Neutrino Oscillations and Astroparticle Physics (5)

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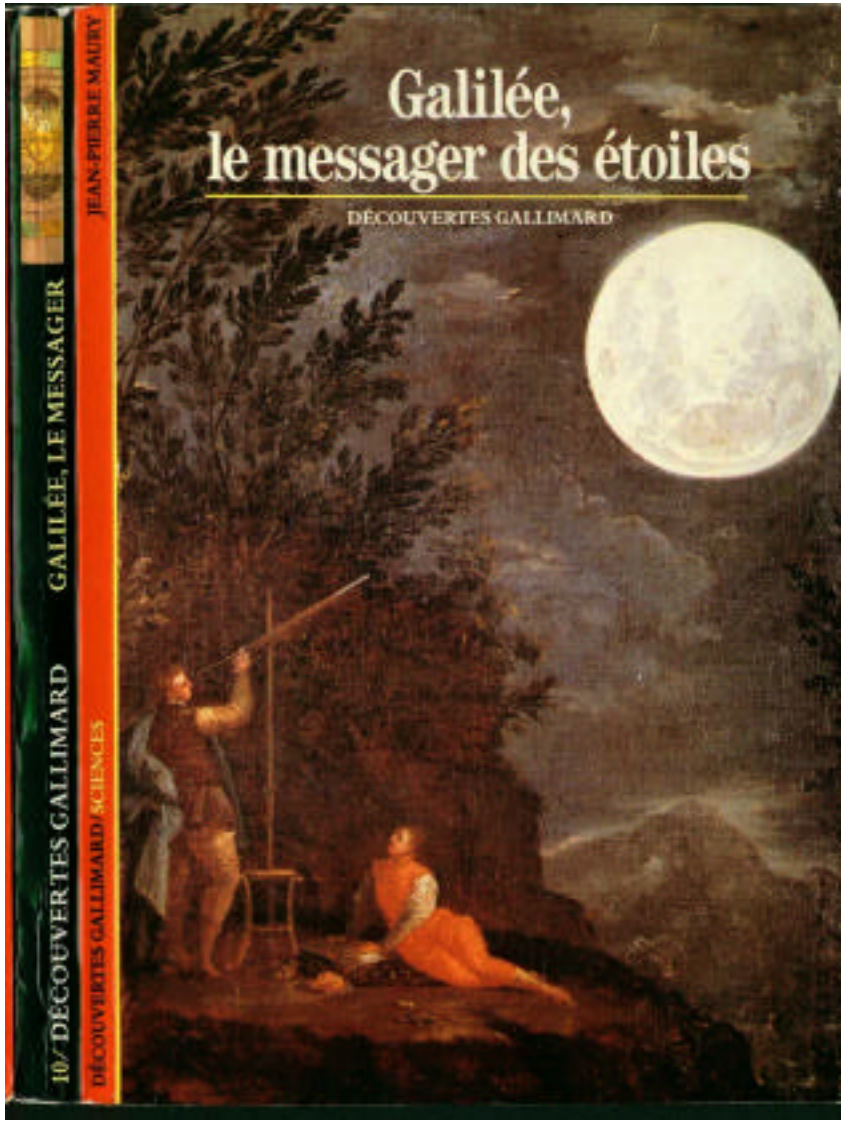
n High Energy Astronomy

Multi-Messanger Astronomy
Cosmic Rays
Gamma Ray Astronomy
Neutrino Astronomy

(References)

Multi-Messenger Astronomy

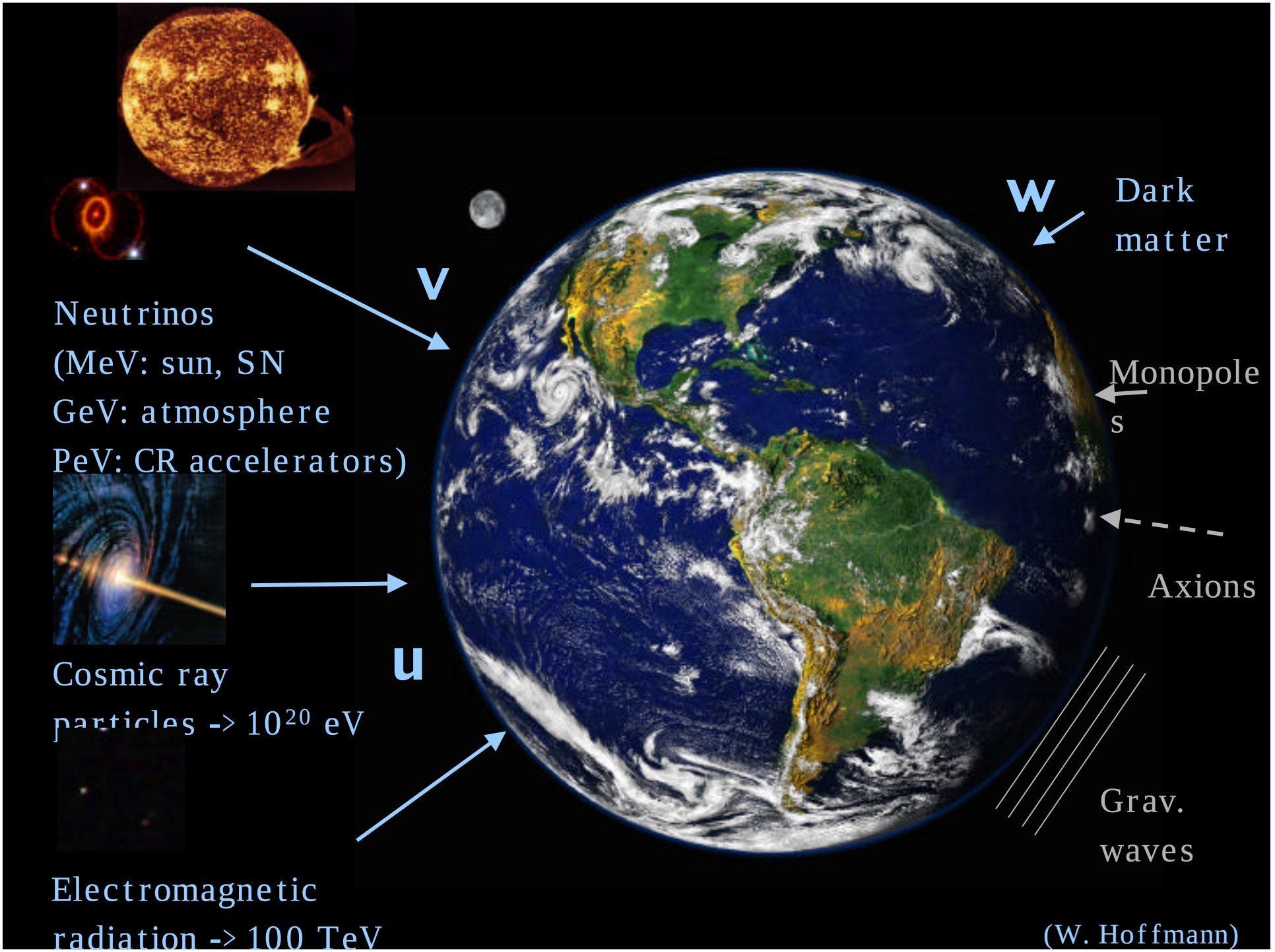


Multi-Wavelength Photons

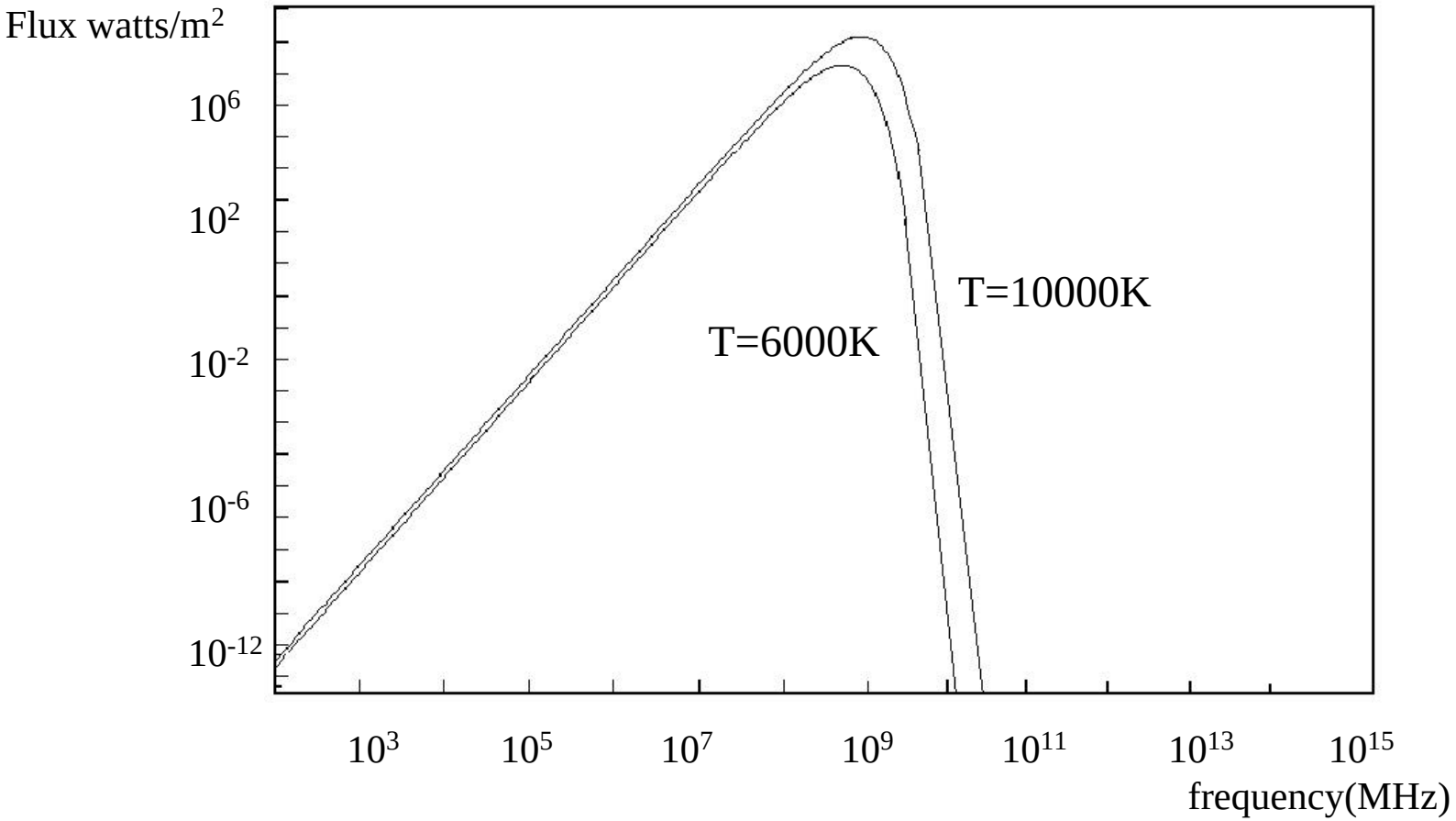
Charged Cosmic Rays

Neutrinos

Gravity Waves


Neutrinos
(MeV: sun, SN
GeV: atmosphere
PeV: CR accelerators)
ν
Cosmic ray
particles -> 10^20 eV
u
Electromagnetic
radiation -> 100 TeV
W
Dark
matter
Monopole
s
Axions
Grav.
waves
(W. Hoffmann)

Thermal Radiation from Stars



Normal Stars surface temperature ~3000 to 30000K

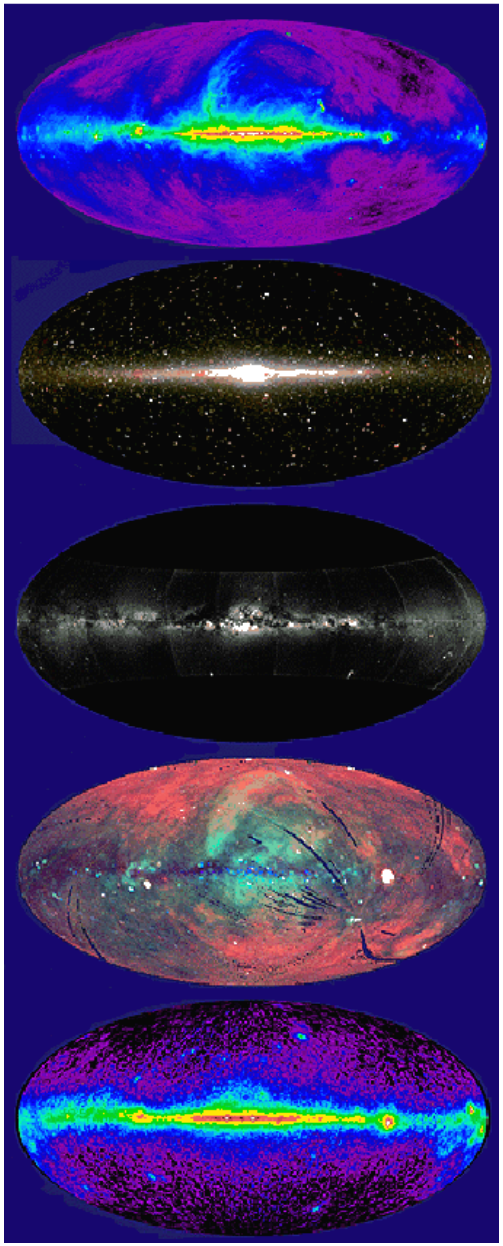
thermal radiation: radio → ultra -violet

non-thermal radiation: X-rays, gamma rays

(higher in energy more extreme is the source)

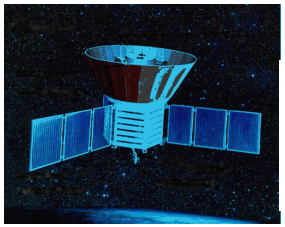
Multi-Wavelength Photons

Radio



Radio télescope
de Bonn

Infrared

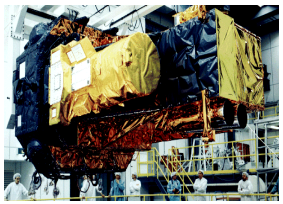


Satellite
COBE

Visible light

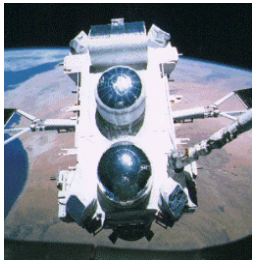
Télescope du
Mont Palomar

X-ray



Satellite
INTEGRAL

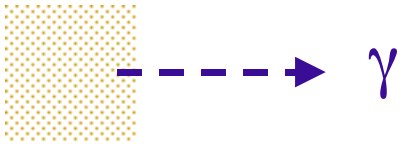
Gamma Ray



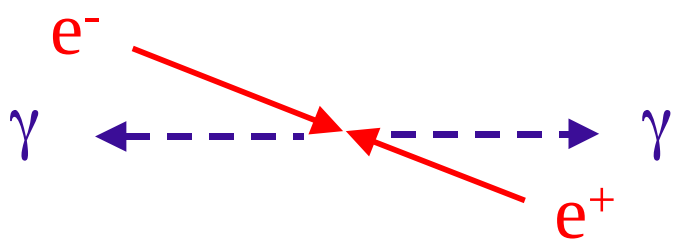
Satellite
CGRO

Production Mechanisms of Photons

Hot plasma (surface of stars)

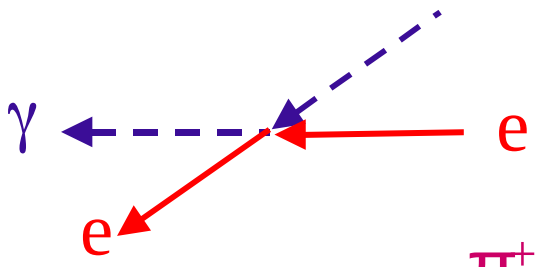


Annihilation of matter/antimatter

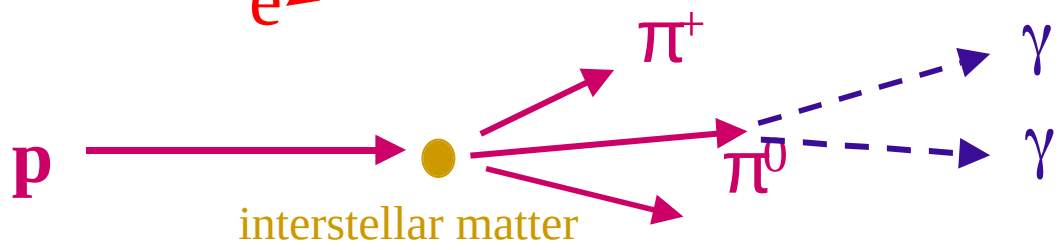


Bremsstrahlung /
Synchrotron Radiation

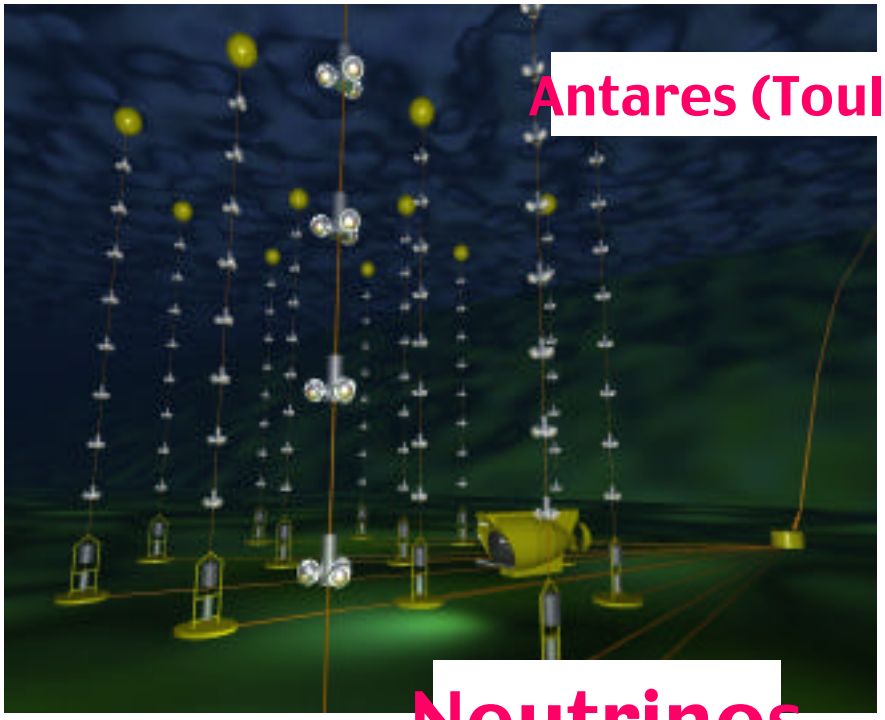
Inverse Compton Scattering



High energy showers



Non-Photonic Astronomy

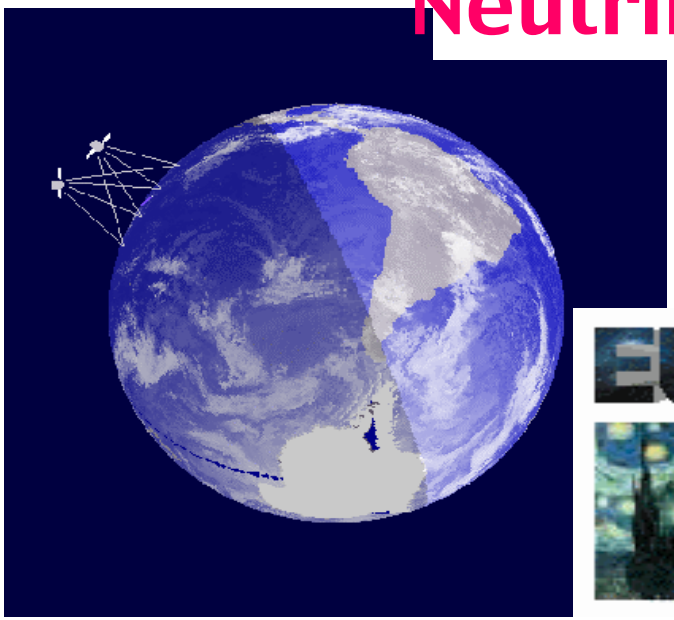


Antares (Toulon)

Neutrinos

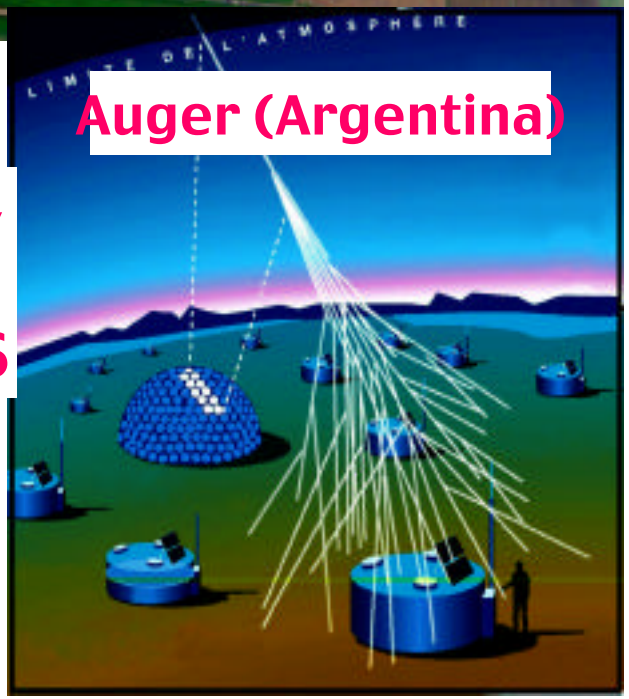
Gravitational Waves

Virgo (Pisa)



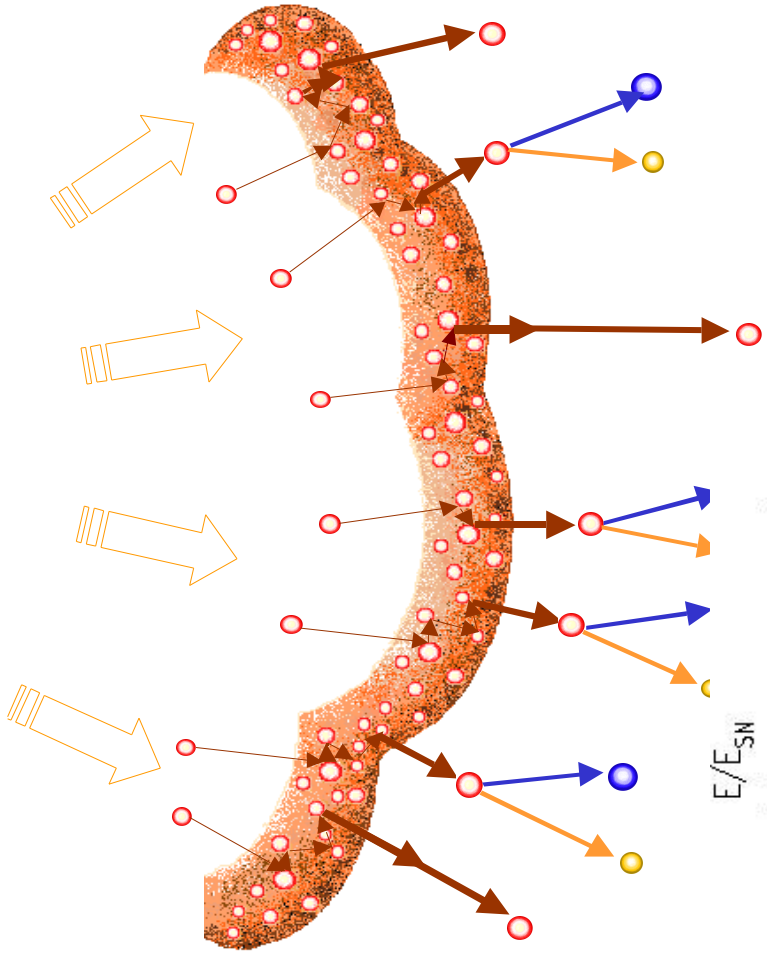
High Energy

Cosmic Rays



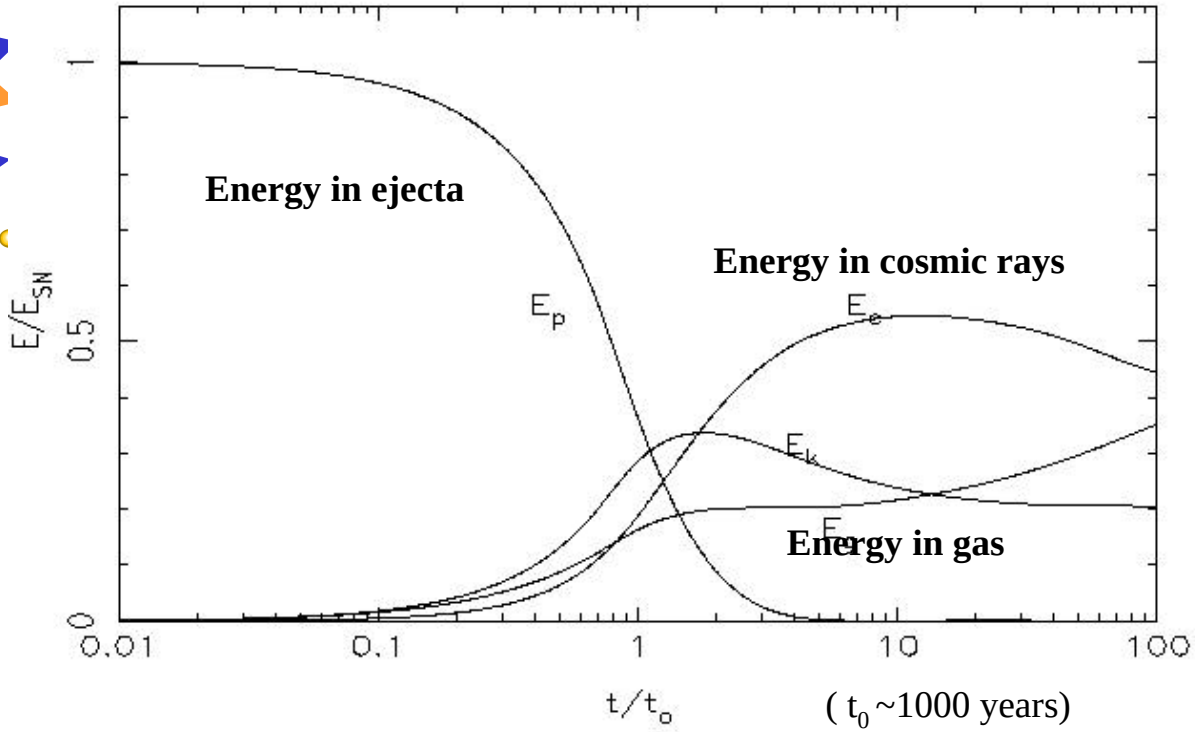
Auger (Argentina)

Acceleration Mechanism of Charged Particles



Simulations indicate can get
~ 50% of energy of supernova explosion
Cosmic Rays by ~1000 yrs

Example of Supernova Remnants



(t_0 ~1000 years)

Production Mechanism of Neutrinos

p accelerated in shock waves:

non-relativistic supernova remnants

relativistic quasars/microquasars

p interact with interstellar matter and produce showers :

$$p/A + p/\gamma \rightarrow \pi^0 + \pi^{\pm} + \ldots$$

$$\downarrow \qquad \downarrow$$

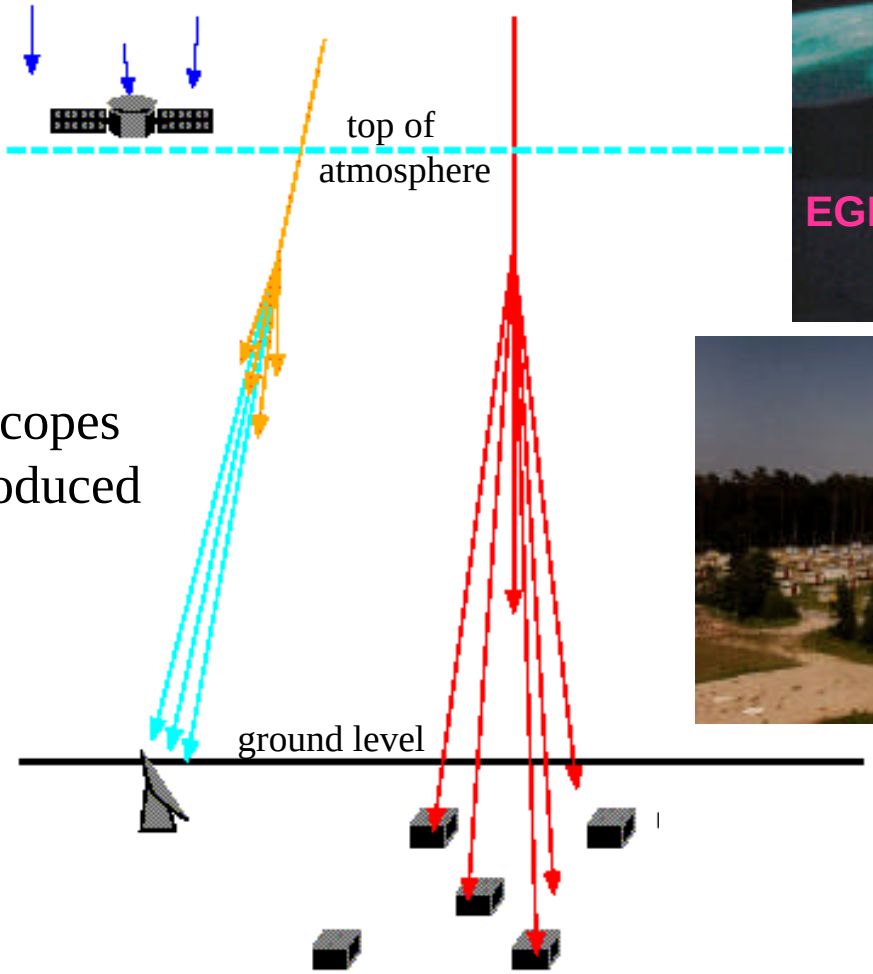
$$\gamma\,\gamma \qquad \nu_\mu\ \mu$$

$$\downarrow$$

$$\nu_\mu\ \nu_e\ e$$

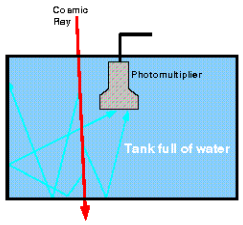
Types of Cosmic Ray Detectors

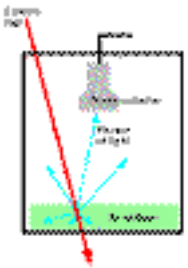
Satellites



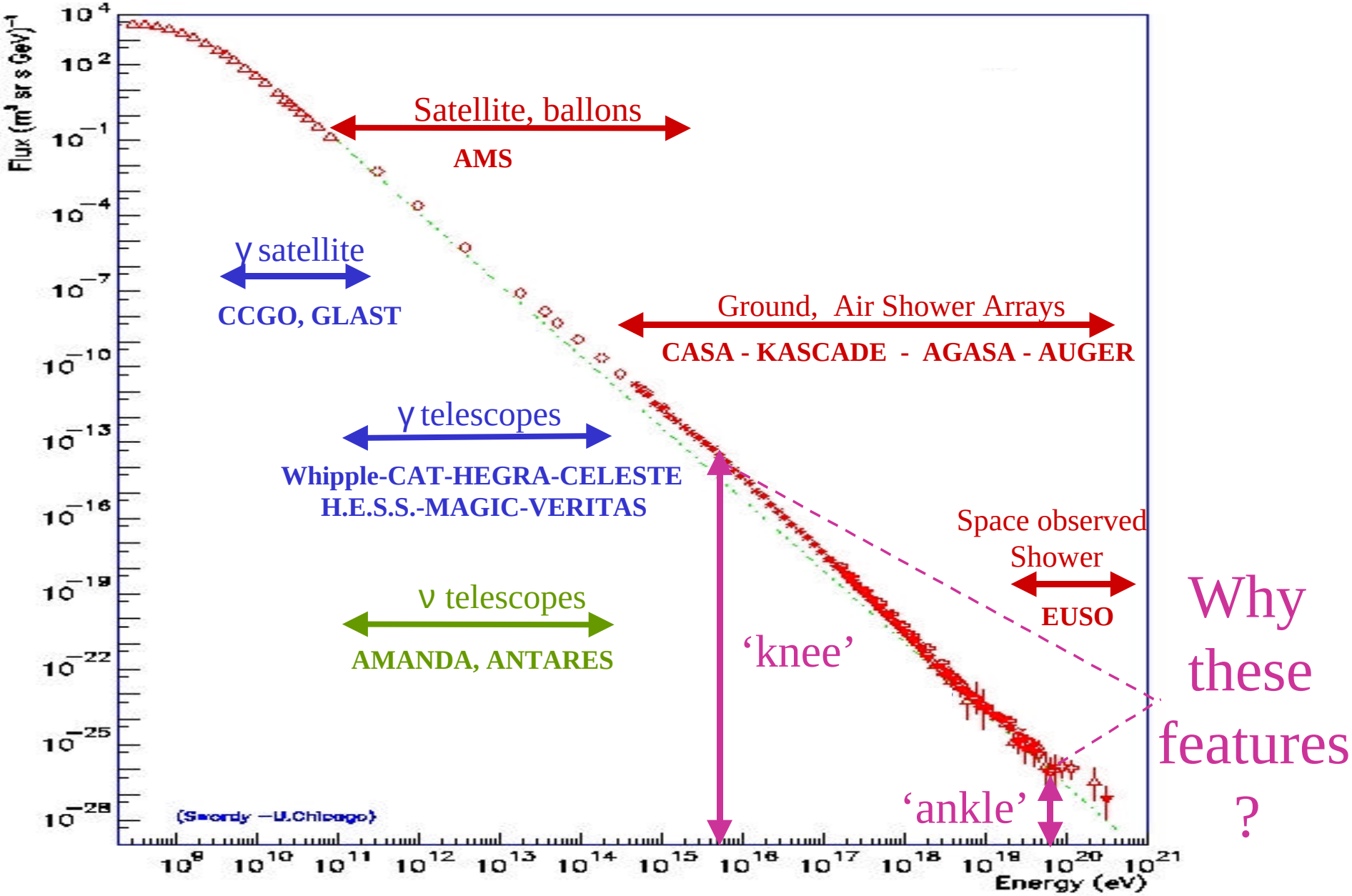
Ground based telescopes looking at light produced in atmosphere

Arrays of particle detectors



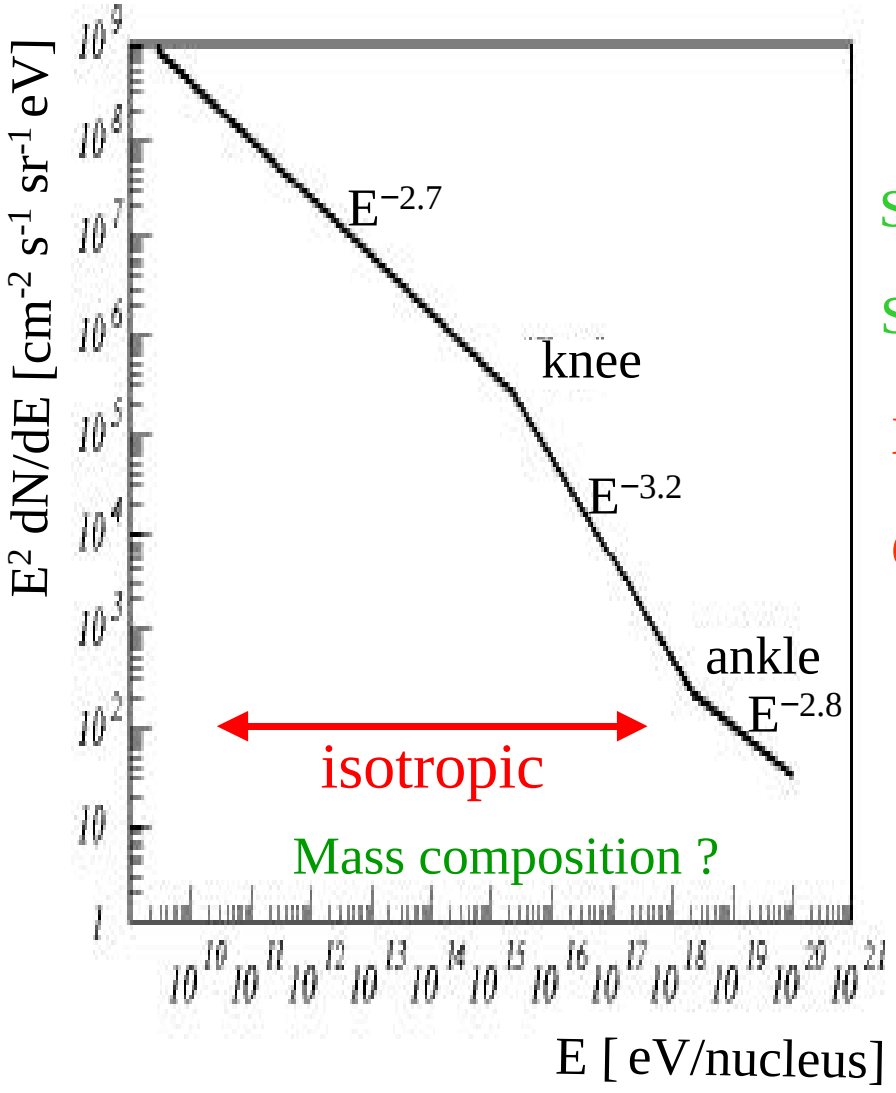


Charged Cosmic Ray Energy Spectrum



Why these features ?

Features of Cosmic Ray Spectrum



Ingredients of models:

$$dN/dE \quad E^{\alpha_{source} + \delta_{propagation}}$$

Source acceleration: $\alpha = -2.0$ to -2.2,..

Source cut-off $E < 10^{18}\, Z \left[\frac{R}{kpc}\right]\left[\frac{B}{\mu G}\right] eV$

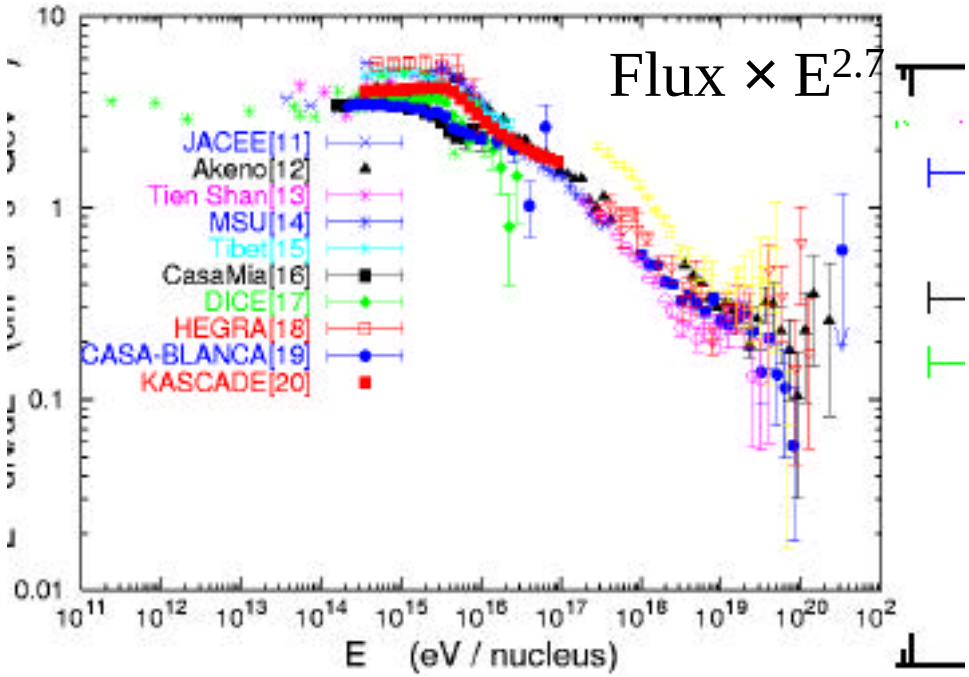
Diffusion models $\delta = -0.3$ to -0.6

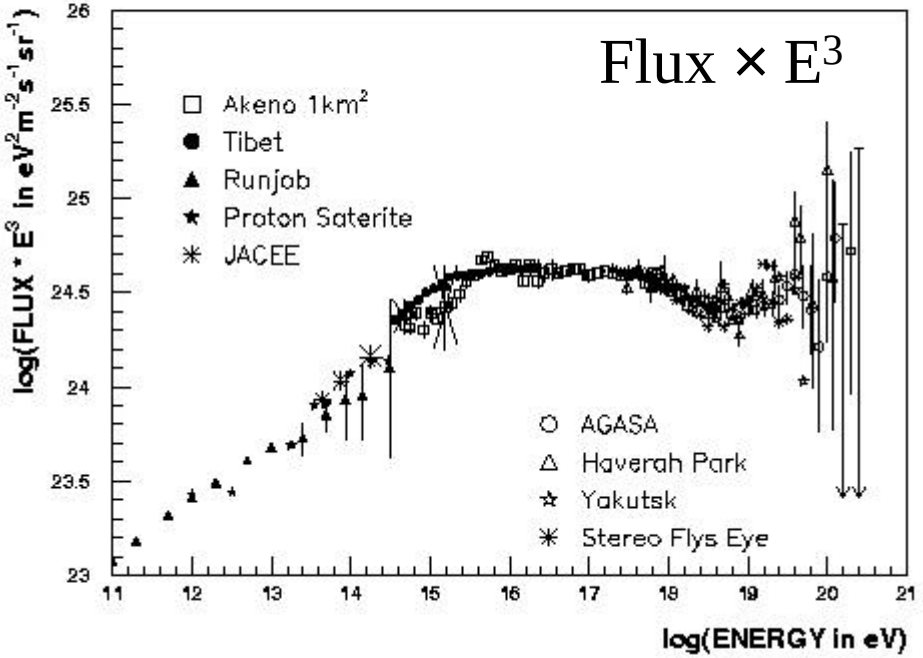
GZK cut-off on CMB γ $E \approx 7\ 10^{19}$ eV

'Conventional Wisdom':

Galactic SNR	$E < 3\ 10^{18}$ eV
Galactic losses	$E > 4\ 10^{14}$ eV
Extragalactic	$E > 3\ 10^{18}$ eV
exotic	$E > 7\ 10^{19}$ eV

Cosmic Rays Spectrum: Knee and Ankle





Explanations of knee (E~3.10^{15} eV)

Astronomy type explanations

- Galactic de-confinement
- Single dominant source
- Single SNR acceleration → multiple SNR acceleration

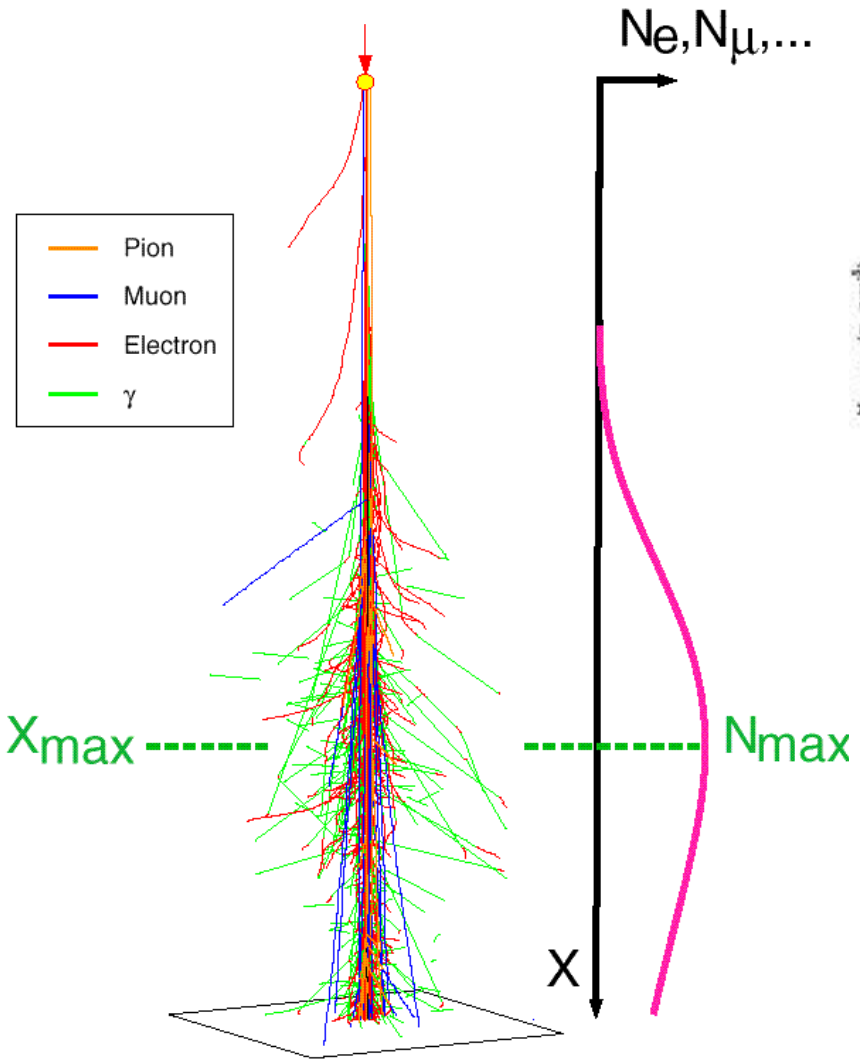
Particle Physics type explanations

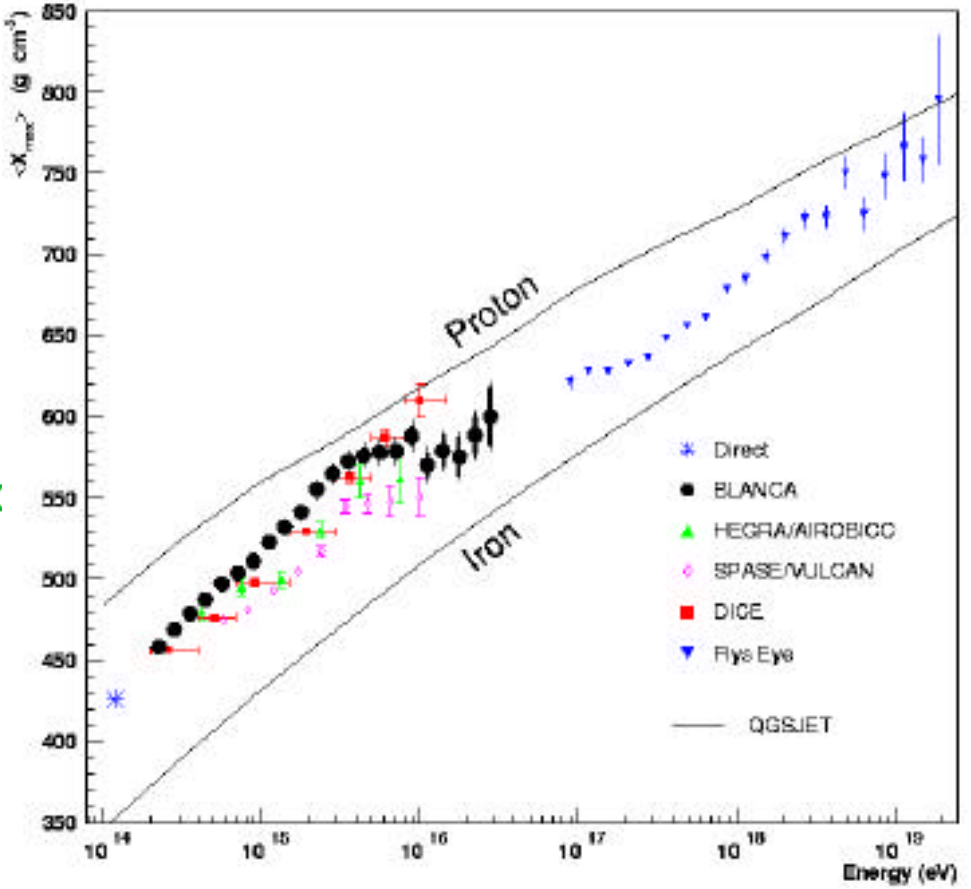
- Absorption on massive neutrinos in galaxy

  Various interactions invoked to give threshold at E = $3\ 10^{15}$ eV.
  eg. $p + \nu_e \rightarrow n + e$, with $M(\nu_e) = 0.1$ eV
  $p + \nu_\mu \rightarrow \Delta + \nu_{\mu,}$, with $M(\nu_\mu) = 100$ eV
  (not very convincing due to various problems: mass, rates)

- New interaction effects in atmosphere

Mass composition from shower depth



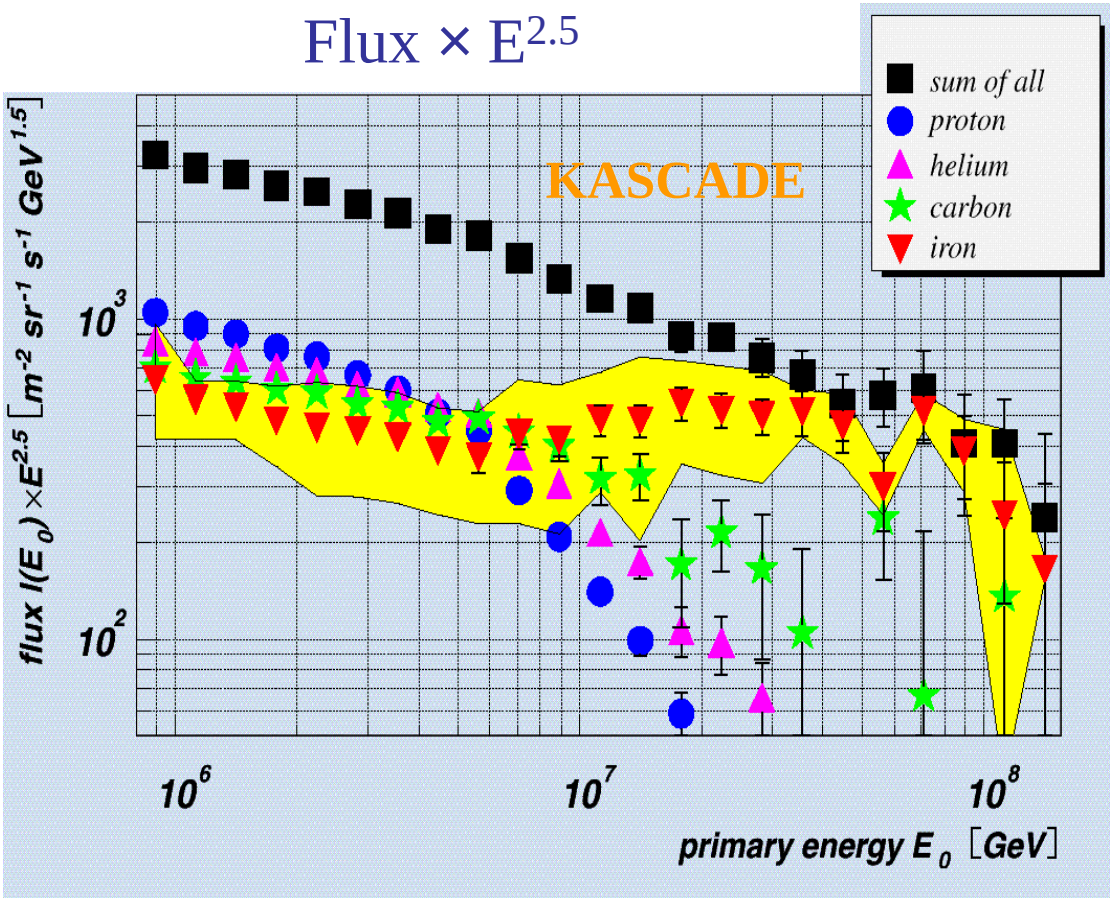


Mass composition at knee

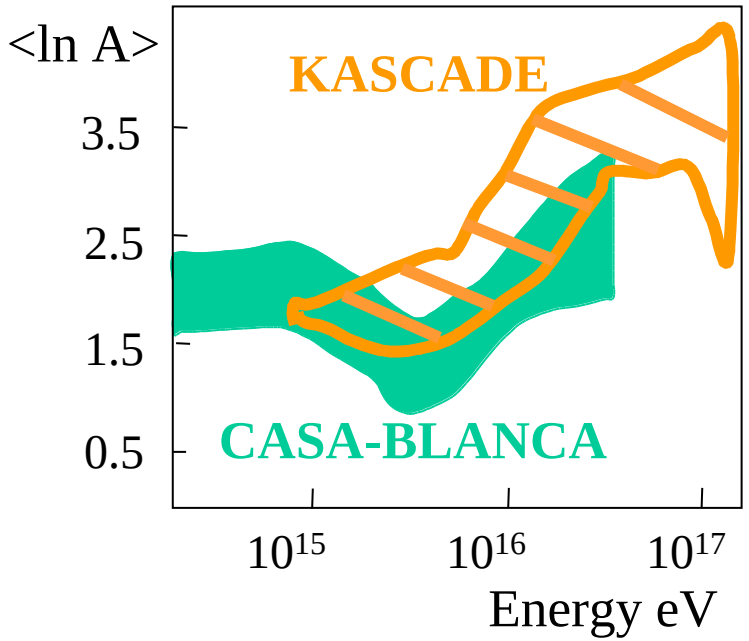
Average shower depth and ratio N_μ / N_e sensitive to primary mass

(NB. Mass composition extracted is very sensitive to Monte Carlo simulation)

Flux × $E^{2.5}$



Mean ln(A)

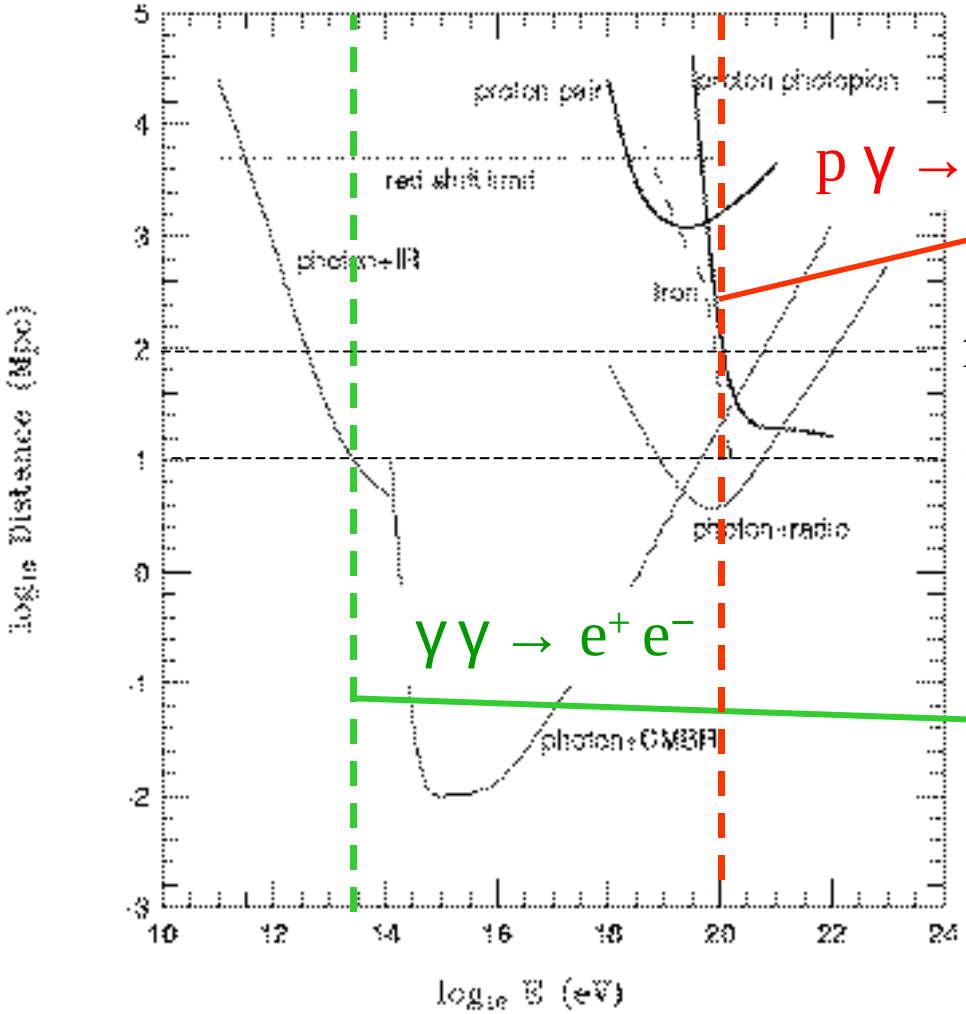


KASCADE series of knees at different energies: p,He,..,C,..,Fe.

E(Knee) Z knee due to source confinement cut-off ?

‘GZK cutoff ’

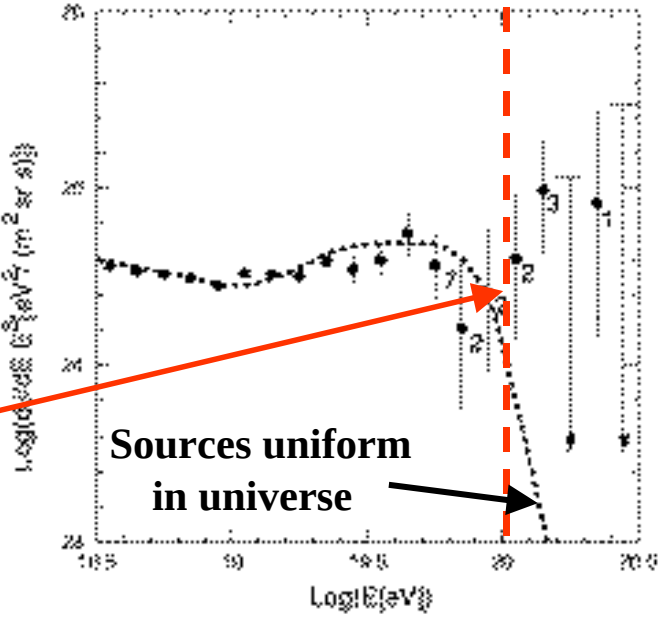
Interaction with background γ
(infrared and 2.7K CMBR)



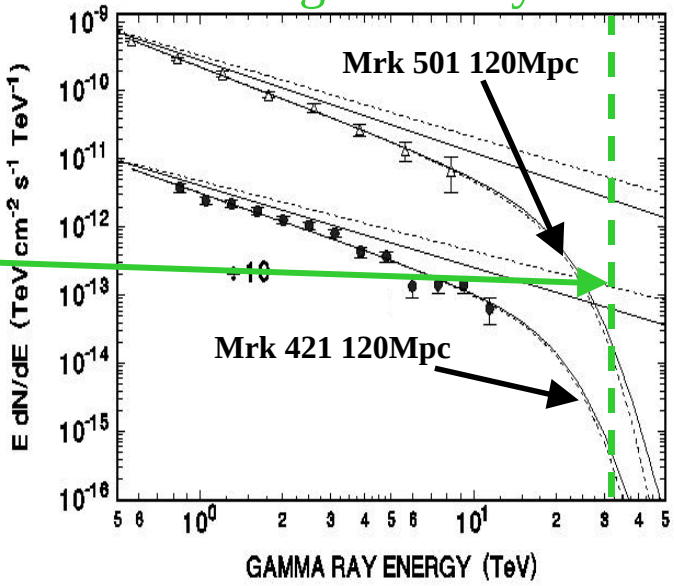
$p\,\gamma \rightarrow \pi N$

$\gamma\gamma \rightarrow e^{+}\,e^{-}$

HE cosmic rays



HE gamma rays



Explanations of Ankle/ E > 10^{20} eV events

Astronomy type explanations

- 'Bottom-Up' : acceleration
  - pulsars in galaxy,
  - radio lobes of AGN (proximity a problem due to GZK, also should see source)

Particle Physics type explanations

- 'Top-Down' : decay of massive particles
  - GUT X particles with mass > 10^{20} eV and long lifetimes
  - Topological defects
  - Neutrinos as messenger particle
- New Physics