Multimessenger Astrophysics

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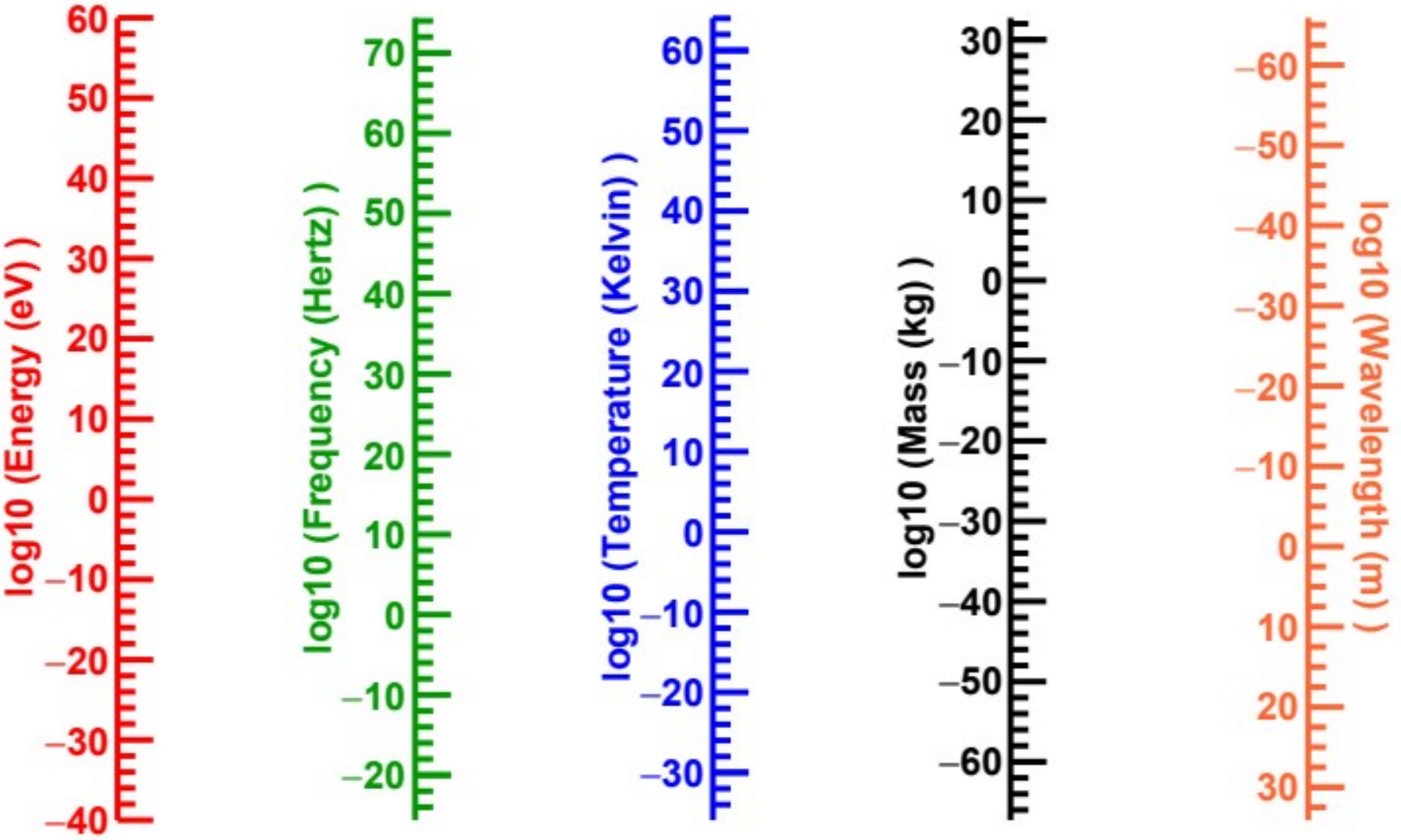
APOEMA

FAPESP

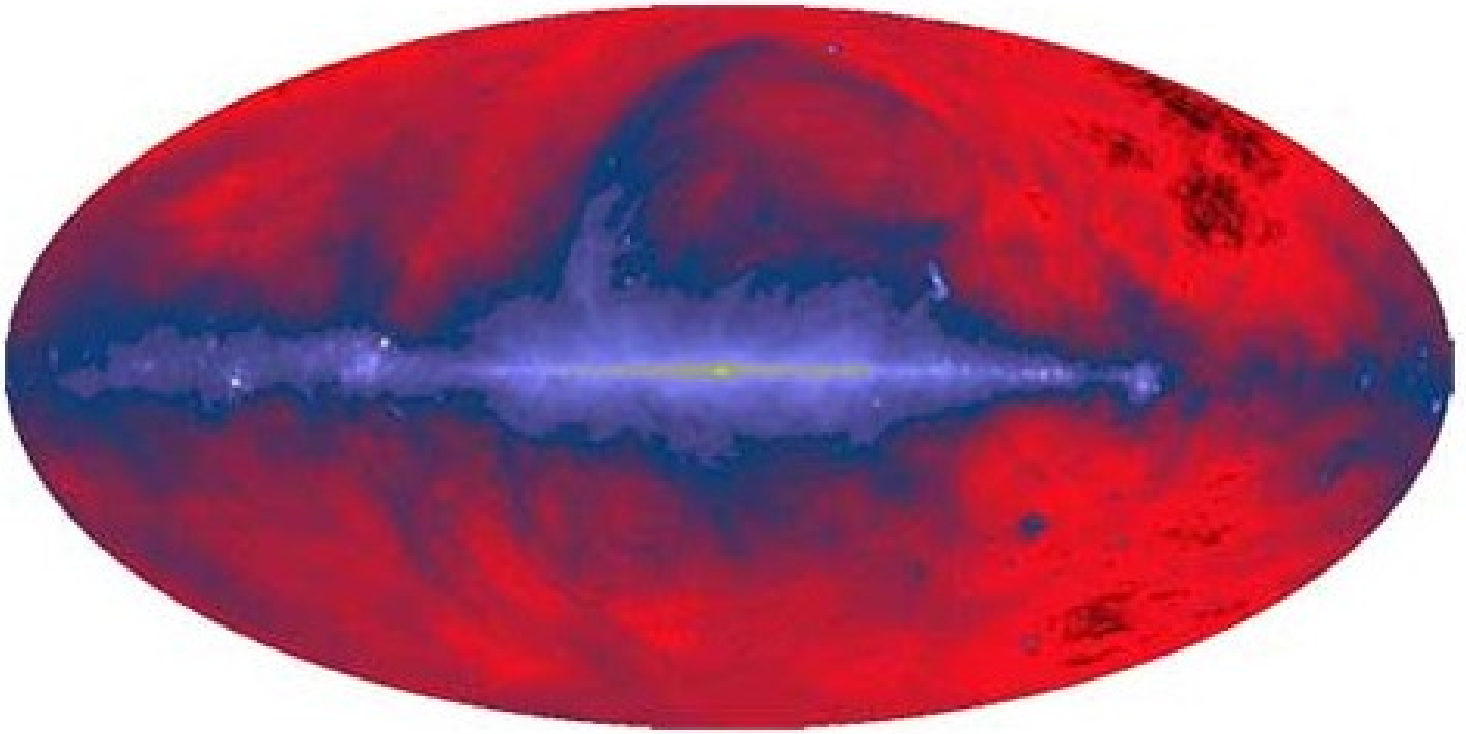
$$E^2 = p^2c^2 + m^2c^4 \qquad E = kT \qquad E = h\nu = \frac{hc}{\lambda}$$



$1\ \mathrm{eV} = 1.6 \times 10^{-19}\ \mathrm{Joule}$

Radio waves

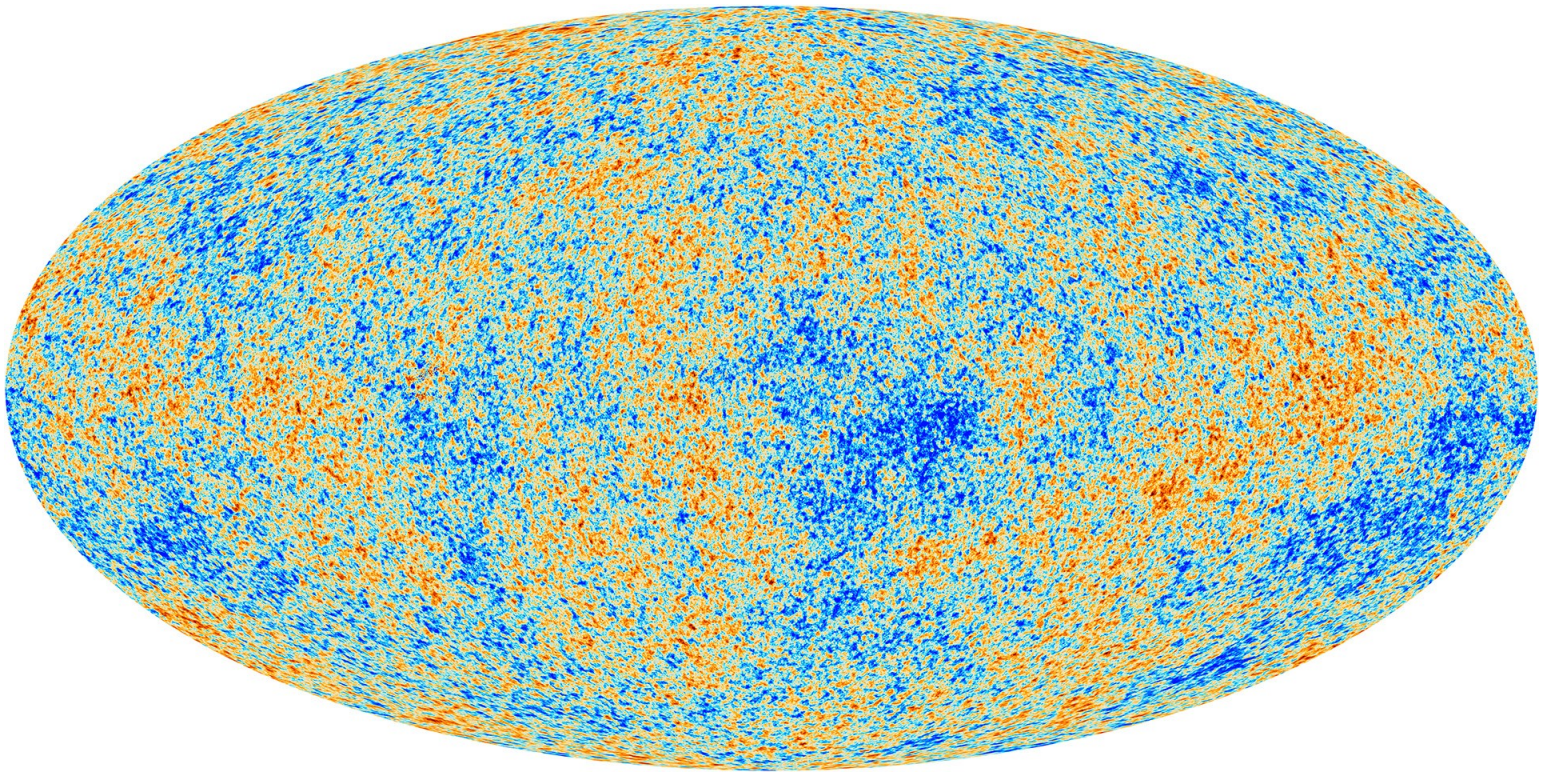
$$E \sim 10^{-6}\ \mathrm{eV} \Leftrightarrow \lambda \sim 1\ \mathrm{m}$$



C. Haslam et al., MPIfR, SkyView

Microwaves

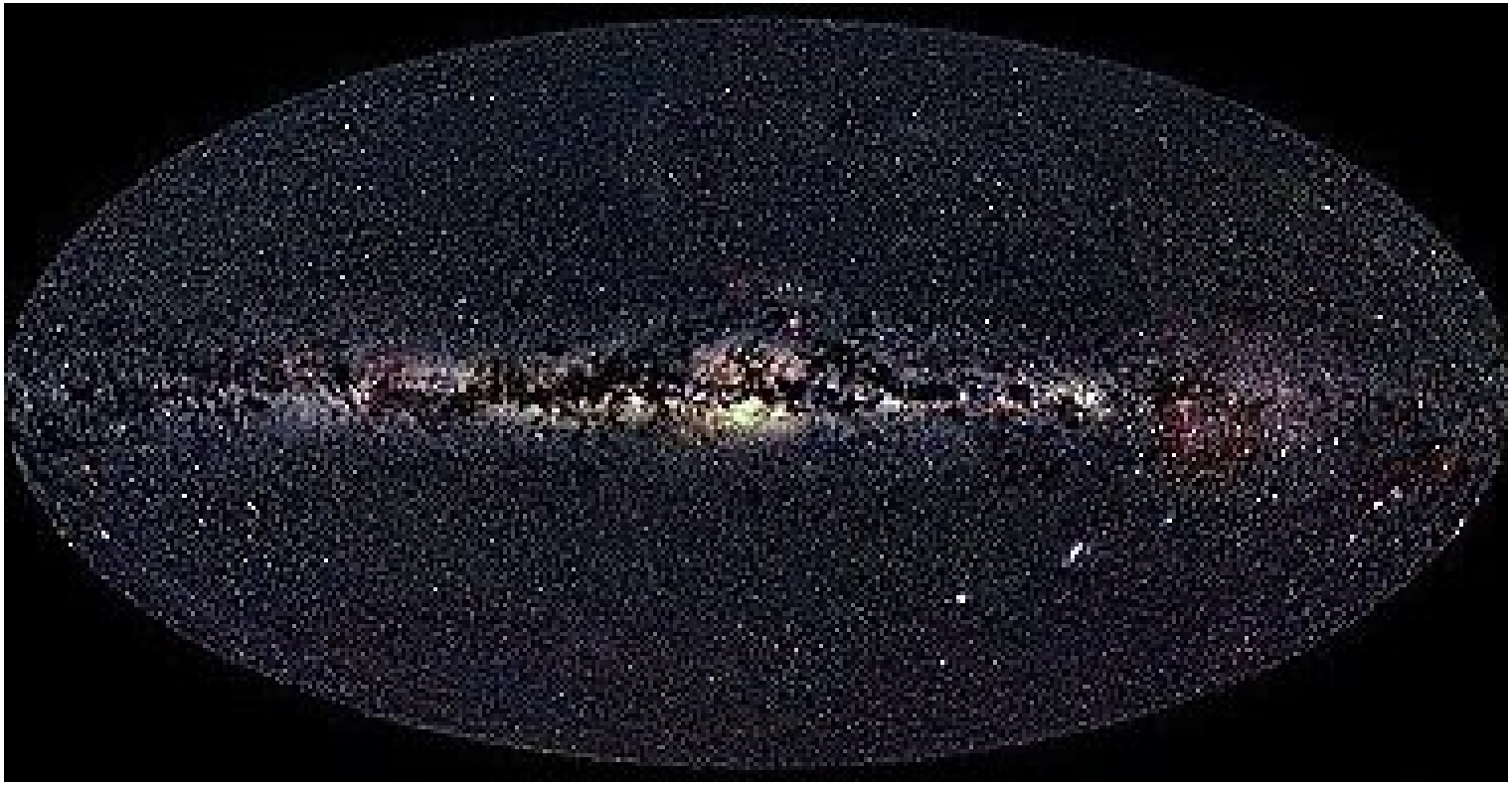
$$E \sim 10^{-4}\ \mathrm{eV} \Leftrightarrow \lambda \sim 10^{-2}\ \mathrm{m}$$



Planck

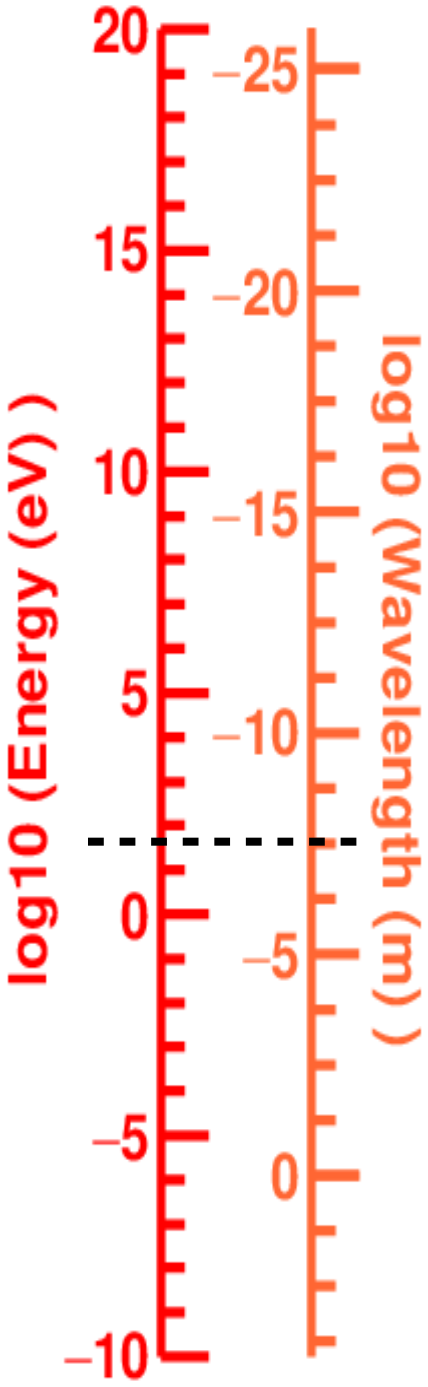
Visible light

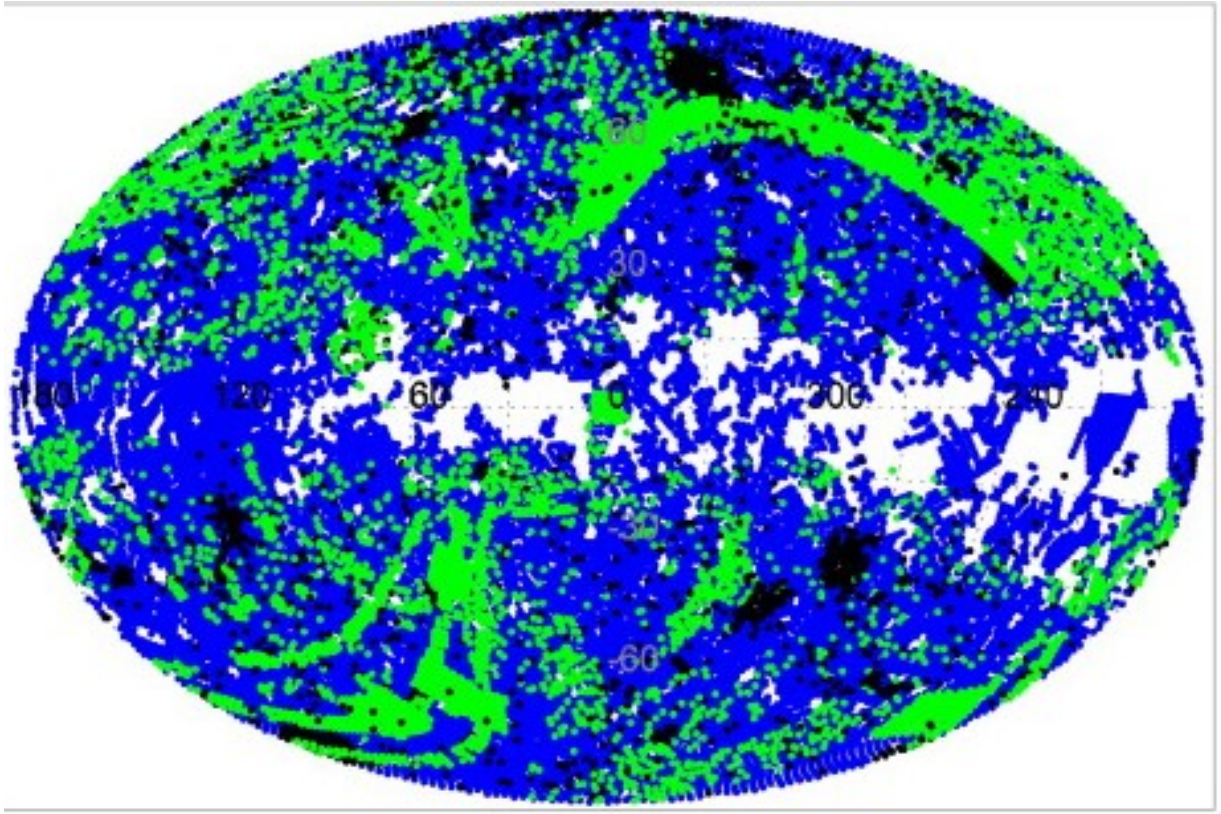
$$E \sim 1 \text{ eV} \Leftrightarrow \lambda \sim 10^{-6} \text{ m}$$



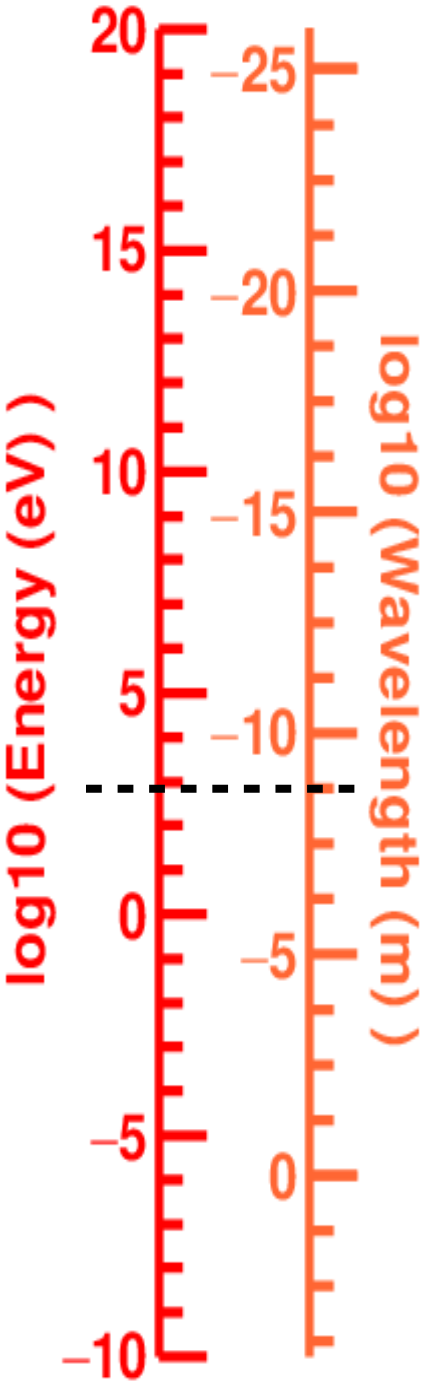
Ultraviolet

$$E \sim 100 \text{ eV} \Leftrightarrow \lambda \sim 10^{-8} \text{ m}$$



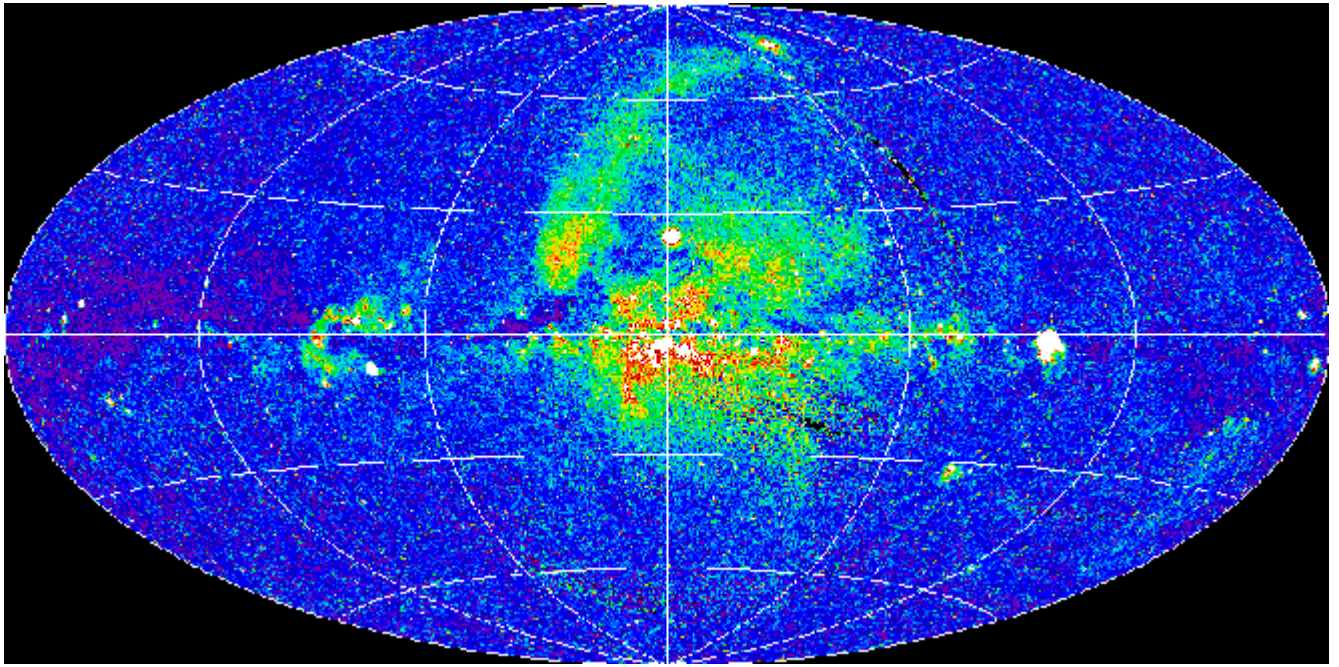


L. Bianchi et.al.,GALEX data



X-rays

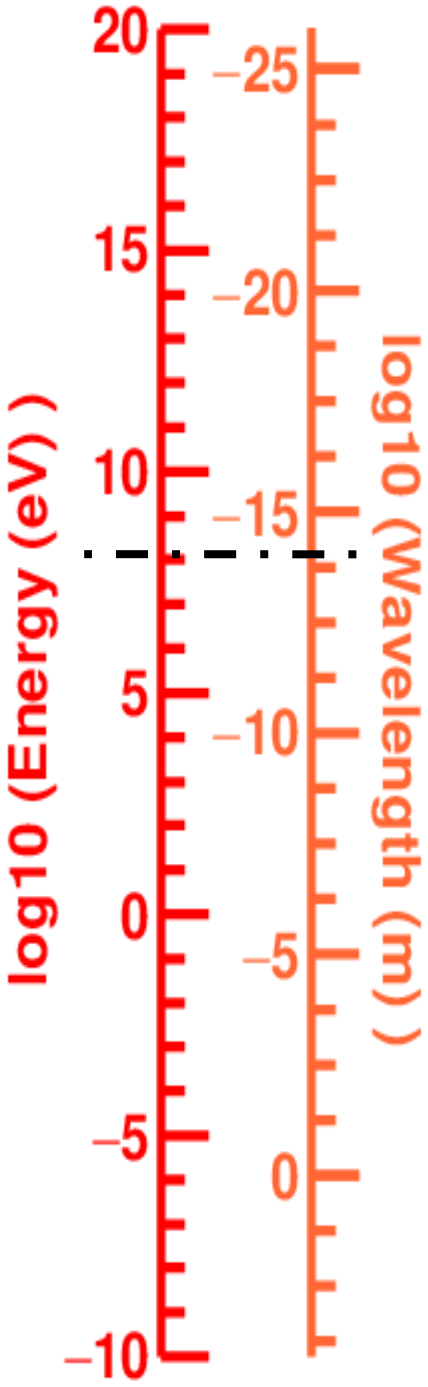
$$E \sim 1500 \text{ eV} \Leftrightarrow \lambda \sim 10^{-9} \text{ m}$$

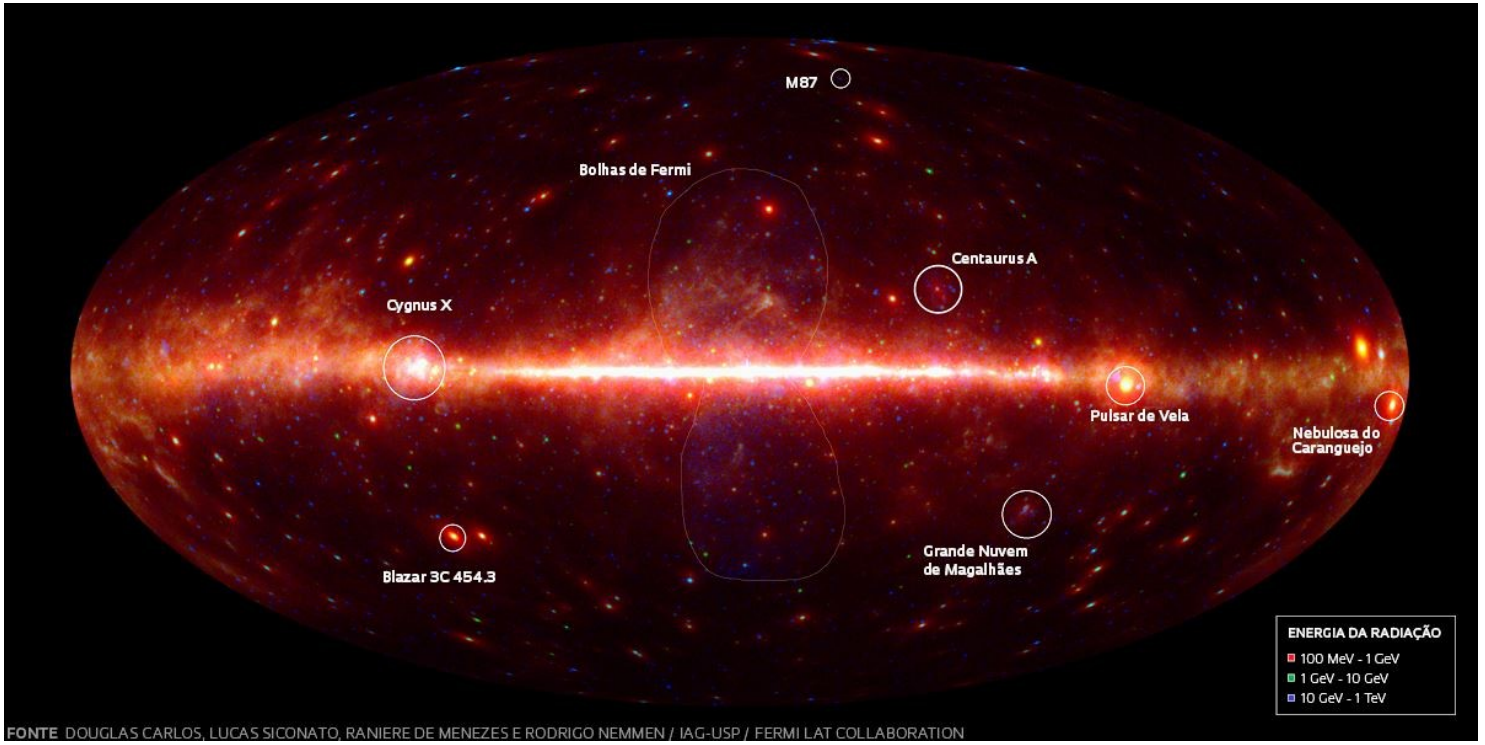


ROSAT - MPE

Gamma-rays

$$E > 10^8 \text{ eV} \Leftrightarrow \lambda < 10^{-14} \text{ m}$$

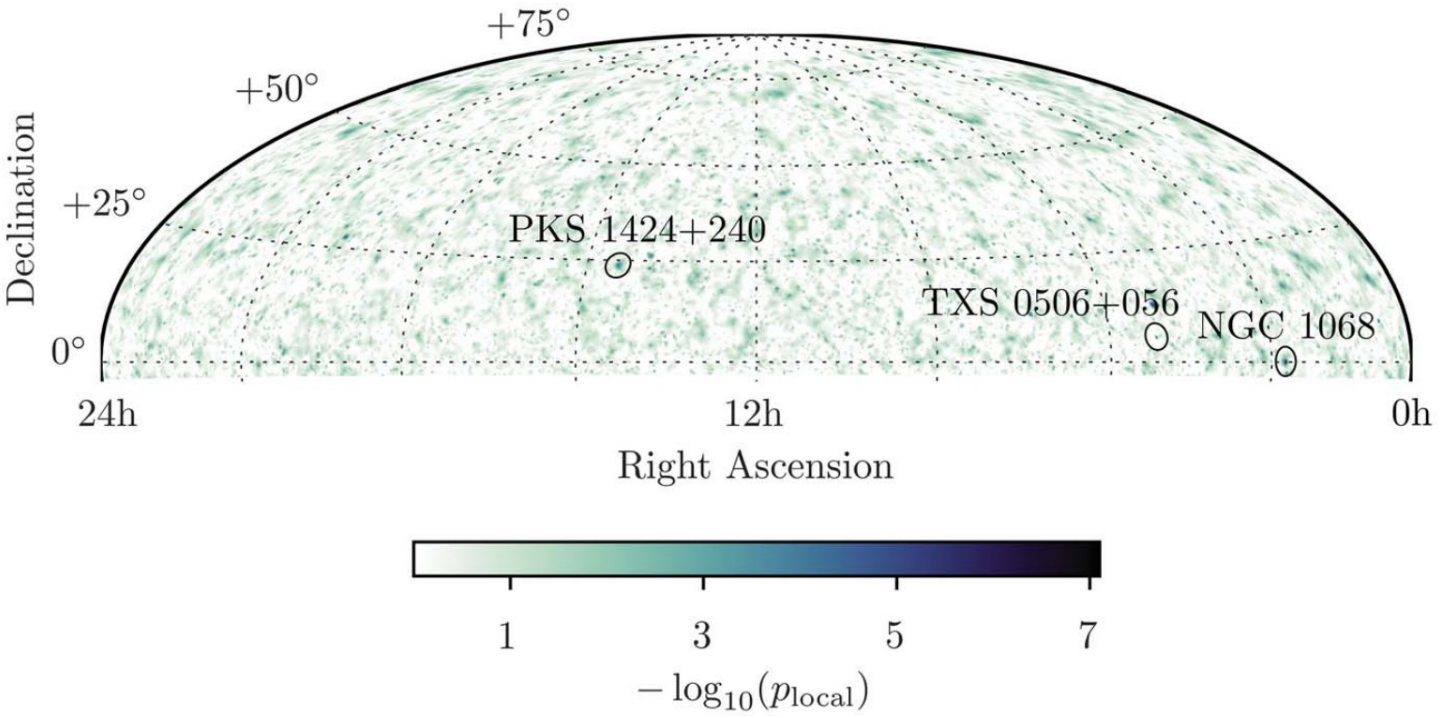




IAG/USP
Fermi-LAT

Neutrinos TeV

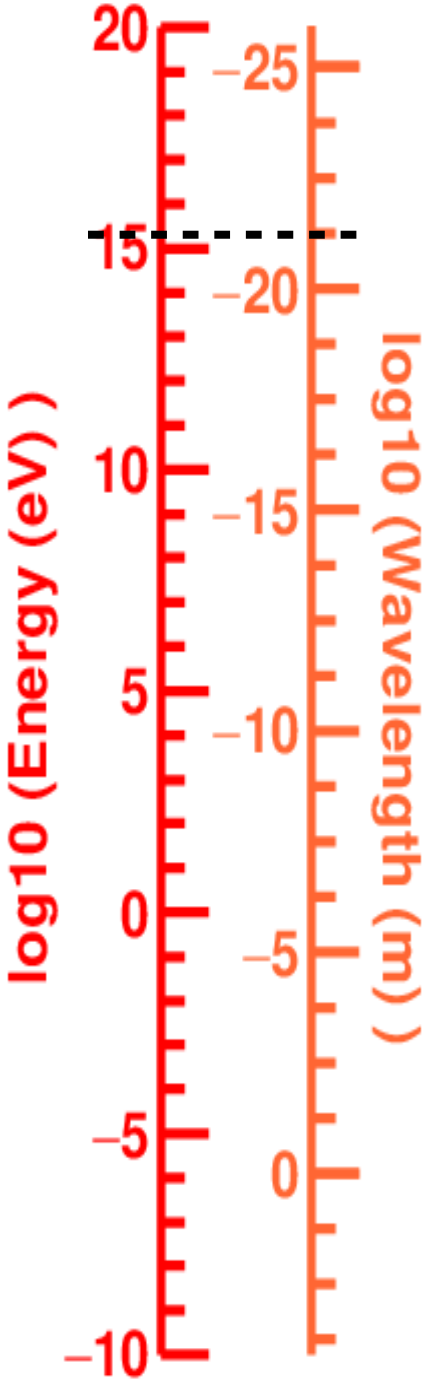
$$E > 10^{12}\ \text{eV} \Leftrightarrow \lambda < 10^{-17}\ \text{m}$$

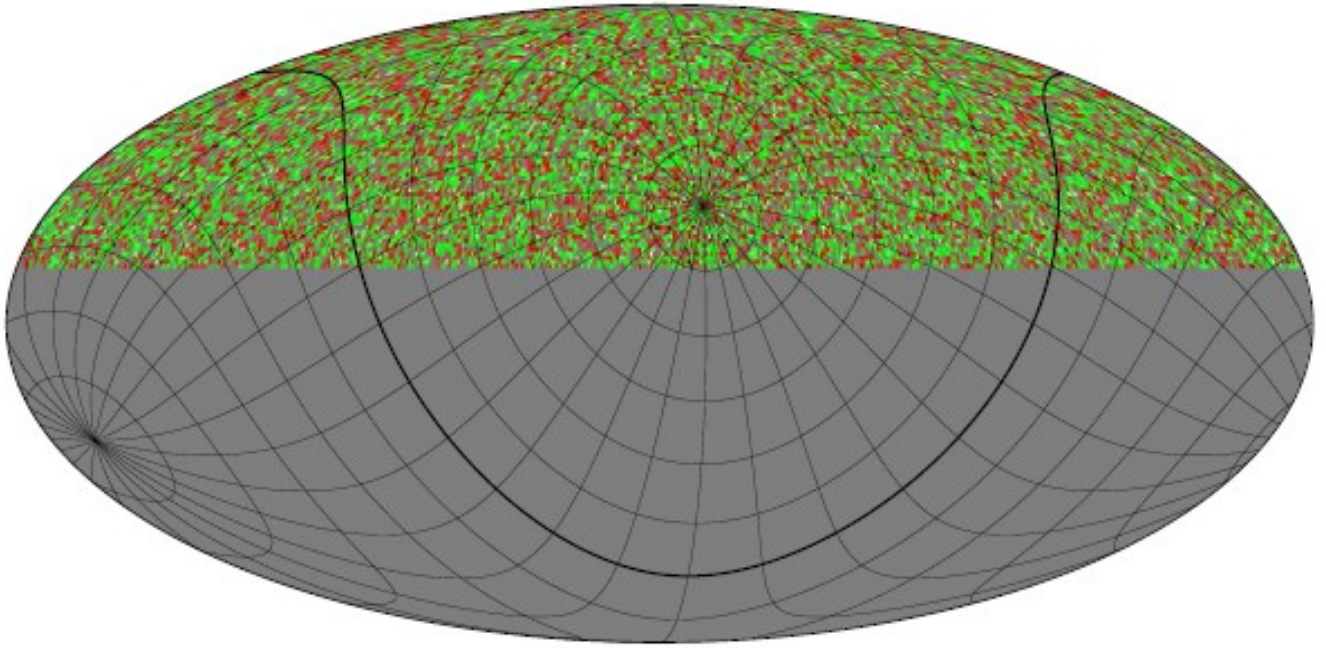


IceCube Collaboration

Charged Particles
Cosmic rays

$$E > 10^{15}\ \text{eV} \Leftrightarrow \lambda < 10^{-21}\ \text{m}$$

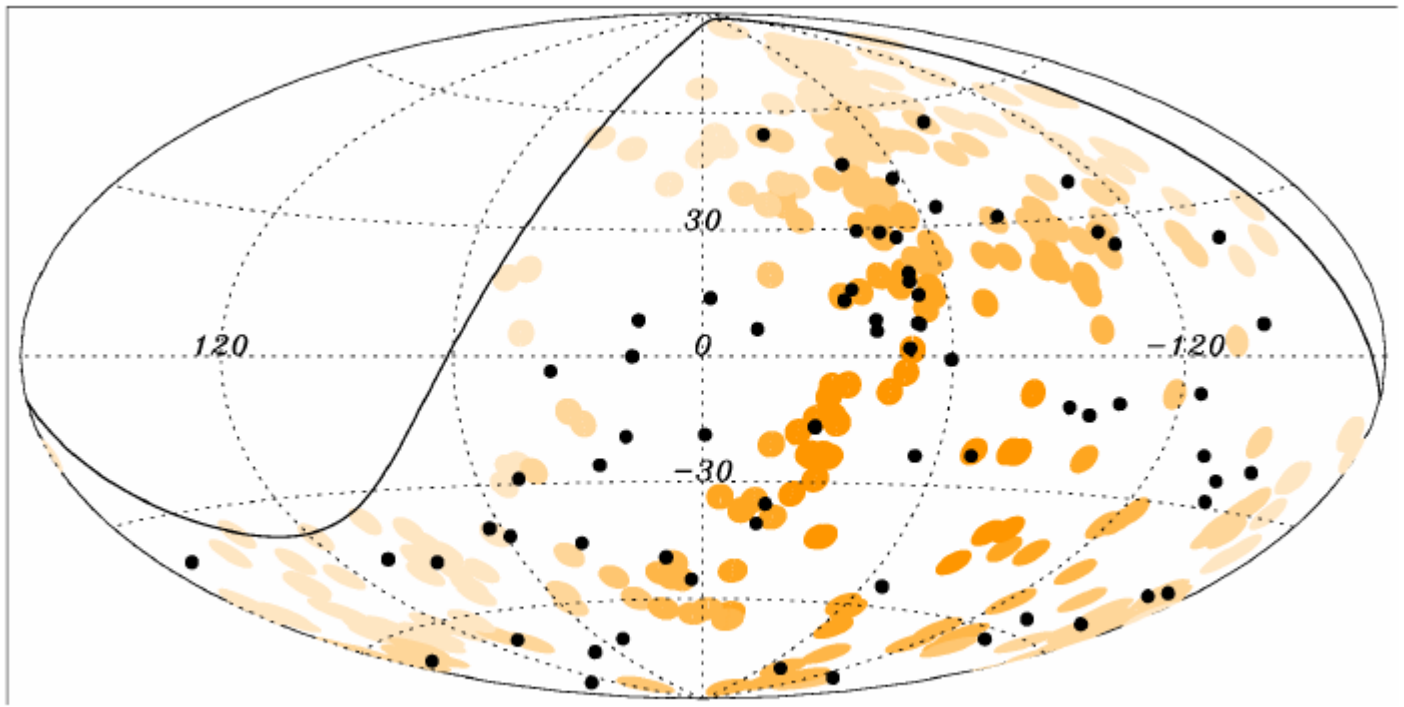




KASCADE

Charged Particles
Cosmic rays

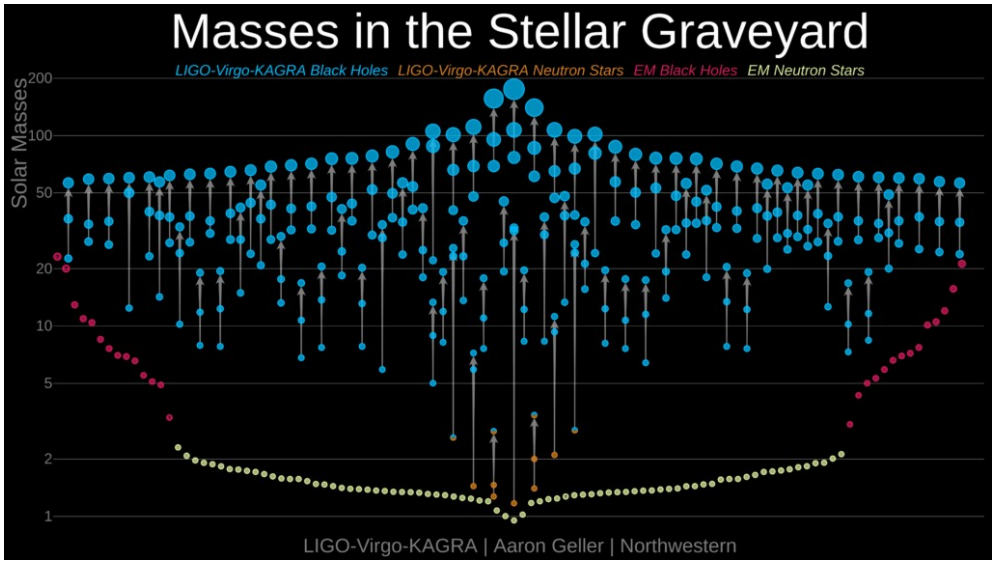
$$E > 10^{19}\ \text{eV} \Leftrightarrow \lambda < 10^{-25}\ \text{m}$$



Cosmic rays EeV = E > 10^{18} eV

$1\ \text{eV} = 1.6 \times 10^{-19}$ Joule

Gravitational waves

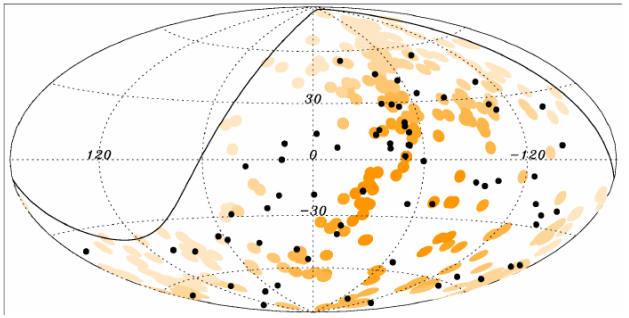


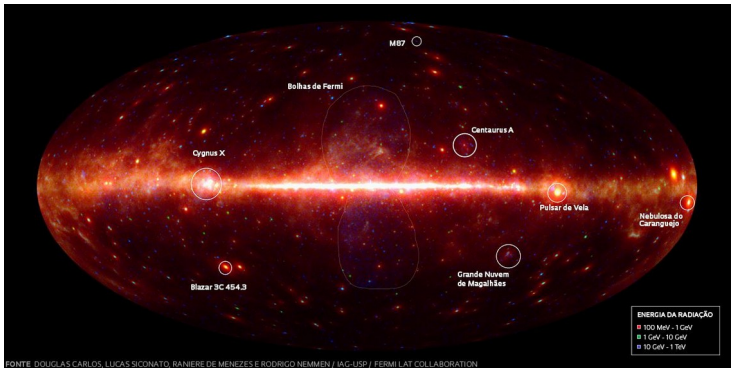
$$E_{released} > 10^{65}\, eV$$

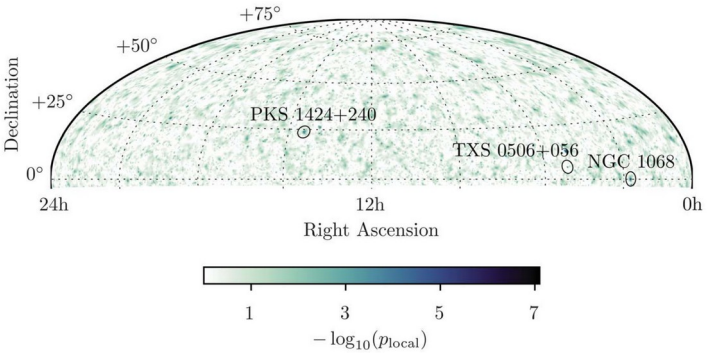
LIGO-Virgo-Kagra

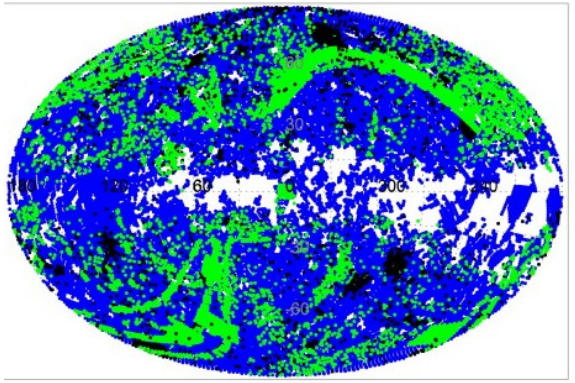
log10 (Energy (eV))

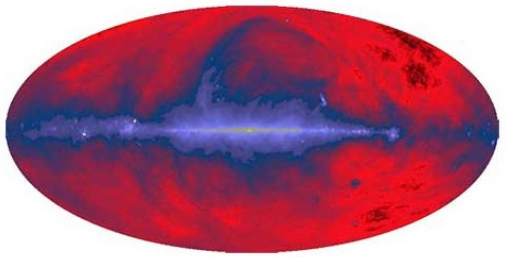
60
50
40
30
20
10
0
−10
−20
−30
−40

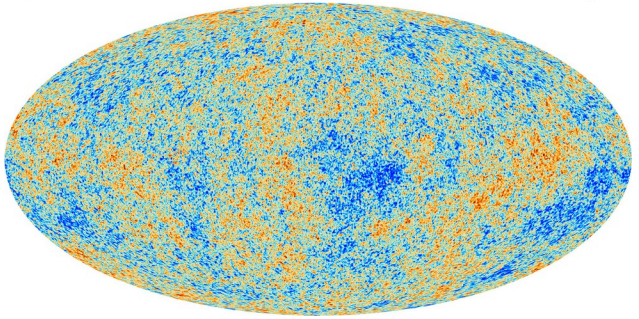






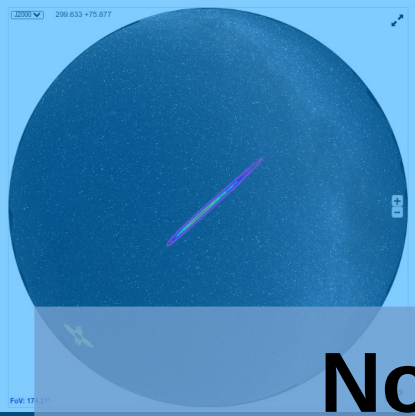


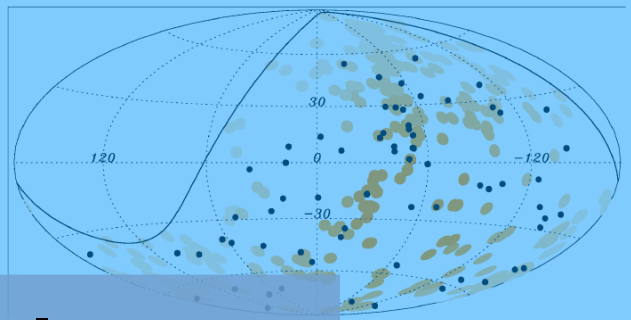




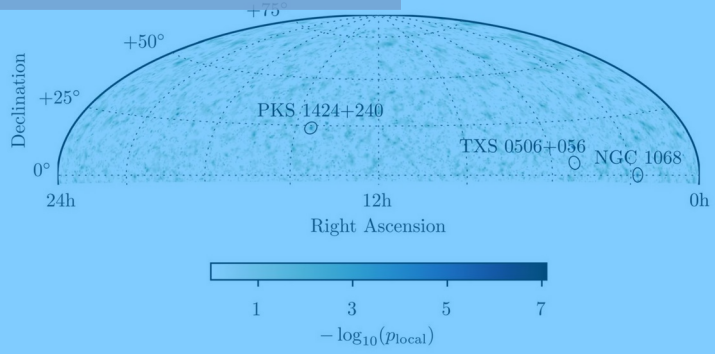
log10 (Energy (eV))

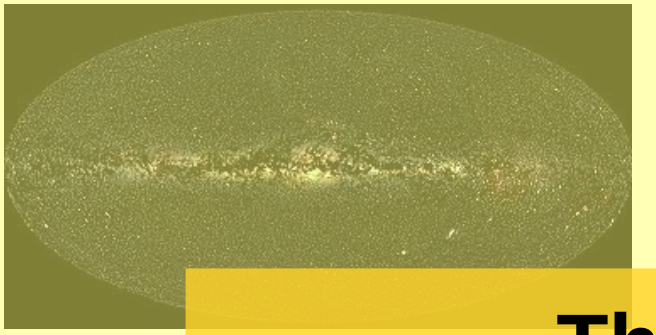
60 50 40 30 20 10 0 −10 −20 −30 −40

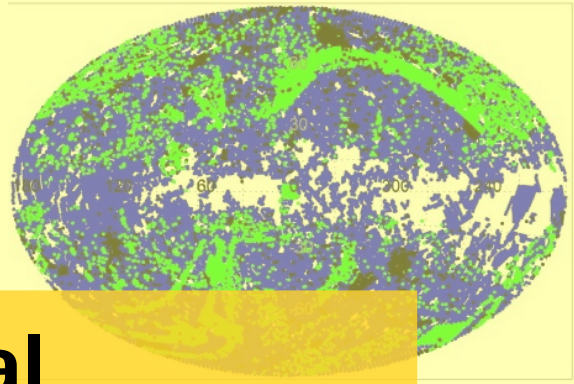




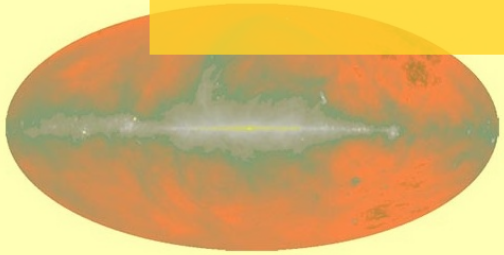
Non-thermal

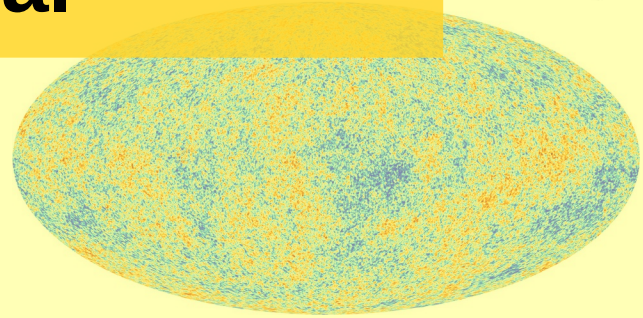




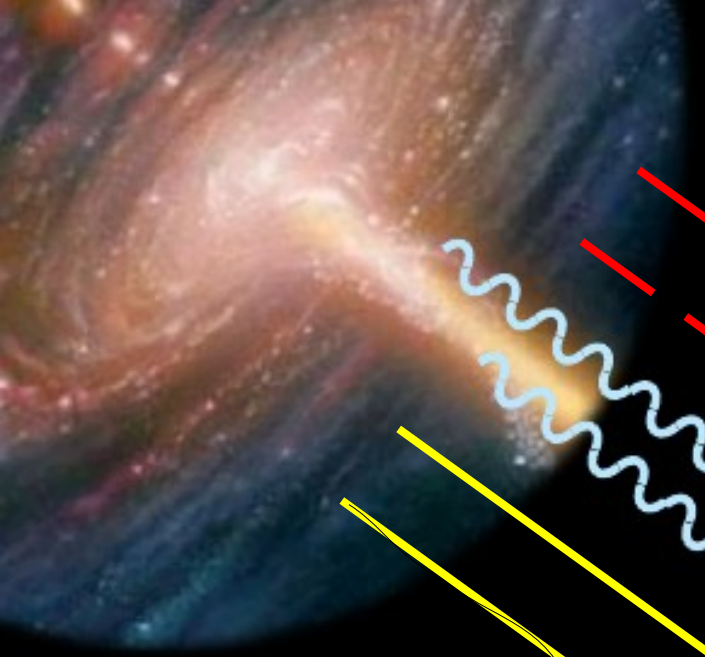


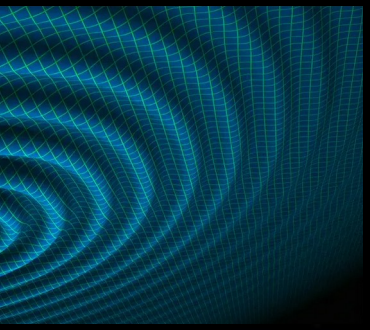
Thermal





Multimessenger Astrophysics





NEUTRINOS

GAMMA RAYS

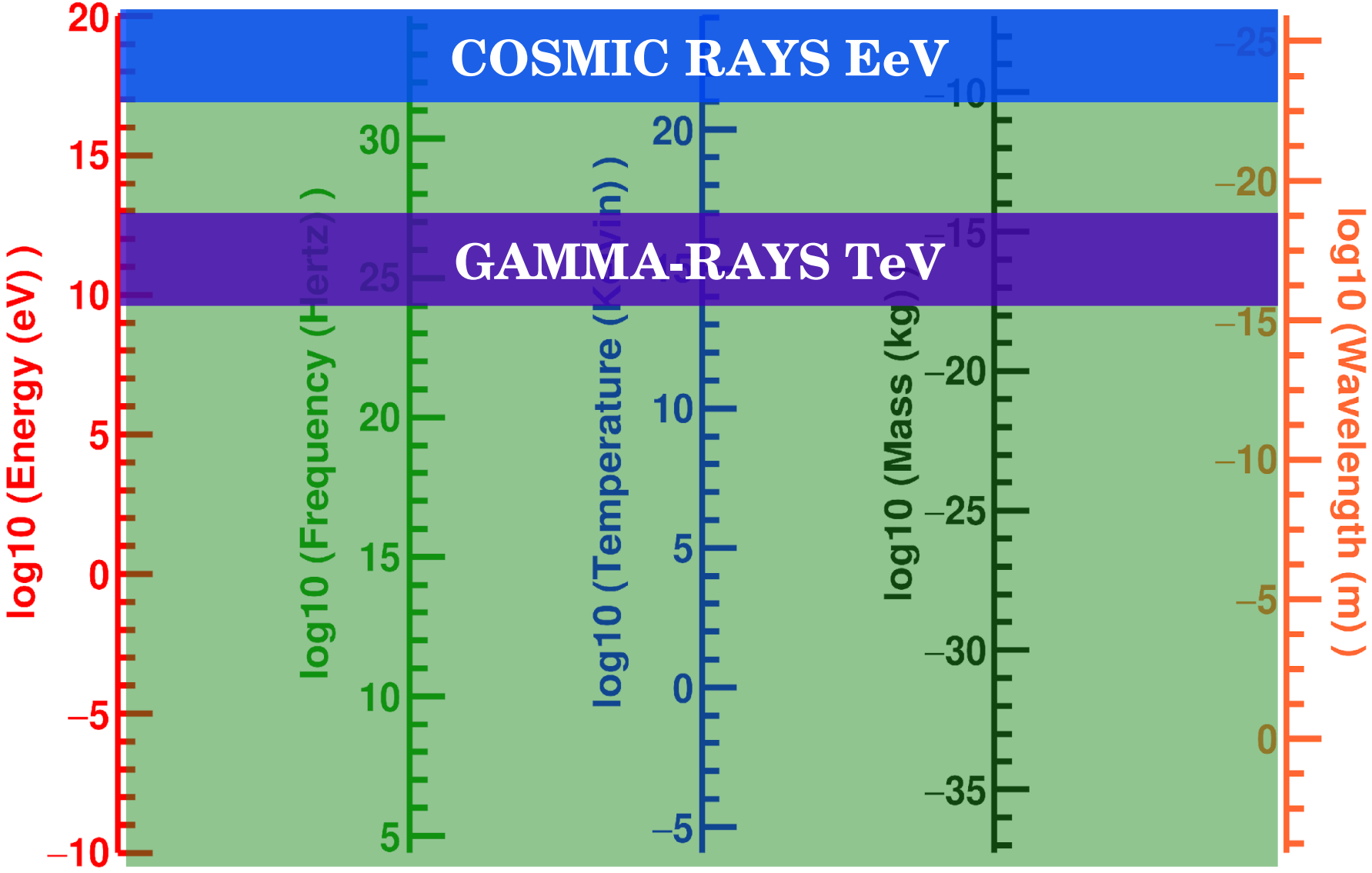
COSMIC RAYS

GRAVITATIONAL WAVES

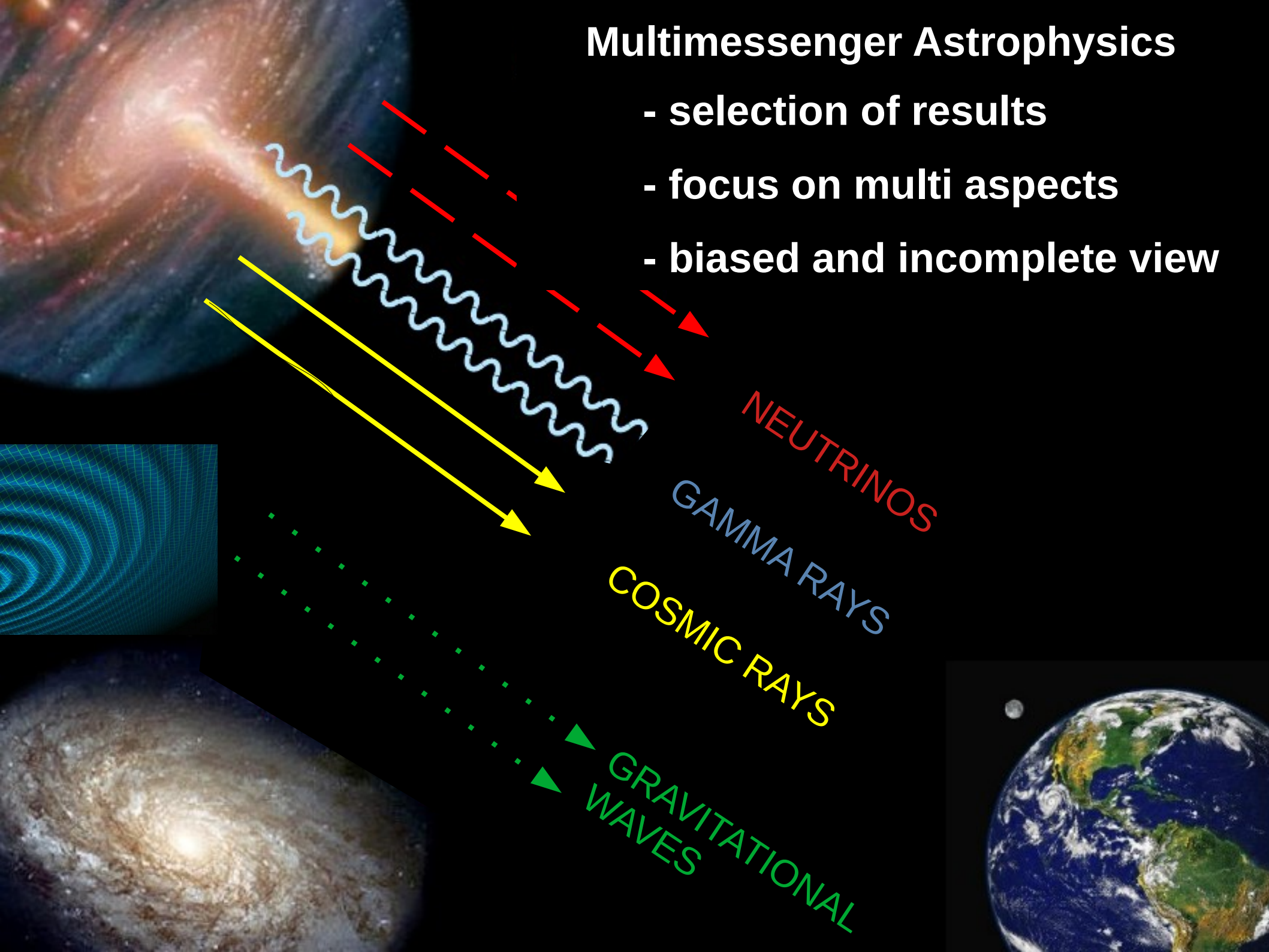
Why ?
Because Multimessenger Astrophysics:

- Probes the highest energetic phenomena
- Highlights physics of the four forces
- Searches for the dark components
- Teaches acceleration mechanisms
- Tests of our current knowledge

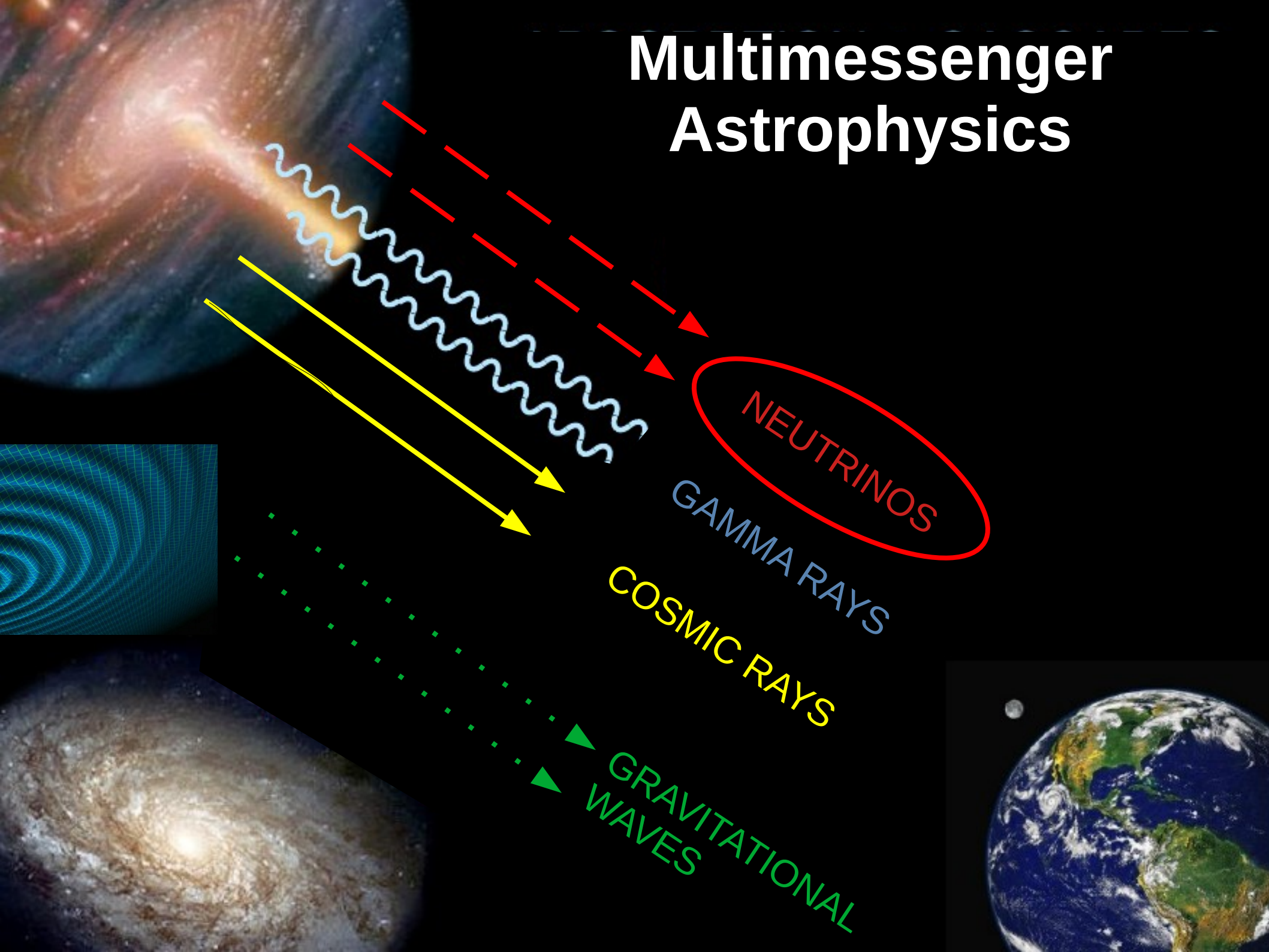
Probes to the highest energetic phenomena



HOME OF THE FOUR FORCES


Multimessenger Astrophysics
- selection of results
- focus on multi aspects
- biased and incomplete view
NEUTRINOS
GAMMA RAYS
COSMIC RAYS
GRAVITATIONAL WAVES

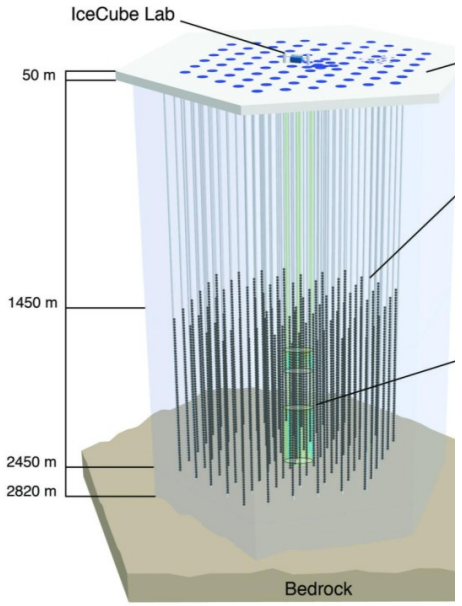
Multimessenger Astrophysics



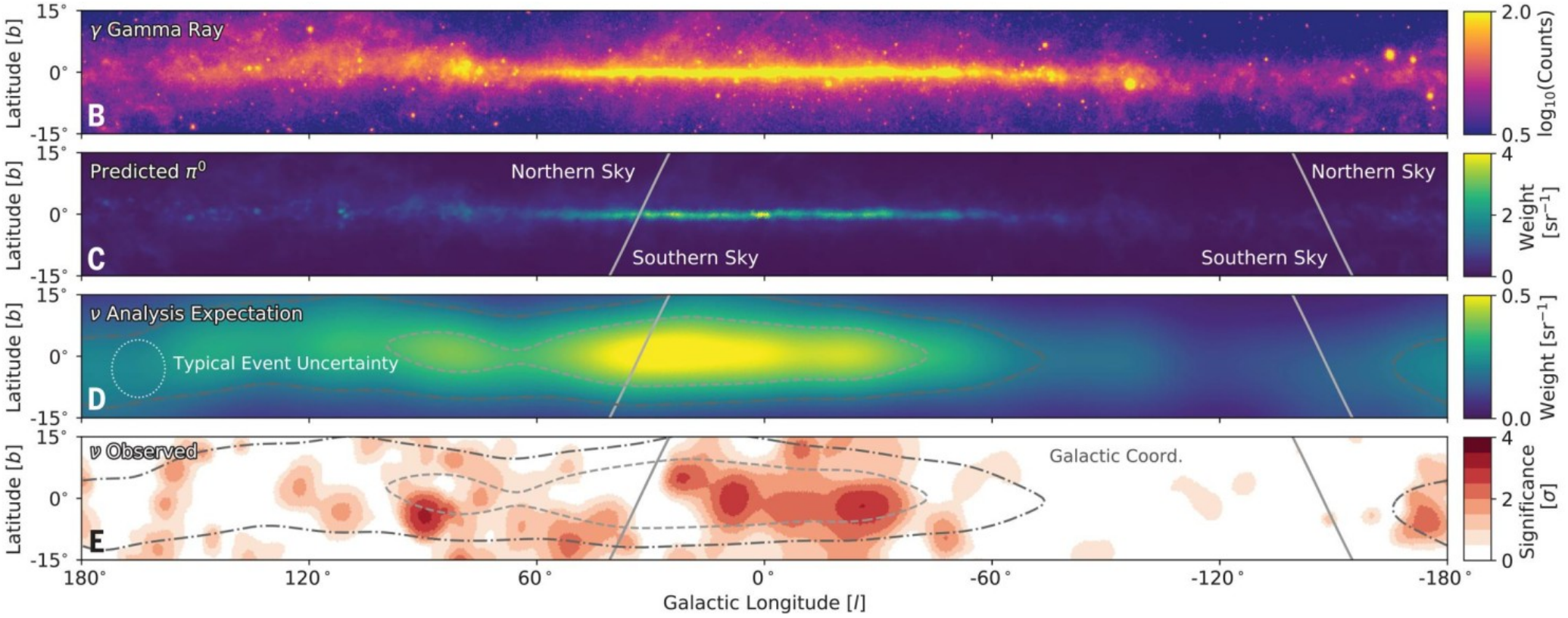
IceCube

Galactic neutrinos

Lisa Schumacher (ICHEP 2024)



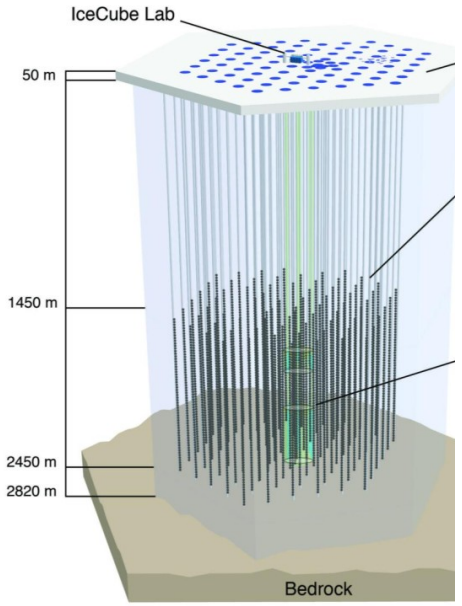
No evidence of correlation with known TeV gamma-ray sources



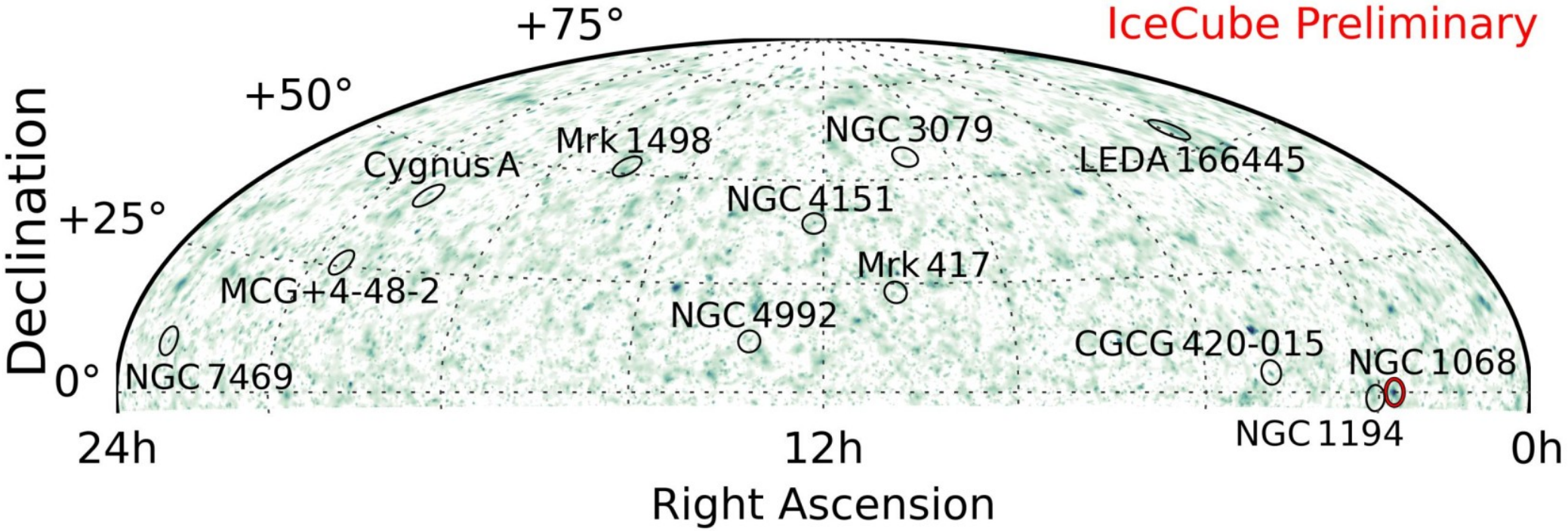
IceCube

Extragalactic neutrinos

Lisa Schumacher (ICHEP 2024)



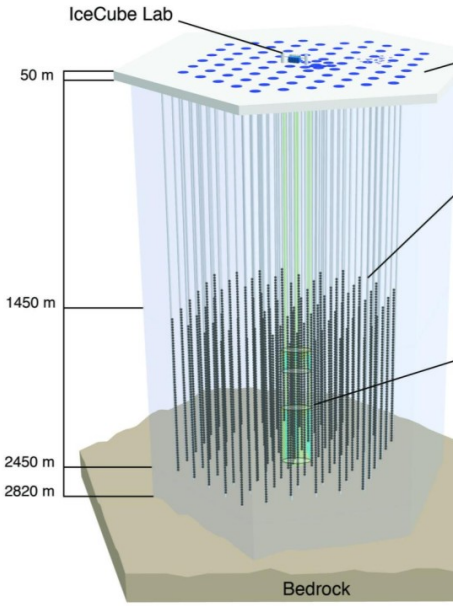
Correlation ??

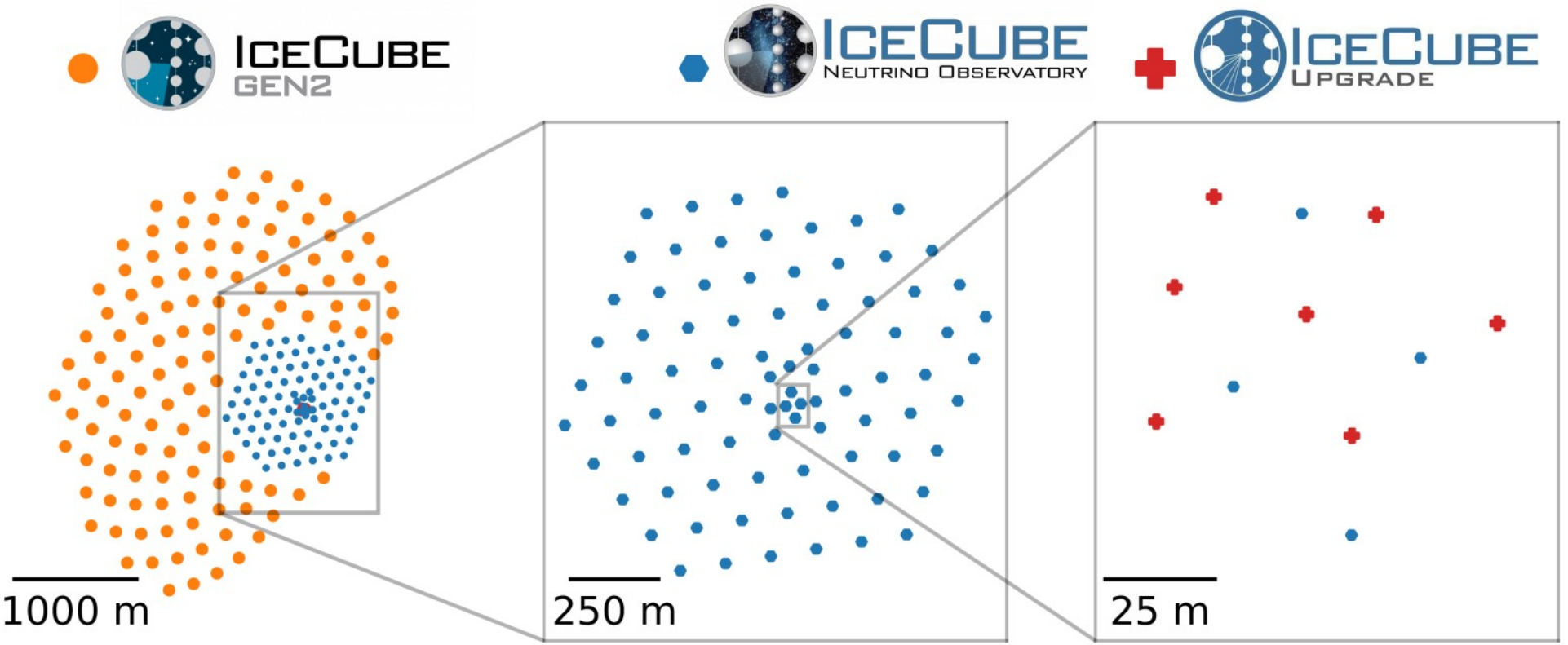


IceCube

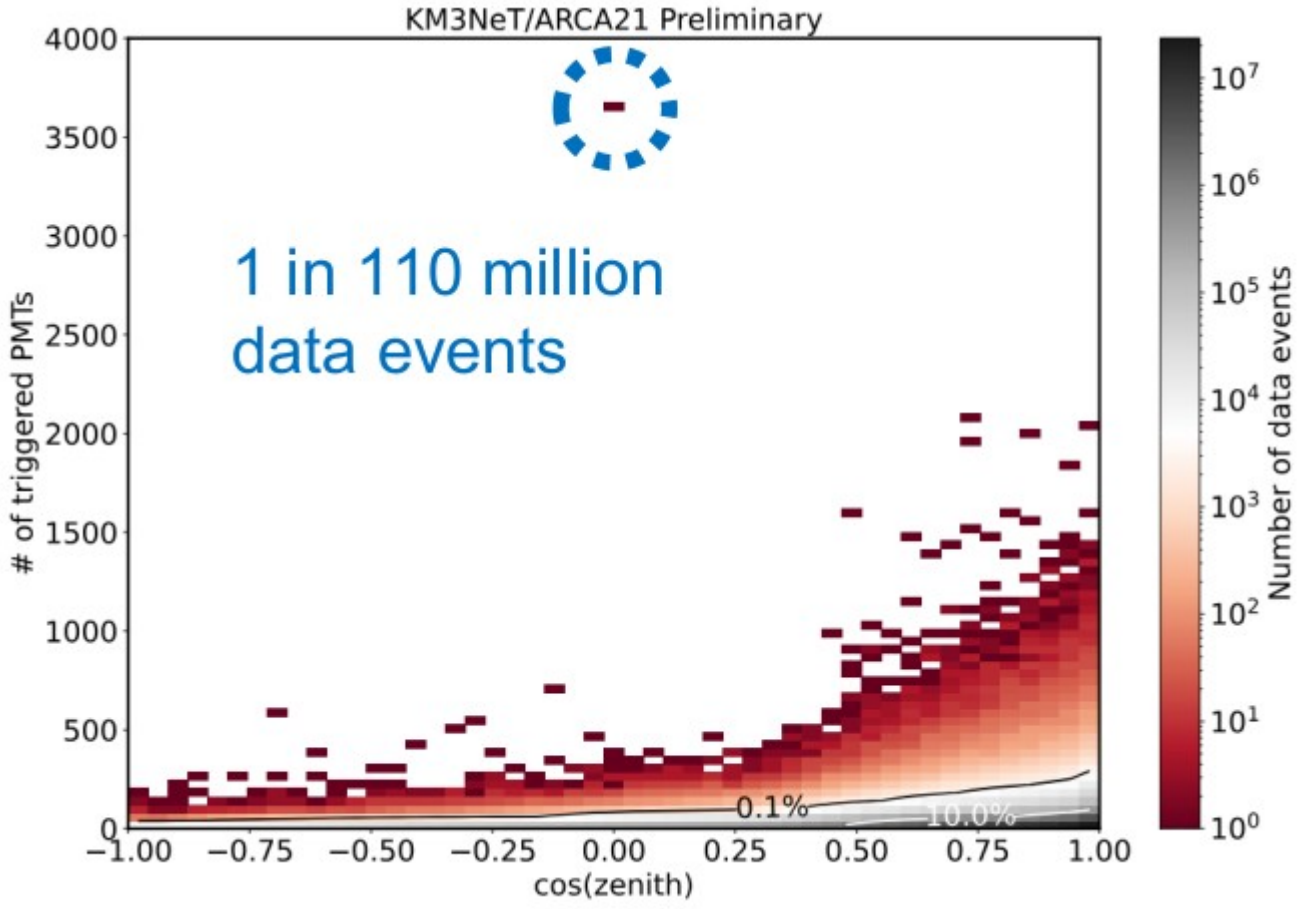
Upgrades

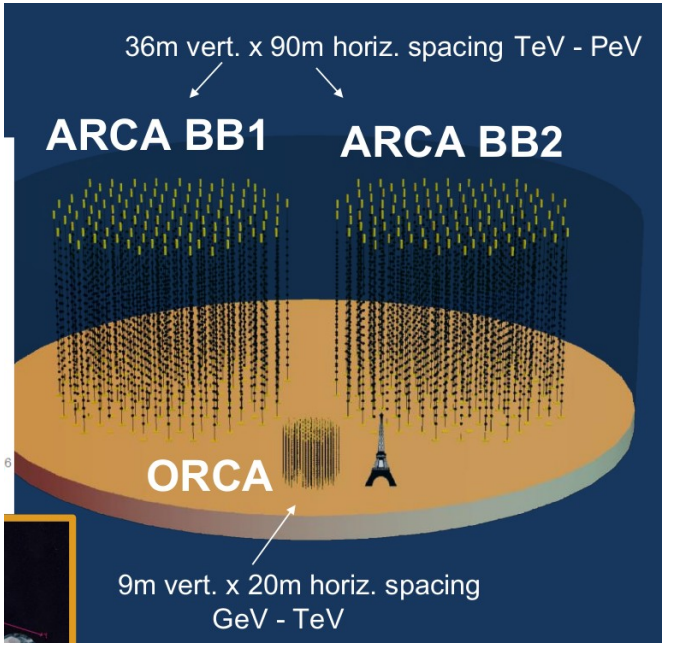
Lisa Schumacher (ICHEP 2024)





News from KM3NeT / ARCA
Paschal Coyle (ICHEP 2024)





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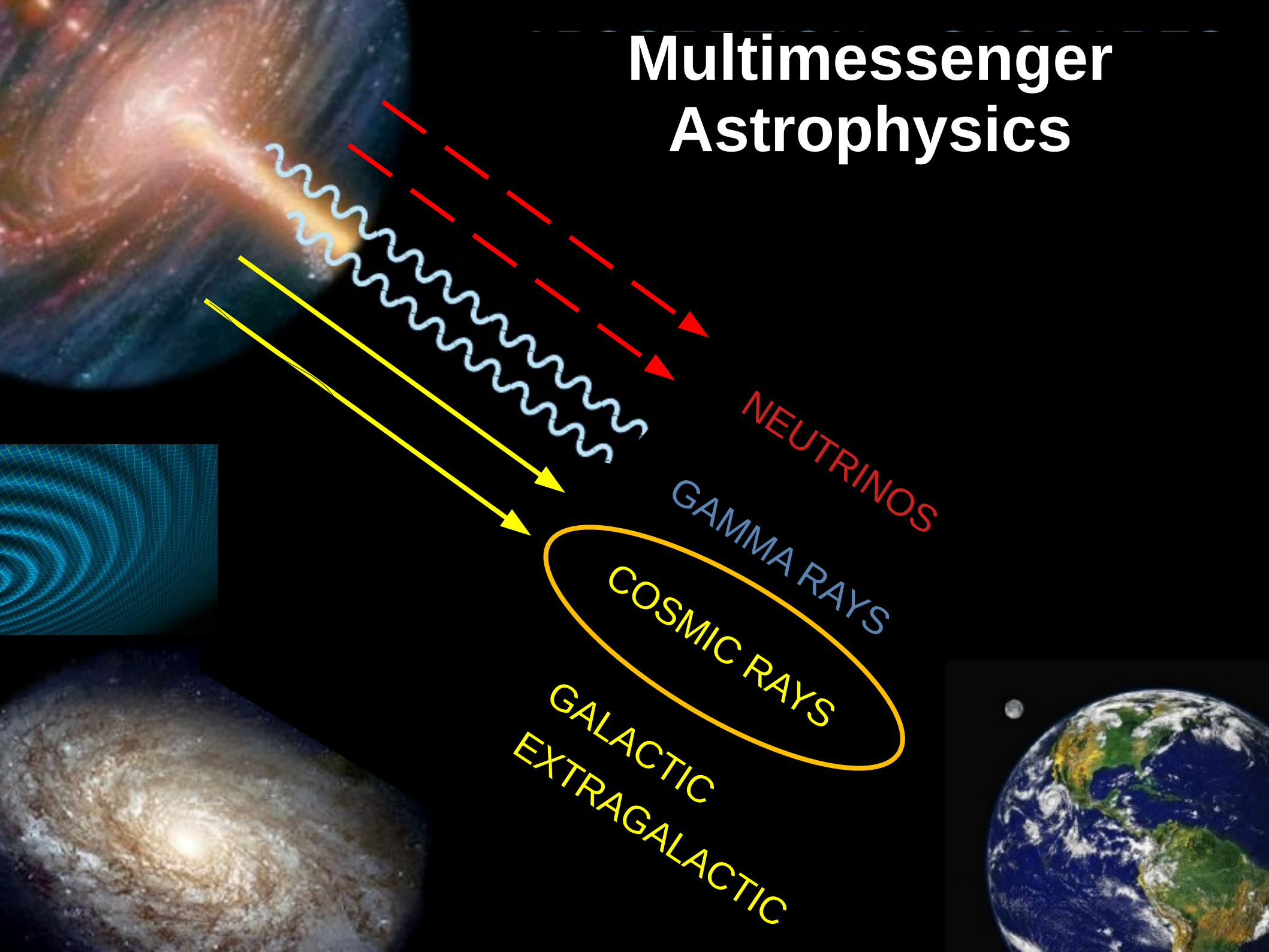
NEWS | 21 June 2024

'Fantastic' particle could be most energetic neutrino ever detected

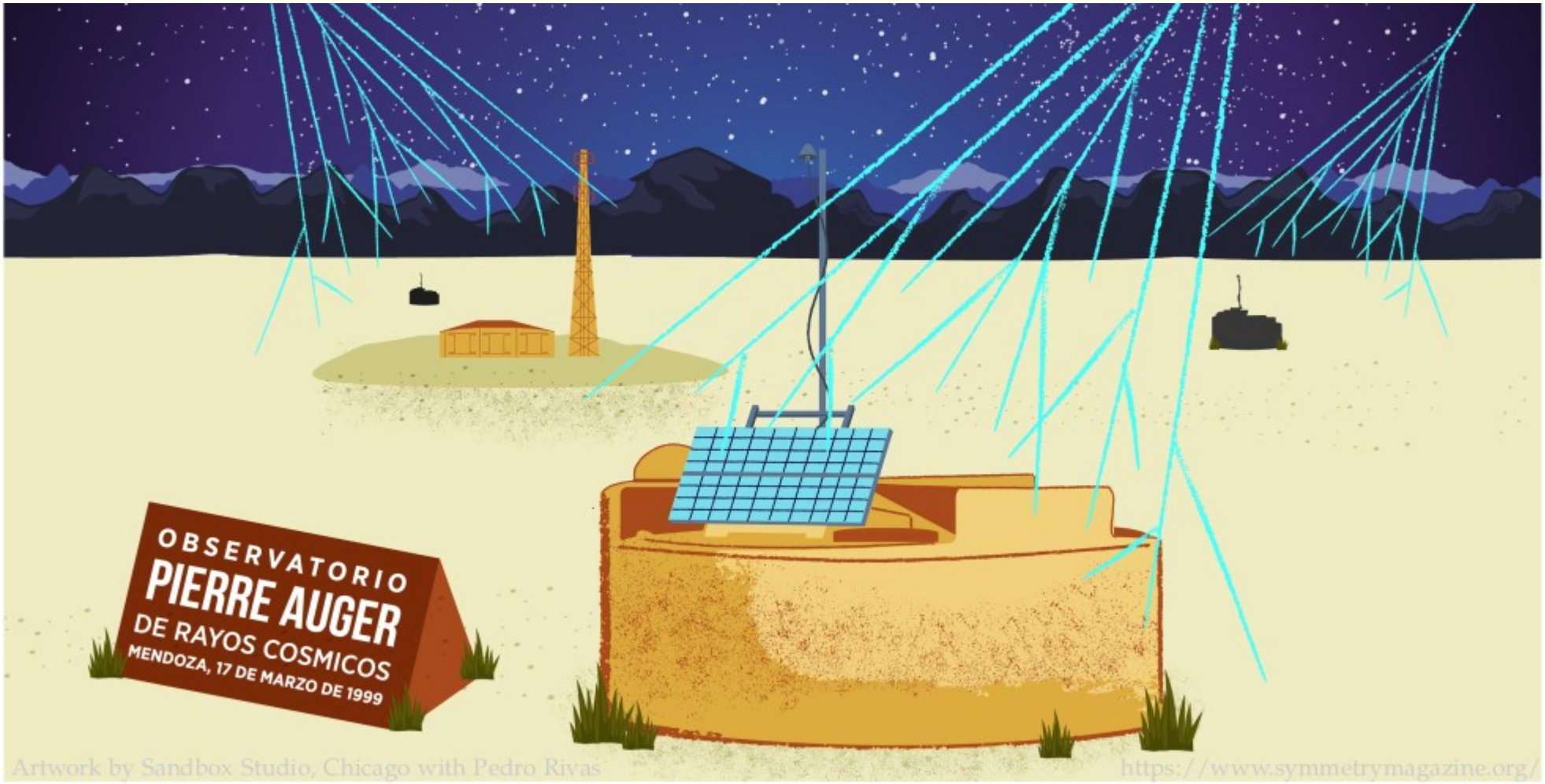
The ultra-high-energy neutrino was spotted by deep-sea detectors and could point to a massive cosmic event.

By Davide Castelvecchi

Multimessenger Astrophysics



Pierre Auger Observatory

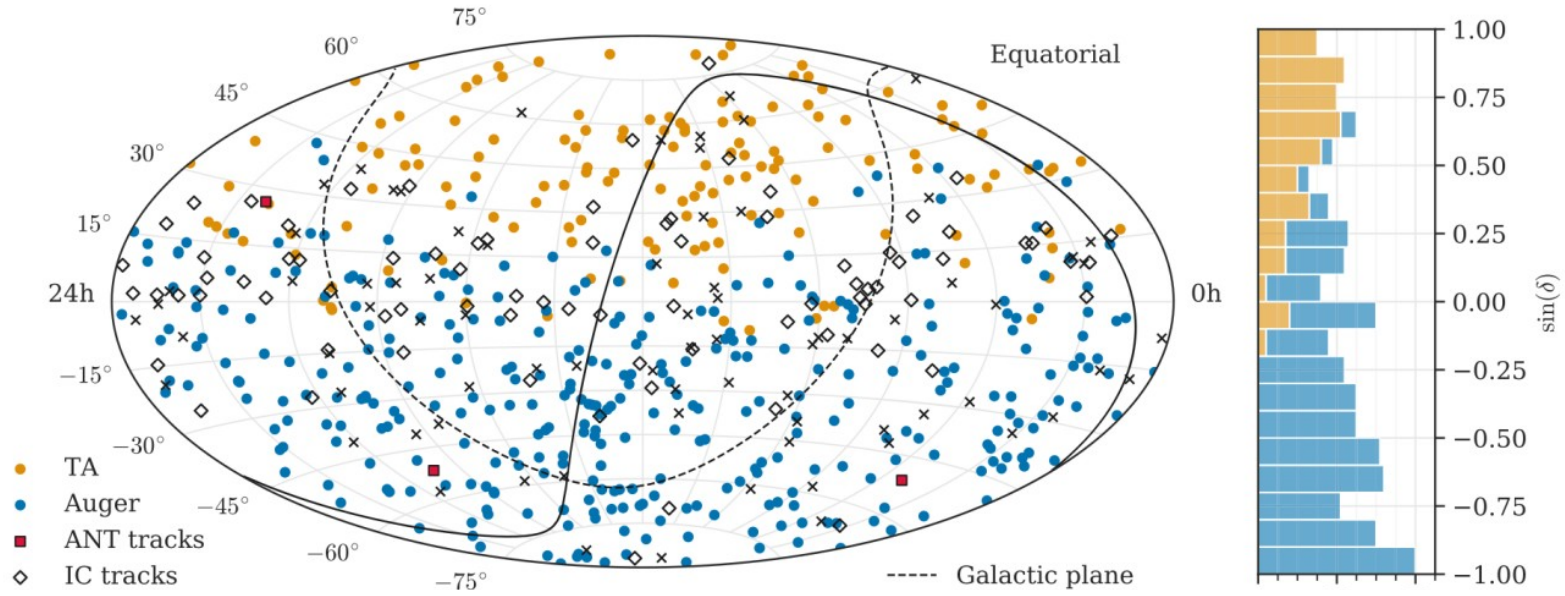


Extragalactic cosmic rays

Pierre Auger Observatory

Alexey Yushov (ICHEP 2024)

UHECR correlation (Auger $E > 52$ EeV) with IceCube and ANTARES neutrinos

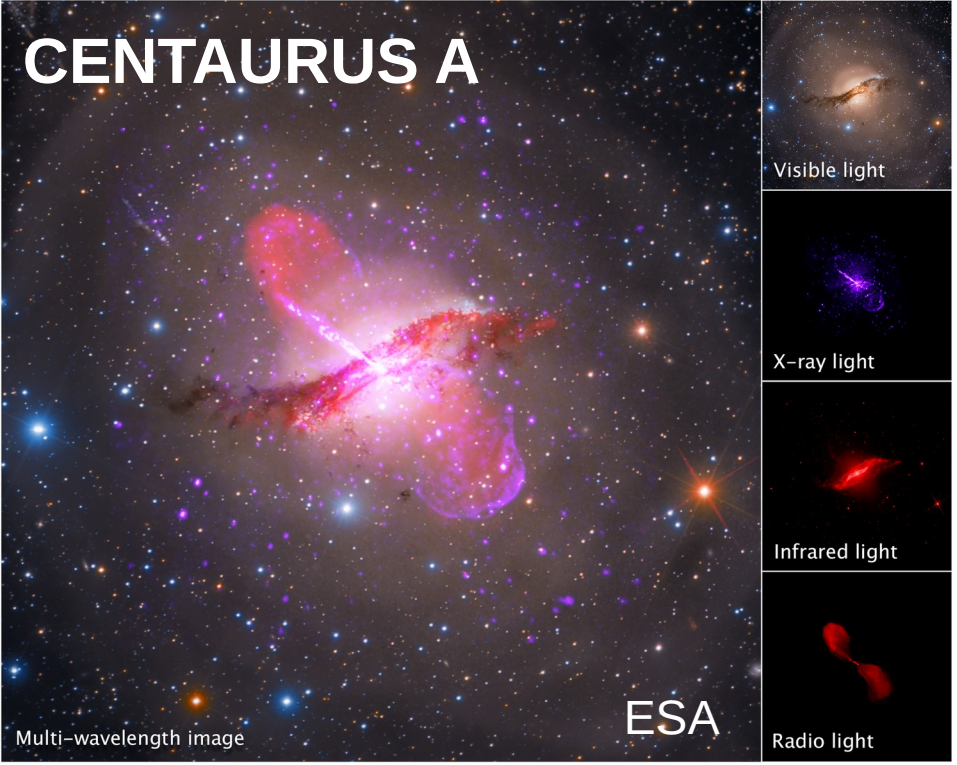


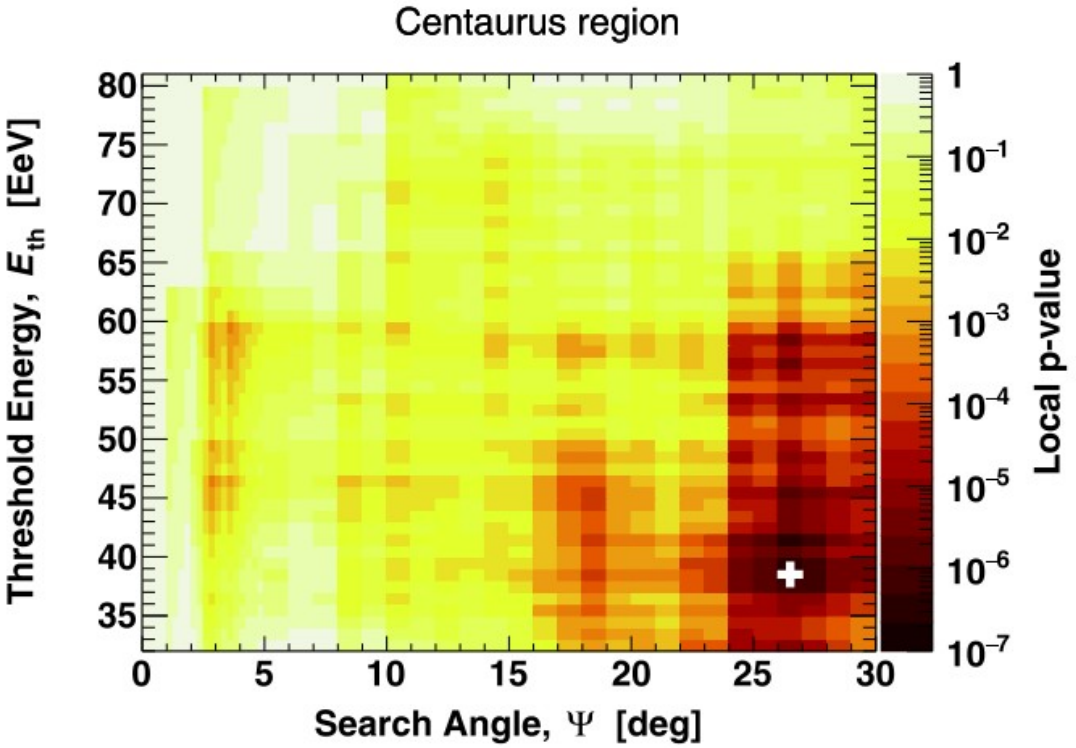
Astrophys. J. 934 (2022) 164

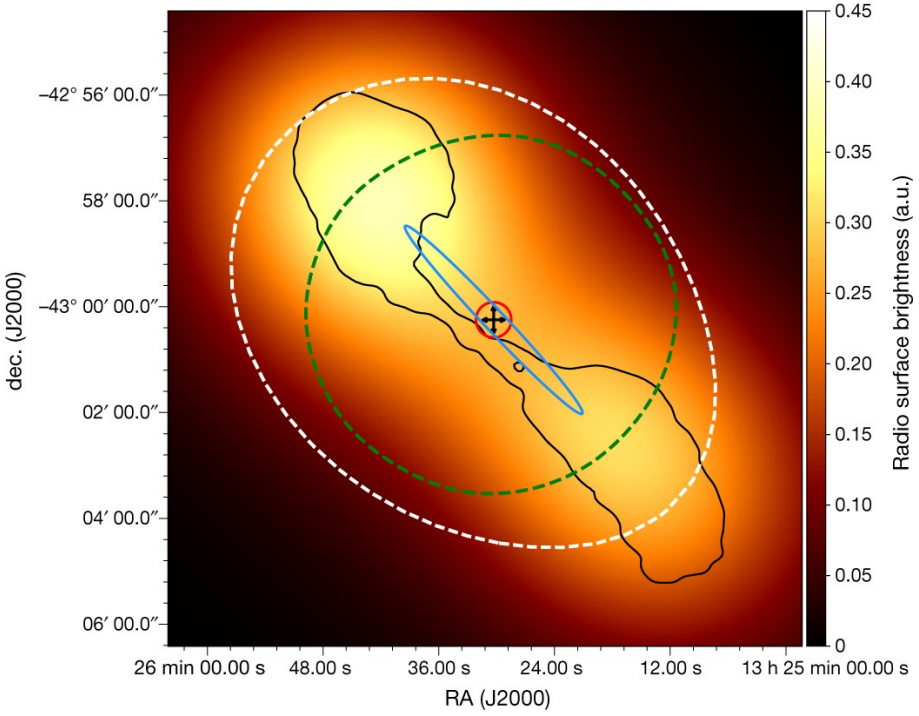
No correlation of extragalatic cosmic rays and neutrinos found

The Astrophysical Journal, 952:91 (11pp), 2023

No photons (10 EeV) found correlating with Gravitational Wave events either







Pierre Auger Observatory

The Astrophysical Journal, 935:170 (24pp), 2022

Nobs = 215

Nexp = 152.0 from isotropy

p-value = 4.5×10^{-5}

H.E.S.S Observatory

Nature volume 582, 356–359 (2020)

Extragalactic cosmic rays
Pierre Auger Observatory
Alexey Yushov (ICHEP 2024)

AugerPrime upgrade: to run until 2035

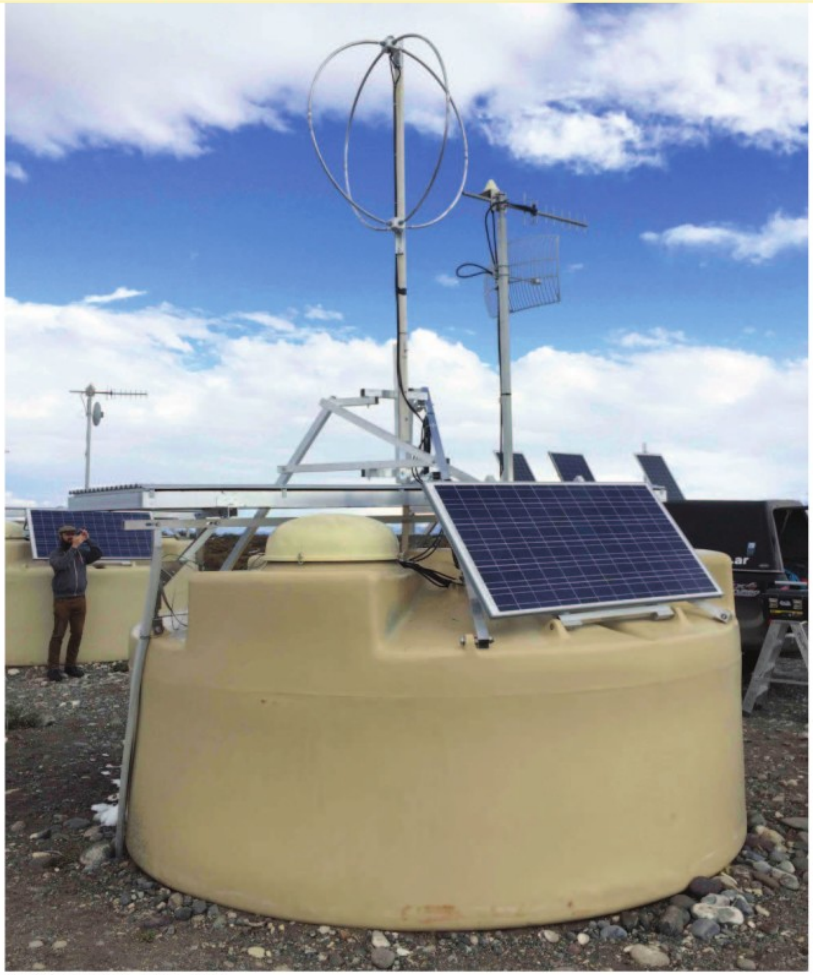
More details: talks of Martin Schimassek (today in Upgrade session) & Lukas Nellen (Computing, July 19)

For each WCD

+ new electronics
+ small PMT
+ 3.8 m^2 scintillator detectors
+ radio antenna

SD (750 m) of 23.5 km^2 area

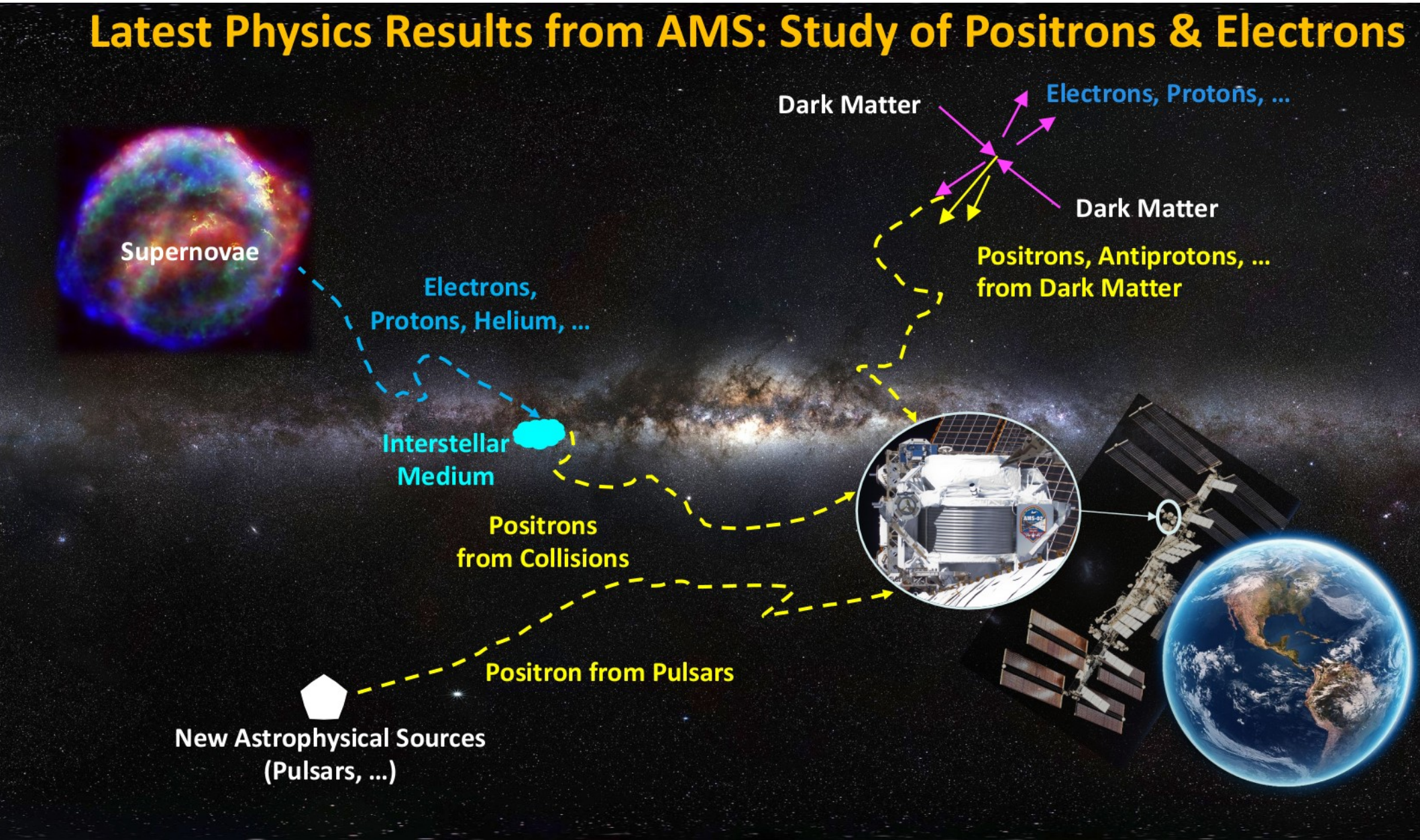
+ underground muon detectors



AugerPrime: EPJ Web Conf., 210 (2019) 06002; PoS(ICRC2023)343, 344, 392

Galactic cosmic rays: AMS

Andrei Kounine (ICHEP 2024)



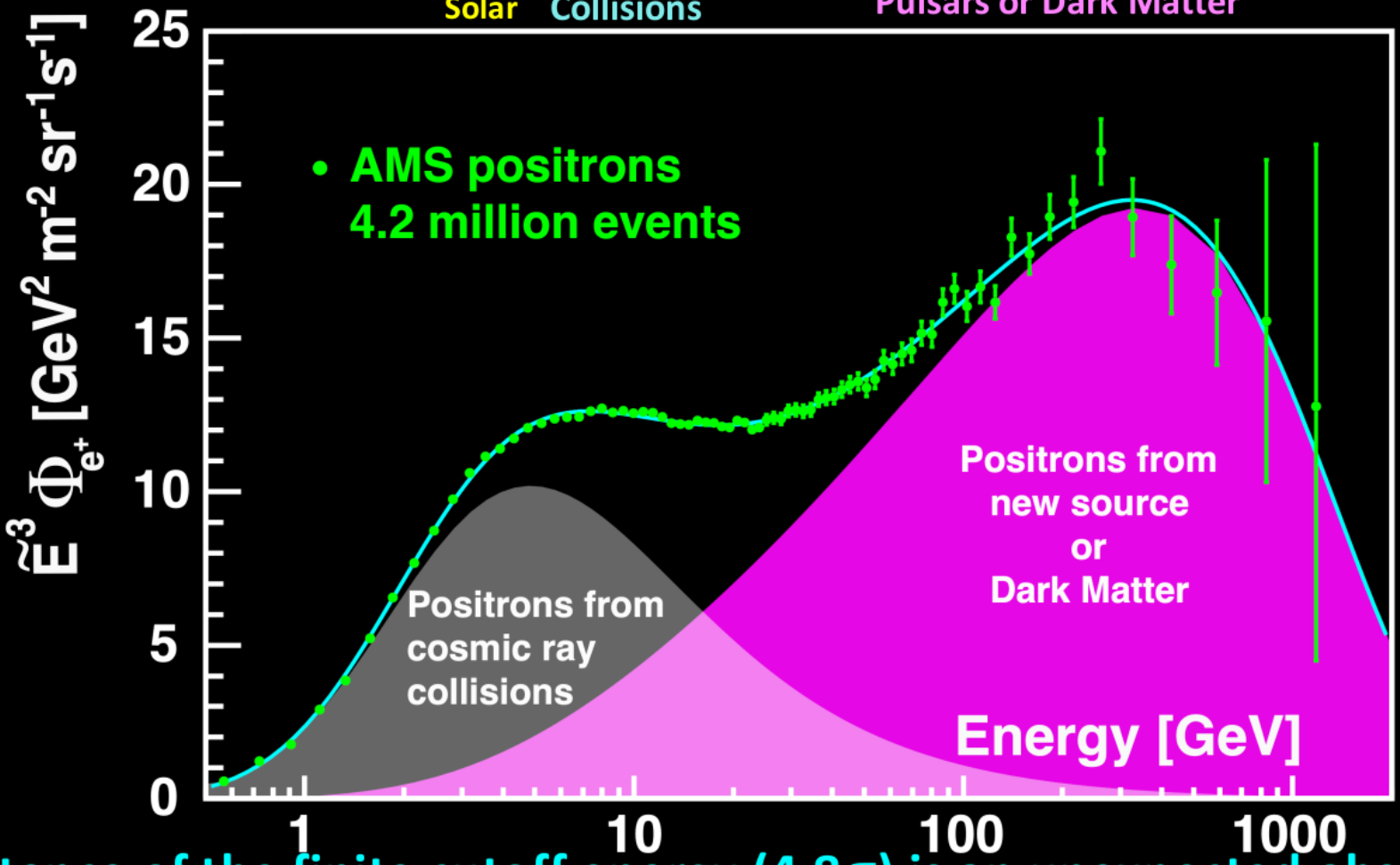
Galactic cosmic rays: AMS

Andrei Kounine (ICHEP 2024)

The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from pulsars or dark matter both with a cutoff energy E_S.

$$\Phi_{e^+}(E) = \frac{E^2}{\widehat{E}^2}\left[C_d(\widehat{E}/E_1)^{\gamma_d} + C_s(\widehat{E}/E_2)^{\gamma_s}\exp(-\widehat{E}/E_s)\right]$$

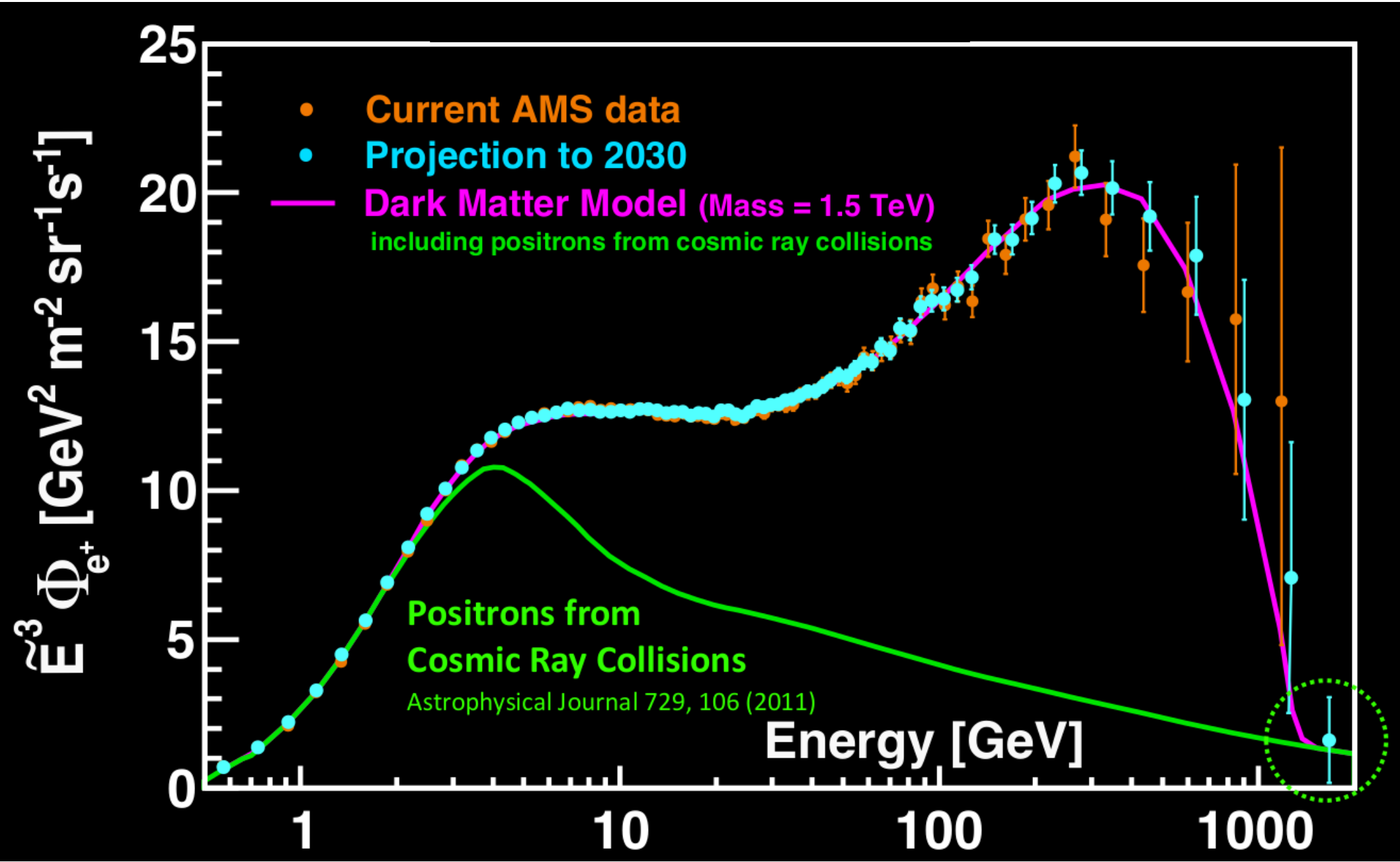
Solar Collisions Pulsars or Dark Matter



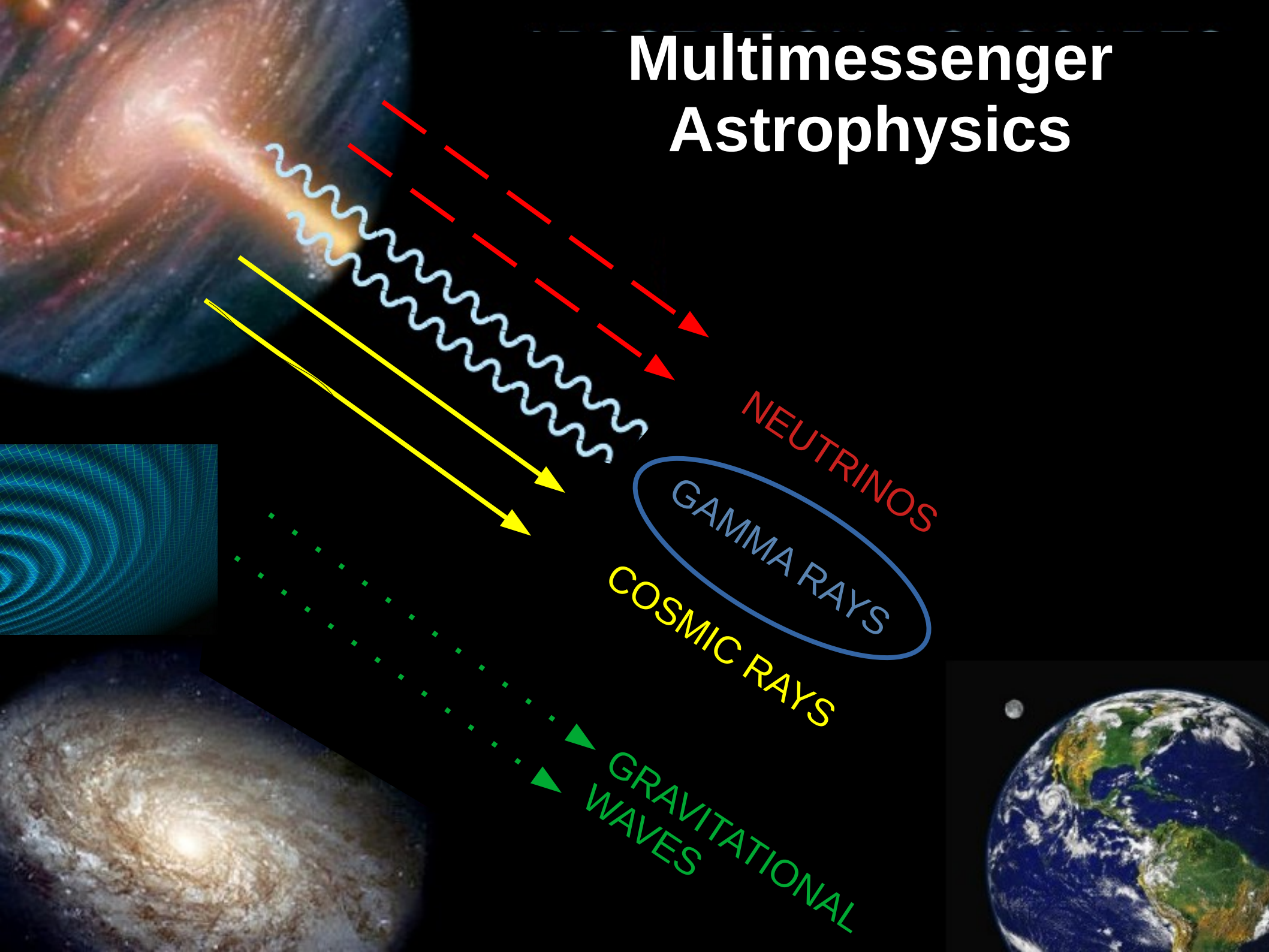
The existence of the finite cutoff energy (4.8σ) is an unexpected observation

Galactic cosmic rays: AMS

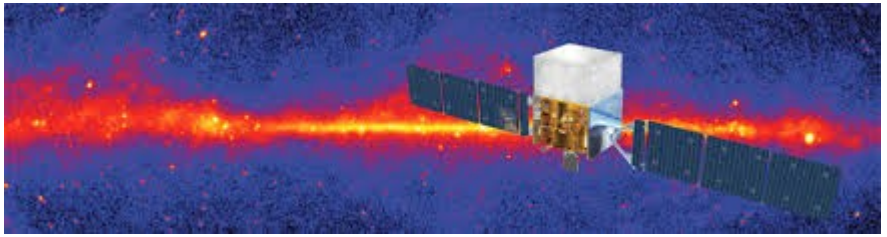
Andrei Kounine (ICHEP 2024)



Multimessenger Astrophysics

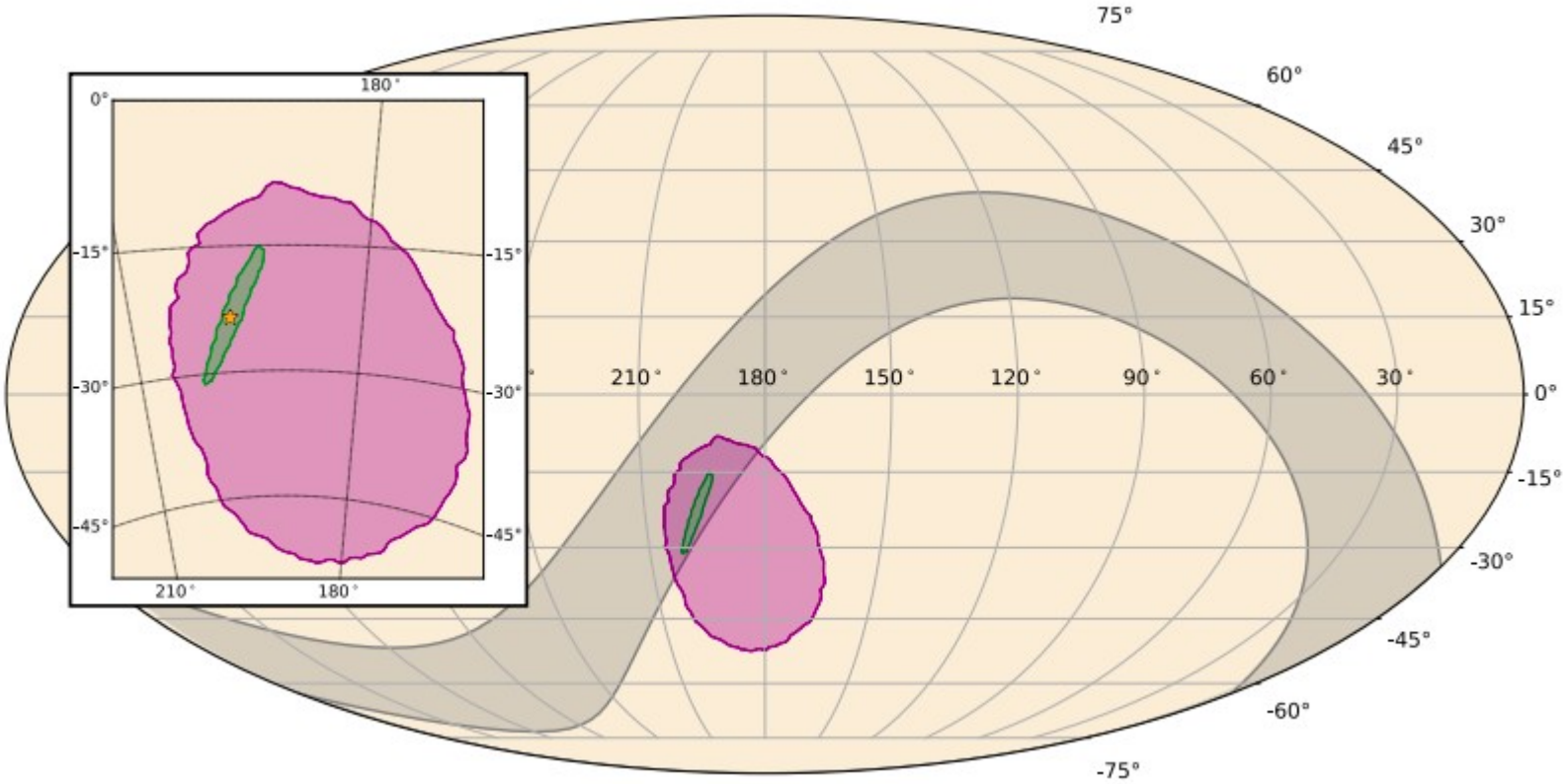


GeV gamma-ray Fermi-LAT



All-sky monitor

Gravitational Waves and Gamma-rays from a Binary Neutron Star Merger: GW170817 and GRB 170817A



LIGO Scientific Collaboration, Virgo Collaboration, Fermi Gamma-Ray Burst Monitor, INTEGRAL

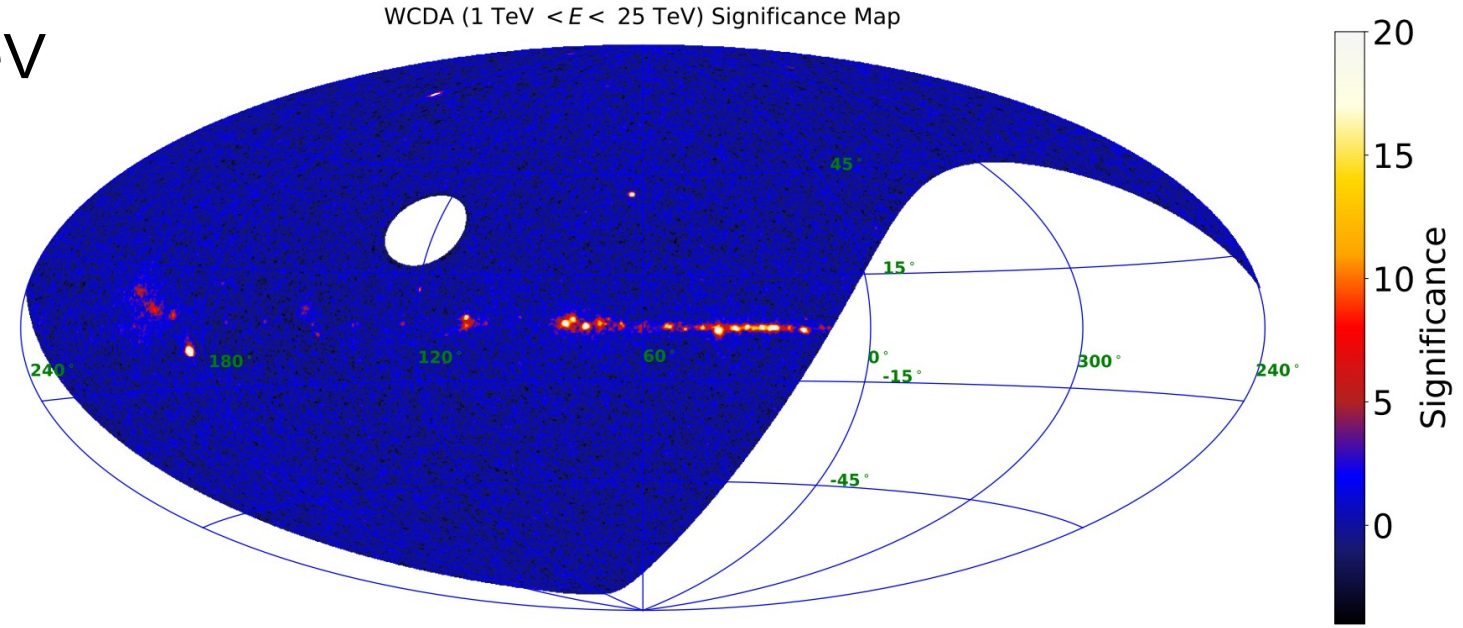
The Astrophysical Journal Letters, 848:L13 (27pp), 2017 October 20

> 100 TeV gamm-ray LHAASO

HIGH ENERGY
WIDE-FIELD OF VIEW

Sources by LHAASO

- Observed 90
- Discovered 32 (TeV)
- 43 above 100 TeV
- 7 “dark” sources



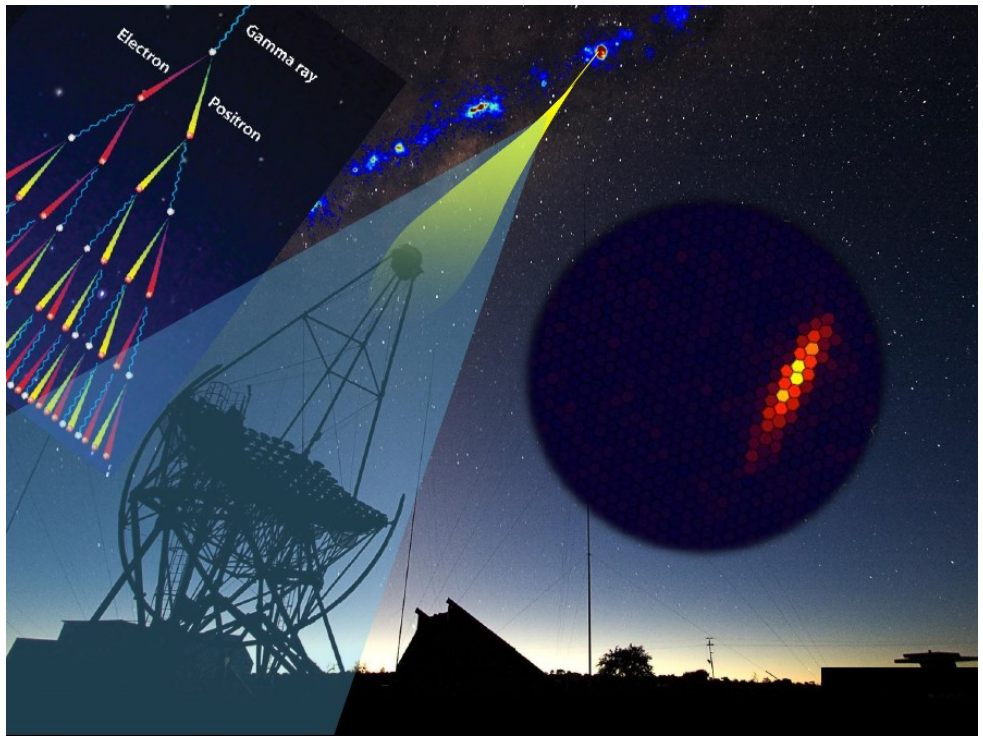
GeV - TeV gamma-ray

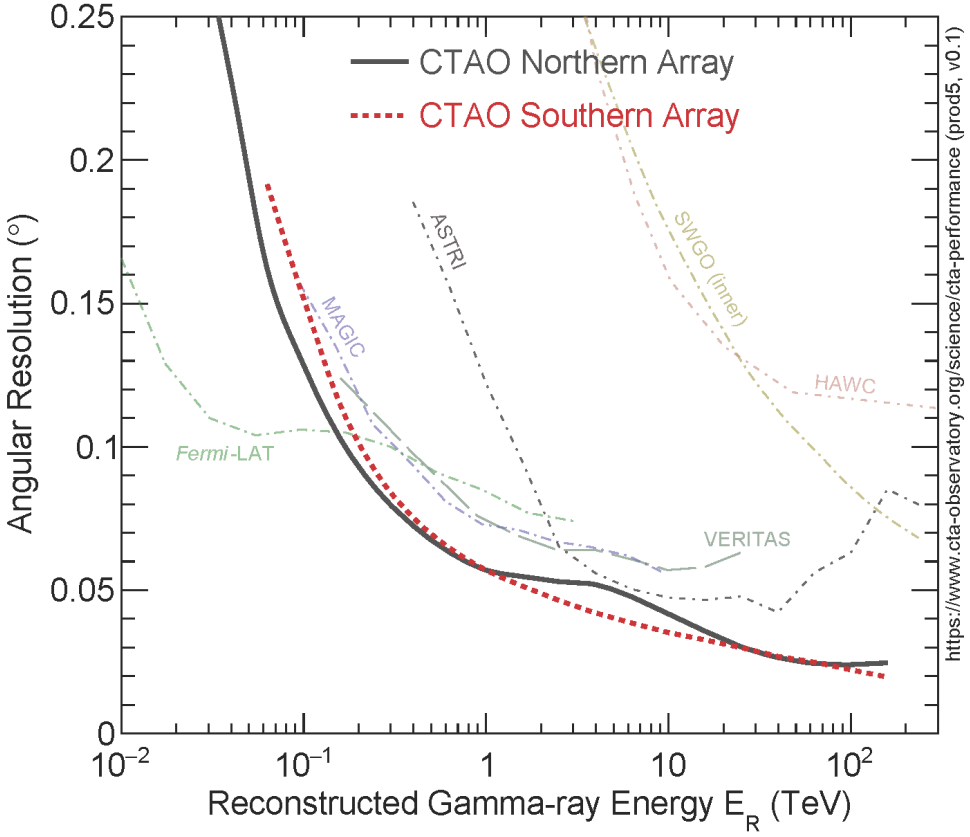
CTAO

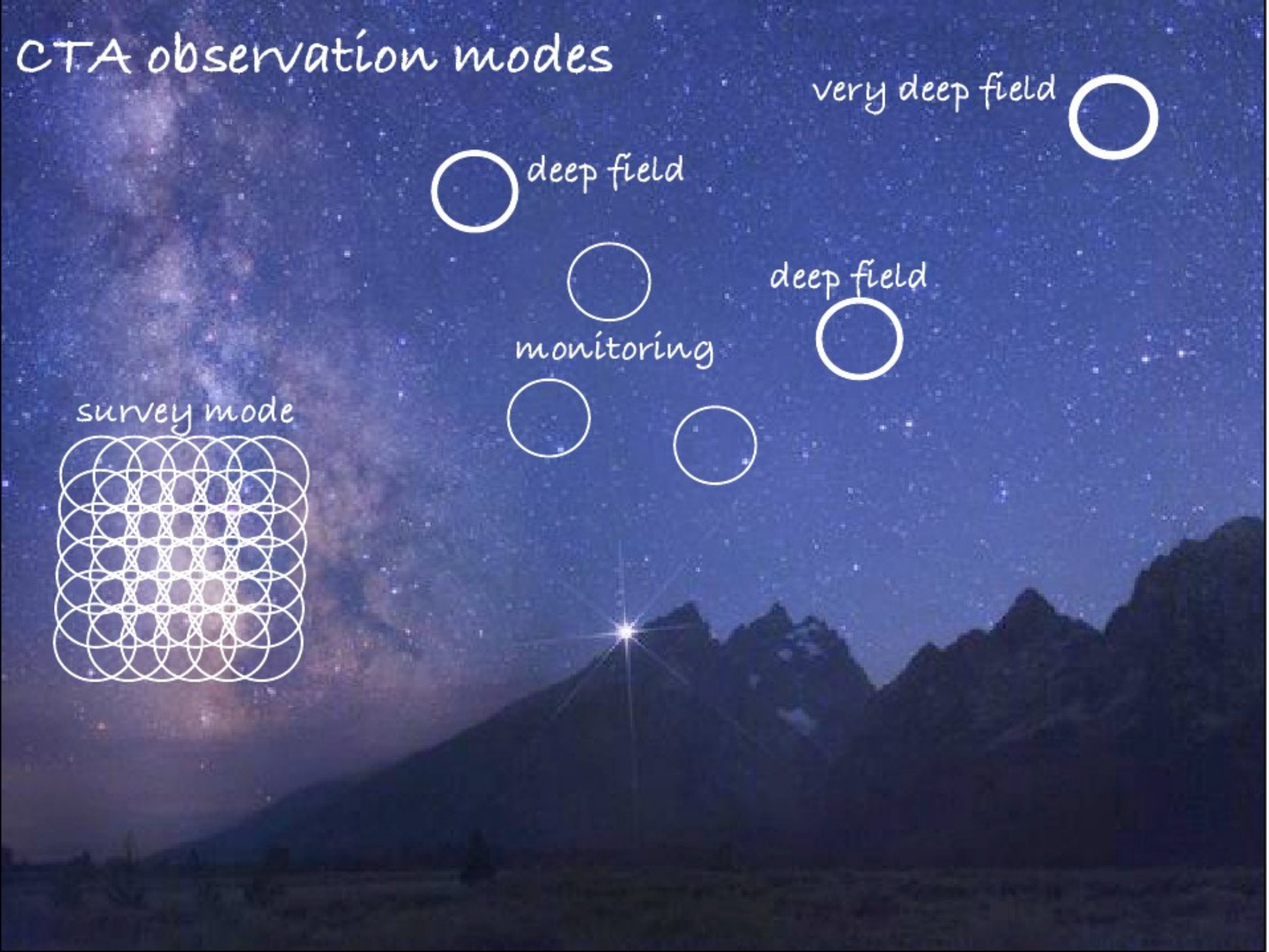
Wide energy range

Improved angular resolution

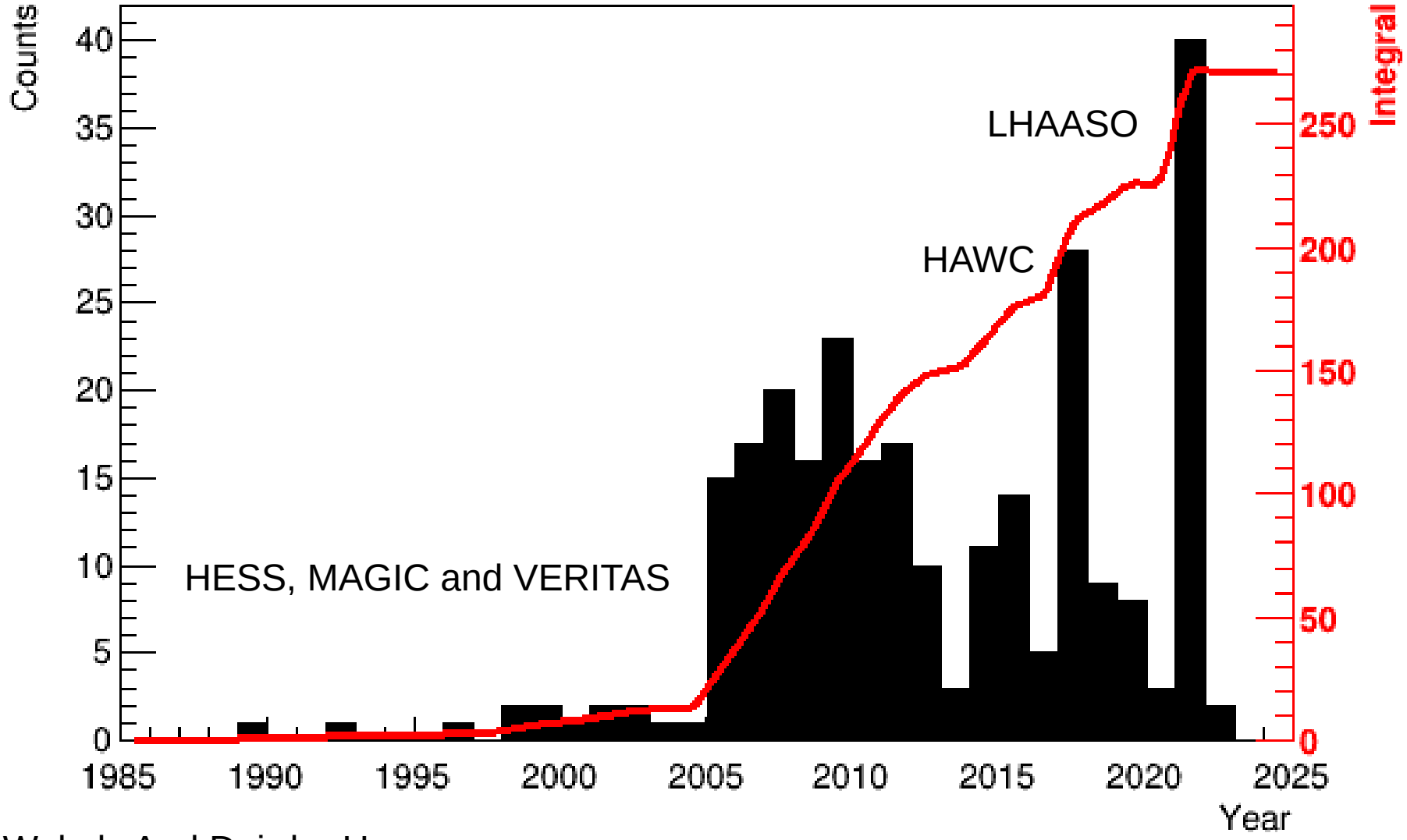
Precision measurements





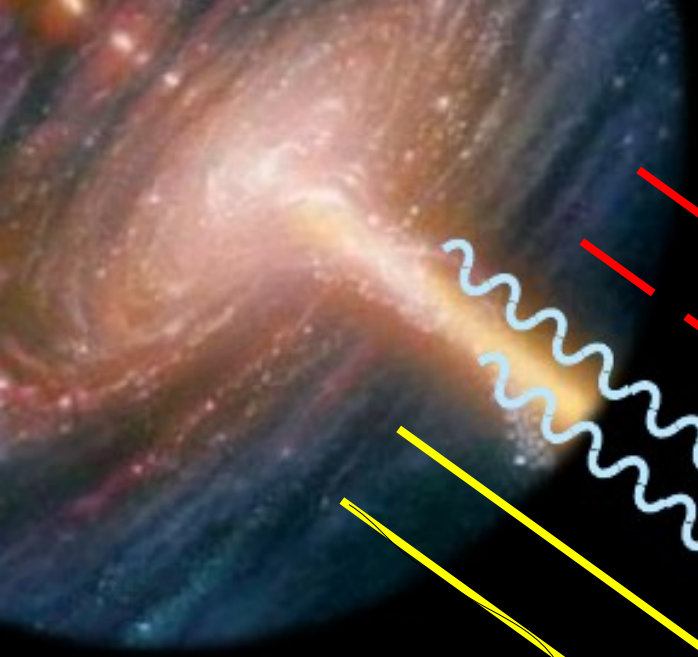

CTA observation modes
very deep field
deep field
deep field
monitoring
survey mode

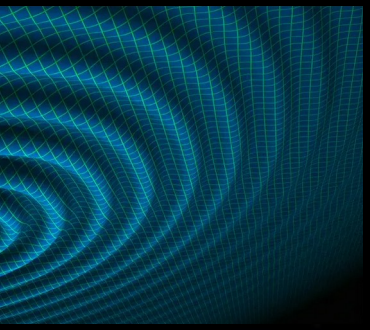
CTAO will detect over 1000 TeV-sources



Scott Wakely And Deirdre Horan:
TeVCat

Multimessenger Astrophysics





NEUTRINOS

GAMMA RAYS

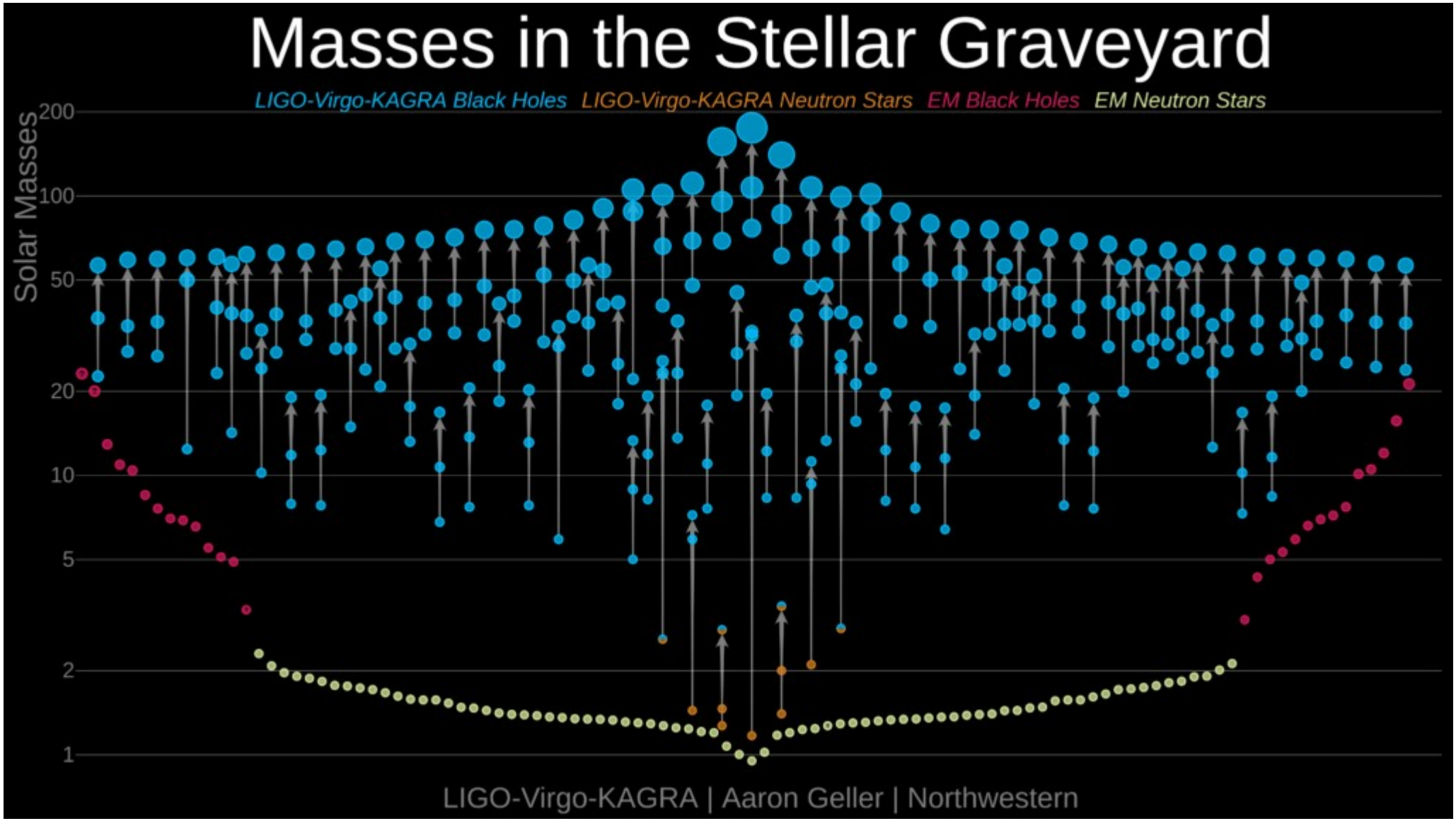
COSMIC RAYS

GRAVITATIONAL WAVES

LIGO-Virgo-KAGRA

Nicolas Arnaud (ICHEP 2024)

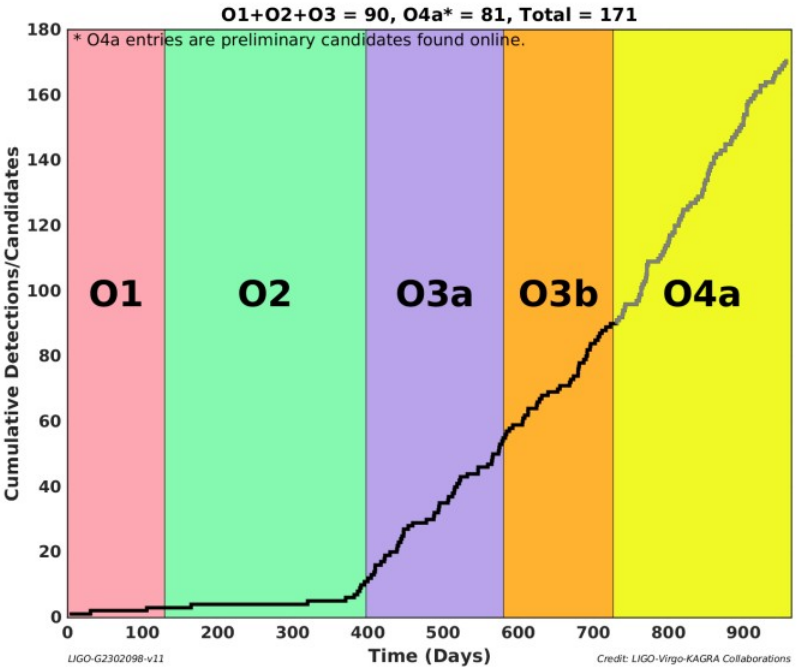
Gravitational wave events



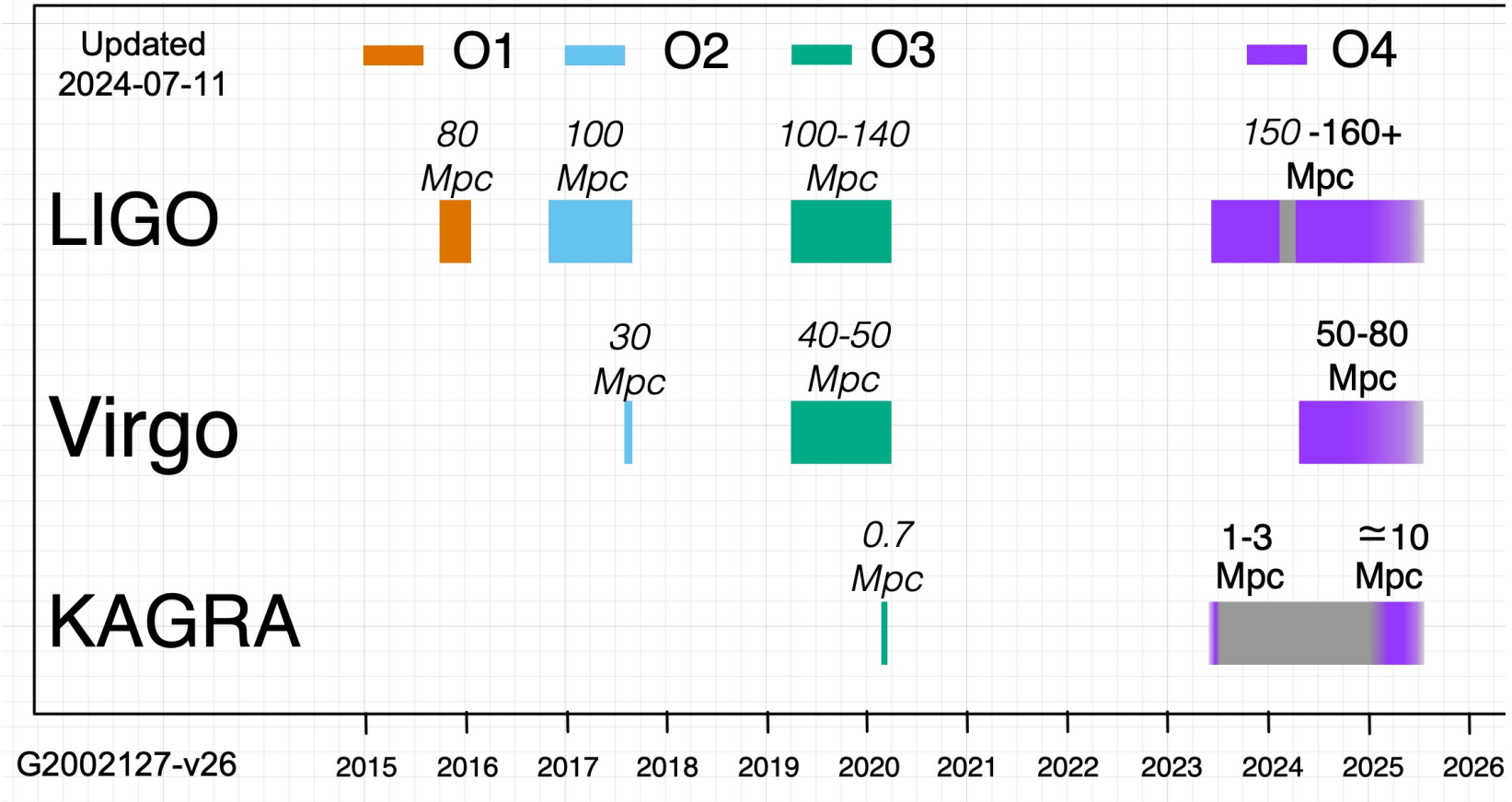
PHYSICAL REVIEW X 13, 011048 (2023)

LIGO-Virgo-KAGRA

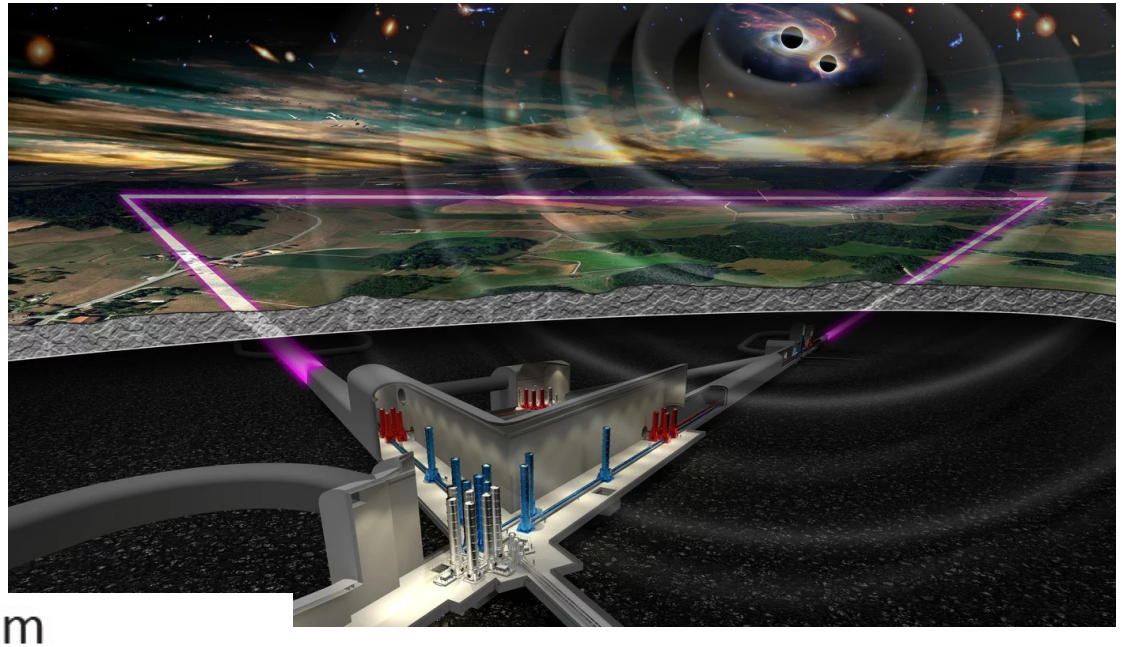
Nicolas Arnaud (ICHEP 2024)



https://observing.docs.ligo.org/plan/

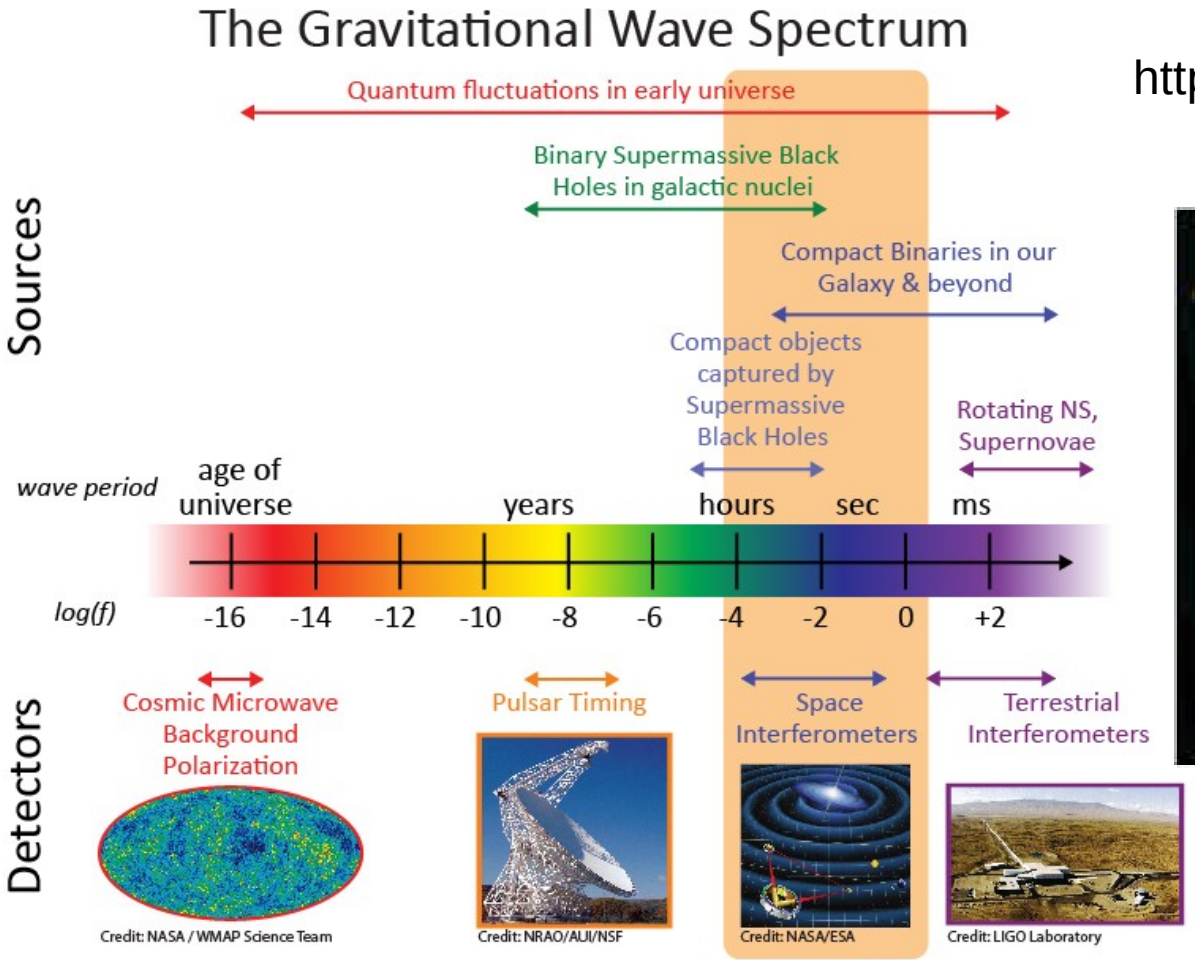


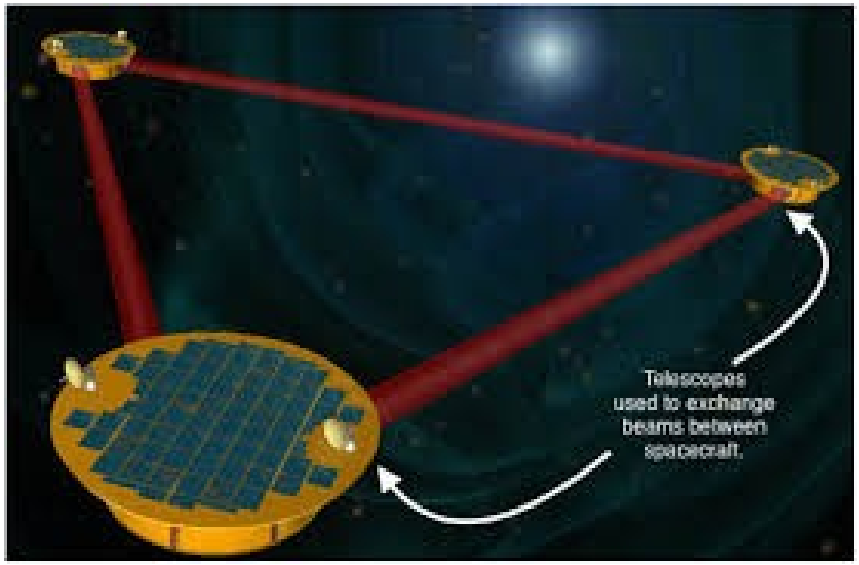
Future GW:
Einstein Telescope
LISA Telescope



https://lisa.nasa.gov/

https://www.aei.mpg.de/einsteintelescope





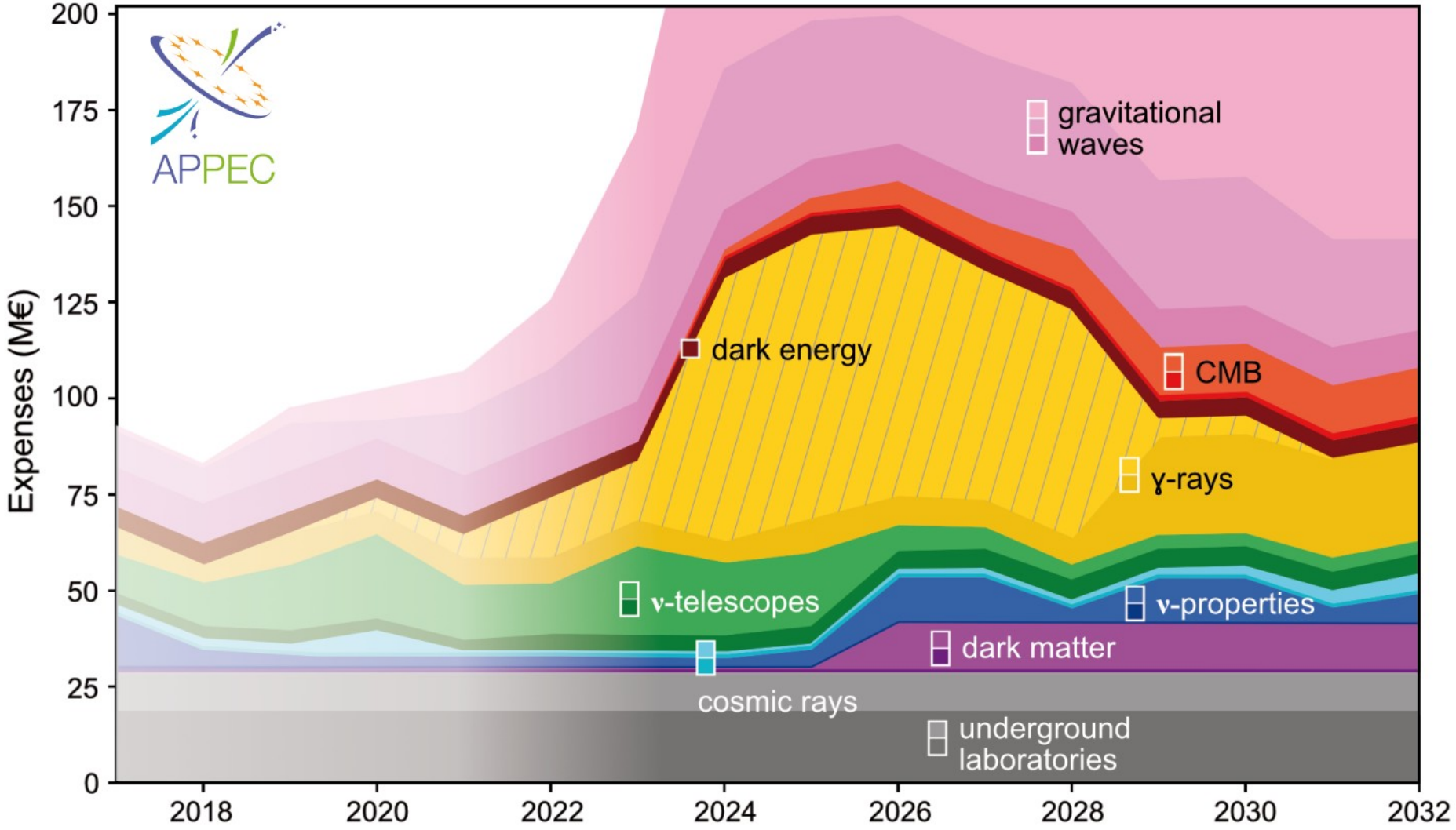
USA 2020 Decadal Survey Priorities:

- **Pathways to habitable worlds**
- **New windows on the dynamic universe**
  - Probe the nature of black holes and neutron stars - and the explosive events that gave rise to them - and understand what happened in the earliest moments in the birth of the universe.
- **Drivers of galaxy growth**

The report says the highest-priority sustaining activity for NASA is the space-based time-domain and **multi-messenger program** - comprised of small- and medium-scale missions. NASA should also pursue a new line of probe missions.

https://science.nasa.gov/astrophysics/resources/decadal-survey/2020-decadal-survey/

European Astroparticle Physics Strategy
Recommendation



https://www.appec.org/roadmap/

Take away message
Multimessenger Astrophysics

- Probes the highest energetic phenomena
- Highlights physics of the four forces
- Searches for the dark components
- Teaches acceleration mechanisms
- Tests of our current knowledge

Multi-bright and multi-challenge future !