



The Gamma Rays Instruments

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Gamma Rays : Specifications

Range from some 100 keV up to the order of TeV

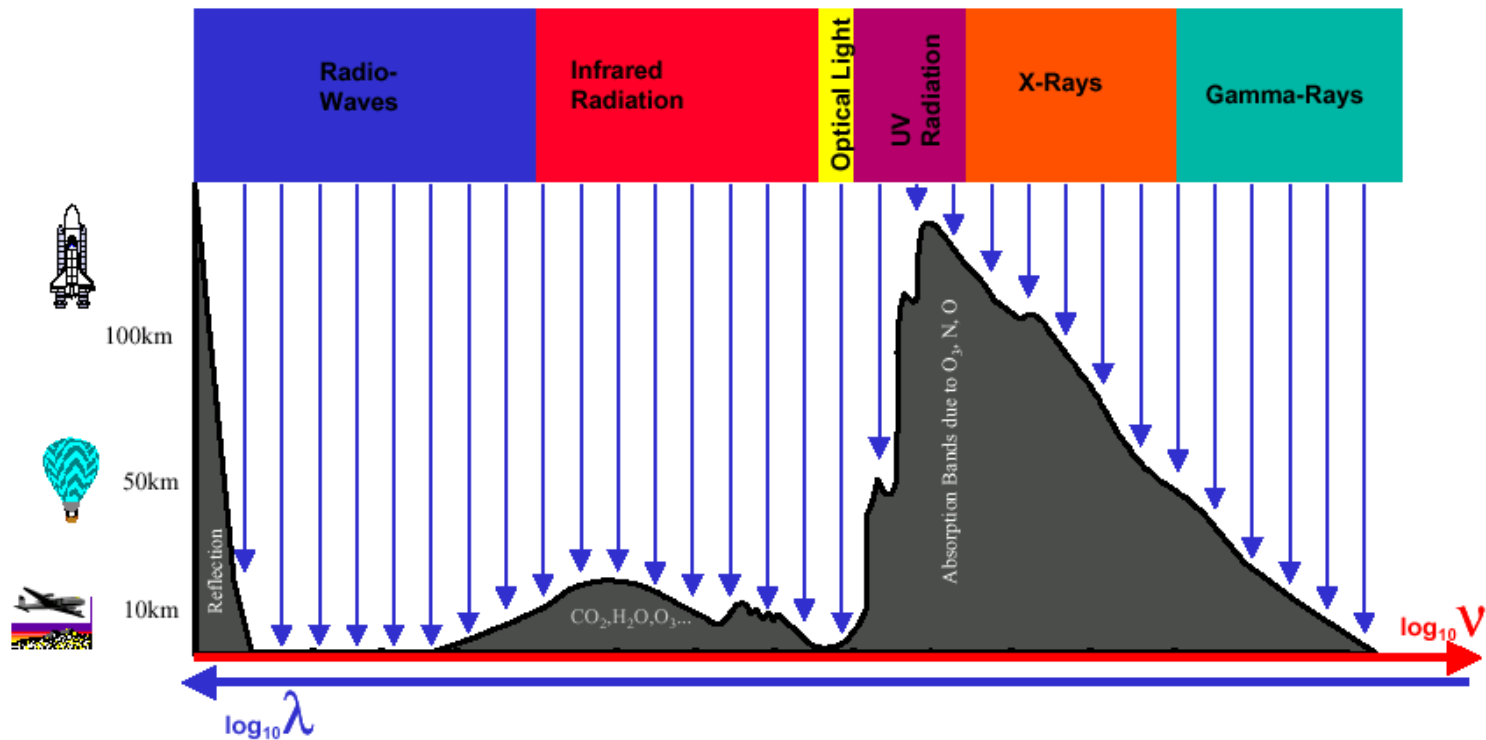


Fig. 1 : Earth's atmosphere transparency to cosmic Electromagnetic radiation (R.Diehl)



Production Processes (1)

- Thermal radiation.

- Nonthermal radiation.

Typical sources for γ -rays. Every particle accelerated in an external field or every system of particles' energy level change can lead to γ -ray emission.

Production Processes (2)

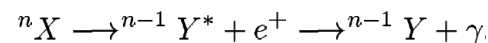
- Accelerated charged particles :

$$E_\gamma = (\gamma - 1)m_e c^2$$

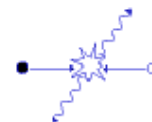
- Inverse compton scattering :

$$E_\gamma \simeq 1.3 \left(\frac{E_e}{(TeV)} \right)^2 \cdot \left(\frac{E_{ph}}{2 \times 10^{-4}(eV)} \right) (GeV)$$

- De-excitation of atomic nucleus :



- Annihilation of particle-antiparticle pair :





Problem: How to catch γ -rays ?

- Unlike optical photons, γ -rays don't interact with a material's surface (mirrors are nonsense here).
- They randomly penetrate to some variable depth of a material before interaction.
- Scattered γ -rays photons don't form diffraction patterns, etc.
- The interaction process varies with the incoming γ -ray beam.



Absorption Processes

- Photoelectric absorption

- Compton scattering :
$$E_1 = \frac{E^2 \cdot (1 - \cos \varphi)}{E \cdot (1 - \cos \varphi) + m_e c^2}$$

- Pair creation

- Quantized absorption



Detection of γ -rays from Space

Below 100 GeV, there are 3 main problems :

- The opaqueness of the atmosphere
- The low γ -rays fluxes
- The background of γ -rays telescopes themselves



Opacity of the atmosphere


- Integrated matter density : ca. $1000\text{g}\cdot\text{cm}^{-2}$
- Mass attenuation for air at 1 MeV : ca. $0.00642\text{cm}^2\cdot\text{g}^{-1}$

So the absorption probability for a 1 MeV photon is 99.8%



Low γ -rays fluxes

- A γ -ray photon carries the equivalent energy of 1 million optical photons.
- Then, they are high penetrating particles.



Background of γ -rays telescopes

- The material of a telescope is permanently irradiated
- As a result : excited nuclei and spallation products
- Consequence : emission of γ -rays, neutrons and delayed γ -rays
- Two sources for the Background : natural radioactivity of the material and activation background



The Charged-Particle Backgd

- Charged particles ionize atoms along their path
- This is used to reject these particles by surrounding the detector with a scintillator
- From this, one get a veto signal for the detector



The Neutral-Particle Backgd

- From external sources : atmospheric and extraterrestrial parts
- From internal sources : material of the telescope
 - Activation of atomic nuclei
 - Decay of natural radioactive elements



Backgd-Suppression Methods

- Passive background suppression method
 - Passive shielding around the active detector elements

- Active background suppression method
 - Plastic vs. NaI, CsI, BGO scintillators materials
 - Tentatives in the past to couple passive and active collimators

 - PSD (Pulse Shape Discrimination)



Γ -ray Detection Techniques

- Scintillation techniques
- Solid-state detectors
- Spark chambers
- Čerenkov detectors



Scintillation Techniques

- Principle : Creation of an optical photon (fluorescence and phosphorescence) after the absorption of a γ -ray photon (via a charged particle).
- Organic Scintillators : emission processes based on transitions within the energy-level of a single molecule.
- Inorganic Scintillators : based on the lattice structure of a crystal
- In both cases, the light gathered is amplified via photomultipliers tubes

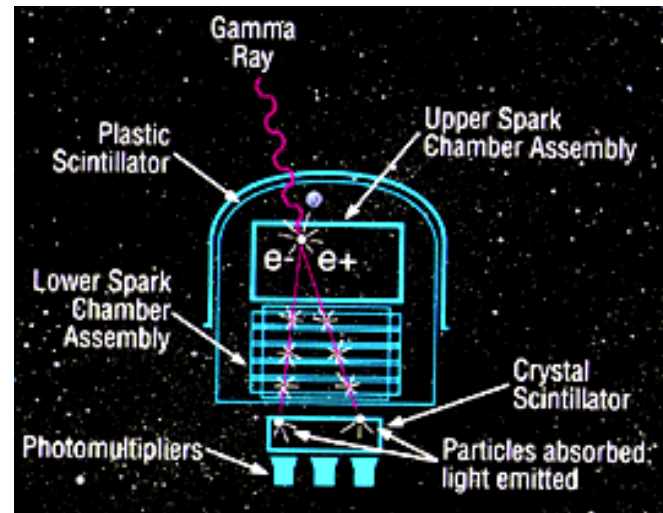
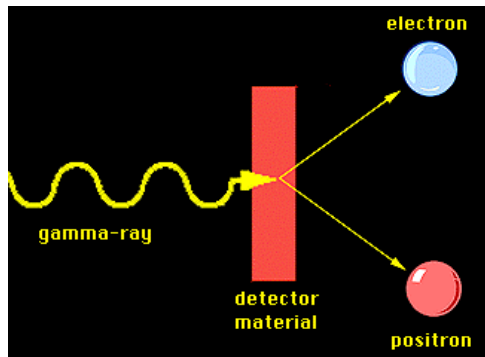


Solid-state Detectors

- Principle : creation of an electron-hole pair in a semiconductor
- Kind of improved inorganic scintillator
- Need to be cooled at low temperatures (thermal radiation)
- Most used : HPGe (High Purity Ge)
 - A high voltage has to be applied (2 to 9 kV across the detector)
 - Has to be cooled to <120 K (90K on SPI) in order to reduce de leakage current

Spark Chambers

- For $>30\text{MeV}$ γ -rays energies, the dominant absorption process is the pair production
- Should possess a conversion medium with a high Z value.





Čerenkov Detectors

- Principle : when a charged particle moves through a transparent medium faster than the local speed of light ($\beta n > 1$), then Čerenkov photons are emitted and can be measured by PMTs.

- Inherent threshold :
$$E_{thr} = m_e c^2 \cdot \left(\frac{n}{\sqrt{n^2 - 1}} - 1 \right)$$

- Corresponding cone angle :
$$\cos \alpha = \frac{1}{\beta n} , \text{ with } \beta = \frac{v}{c} \text{ and } n \text{ the refractive index}$$

Sensitivity of γ -ray Telescopes

- Sensitivity of a γ -ray telescope :
$$F_{\min}(E, \Theta, \Phi) = n \cdot \sqrt{\frac{dF_B(E) \cdot \Delta E \cdot \Delta \Omega}{A_{\text{eff}}(E, \Theta, \Phi) \cdot T_{\text{obs}}}}$$

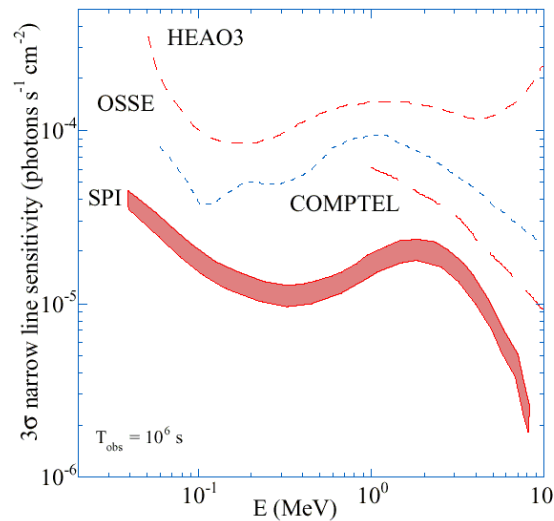


Fig.: Comparison of the sensitivity of different instruments

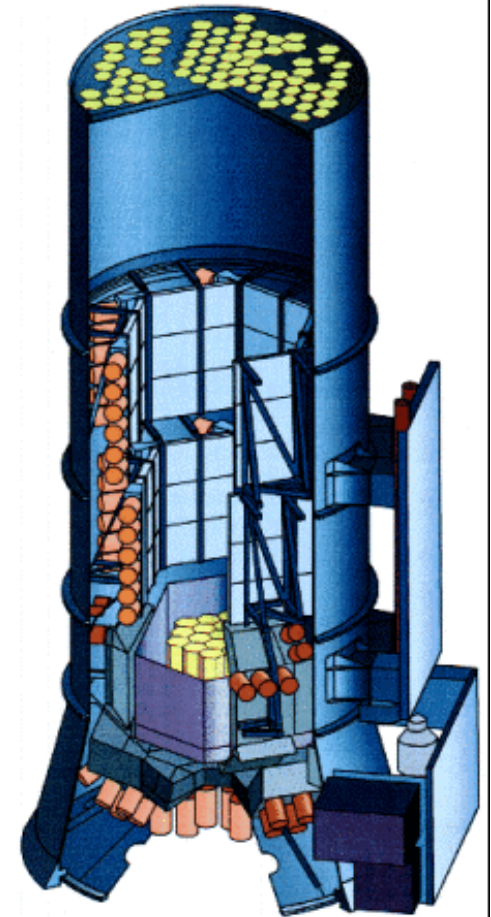
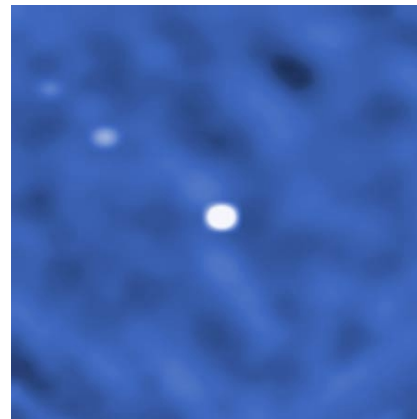
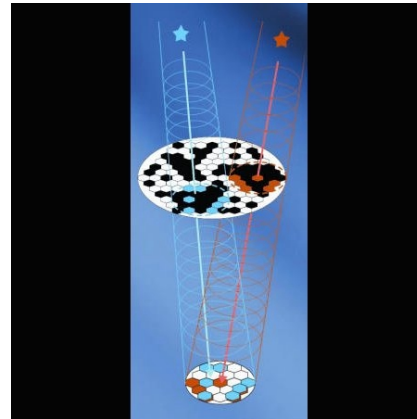


Some Examples

- SPI
- COMPTEL
- EGRET
- Whipple Telescope
- BATSE

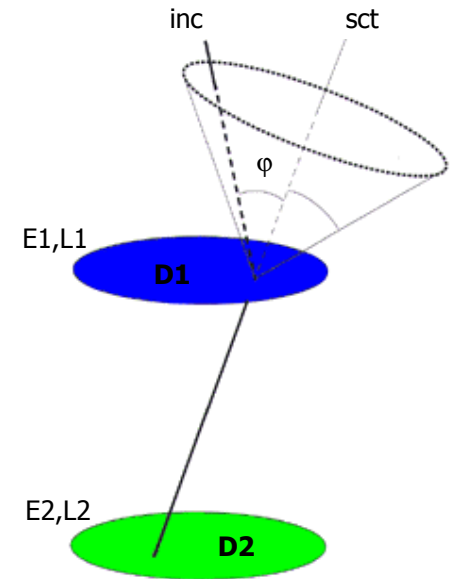
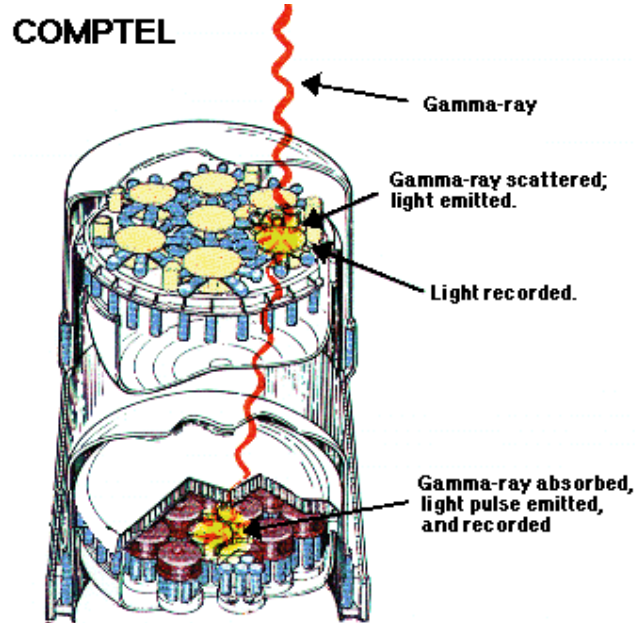
Spectrometer on Integral (SPI)

- A coded-aperture mask with 63 opaque and 64 transparent elements
- Main detector : 19 high-energy resolution Ge crystals
- Very precise measurements between 20keV and 8 MeV
- Cooled by a cryostat in Be.
- A 511kg BGO shield surrounds the detector. (Total mass : 1,3t)



Compton Telescope (COMPTEL)

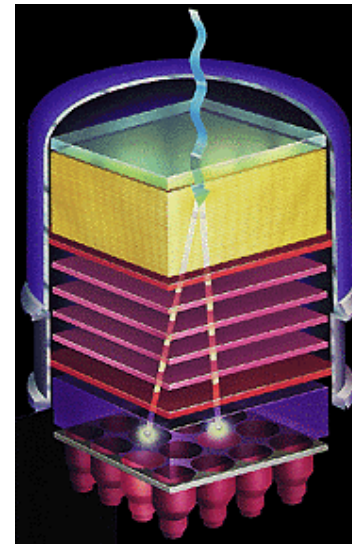
- Measurements between 700 keV and 30 MeV
- 2 detectors planes D1 and D2 separated by 2m.
- Incoming angle not known : the circle event
- Surrounded by a thin scintillator



$$\sigma_{\phi} (\text{deg.}) = \frac{1.247}{1 - \exp\{-0.854 \cdot (E_{MeV})^{0.9396}\}}$$

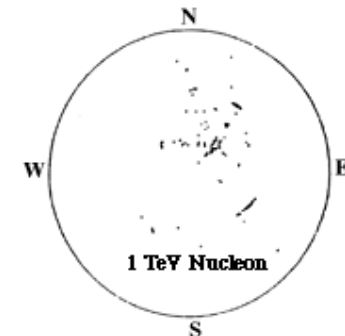
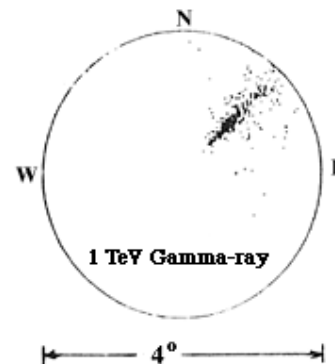
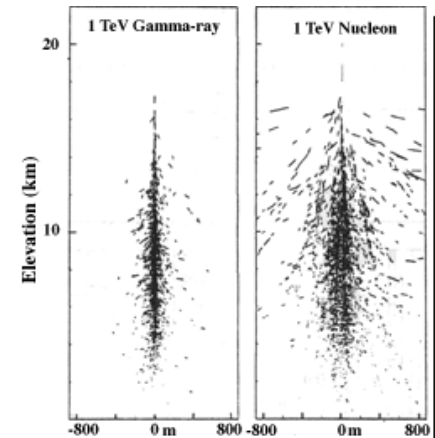
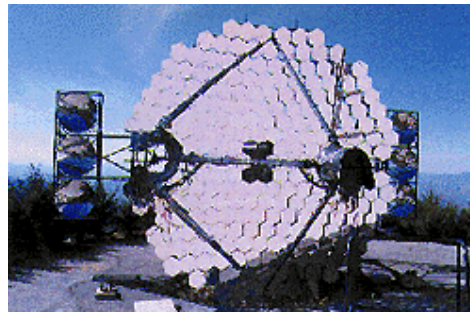
EGRET

- Energetic Gamma-Ray-Experiment Telescope (EGRET)
- Measurements between 20 MeV and 30 GeV
- Field of view of 1.5sr.



Whipple Telescope

- In Arizona
- Detection in the order of TeV
- IAC technique
- Detected the first TeV gamma-ray from M1.
- Differentiation between hadron and electron showers



BATSE

- Burst And Transient Source Experiment (BATSE)
- Located at the corners of CGRO
- Composed by 8 thin scintillation modules
- Each composed by two detectors, LAD and SD





Data-Analysis Problems

- The signal-to-background ratio is often as low as few percents
- The response function of telescopes spreads data from a single point source over a wide range of measured parameters
- In general, measurements obtained can be expressed as :

$$D = R \cdot I + B + N$$

- But γ -ray data and their results are more affected by the data analysis methods due to the probabilistic interactions of photons with the telescope components

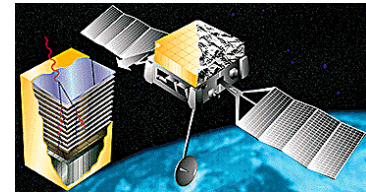
Future Instrumentation

Advanced Compton Telescopes

- Time Projection Drift Chamber Compton telescopes
- Silicon-Tracker Compton Telescopes
- Compton Telescopes with Ge Planar-Strip Detectors

Advanced Pair-Production Telescopes

- Gamma-ray Large-Area Space Telescope (GLAST)



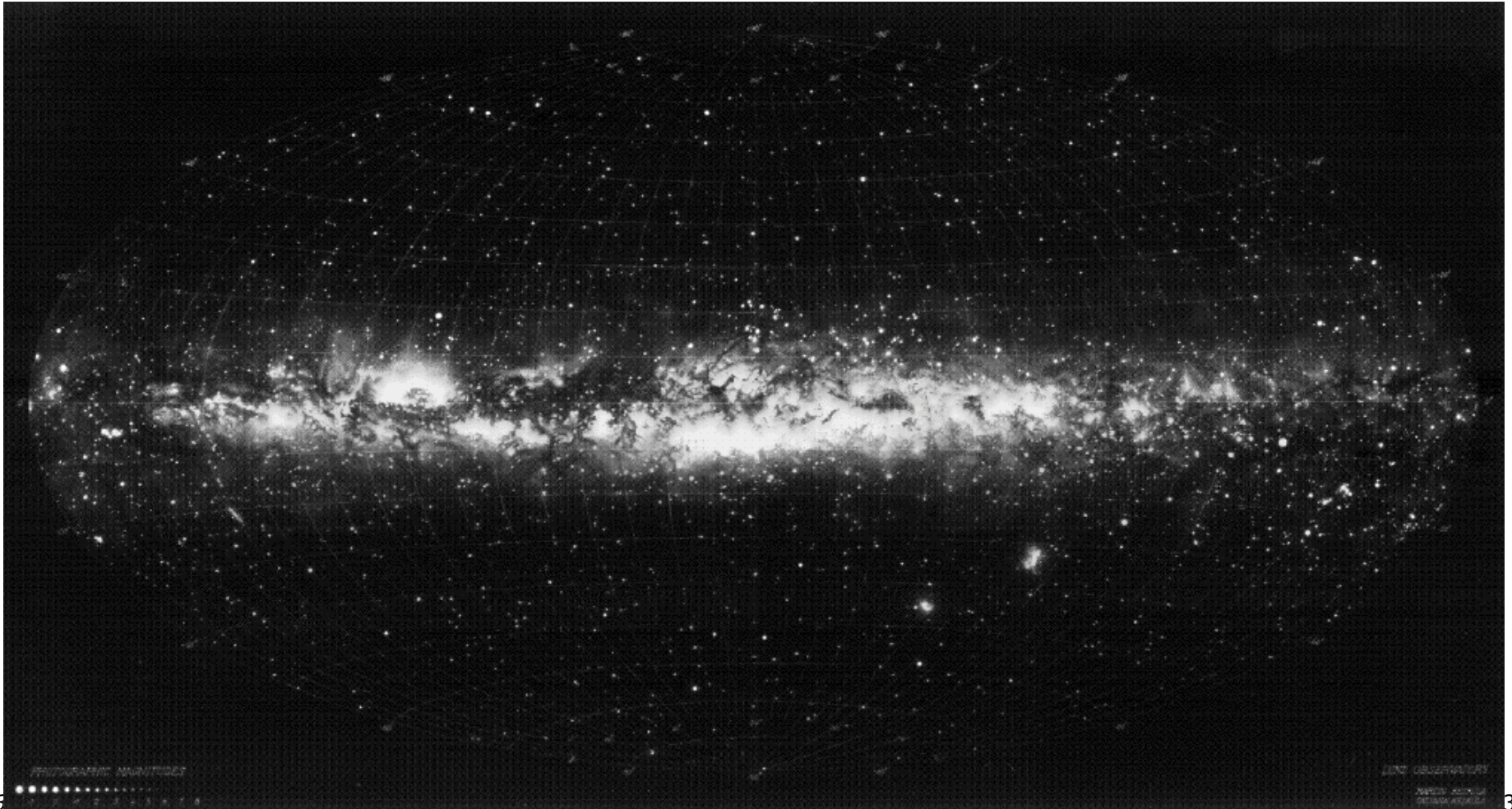
The Gamma-Ray Lens



γ -rays : a new point of view...

- The entire sky as seen by the gamma-ray telescopes
- How would your living-room look like in gamma-rays ?

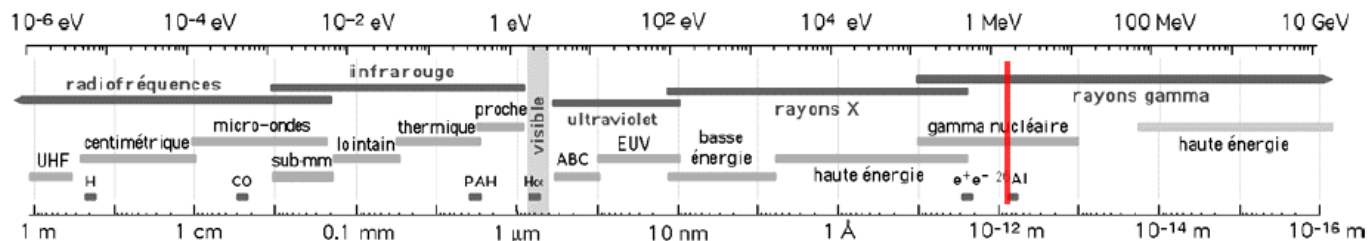
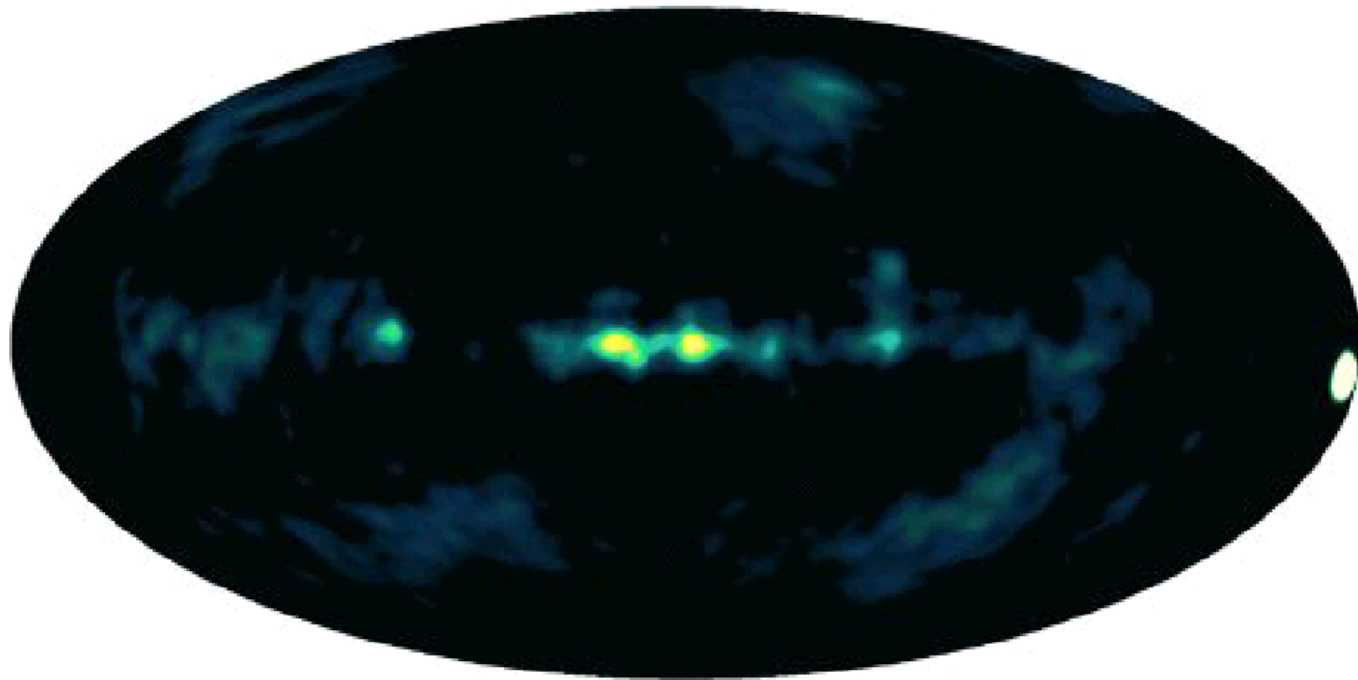
The sky in the visible wavelength



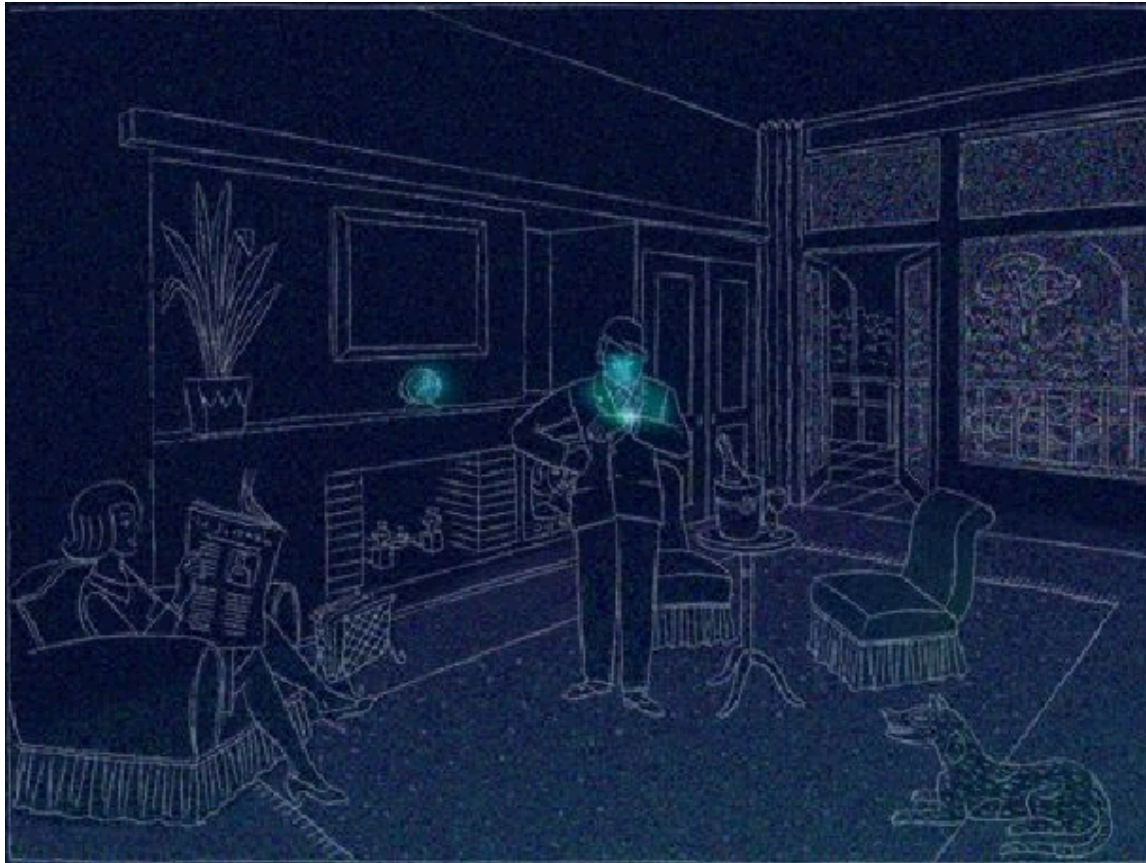
The living-room in the visible



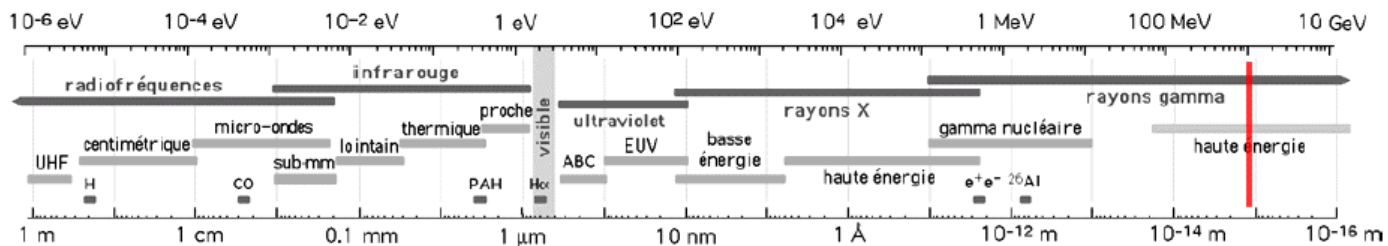
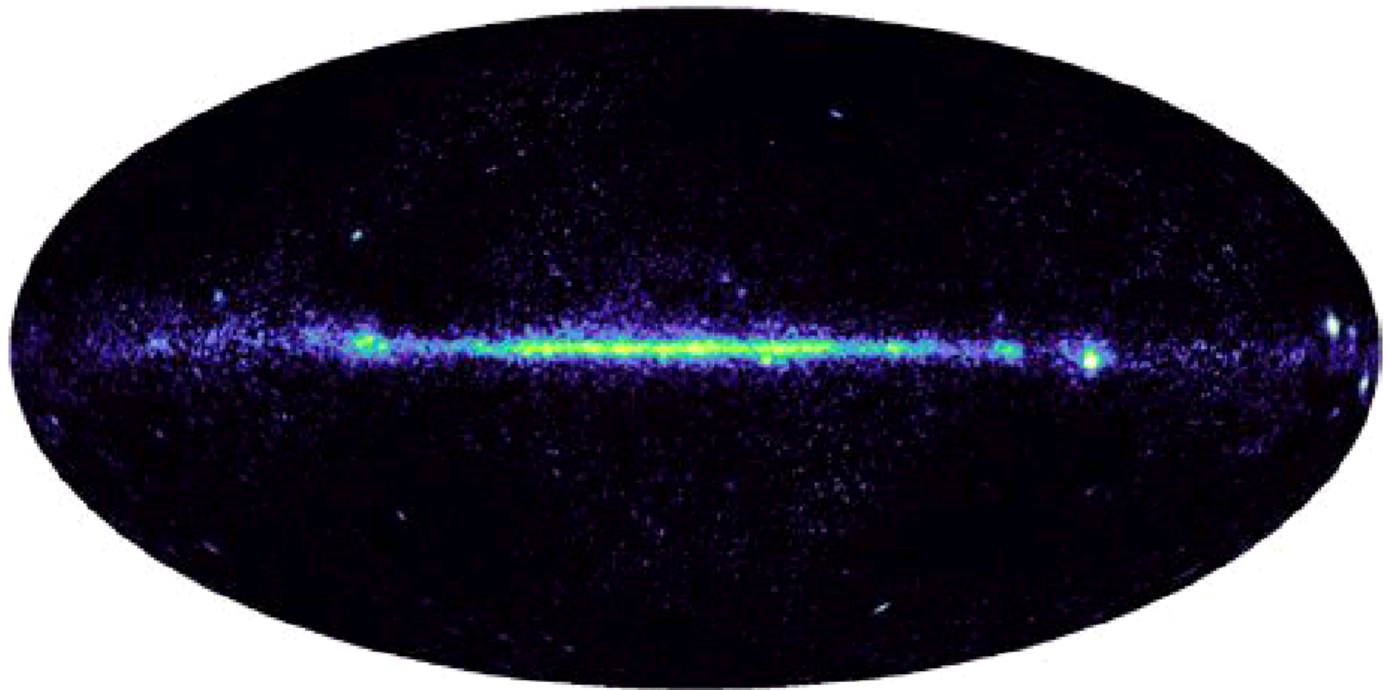
The sky in the gamma (1MeV)



The living-room at 1 MeV



The sky in gamma (1GeV)



The Living-room at 1 GeV





Some References

- Diehl, R. (Gamma-Ray production and absorption processes), 2000
- Lichti, G., Georgii, R. (Gamma-Ray instruments), 2000
- Schönfelder V., et al. (Detection of classical Novae with SPI), 1999
- Von Ballmoos P., Loustal (Atlas de la lumière), 1998
- Weidenspointner, G. et al. (COMPTEL instrument line background), 2000
- ...



Interaction of Gamma Rays

- Better described as particles than as waves
- Scattering off e^- is the main attenuation effect for low energy γ -rays photons. This process is called « Thompson Scattering » :

$$\sigma_T = \frac{8\pi}{3} \cdot r_e^2$$

- For MeV γ -rays, interactions with nuclei become more important and leads to « Compton Scattering » off electrons or protons

$$\sigma_{KN} = r_e^2 \cdot \frac{\pi m_e c^2}{E_\gamma} \cdot \left\{ \ln \left(\frac{2E_\gamma}{m_e c^2} + \frac{1}{2} \right) \right\}$$