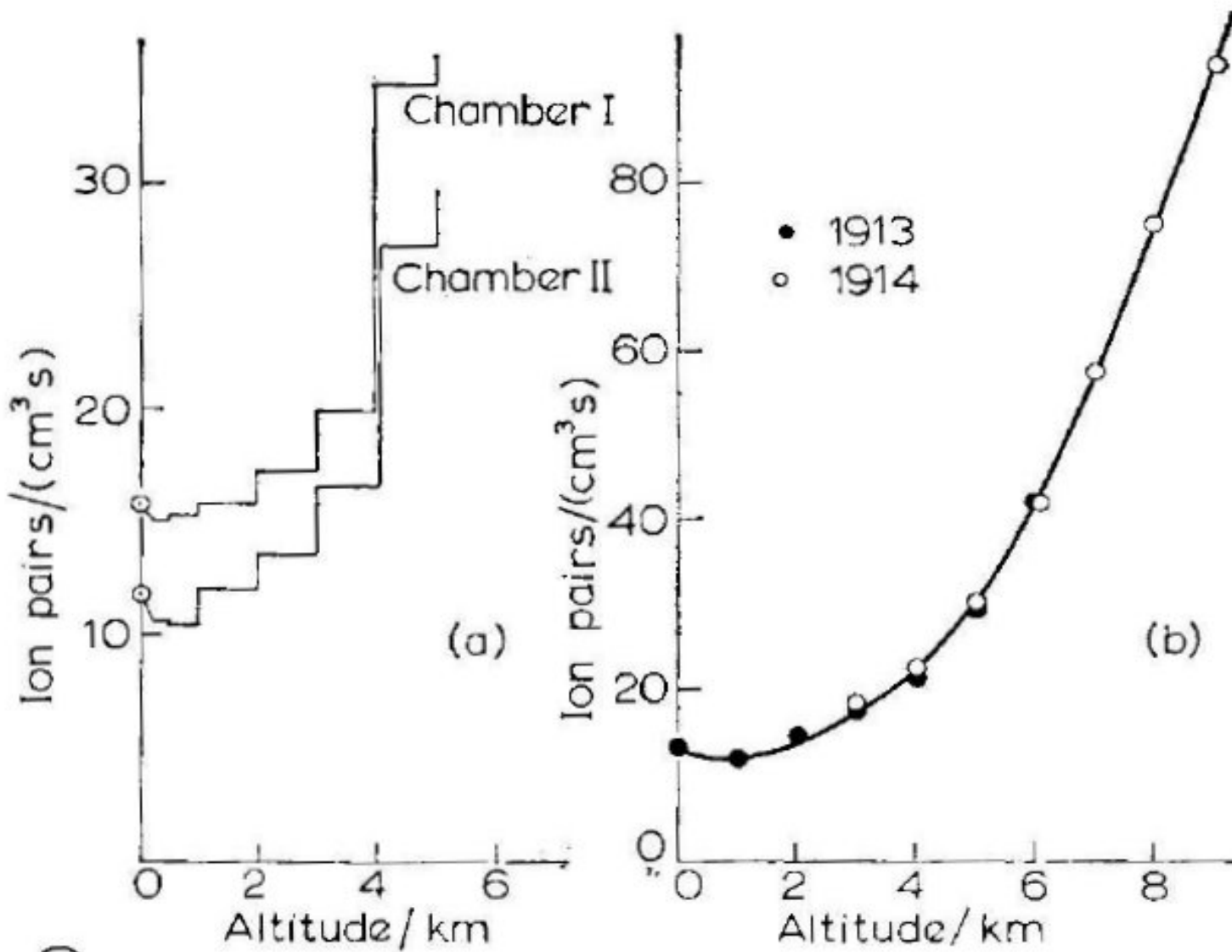


A intensidade da radiação deve diminuir
com a altitude

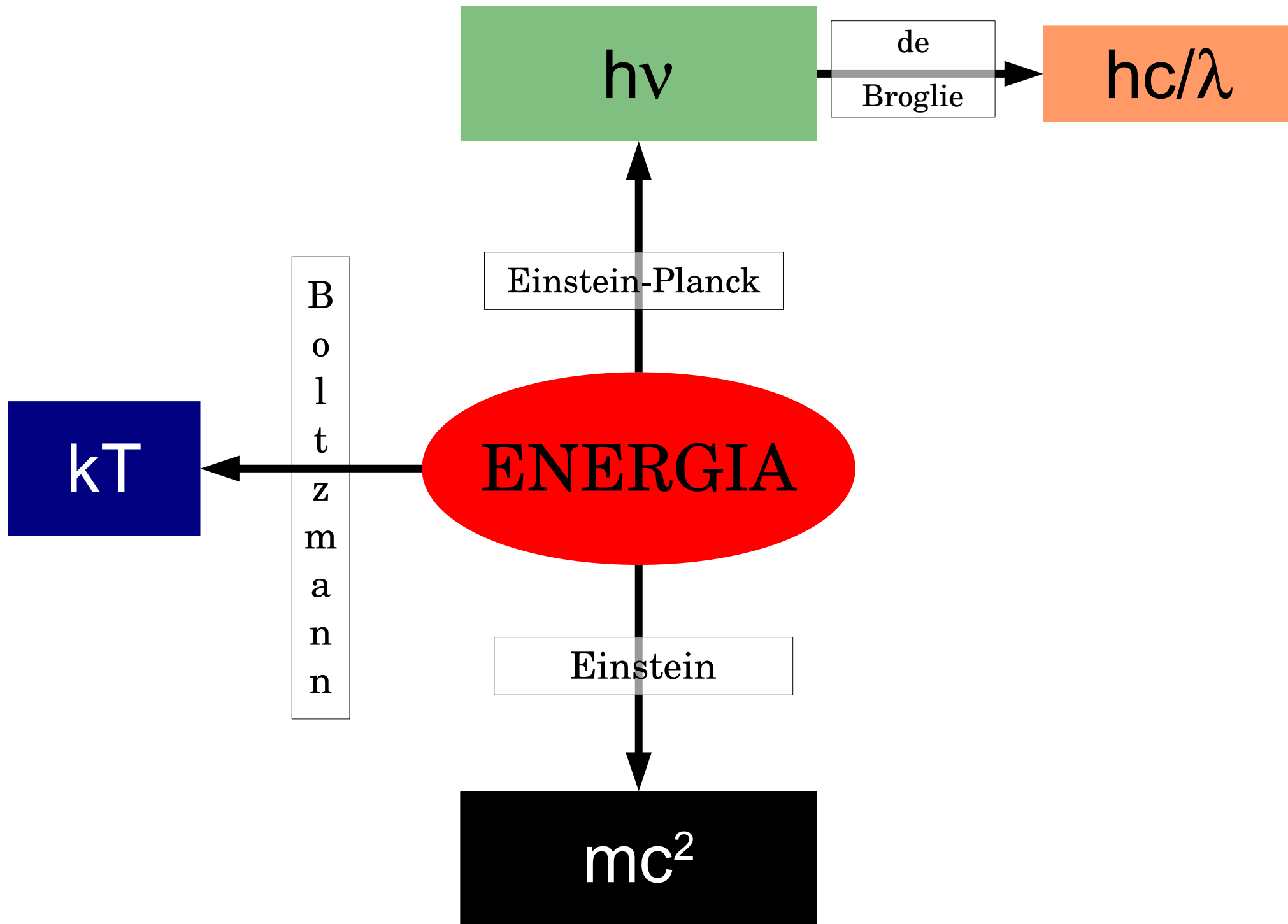
Raios ou Radiação Cósmica:

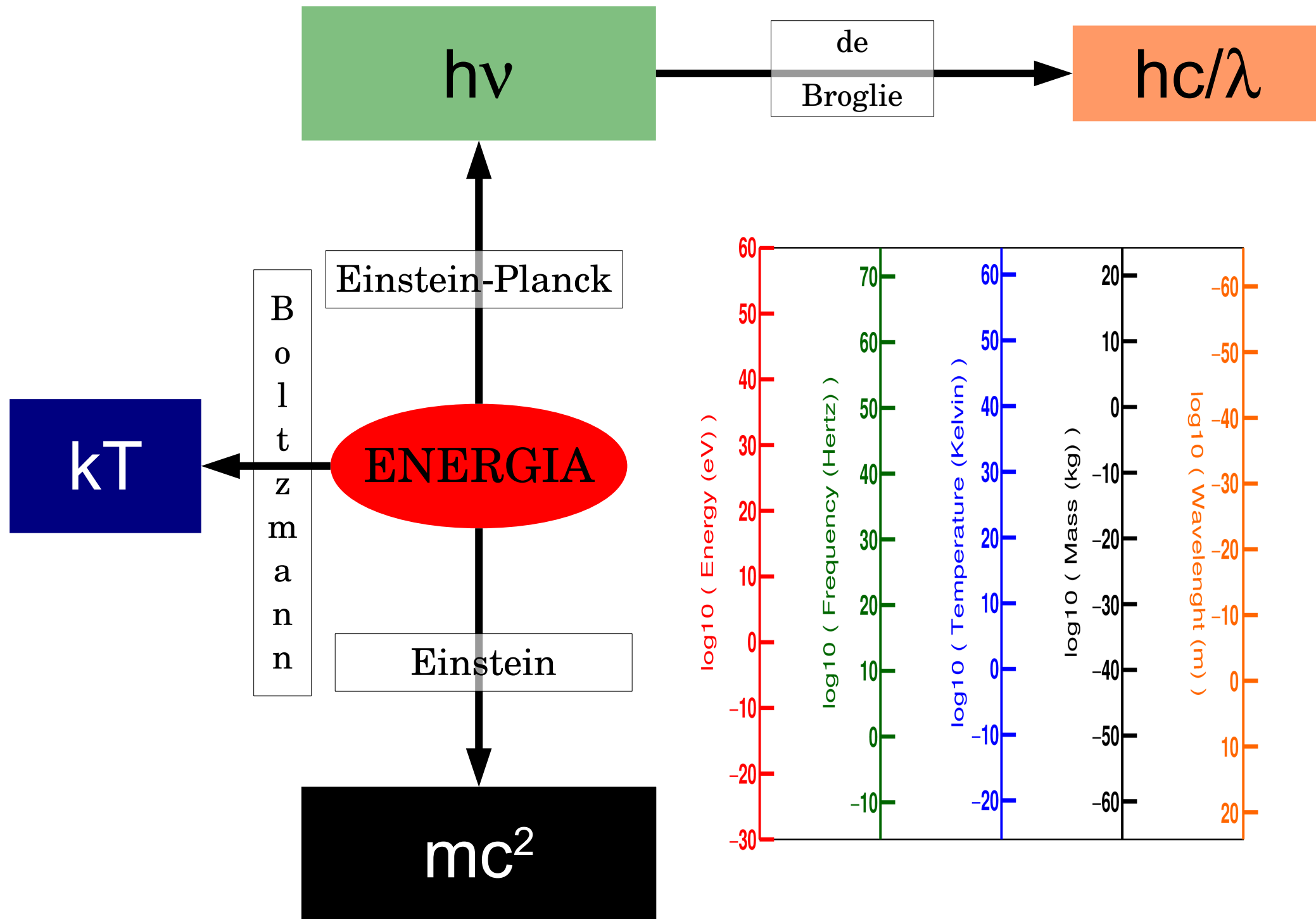


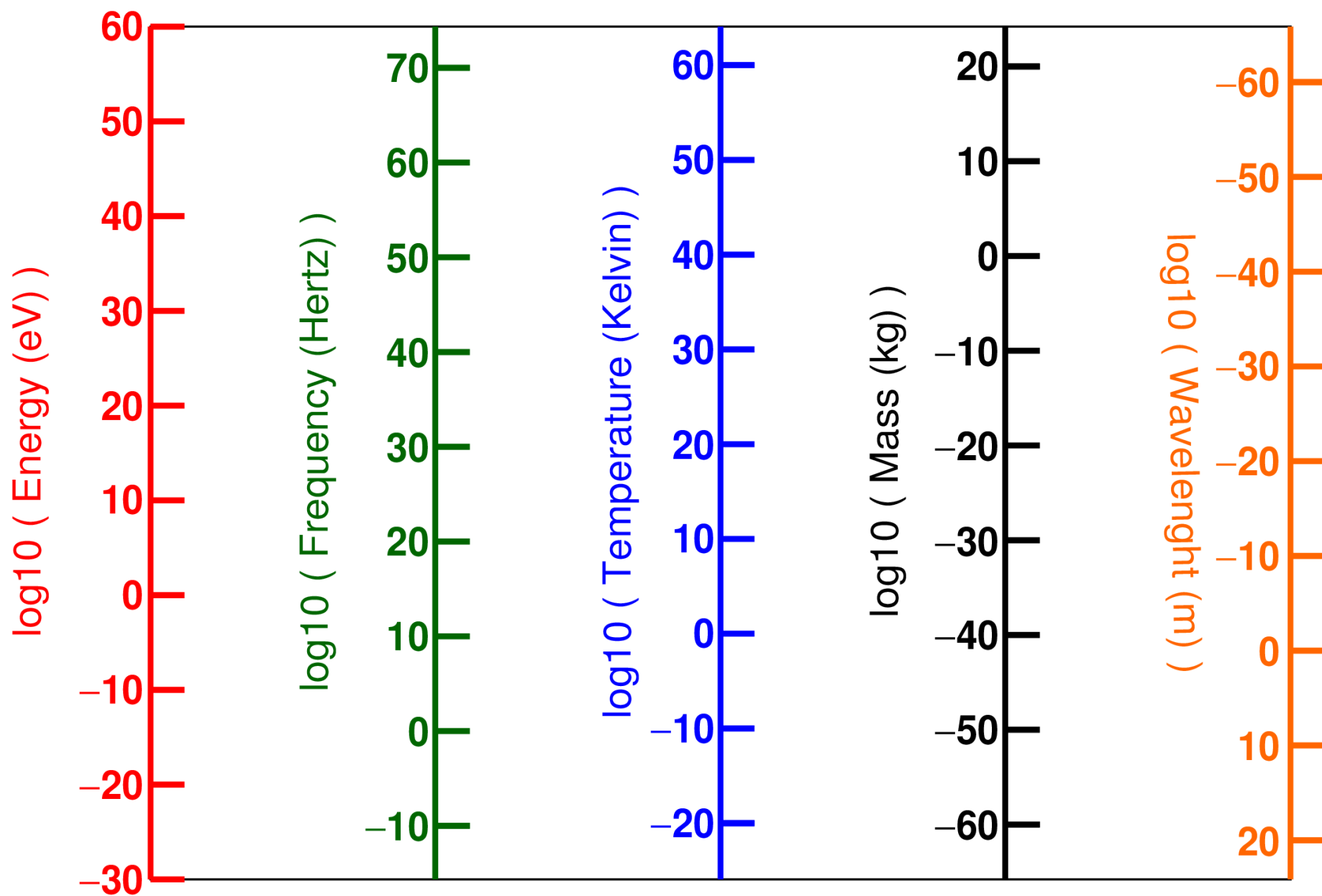
Victor Hess realizou medidas com balões e mostrou que a intensidade da radiação aumentava com a altitude



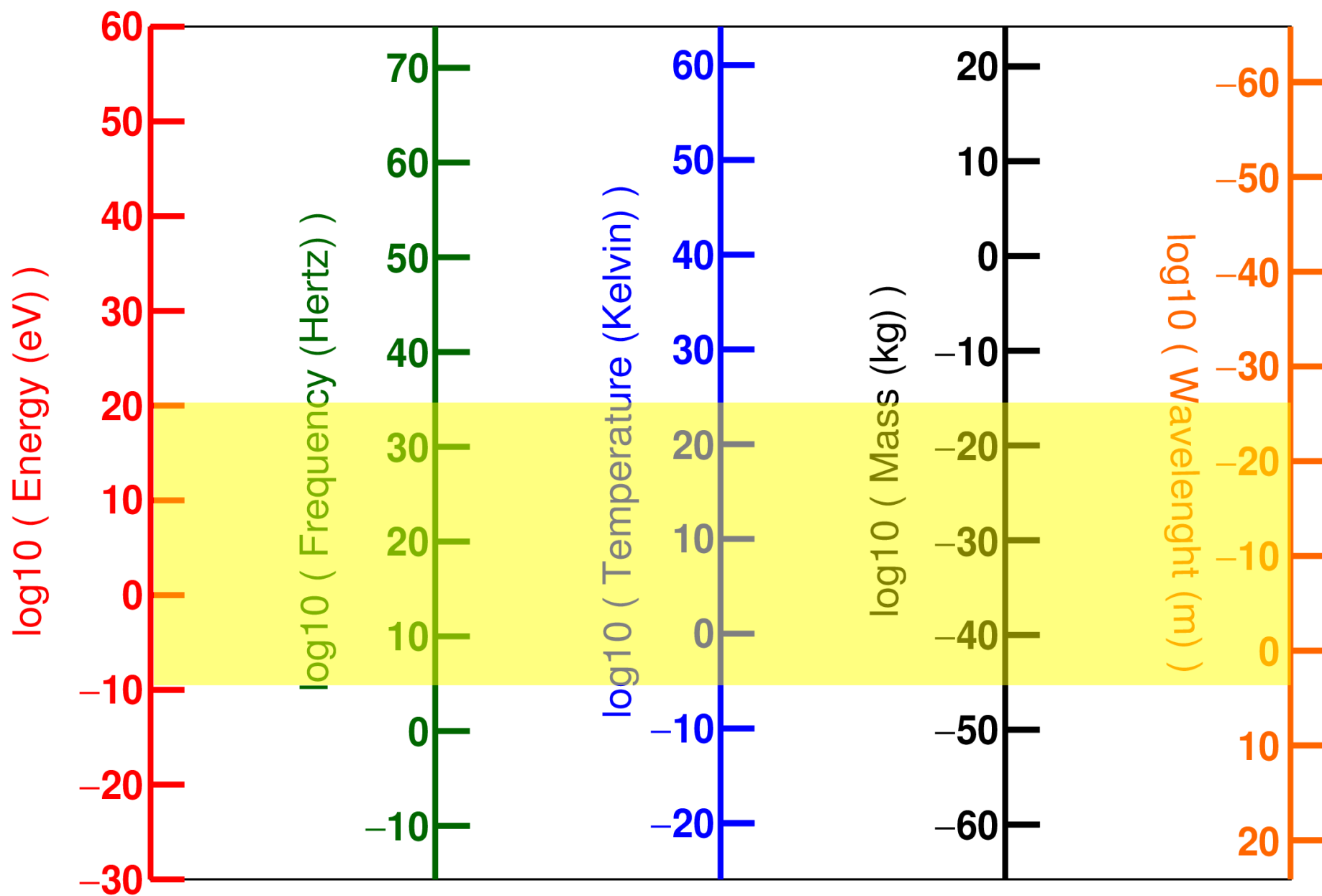
Fonte está fora Terra: Raios ou Radiação Cósmica

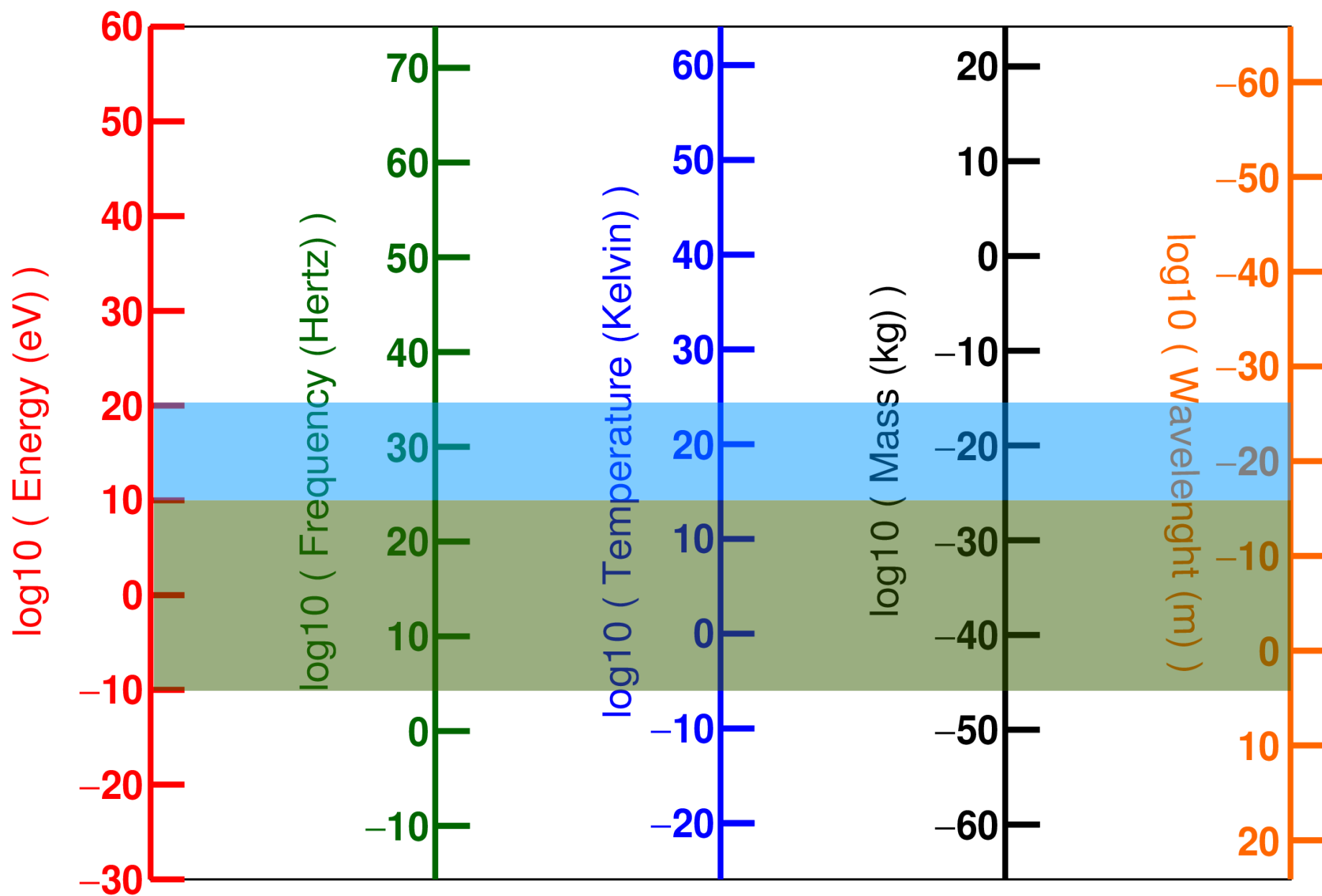


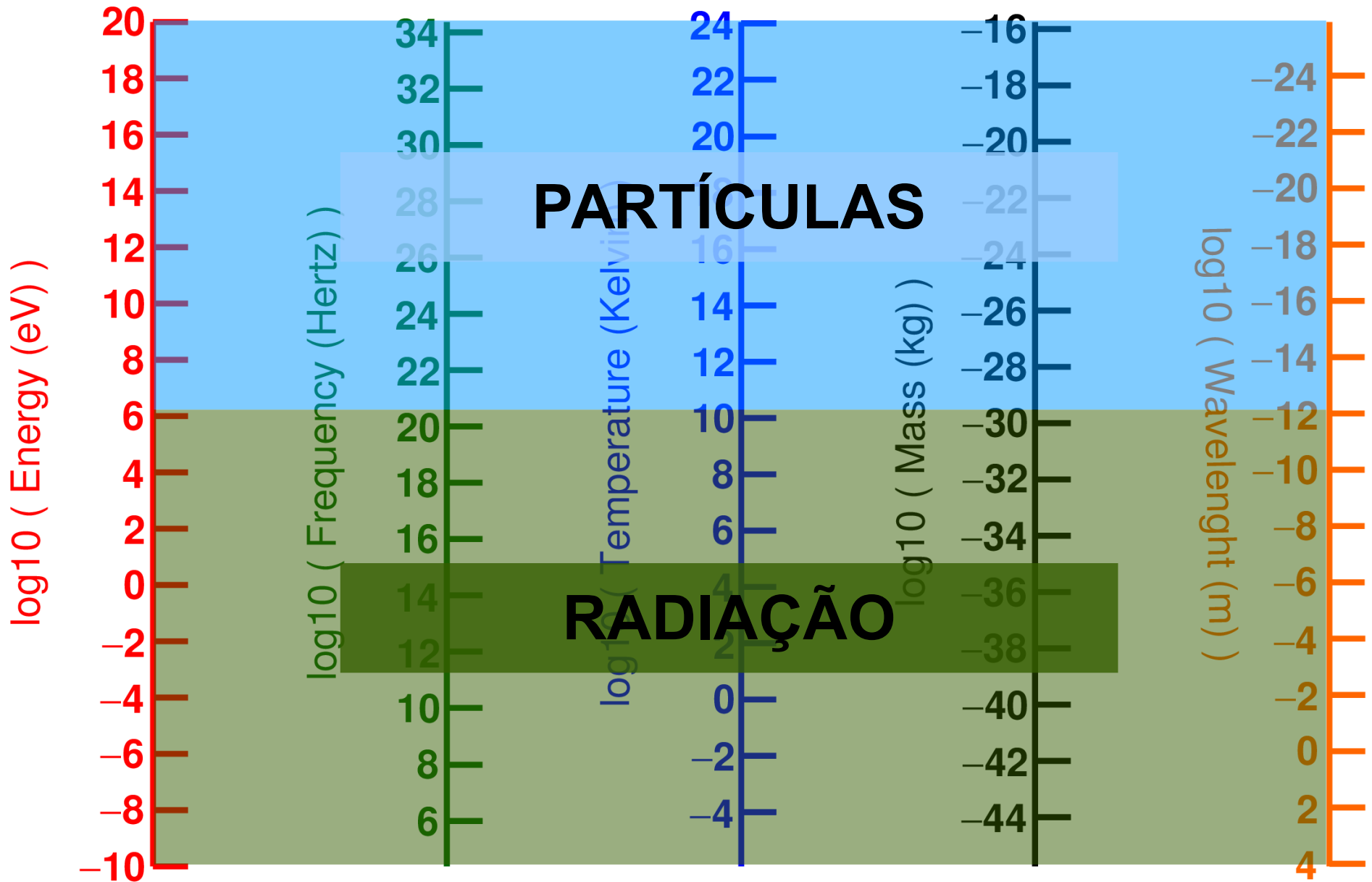




1 Joule = 1.6×10^{-19} eV

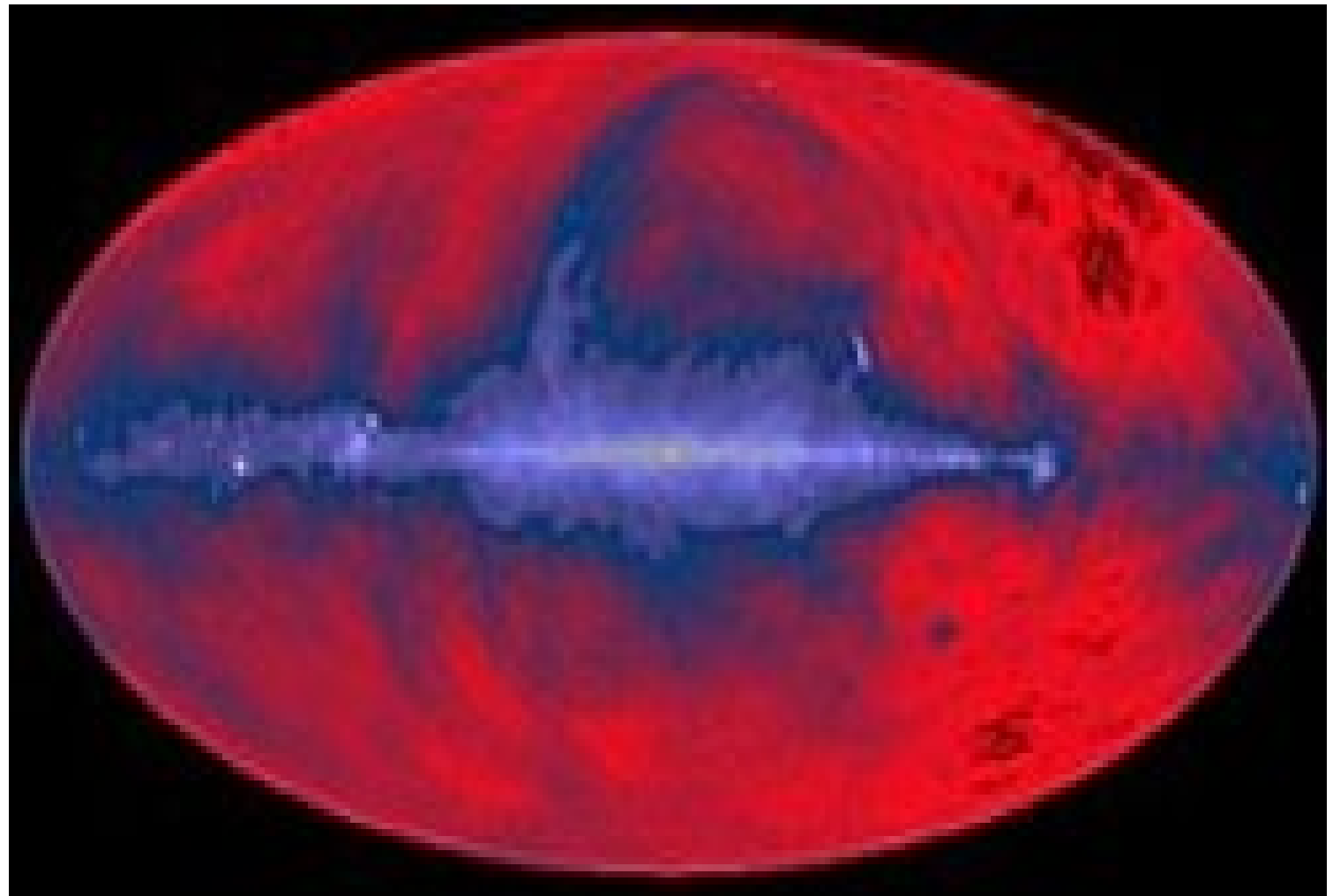
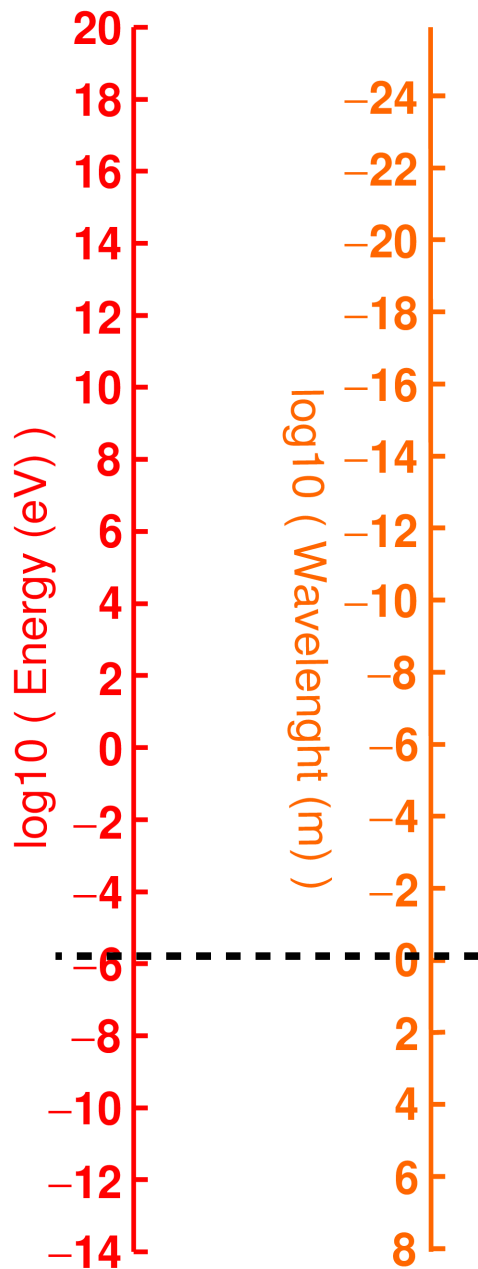






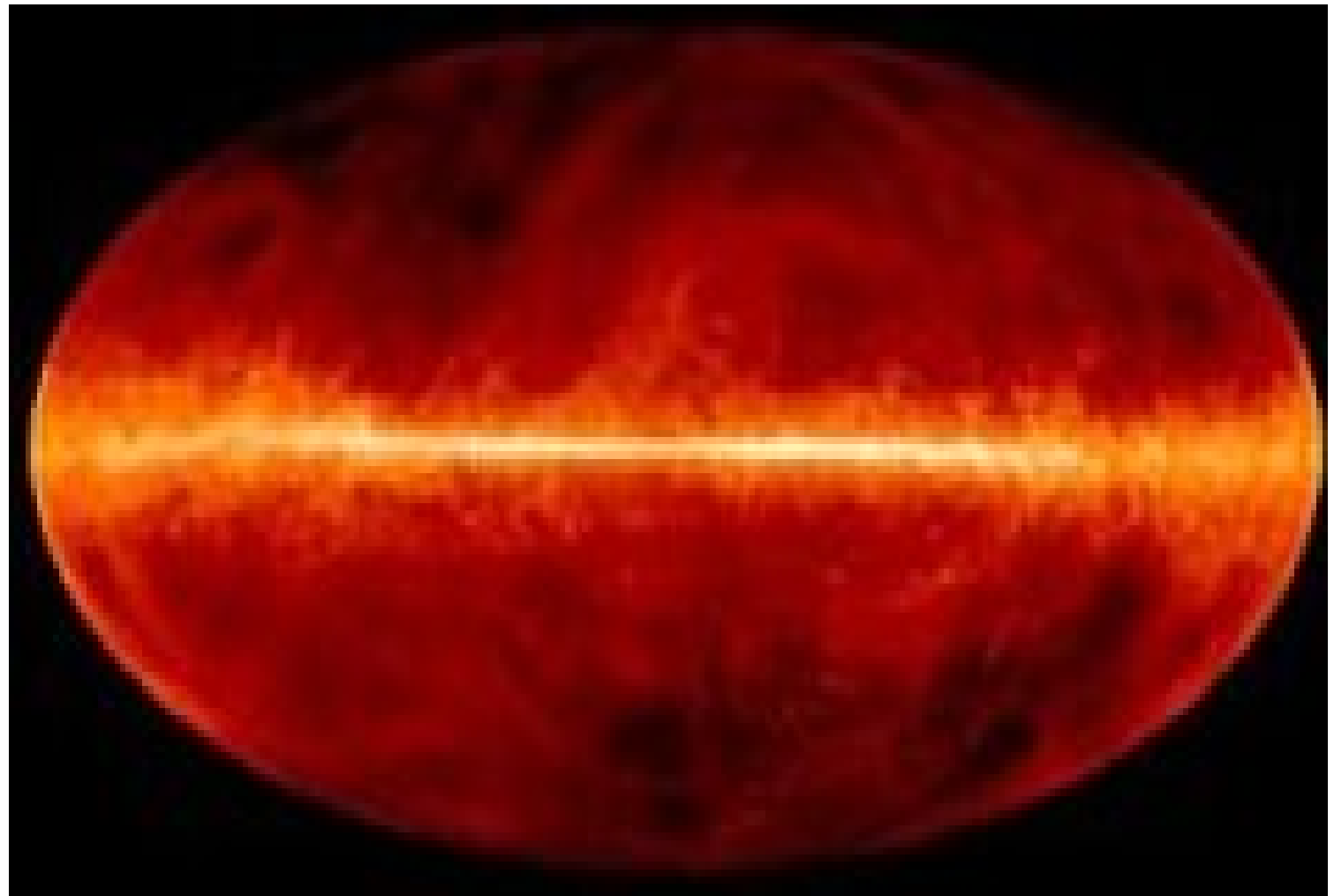
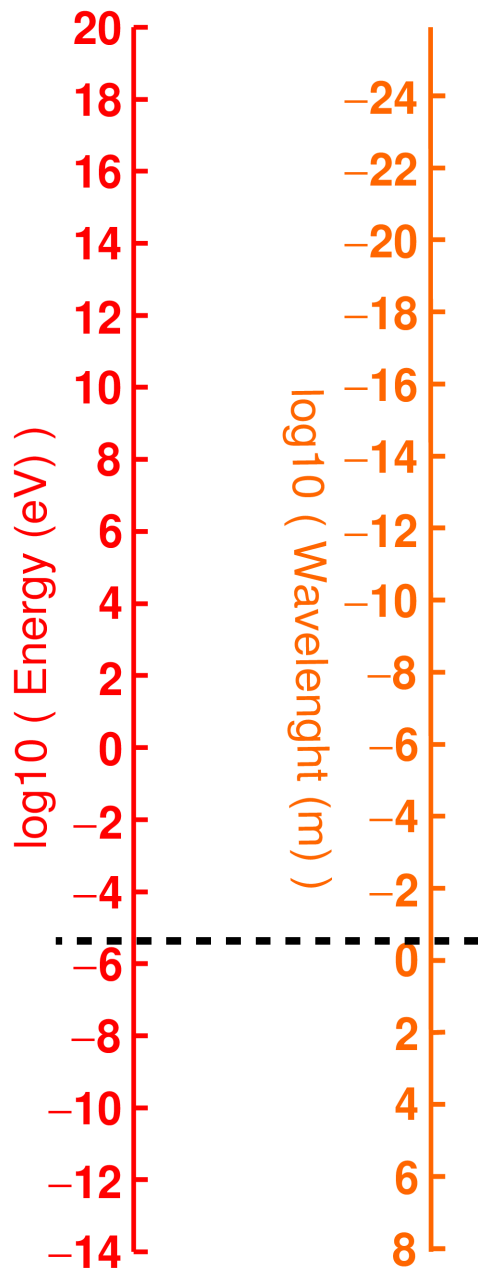
Rádio (408 MHz)

C. Haslam et al., MPIfR, SkyView

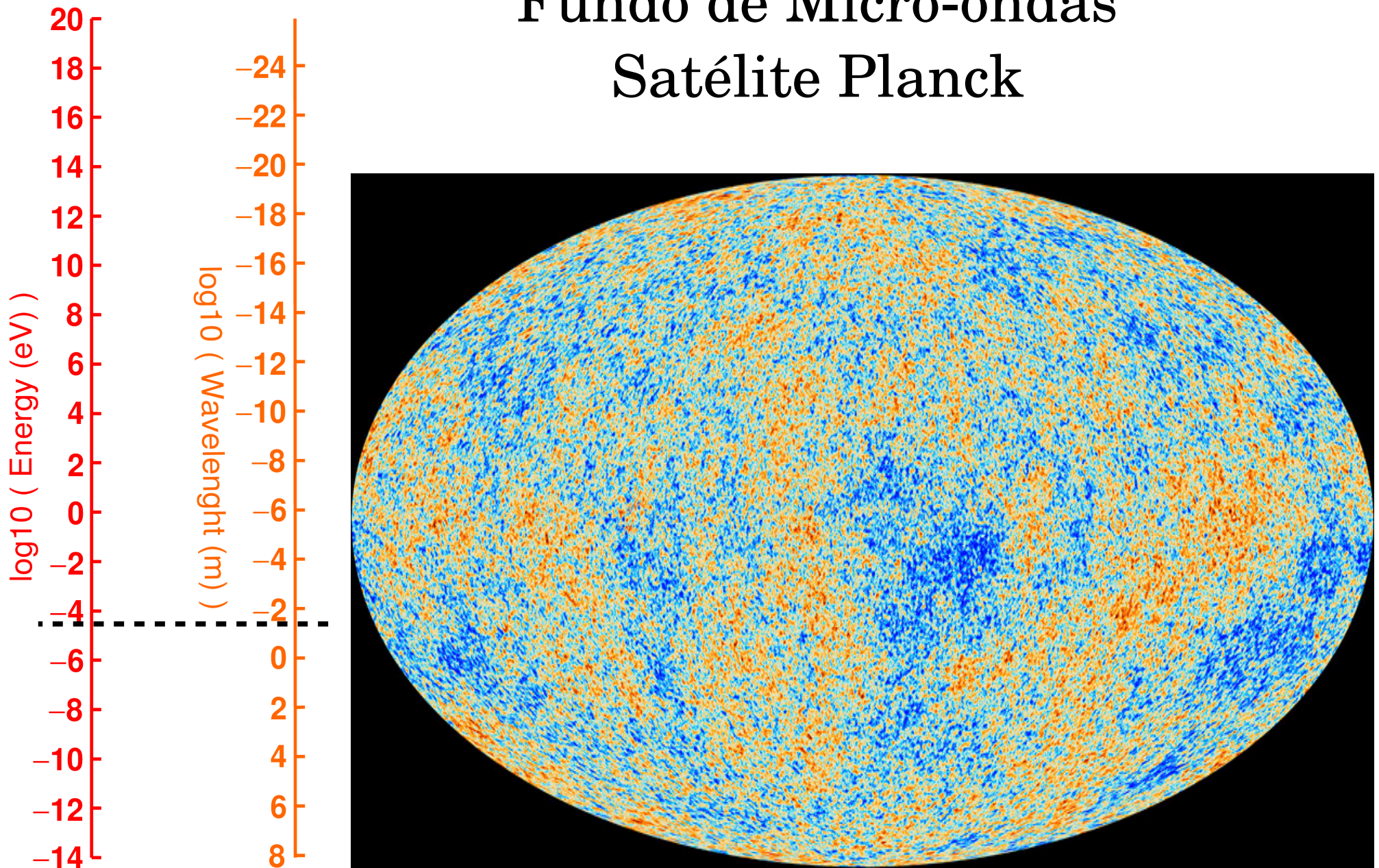


Rádio (1420 MHz)

J. Dickey et al., NRAO, SkyView

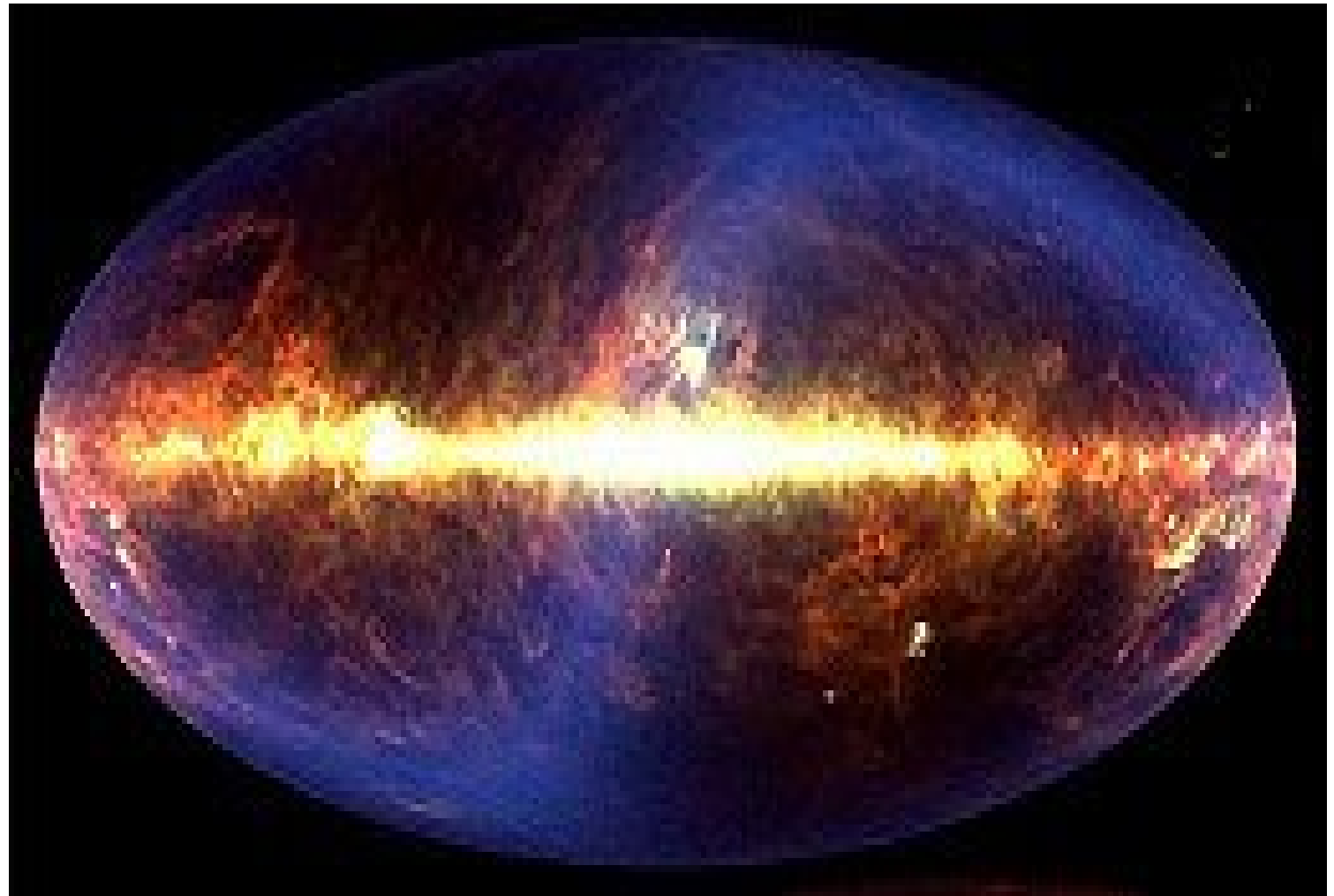
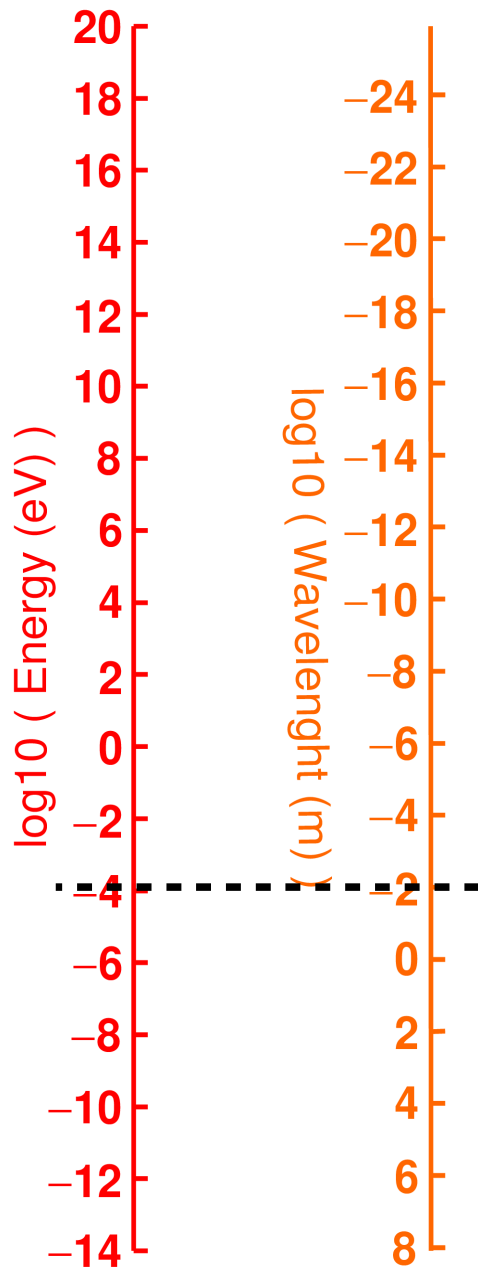


Fundo de Micro-ondas Satélite Planck



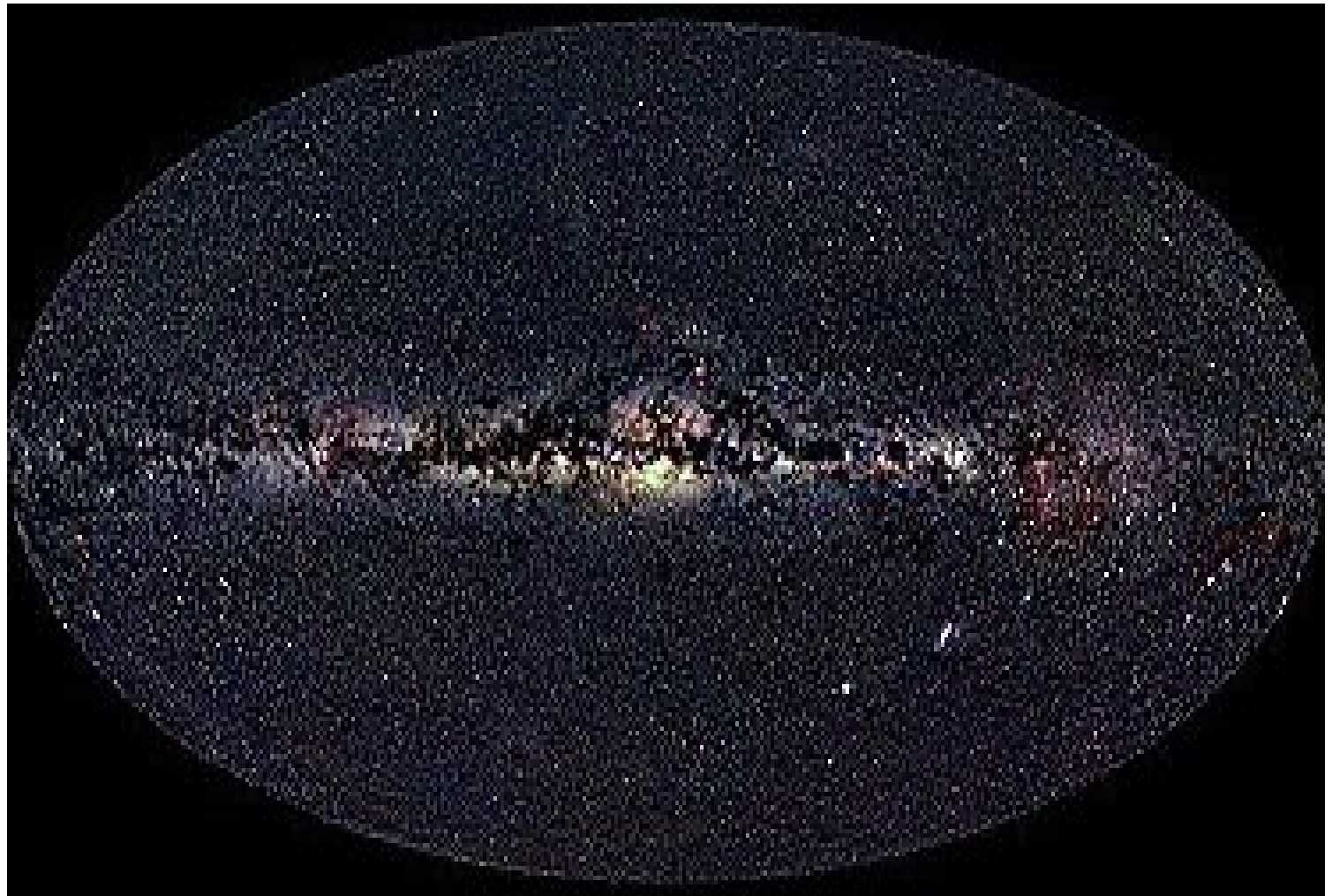
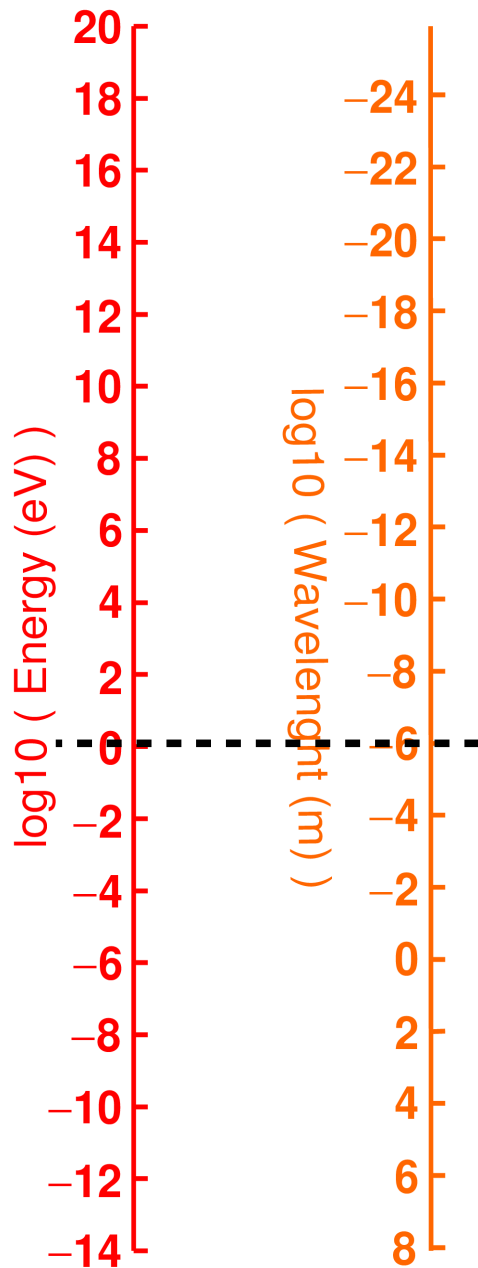
Infravermelho

Dirbe Team, COBE, NASA



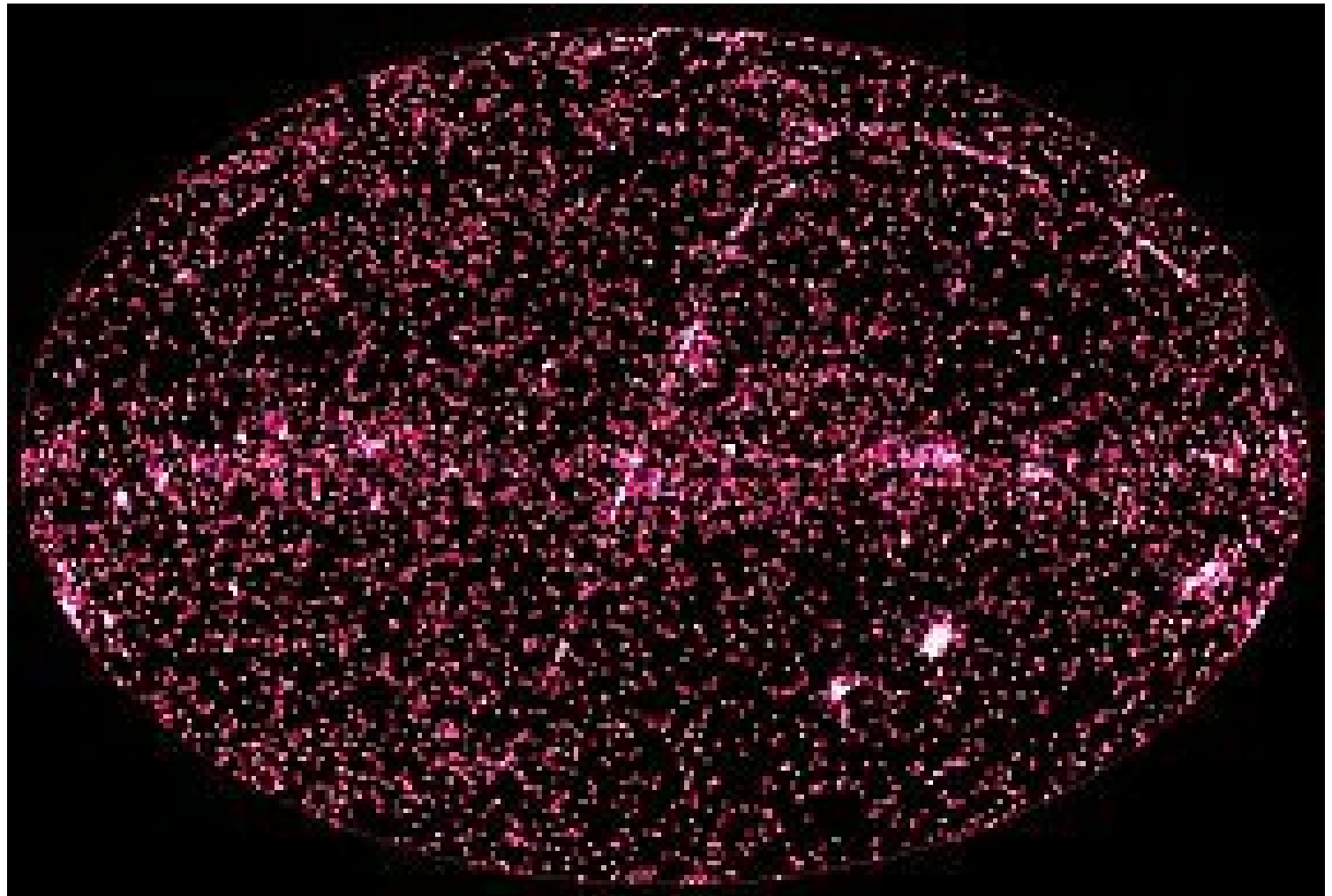
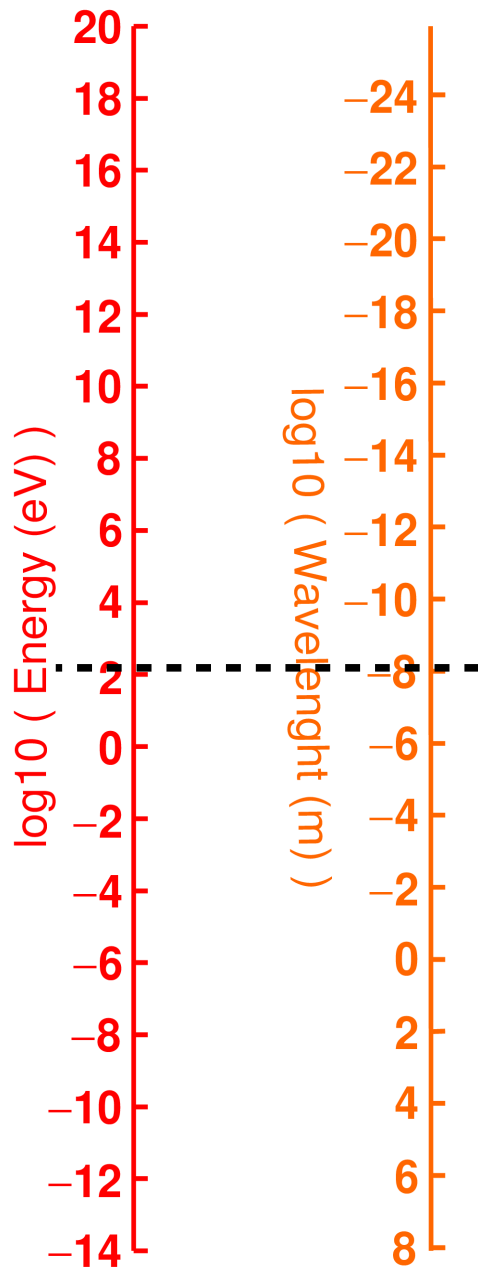
Visível

por Axel Melinger



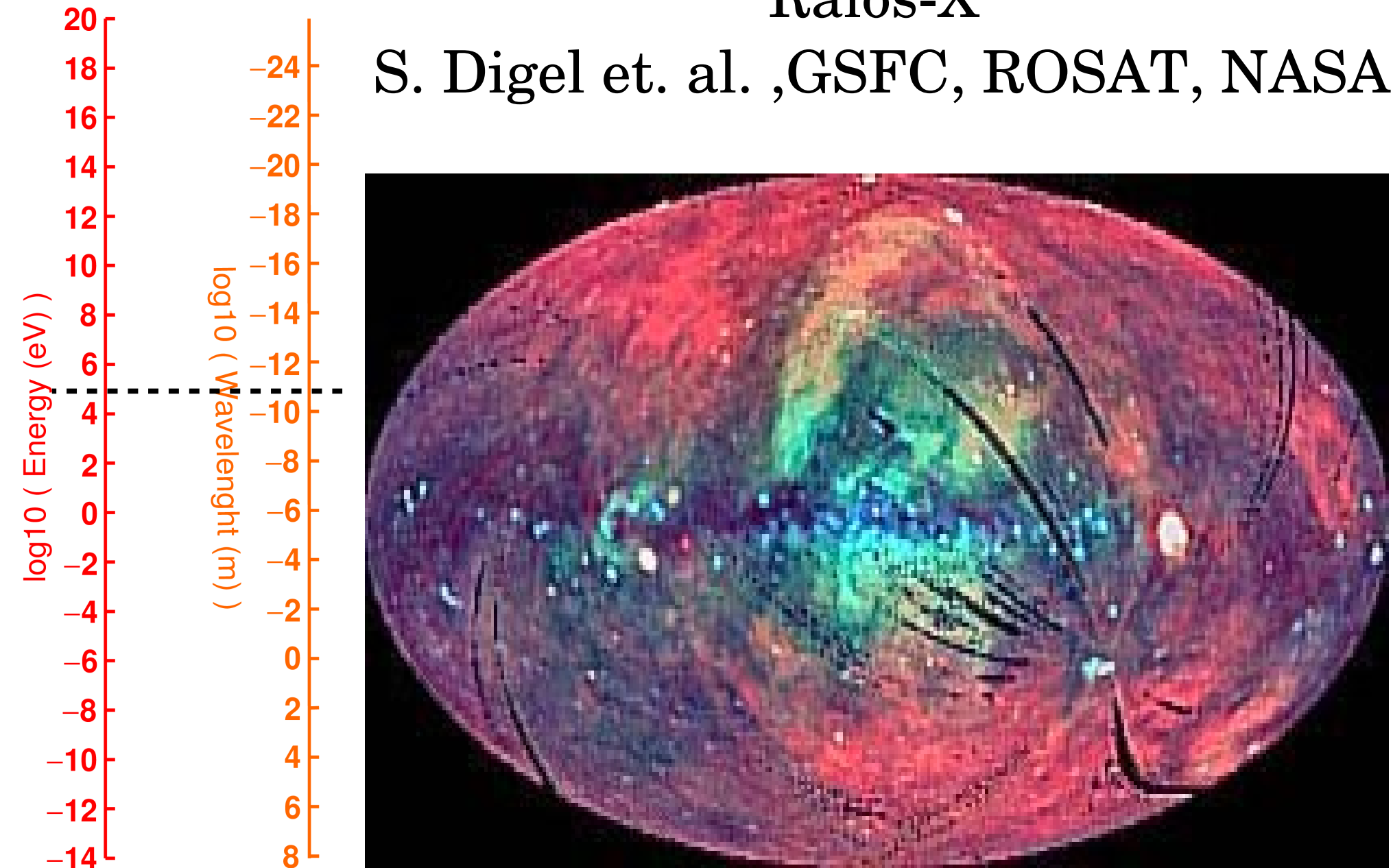
Ultravioleta

J. Bonnell et.al., GSFC, NASA



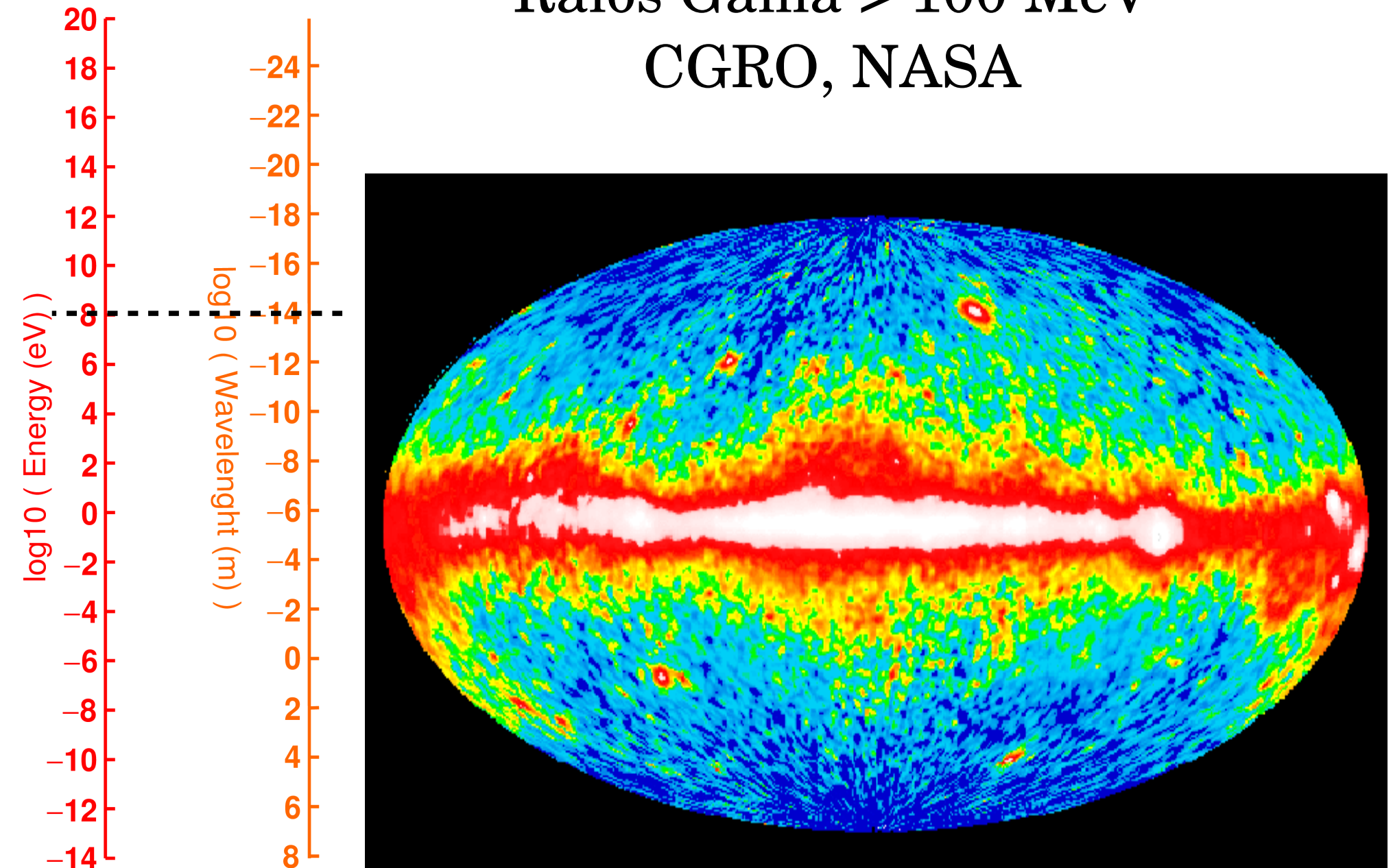
Raios-X

S. Digel et. al. ,GSFC, ROSAT, NASA



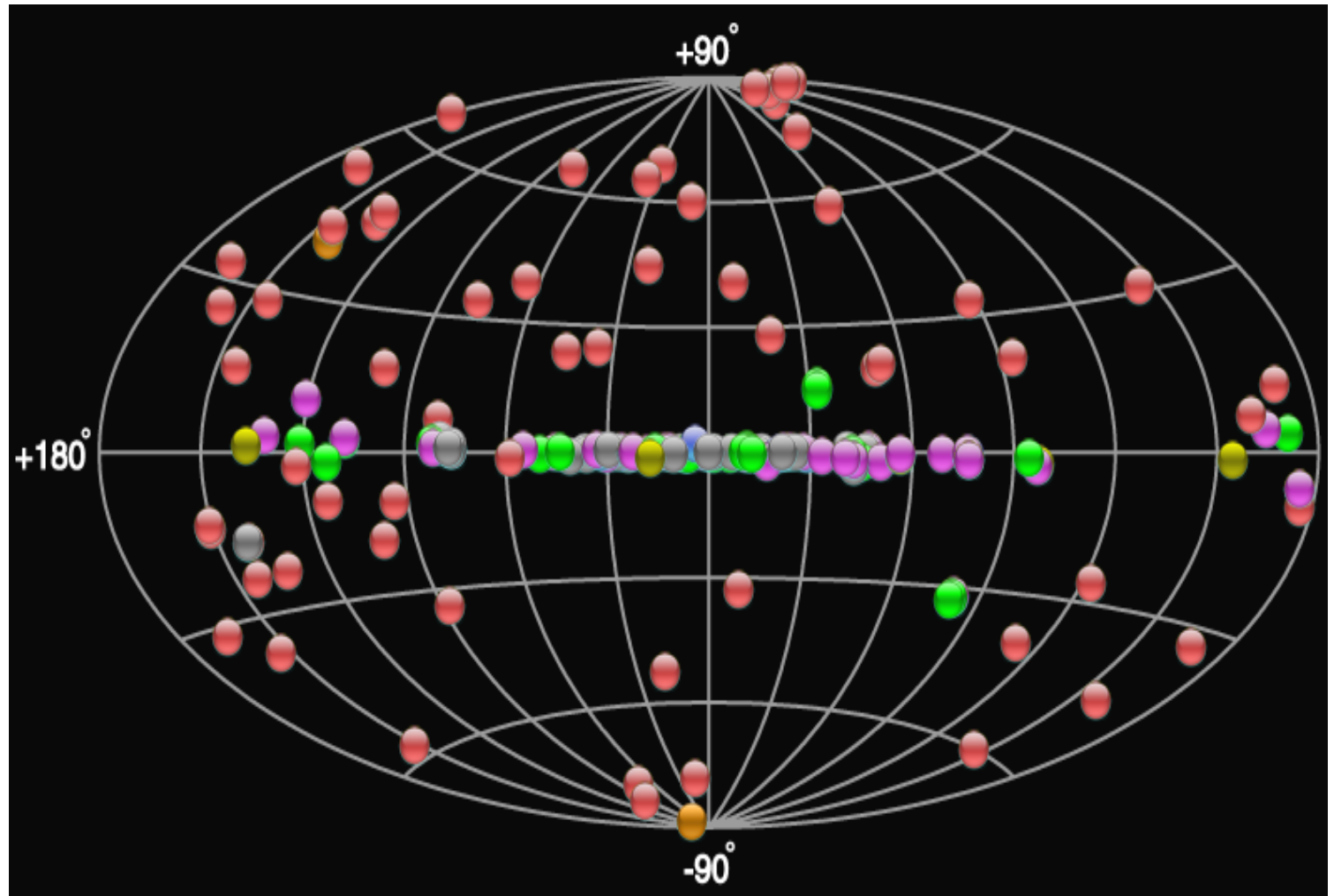
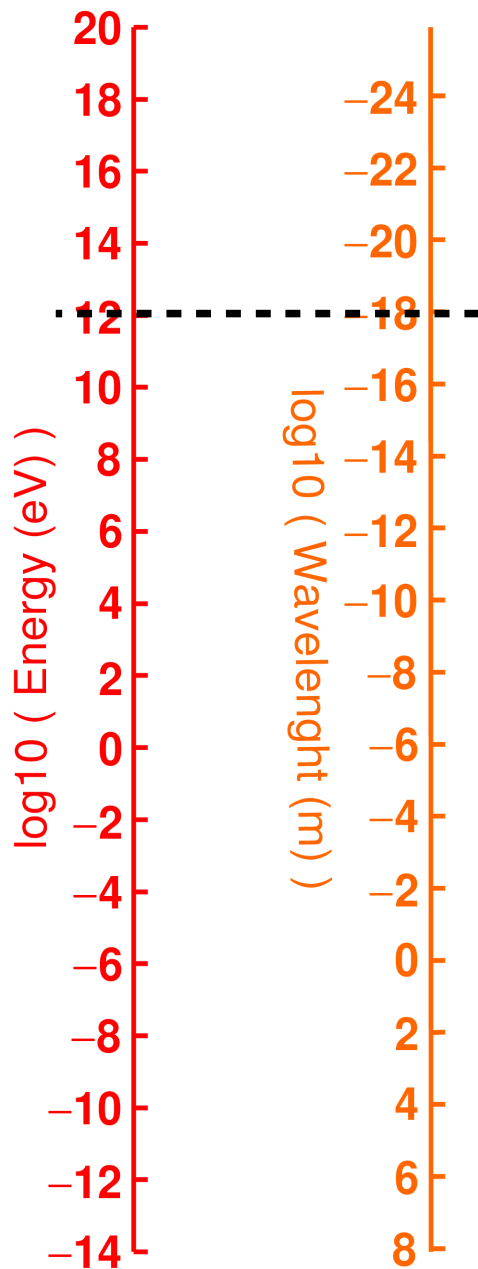
Raios Gama > 100 MeV

CGRO, NASA



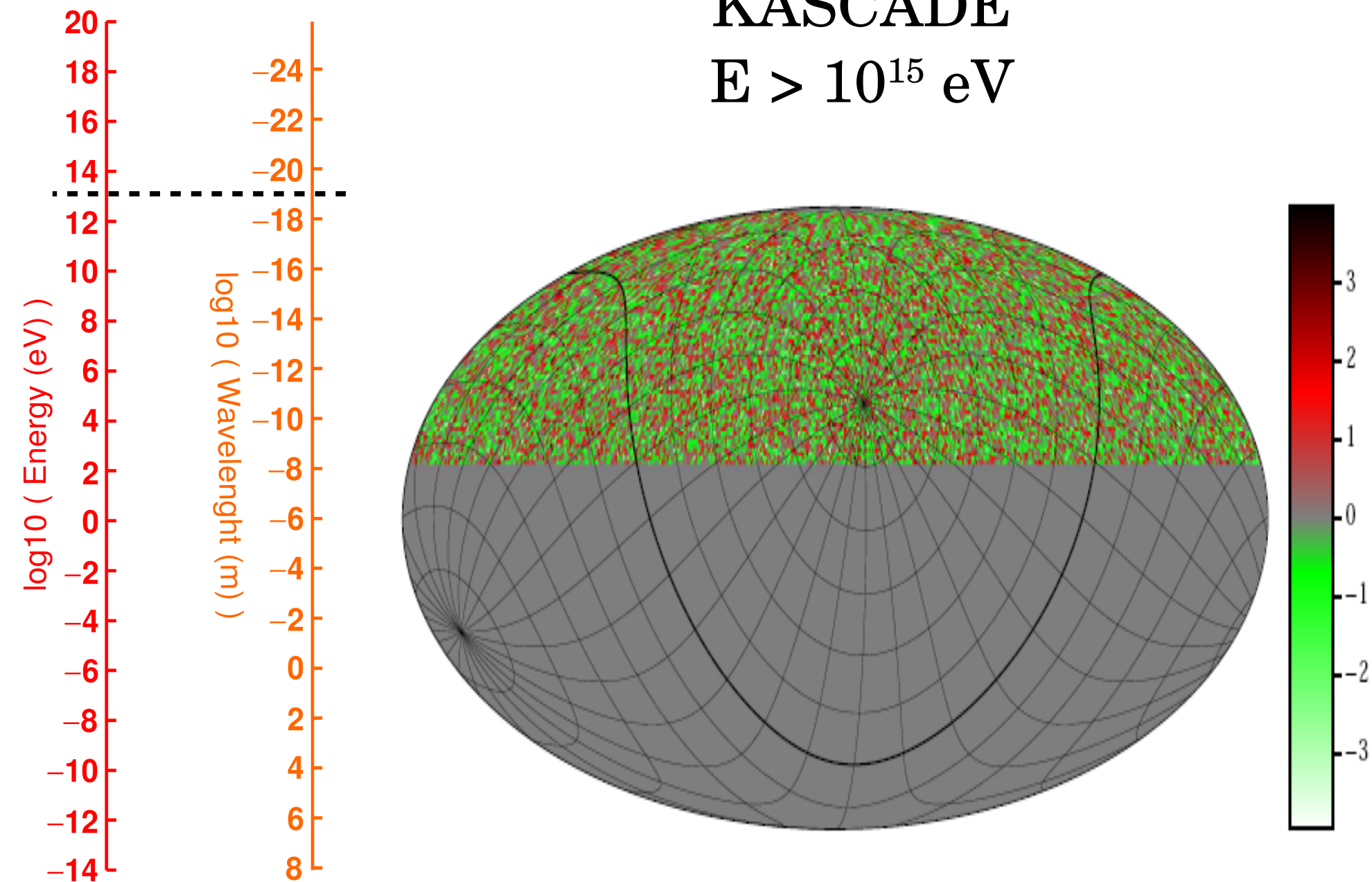
Raios Gama $> 10^{12}$ eV

TeVCat



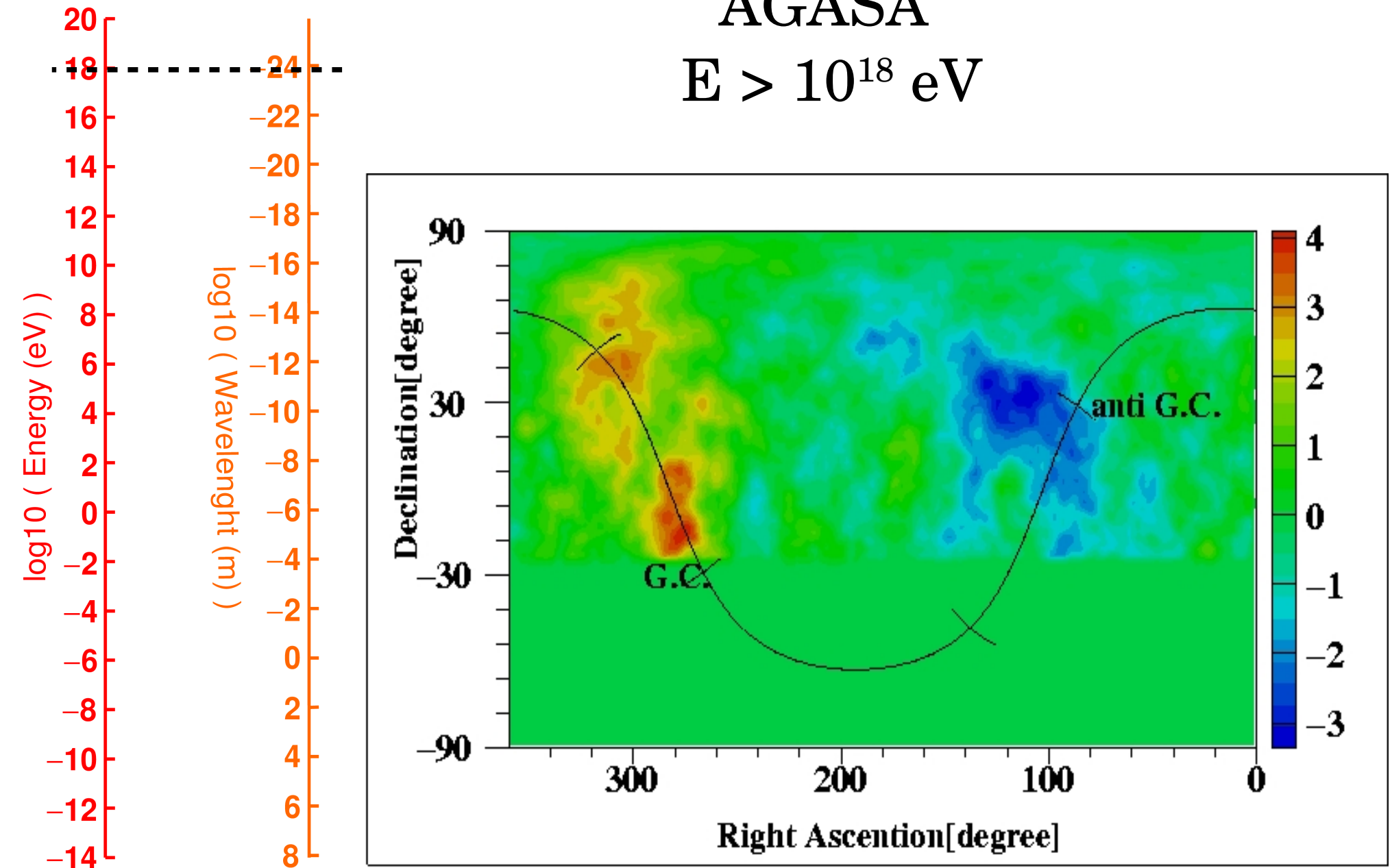
KASCADE

$E > 10^{15}$ eV



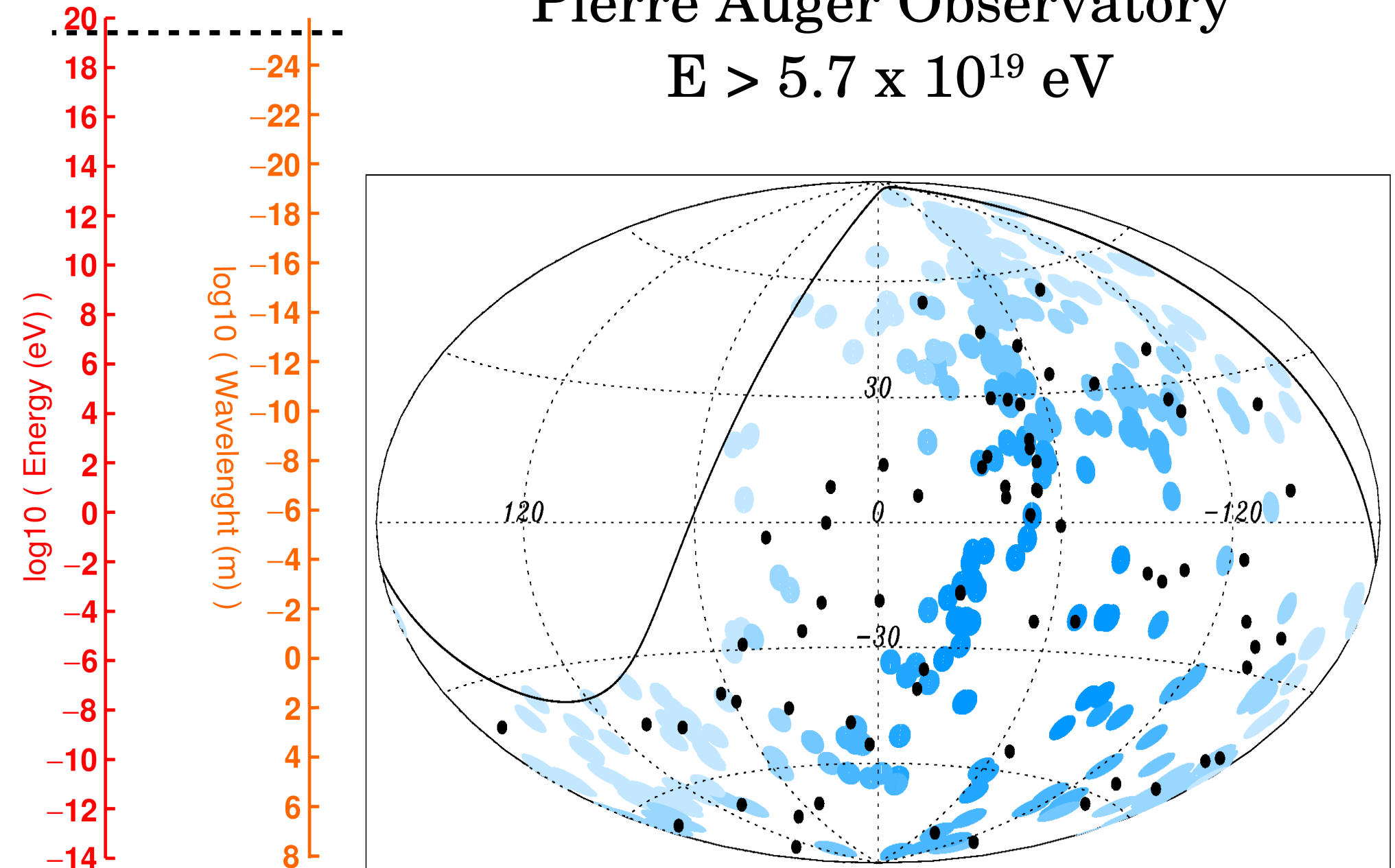
AGASA

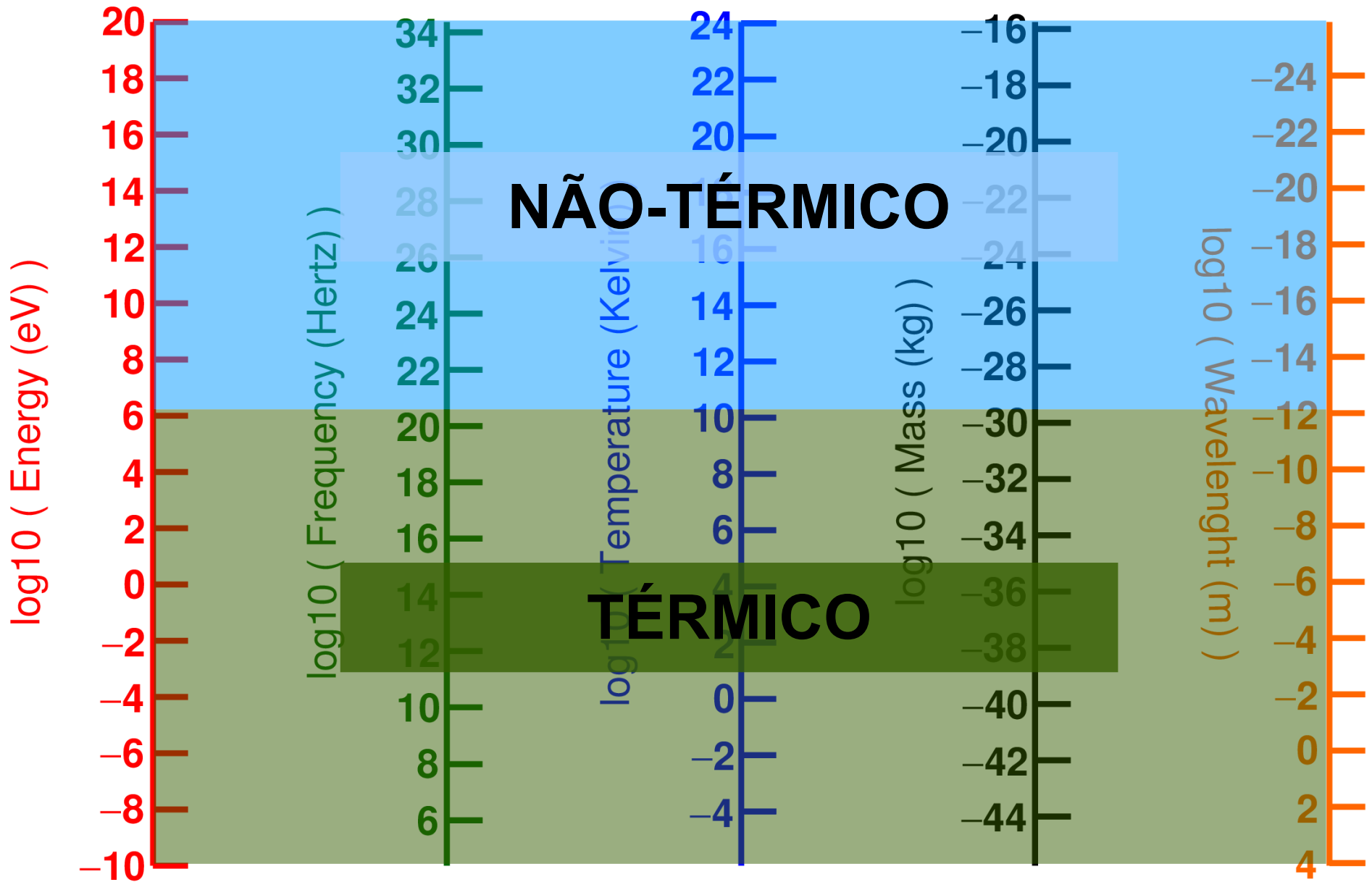
$E > 10^{18}$ eV



Pierre Auger Observatory

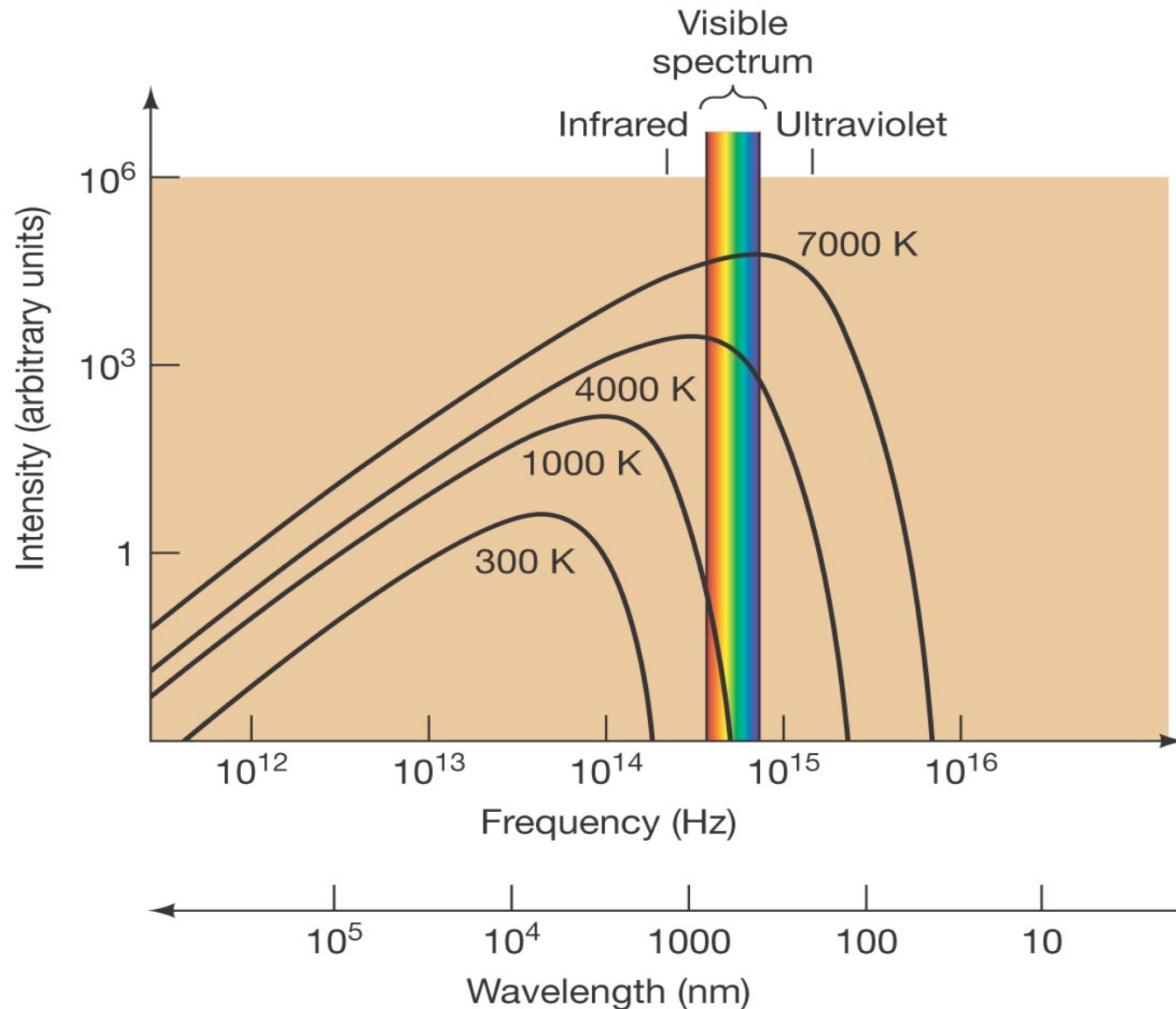
$$E > 5.7 \times 10^{19} \text{ eV}$$

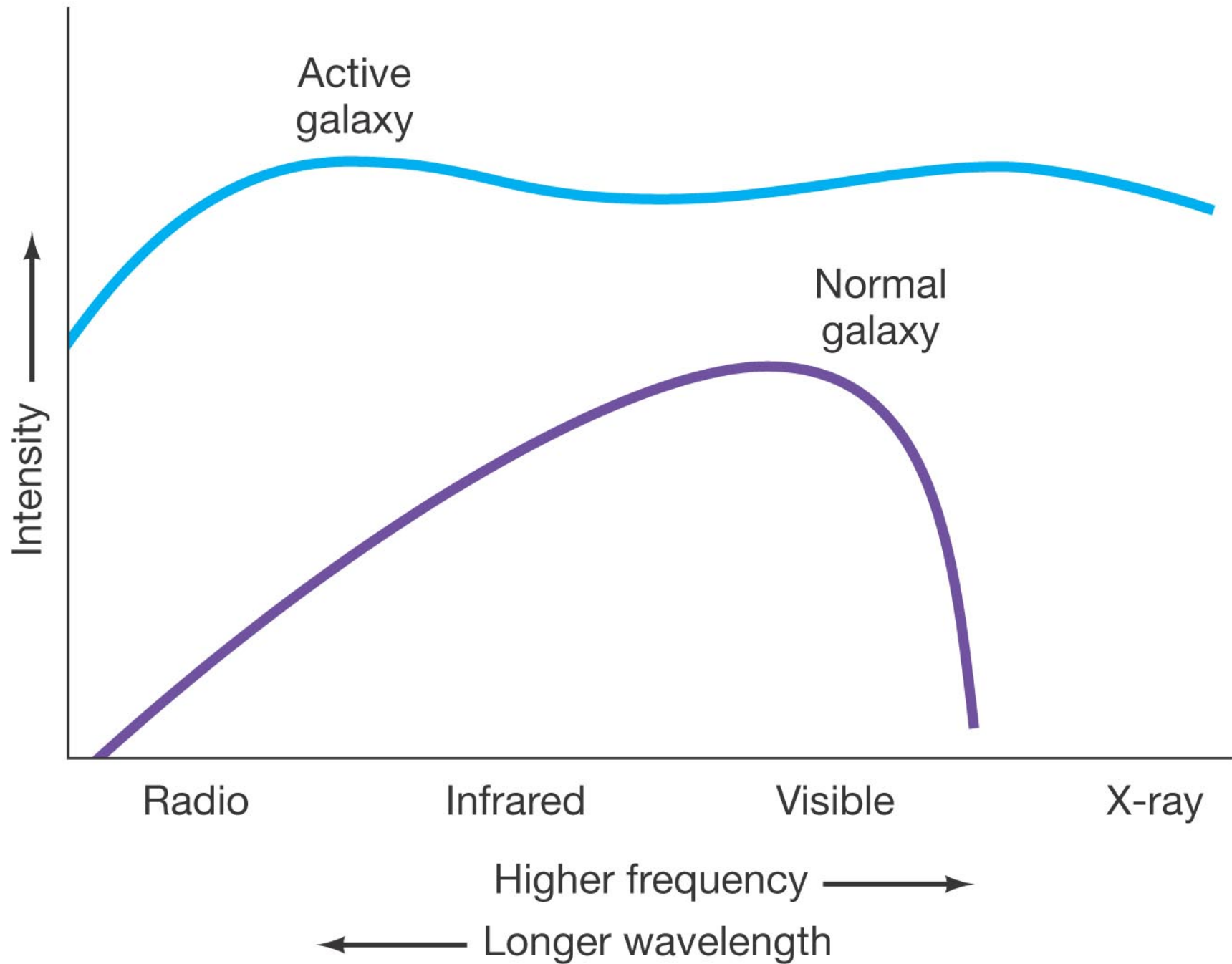




Emissão térmica

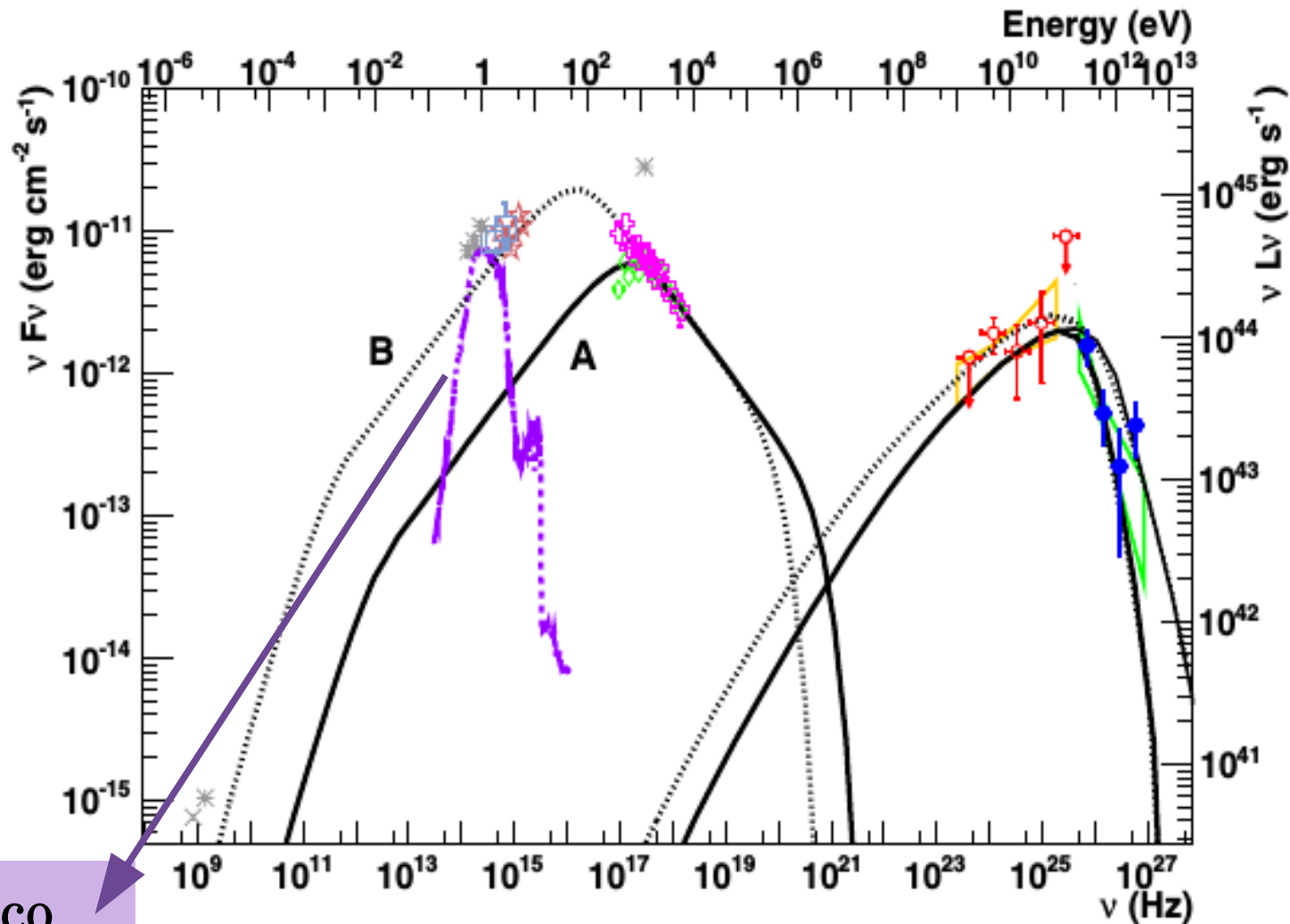
Radiação de corpo negro





Emissão não-térmica

H.E.S.S. Collaboration et al.: Discovery of VHE γ -ray emission of 1RXS J101015.9–311909



Térmico
com absorção

H.E.S.S. Collaboration A&A 539, A149 (2012)

Não térmica - Aceleração

- Mecanismo de Fermi: 1^a e 2^a ordem
 - Colisões das partículas com ondas de choque magnetizadas
 - Processo coletivo: muita energia do meio concentrada em poucas partículas
 - Elite energética
- Produção de radiação:
 - Radiação Sincrotron
 - Bremsstrahlung – Radiação de Freamento
 - Efeito Compton Inverso



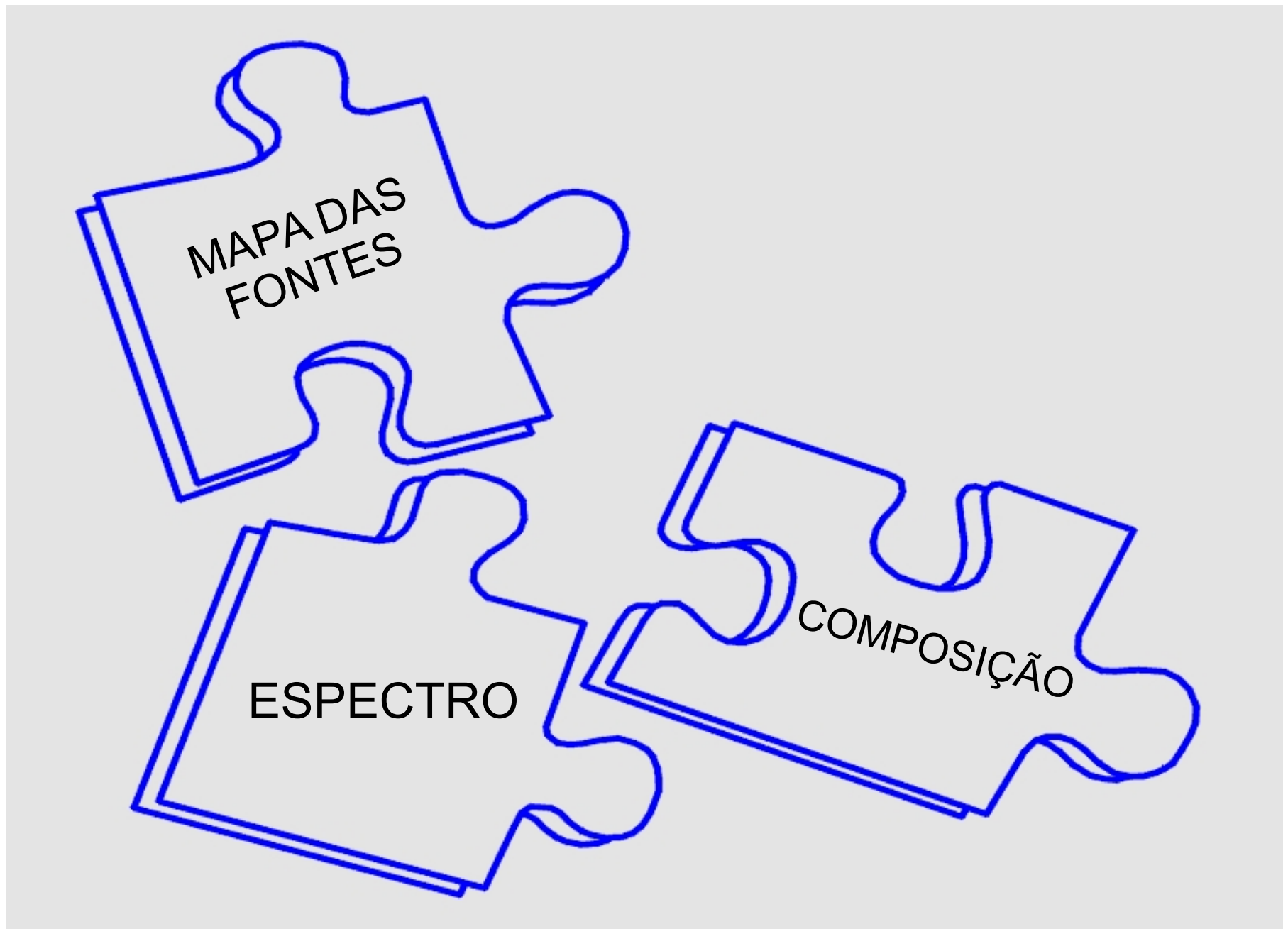
Astrofísica de Partículas

A ciência que estuda os processos físicos ocorrendo em objetos astrofísicos através da detecção de partículas de alta energia.

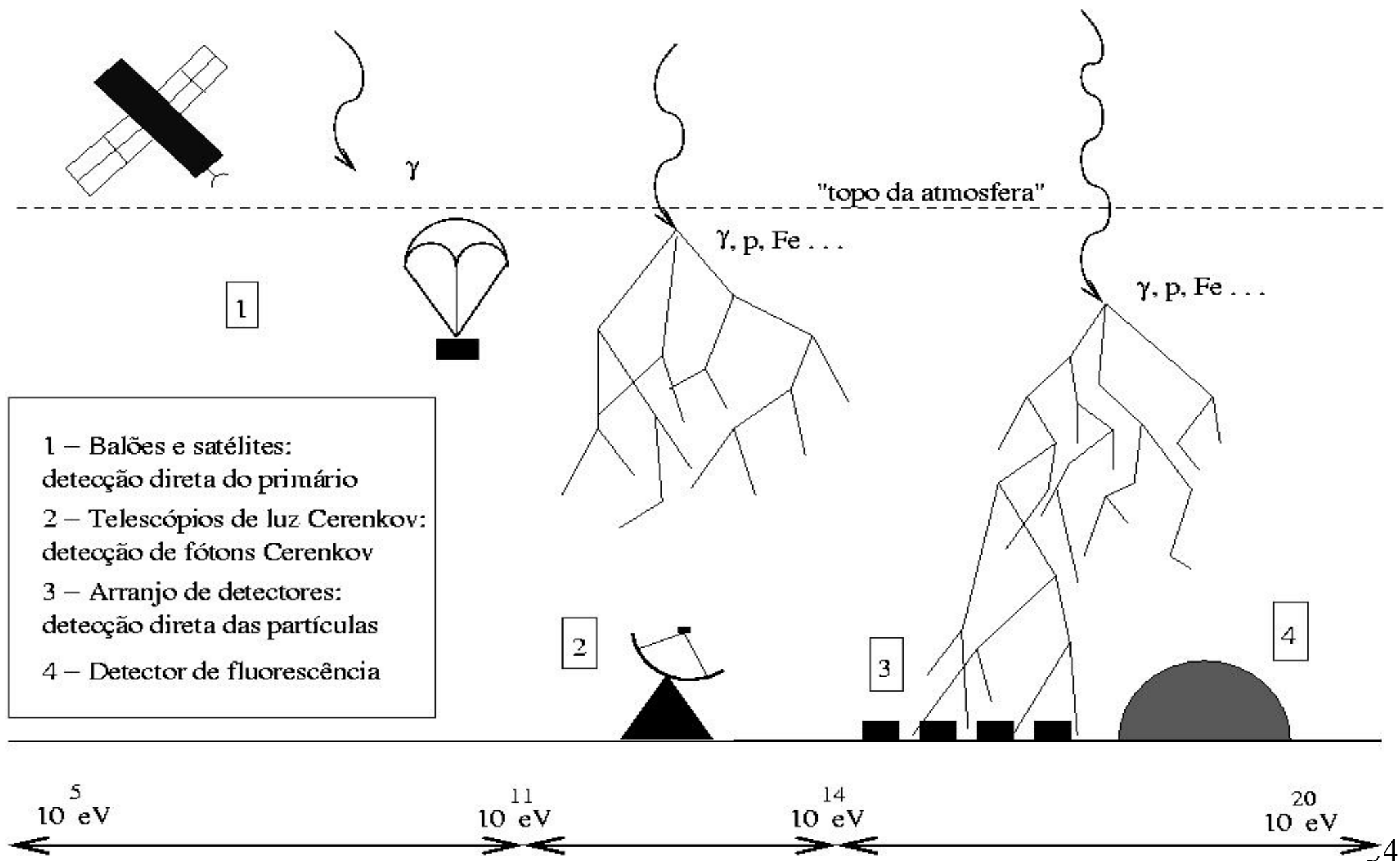
Astrofísica das fontes

Interação entre
partículas

Astrofísica de partículas

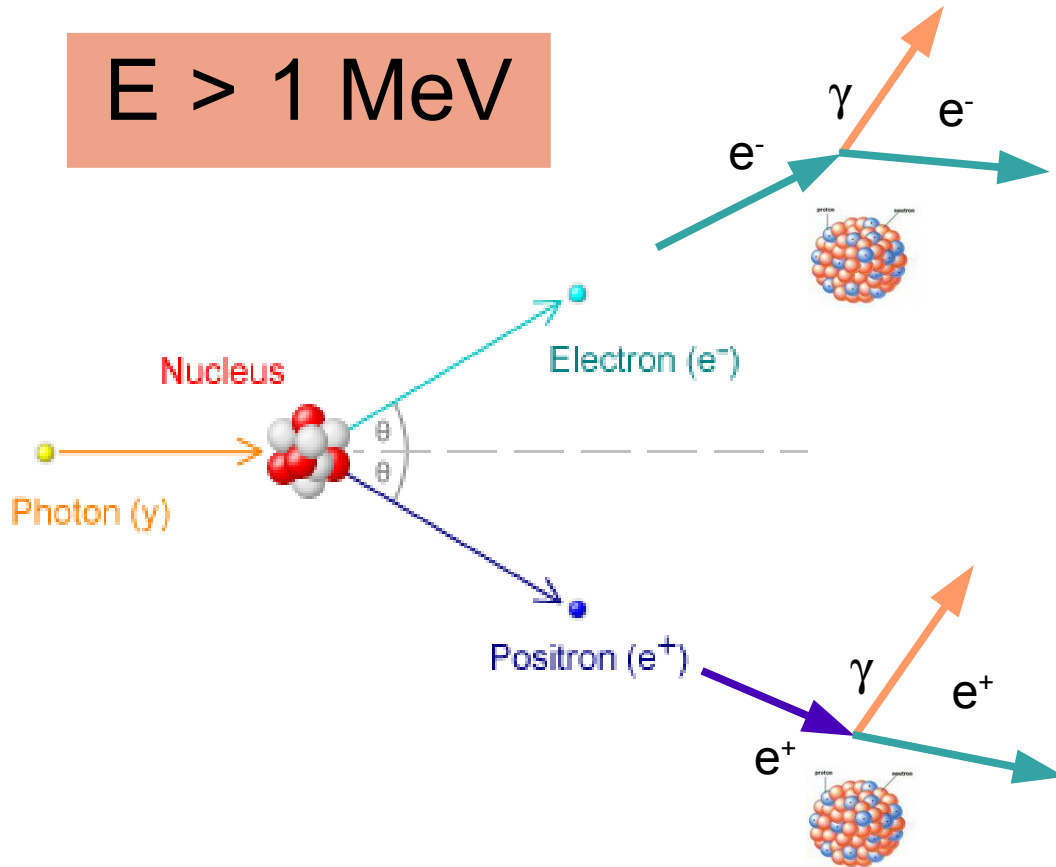


Experimentos de Raios Cósmicos

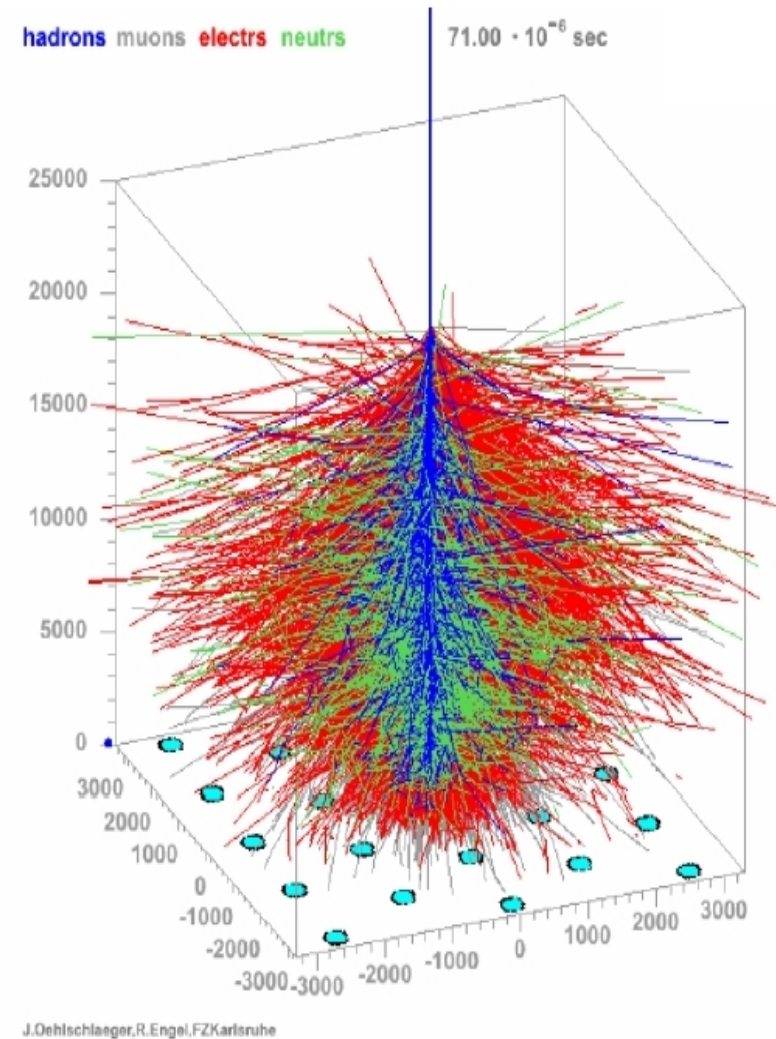


Chuveiro de Partículas

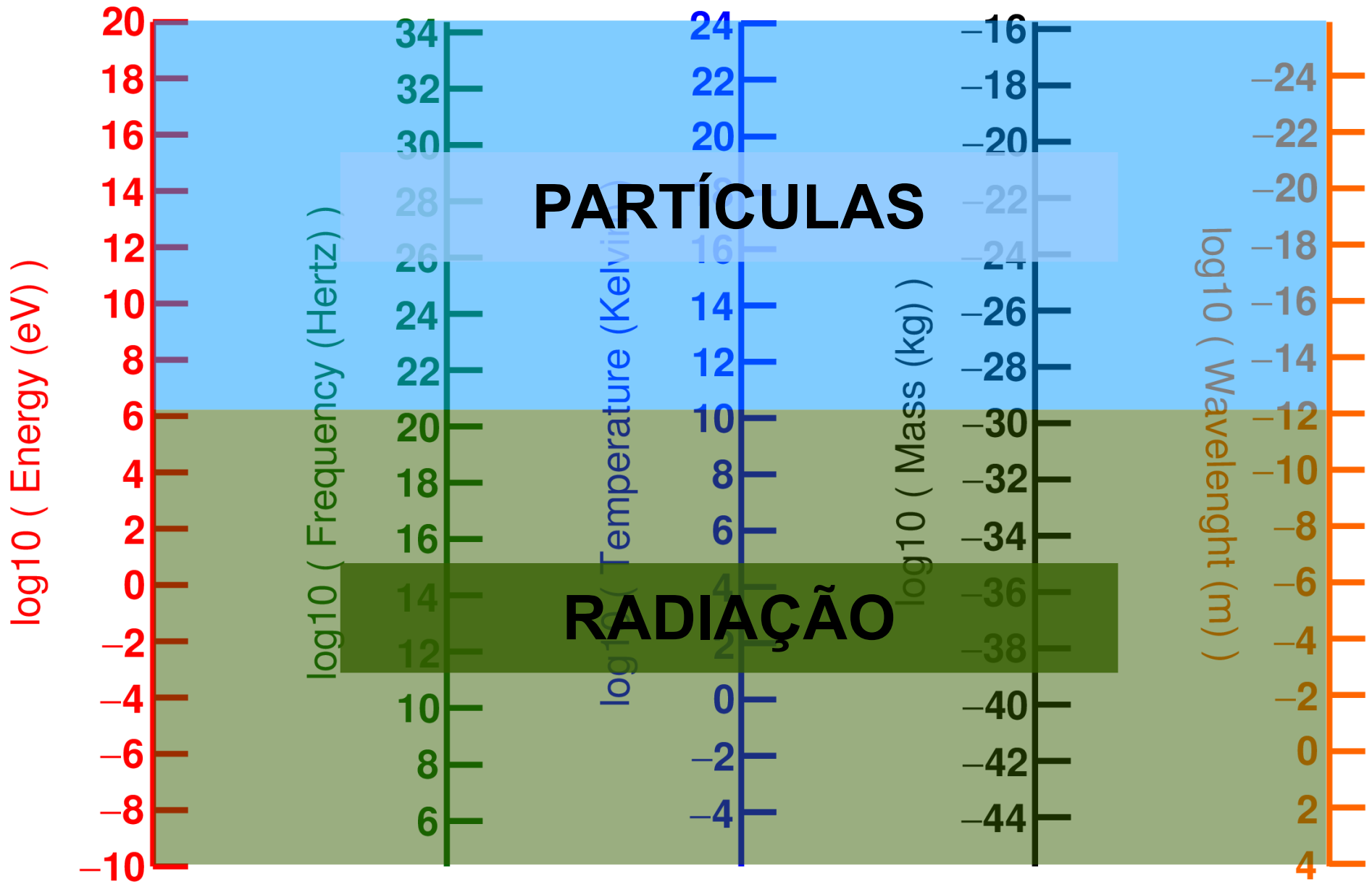
$$E > 1 \text{ MeV}$$

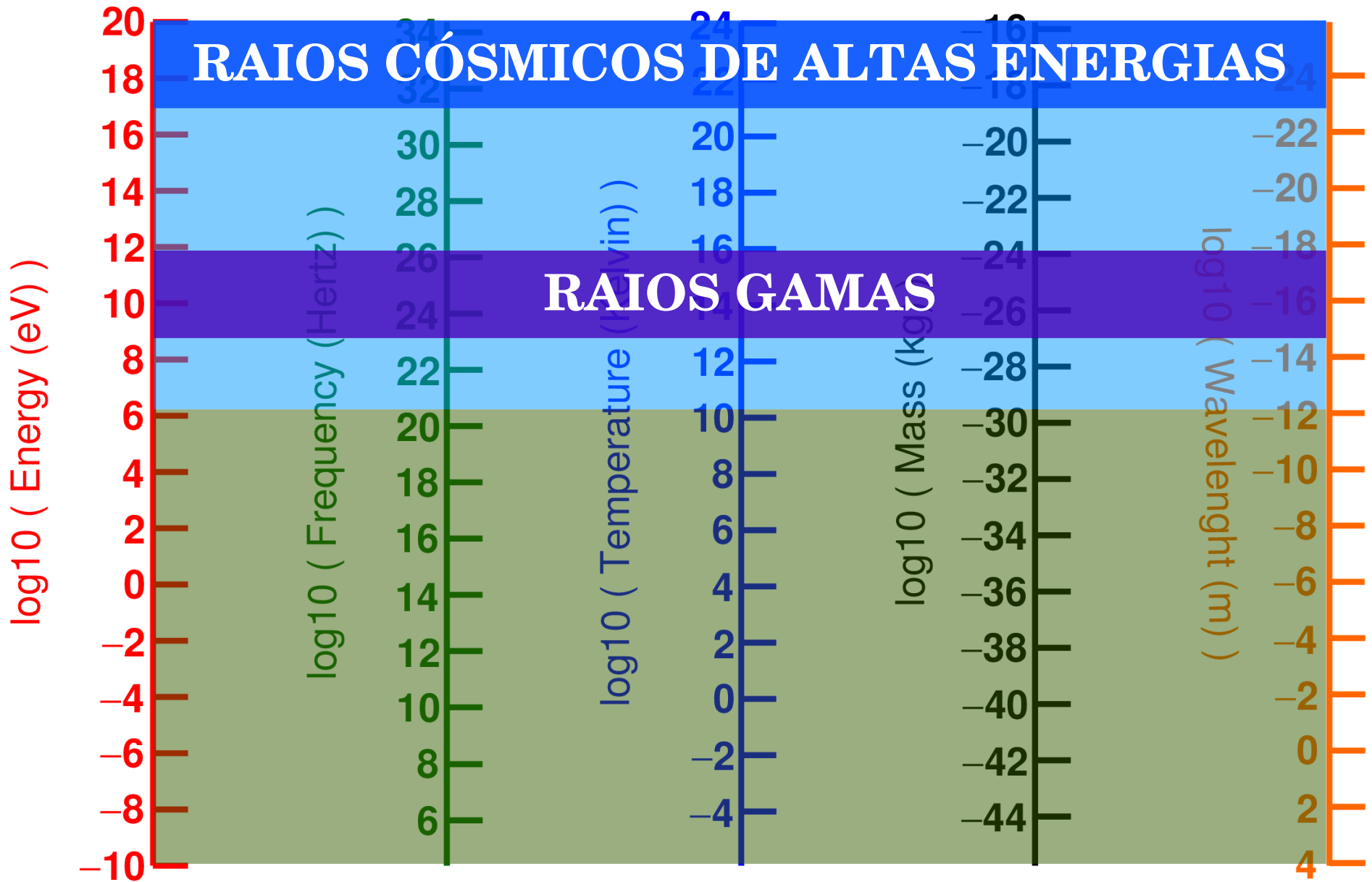


Muitas partículas
e radiação produzidas
no caminho

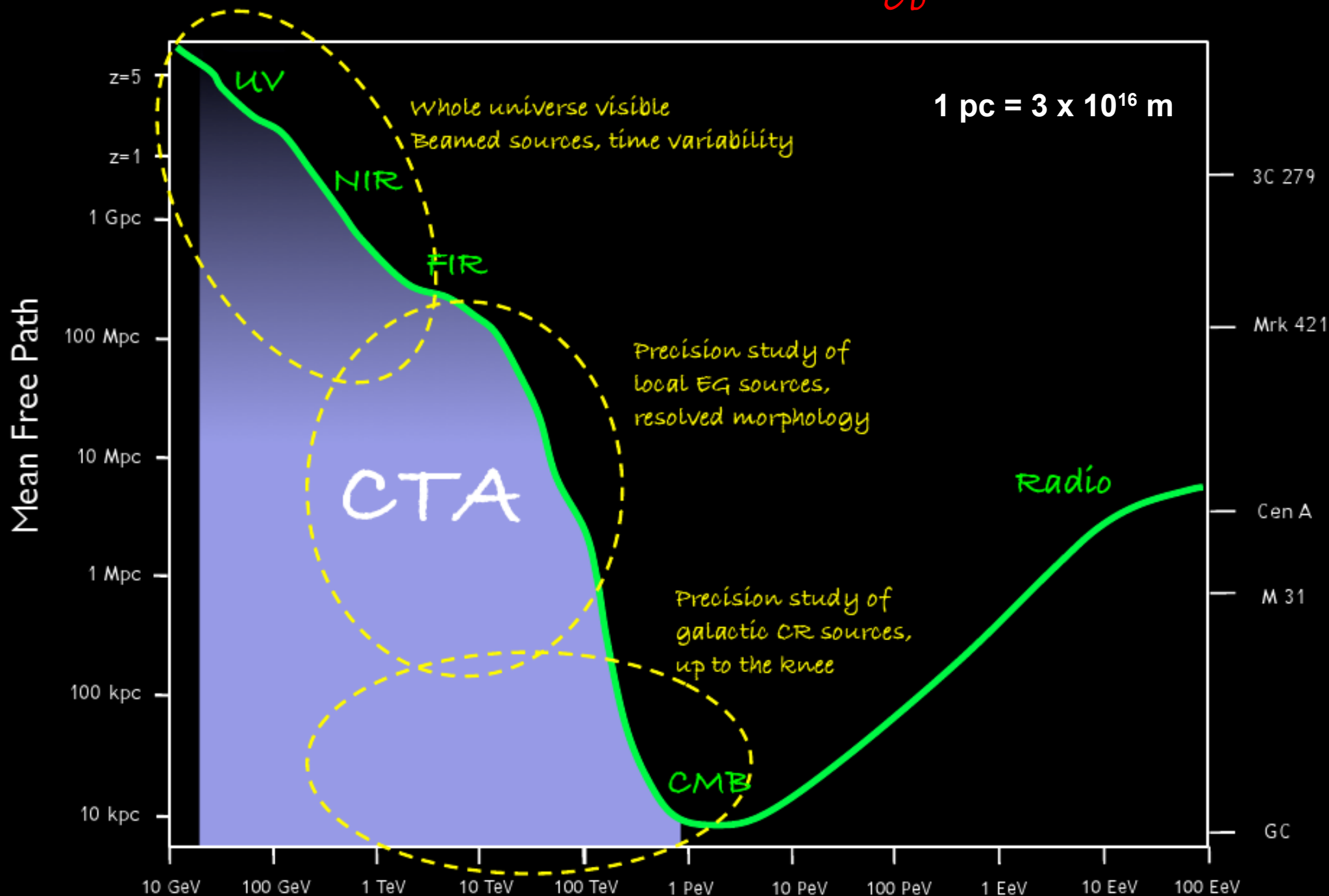


Chuveiro Atmosférico



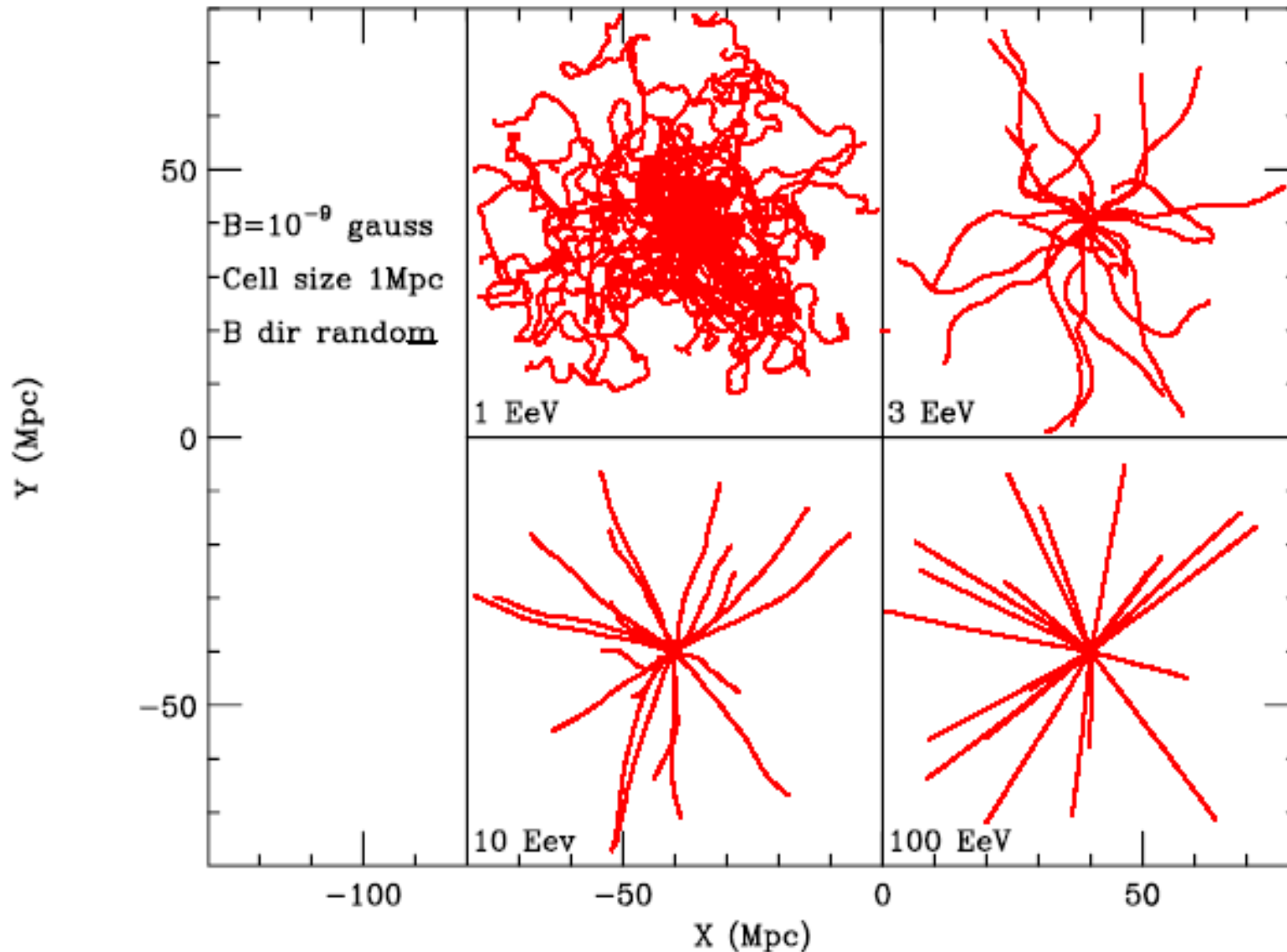


The Gamma Ray Horizon $\gamma + \gamma_{CB} \rightarrow e^+e^-$



Propagação

3D trajectories projected on X-Y plane



1 pc = 3×10^{16} m

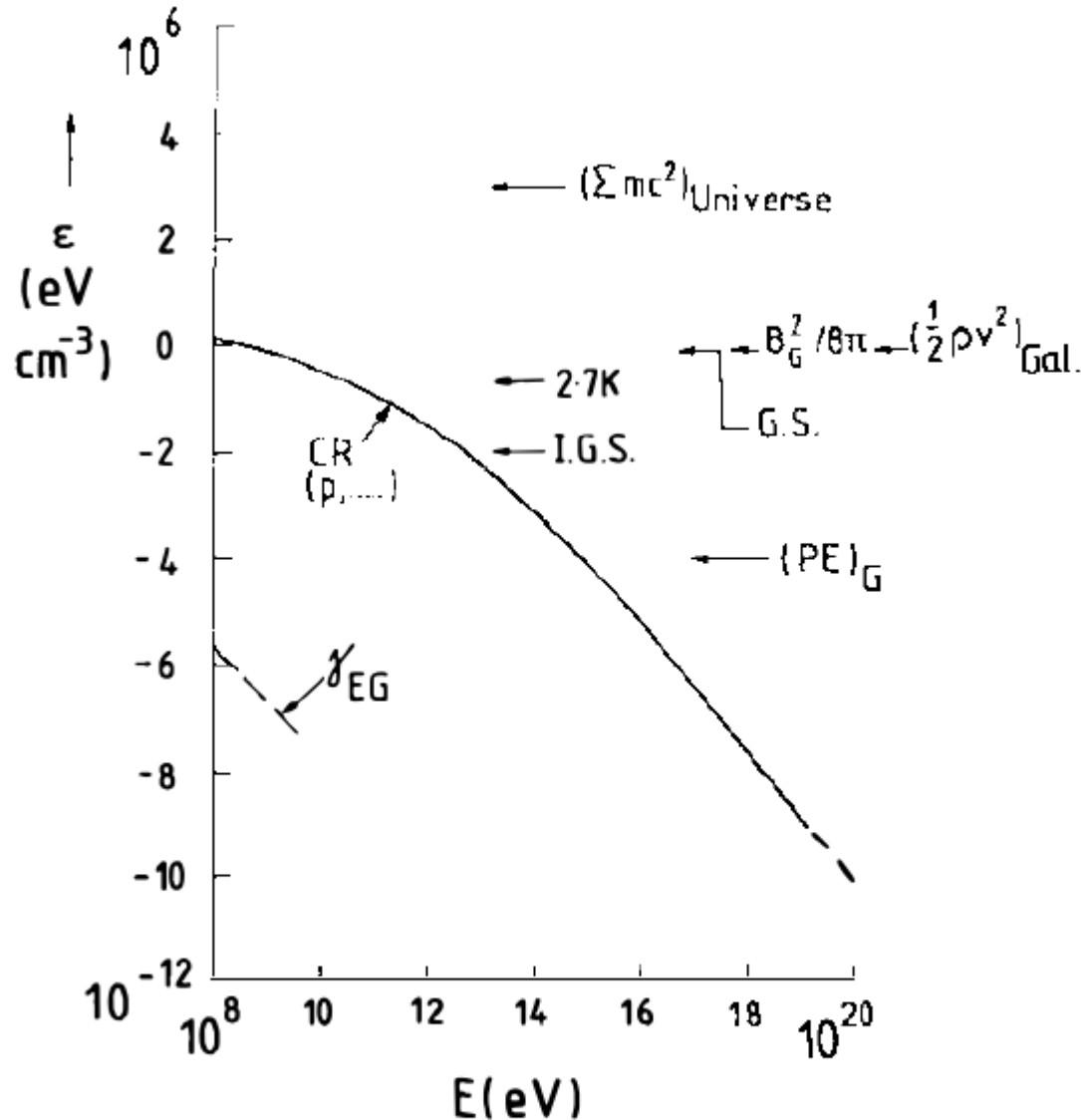


Figure 5 Cosmic-ray energy density as a function of the threshold CR particle energy. Curves are shown for both particles and γ rays. The arrows relate to energy densities for a variety of other phenomena: $(\Sigma mc^2)_{\text{universe}}$ = rest energy of total mass in the universe; $B_G^2/8\pi$ is the Galactic magnetic field; $(\frac{1}{2} \rho v^2)_{\text{Gal}}$ represents Galactic gas clouds; G.S. is Galactic starlight; I.G.S. is intergalactic starlight; and $(PE)_G$ is the gravitational potential energy of galaxies.

Densidade de Energia

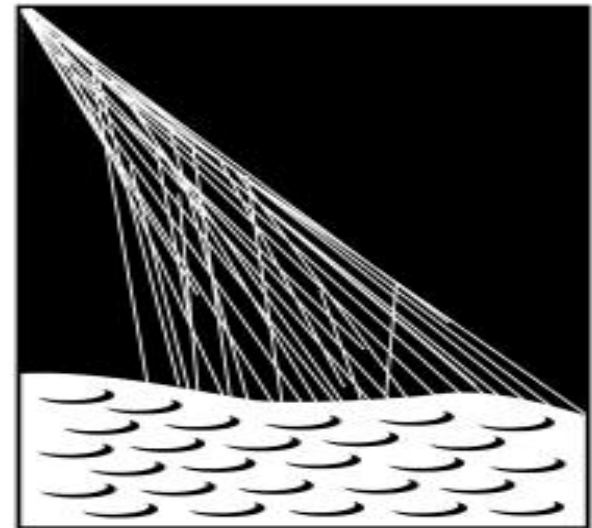
Raios C3smicos
1 MeV m⁻³

Campo Magn3tico Gal
0.2 MeV m⁻³

Luz - Estrelas (Local)
0.3 MeV m⁻³

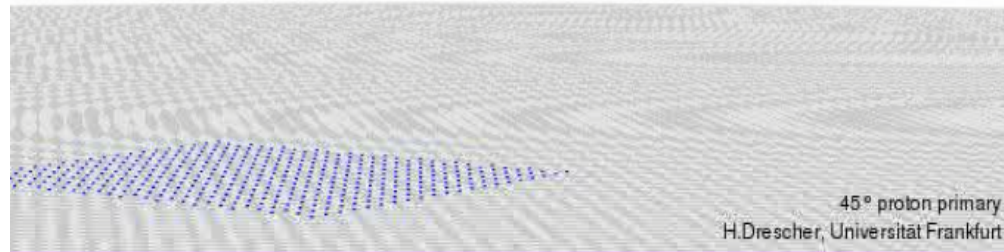
Fundo Micro-ondas
0.3 MeV m⁻³

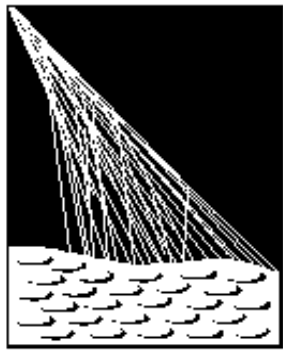
Experimentos que participamos



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time=-266 μ s



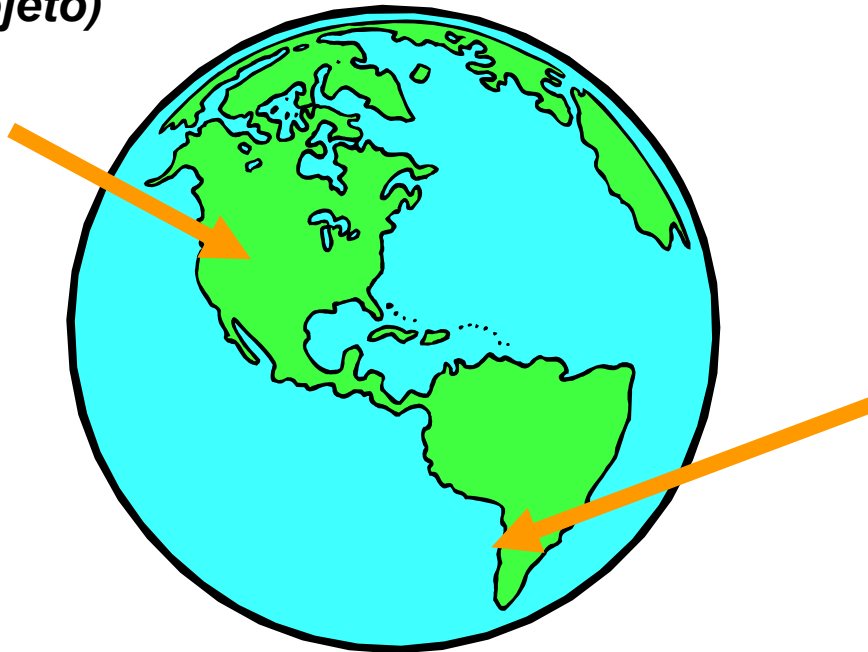


**PIERRE
AUGER**
OBSERVATORY

Observatório Pierre Auger

O maior experimento de raios cósmicos já construído para medir com grande estatística a região de energia acima de 10^{18} eV

Colorado, EUA
(em projeto)



Mendoza, Argentina
(em funcionamento)



Observatório Auger

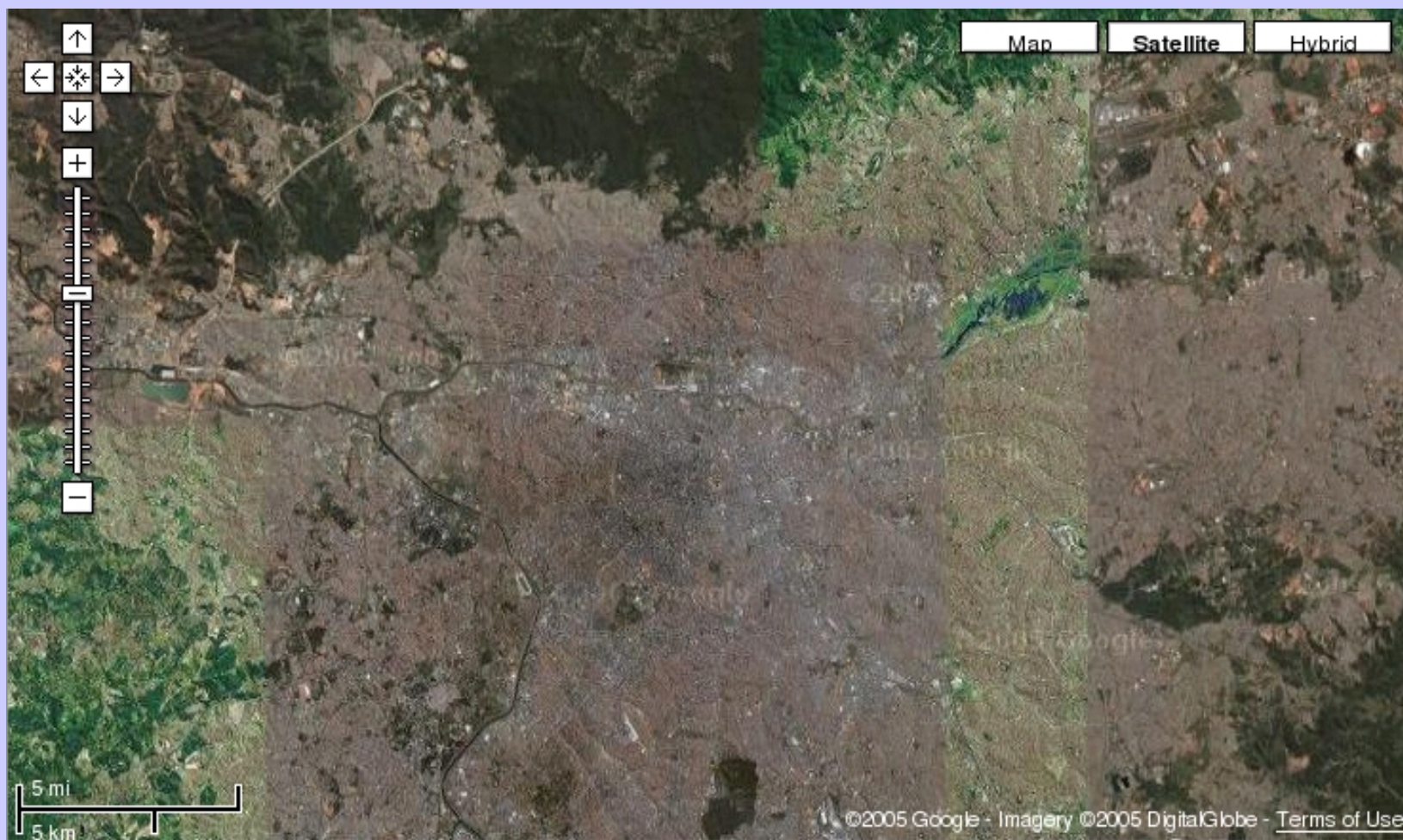


Em funcionamento:

- 1624 tanques**
- 24 telescópios**



Observatório Auger



50 km

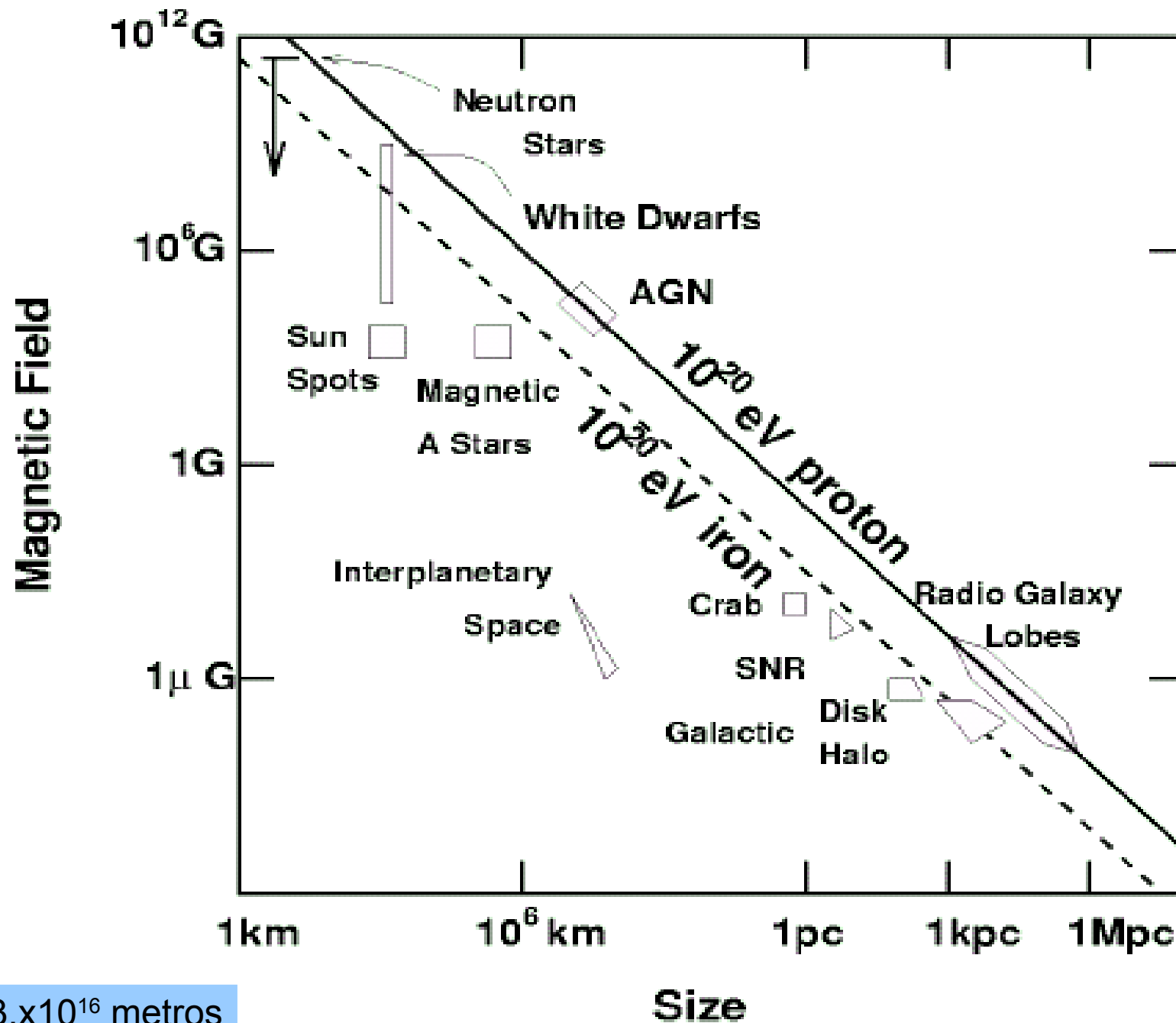
60 km

Pierre Auger Observatory

Argentina Site

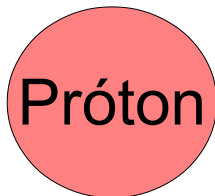
Qual é o problema em astrofísica
abordado pelo Auger ?

$$E_{eV} < 10^{15} Z \times B_{\mu G} \times R_{SNR, pc}$$

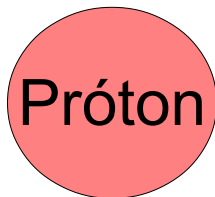


Perda de Energia Colisão com fótons

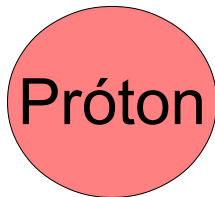
$$E = 5 \times 10^{19} \text{ eV}$$



$$E = 5 \times 10^{19} \text{ eV}$$



$$E = 5 \times 10^{19} \text{ eV}$$



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



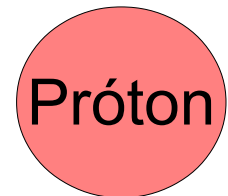
$$E = 8 \times 10^{19} \text{ eV}$$



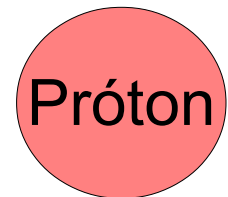
$$E = 6 \times 10^{19} \text{ eV}$$



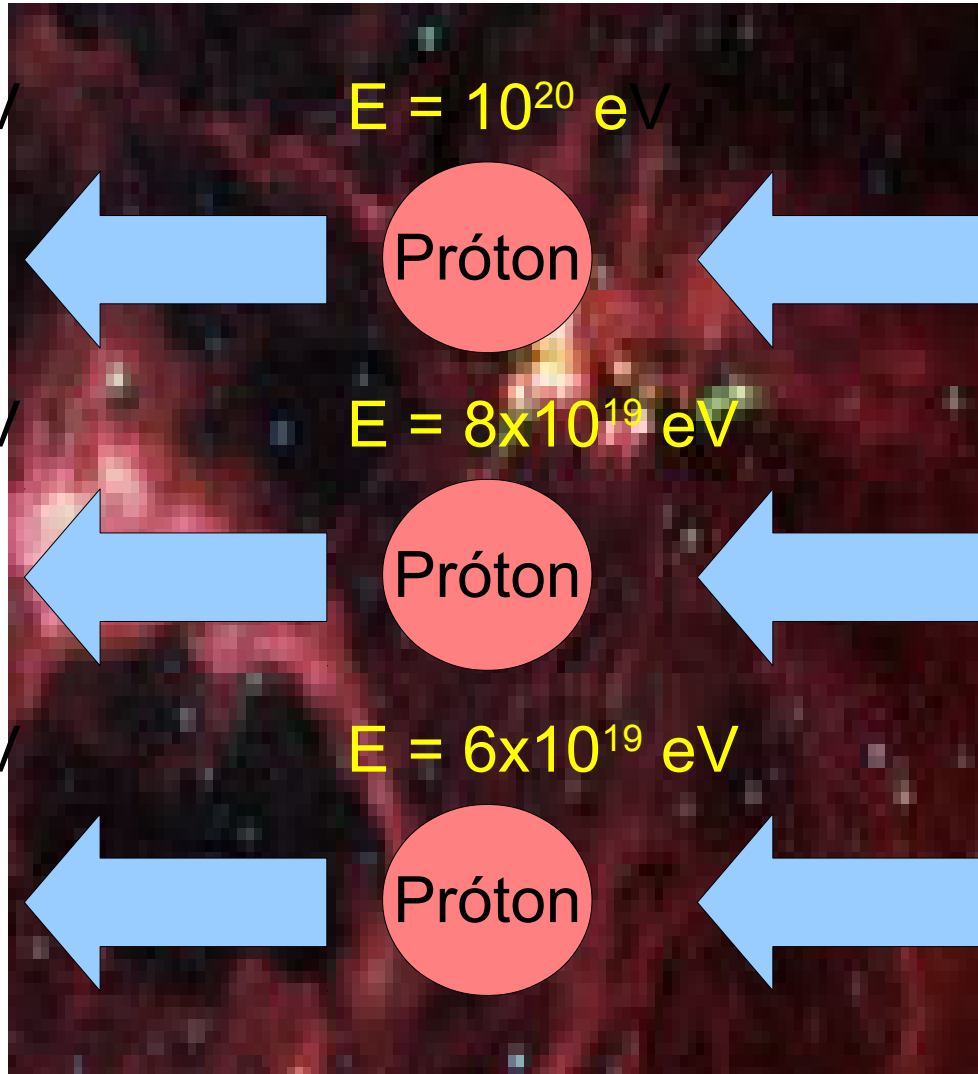
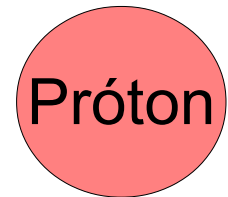
$$E = 10^{21} \text{ eV}$$

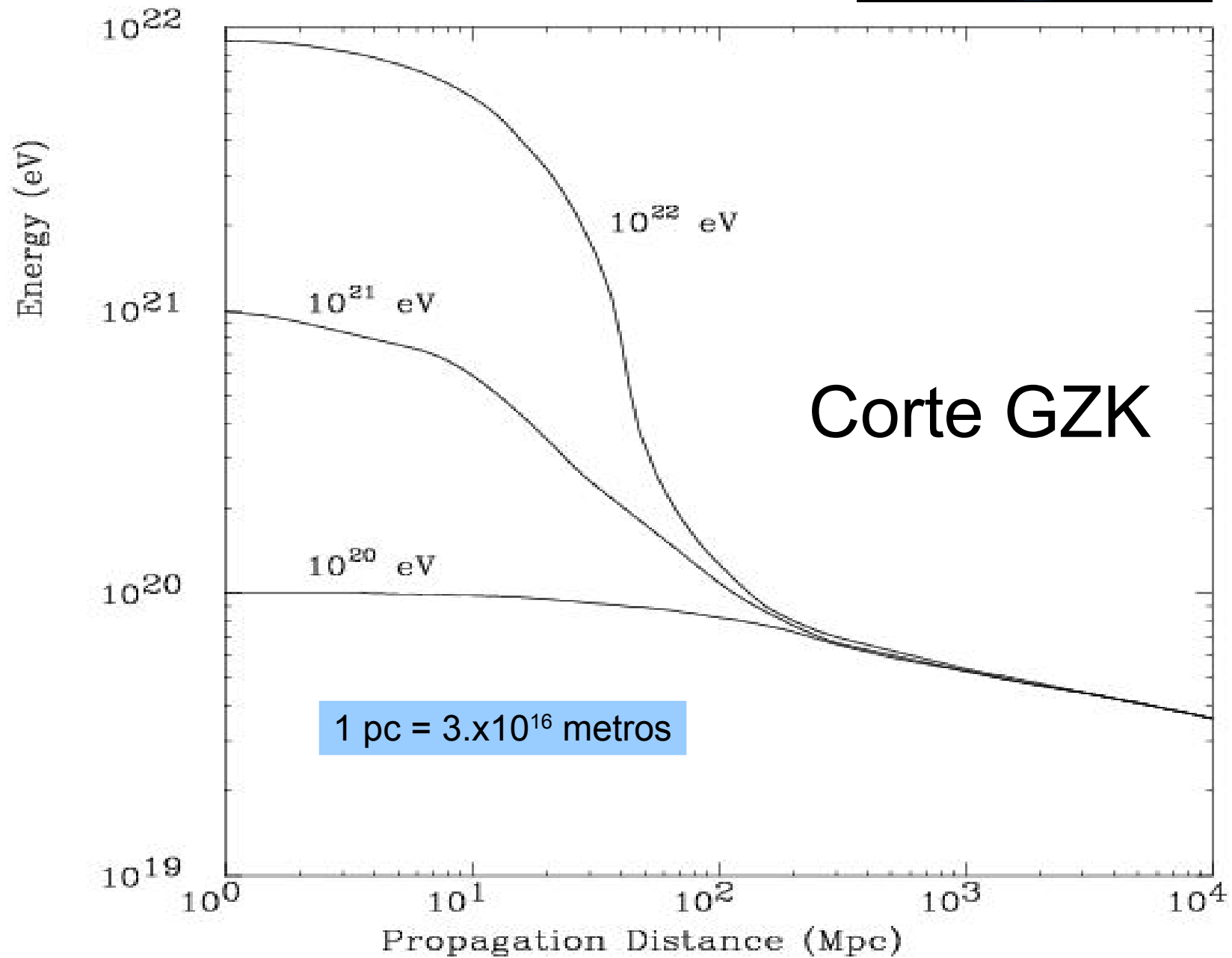
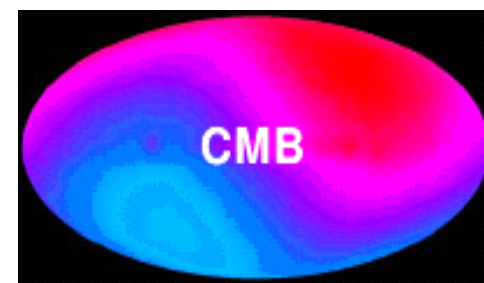
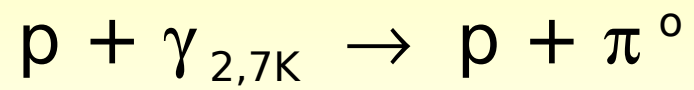


$$E = 10^{20} \text{ eV}$$

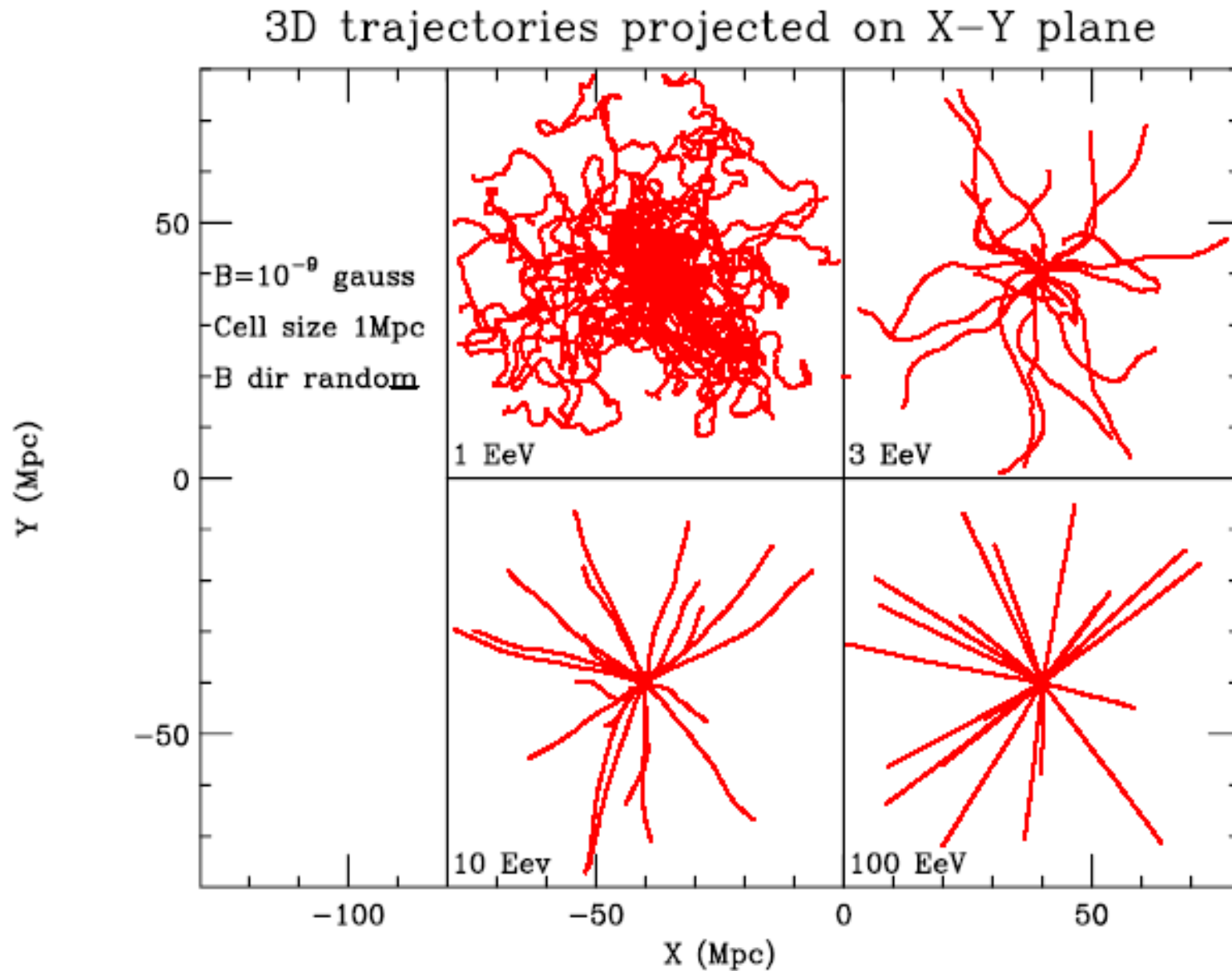


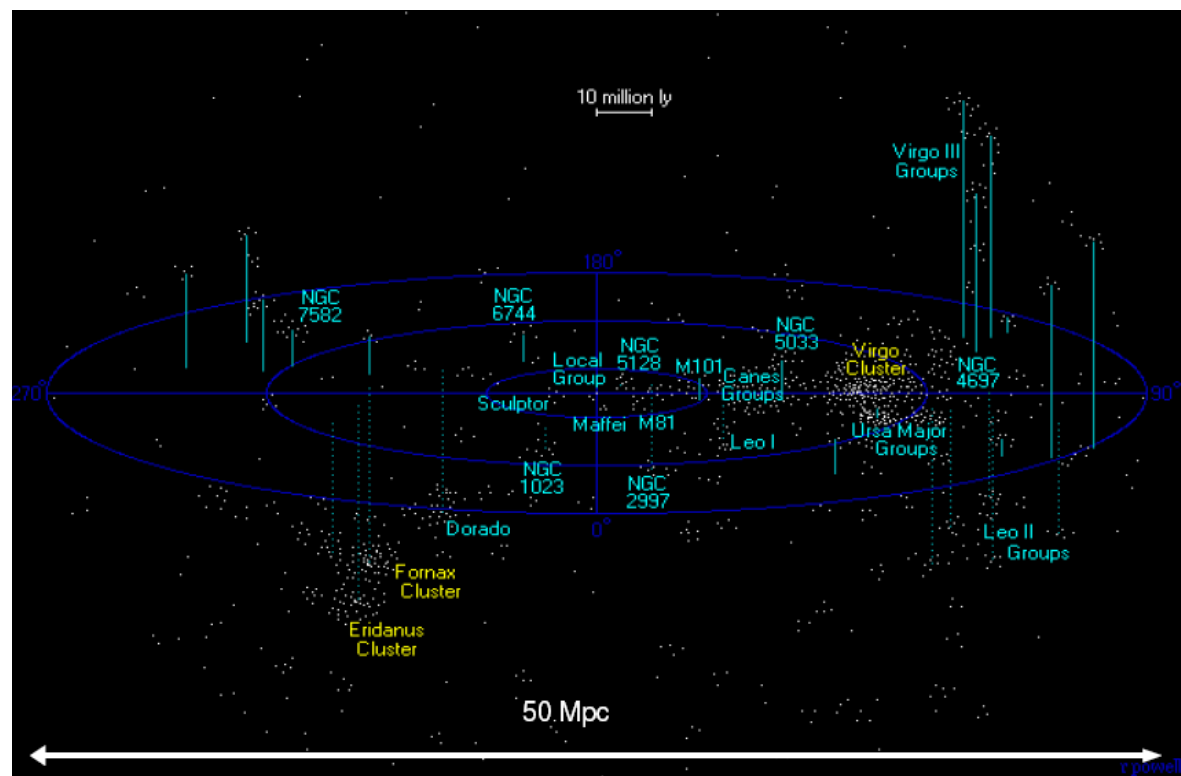
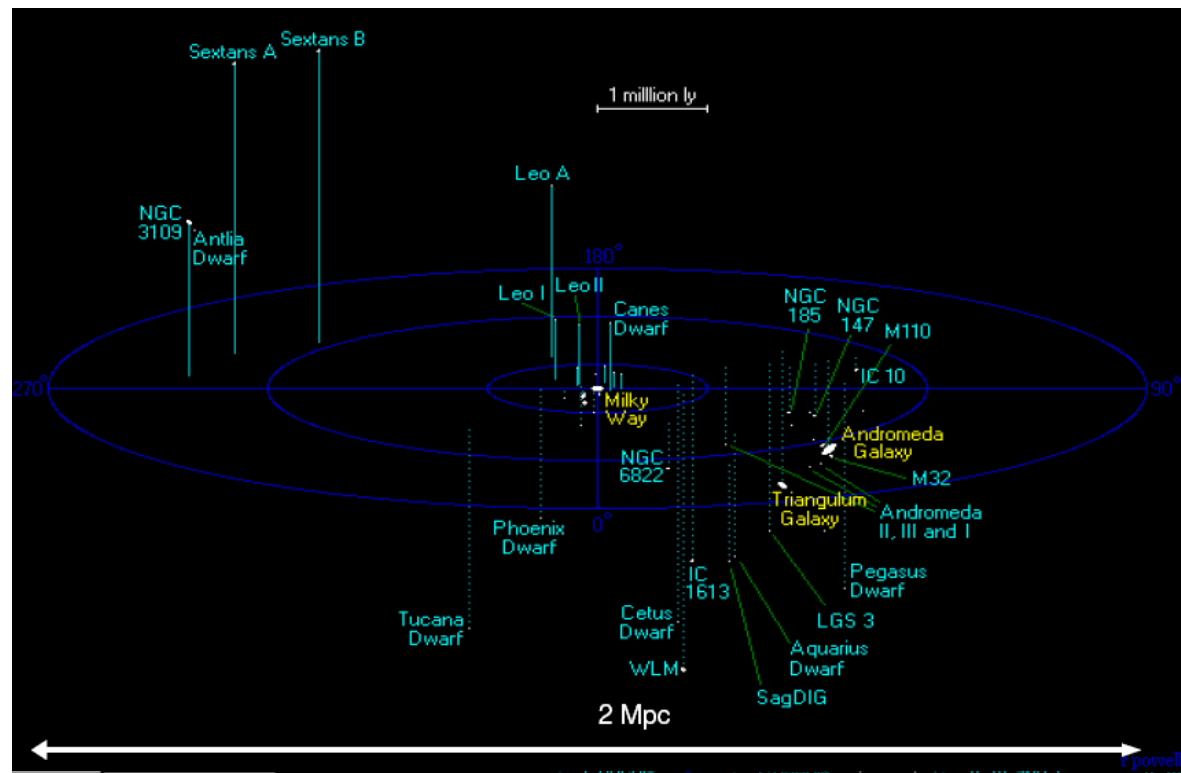
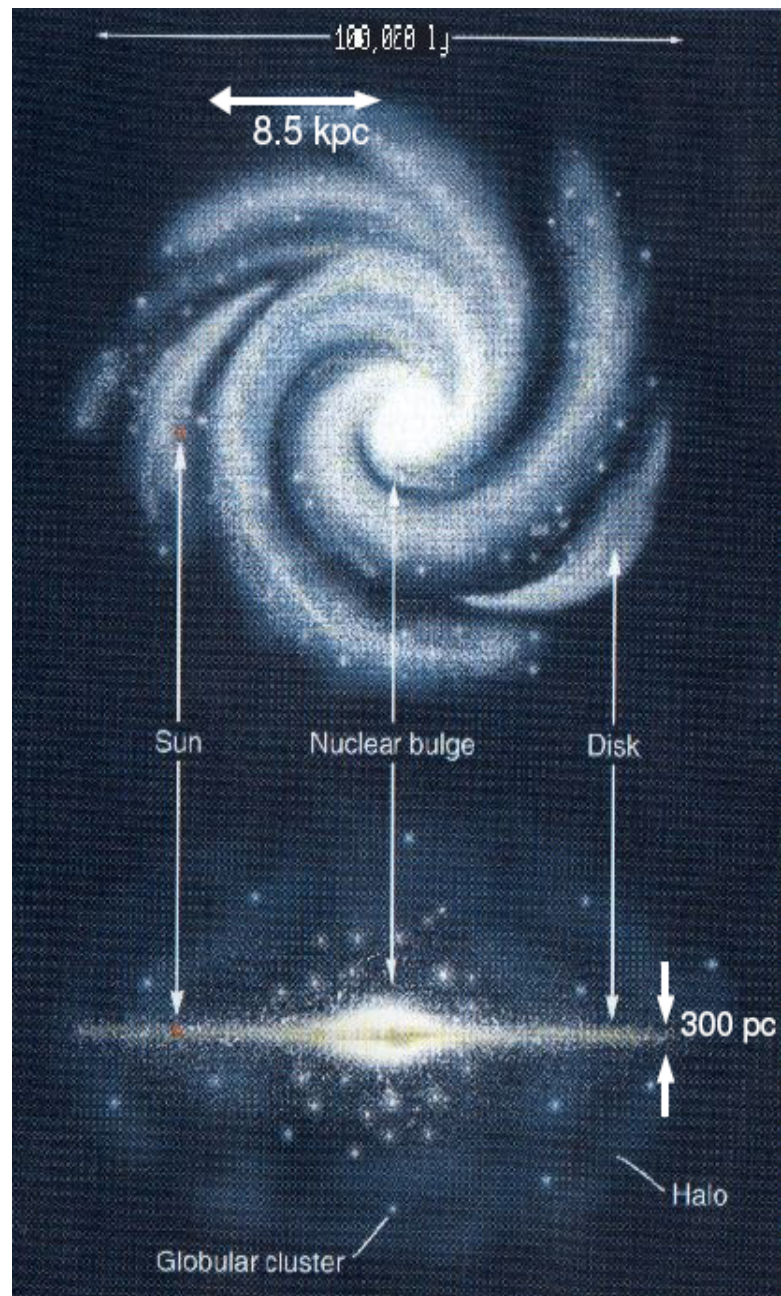
$$E = 8 \times 10^{19} \text{ eV}$$

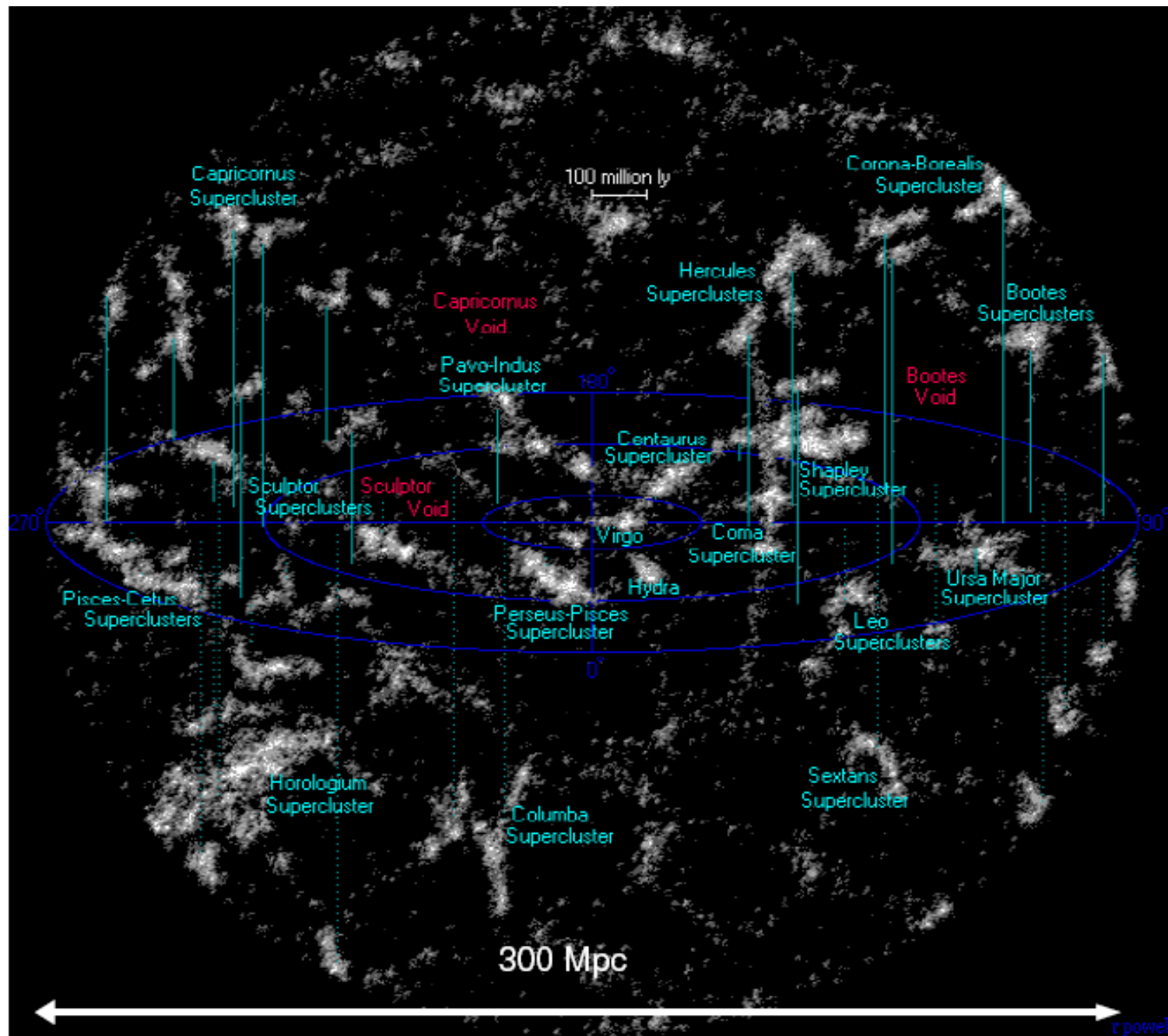




Propagação quasi-retilínea







Fatos:

- Existem poucas fontes capazes de acelerar partículas com energia maior que 10^{19} eV
- As fontes têm que estar próximas
- O universo é altamente anisotrópico e "vazio" dentro de 100 Mpc
- O desvio dessas partículas no campo magnético é pequeno

Fatos:

- Existem poucas fontes capazes de acelerar partículas com energia mais elevada

- As fontes têm

- O universo é isotrópico e homogêneo a escalas maiores que 100 Mpc

- O campo de velocidades das partículas no campo magnético é pequeno

Astronomia de partículas

Astronomia:

LUZ



1609 Galileu Galilei

PARTÍCULA

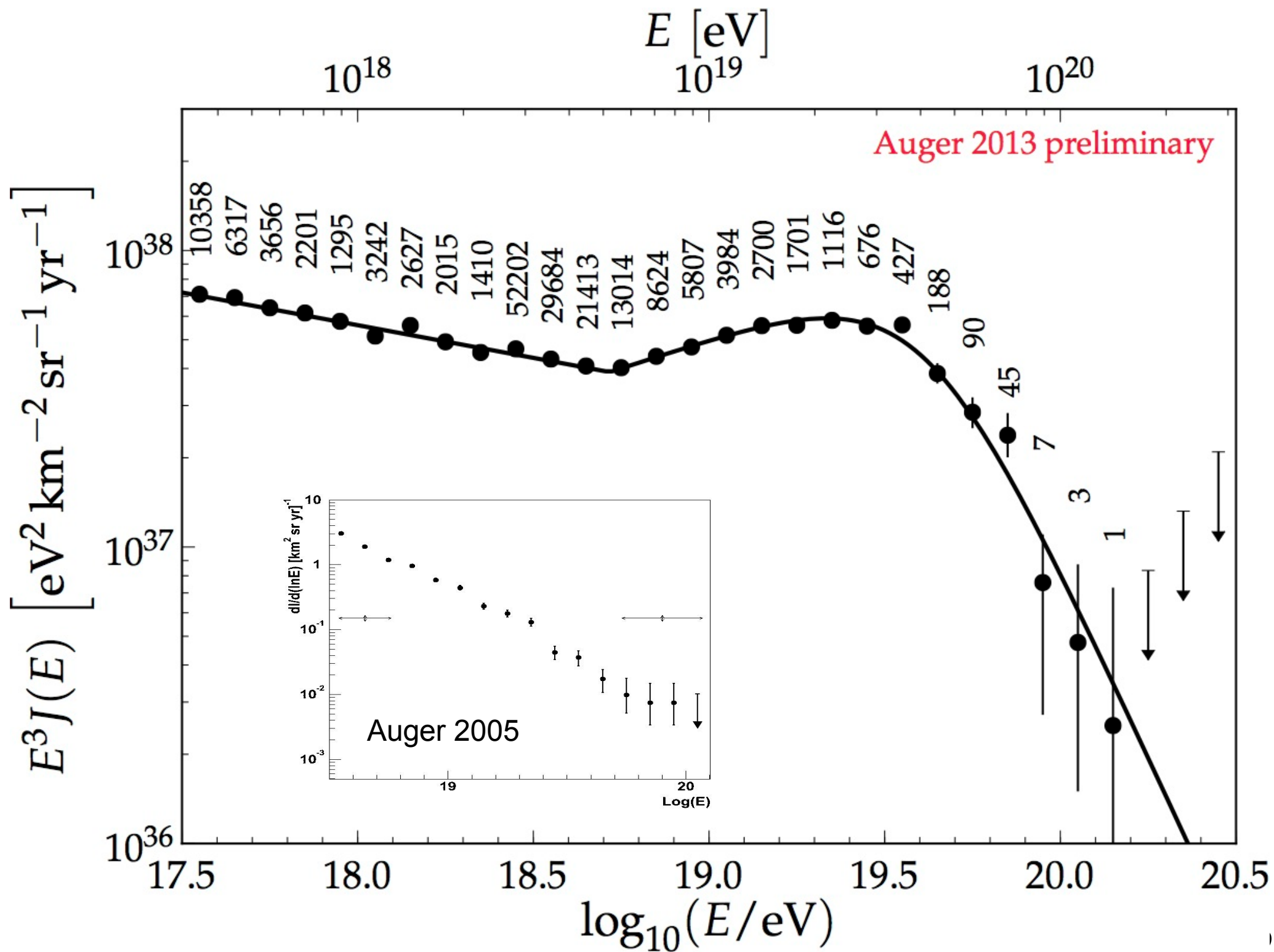


2009 Observatório
Pierre Auger

COMO SE FAZ
ASTROFÍSICA COM
PARTÍCULAS?

Astrofísica de partículas

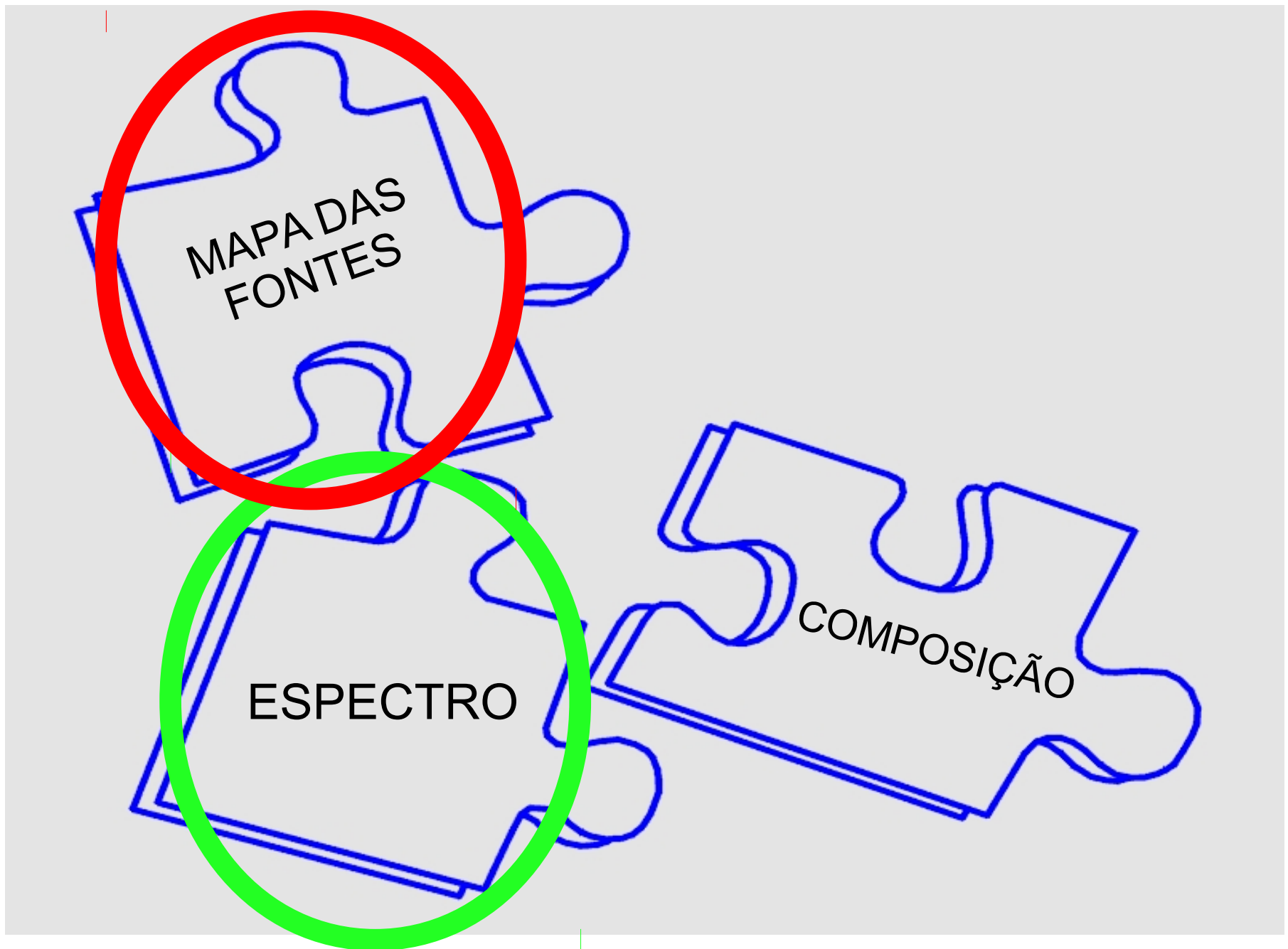




Auger: Resultados

Espectro: Corte GZK presente

Astrofísica de partículas

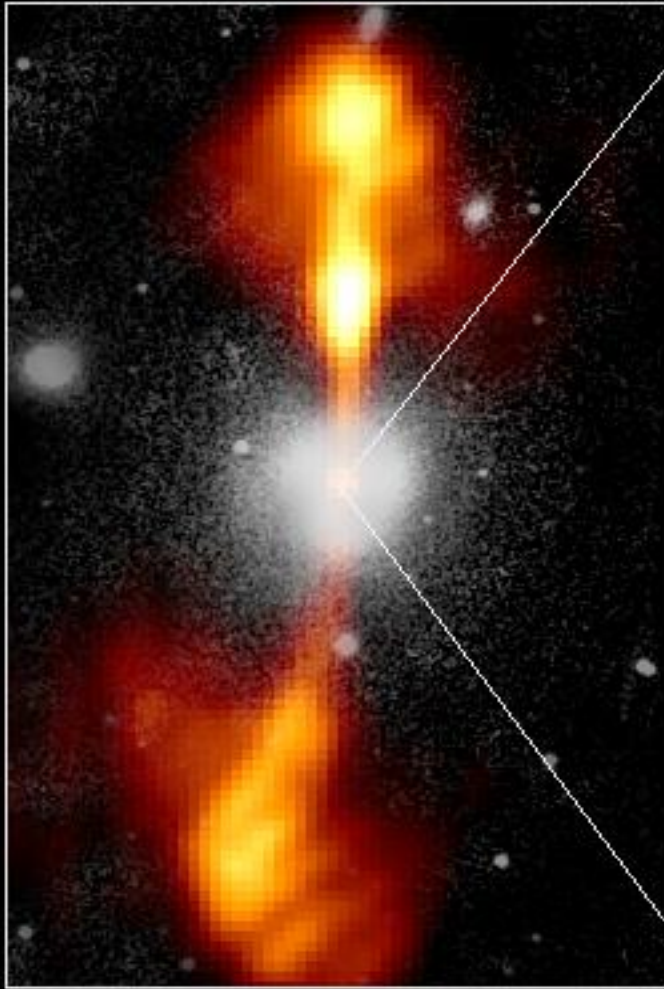


Core of Galaxy NGC 4261

Hubble Space Telescope

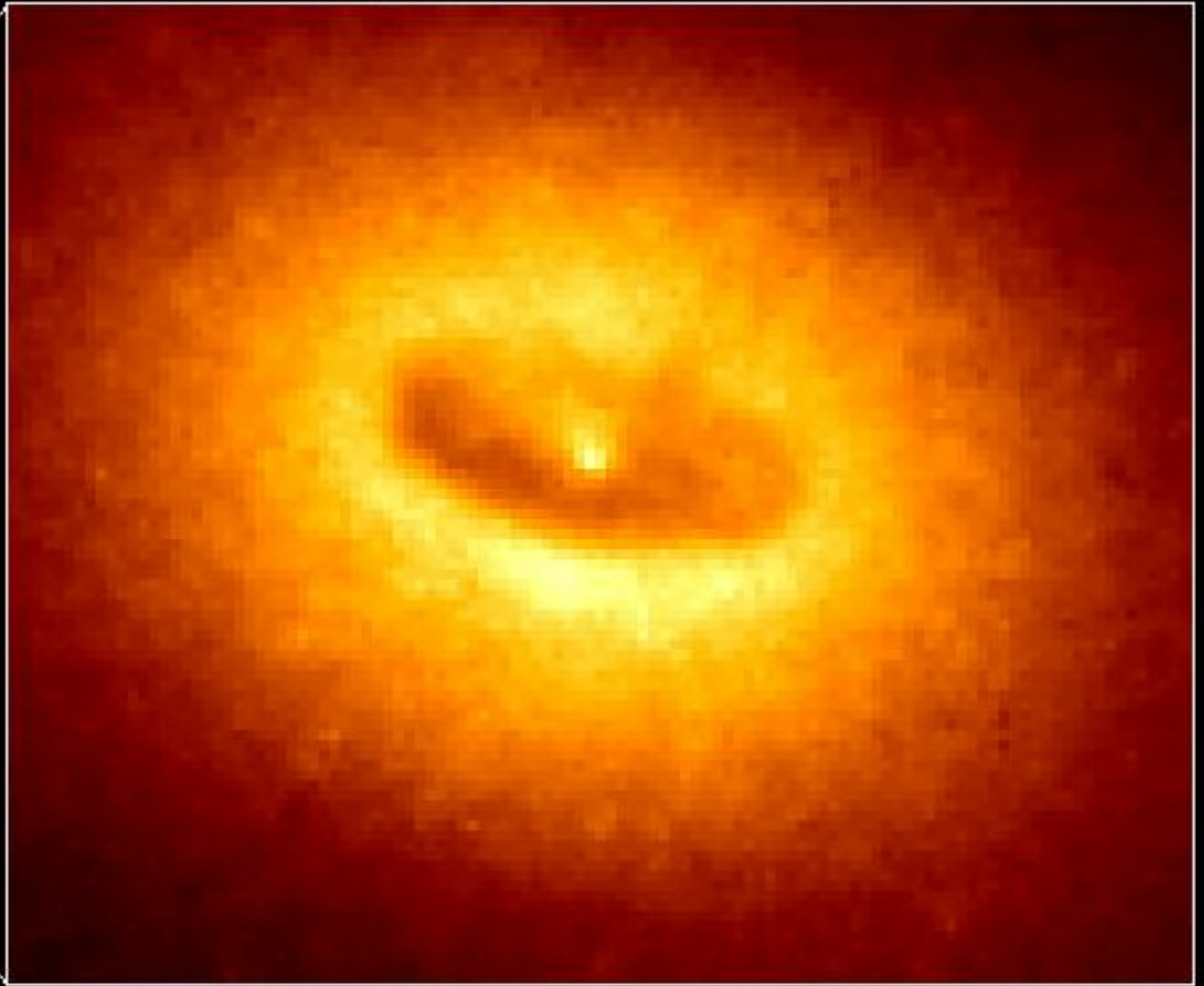
Wide Field / Planetary Camera

Ground-Based Optical/Radio Image



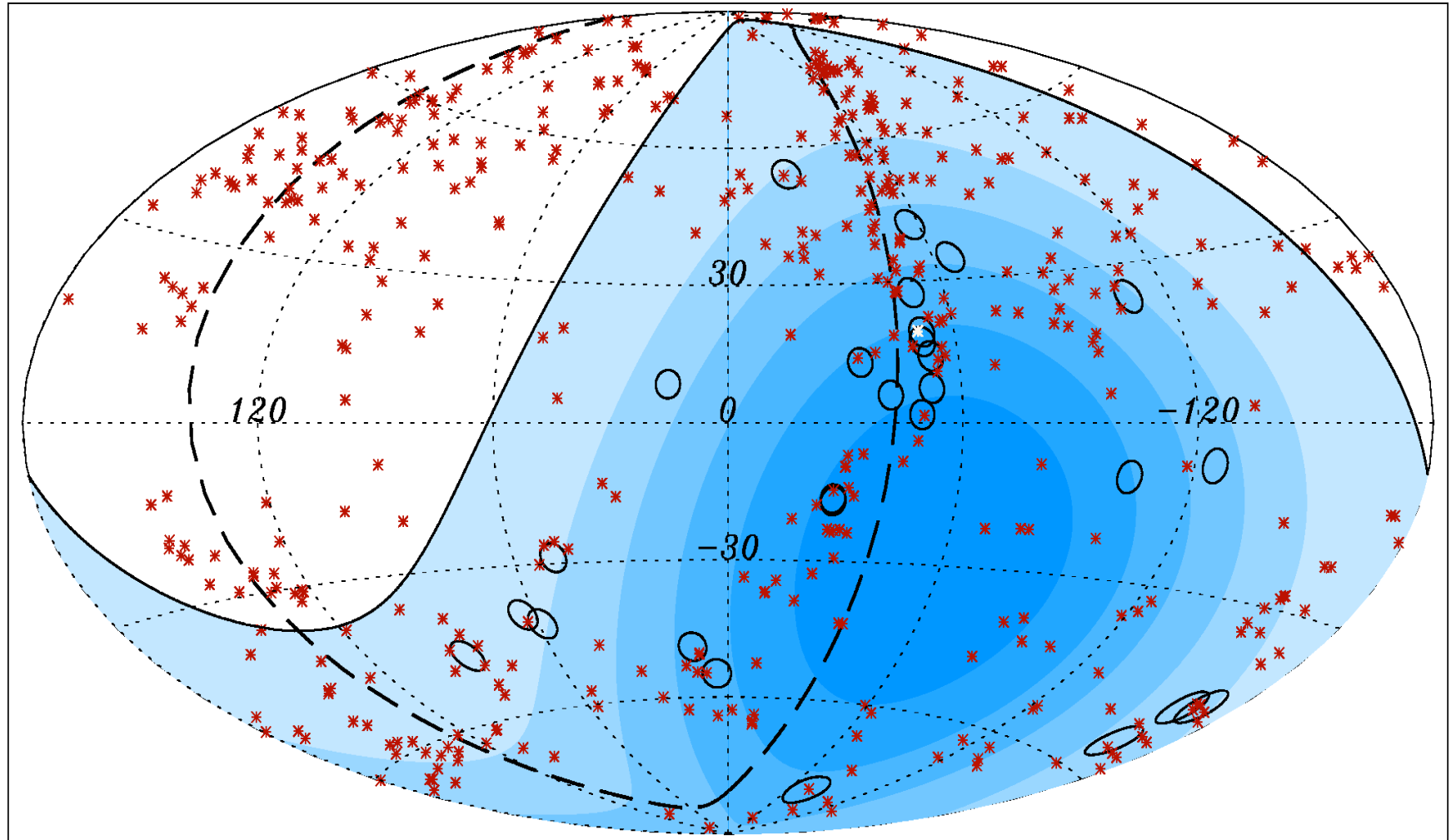
380 Arc Seconds
88,000 LIGHTYEARS

HST Image of a Gas and Dust Disk



1.7 Arc Seconds
400 LIGHTYEARS

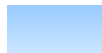
Pierre Auger Collaboration, Science (2007)



Eventos com energia acima de 5.7×10^{19} eV



Núcleos Ativos de Galáxias (AGN)



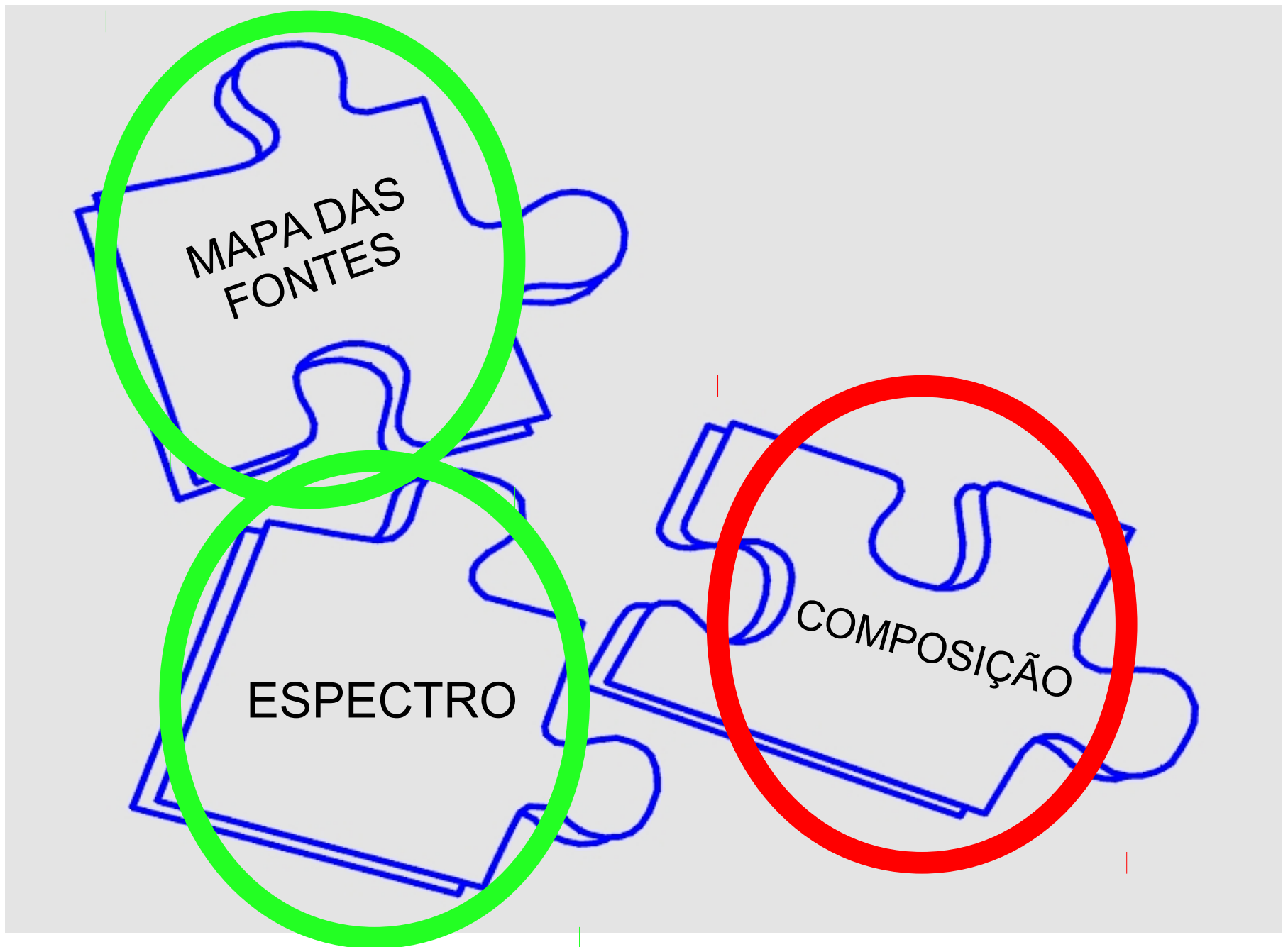
Exposição do Observatório

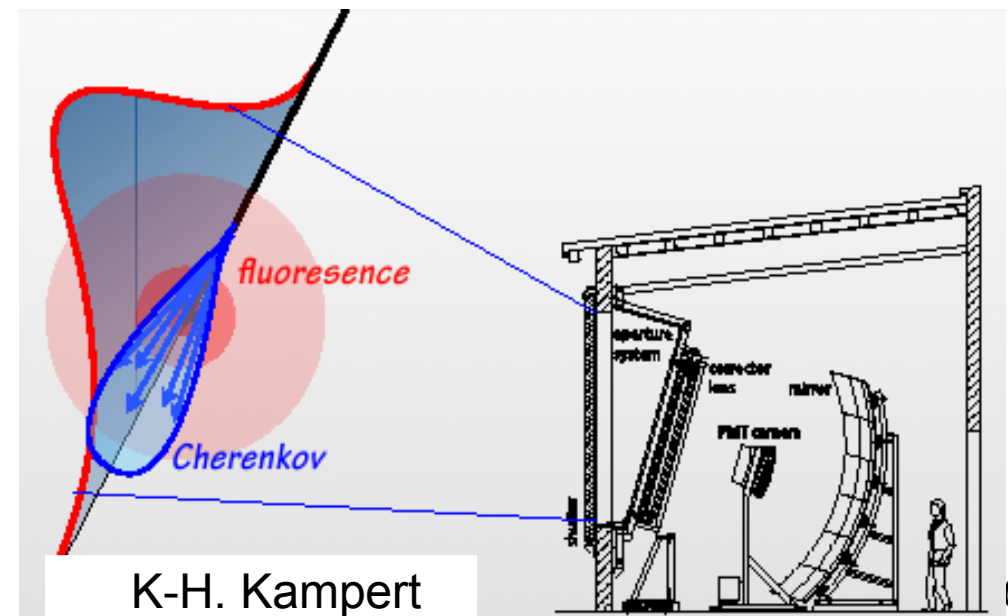
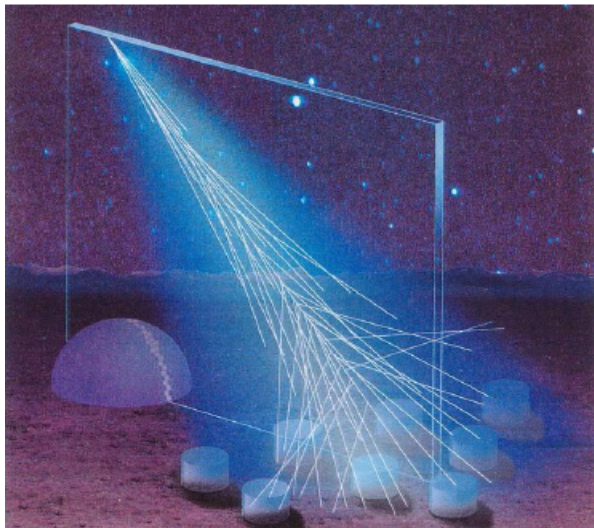
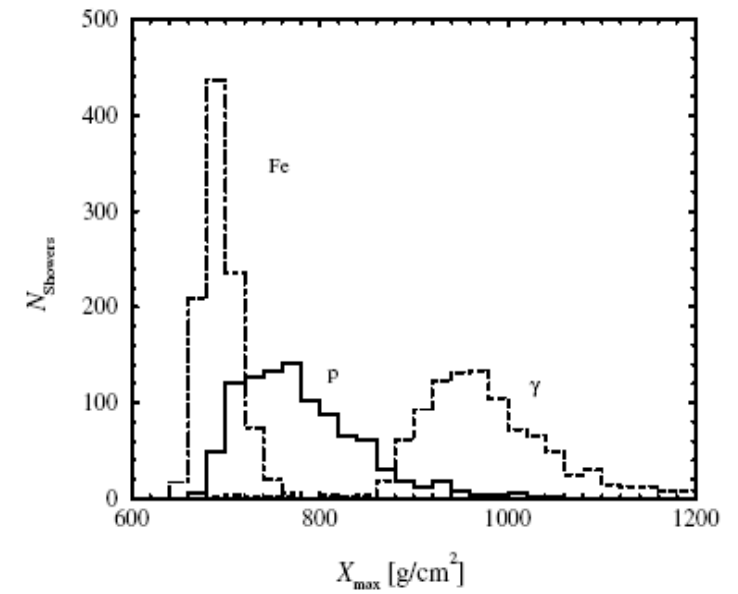
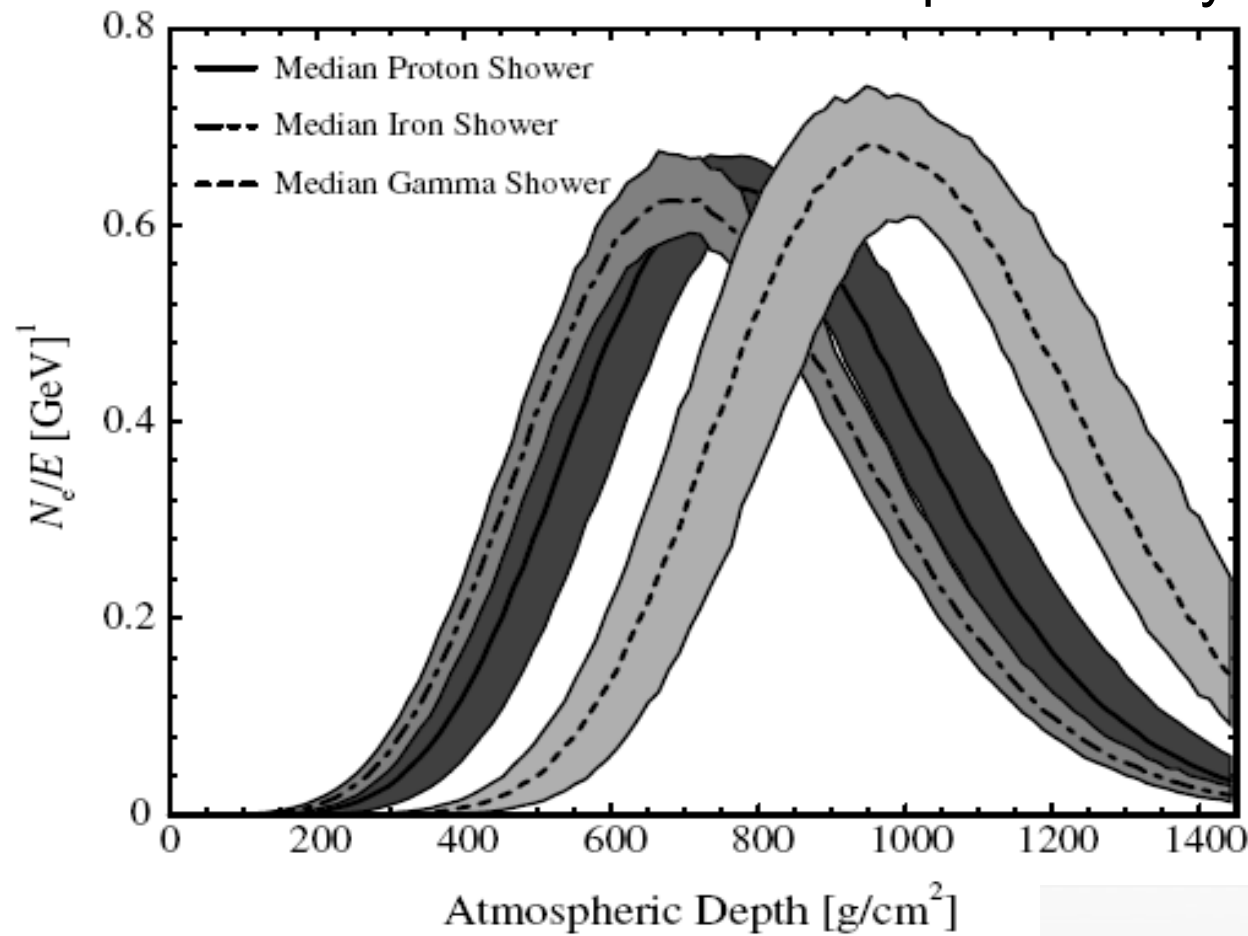
Auger: Resultados

Espectro: Corte GZK presente

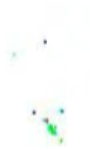
Mapa das fontes: Evidências de Anisotropia

Astrofísica de partículas



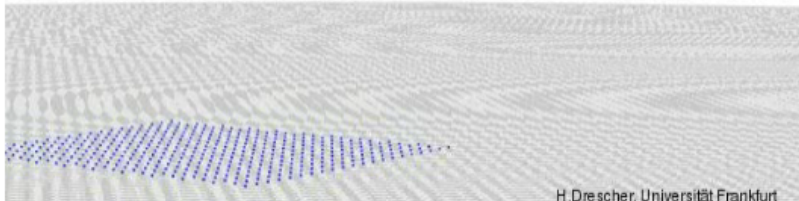


Ferro

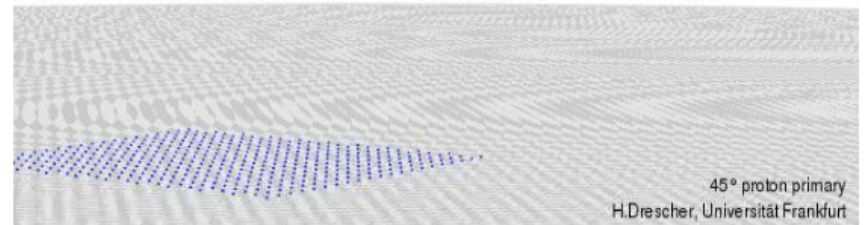


Próton

time=-160 μ s



H. Drescher, Universität Frankfurt



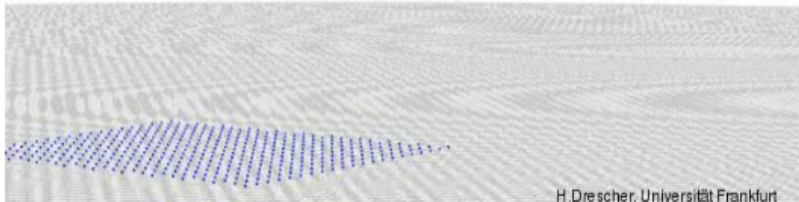
45° proton primary
H. Drescher, Universität Frankfurt

Ferro

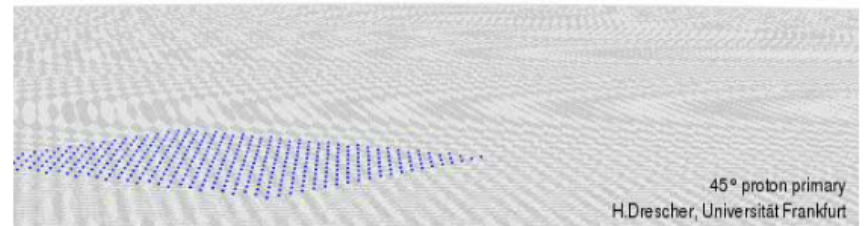


Próton

time=-106 μ s

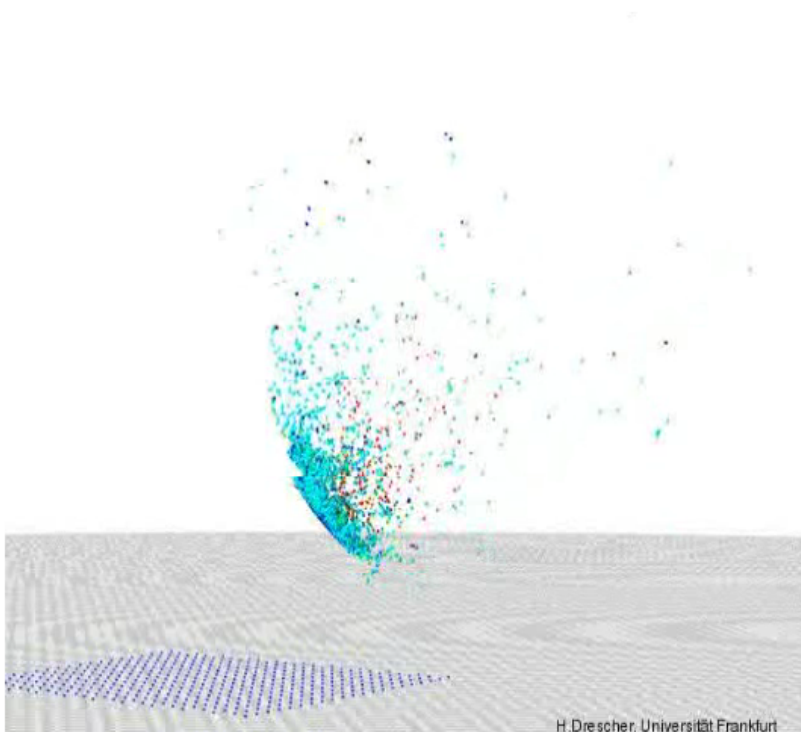


H. Drescher, Universität Frankfurt



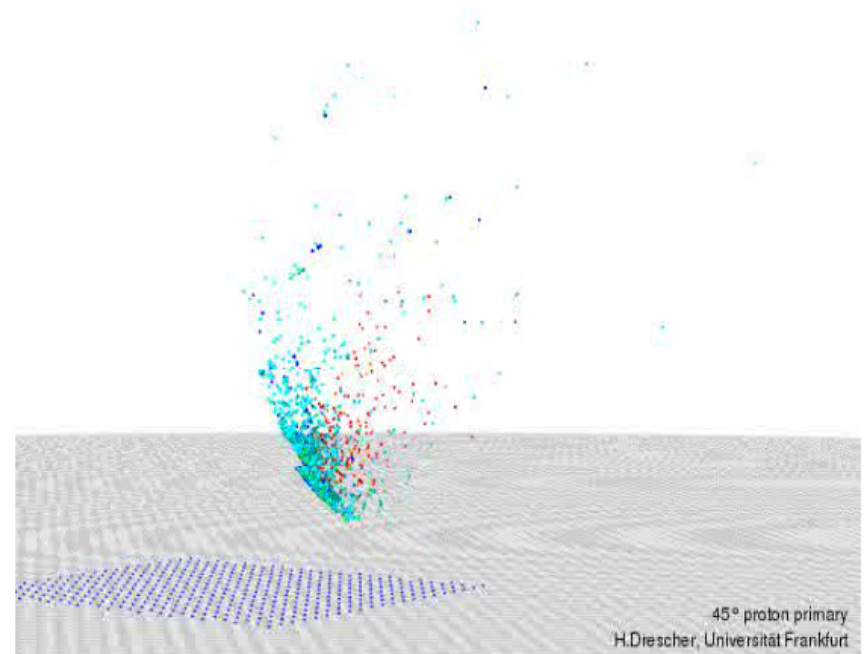
45° proton primary
H. Drescher, Universität Frankfurt

Ferro

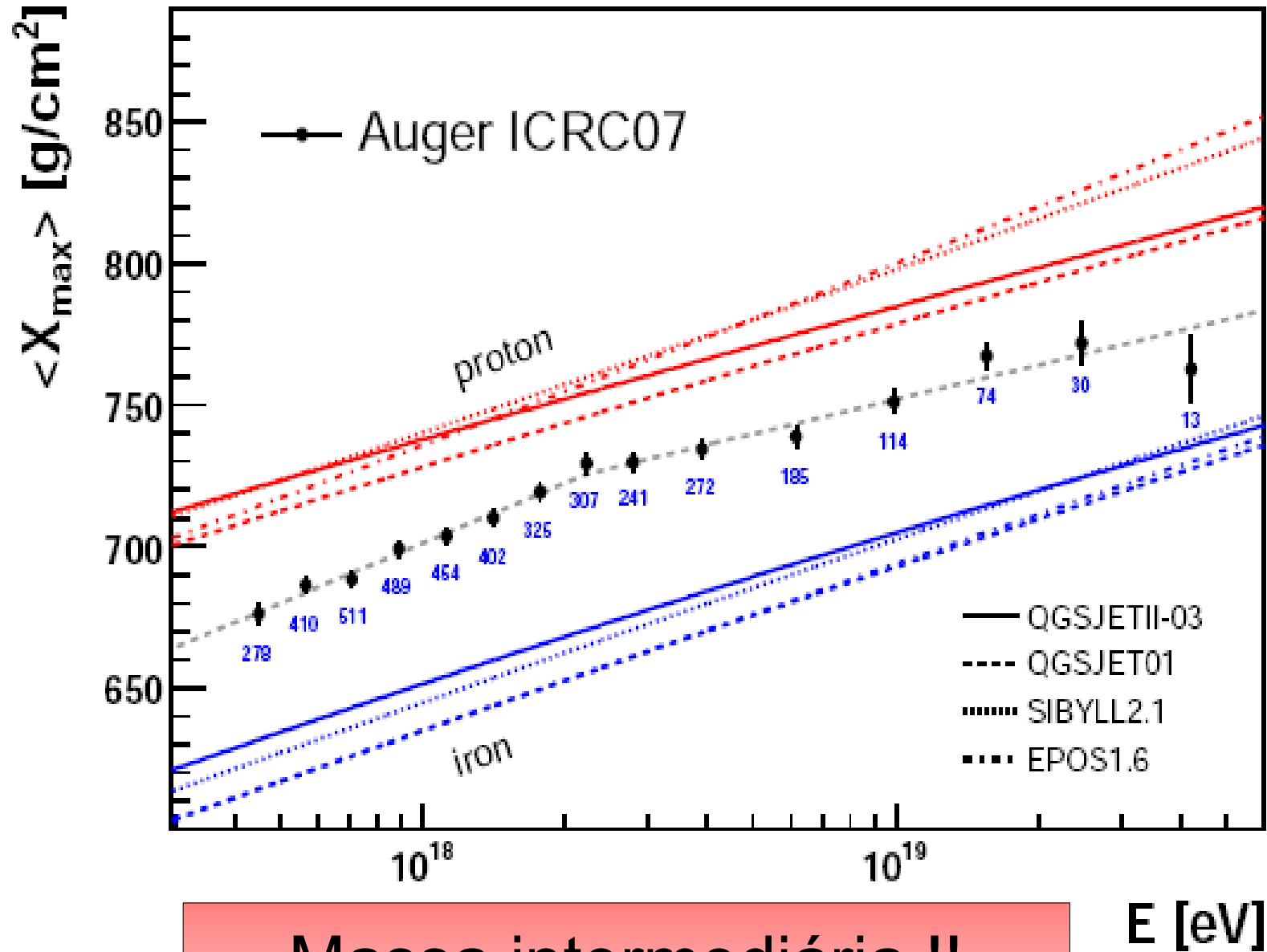


Próton

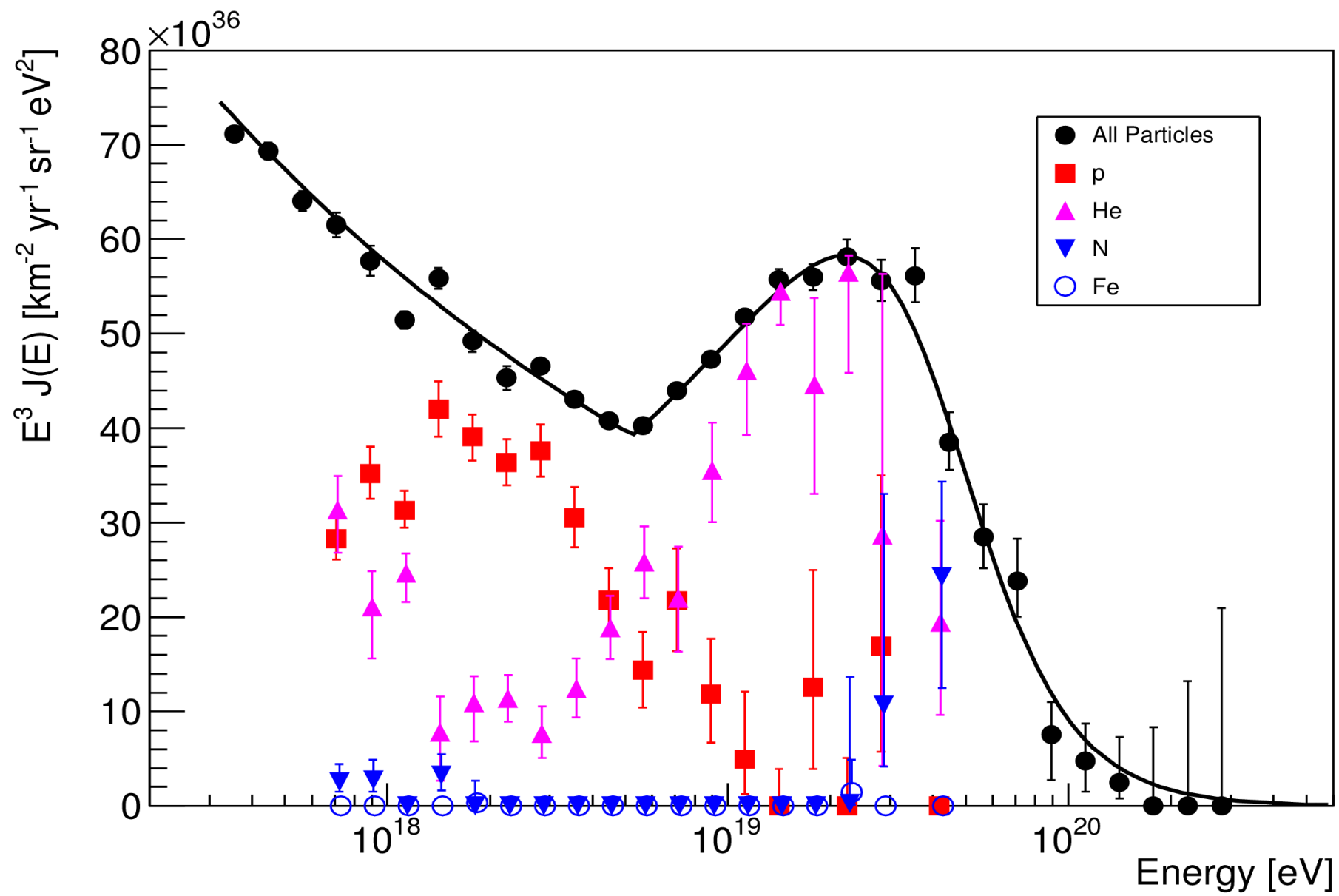
time=-43 μ s



Técnica tradicional



Massa intermediária !!



Auger: Resultados

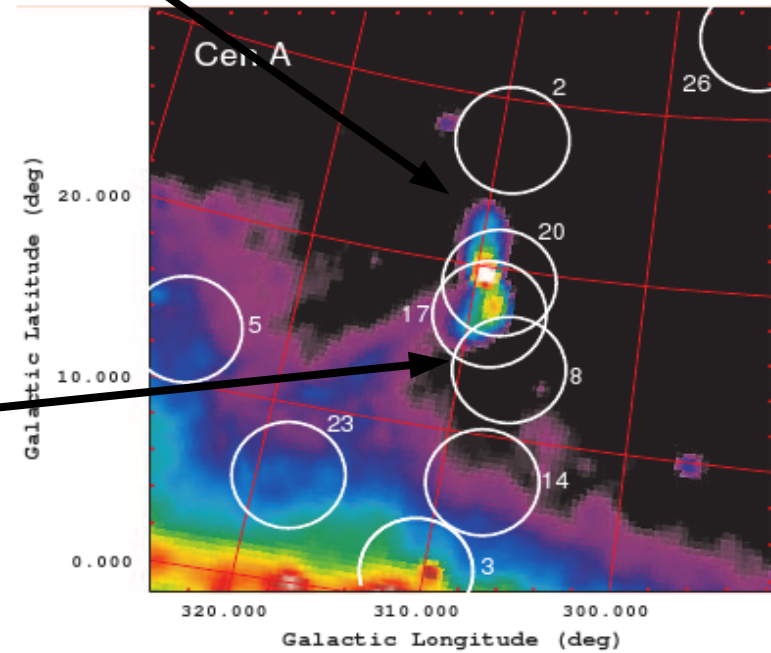
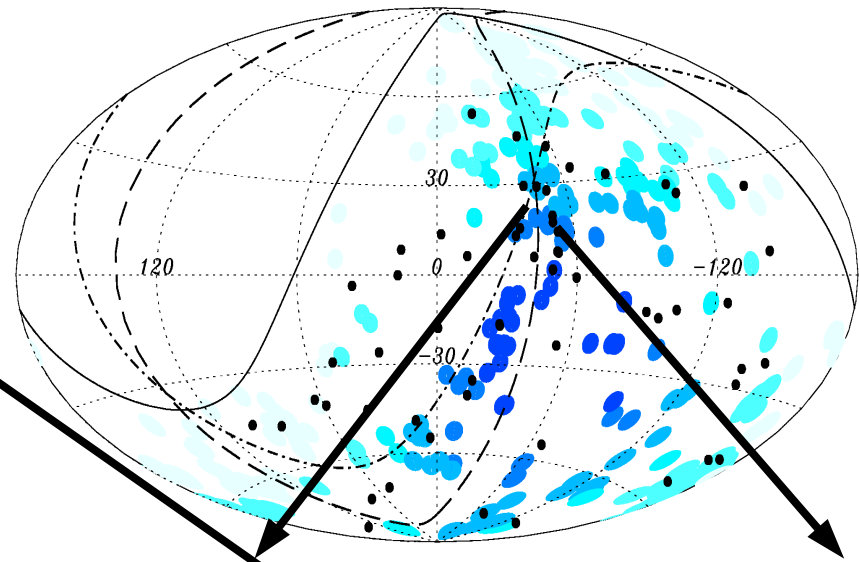
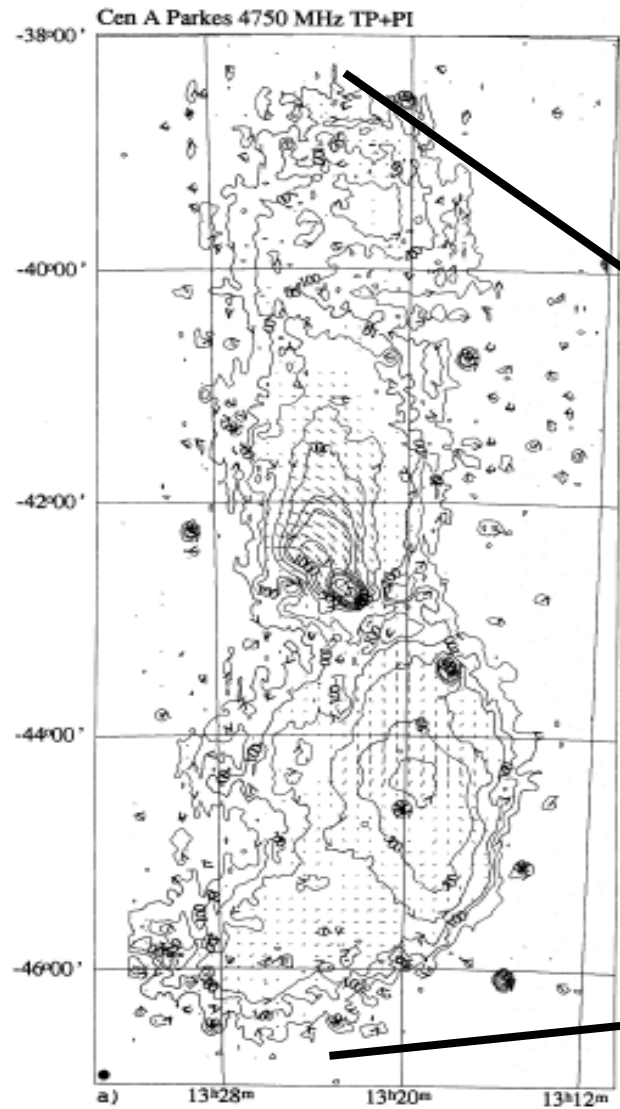
Corte GZK presente

Evidências de Anisotropia

Desvio angular compatível com proton

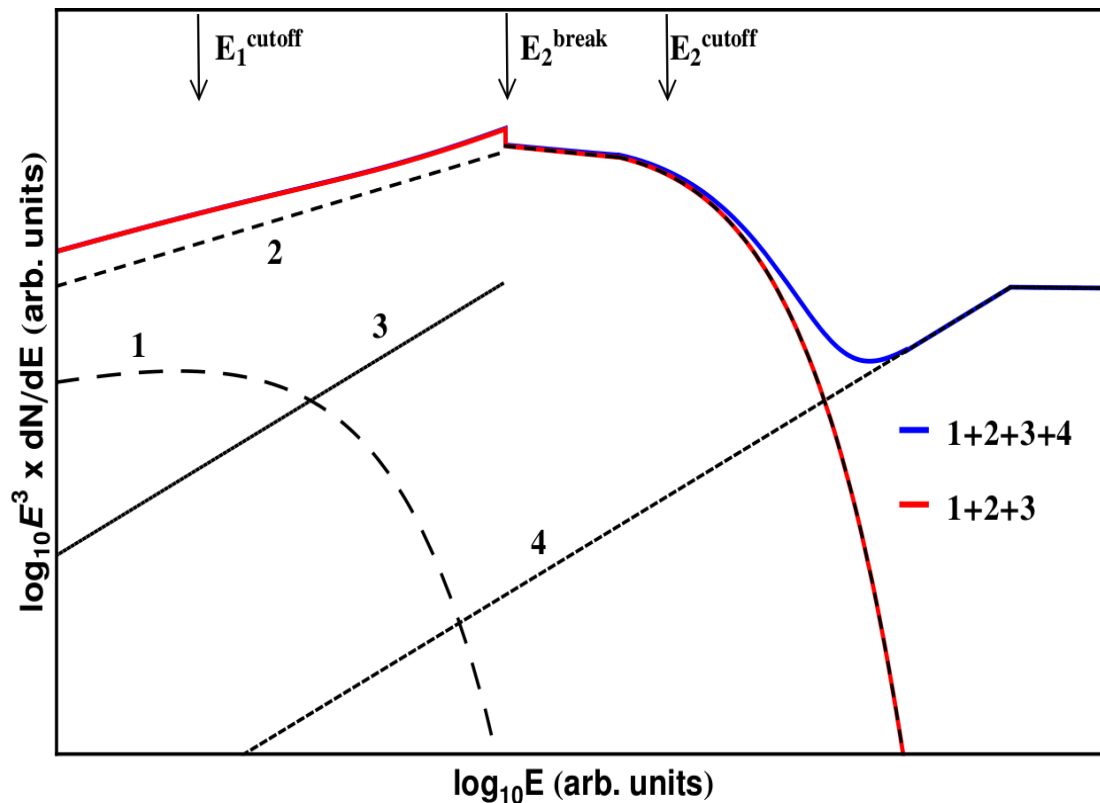
Medidas da composição indicam massa
intermediária

Cen A

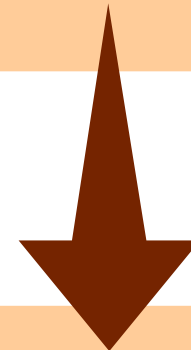


Cen A + Milky Way

Is it possible that Cen A + Milky Way
accounts for the large majority of
cosmic rays we measure on Earth ?



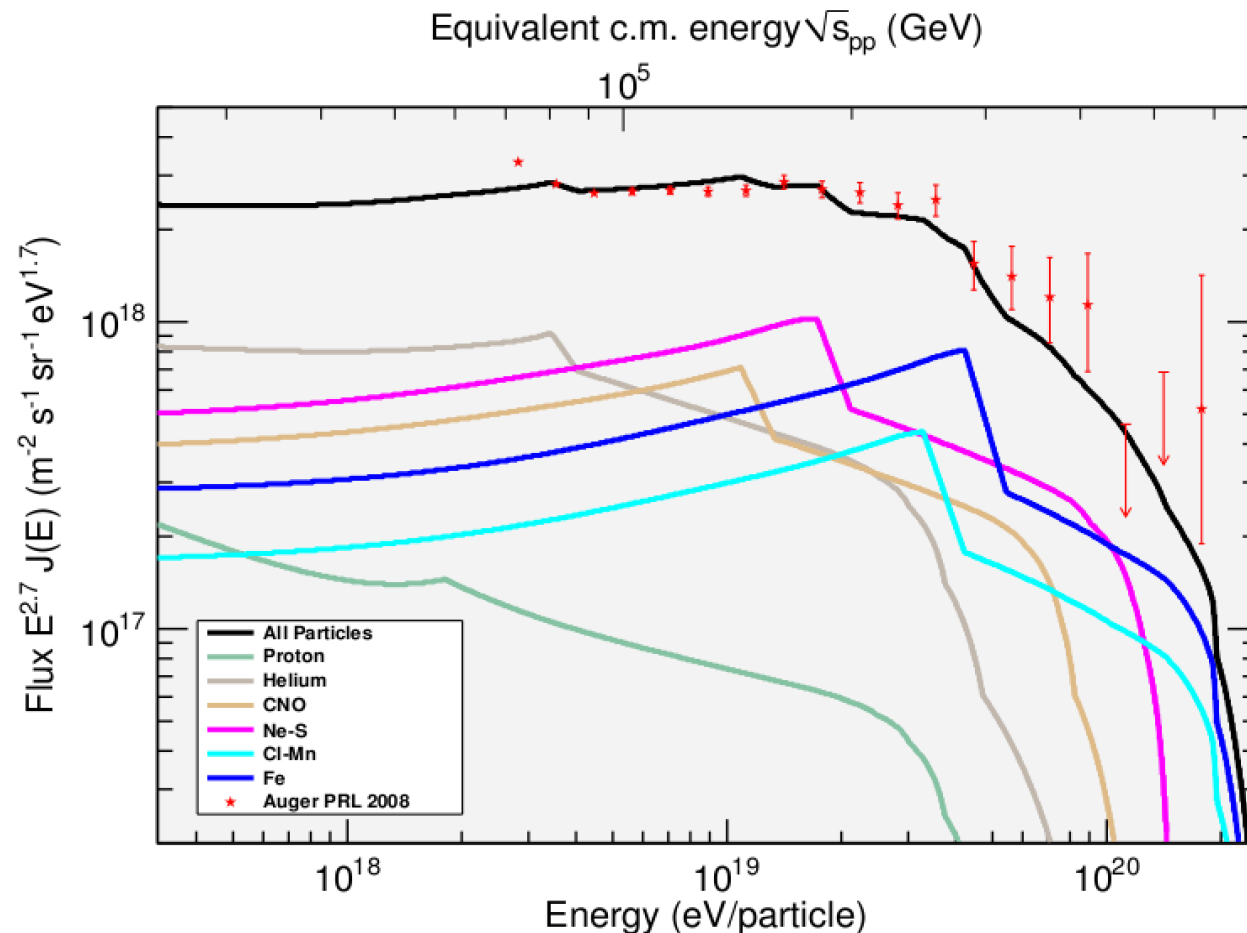
Supernovae up to 10^{16} eV



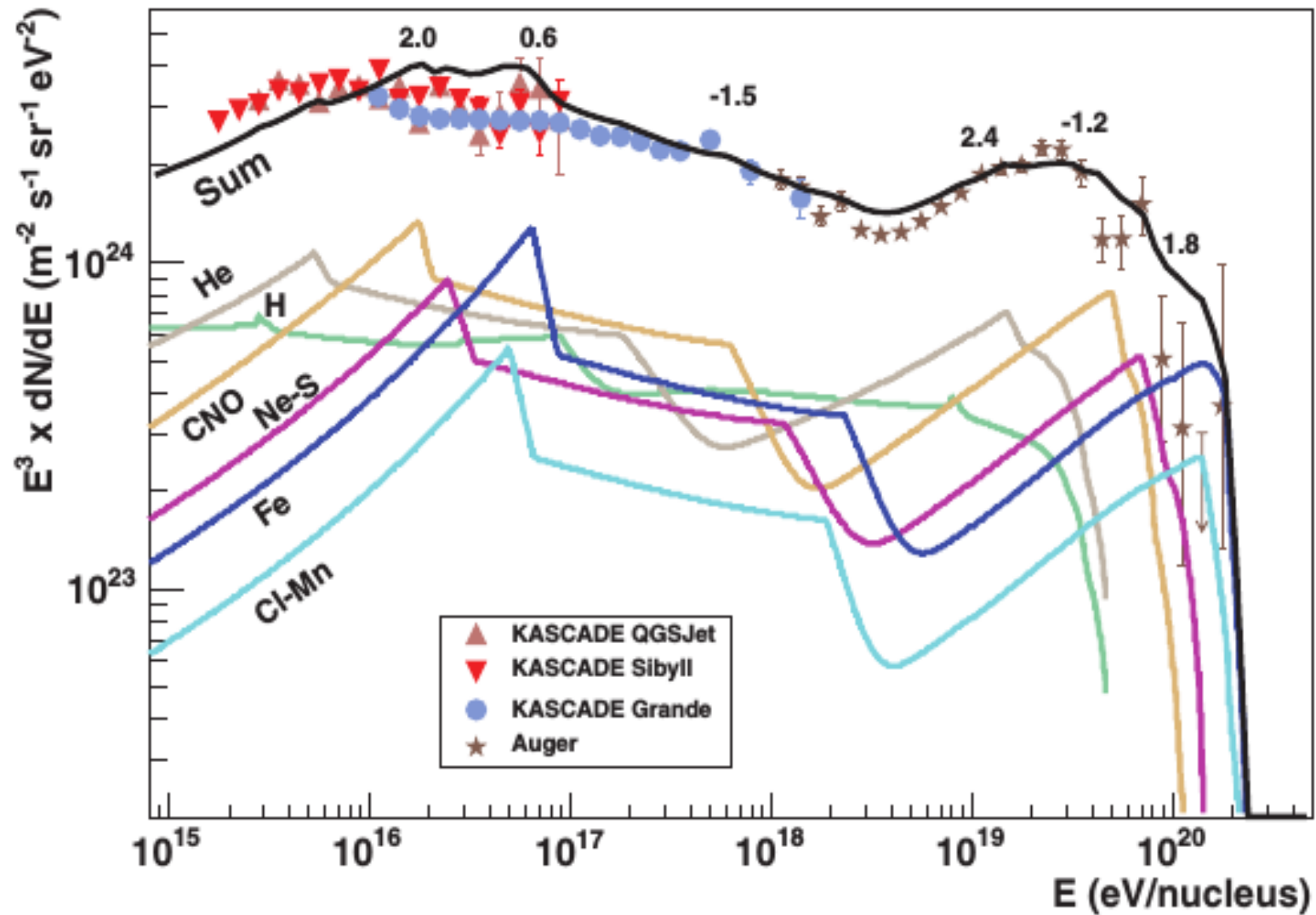
Reacceleration in the
jets up to 10^{20} eV

Modeling Cen A

$$L_{\text{jet}} \gtrsim 10^{47} \text{ erg s}^{-1} f_{\text{int}} \left(\frac{E_{\text{max}}}{Z \times 10^{21} \text{ eV}} \right)^2,$$

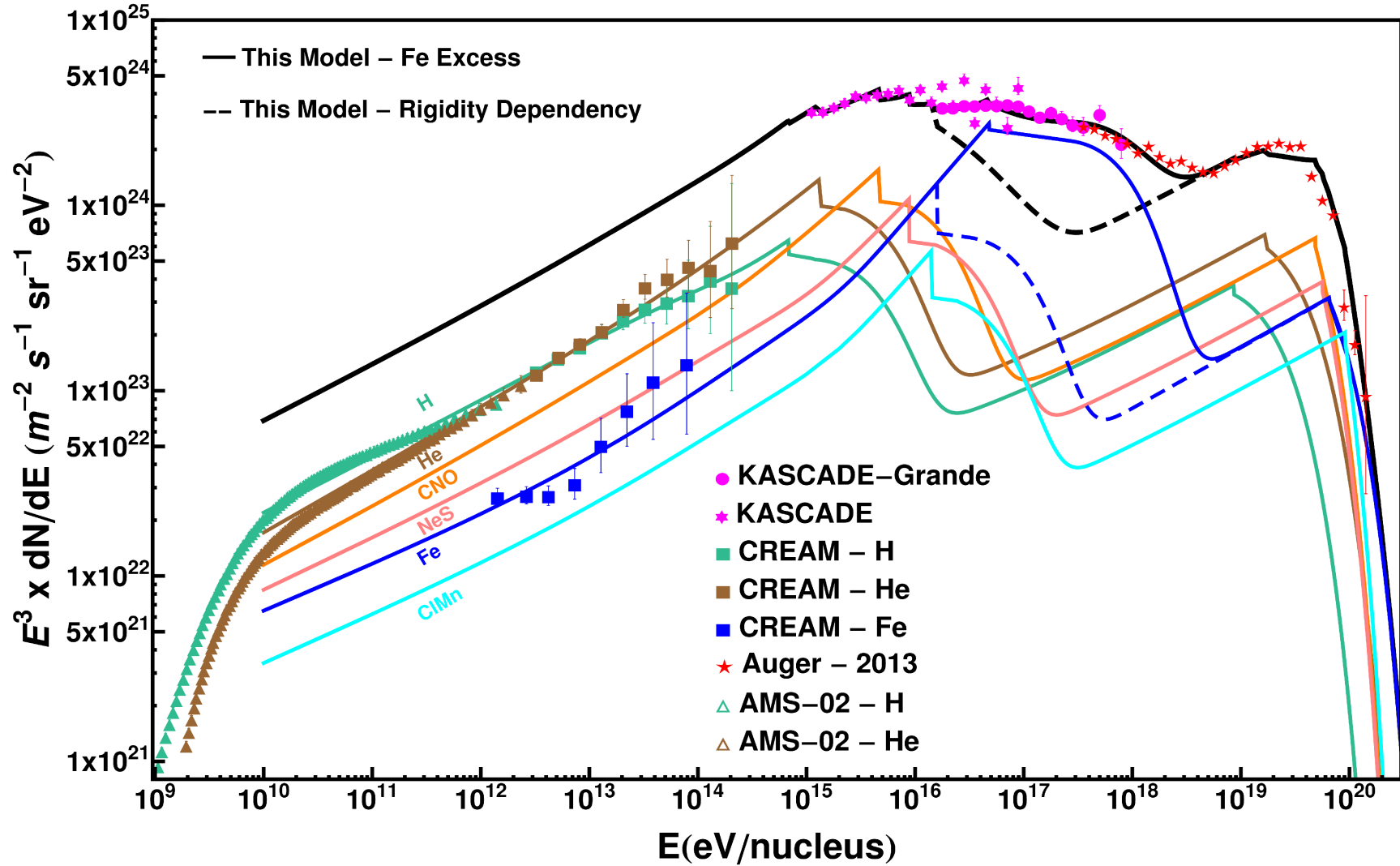


Modeling Cen A



P. Biermann and V. de Souza, APJ, 746:72 (2012)

Modeling Cen A



Open questions

Is the flux suppression due to the interaction with the CMB or is it the sources running out of power ?

How to reconcile correlation with AGN and $Z > 1$?

- Weaker magnetic fields ?
- Close by source ?

Open questions

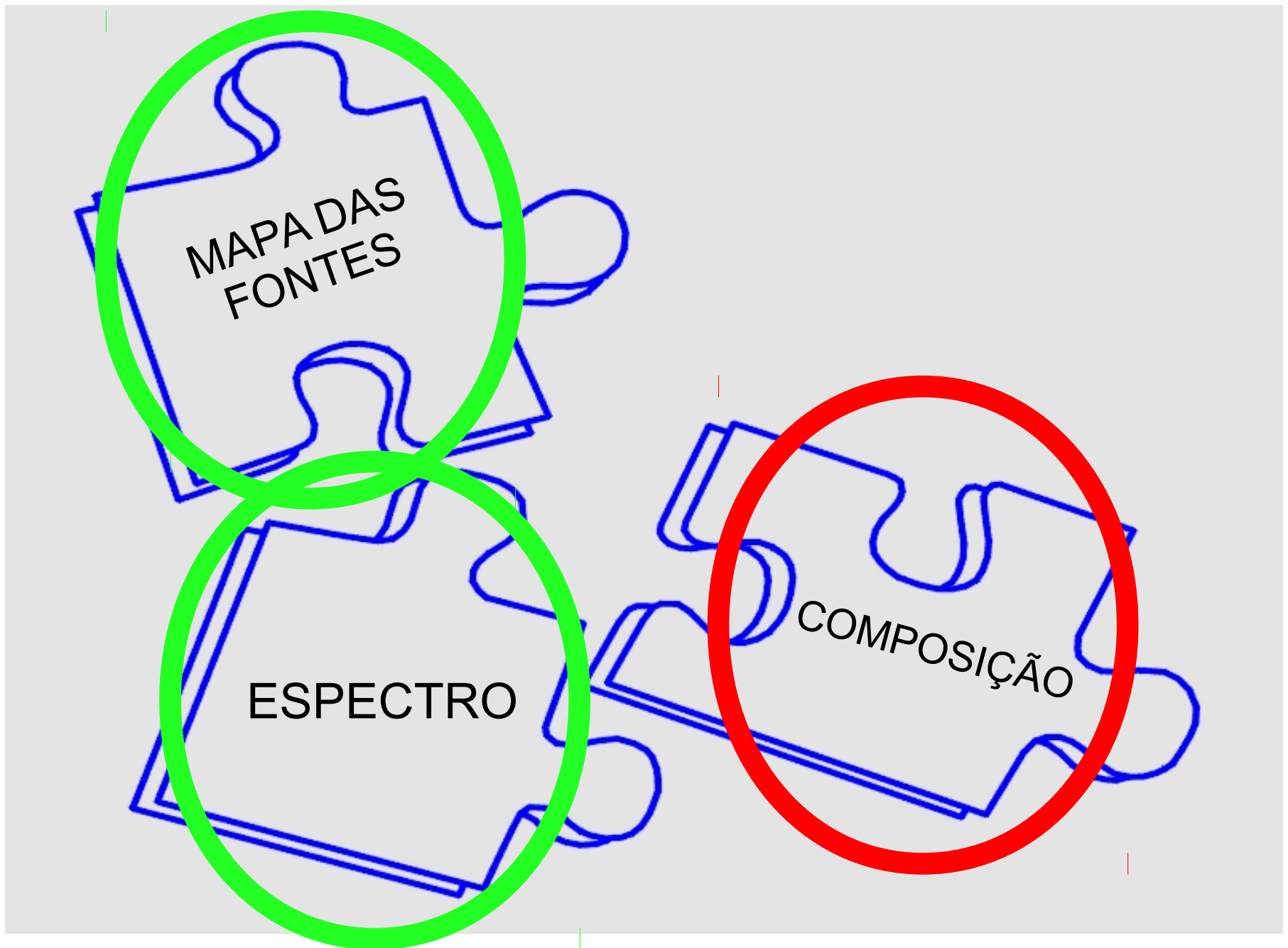
Are AGNs the sources or only tracers ?

Can we study particle physics
with energies above LHC ?

Answers are expected from:

- Continuous operation of the Pierre Auger Observatory for at least one decade
- Multiparametric analysis
 - Muon: AugerPrime
- Multi-messenger approach:
 - Neutrinos
 - GeV-TeV gamma rays

Astrofísica de partículas



Trabalho no IFSC

Forma do espectro para $E > 10^{19.5}$

Identificação das fontes

Determinação do tipo da partícula primária

Extensões: HEAT e AMIGA

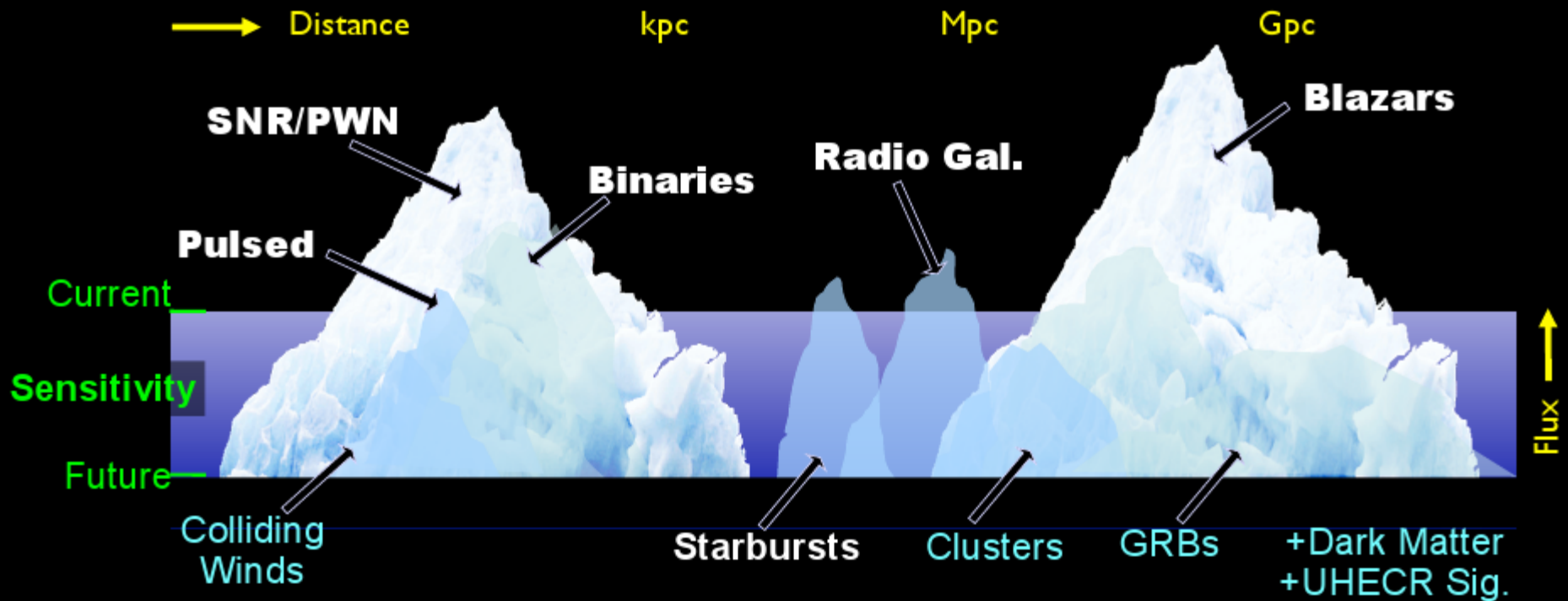


... an advanced facility for ground-based gamma-ray astronomy



Discovery Potential

adapted from
Horan & Weekes 2003

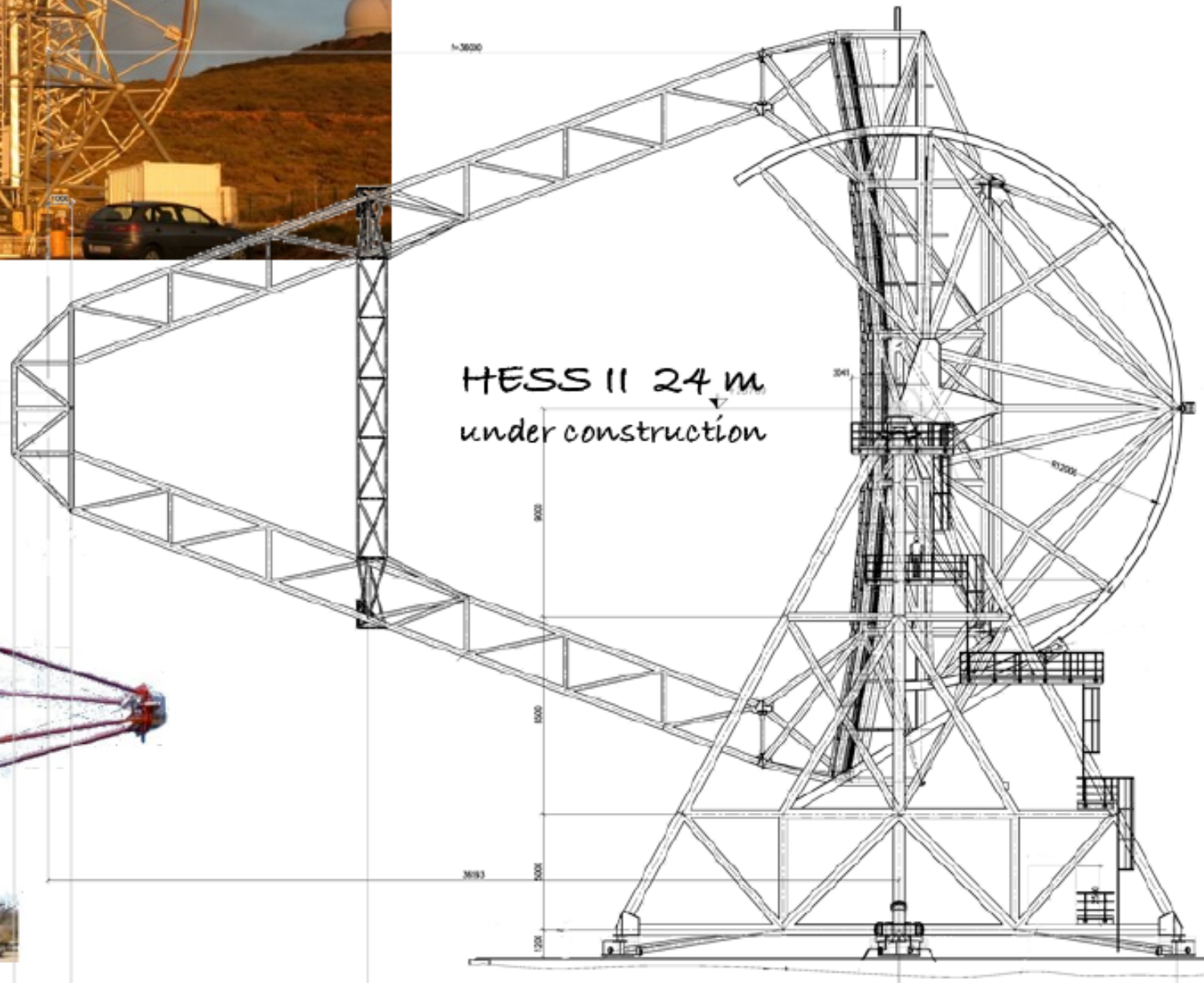


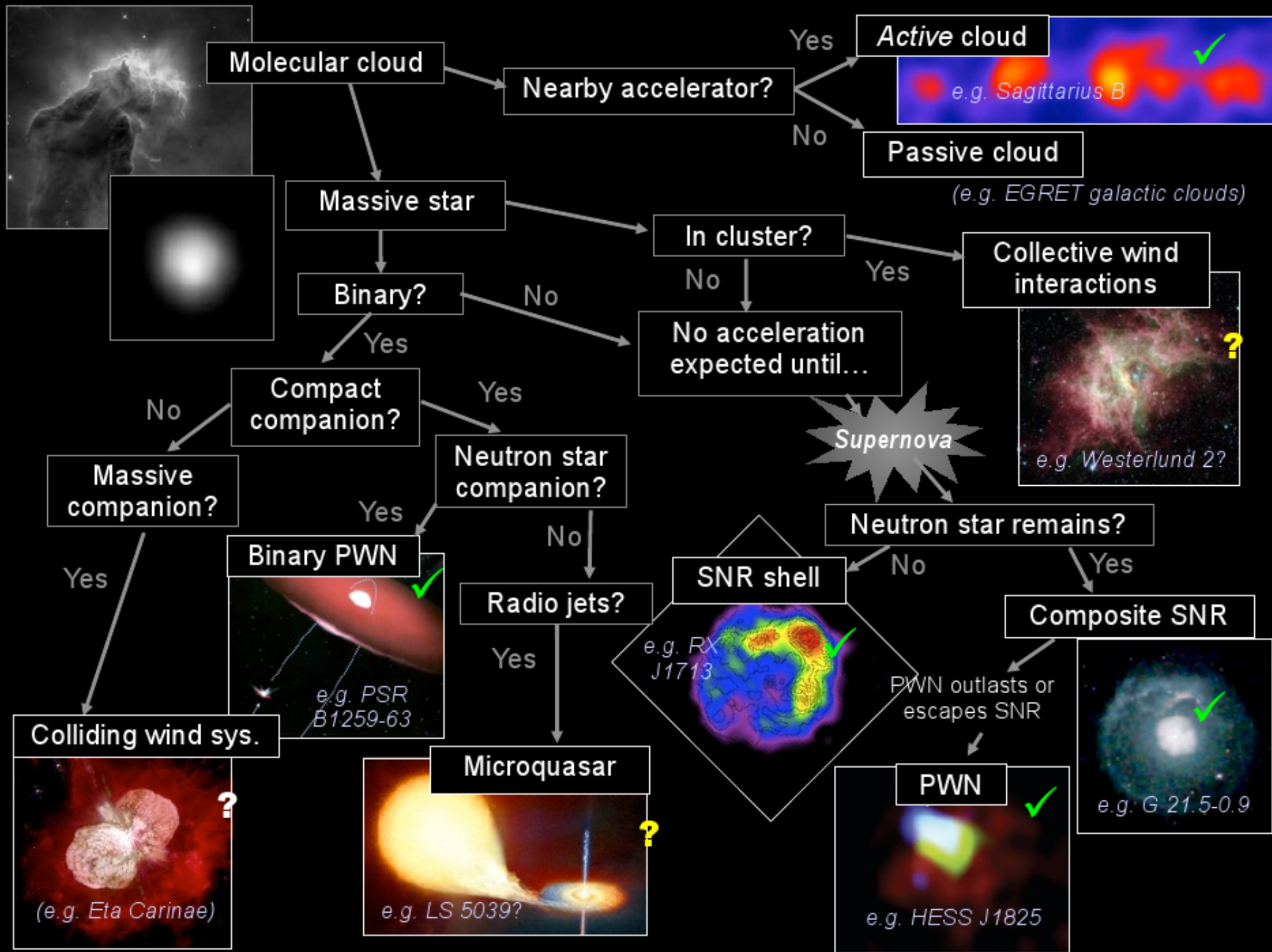


Building blocks could be ...

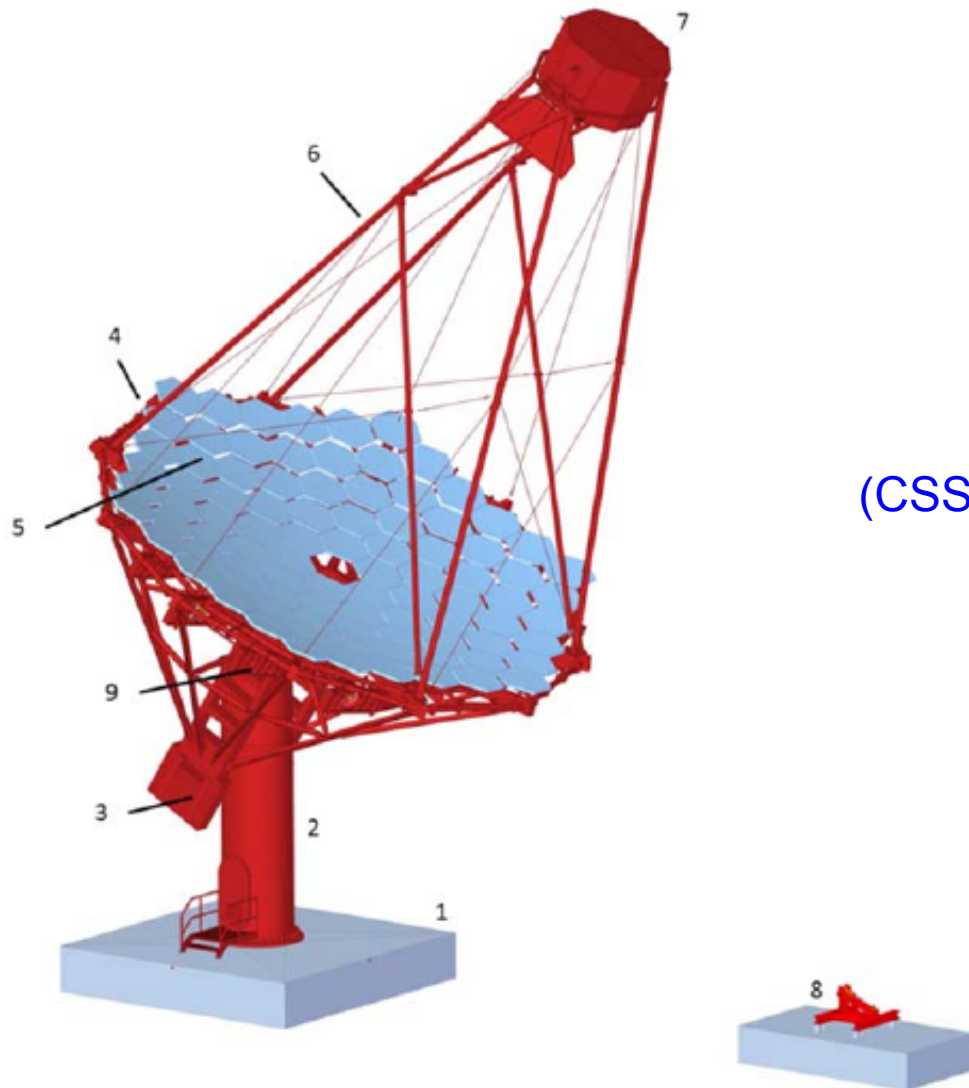
to scale

HESS I 12 m



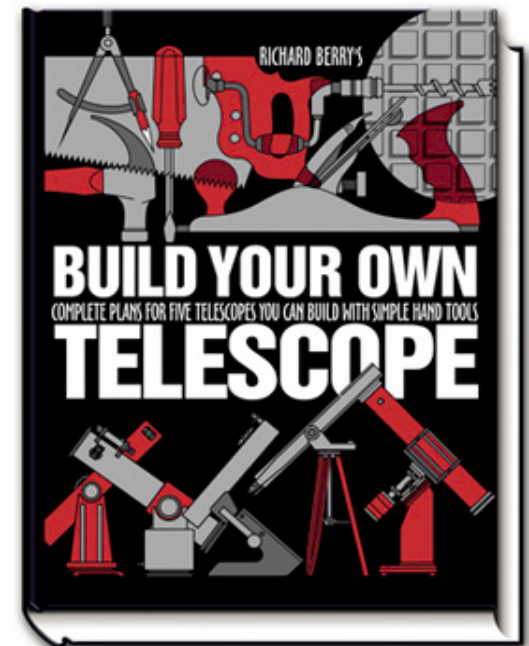


Building telescopes: MST



- 1 – Foundation
- 2 – Tower
- 3 – Counterweight
- 4 – Optical Support Structure
- 5 – Mirrors
- (CSS) 6 – Camera Support Structure
- 7 – Camera
- 8 – Camera Lock
- 9 - Head

Figure 1: Description of the telescope structure



Building the CSS in Brazil

- 2011:
 - Studying the demands and searching for partner companies
- 2012:
 - Funds secured
 - Development of the conceptual design
- 2013:
 - Conceptual design approved
 - Development of the detailed design
- 2014:
 - Prototype construction
 - Prototype transport, instalation and test
- 2015:
 - Funding request to produce 25 CCS



CSS Detailed Analysis

LOAD CASE 03:

- Horizontal
- 50 km/h
- Ice load
- Wind load X

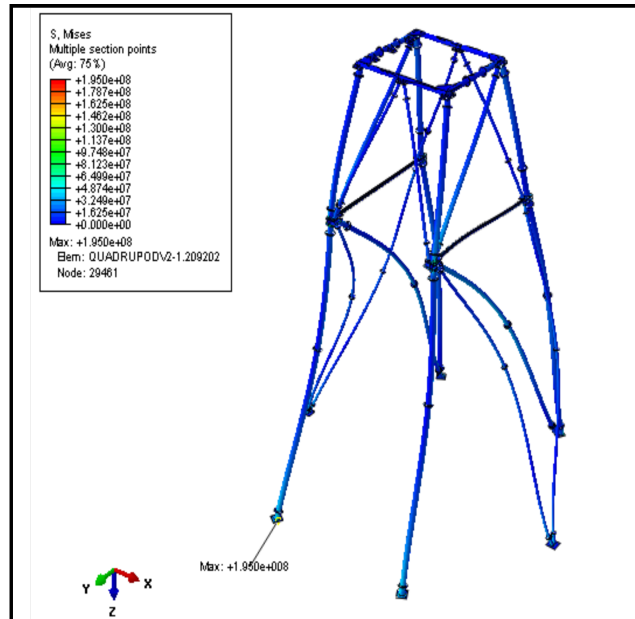


Figure 14: Case 03 stress and displacement analysis

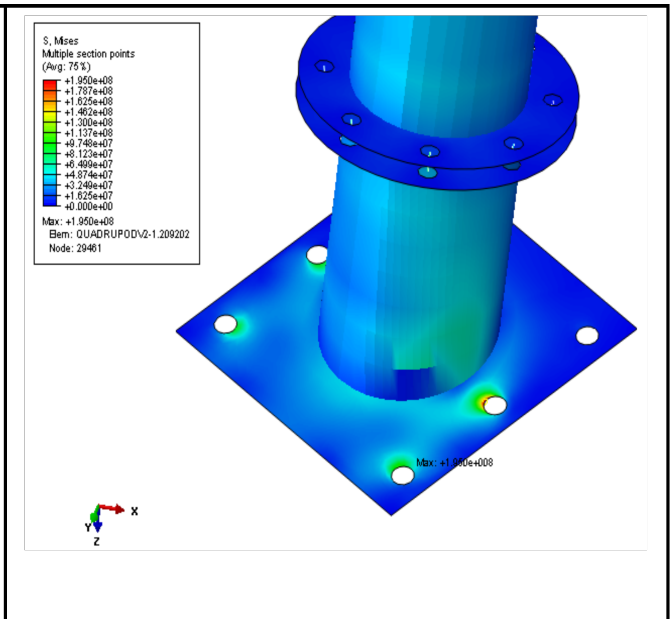
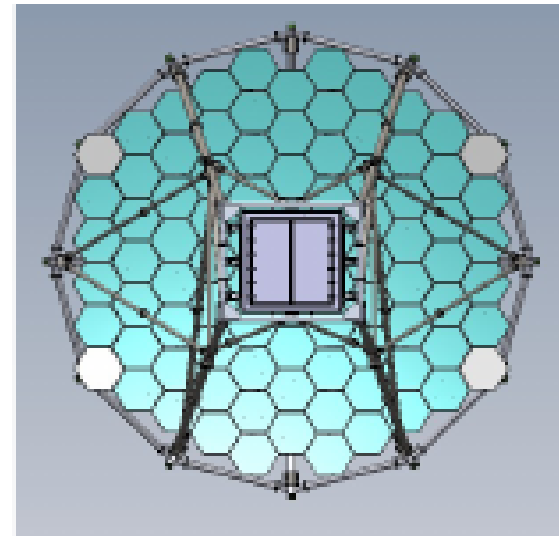
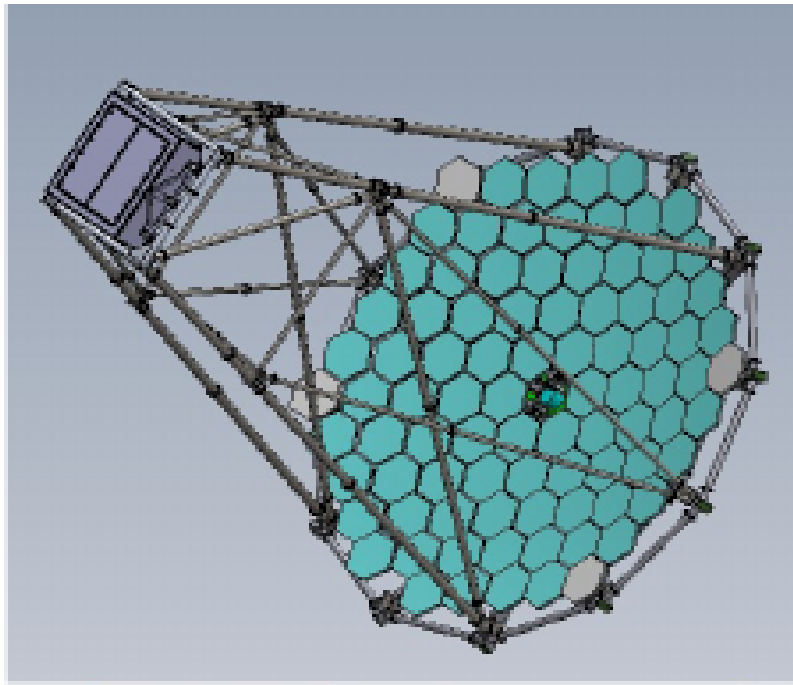


Figure 15: Case 03 stress detail

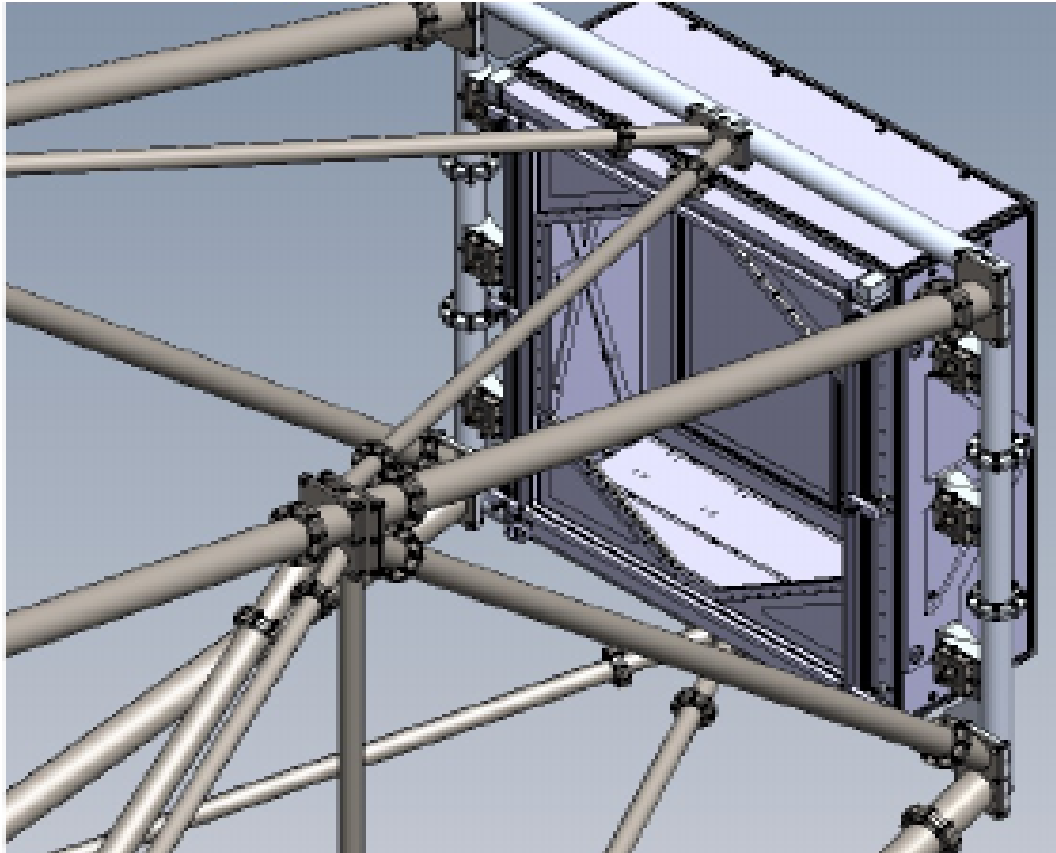
Input				Output				
Case	Wind Load	Ice Load	Gravity	Global Displacement (mm)	Camera Displacement (mm)	Stress (MPa)	Buckling factor	Safety Coefficient
3	X+ 50 km/h	Superior	Y-	23,31	5,31	195	7,11	1,59

PASSED ALL LOAD CASES

CSS Construction



Adjustment Device



Move tons with
milimeter precision

Brazilian technology
for CTA

Patent requested



Brazilian CSS: Mounting @ Berlin



Brazilian CSS: Mounting @ Berlin



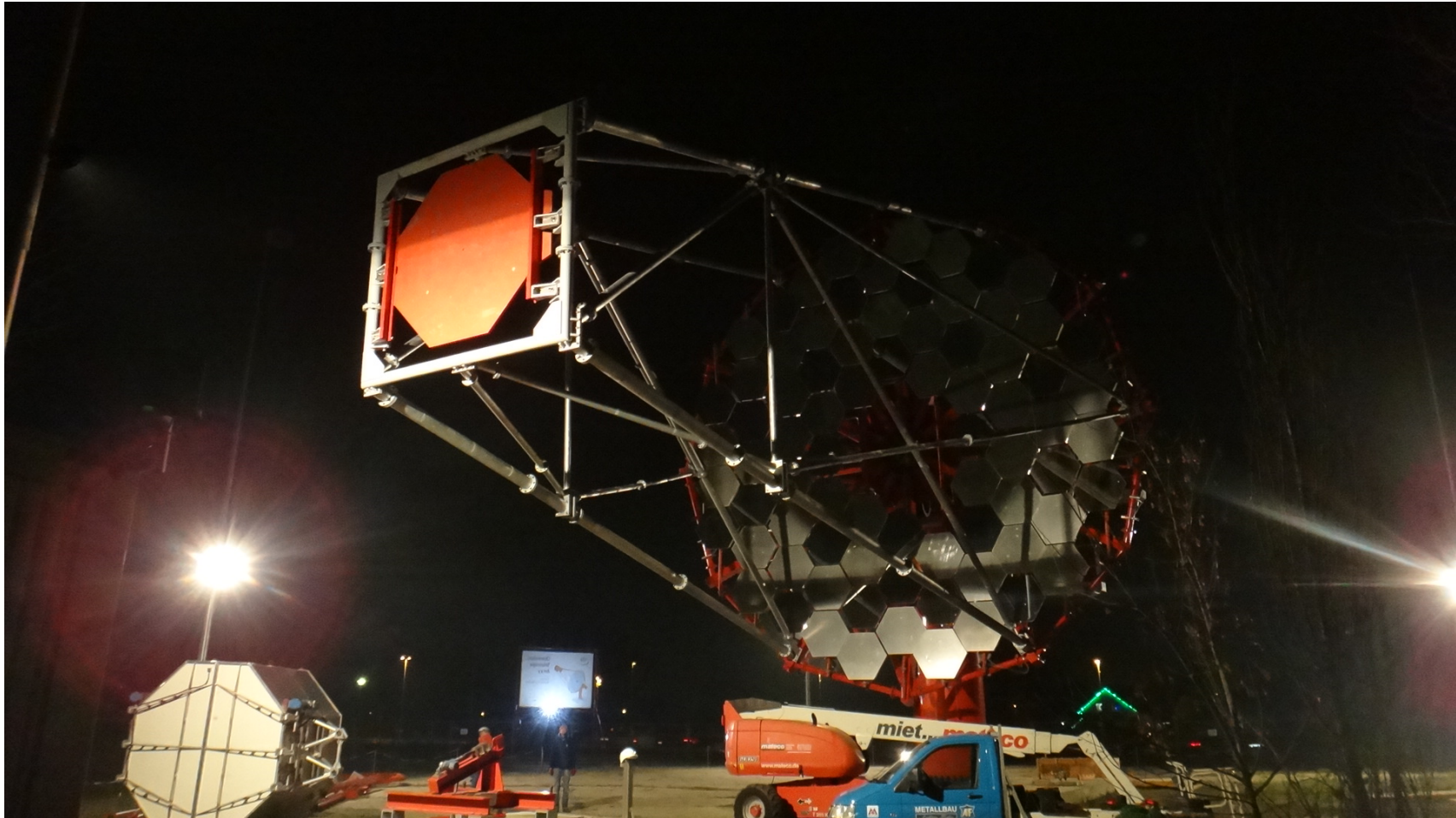
Brazilian CSS: Mounting @ Berlin



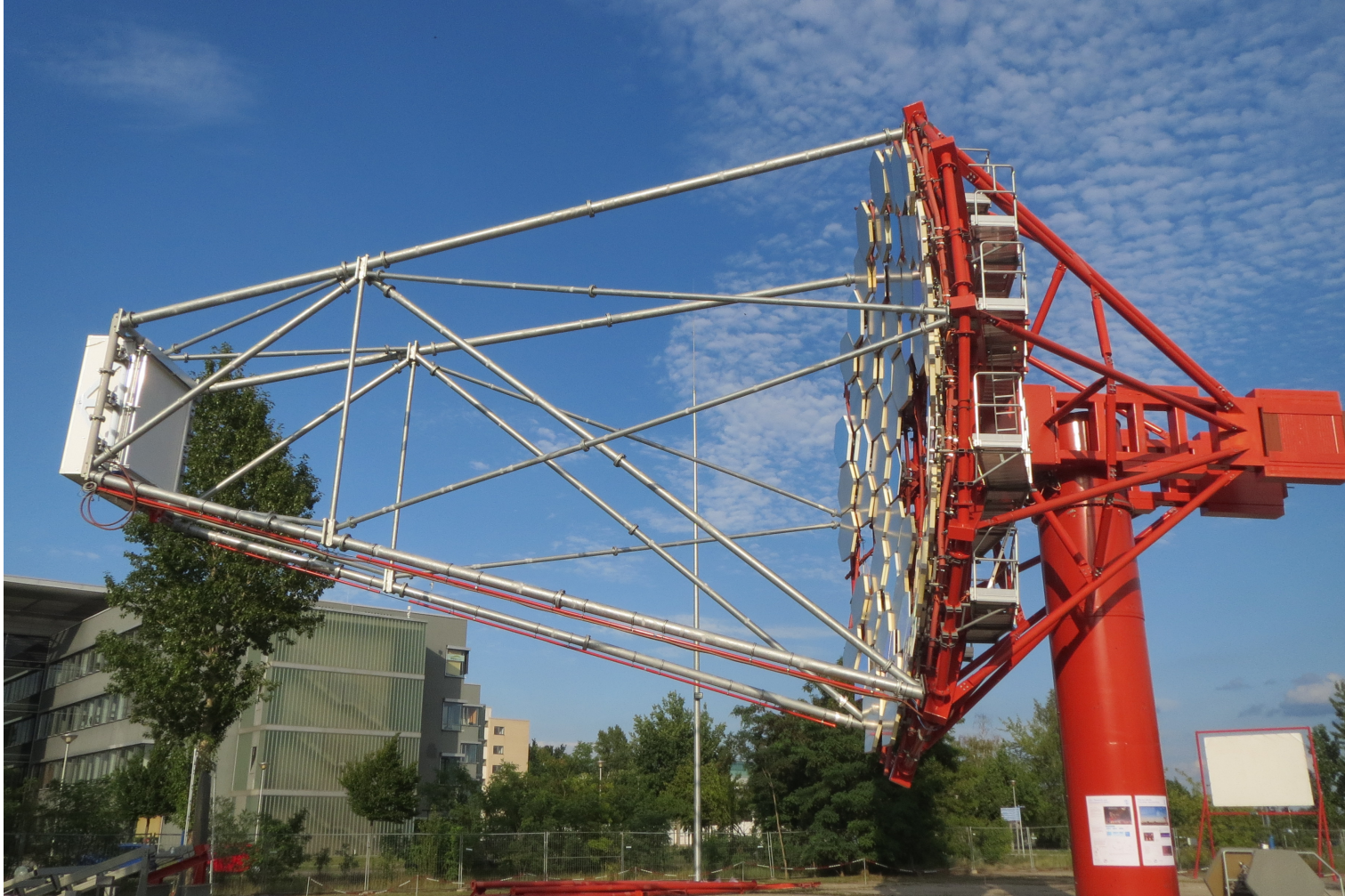
Brazilian CSS: Mounting @ Berlin



Brazilian CSS: Mounting @ Berlin



Brazilian CSS: Mounting @ Berlin

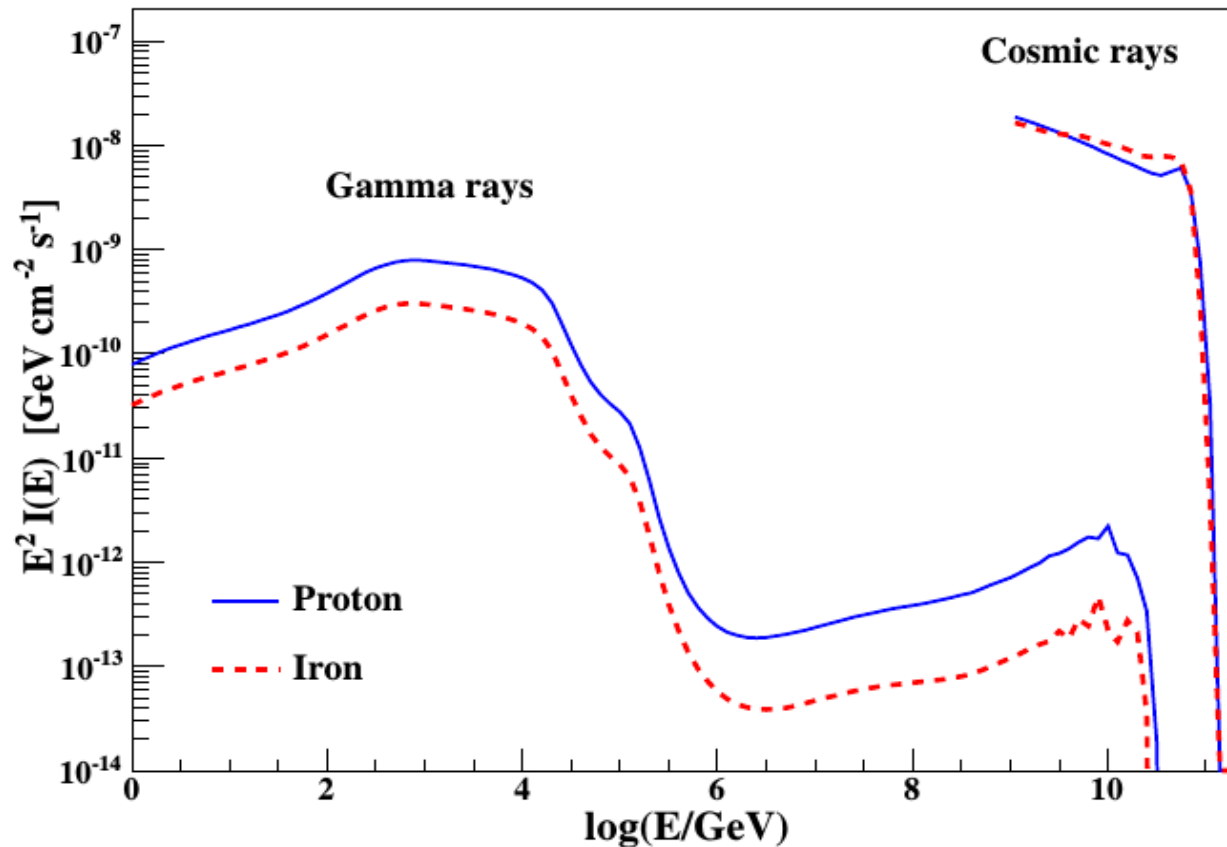


While CTA is not ready....

- We are warming up:
 - Dark matter
 - Lorentz Invariance Violation
 - Cosmic acceleration and gamma rays
 - Detector configuration

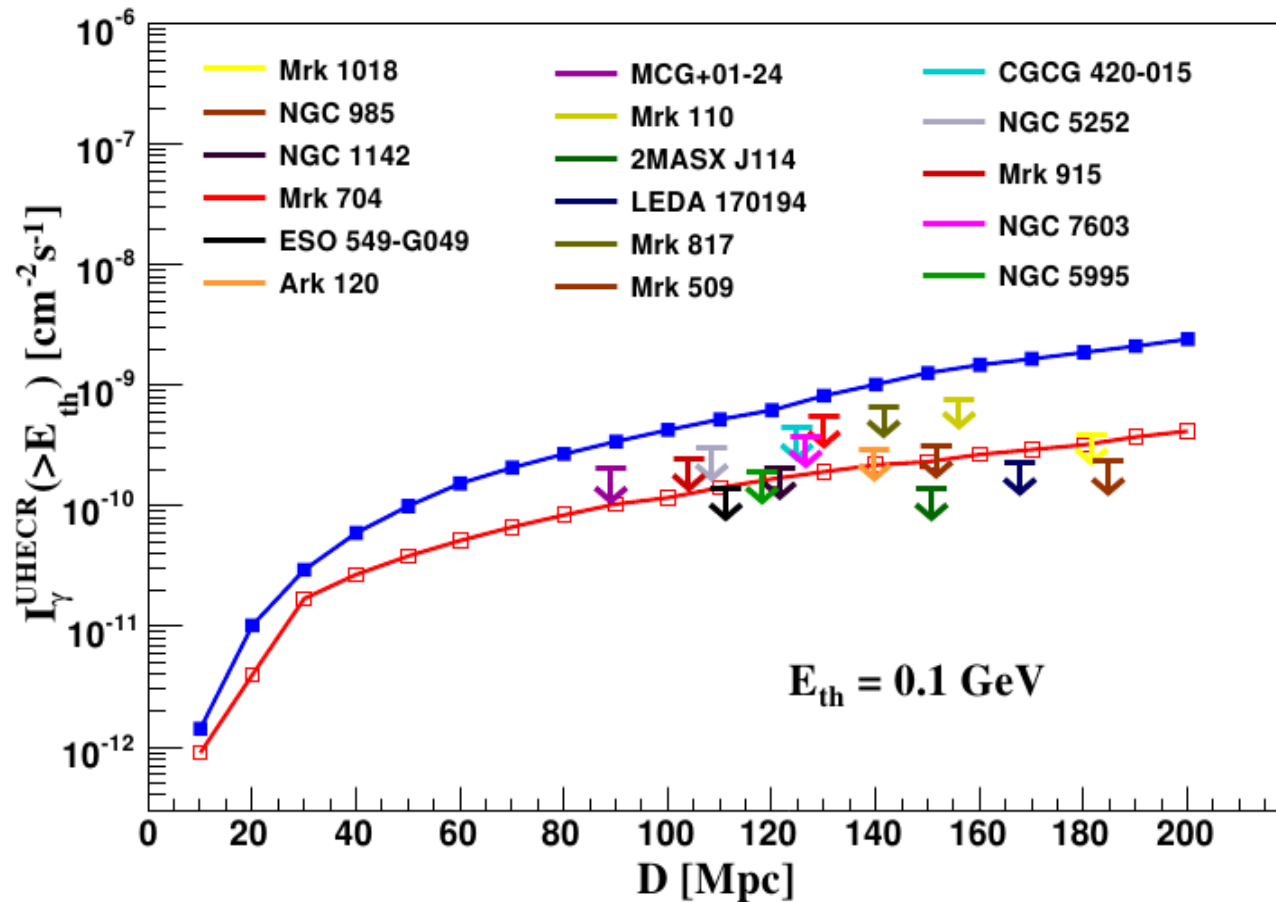
An upper limit on the cosmic-ray luminosity of individual sources from gamma-ray observations

A.D Supanitsky and V. de Souza, JCAP 12 (2013) 023



$$L_{CR}^{UL} = I_{\gamma}^{UL}(> E_{\gamma}^{th}) \frac{4\pi D_s^2 (1 + z_s) \langle E \rangle_0}{K_{\gamma} \int_{E_{\gamma}^{th}}^{\infty} dE P_{\gamma}(E_{\gamma})},$$

Upper limits on the total cosmic-ray luminosity of individual sources



Sources:

3 Radio Galaxies

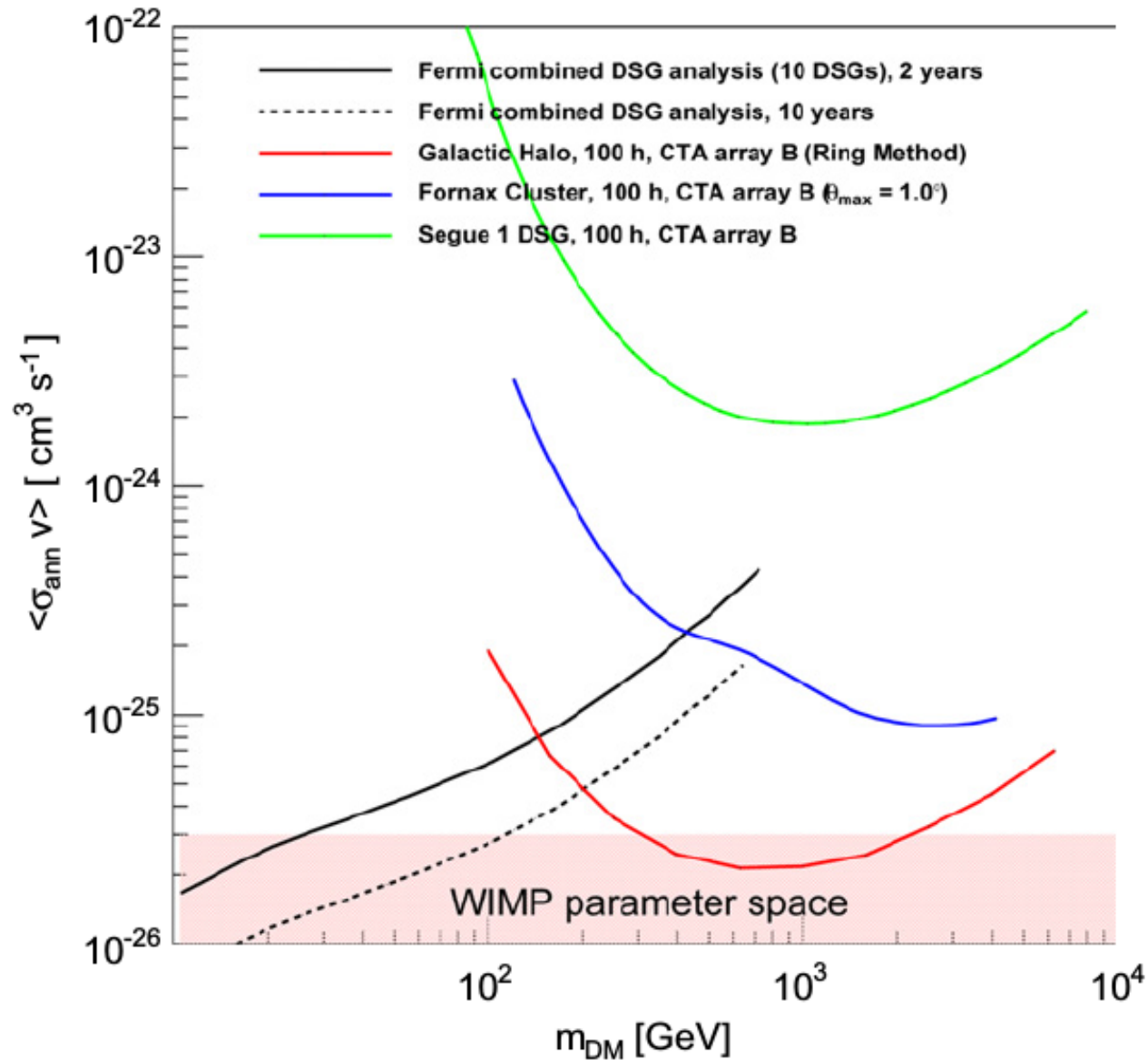
21 Seyfert

25 Fermi

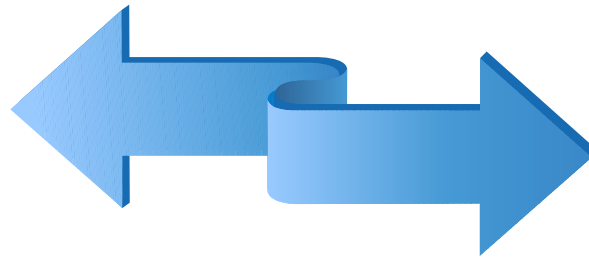
1 MAGIC

2 VERITAS

Dark Matter

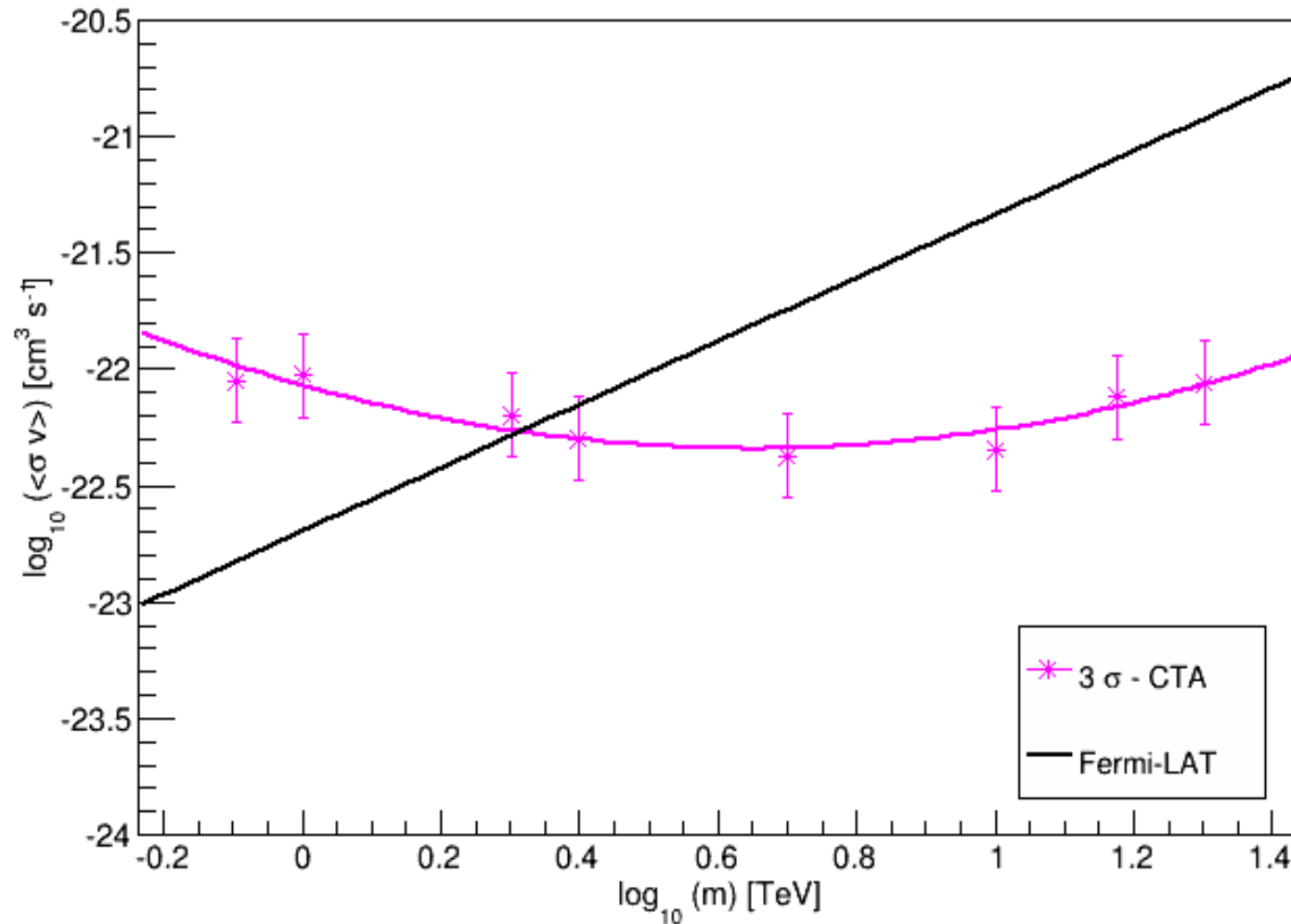


Fermi

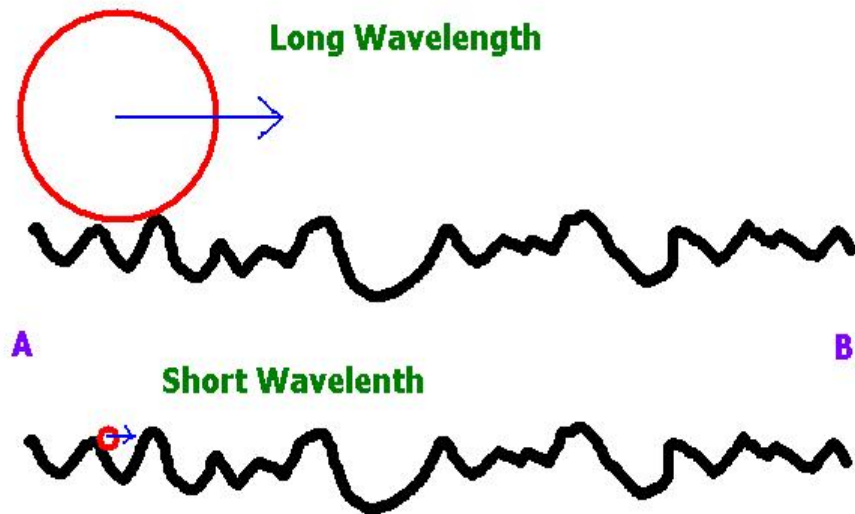


CTA

Sculptor

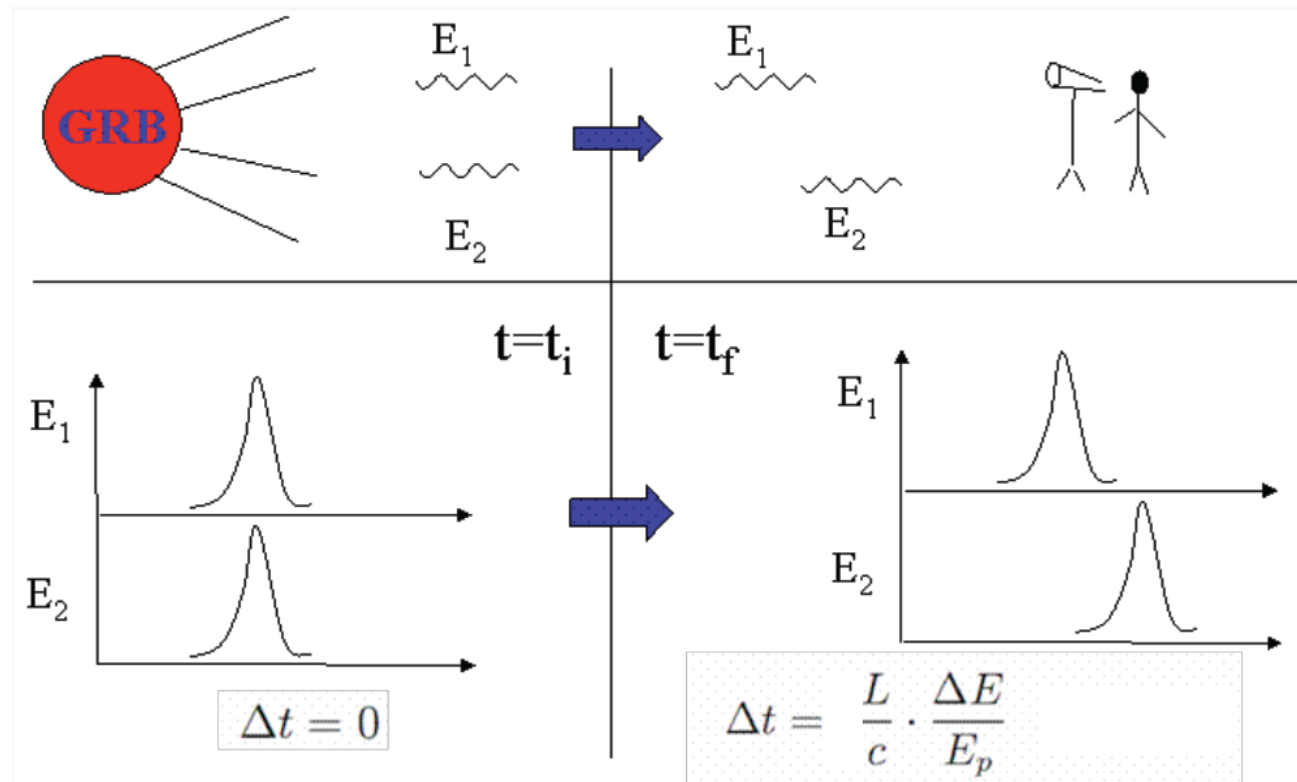


speed of light



$$\Delta t \sim \frac{E^n - E_0^n}{E_{QG}^n} \frac{L}{c}$$

$$E_{QG} \sim 10^{28} \text{ eV}$$

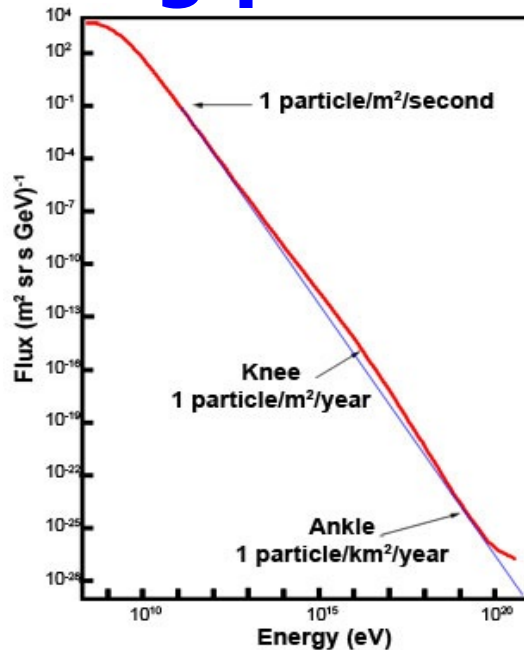


Mensagem pra levar pra casa:

- Astrofísica de partículas é uma área com grande potencial de descobertas fundamentais e propícia para a inovação tecnológica
- A comunidade brasileira ocupa uma posição de destaque no cenário internacional
- Observatório Pierre Auger:
 - Resultados históricos já publicados
 - Ainda tem muito a produzir na próxima década
- Cherenkov Telescope Array (CTA)
 - O próximo experimento em Astrofísica de Partículas

Astro-particle physics @ IFSC-USP

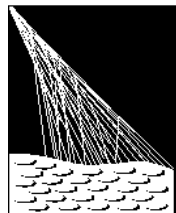
Studying particles from outside the Solar System



Open questions:

- Where do they come from ?
- How are they produced ?
- What is the Universe made of ?

Experiments:



PIERRE
AUGER
OBSERVATORY

&

Theory:

Astro + Computacional
+ Particle Physics

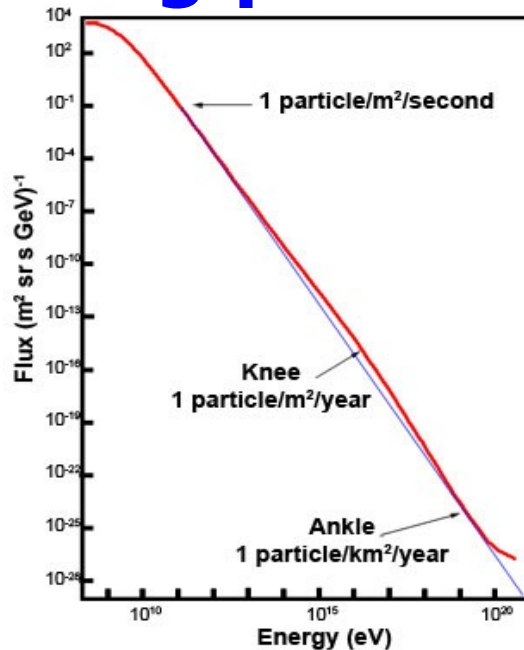
Contact:

Prof. V. de Souza (vitor@ifsc.usp.br)

Profa. M. Vecchi (manuela.vecchi@ifsc.usp.br)

Astro-particle physics @ IFSC-USP

Studying particles from outside the Solar System



Open questions:

- Where do they come from ?
- How are they produced ?
- What is the Universe made of ?

Prof. Vitor de Souza e Profa. Manuela Vecchi

Pos-doc: Maximo Ave

Doutorado: Raul Prado Ribeiro

Mestrado: Rodrigo Guedes Lang, Guilherme de Sousa, Alexandre Benatti,
Victor Barbosa Martins, Vinícius Mikuni, Vitor Lordello

IC: Danielle Kaori, Rafael Geurgas, Eliane Karasawa, Eduardo Ferronato
Bueno, Lucas M. Maia, Anderson Aparecido do Espirito Santo