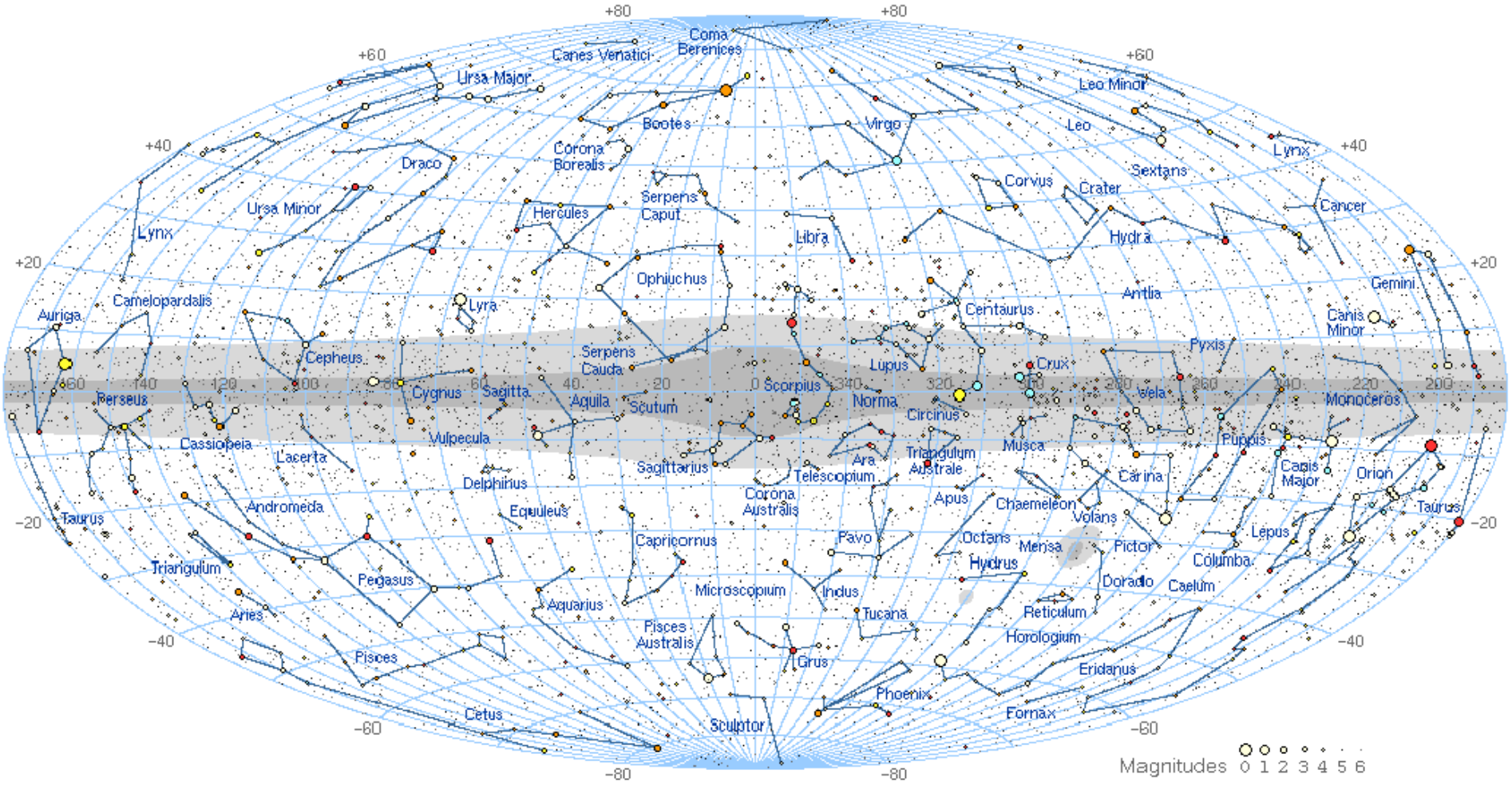
Astroparticle
A selected introduction

J. Masbou, Subatech – Université de Nantes

Let's have a look to the sky

Let's have a look to the sky



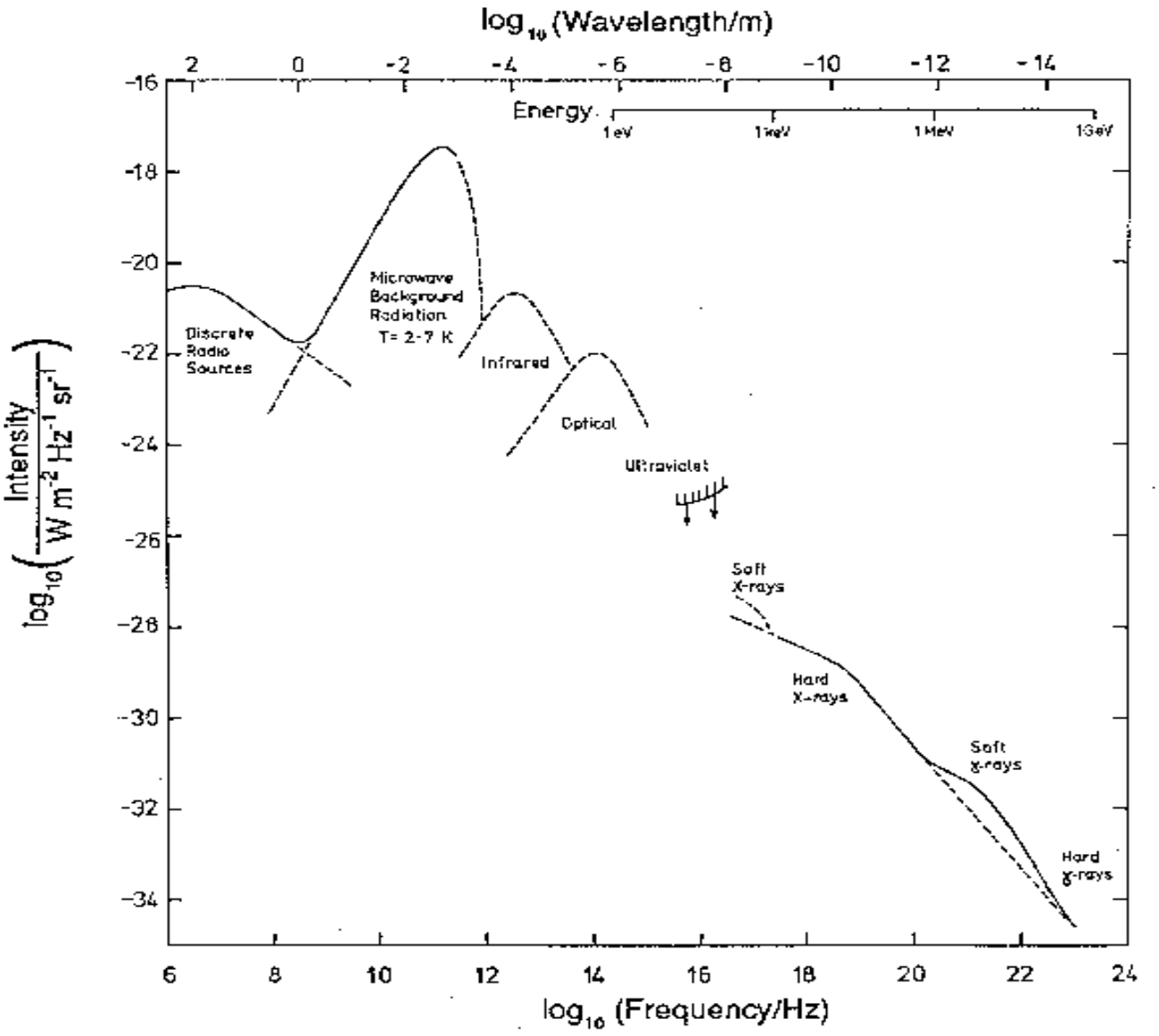
Let there be light

All what we know is astrophysics is thanks to the light !

- Temperatures, stars masses, galaxies, magnetic fields, chemical composition, age of stars and structures…

- Nuclear reactions, galactic and extragalactic hydrodynamics, MHD, explosions, nucleosynthesis,
  past, future… EVERYTHING !

A multiwavelength Sky

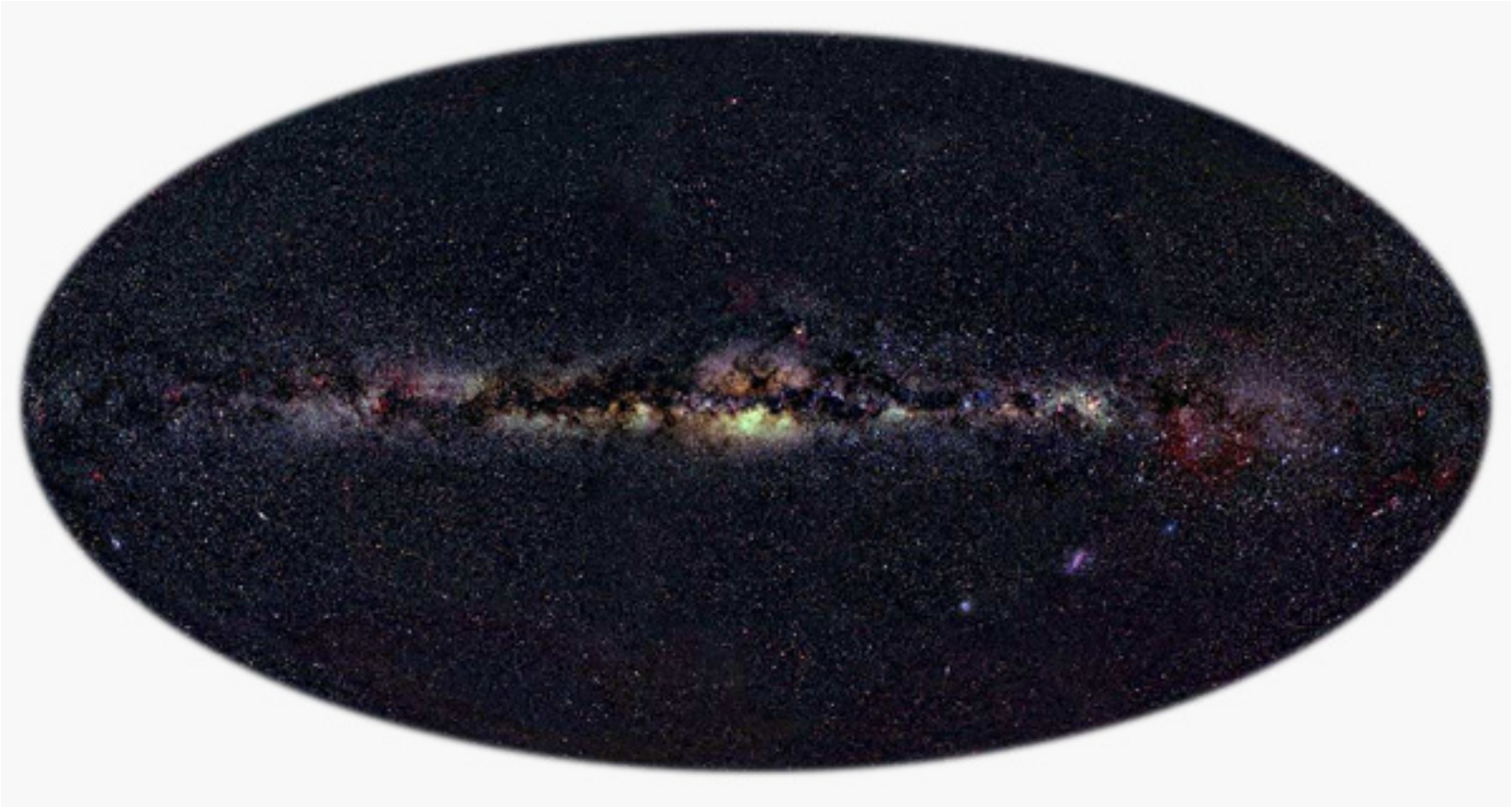


Our galaxy

The optical Milky Way

Our galaxy

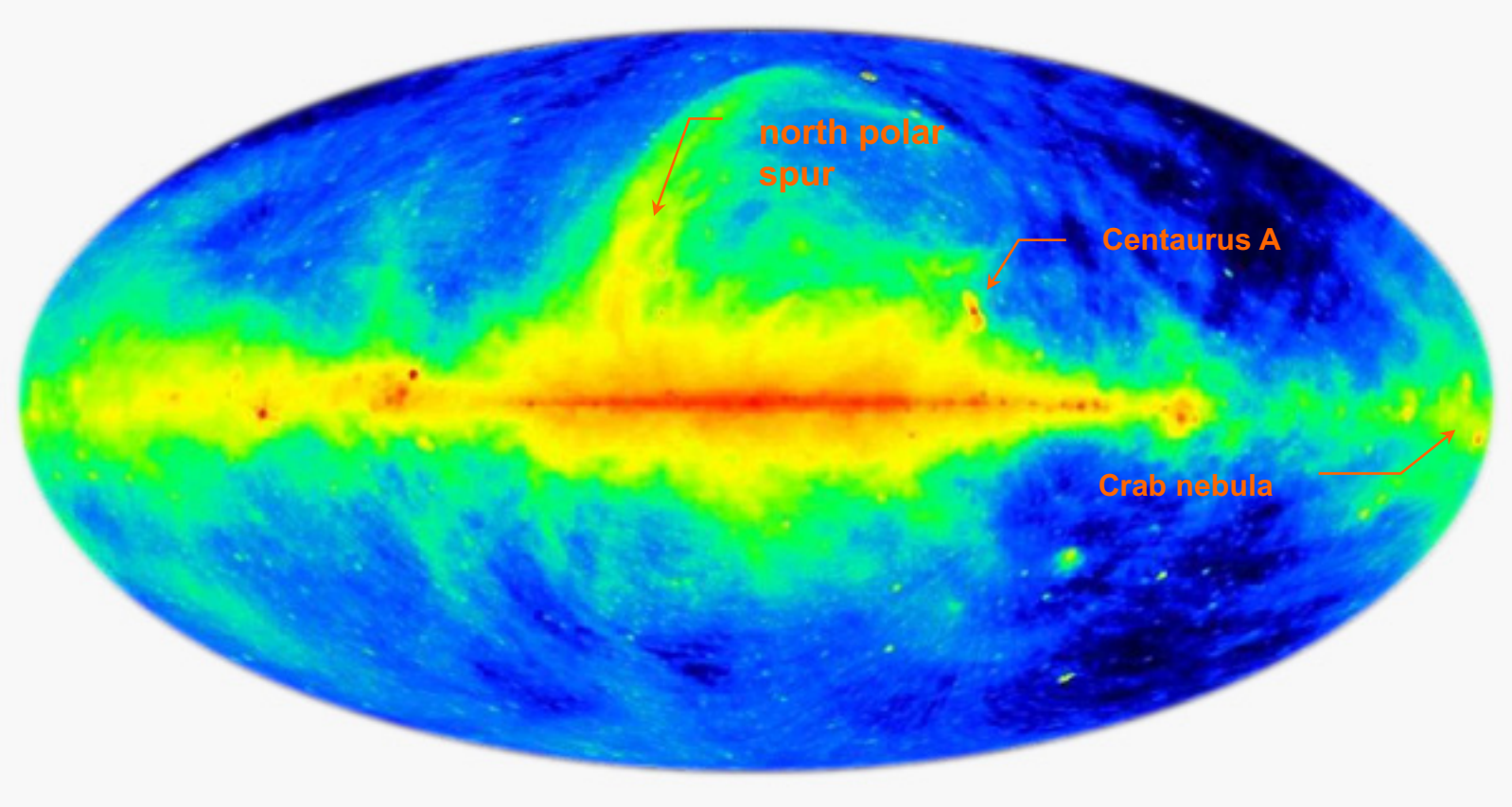
Visible Light
500 THz / 400 - 700 nm / 1 eV



Visible light is absorbed by interstellar dust clouds.
Only stars close enough to the solar system (few parsec) are seen.

Our galaxy

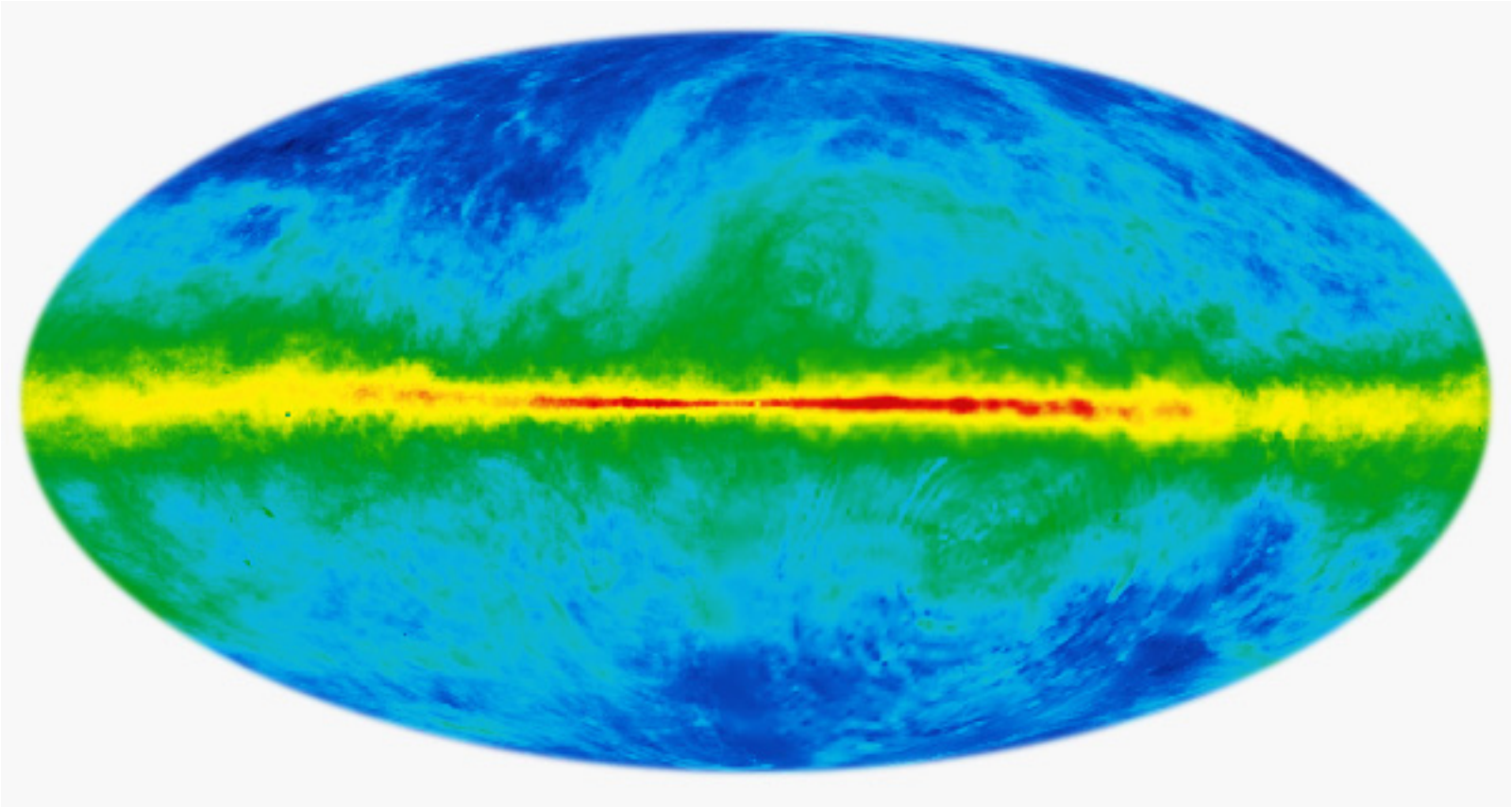
Milky Way : Radio at 73 cm
408 MHz / 73.5 cm / 1.6 10^{-6} eV



Radio wave essentially from the movement of ultra relativistic electrons probably issue from supernovae remnants in the galactic magnetic field.

Our galaxy

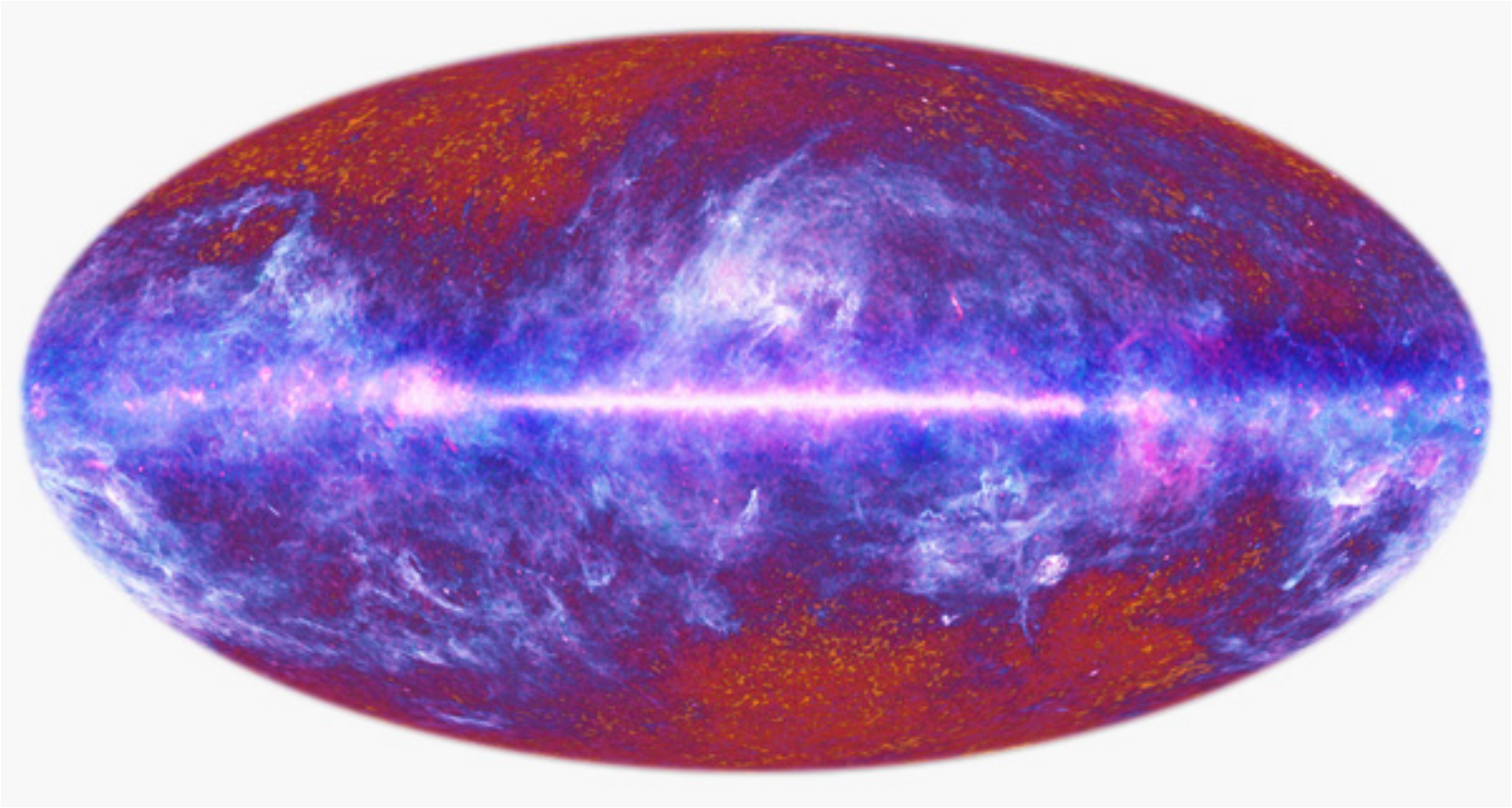
Milky Way : Radio at 21 cm
1.42 GHz / 21.1 cm / 5.9 10^{-6} eV



Hyperfine transition of hydrogen, neutral at low temperature.
Structures are due to the column density of atomic hydrogen clouds along the line of sight showing the presence of interstellar clouds.

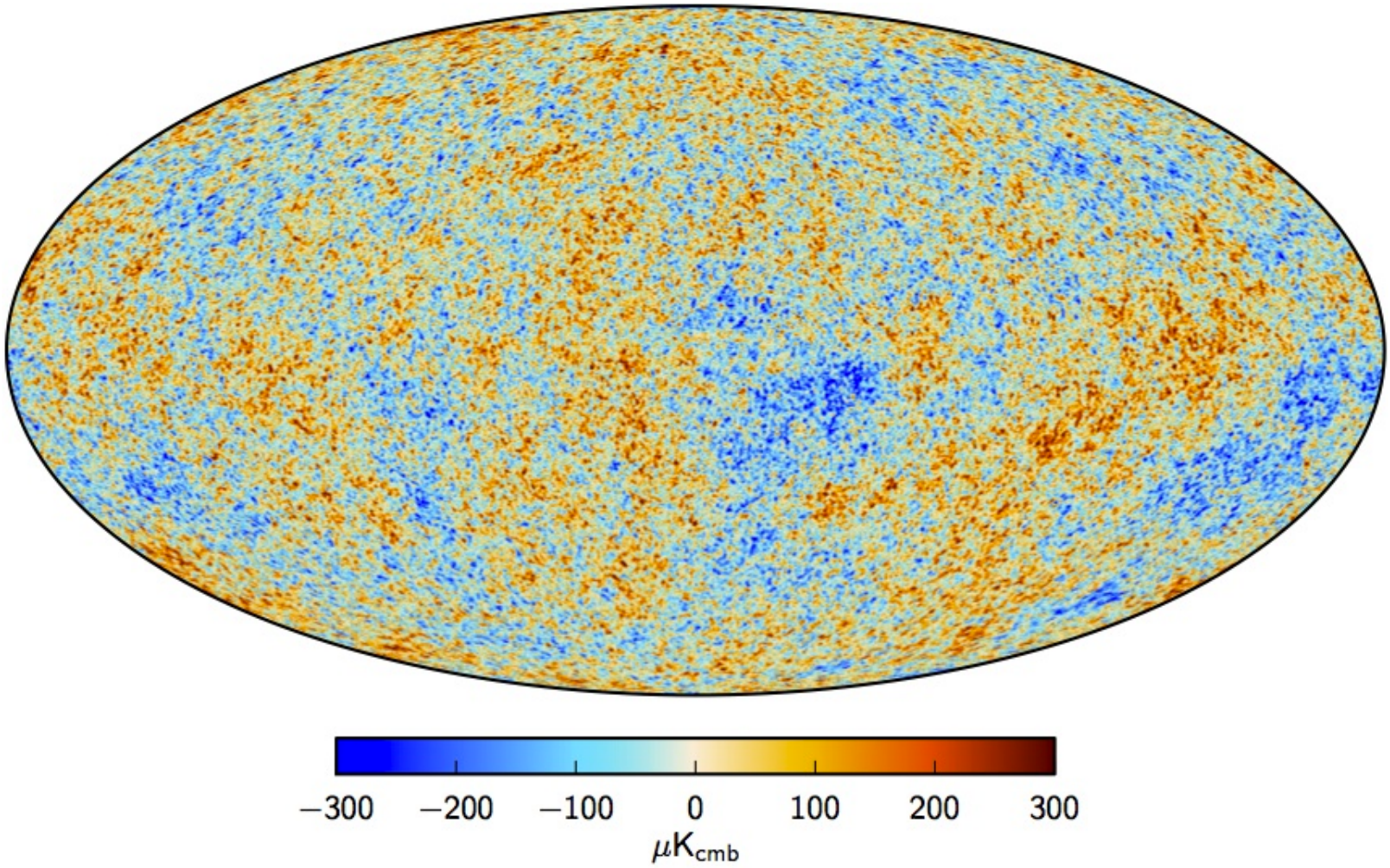
Our galaxy

Microwave
500 GHz / 200 μm / 2 10^{-3} eV



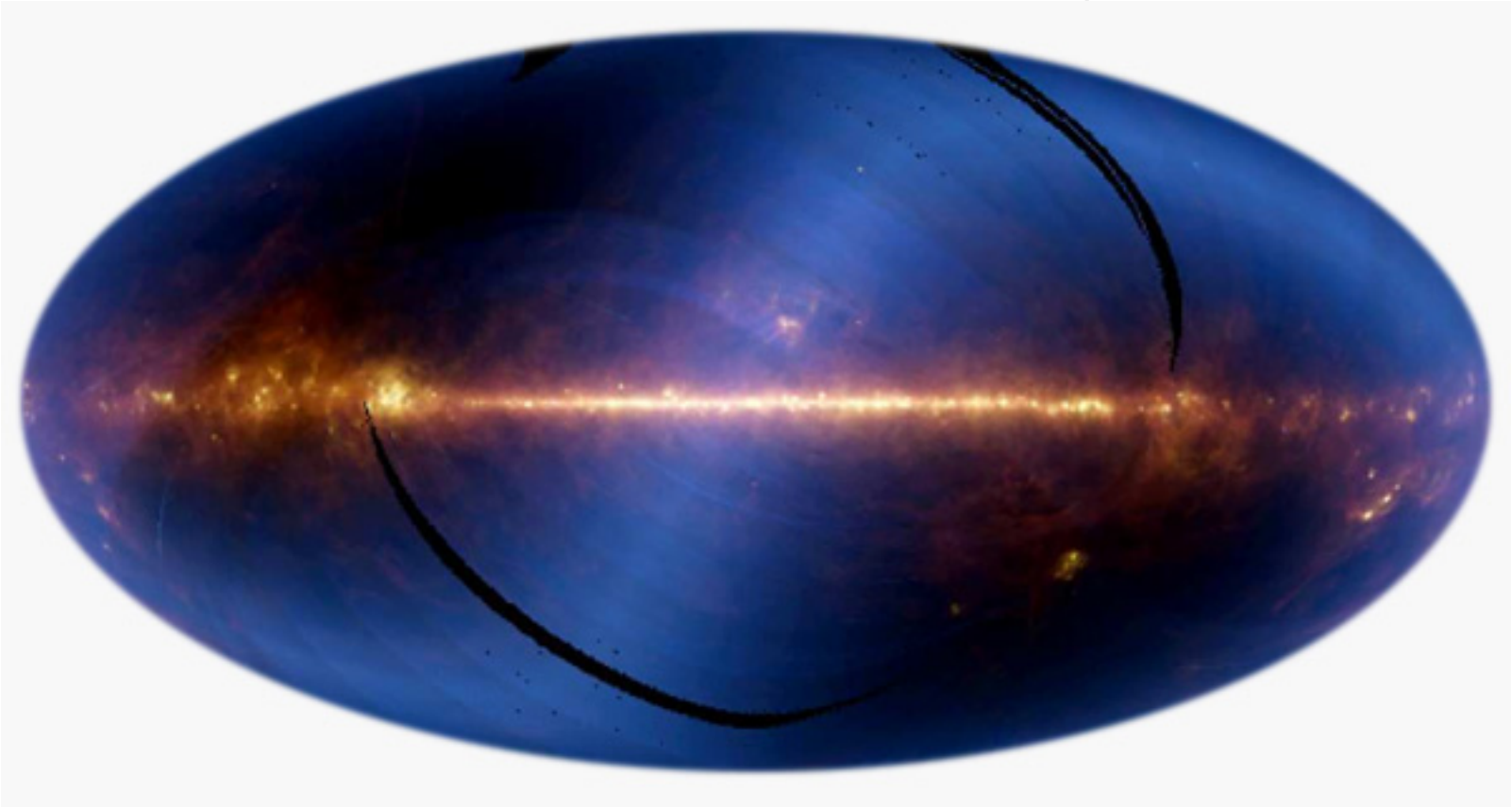
Red clumpy spots : Cosmic Microwave Background
Foreground : Magnetic field in the galaxy (synchrotron effect on electron)

Microwave
500 GHz / 200 μm / 2 10^{-3} eV



Our galaxy

Far Infrared
5 THz / 60 μm / 0.02 eV)



Thermal emission, due to interstellar dust heated by starlight.

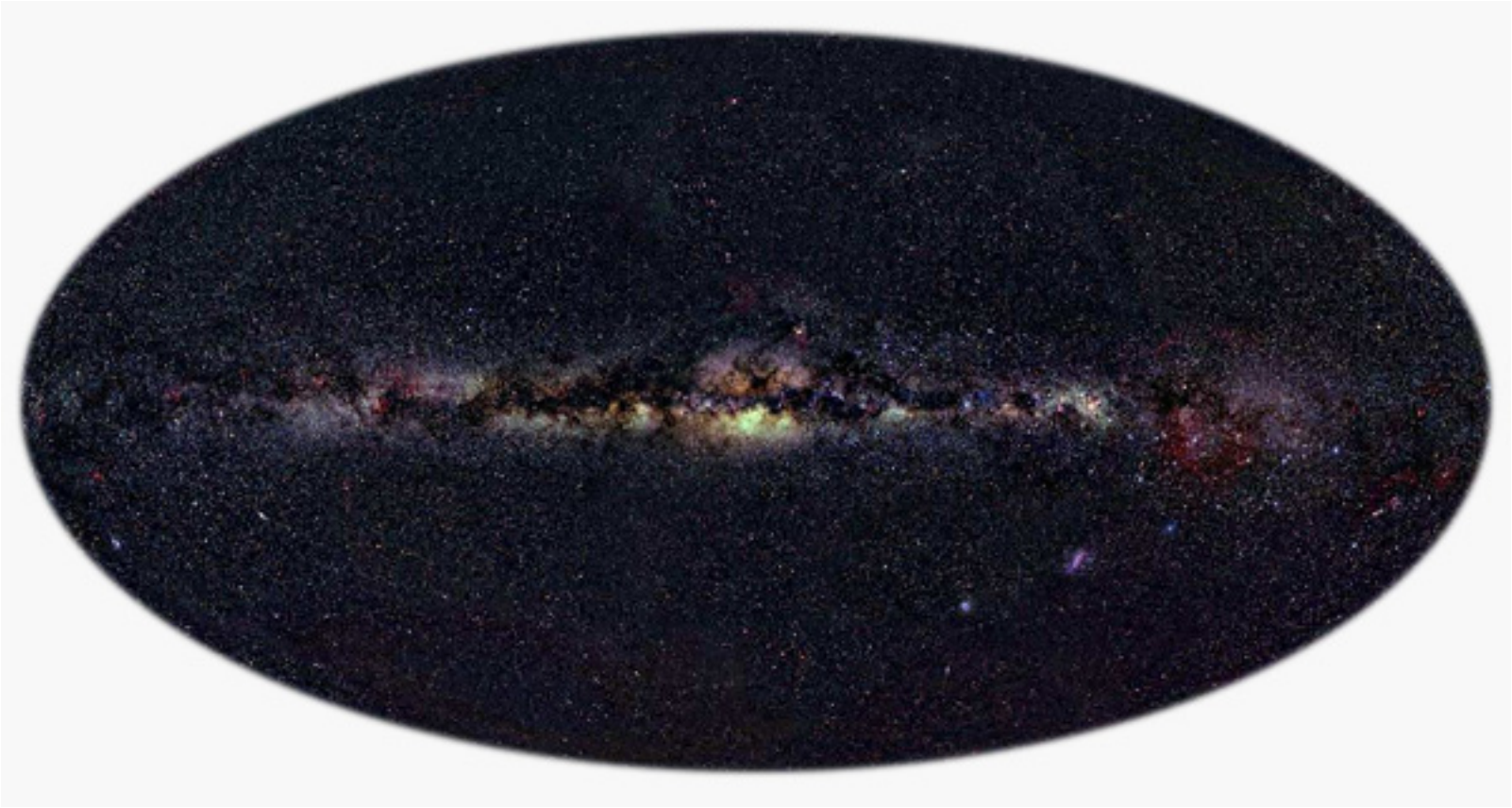
Our galaxy

Infrared Sky
150 THz / 2 µm / 0.6 eV

Giant stars emission in the disk and in the bulb

Our galaxy

Visible Light
500 THz / 400 - 700 nm / 1 eV



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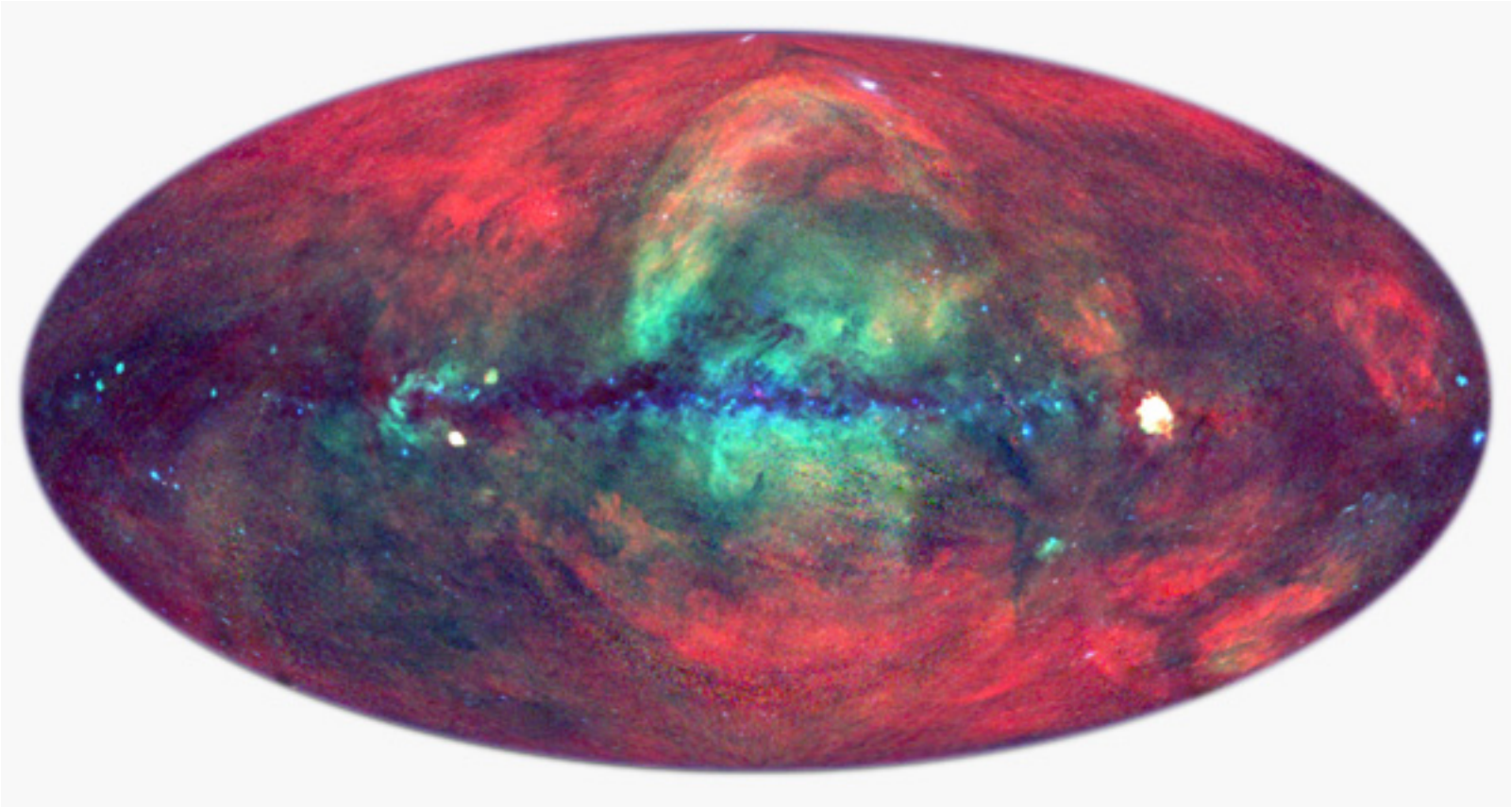
Only stars close enough to the solar system (few parsec) are seen.

Our galaxy

X-Rays

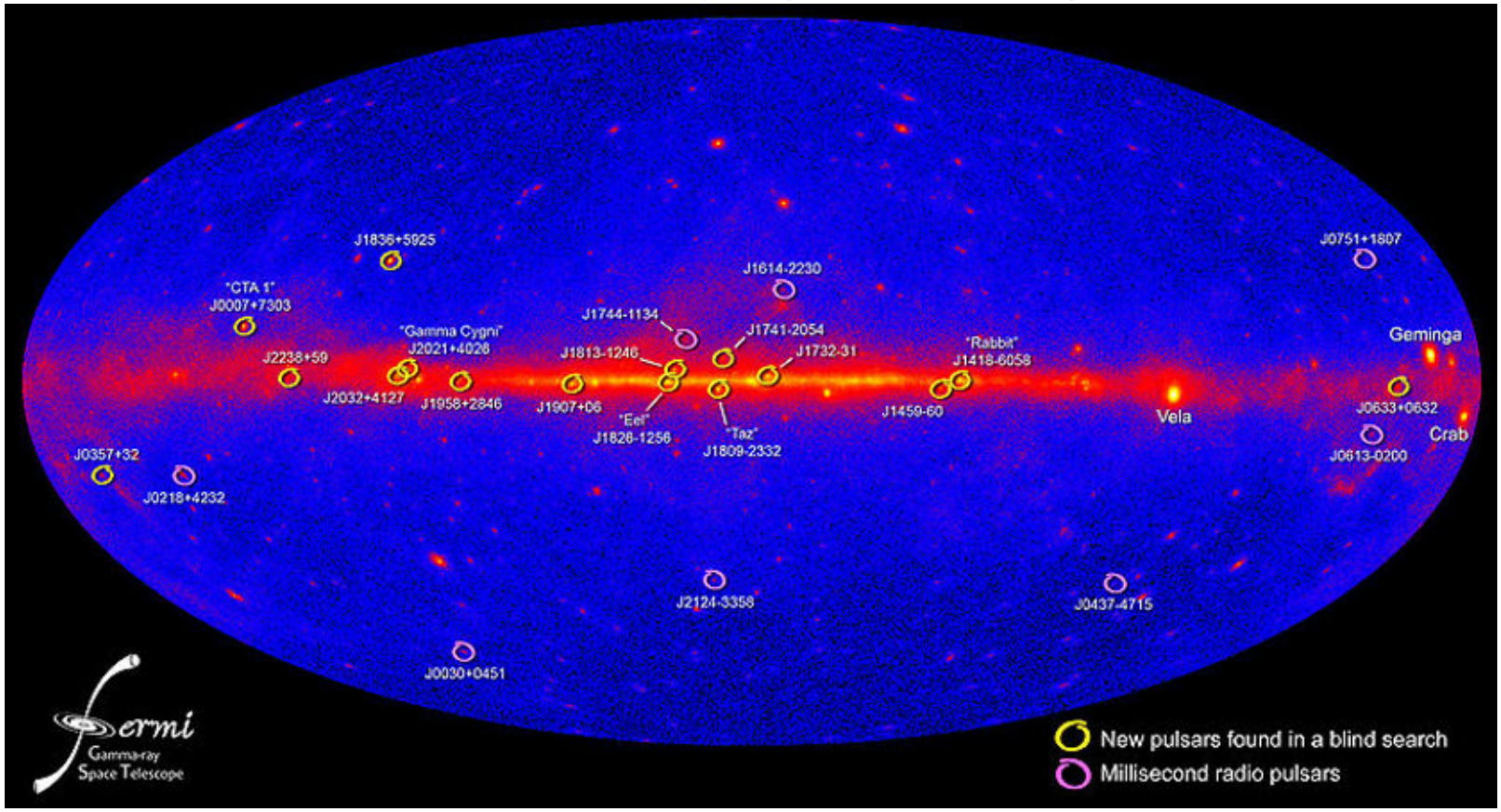
3,60 10^{17} Hz / 0,83 nm / 1.5 keV



Diffuse X-ray emission from overheated and shocked gas.
The dark band shows the absorption from cold gaz of our galaxy.

Our galaxy

High Energy Sky
Gamma rays (>100 MeV)



The gamma emission is due to collision between cosmic rays (atoms and relativistic particles) and interstellar clouds, to bremsstrahlung and inverse Compton process

Let there be light

All what we know is astrophysics is thanks to the light !

- Temperatures, stars masses, galaxies, magnetic fields, chemical composition, age of stars and structures…

- Nuclear reactions, galactic and extragalactic hydrodynamics, MHD, explosions, nucleosynthesis,
  past, future… EVERYTHING !

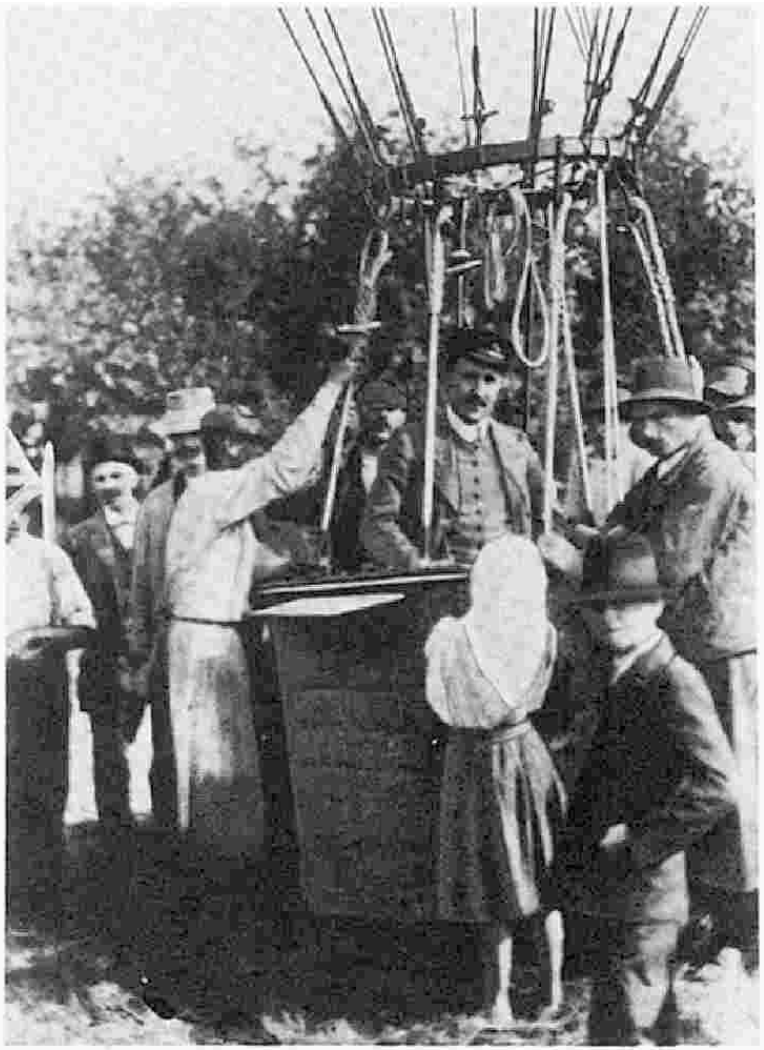
Well, almost everything…

- Non-luminous messengers : Cosmic Rays !
- Rare but precious : ~ **4 CR/cm²/s**
  ~30 µg/s on entire earth (**1kg** per year !)

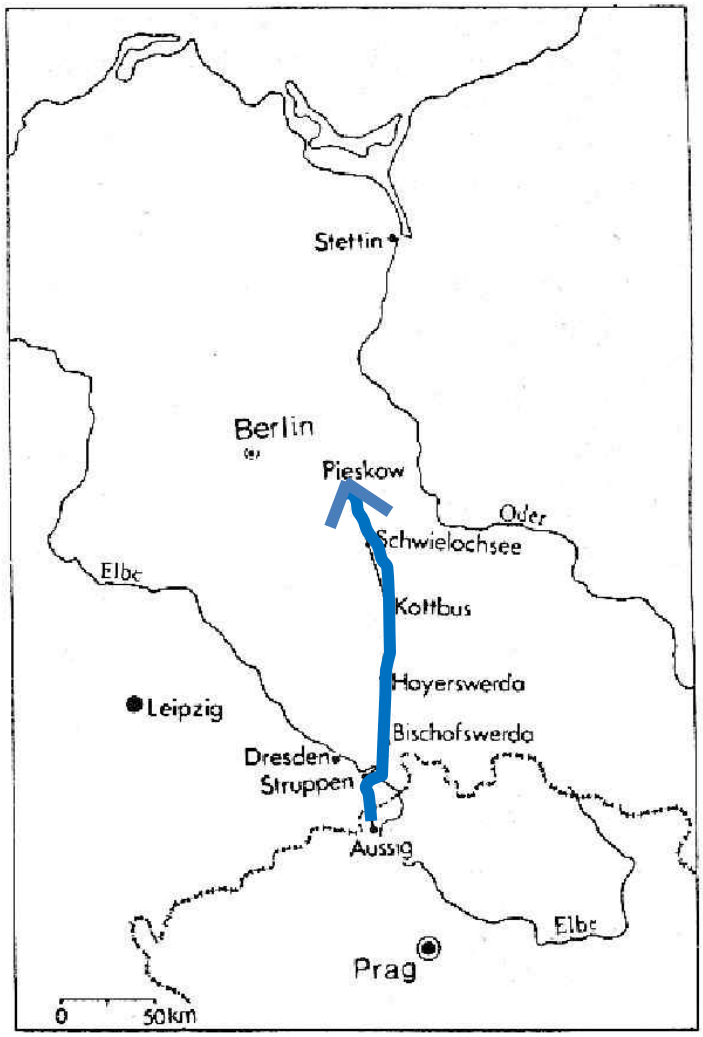
- CR astronomy is (almost) impossible…
- Directions randomized by magnetic fields
- What we would know if it was the same for photons !

- …but not astrophysics !
- Energy spectra and chemical composition tells us a lot…

Lets go higher !

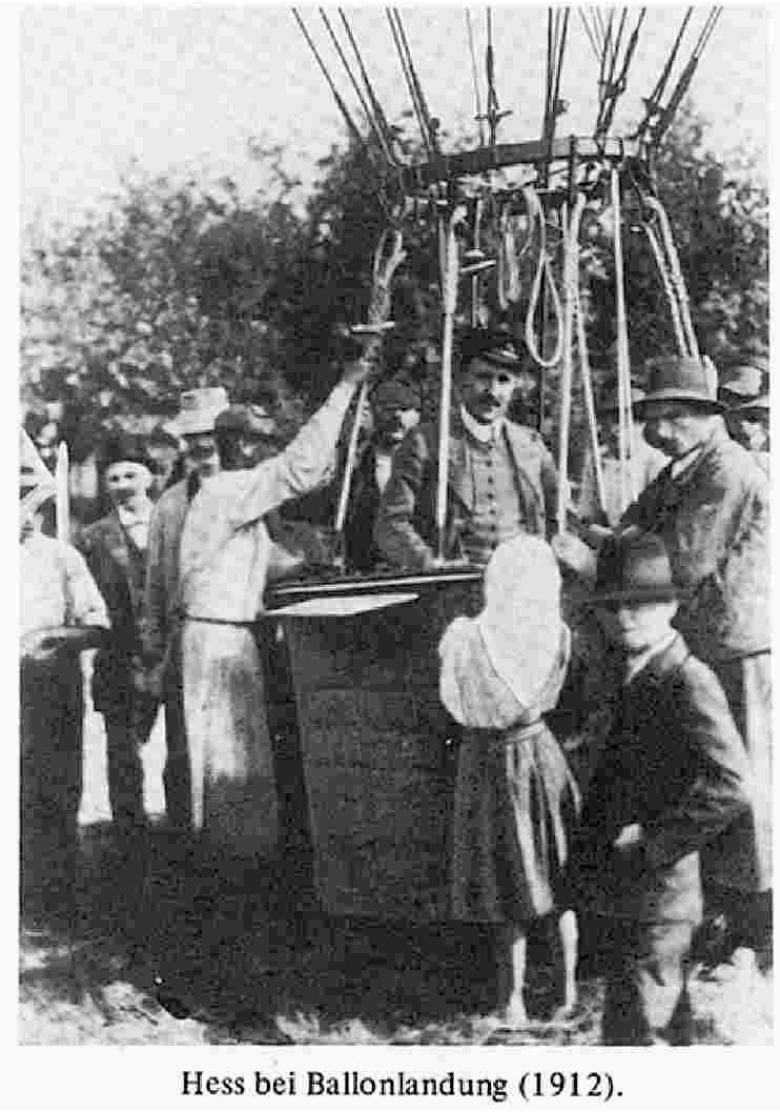


Hess bei Ballonlandung (1912).



Route des Entdeckungsfluges der kosmischen Strahlung.

Lets go higher !



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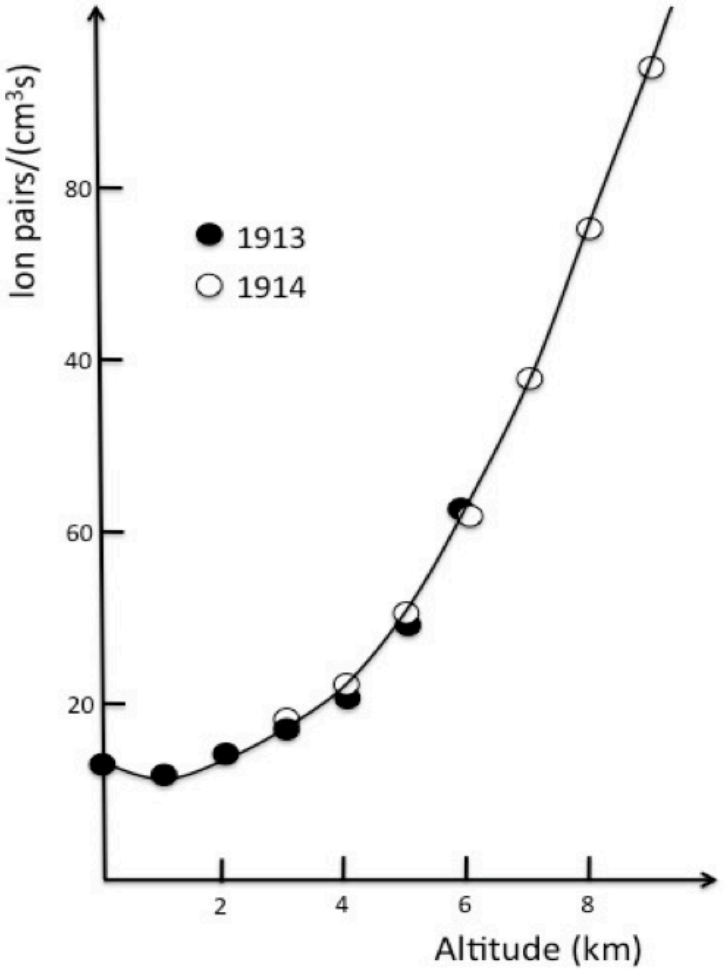
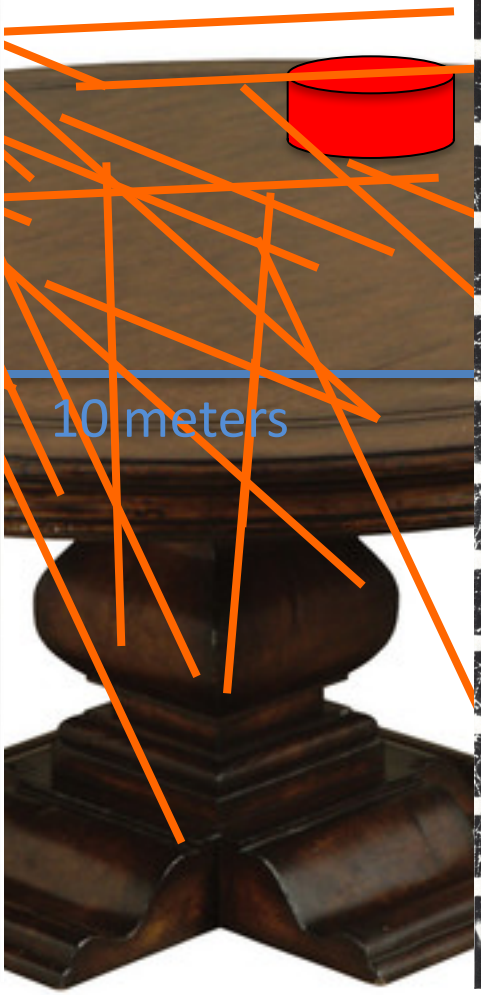
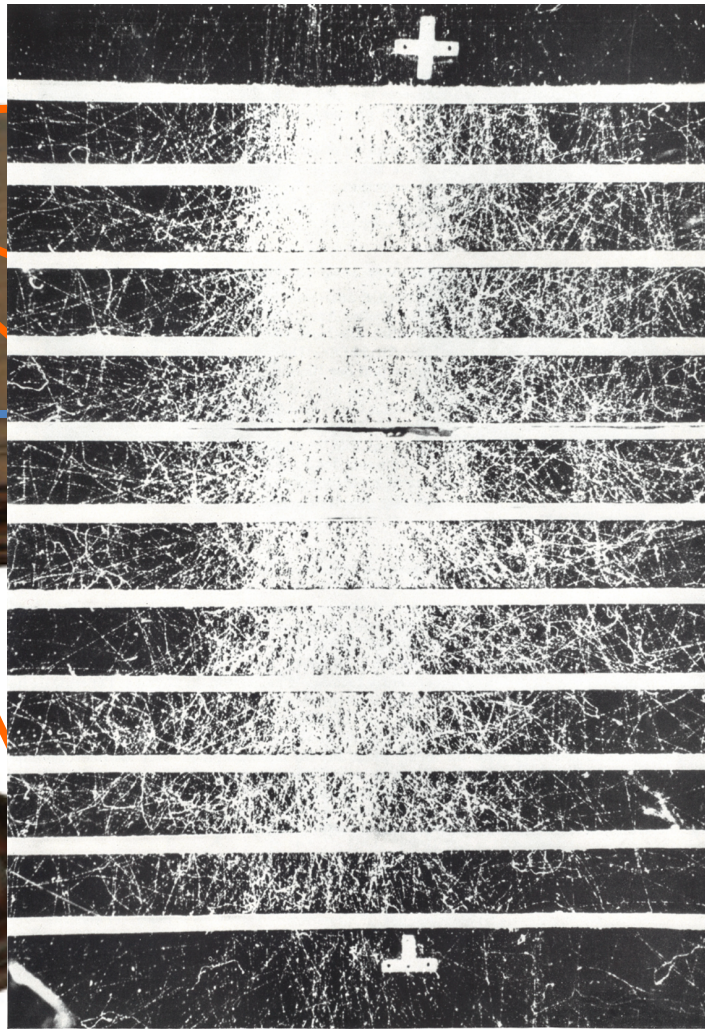


« The result of these observations seems to be explained in the simplest manner by assuming that an extremely penetrating radiation enters the atmosphere from above » (V. Hess)

Pierre Auger : Detection in coincidence

Atmospheric showers





A lot of new particles !

1932 Positron → Antimatter

1936 Muon

1949 Pion

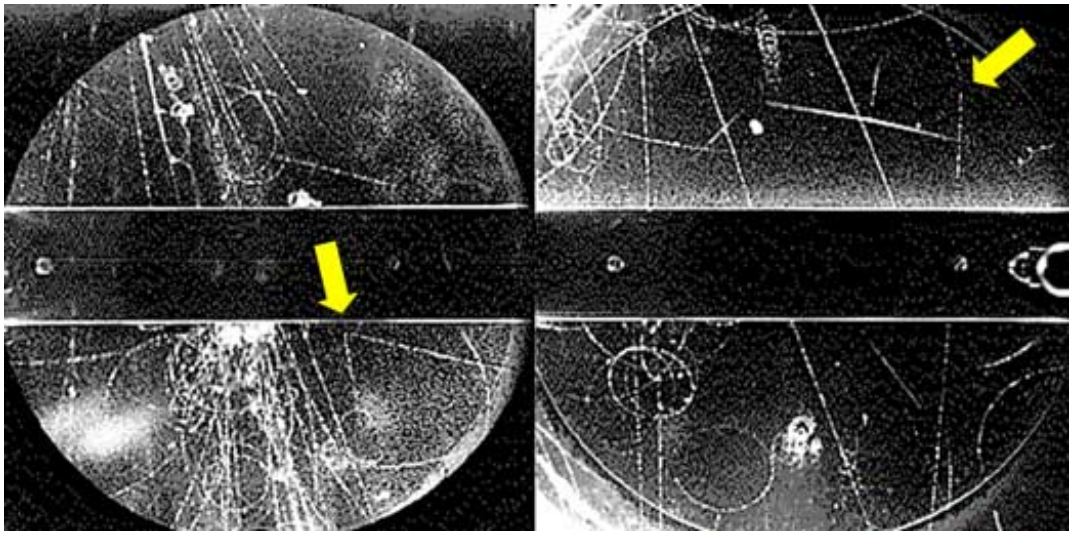
1949 Pions (π)

1949 Kaons (K)

1949 Lambda (Λ)

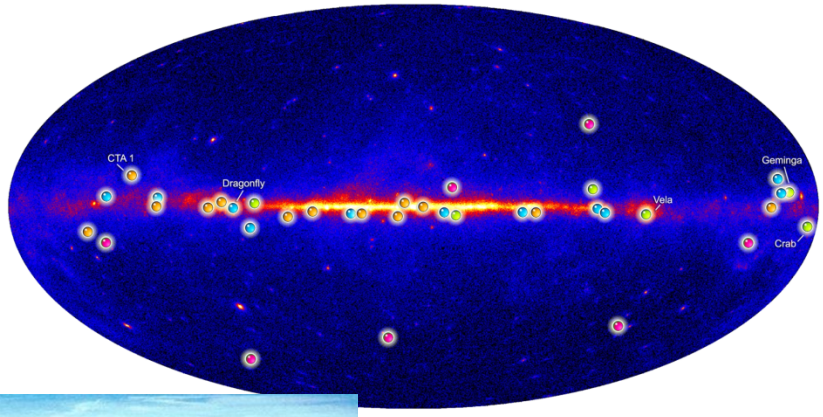
1952 Xi (Ξ)

1953 Sigma (Σ)

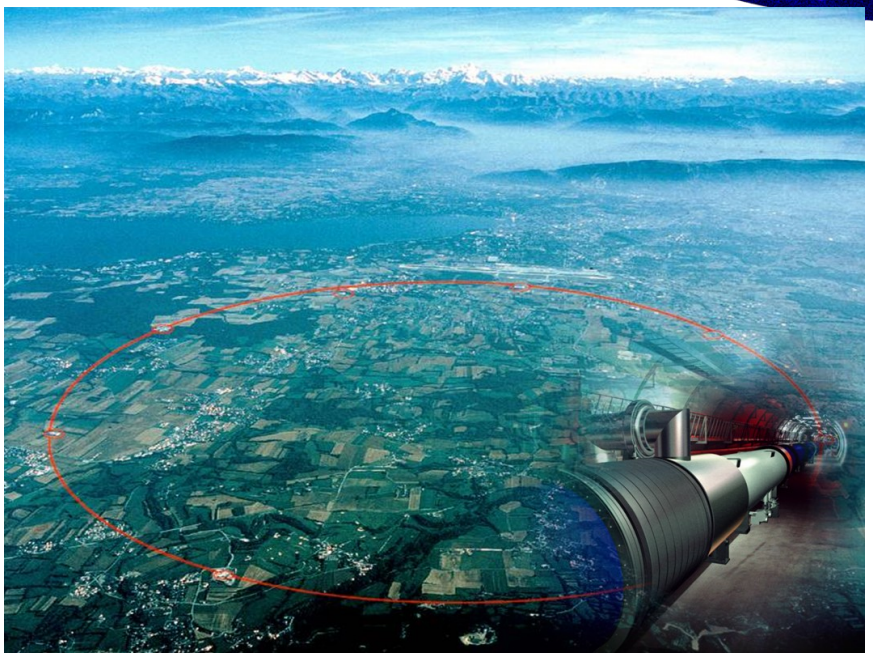


A new science is born :
Particle Physics !

Cosmic Rays

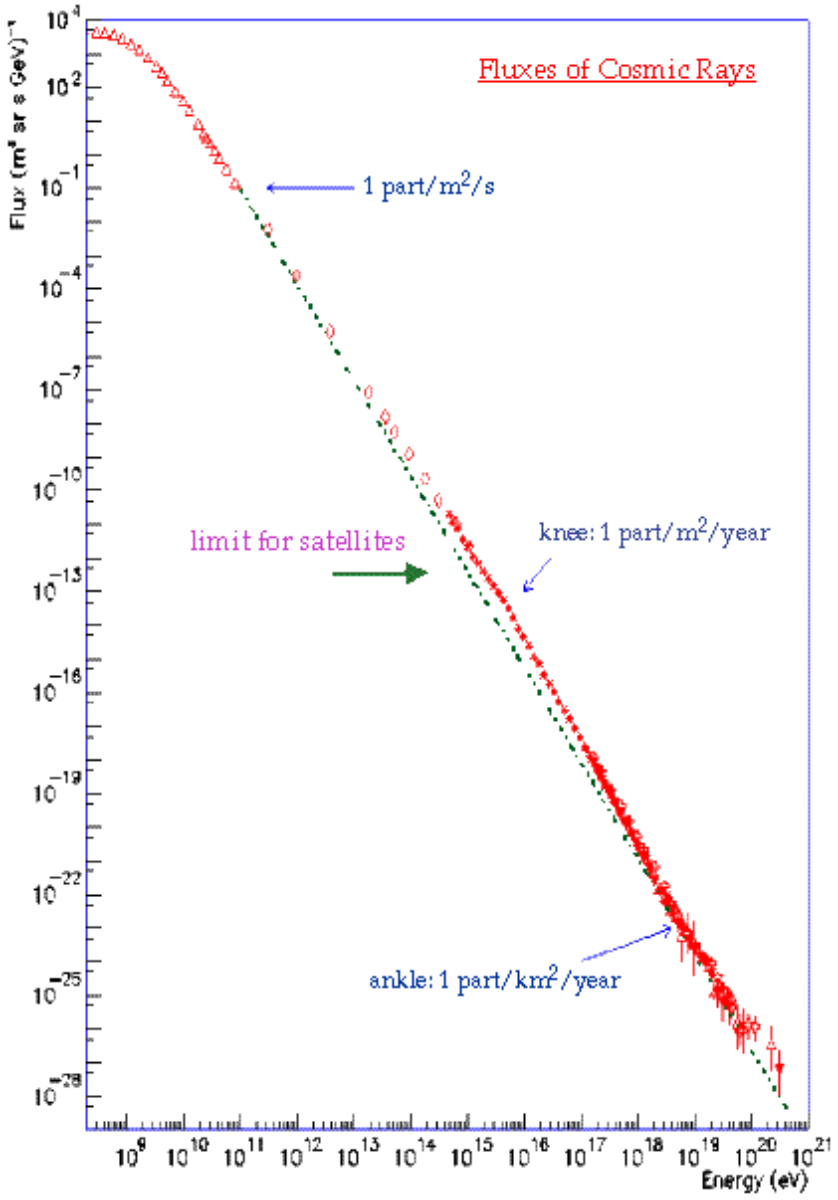


Astrophysic



Particle Physics

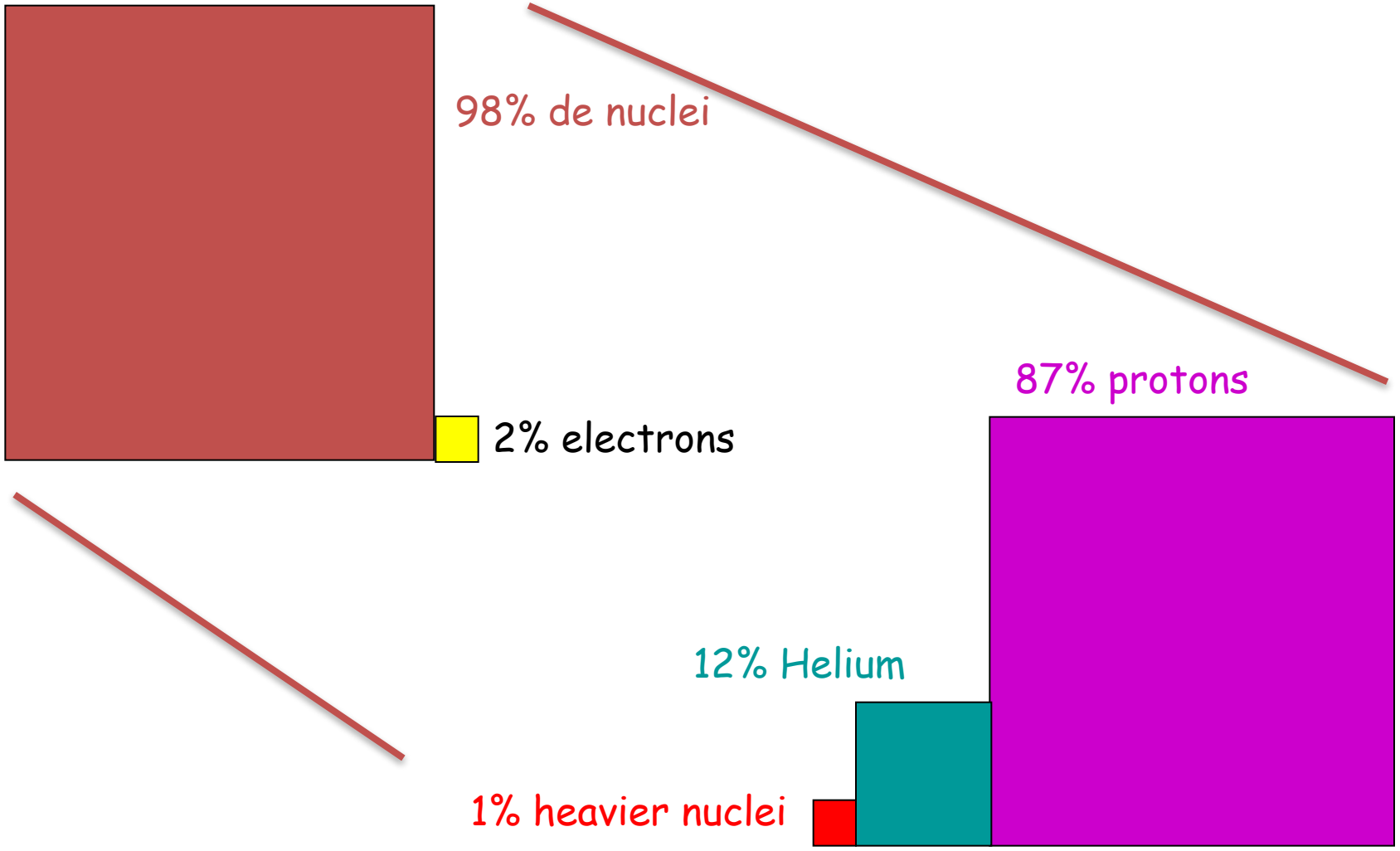
The "all" paticle sectrum



$$\frac{dI}{dE} \propto E^{-\gamma} \quad ou \quad I(>E) \propto E^{-(\gamma-1)}$$

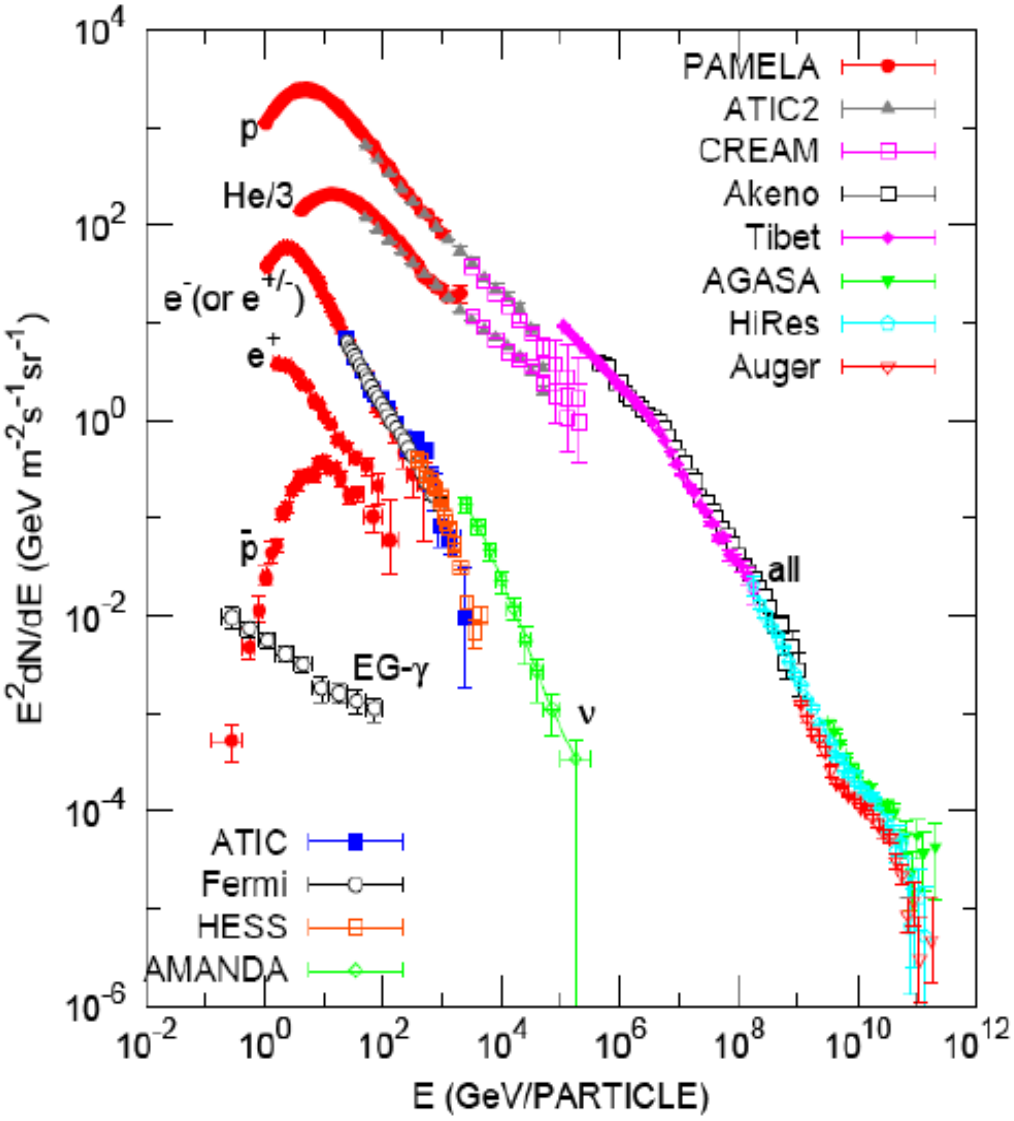
- Regular spectrum over 12 decades in energy, and 32 decades in flux !!!
- Small break near 3×10^{15}eV : the "knee"
- An other one near 10^{18}eV : the "ankle"
- Spectrum badly known at the two extremities
  - Geomagnetic "shield" + Solar modulation
  - Extreme rareness…

Composition

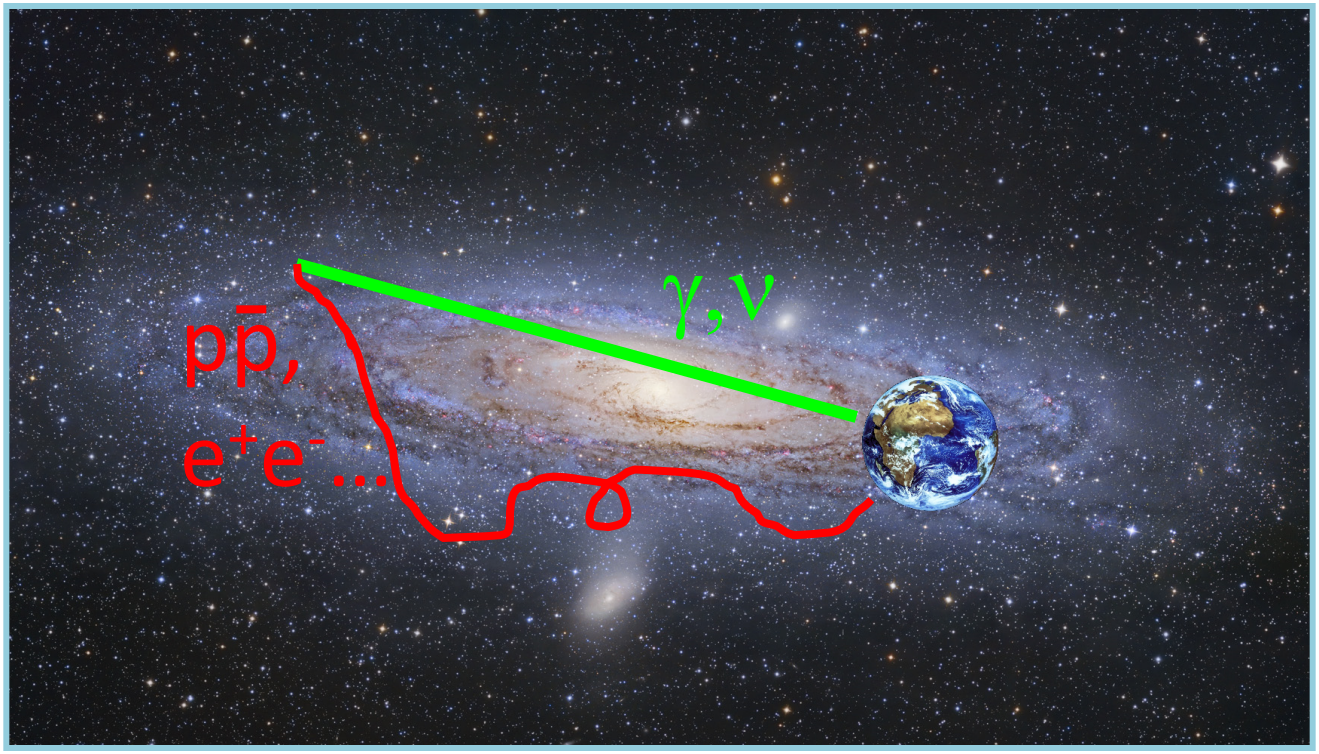


Flux : 4 RC/cm^2/s $\Rightarrow$ 1 kg/year << 40 000 ton/year (meteorites)

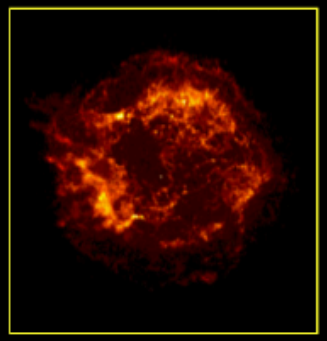
Composition



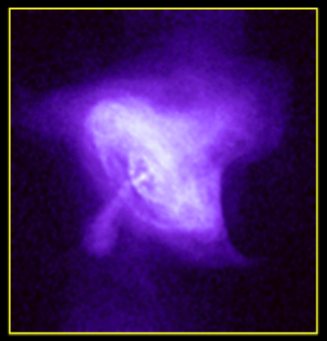
Propagation



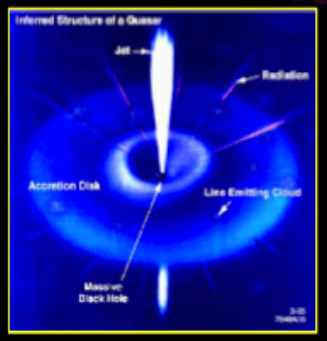
Science topics



SNRs



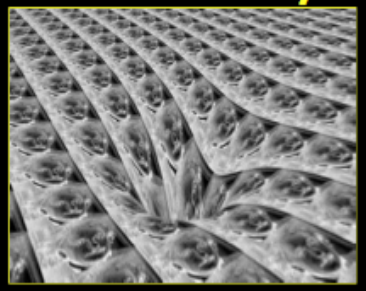
Pulsars and PWN



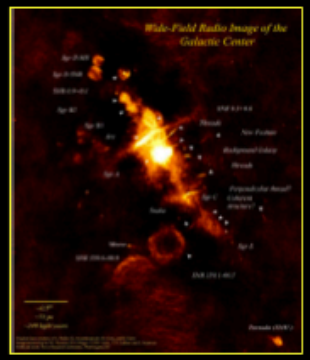
AGNs

Origin of cosmic rays

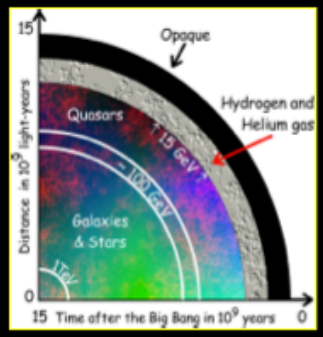
Space-time & relativity



Dark matter



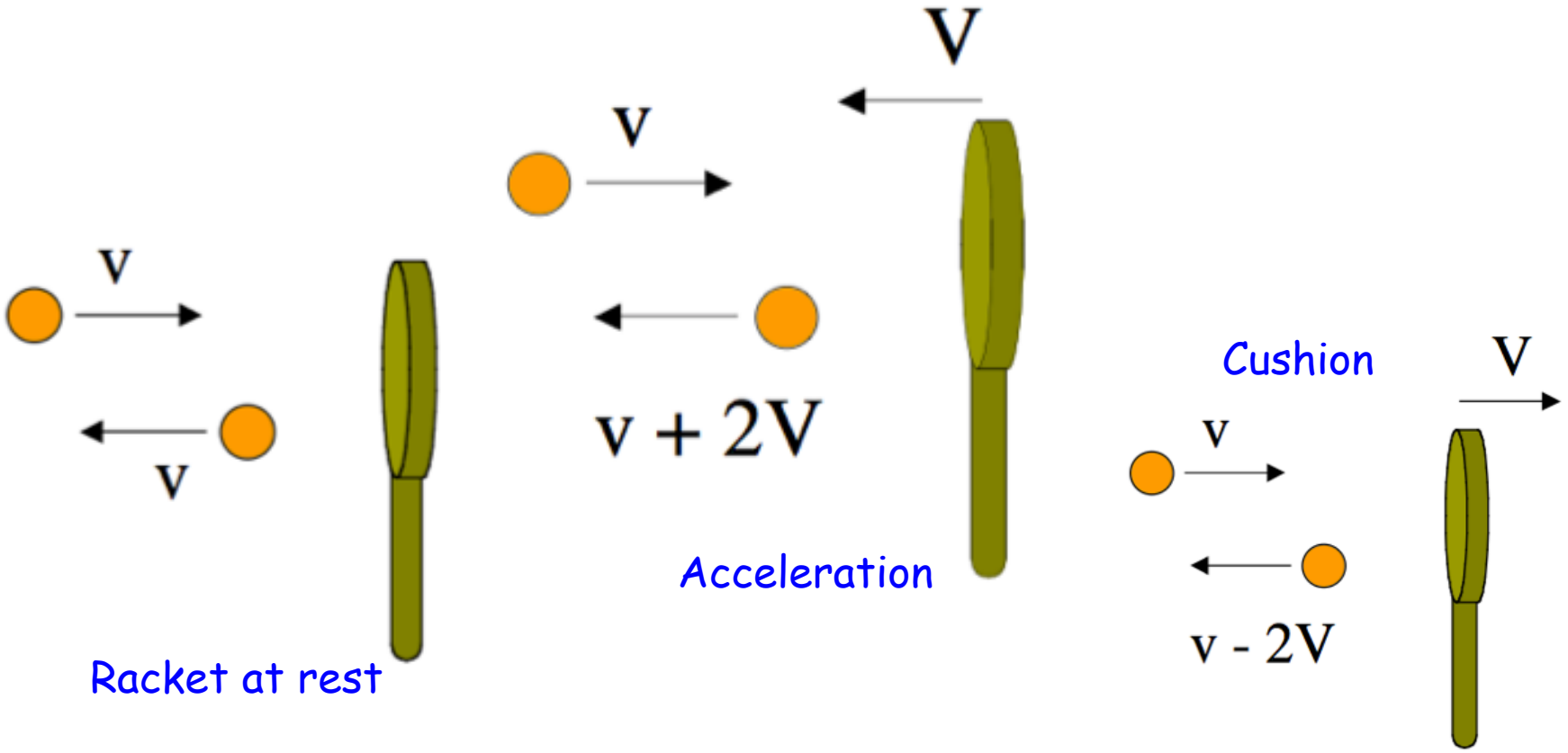
GRBs



Cosmology

Fermi Mecanism : Acceleration Principle

- Only charged particle can be accelerated
- A chock is needed
- The power low spectrum is very well explained (some things still need to be understood)
- Tennis analogy :



Hillas Criteria – Maximum Energy

- Movement of a charged particle in B field: Larmo radius

$$R_L = \frac{P}{qB} \approx \frac{E}{qBc}$$

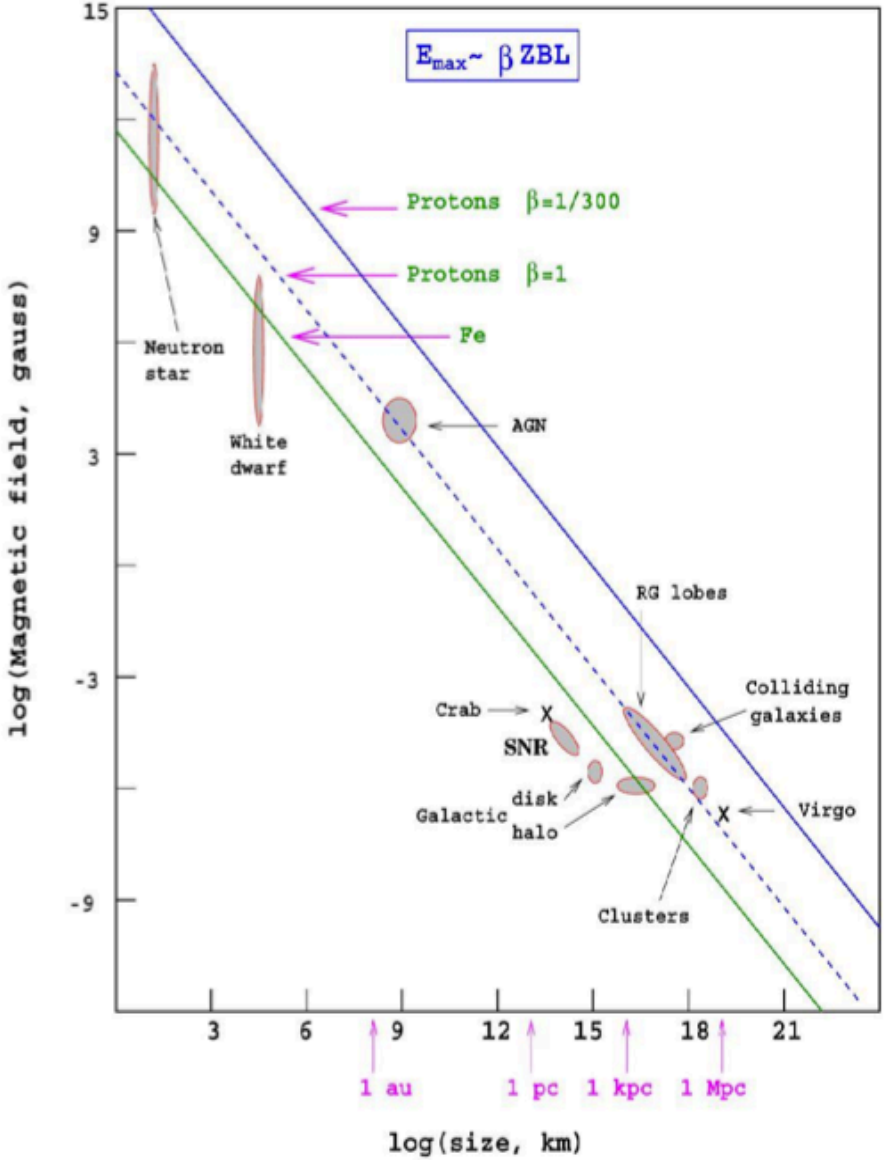
- Confinement: source size $> R_L$

$$E_{max} \approx qBcR$$

- For a moving accelerator

$$E_{max} \approx \Gamma qBcR$$

- Line of slope -1 in log(R) - log(B) plot



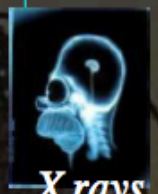
Electromagnetic spectrum

keV MeV GeV TeV PeV EeV

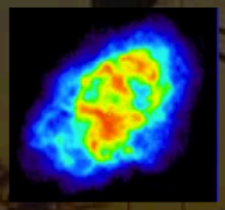
10^{-6} 10^{-3} 10^{0} 10^{3} 10^{6} 10^{9} 10^{12} 10^{15} 10^{18} E (eV)

1 10^{-3} 10^{-6} 10^{-9} 10^{-12} 10^{-15} 10^{-18} 10^{-21} 10^{-24} λ (m)

10^{8} 10^{11} 10^{14} 10^{17} 10^{20} 10^{23} 10^{26} 10^{29} 10^{32} ν (Hz)



Radio *IR* *Visible* *UV* *X rays* *γ rays*



Cold objects (10K), Dust,...
Synchrotron emission of accelerated electrons

Hot objects (~2000K), sun, nebula

Very hot compact objects (~10^{6}K), pulsars, black holes...
Size ~km

VHE
(Very High Energy)

UHE
(Ultra High Energy)

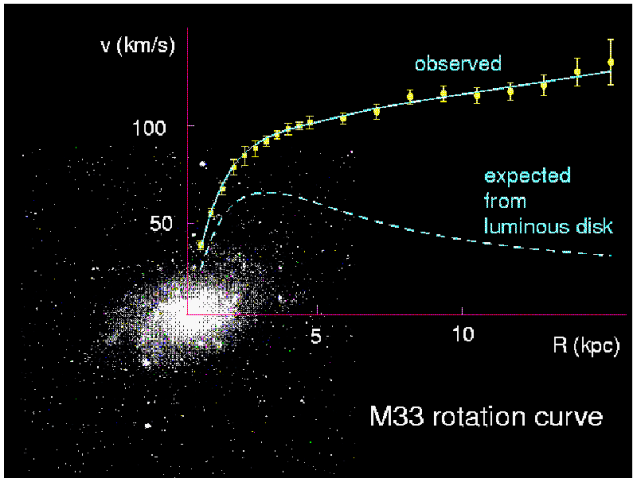
Extreme objects, non-thermal processes (Particle acceleration in shocks)
Inverse Compton, Bremstrahlung, Annihilation, Pion disintegration

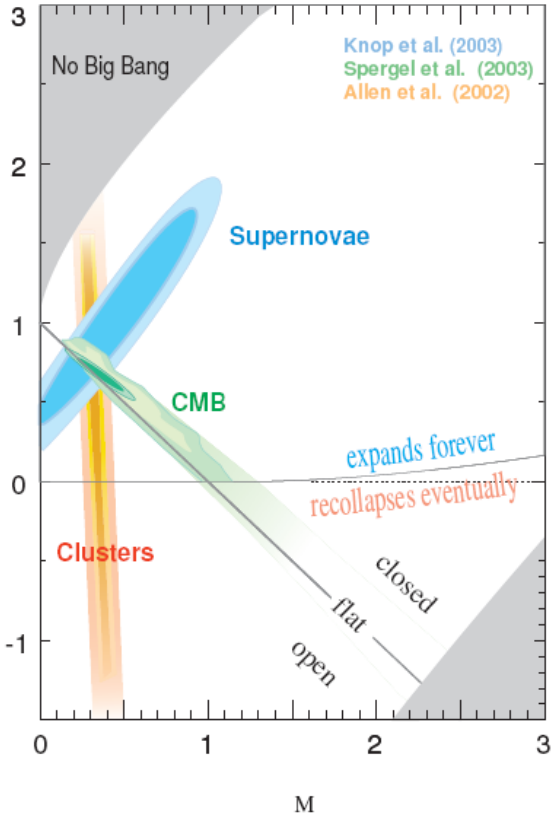
Ce que la matière noire n'est pas

Ce que la matière noire n'est pas

➔ Barnard 68 : nuage moléculaire très froid ~ 500 a.l. transparent en infrarouge

Matière noire



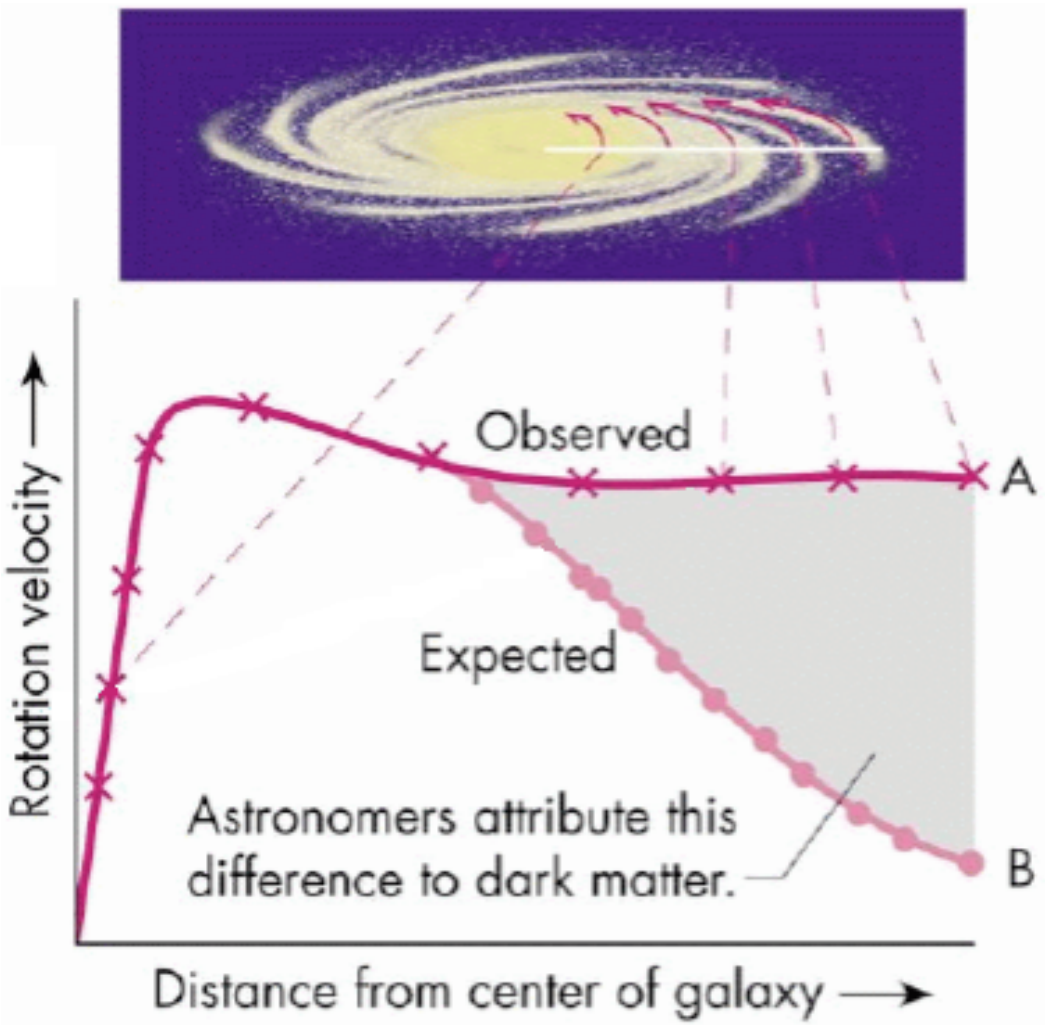


Indices en faveur de la matière noire :

- Galaxies
- Amas de galaxies
- Mesures cosmologiques

Matière d'origine inconnue

Les galaxies

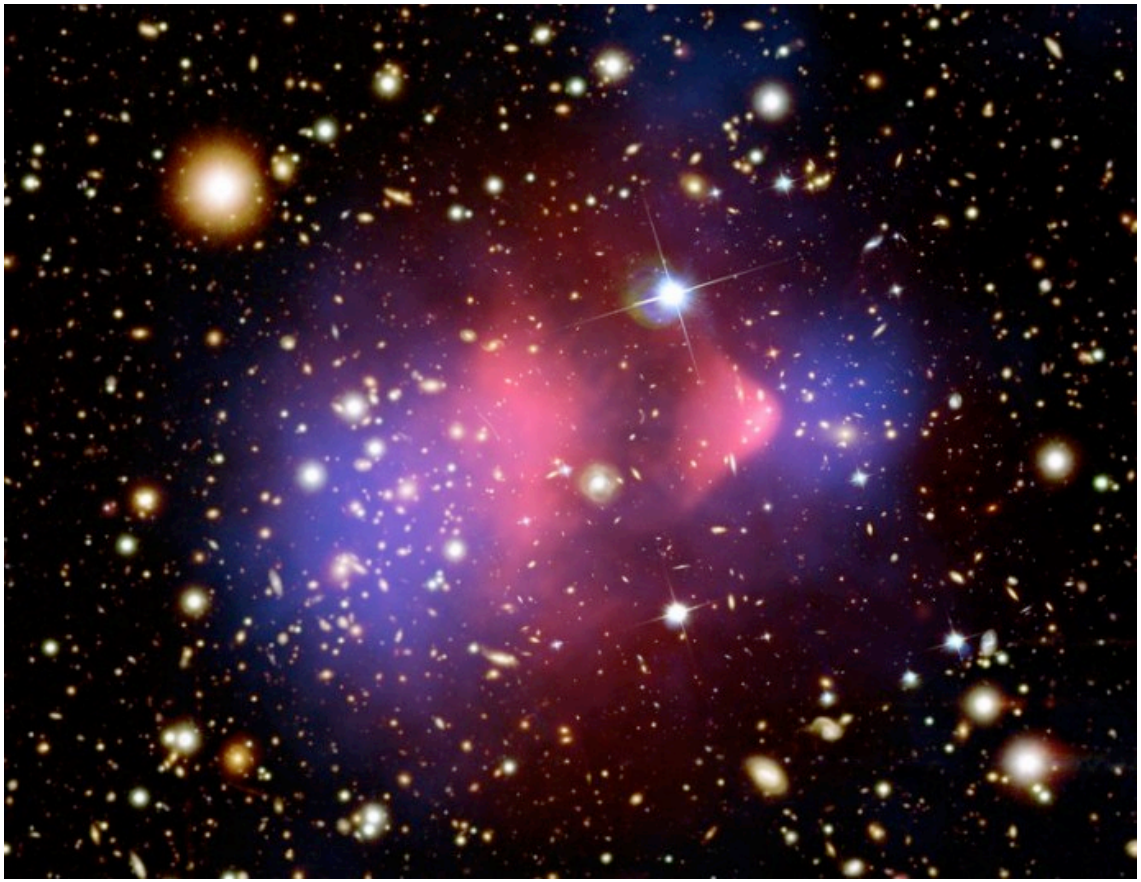


La vitesse des étoiles est quasiment constante
lorsque qu'on s'éloigne du centre
Alors que l'on s'attend à ce qu'elle diminue

➔ Présence d'un halo de matière invisible 5-10 fois plus massif que la matière visible

Travaux Vera Rubin ~1970

Les collisions d'amas de galaxie

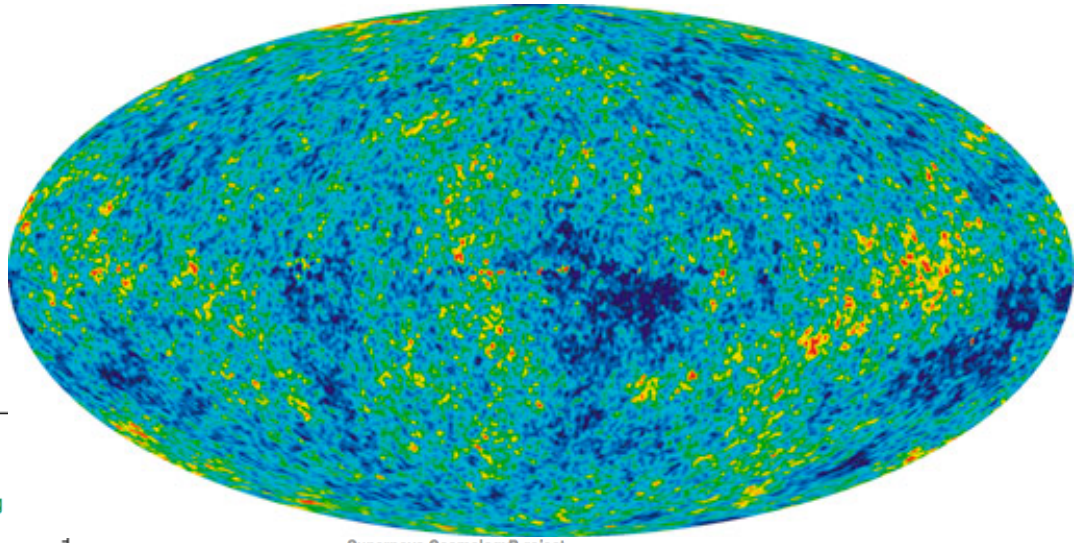


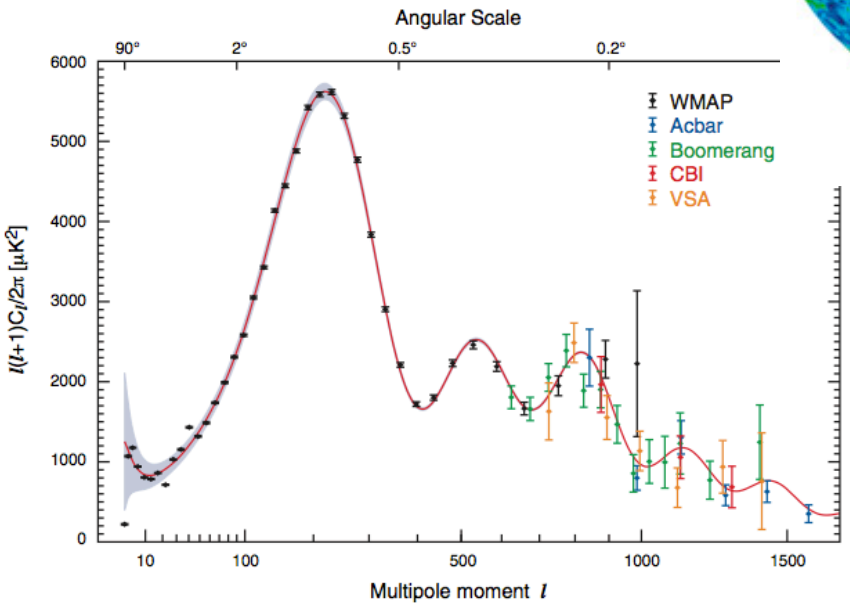
Image, observée par Hubble, du **Bullet Cluster** (Amas de la balle), ré sultant de la collision de deux amas, à laquelle est superposée le gaz chaud en rouge vu par Chandra (X) et la distribution de matière en bleu déduite par lentille gravitationnelle.

➔ La masse dans l'amas est dominée par de la matière noire qui, contrairement au gaz chaud, n'est pas ralentie lors de la collision car elle interagit très peu.

Le fond diffus cosmologique

Le fond cosmologique correspond aux photons qui se sont échappés lors du découplage entre la lumière et la matière (300000 ans après le Big Bang).

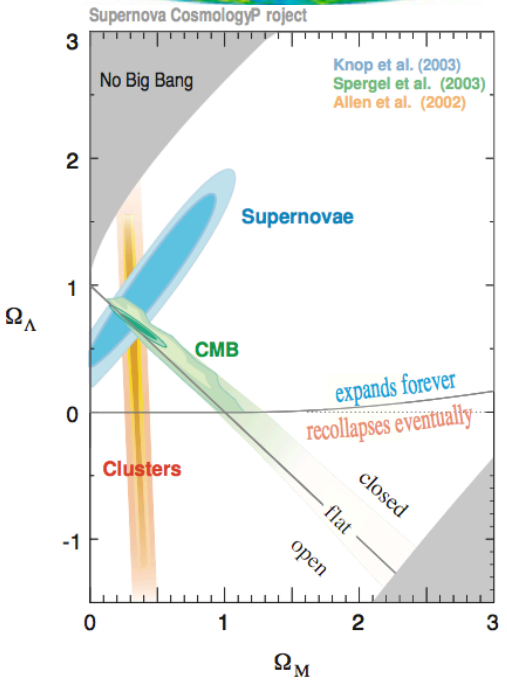




$\Omega_b = 0.0449 + / - 0.0028$

$\Omega_{DM} = 0.222 + / - 0.026$

$\Omega_\Lambda = 0.734 + / - 0.029$



Abondance cosmologique des WIMP

Les neutralinos peuvent s'annihiler et former d'autres paires particules-antiparticules

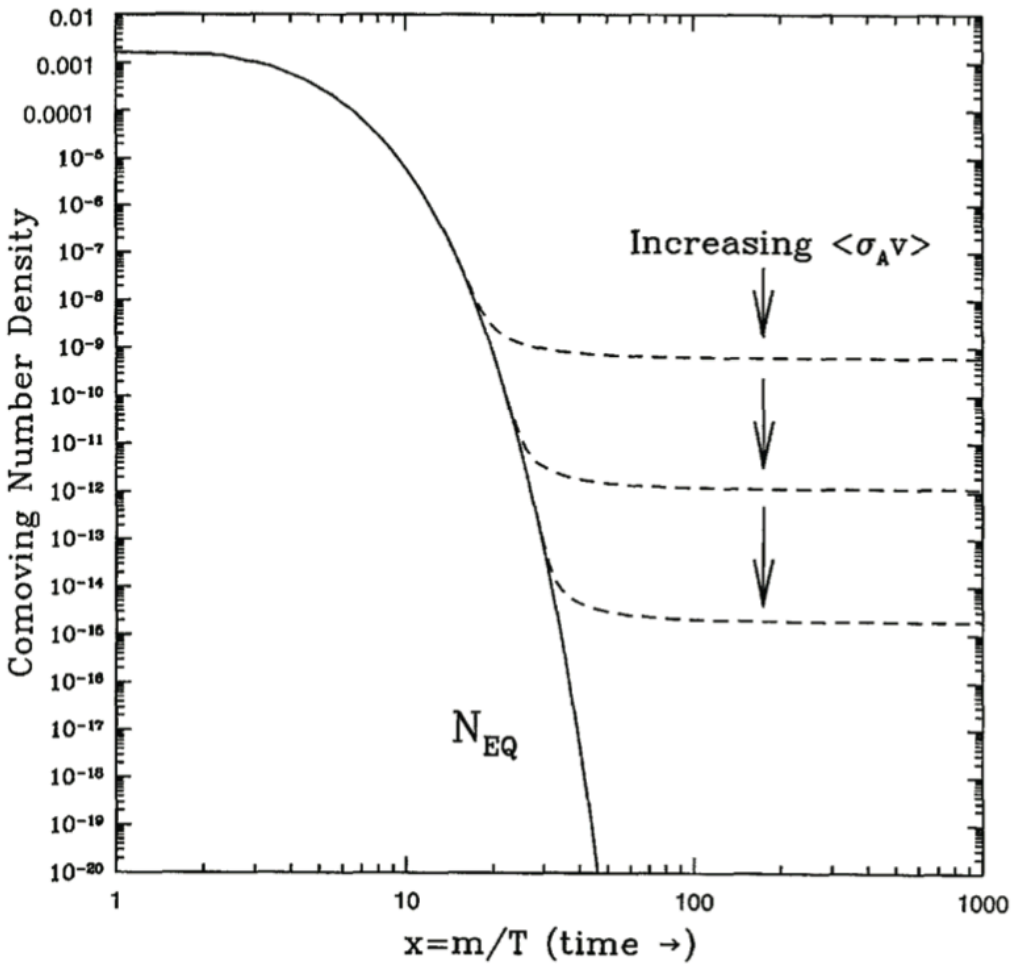
$$\chi\chi \rightarrow \psi\bar{\psi}$$

L'évolution de la densité suit :

$$\frac{dn}{dt} + 3Hn = -\langle\sigma v\rangle(n_\chi^2 - (n_\chi^{eq})^2)$$

La densité relique peut s'exprimer :

$$\Omega_\chi h^2 \approx \frac{3 \times 10^{-27}\ cm^3.s^{-1}}{\langle\sigma v\rangle}$$



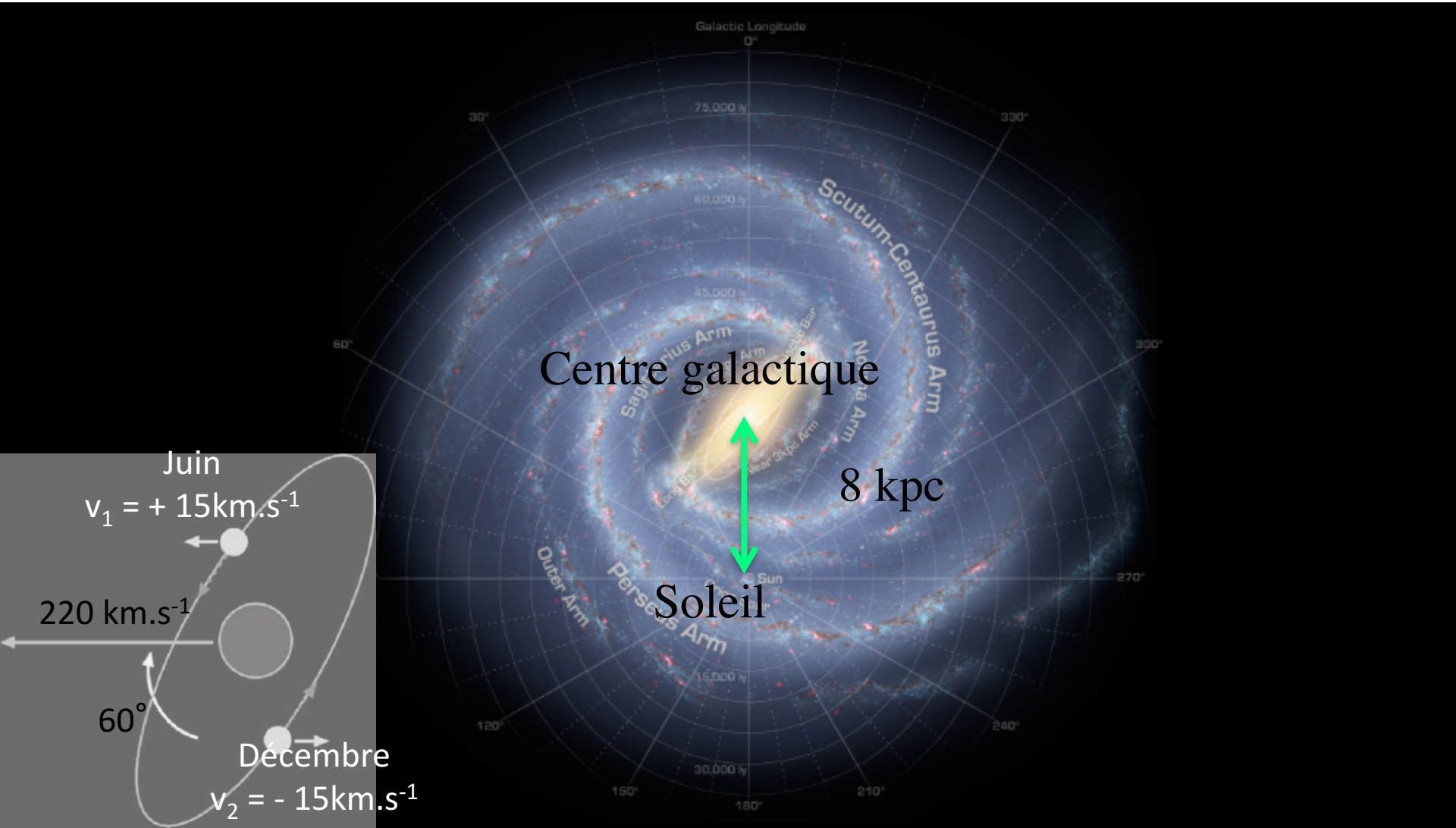
Comme $\Omega h^2 \sim 10^{-1}$.

alors $\langle\sigma v\rangle \sim 10^{-26}\ cm^3.s^{-1}$ ~ interaction faible

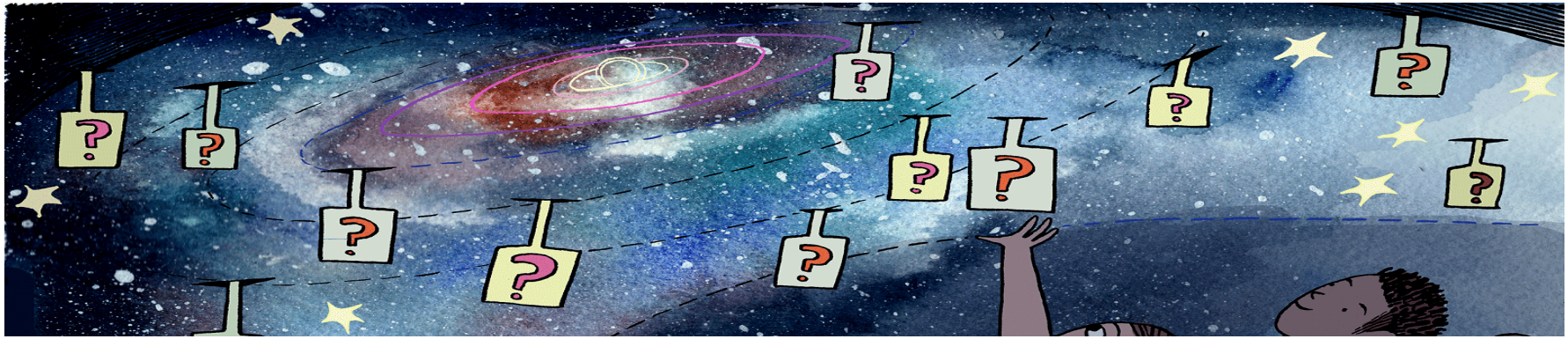
Mesure locale

L'étude des vitesses des étoiles dans le voisinage du système solaire permet d'estimer la densité locale de matière noire.

$$\rho_\chi = 0.3 \pm 0.1 \text{ GeV/cm}^3$$



Matière noire



80 % de la matière est de nature non baryonique

WIMP :
Weakly Interactive
Massive Particle

Nous recherchons des particules :

- Non relativistes
- Neutres
- Faible section efficace, $<\sigma v>$~interaction faible

Candidats :

- Extension supersymétrique (SUSY) du Modèle Standard
- Modèles à dimensions supplémentaires universelles (UED)

➔ $GeV < m_{DM} < TeV$

➔ *See talk of Chloé THERREAU*

Menu of the day

➔ L'expérience H.E.S.S. et son futur C.T.A.
➔ Pulsars at very high energy (Marion JACOB)
➔ Variabilité des noyaux actifs de galaxie au très hautes énergies avec H.E.S.S (Gabriel EMERY)
➔ COFFEE BREAK
➔ Gamma-Ray Burst detection at very high energy (Quentin PIEL)

➔ Étude des sources gamma HESS J1640.6-4633 et HESS J1641.0-4619 : source d'accélération de rayons cosmiques de hautes énergies (Arnaud MARES)

➔ Calibration of the XENON1T experiment for the search of new physics (Chloe THERREAU)