Laboratoire d'Annecy de Physique des Particules

JRJC Astroparticle session

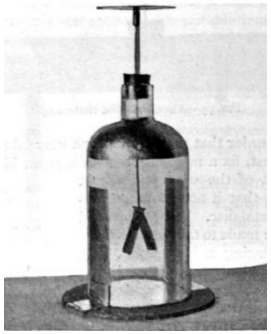
Sami Caroff (LAPP)

18 octobre 2021

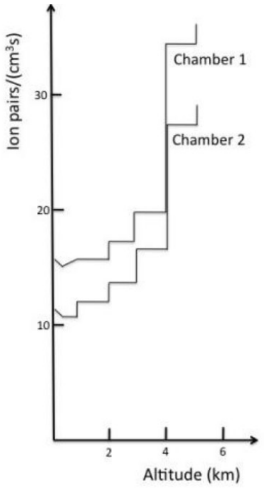
cnrs

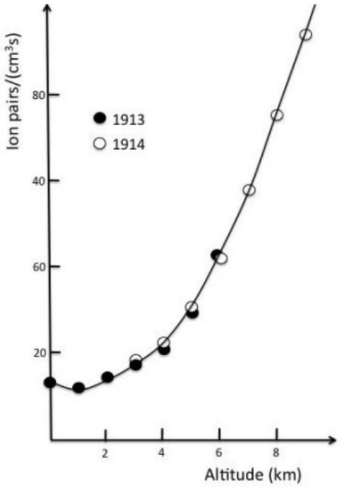
UNIVERSITÉ SAVOIE MONT BLANC

The first hints of cosmic rays



- **1896 :** Discovery of radioactivity, can naturally explains the spontaneous **discharge of electroscope** (natural radioactivity from the ground)
- **1907-1911 :**
  - **Domenico Pacini** : Reduction of 30 % of radiation on water compared to the coast, **ground radioactivity can only explain partly the results**
  - Reduction of 20 % below 3m of water, **first hint of a radiation coming from the sky**
- **1911-1913 :**
  - **Victor Hess** : Balloon experiments, **ionisation increases with altitude** (up to 1.5 km), clear proof of extraterrestrial radiation → **discovery of cosmic rays**

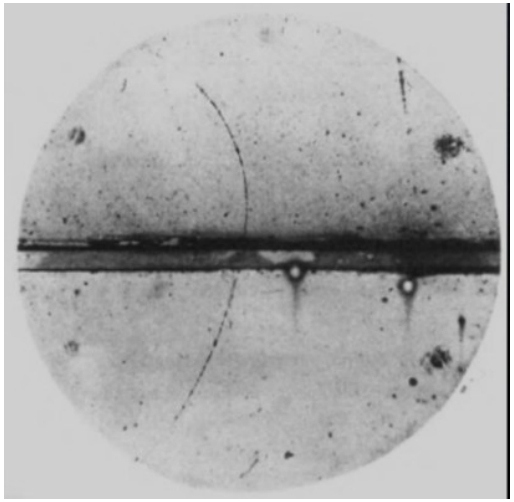


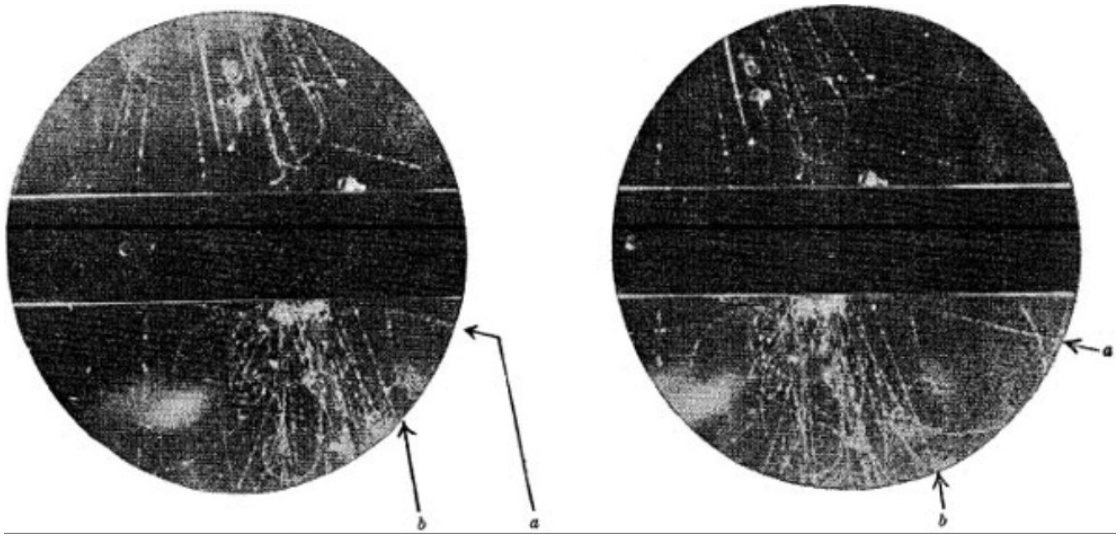


A providence for particle physics

Cosmic rays provide free collision of accelerated particles in the atmosphere, many secondary particles can be observed at high altitude

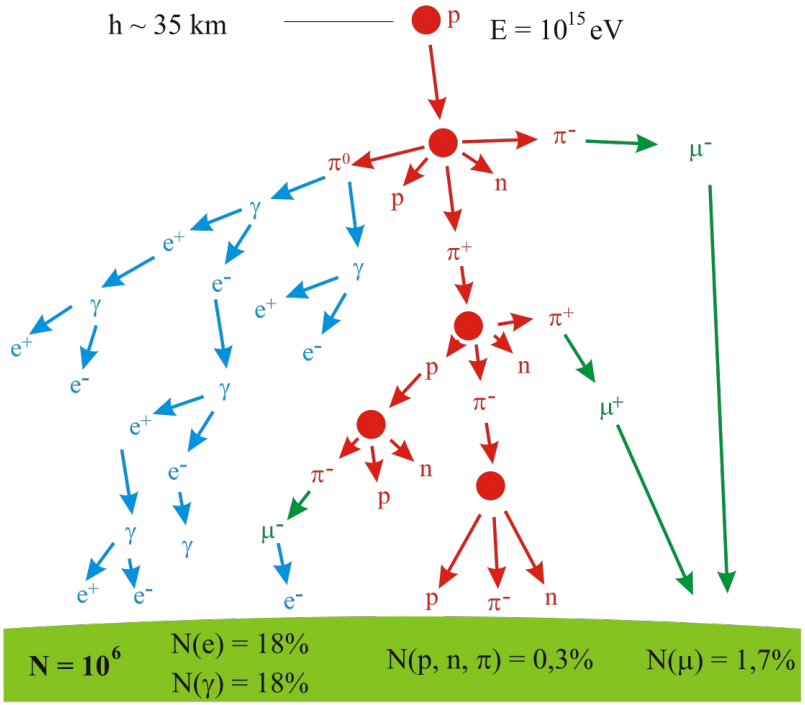
- **1932 :** Discovery of the **positron** by Robert Millikan (anti-matter discovery)
- **1936 :** Discovery of the **muon** (Anderson and Neddermeyer)
- **1947 :** Discovery of **pion** and **kaon**
- **1951 :** First **strange baryon**
- **1950s : Particle accelerators** provide artificial cosmic rays and better controlled, first golden age of cosmic ray for new physics ended
- **Now :** Search for **anomalies** in the cosmic rays for news physics is still a very active field





The question of cosmic ray origin

- **1939 : Pierre Auger** et al. → long horizontal distance **coincidence counters**
- **Ancestor of all ground observatory of cosmic ray**
- Coincident counts up to ~100m
- Clear evidence of **air shower initiated by high energetic primary particle**
- First evaluation of energy of primary particles : **Energy up to 10^{15} eV** !!!



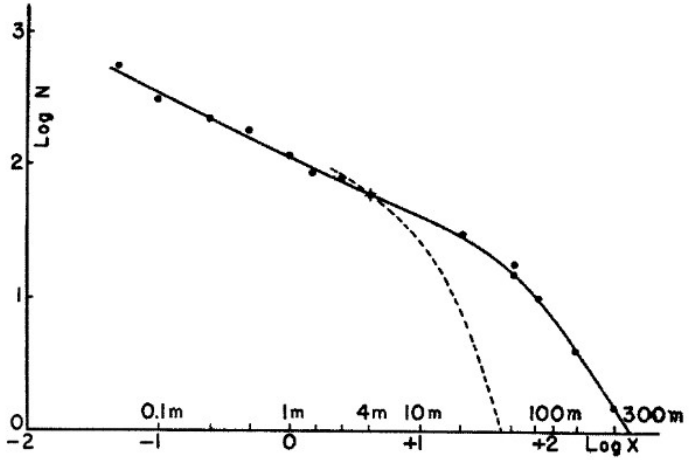
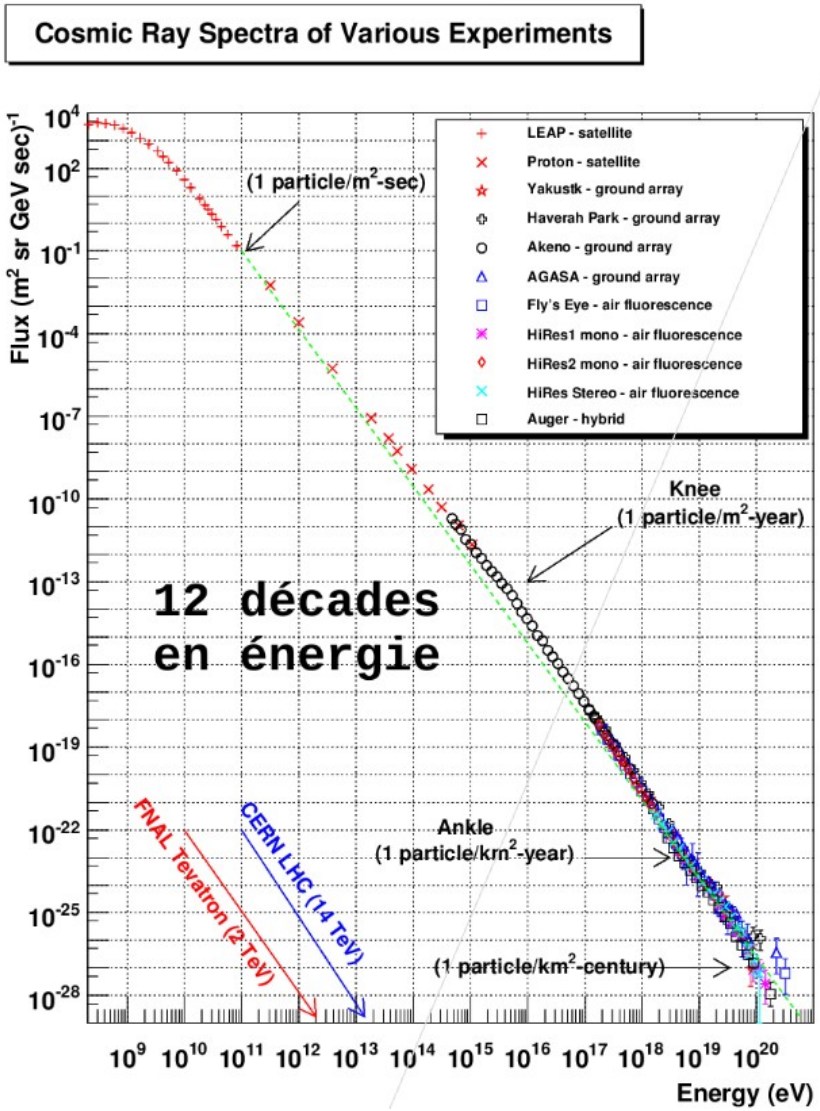


FIG. 1. Results with two parallel and horizontal counters.

CONCLUSION

One of the consequences of the extension of the energy spectrum of cosmic rays up to 10^{15} ev is that it is actually impossible to imagine a single process able to give to a particle such an energy.

Cosmic ray characteristics



- Power law spectra :

Let's suppose a **multiplicative energy increases** after k process

$$E = \beta^k E_0$$

Let's add a **probability P to escape** after each step

$$N(\geqslant E) = N_0 P^k$$

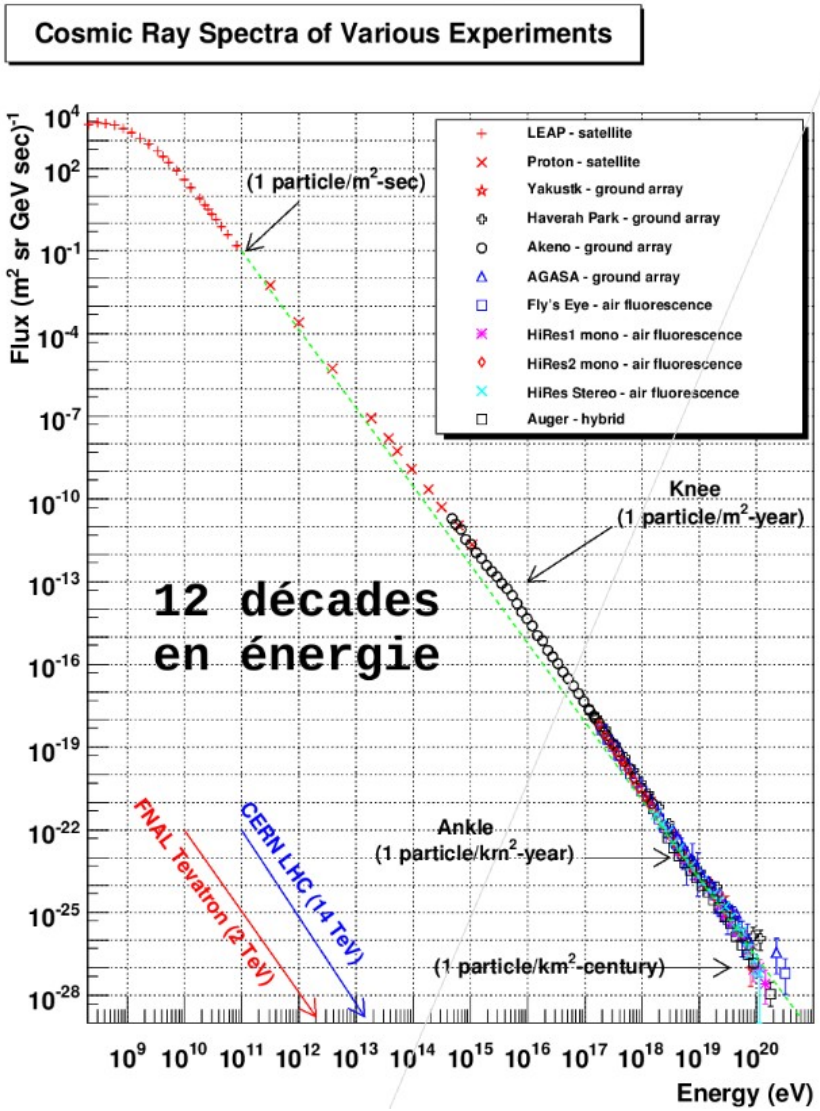
Let's combine them !

$$\frac{N(\geqslant E)}{N_0} = \left(\frac{E}{E_0}\right)^{\ln P / \ln \beta}$$

A **power law spectrum** emerges from these very simple assumptions :

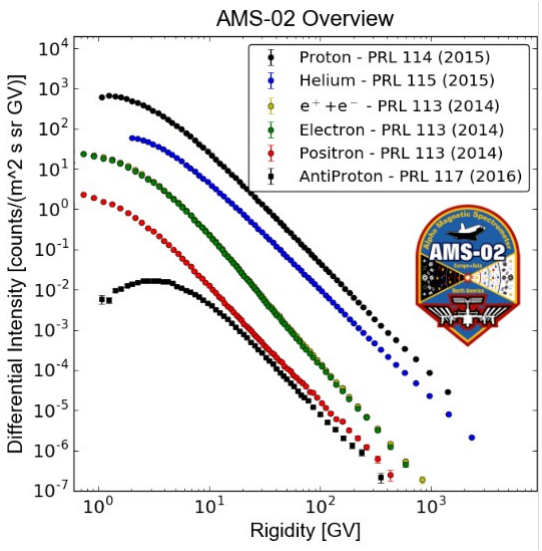
- **Fermi acceleration**, stochastic collision with magnetic inhomogeneities

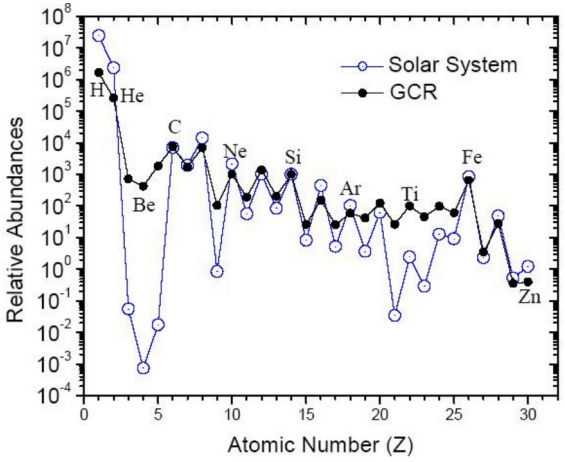
Cosmic ray characteristics

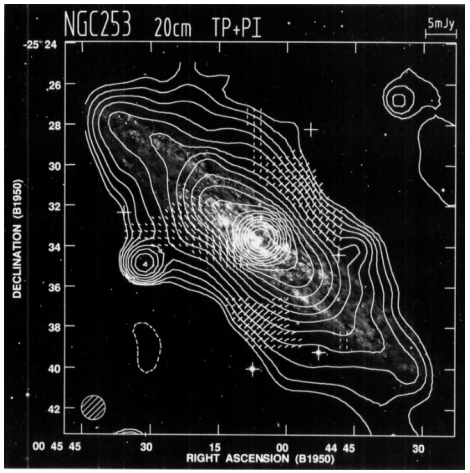


- Power law spectra :
  - Extended in 12 decades in energy
  - E < 3 PeV : index 2.7
  - 3 PeV < E < 300 PeV : index 3.1
  - 300 PeV < E < ~EeV : index 3.3
  - E > ~EeV : index 2.7
- Energy between knee and ankle trusted to be the **transition between galactic and extra-galactic cosmic rays**

Galactic cosmic rays characteristics

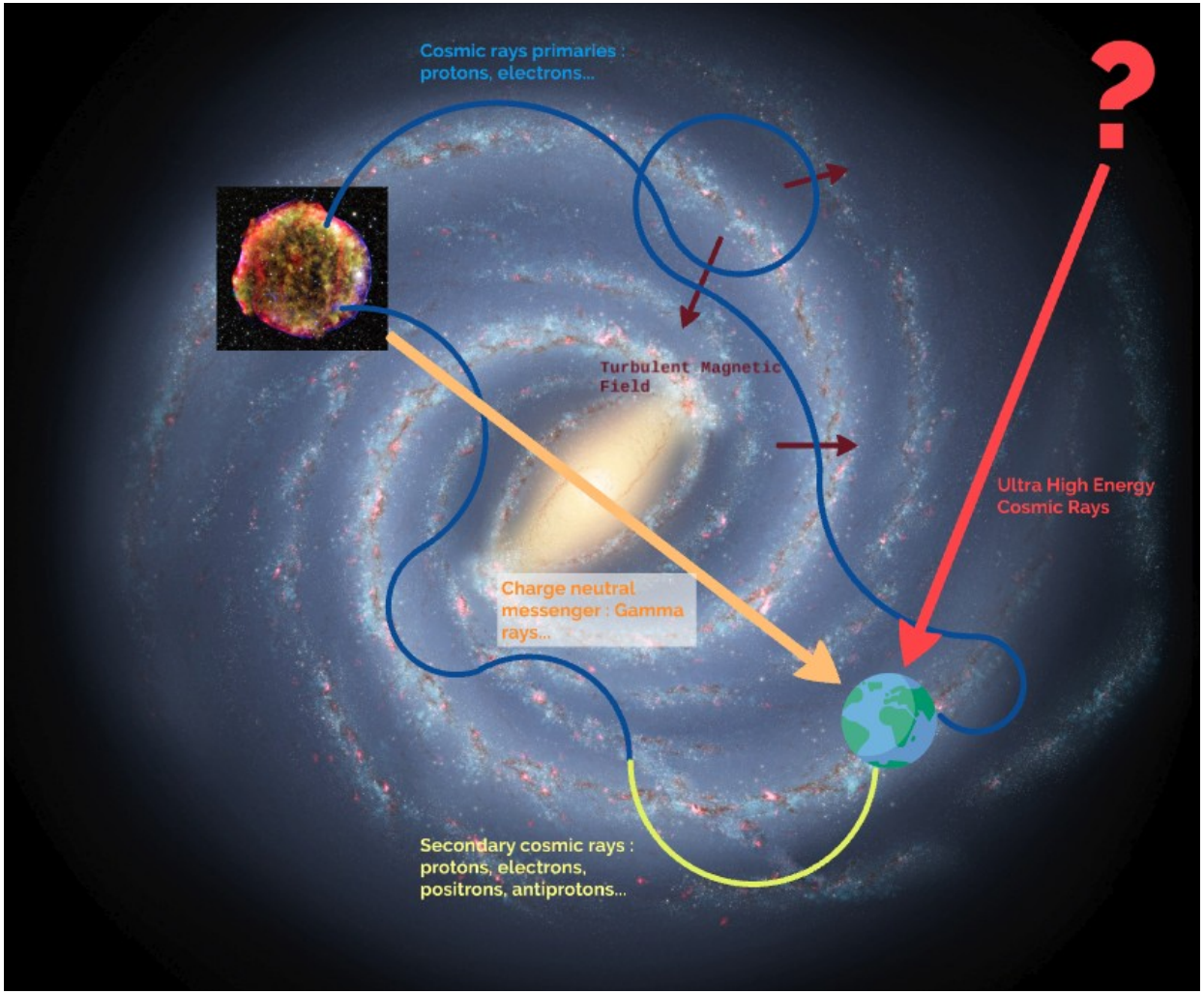






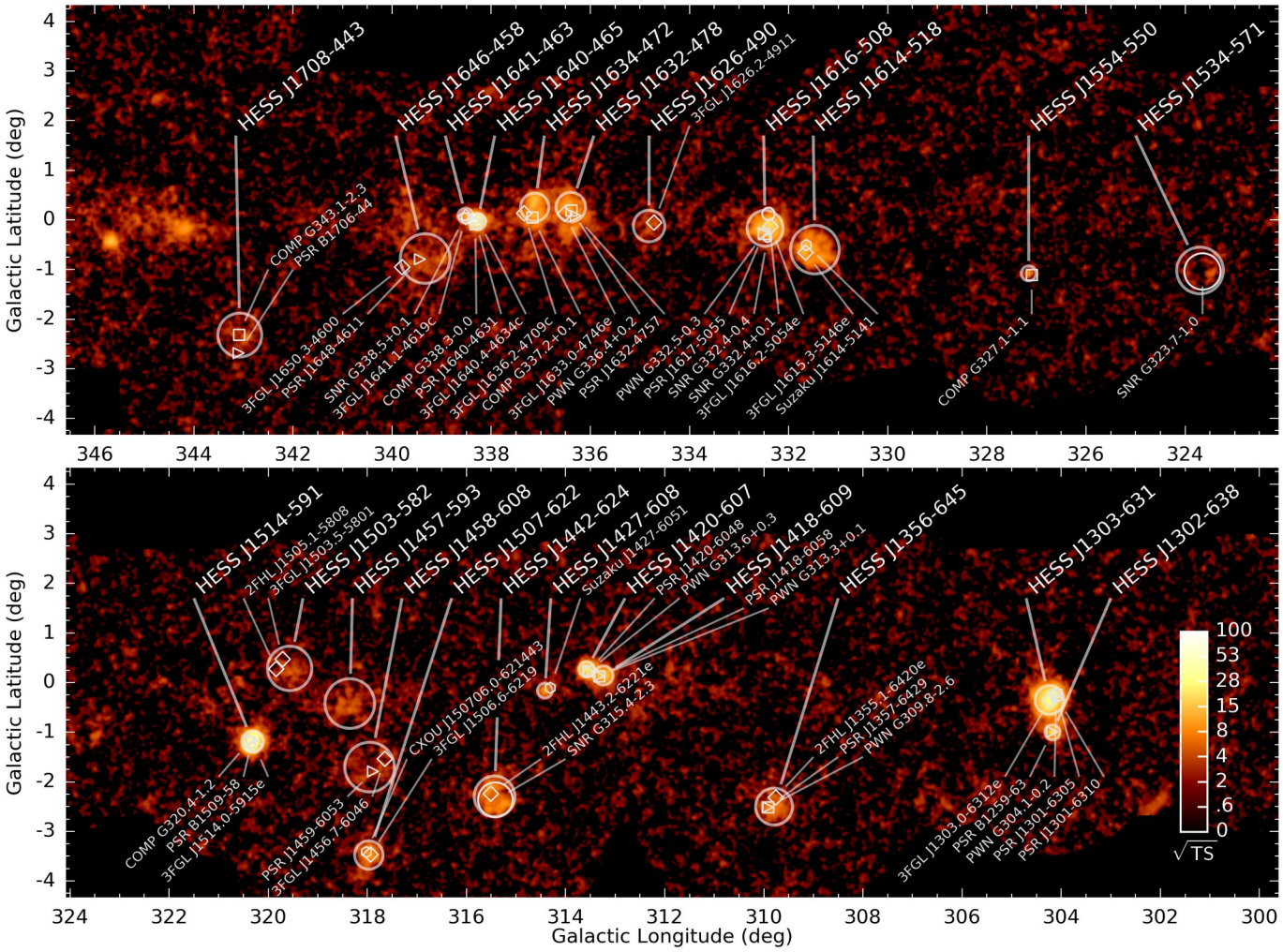
- Composition :
  - Mainly **protons (90%)** and **Helium (9%), heavier nuclei and electrons (1%)** → dominated by **matter** (anti-matter < 0.1%)
  - Similar nucleus abundance than the **solar system** (taking into account spallation of nucleus)
  - Compatible with the idea of **acceleration of interstellar medium**
- Cosmic rays observed in the **whole Milky Way** and also **indirectly in other galaxies** (radio emission due to synchrotron energy losses)
- All this made **supernova remnants** as very plausible accelerators for galactic cosmic rays
  - Supernovae remnant provides **shock waves** where Fermi acceleration of interstellar medium is plausible

Messengers



- Charged cosmic ray deflected by **magnetic field**
- **Loss of their original direction** → can't be used to determine their **origin**
- Need to use **charge neutral messenger**, such gamma rays
- **UHECR less affected by magnetic field**
- Original direction is not loss → can be used to determine their origin…
- … but **low stat** at high E

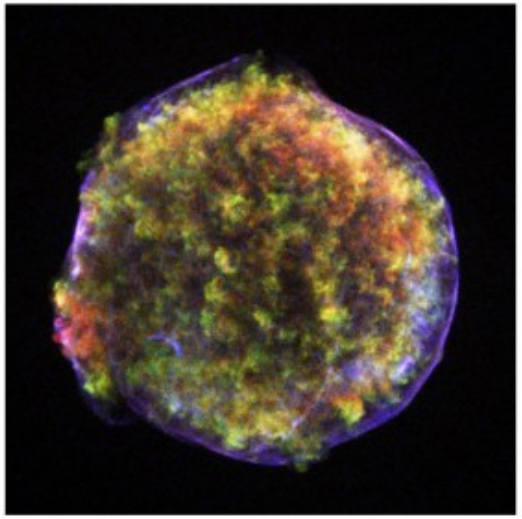
Neutral messenger : Gamma rays



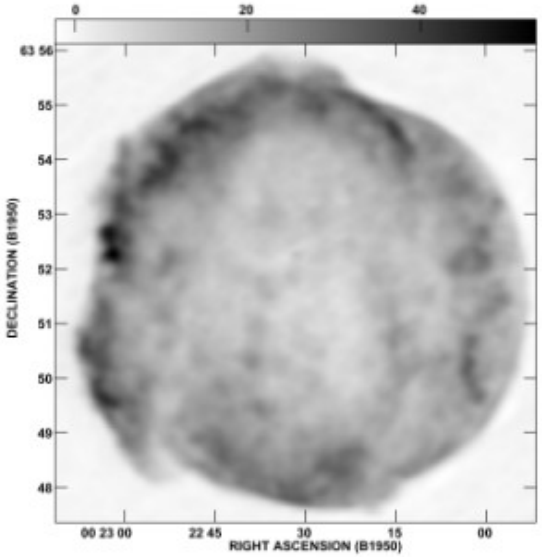
- View of the **Galactic plane** for TeV gamma-rays by **H.E.S.S.** (~TeV)
- Gamma ray production through **IC, neutral pion decay**
- **Direct image of accelerator of charged particles in Milky way**

Supernova remnants as main CR accelerator

Infrared, optical, X rays

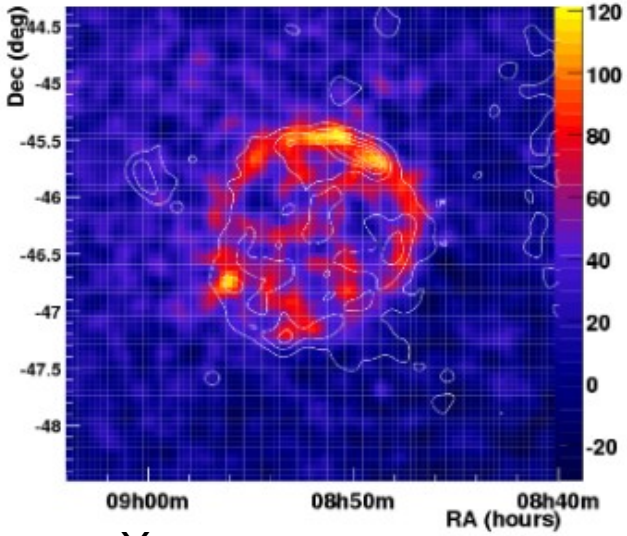


Radio



Tycho Brahe SNR

- Infrared and optical : **hot gaz and dust**
- X Rays : **Bremsstrahlung**
- Radio : **Synchrotron** radiation
- Gamma rays : **Inverse Compton scattering and/or neutral pion decay**



RXJ0852.0-4622

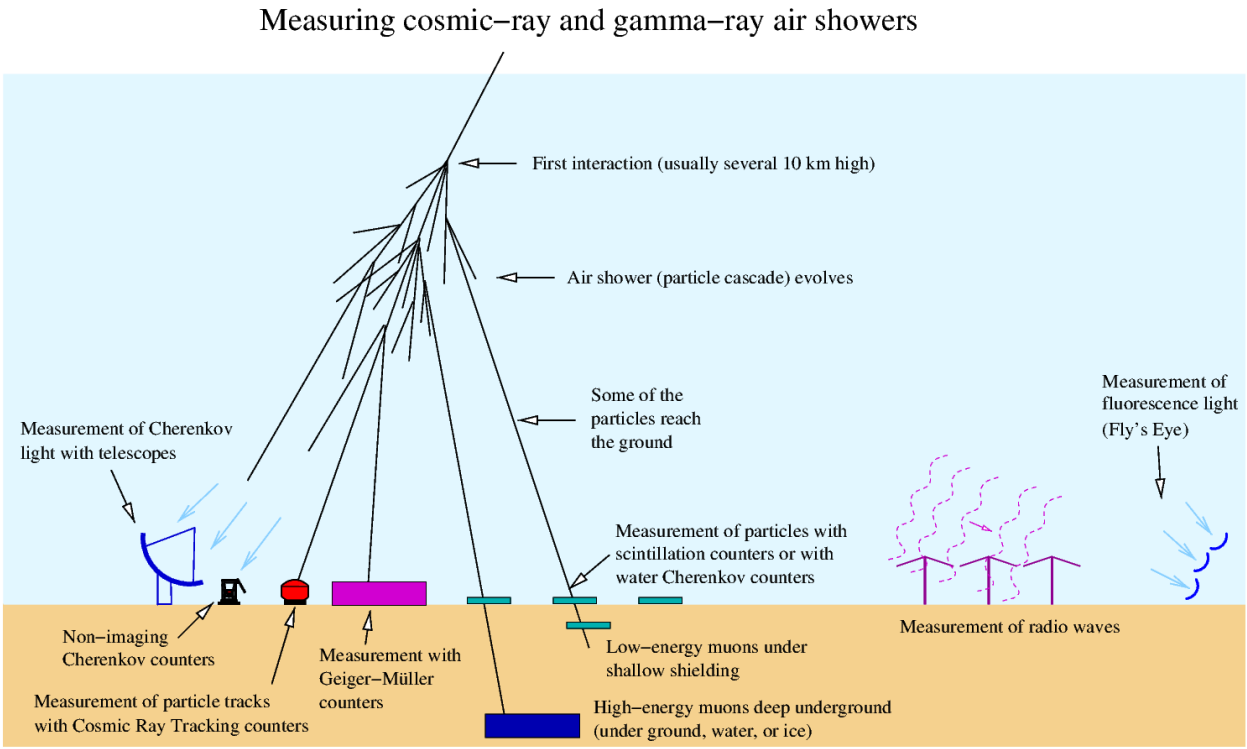
X rays, gamma rays

- **Correlation** of presence of **shock wave** and **highly energetic particles**
- Open questions :
  - Able to accelerate **up to PeV** ?
  - Dominance of **leptonic** or **hadronic** ?

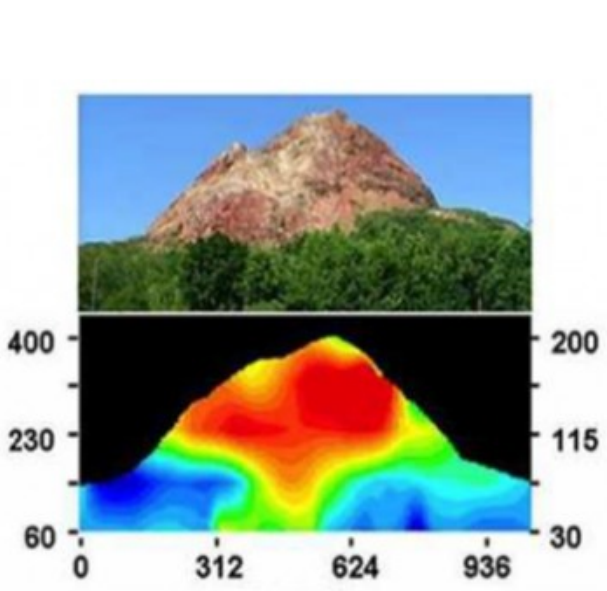
Detection methods

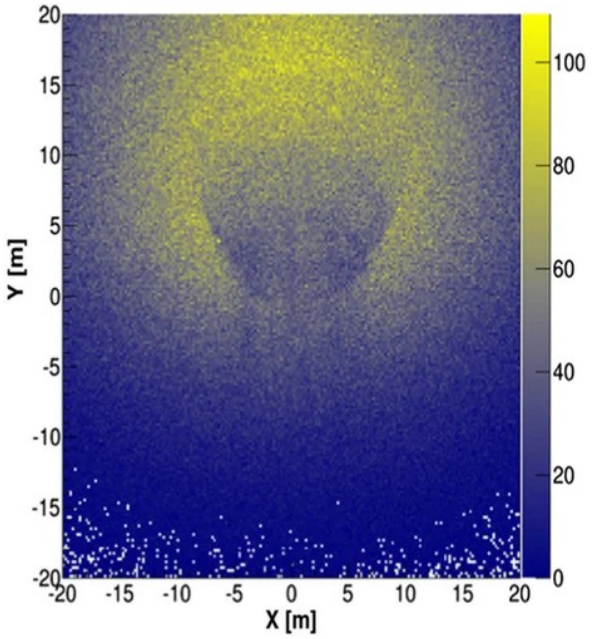
- **Direct detection** :
  - Only possible in **space** (atmosphere opaque to CRs)
  - Power law spectra → need detector **surface for statistics** → limited in space

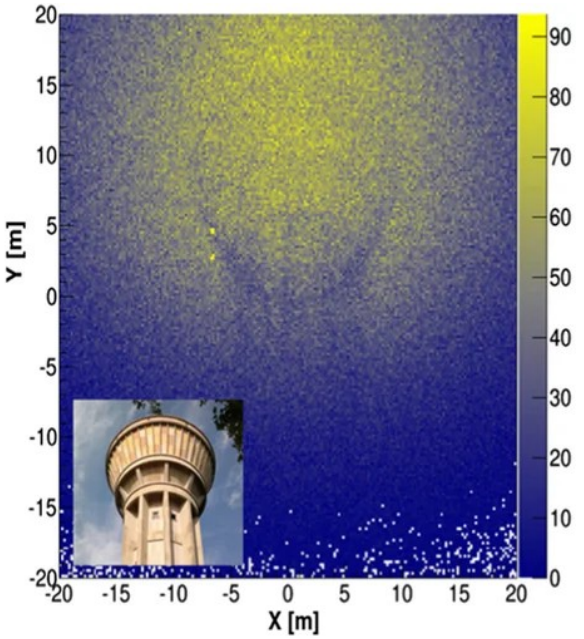
- **Indirect detection** :
  - **Multiple messenger** to measure the air shower
    - **Air Cherenkov light** (blue, UV)
    - **Radio**
    - **Charged Particles**
    - **Fluorescence** (UV)
- This session will include **all** these detection types !



Muography

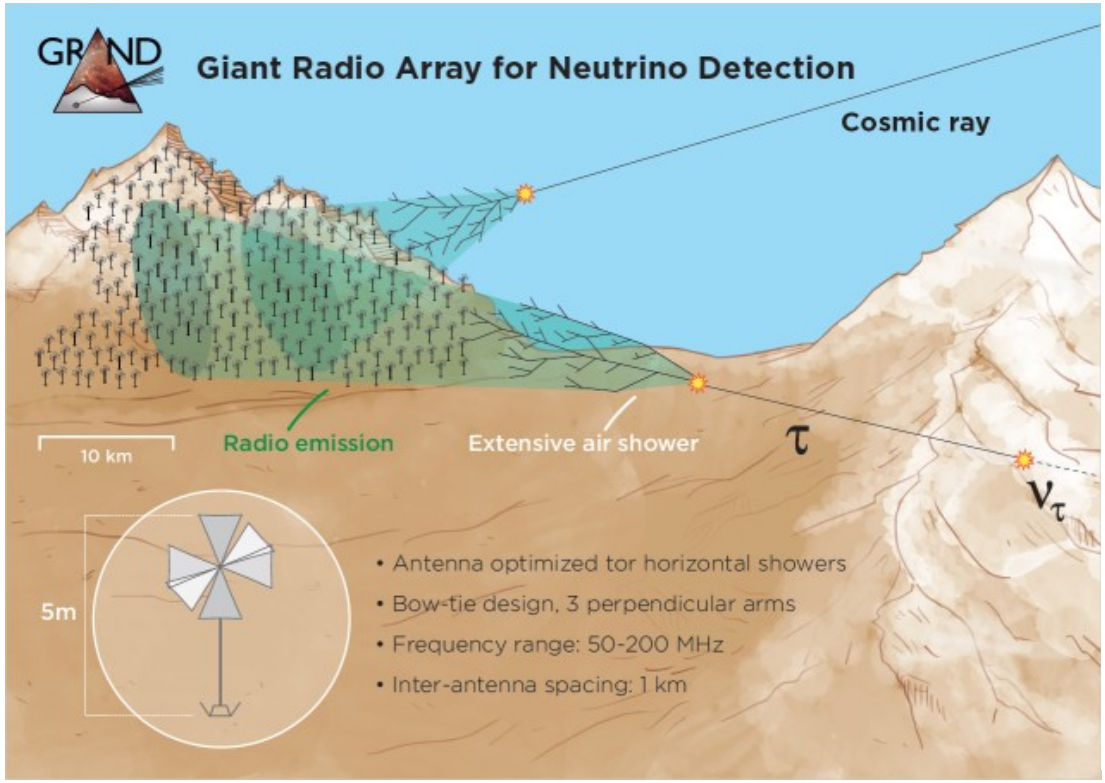


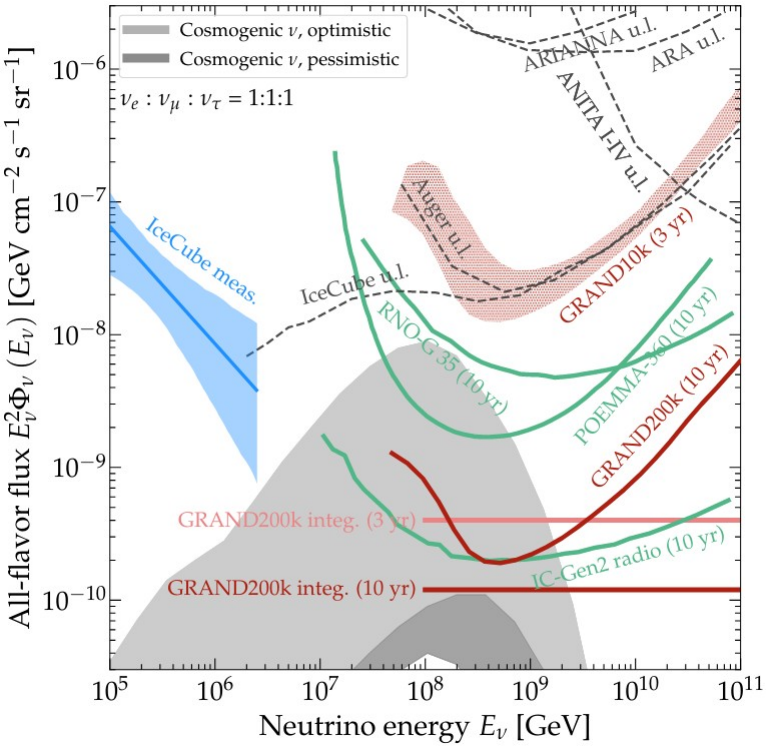




- Same spirit than in the 1930s, **CR provide muons for free**, let's use them
- Muons are highly penetrative, variability of muon flux can permits to assess **under and over density of matter for big structures**
- Provide a **non invasive** and **non destructive** method to scan big structures
- Usefull for **Geology** (volcano...), **Archeology** (pyramids...), civil engineering…
- **Cf Kinson Vernet presentation, « 3D Volcano Imaging Using Transmission Muography »**

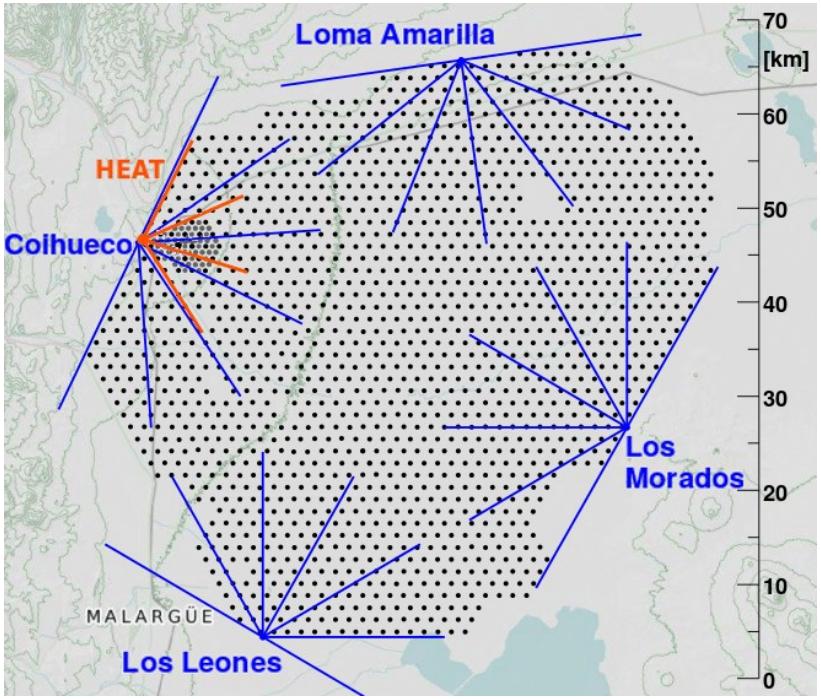
Air Shower detection with radio

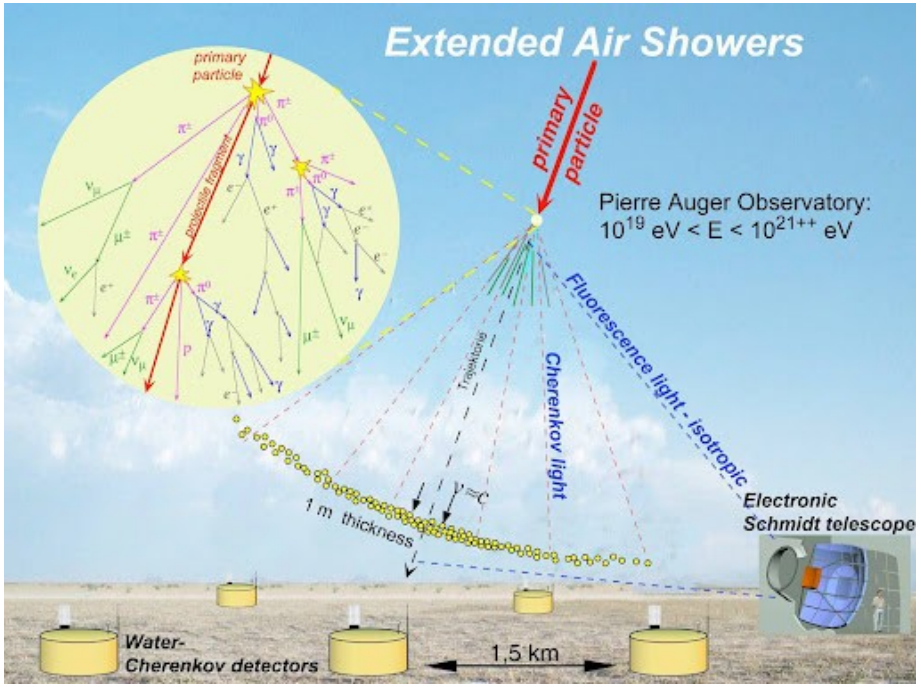




- Radios antennas are **cheap**, **giant arrays** are less expensive
- Detection of air shower for **E > 10^{17} eV**
- Well adapted for **inclined showers**, radio not attenuated by atmosphere
- Use mountains as target to convert **neutrinos tau → tau → air shower**
- **Cf Simon Chiche presentation « Radio Morphing: Towards a fast computation of air-shower radio signals »**

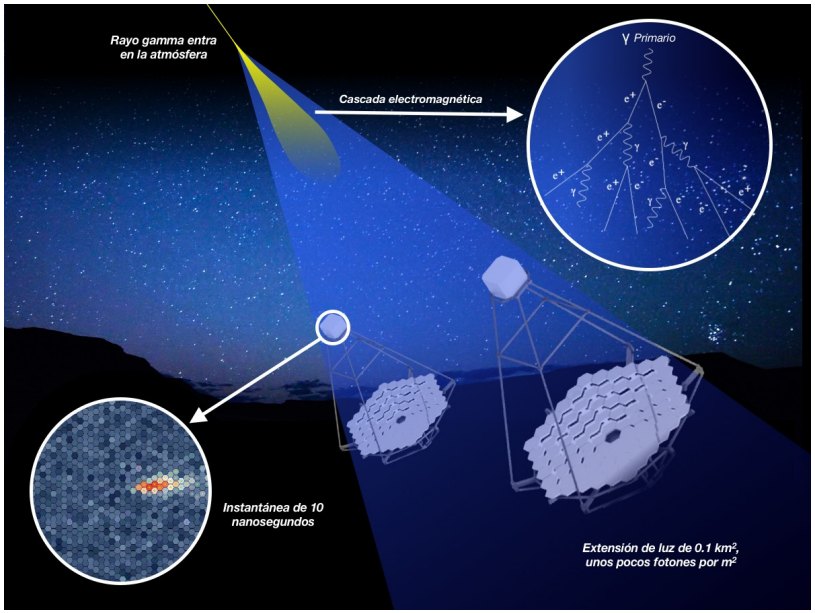
Ultra High Energy Cosmic Ray

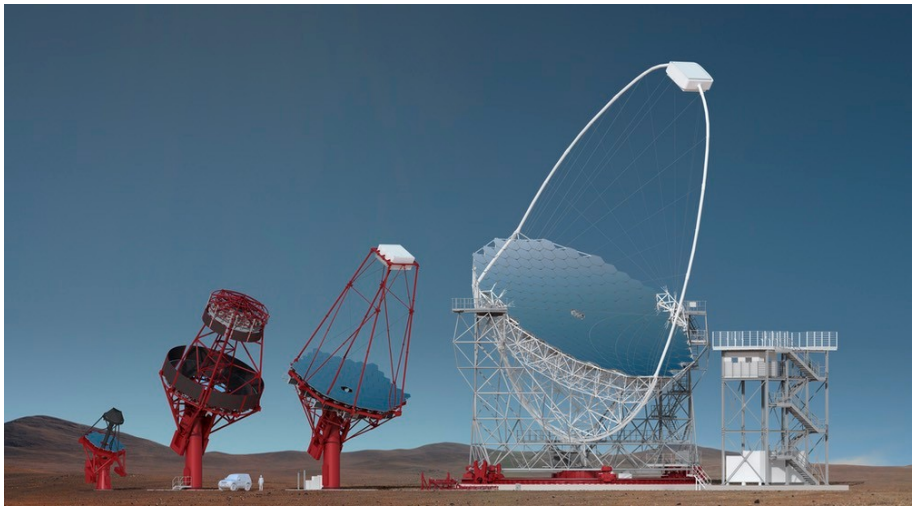




- **AUGER : Very vast array** of **water Cherenkov detector**, coupled with **fluorescence light detector**
- **E > 10^{19} eV**, very **rare** event → need a big surface
- UHECR → not affected by galactic and extra-galactic magnetic fields → **cross correlation with sources** can help for understanding of their **origin**
- **Extra galactic origin** favored so far (Active Galactic Nuclei, Starburst Galaxies, Gamma Ray Burst)
- **Contribution by Sullivan Marafico «Study of the origins of ultra high energy cosmic rays »**

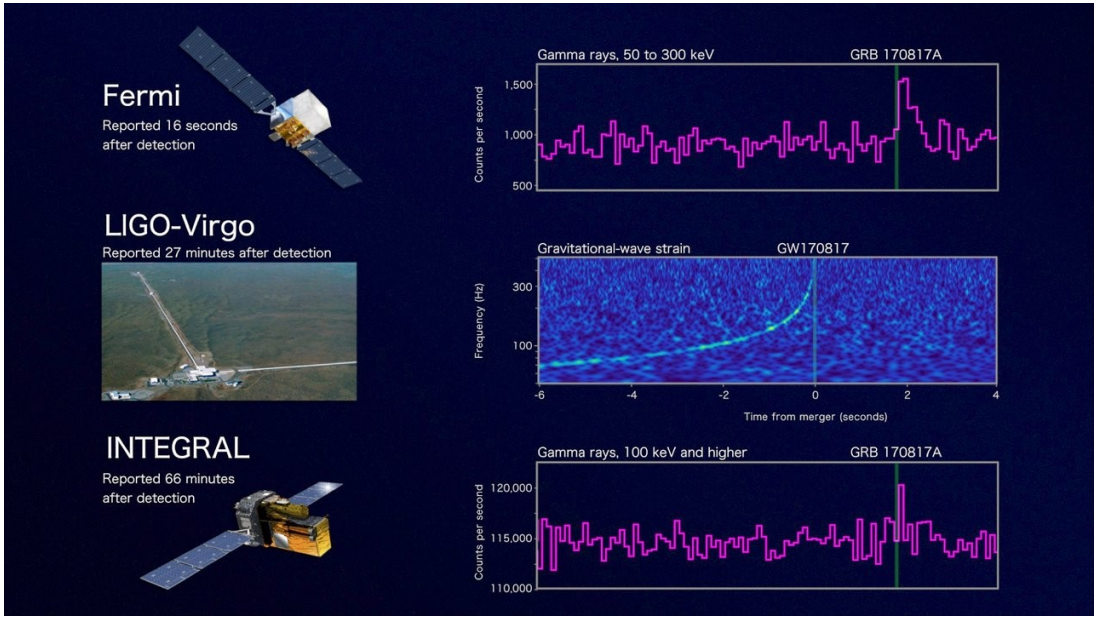
Gamma Ray Bursts

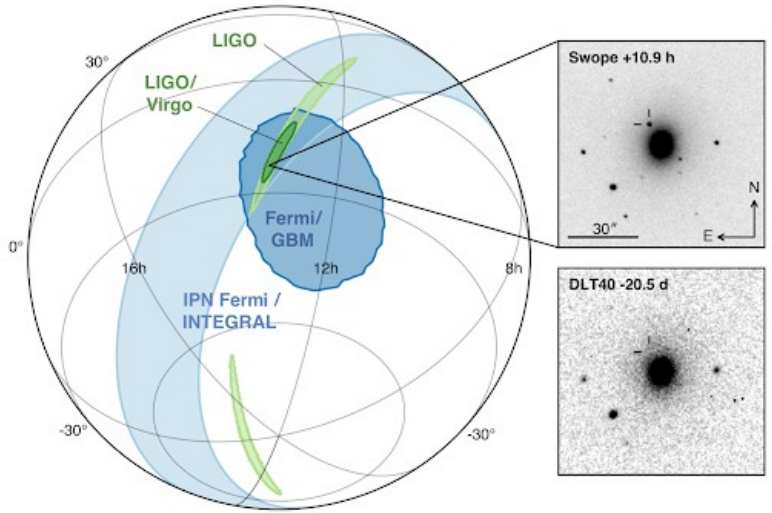




- **Cherenkov Telescope Array** : Vast array of Cherenkov Imaging Telescope – first phase :
  - North site : **La Palma** (4 LSTs + 9 MSTs)
  - South site : **Paranal Chile** (14 MSTs + 37 SSTs)
- **LST prototype** installed @ La Palma
- **Gamma Ray Bursts** are extreme and very energetic transients events, plausible producer of UHECR
- **Most distant sources observable** can be used for many fundamental topics (EBL measurement, Lorentz Invariance Violation)
- Very **challenging** observation for IACTs because of the **FoV (~5° for LST)**
- Need **external alert** by extended FoV experiments (Fermi GBM, SWIFT, Ligo/Virgo)
- **Cf Mathieu de Bony : « First observations of gamma-ray burst with the Large Sized Telescope »**

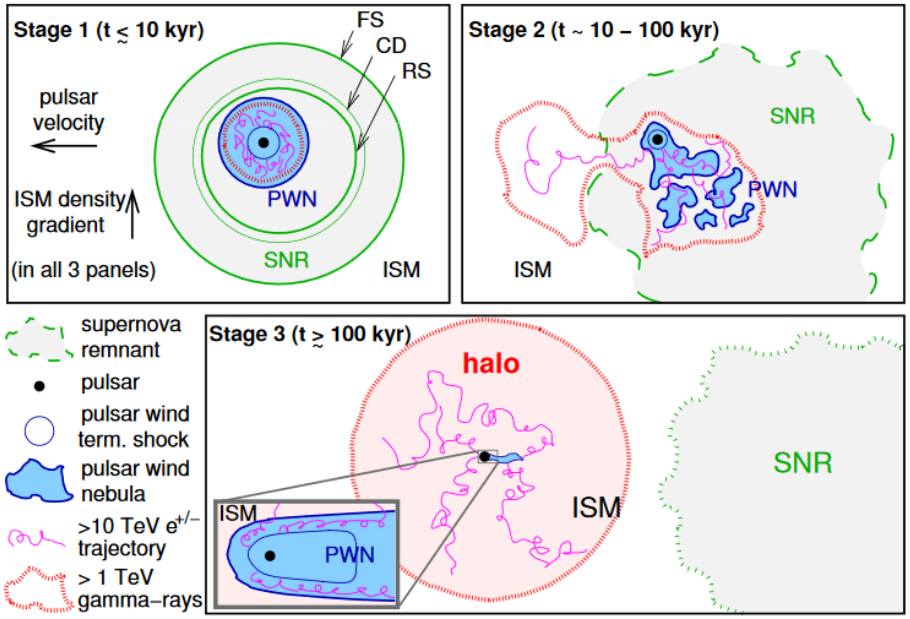
Gamma Ray Bursts

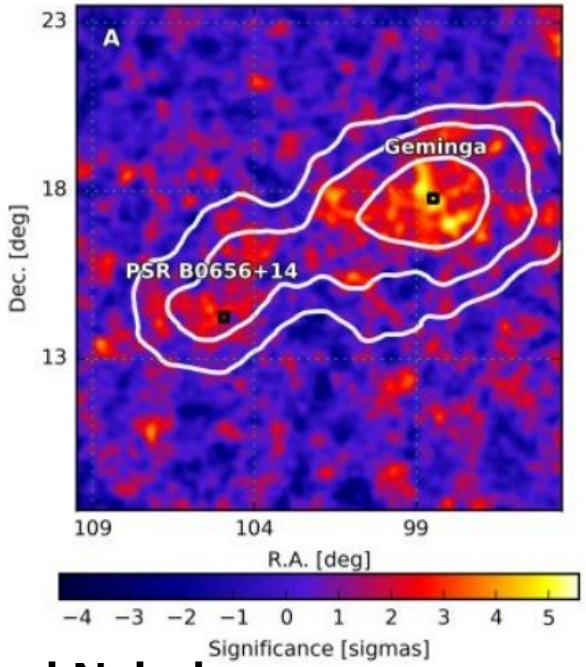




- For **short GRBs**, trusted to be caused by **neutron star merger**…
- ...that are able to produce observable Gravitationnal Wave observable by LIGO/VIRGO
- First **multi messenger Electromagnetic and Gravitationnal Wave** observation : GW 170817 and GRB 170817A !
- Since then, multimessenger association of GW and GRB is a **key topic**
- GW can provide merger information a bit before the electromagnetic counterpart
- **Cf Matteo Pracchia : « A joint GW–GRB Bayesian study for low-luminosity short GRB population »**

TeV halos





- **TeV halos** → last stage of evolution of **Pulsar Wind Nebula**
- **Leptonic particles** produced by pulsar supposed to diffuse in the pulsar vicinity
  - Perfect **laboratory for the understanding of charged particle diffusion**
  - Many questions asked by Geminga HAWC observations → **particle diffusion speed is 100 time less than expected**
  - **Geminga** is trusted to be the main candidate for **positron excess** offenly interpreted as **Dark Matter signal**
- Difficult to observe them with CTA → **extent of source ~ FoV size**
- **Pauline Chambery : « In search of TeV halos, new astrophysical objects to reveal our gamma sky map »**

Conclusion

- Astroparticle is a **very rich and diverse field**, difficult to summarize…
- **6 contributions with 5 different types of instruments !**
- Main idea is to **use the universe as a laboratory**, provide free accelerator of particles, probes for very **various topics**:
  - **Astrophysics**
  - **New physics**
  - **Cosmology**
  - **Galactic physics**
  - **Geology**
  - **Archeology**
  - ...
- Contributions reflect well the **diversity of the field**