Astroparticle physics

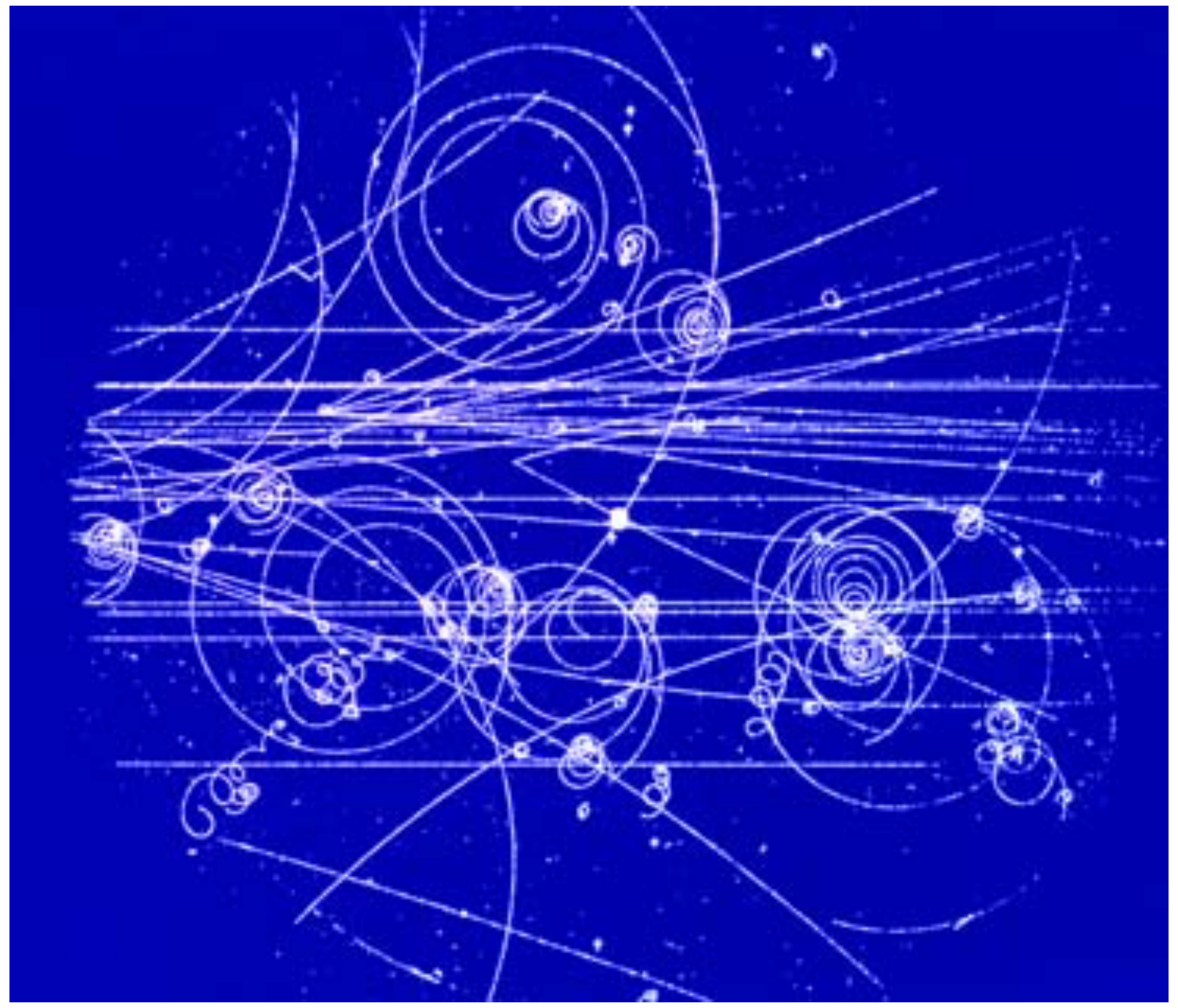
Ruben Conceição

LIP summer internship workshop, Lisboa, July 19th 2020

What is Astroparticle physics?

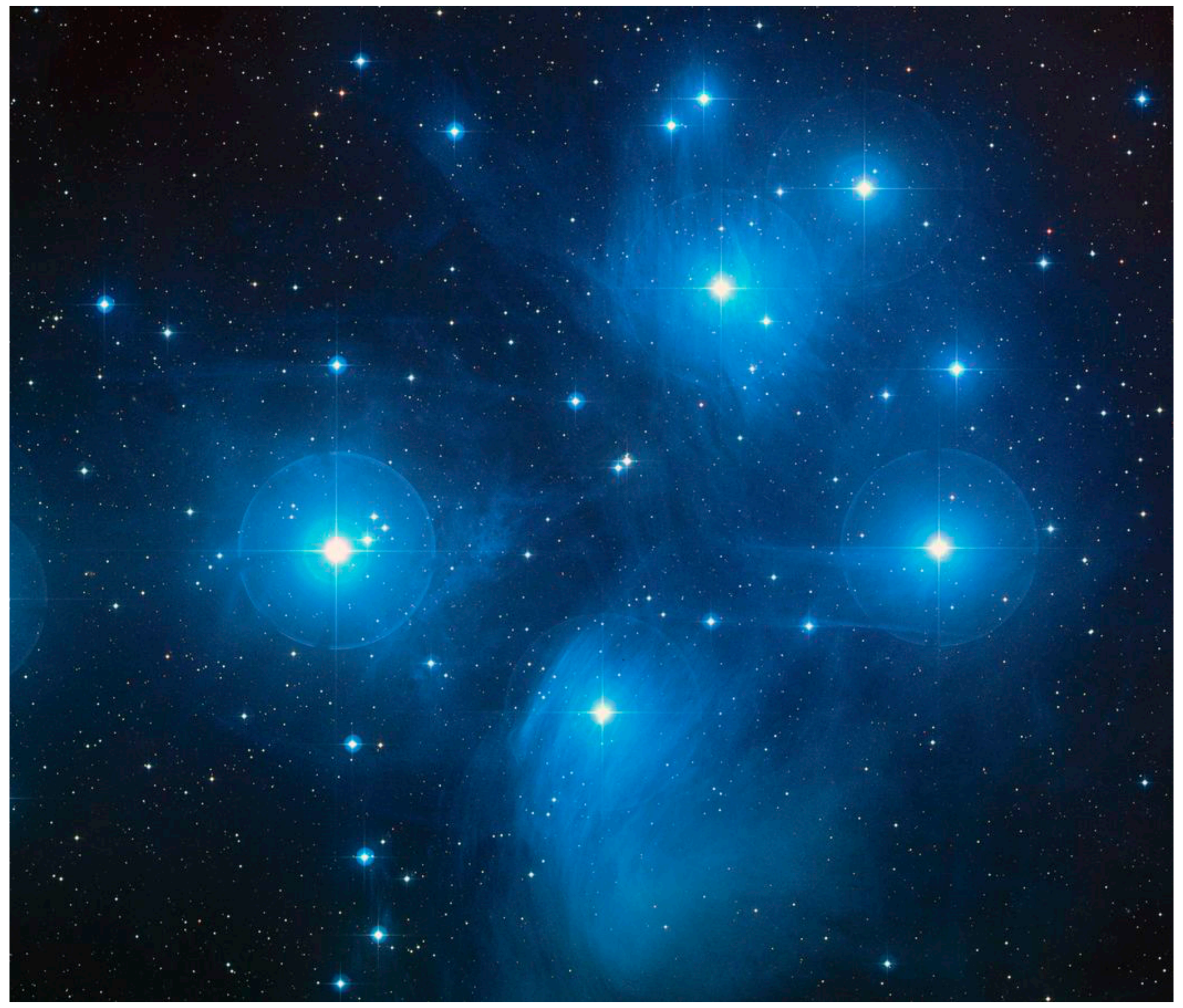
What is Astroparticle physics?

Particle Physics



Study the properties of matter and interactions

Astrophysics / Cosmology



Study Universe's evolution and surrounding astrophysical objects

Astroparticle physics

Particle phyiscs

Astrophysics

Cosmology

Understand the dynamics of our Universe through the radiation/particles collected at Earth

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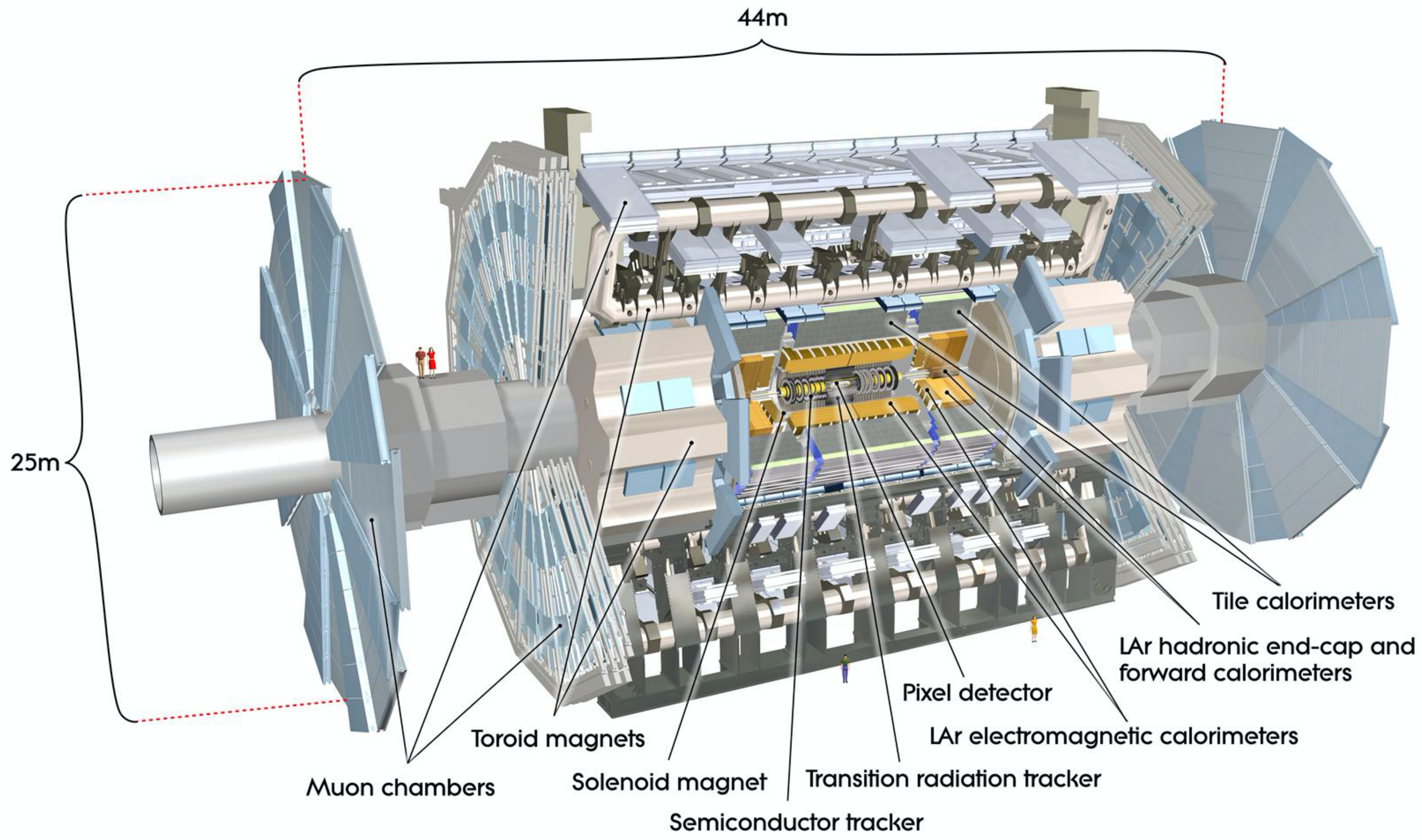
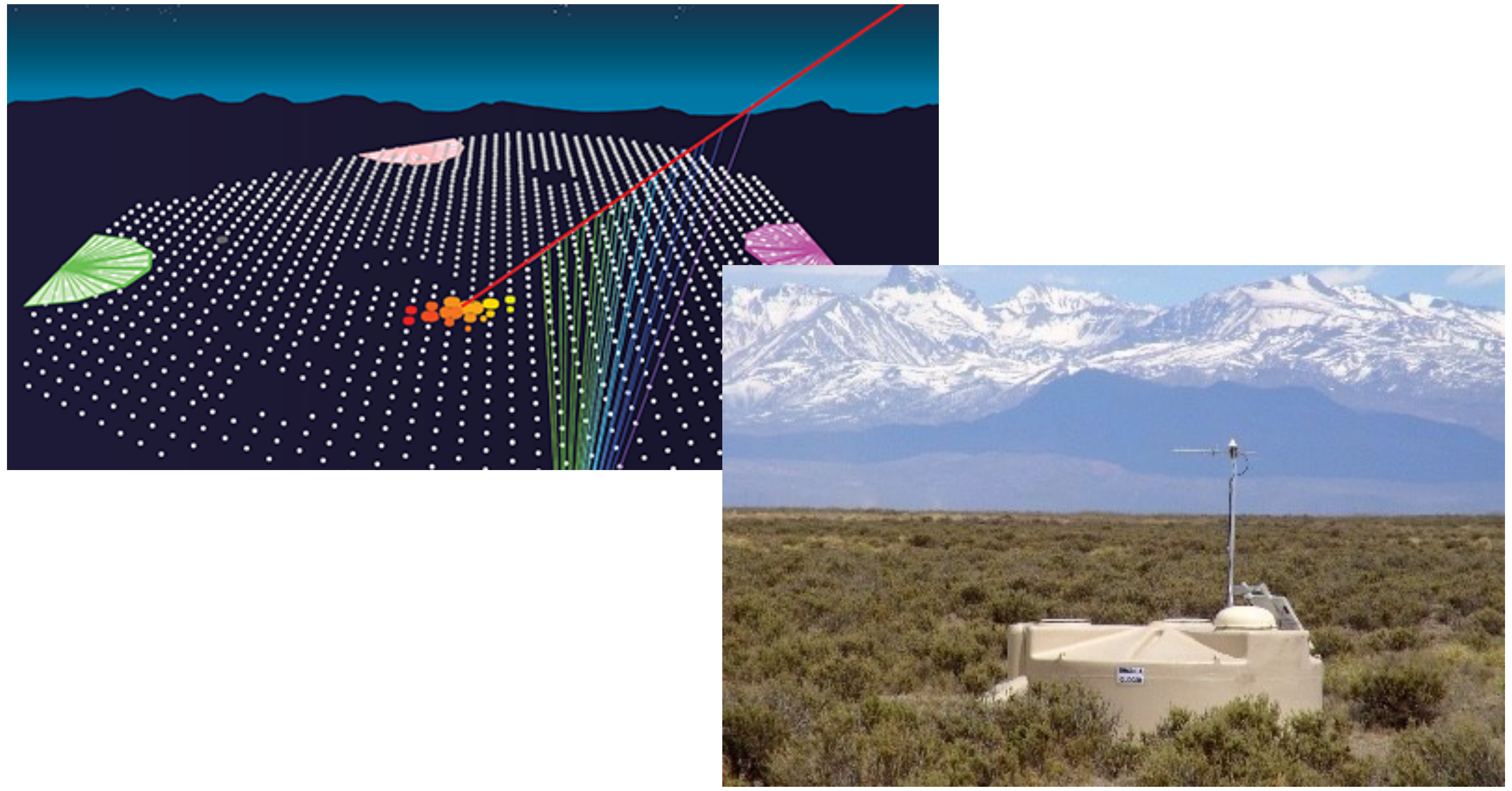
Why?

Accelerator Experiment



- Controlled environment:
  - Beam, background…

Astroparticle Experiment



- Access energy, space and time scales unattainable in Earth

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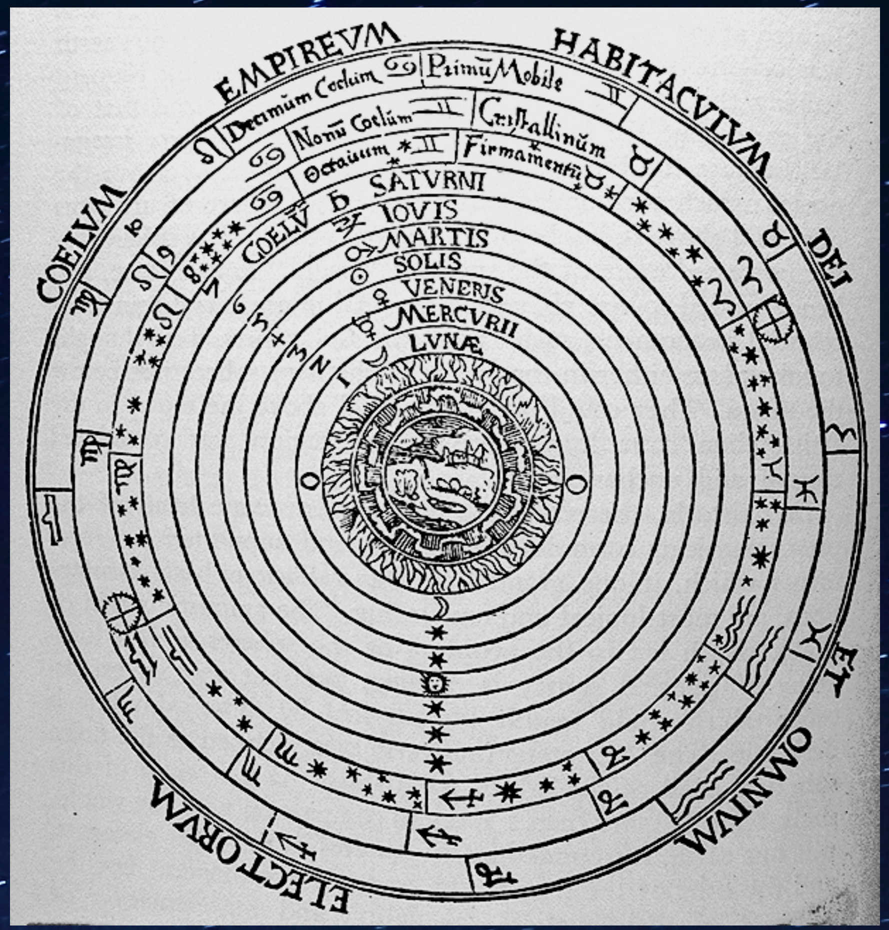
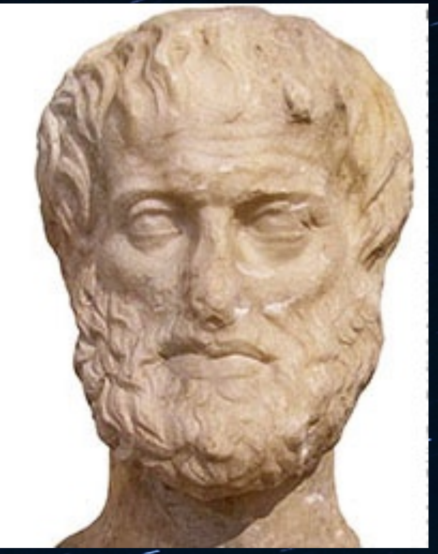
Photons

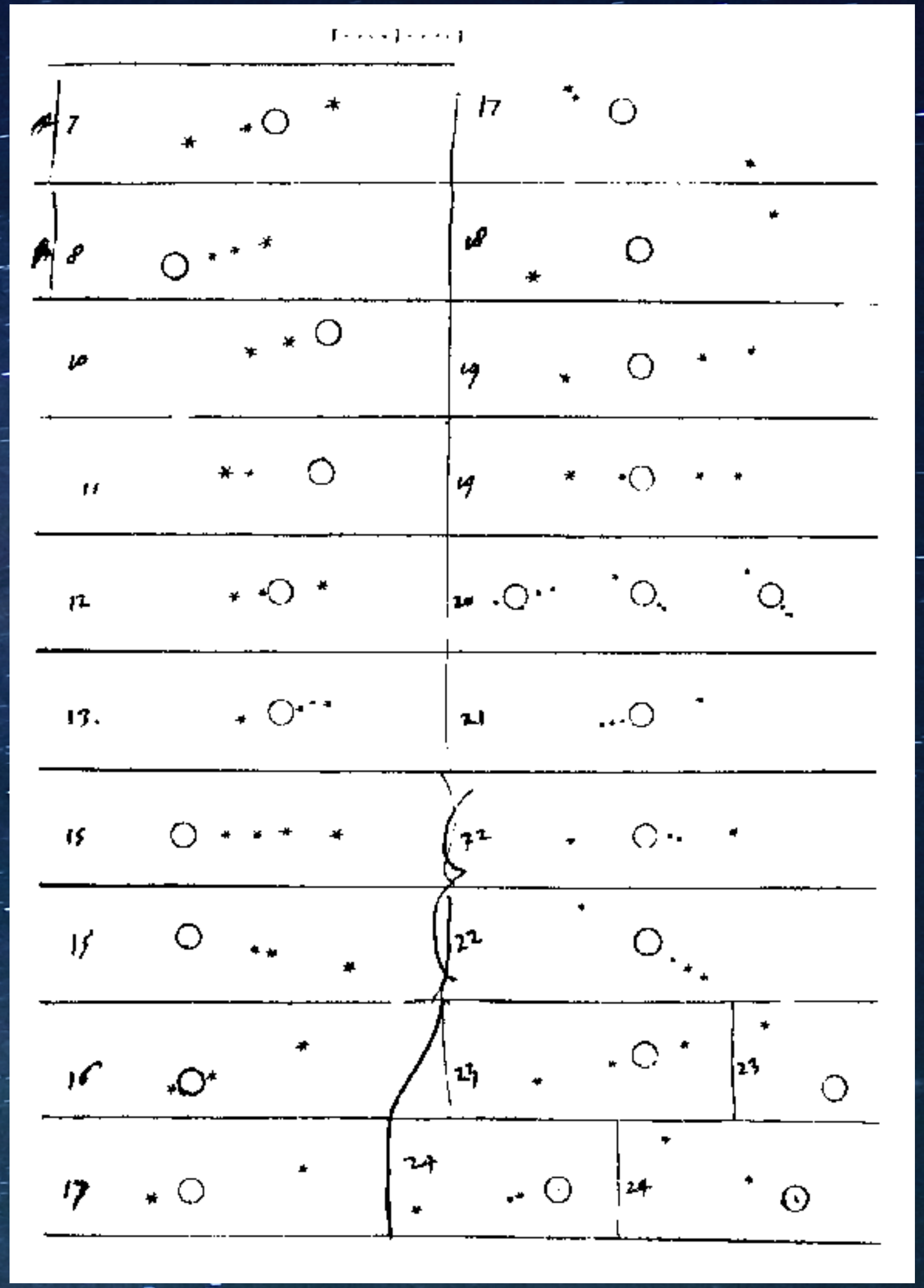
(visible light)

Photons

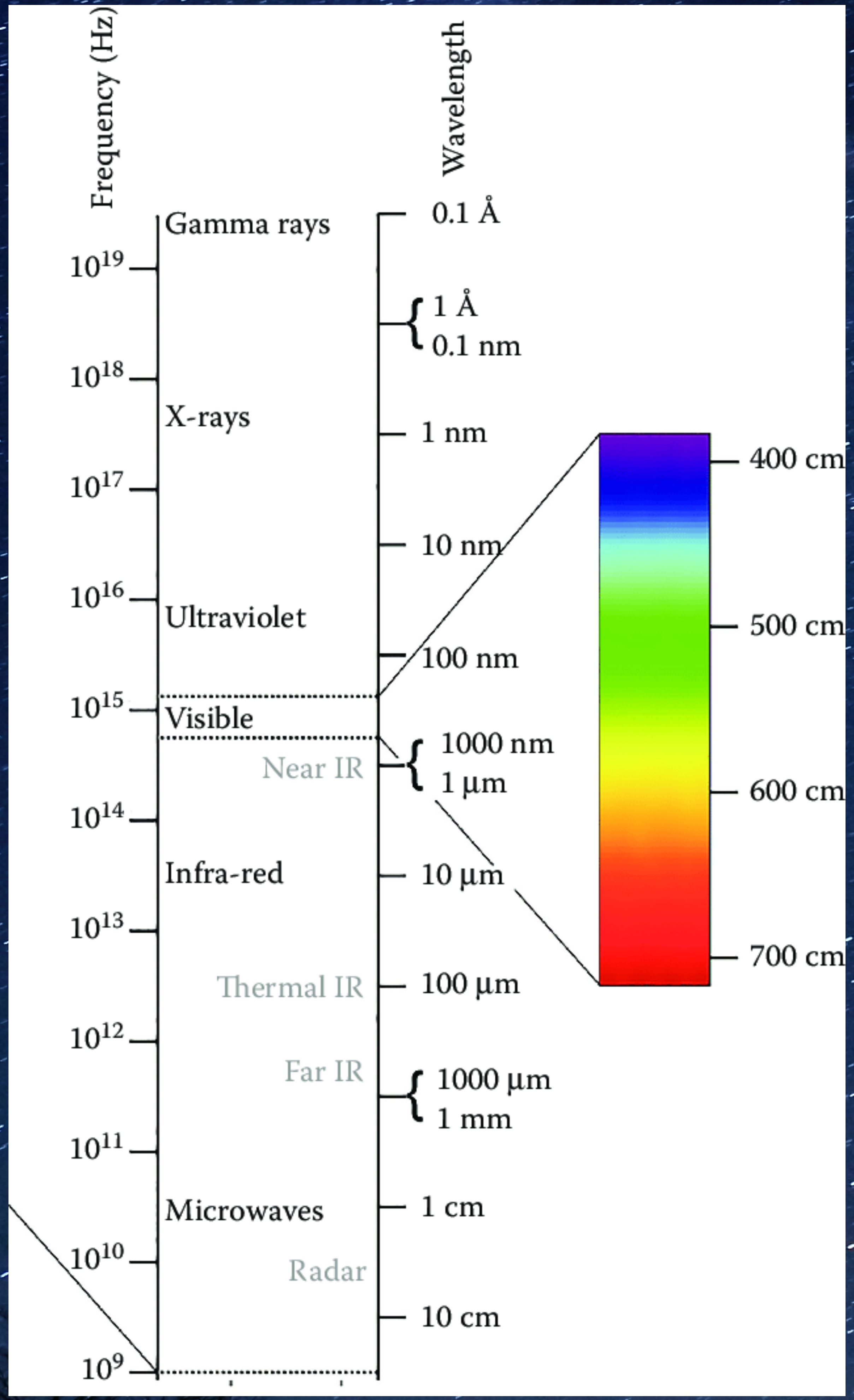
(visible light)

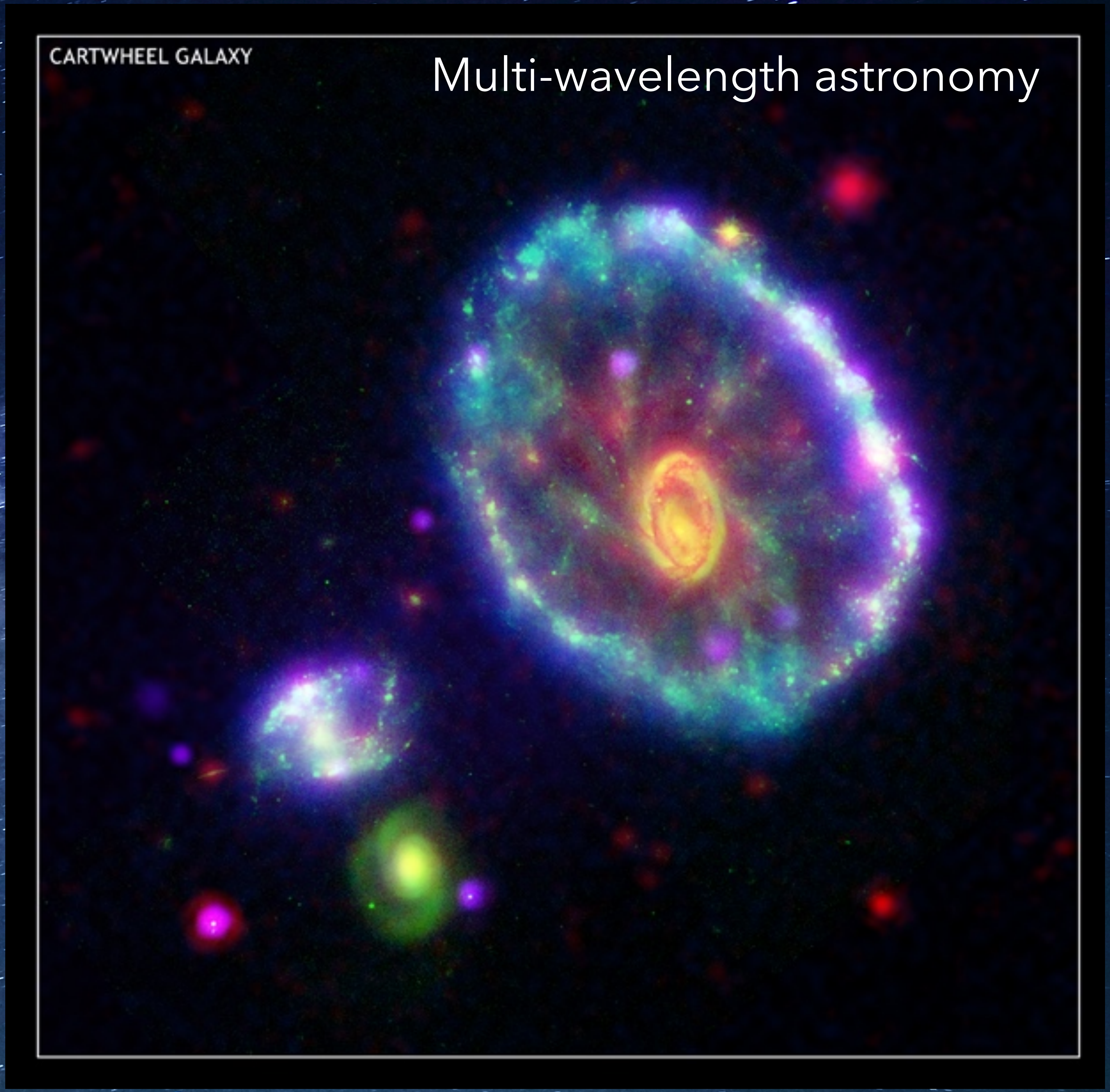






Photons (other wavelengths)





Photons


Photons
Charged
cosmic rays


Photons
Neutrinos
Charged cosmic rays


Photons
Neutrinos
Charged cosmic rays
Gravitational waves

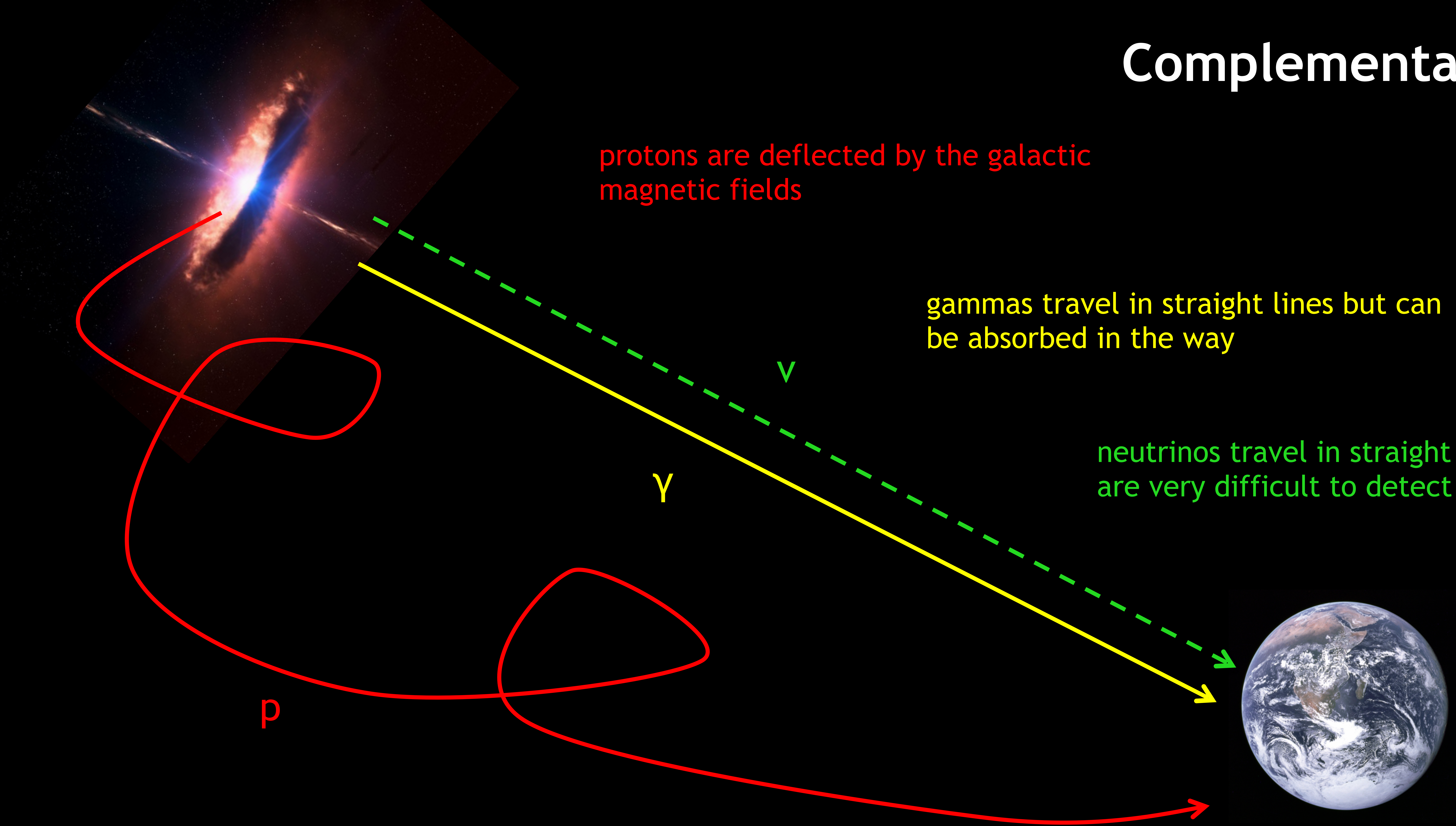

Photons
Neutrinos
Test the dynamics of our cosmos
Charged cosmic rays
Gravitational waves

Complementarity

protons are deflected by the galactic magnetic fields

gammas travel in straight lines but can be absorbed in the way

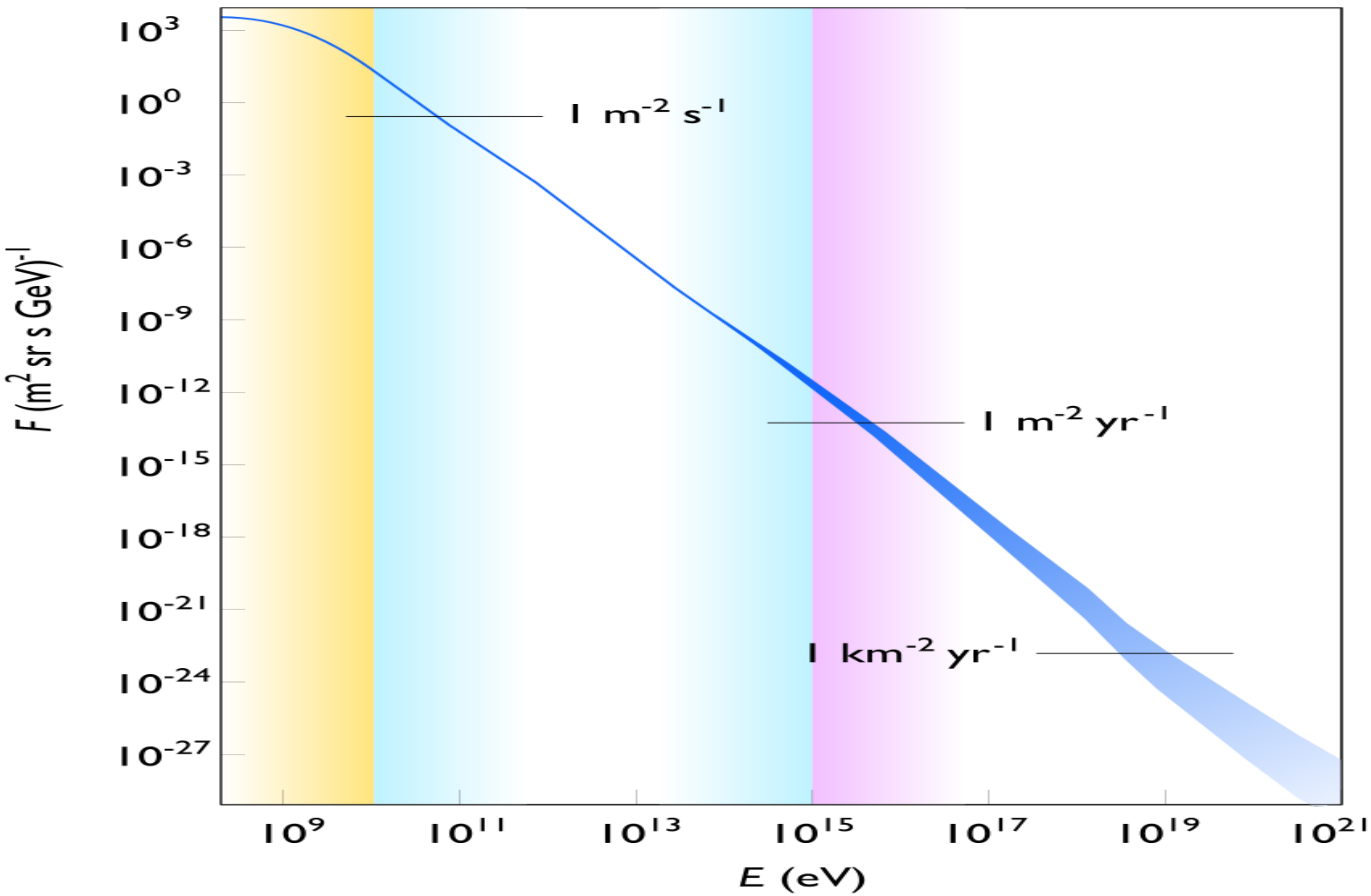
neutrinos travel in straight lines but are very difficult to detect



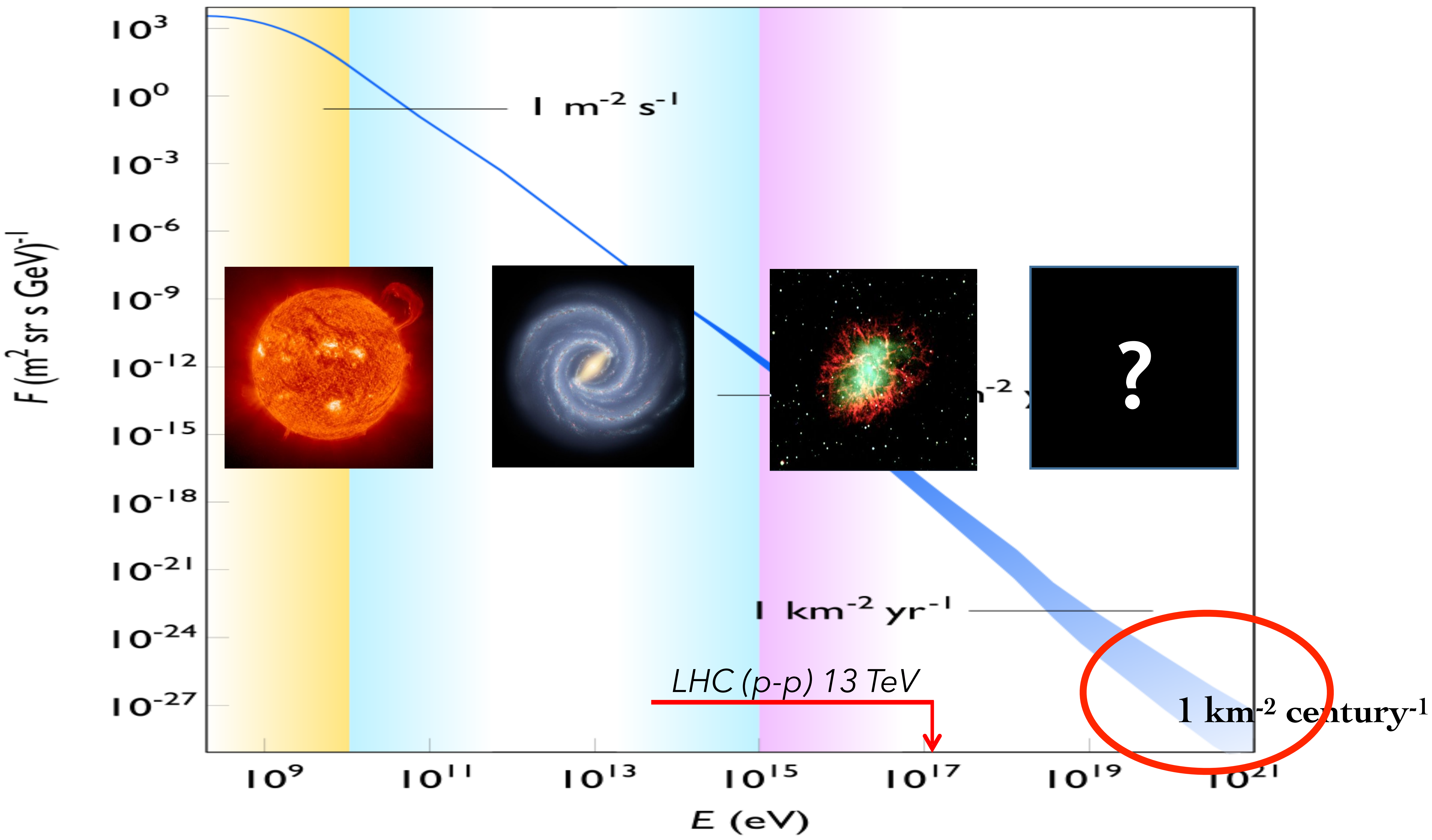

Photons
Neutrinos
Charged cosmic rays
Gravitational waves

Cosmic ray energy spectrum

(Charged particles continuously bombarding Earth)



Ultra High Energy Cosmic Rays



GZK effect

A practical example of how astroparticle physics works…

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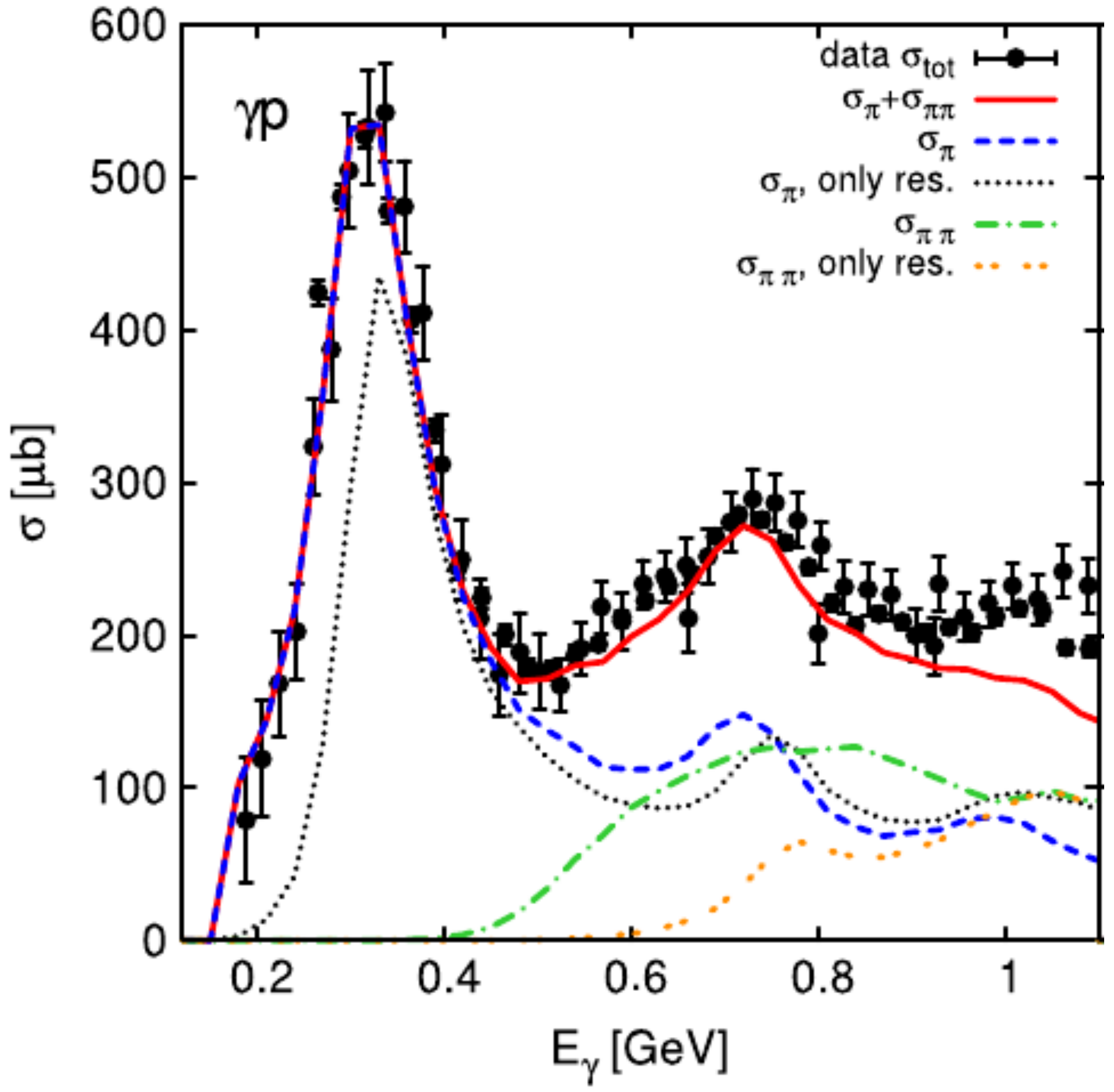
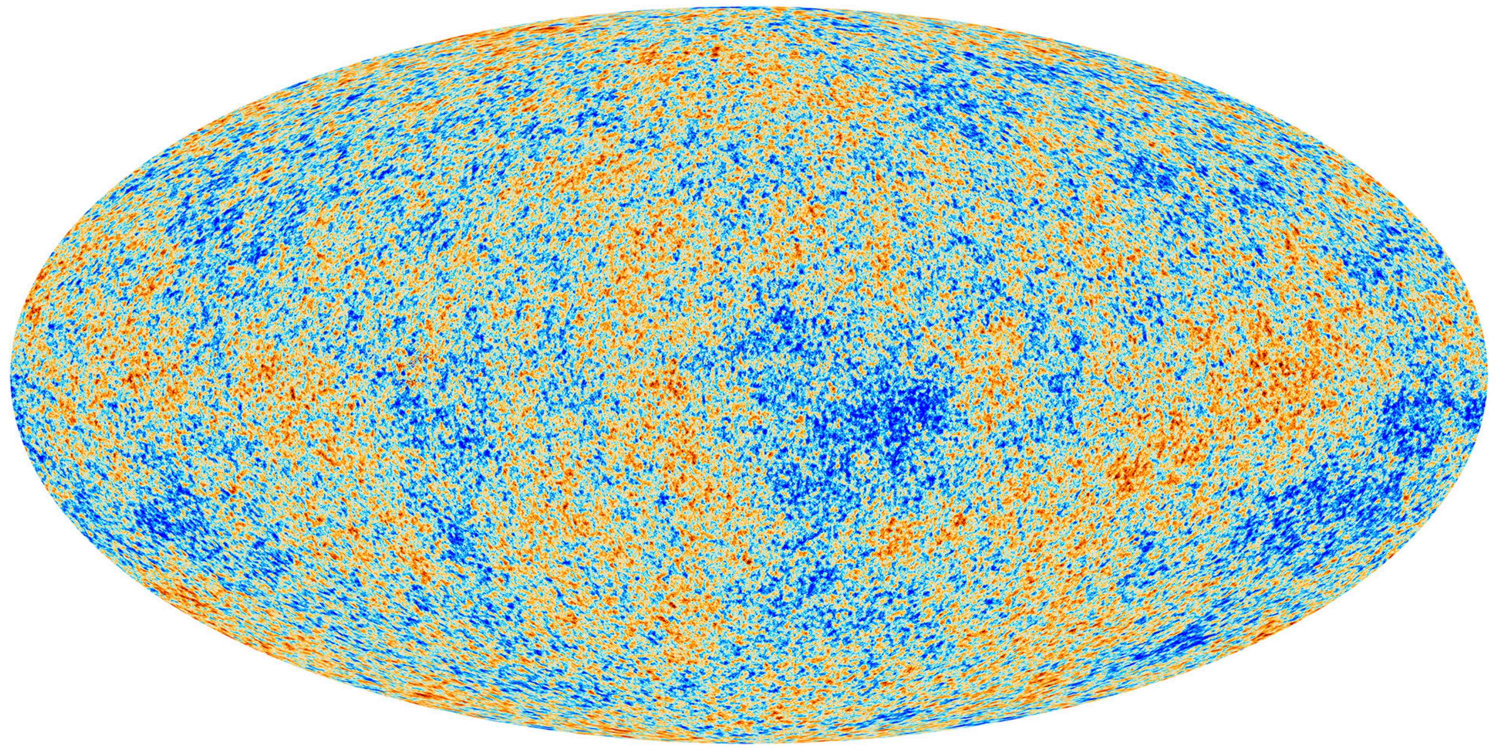
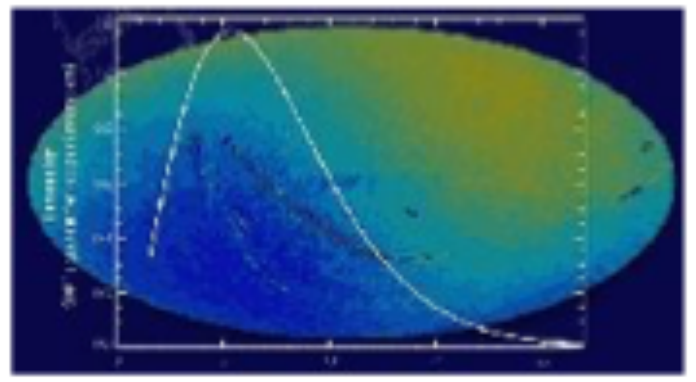
An example: GZK effect





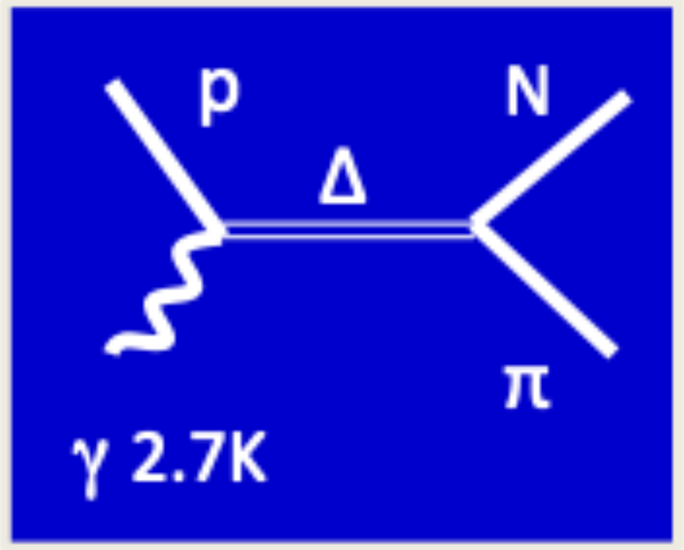
- ✧ Discovery of the Δ baryon in accelerator measurements
- ✧ Discovery of the cosmic microwave background

GZK effect

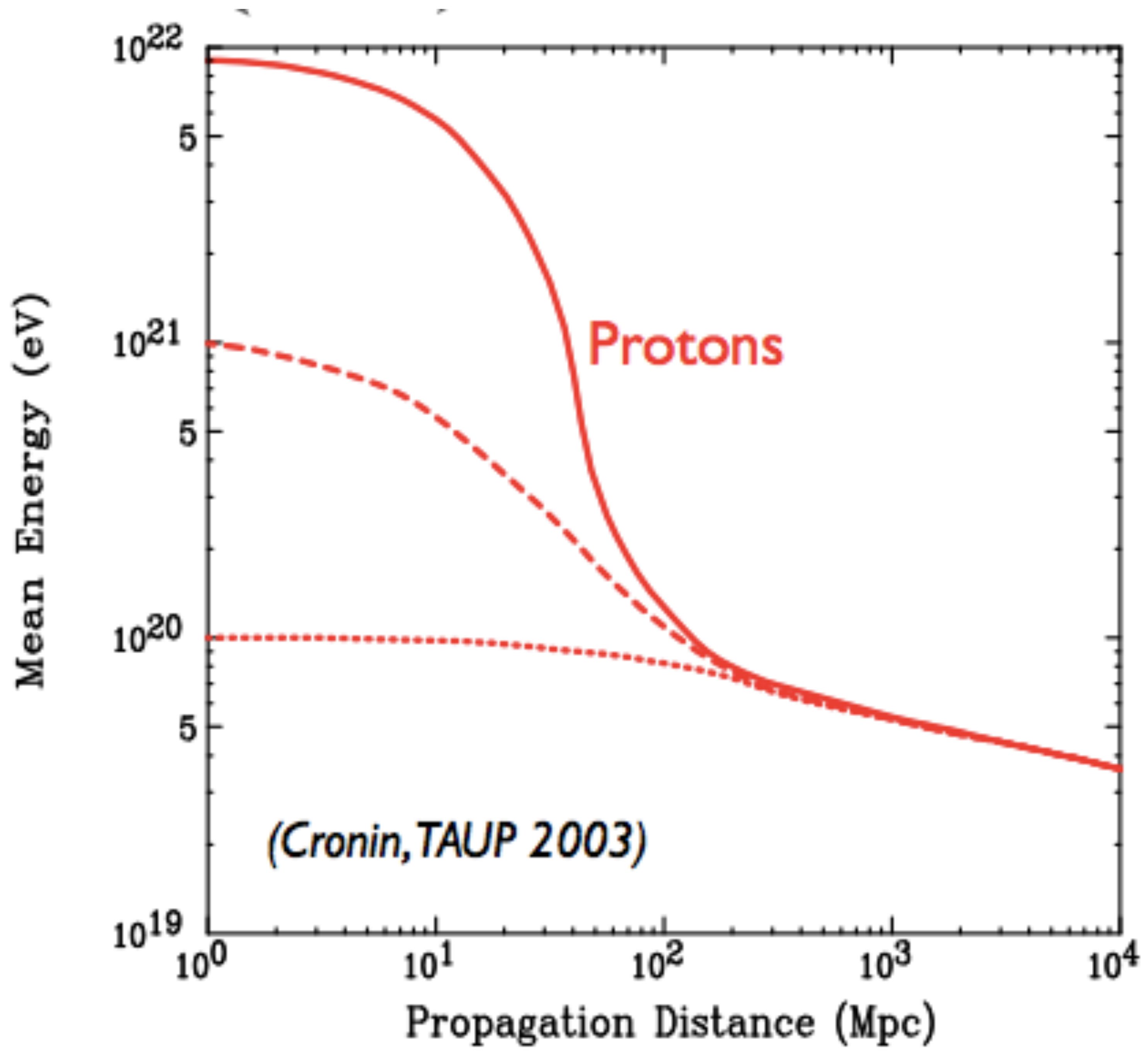


- ✧ GZK cuttoff
  - Greisen, Zatsepin, Kuz'min (1966)
  - Cosmic ray interaction with CMB
  - Energy loss process

$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow p + \pi^{0}$$
$$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow n + \pi^{+}$$

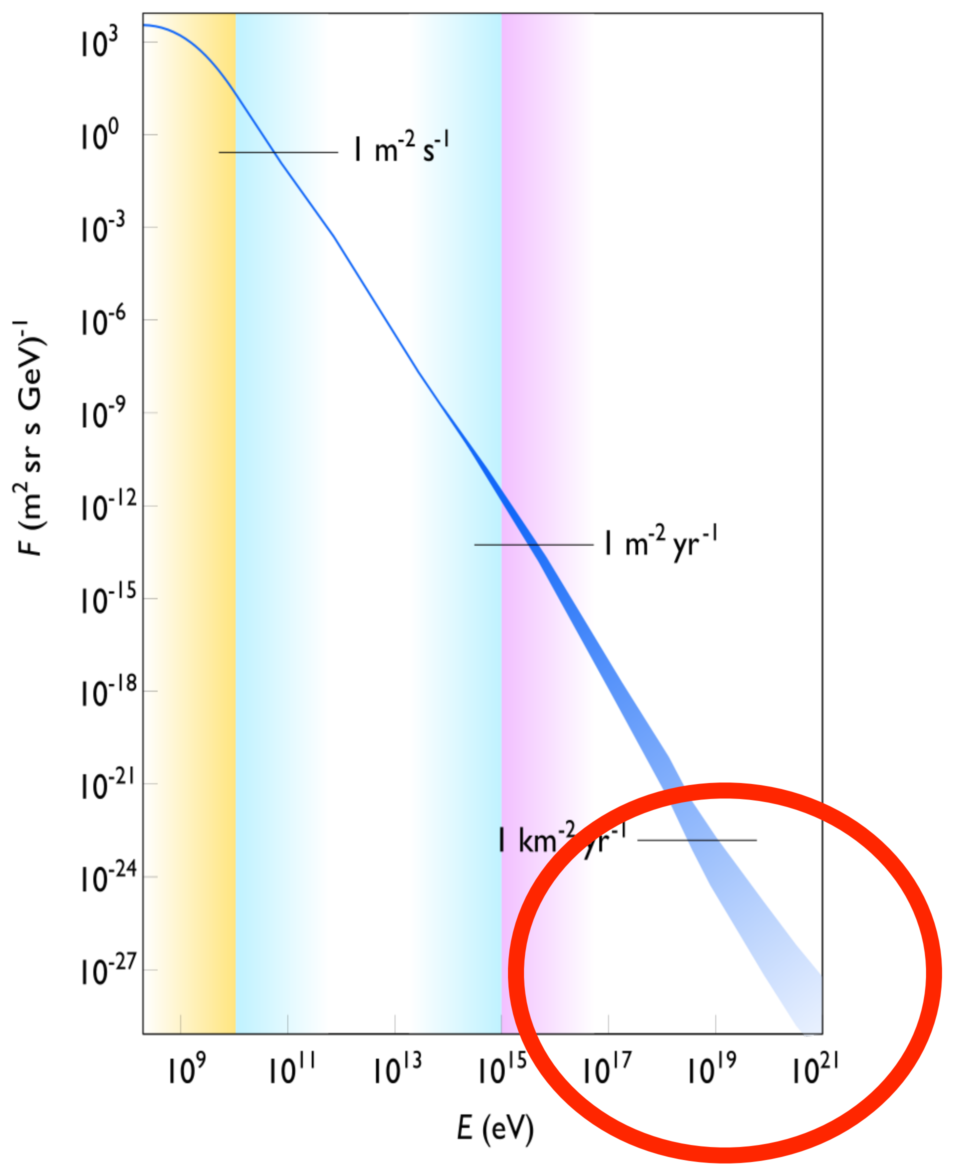


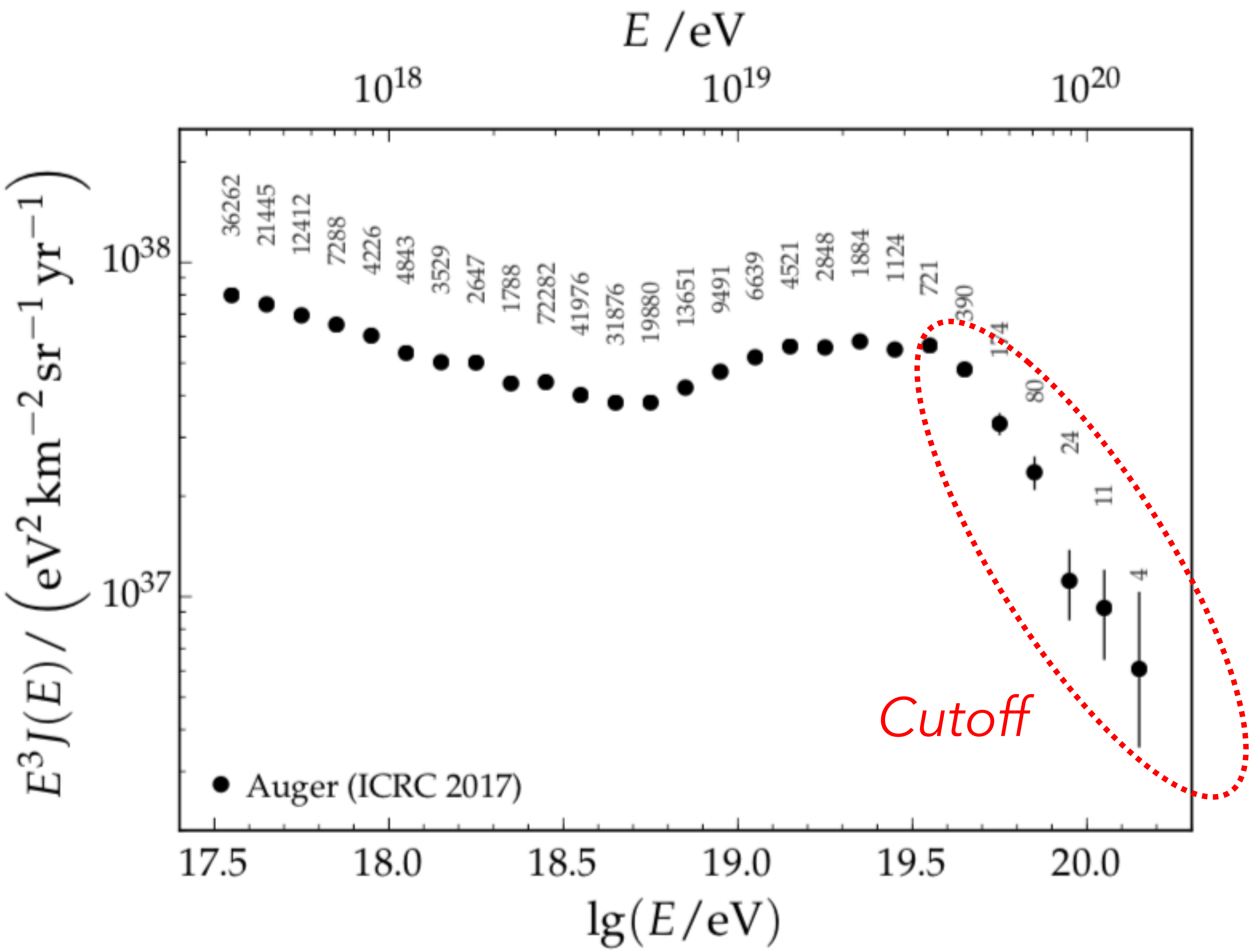
- Prediction: CR energy spectrum should have a cutoff around E ~ 10^{20} eV



UHECR energy spectrum

Pierre Auger Collaboration





Put strong constraints on UHECR production and propagation

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Photons
Neutrinos
Charged cosmic rays
Gravitational waves

Neutrino oscillations

Yet another, more recent, example…

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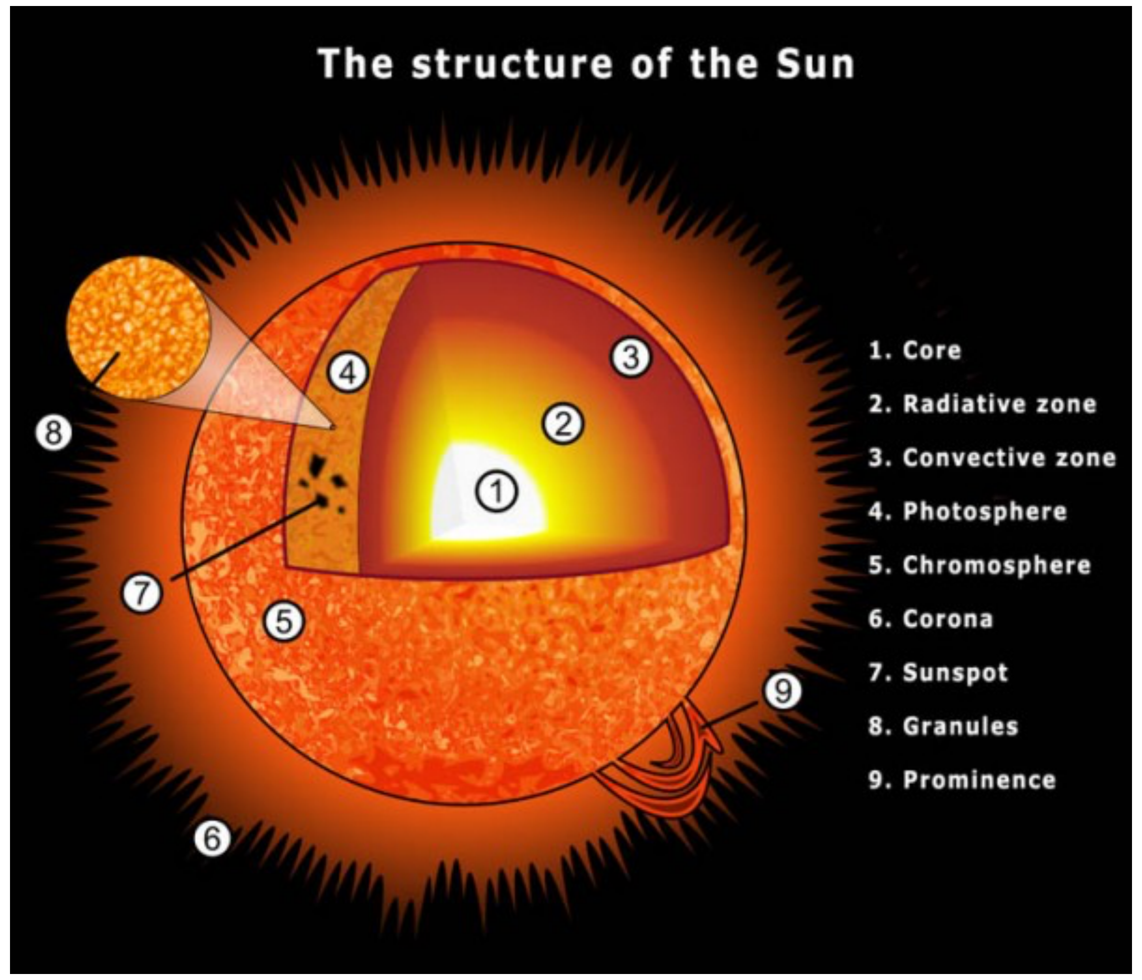
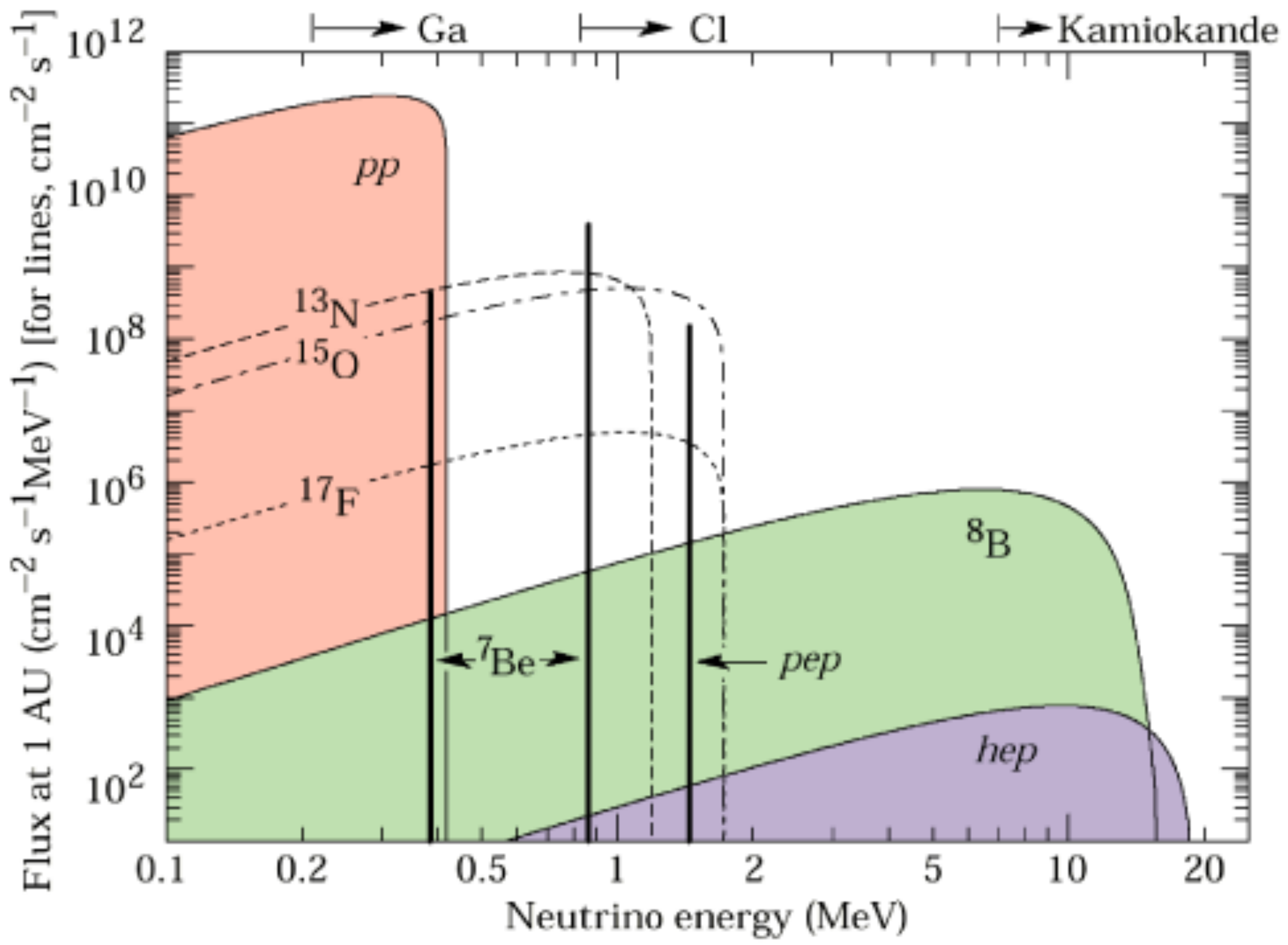
Solar Neutrinos

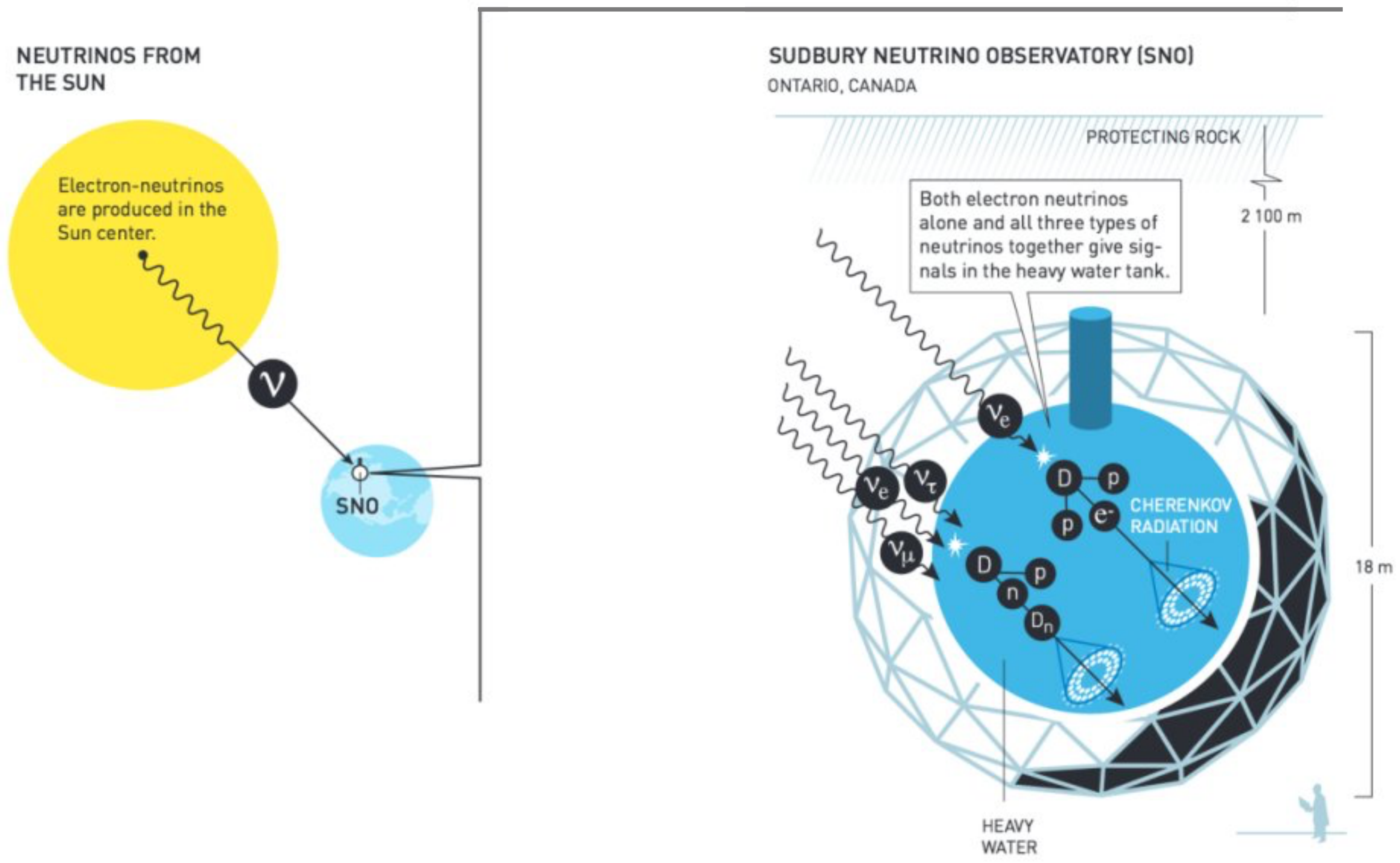
- Standard Solar Model
  - Built upon our knowledge over:
    - Solar dynamics
    - Interaction cross-sections



- It was noted since the 60's that the prediction of the flux of solar neutrino exceeded the observations



Neutrino oscillation



- ✧ Neutrino oscillation was found while trying to solve the Solar neutrino problem
- ✧ Nobel prize 2015 (A. MacDonald [SNO] ; T. Kajita [Super-Kamiokande])

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Photons

Neutrinos

Charged cosmic rays

Gravitational waves

(Very) High Energy Gamma Rays

- Astrophysical gamma rays
  - Energy region of interest from GeVs to hundreds TeVs
- Scientific interest:
  - Key to understand the **acceleration mechanism** of cosmic rays in our galaxy
  - Violent astrophysical phenomena: pulsars and black holes
  - Galactic magnetic fields
  - Photon radiation fields in the Universe
  - Indirect search of **dark matter** (WIMP interactions)
  - Test fundamental properties of quantum gravity
  - …

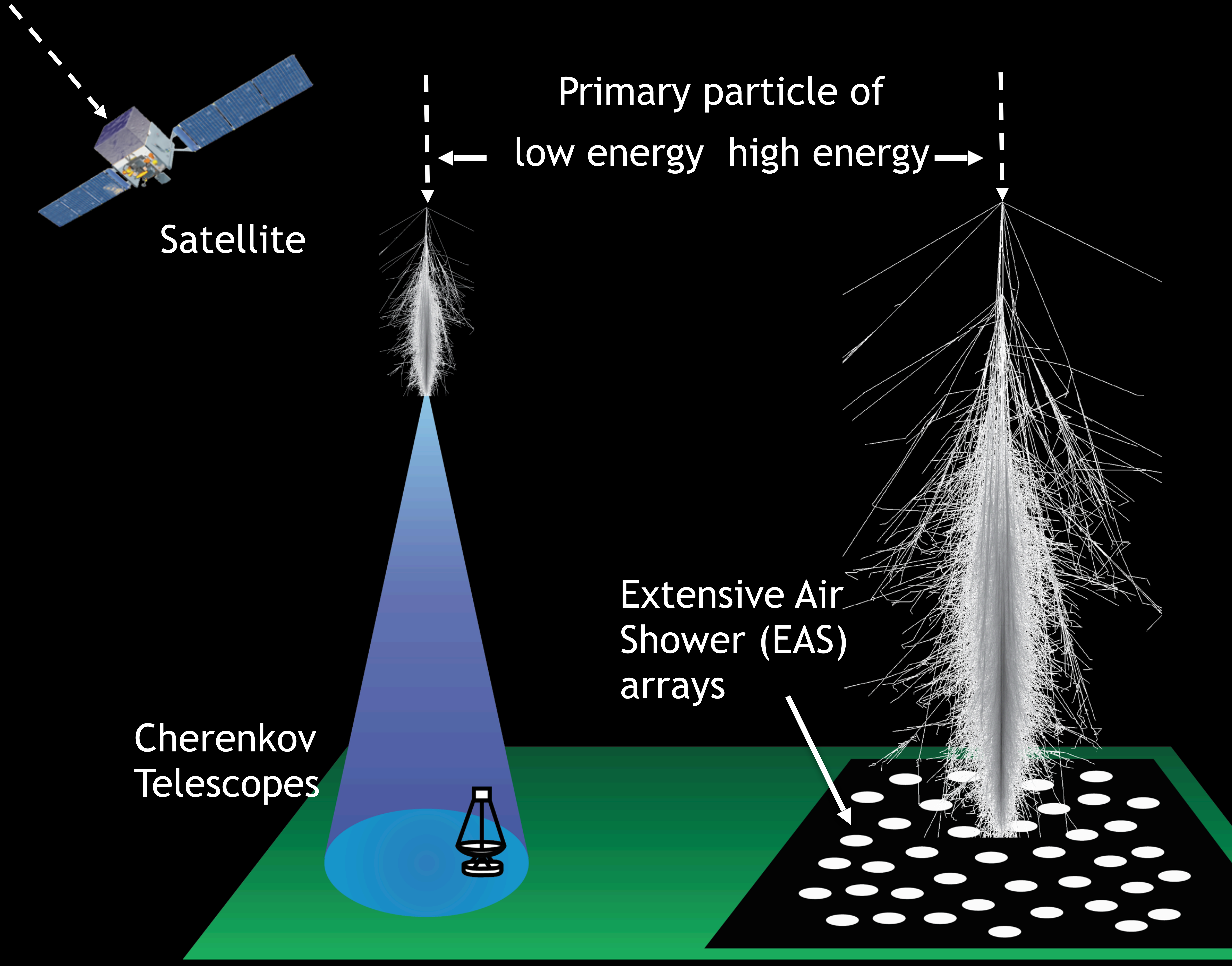
How to detect?

High-energy gamma rays

- 10 MeV - 100 GeV
- **Satellites**

Very-high-energy gamma rays

- 100 GeV - 100 TeV
- **Cherenkov telescopes**
    - Small duty cycles
    - Small field-of-view
    - Good energy and direction reconstruction
- **EAS arrays**
    - Large field of view
    - Duty cycle ~100%
    - Poorer energy and direction reconstruction



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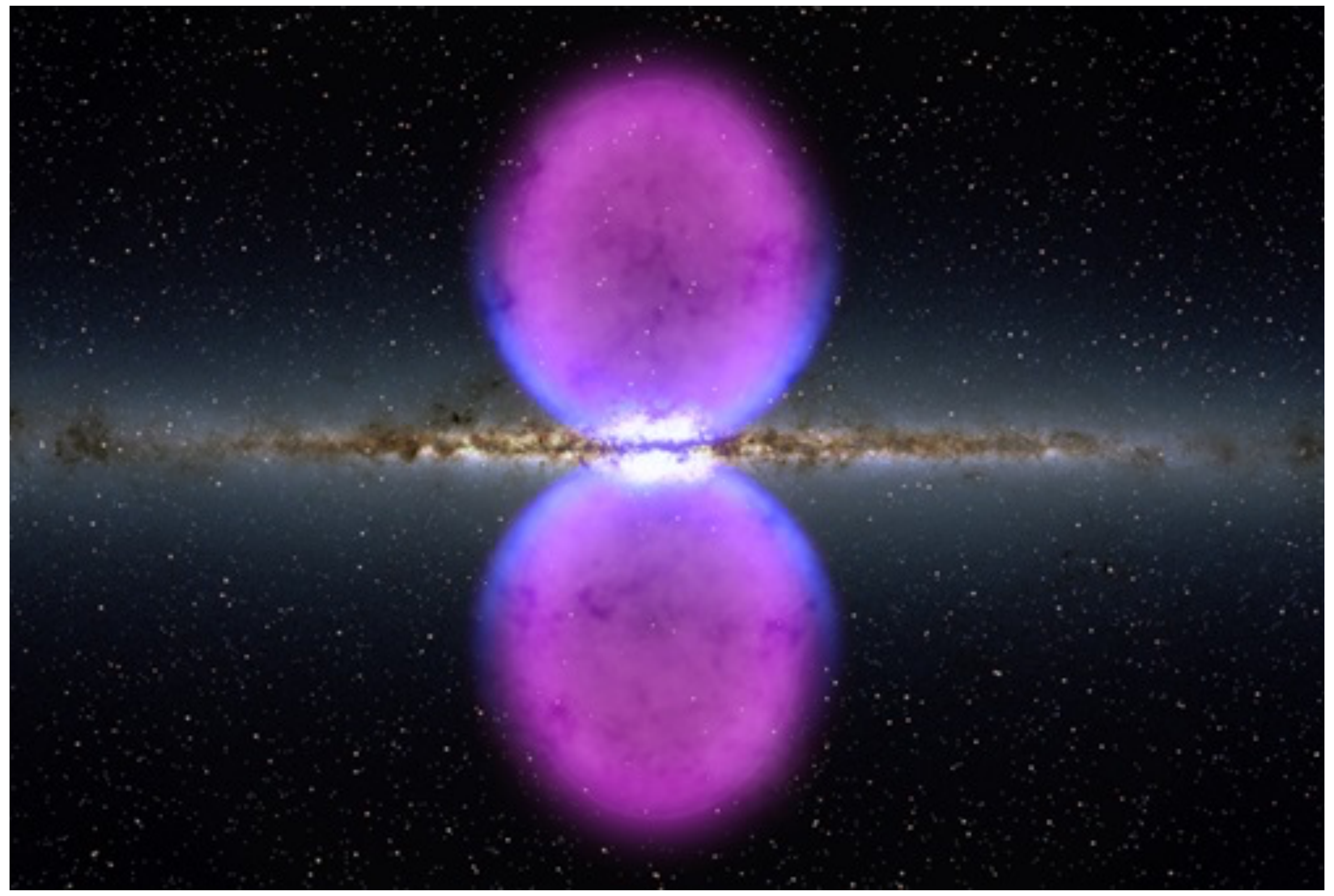
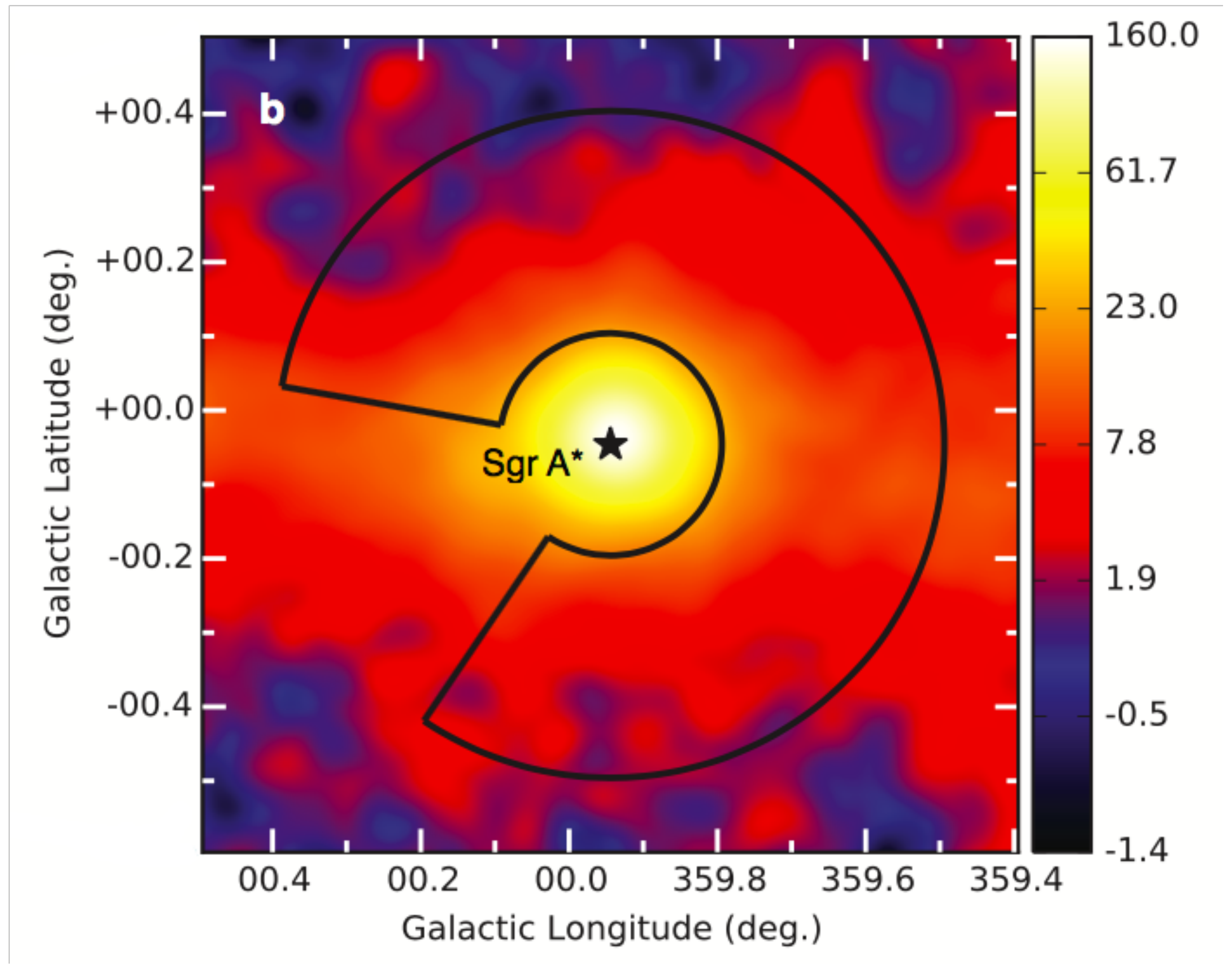
VERITAS
MAGIC
LHASSO
CTA
HAWC
CTA
SWGO
HESS
Built IACT
Built Array
Planned IACT
In construction Array

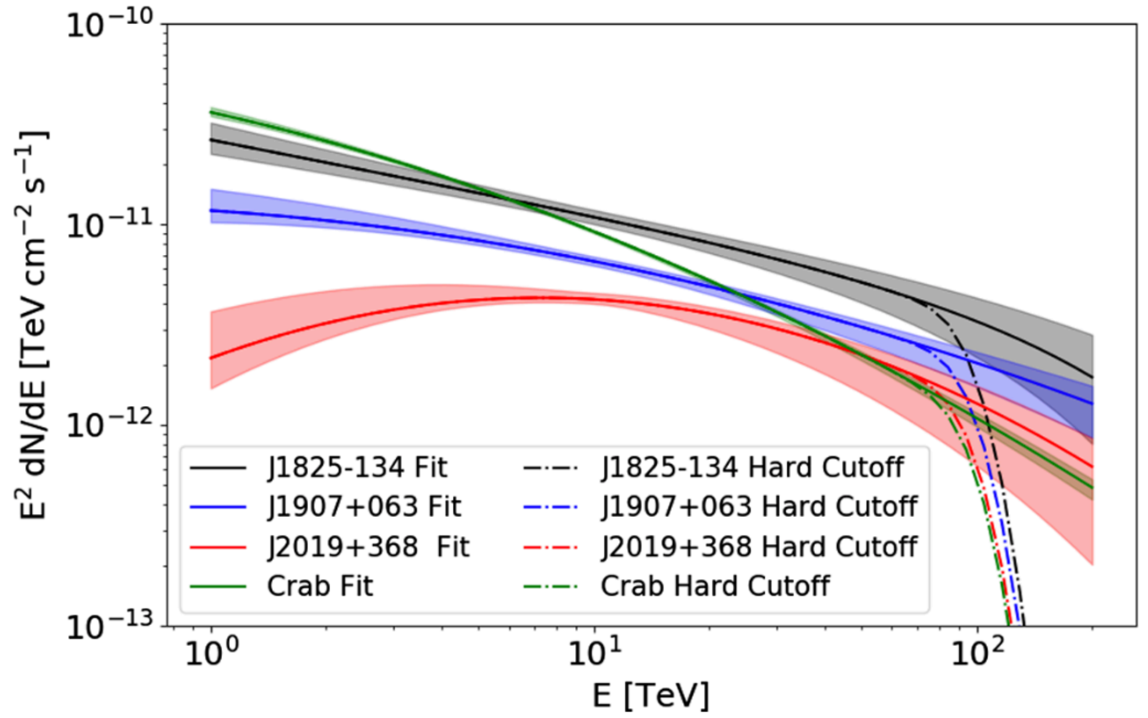

LHASSO
Built Array
In construction Array

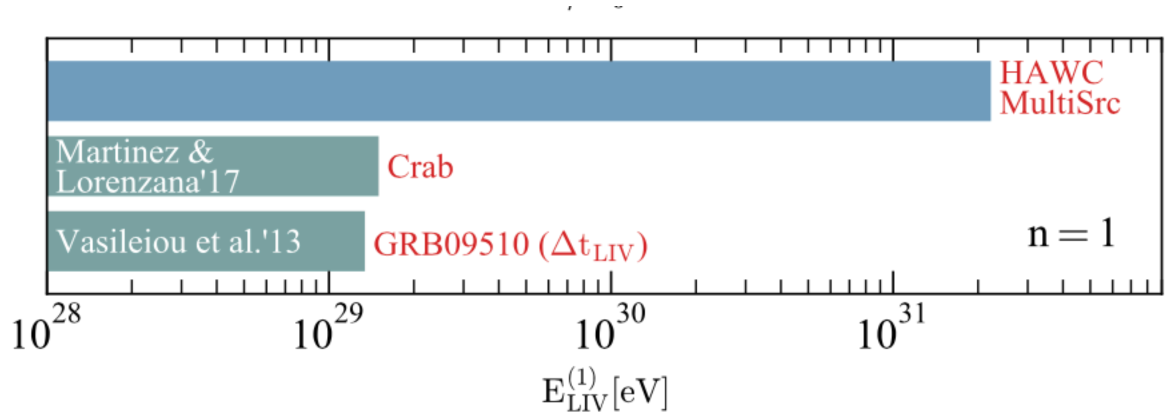

Complementary to the powerful
Cherenkov Telescope Array project
cta
cherenkov telescope array
Galactic Center
CTA
SWGO
Scorpius
Sagittarius

Some interesting highlights…

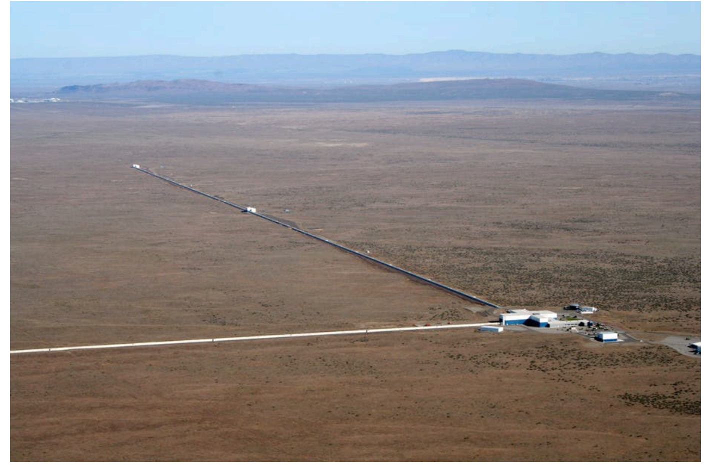








- ✧ Fermi bubbles - gamma ray emission (up to ~100 GeV) in outbursts from our galaxy
- ✧ HESS data suggests that there might be a PeVatron (1000 TeV) source in the galactic center
- ✧ Observation of photons from Crab with E > 100 TeV *(last year)*



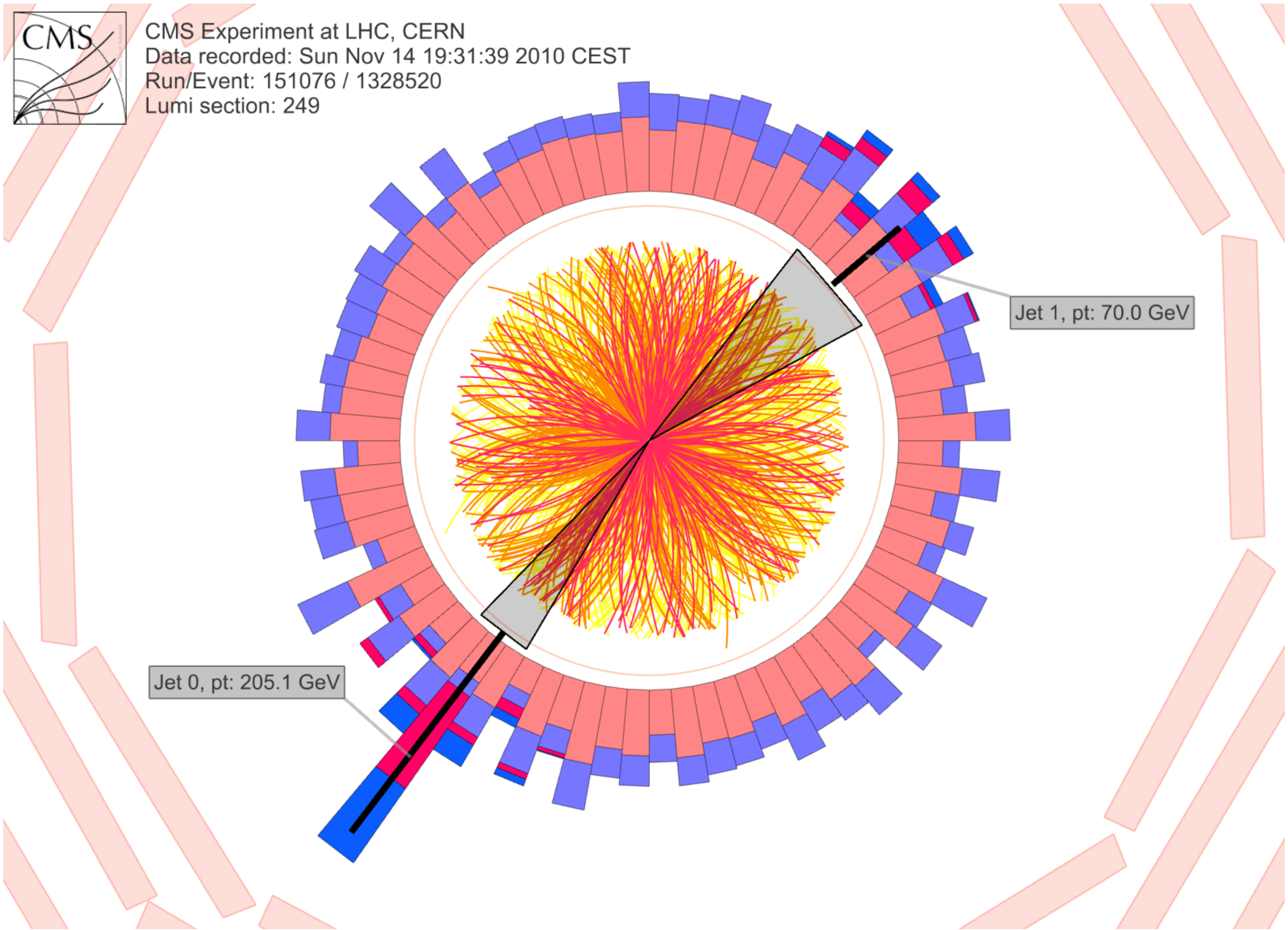


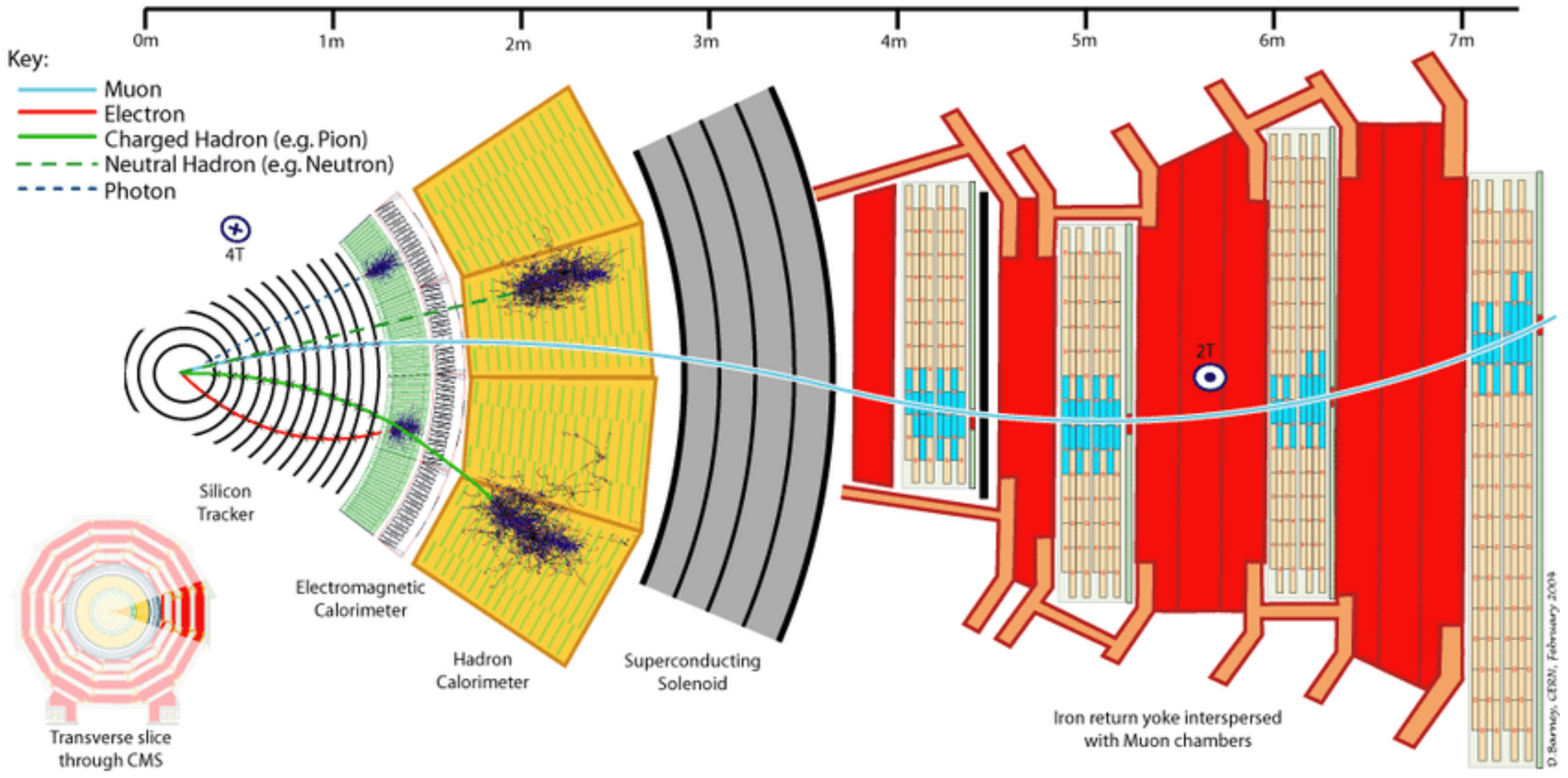
Multi-messengers

The opening of a new era…

A plethora of measurements…

- The importance of complementary and calibrated measurements
  - An example at the LHC





- Observation of jet-quenching phenomena (yesterday's talk) using ***Z0 + jet*** measurements

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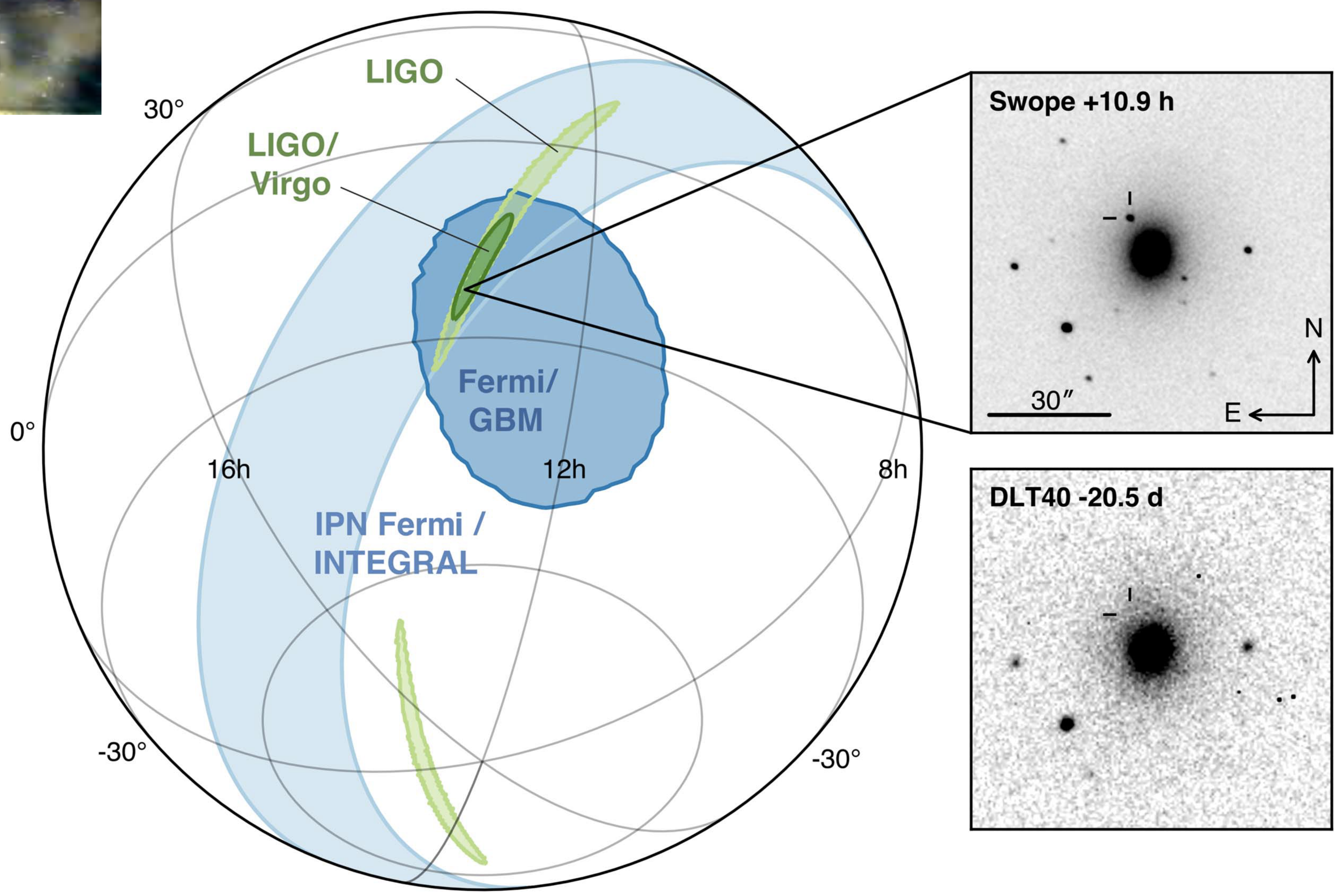
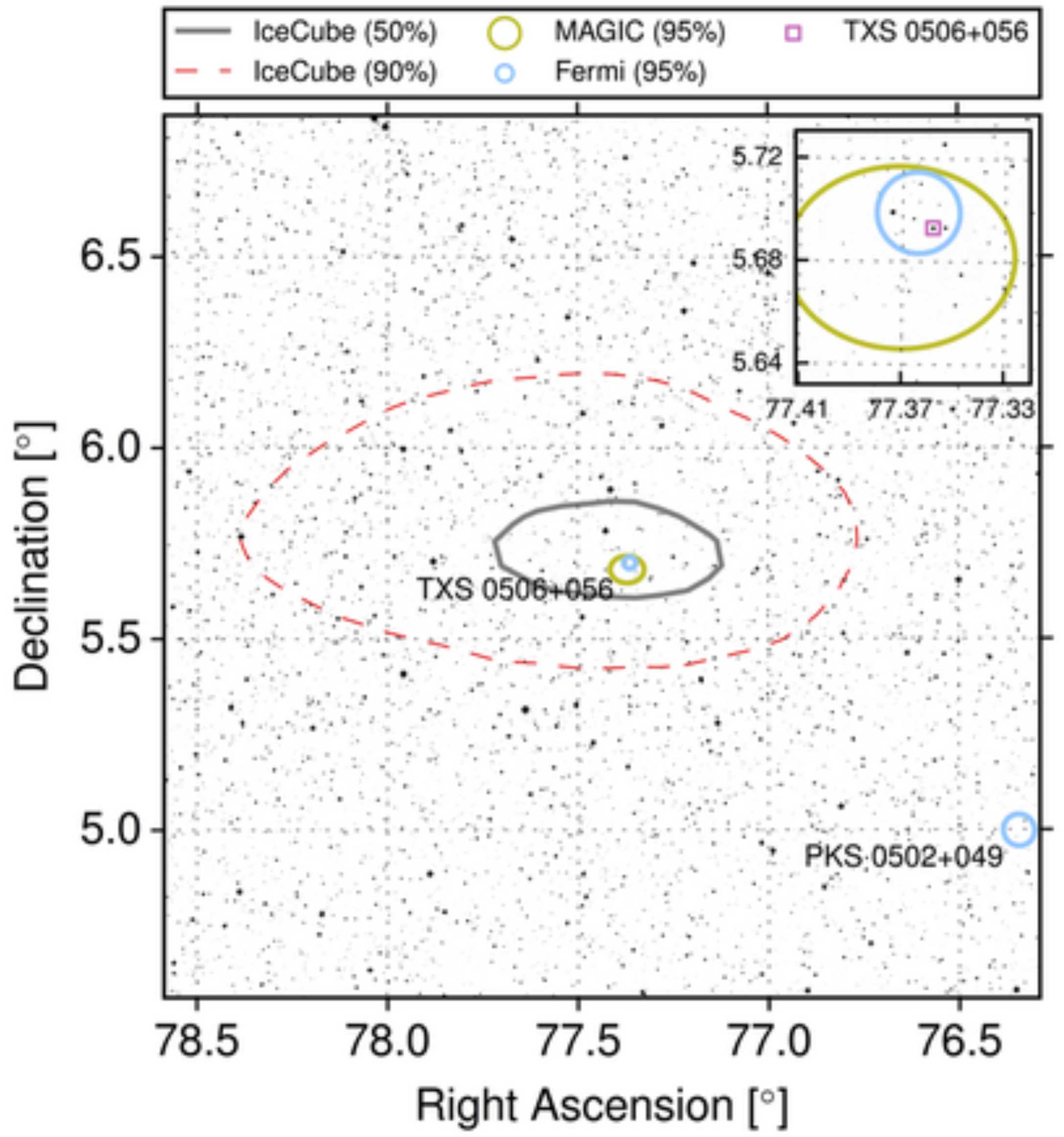
Recent Multi-messenger Observations

Observation of a Binary Neutron Star Merger



LIGO, VIRGO, INTEGRAL,
Fermi, IceCube, Pierre Auger … (2017)

Observation of a neutrino and a gamma-ray flare from the same source



Icecube, MAGIC, Fermi-LAT … (2018)

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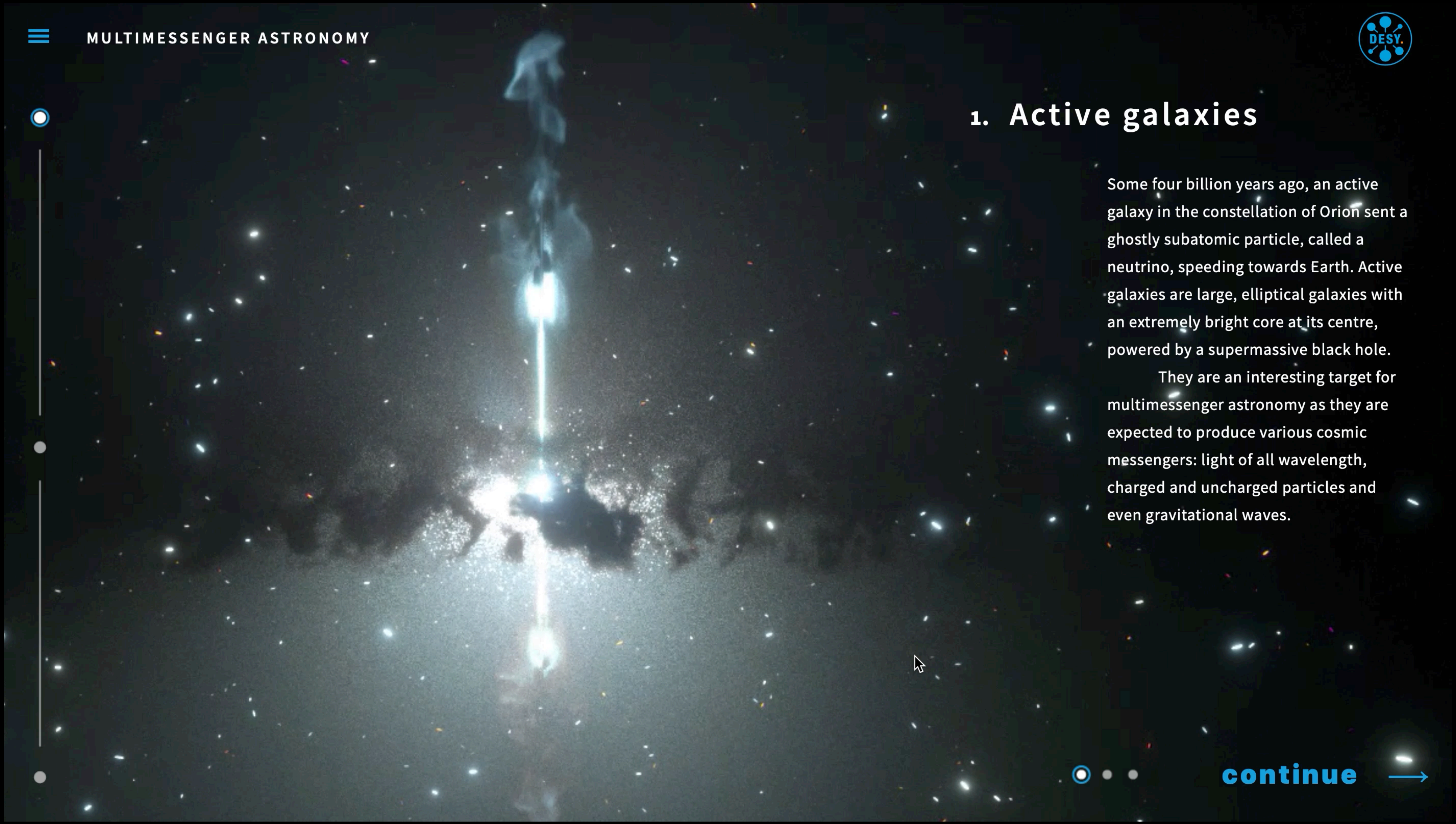

https://multimessenger.desy.de

Summary

- ✧ Astroparticle physics (Multi-Messengers)
  - ✧ Use astrophysical messengers and known particle physics to gain a deeper understanding of the dynamics of our Universe
  - ✧ Rapidly evolving field
  - ✧ Lots of ambitious projects
  - ✧ Will soon provide important tests to our knowledge over fundamental physics

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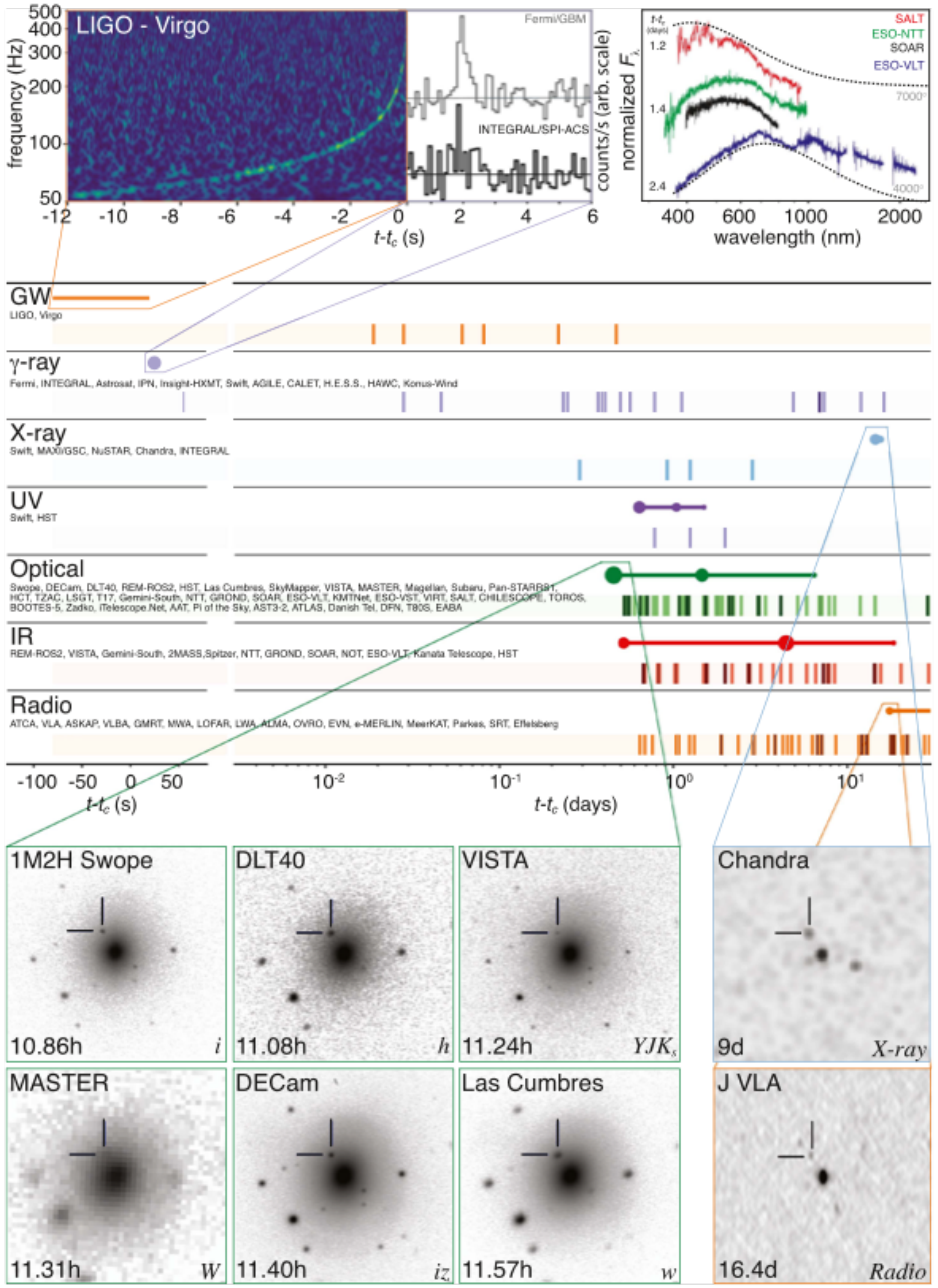
Backup slides

Multi-messenger observation of a Binary Neutron Star Merger

- Observe the same phenomenon with different instruments
- Follow the evolution in time
- Different wavelengths ⇒ different kind of interactions ⇒ different phenomena



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