Laboratoire d'Annecy-le-Vieux de Physique des Particules

# Astroparticle Session

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26/10/2023

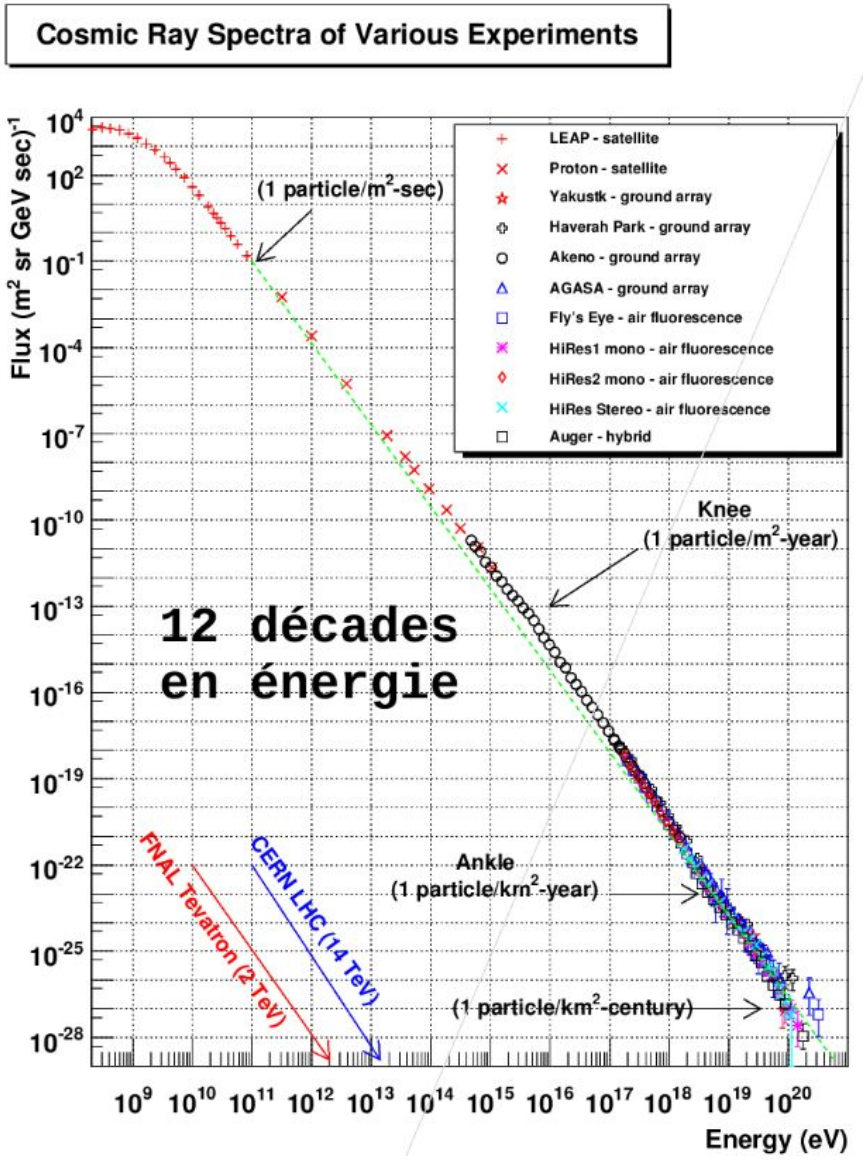
cnrs

UNIVERSITÉ SAVOIE MONT BLANC

# Astroparticle ?

- Started with the first detection of radiation coming from sky in 1913 by Viktor Hess, leading to the cosmic ray discovery
- First proof of a new messenger than light to understand the cosmos
- Fairly used for particle physics in the 30-50s before better controlled accelerator took over
- Vast field today, covering various experiments, type of messenger and topics (astrophysics, cosmology, particle physics, geology, archeology…)

# Cosmic ray characteristics

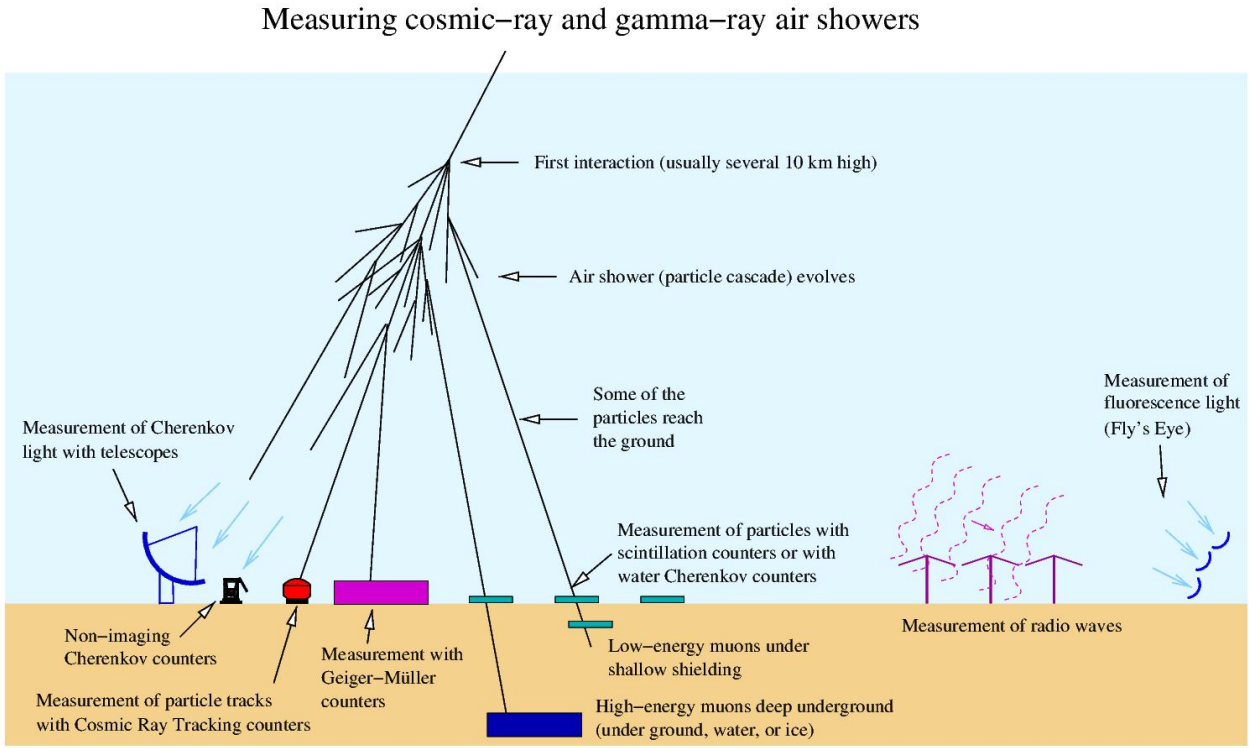



- High energetic particles coming from space
- Power law spectra :
  - Extended in 12 decades in energy
  - E < 3 PeV : index 2.7
  - 3 PeV < E < 300 PeV : index 3.1
  - 300 PeV < E < ~EeV : index 3.3
  - E > ~EeV : index 2.7
- Energy between knee and ankle trusted to be the **transition between galactic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

# 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)



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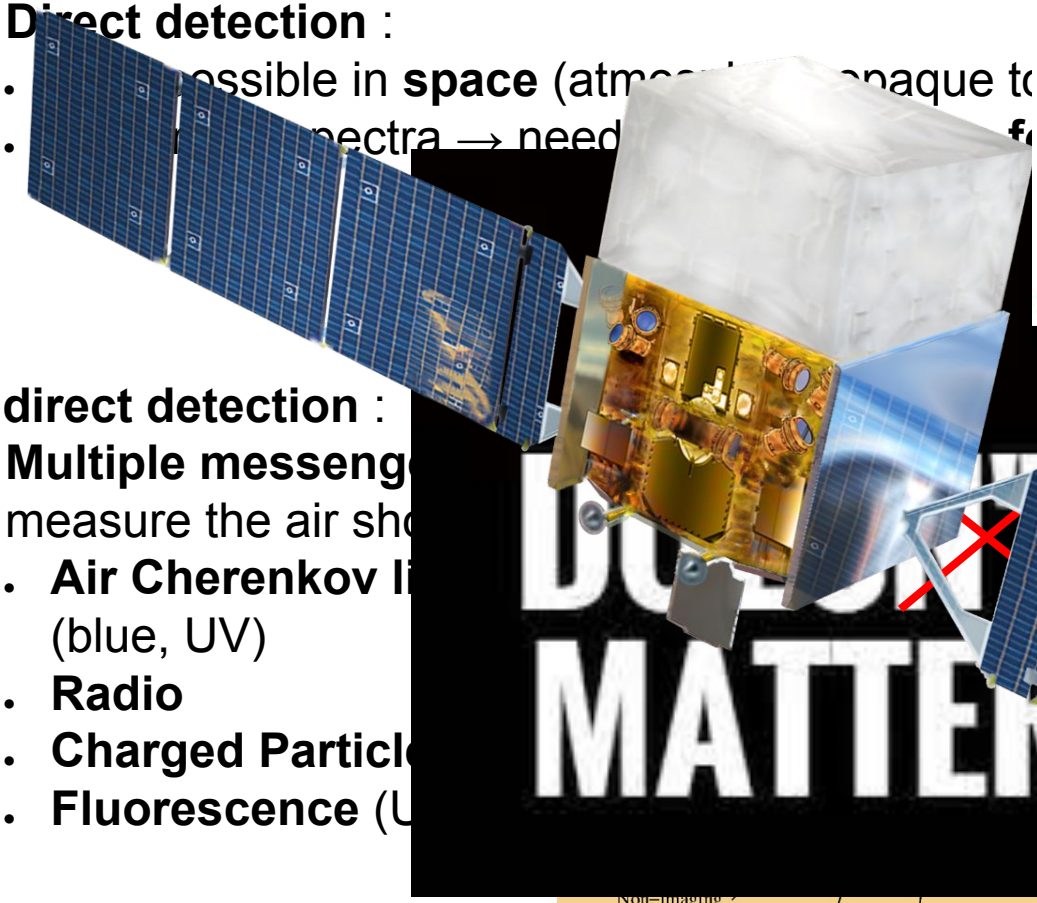




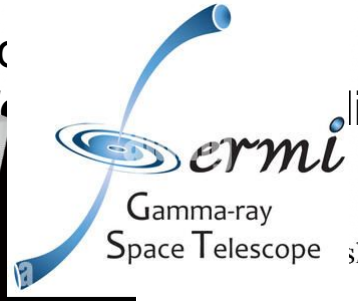


showers

20 MeV - 300 GeV

# Detection methods

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  - os
  -

- **Indirect dete**
  - **Multiple m**
    measure th
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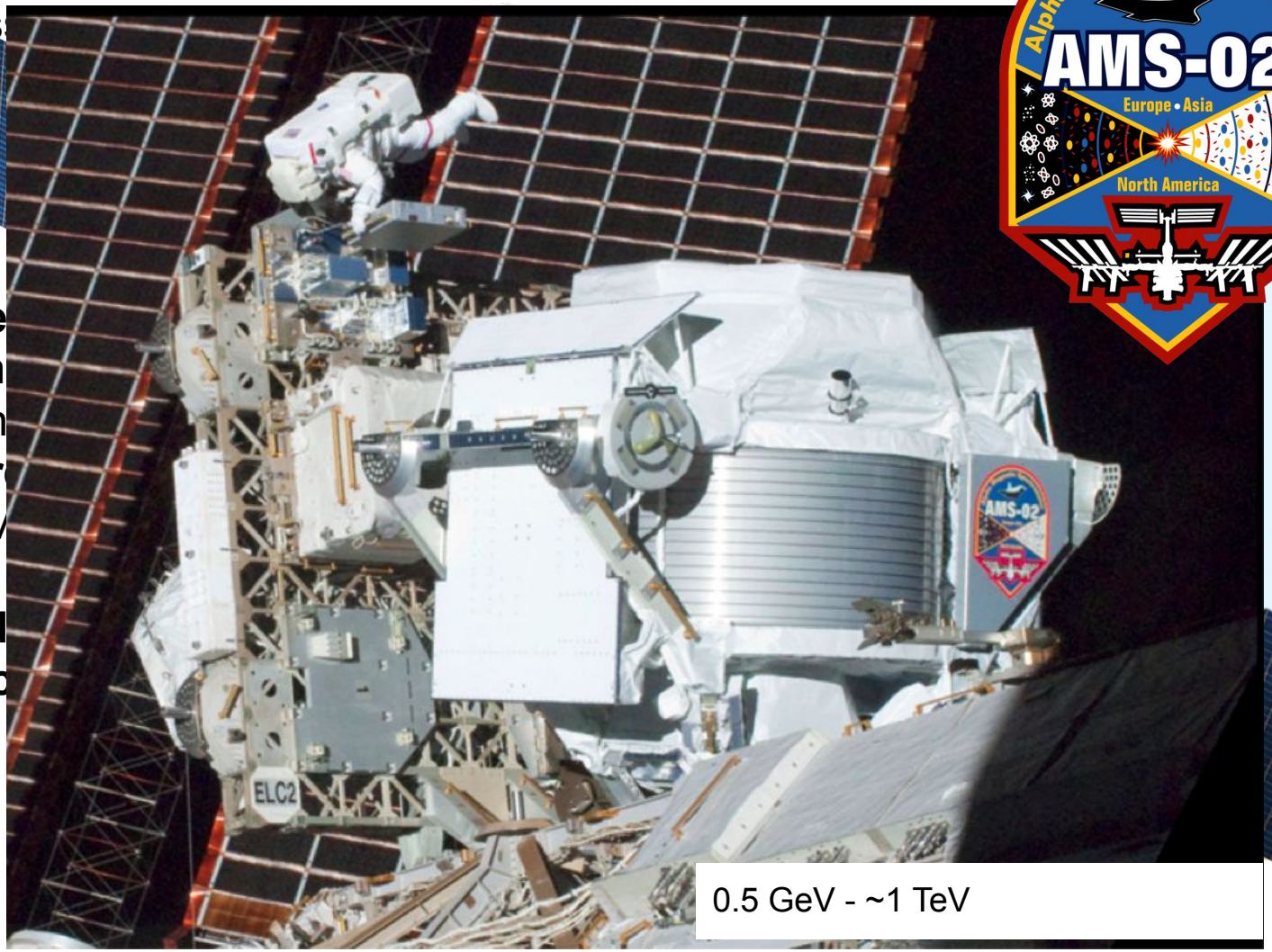
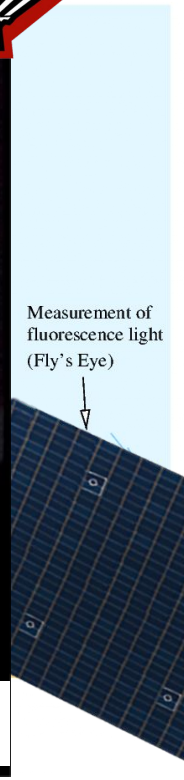
      (blue, UV
    - **Radio**
    - **Charged**
    - **Fluoresc**




0.5 GeV - ~1 TeV



# Detection methods

- **Direct detection** :
  -
- 
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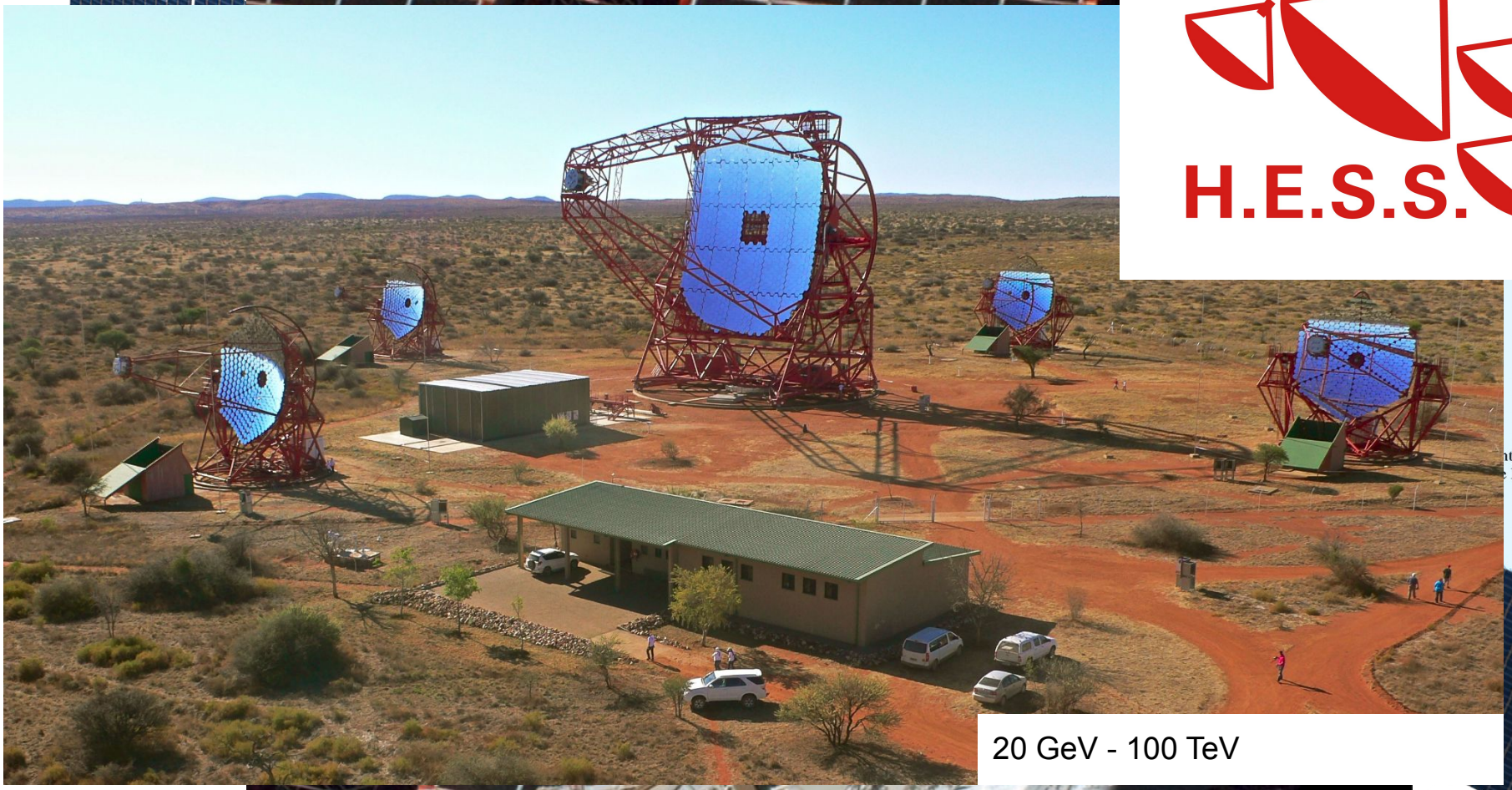

20 GeV - 100 TeV

# Detection methods

- **Direct detection** :
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# Detection methods

- **Direct detection** :
  - [illegible]os
- [illegible]
- [illegible]

PREFOU

**P**latform for **R**esearch on **E**missions of **F**ermions **O**riginating from the **U**niverse

# Detection methods

- **Direct detection** :
  - os
- 
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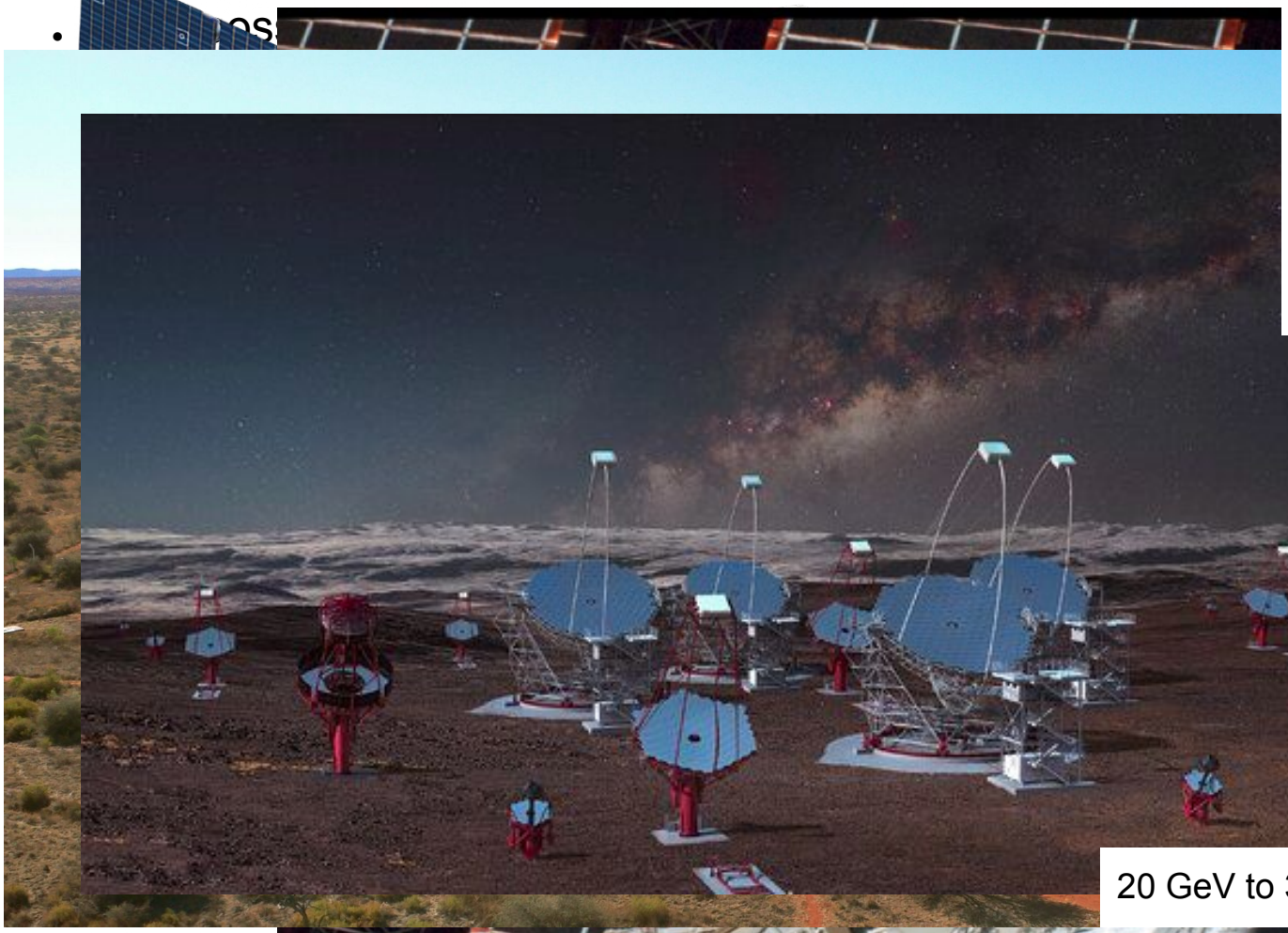

cherenkov telescope array

20 GeV to 300 TeV

# Detection methods

- Direc
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LHAASO
高海拔宇宙线观测站

300 GeV - 1 PeV

# Detection methods

- Di
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-
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# Detection methods

- Direc
  -
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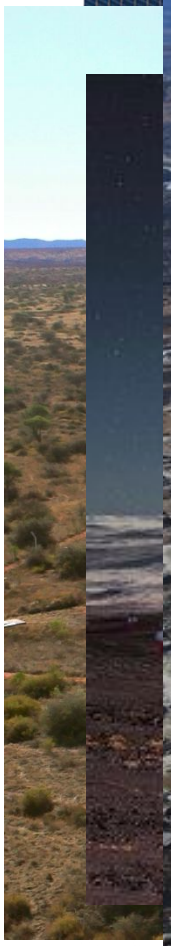
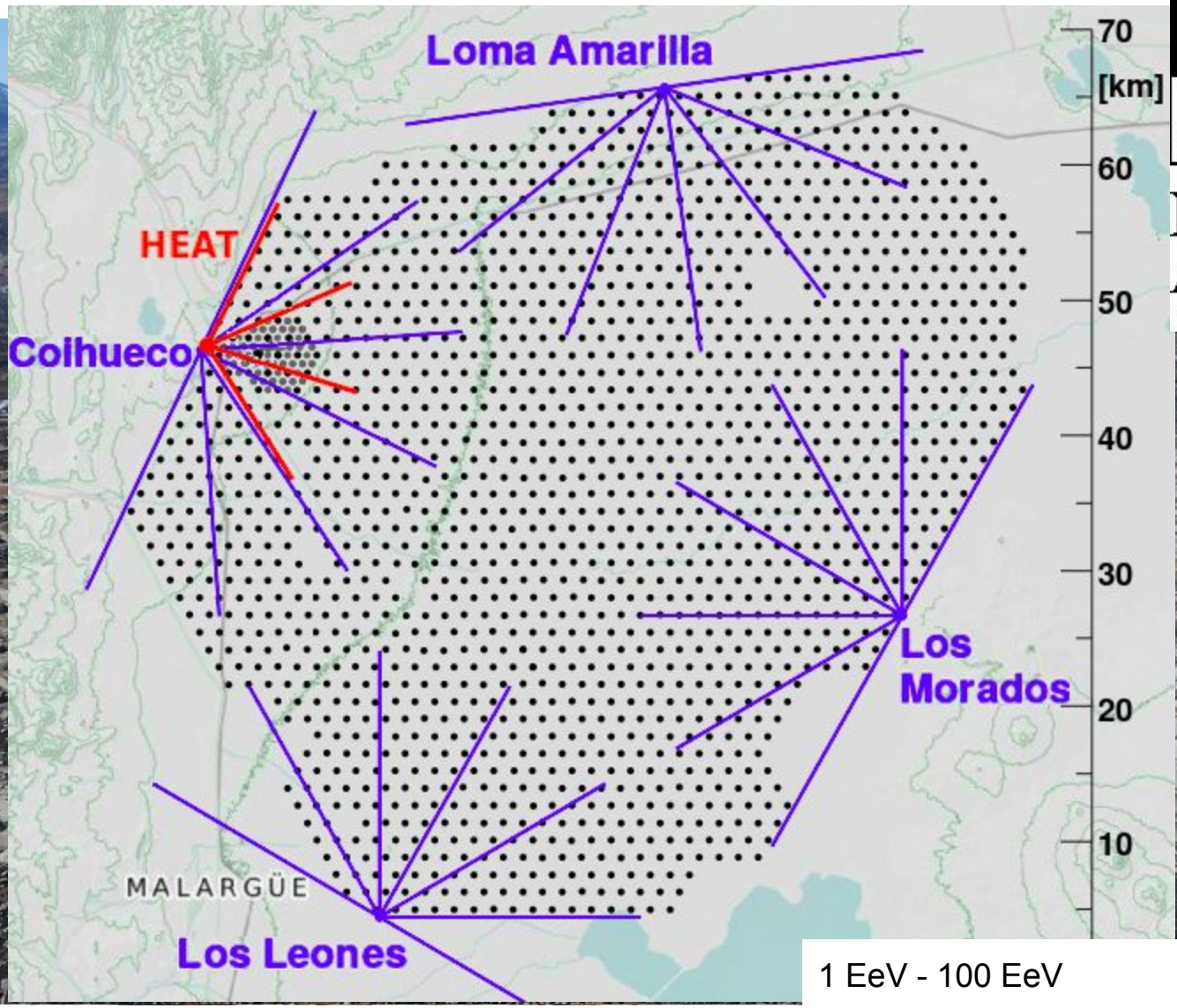
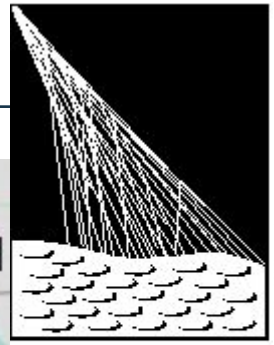
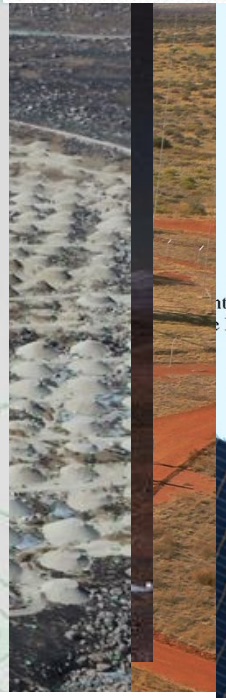
-





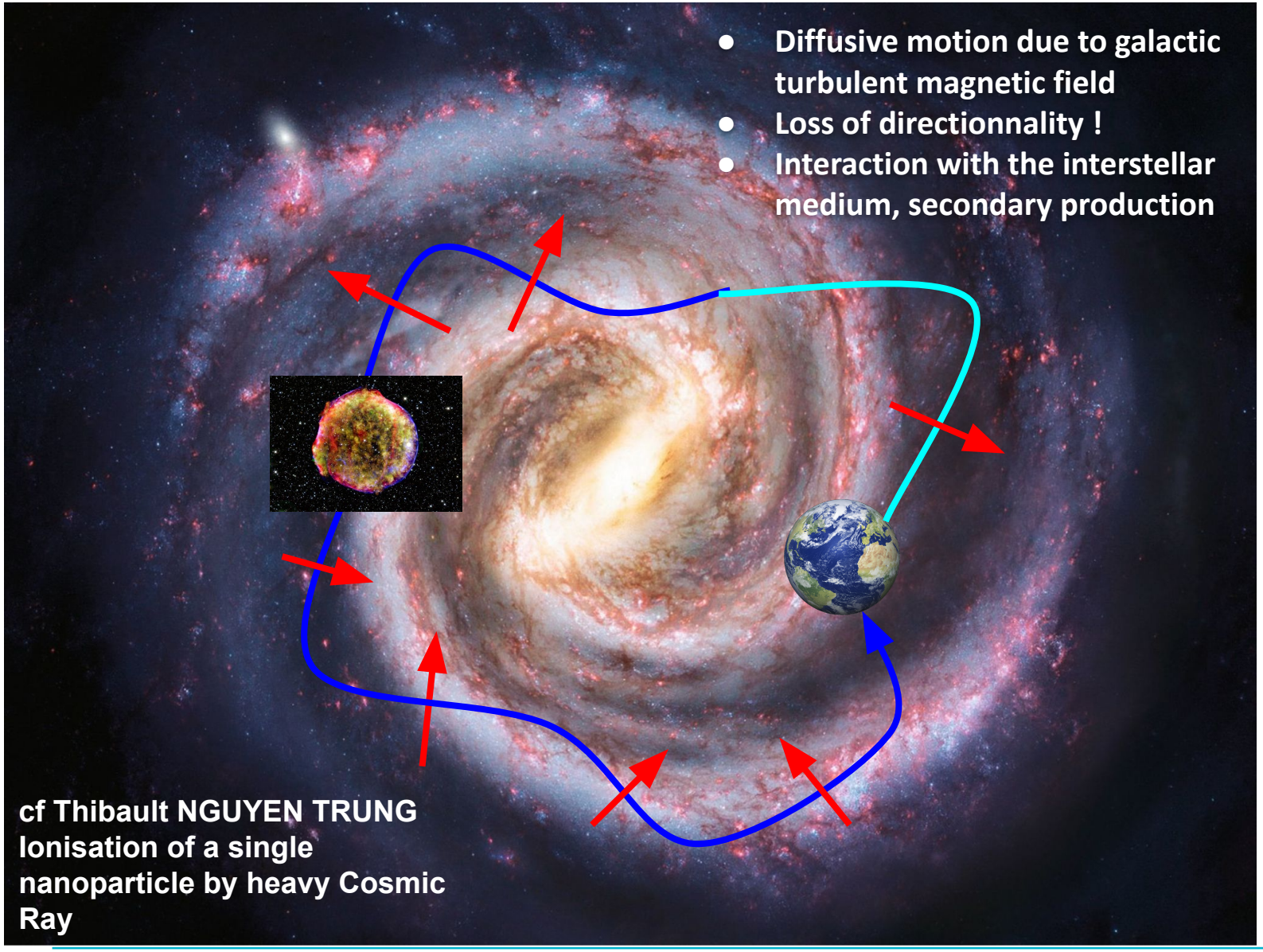



PIERRE AUGER OBSERVATORY

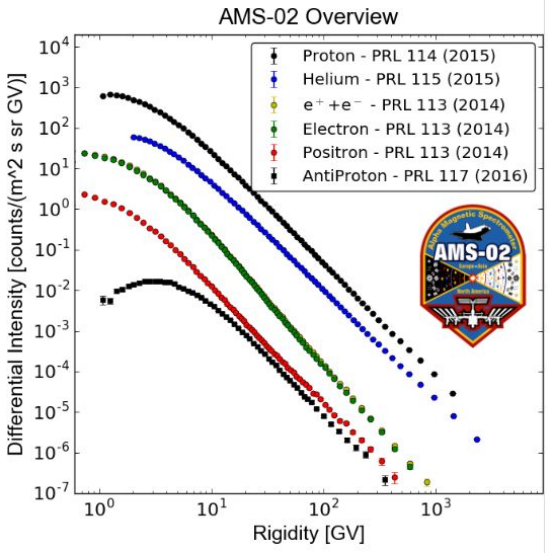


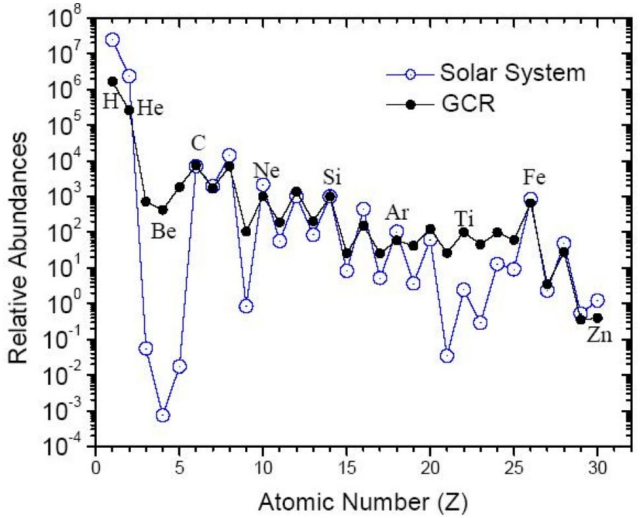
1 EeV - 100 EeV

# Cosmic messengers - charged cosmic rays



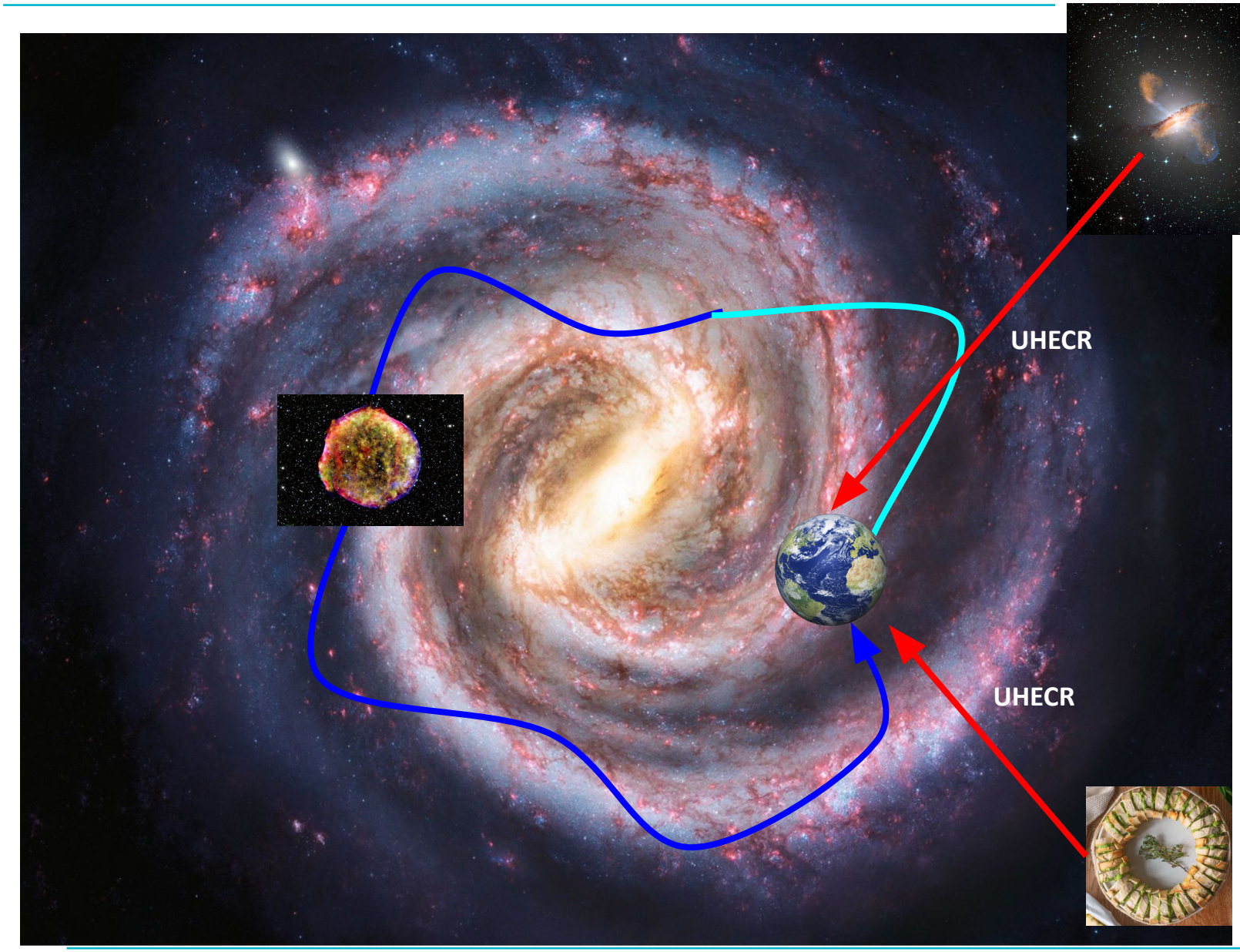
# Galactic cosmic rays characteristics




- 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**
- 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

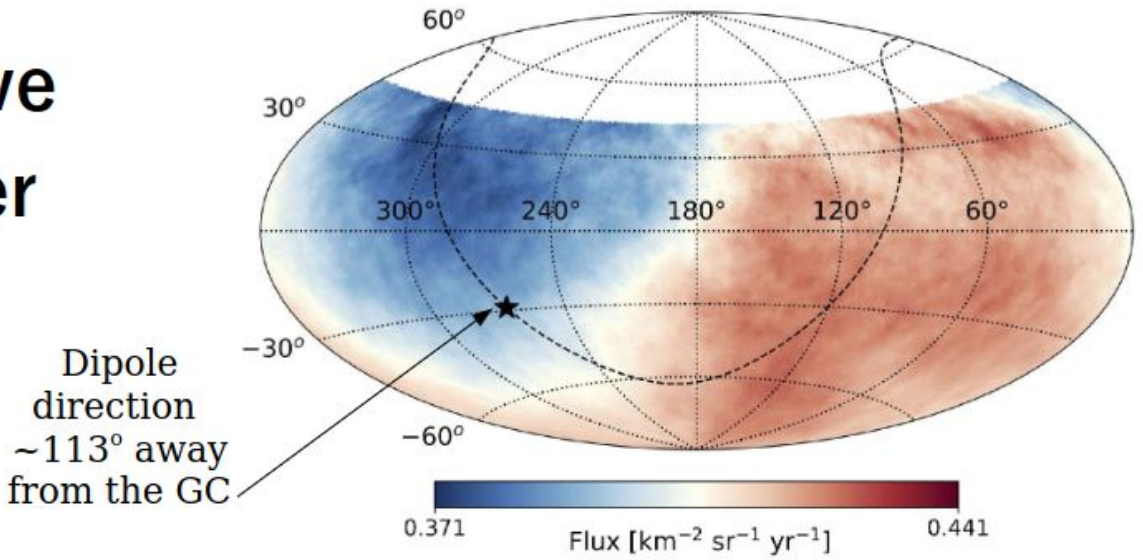
# UHECR Cosmic rays ?



# UHECR dipole

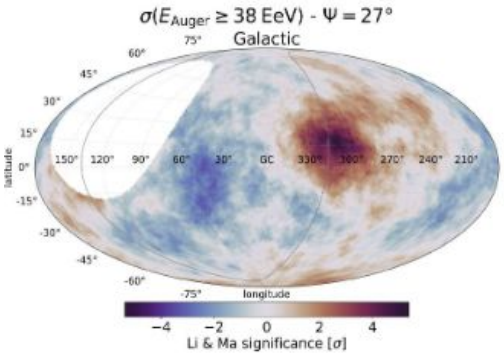
**6.9 σ dipole above 8 EeV with Auger**

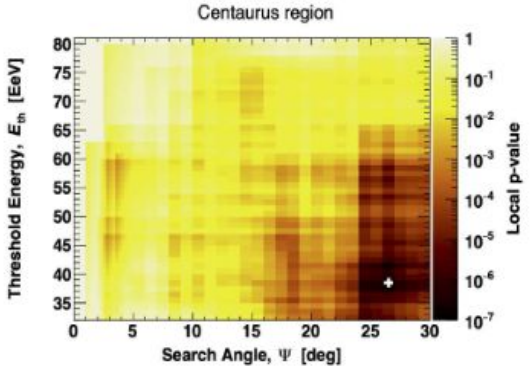
**G. Golup 252**



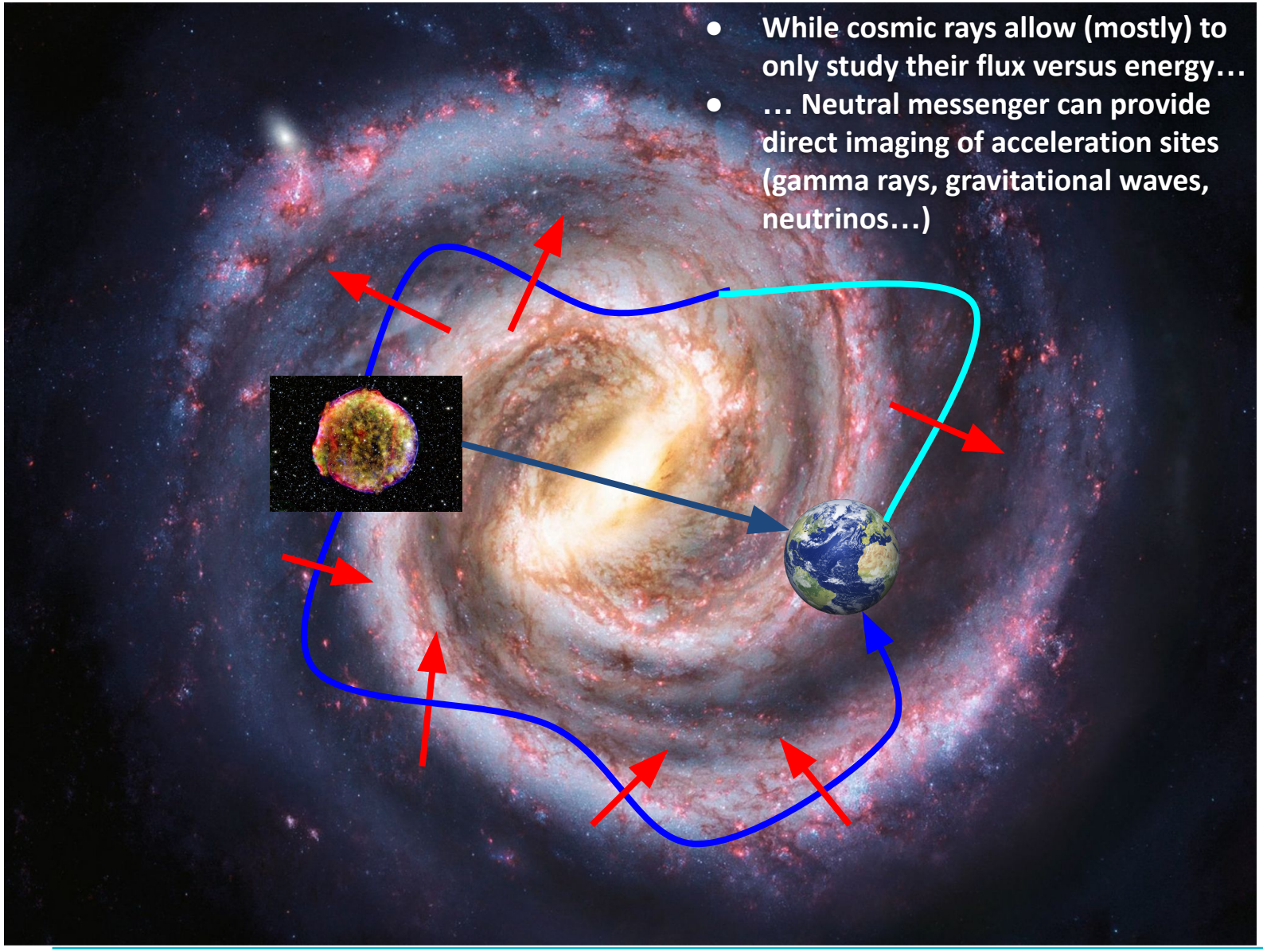

Equatorial coordinates, smoothed by a top-hat window of 45°.

**4.0 σ excess from Cen A** **G.**

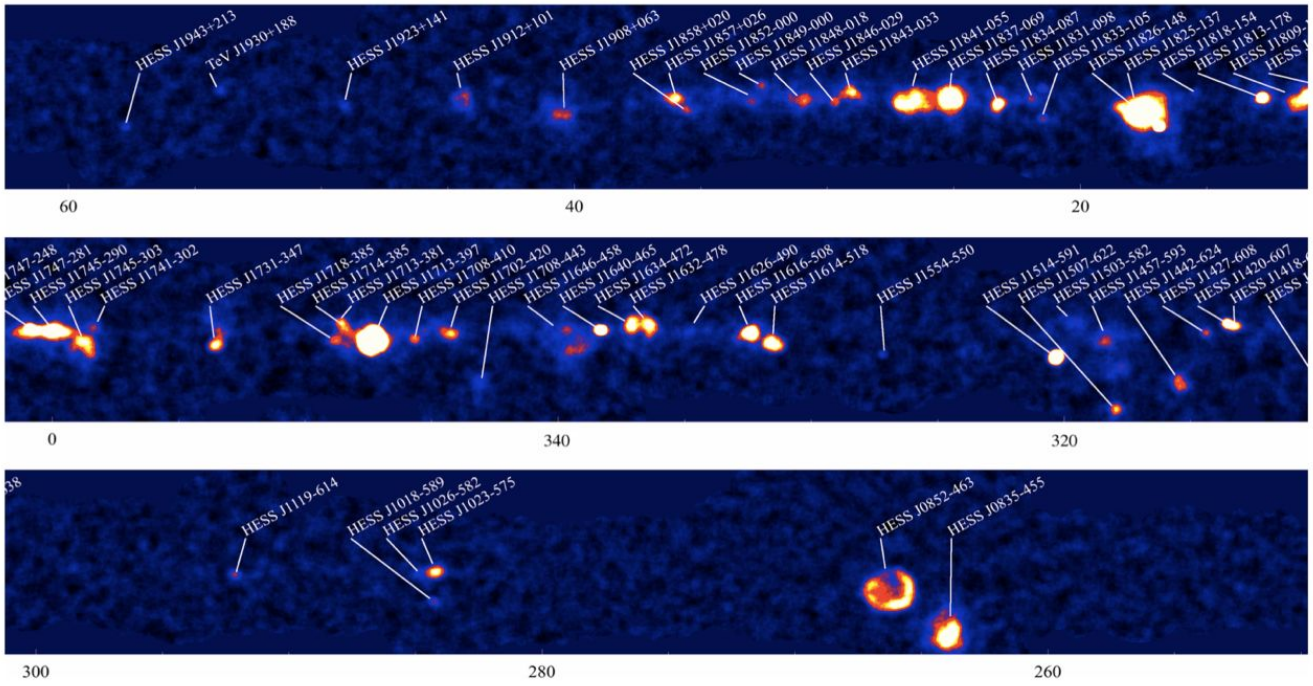


# Cosmic neutral messengers



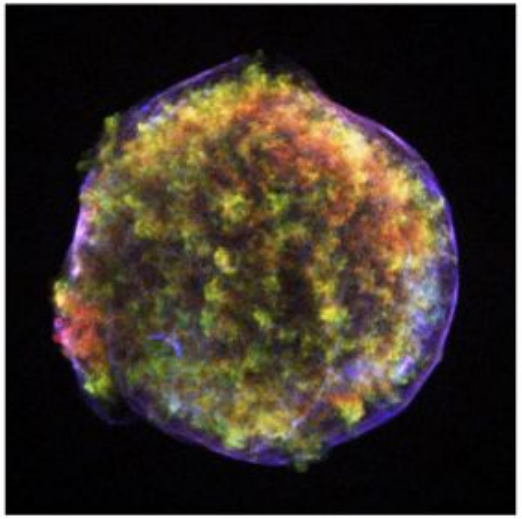
# Neutral messenger : Gamma rays




- 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**

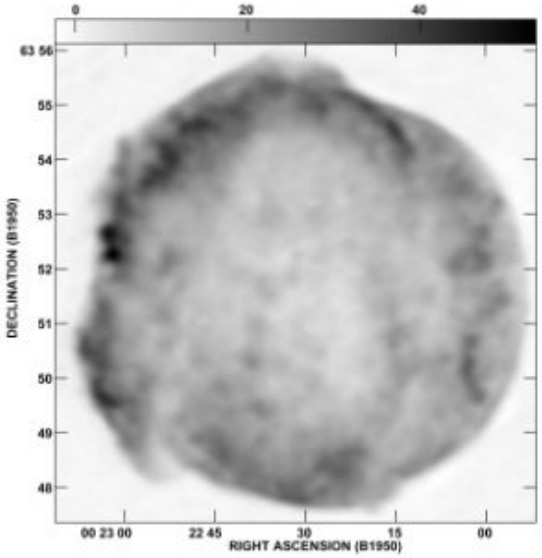
# Supernova remnants as main CR accelerator

Infrared, optical, X rays

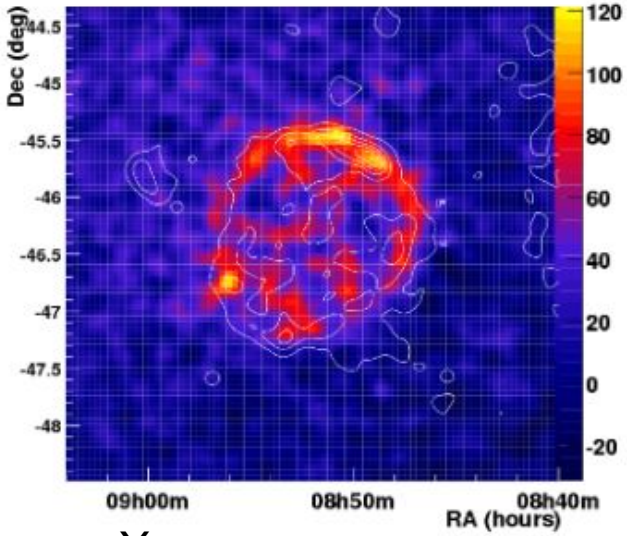


Tycho Brahe SNR

Radio




- 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** ?

Cf Marie-Sophie talk, Study of the PeVatron candidate SNR G106.3+2.7 observed at Large Zenith Angle with LST-1 and MAGIC

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Infrared, optical, X rays

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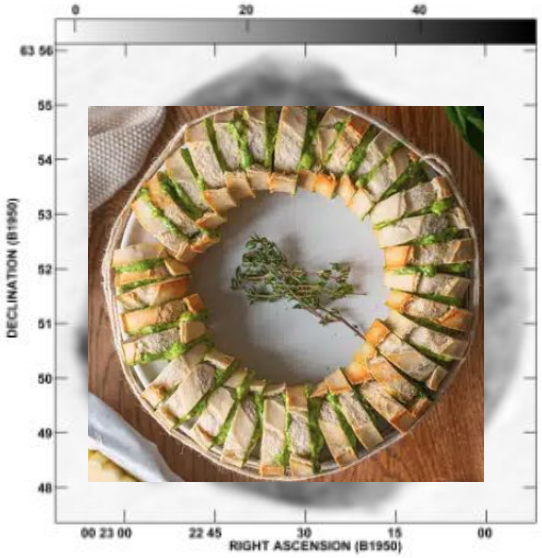


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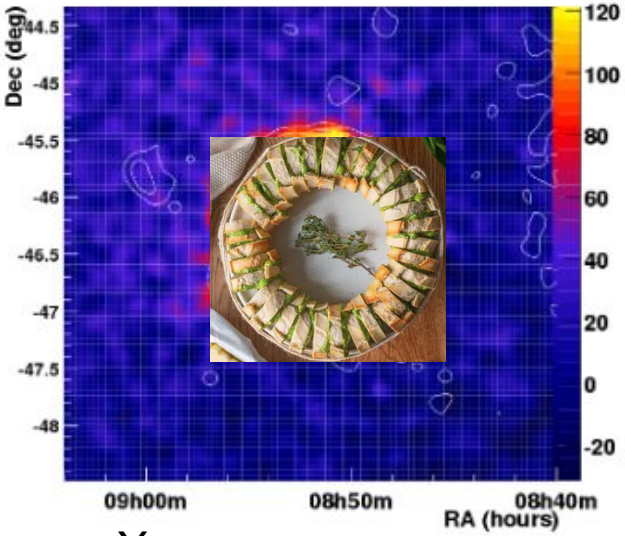


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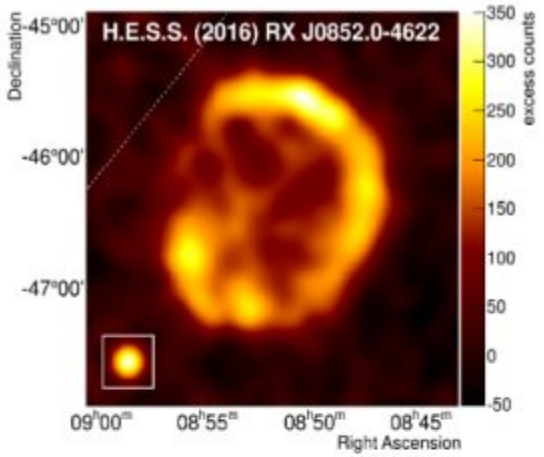


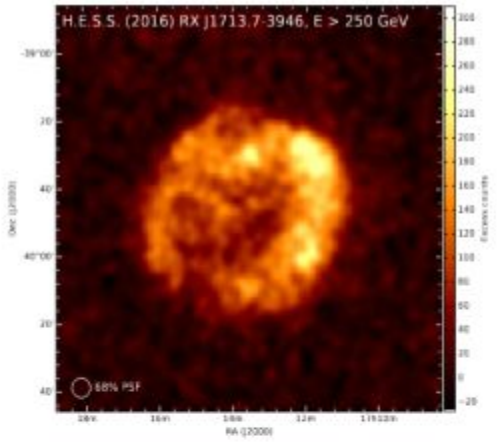


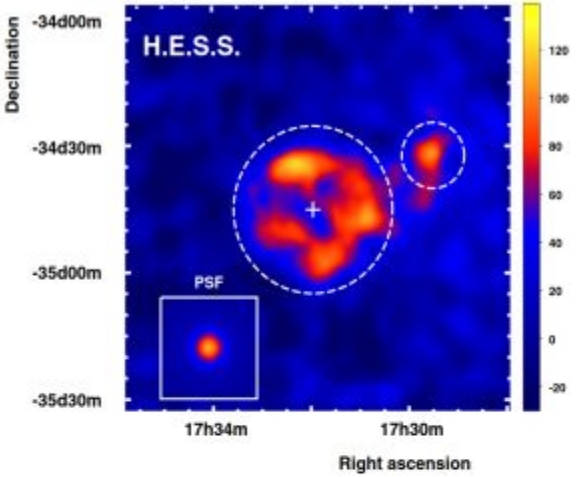


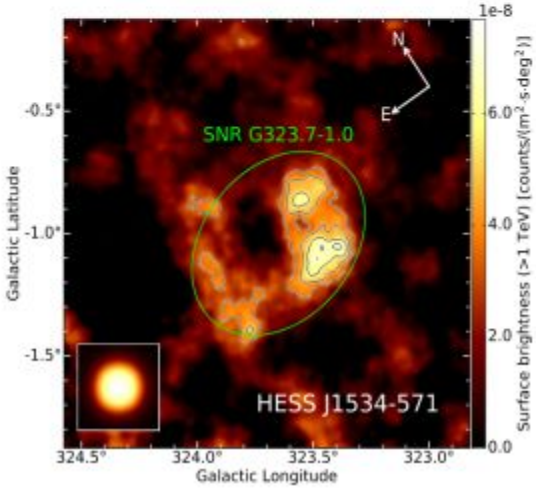


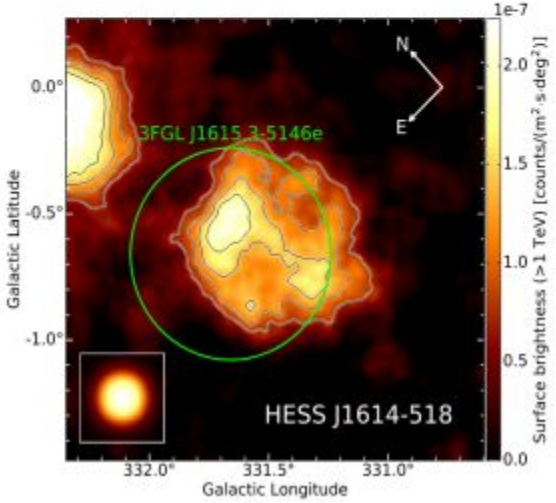


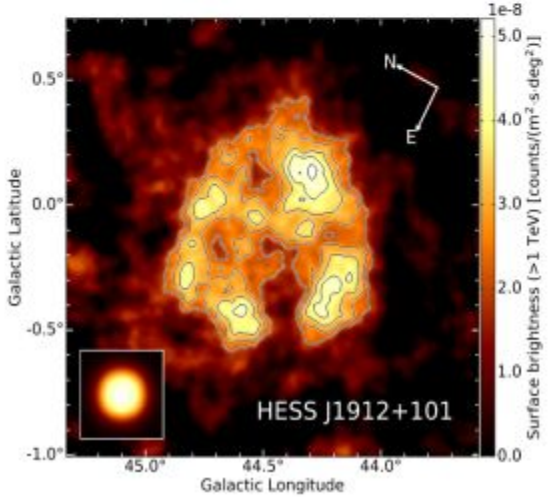

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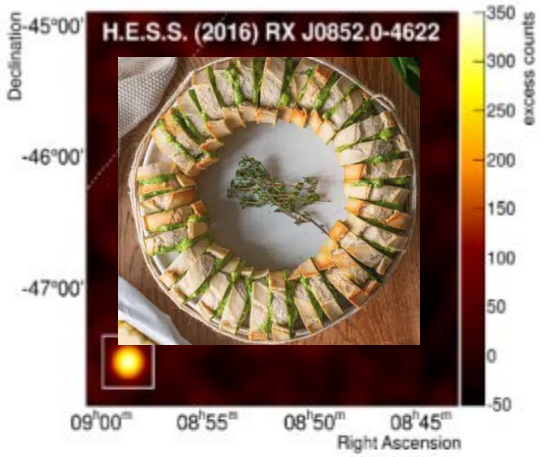
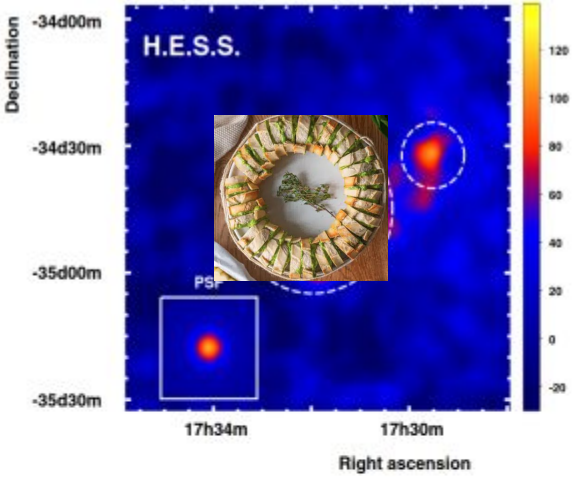
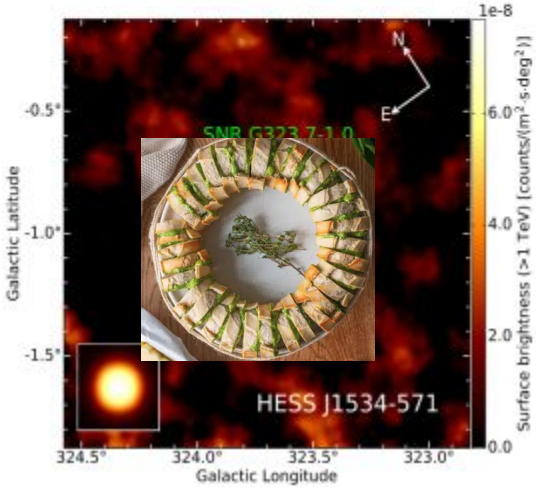
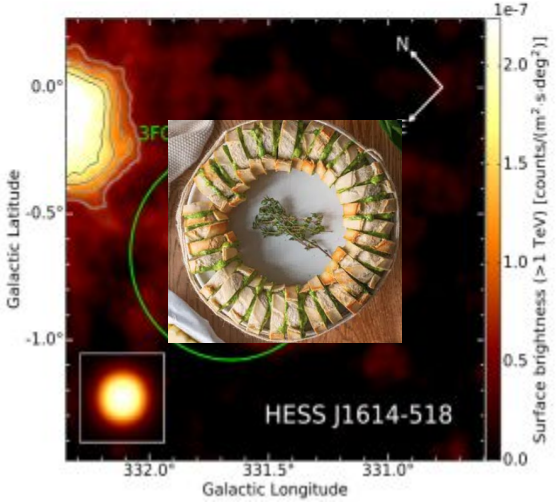
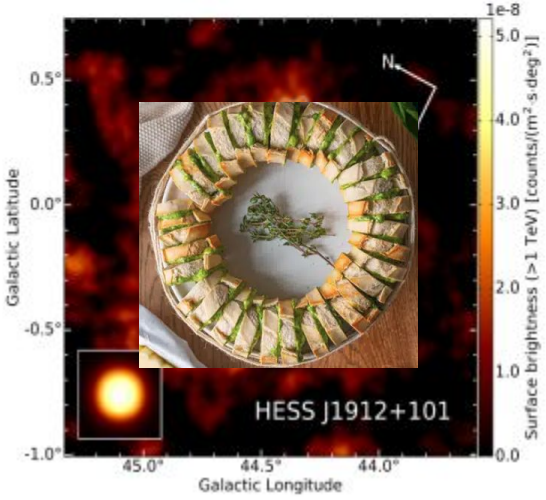




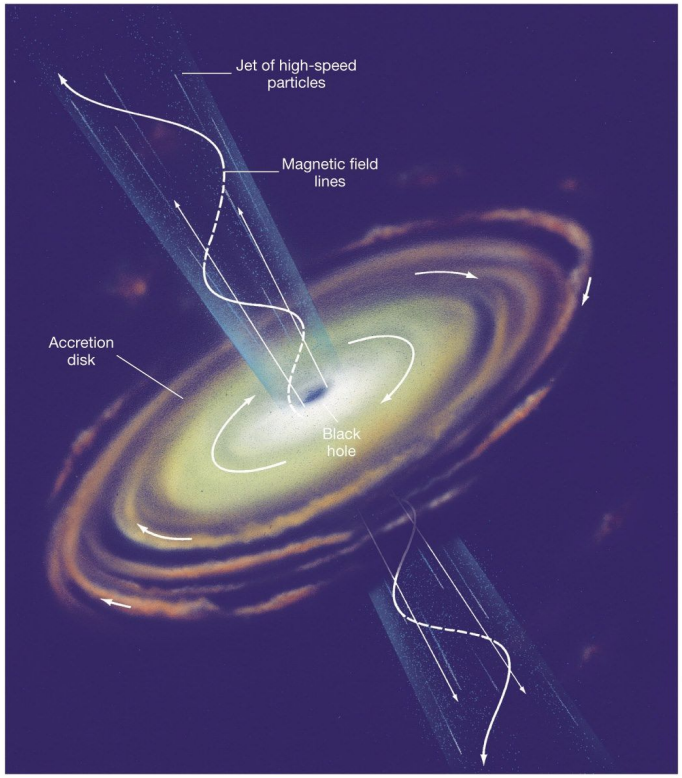


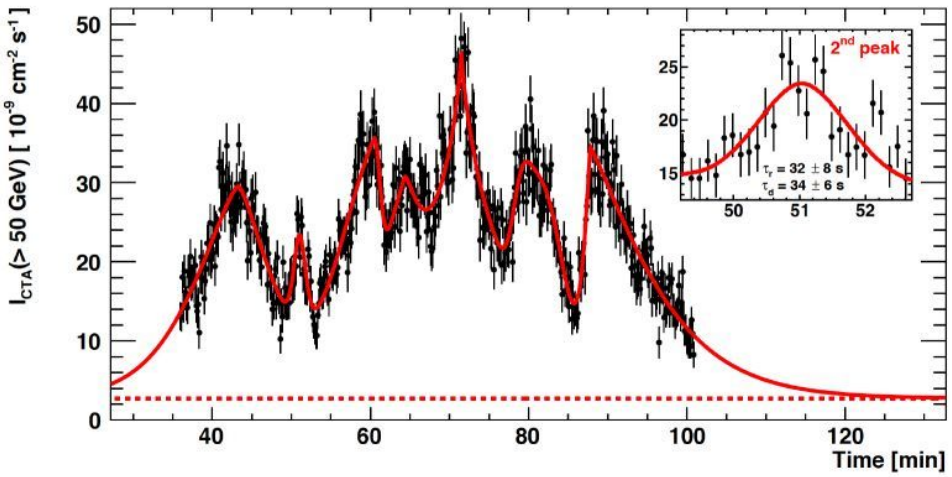



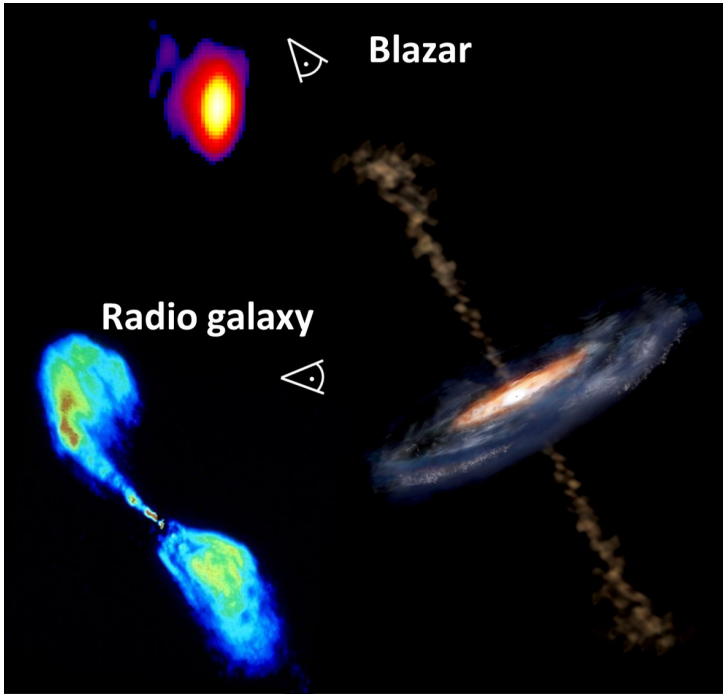
# Active Galactic Nuclei - Blazars



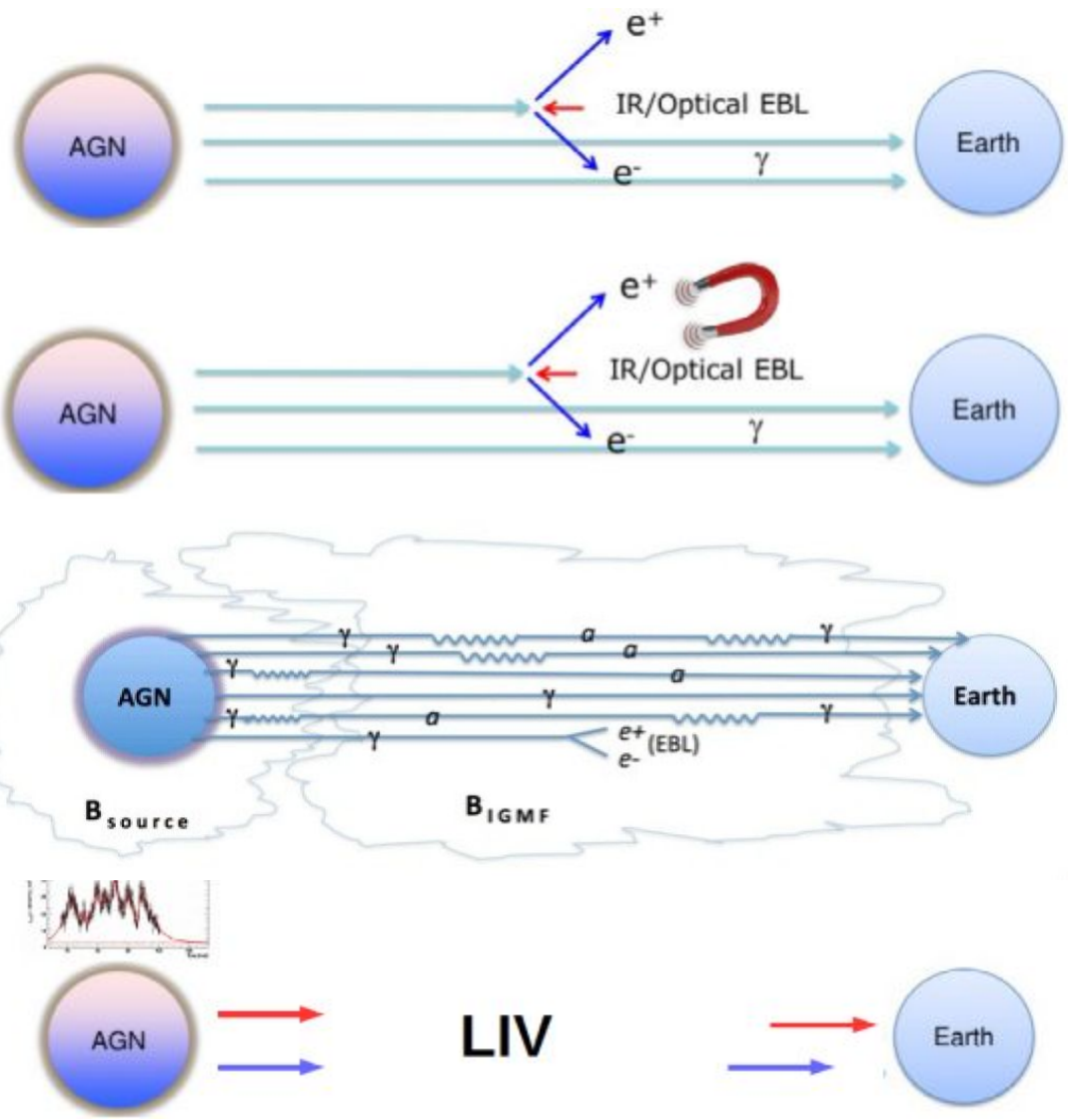




- Accreting matter in a central black hole, ionised rotating matter creating a rotating magnetic field
- Ultra relativistic jet of charged particles -> shock wave in the jet -> boosted emission by relativistic beaming
- Called “Blazar” in case the observer is in the jet
- Fast variability observed in the jet, due to the compactness of the acceleration region (near black hole environment)
- cf Guillaume Grolleron contribution : Investigating AGN Variability with the Cherenkov Telescope Array and nectarCAM

# Active Galactic Nuclei - Blazars



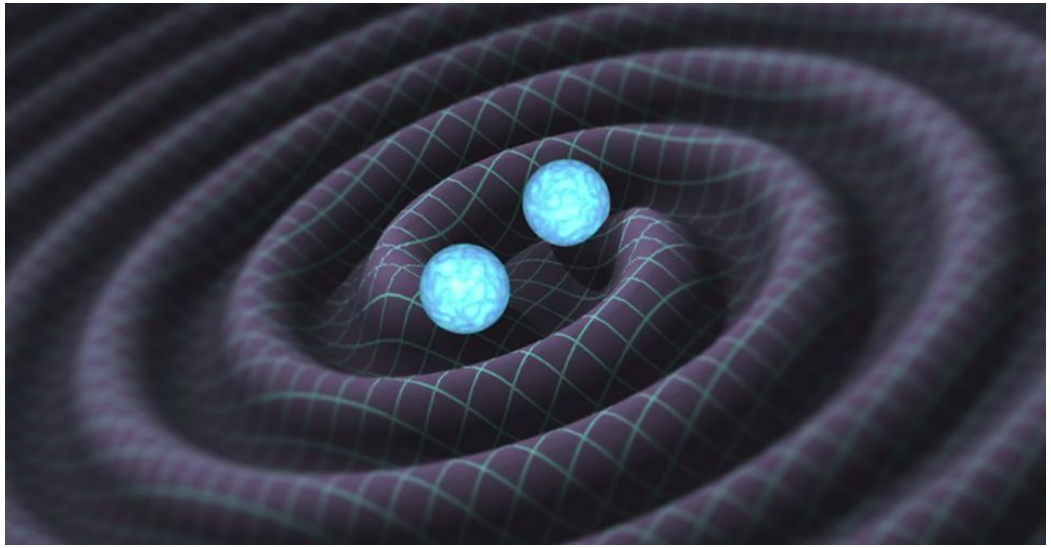

# Blazars - Propagation effects



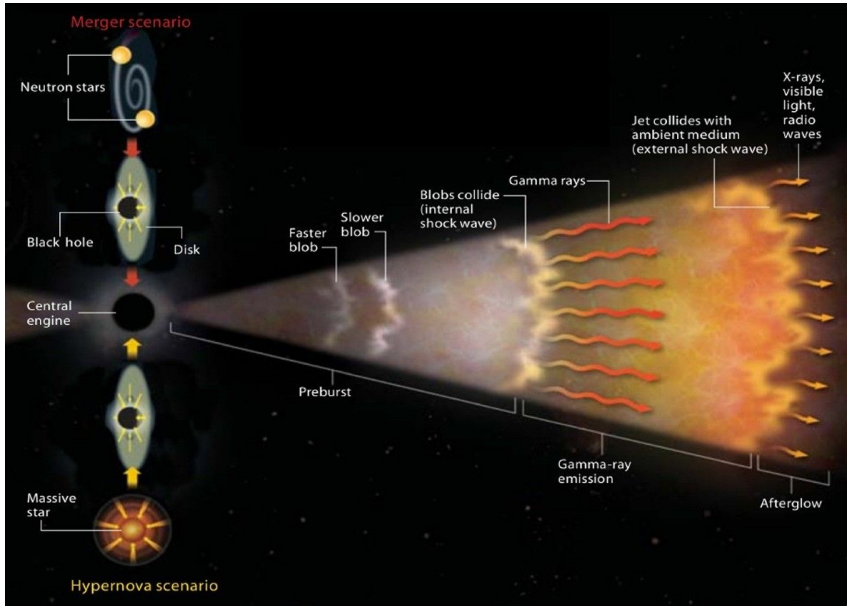

- Extragalactic Background light absorption
- Positrons or electrons can be produced and reemit gamma-rays (echo)
- intergalactic Magnetic fields can impact positrons and electrons trajectory (extended echo)
- Hypothetical oscillation between axion-like particle and gamma rays due to magnetic field (absorption)
- Lorentz Invariance Violation at Planck Scale (E~10^19GeV),, delay between high and low energy gamma rays

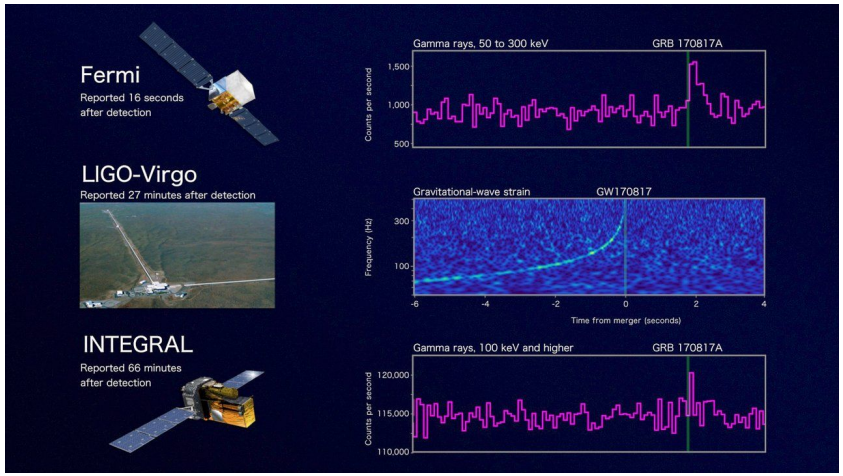
cf Cyann Plard contribution : Lorentz invariance violation search with the Cherenkov Telescope Array Observatory Large-Sized Telescope

# Gravitational waves

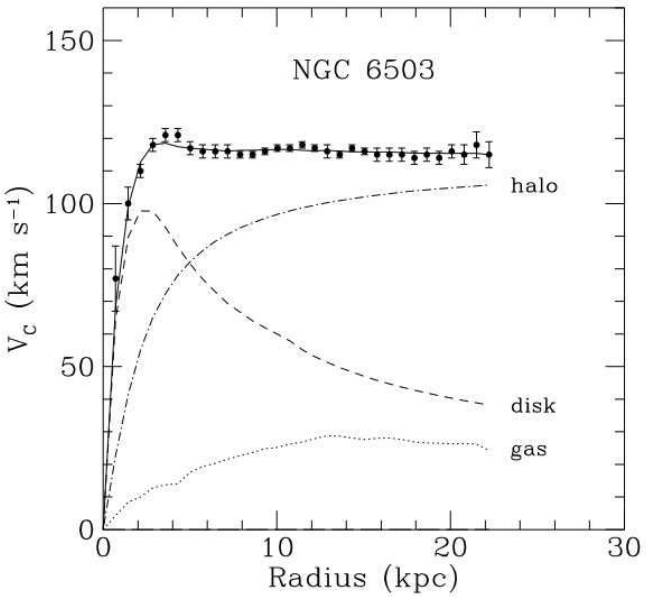


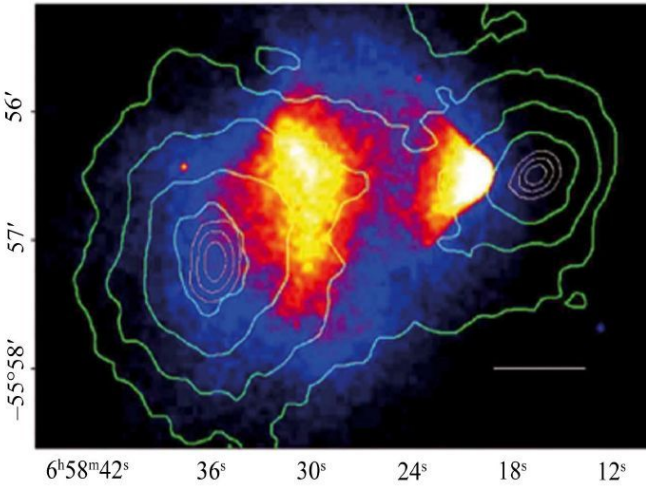
- Space time perturbation linked to the rotation of dense and asymmetric objects
- BH-BH mergers, BH-NS, NS-NS
- Similar engine than AGN, Black hole surrounded by accreting matter -> jet -> particle acceleration -> EM couterpart
- Should be associated with other messengers (neutrinos, UHECR ?), not detected so far

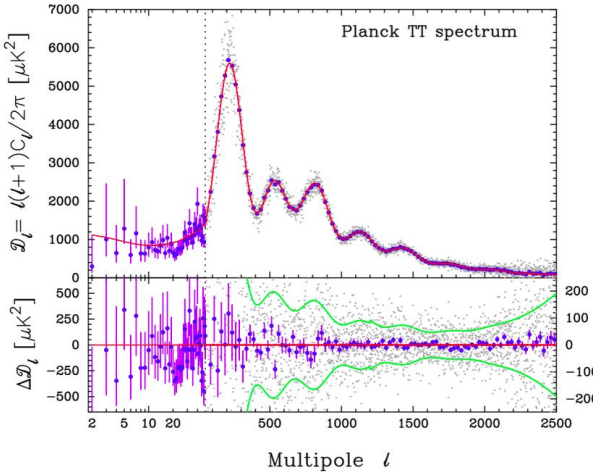


# Dark matter

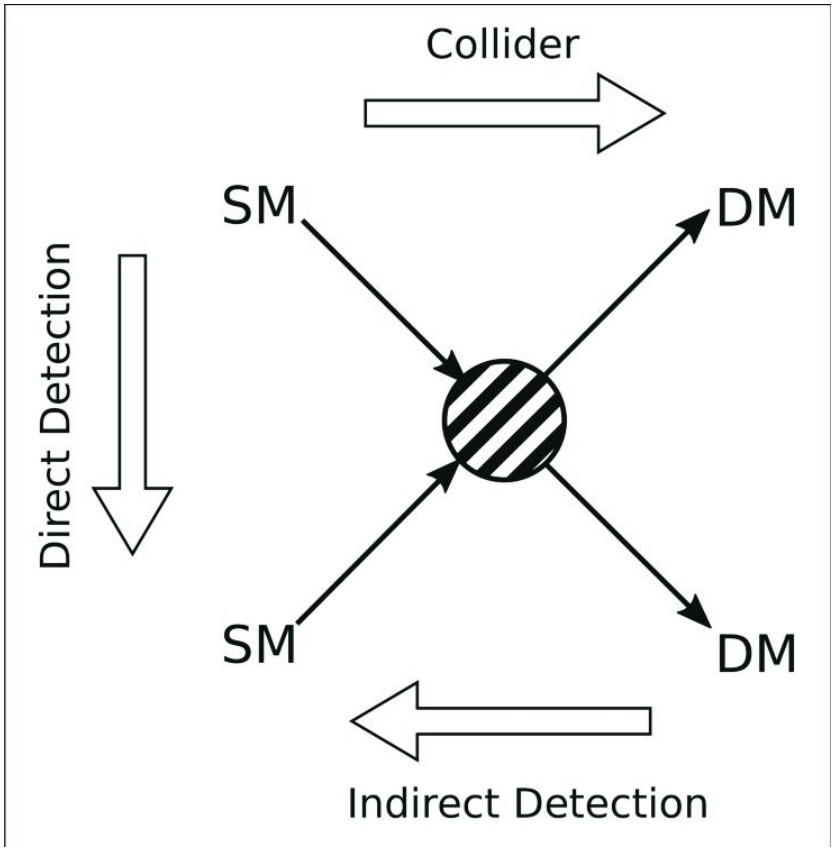


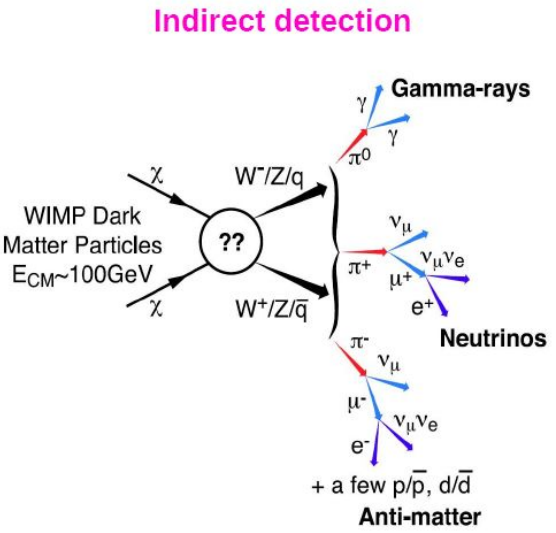




- Coherent observation of lack of visible matter at galactic, galactic cluster and cosmological scale
- No standard model candidate can explain these observations
- Leads to postulate the existence of a matter
  - Dark (feeble cross section, and no electric charge)
  - Stable (at least stable enough to remain until today)
  - Cold (at least cold enough to explain large scale structure)

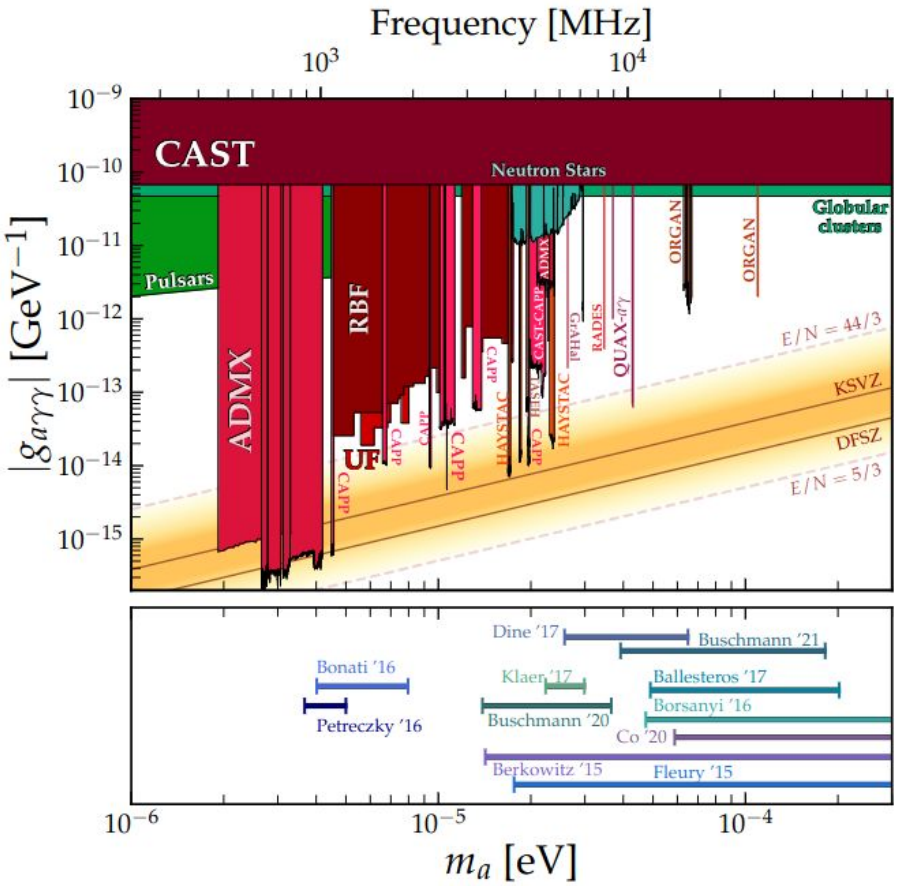
# Dark matter detection




- No clear detection yet with indirect detection so far…
- Many probes, but difficult to distinguish from standard astrophysical scenario
- Direct detection provide a more controlled way to detect those particles
- But far to be straightforward due to the low cross section + CR background

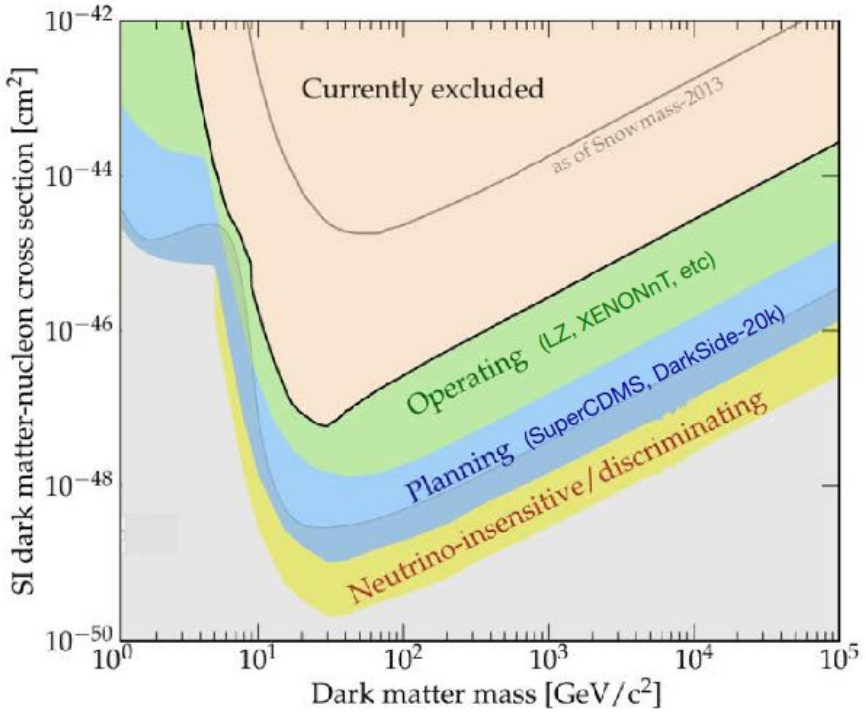
# Axions Versus WIMP




E range : 10^-12-0.01 eV

Conversion of Axion to light with B-field

cf Vijay Dabhi contribution : Direct detection of Axion dark matter with MADMAX




E range : 1 GeV - 100 TeV

Search for collisions in deep underground laboratory to isolate from CRs

cf Yongyu PAN contribution : Search for WIMPs and light DM with XENONnT experiment

# Conclusions ?

- Charged Cosmic rays :
  - loss of directionnality + propagation effect, difficult to probe the sources
  - Influenced by solar and terrestrial magnetic field at low E
  - But direct probe of galactic accelerators
- UHE Cosmic rays :
  - less loss of directionnality, can directly probe extragalactic acceleration sources
  - But low statistics…
- Gamma-ray :
  - Indirect manifestation of CR acceleration in source
  - But depend on ambient medium (B field, matter density, photon field)
  - difficult to retrieve initial particle population due to that
- Neutrinos :
  - indirect but can complement gamma ray analysis
  - but low stat…
  - But first “detection” of sources (hints for galactic emission and AGNs)
- GW :
  - Produce by the merger before the collapse so can be used to trigger other observation !
- Dark Matter :
  - Huge range of energy and candidate… but more and more narrowed by very various experiment
  - We really need to detect it, good luck guys
- Multi-messenger is the way for the next decades, and start to really became real :
  - GW + gamma already done, more event please !
  - Some hints for Neutrinos + gamma and CR + gamma
  - It will probably need the next generation of detectors
  - You will take care of that, we need you

# Conclusions ?

- Charged
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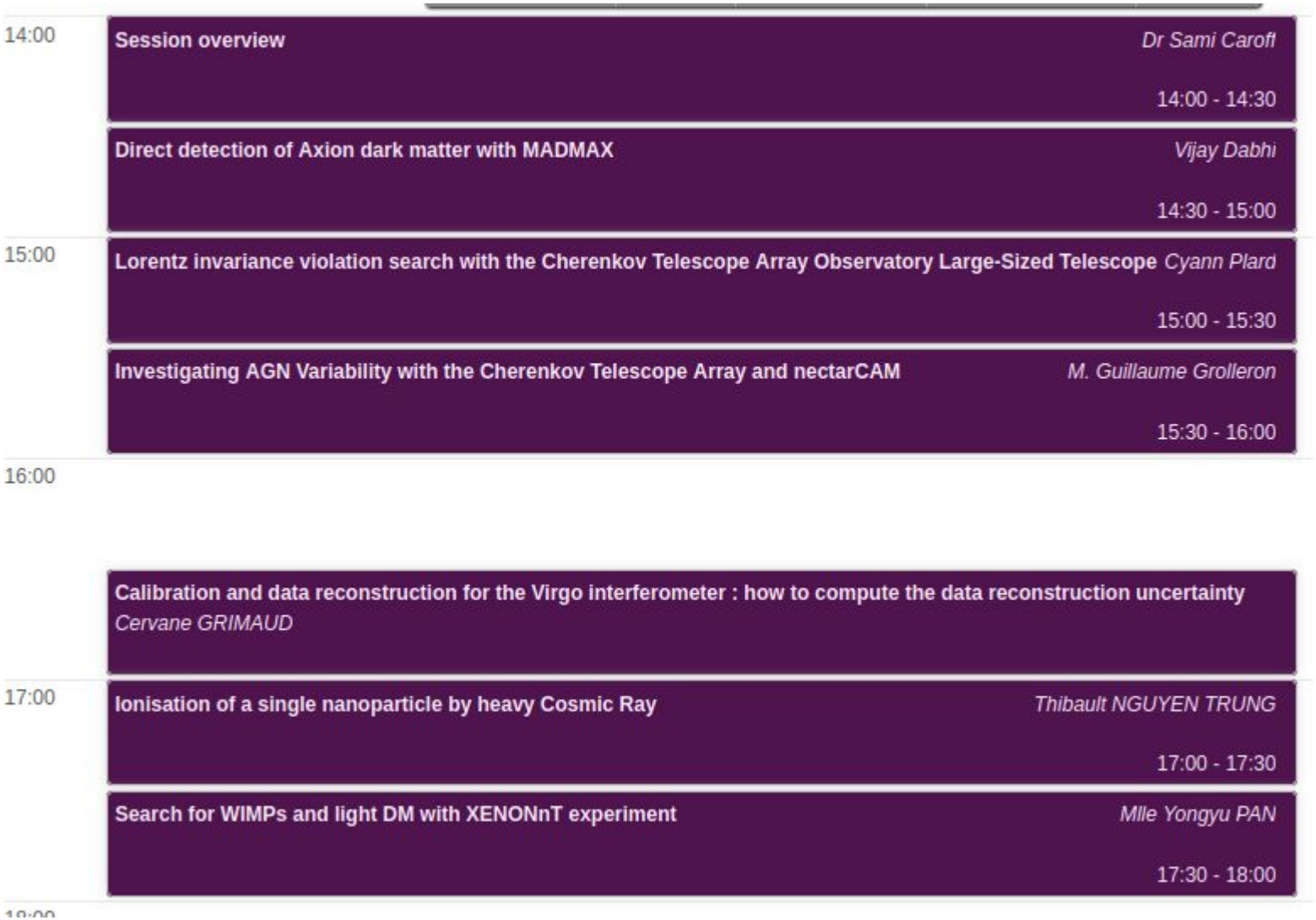
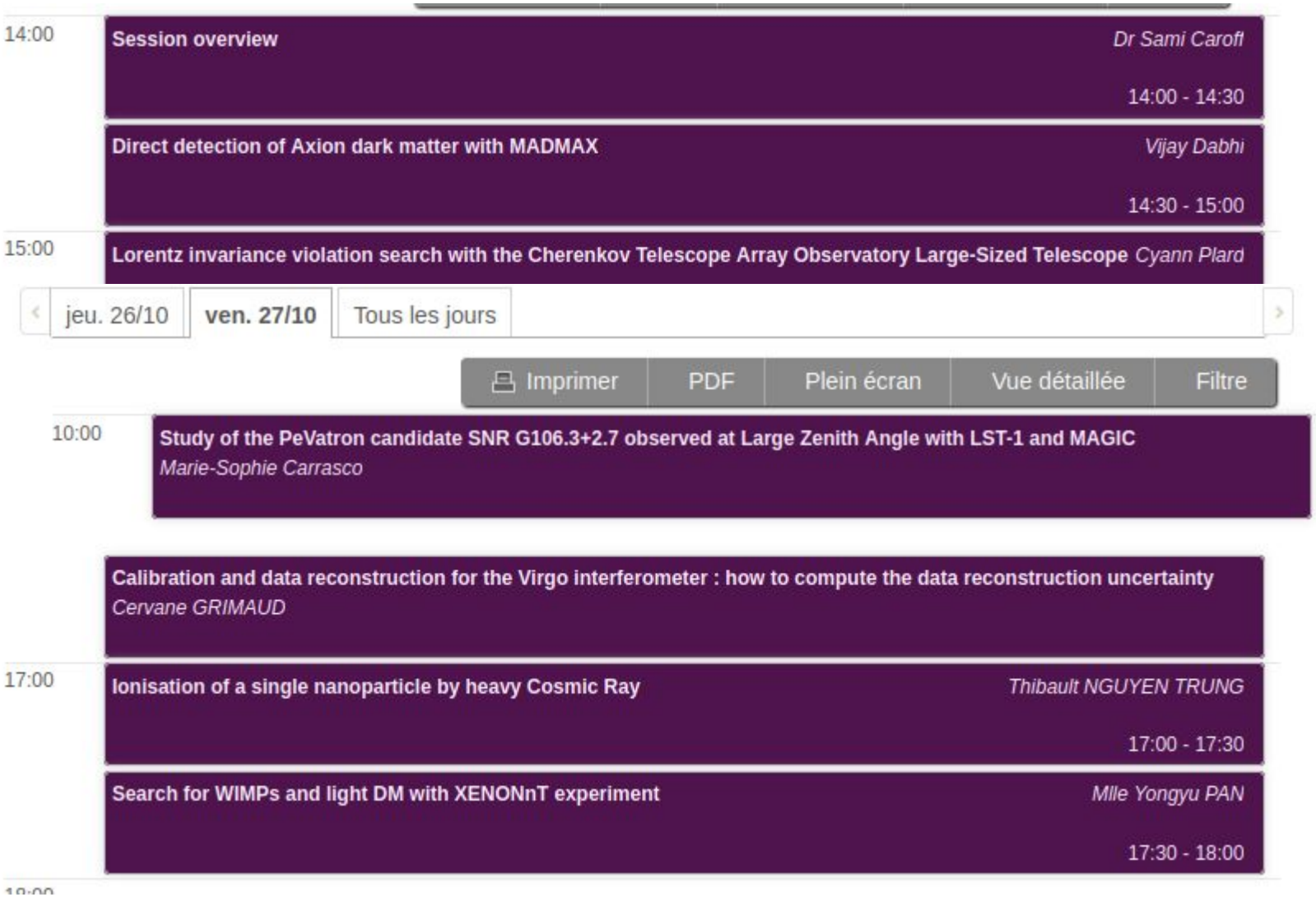
# Session : everyone



# Session : and Marie-Sophie…



# A last DALL-E 3 weird image