

Space Observatories for the Highest Energy Cosmic Particles

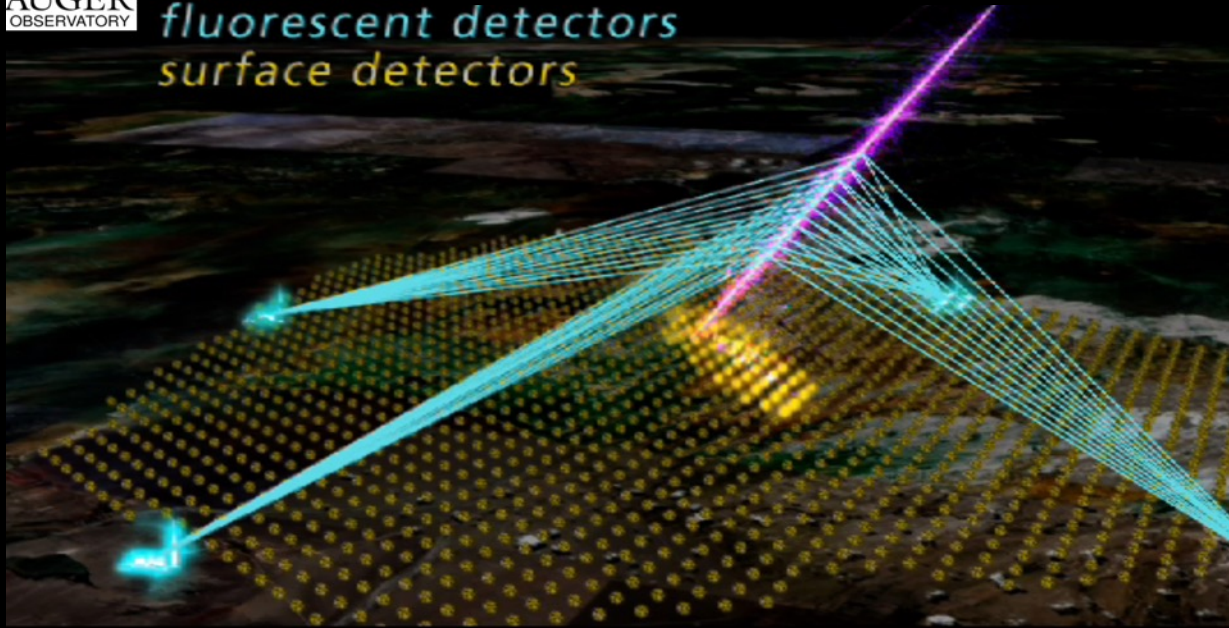
Cosmic Rays and Neutrinos

POEMMA & EUSO-SPB



PIERRE
AUGER
OBSERVATORY

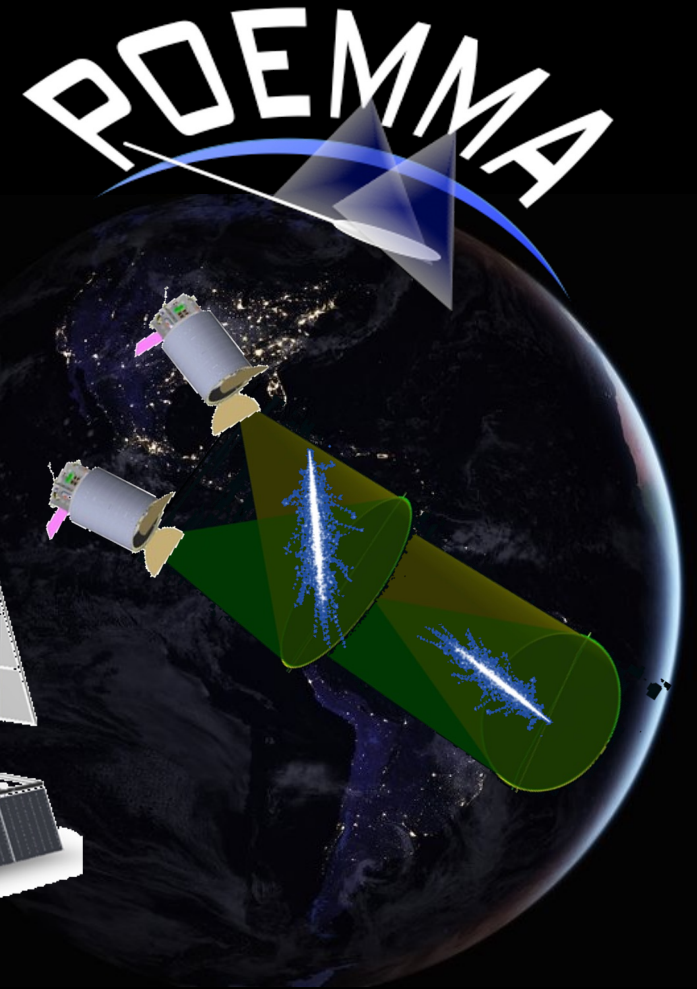
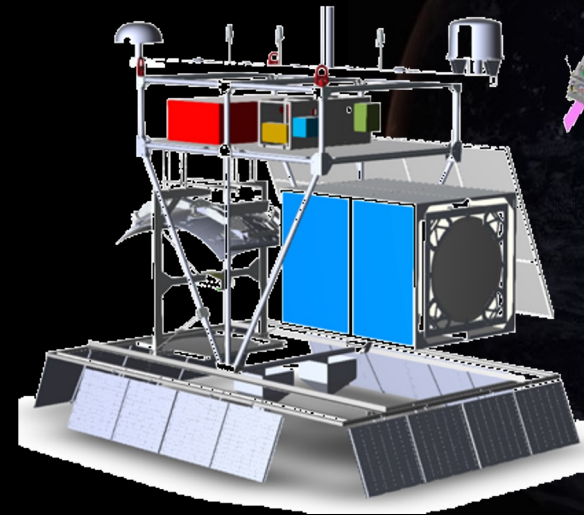
fluorescent detectors
surface detectors



EUSO-SPB₁



EUSO-SPB₂



INPE,

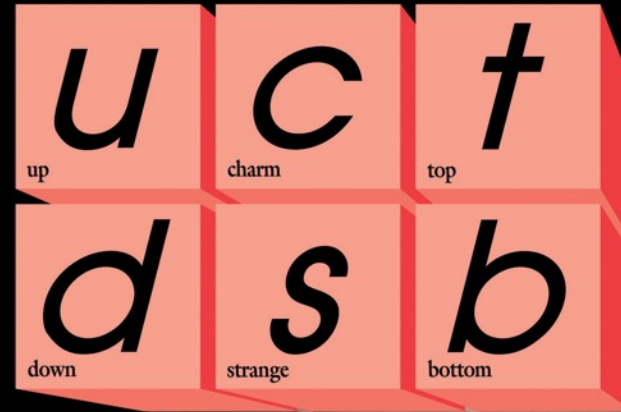
September 21, 2023

Angela V. Olinto

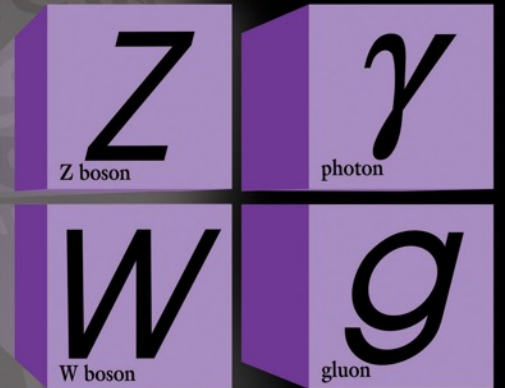


THE UNIVERSITY OF
CHICAGO

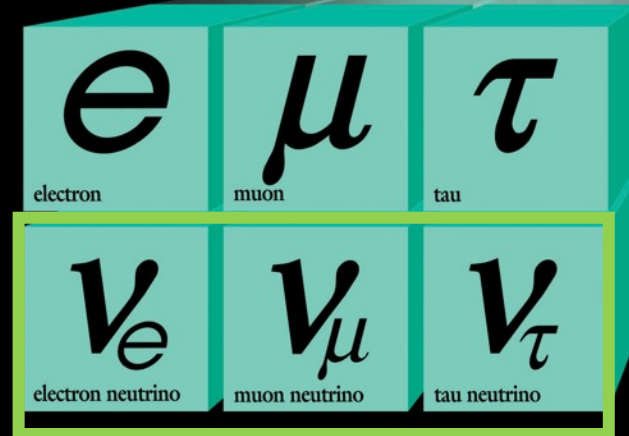
Quarks



Forces

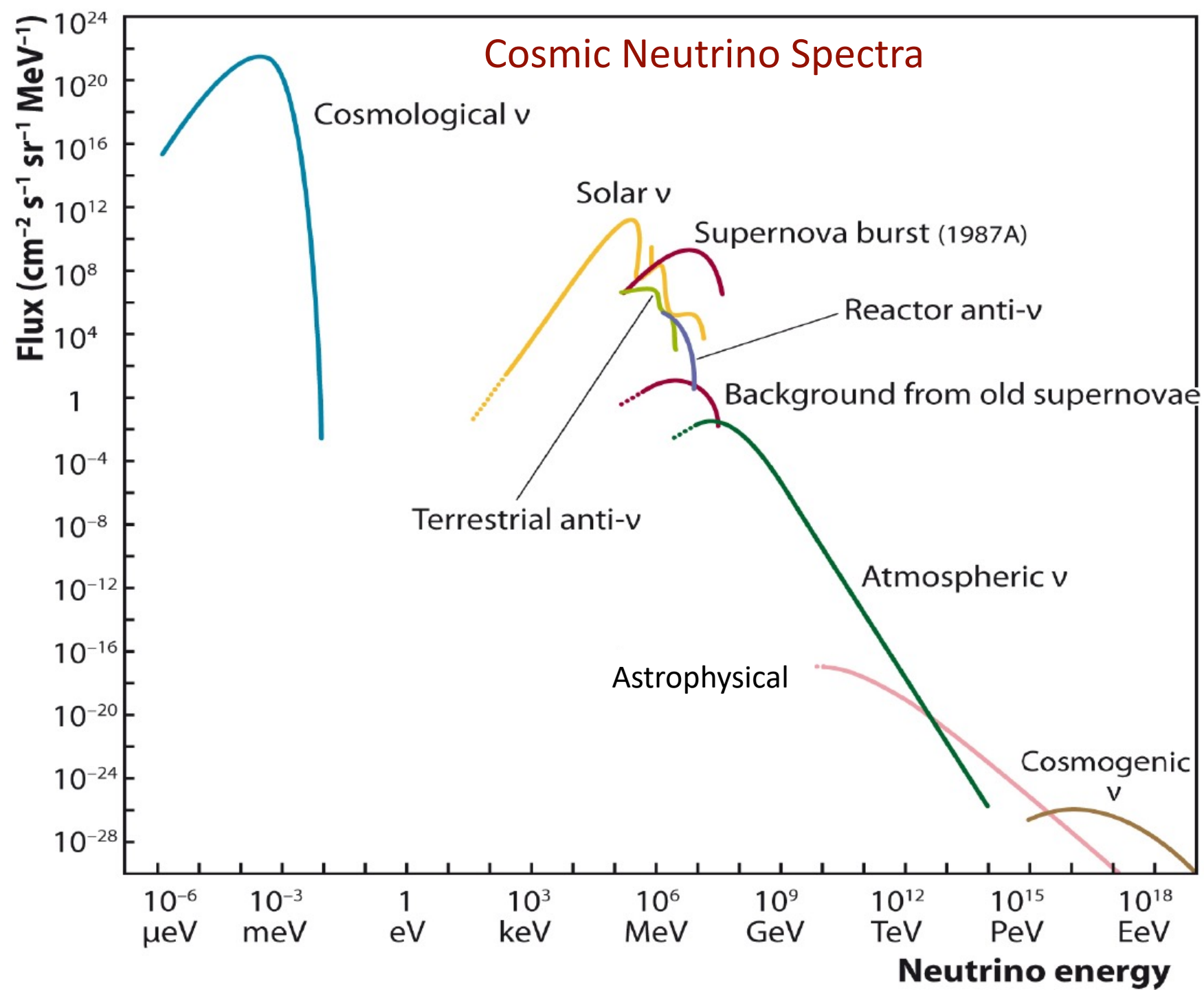


Neutrinos

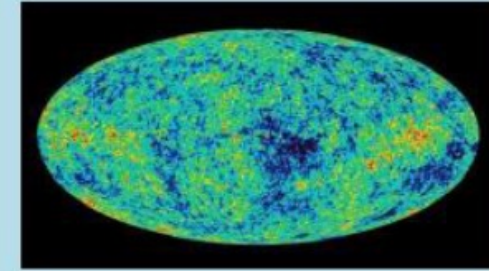
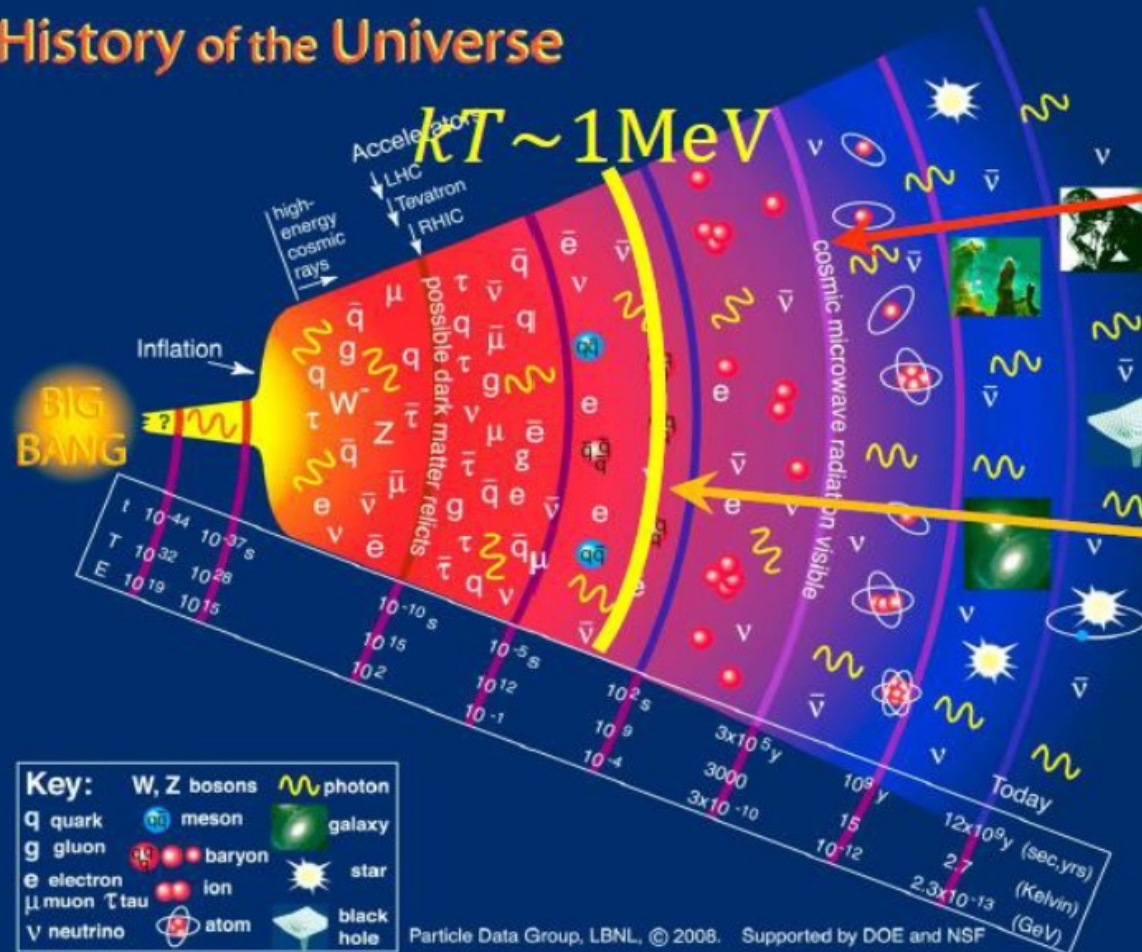


Leptons

Cosmic Neutrino Spectra



History of the Universe



CMB

$$n_\gamma = 411/\text{cm}^3$$

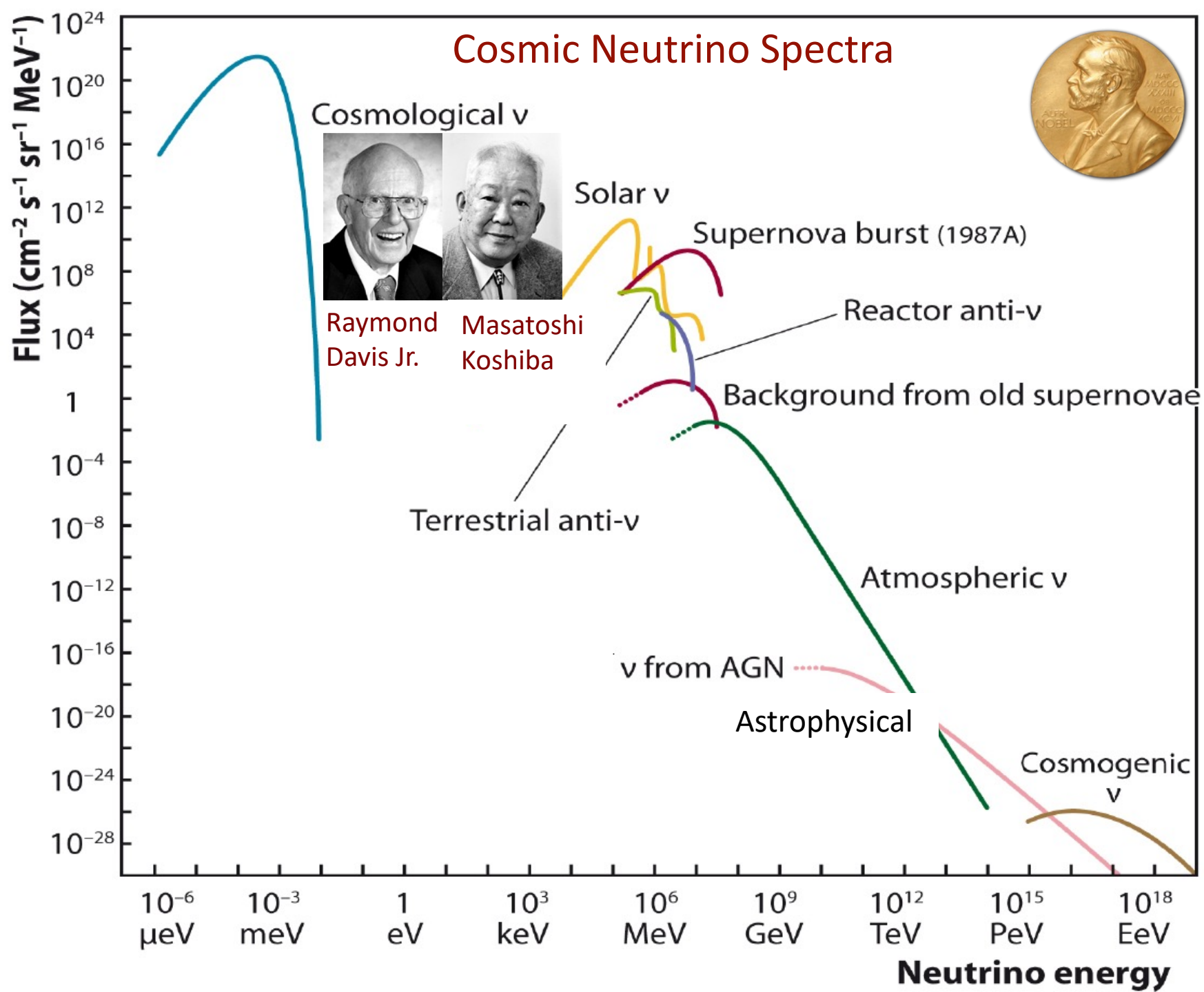
$$T_\gamma = 2.73 \text{ K}$$

CvB

$$n_\nu = n_{\bar{\nu}} = \frac{3}{4} \left(\frac{T_\nu}{T_\gamma} \right)^3 \frac{n_\gamma}{2}$$

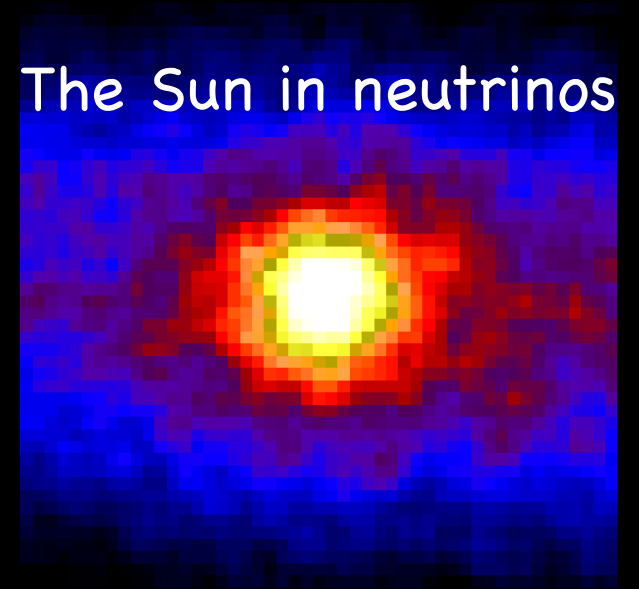
$$= 56/\text{cm}^3$$

$$T_\nu = \left(\frac{4}{11} \right)^{\frac{1}{3}} T_\gamma = 1.95 \text{ K}$$



2002 Nobel Prize in Physics

The Sun in neutrinos



Raymond Davis Jr.



Homestake Experiment

KamiokaNDE

Kamioka Nucleon Decay Experiment

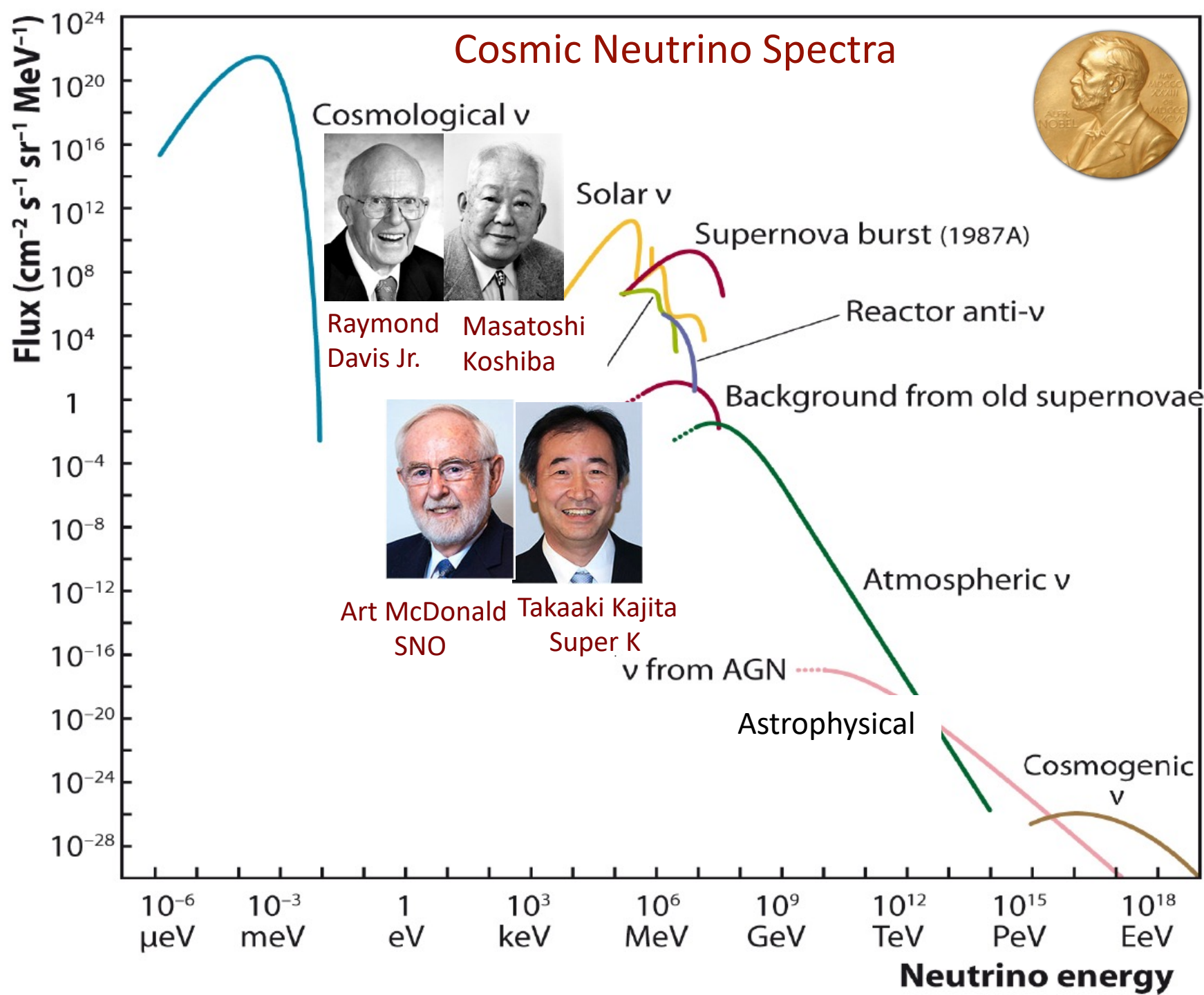


Masatoshi Koshiba



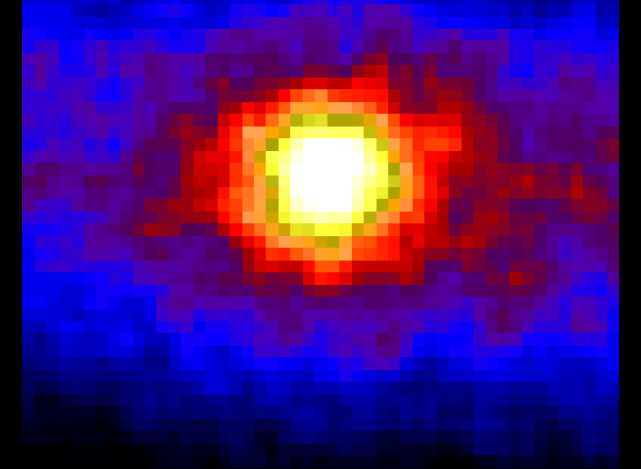
SN 1987A

東京大学宇宙線研



2002 Nobel Prize in Physics

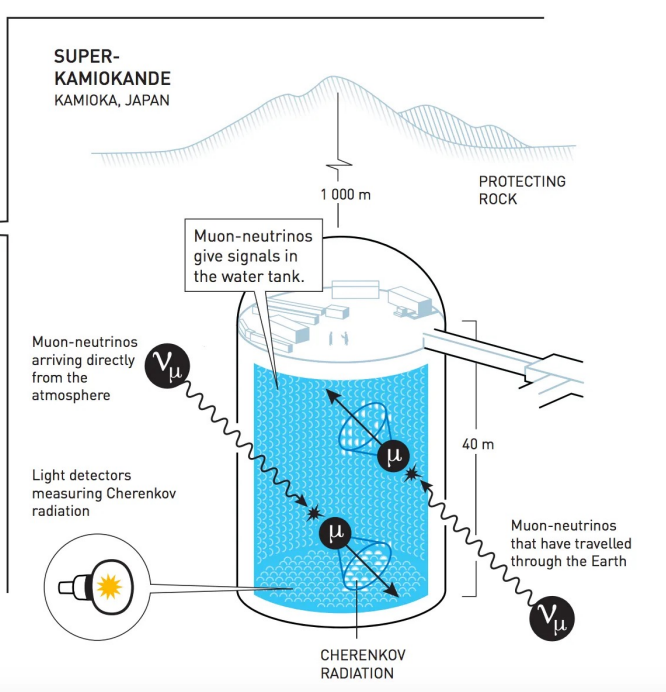
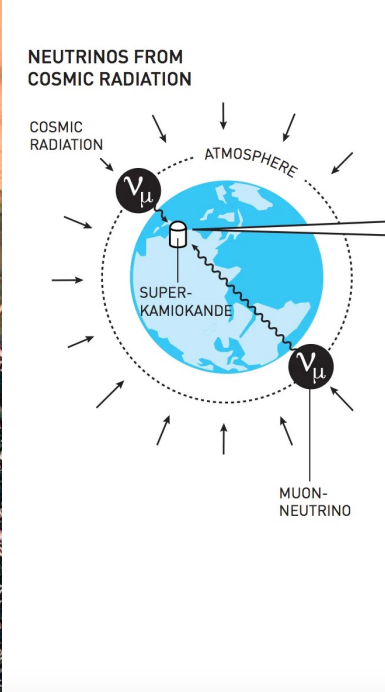
The Sun in neutrinos



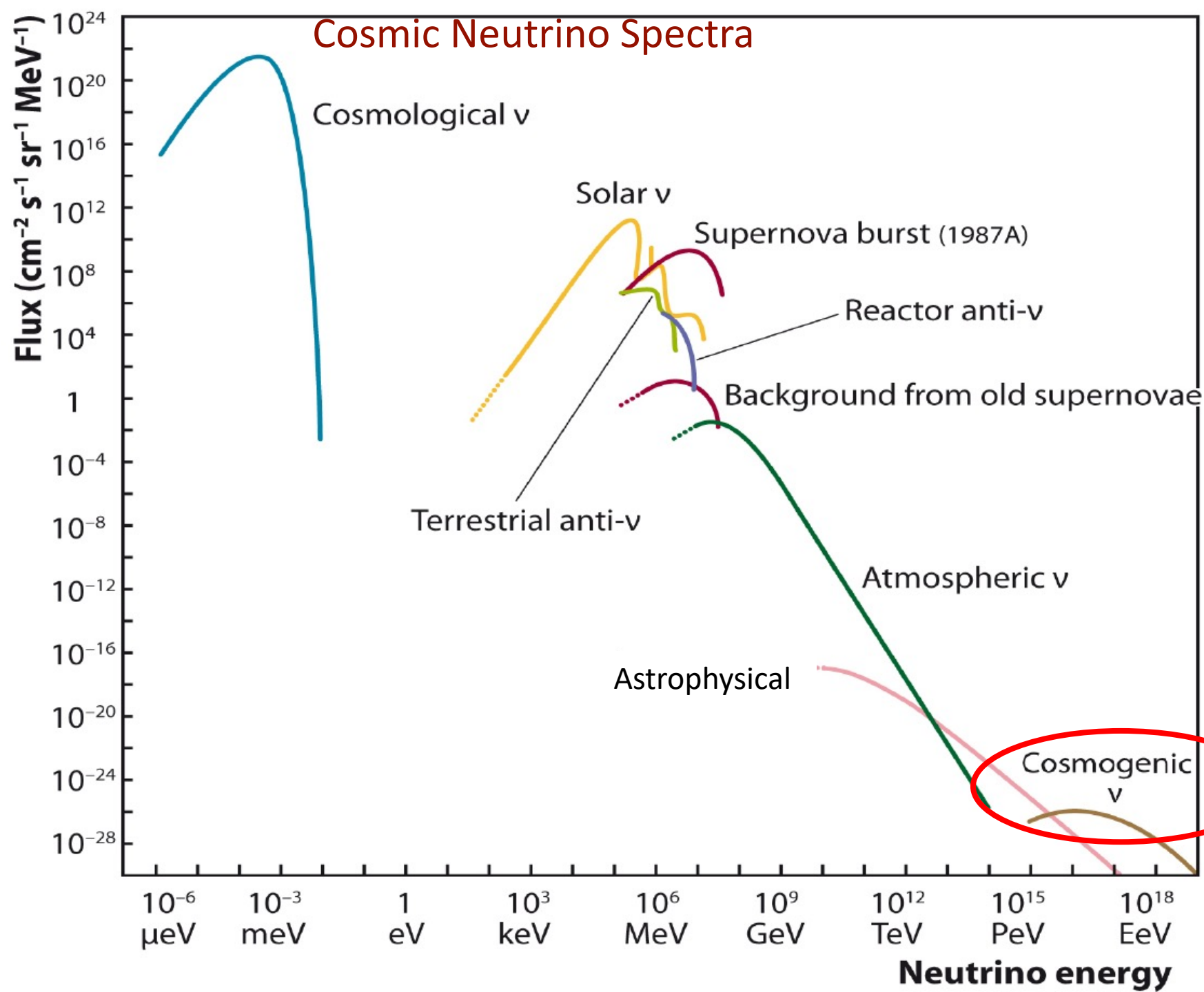
2015 Nobel Prize in Physics
Neutrino Oscillations



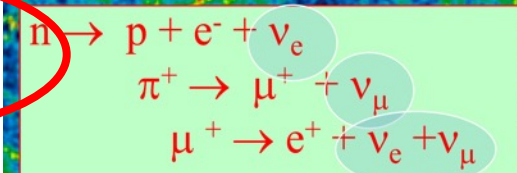
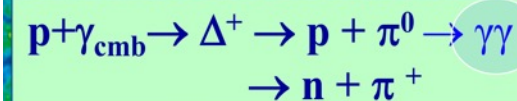
LEPTONS	$<2.2 \text{ eV}/c^2$	$<0.17 \text{ MeV}/c^2$	$<15.5 \text{ MeV}/c^2$
	0	0	0
	1/2	1/2	1/2
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino



Cosmic Neutrino Spectra



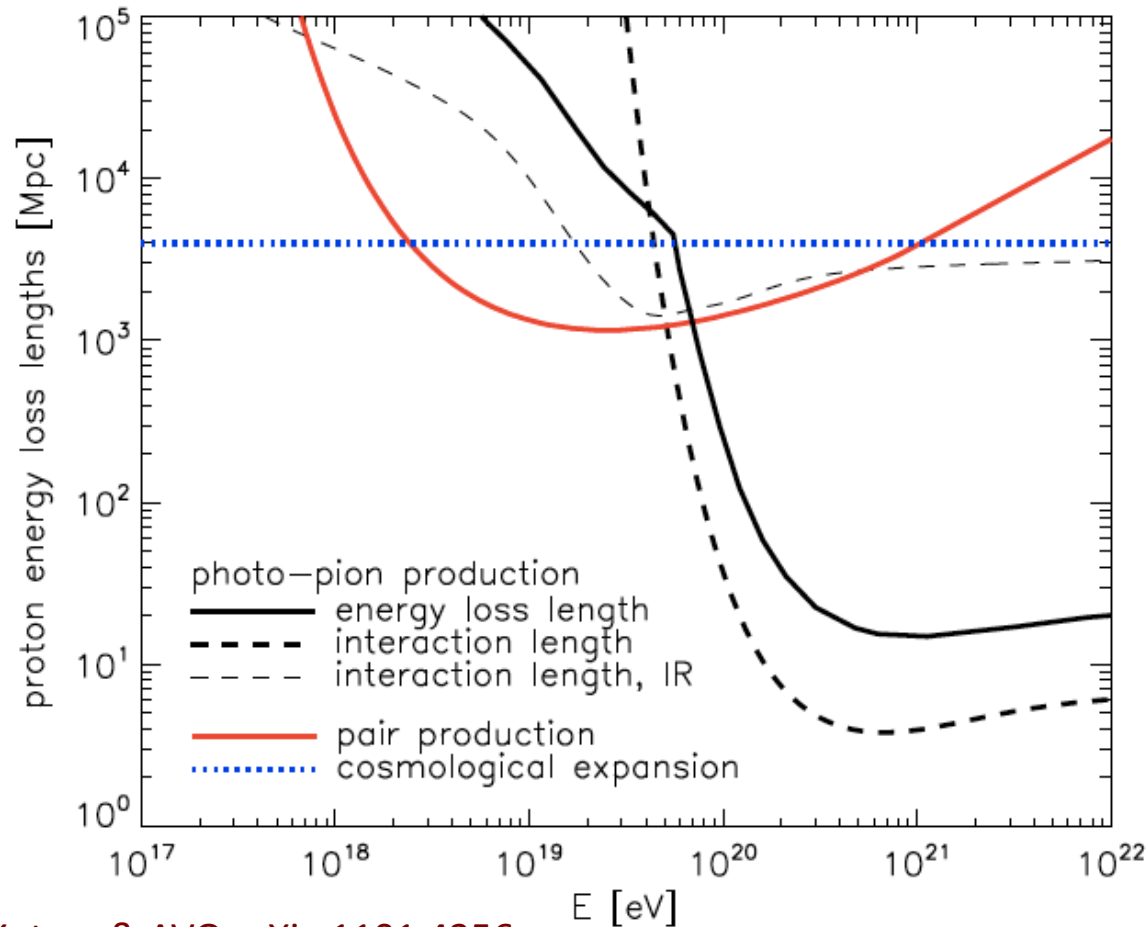
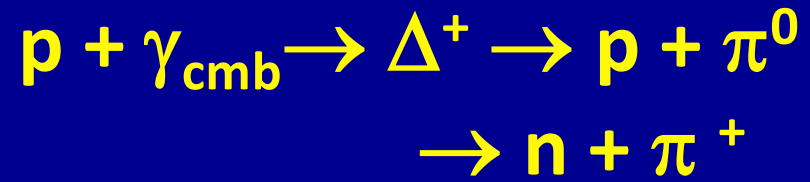
Cosmogenic (GZK, BZ*)
Neutrinos & Photons



GZK Cutoff

Greisen,
Zatsepin, Kuzmin
1966

Greisen-Zatsepin-Kuzmin Effect

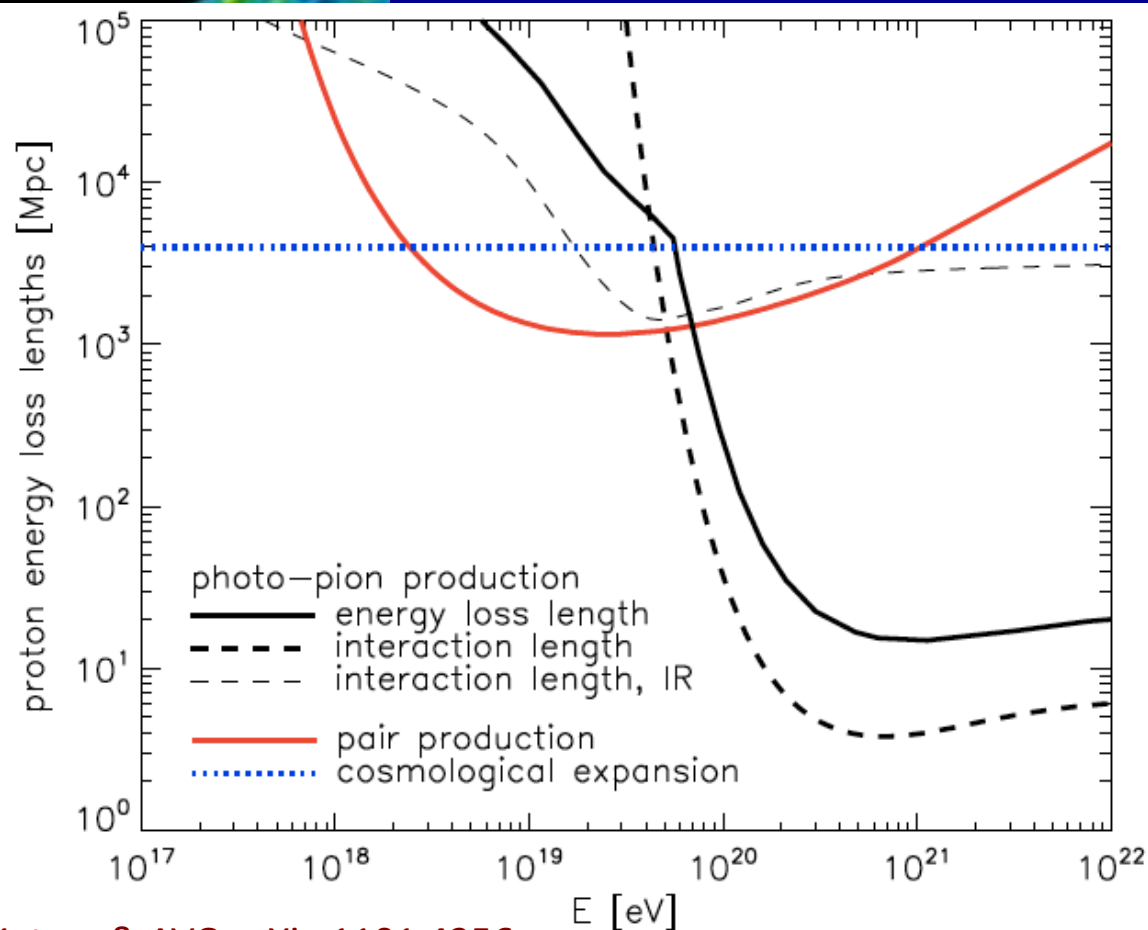
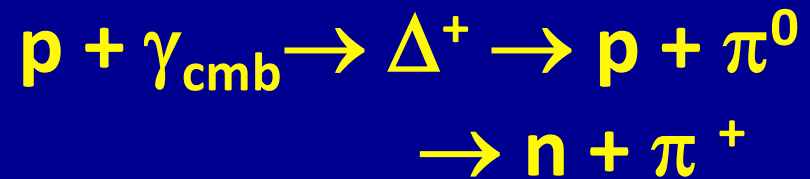


Kotera & AVO arXiv:1101.4256

GZK Cutoff

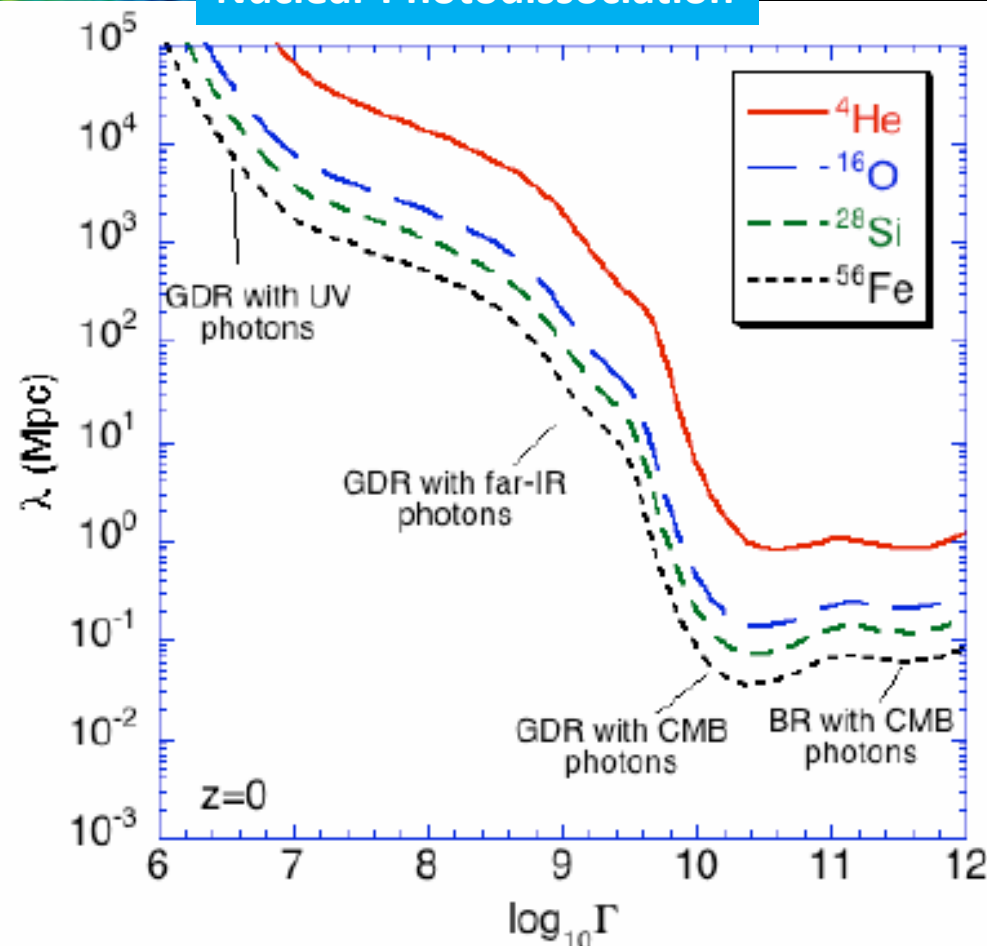
Greisen,
Zatsepin, Kuzmin
1966

Greisen-Zatsepin-Kuzmin Effect



Kotera & AVO arXiv:1101.4256

Nuclear Photodissociation

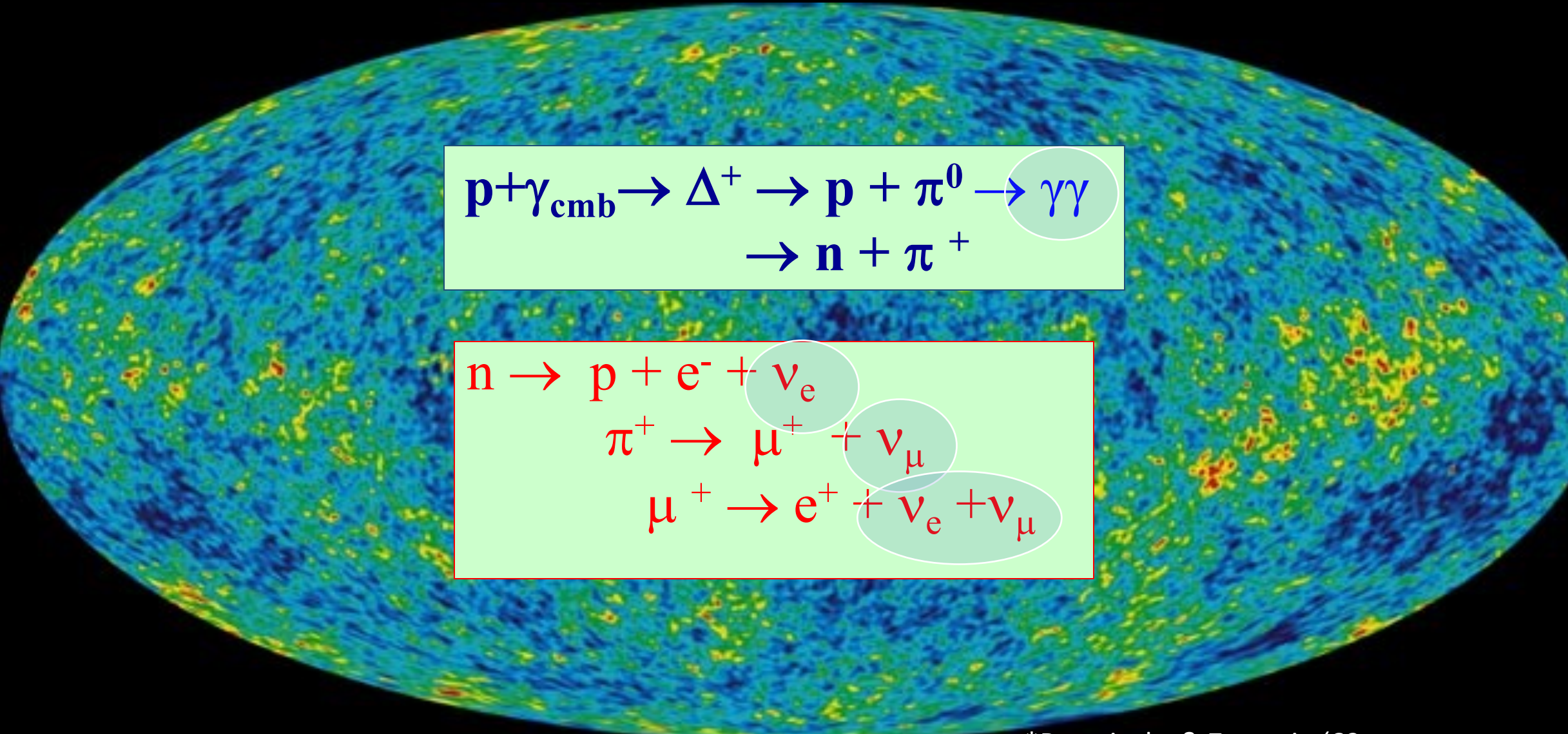


Allard, Busca, Deceprit, AVO, Parizot arXiv:0805.4779

GDR: Giant Dipole Resonance

BR: Baryonic Resonances

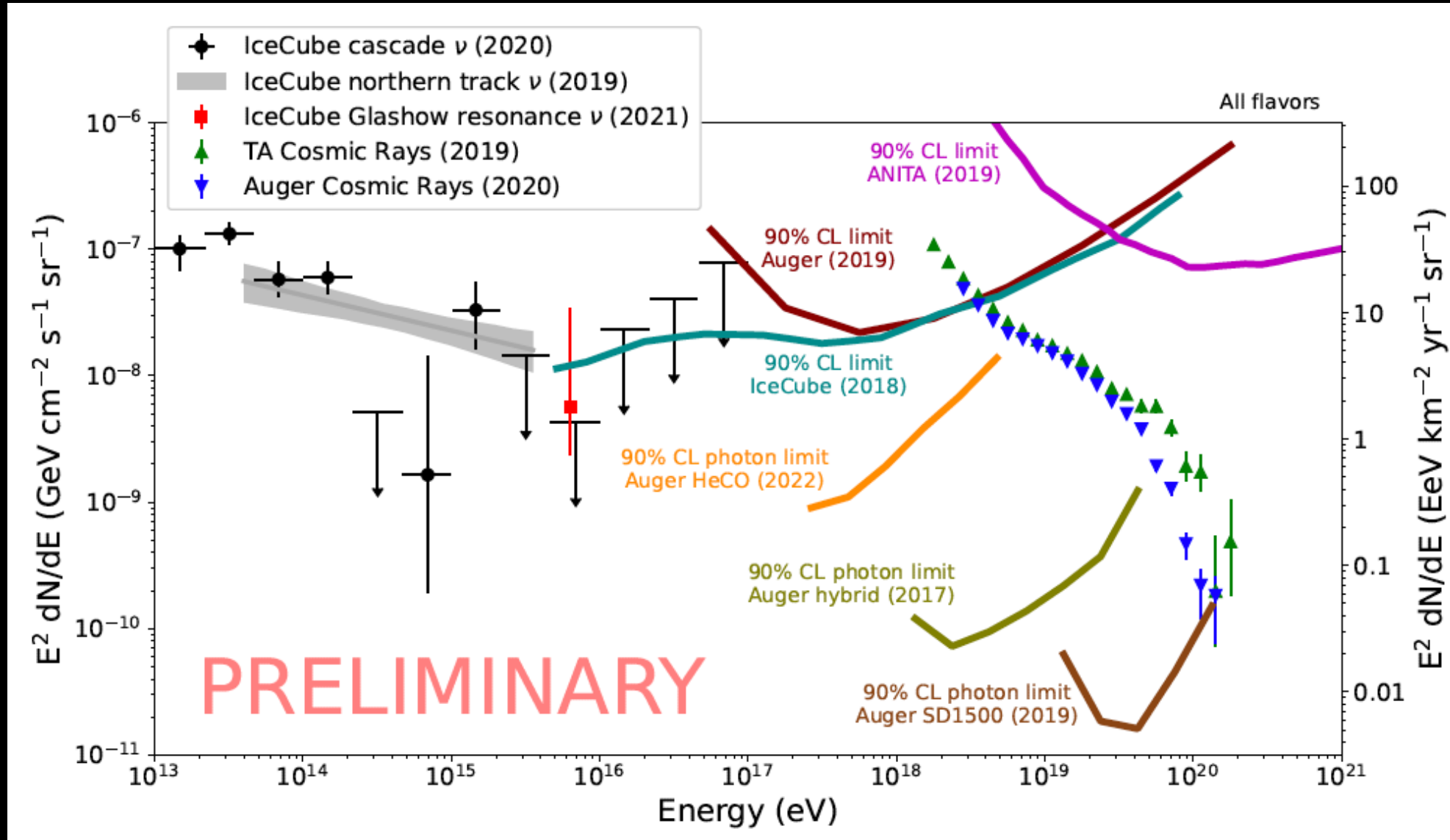
Cosmogenic (GZK, BZ*) Neutrinos & Photons

A full-sky map of the Cosmic Microwave Background (CMB) temperature fluctuations, showing a complex pattern of blue and yellow spots against a black background.
$$\mathbf{p} + \gamma_{\text{cmb}} \rightarrow \Delta^+ \rightarrow \mathbf{p} + \pi^0 \rightarrow \gamma\gamma$$
$$\rightarrow \mathbf{n} + \pi^+$$

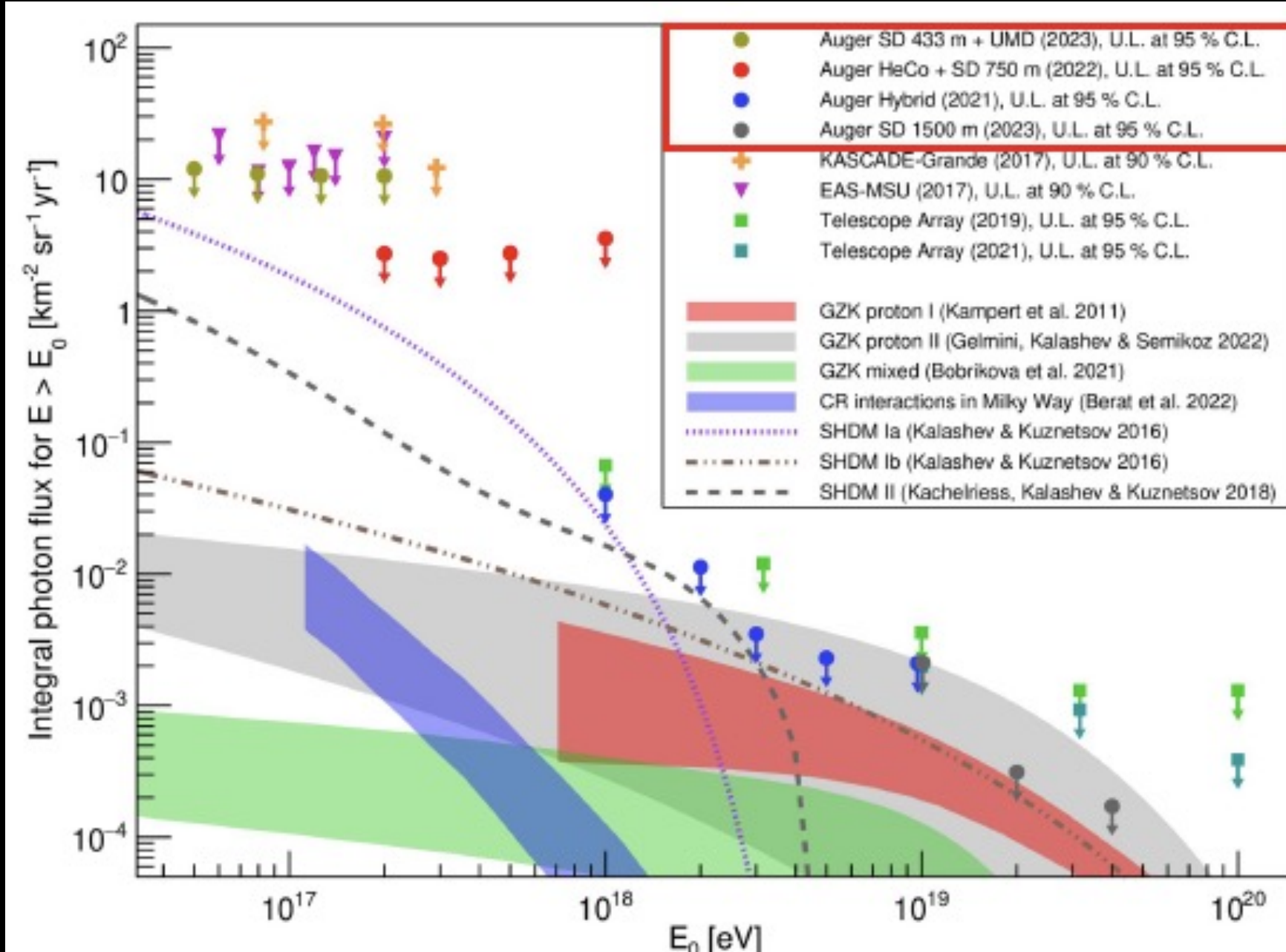
$$\mathbf{n} \rightarrow \mathbf{p} + \mathbf{e}^- + \nu_e$$
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow \mathbf{e}^+ + \nu_e + \nu_\mu$$

*Berezinsky & Zatsepin '69

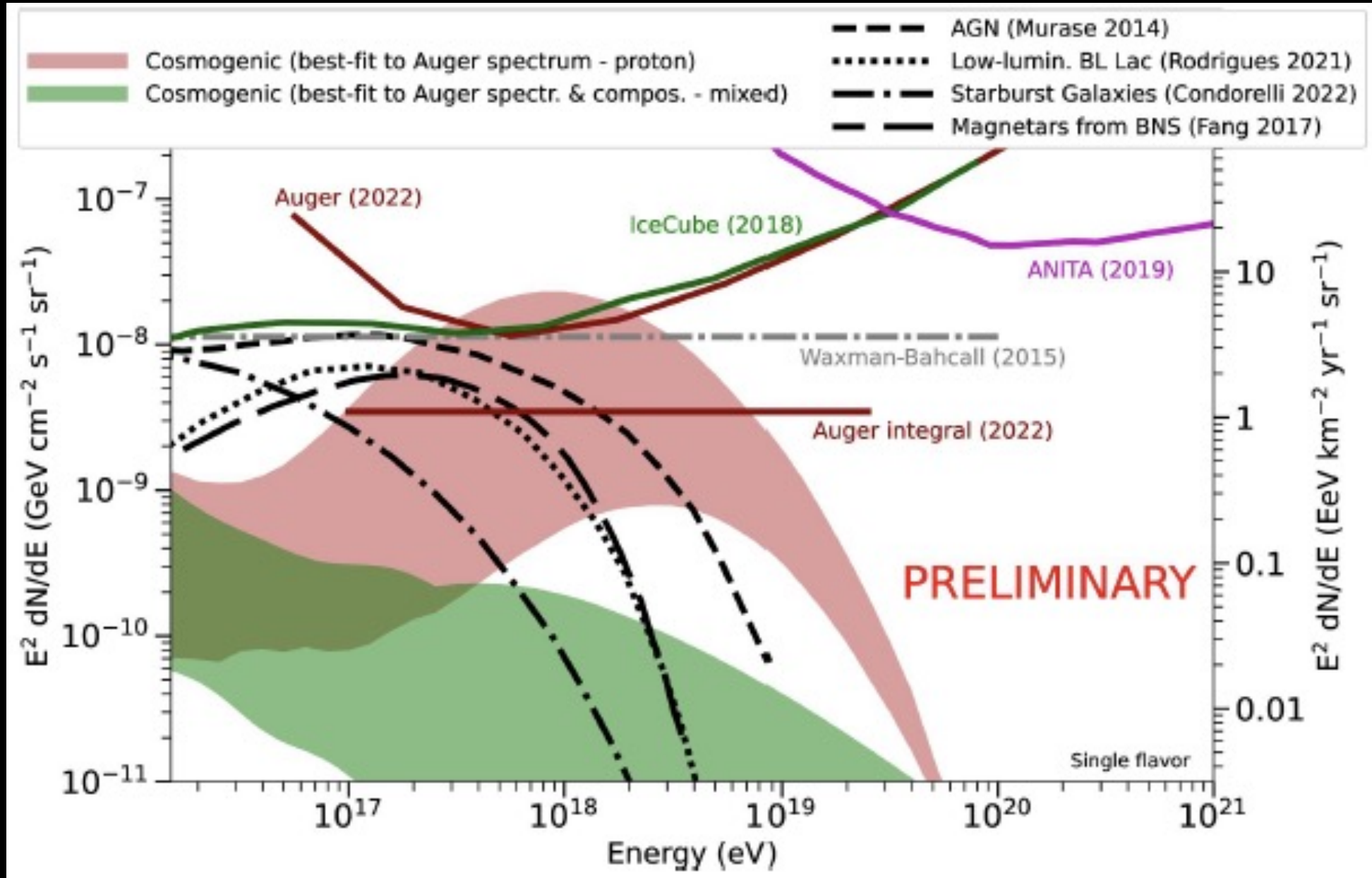
Limits on Neutrino and Gamma-Rays at UHE

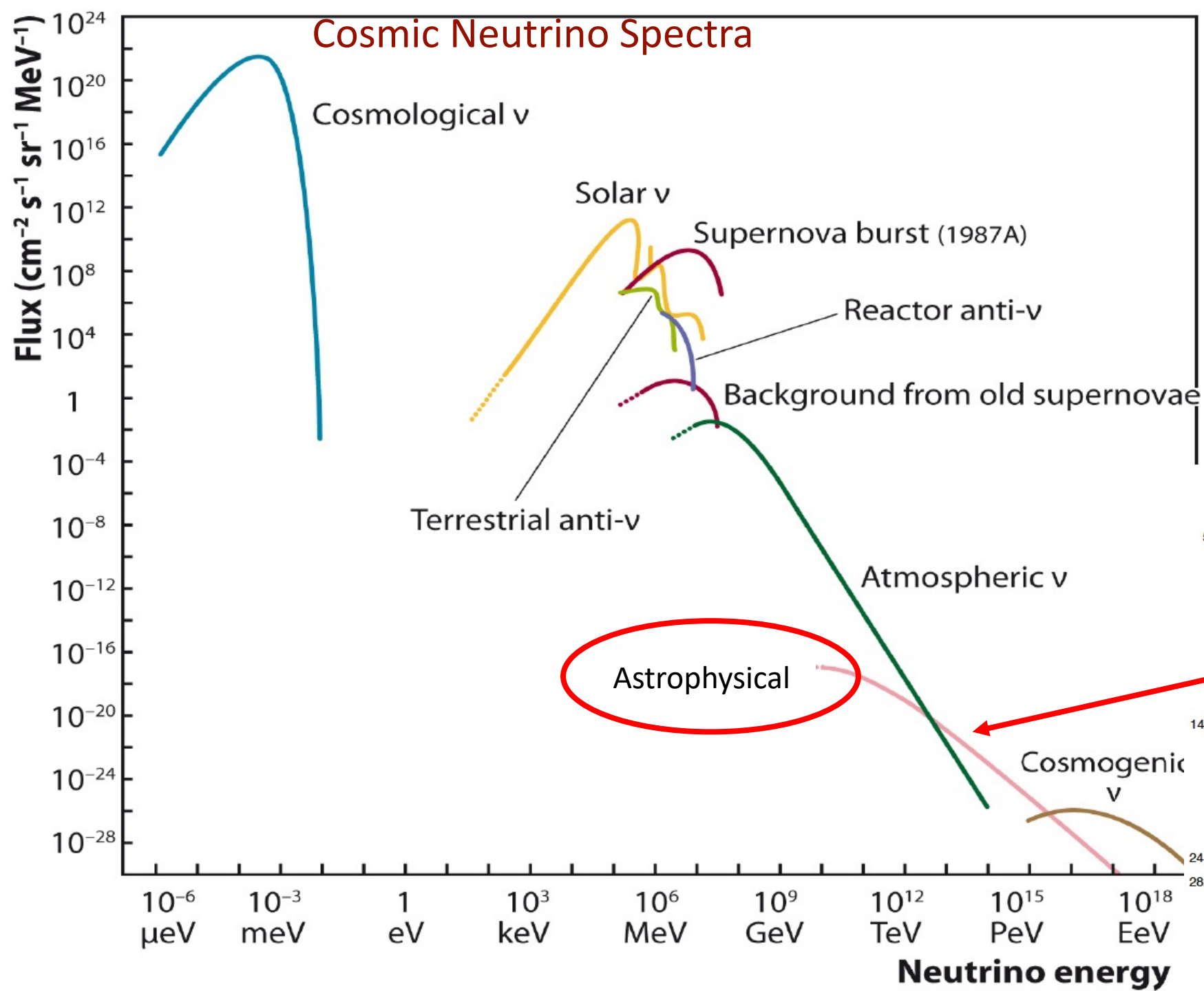


Auger UHE Photon limits ICRC 2023

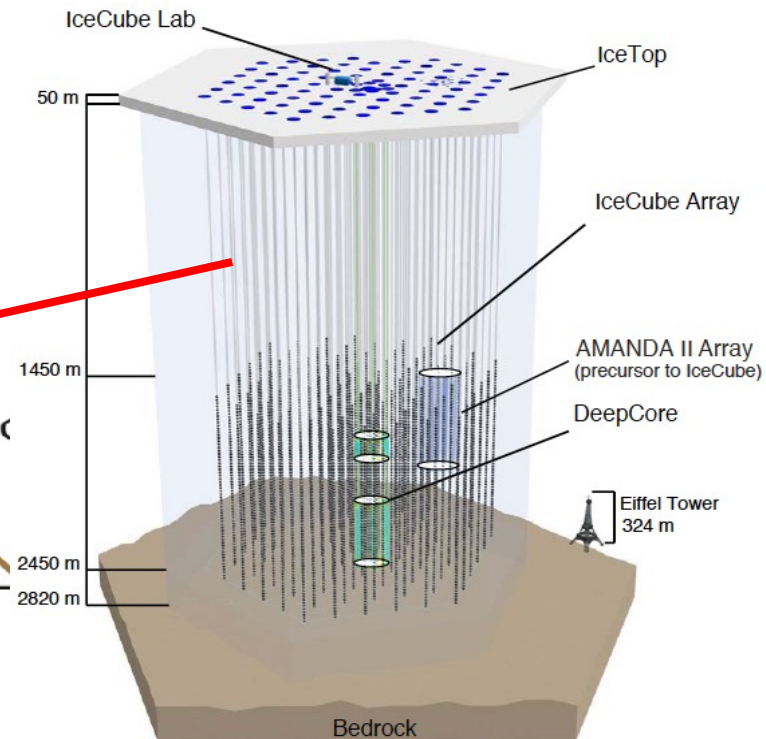


Auger Neutrino limits ICRC 2023

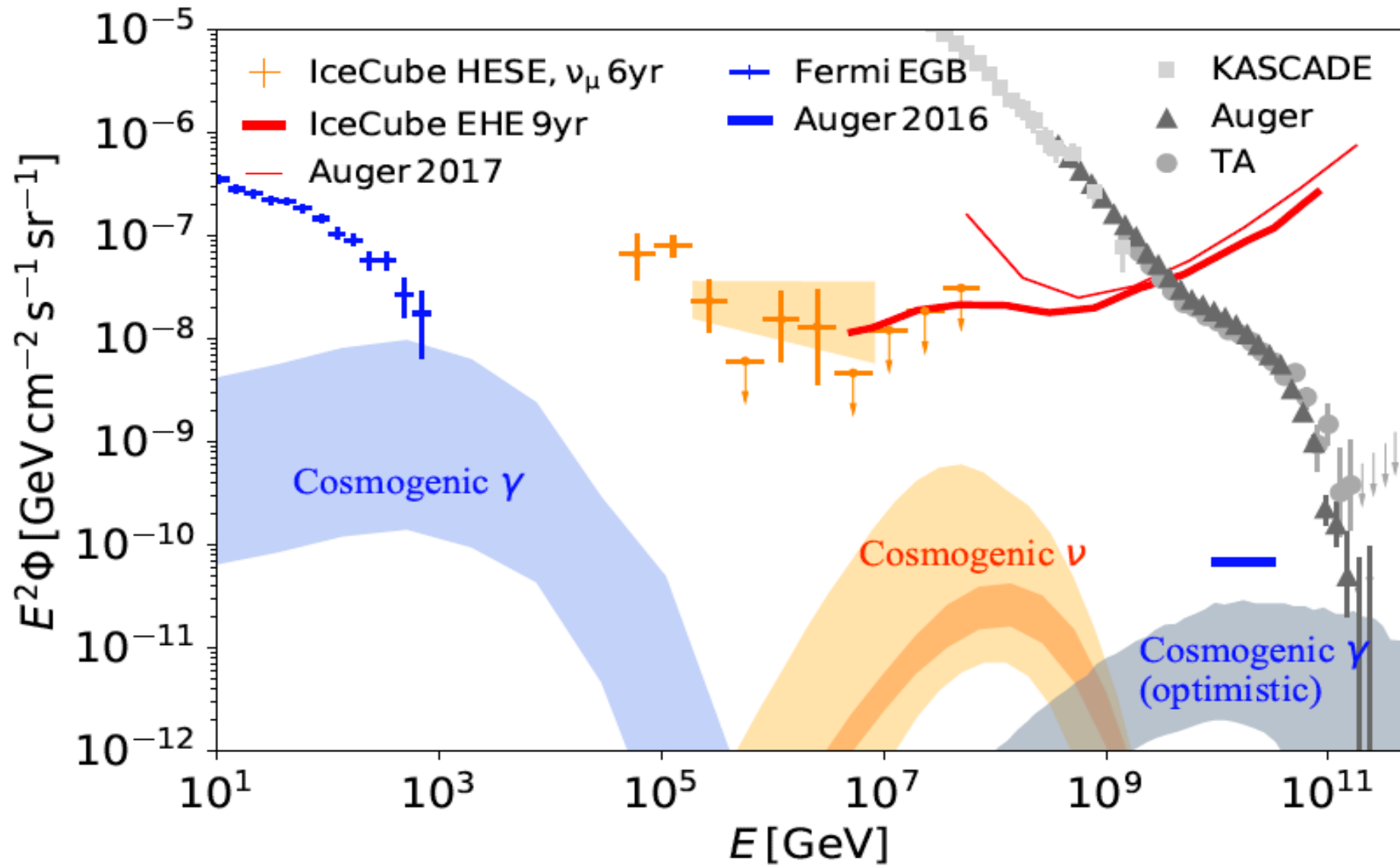




IceCube

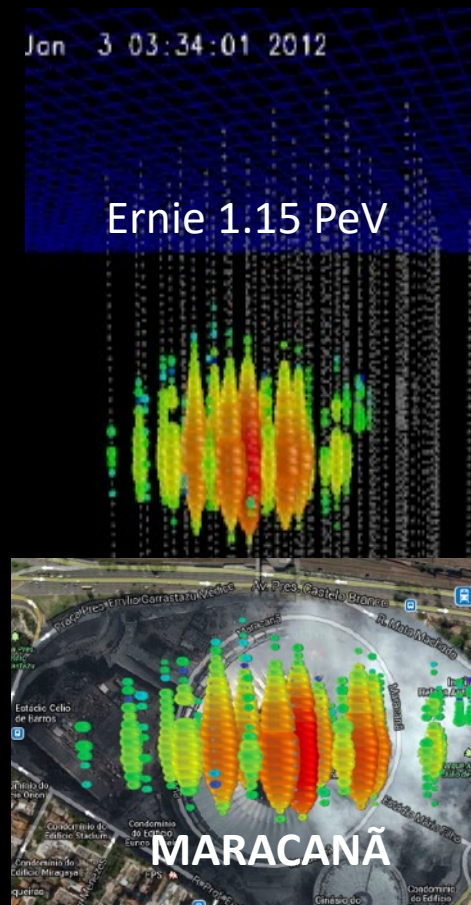
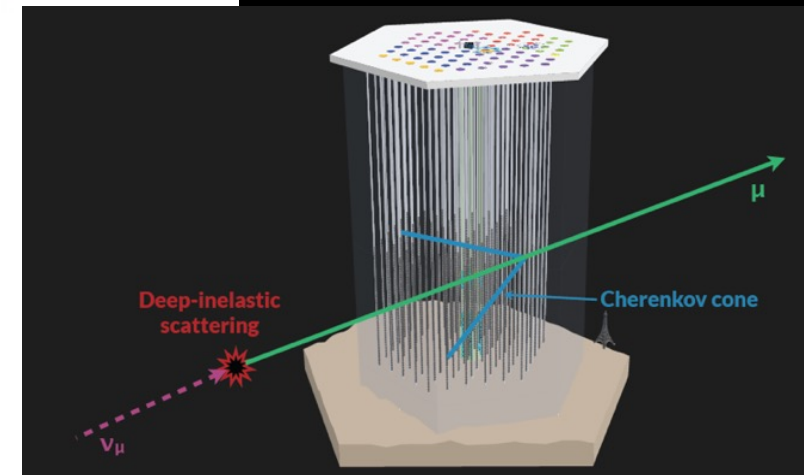
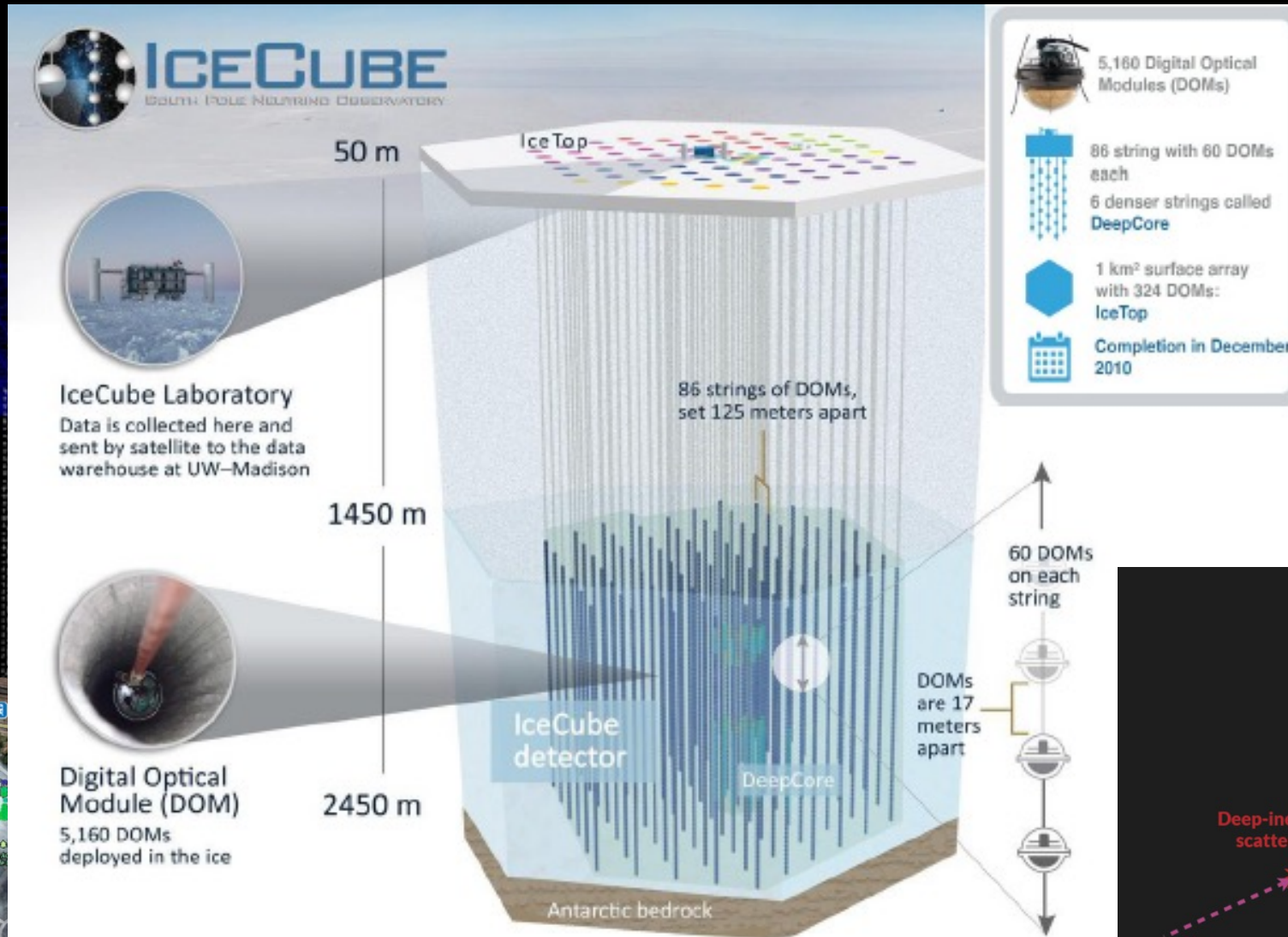


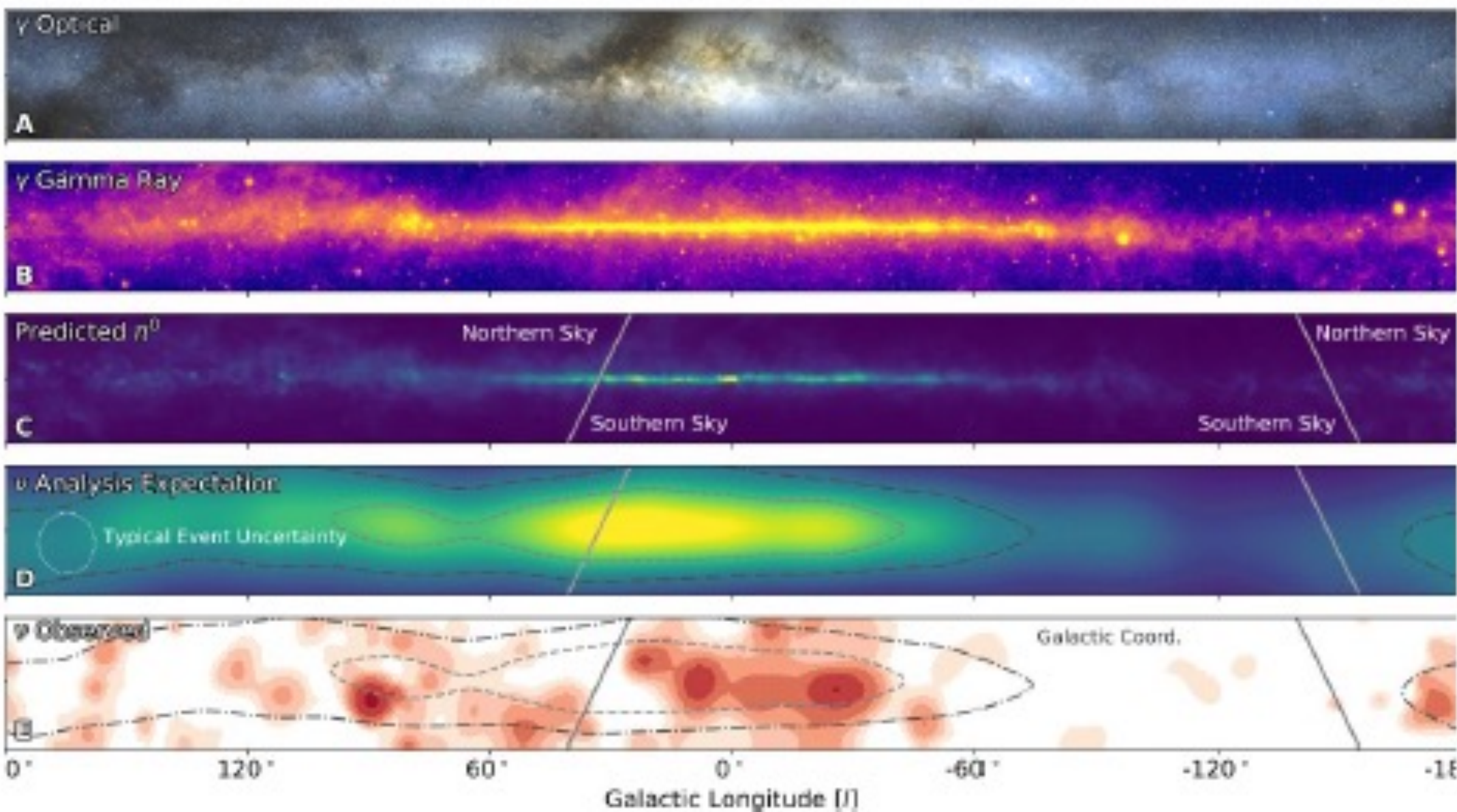
Cosmogenic Messengers



What are the sources of **Astrophysical Neutrinos**?

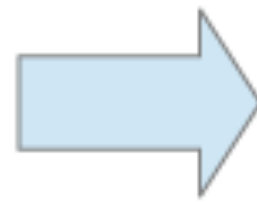
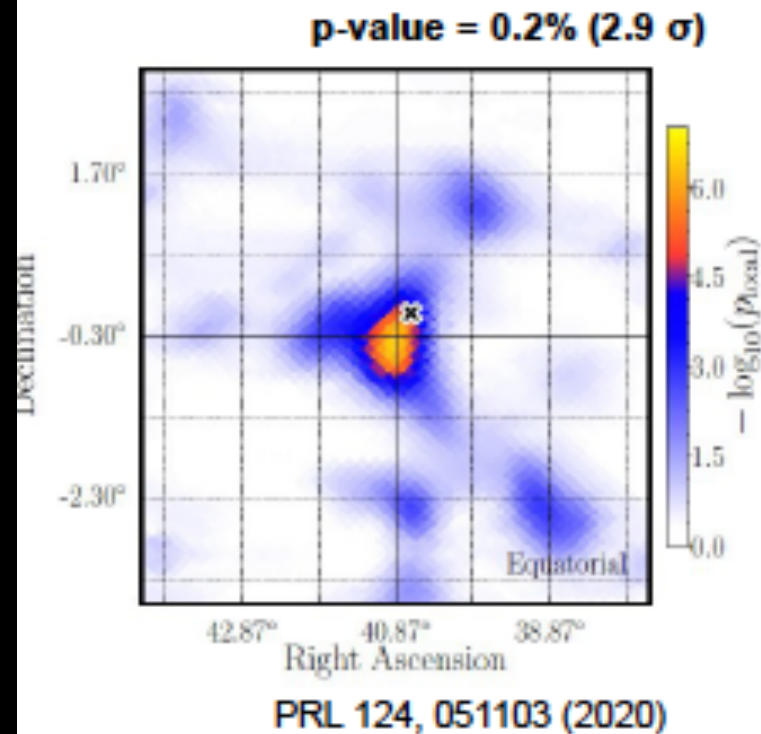
Extragalactic Neutrino Astronomy begins: IceCube



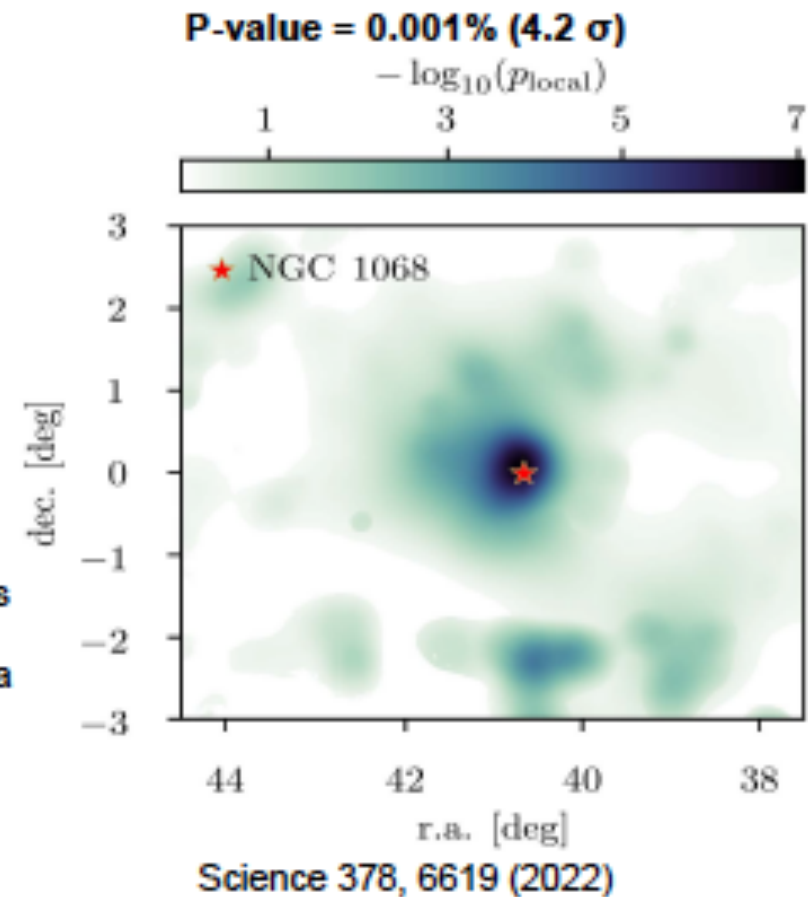


NGC 1068

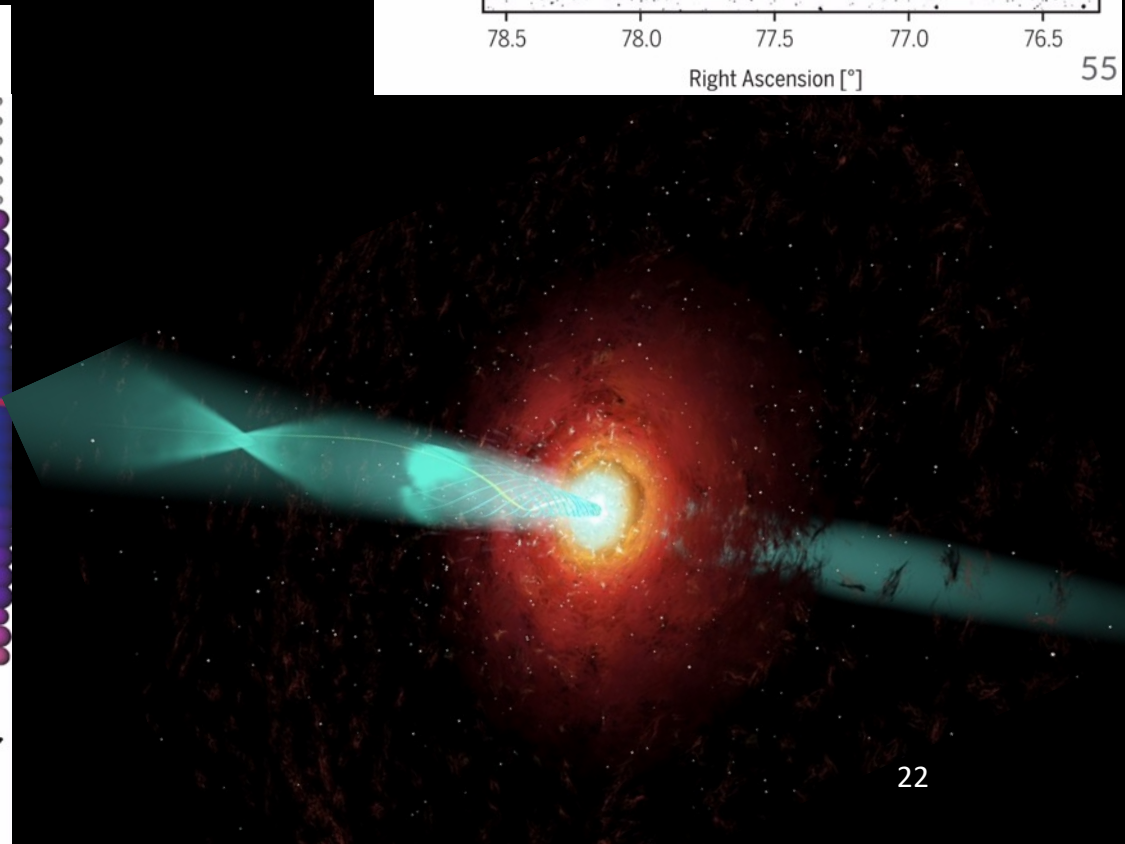
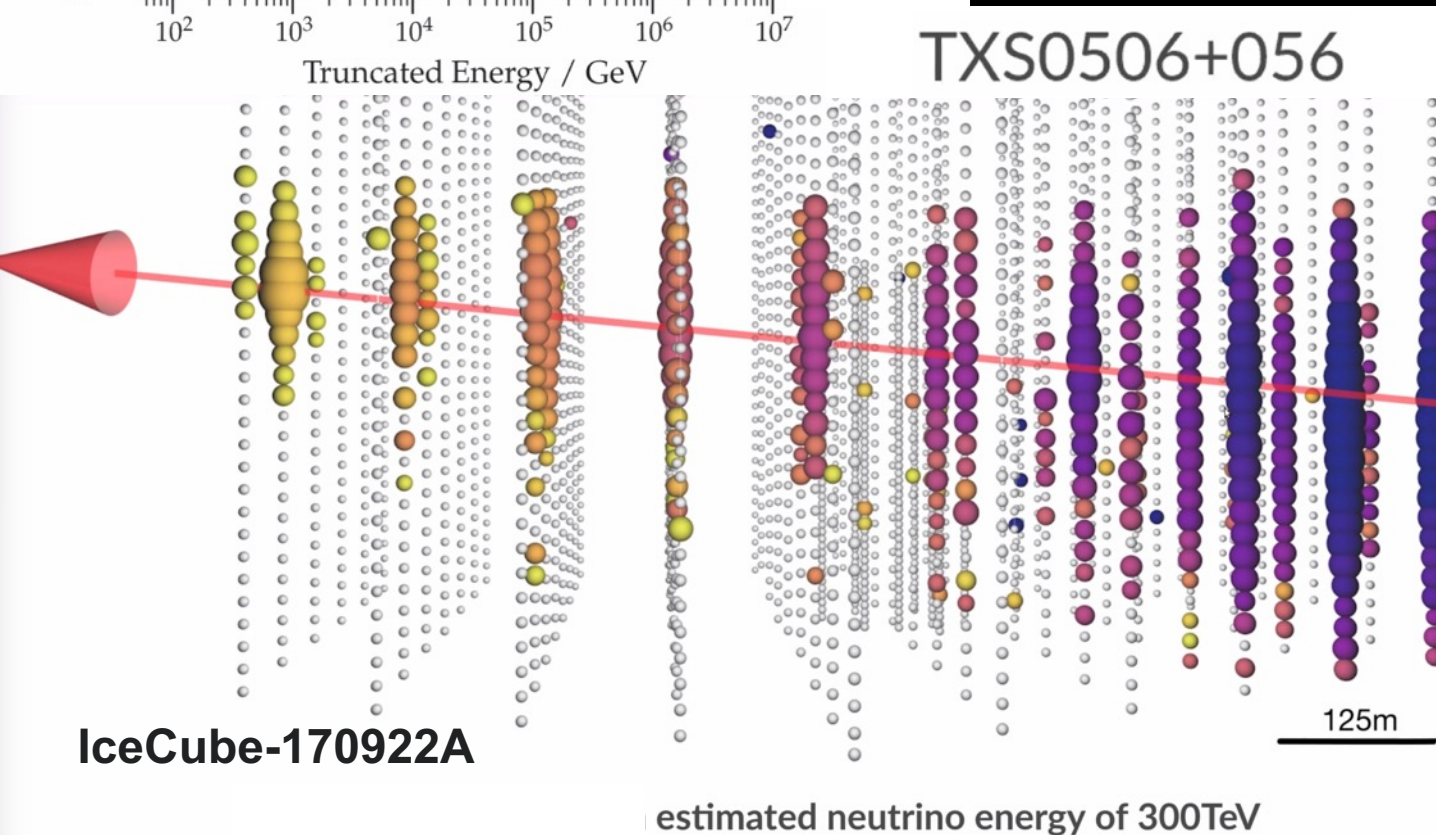
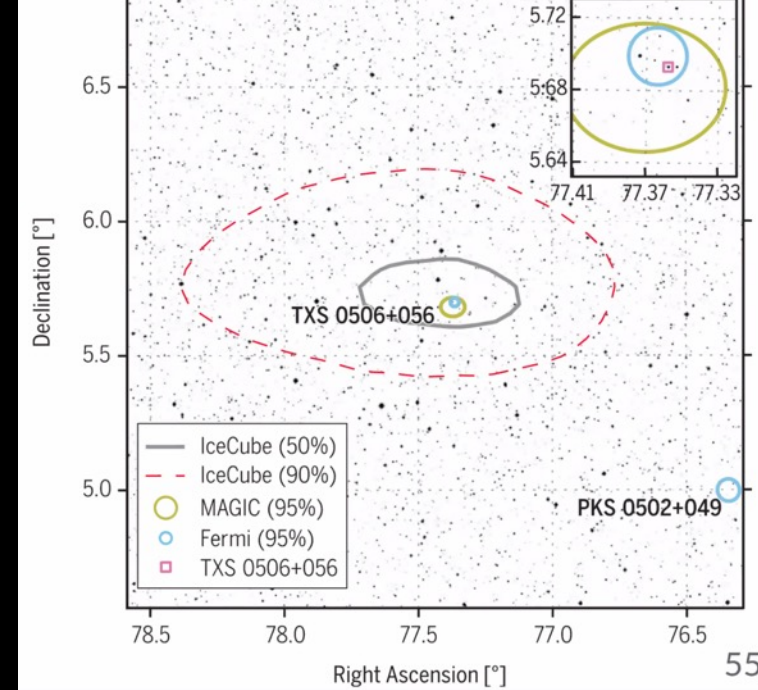
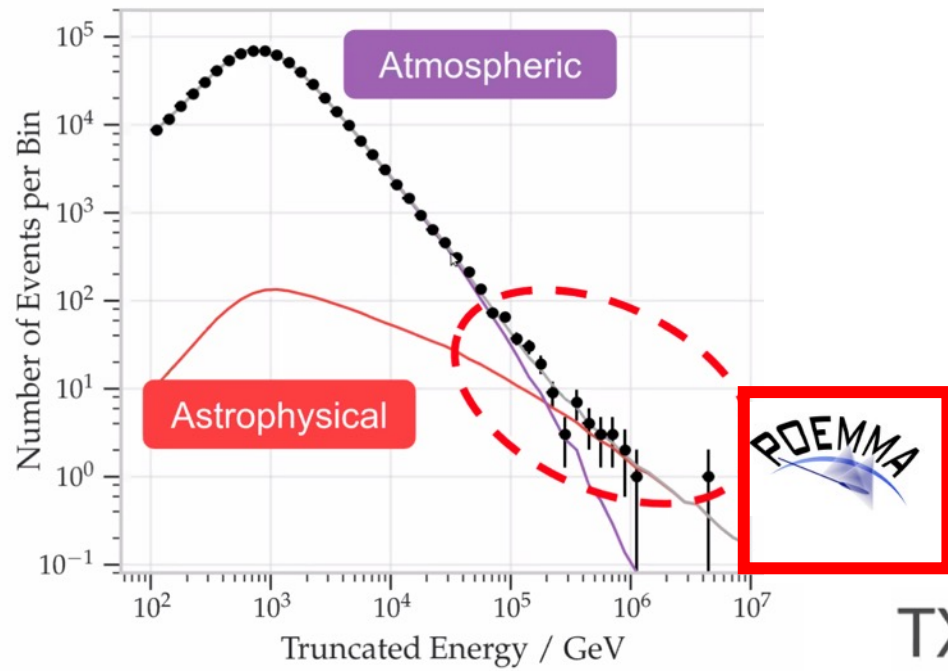
- Starburst Galaxy
- Seyfert II
- 14 Mpc



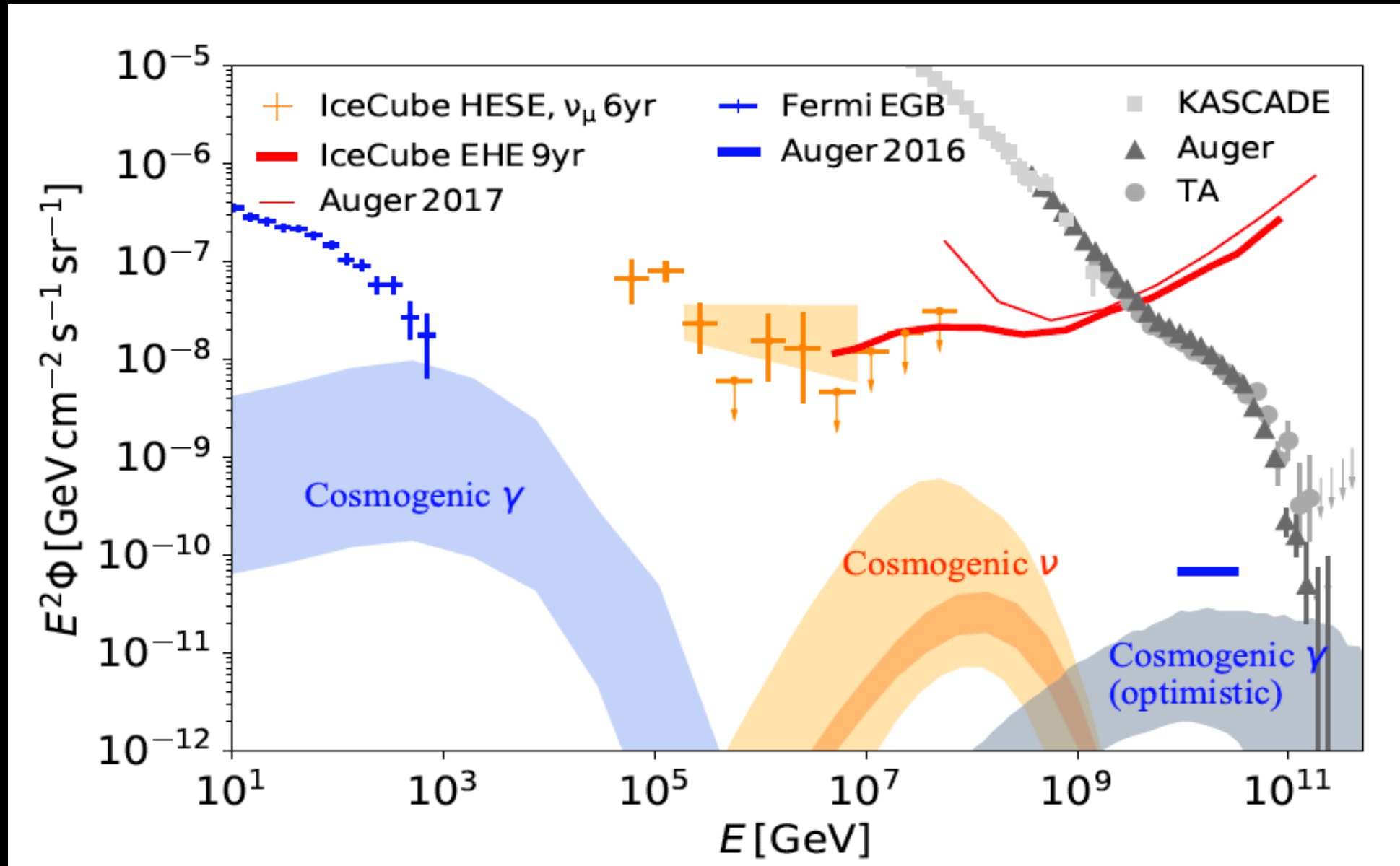
Low Level Data quality
improvements (pass 2)
+
Improved reconstructions
+
Additional 2 years of data



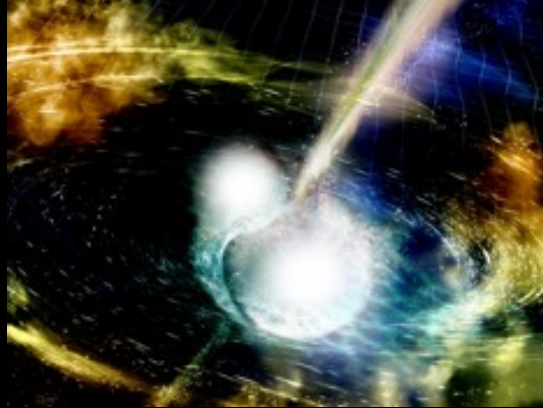
Astrophysical Neutrinos



Cosmogenic Messengers



Transient Energetic Cosmic Events



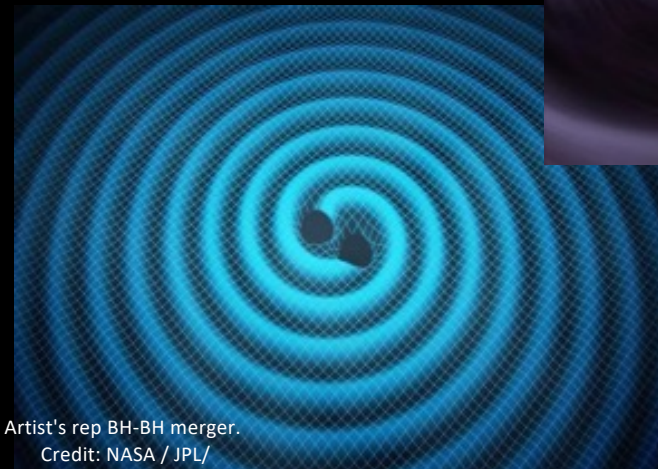
Artist's rep NS-NS merger.
Credit: NSF/LIGO/SSU/A. Simonnet.



Artist's rep WD-WD merger
Credit: Ars Technica

Binary Neutron Star Mergers
Binary Black Hole Mergers
Neutron Star –Black Hole Merge

NS-NS m
Credit: NASA,



Artist's rep BH-BH merger.
Credit: NASA / JPL/
Swinburne Astron.Prods



Blazar Flares

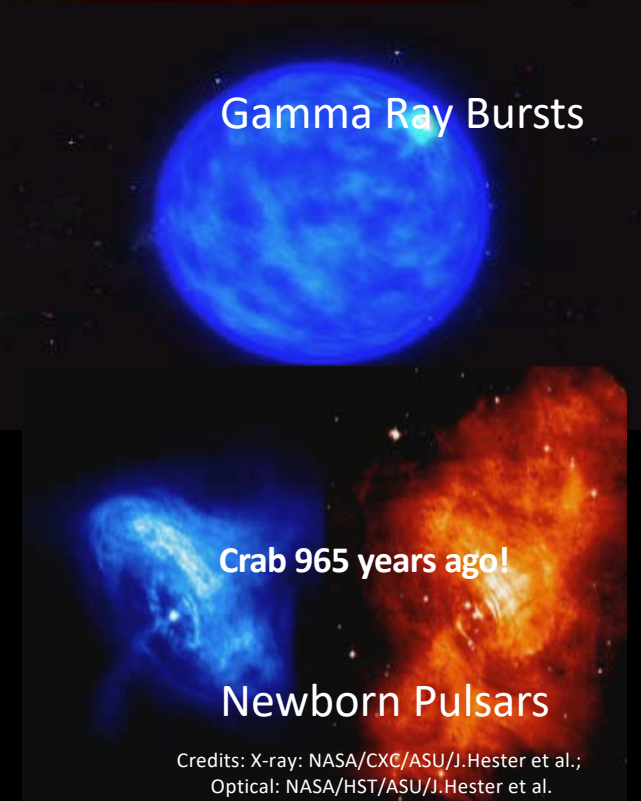


Artist's rep TDE (star torn BH).
Credit: NASA / CXC / M. Weiss

Tidal Disruption Events

M87

EVENT HORIZON TELESCOPE
COLLABORATION/MAUNAKEA
OBSERVATORIES/ASSOCIATED PRESS



Gamma Ray Bursts

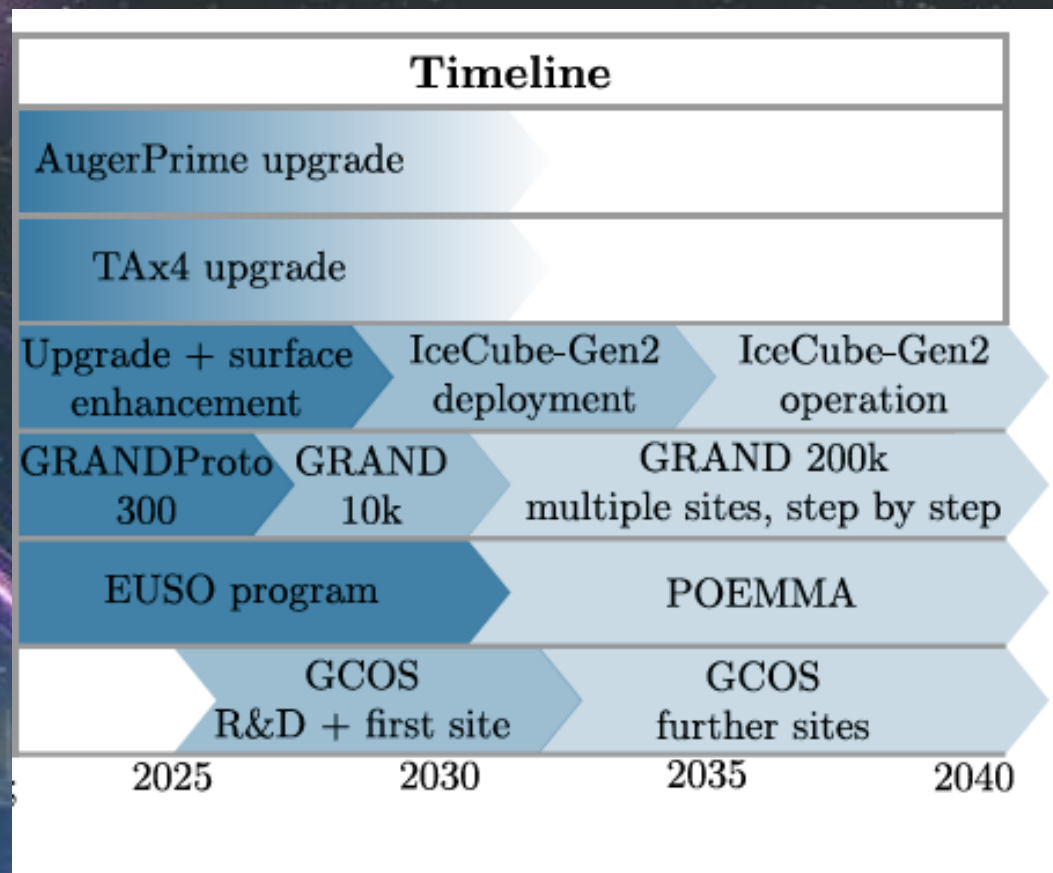
Crab 965 years ago!

Newborn Pulsars

Credits: X-ray: NASA/CXC/ASU/J. Hester et al.;
Optical: NASA/HST/ASU/J. Hester et al.

Future Outlook

Future Outlook UHECRs



Future Outlook Neutrinos

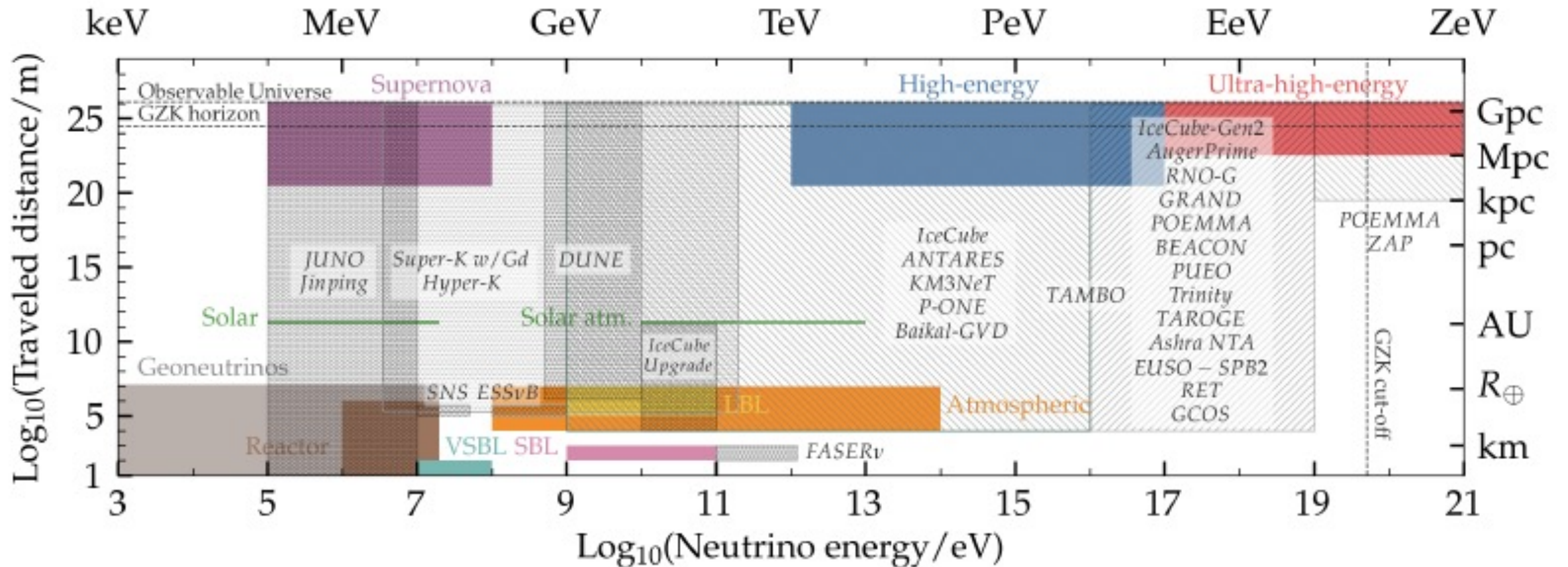
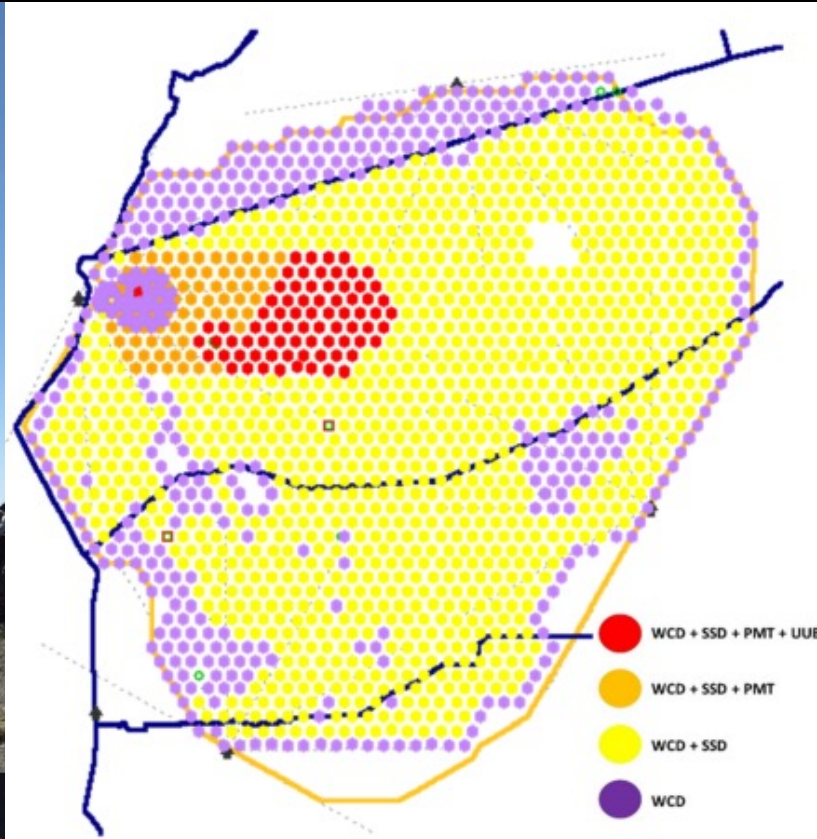
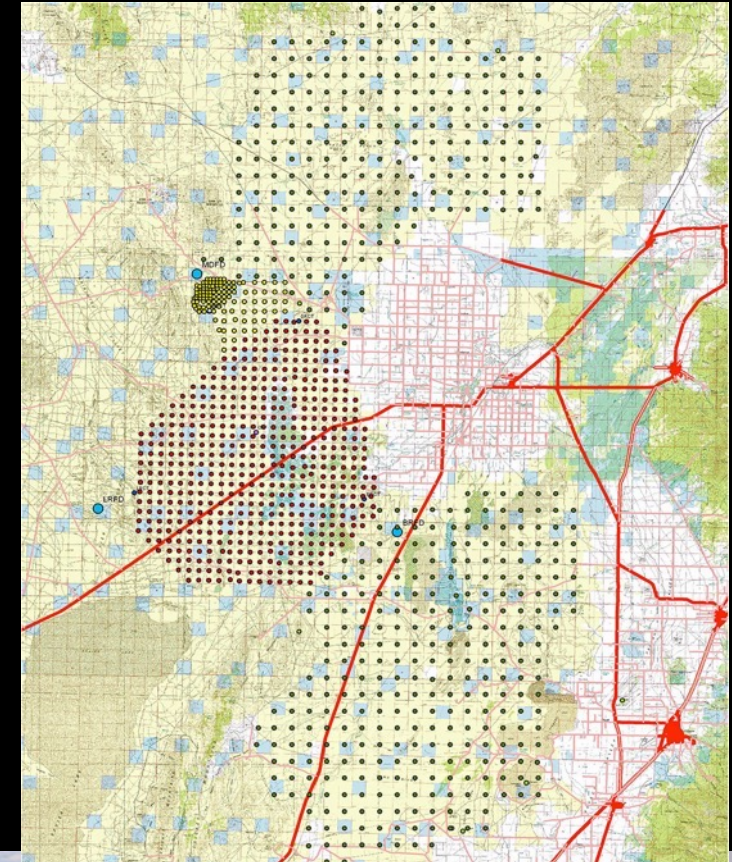


Figure 1. Distribution of neutrino sources in energy and distance traveled to the detector, and present and future experiments aimed at detecting them. We focus on high-energy and ultra-high energy neutrinos. Updated from Ref. [4].

AugerPrime



TAX4

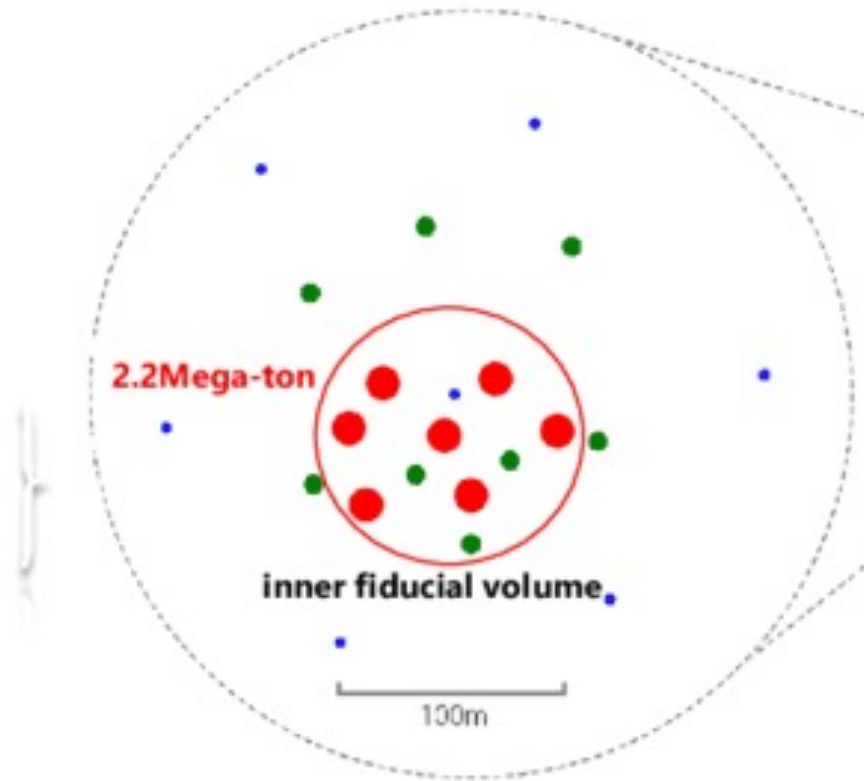


IceCube-Gen2

IceCube Upgrade (planned 2023-)

Optimized for

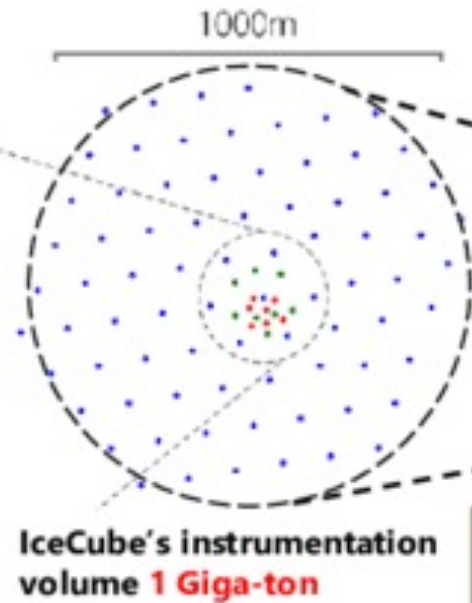
- GeV neutrinos
- Calibration of the IceCube detector



IceCube (2005-)

Optimized for

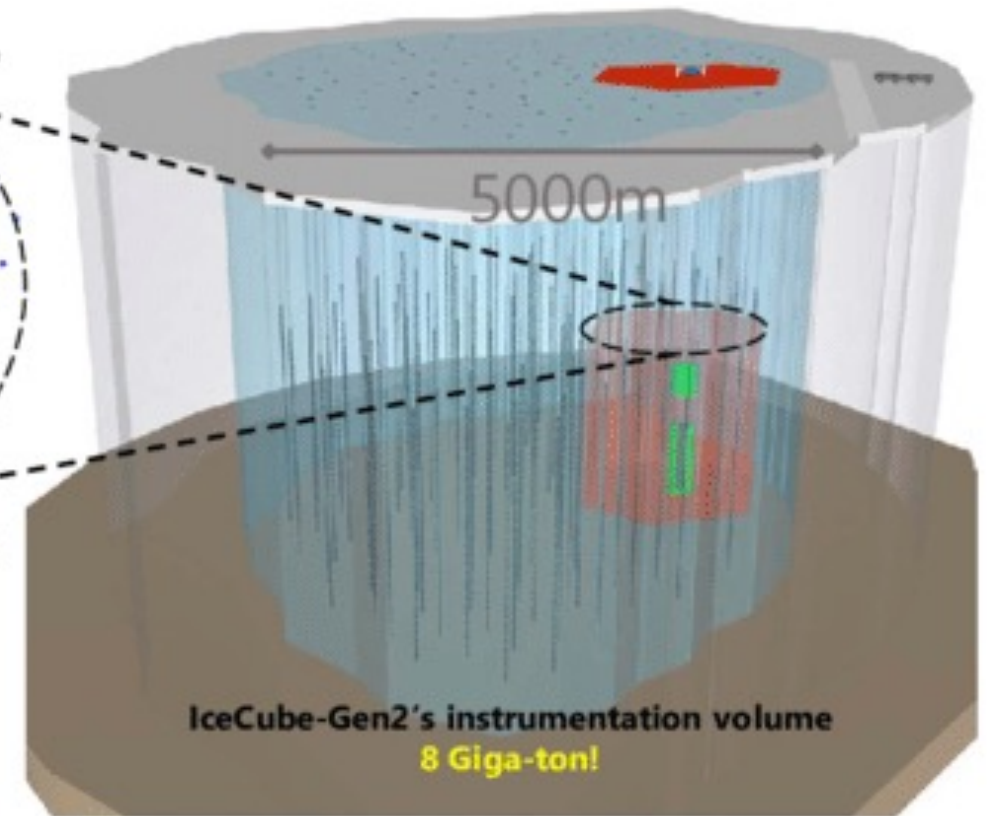
- Diffuse high energy cosmic neutrinos



IceCube-Gen2 (planned 2026-)

Optimized for

- Cosmic neutrino point sources





Probe Of Extreme Multi-Messenger Astrophysics
UHECRs and Cosmic Neutrinos

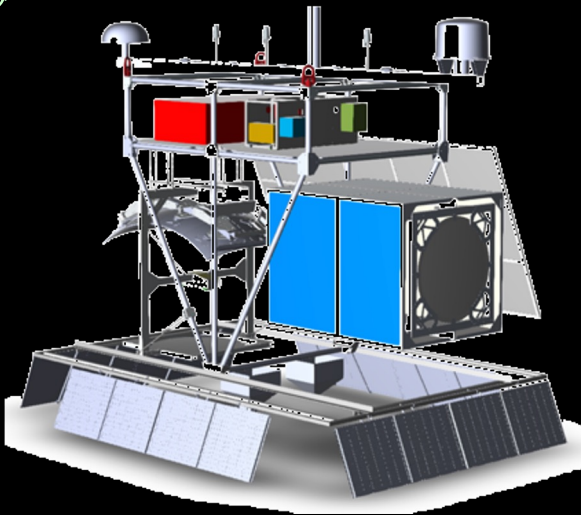
POEMMA Roadmap Update

Probe Of Extreme Multi-Messenger Astrophysics

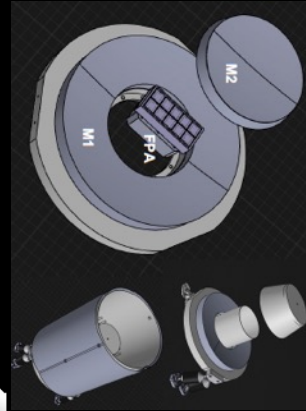
Mini-EUSO (2019)



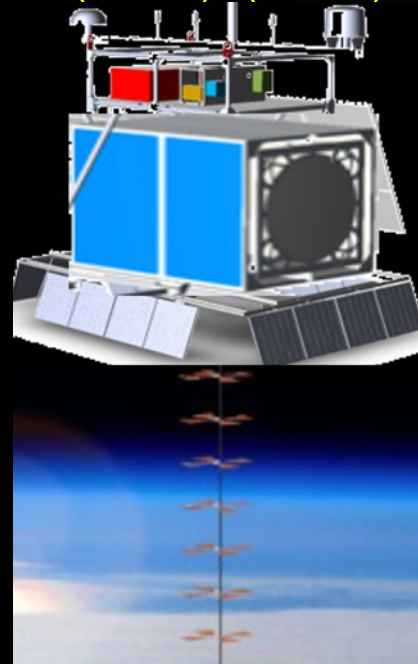
EUSO-SPB2
(2023)



Terzina
(2026)

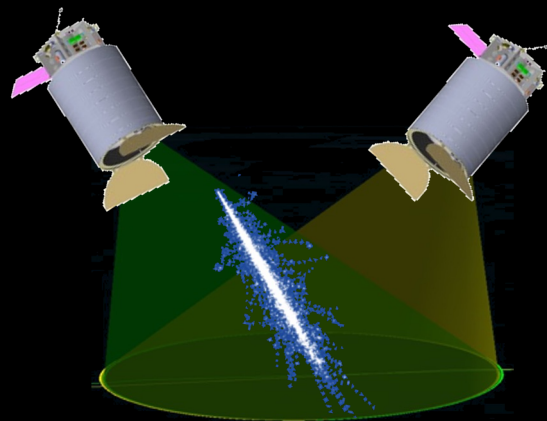


POEMMA-
Balloon + Radio
(PBR) (2026)



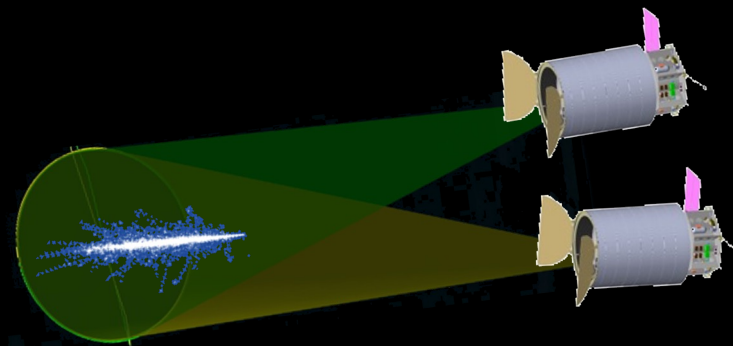
EUSO-SPB1 (2017)





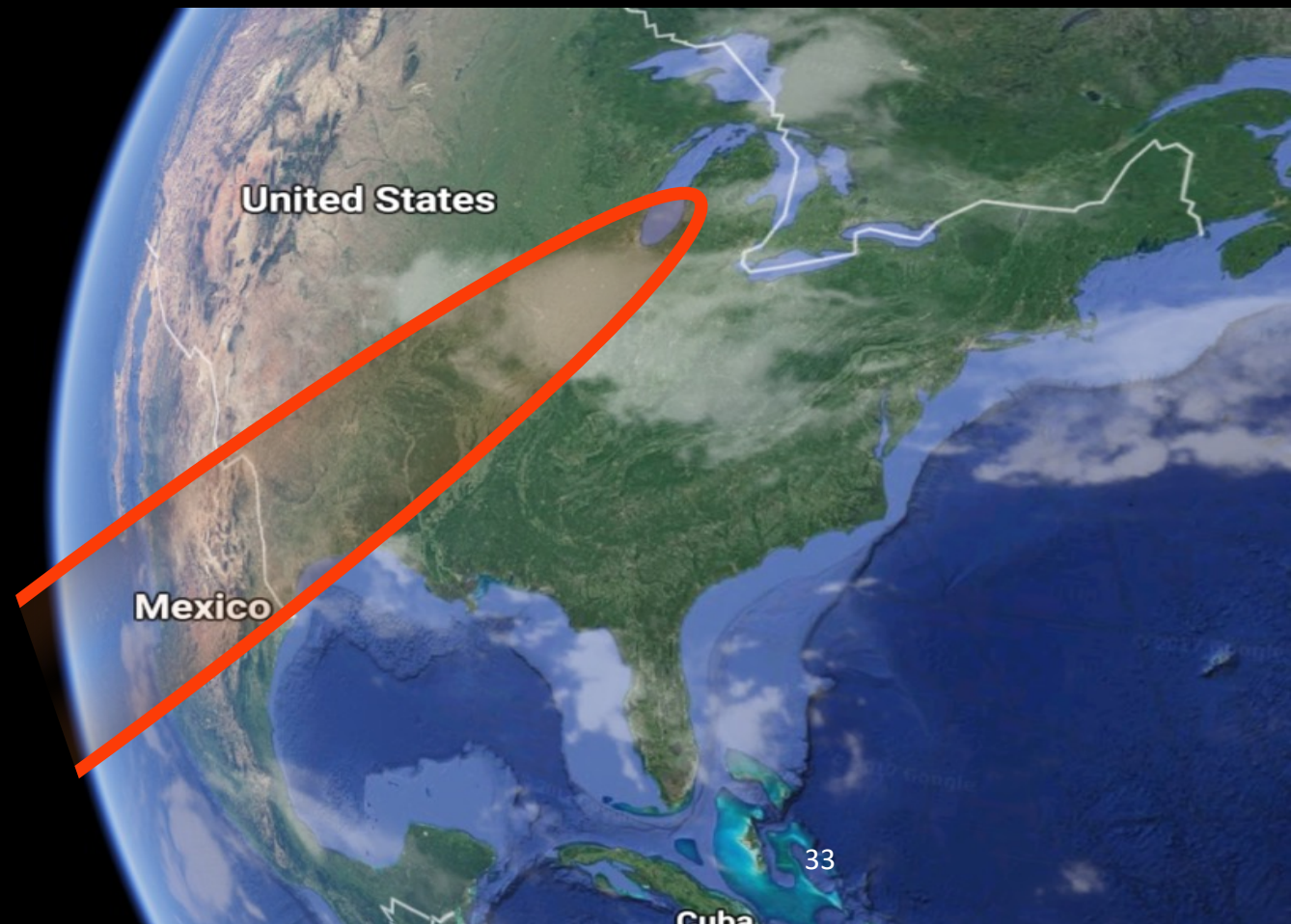
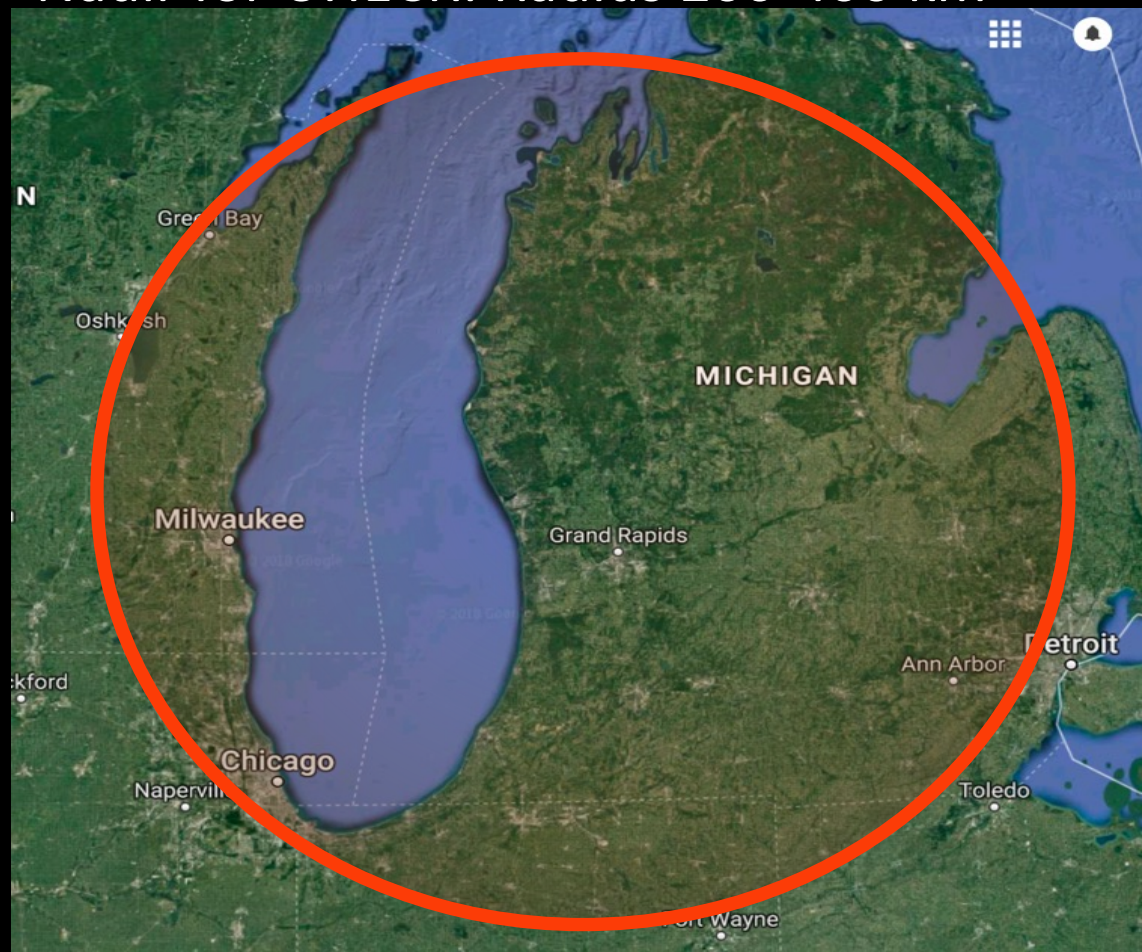
ROEMMA

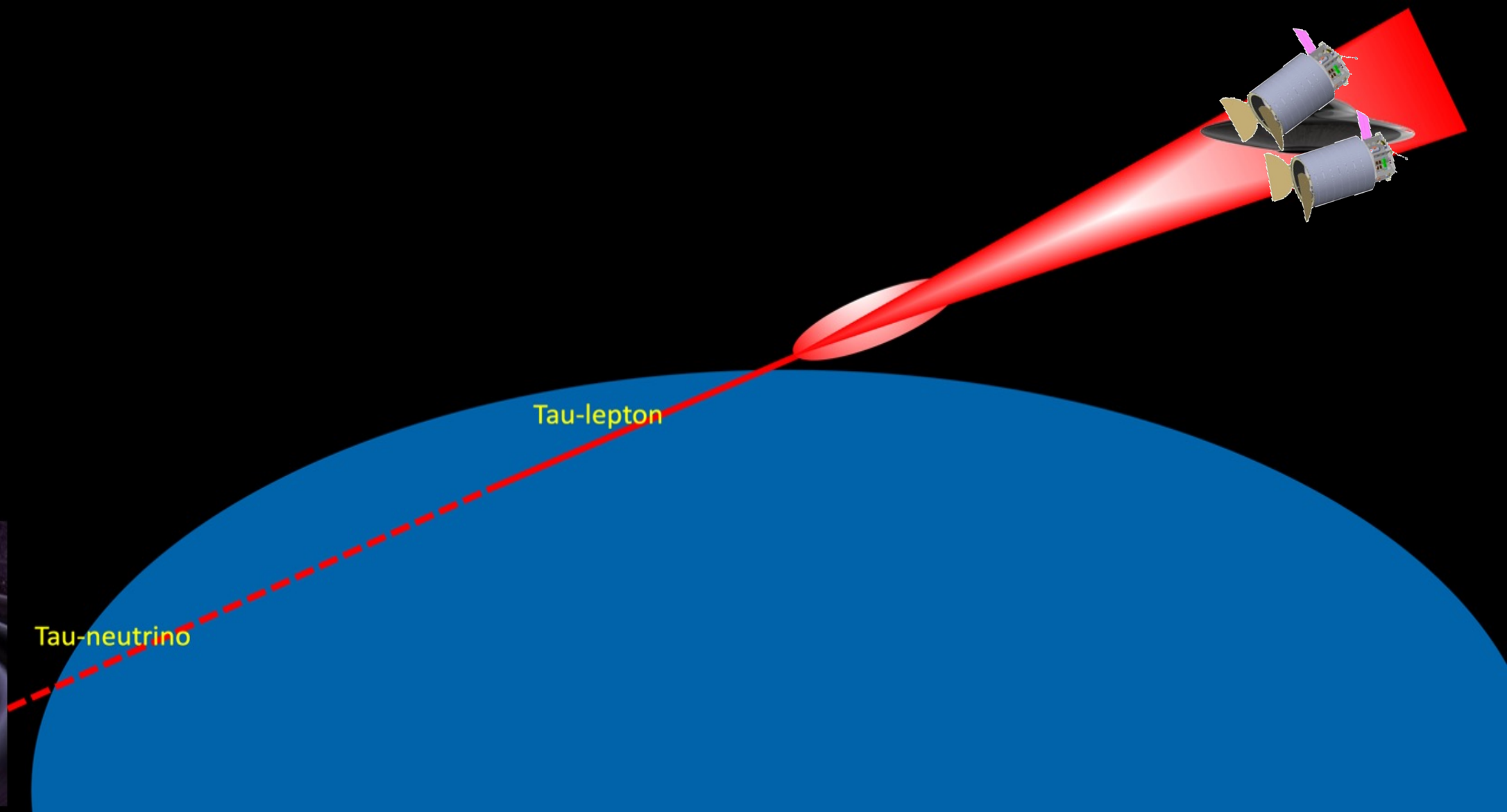
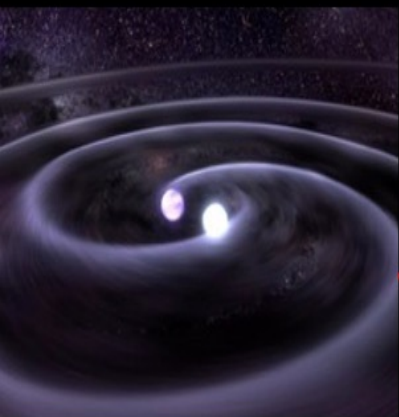
Observing Modes



Nadir for UHECR: Radius 200-400 km

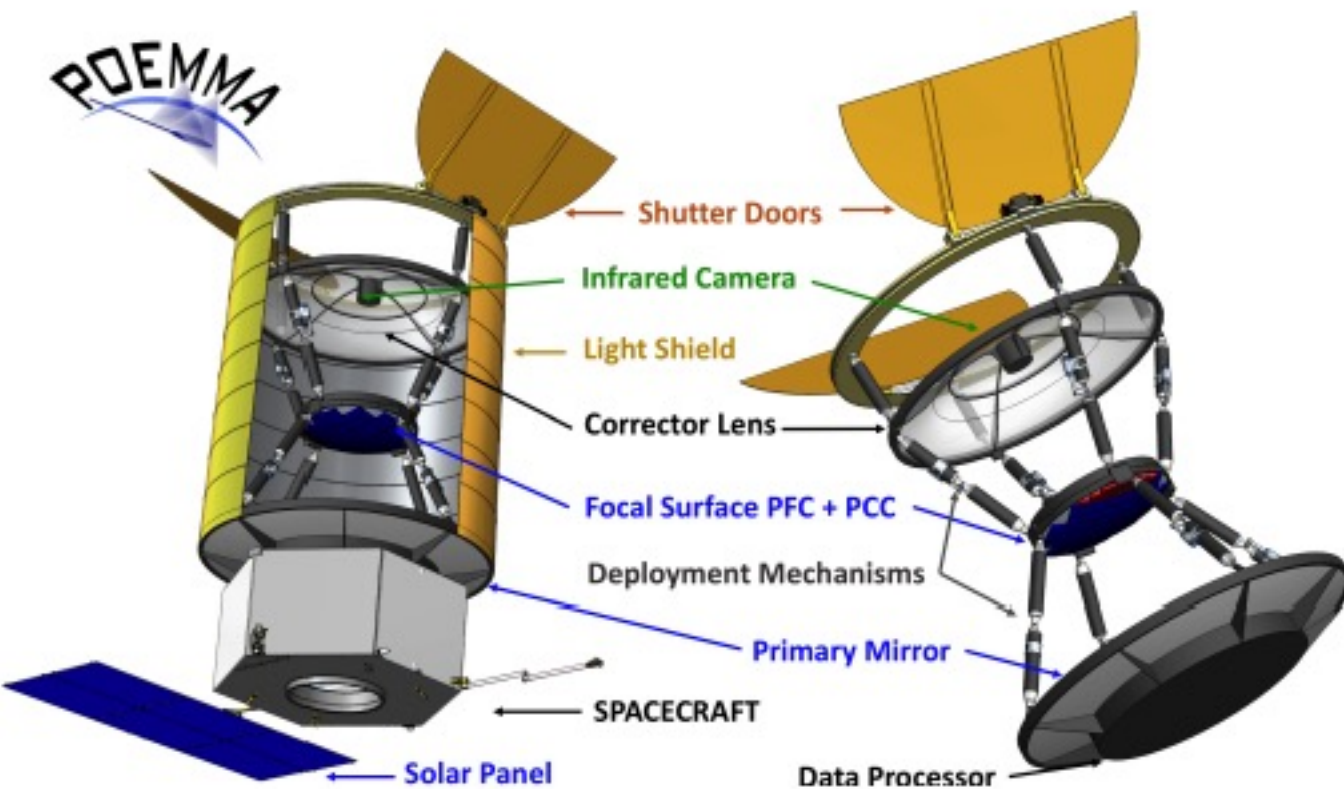
Limb for Neutrinos UHECR: $2-4 \cdot 10^3$ km



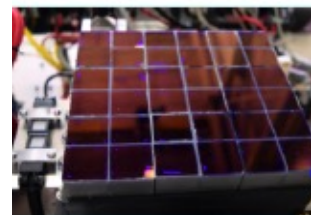


Tau-lepton

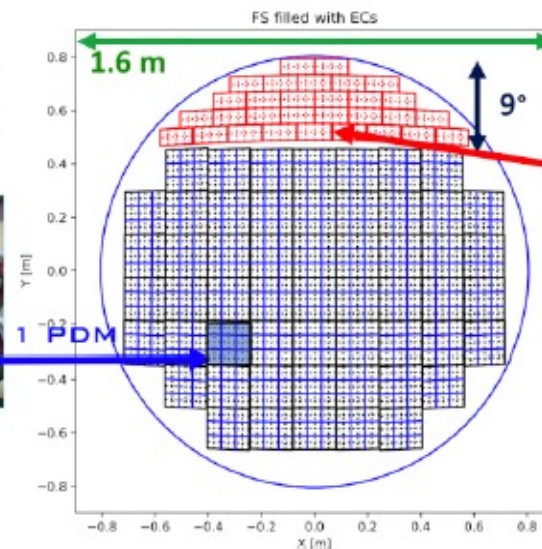
Tau-neutrino



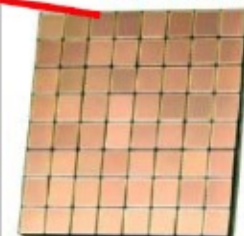
**PFC: POEMMA
FLUORESCENCE
CAMERA**



MAPMTs

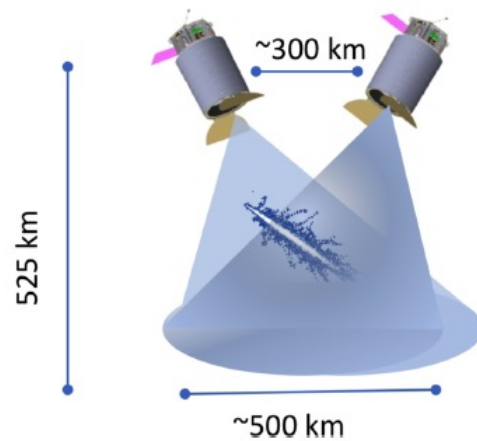


**PCC: POEMMA
CHERENKOV
CAMERA**

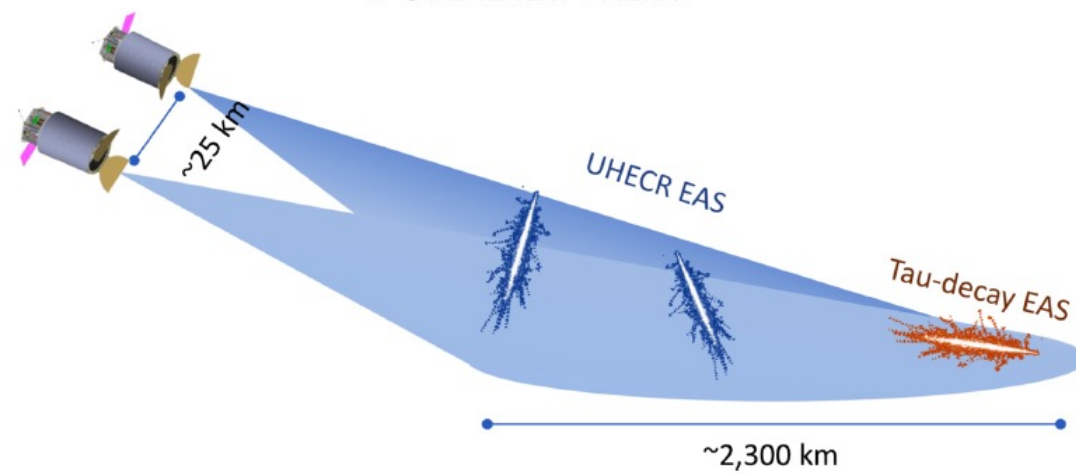


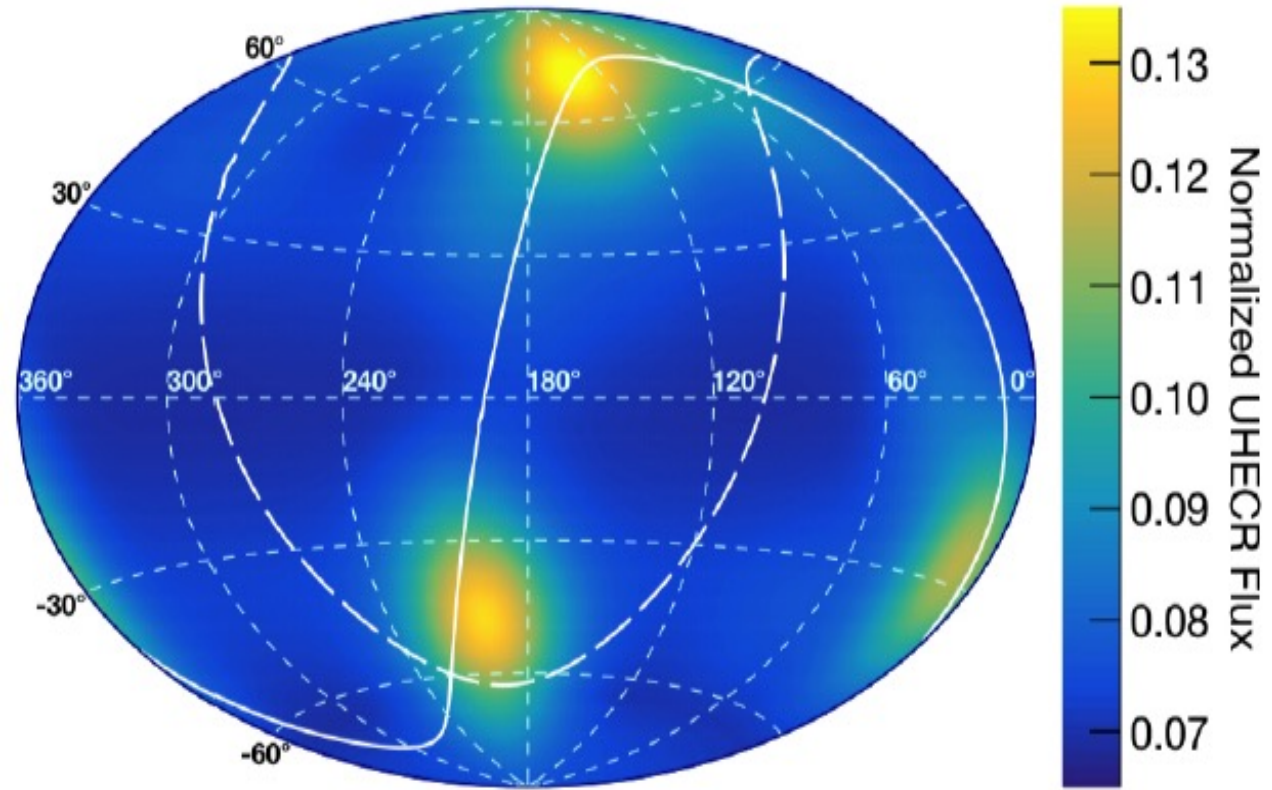
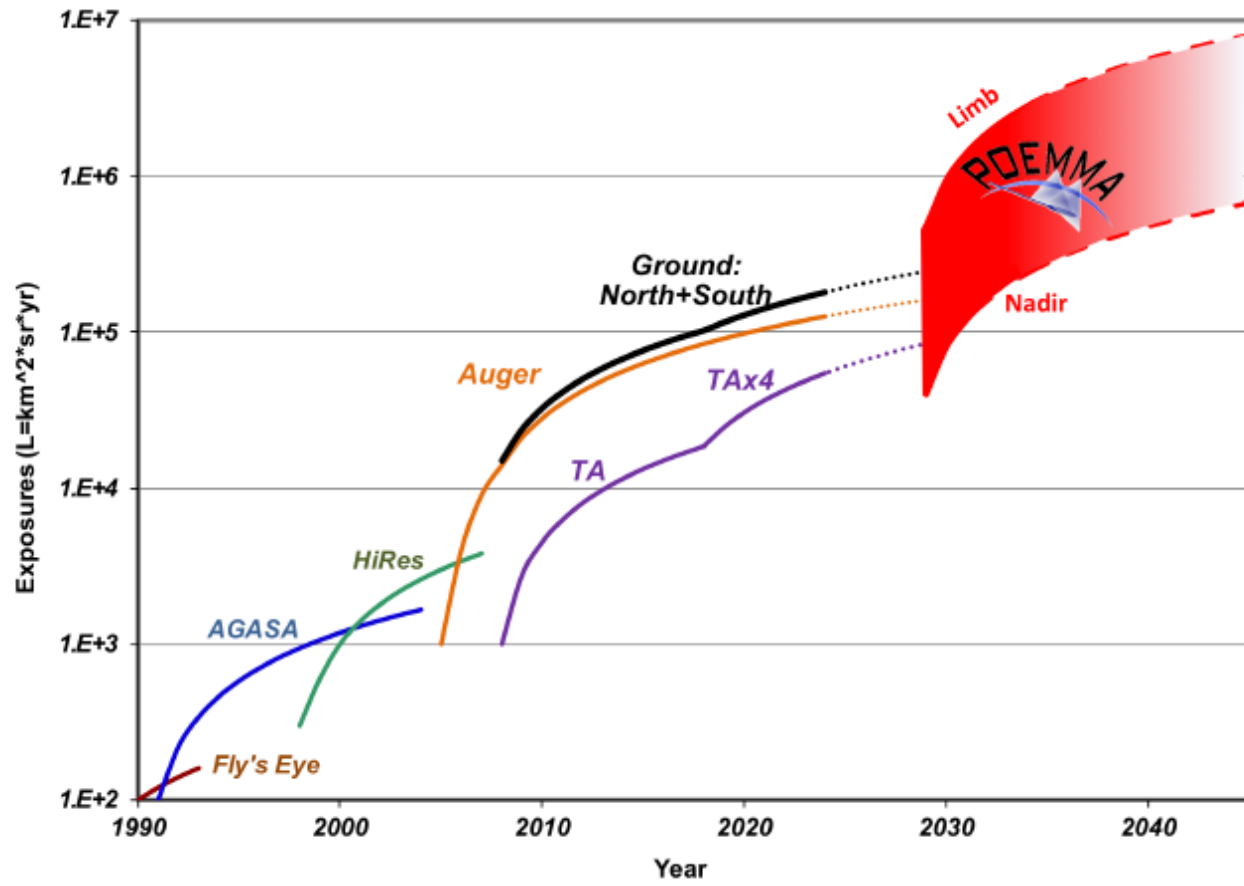
SiPMs

POEMMA-Stereo



POEMMA-Limb







JEM-EUSO program

Joint Experiment Missions
Extreme Universe Space Observatory

300 researchers from 16 countries

EUSO-TA (2013-)

EUSO-Balloon (2014)

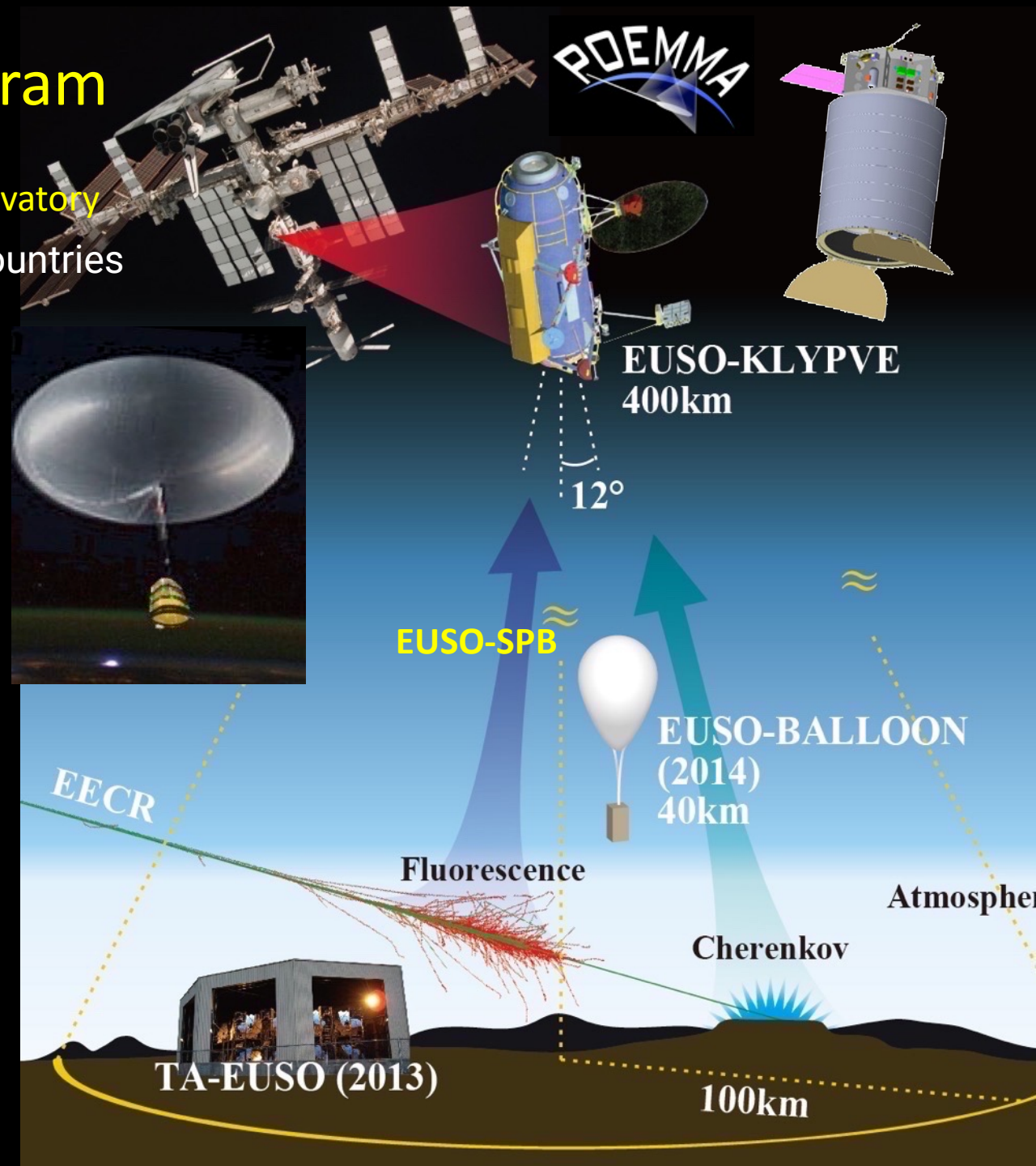
EUSO-SPB1 (2017)

Mini-EUSO (2019)

EUSO-SPB2 (2023)

K-EUSO (2025+)

POEMMA (2030+)

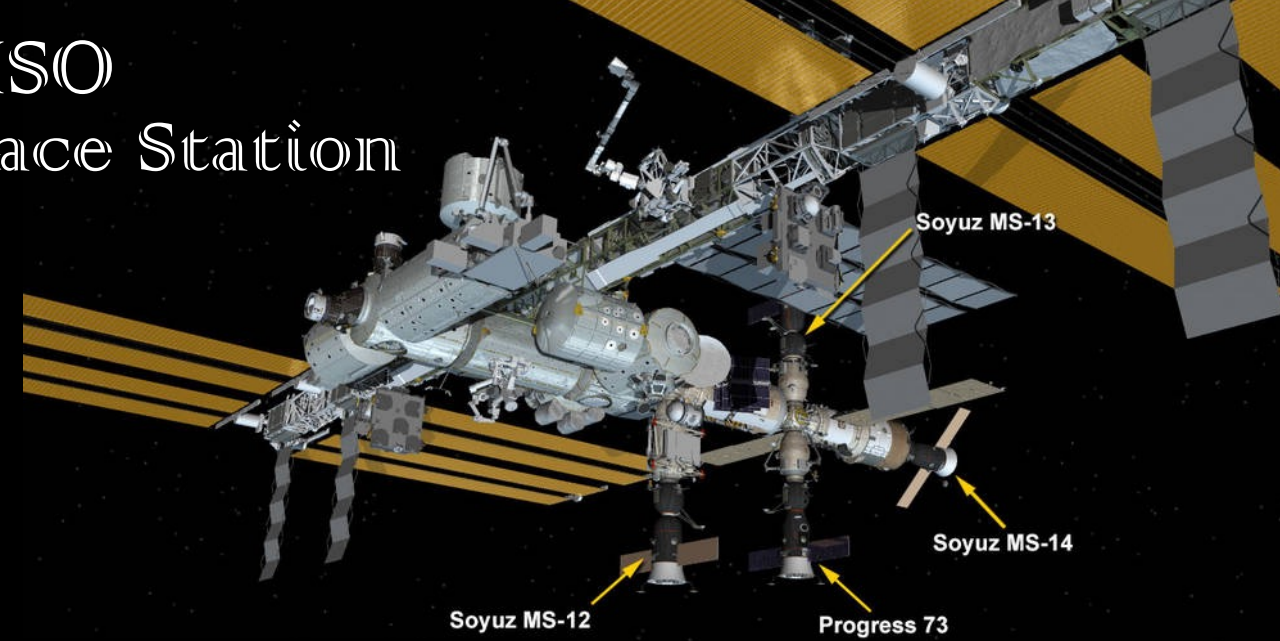
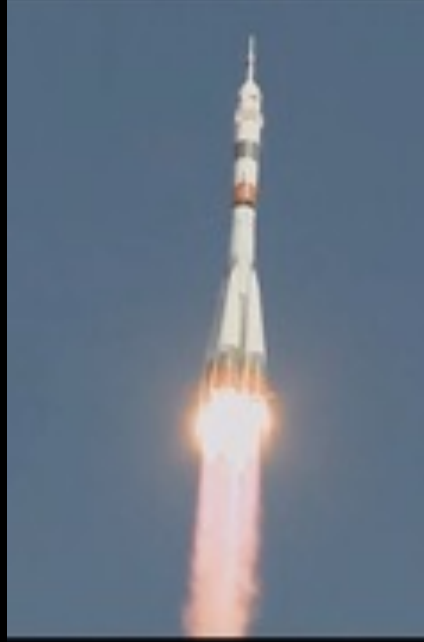


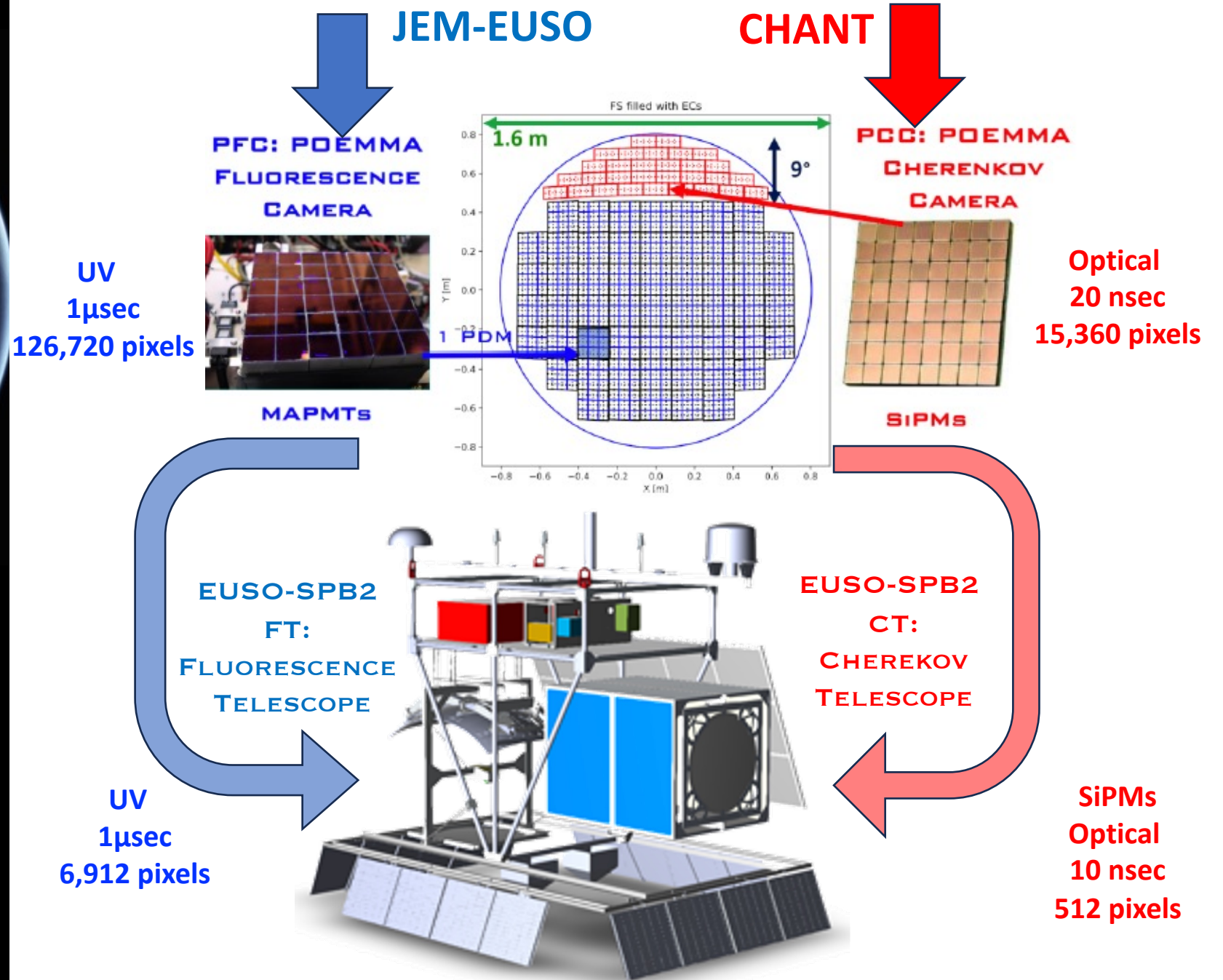


EUSO-SPB 1
launch, April 24, 2017
23:51 UTC

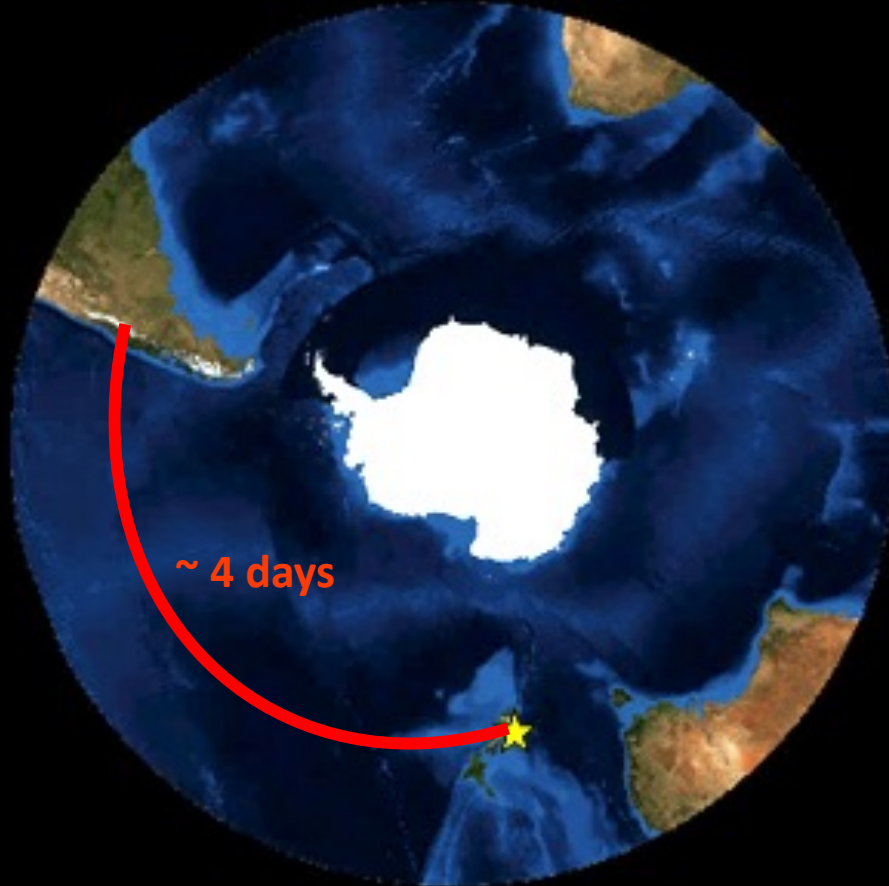


Mini-EUSO International Space Station ISS

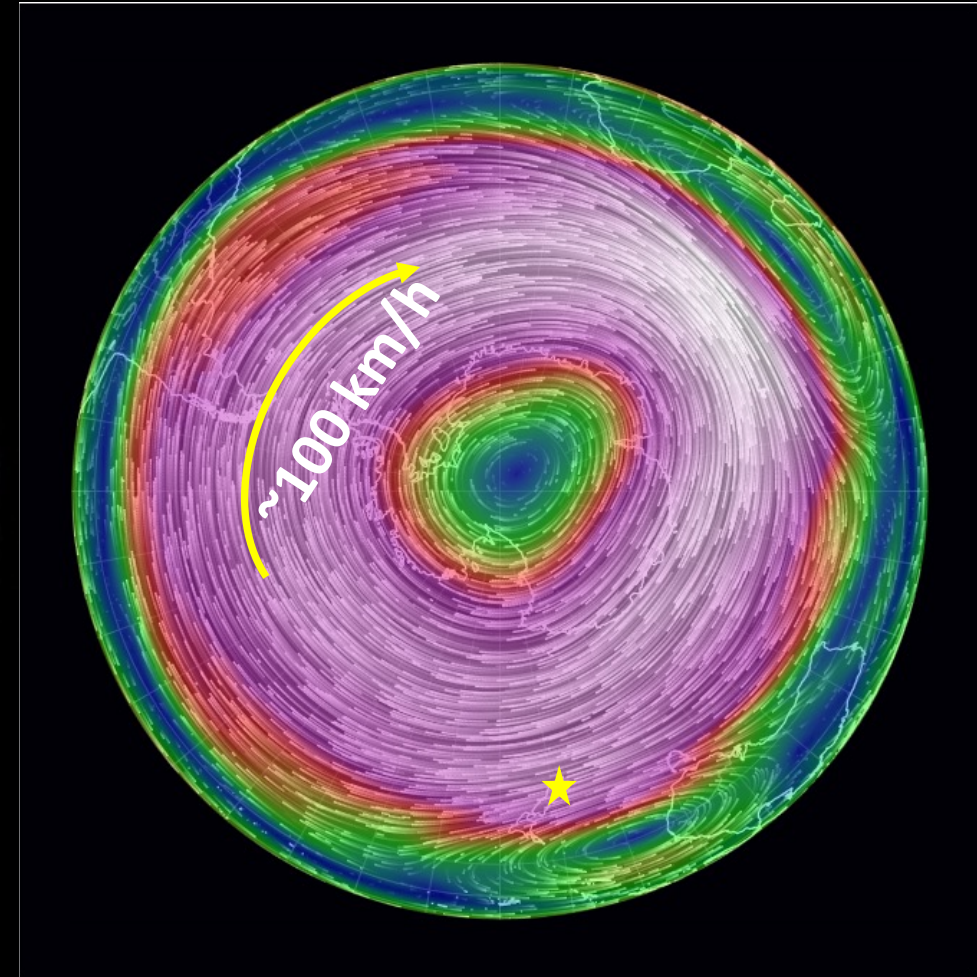




Why New Zealand?



Wanaka
South Island
New Zealand



air flow at ~30 km June 9th 2017

<https://earth.nullschool.net/#current/wind/isobaric/10hPa/orthographic=180,-90,300>



EUSO-SPB2 2023 flight



Fluorescence from UHECRs

Cherenkov Emission from UHECRs
Tau Neutrino Events

UHECRs
Fluorescence

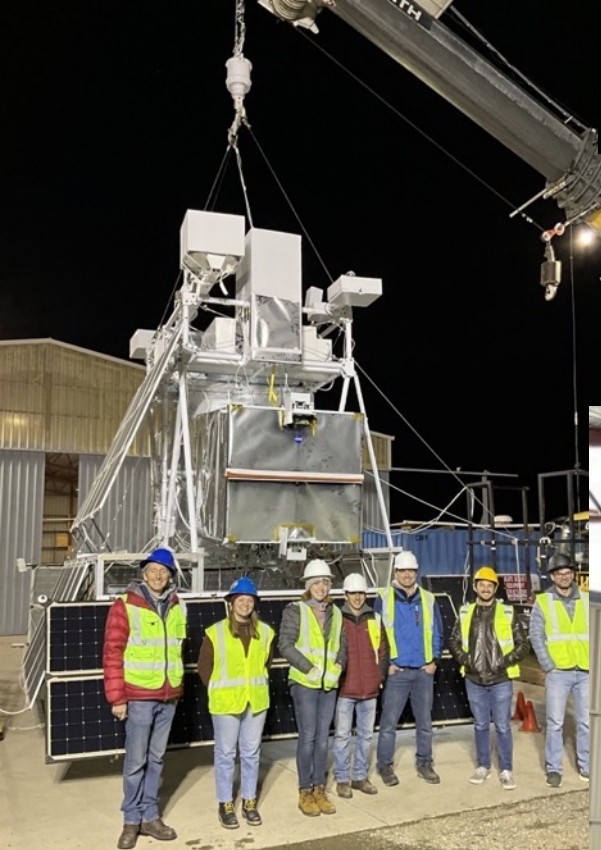


Cherenkov

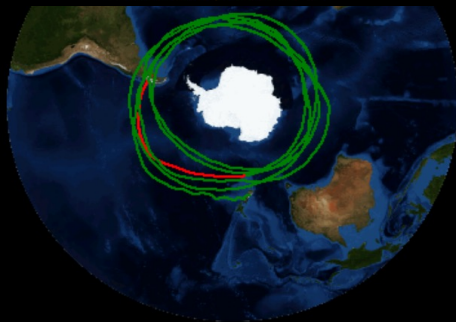
Tau lepton

Tau Neutrino

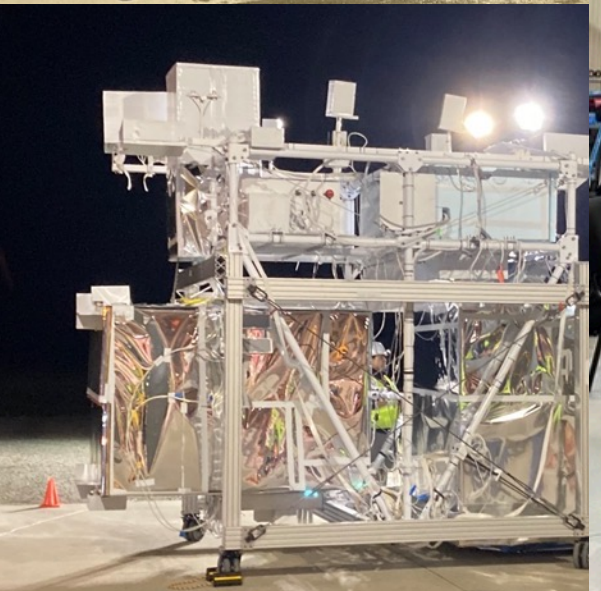
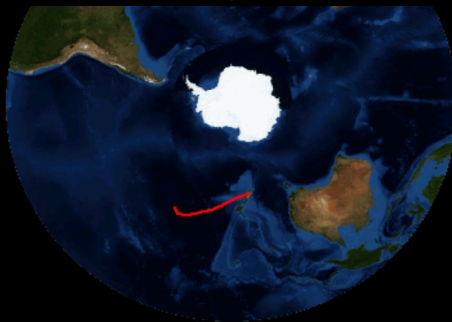
CRs $E > \text{PeV}$



Flight Ended
Total Flight Time
39 Days 13 hours 35 minutes
Launched April 15, 2023



Flight Ended
Total Flight Time
1 day 12 hours 53 minutes
Launched May 13, 2023



13 MAY, 2023 00:02:
COLUMBIA SCIENTIFIC
BALLOON FACILITY

EUSO-SPB2
May 13 flight
2 nights
commissioning
+ data

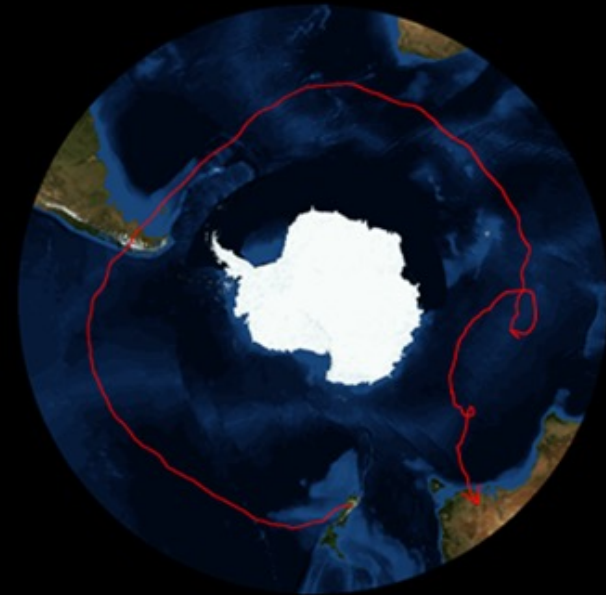


NASA WANAKA Campaigns
Super Pressure Balloon (SPB)
EUSO mission 2017 & 2023



2015

NASA Engineering Flight



32 d 5 h

2016

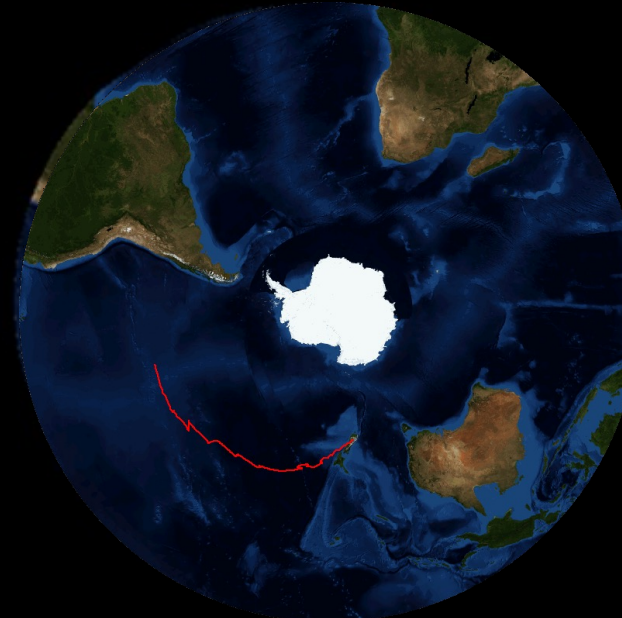
COSI



46 d 20 h

2017

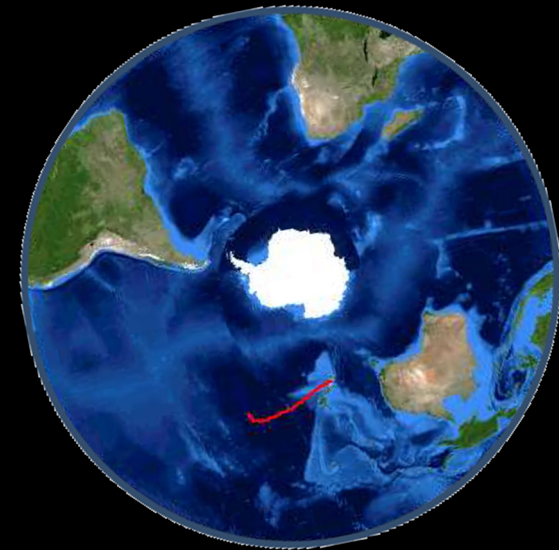
EUSO-SPB



12 d 4 h

2023

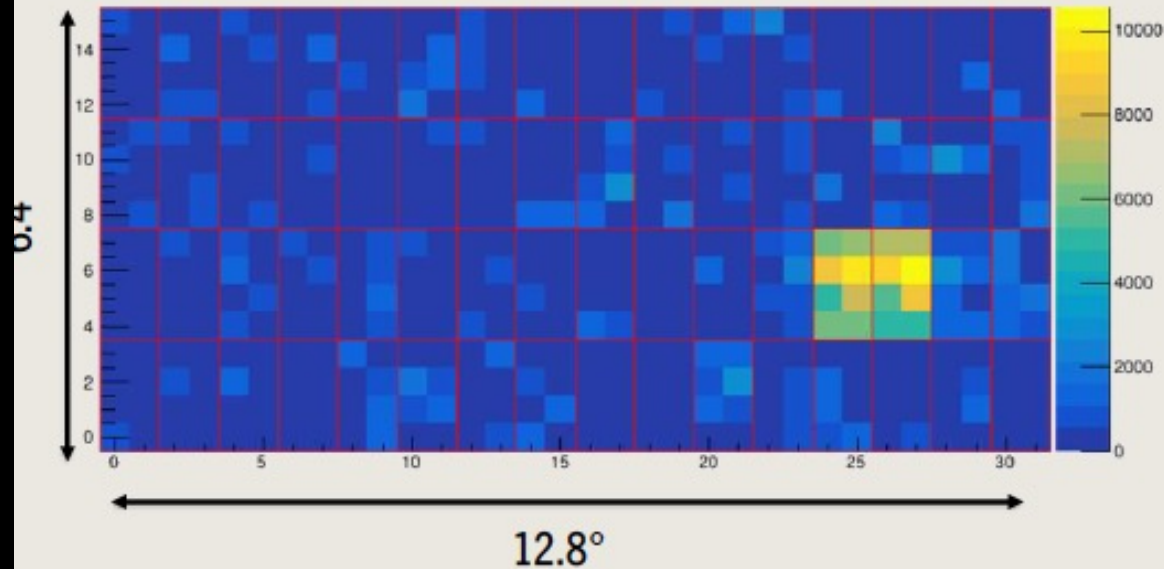
EUSO-SPB2



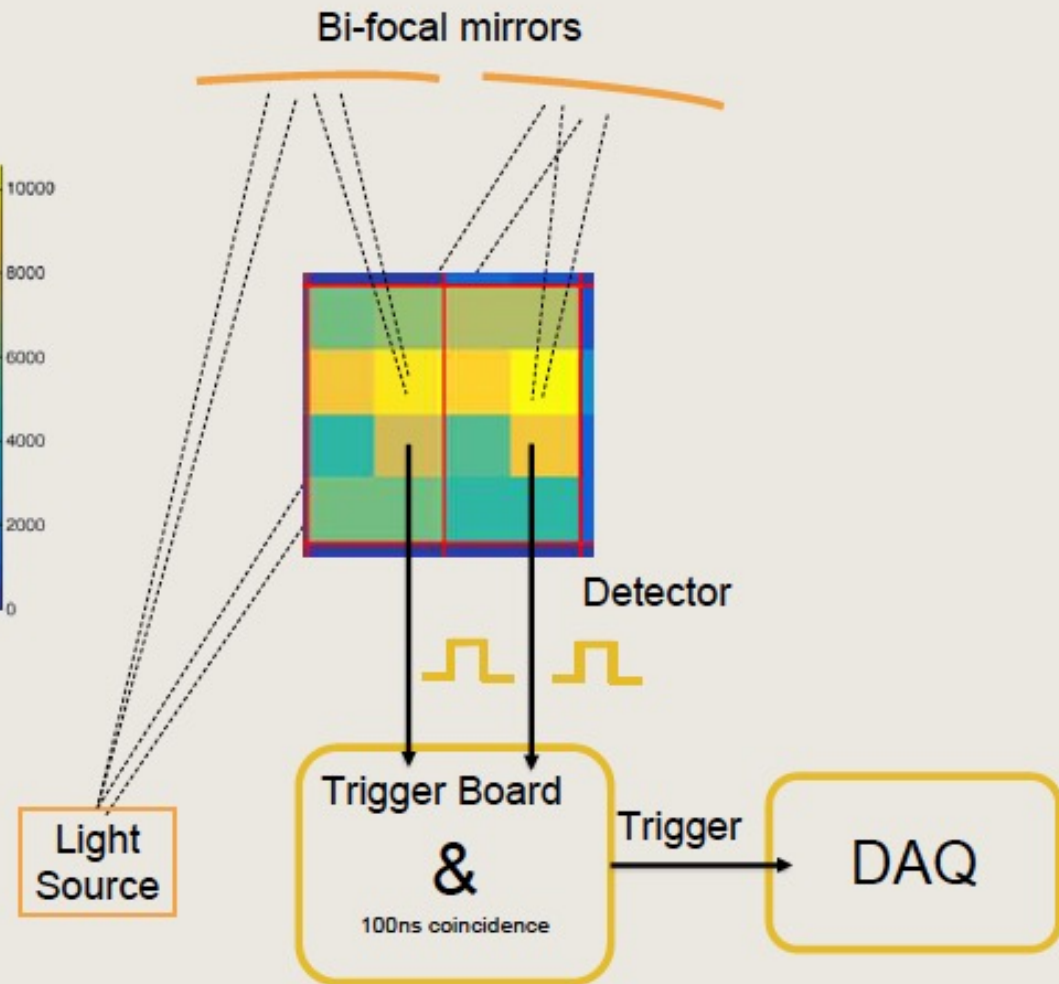
1.5 d (37hrs)!!!

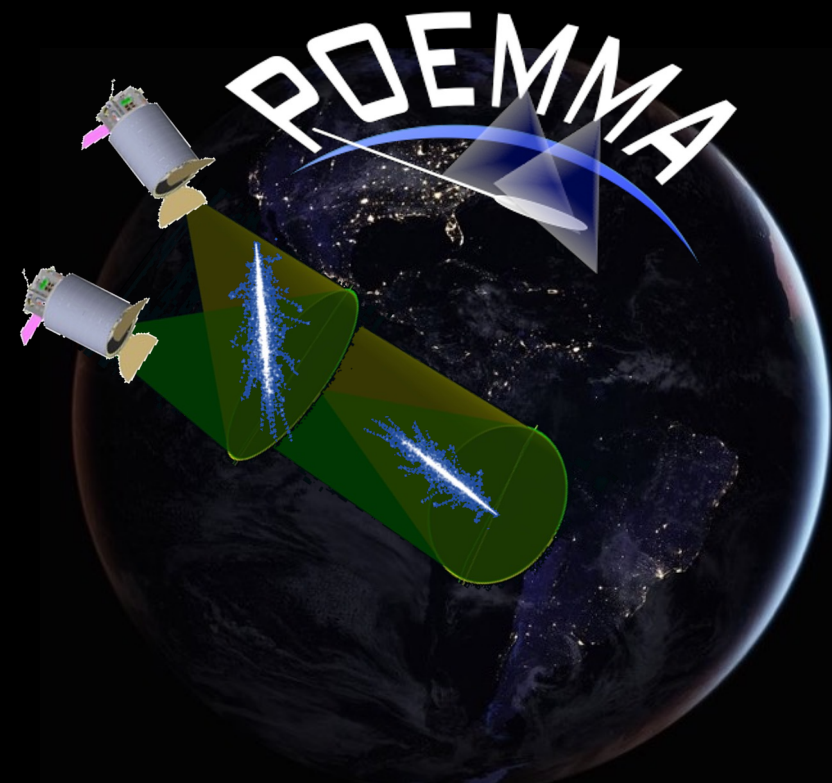
Event Types

- BiFocal Events
- Air Shower Cone
- Direct Hits



Bifocal Optics and Trigger Logic





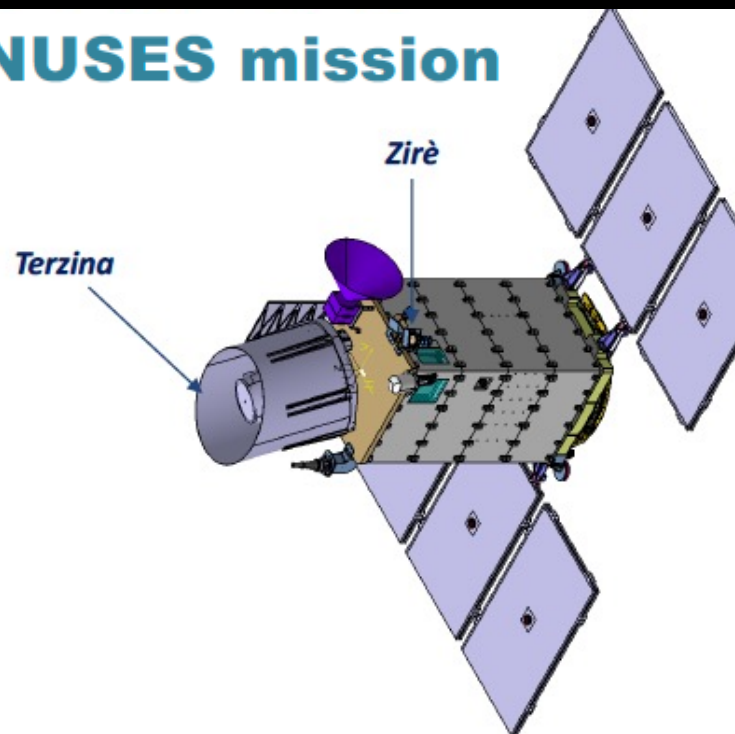
POEMMA ROADMAP

EUSO-SPB2 (2023)

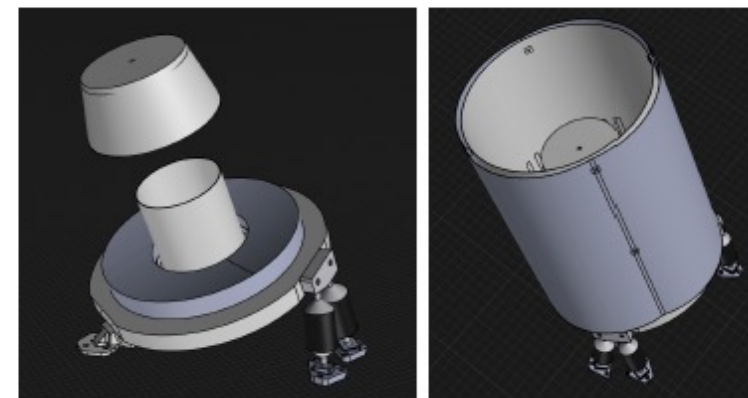
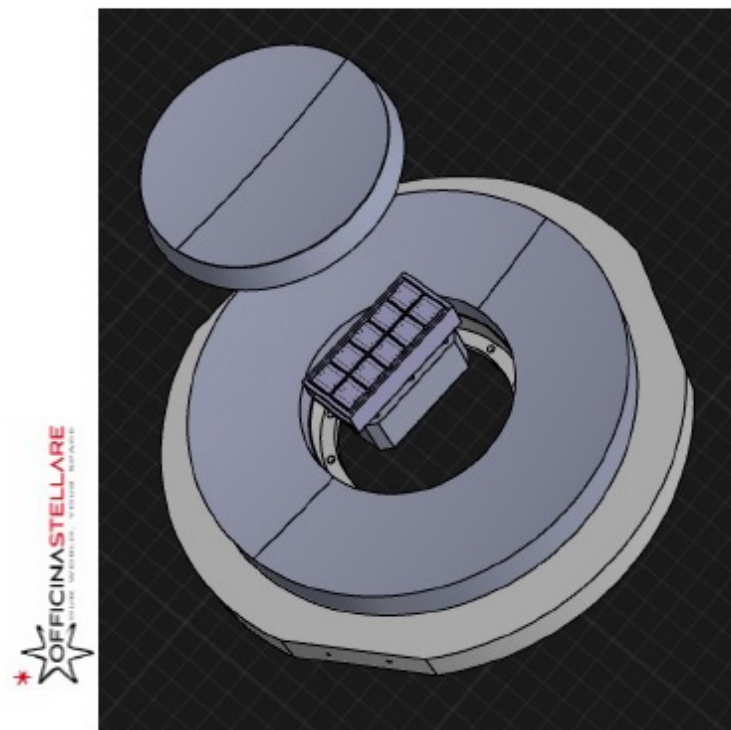
Terzina (2026)

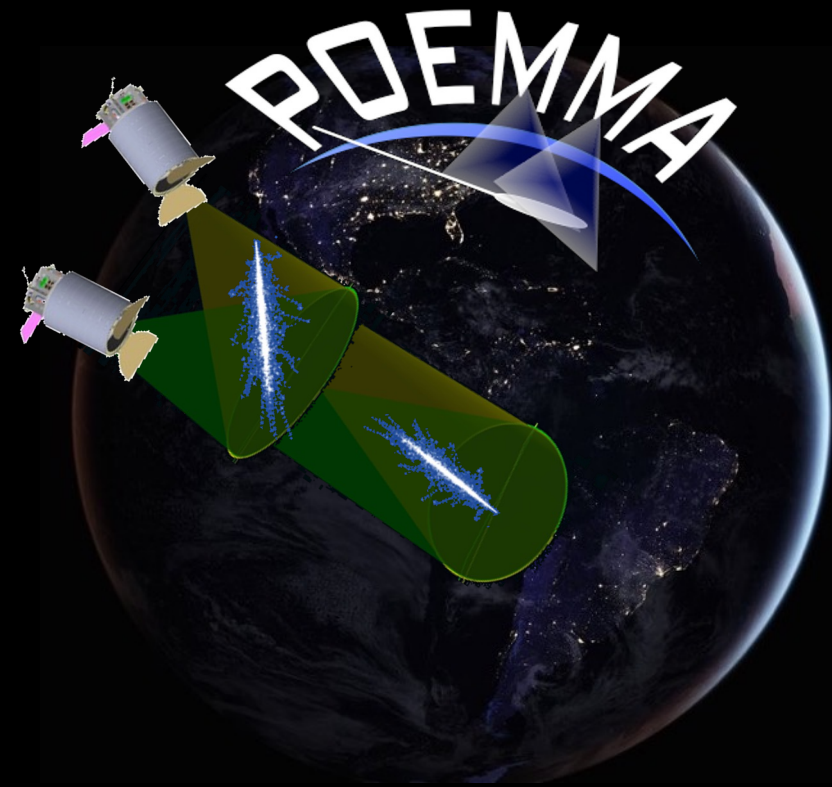
CRI11-01
Sat July 29th, 10:15 AM
Roberto Aloisio
The Terzina instrument
on board the NUSES
space mission

NUSES mission



Terzina telescope





POEMMA ROADMAP

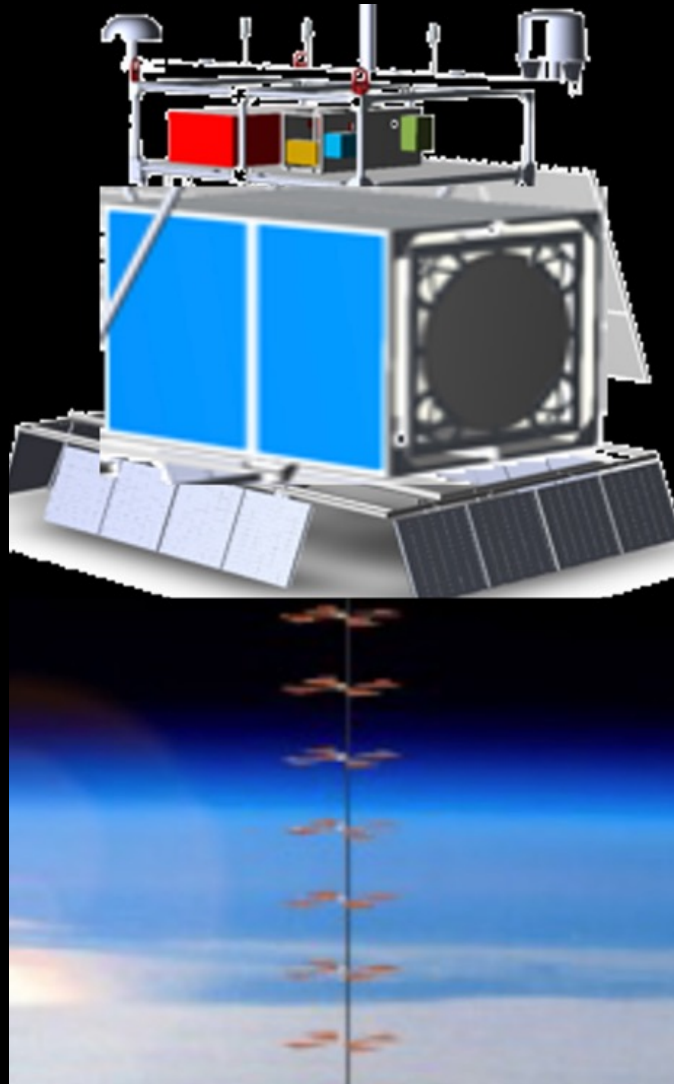
EUSO-SPB2 (2023)

Terzina (2026)

PBR (2026)

(POEMMA-Balloon-Radio)

POEMMA-Balloon + Radio PBR (2026)



PBR :

Larger Telescope than EUSO-SPB2

Hybrid Focal Surface = POEMMA

All space qualified components

Fluorescence

- UHECRs from zenith to High Altitude EASs

Cherenkov

- Below the limb for Targets of Opportunity Neutrino sources
- Above the Limb CRs

Radio

- Low Freq for coincidence with Cherenkov

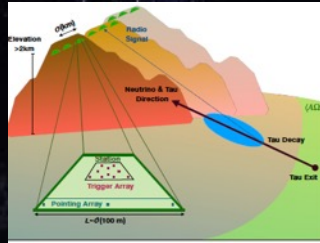
Infrared camera; LEDs, auxiliary devices

Future detectors of UHE CRs and Neutrinos

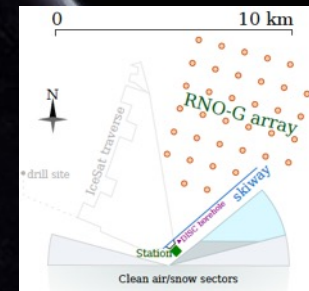
Future Looks Bright!



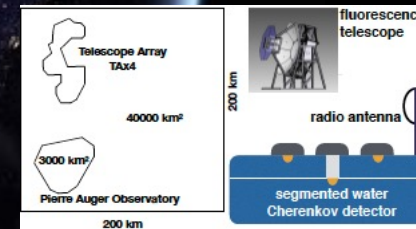
BEACON, Trinity,
AshraNTA, TAROGE



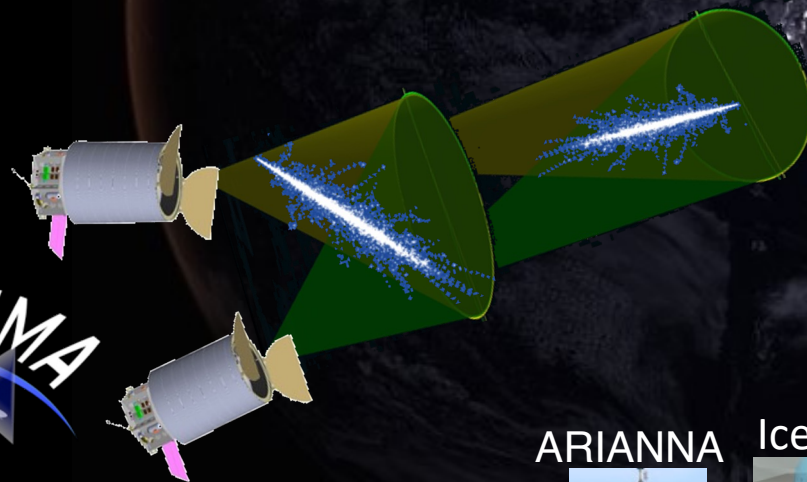
RNO-G



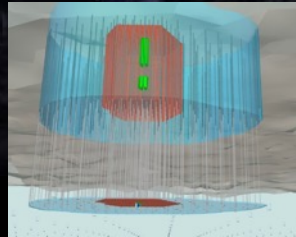
GCRO



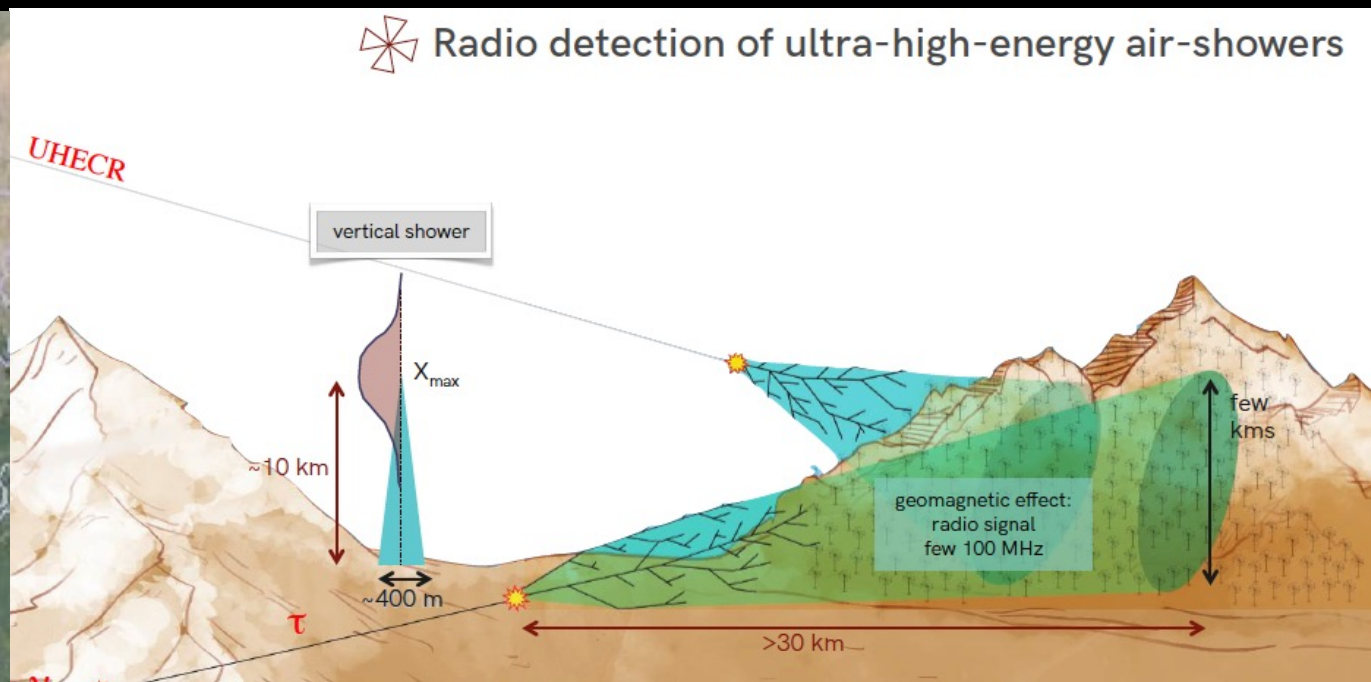
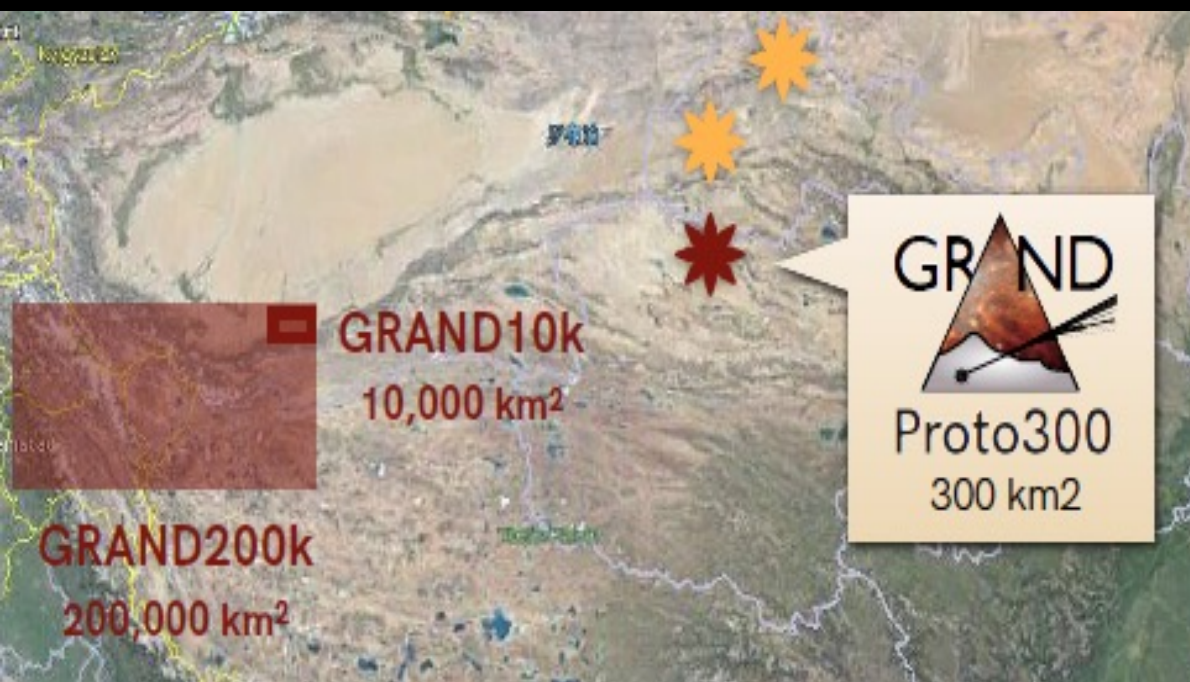
POEMMA



ARIANNA IceCube-Gen2



Giant Radio Array for Neutrino Detection (GRAND)



EUSO-SPB1 Launch from Wanaka, NZ

April 24, 2017





2011 29