Experimental Astroparticle 2

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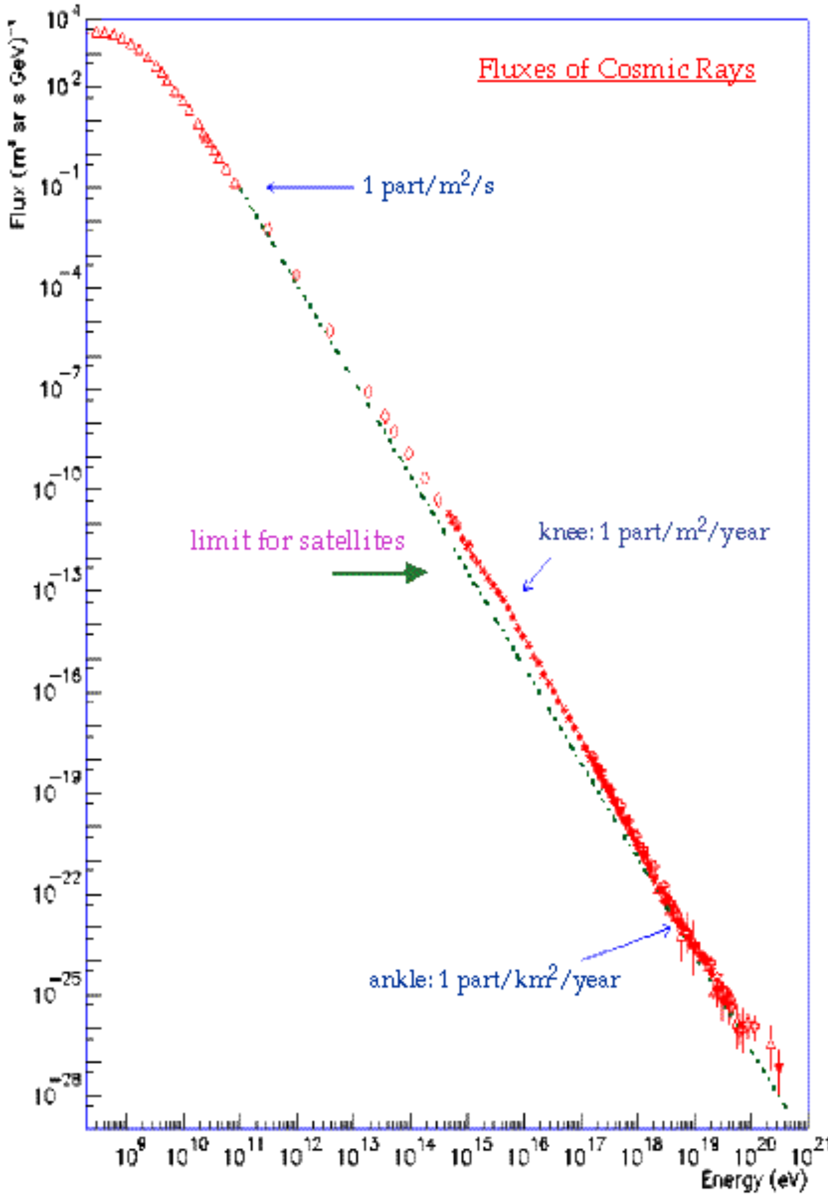
Subatech

Xe
XENON
Dark Matter Project

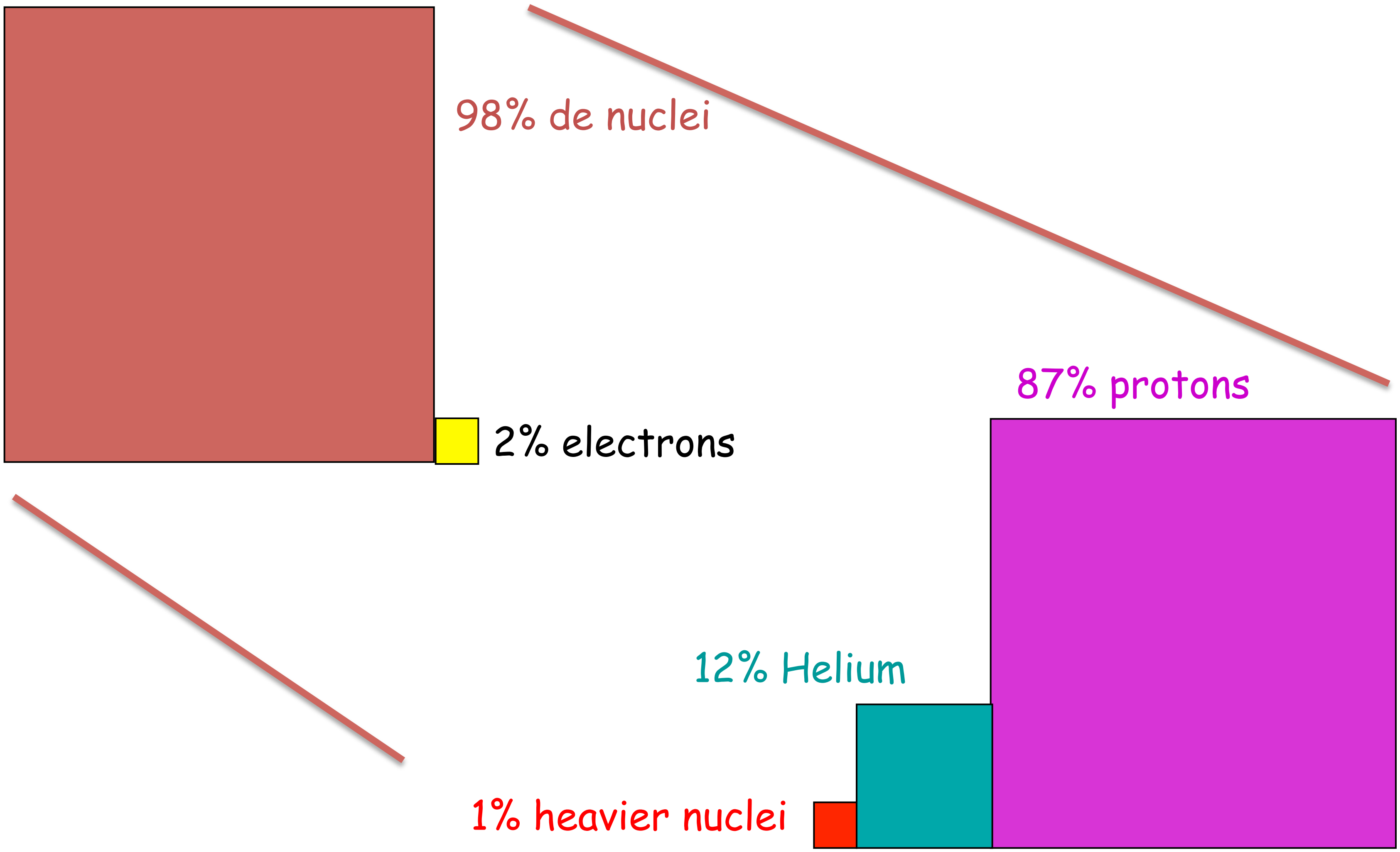
The "all" paticle sectrum



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

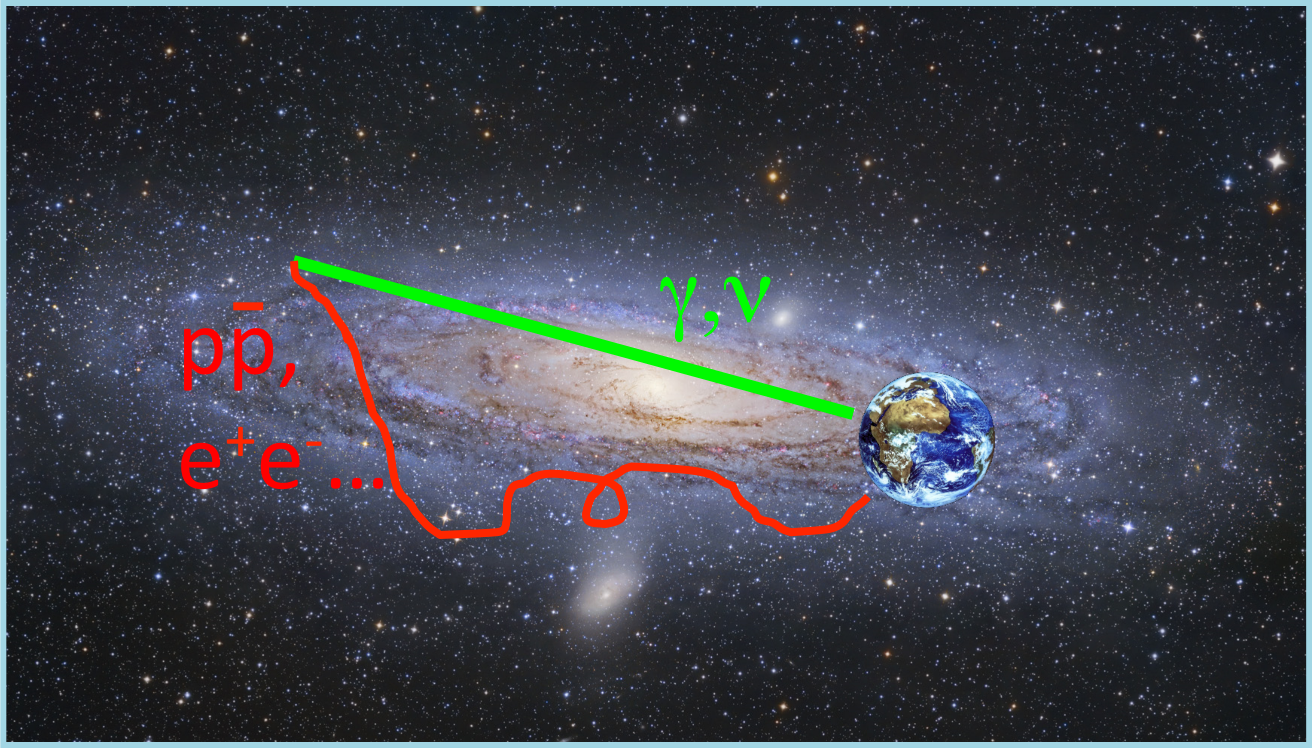
- Regular spectrum over 12 decades in energy, and 32 decades in flux !!!
- Small break near 3×10^{15}eV : the "knee"
- An other one near 10^{18}eV : the "ankle"
- Spectrum badly known at the two extremities
  - Geomagnetic "shield" + Solar modulation
  - Extreme rareness…

Composition

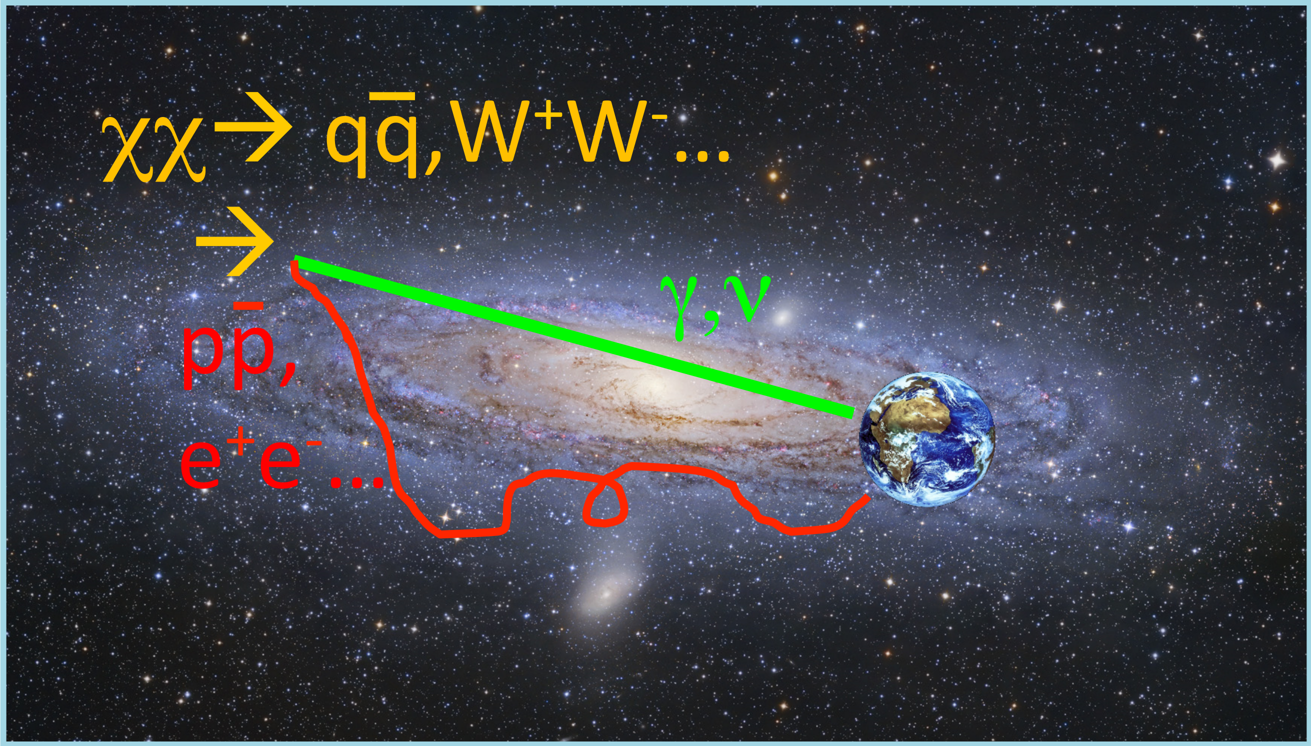


Flux : 4 RC/cm^2/s $\Rightarrow$ 1 kg/year << 40 000 ton/year (meteorites)

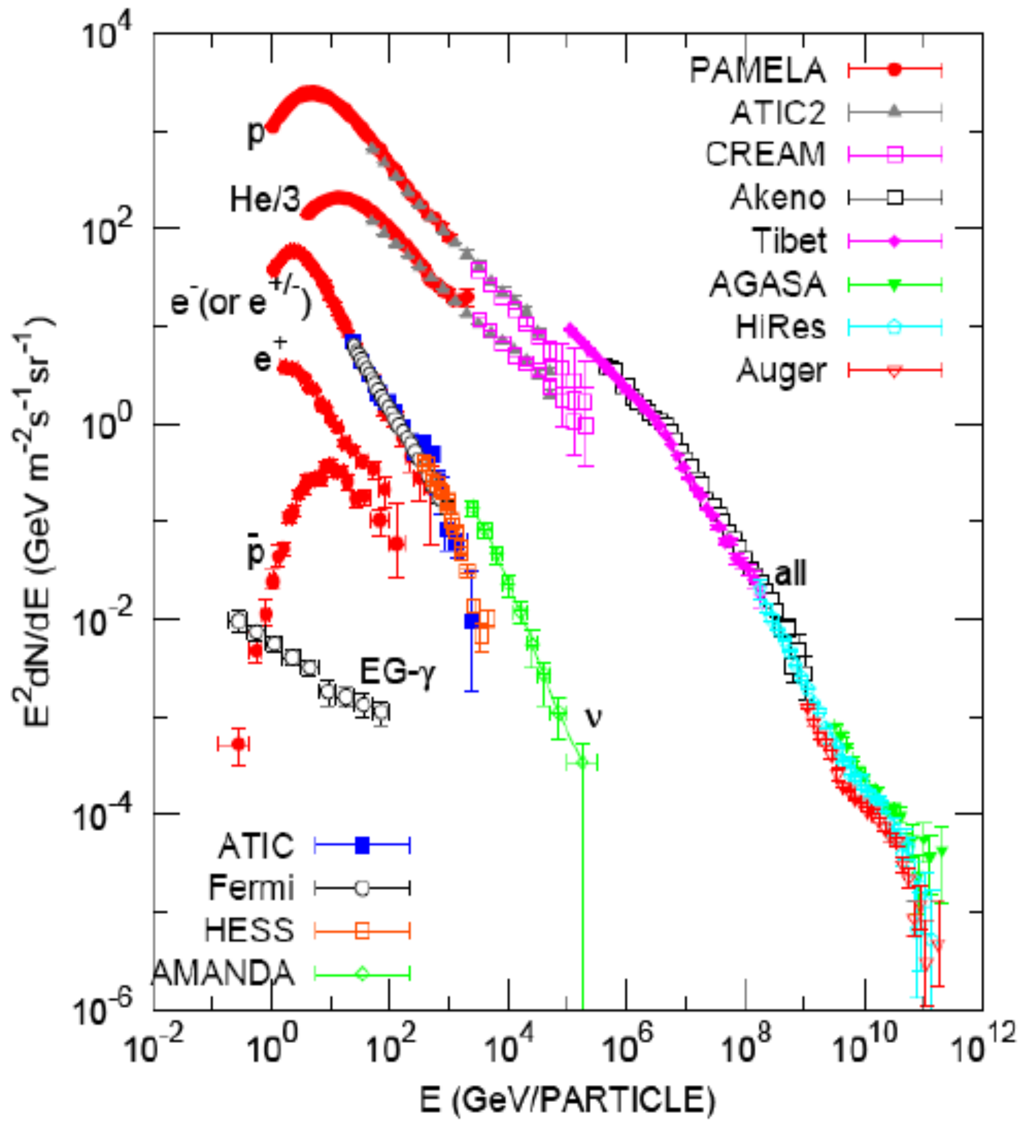
Propagation



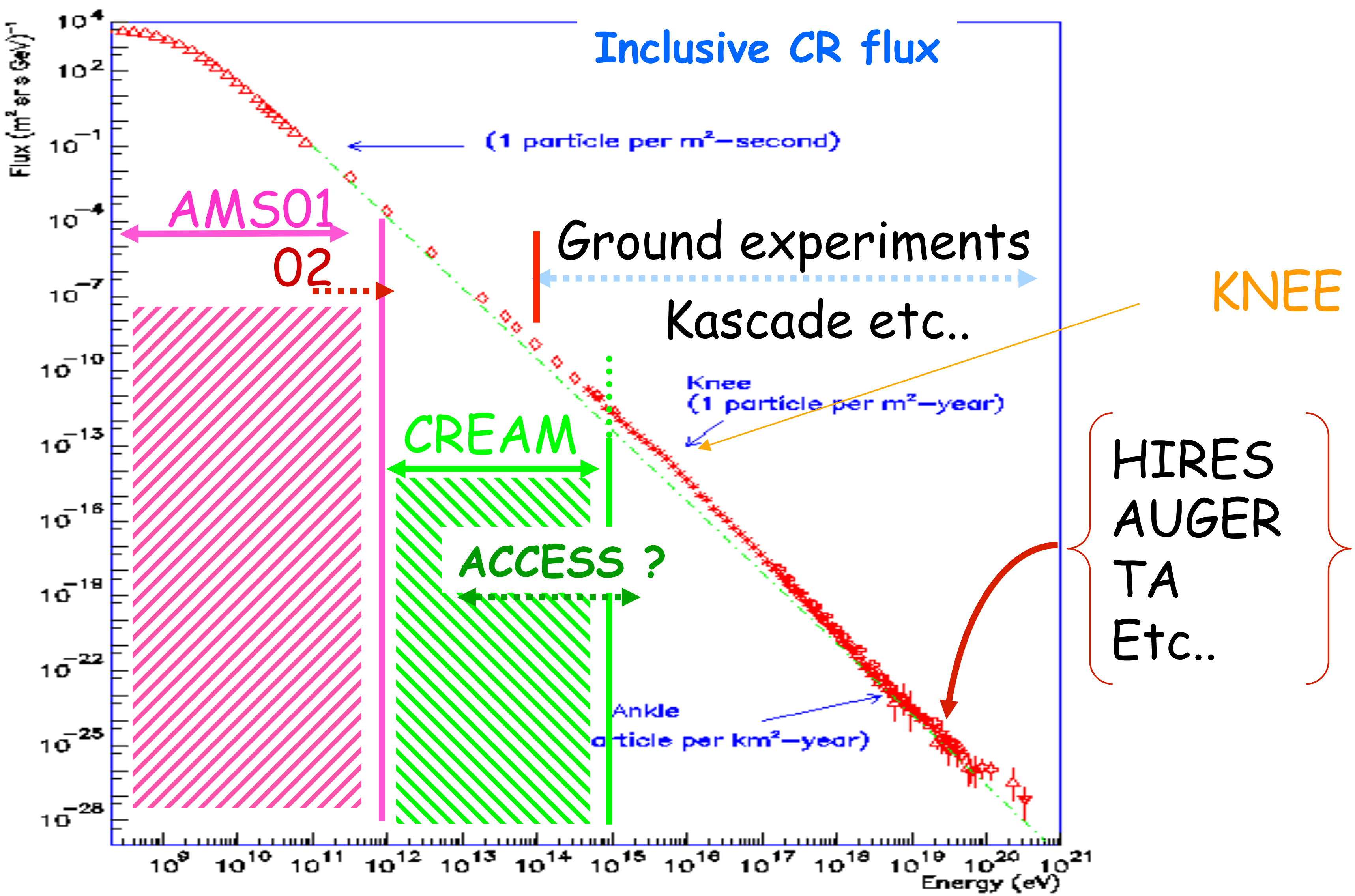
Propagation



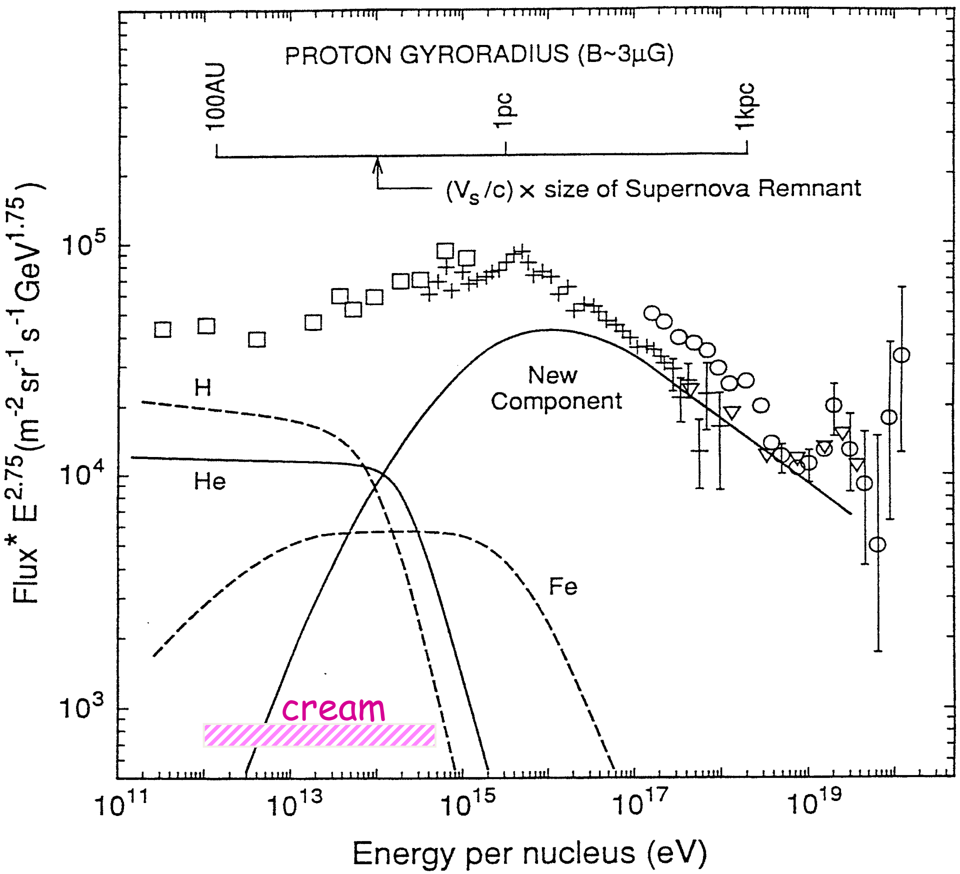
Composition



Experimental context



The knee



- Is the knee due to:
- Acceleration mechanisms

or to changes :

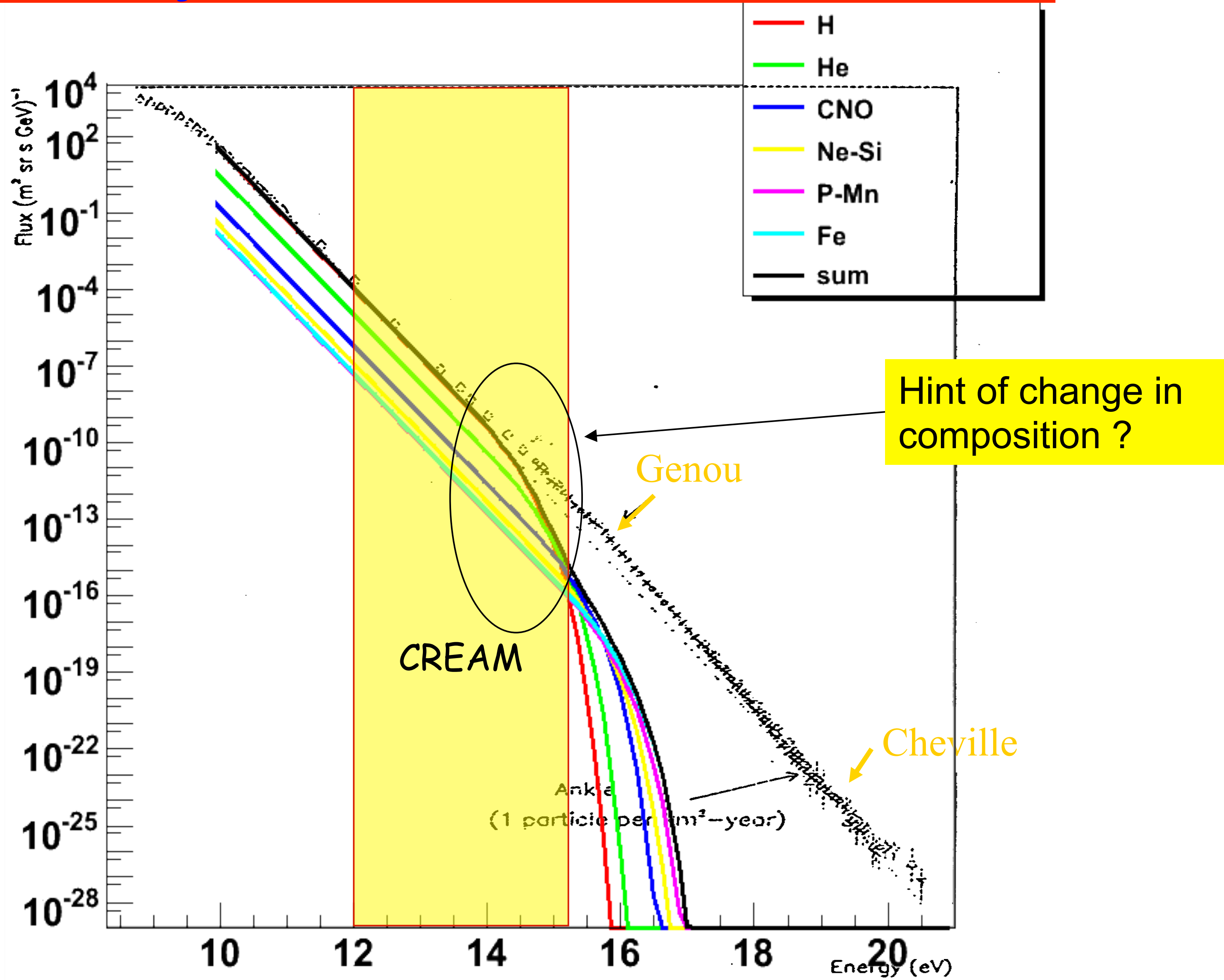
- in propagation?
- in CR sources?
- in interaction properties

(threshold) ?

⇨ A diffuse SNR shock acceleration with E_{max} implies a change in composition around ~10^{14} eV.

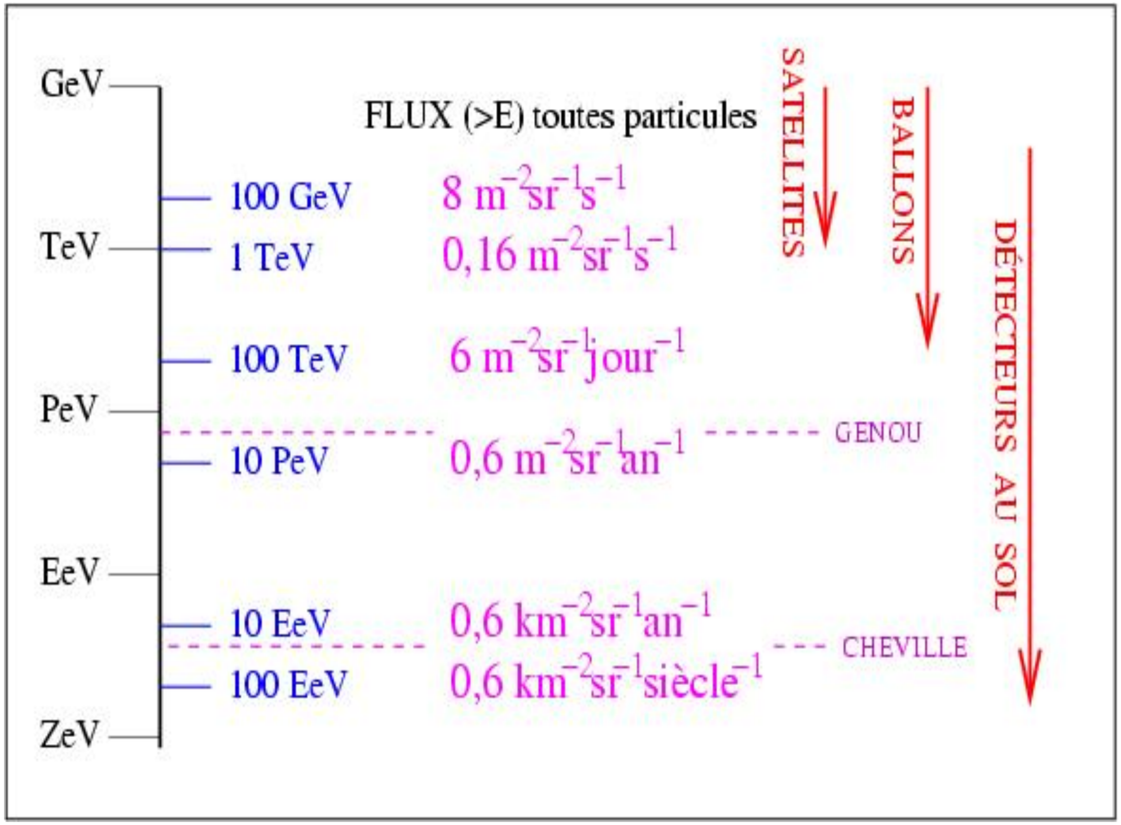
SNR energy limit: E_{max} ~ Z • 10^{14} eV

Composition of the knee

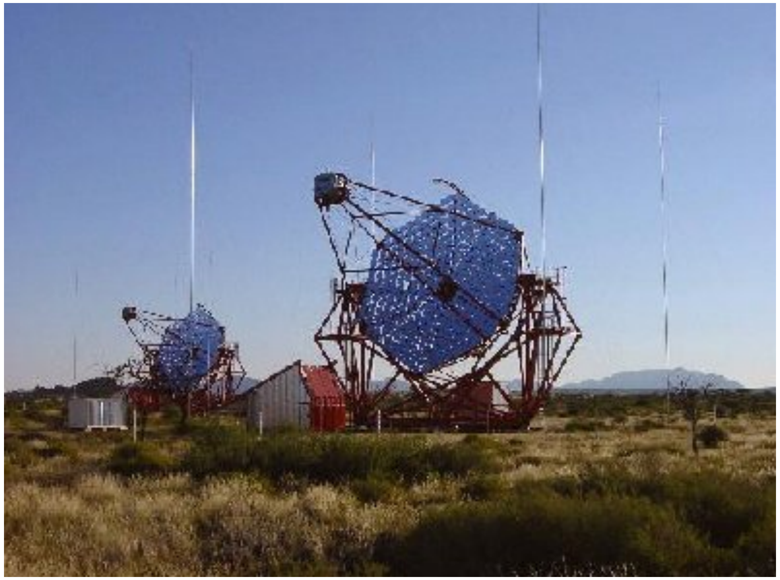


Julien Masbou, GraSPA, July 2016

What type of detector ?



The atmosphere as a detector



H.E.S.S.

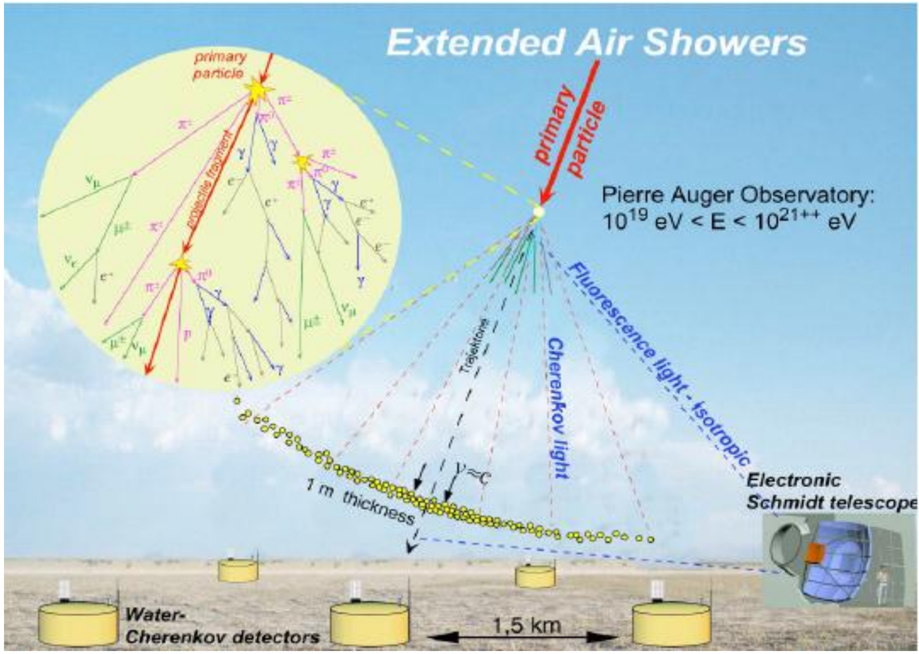
γ

Pierre Auger Observatory

proton

Temploral aspect

- During the shower development, a thin layer of charged particle move to the ground
- A bit "curved"
- ~10m thick



Observables from the ground

- Only secondary particles of the shower reaches the ground
- Depending on the energy and the altitude:
  - Few residuals hadrons, because hadronic components quickly absorbed
  - $e^{\pm}$: the most numerous at the maximun of the shower
  - $\mu^{\pm}$: reach (almost) always the grounds, very penetrating up to underground !
  - Secondary γ detected after e^+e^- conversion (Cherenkov effect in water)

- Photons emitted along the development of the shower (Cherenkov or fluorescence)

  → 3D calorimetric information

- Radio emission from the particles

Electromagnetic / hadronic Showers

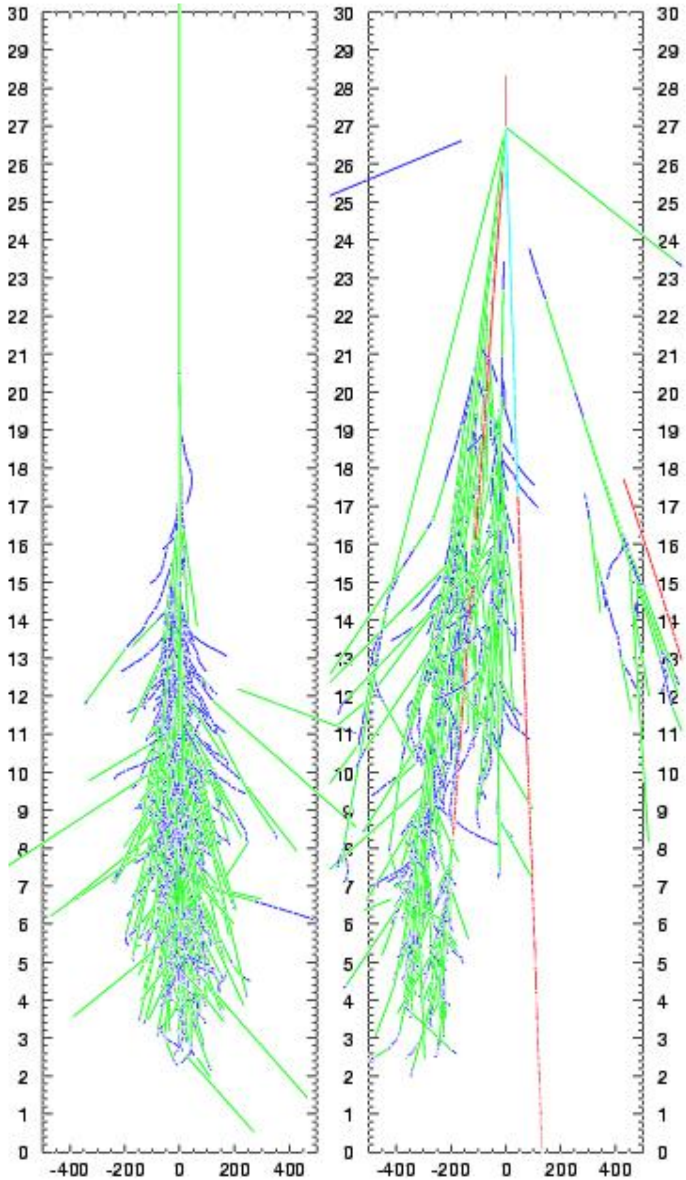
Shower from γ of 300 GeV

Symmetry of revolution

Small transverse momentum

Few muons

Mainly e^+e^- and γ



Shower from proton of 300 GeV

Big transverse momentum

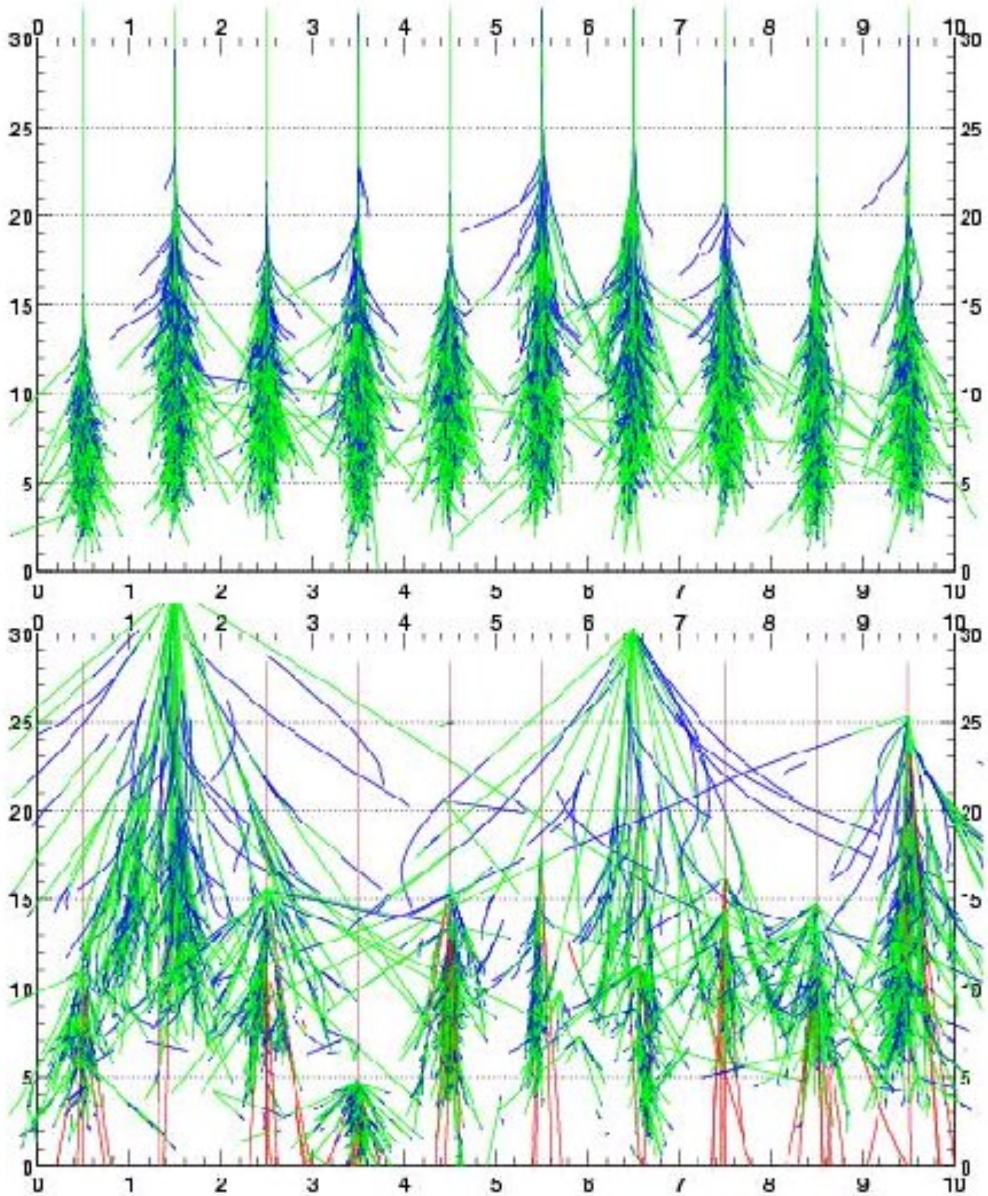
Presence of muons

Possibility of sub-electromagnetic showers

Electromagnetic / hadronic Showers

10 γ of 300 GeV

10 protons of 300 GeV



The atmosphere as a detector

- Gamma-ray astronomy > 100 GeV
  - Cherenkov experiments (HESS, MAGIC, CANGAROO, VERITAS)
  - Wide field of view experiments (MILAGRO, TIBET-ARGO)

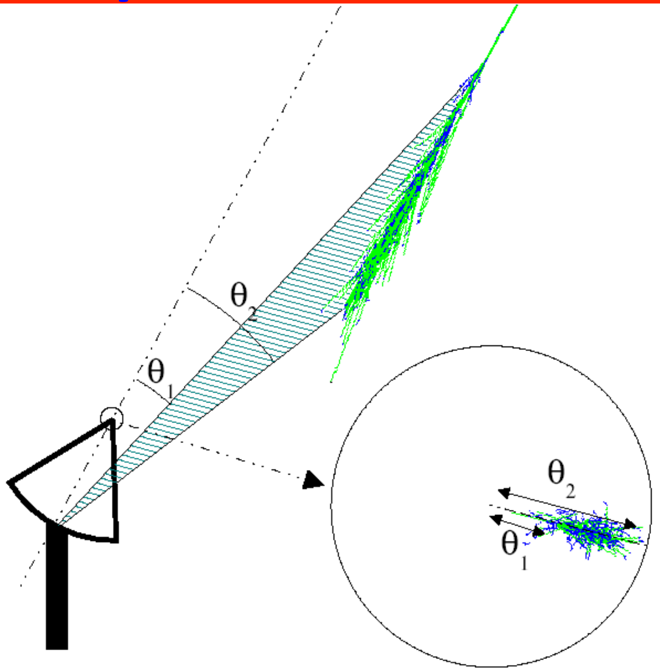
- Ultra High Energy Cosmic Ray Experiment
  - An hybride detector (Pierre Auger Observatory)

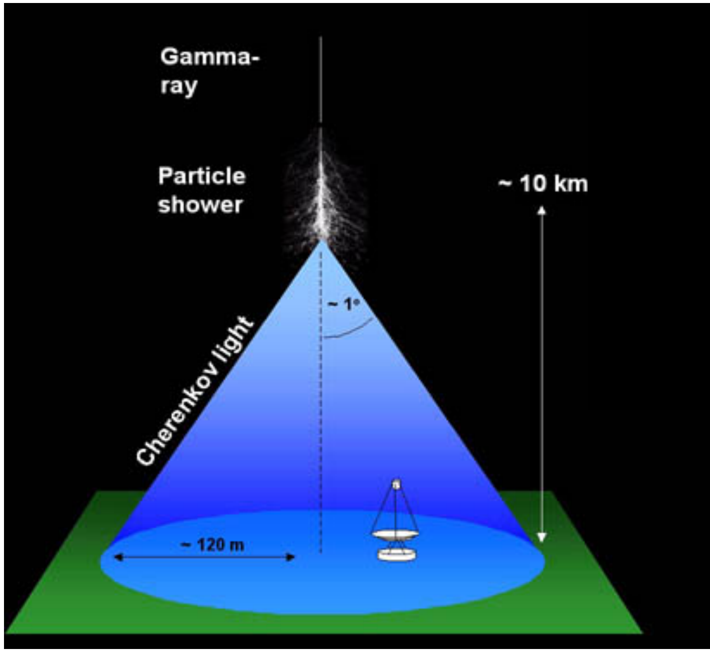
The atmosphere as a detector

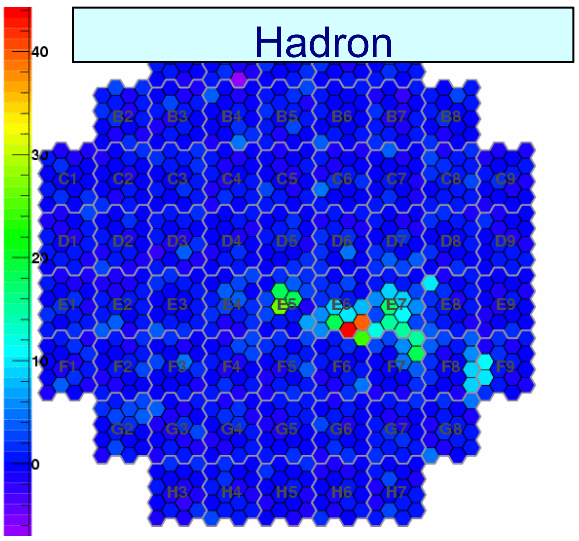
- Atmospheric Cherenkov telescope
  - Limited field of view (5° for H.E.S.S.)
    - Follow the travel of the source in the sky
  - Can work only during night time, no moon and good weather
  - High discrimination power between gamma and hadron

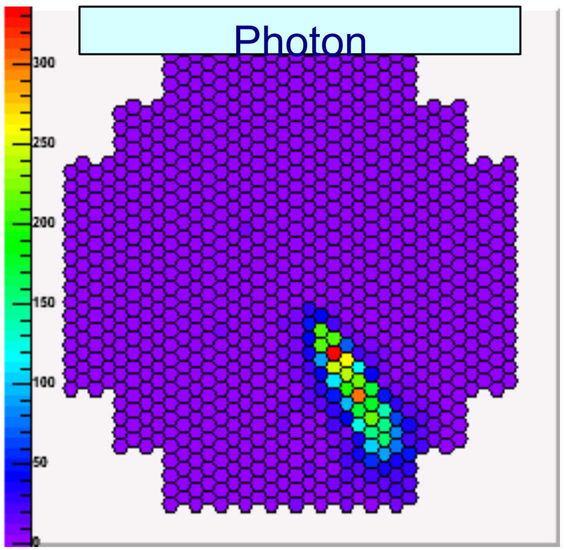
- Surface detectors (secondary particles on the ground)
  - Large field of view (~ 1 sr)
  - High working time
  - Low discrimination

Atmospheric Cherenkov telescope









Cherenkov telescopes

MAGIC 2 :

2 telescopes

Ø 17m (3.5°)

E > 60 GeV

Veritas :

4 telescopes

Ø 12m (3.5°)

E > 85 GeV

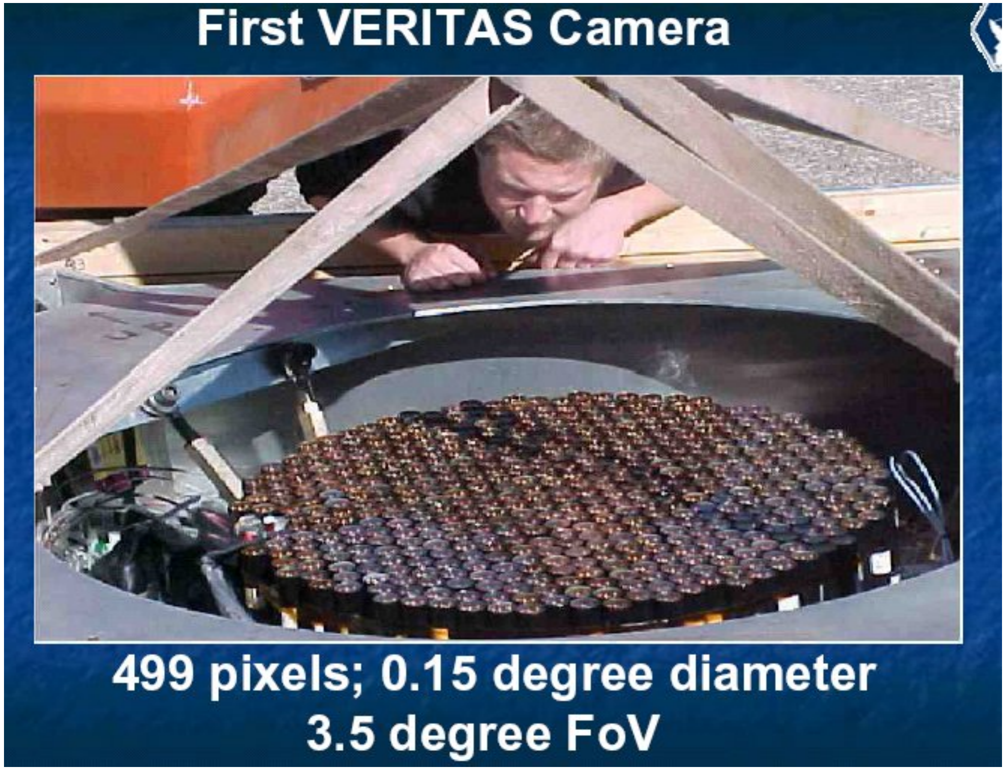
H.E.S.S. 2 :

4 telescopes +1

Ø 13m (5°) + Ø 28m

E > 20 GeV

Camera properties



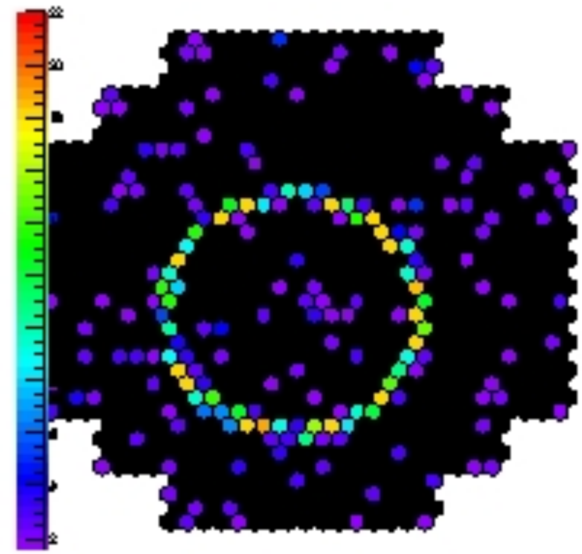
VERITAS **MAGIC**

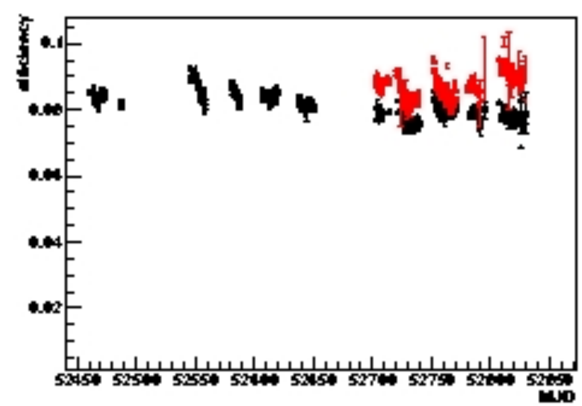
Muons for monitoring the detector

- Muons falling on the miroir of a telescope create an annulus, its equation is perfectly known

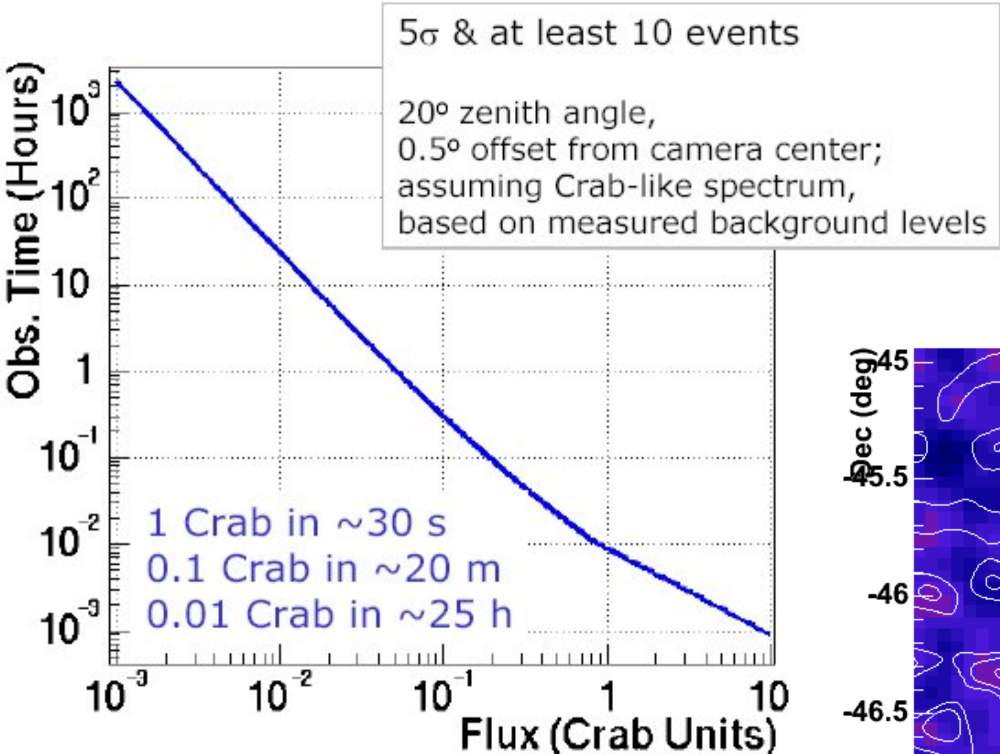
- Comparaison with real signal gives the global efficiency including :
- absorption in the atmosphere
- Reflectivity of miroirs
- Quantum efficiencies of PMTs

- The evolution of the detector as function of the time is automatically taken into account in the analysis.



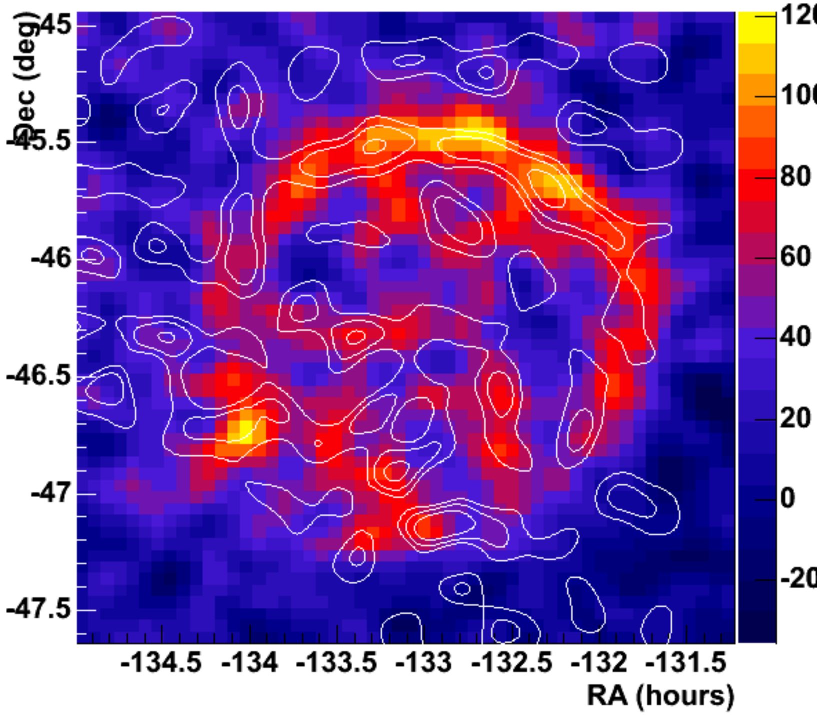


Sensitivity to gamma sources



Large sources:

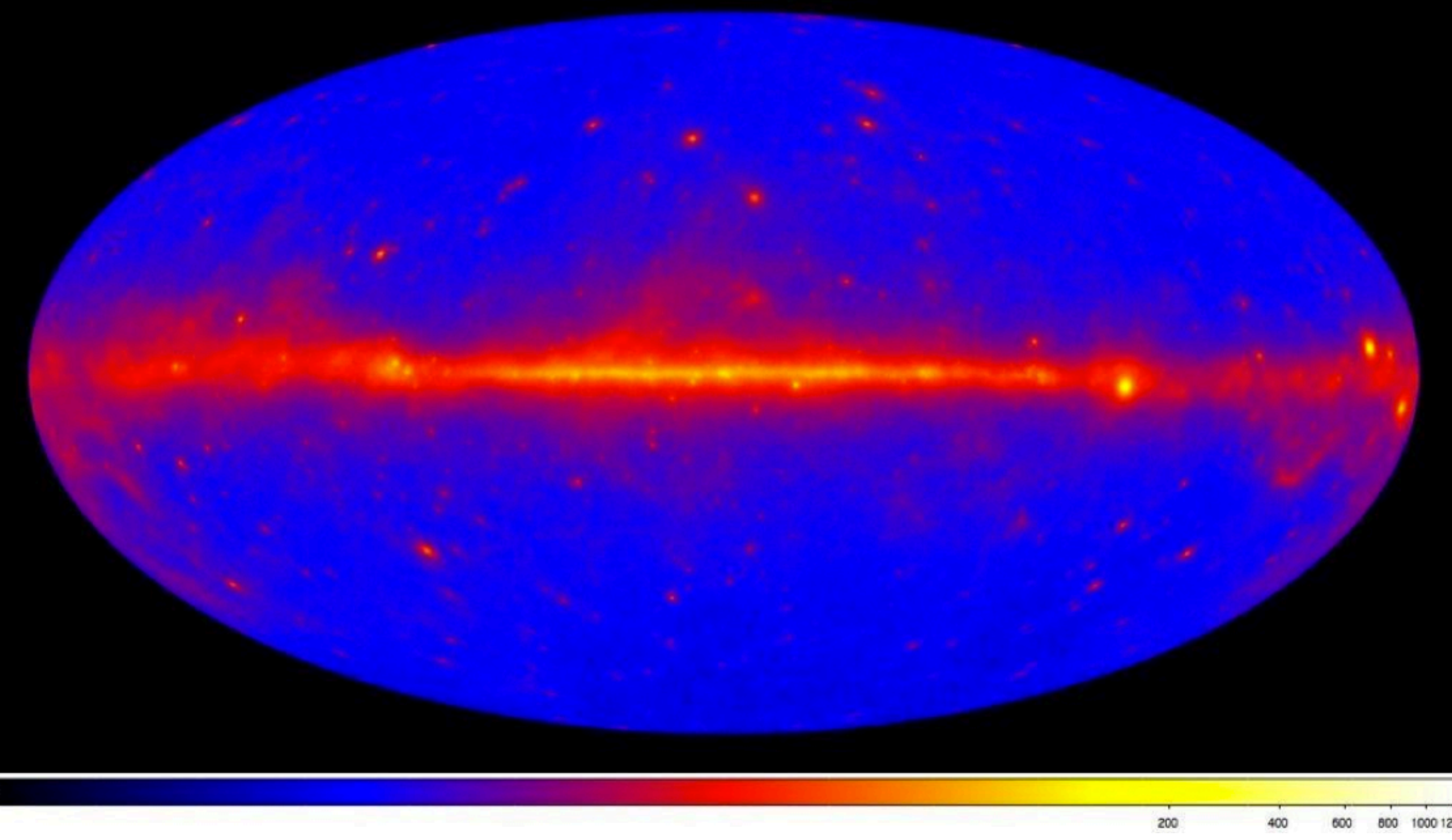
Vela Junior
(diameter 2°)



- > 100 sources in 2012
- 6 in 2003

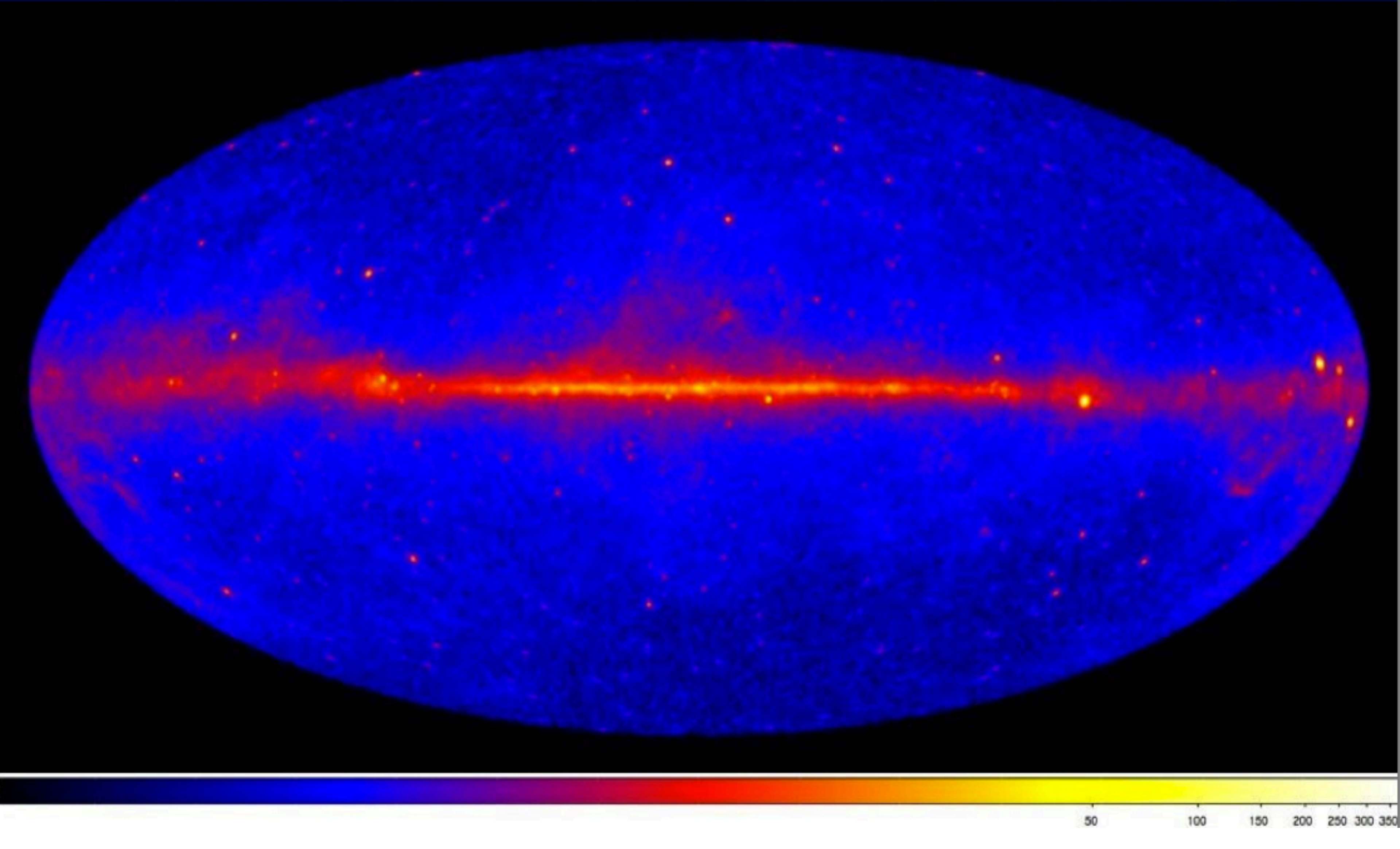
Fermi LAT > 100 MeV

- 3×10^7 photons, <E> = 800 MeV, $\Delta E/E$ = 100 %



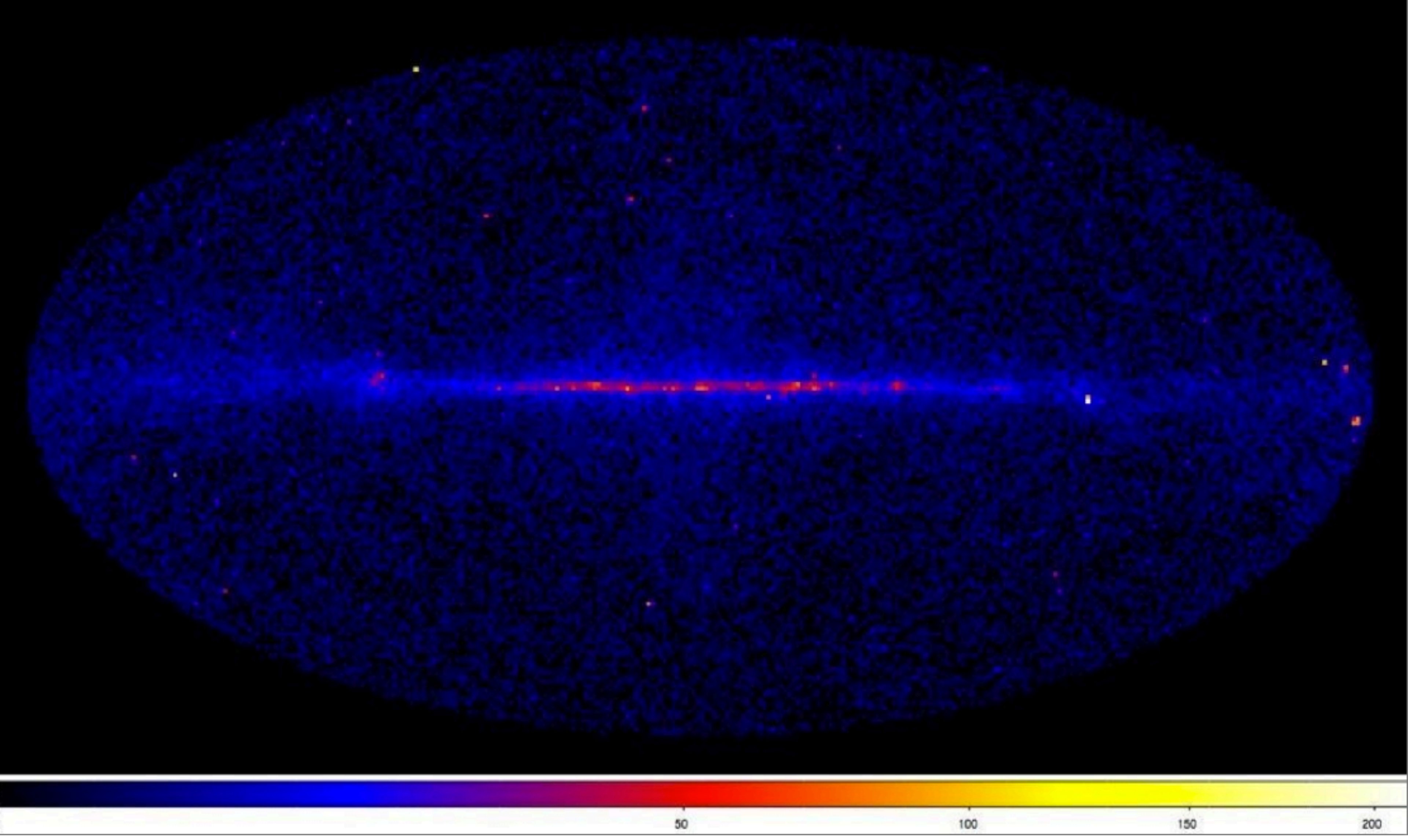
Fermi LAT > 1 GeV

- 2×10^6 photons, $\langle E \rangle = 3$ GeV, $\Delta E/E = 17$ %



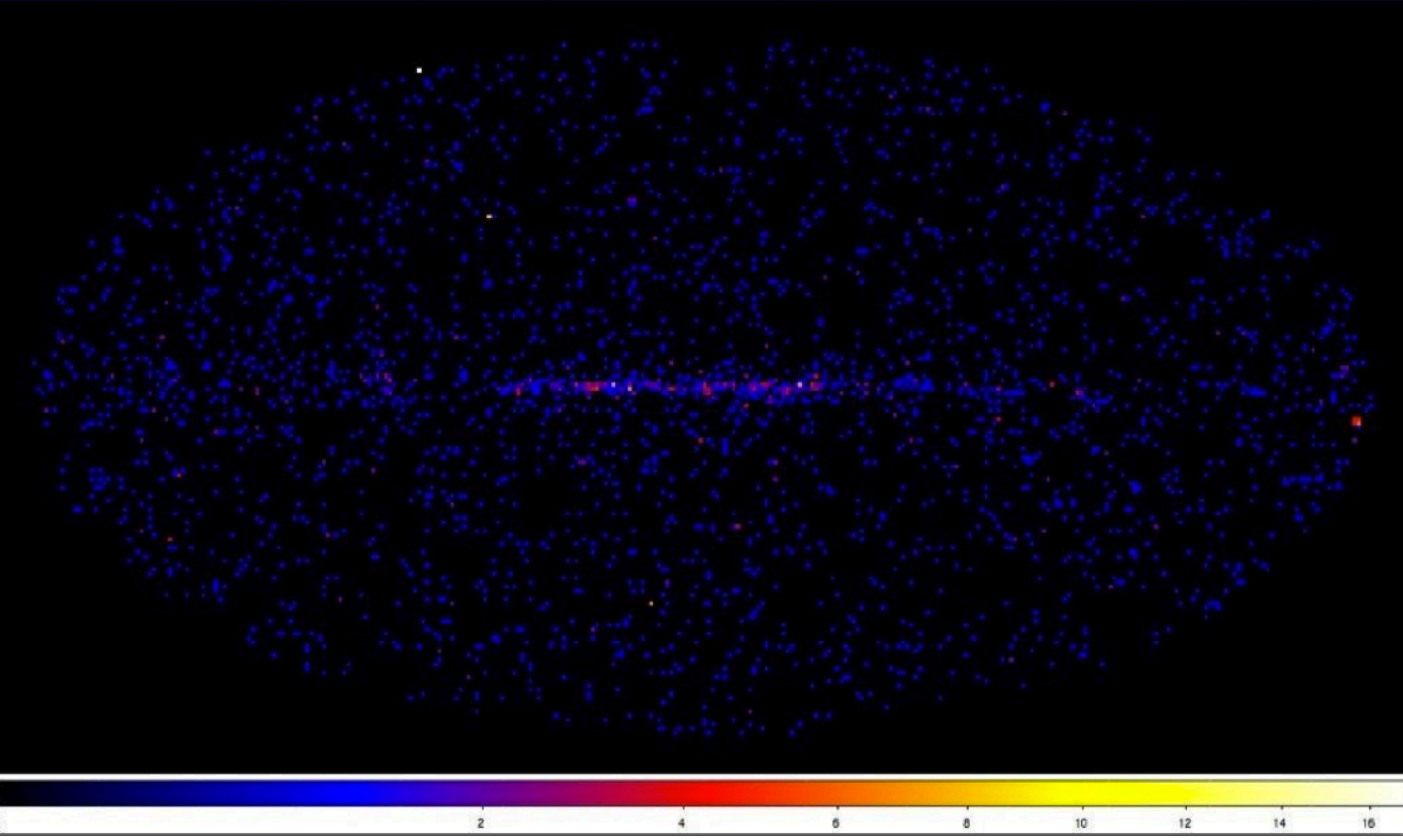
Fermi LAT > 10 GeV

- 7×10^4 photons, <E> = 30 GeV, $\Delta E/E = 0{,}6$ %



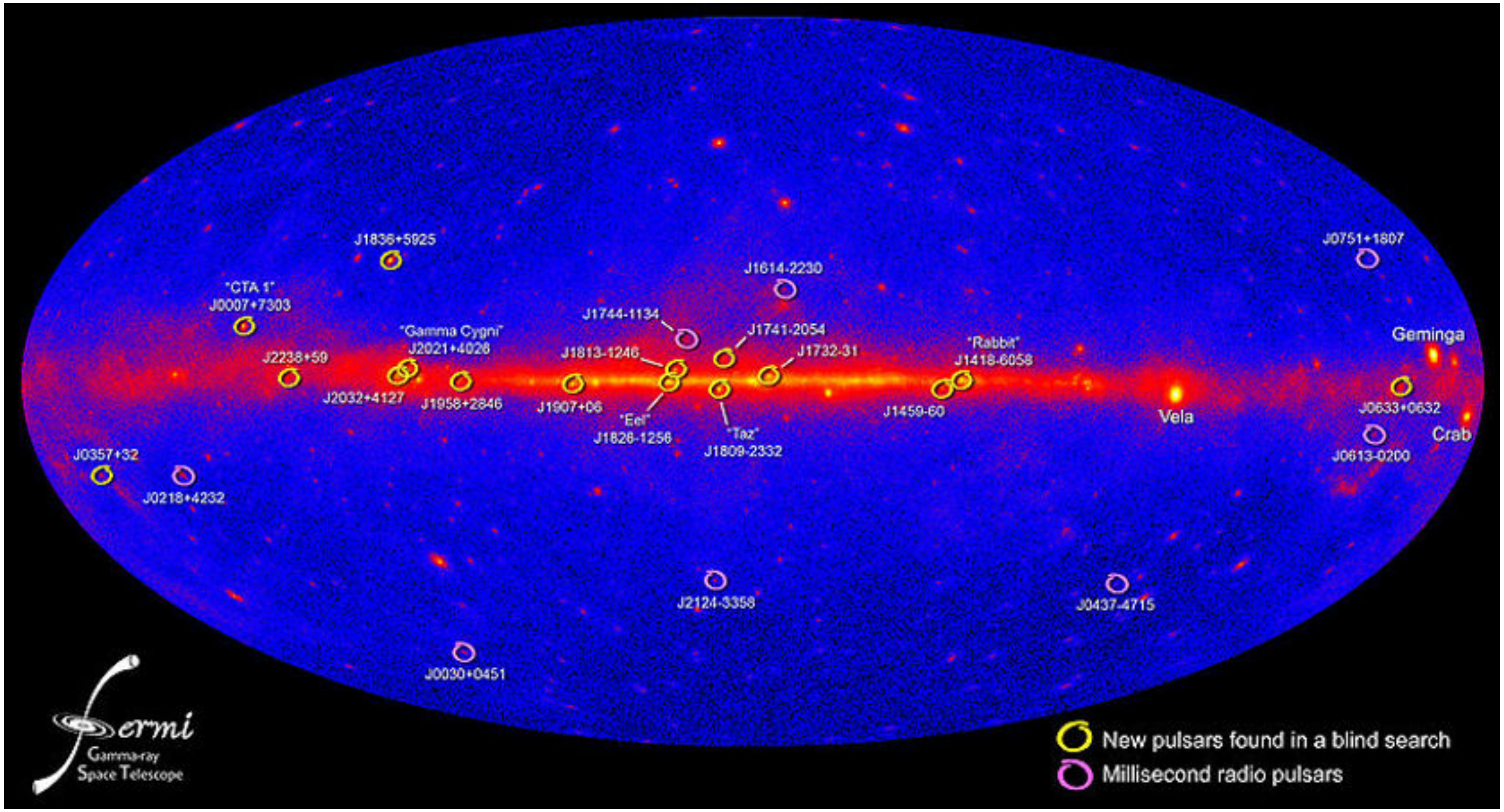
Fermi LAT > 100 GeV

- 3×10^{3} photons, <E> = 150 GeV, ΔE/E = 0,02 %



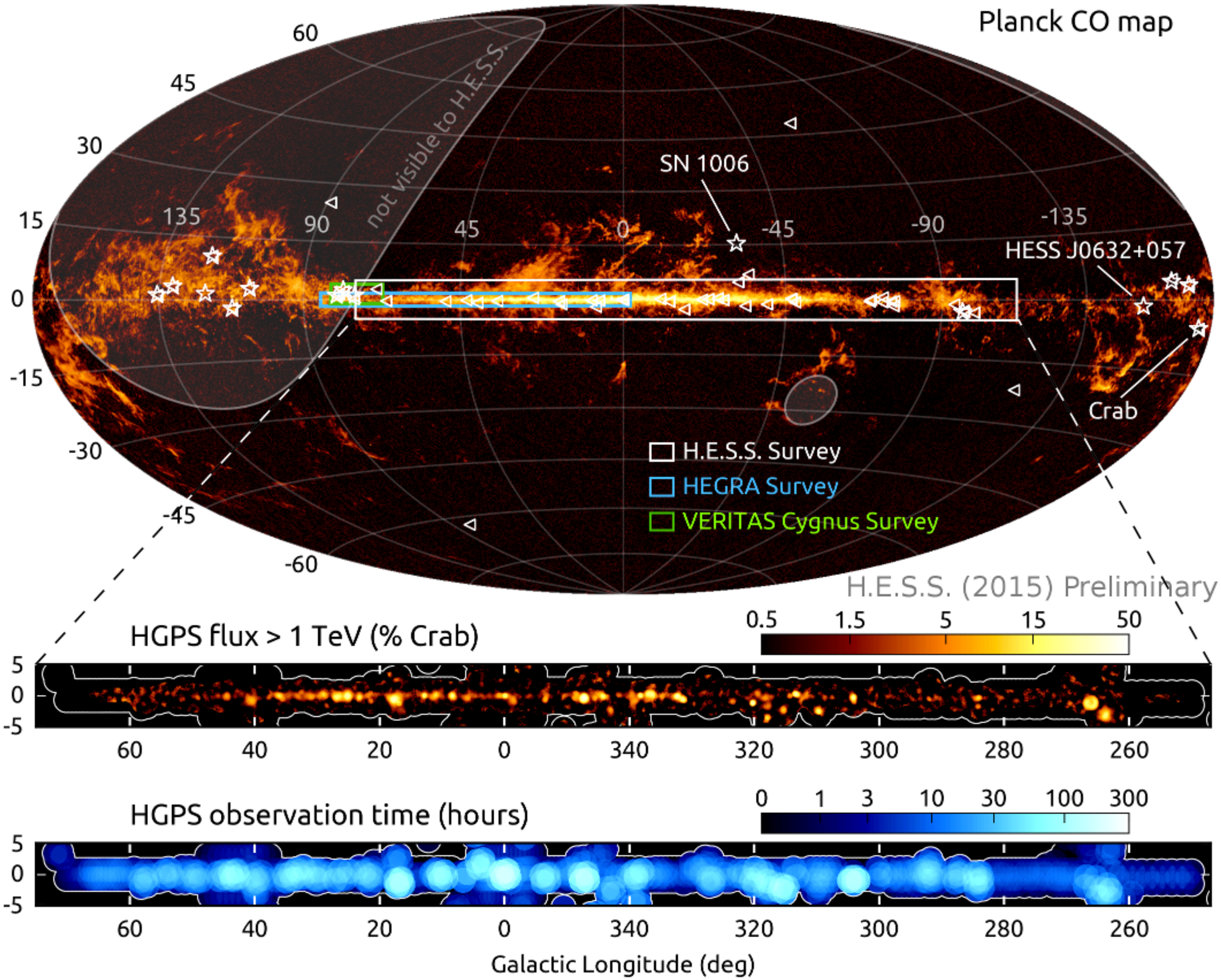
Our galaxy

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

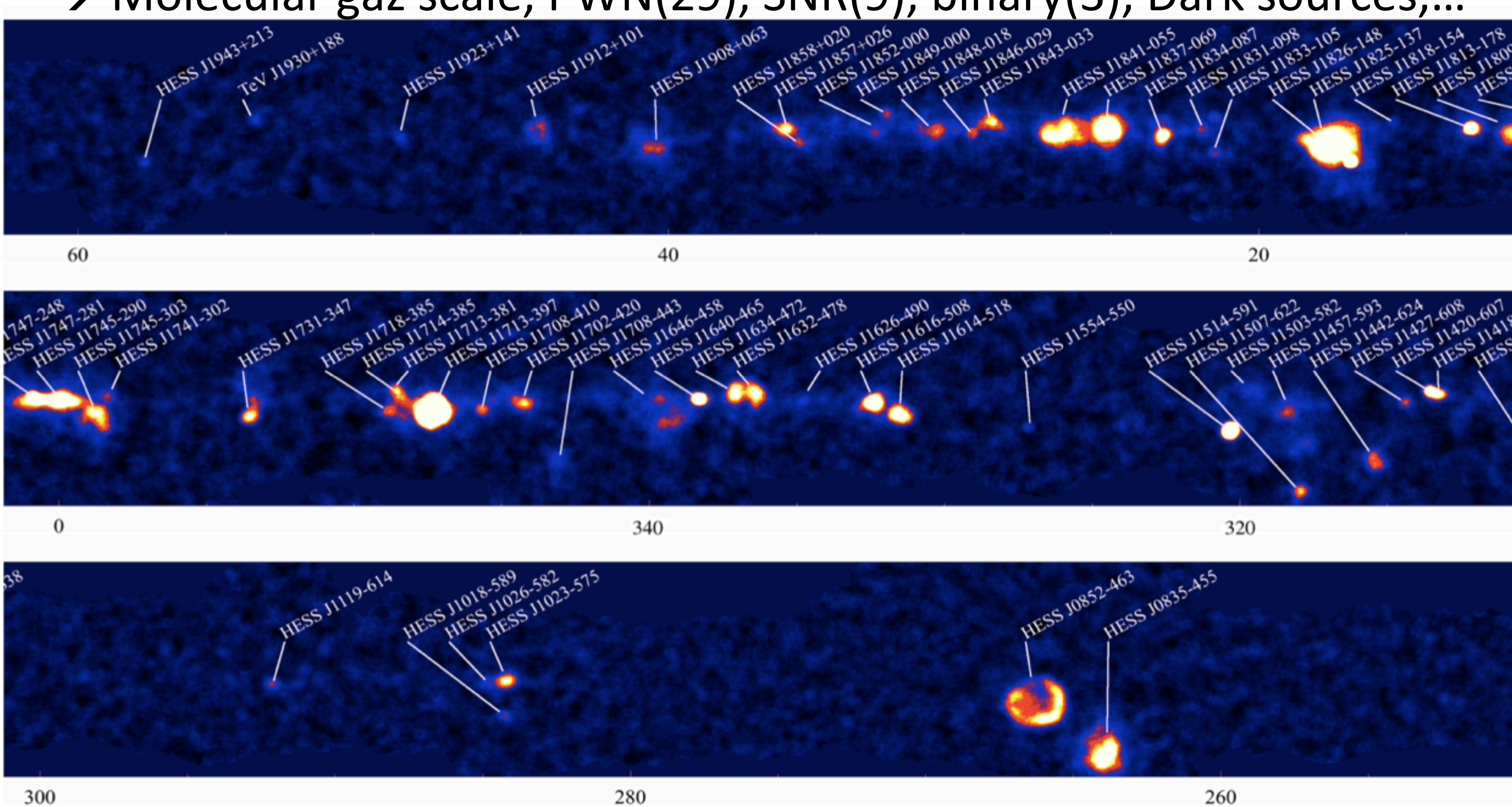
H.E.S.S. Galactic Plan Survey



H.E.S.S. Galactic Plan Survey

- Inner part of the Galaxy, 1400 h of data + dedicated pointing on 56 sources

→ Molecular gaz scale, PWN(29), SNR(9), binary(3), Dark sources,…



The Galactic Center

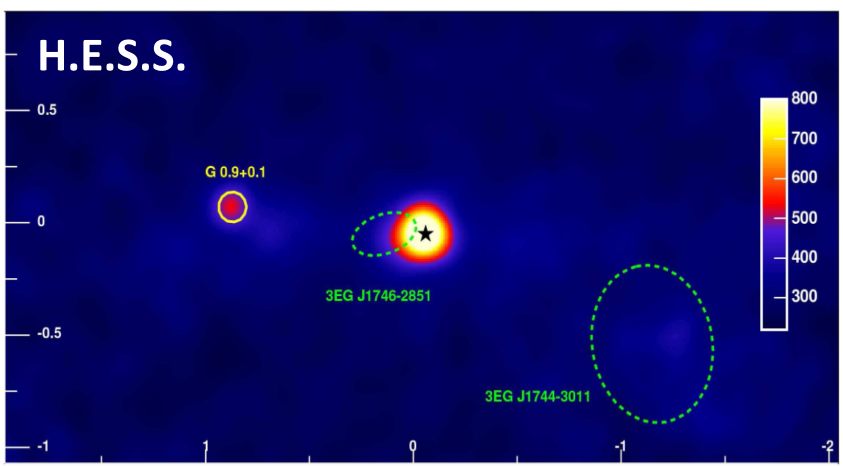
In principle the best option :

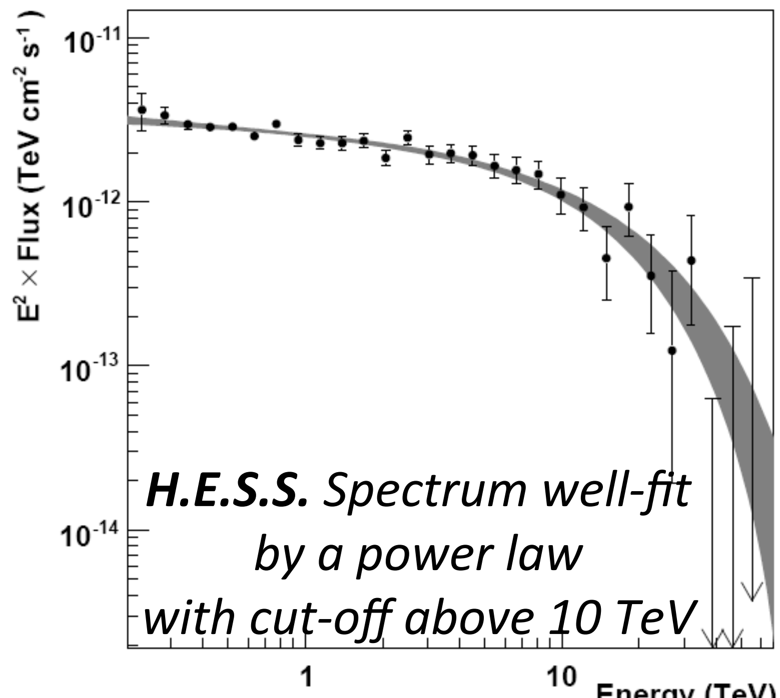
- Very near, and high DM concentration expected
  → Flux should be high.
- HESS and MAGIC reported a point-like source

a very massive neutralino, not compatible with WMAP cosmology.

Aharonian et al. (H.E.S.S., 2004) P.R.L., 97221102 / A&A 503 (2009)

Albert et al. (MAGIC, 2005) A.J., 638





H.E.S.S. *Spectrum well-fit by a power law with cut-off above 10 TeV*

The Galactic Center

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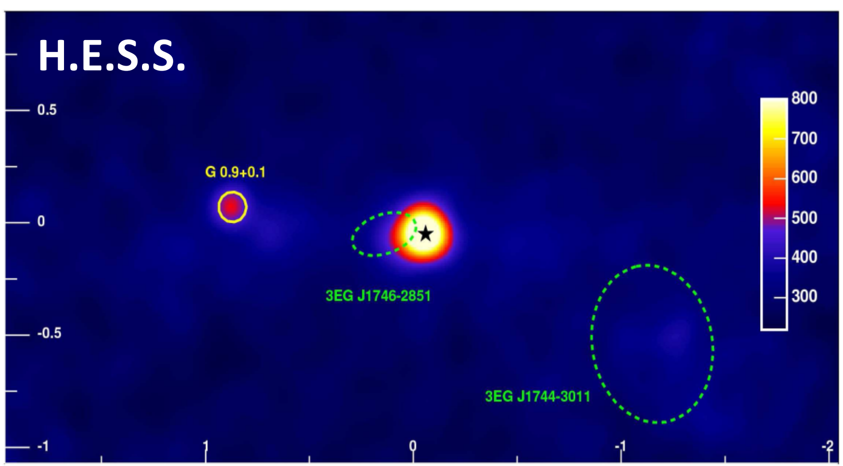
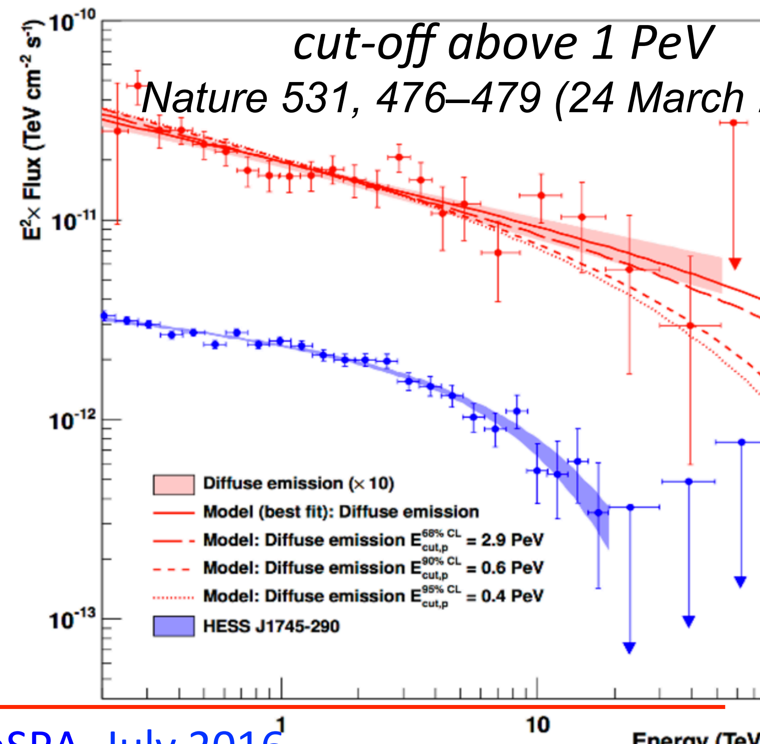
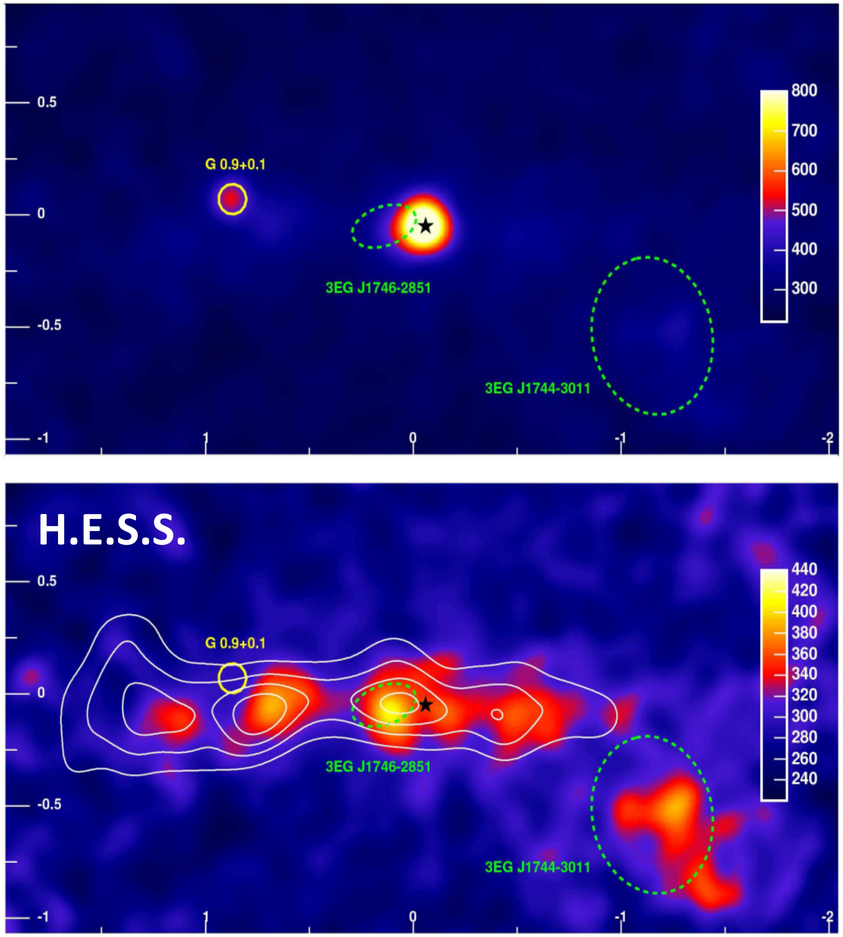


cut-off above 1 PeV

Nature 531, 476–479 (24 March 2016)



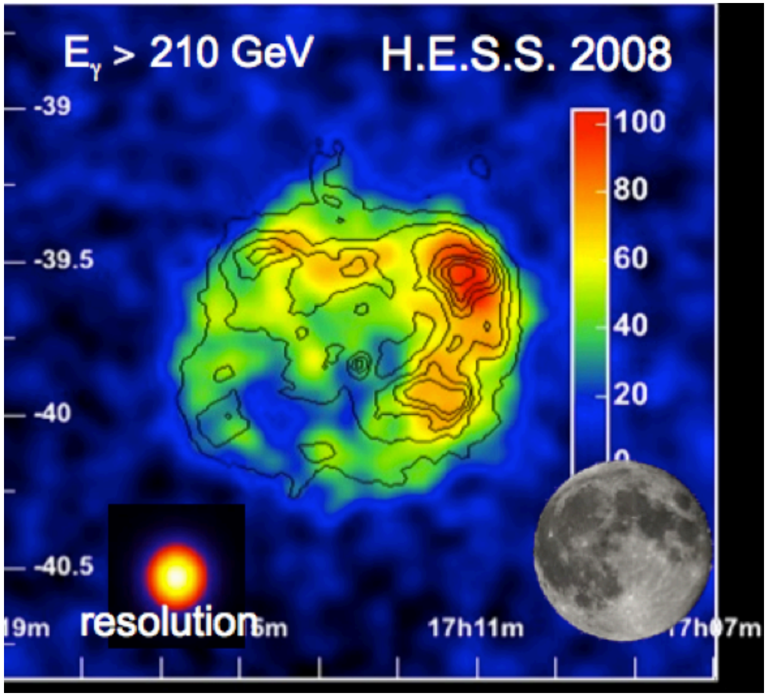
The Galactic Center



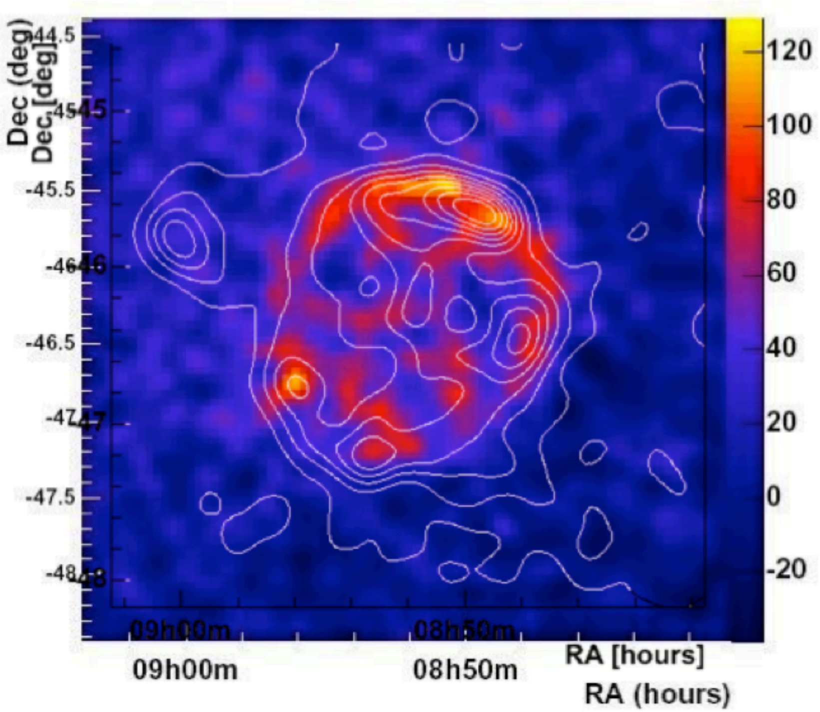
Later on an extended emission was discovered,
but associated to the galactic plane and molecular clouds.

Aharonian et al. (H.E.S.S., 2006), Nature 439

Supernovae remanent



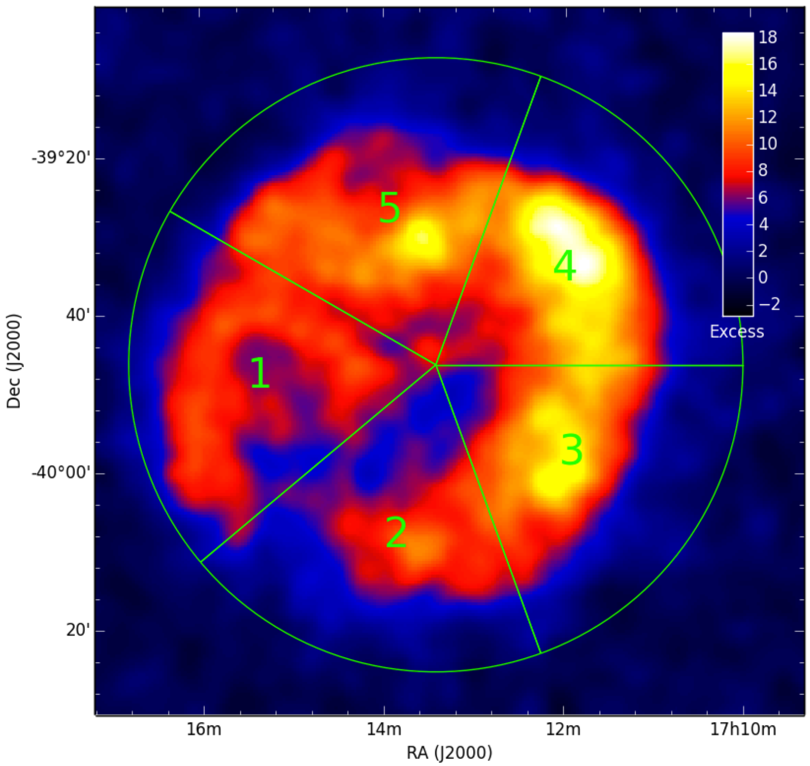
RX J1713.7-3946



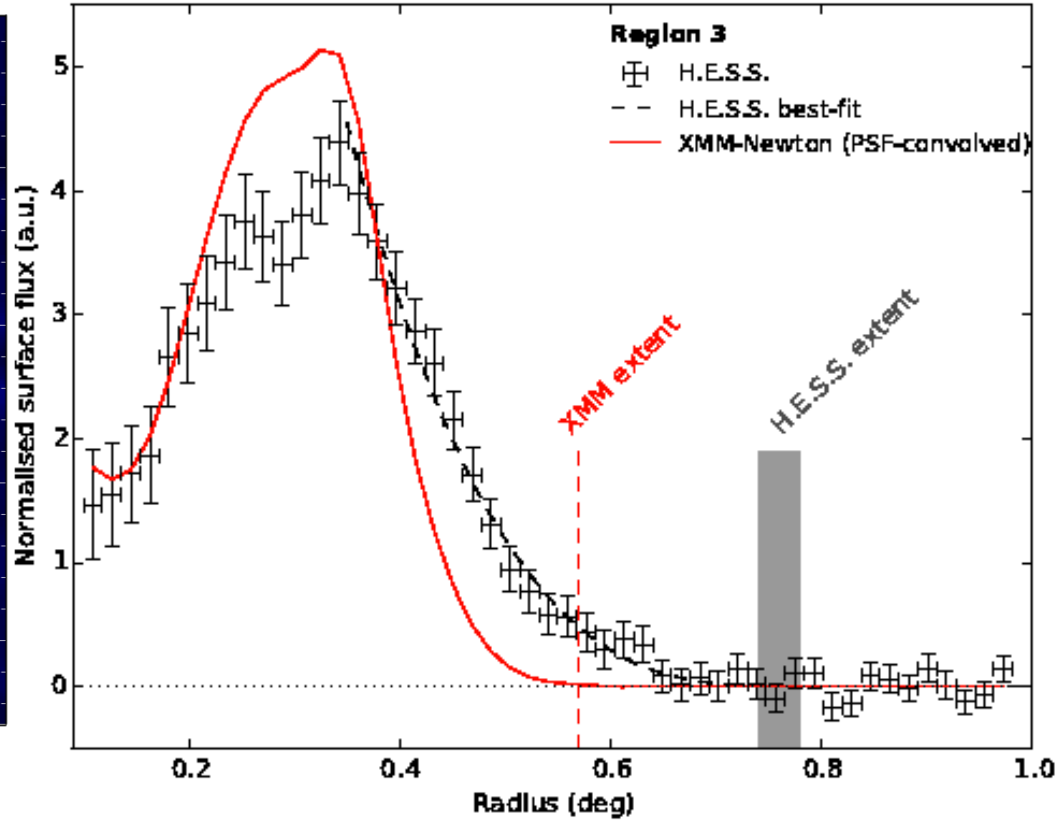
RX J0852.0-4622

- Stricking correlation between X-ray and γ-ray emission
- SNRs are proved to accelerated particules up to 100 TeV
- Type of particle unknown

Supernovae remanent



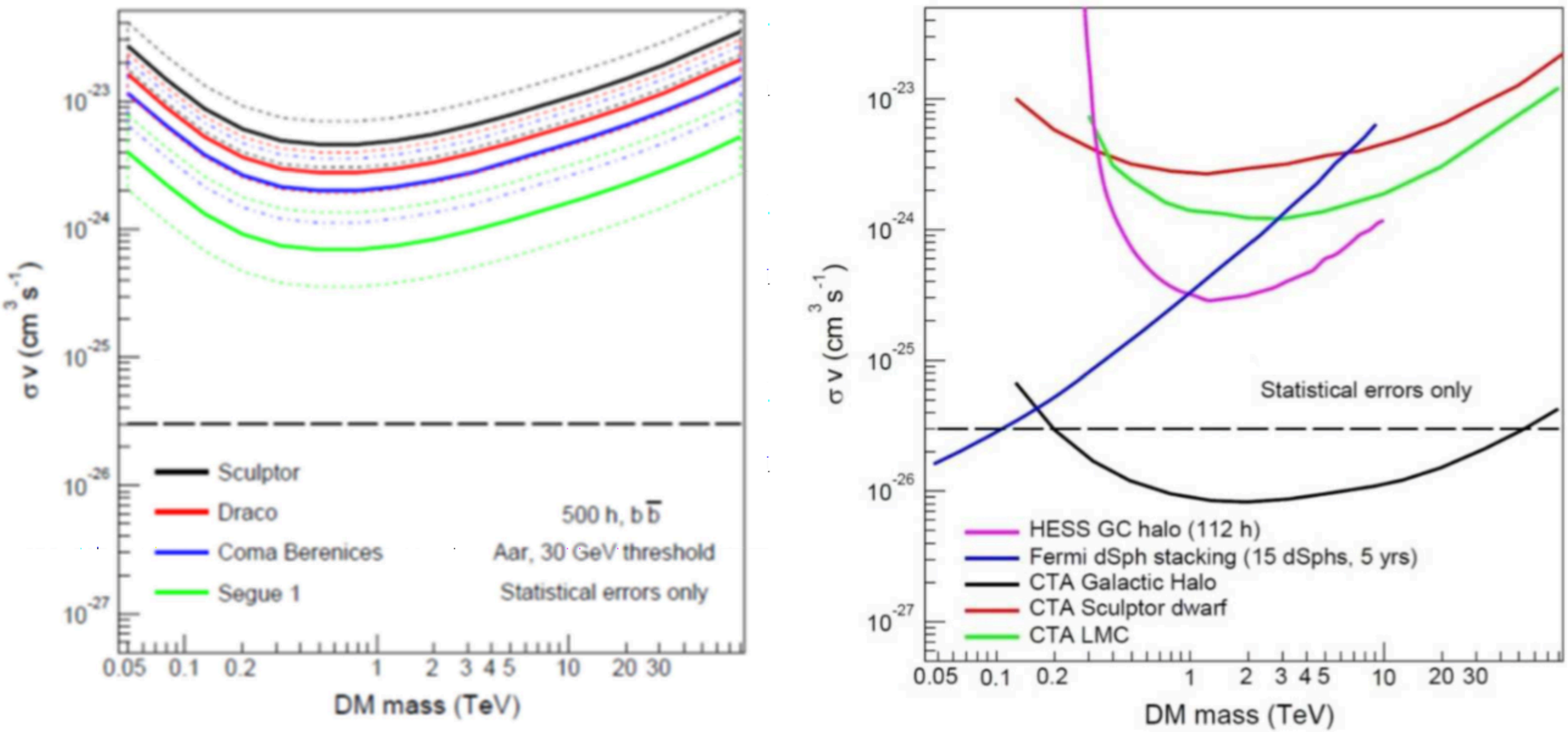
RX J1713.7-3946



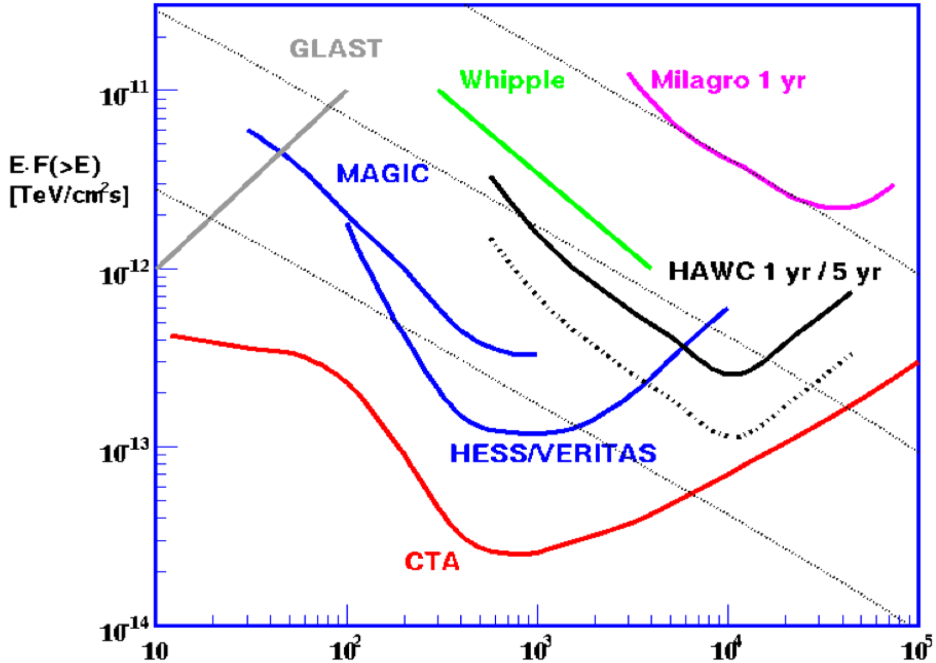
Indication for the first time:

- diffusion of particles outside the shell
- escape of high energy particles, most likely of hadronic origin

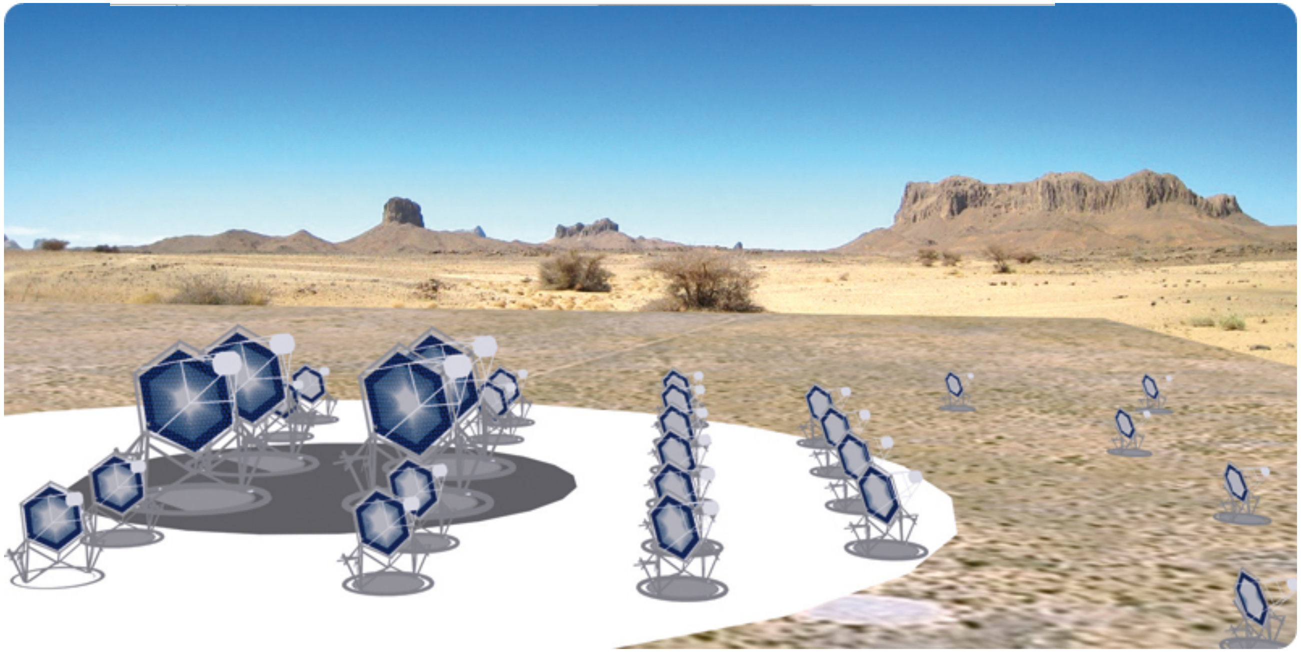
Indirect Dark matter searches



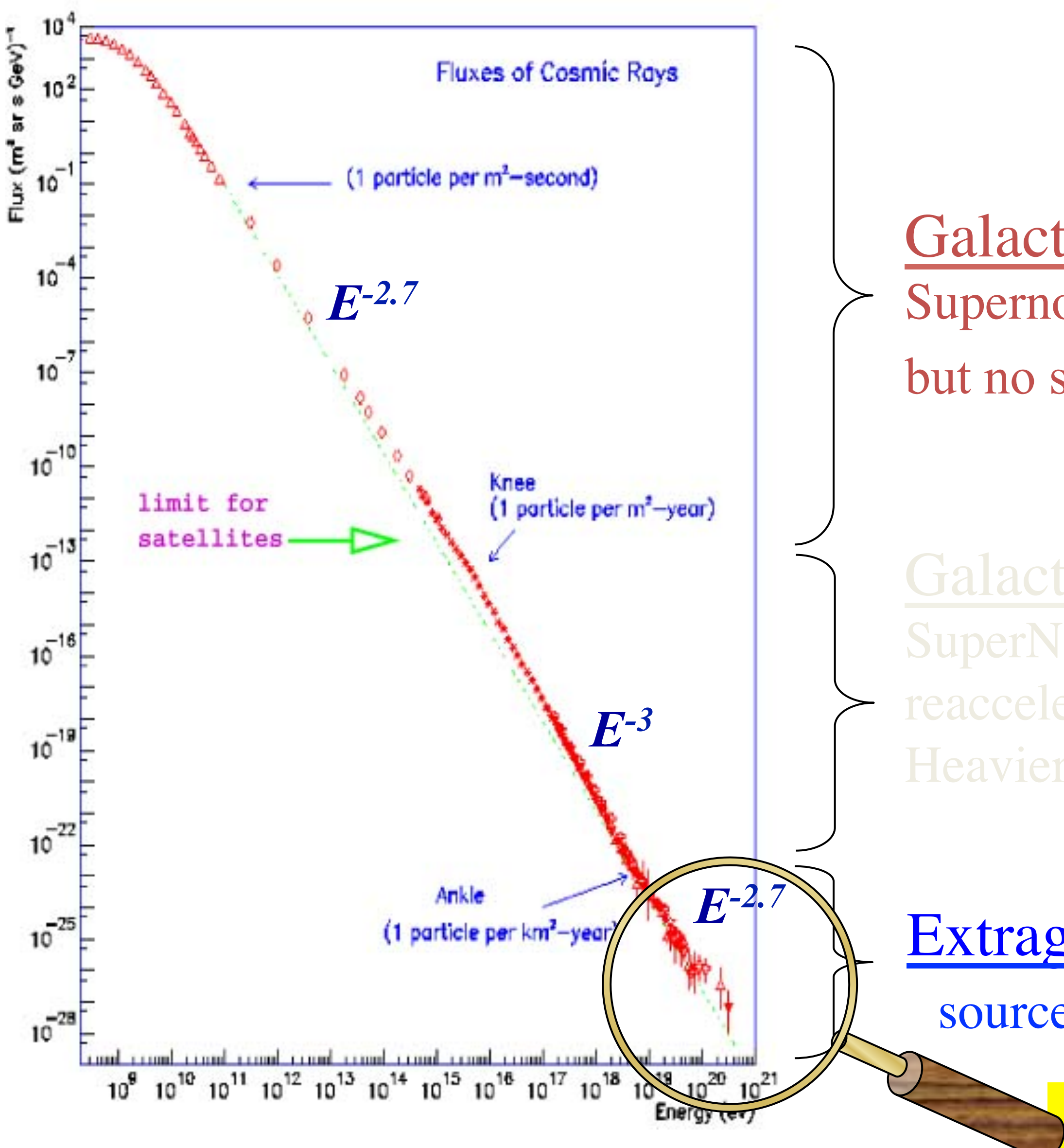
Future



GLAST
Whipple
Milagro 1 yr
MAGIC
HAWC 1 yr / 5 yr
HESS/VERITAS
CTA
E.F(>E) [TeV/cm²s]
10^{11}
10^{12}
10^{13}
10^{14}
10
10^2
10^3
10^4
10^5



The Ankle



Galactic CR :
Supernovae, MIS,
but no source pointing!

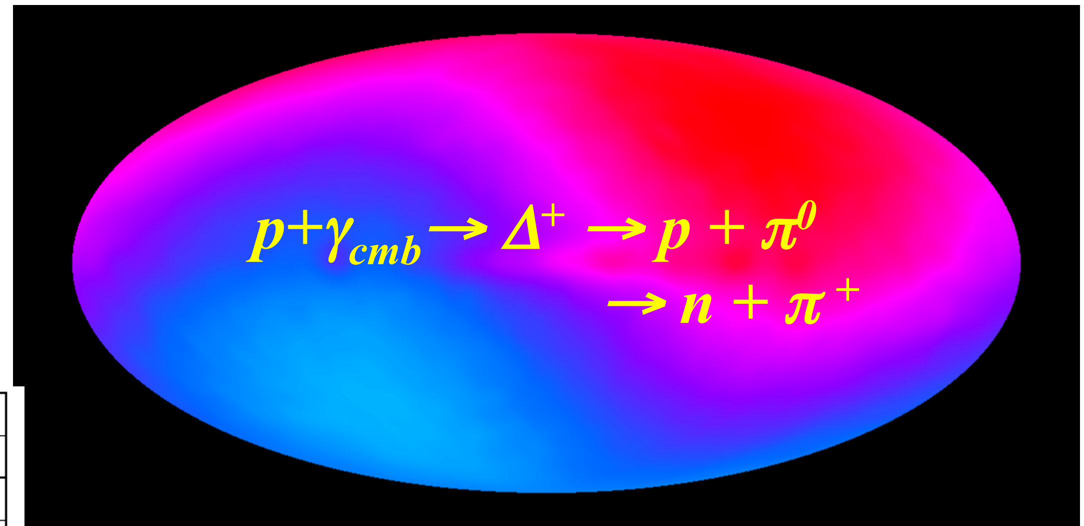
Galactic ?
SuperNovae? Superbubles?
reacceleration?
Heavier nuclei → protons ?

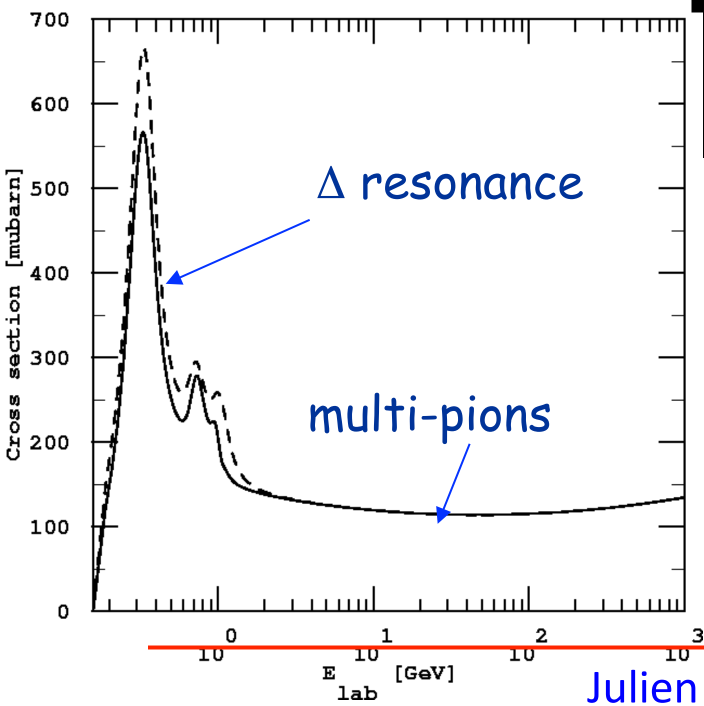
Extragalactic ?
source ?, composition ?

UHECR, terra incognita

GZK Cutoff

An extrem case of relativistic kinematics !!!

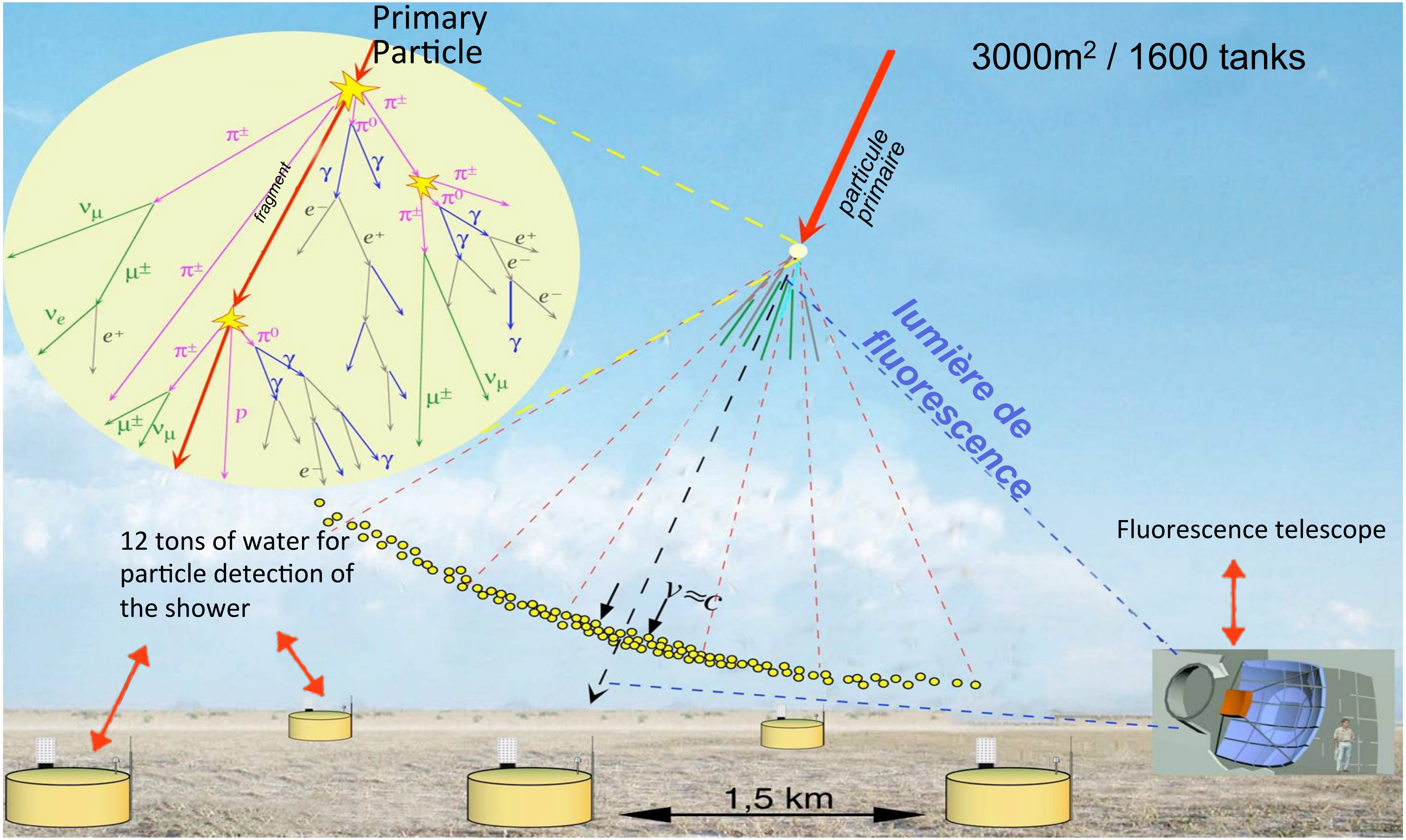




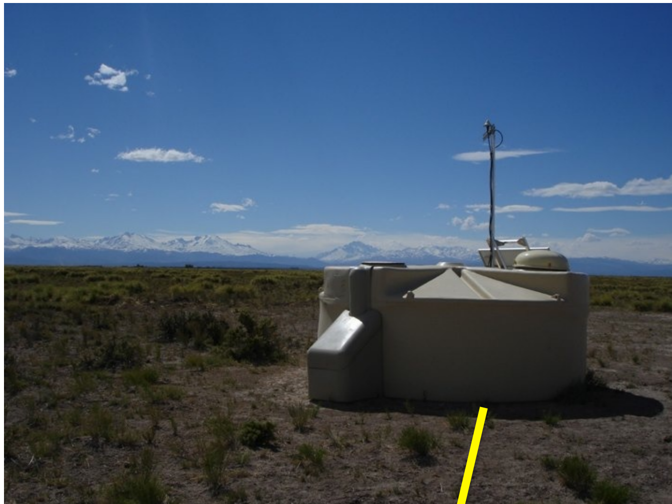
GZK "cutoff"

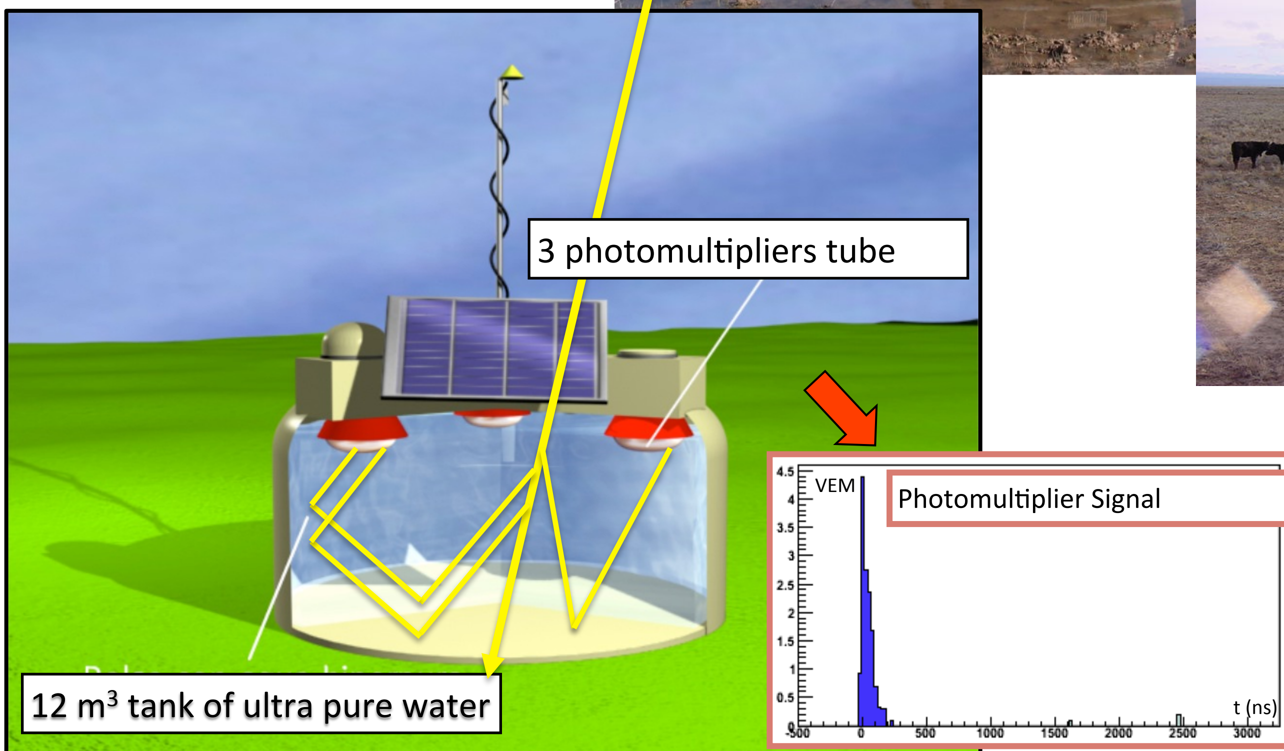
Greisen '66, Zatsepin & Kuzmin '66

Pierre Auger Observatory



Pierre Auger Observatory





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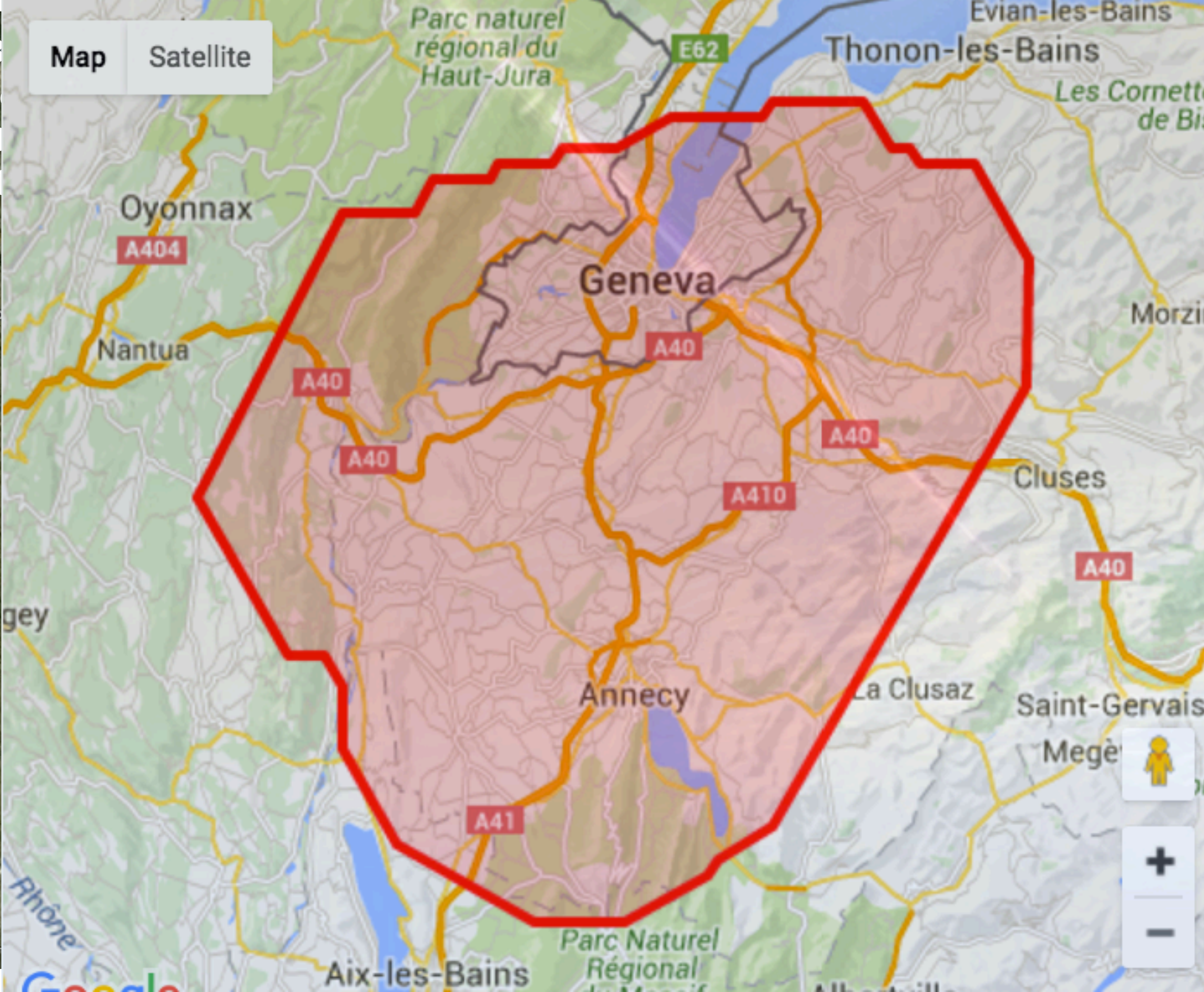
4
fi

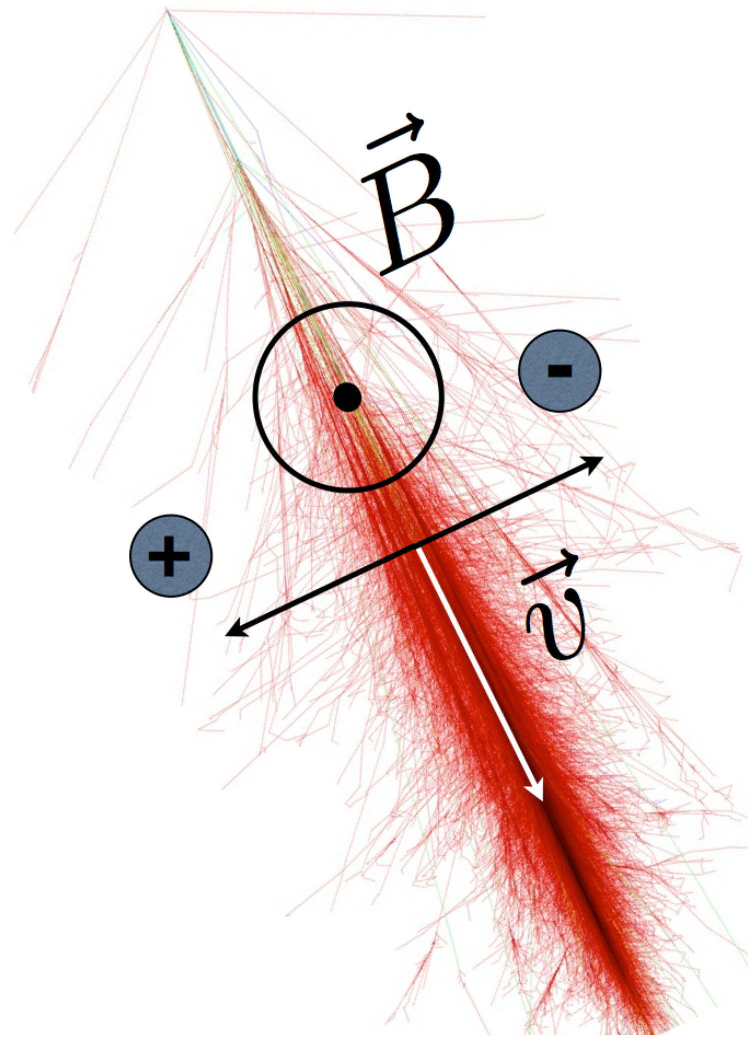


Map
Satellite
Parc naturel régional du Haut-Jura
E62
Evian-les-Bains
Thonon-les-Bains
Oyonnax
A404
Nantua
Geneva
A40
A40
A40
A40
A40
A40
A410
Cluses
Annecy
La Clusaz
A41
Rhône
Parc Naturel Régional
Aix-les-Bains

Radio detection of showers

Charges moving

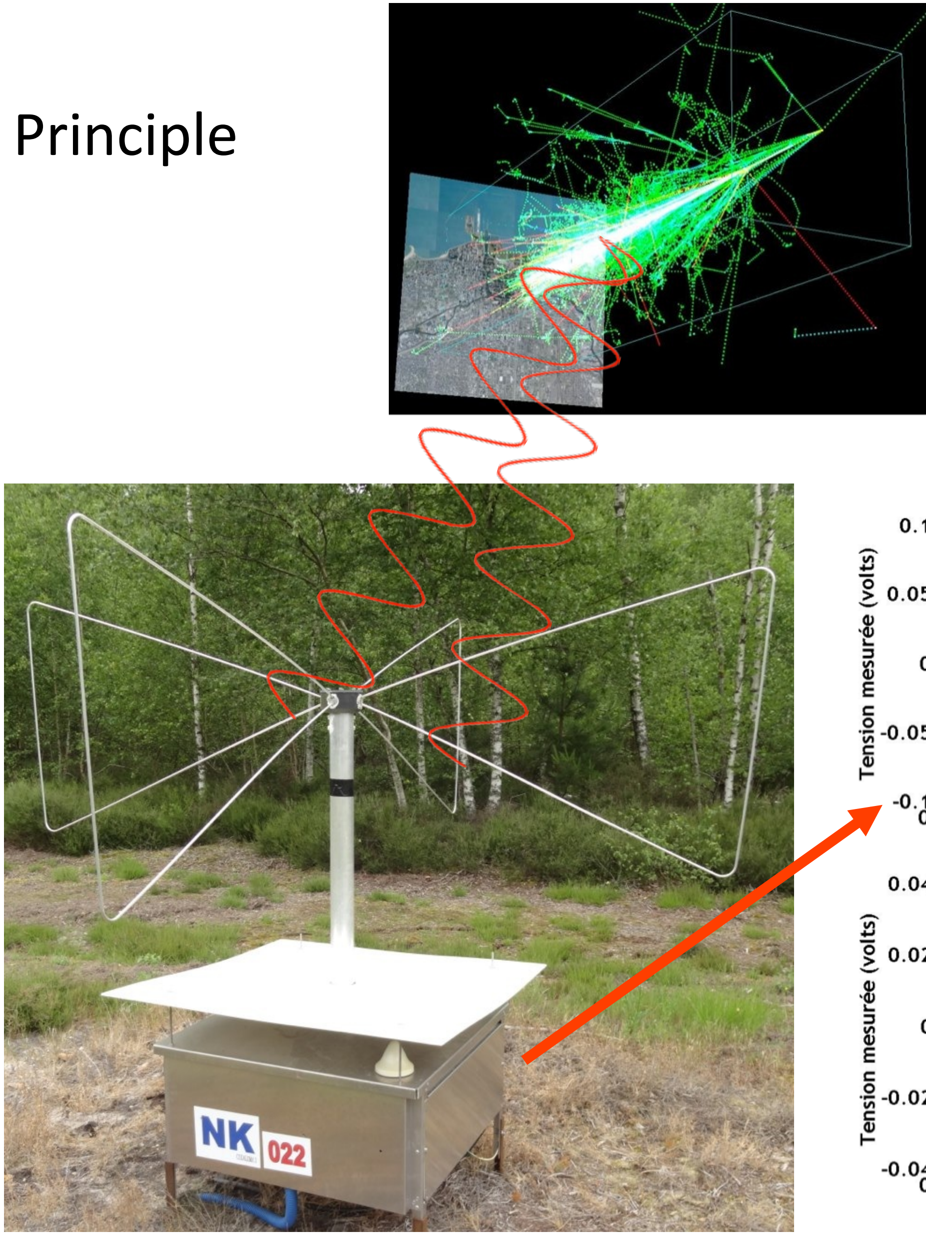
Electromagnetic waves

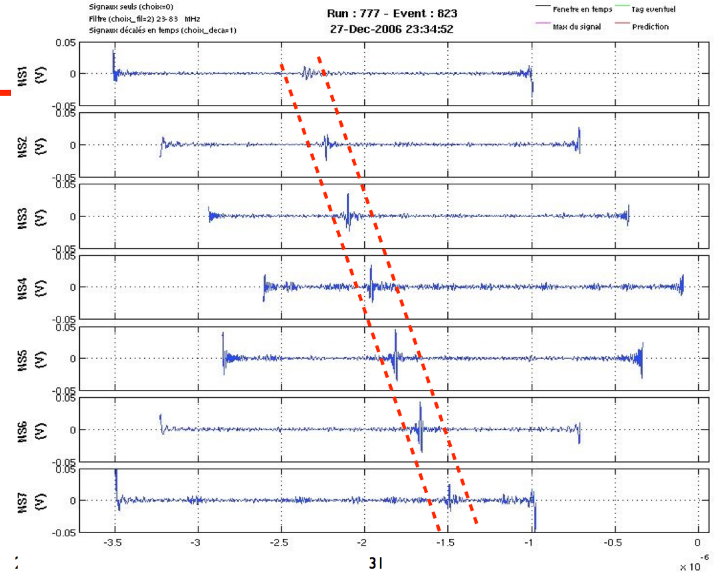


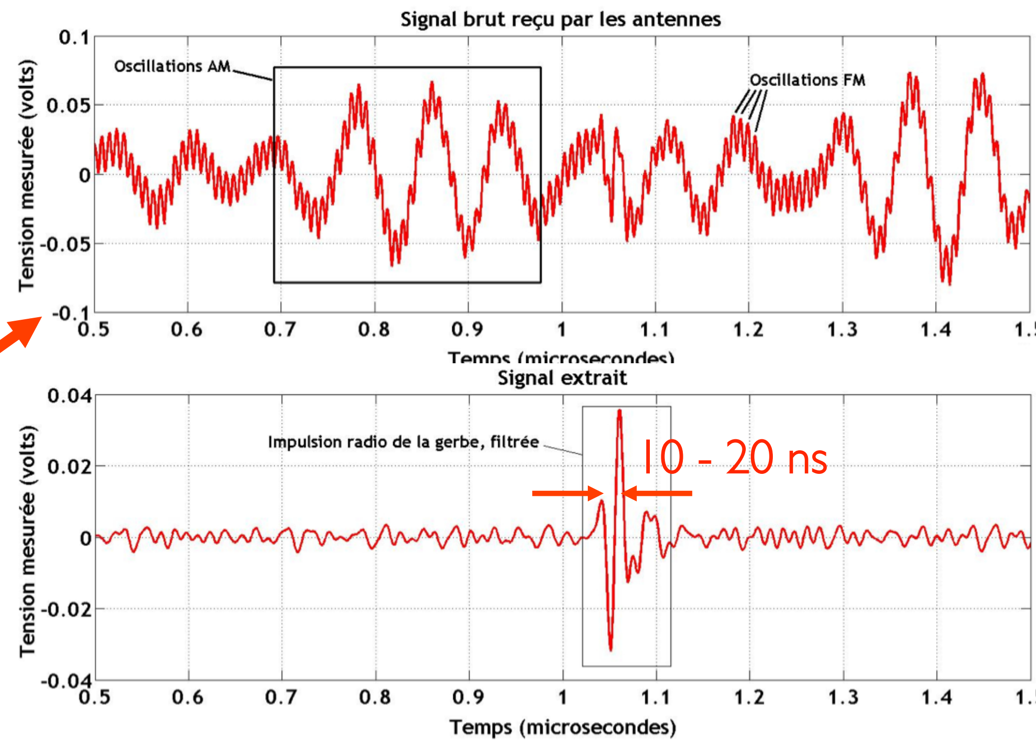
- The whole signal is visible
- Sensitive to the engergy
- High observation time
- Low cost

Radio detection of showers

Principle

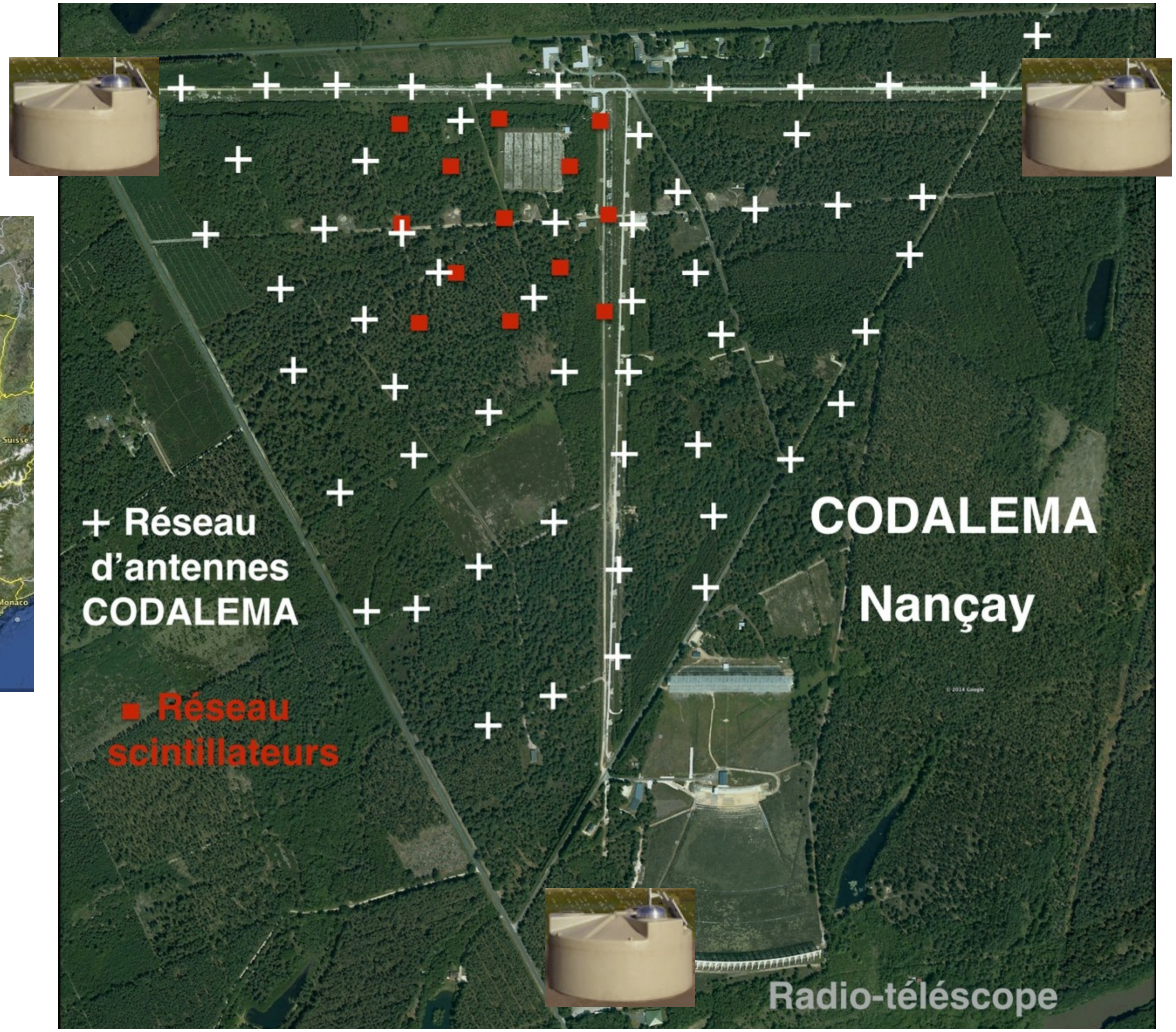




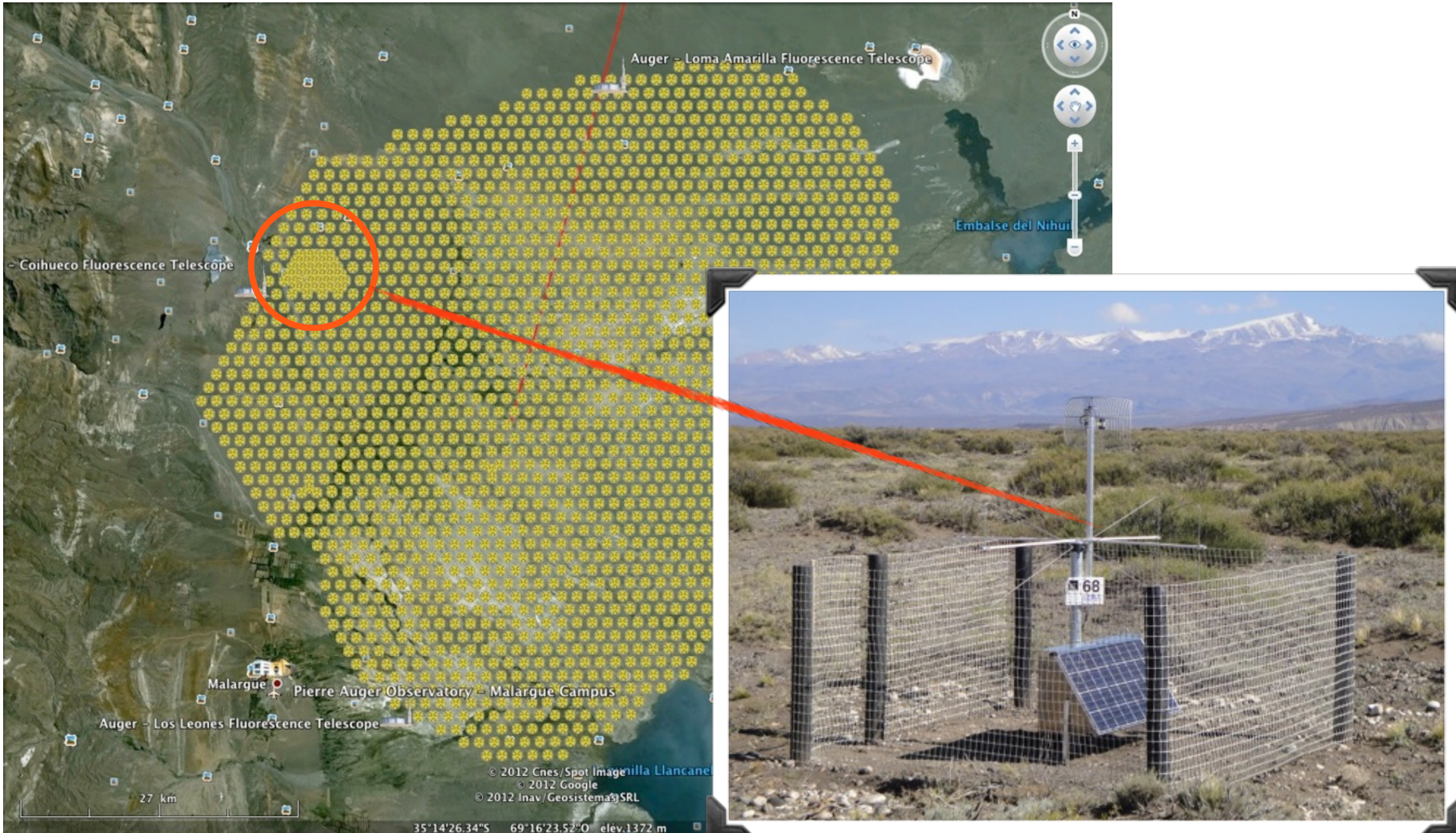


CODALEMA

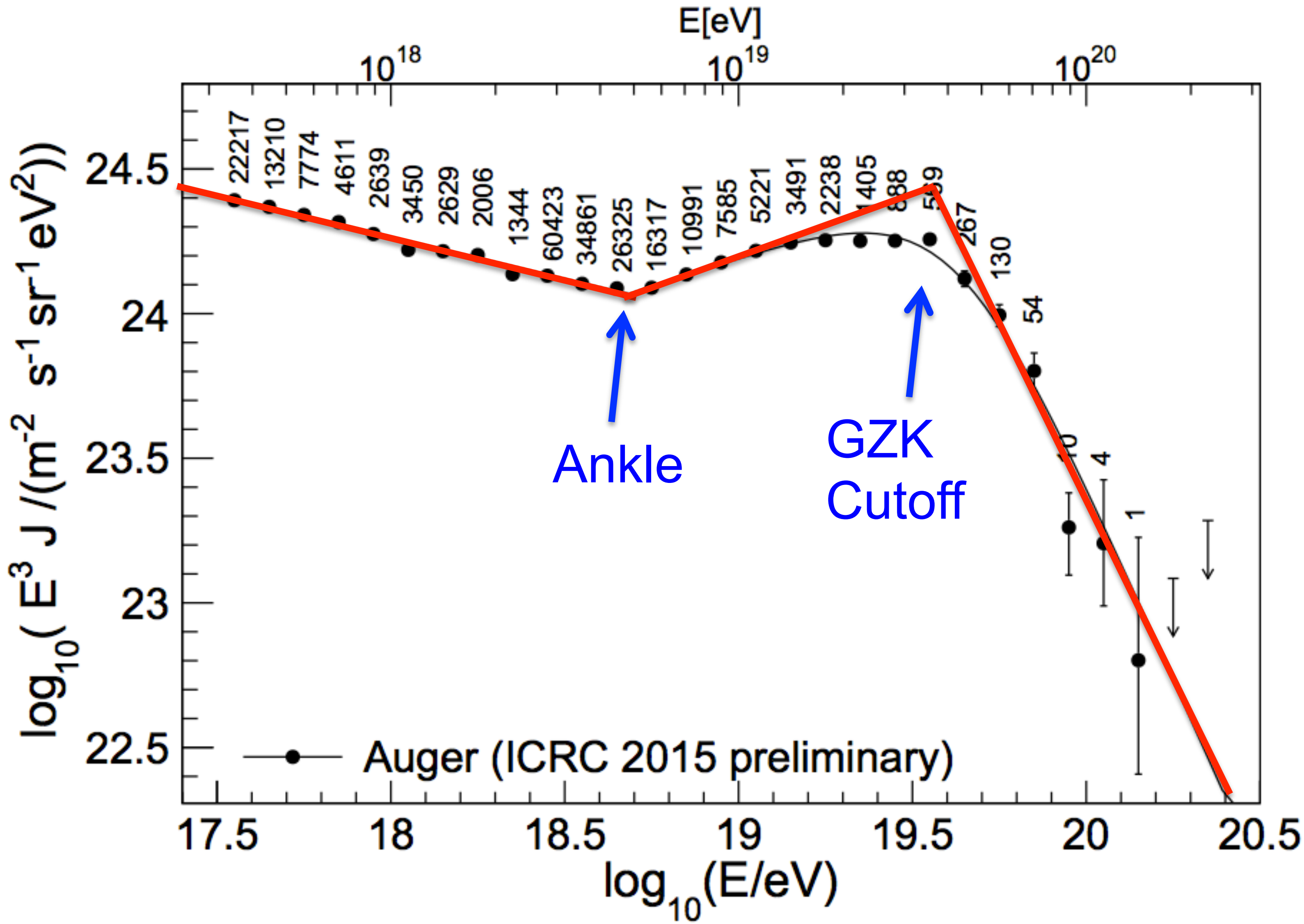
Observatory of radioastronomy of Nançay (Cher)



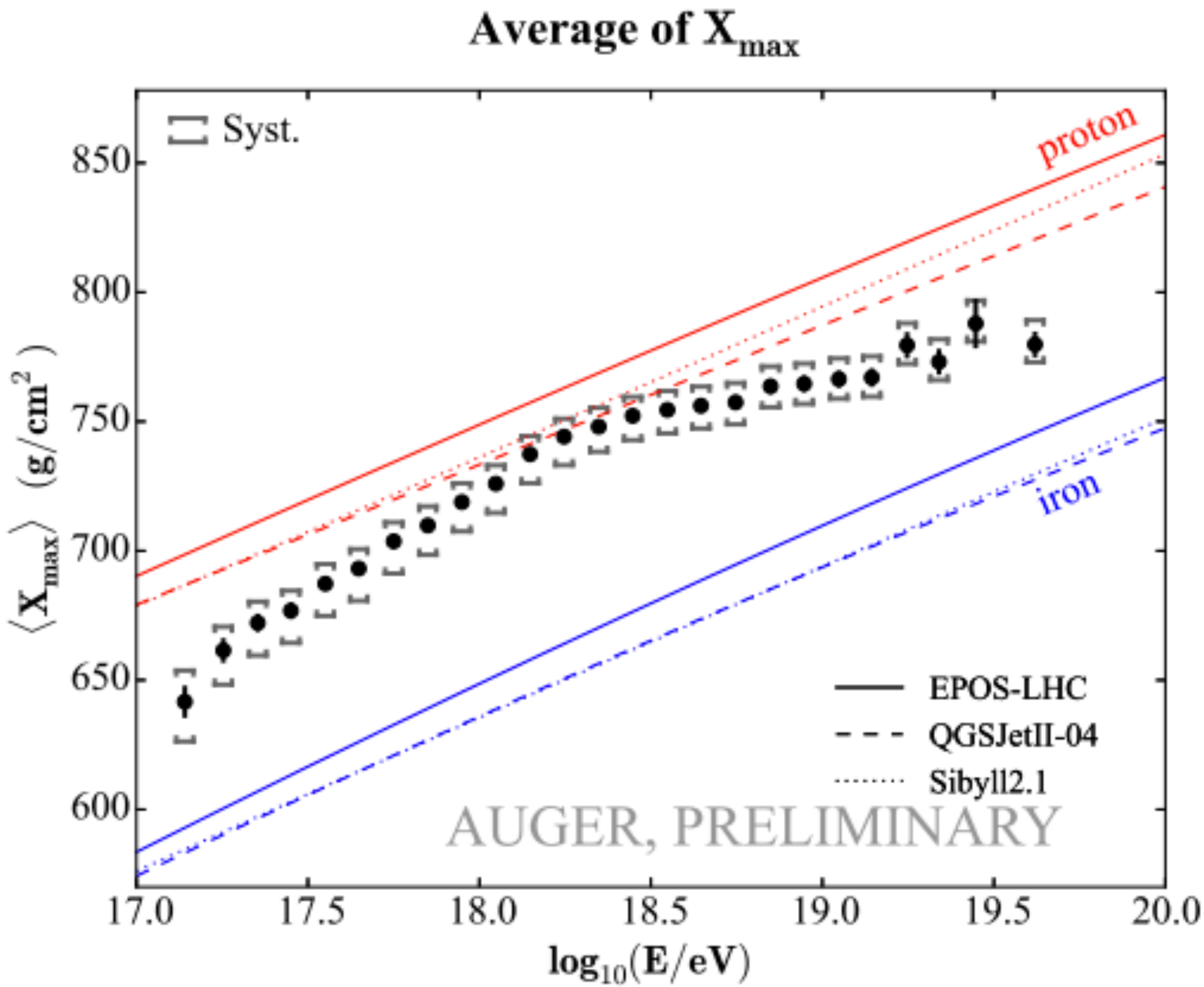
Auger Observatory + Radio = AERA



GZK Cutoff


E[eV]
10^{18}
10^{19}
10^{20}
$\log_{10}(E^3 J/(m^{-2} s^{-1} sr^{-1} eV^2))$
24.5
24
23.5
23
22.5
17.5
18
18.5
19
19.5
20
20.5
$\log_{10}(E/eV)$
Auger (ICRC 2015 preliminary)
Ankle
GZK
Cutoff

GZK Cutoff: Composition



GZK Cutoff Map