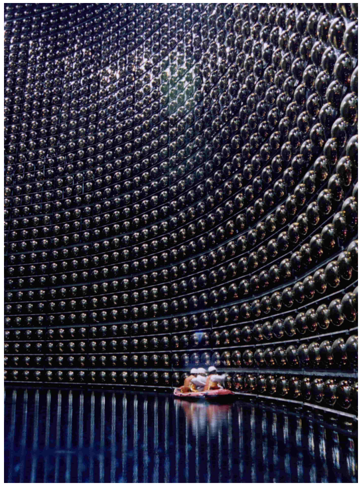
This presentation was created based on the slides by
Vitor de Souza
http://cosmicraysschool.ufabc.edu.br/pres/Vitor.odp
from his talk at the
4th School on Cosmic Rays and Astrophysics
UFABC - Santo André - São Paulo - Brazil
August 25 to September 03 – 2010
http://cosmicraysschool.ufabc.edu.br

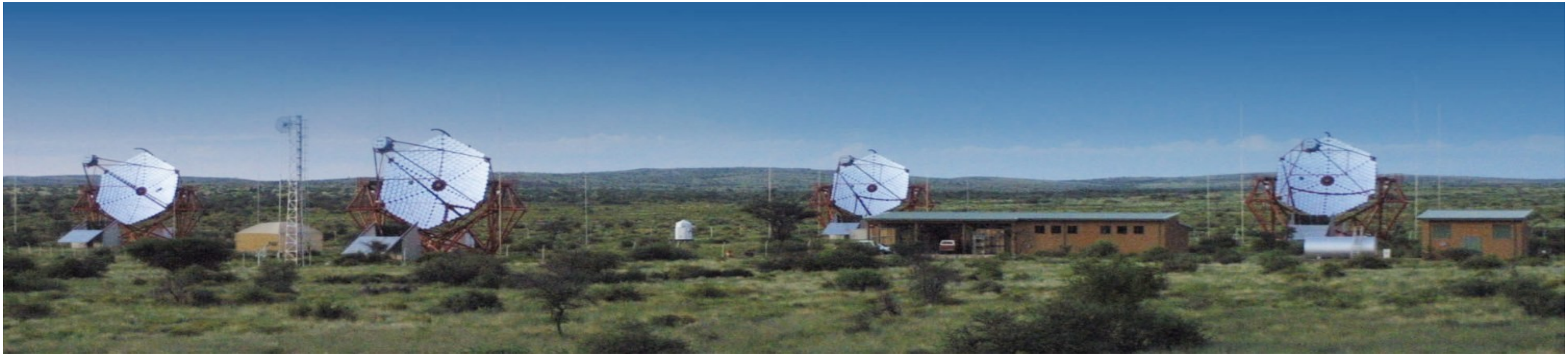
The multimessenger approach to astroparticle physics



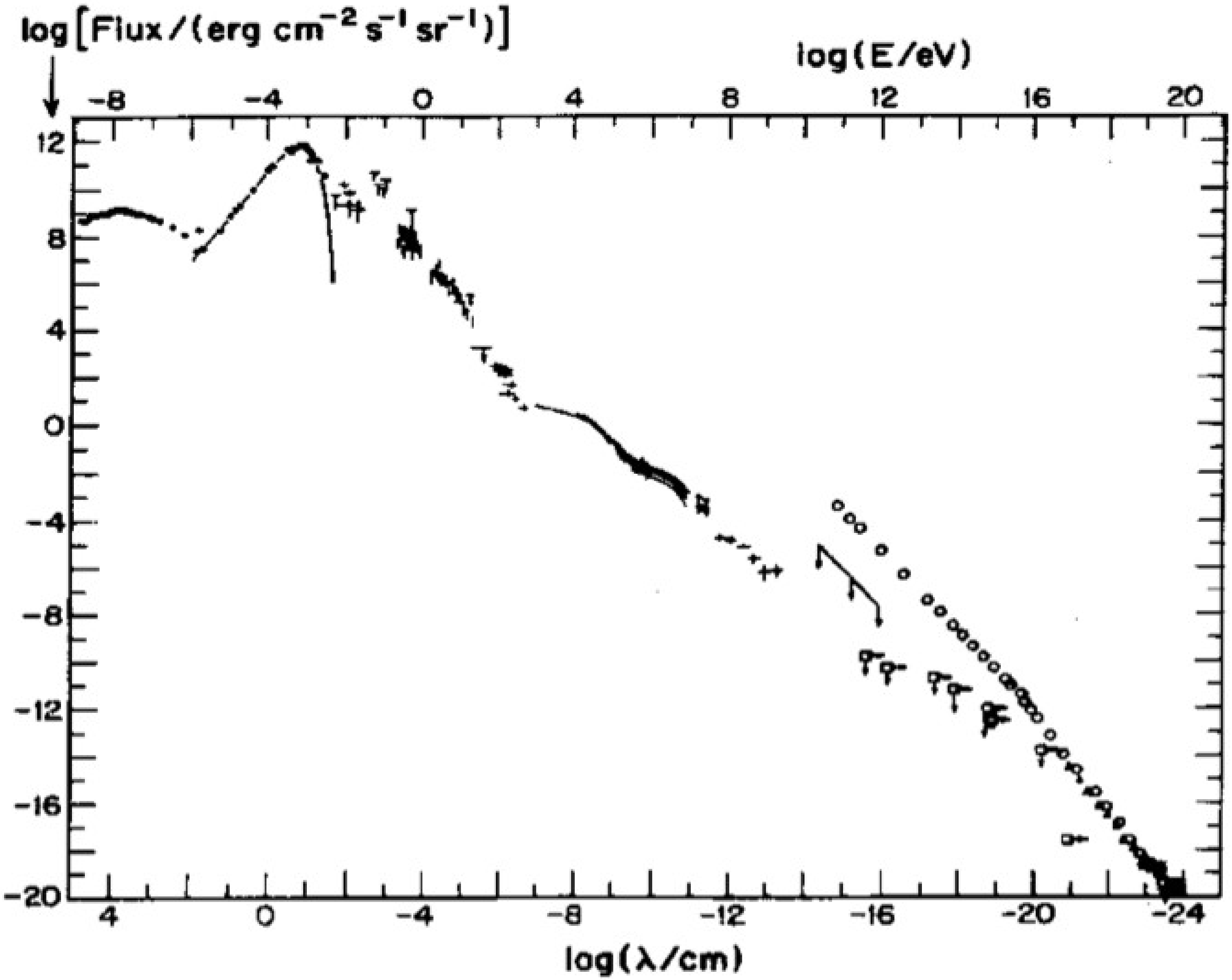
Célio A. Moura
Universidade Federal do ABC
UFABC

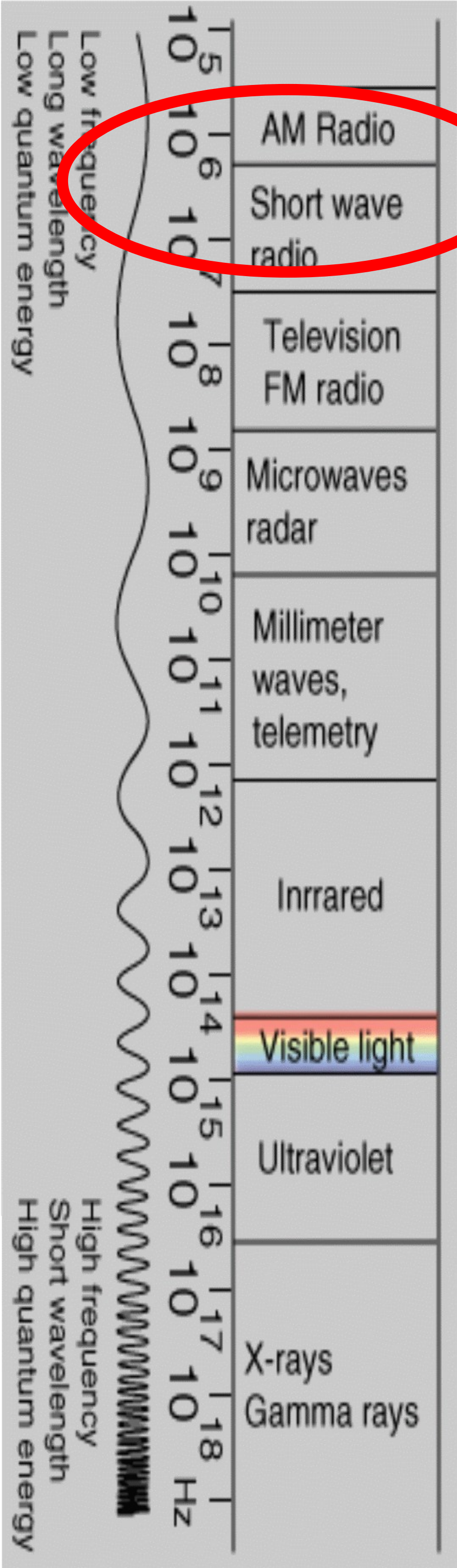
Seminario – Facultad de Ciencias Físico Matemáticas – BUAP

October 27, 2010

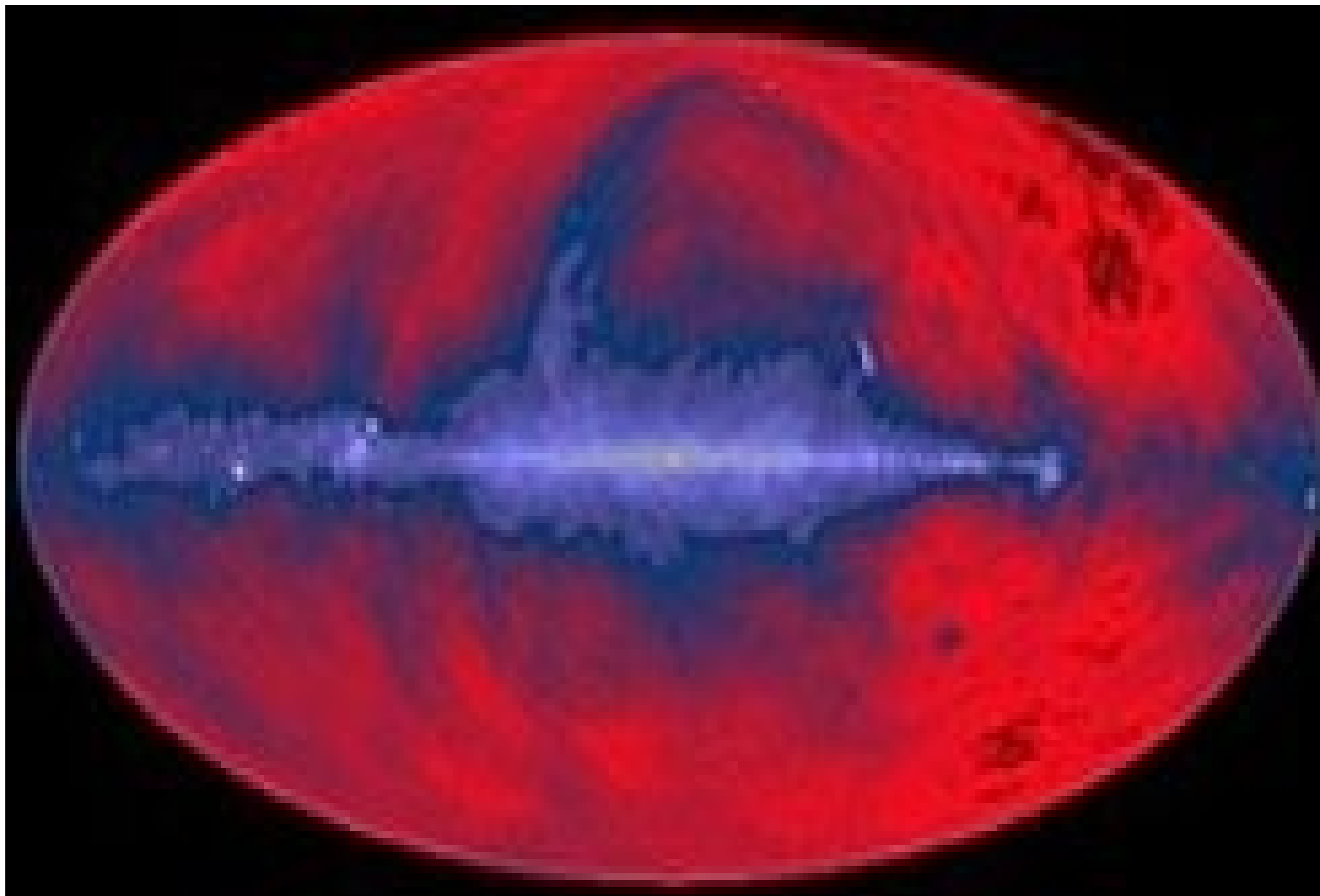


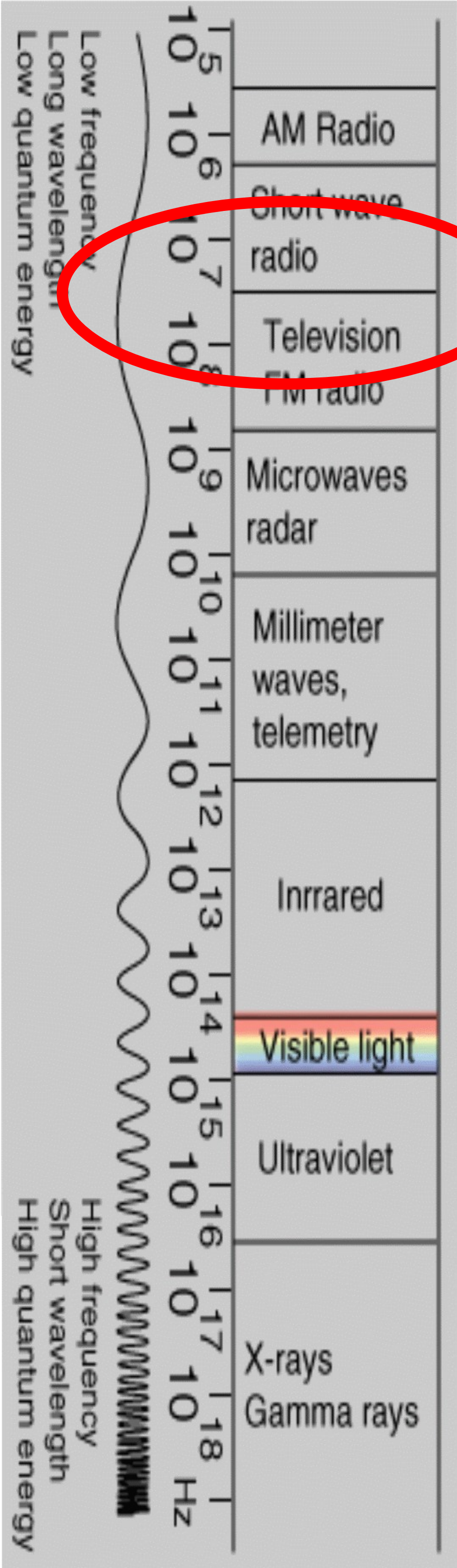
Energy Spectrum



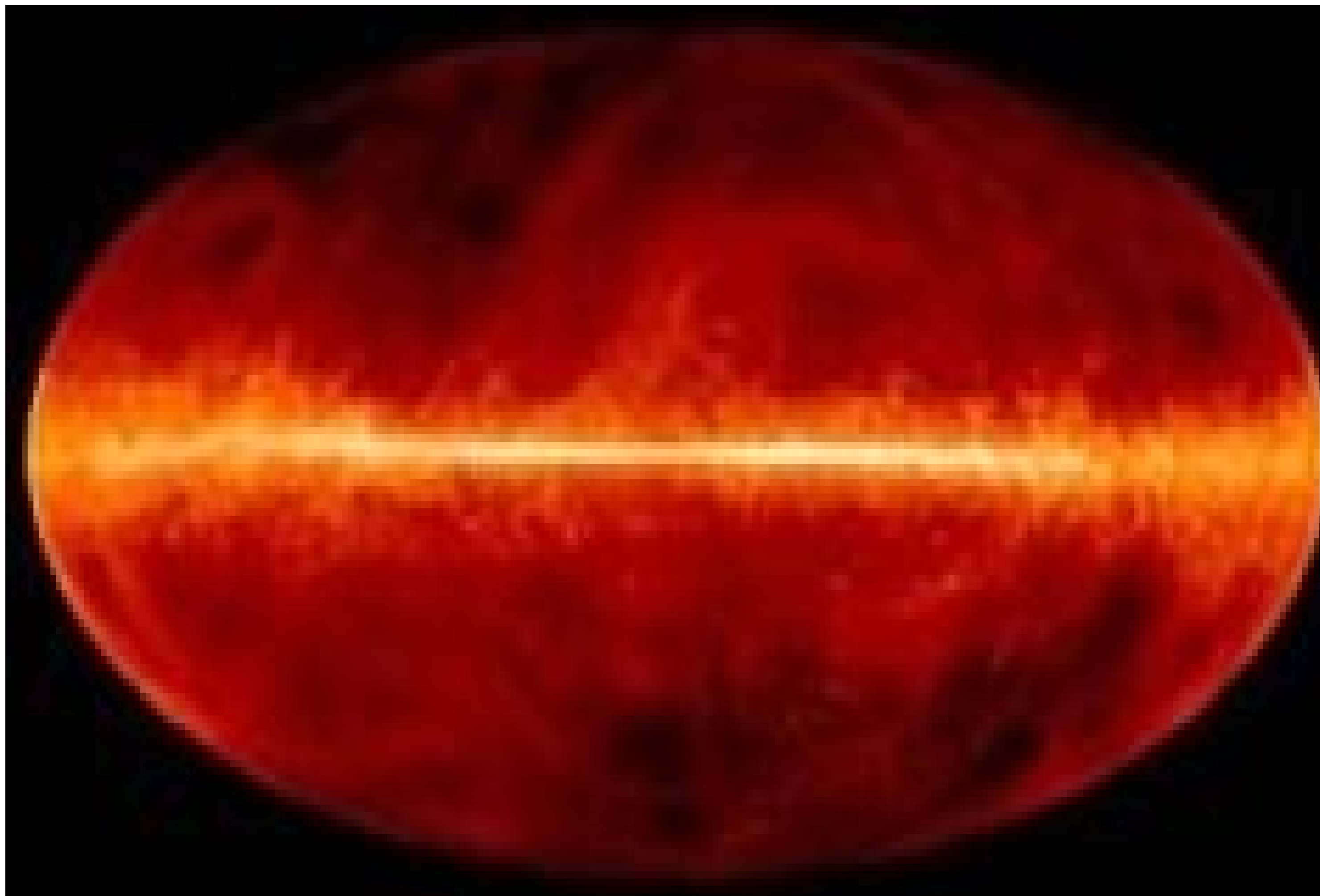


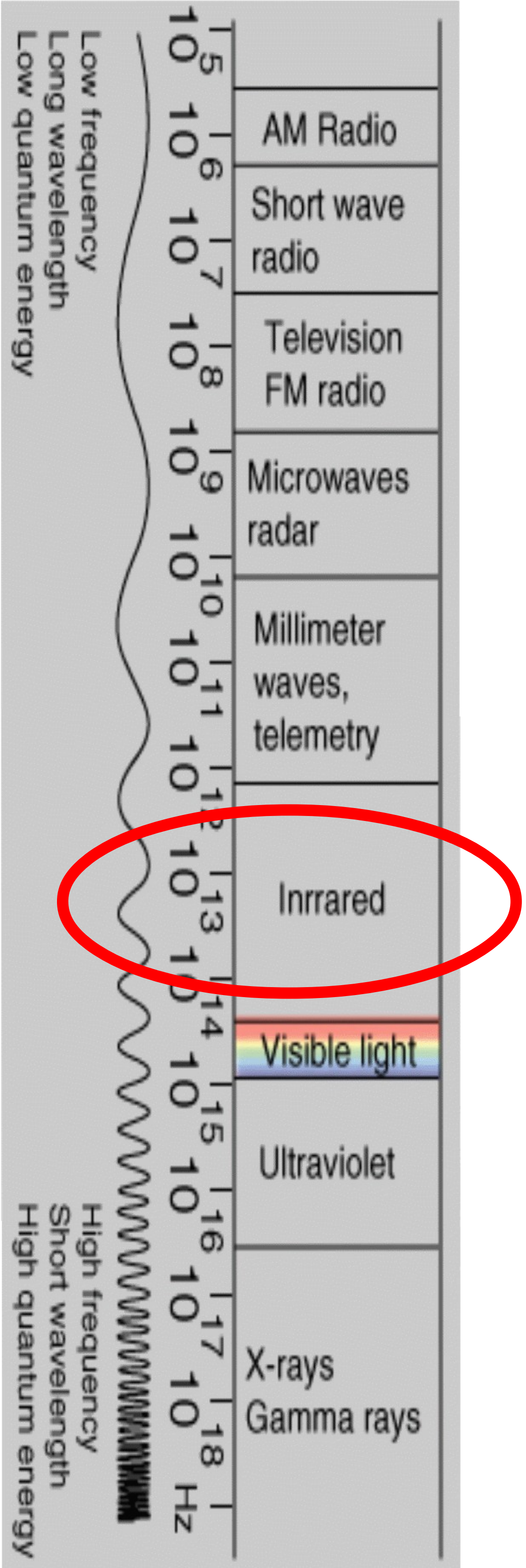
Via Láctea: Rádio (408 MHz)
C. Haslam et al., MPIfR, SkyView



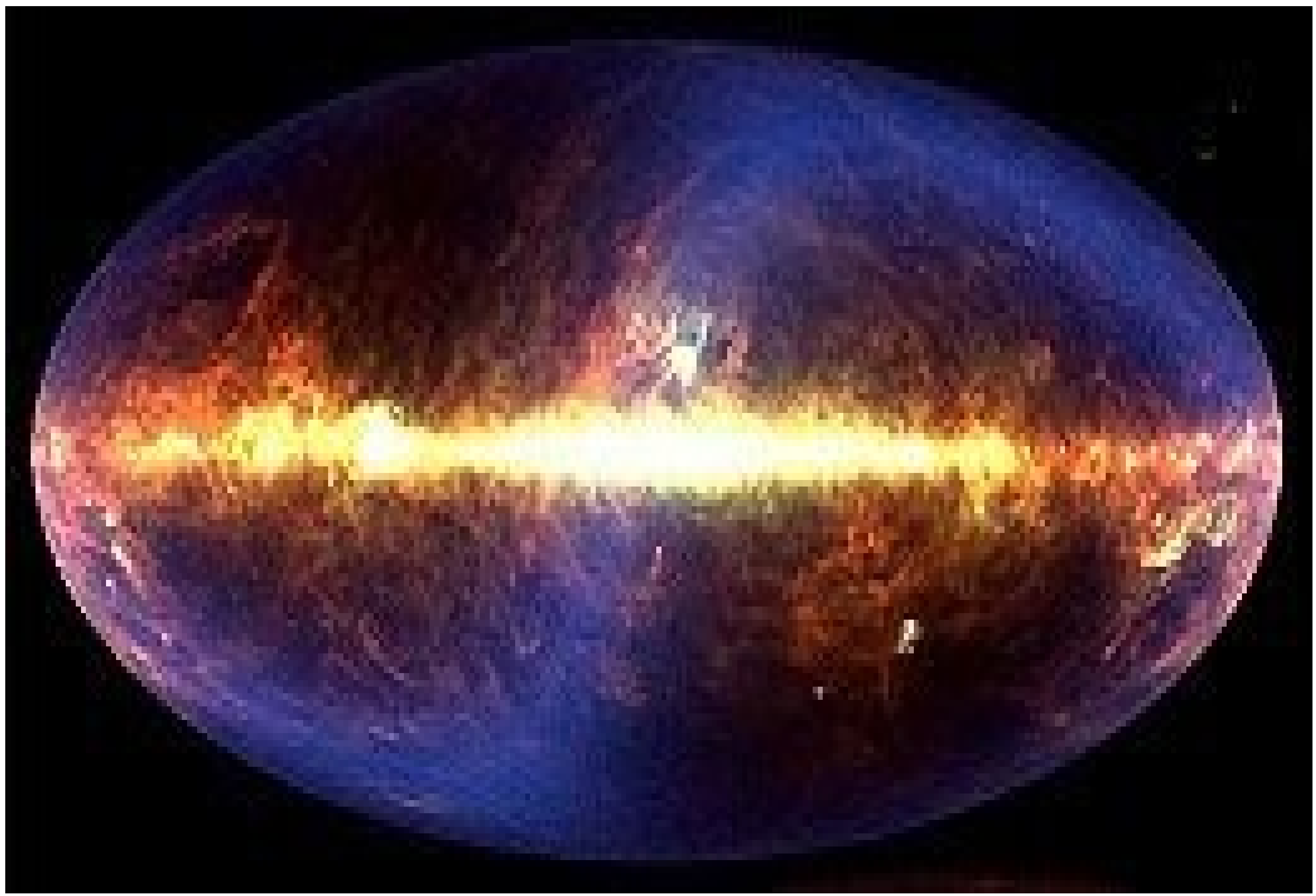


Via Láctea: Rádio (1420 MHz)
Dickey et.al. UMn. NRAO SkyView

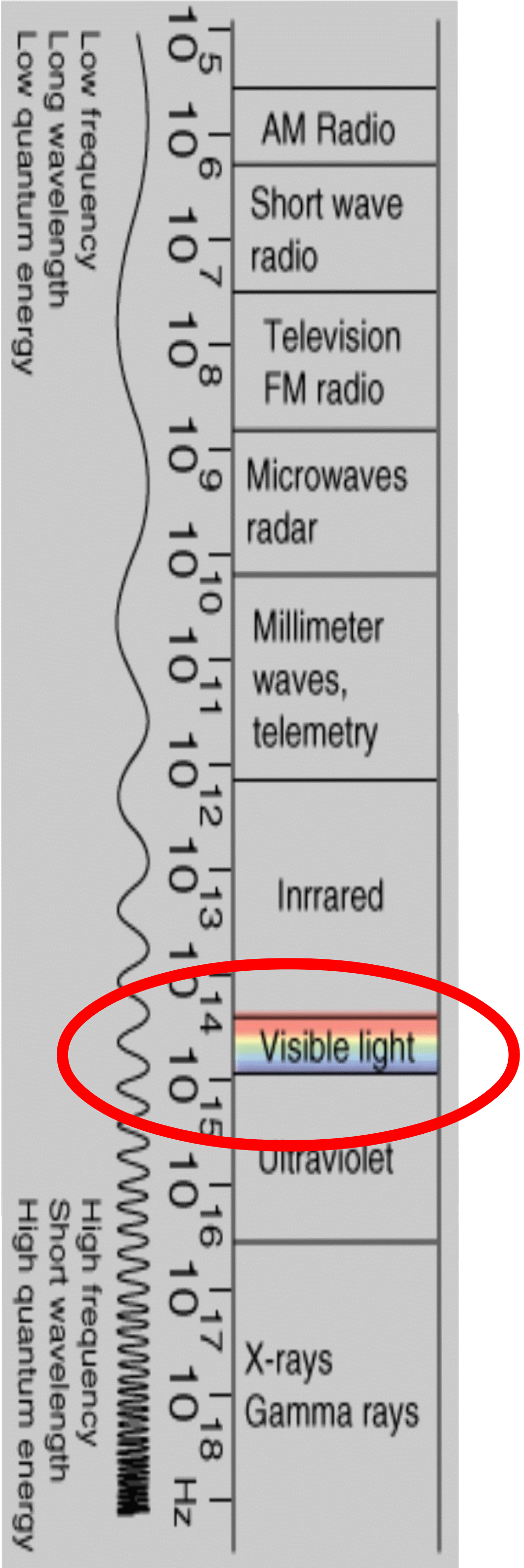


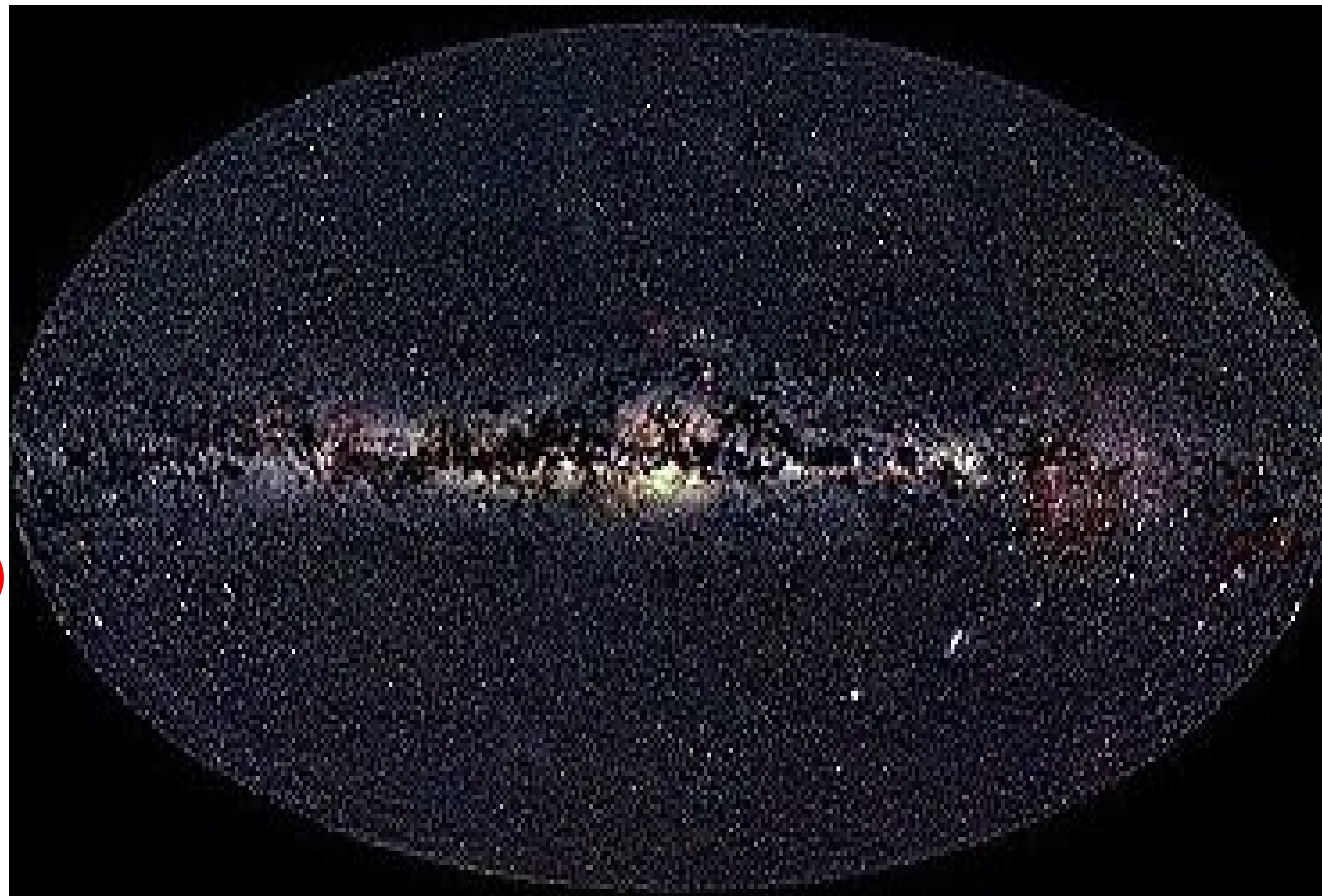


Via Láctea: Infravermelho
Dirbe Team, COBE, NASA

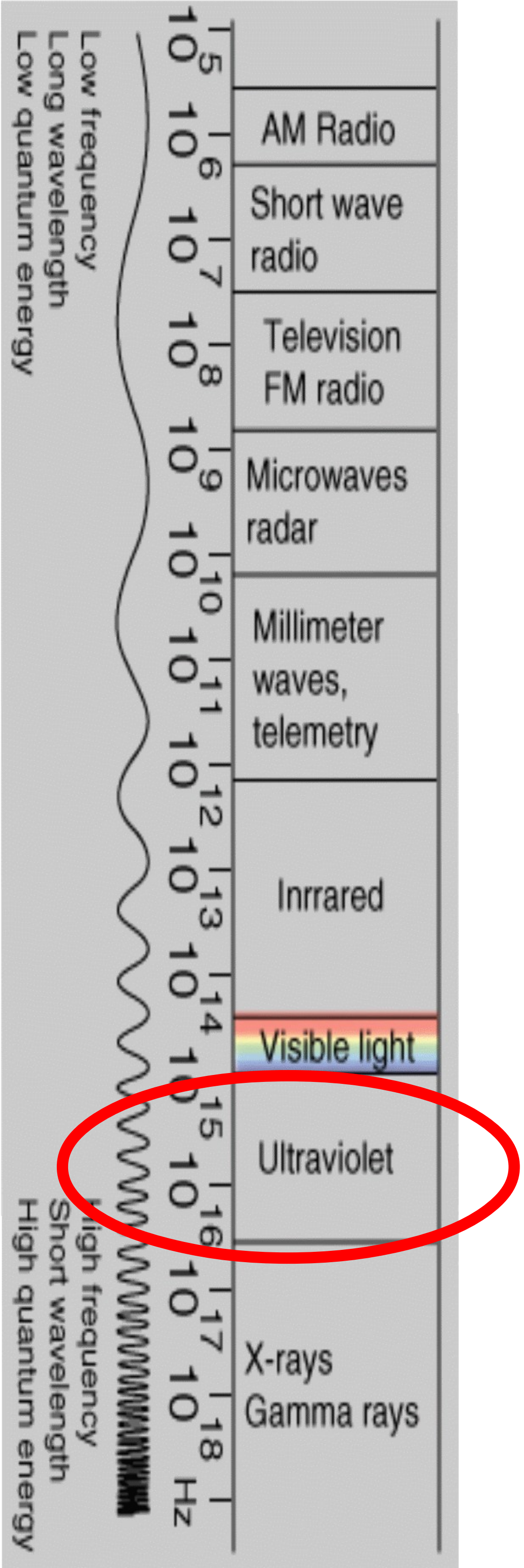


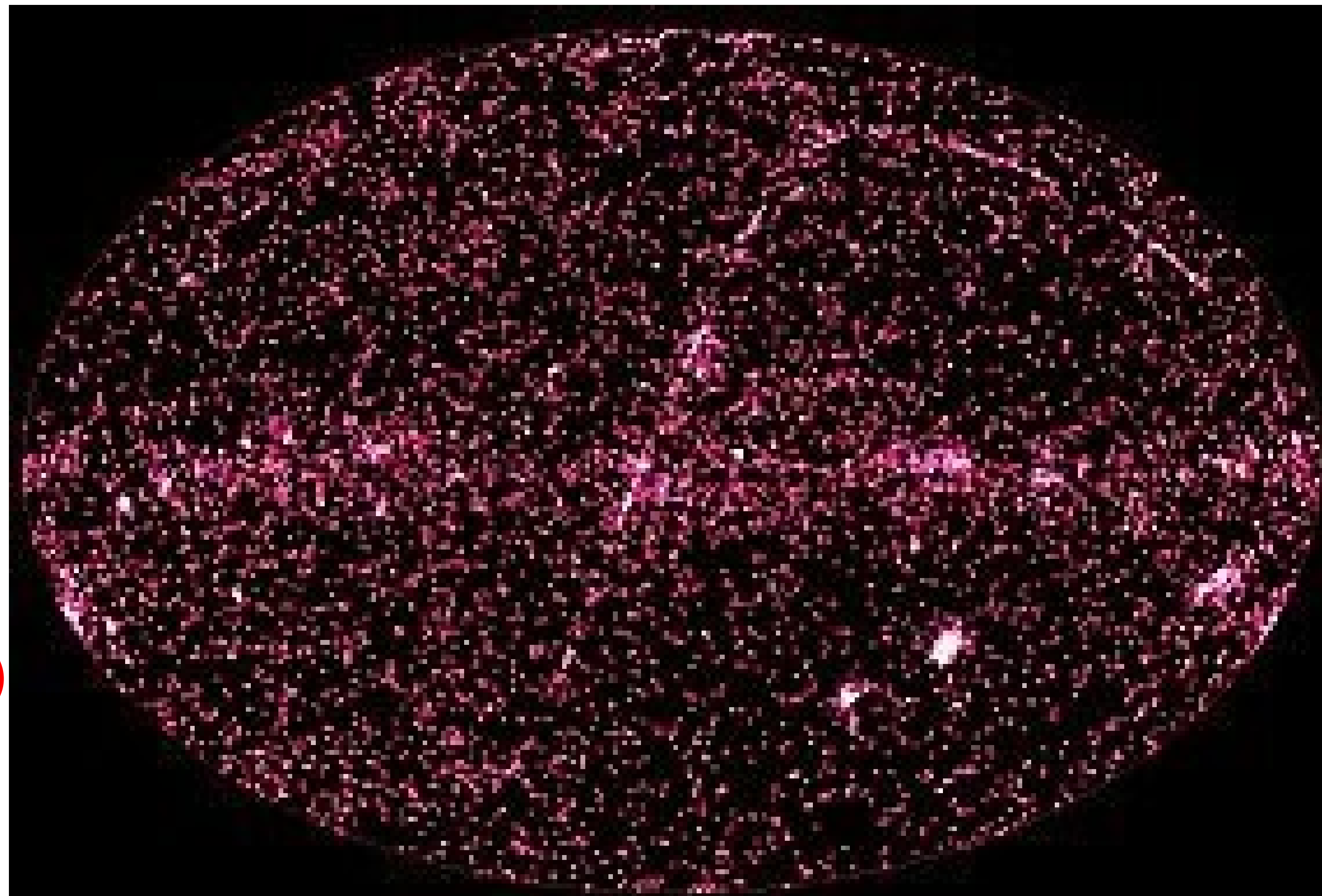
Via Láctea: Vísivel por Axel Melinger



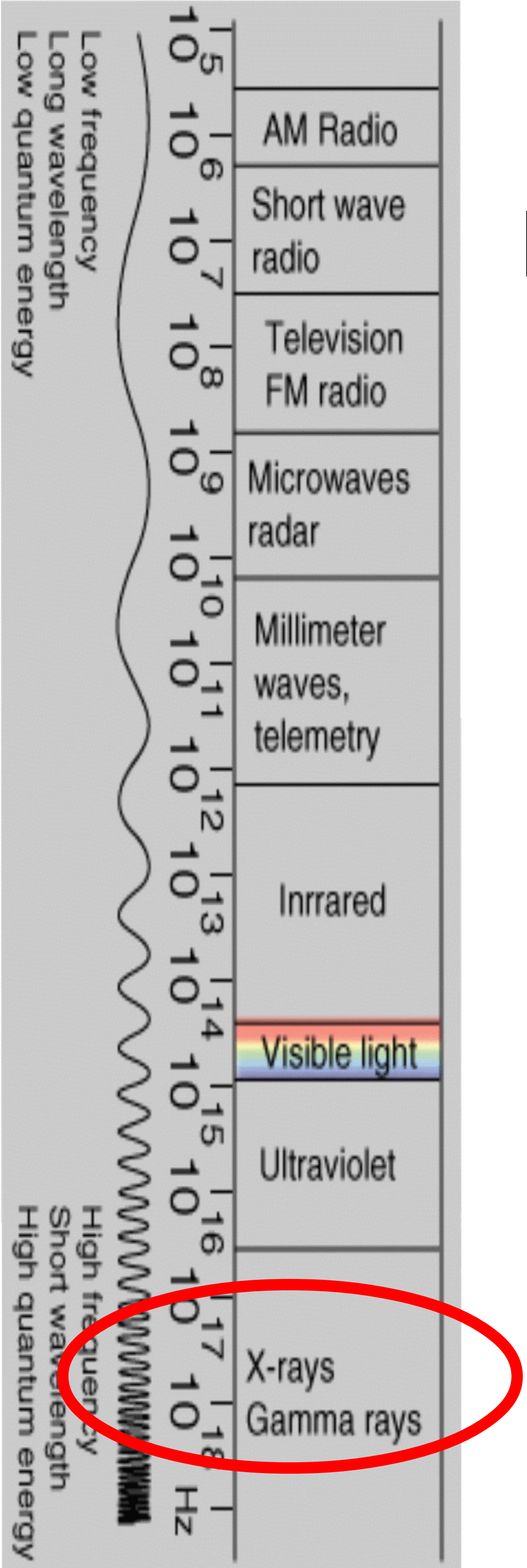


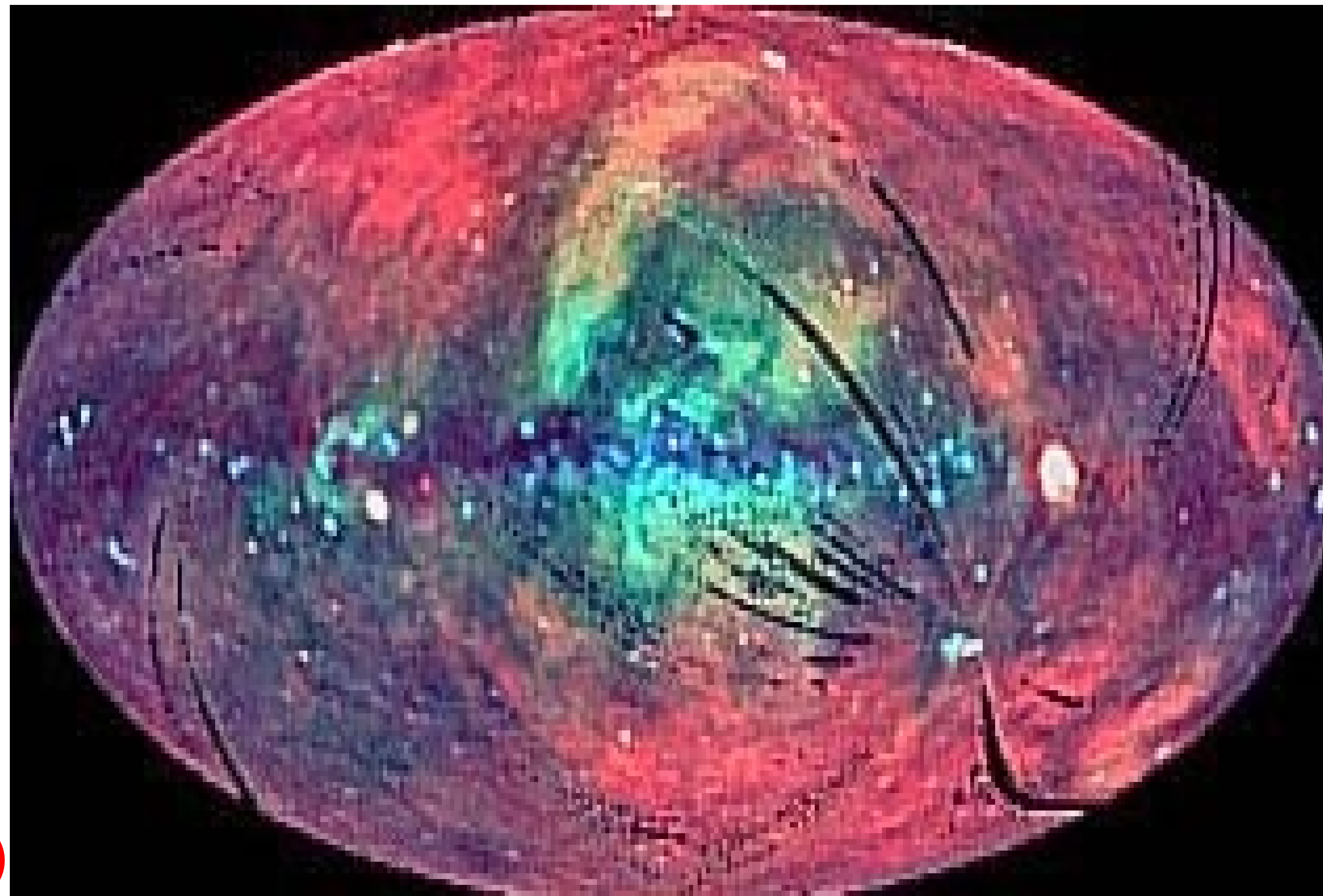
Via Láctea: Ultravioleta
J. Bonnell et.al.(GSFC, NASA)



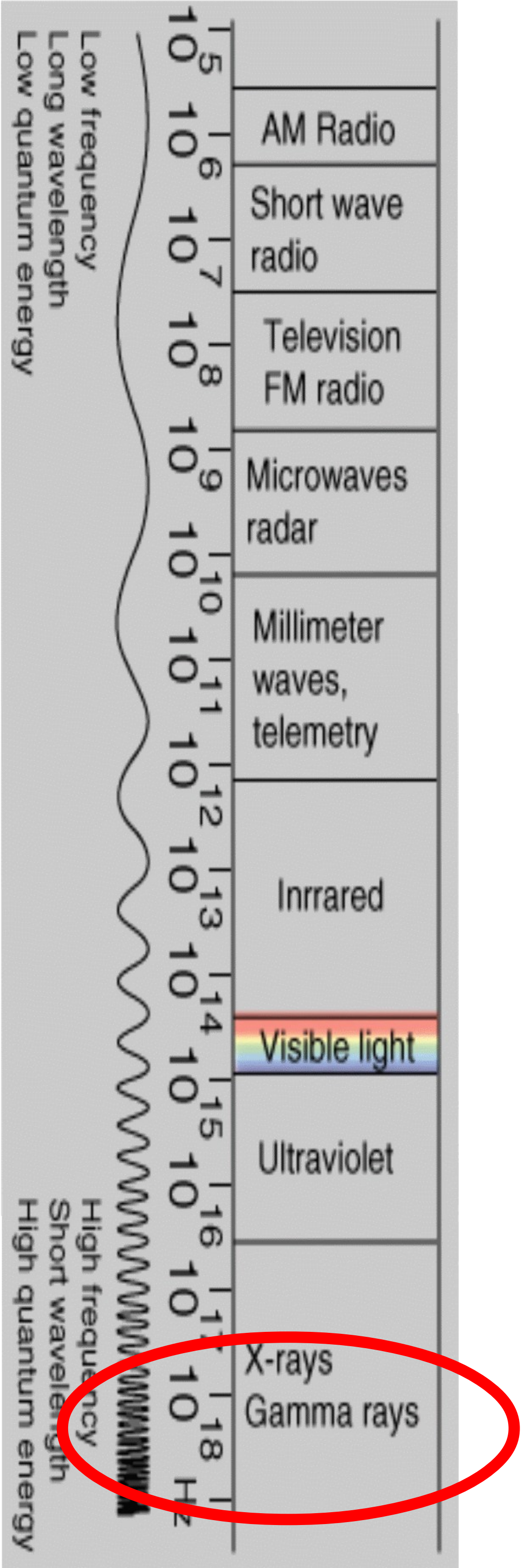


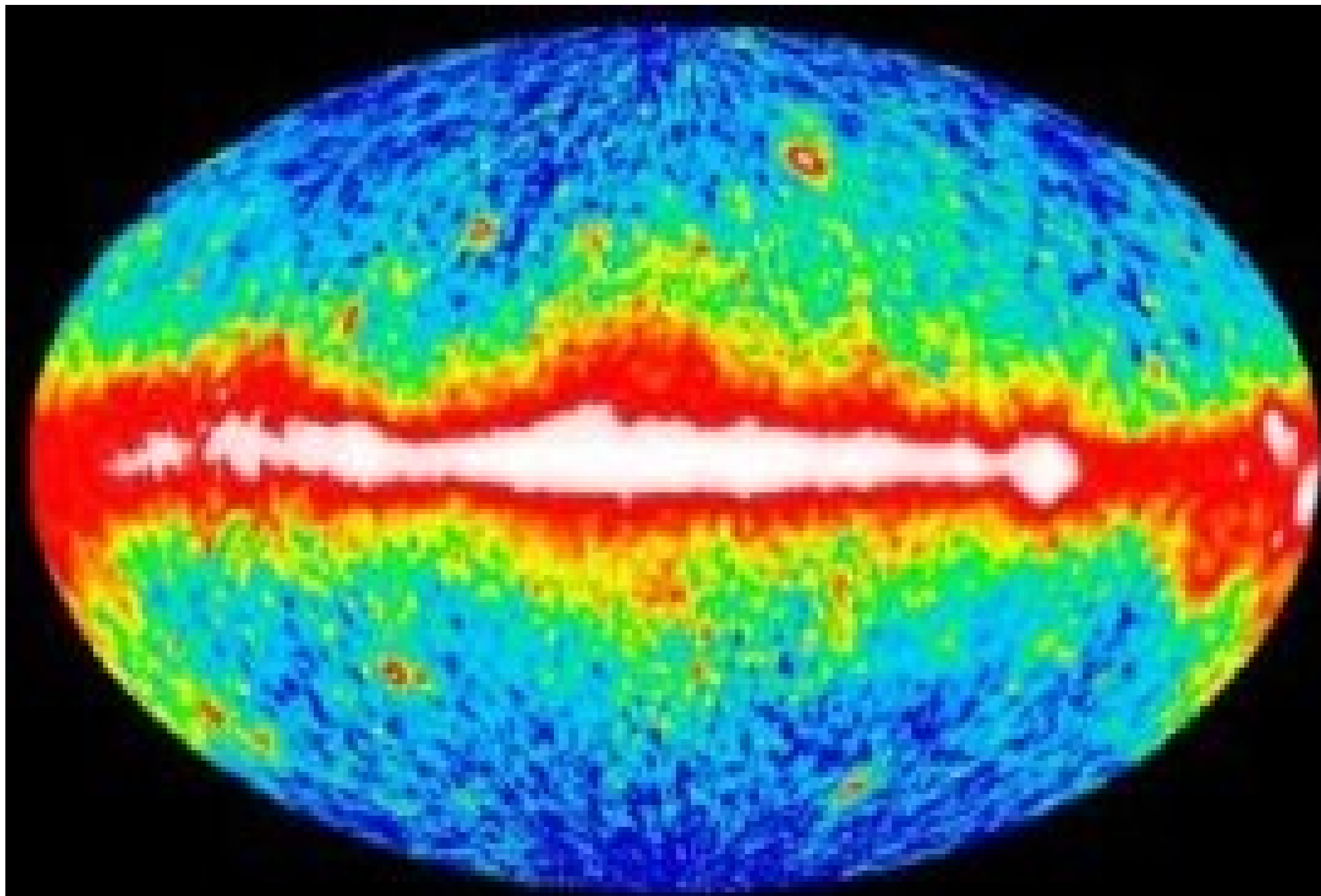
Via Láctea: Ráios X
Digel et. al. GSFC, ROSAT, NASA



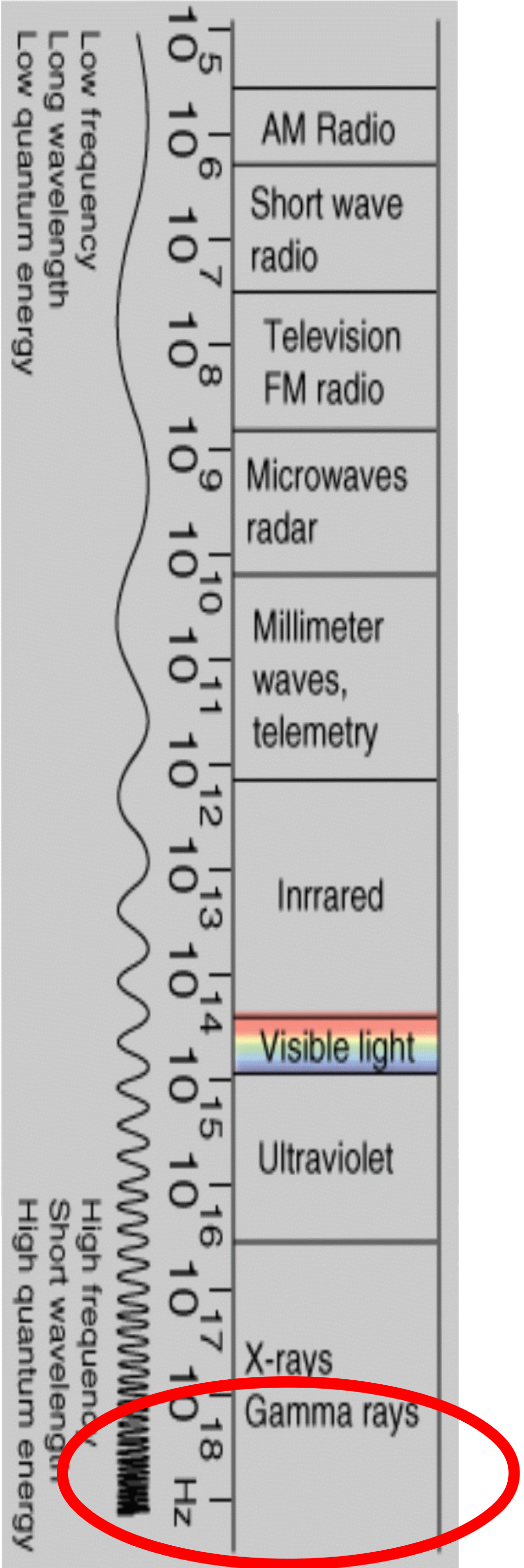


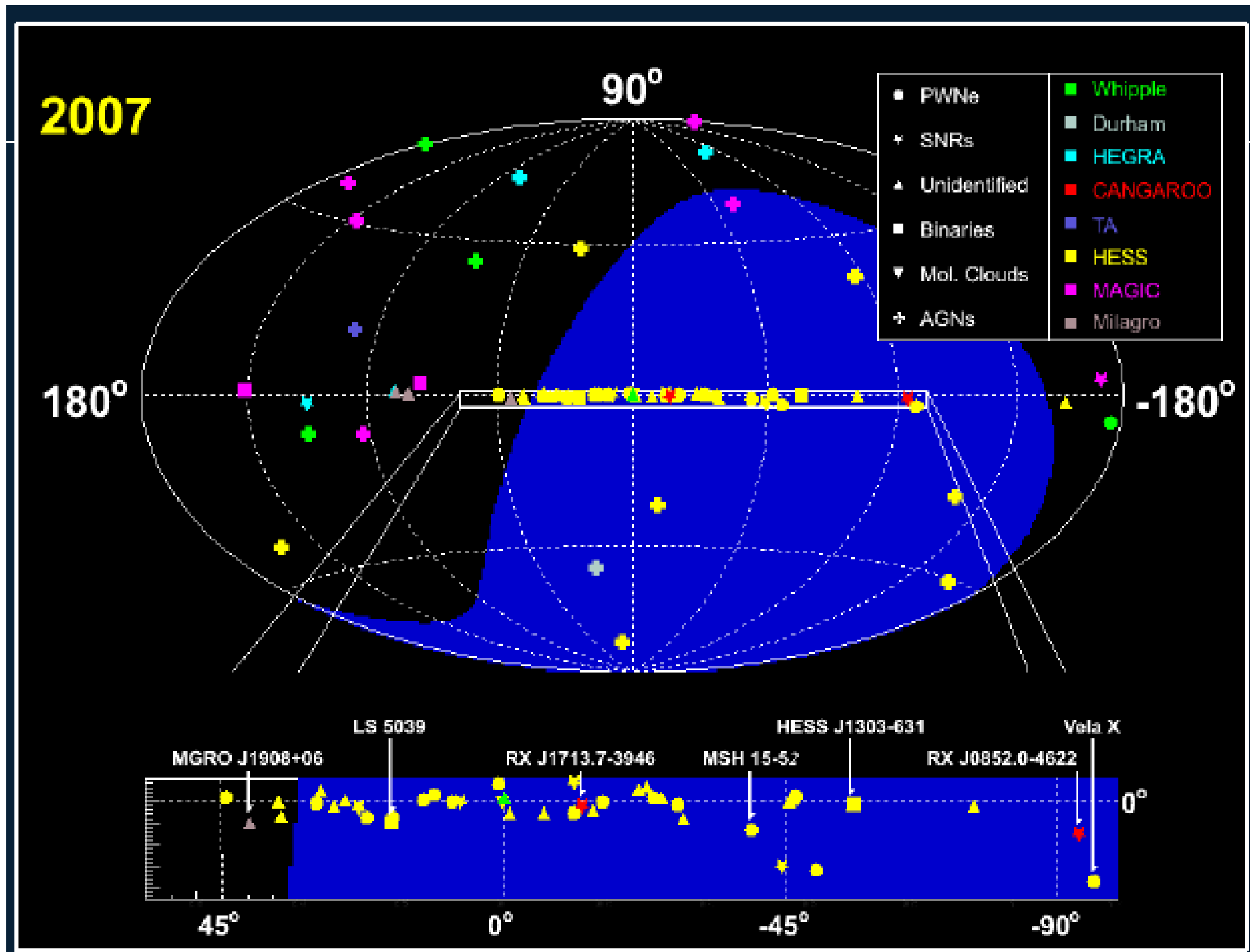
Via Láctea: Ráios Gama
> 100 MeV (CGRO, NASA)





Point Sources
Gamma Rays > 10^{12} eV
Cerenkov Telescopes, by Jim Hinton



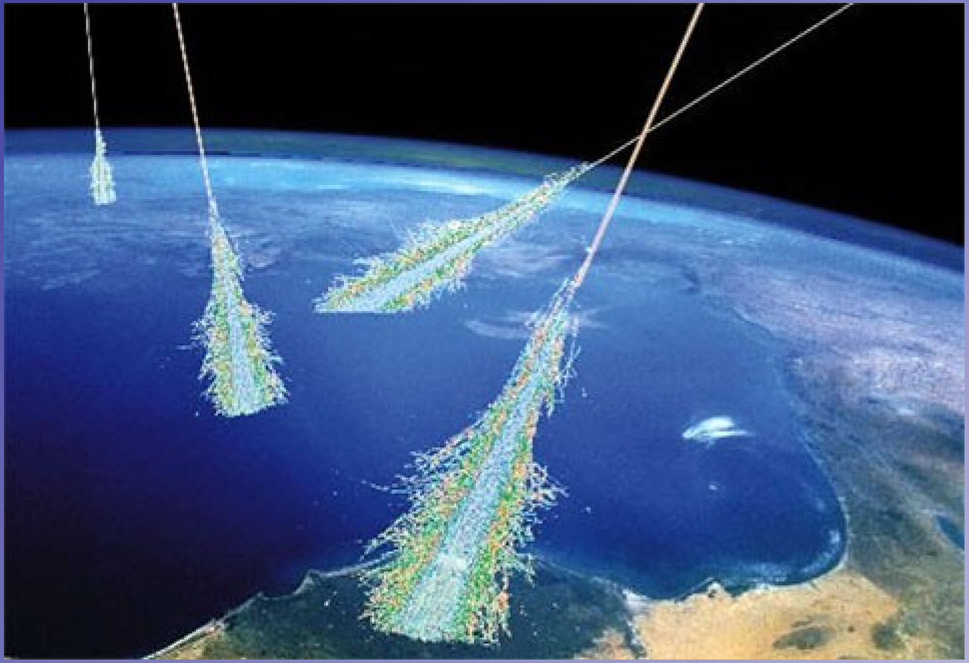


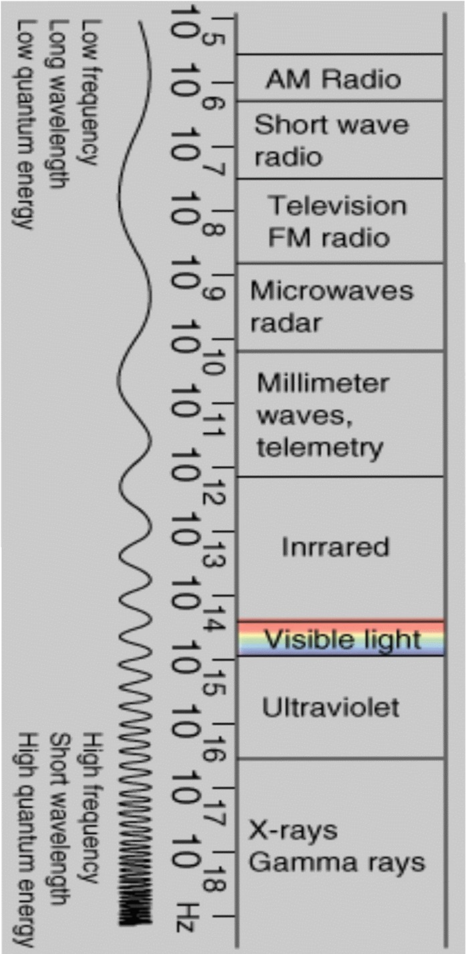
Other messengers

$$p + \gamma \rightarrow \Delta^+ \begin{cases} p & + & \pi^0 \\ n & + & \pi^+ \end{cases}$$

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

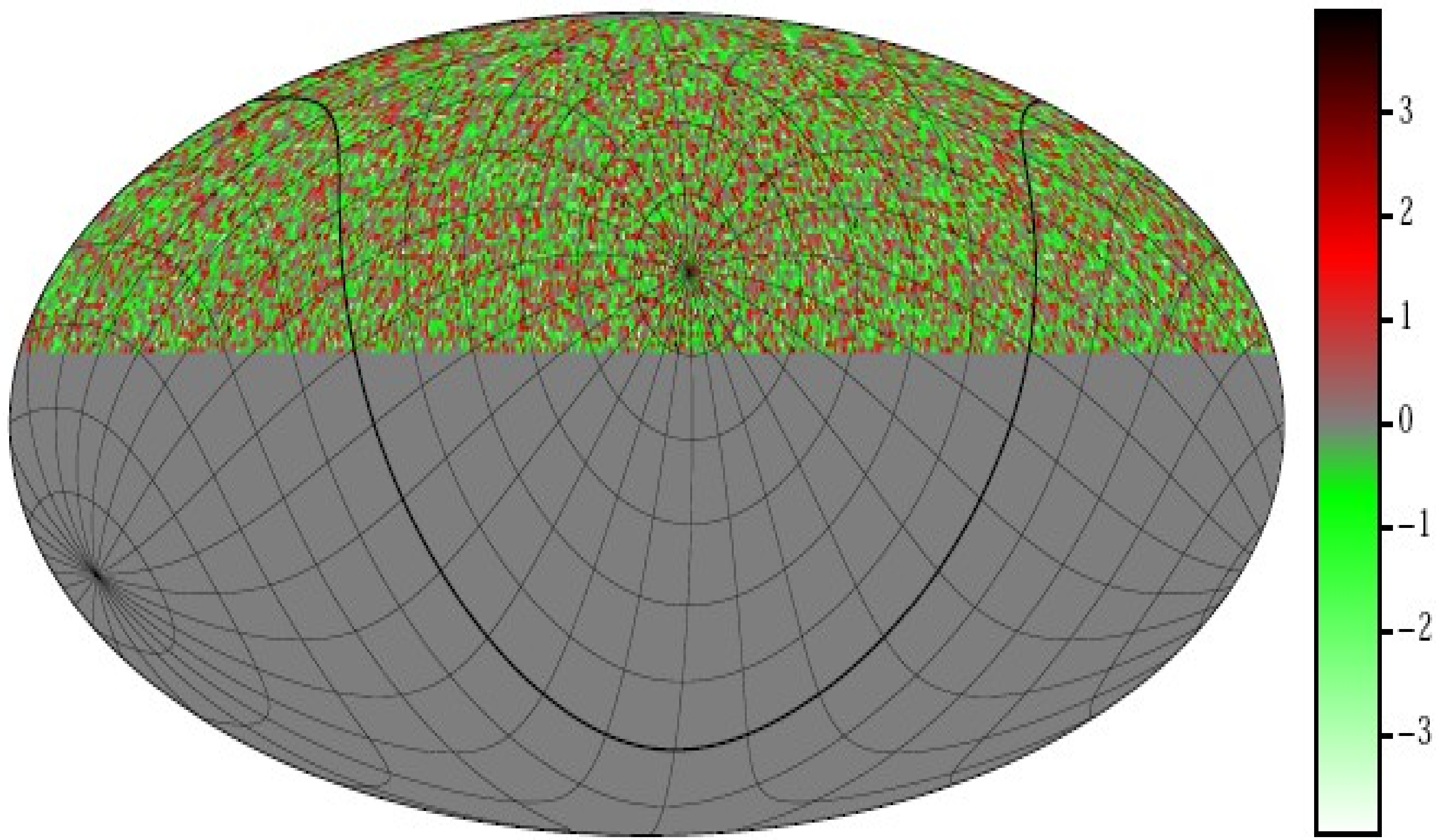
$$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$$





KASCADE

$E \sim 10^{16}$ eV

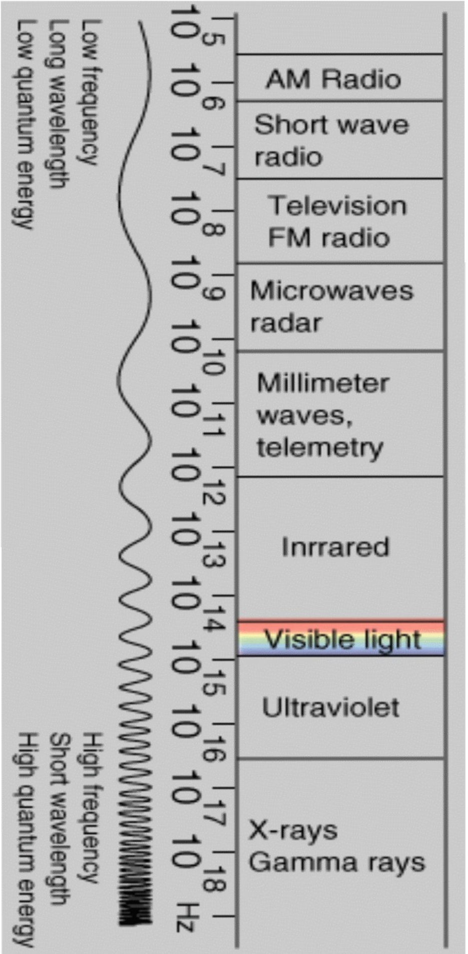


TeV = 10^{12} eV

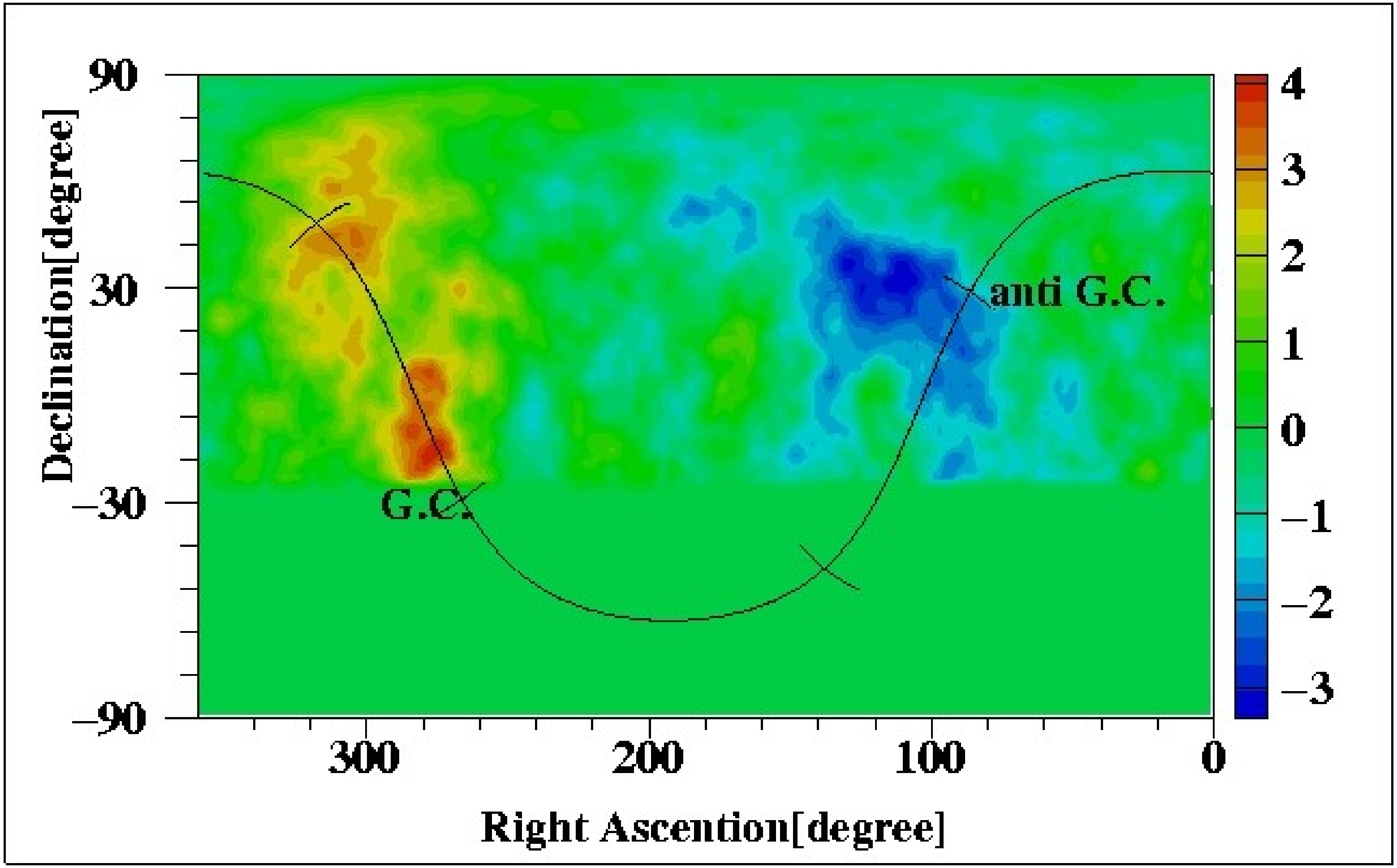
PeV= 10^{15} eV

EeV= 10^{18} eV

ZeV= 10^{21} eV



AGASA
$E > 10^{18}$ eV

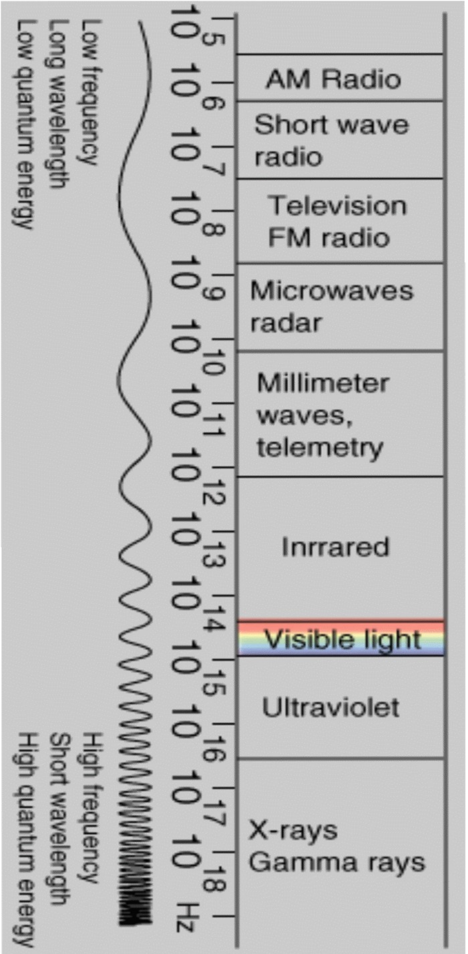


TeV = 10^{12} eV

PeV= 10^{15} eV

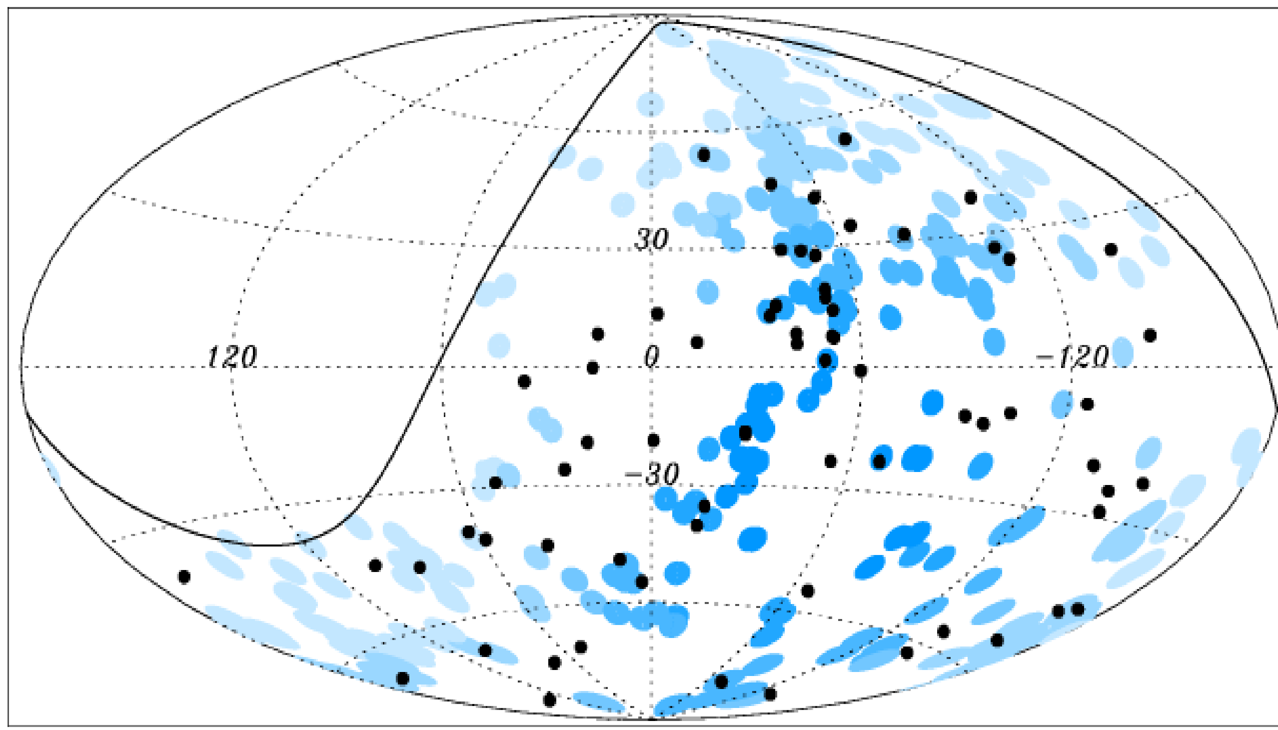
EeV= 10^{18} eV

ZeV= 10^{21} eV



Auger

E > 5.7 x 10^{19} eV



TeV = 10^{12} eV

PeV= 10^{15} eV

EeV= 10^{18} eV

ZeV= 10^{21} eV

Astroparticle Physics

Second ASPERA* Astroparticle physics is a new multidisciplinary field of research that deals with the study of particles coming from the Universe.

*It is an European network of national government agencies responsible for coordinating and funding national research efforts in Astroparticle Physics.

Astroparticle Physics

The study of the physics phenomena occurring in astronomical objects by measuring the high energy particles they produce.

Astrophysics

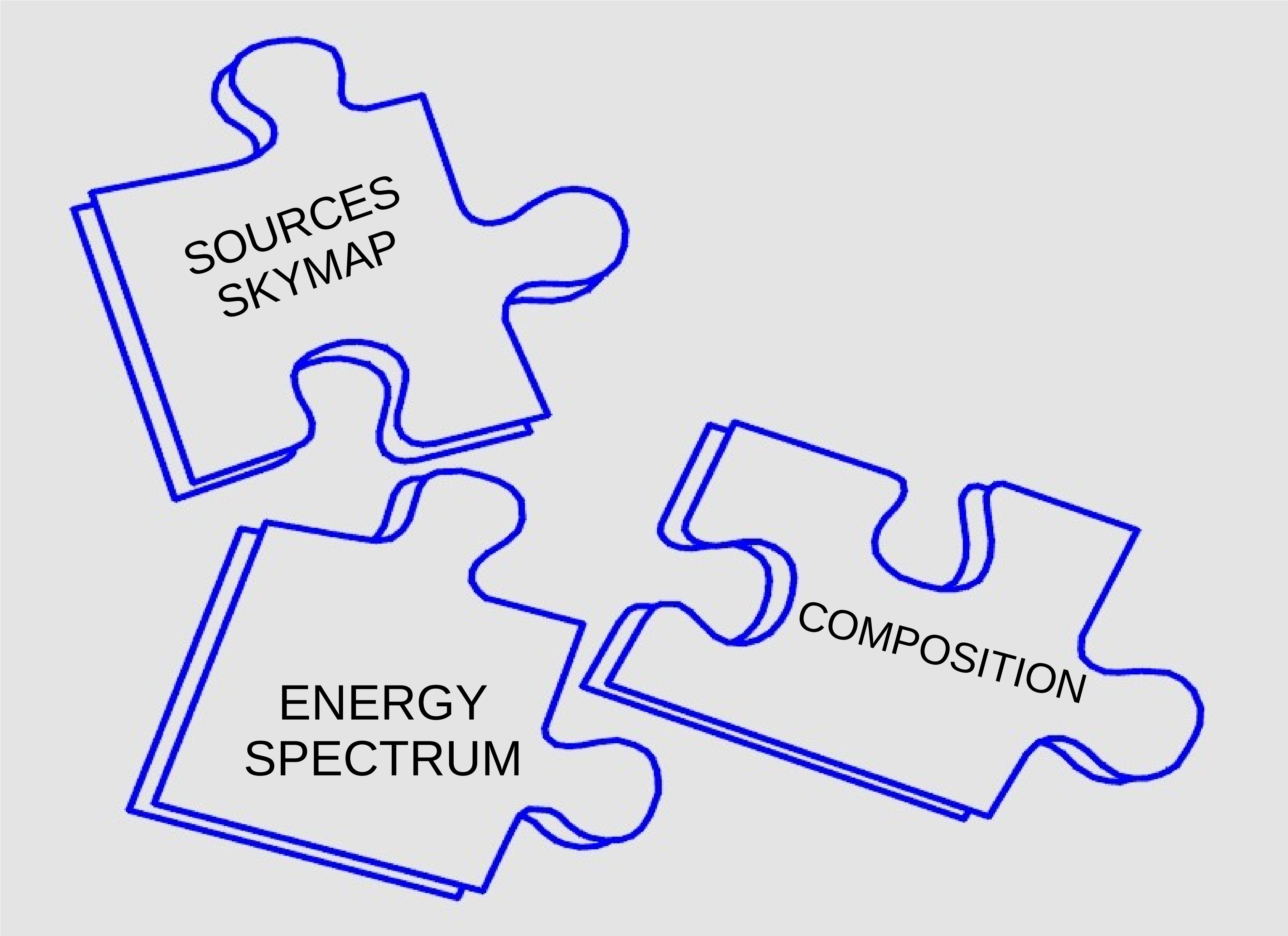
Particle Physics

Cosmology

HOW DO WE DO

ASTROPARTICLE PHYSICS ?

Astroparticle Physics

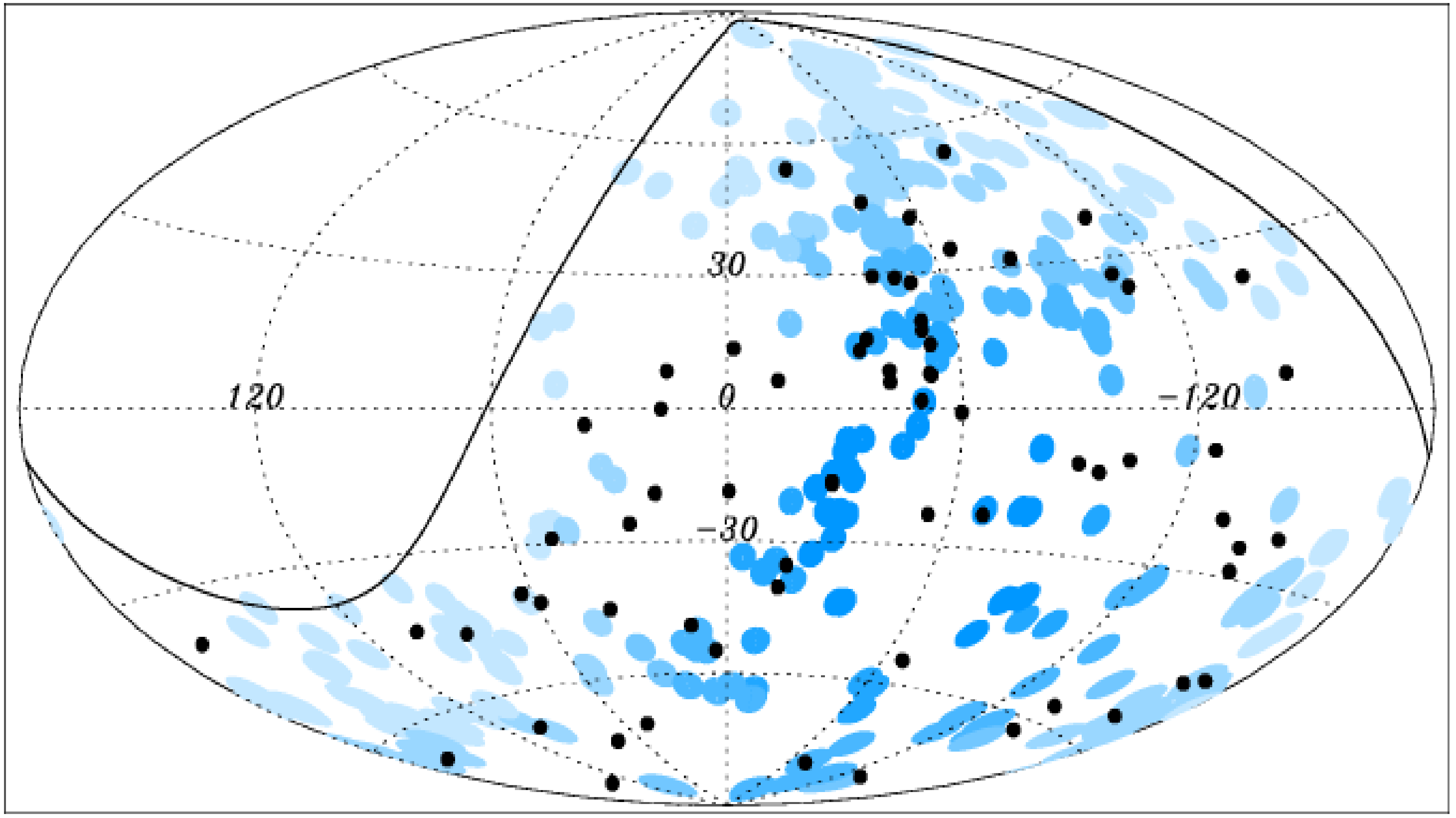


WHAT CAN WE LEARN

FROM NATURE BY

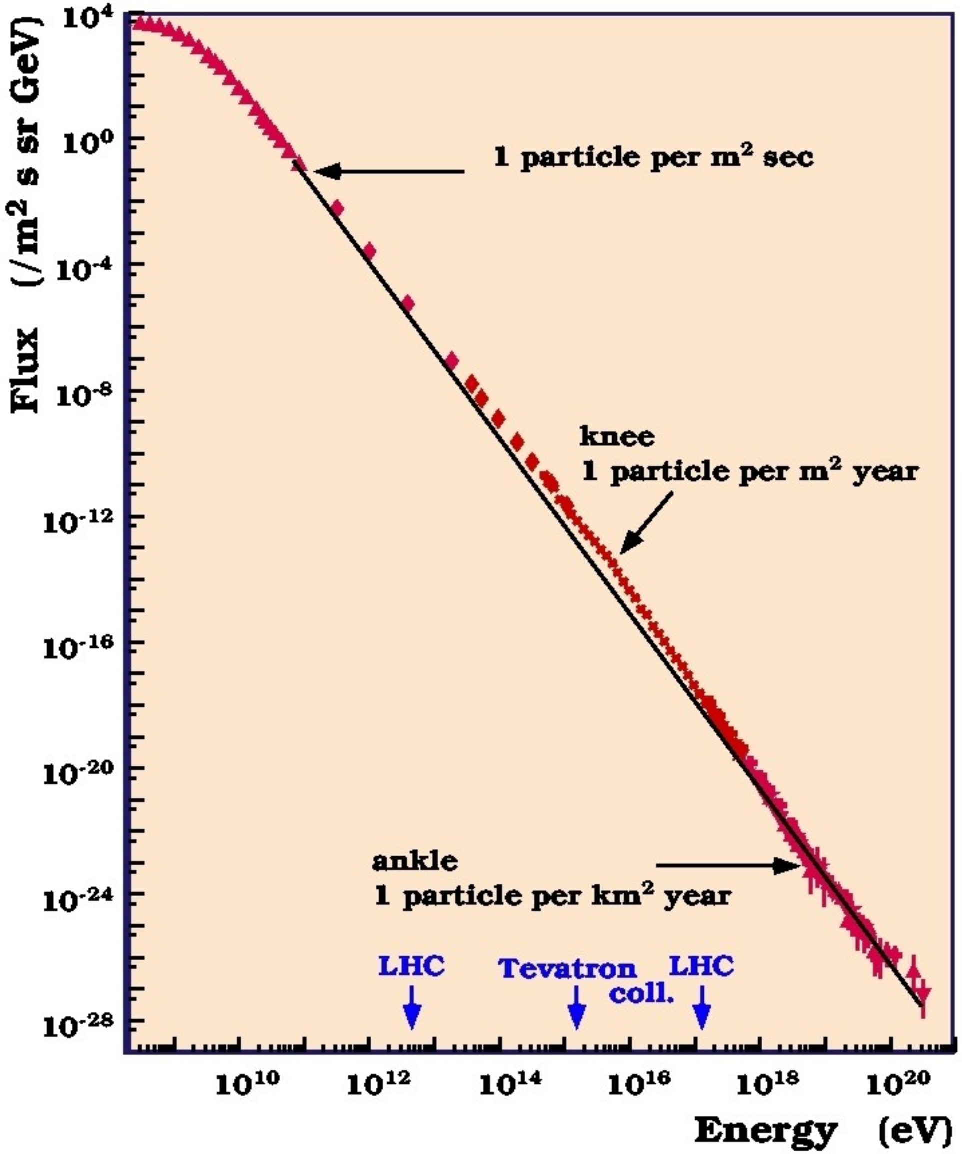
UNSCRAMBLING THIS PUZZLE ?

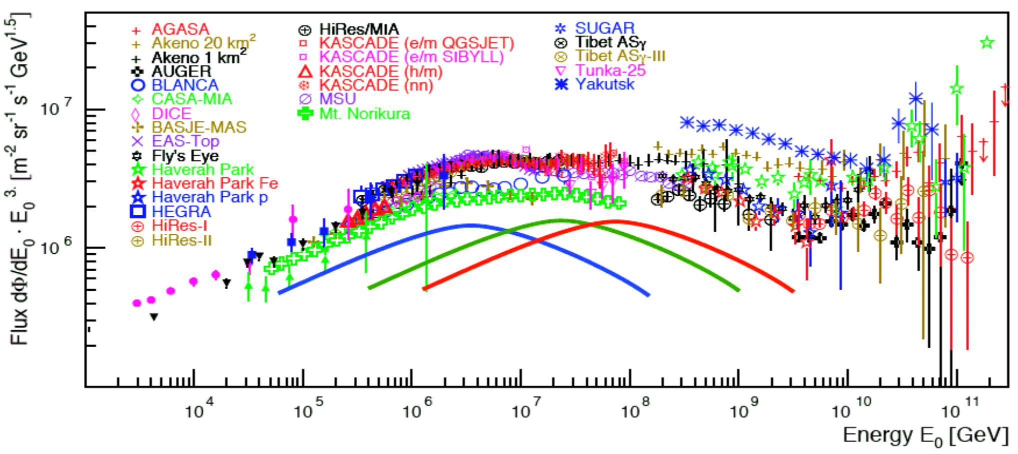
Source Skymap

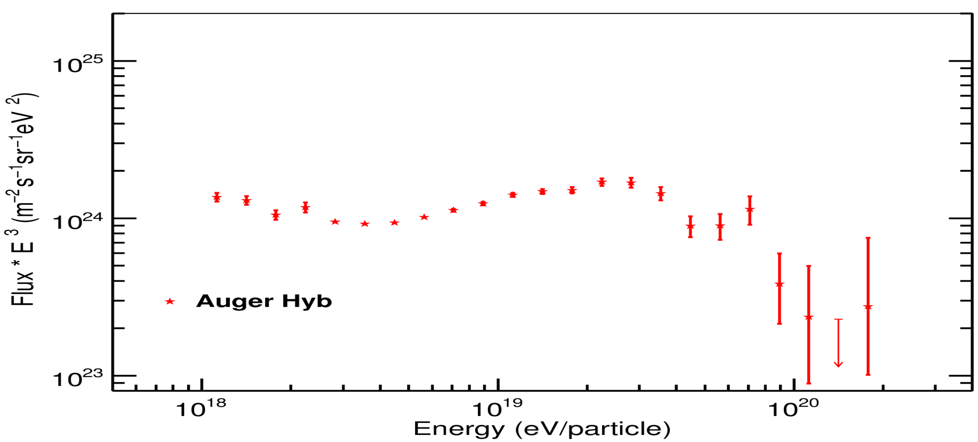


Source type identification

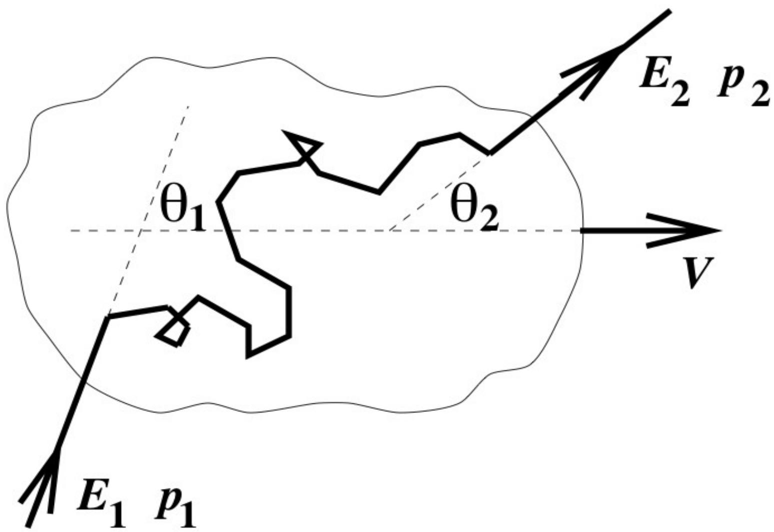
Energy Spectrum

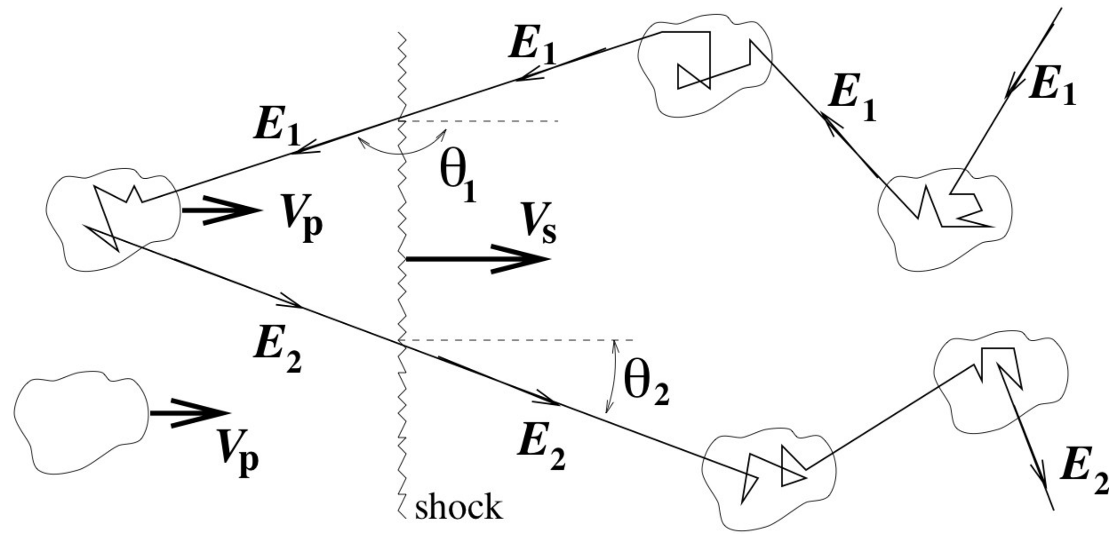






Acceleration





$$\frac{\langle \Delta E \rangle}{E} \sim \beta^2$$

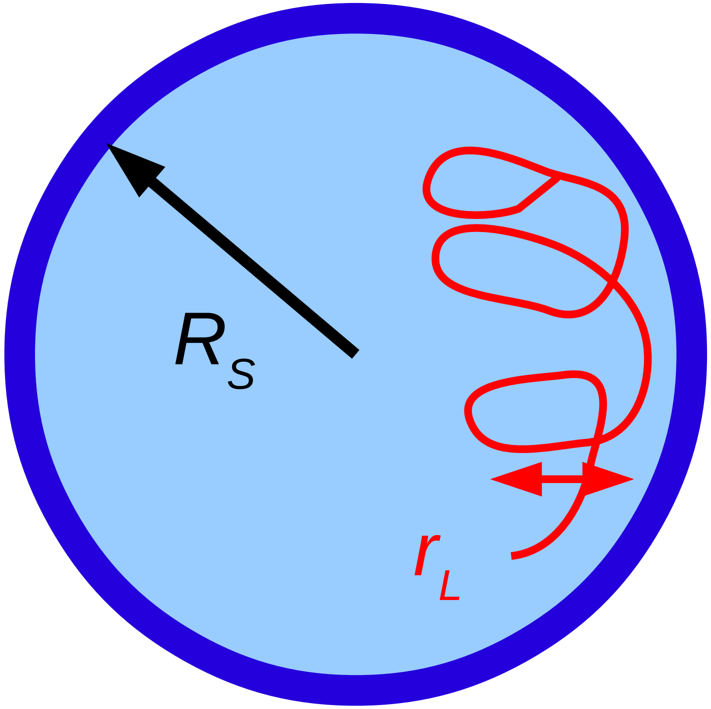
$$\frac{\langle \Delta E \rangle}{E} \sim \beta$$

(Original) Fermi acceleration mechanism (second ordem).

First order acceleration Fermi mechanism.

Keep the particle inside the acceleration region

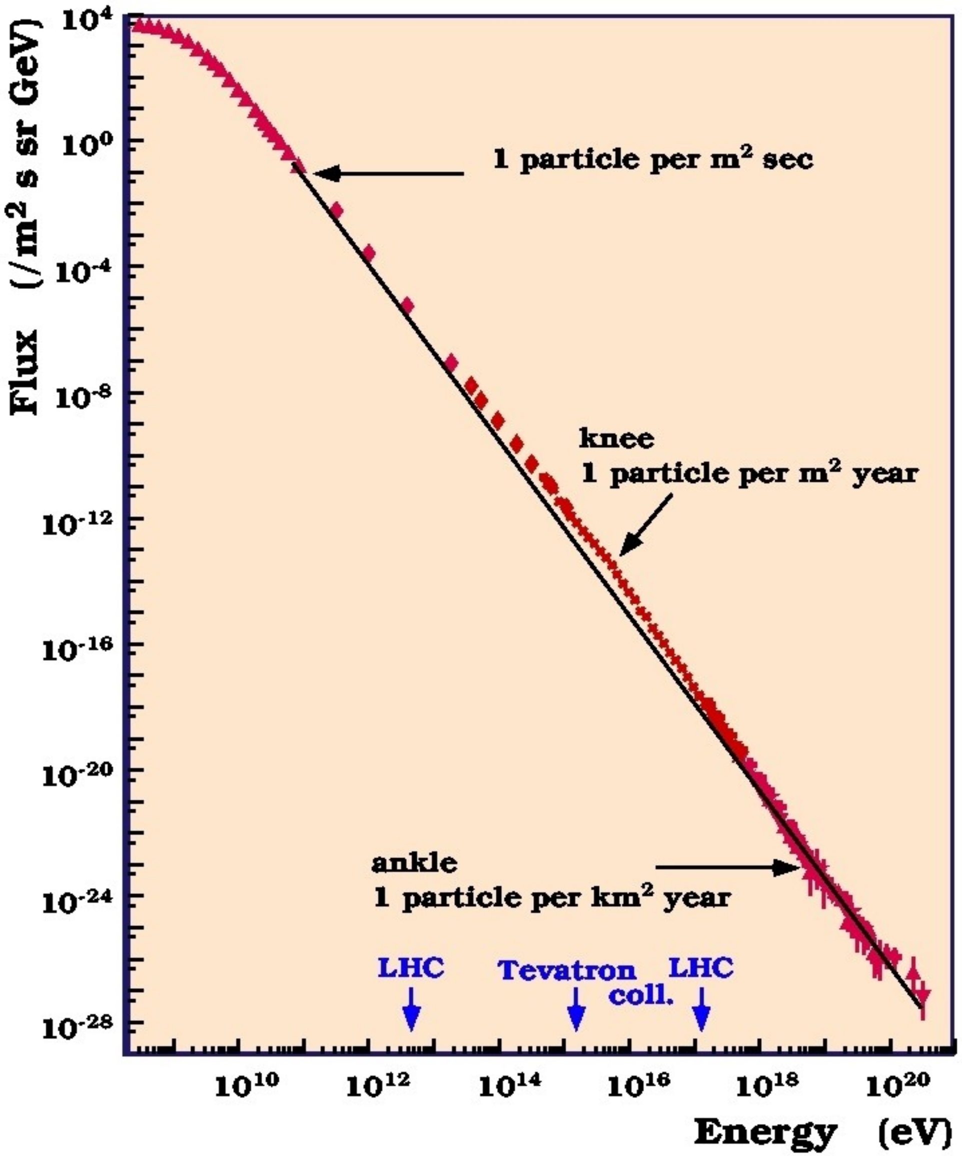
$$r_{L,pc} \approx \frac{10^{-6}}{Z} \times \frac{E_{GeV}}{B_{\mu G}}$$



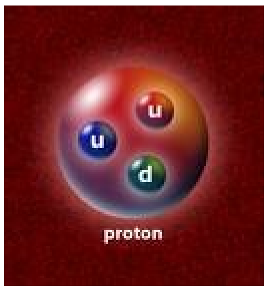
$$E_{ev} < 10^{15} \times Z \times B_{\mu G} \times R_{S,pc}$$

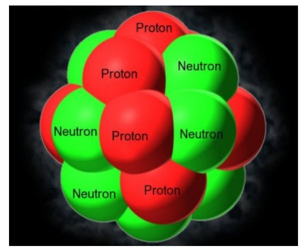
Energy spectrum

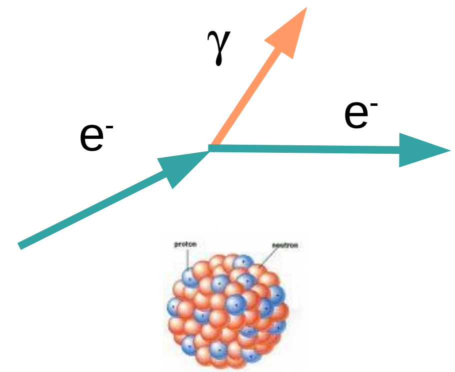
- Magnetic field
  - Intensity
  - Structure
- Shock wave speed
- Size of the region
- Particle charge
- Injection speed
- Scape probability



Composition

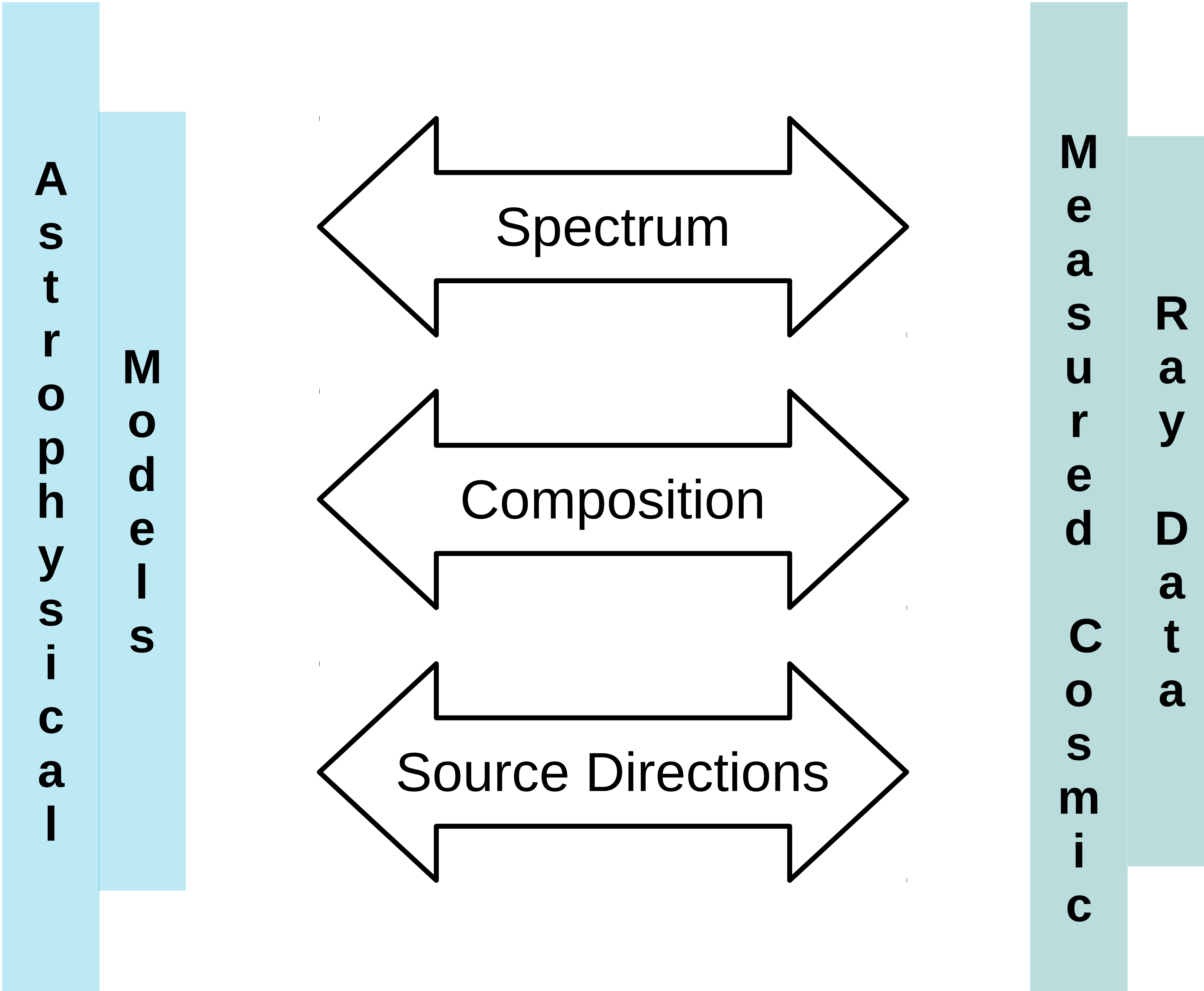




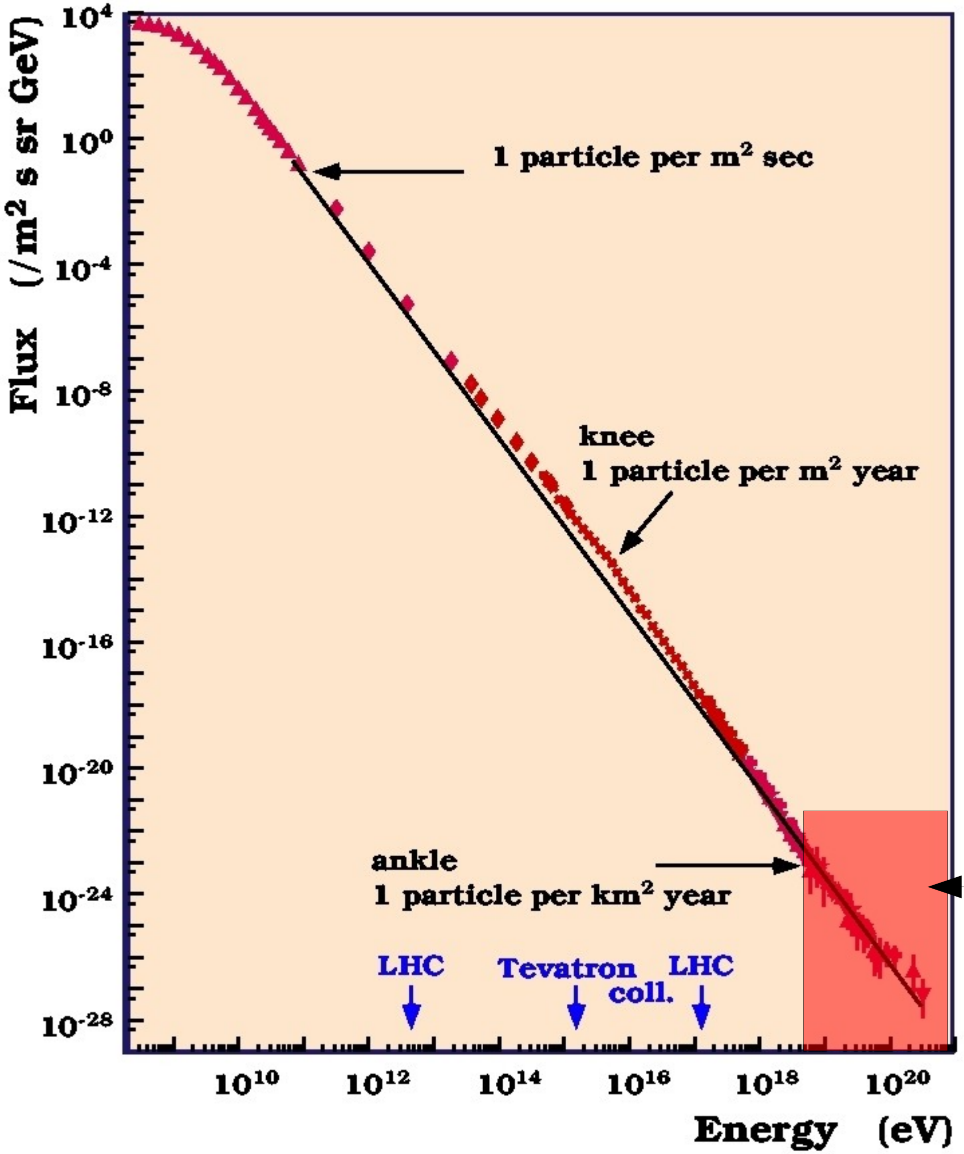


$$r_{L,\,pc} \approx \frac{10^{-6}}{Z} \times \frac{E_{GeV}}{B_{\mu G}}$$

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


Astrophysical Models
Spectrum
Composition
Source Directions
Measured Cosmic Ray Data

20 years ago...

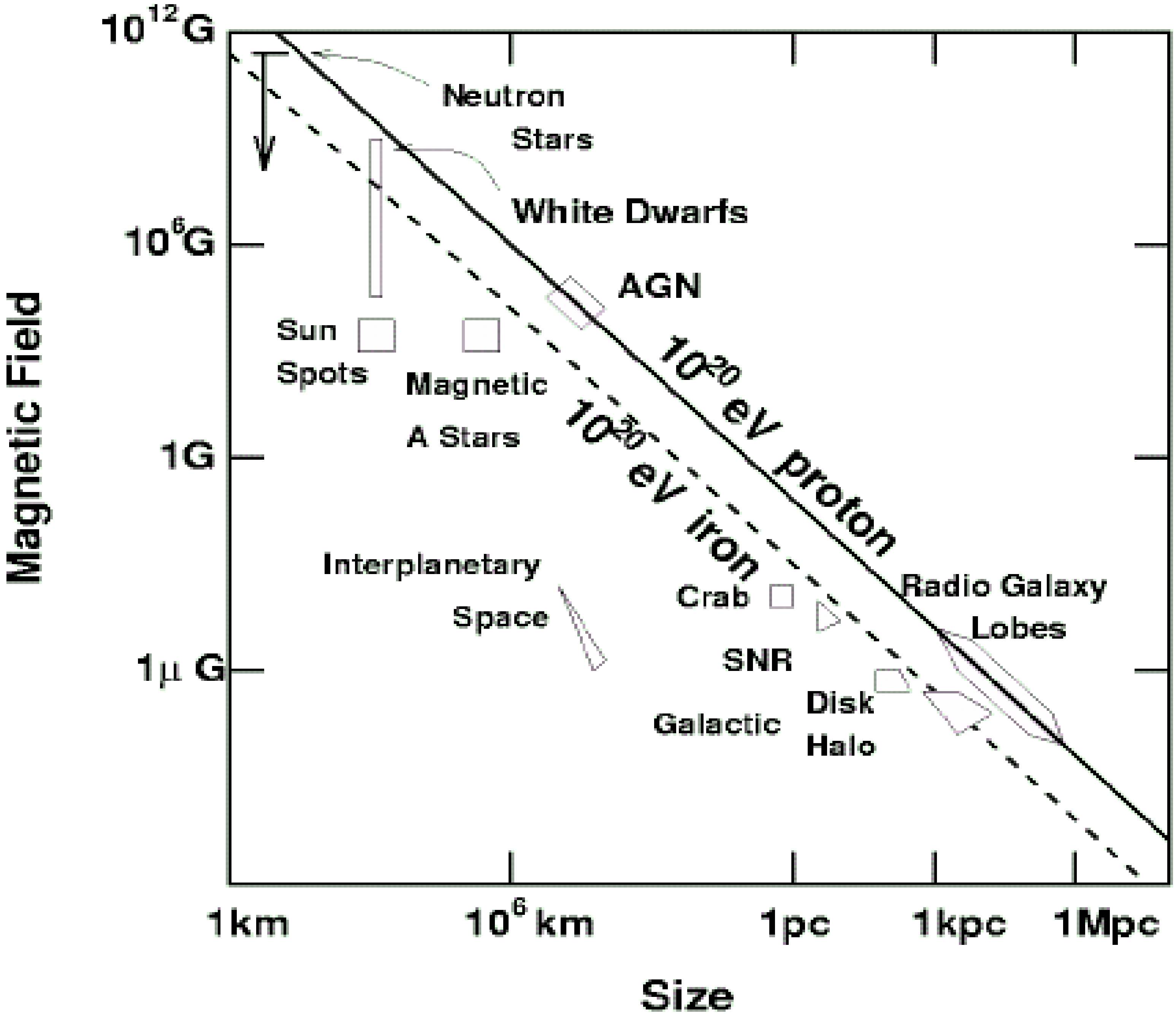


Pierre Auger Observatory Science Case

$E > 10^{19}$ eV

Interesting !

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

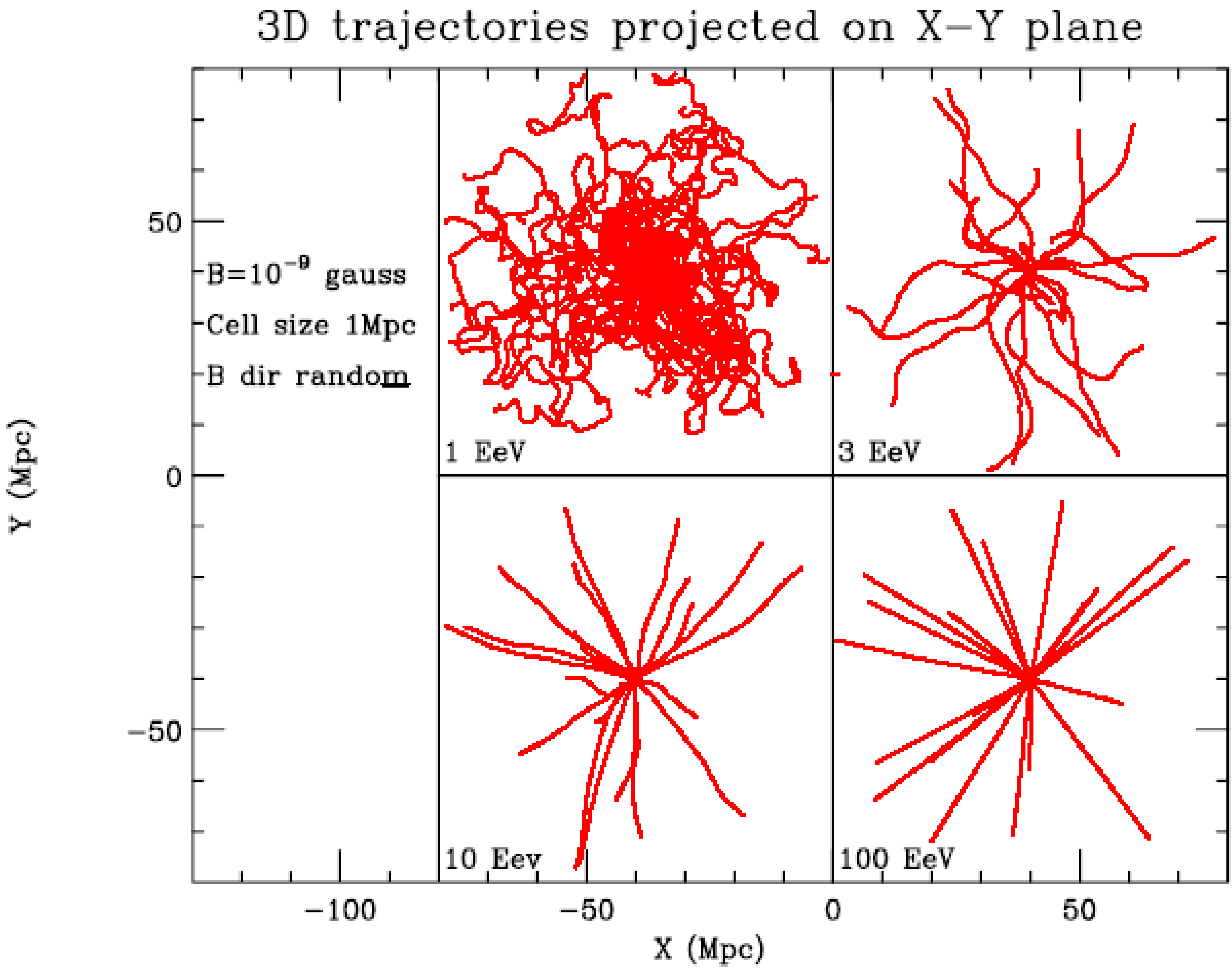


M. Hillas

Interesting points:

There are only a few sources able to accelerate particles beyond 10^{19} eV

Propagation



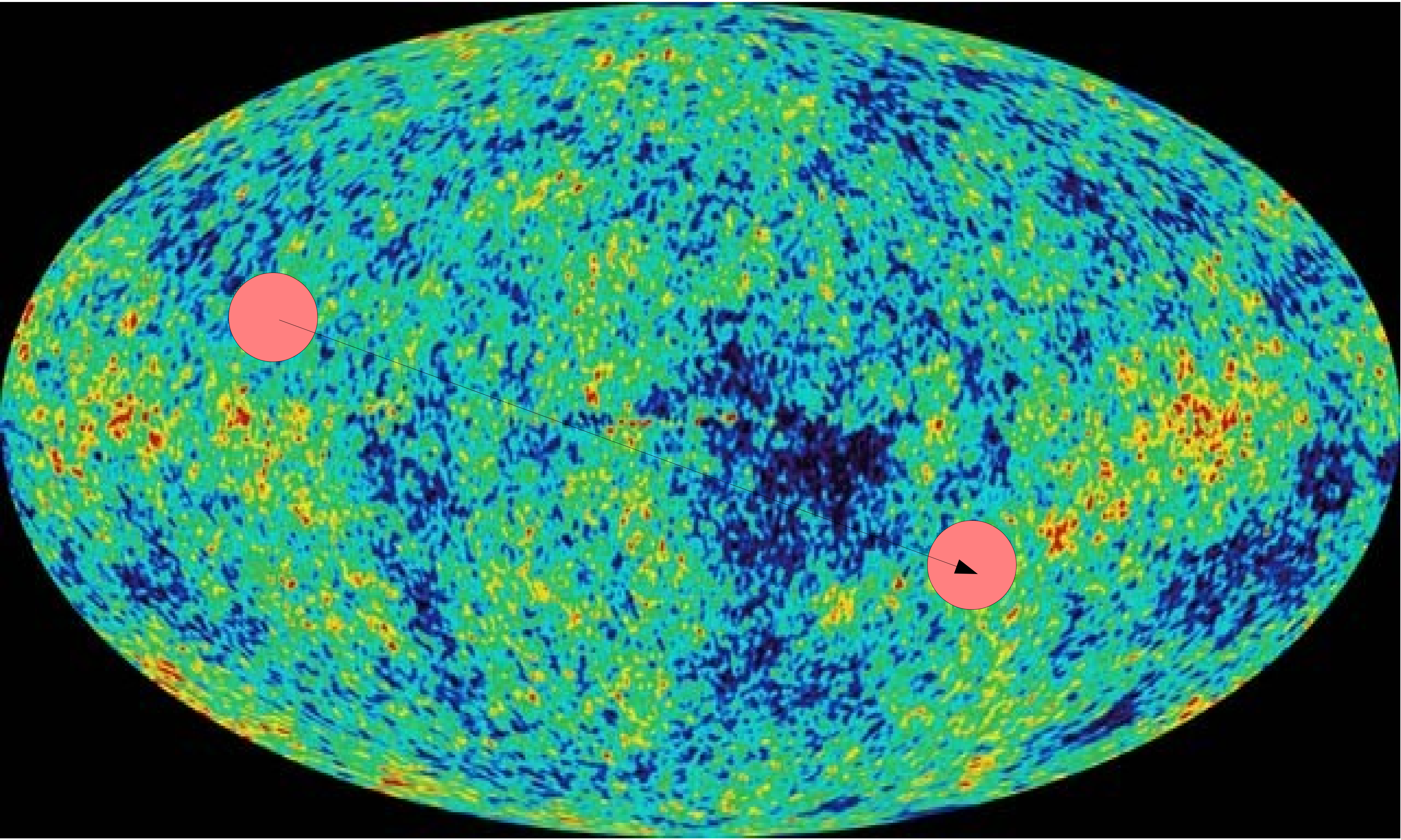
J. Cronin

Interesting points:

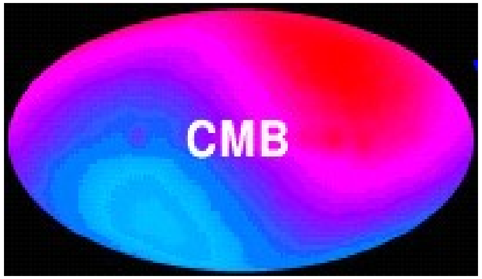
There are only a few sources able to accelerate particles beyond 10^{19} eV

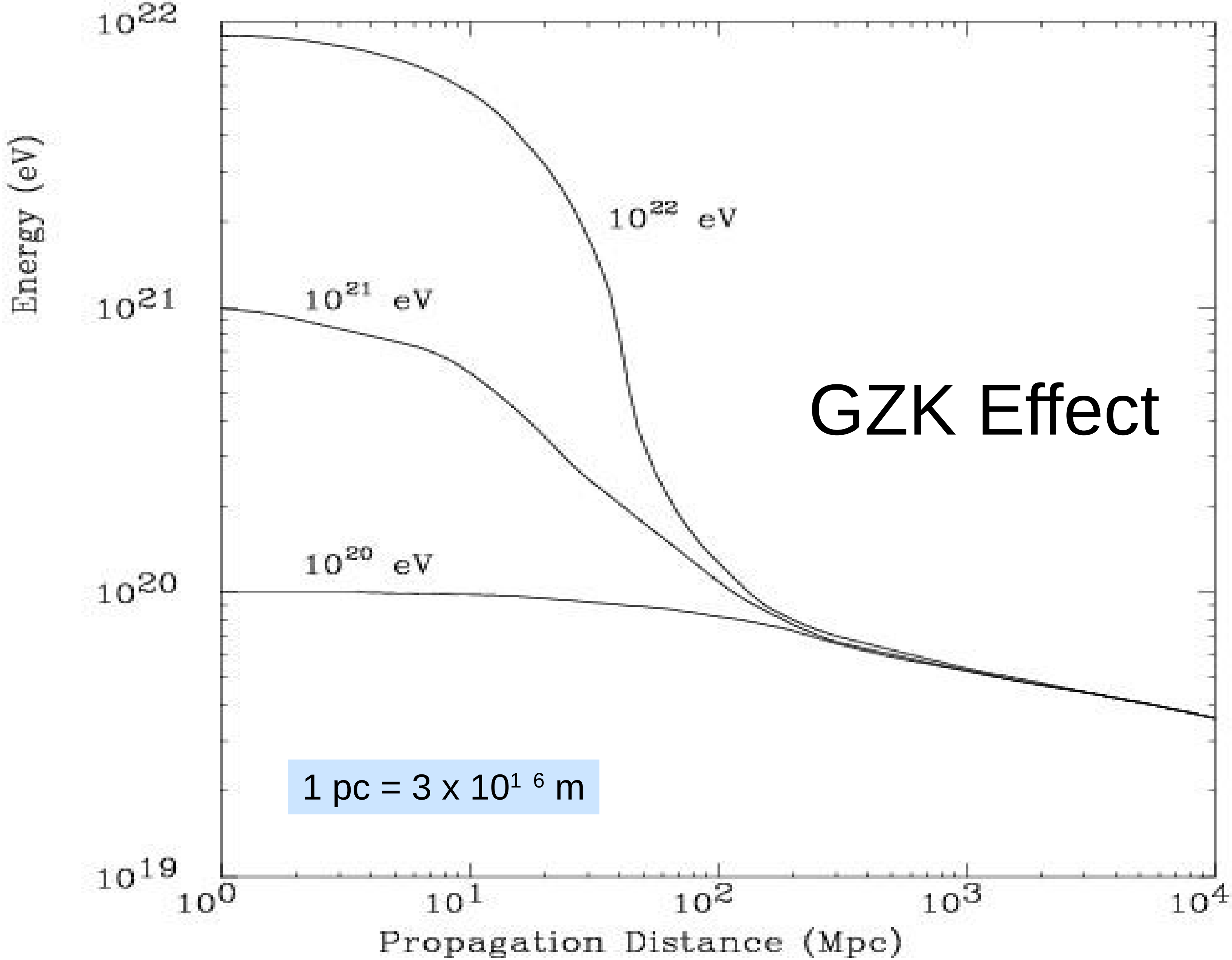
- Particle propagate straight from the source to Earth

Universe is not empty



$$p + \gamma_{2,7\,K} \rightarrow p + \pi^{o}$$





J. Cronin

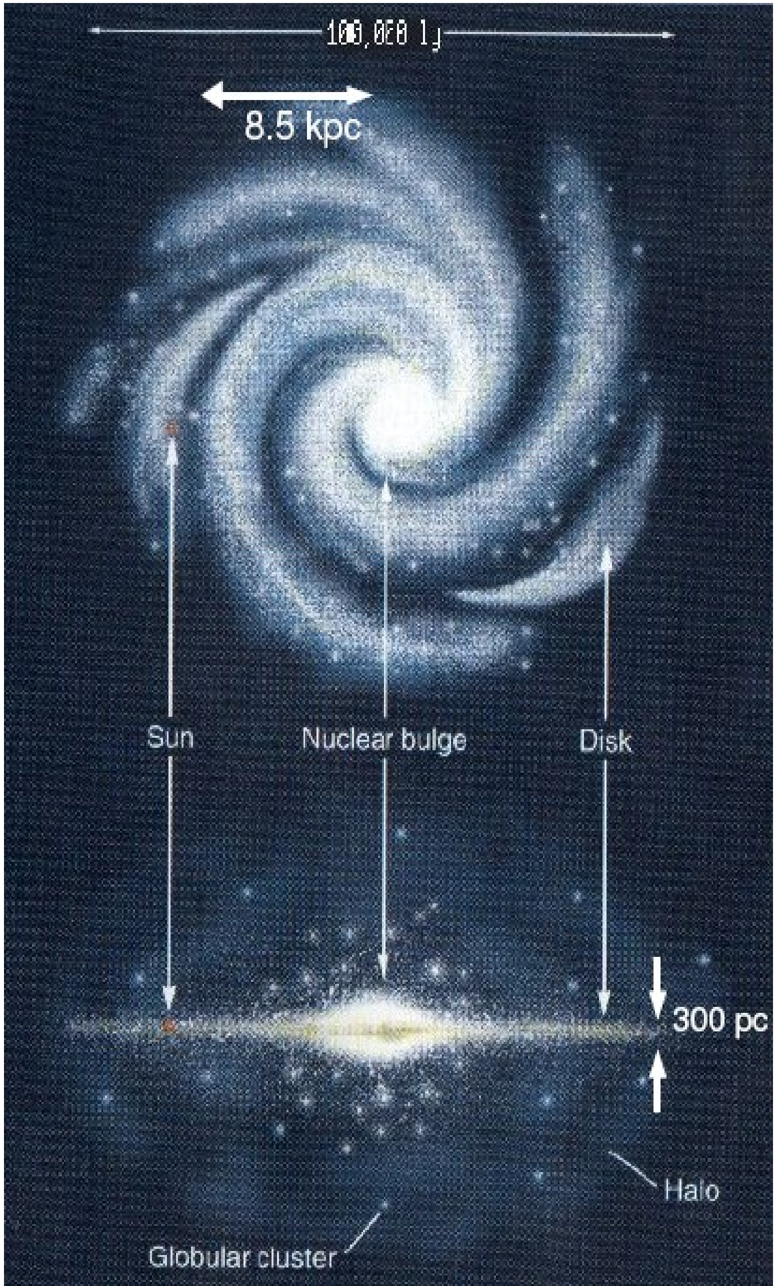
Interesting points:

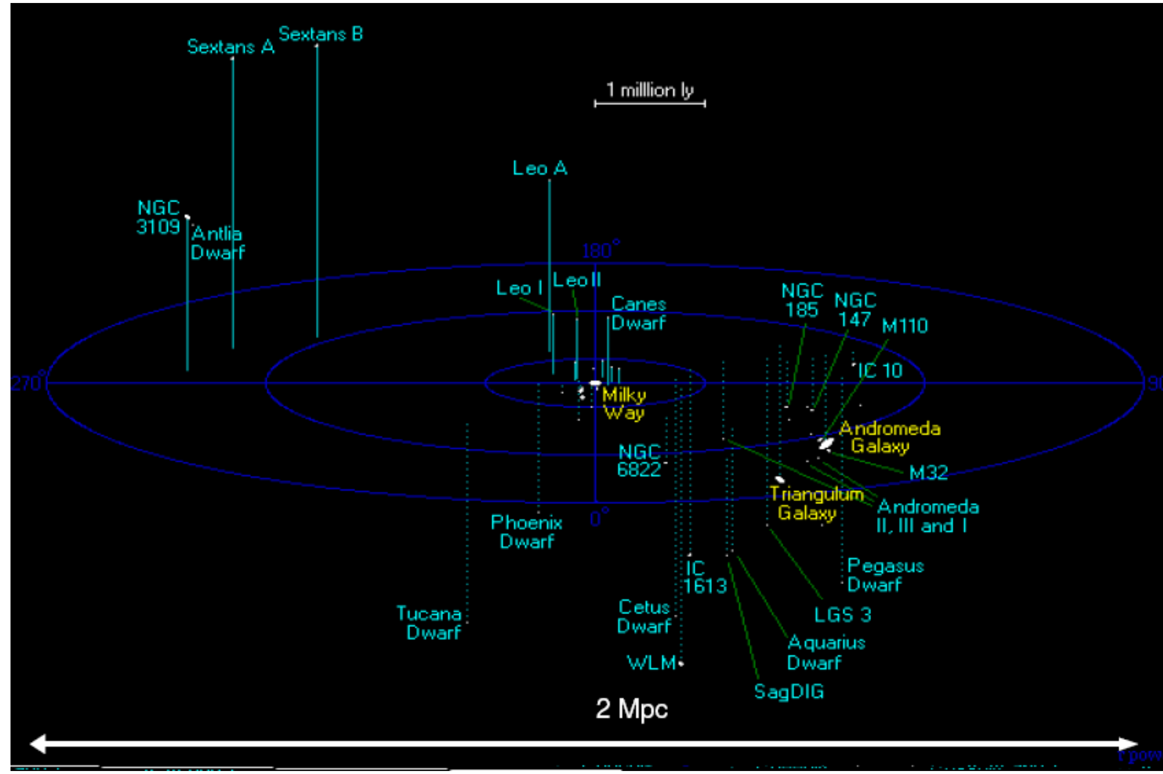
There are only a few sources able to accelerate particles beyond 10^{19} eV

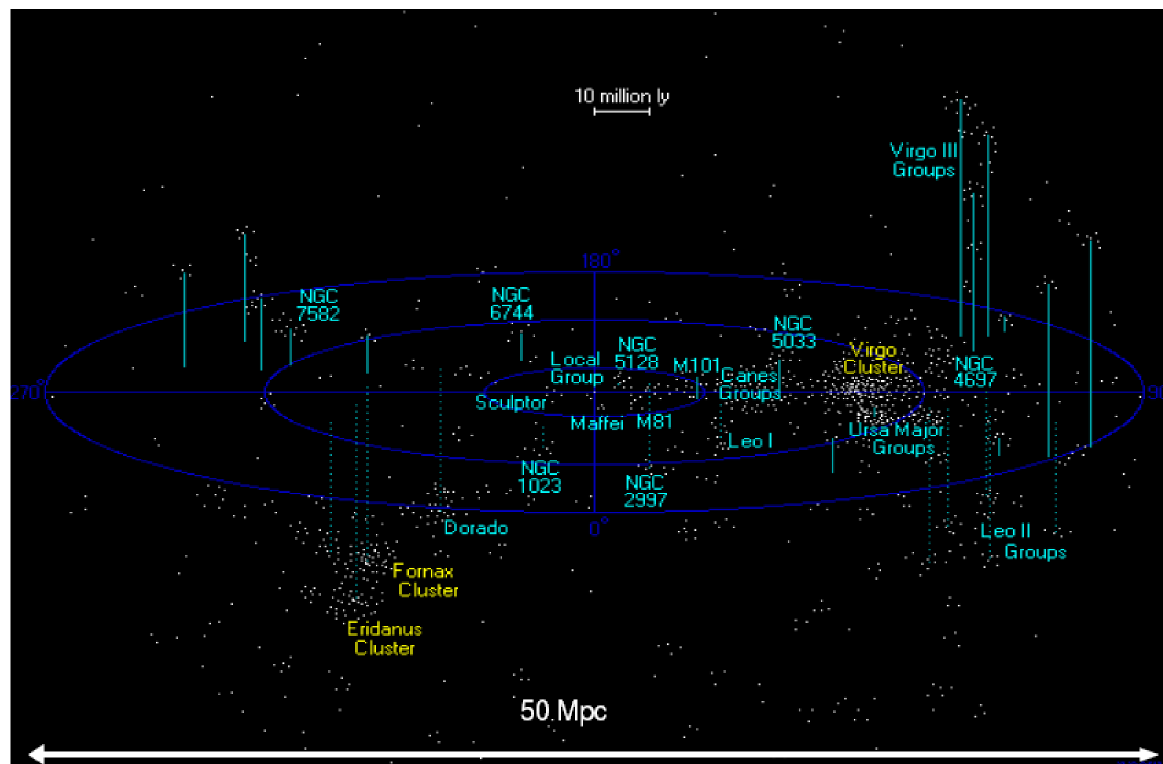
- Particle propagate straight from the source to the Earth

Sources are not far away ($D < 100$ Mpc)

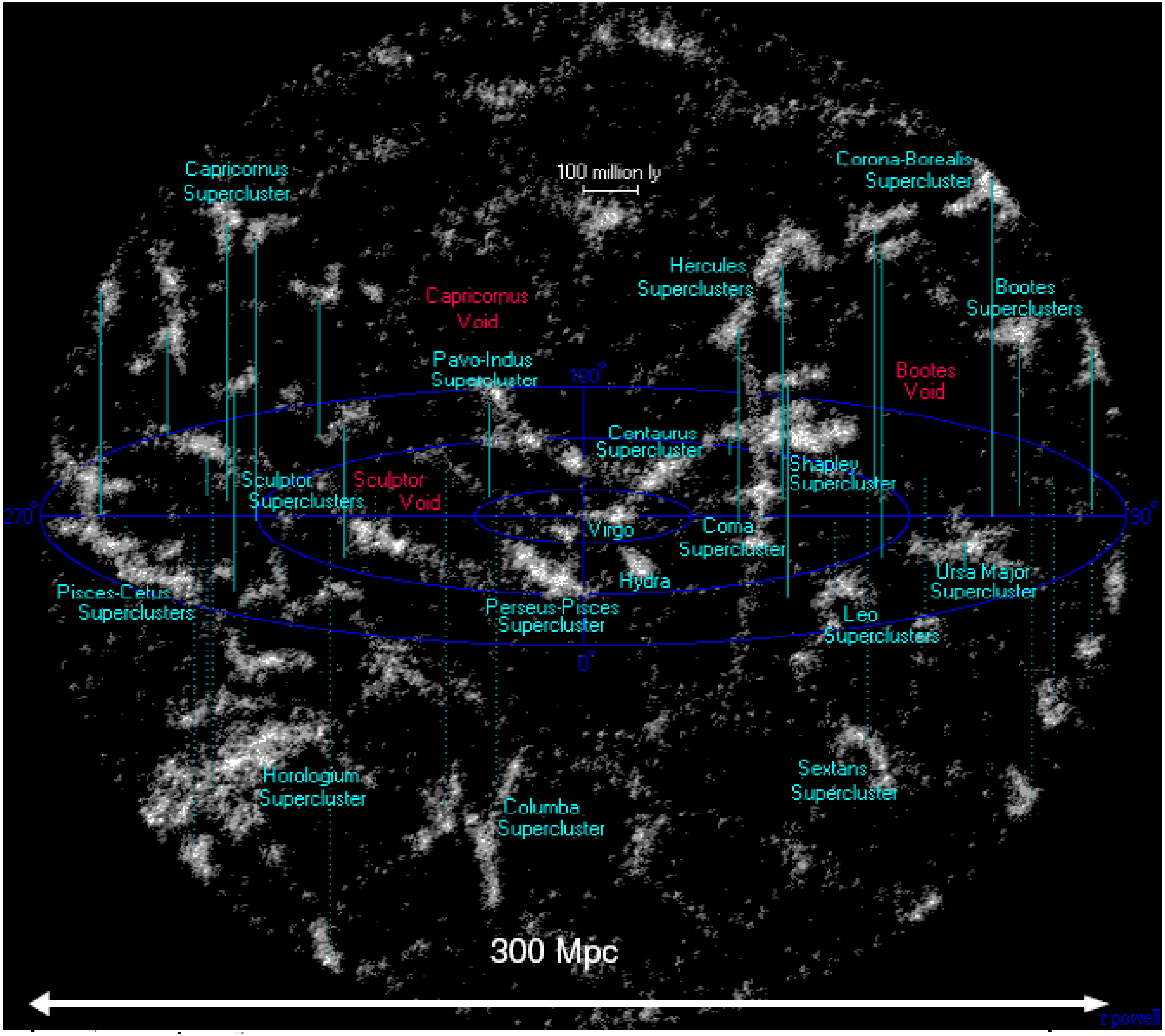
1 pc = 3×10^{16} m







Slide: Silvia Mollerach



Slide: Silvia Mollerach

1 pc = 3×10^{16} m

Interesting points:

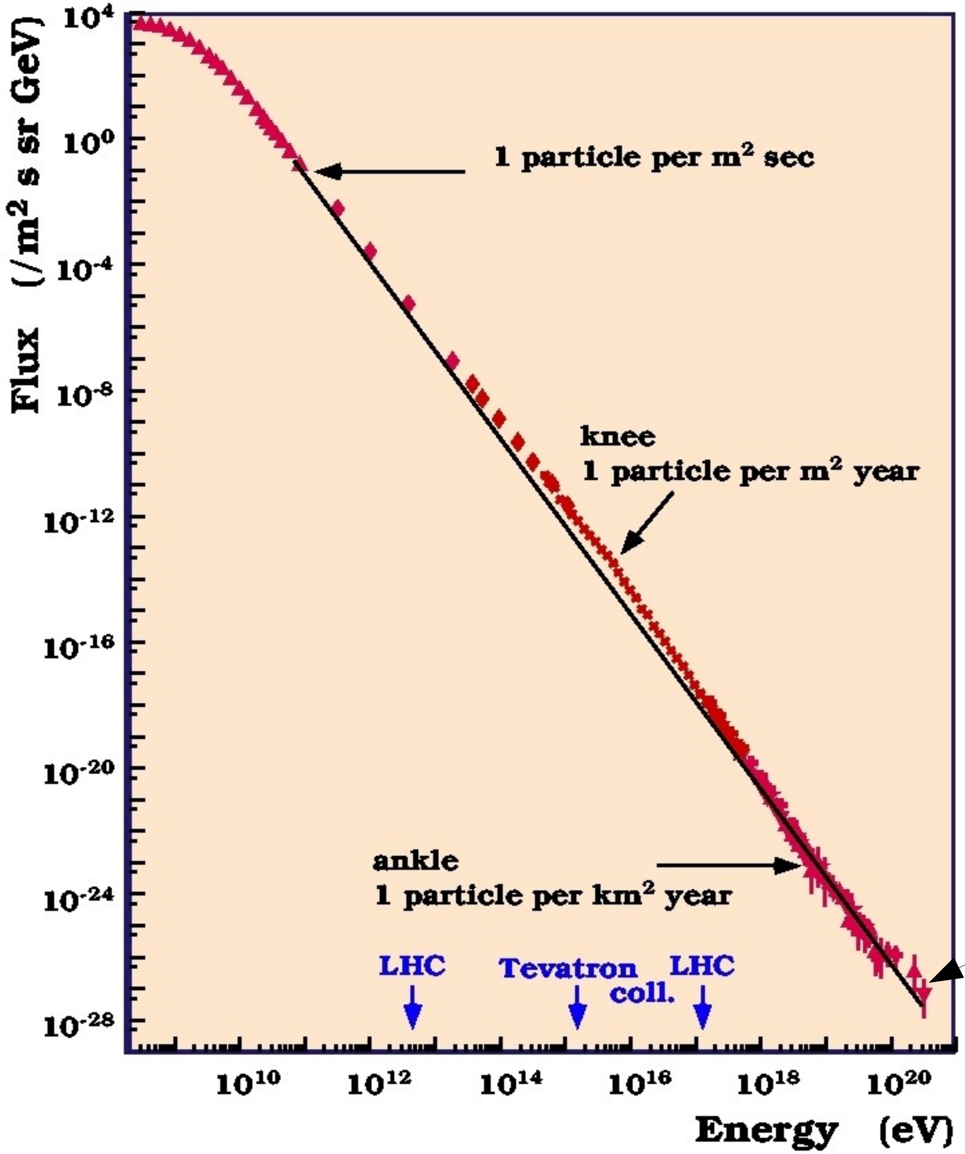
There are only a few sources able to accelerate particles beyond 10^{19} eV

- Particle propagate straight from the source to the Earth

Sources are not far away ($D < 100$ Mpc)

The Universe is anisotropic and has voids inside 100 Mpc

Characteristics



Large Collection Area

Pierre Auger Observatory = 3000 km^2

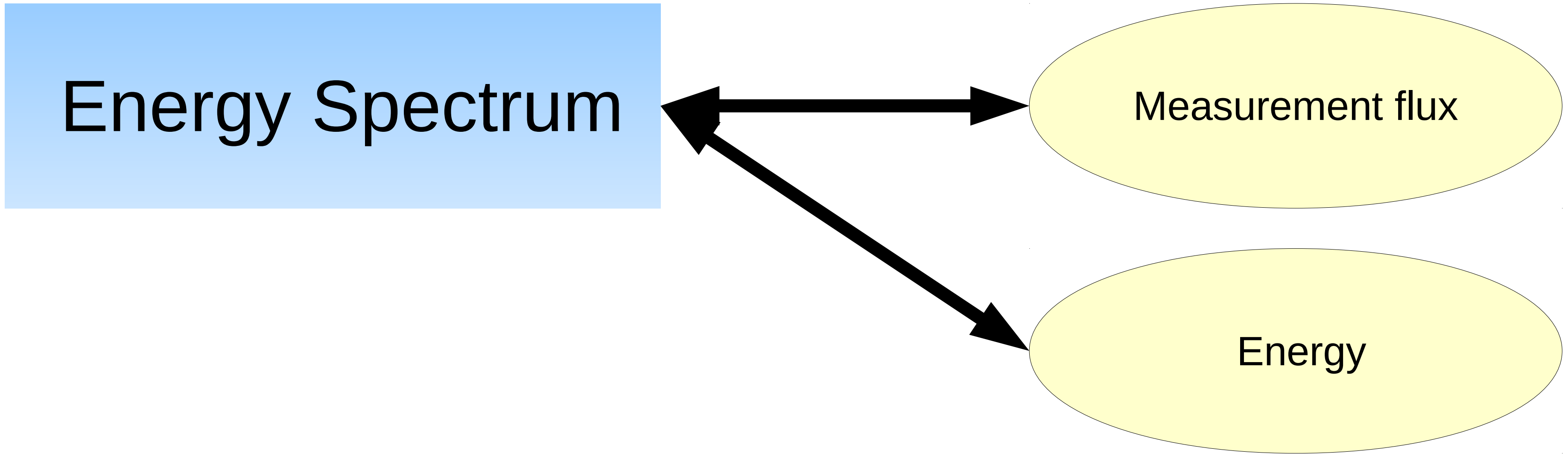
1 particle per km^2 per century

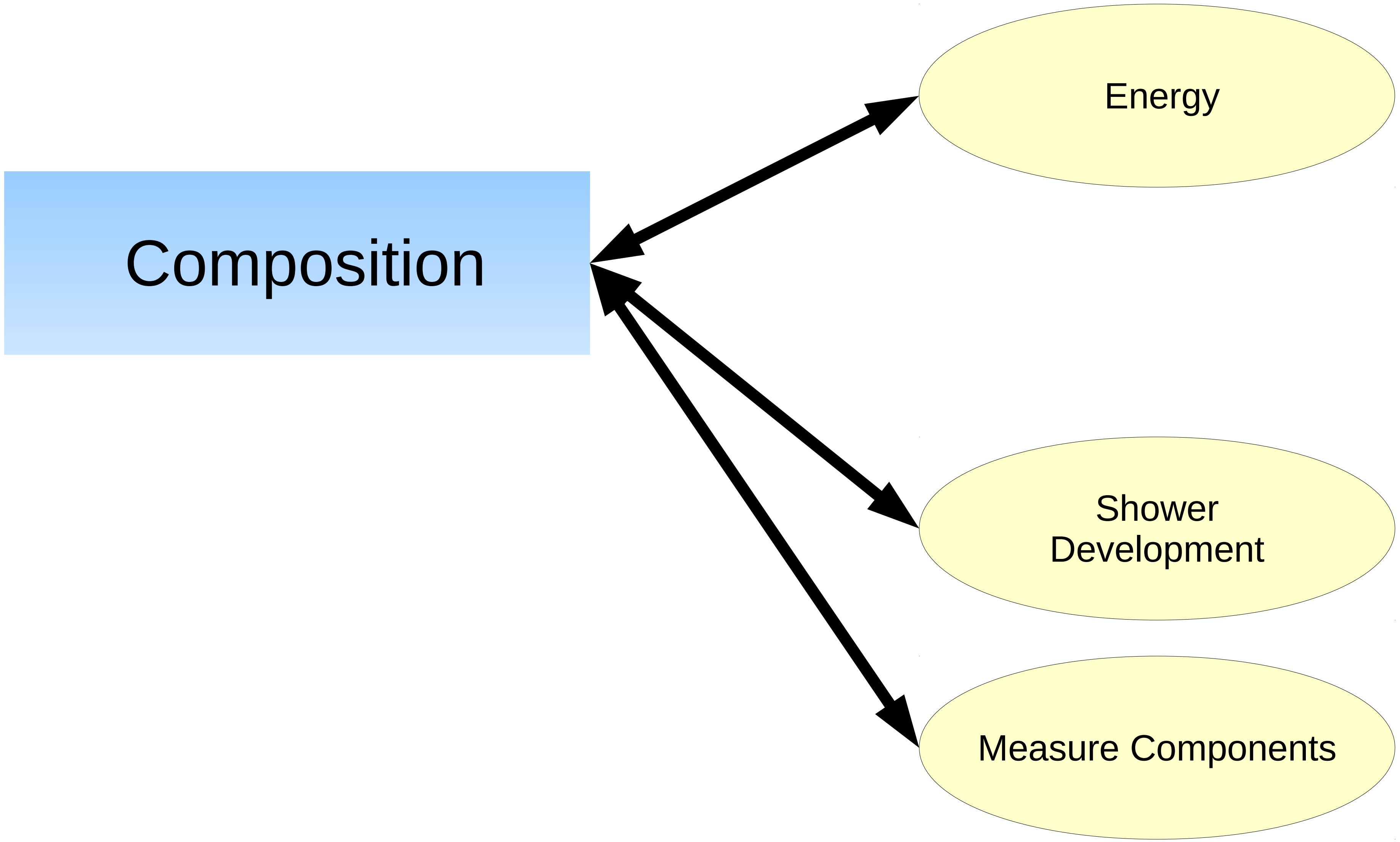
Energy Spectrum

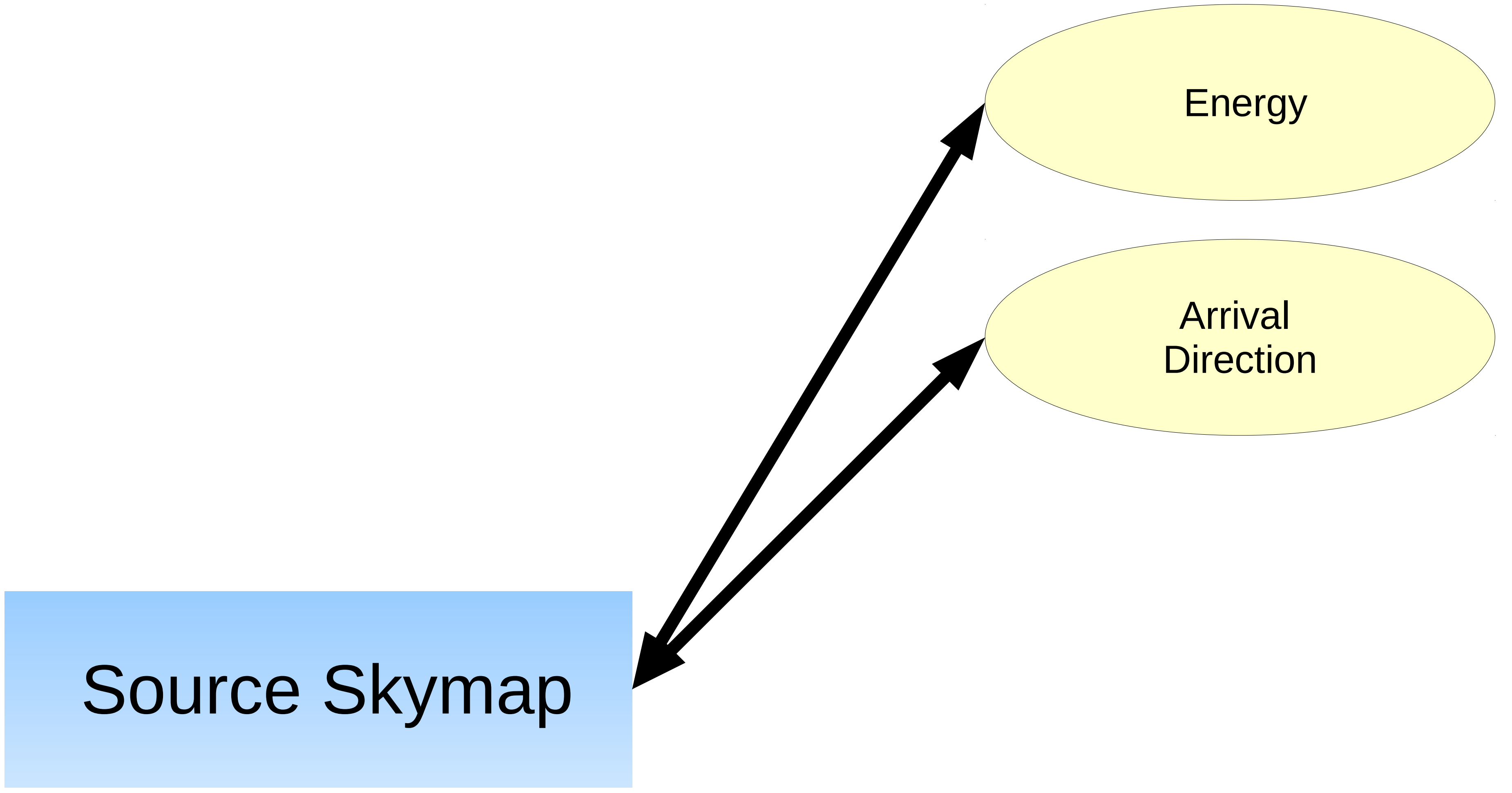
Composition

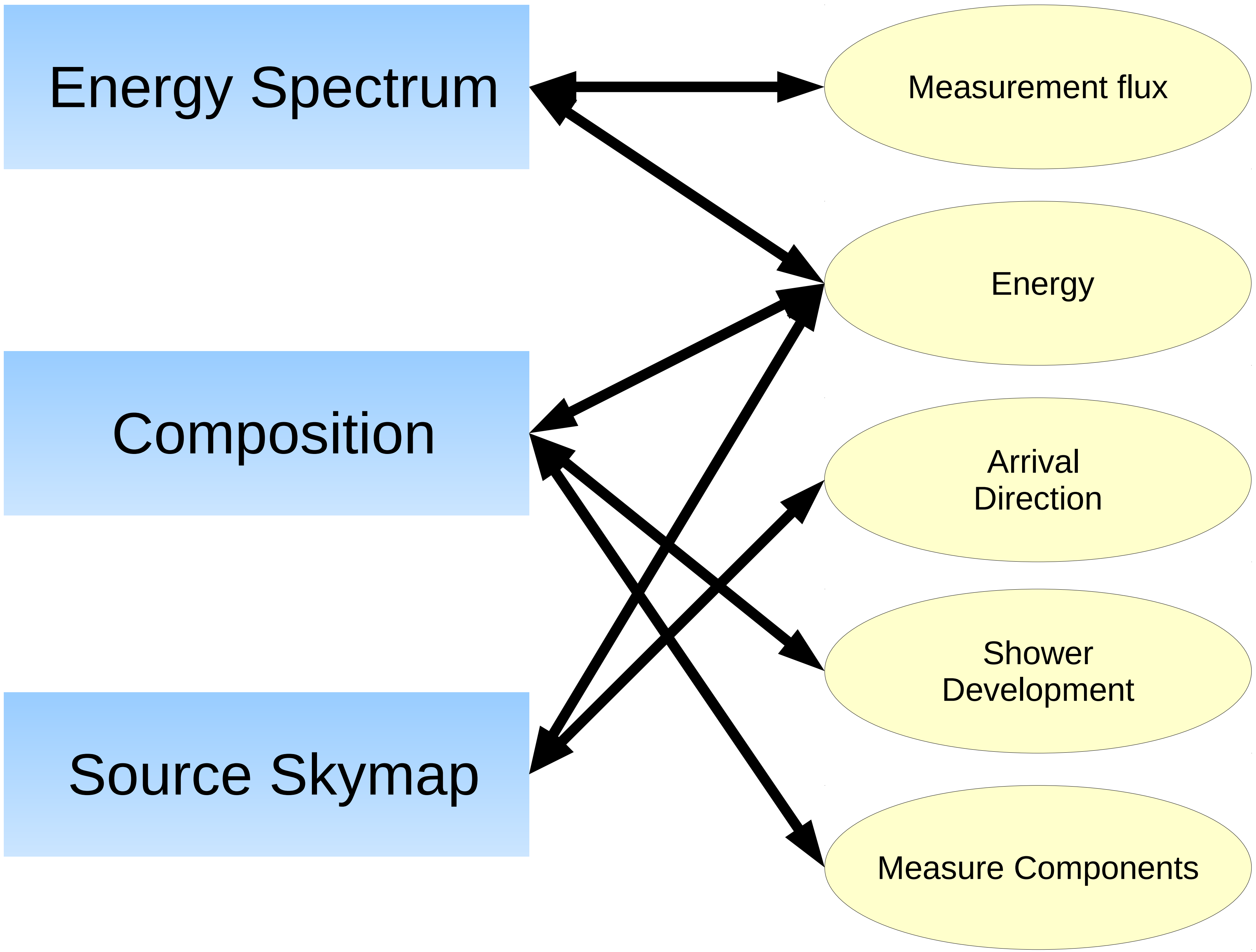
Source Skymap

?


Energy Spectrum
Measurement flux
Energy


Composition
Energy
Shower
Development
Measure Components


Energy
Arrival
Direction
Source Skymap

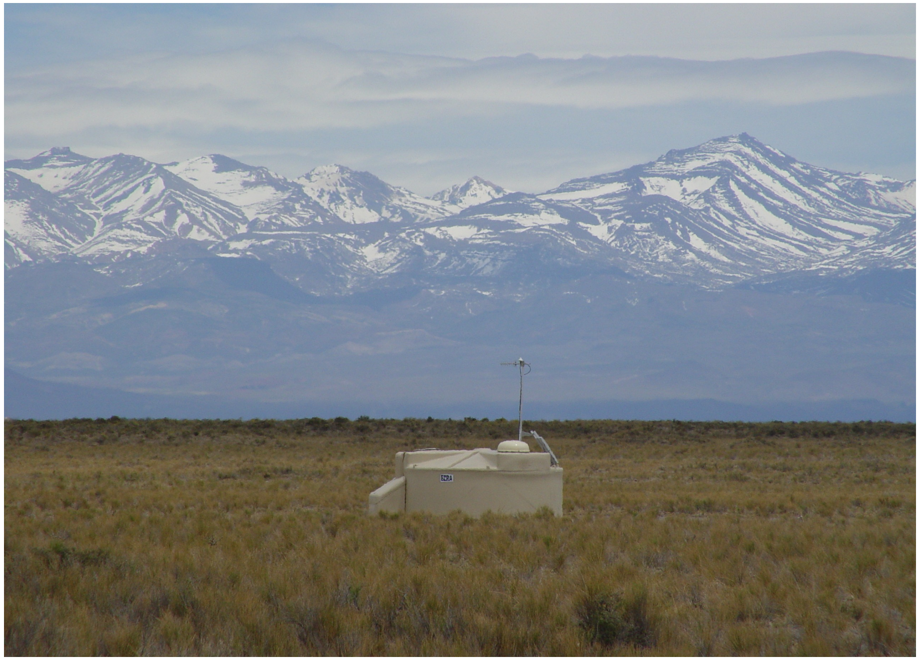


Energy Spectrum
Composition
Source Skymap
Measurement flux
Energy
Arrival
Direction
Shower
Development
Measure Components

UHECR Detector Techniques

Ground Arrays

Fluorescence Telescopes



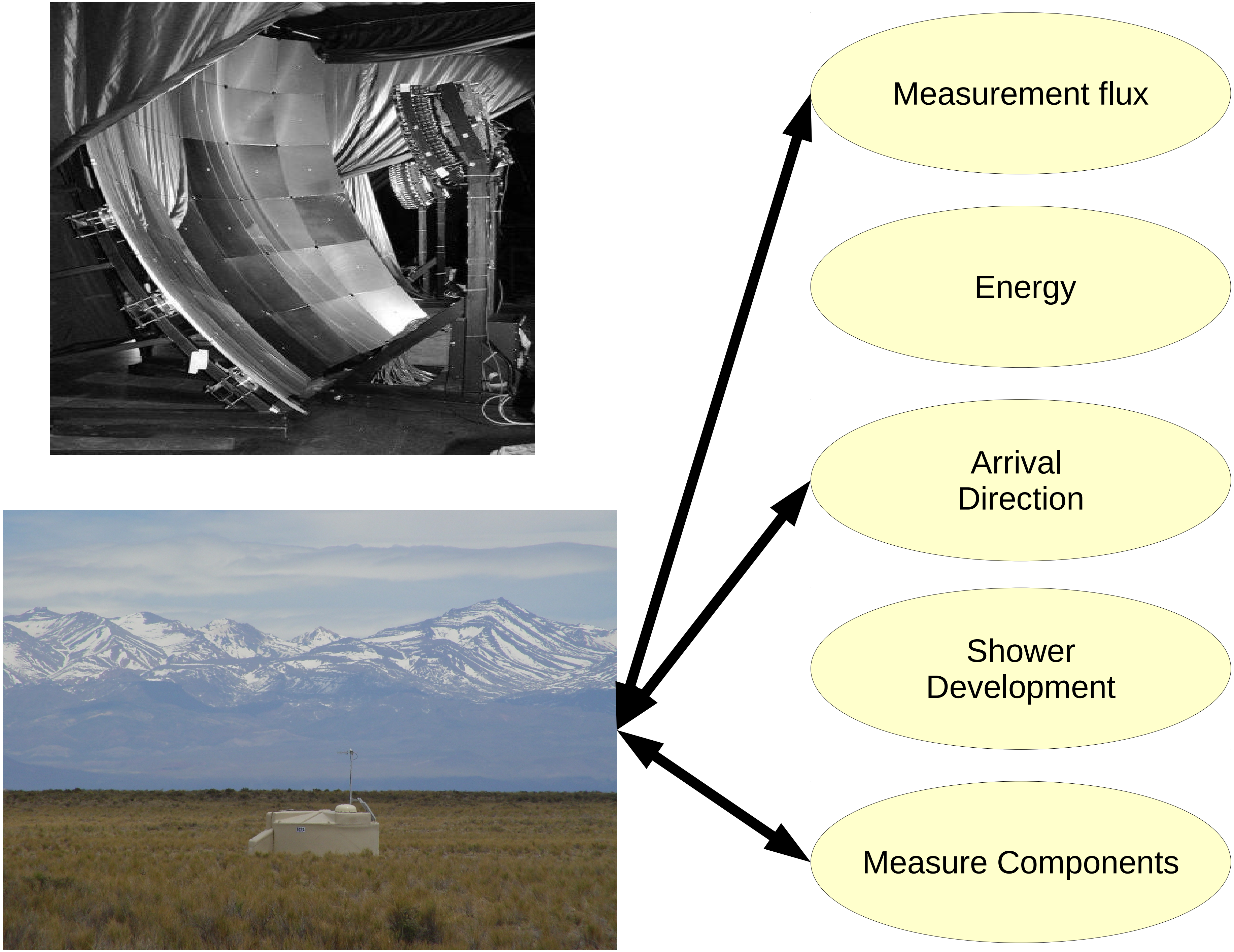
Measurement flux

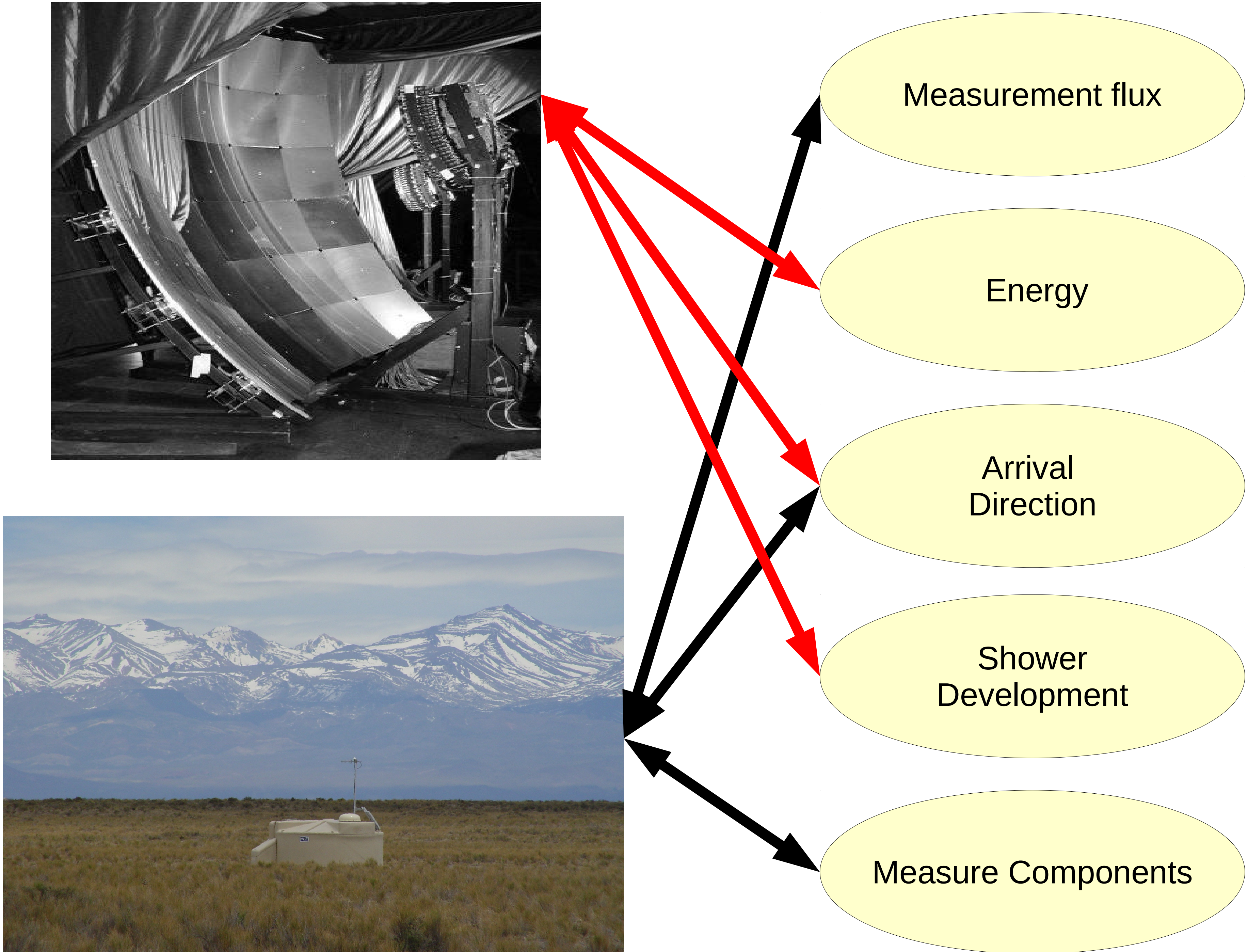
Energy

Arrival Direction

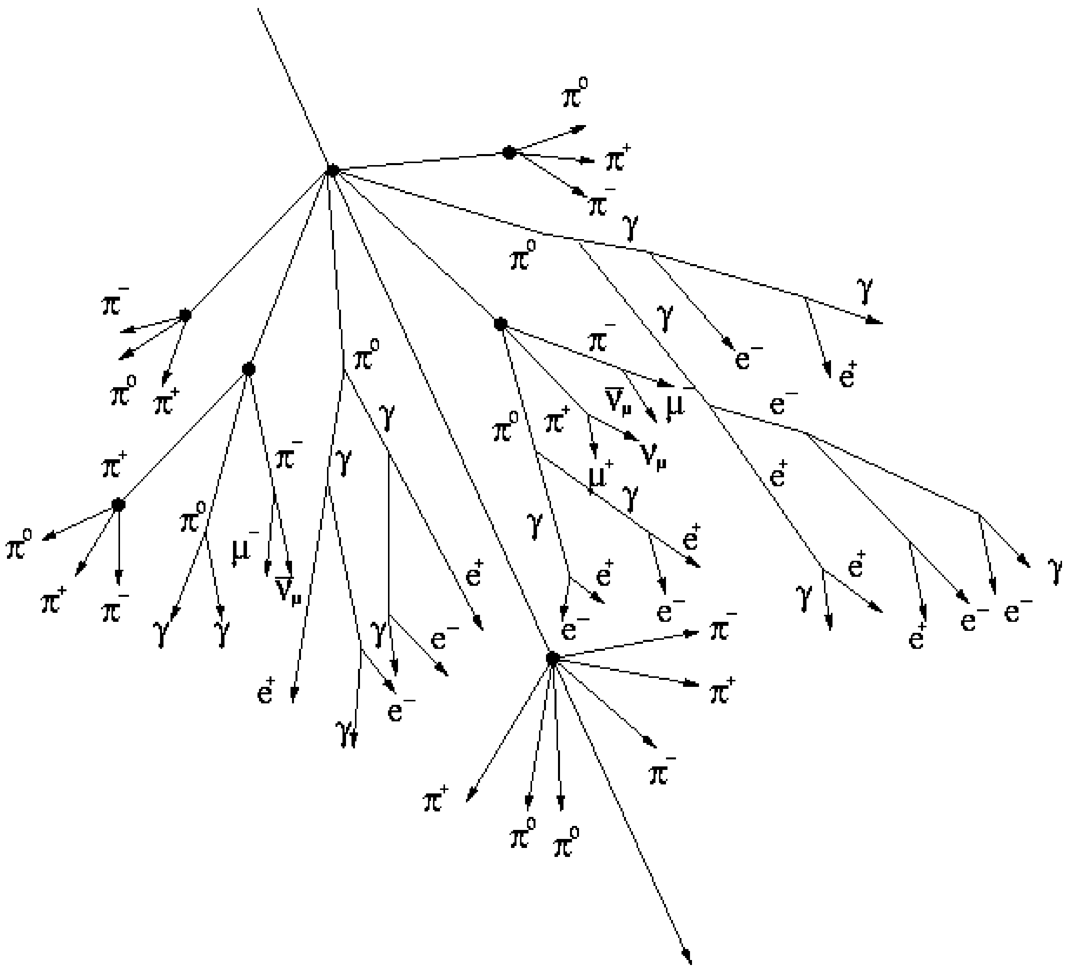
Shower Development

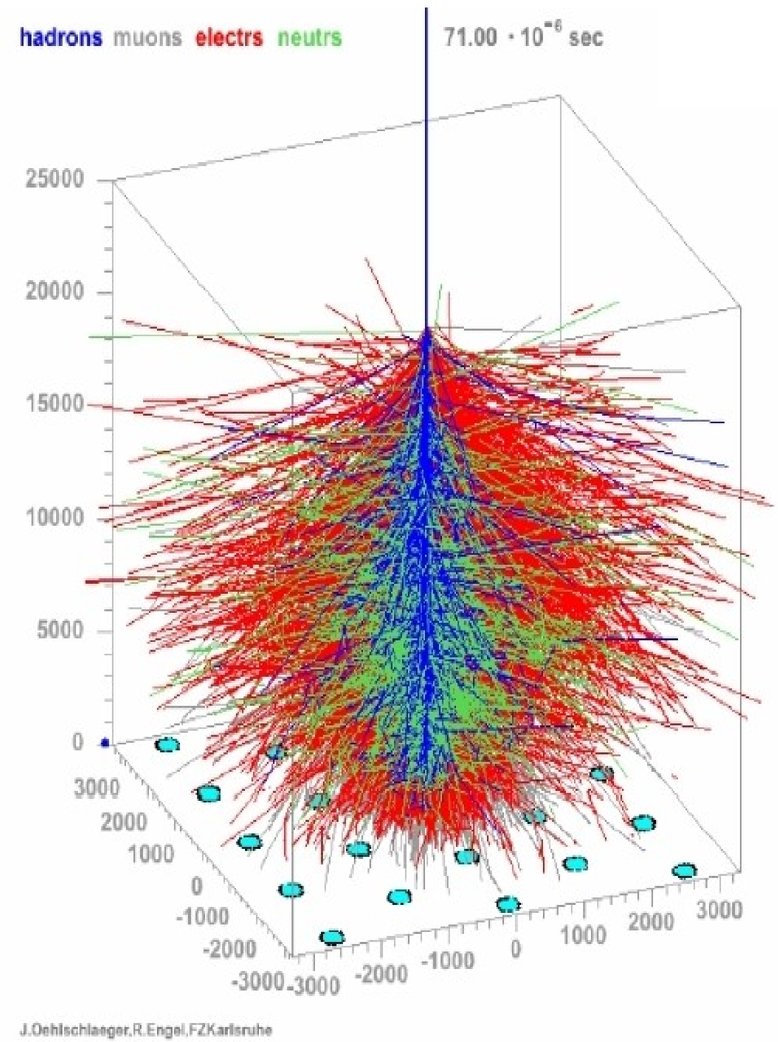
Measure Components

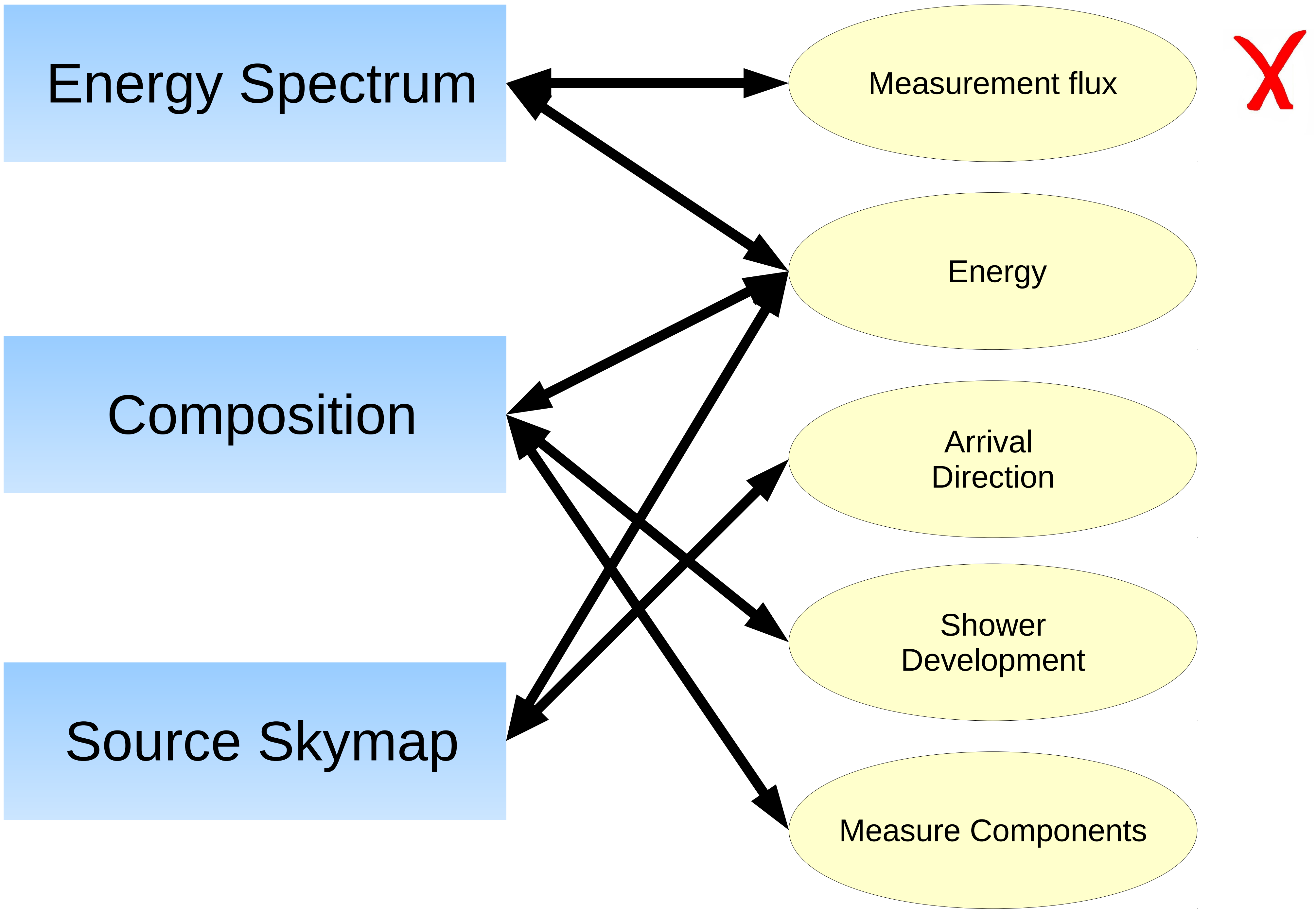

Measurement flux
Energy
Arrival Direction
Shower Development
Measure Components


Measurement flux
Energy
Arrival
Direction
Shower
Development
Measure Components

Extensive Air Shower

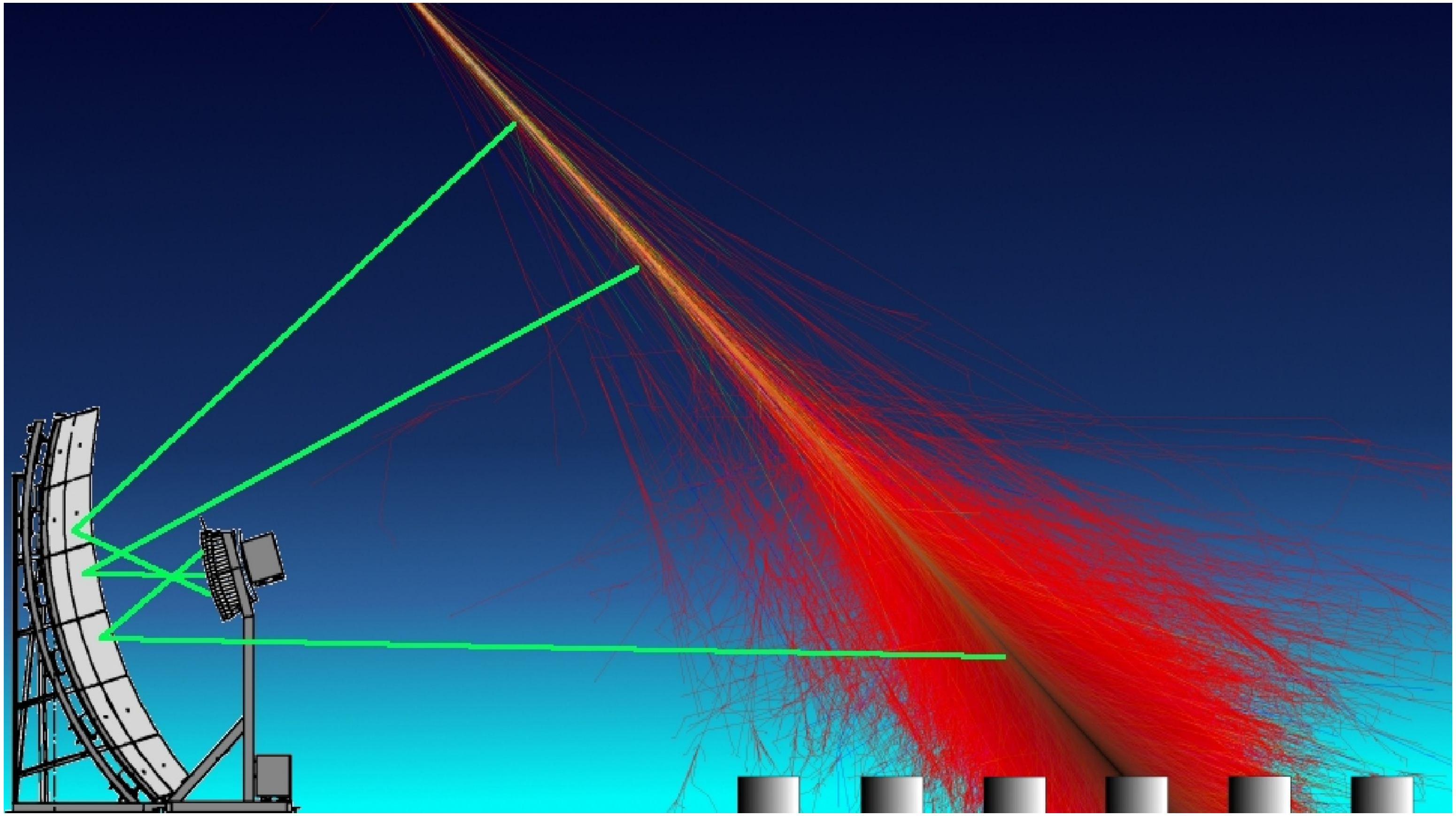






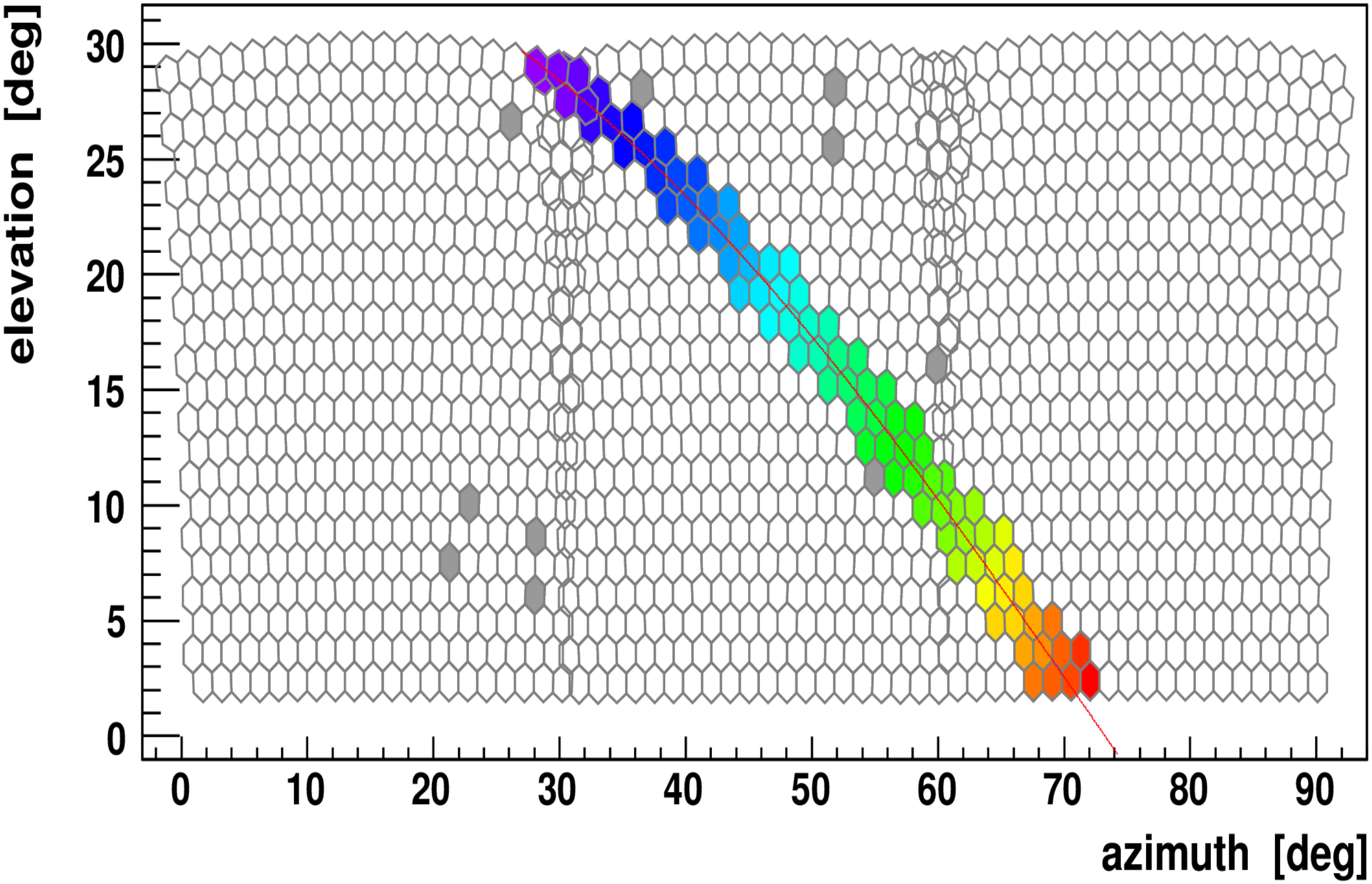
Energy Spectrum
Composition
Source Skymap
Measurement flux
Energy
Arrival Direction
Shower Development
Measure Components

Telescope view



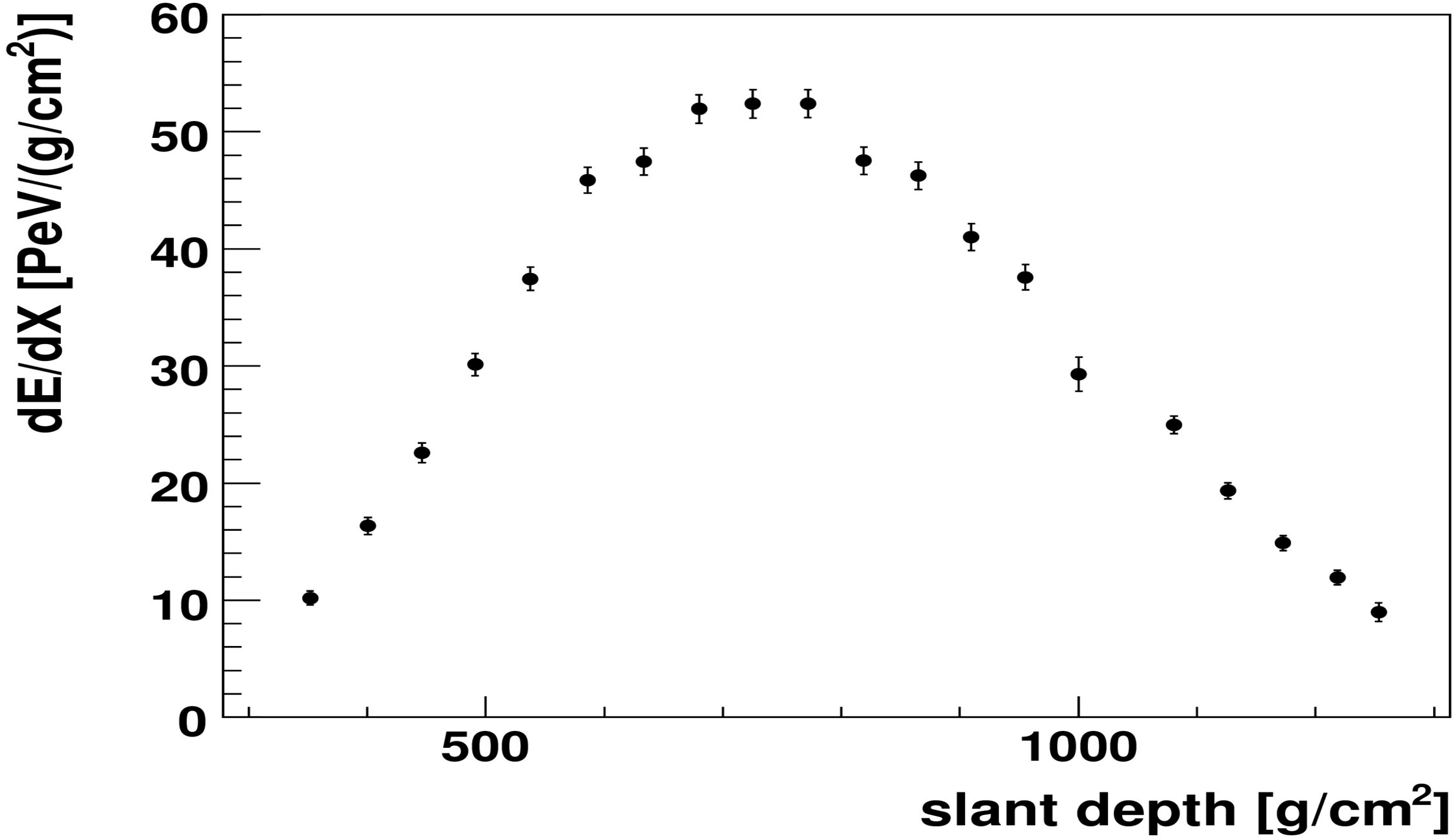
Telescopes measure the intensity and arrival time
of the fluorescence light

Camera view



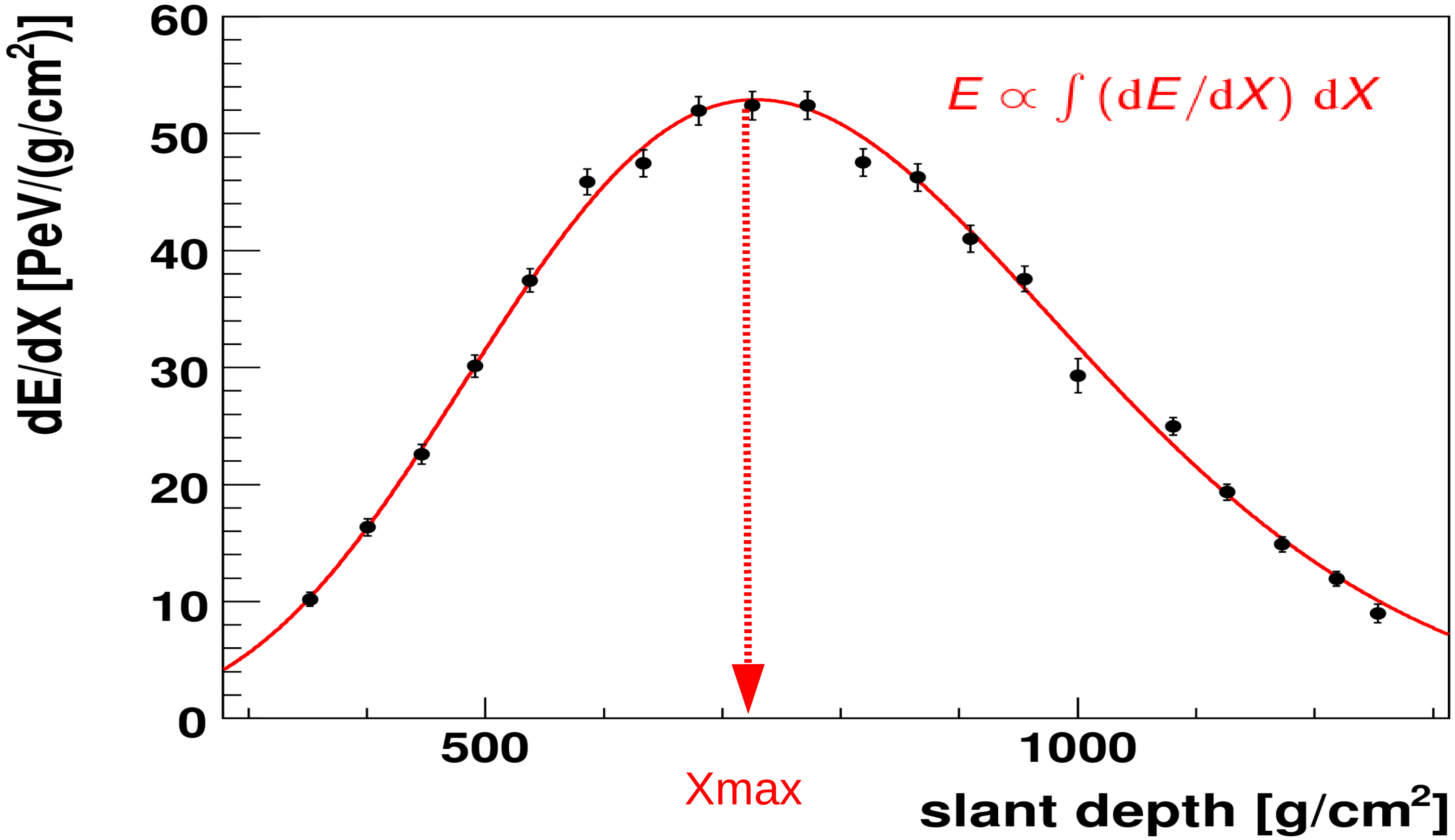
Telescopes measure the intensity and arrival time of the fluorescence light

Longitudinal Profile

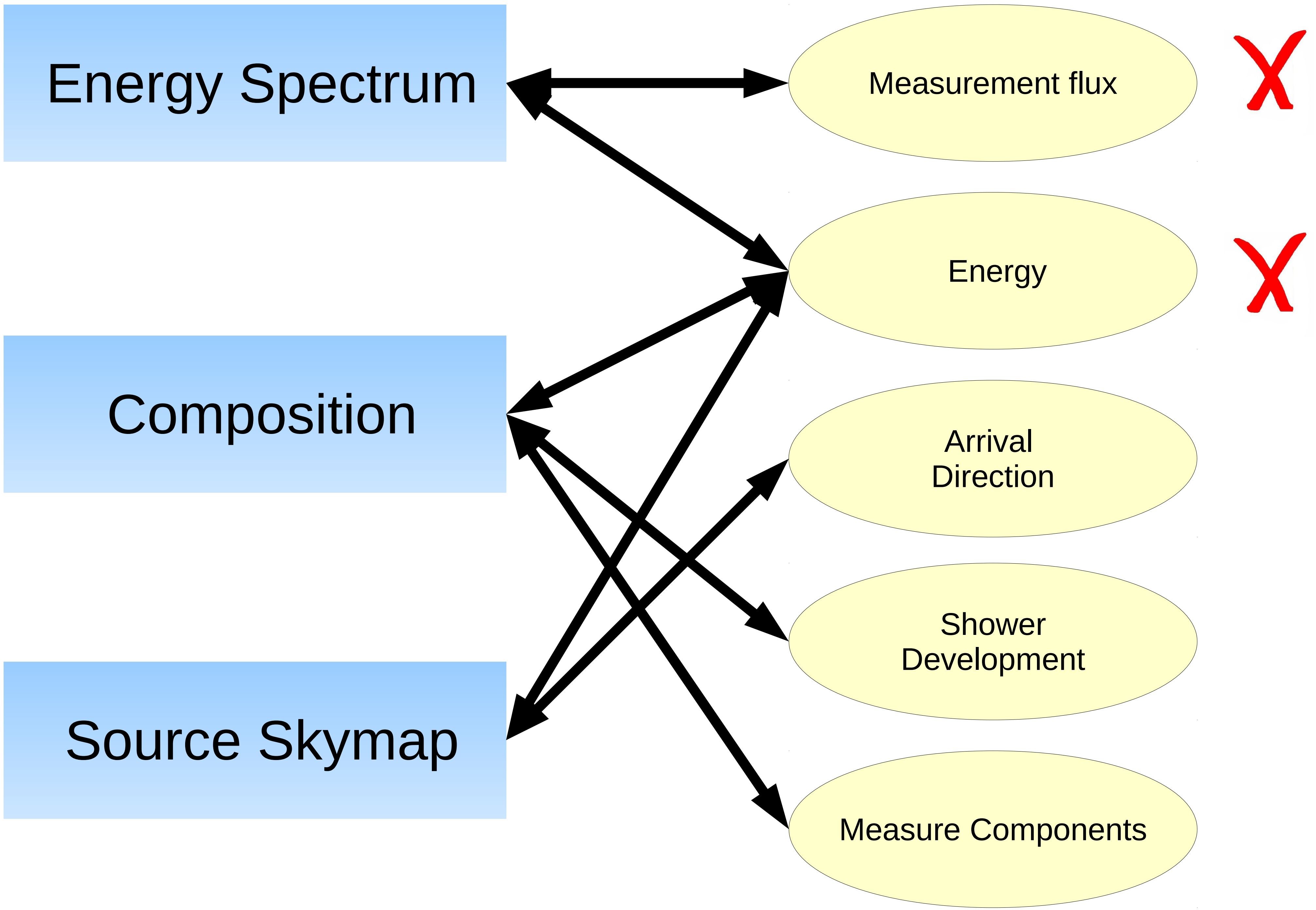


The intensity as a function of elevation can be transformed into the energy deposited in the atmosphere as a function of depth

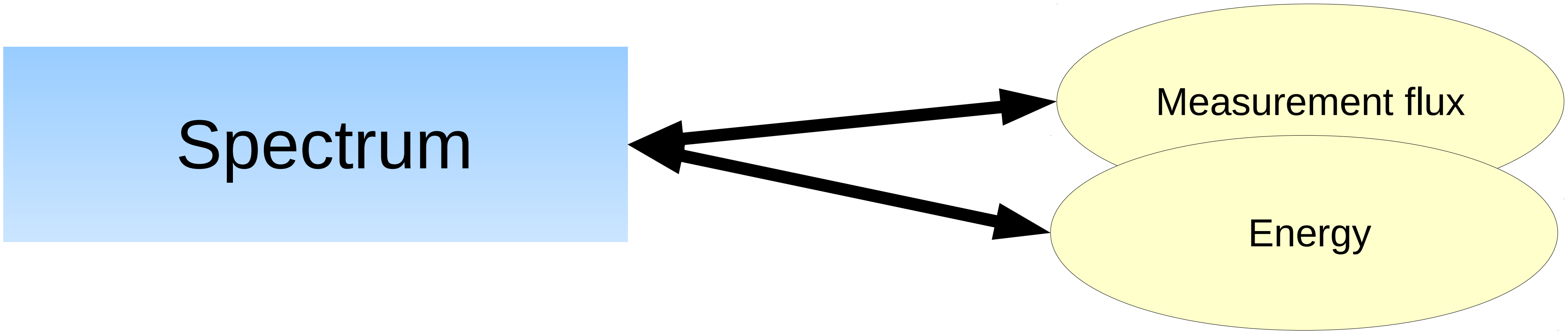
Fitting the Longitudinal Profile

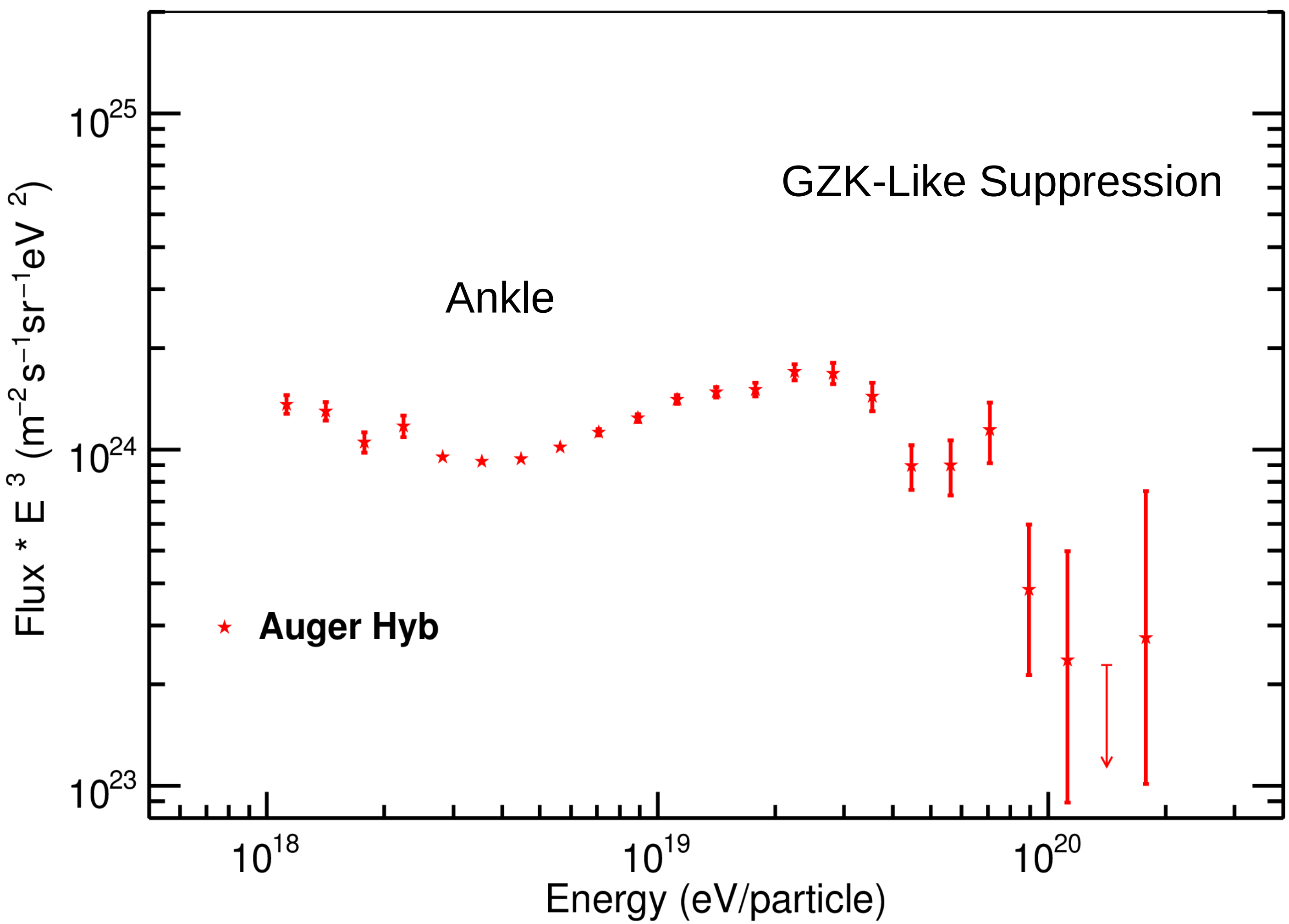


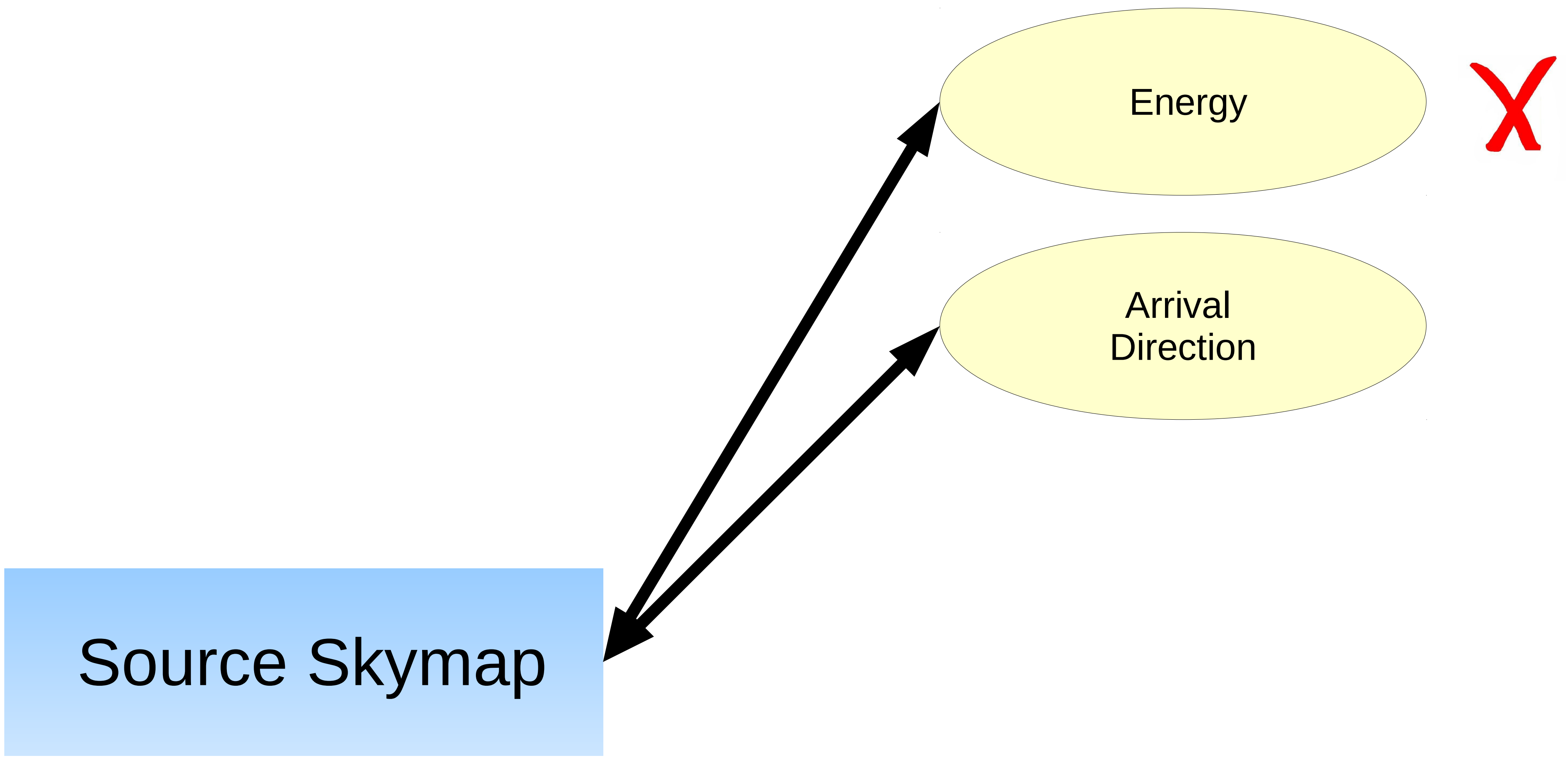
The total calorimetric energy of the shower is proportional to the integral of the energy deposited



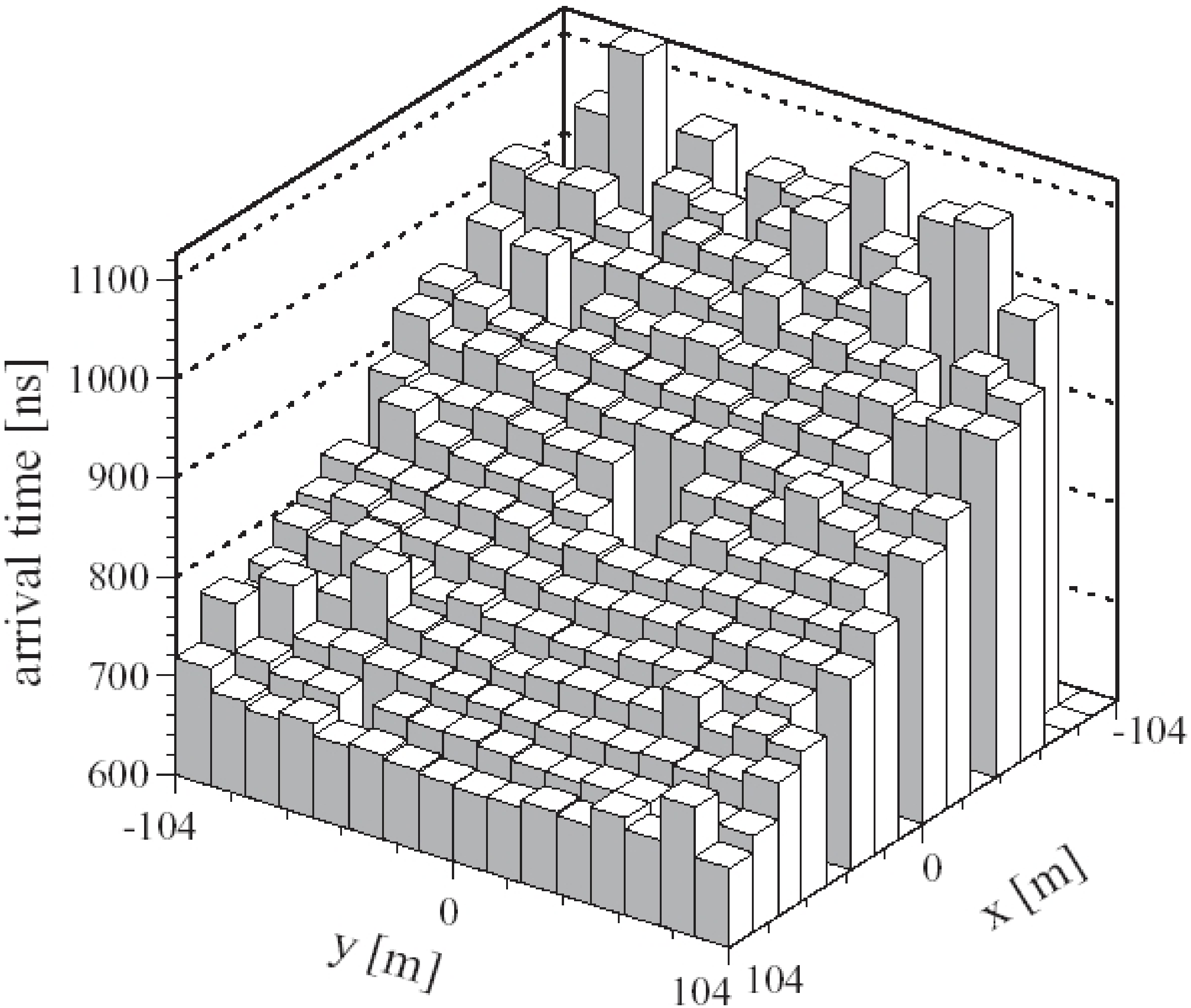
Energy Spectrum
Composition
Source Skymap
Measurement flux
Energy
Arrival Direction
Shower Development
Measure Components


Spectrum
Measurement flux
Energy

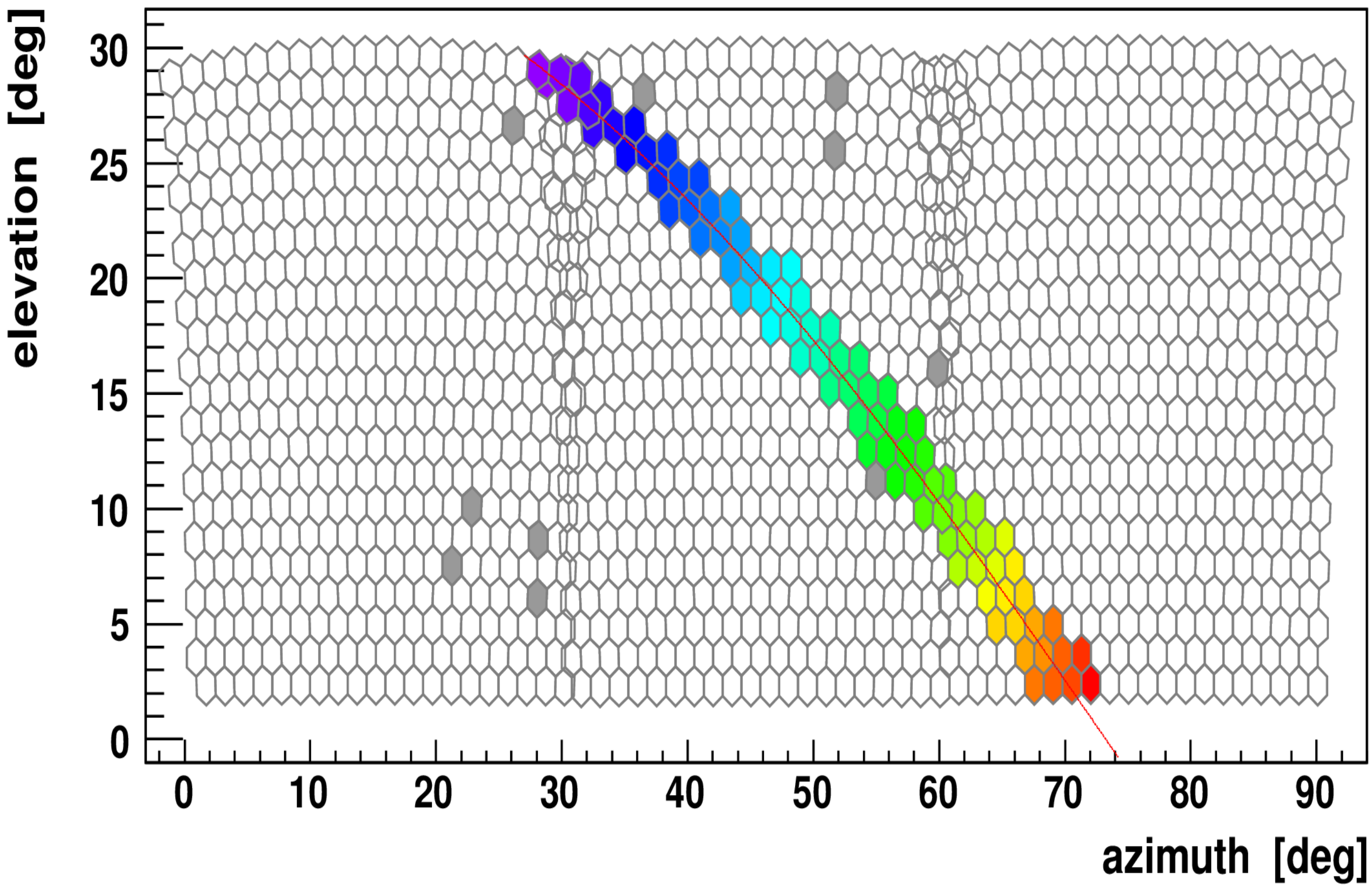

GZK-Like Suppression
Ankle
Auger Hyb
Flux * E 3 (m−2s−1sr−1eV 2)
Energy (eV/particle)
10^25
10^24
10^23
10^18
10^19
10^20


Energy
Arrival Direction
Source Skymap

Arrival Direction



Camera view



Telescopes measure the intensity and arrival time of the fluorescence light

Hybrid Angular Resolution

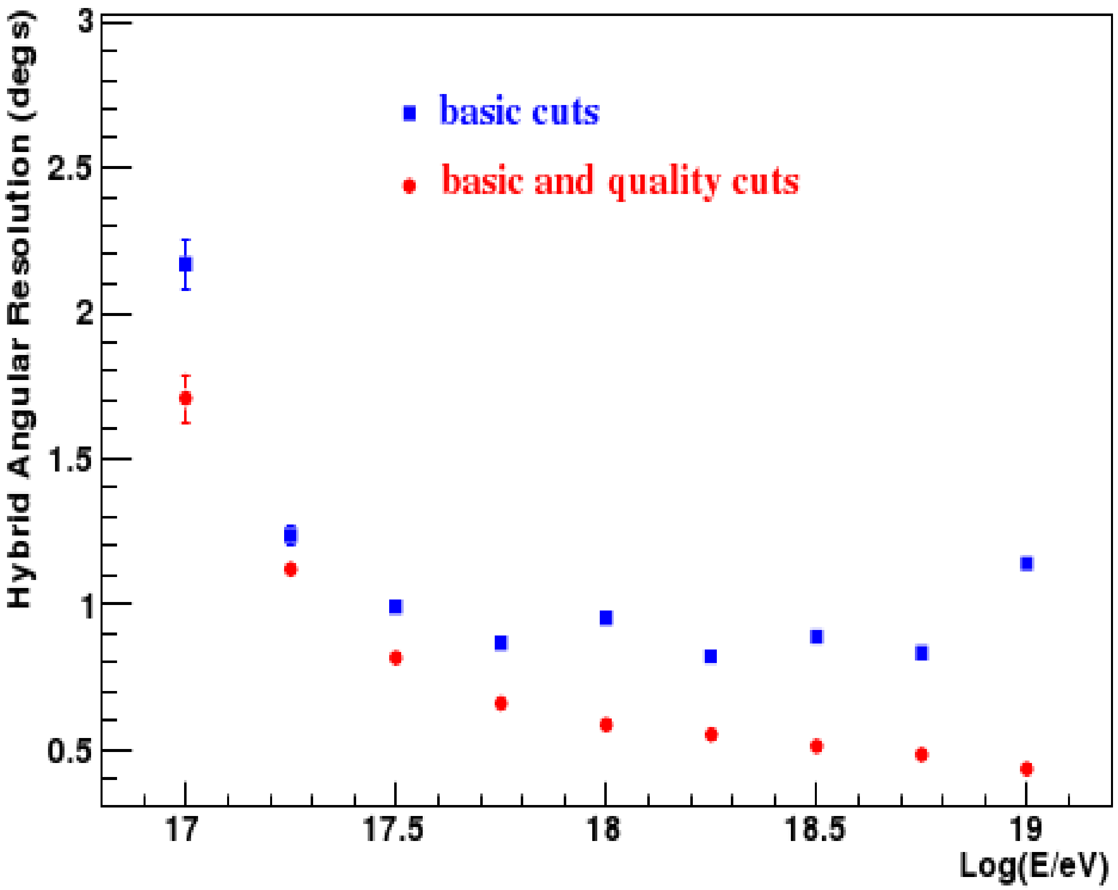
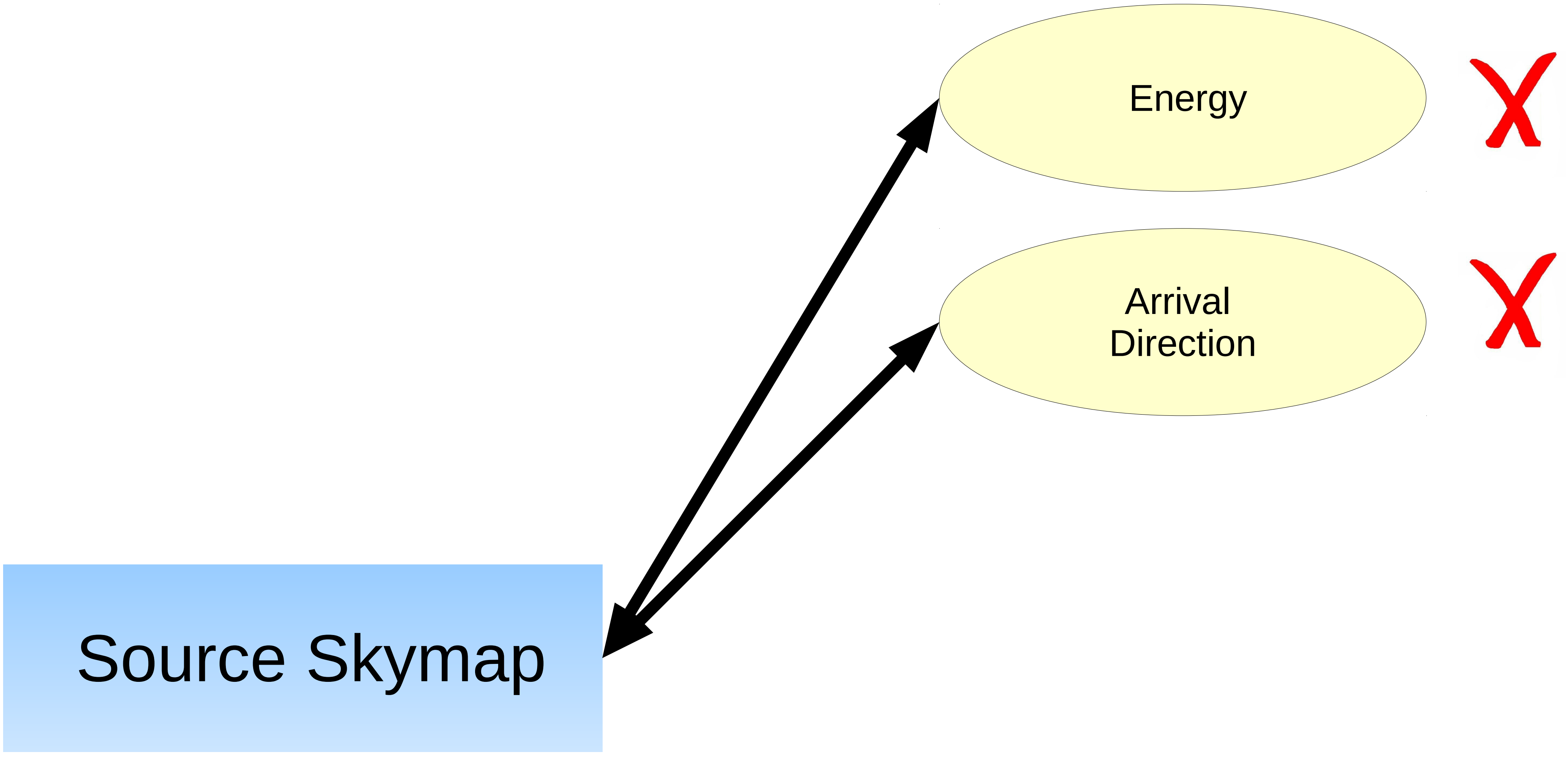
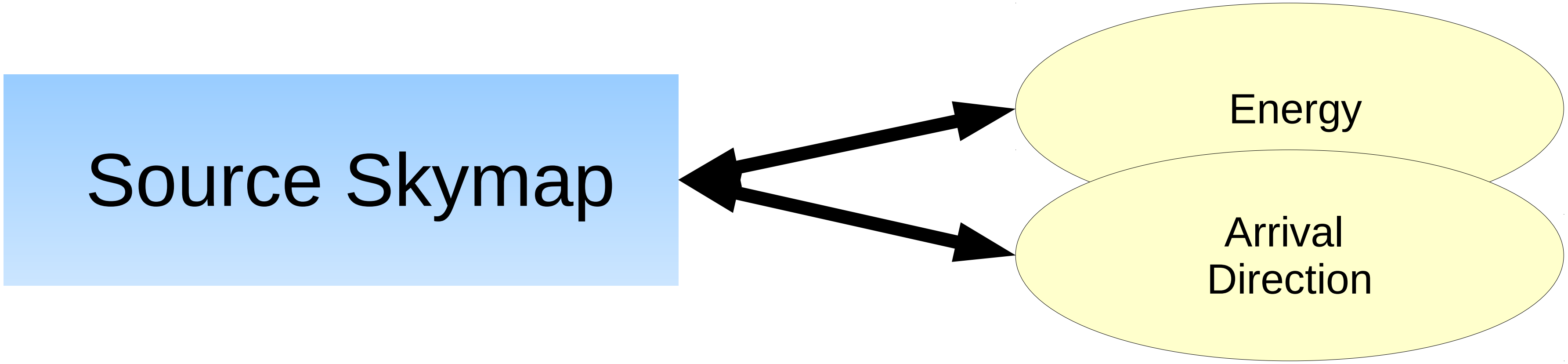


Figure 4: Hybrid angular resolution as a function of the true energy.


Energy
Arrival
Direction
Source Skymap



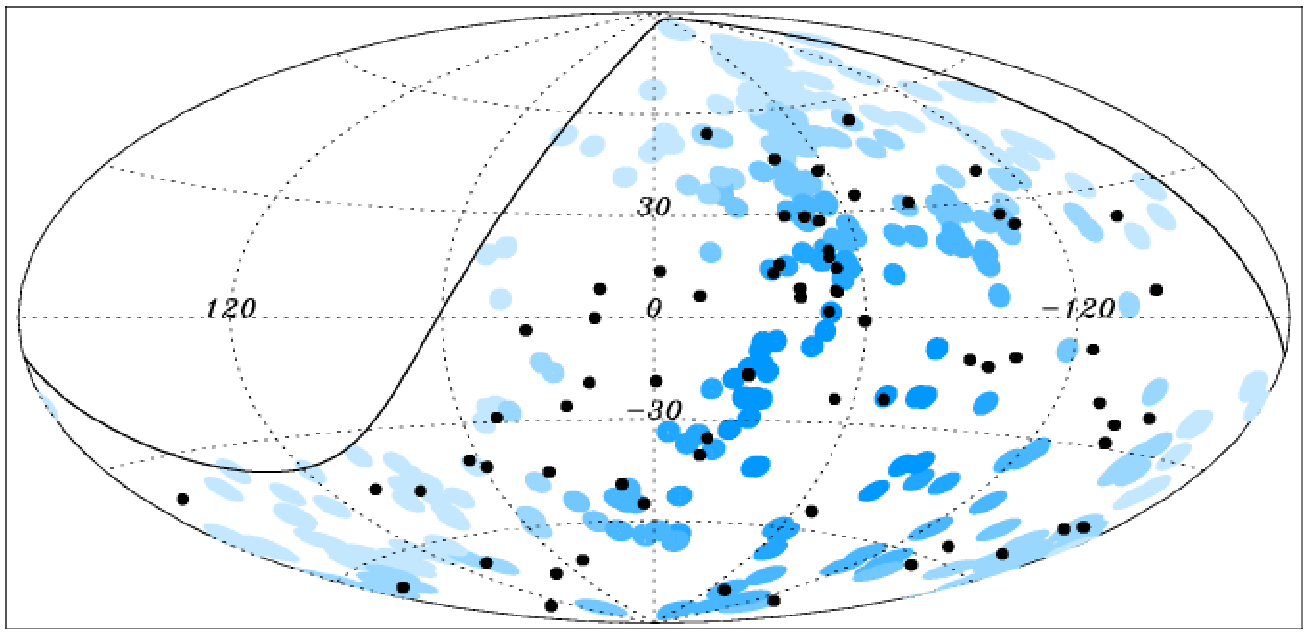


Figure 1: The 69 arrival directions of CRs with energy $E \geq 55$ EeV detected by the Pierre Auger Observatory up to 31 December 2009 are plotted as black dots in an Aitoff-Hammer projection of the sky in galactic coordinates. The solid line represents the field of view of the Southern Observatory for zenith angles smaller than 60°. Blue circles of radius 3.1° are centred at the positions of the 318 AGNs in the VCV catalog that lie within 75 Mpc and that are within the field of view of the Observatory. Darker blue indicates larger relative exposure. The exposure-weighted fraction of the sky covered by the blue circles is 21%.

AGN Correlation

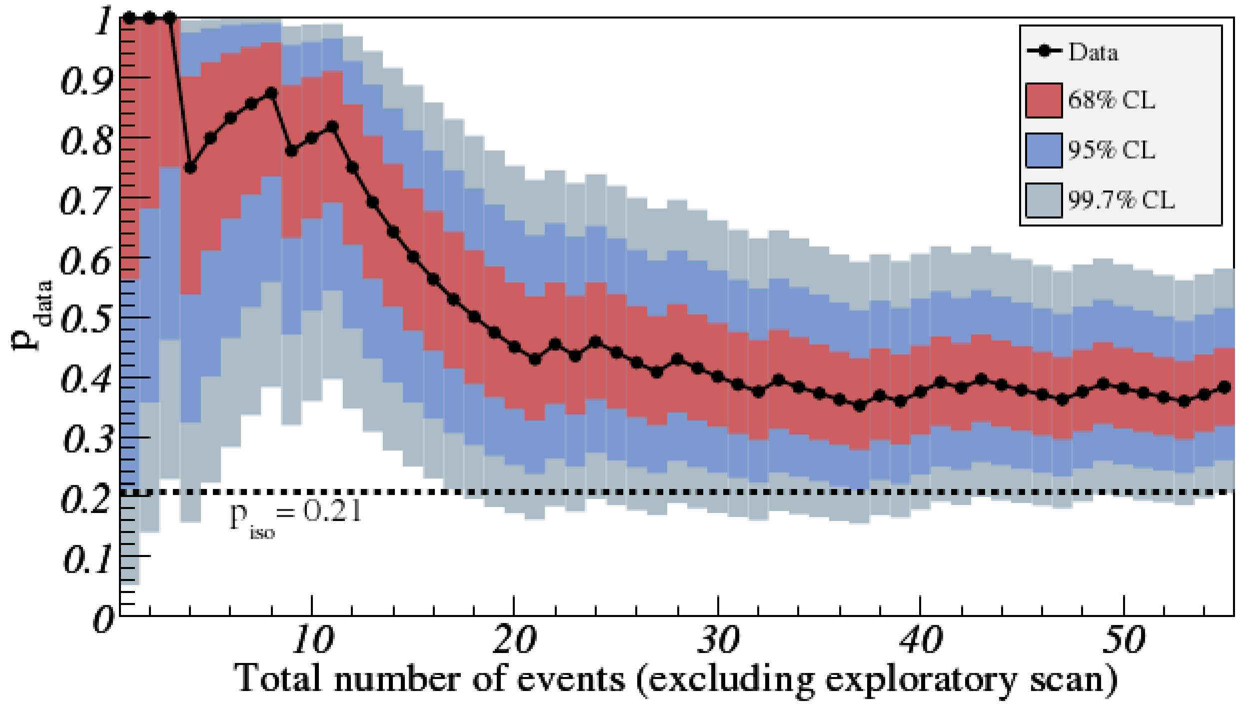
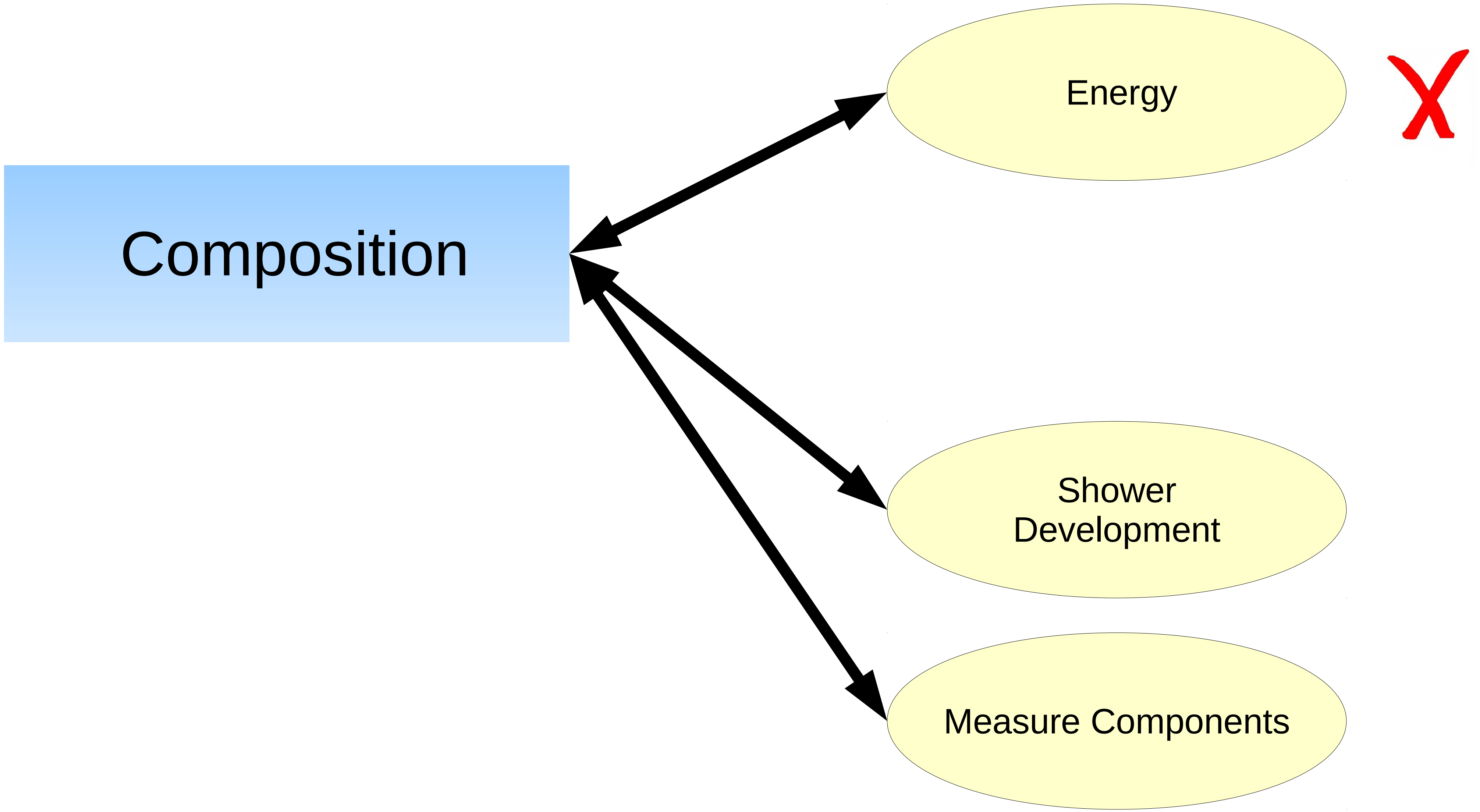
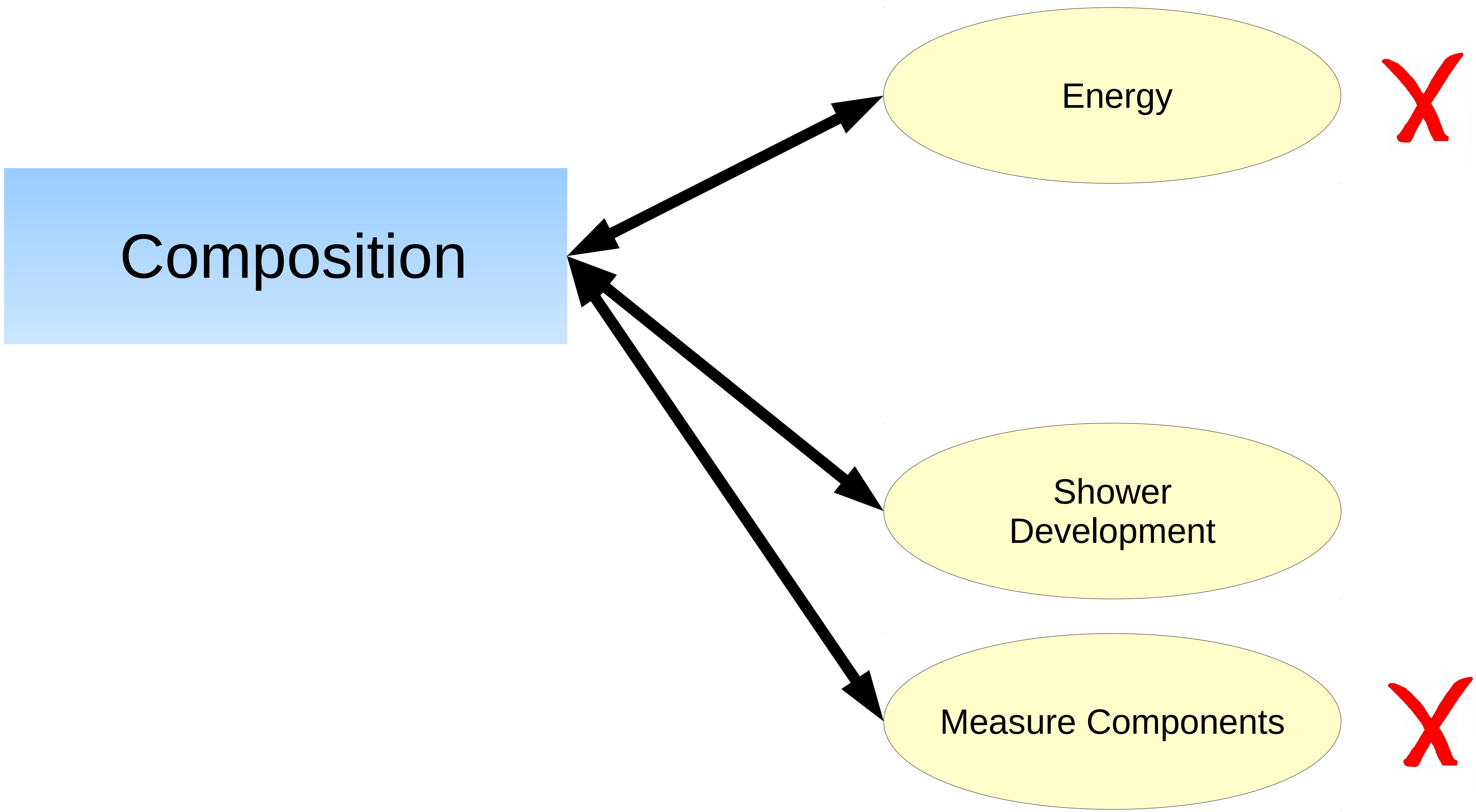
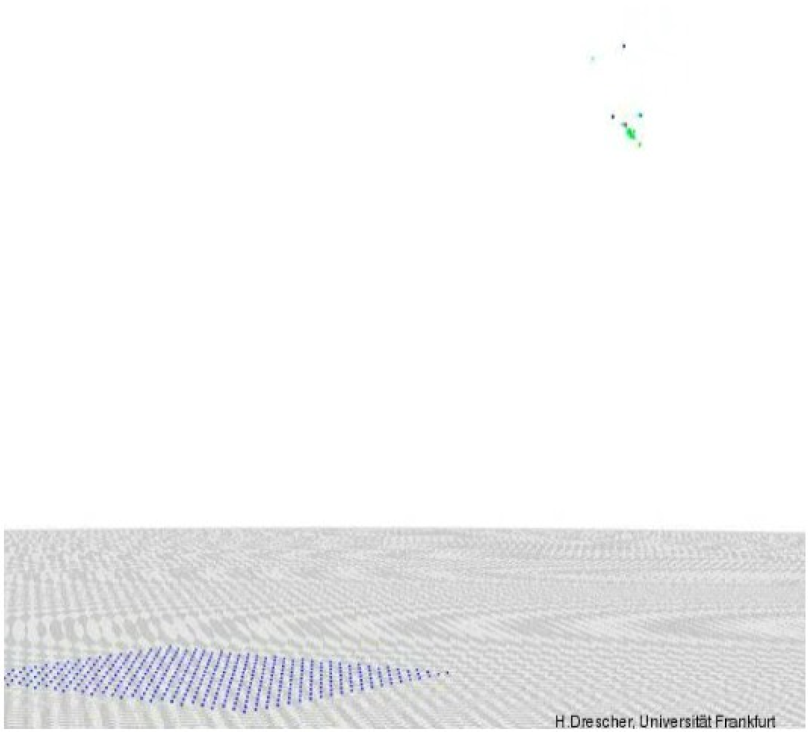


Figure 2: The most likely value of the degree of correlation $p_{\mathrm{data}} = k/N$ is plotted with black dots as a function of the total number of time-ordered events (excluding those in period I). The 68%, 95% and 99.7% confidence level intervals around the most likely value are shaded. The horizontal dashed line shows the isotropic value $p_{\mathrm{iso}} = 0.21$. The current estimate of the signal is $(0.38^{+0.07}_{-0.06})$.

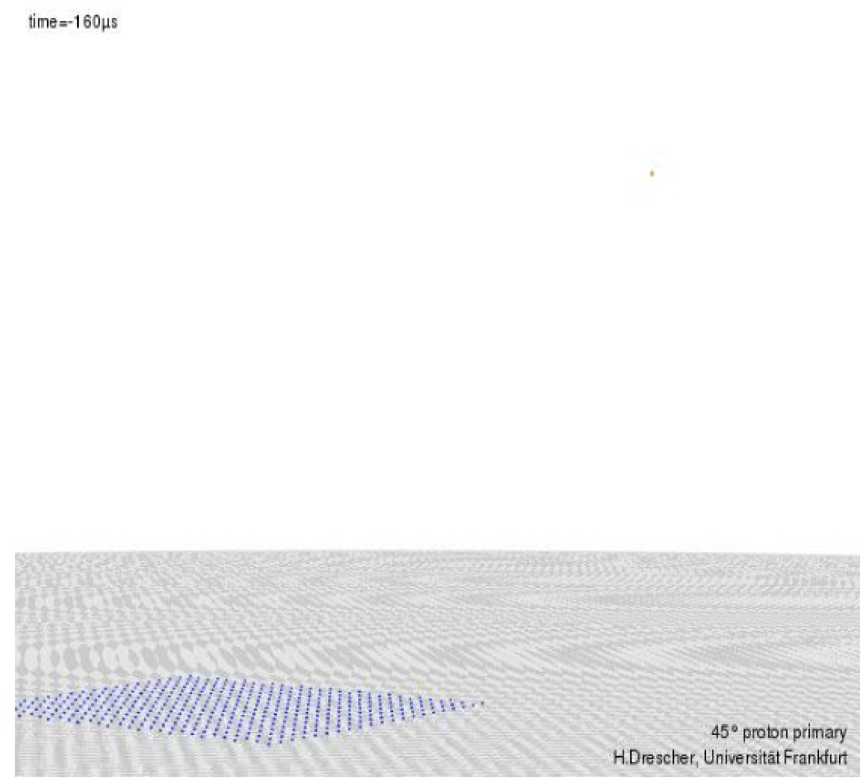

Composition
Energy
Shower
Development
Measure Components


Composition
Energy
Shower
Development
Measure Components

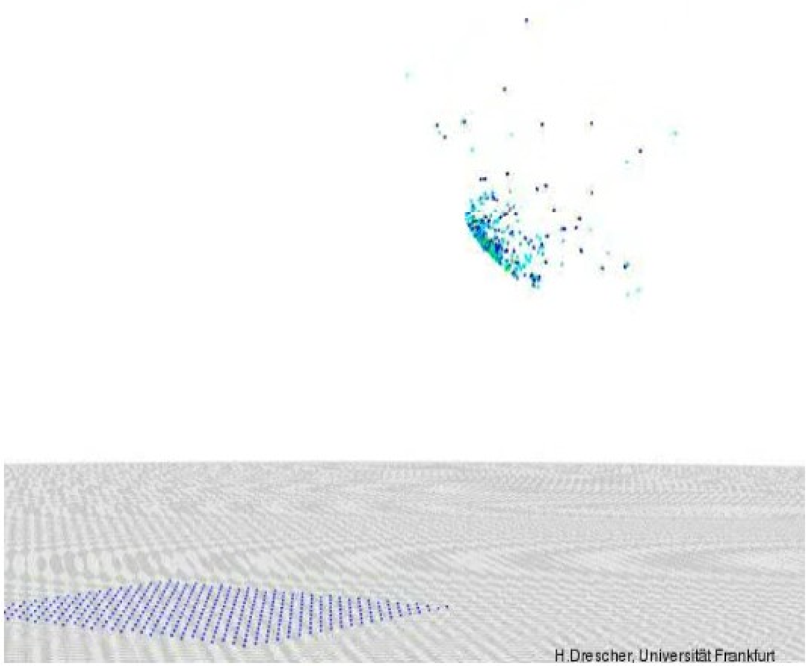
Ferro



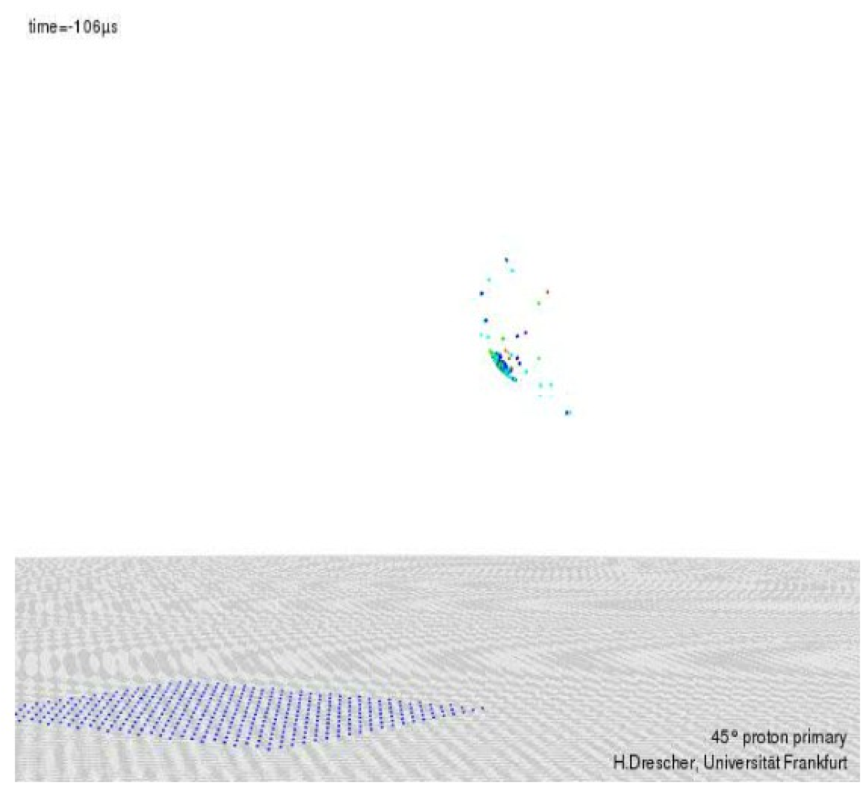
Próton



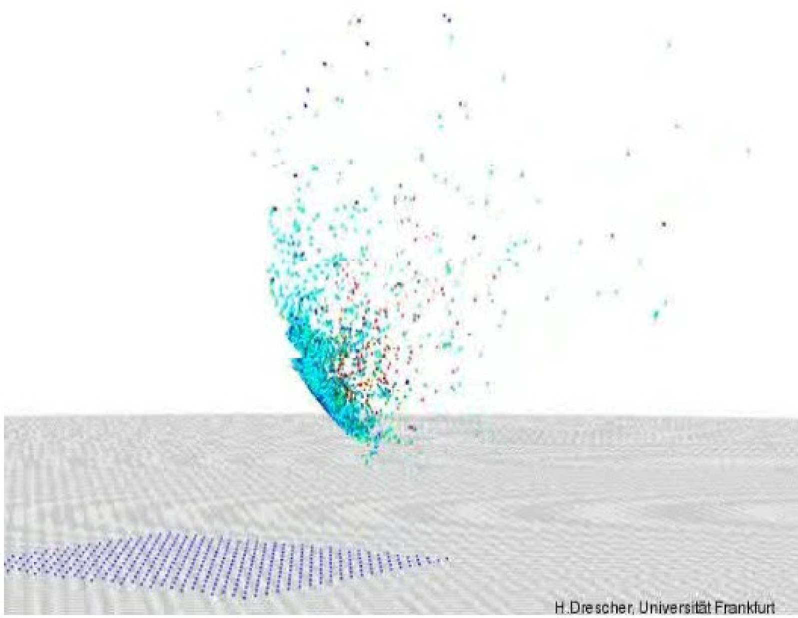
Ferro



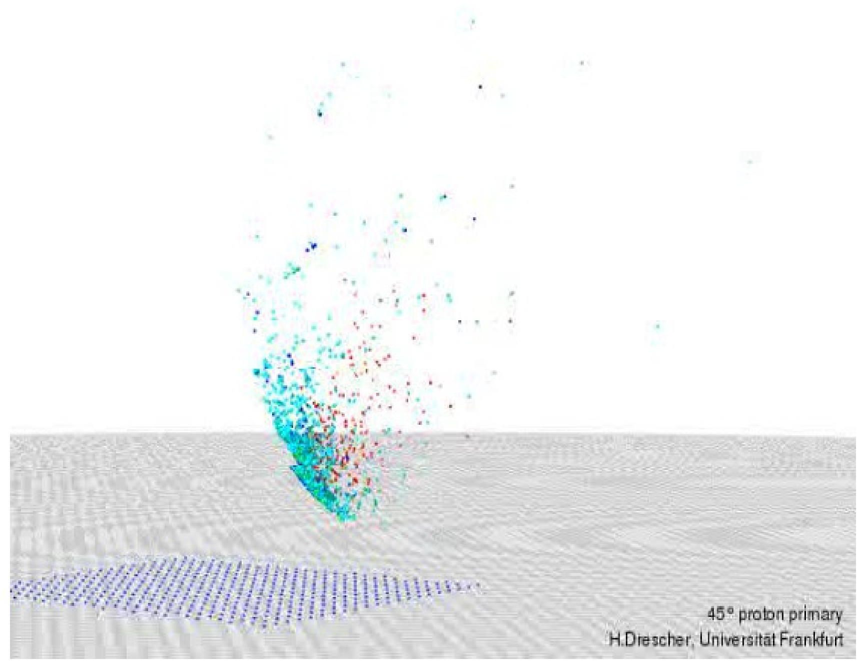
Próton

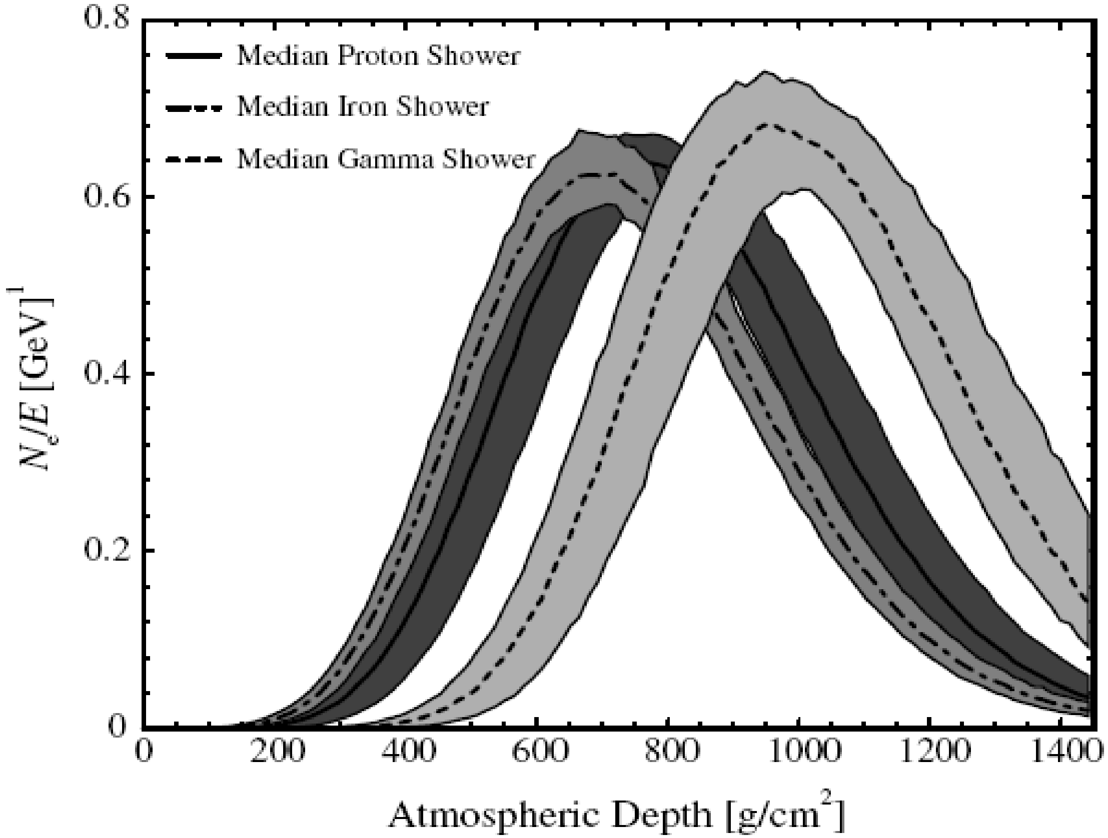


Ferro

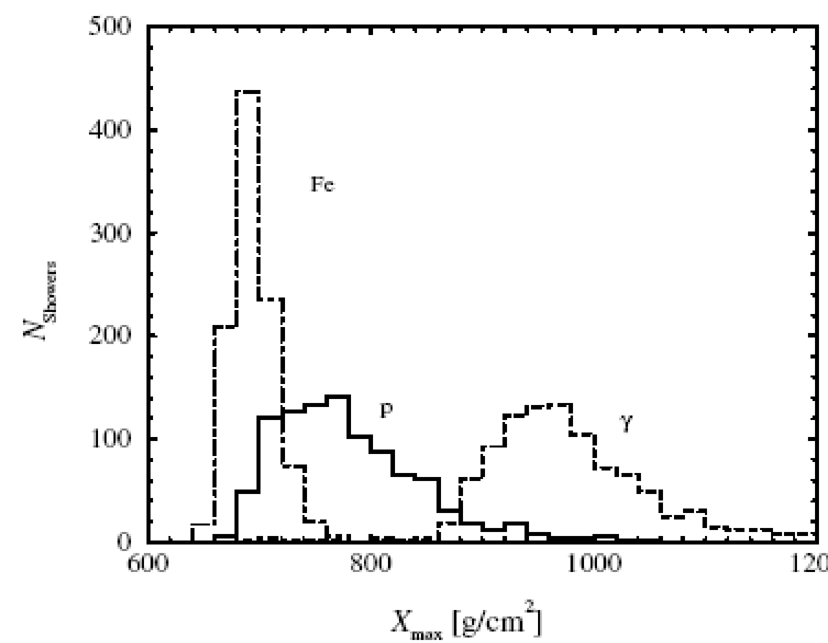


Próton

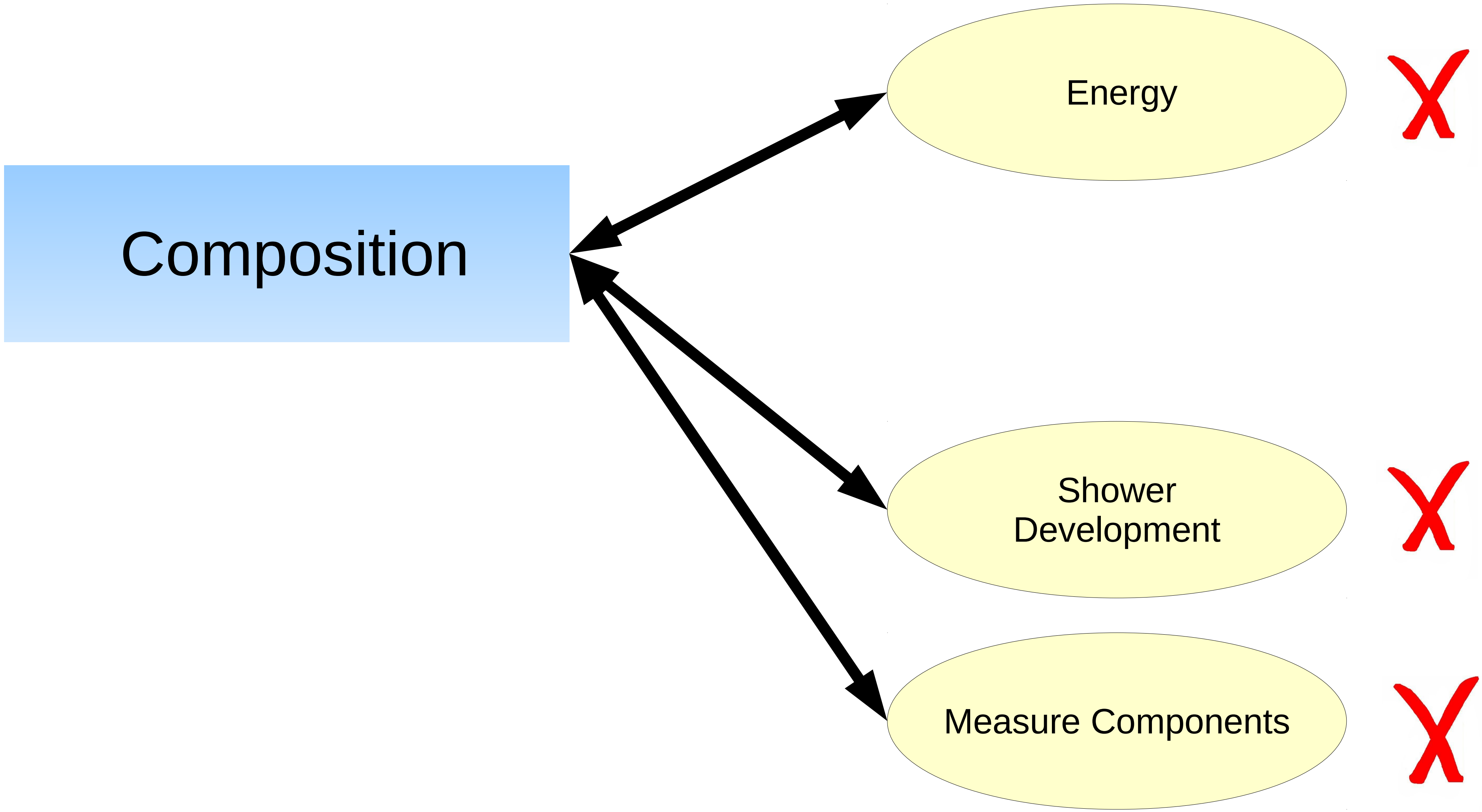




Median Proton Shower
Median Iron Shower
Median Gamma Shower
N_e/E [GeV]$^{-1}$
Atmospheric Depth [g/cm^2]



Fe
P
γ
$N_{Showers}$
X_{max} [g/cm^2]


Composition
Energy
Shower
Development
Measure Components

No photons detected

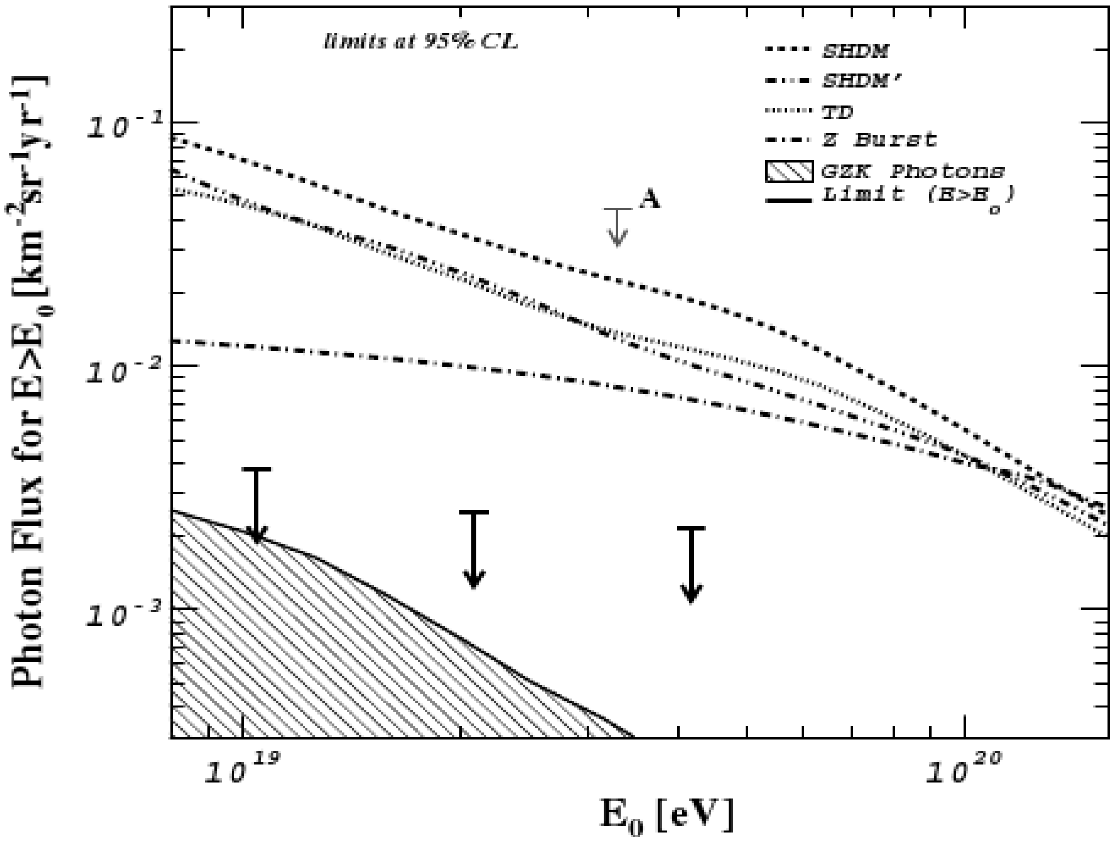


Fig. 8. The upper limits on the integral flux of photons derived in this work (black arrows) along with predictions from top-down models (SHDM, TD and ZB from Ref. [21], SHDM' from Ref. [12]) and with predictions of the GZK photon flux [21]. A flux limit derived indirectly by AGASA ("A") is shown for comparison [29].

No neutrinos detected

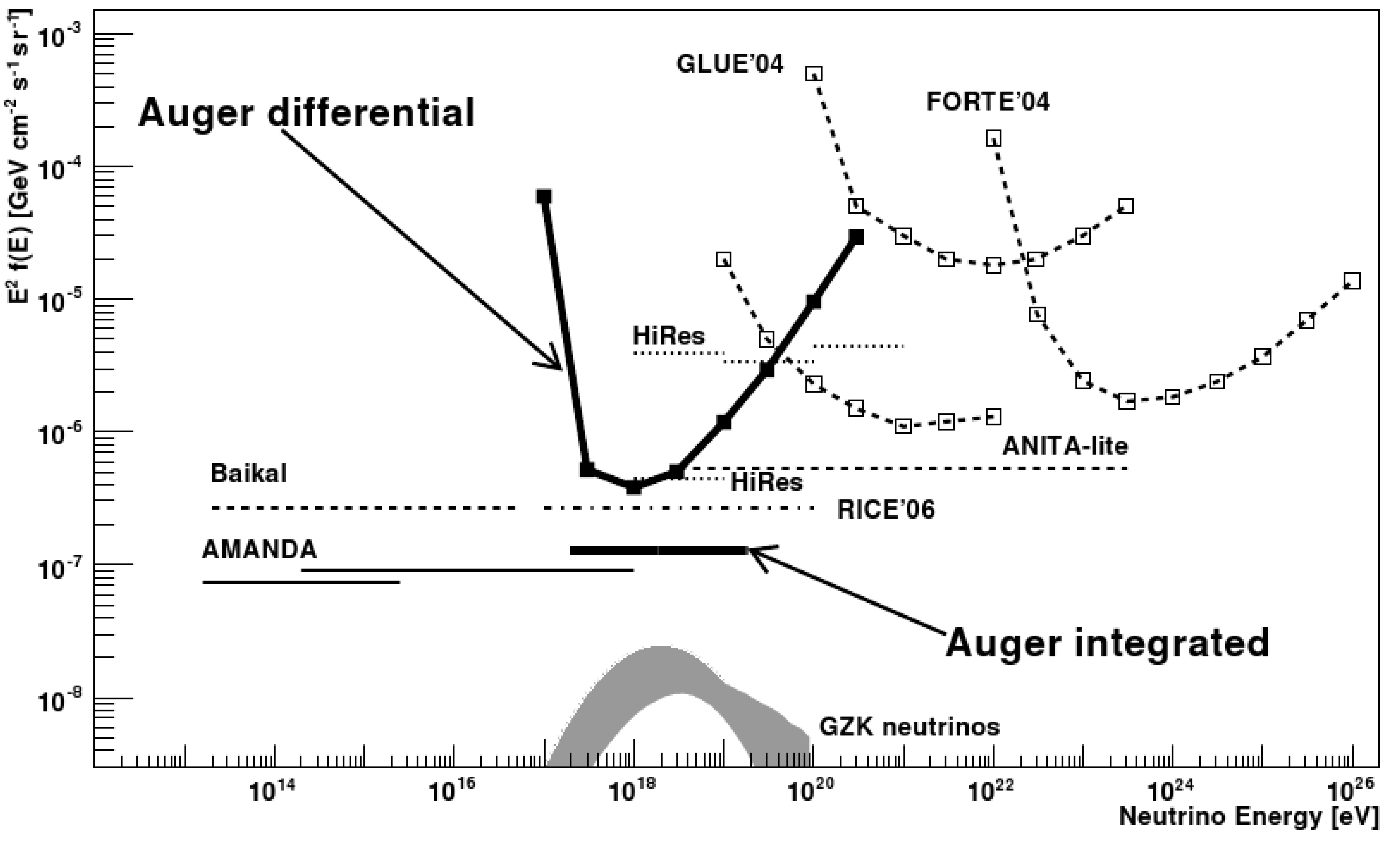
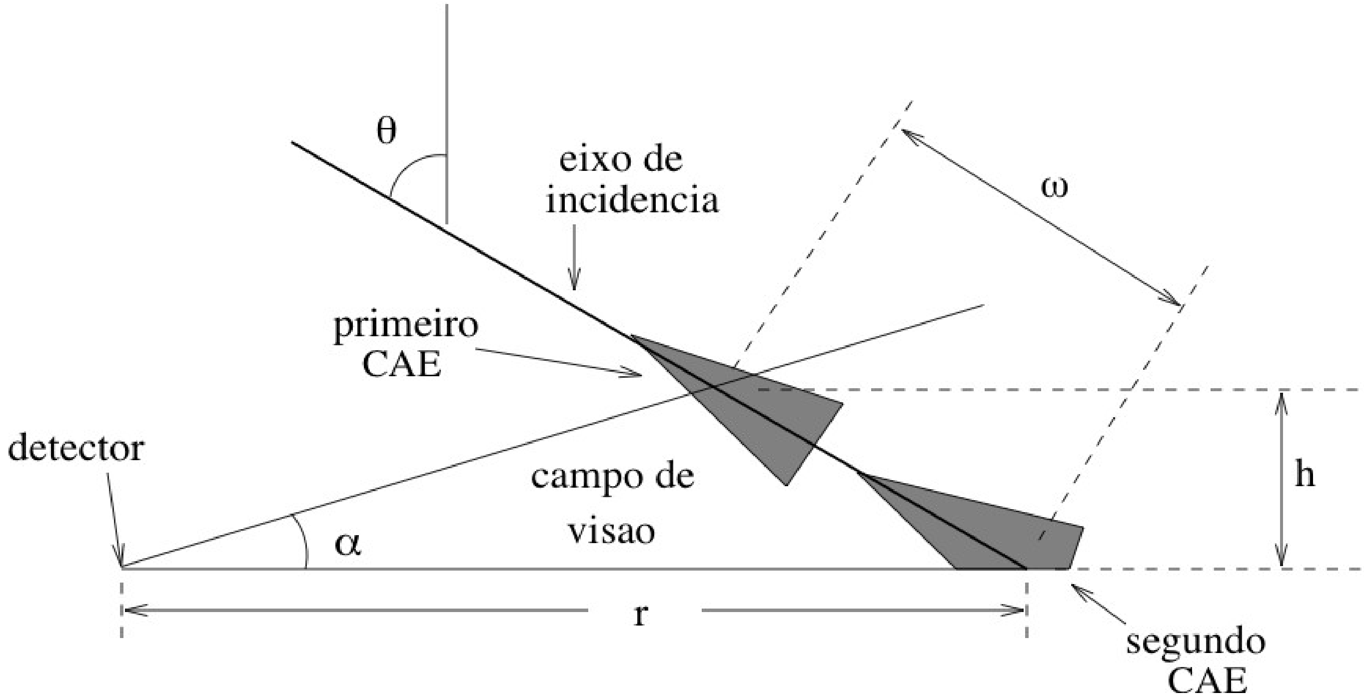


FIG. 3: Limits at 90% C.L. for a diffuse flux of ν_τ from the Pierre Auger Observatory. Limits from other experiments [36–43] are converted to a single flavour assuming a 1 : 1 : 1 ratio of the 3 neutrino flavours and scaled to 90% C.L. where needed. Two different formats are used: differential (squares) and integrated (constant lines). The shaded curve shows the range of expected fluxes of GZK neutrinos from Ref. [10, 11], although predictions almost 1 order of magnitude lower and higher exist.

Double Bangs in the Atmosphere

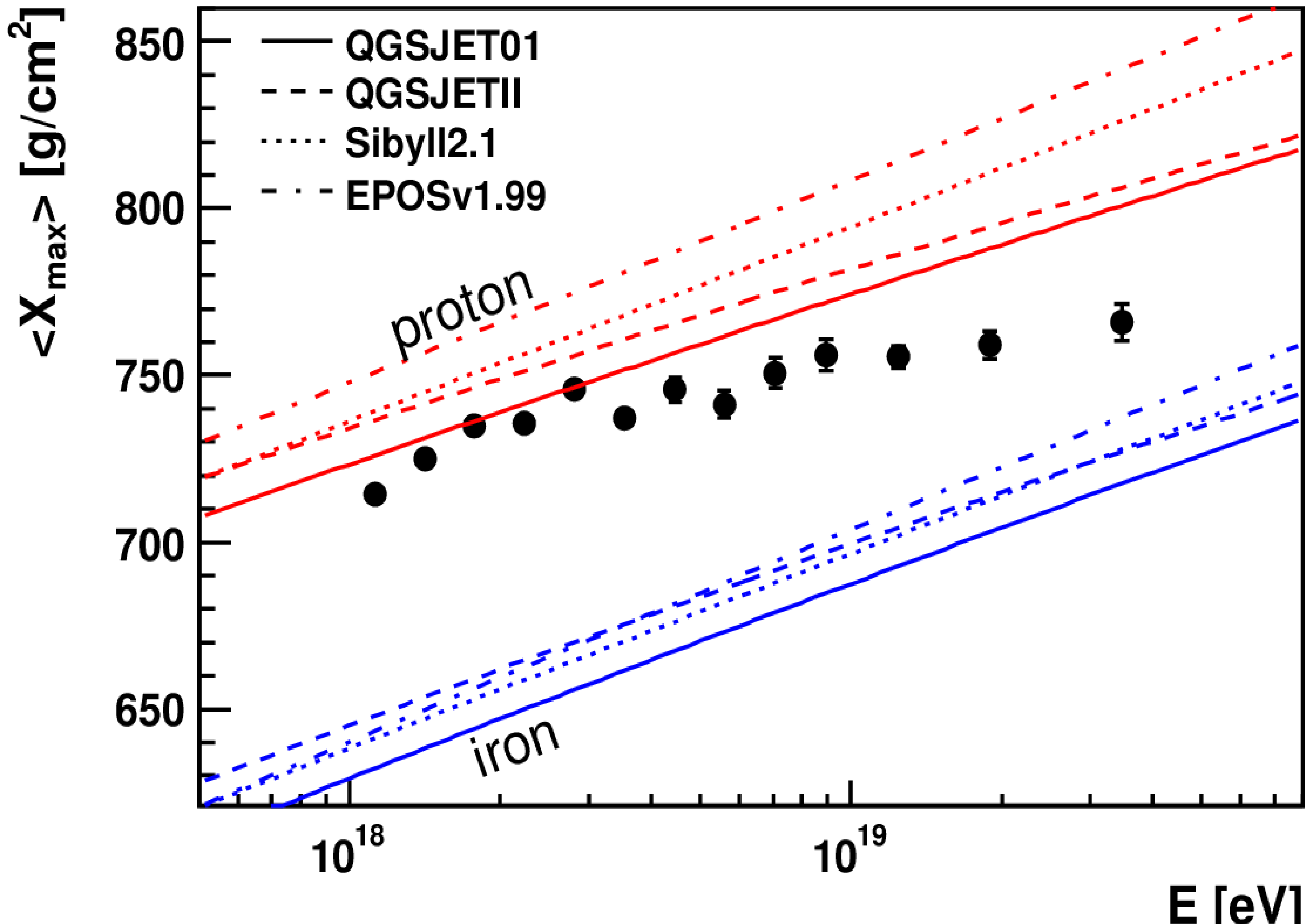


$$L \simeq \frac{E_\tau}{[\mathrm{EeV}]} \times 49\ \mathrm{km}$$
$$\simeq (1-y)\frac{E_\nu}{[\mathrm{EeV}]} \times 49\ \mathrm{km}$$

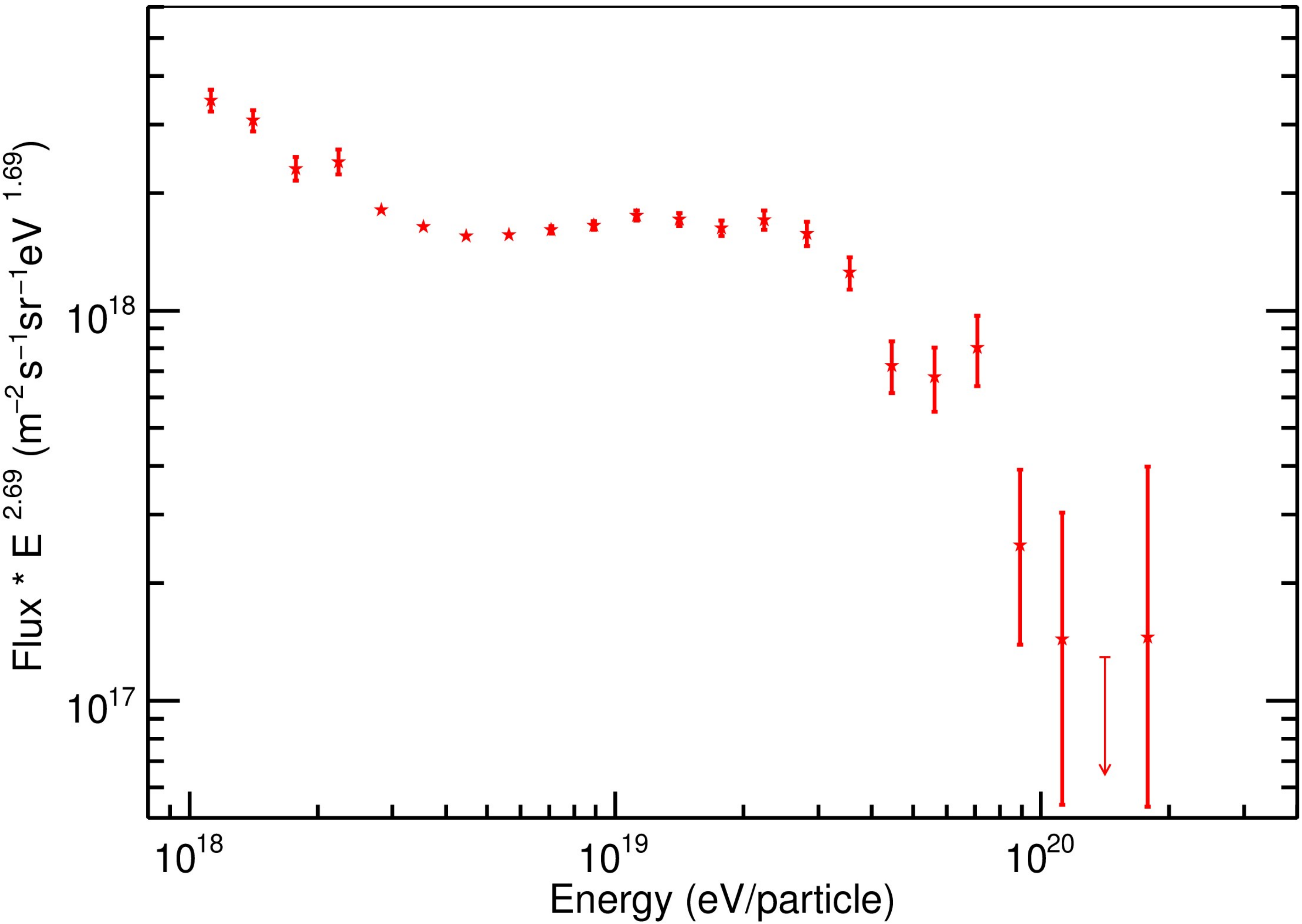
$$E_2 \approx 2E_\tau/3$$
$$\approx \frac{2}{3}(1-y)E_\nu$$

M. M. Guzzo and C. A. Moura, Astropart. Phys. 25, 277 (2006) [arXiv:hep-ph/0504270].

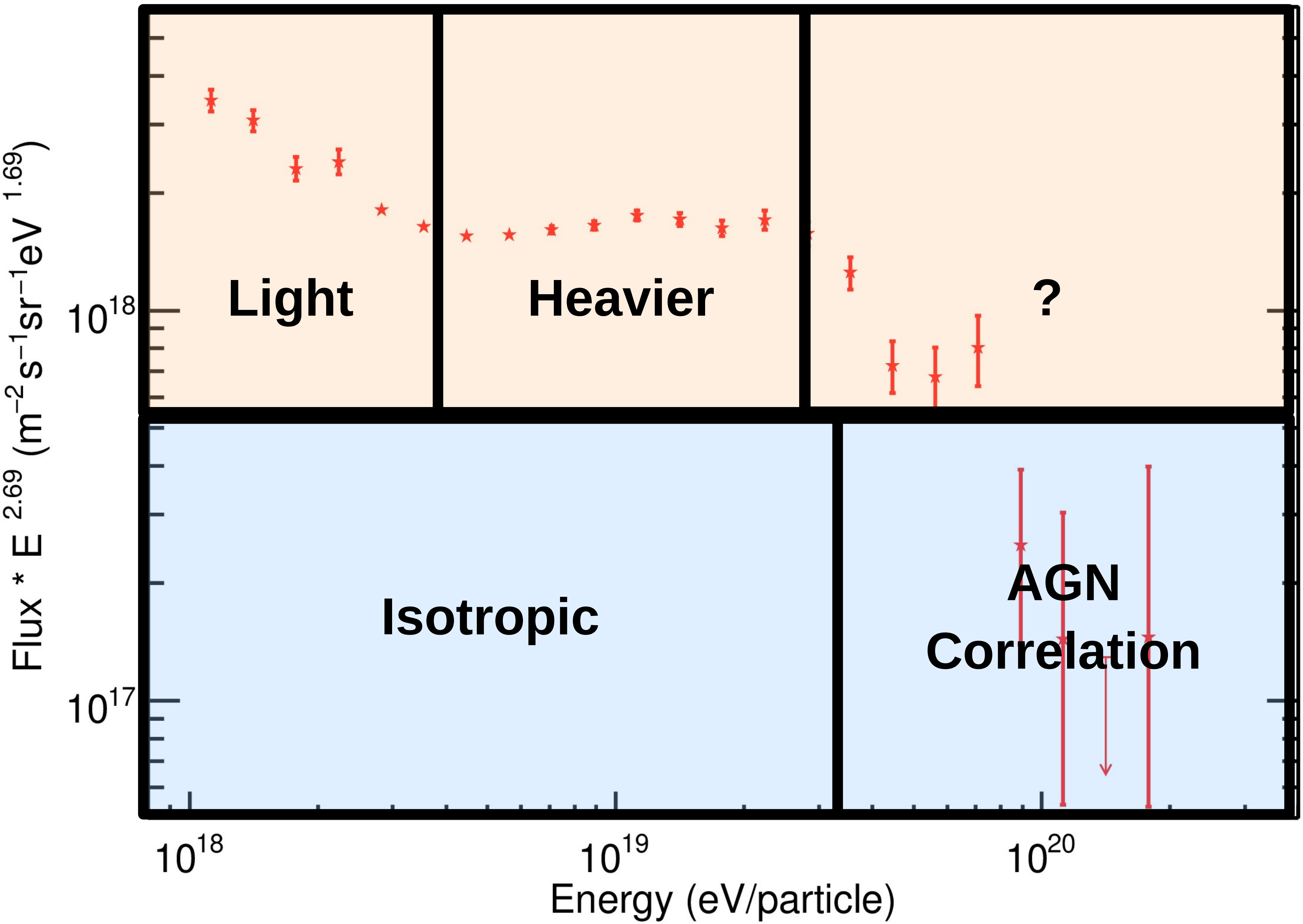
Composition



UHECR Puzzle



UHECR Puzzle



Questions

Is the suppression above $5x10^{19}$ eV due to interaction with the CMB or is it due to the source limit ?

How to reconcile the AGN correlation with A > 1 ?

Very low magnetic fields ?

Nearby source with enhanced flux and power ?

Questions

Are AGNs the sources

or are they only tracers ?

Is the composition change astrophysical

or do we need new particle physics for

$E_{lab} > 10^{18}$ eV ~ $E_{c.m.} > 5 \times 10^{14}$ eV ?

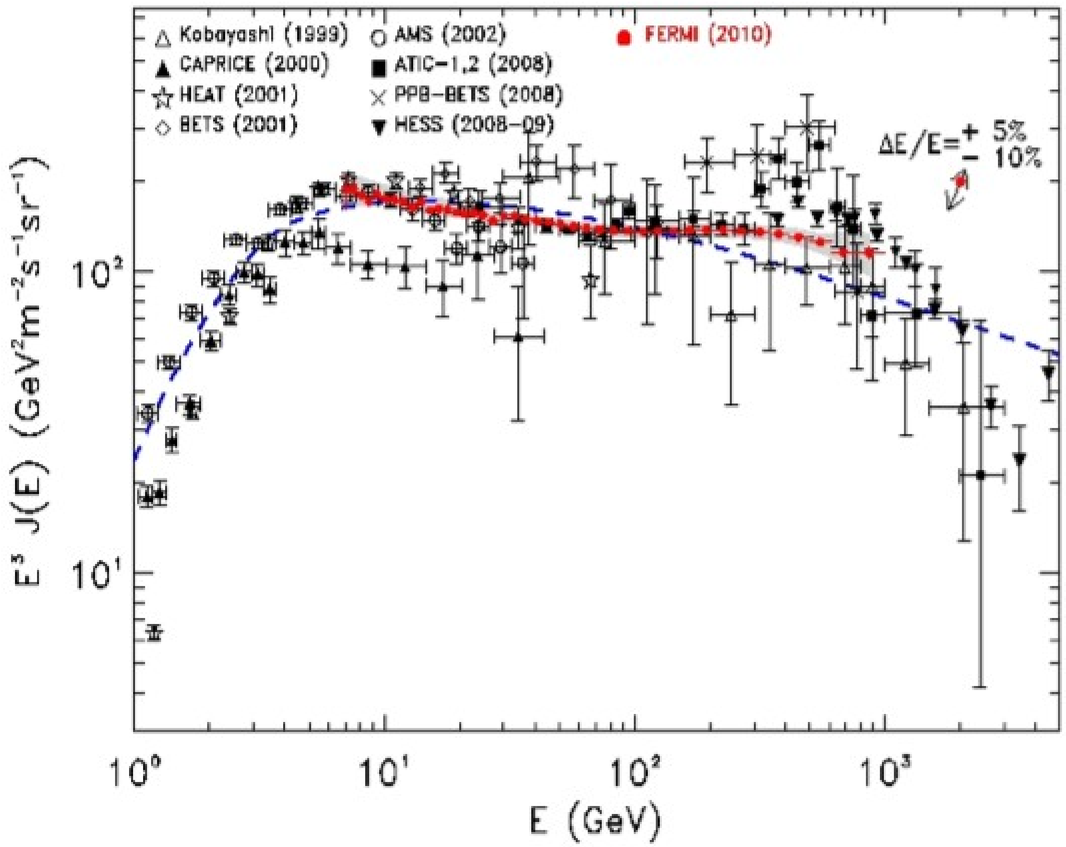
Questions

Is there something we do not understand

in the shower development ?

Questions

Is there any relation of all this with DM and DE?



Answers may come from

Auger, Auger North, JEM-EUSO:

nuclei, gammas, neutrinos;

IceCube, KM3Net (ANTARES, NEMO, NESTOR):

neutrinos;

Fermi, HESS, Magic:

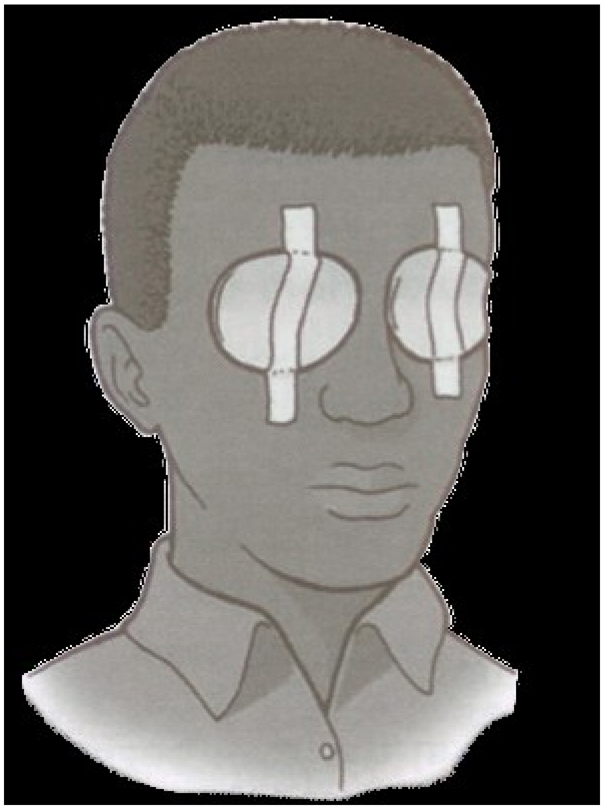
gammas.

Pamela, Fermi, CDMS, Xenon, DAMA, etc.

DM

WMAP and similars-> DE

20 years ago...



Astroparticle Physicist

Astroparticle Physics Puzzle

Today

Astroparticle Physicist

PIERRE
AUGER
OBSERVATORY

Astroparticle Physics
Puzzle