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Ultra High Energy Cosmic Rays

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Contents

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I : Introduction

- Discovery : Victor Hess (1912)
- Air showers of secondary particles : Pierre Auger (1938)

$$\text{Size} \Longrightarrow E > 10^{15} eV$$

[Fig 1.1]

What we know today :

The region between 10^{9}eV et 10^{10}eV dominate the energy spectrum.

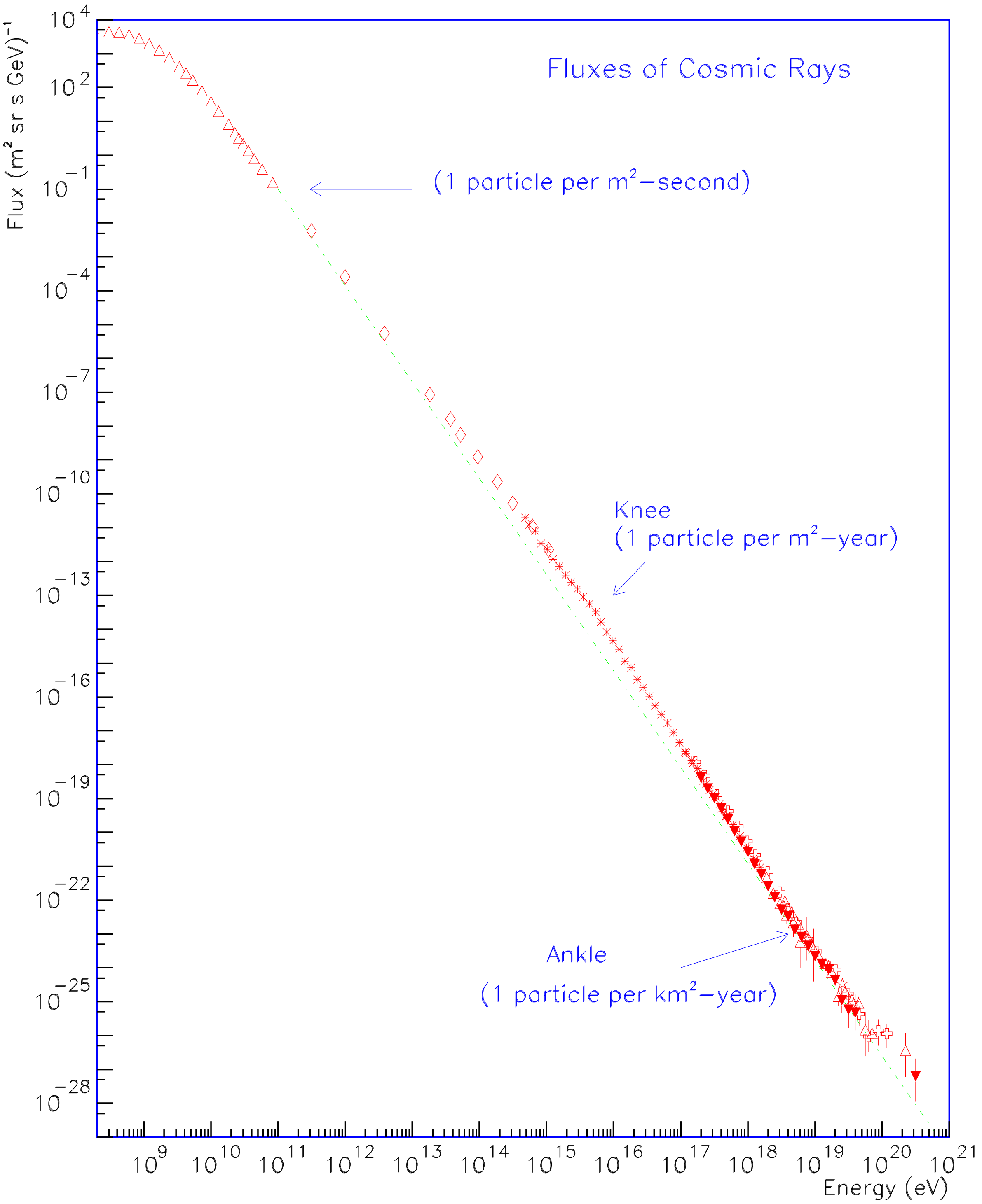
Origin:

- Around 10^{9}eV : Galactic but solar modulated
- Between 10^{9}eV and 10^{15}eV : Galactic (SNR)
- Between 10^{15}eV and 10^{18}eV-10^{19}eV : Confused situation
- Above 10^{19}eV : Unknown but very likely extra-galactic.

[Fig 1.2]

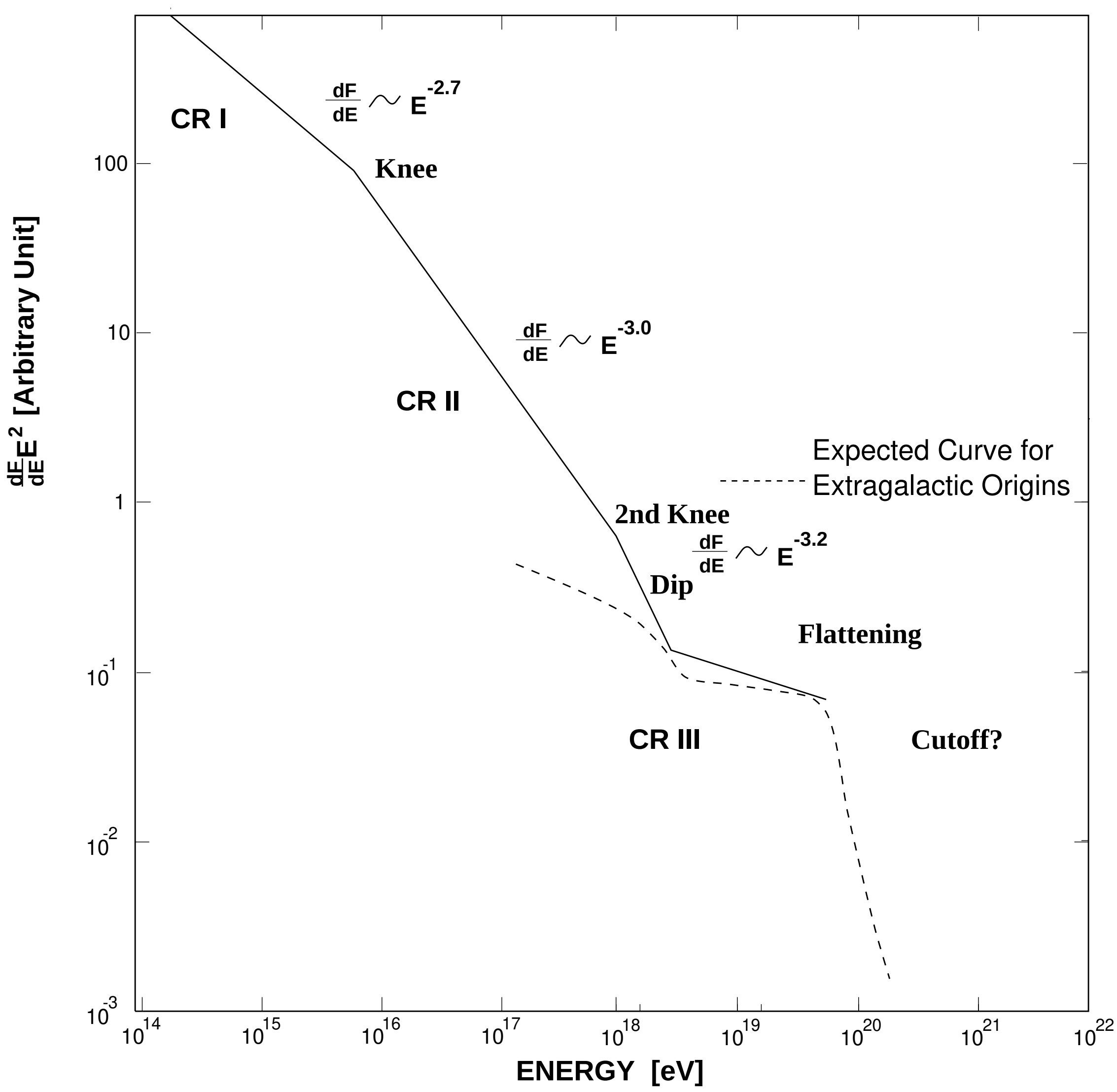
Different nature between 10^{15}eV and 10^{19}eV, but still not understood despite 30 years of effort.

Observed spectrum (all particles)



[Fig 1.1]

Observed spectrum (characteristics)



[Fig 1.2]

Energetics of Galactic CR

CR energy density :

$$\mu_{CR} = \frac{4\pi}{C} \int E\mathcal{F}(E)dE \approx 1eV/cm3$$

Energy production - stationary state - :

$$L_{CR} \sim \frac{\mu_{CR} V}{\tau_{CR}}$$

τ_{CR} in the Galaxy ?

- Nuclei abundance $\Longrightarrow N \approx 5\; g/cm^2$
- Gas density $\rho = M_g/V$
- Confinement $\tau_{CR} = N/(C\rho) \;\; (\sim 10^8 \;\; ans)$

Thus :

$$L_{CR} = \frac{C\mu_{CR}M_g}{N} \sim 10^{48}\text{erg/an}$$

10 % of the SN gas kinetic energy.

also :

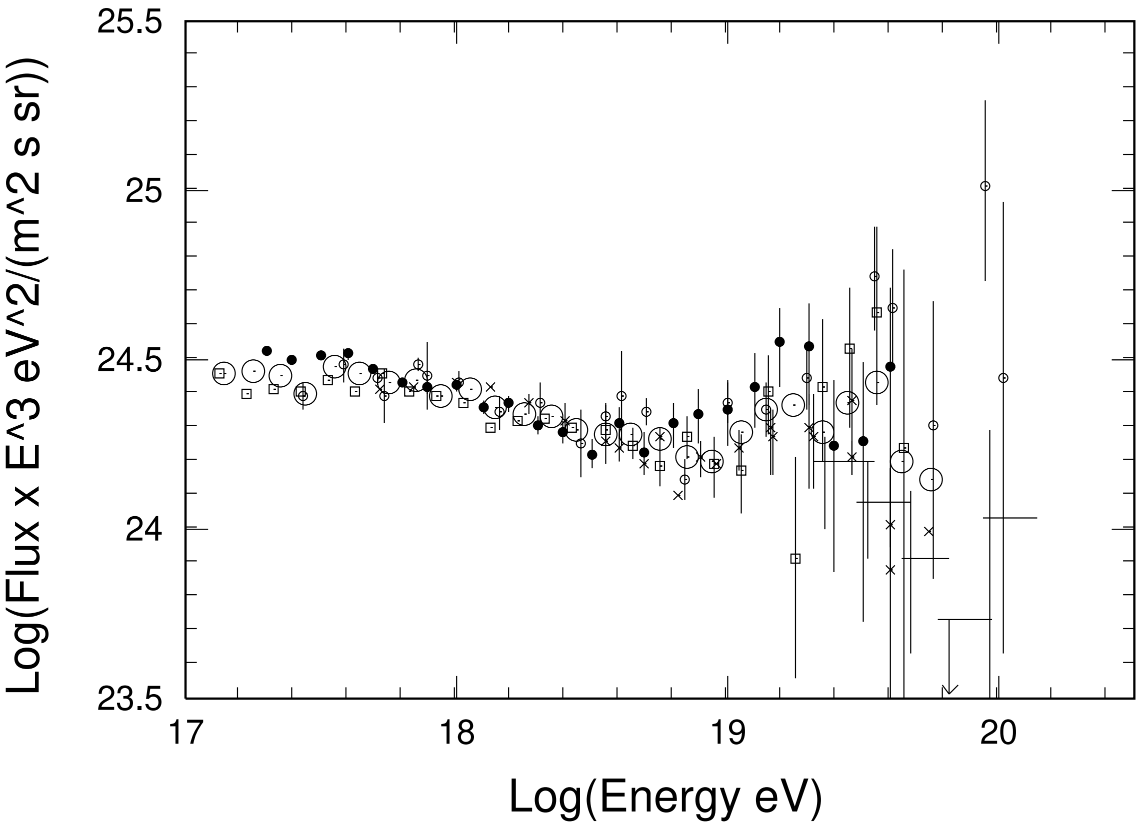
$$\mu_{CR} \approx \frac{B^2}{8\pi} \approx \frac{1}{2}\rho_g^2 v_t^2$$

Up to 10^{15}eV CR are mainly galactic and are accelerated by SNR.

Remarks :

Gammas from the decay of π^0 produced by CR interaction in the SMC confirm this hypothesis.

Observed spectrum above 10^{17}eV



- change of primary mass. Heavy towards light.
- change of origin. Galactic towards extra-galactic.

[Fig 1.3]

Above 10^{19}eV

- Production mechanisms? How to obtain such a high energy ?
- Primary nature (Composition) ?
- Sources distribution ? Where do they come from and how do they reach us ?
- Where does the spectrum ends ?

The very existence of cosmic rays above 10^{19}eV is a mystery... which we want to solve.

Orders of magnitude

à 10^{19}eV

- Energy : 510^{19}eV $\approx$ 10 Joule $\approx$ 2g of lead out of a hunt gun (350 km/h).
- Flux : One event per 50 km^2 and per year $\Longrightarrow$ detection surface $\approx$ 1000km^2
- Density : At ground level $\approx$ 10^{10} - 10^{11} particles, >99% EM (10 MeV) <1% muons (1GeV)
- Size : 20 km^2 foot print (1 part/m^2 at 1.5 km from the axis)
- Opacity : MFP $\approx$ 10-100Mpc i.e. between 10^{-9} and 10^{-6} of the Universe (10 Gpc)

World record: E = 3×10^{20}eV 50 Joule (tennis ball above 100 km/h, 100 millions times a LHC beam)

Astrophysical Miscellanea

* Large Scale Structures (1pc = 3.26 light-years)

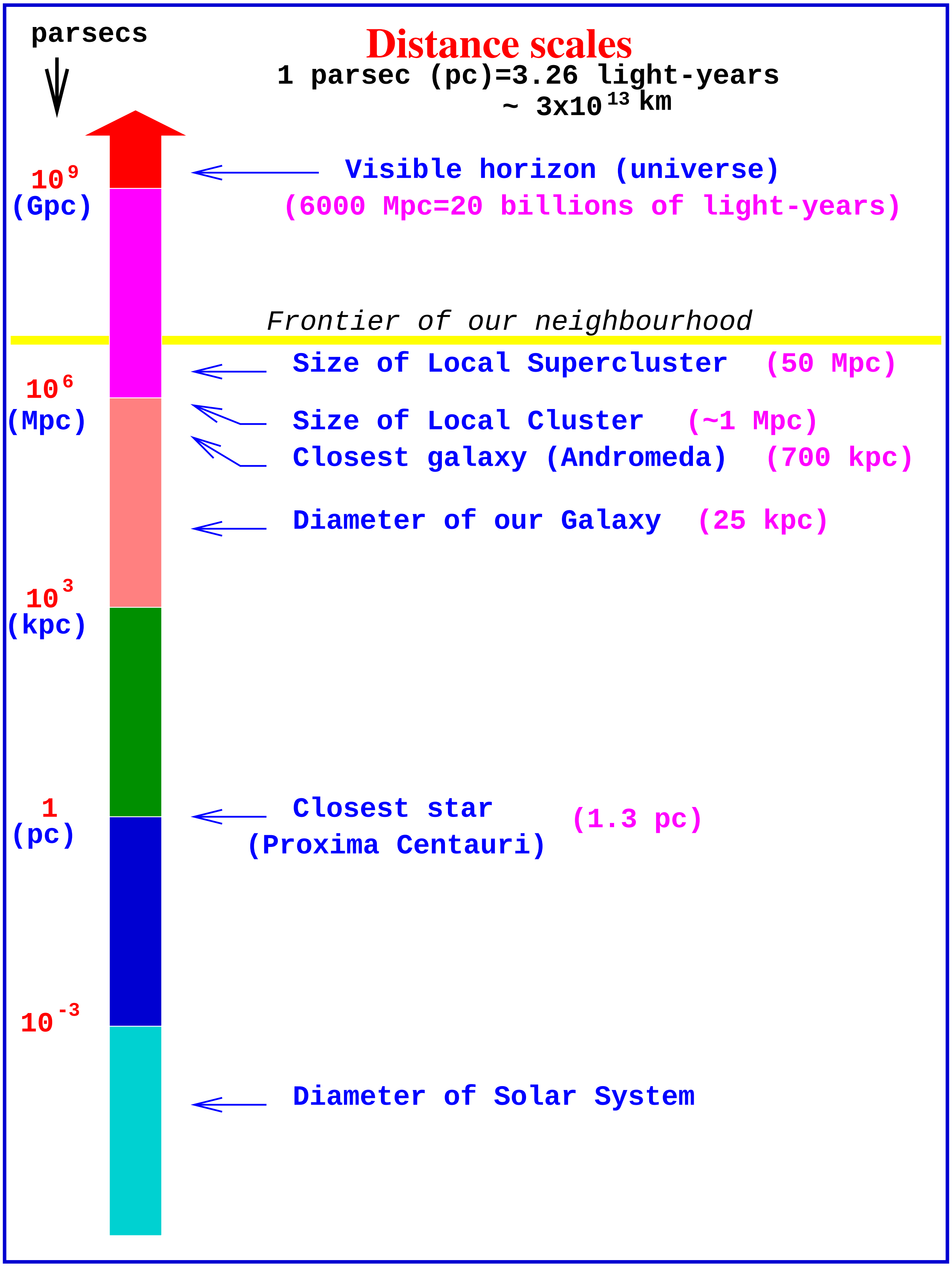
Typical star (Sun)	M = 2×10^{30} kg
Typical galaxy (Milky Way)	10^{11} M -diameter 30 kpc
Closest small galaxy (Magellanic Cloud)	@ 60 kpc
Closest large galaxy (Andromeda/M31)	@ 600 kpc
Farthest visible galaxy (horizon)	@ 6000 Mpc
Typical cluster of galaxies	300 - 1000 galaxies
Closest cluster (Virgo)	2500 galaxies @ 30 Mpc

* Magnetic Fields (1 gauss = 10^{-4} T)

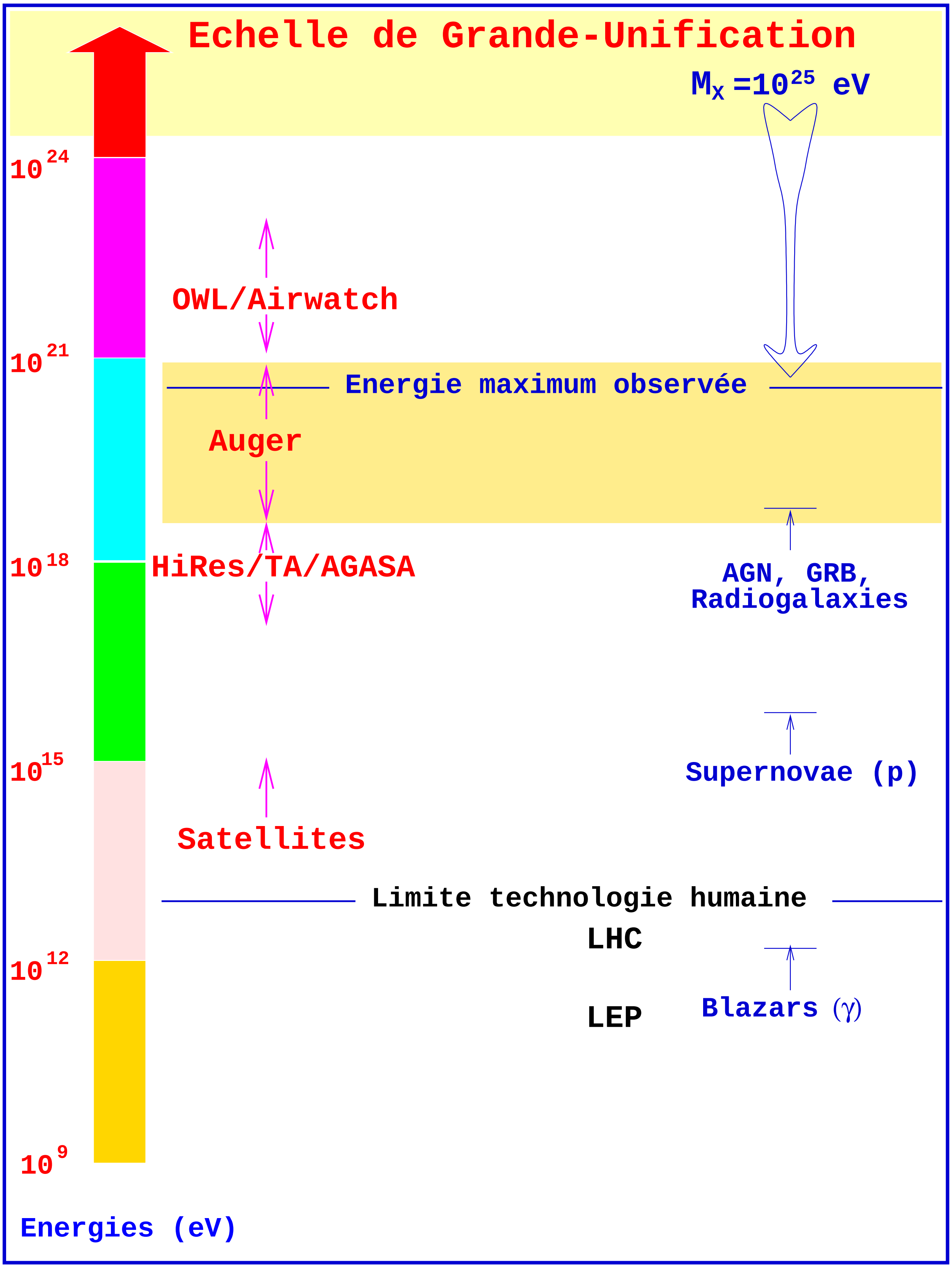
Earth	0.5 G
Sun	1 - 5000 G
Galaxy	a few micro-G
Intergalactic medium	< nano-G
Neutron star	10^{12} G

* Cosmic Microwave Bacground Radiation

Black body spectrum	T=2.7K
Wavelength at spectrum peak	$\lambda =$ 2 mm
Mean energy of photons	~ 10^{-3} eV
Density of photons	~ 400/cm^3


Distance scales
1 parsec (pc)=3.26 light-years
~ 3x10^13 km
parsecs
10^9
(Gpc)
Visible horizon (universe)
(6000 Mpc=20 billions of light-years)
Frontier of our neighbourhood
Size of Local Supercluster (50 Mpc)
10^6
(Mpc)
Size of Local Cluster (~1 Mpc)
Closest galaxy (Andromeda) (700 kpc)
Diameter of our Galaxy (25 kpc)
10^3
(kpc)
1
(pc)
Closest star
(Proxima Centauri)
(1.3 pc)
10^-3
Diameter of Solar System

Mécanismes d'accélération



Contemporary astrophysics is faced by a number of acute problems.

One of them concerns dark matter, which one might (perhaps mischievously) qualify as the study of particles which should exist... but until further notice, don't.

Ultra high energy cosmic rays constitute the inverse problem: particles which do exist... but perhaps shouldn't.

Ludwik M. Celnikier