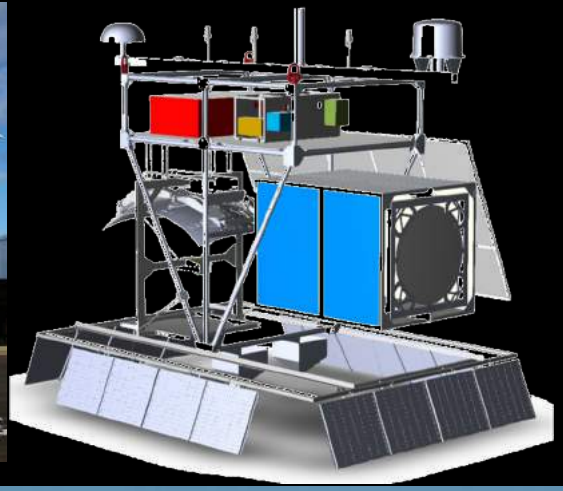
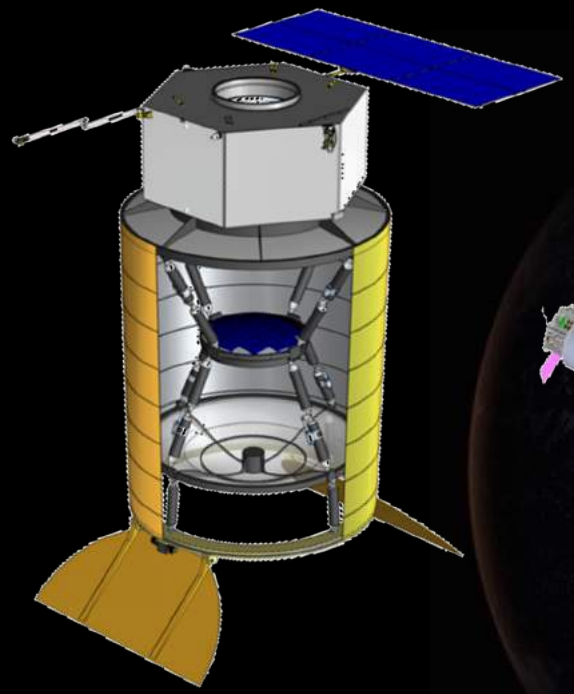
Space Observatories for Ultrahigh Energy Astroparticles

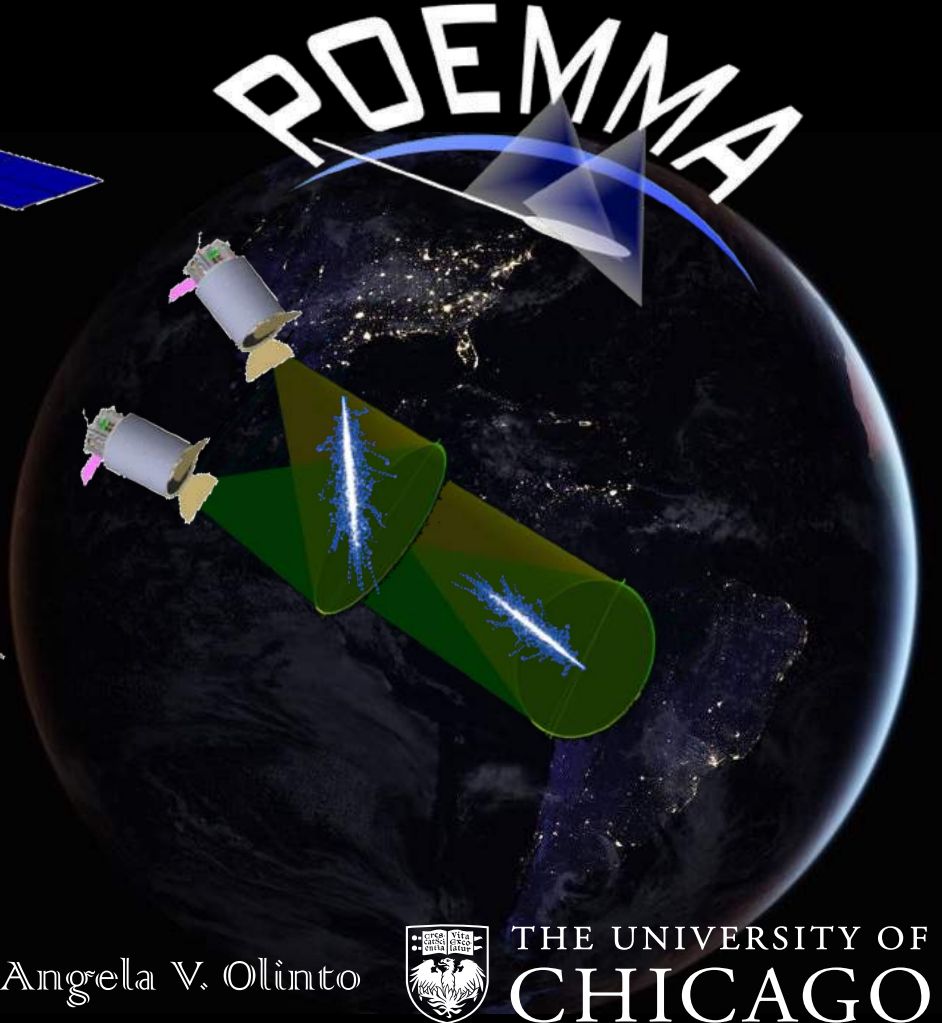
POEMMA & EUSO-SPB

EUSO-SPB1

EUSO-SPB2







SLIAFAE Nov 12 2021

Angela V. Olinto

THE UNIVERSITY OF CHICAGO

Astroparticle Physics Questions:

What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

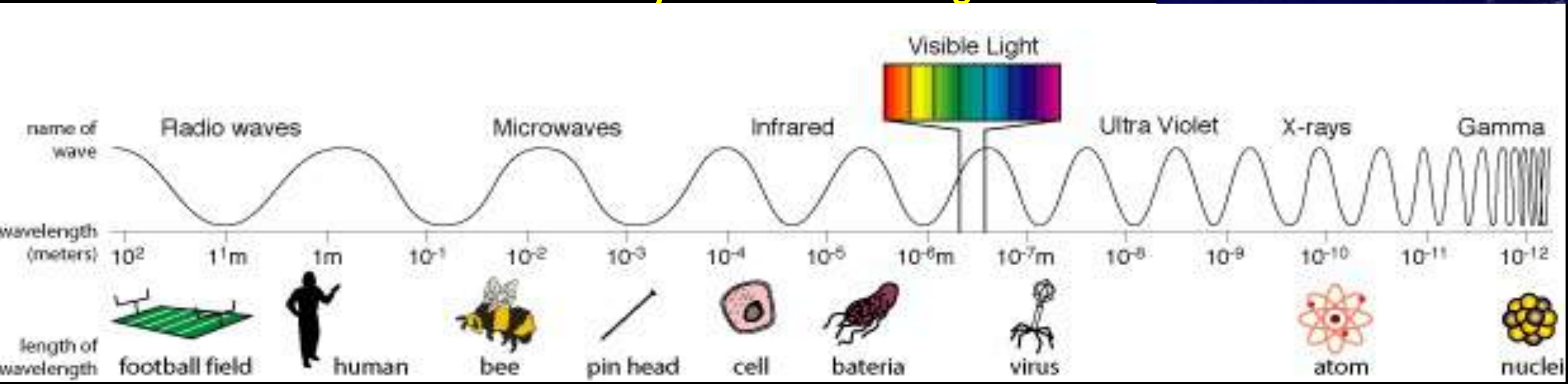
Measure Spectrum, Composition, Anisotropies $E>10^{19}$ eV = 10 EeV

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

Multi-Messenger coincidence gamma-ray, gravitational waves, and neutrinos with $E>10^{16}$ eV = 10 PeV

What is the physics and astrophysics at energies >> "ground-based" accelerators? Are there Extra-Dimensions, Supermassive Dark Matter, Topological Defects?

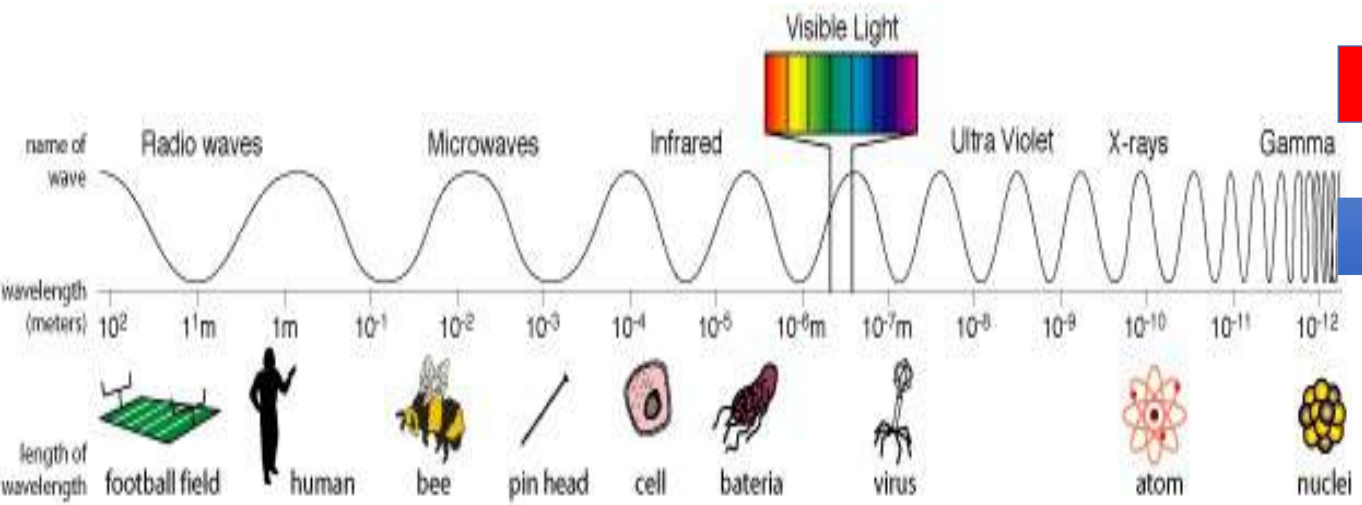
Astronomy: 14 orders of magnitude

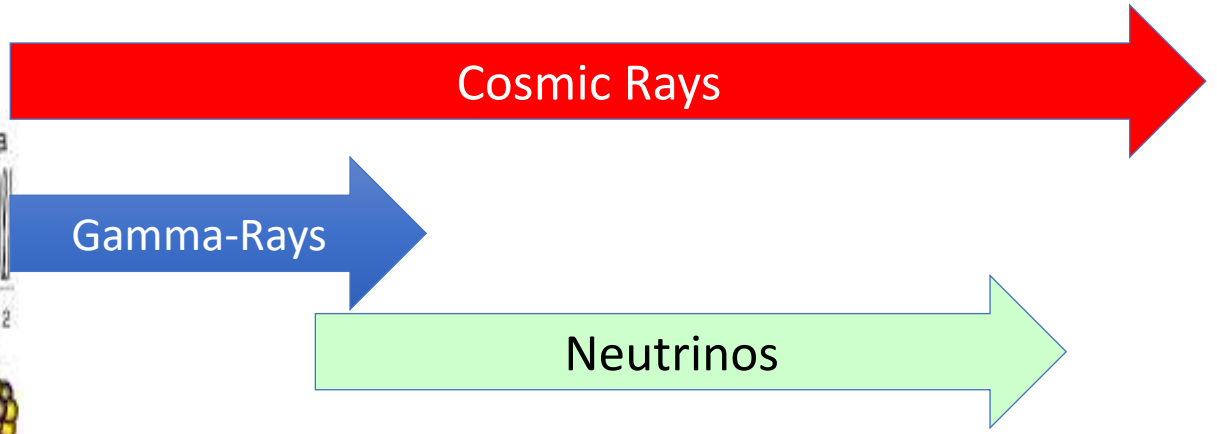


Cosmic Particles

Cosmic Rays = relativistic atomic nuclei: Hydrogen (protons), He, heavier elements

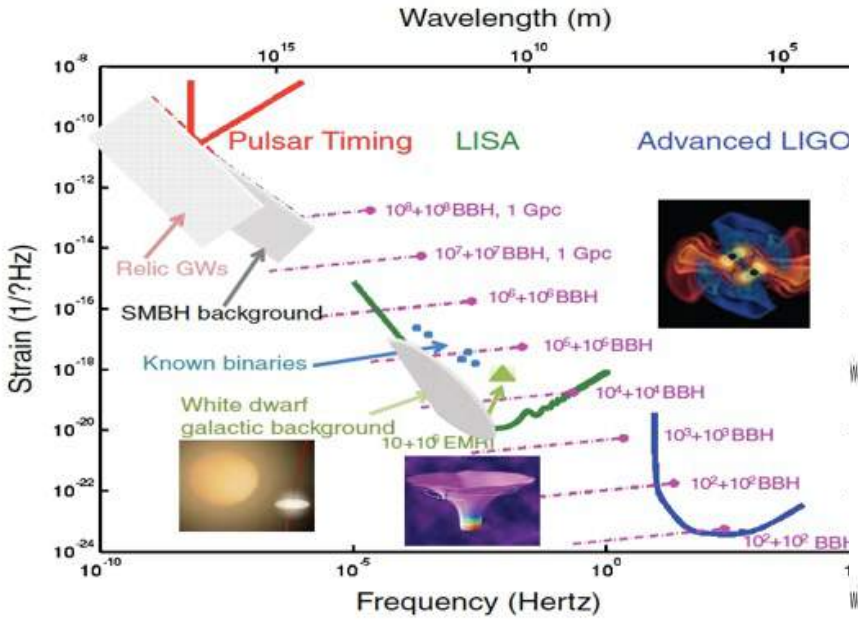
~ double the energy range for Astrophysics

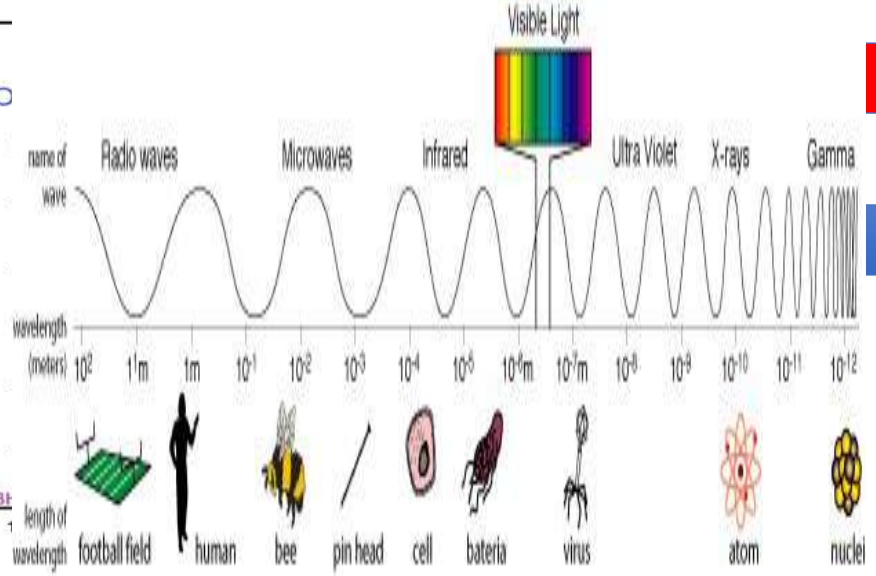




Multi-Messengers

~ triple the energy range for Astrophysics : 40 orders of magnitude



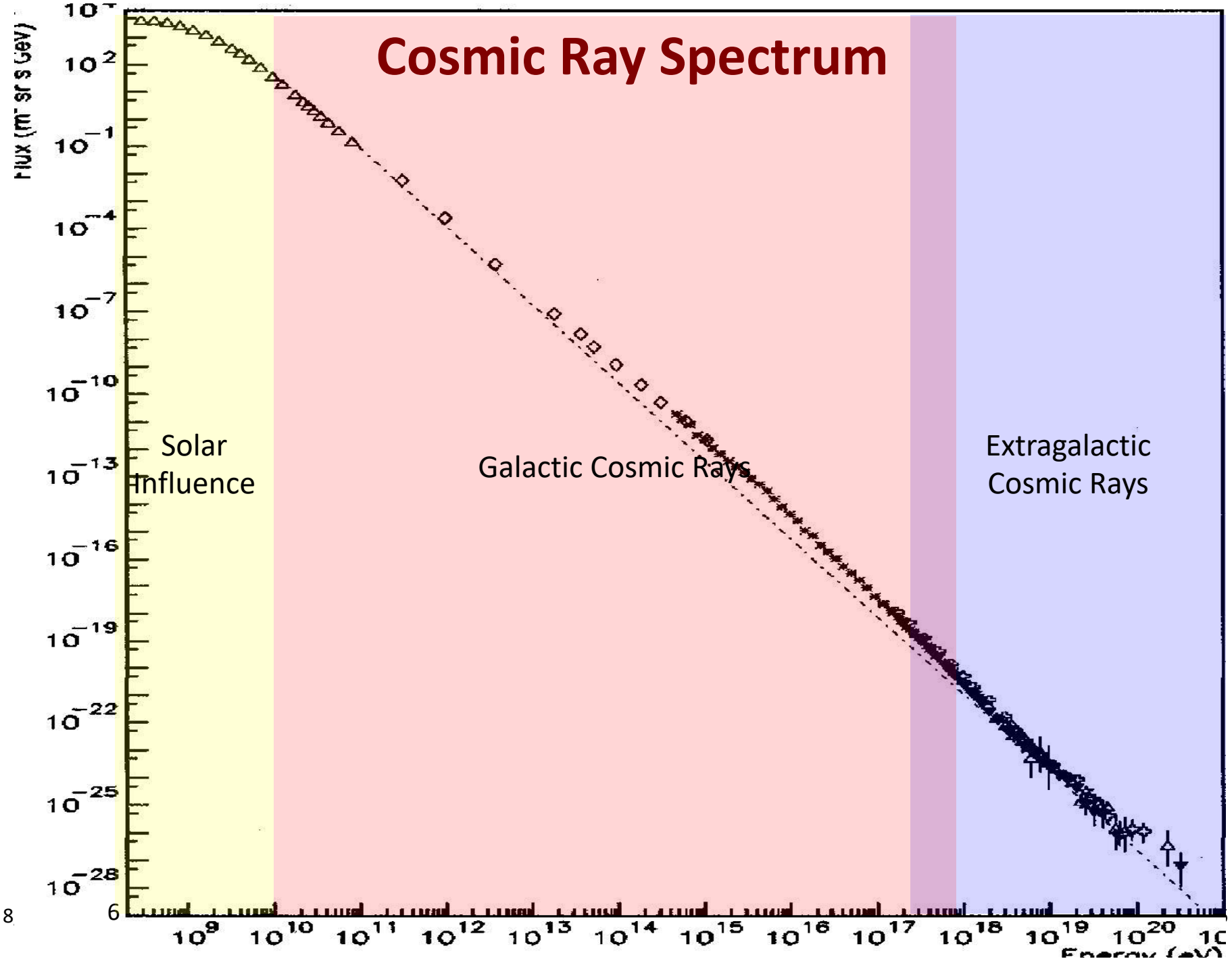


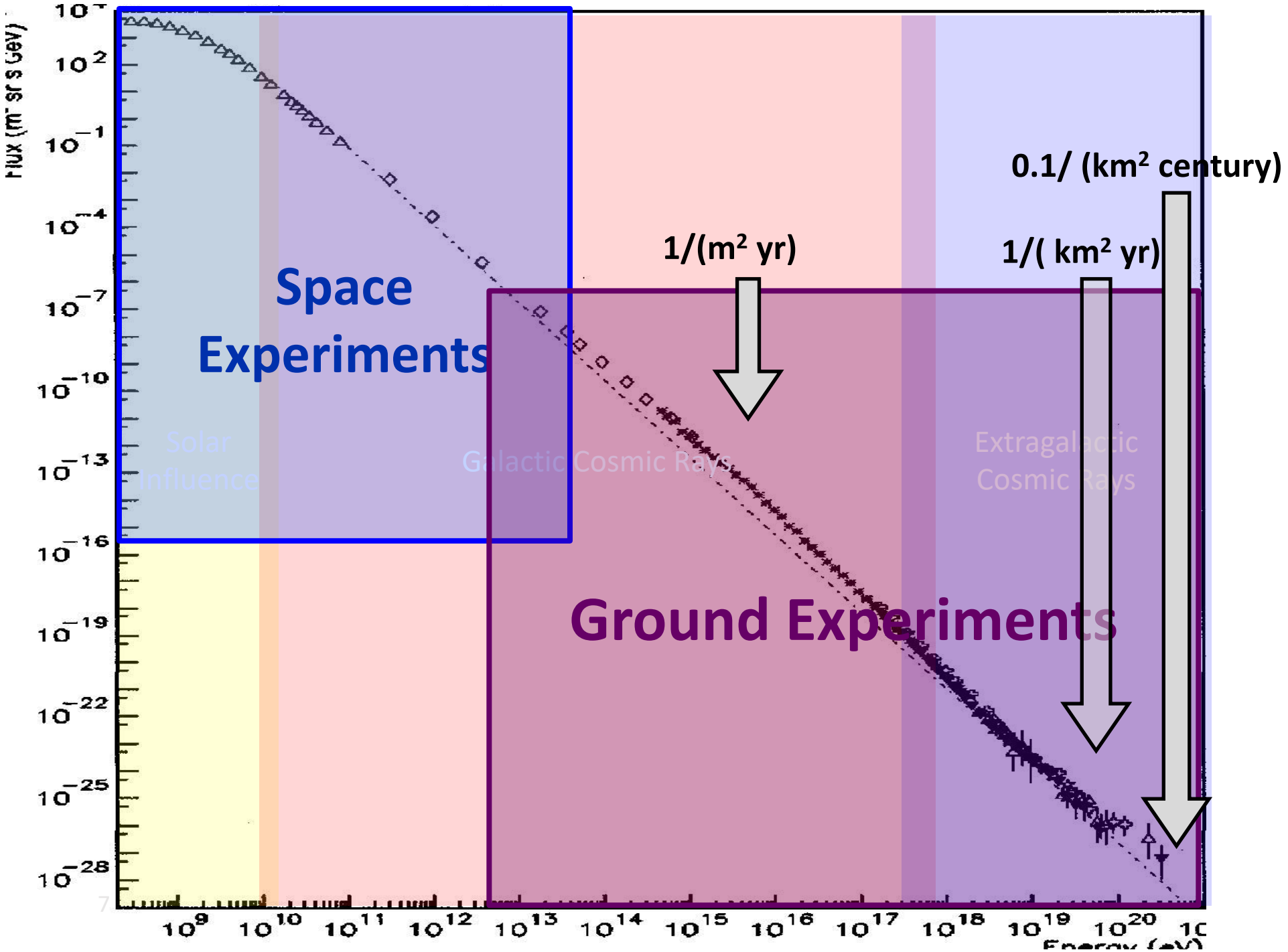
Cosmic Rays

Gamma Rays

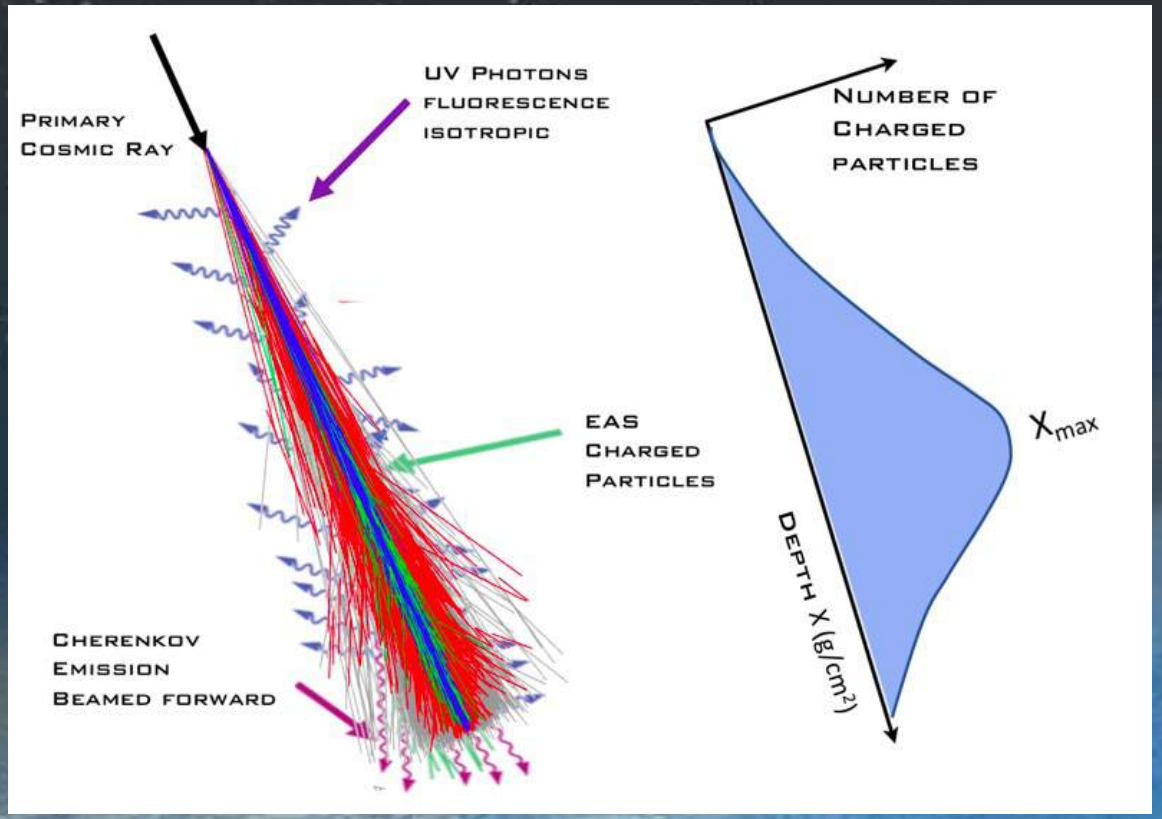
Neutrinos

Cosmic Ray Spectrum




Space
Experiments
Ground Experiments
1/(m² yr)
1/(km² yr)
0.1/ (km² century)
Solar
Influence
Galactic Cosmic Rays
Extragalactic
Cosmic Rays

Extensive Air Showers



Leading Observatories of Ultrahigh Energy Cosmic Rays

Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes

Pierre Auger Observatory

Mendoza, Argentina

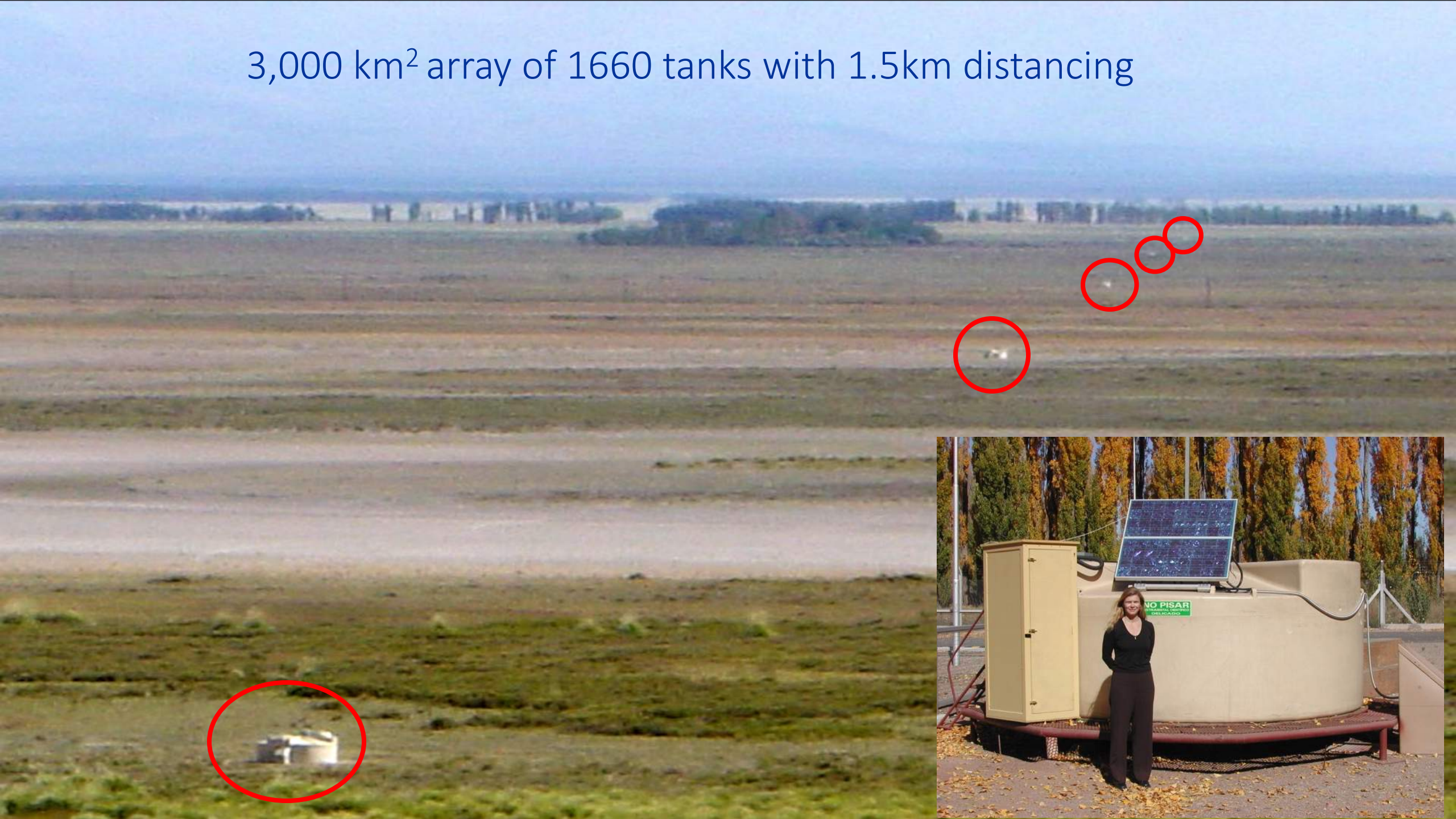
(19 country collaboration)

3,000 km^2 array

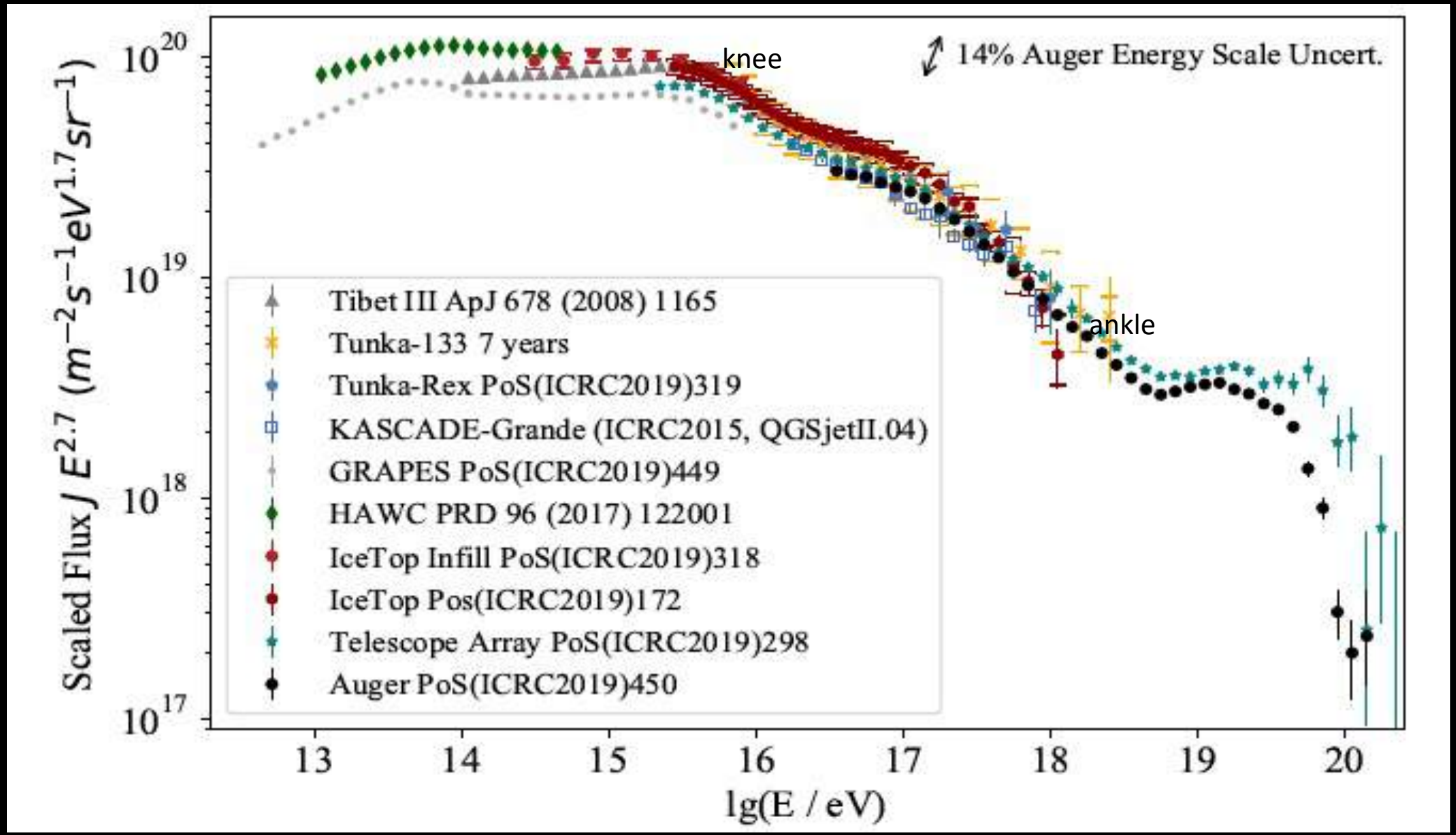
4 fluorescence telescopes

- see talk by Federico Sanchez

3,000 km^2 array of 1660 tanks with 1.5km distancing



4 telescopes
overlooking the site

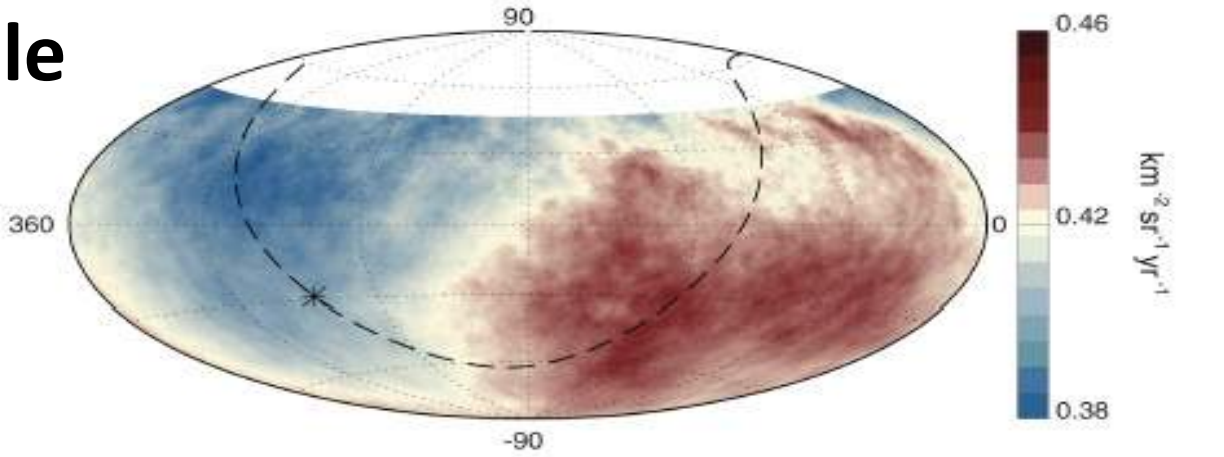


F. G. Schröder '19

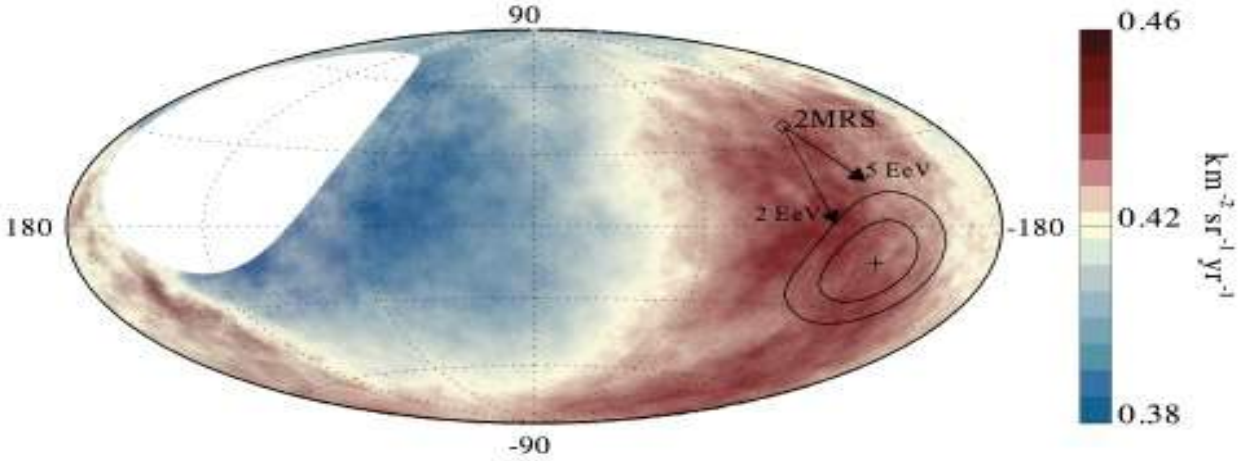
Auger Dipole

E > 8 EeV, 6.5%

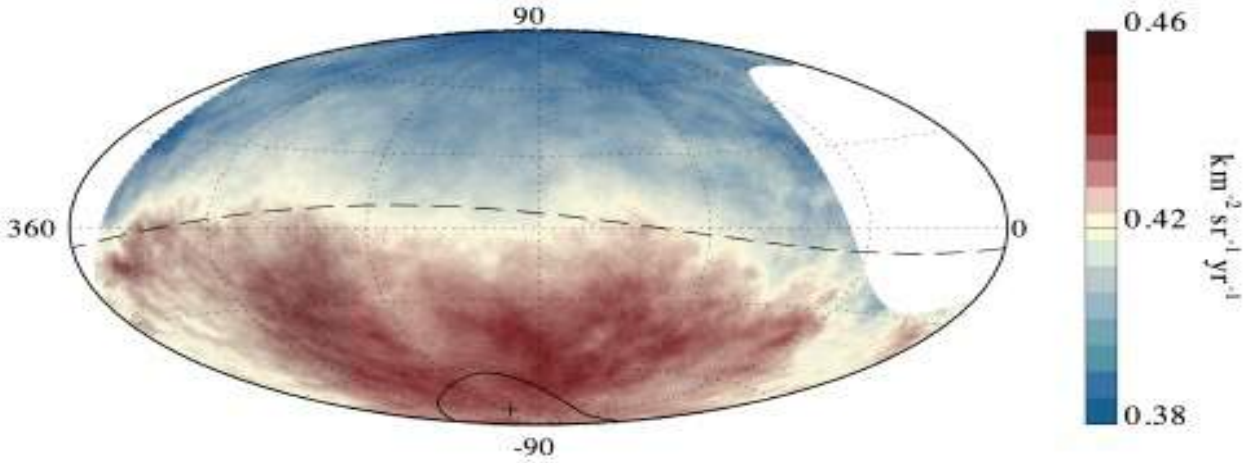
Equatorial



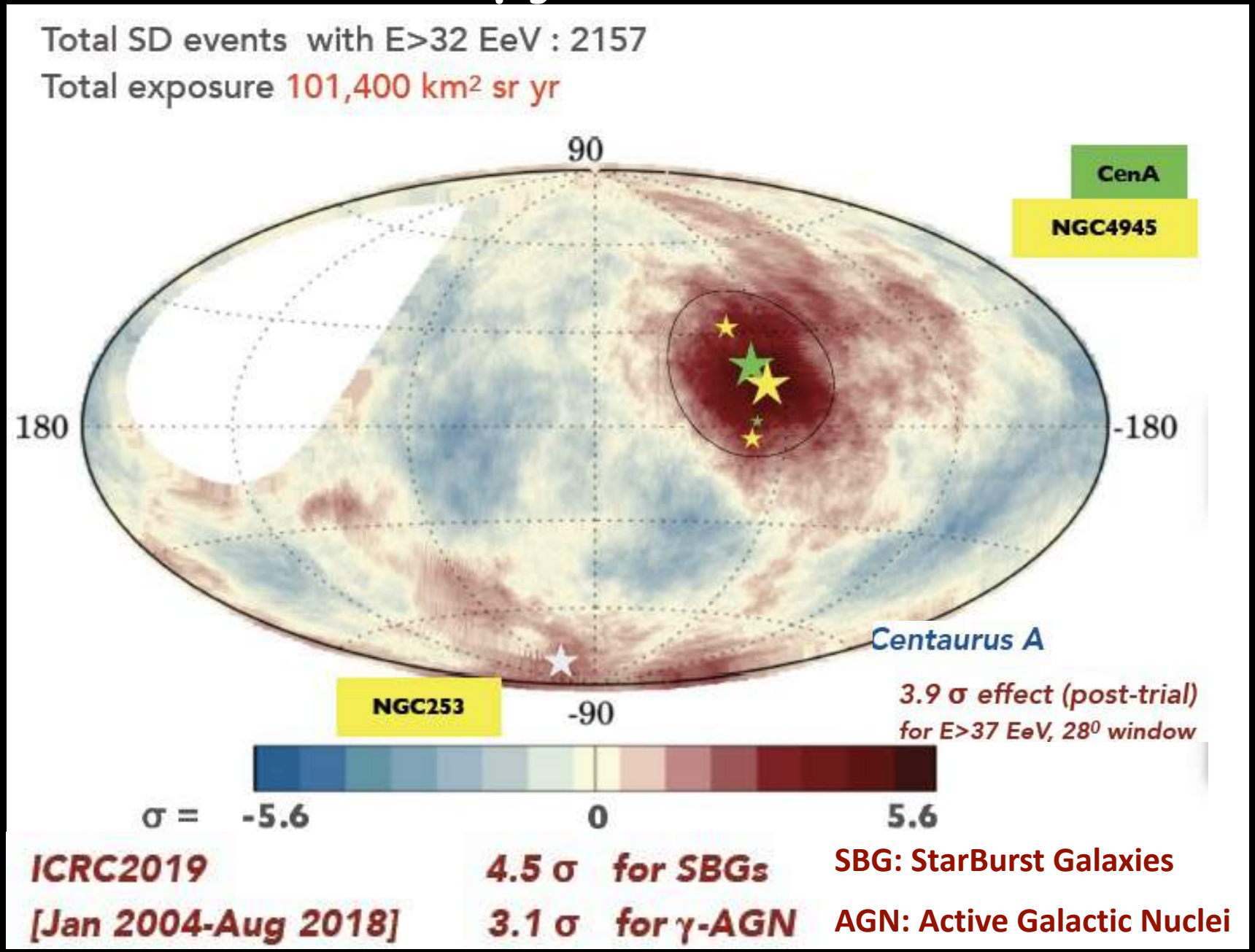
Galactic



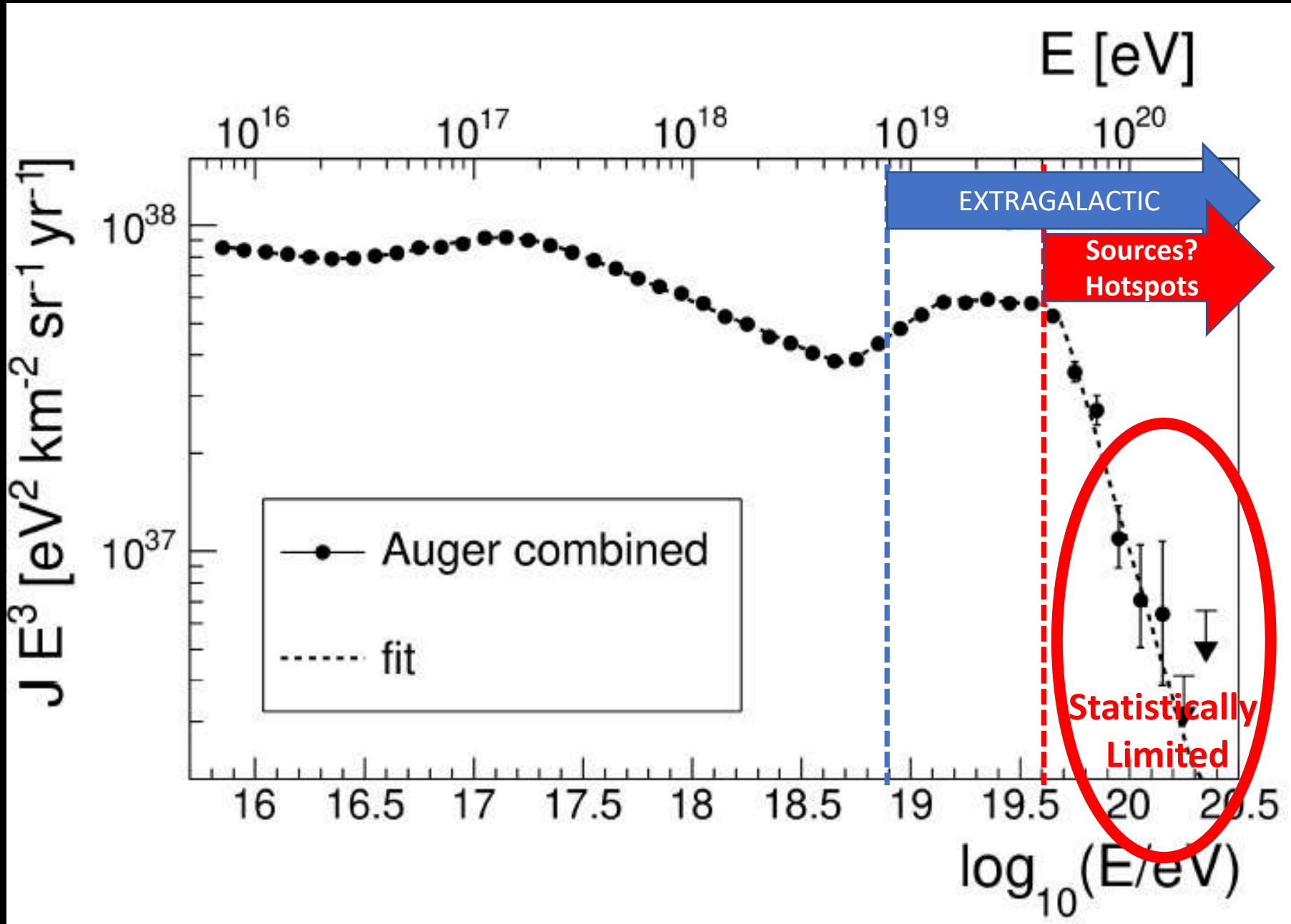
Super Galactic



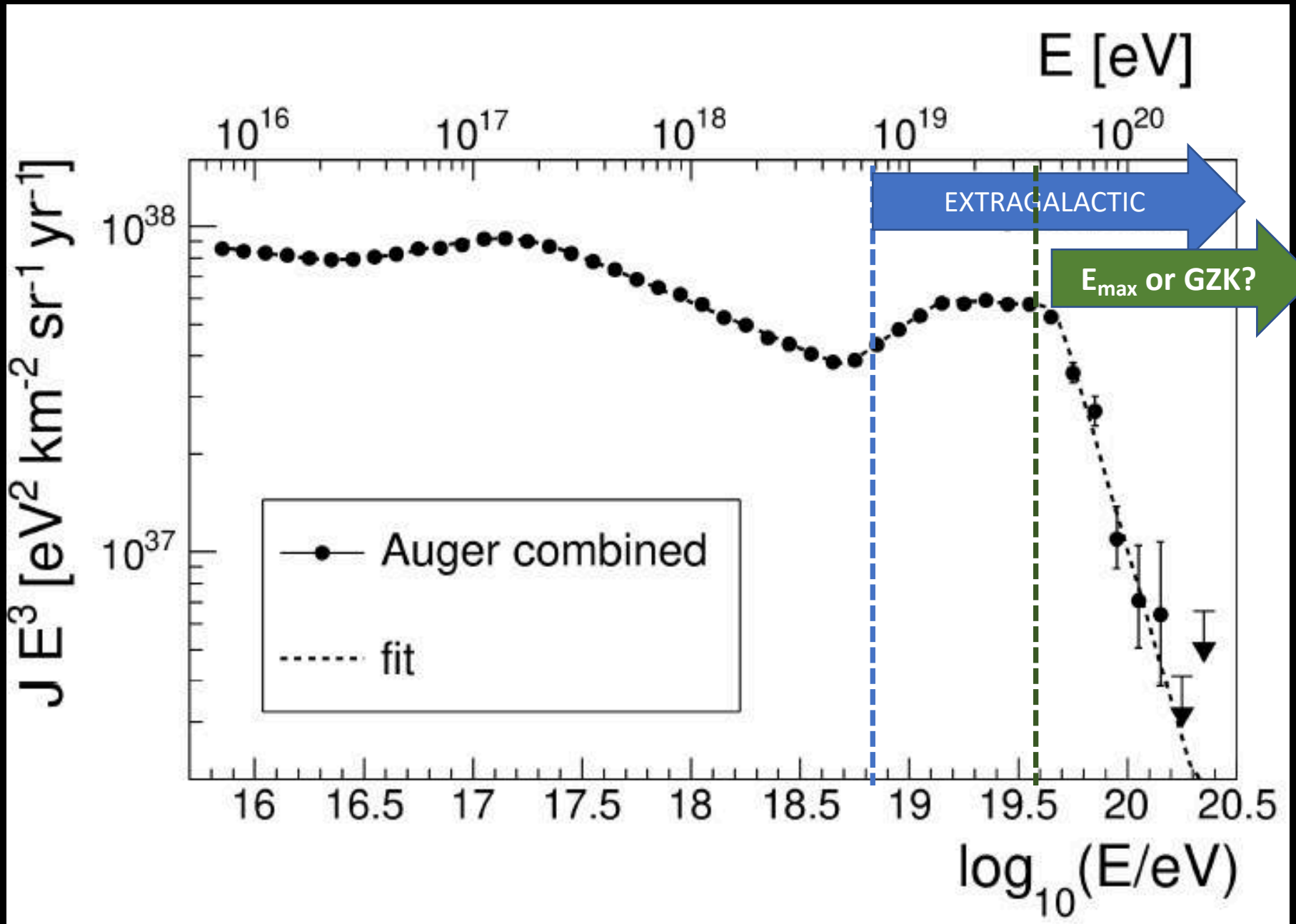
Anisotropy Hints > 40 EeV



Auger Spectrum ICRC 2021



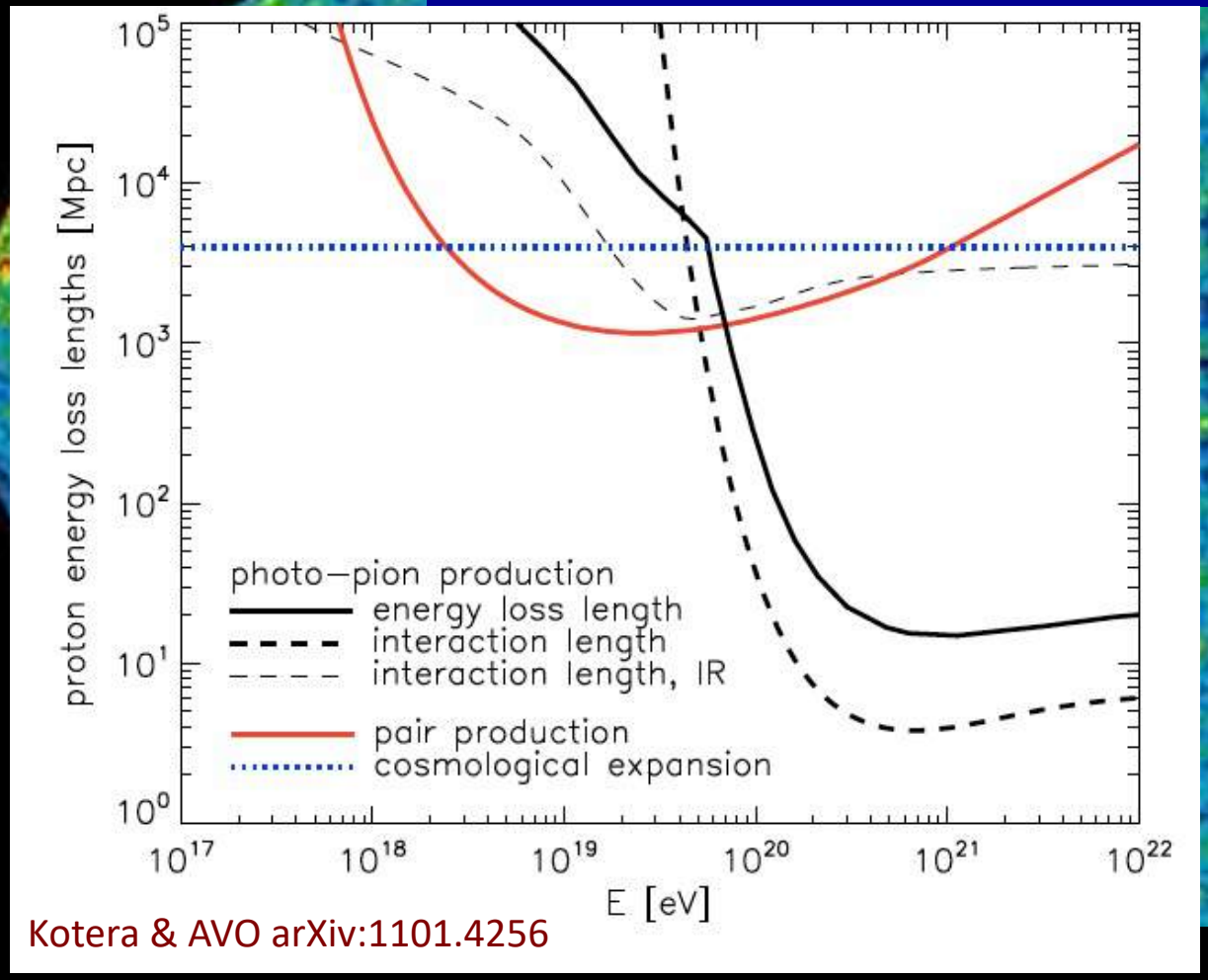
Auger Spectrum ICRC 2021



GZK Cutoff
Greisen,
Zatsepin, Kuzmin
1966

Greisen-Zatsepin-Kuzmin Effect

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



Kotera & AVO arXiv:1101.4256

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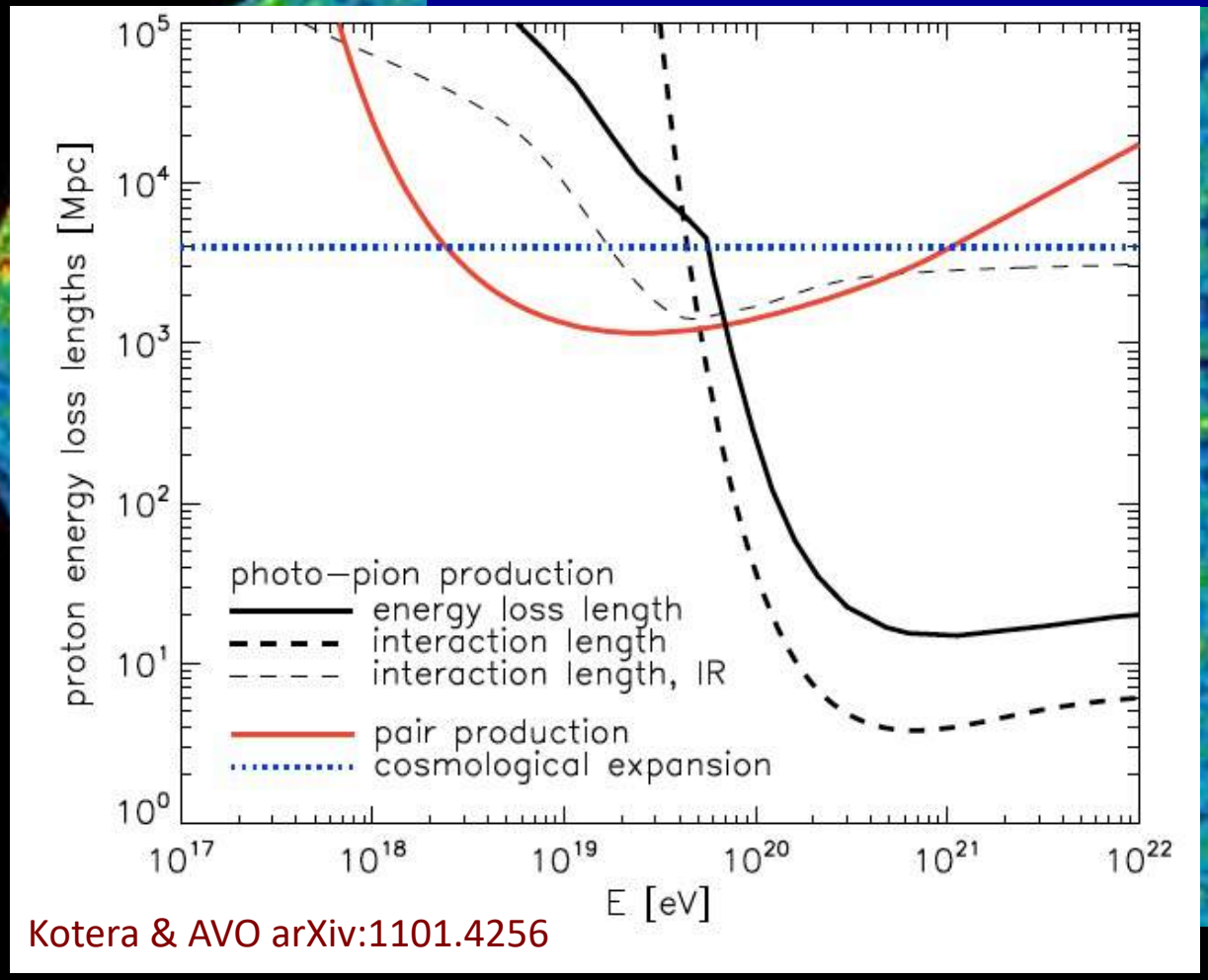
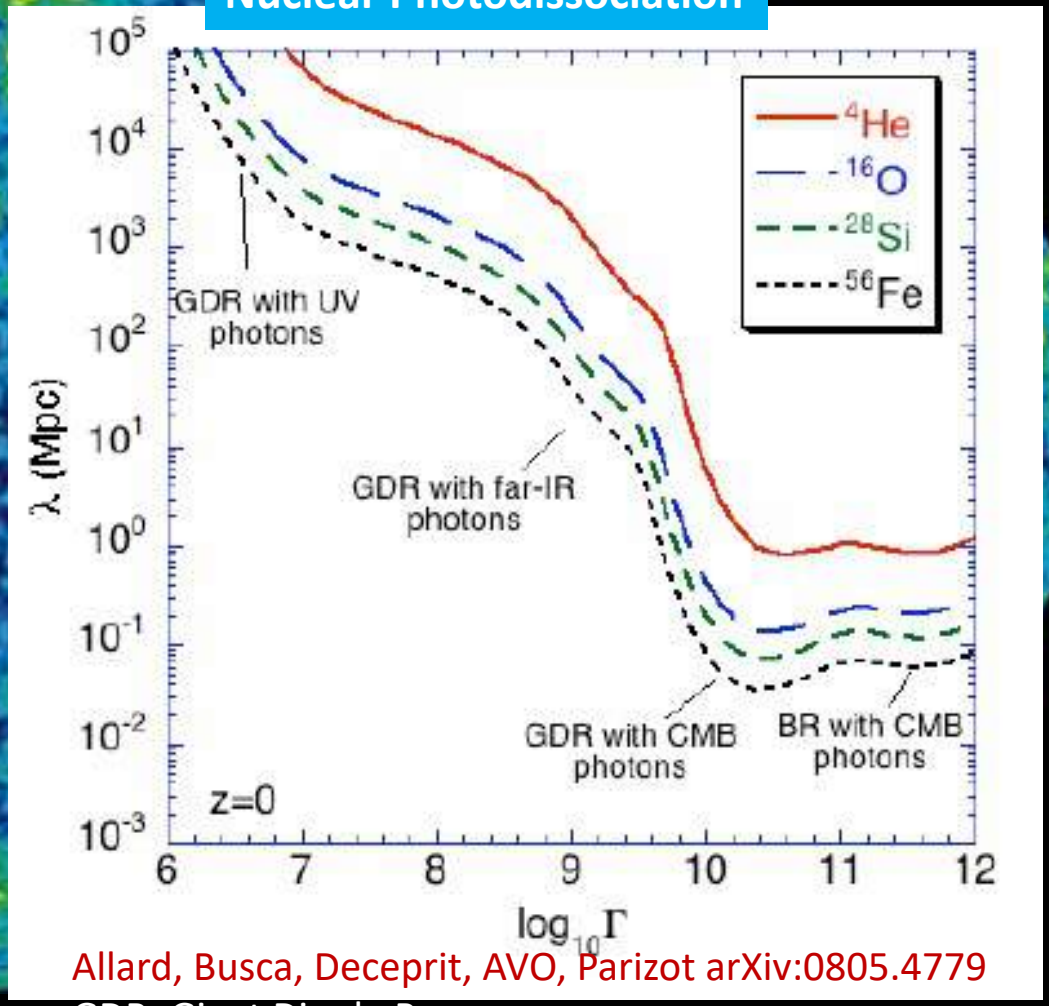


Kotera & AVO arXiv:1101.4256

Nuclear Photodissociation

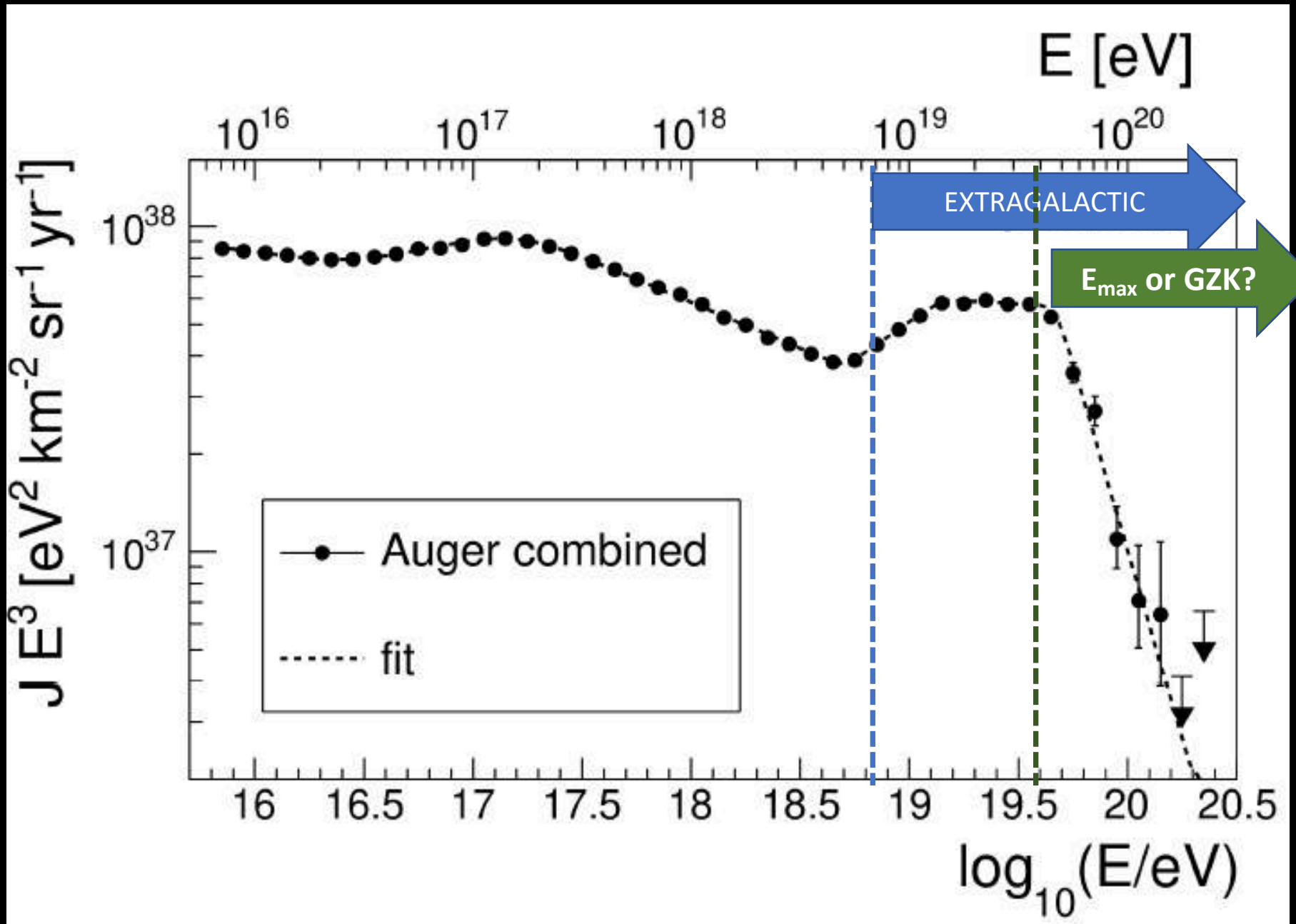


Allard, Busca, Deceprit, AVO, Parizot arXiv:0805.4779

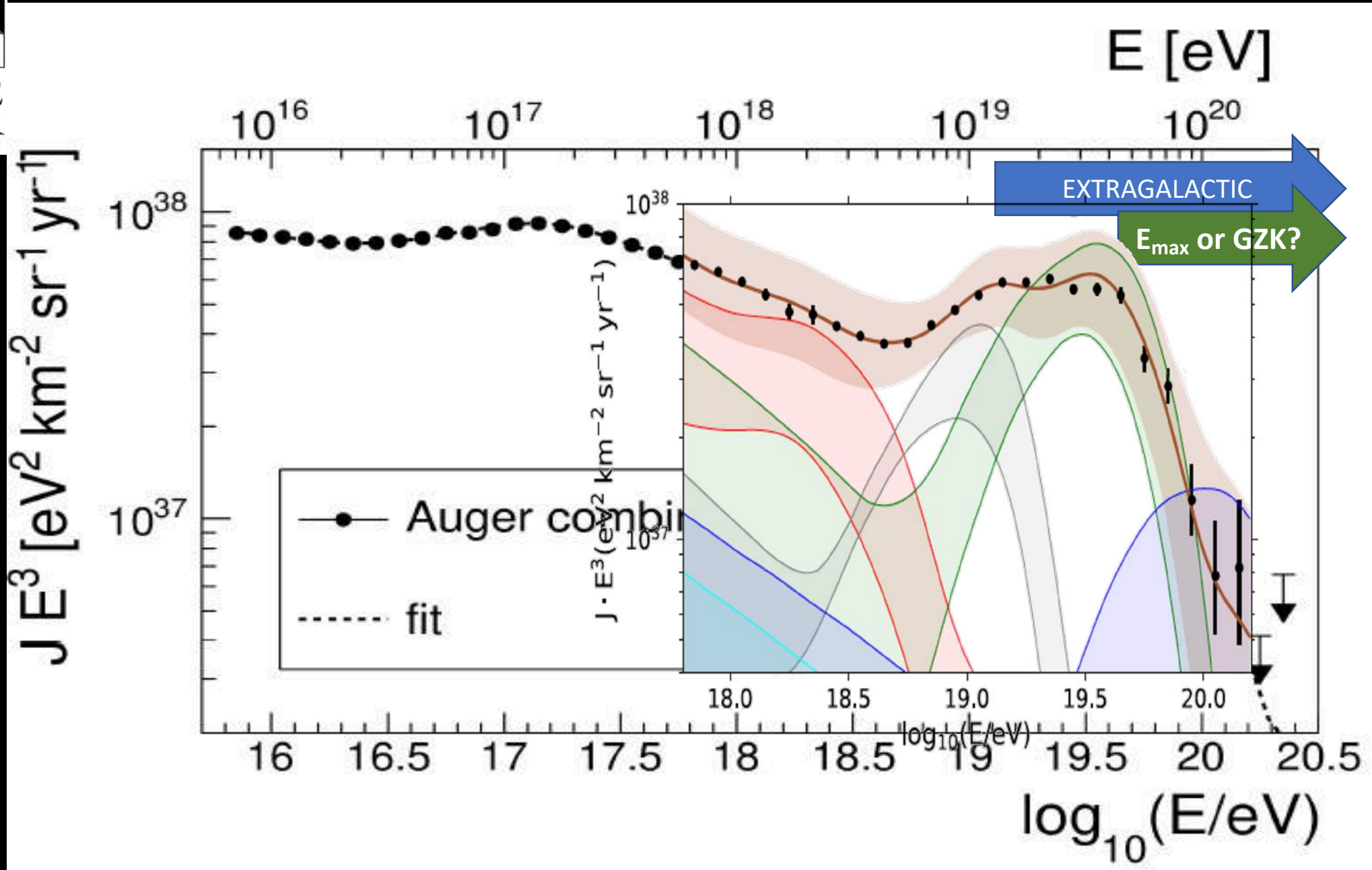
GDR: Giant Dipole Resonance

BR: Baryonic Resonances

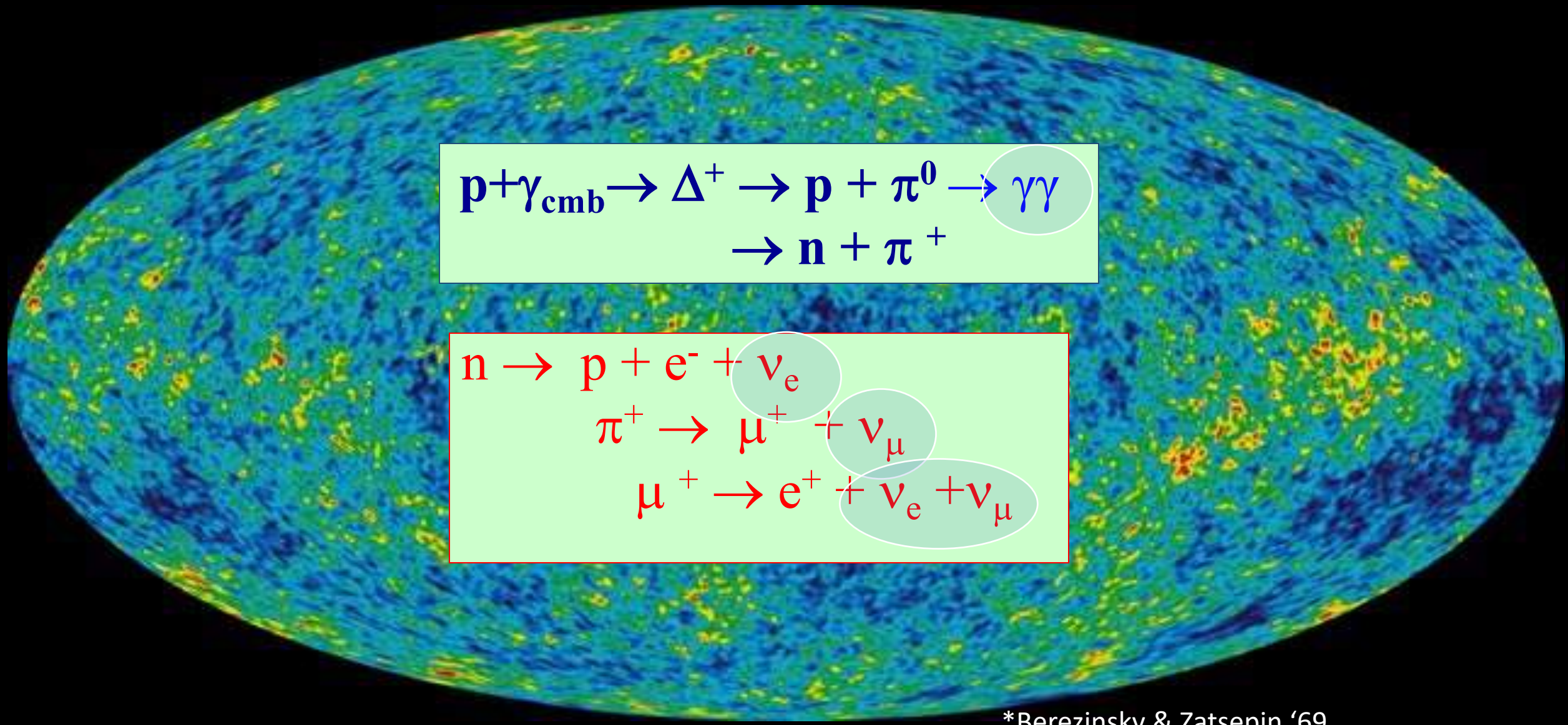
Auger Spectrum ICRC 2021



Auger Spectrum+Composition ICRC 2021



Cosmogenic (GZK, BZ*) Neutrinos & Photons

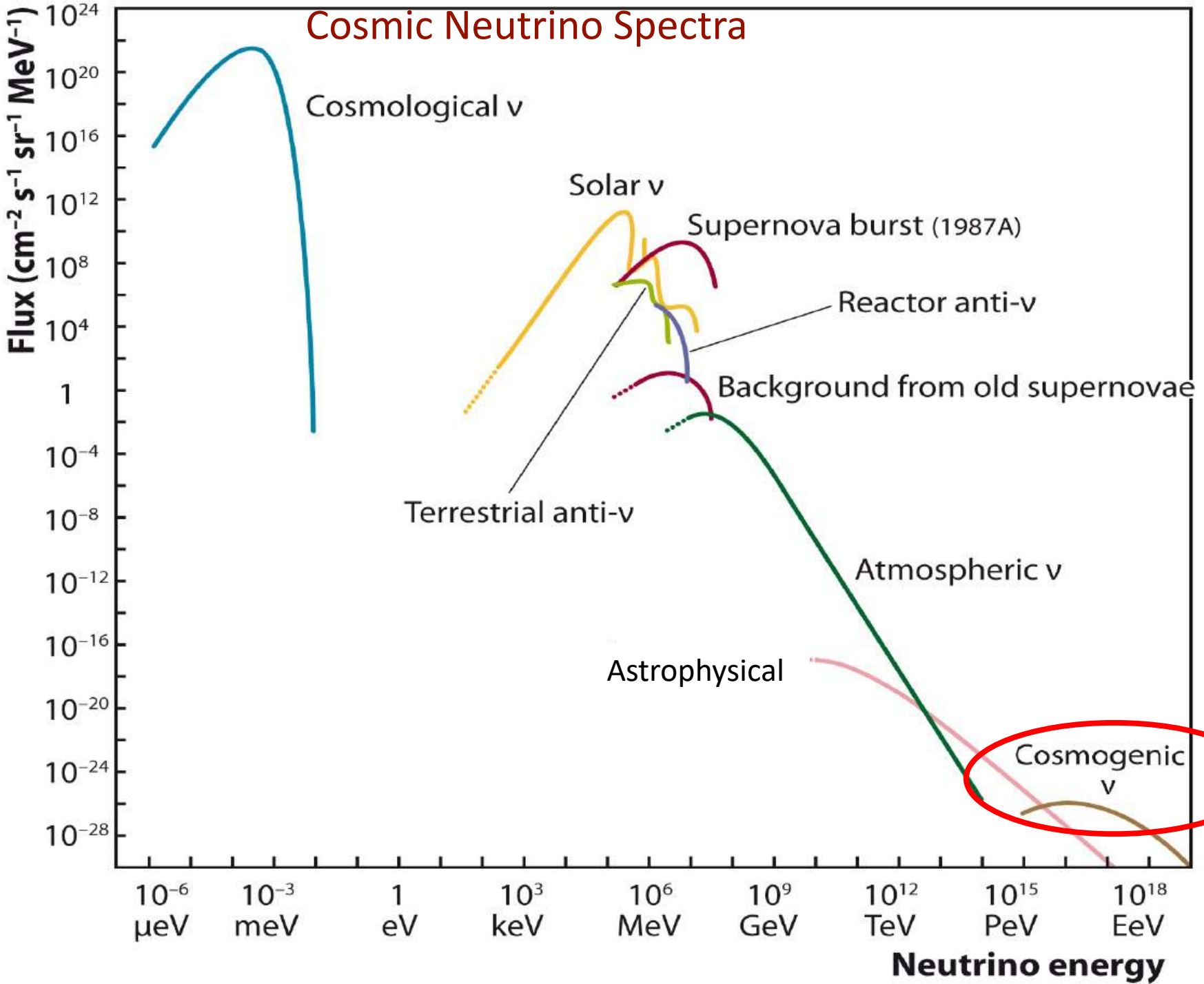


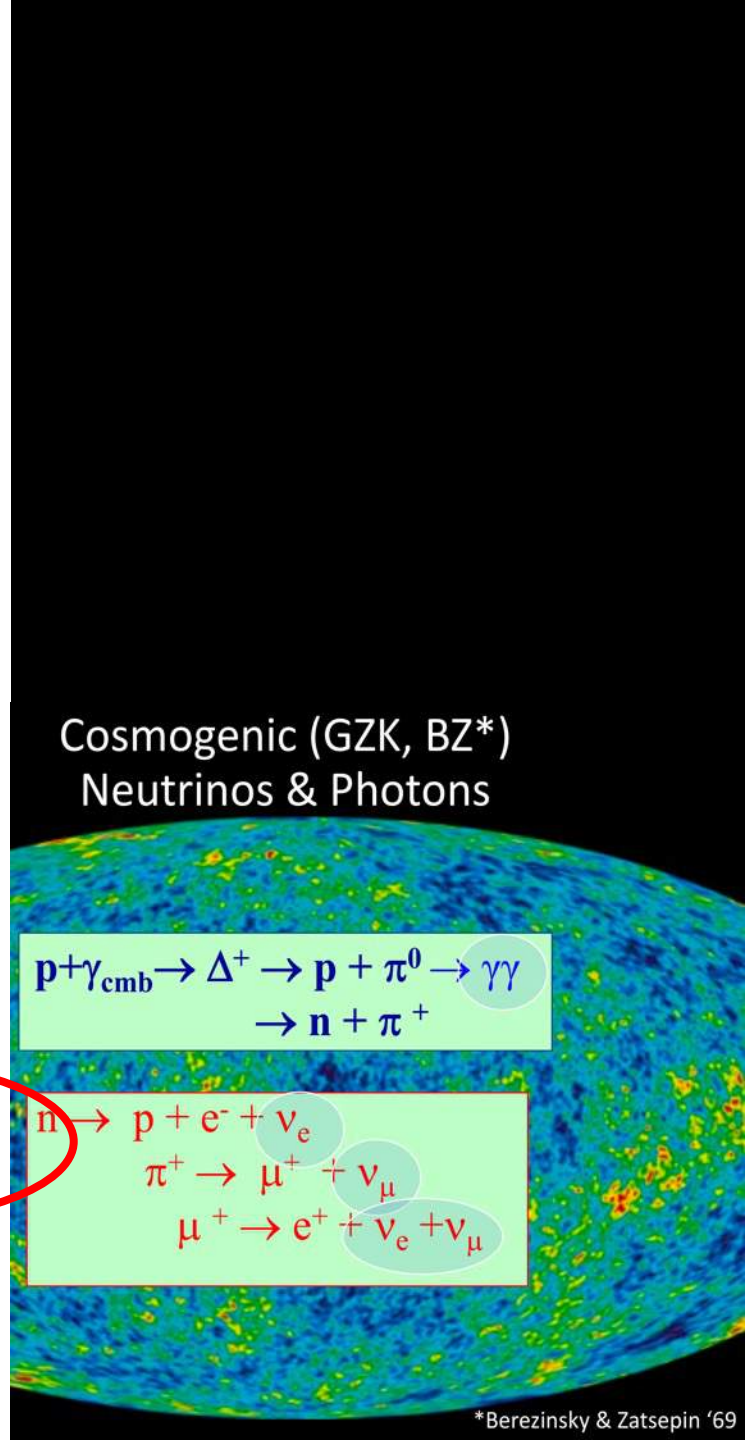
$$p + \gamma_{cmb} \rightarrow \Delta^{+} \rightarrow p + \pi^{0} \rightarrow \gamma\gamma$$
$$\rightarrow n + \pi^{+}$$

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

*Berezinsky & Zatsepin ‘69

Cosmic Neutrino Spectra





Cosmic Neutrino Spectra

Cosmological ν

Raymond Davis Jr.

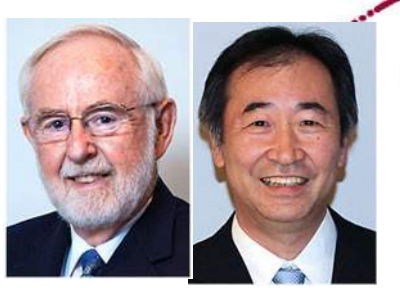
Masatoshi Koshiba

Solar ν

Supernova burst (1987A)

Reactor anti-ν

Background from old supernovae



Art McDonald SNO

Takaaki Kajita Super K

Atmospheric ν

ν from AGN

Astrophysical

Cosmogenic ν

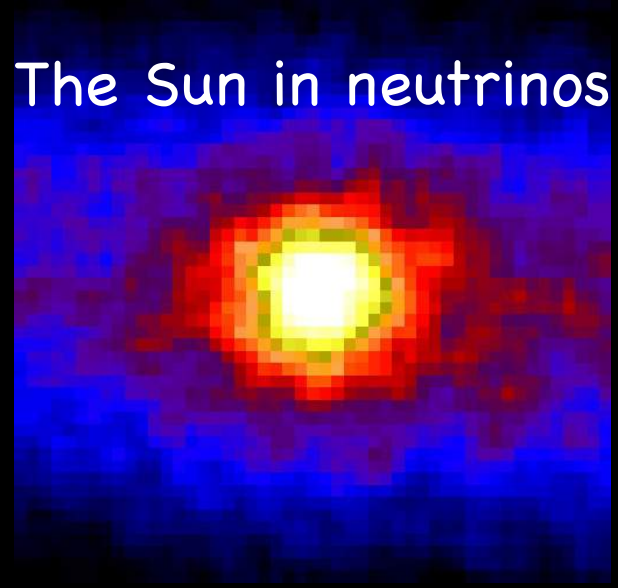
Flux ($cm^{-2}\ s^{-1}\ sr^{-1}\ MeV^{-1}$)

10^{24} 10^{20} 10^{16} 10^{12} 10^{8} 10^{4} 1 10^{-4} 10^{-8} 10^{-12} 10^{-16} 10^{-20} 10^{-24} 10^{-28}

10^{-6} μeV, 10^{-3} meV, 1 eV, 10^{3} keV, 10^{6} MeV, 10^{9} GeV, 10^{12} TeV, 10^{15} PeV, 10^{18} EeV

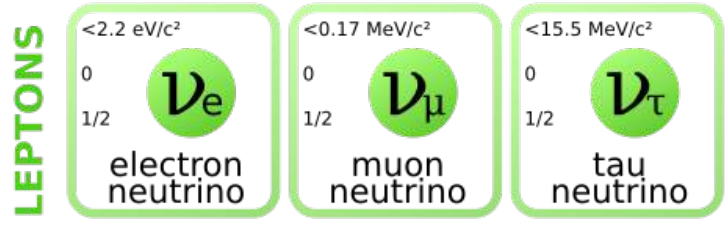
Neutrino energy

2002 Nobel Prize in Physics

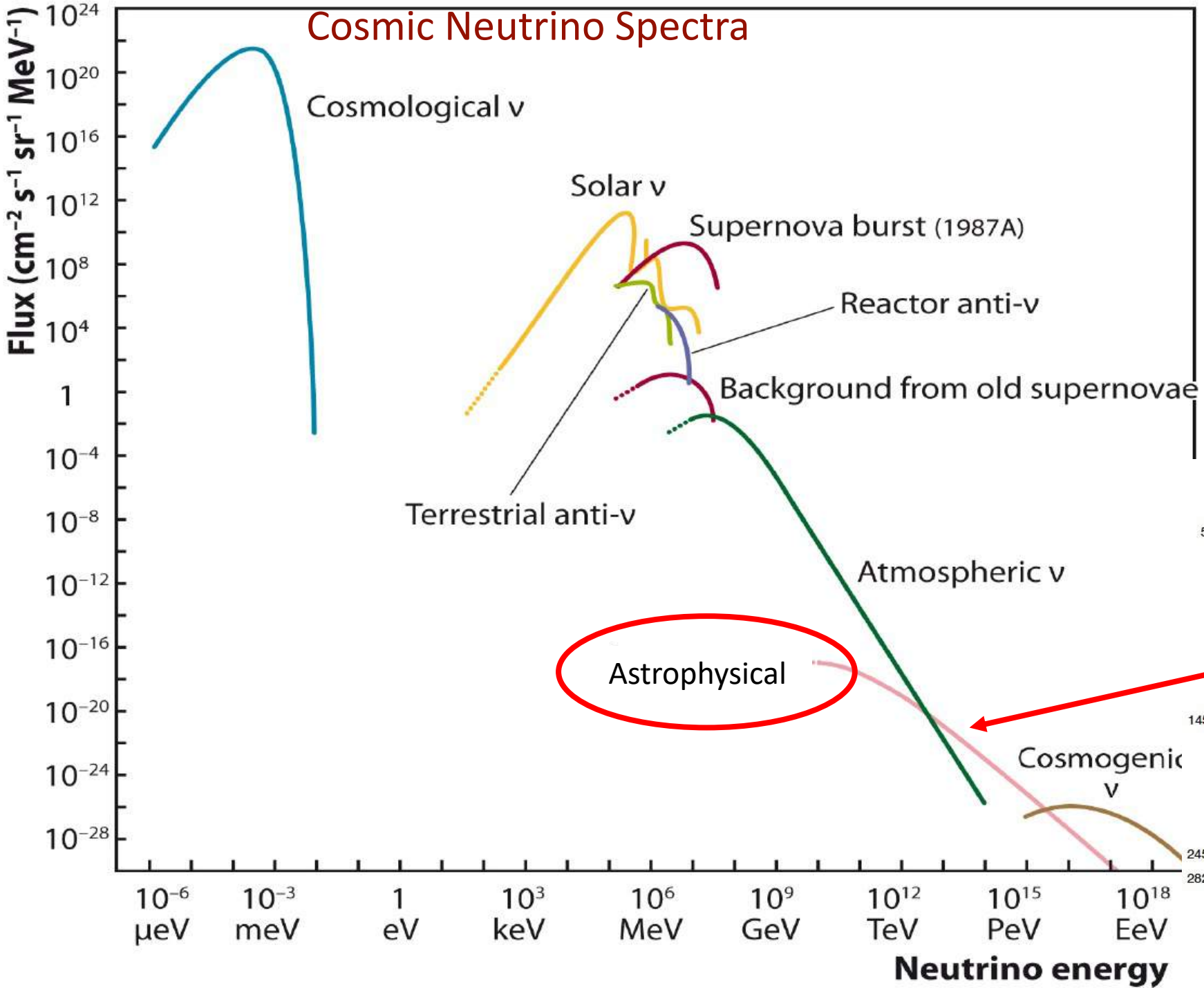


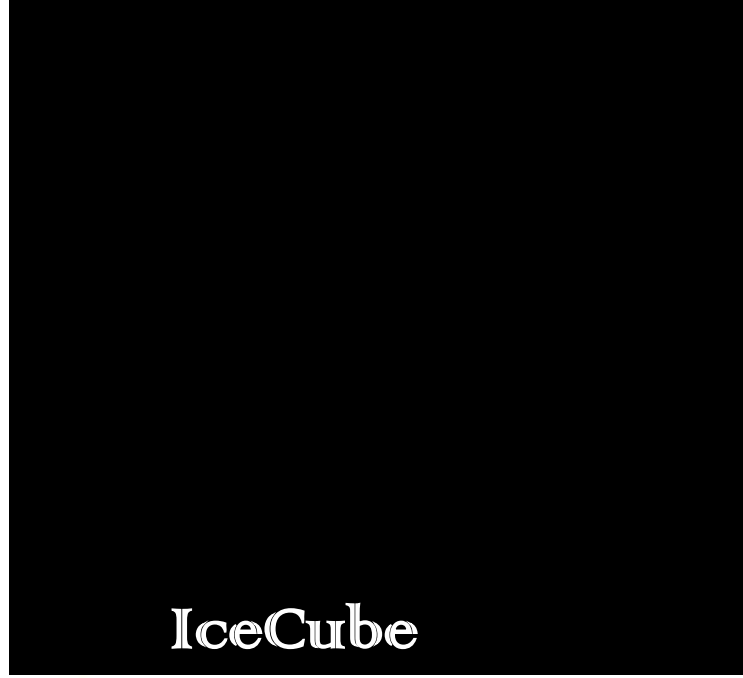
2015 Nobel Prize in Physics

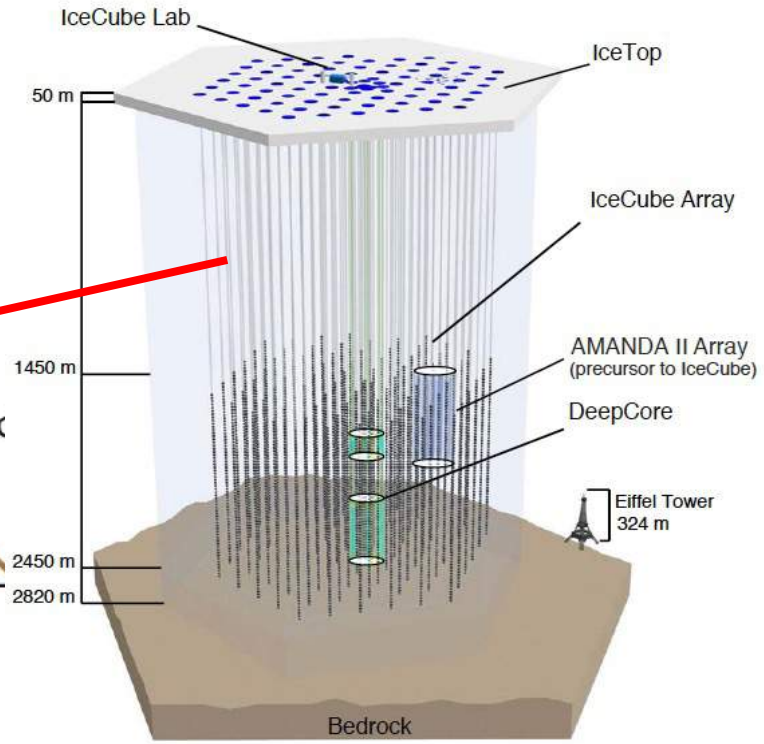
Neutrino Oscillations



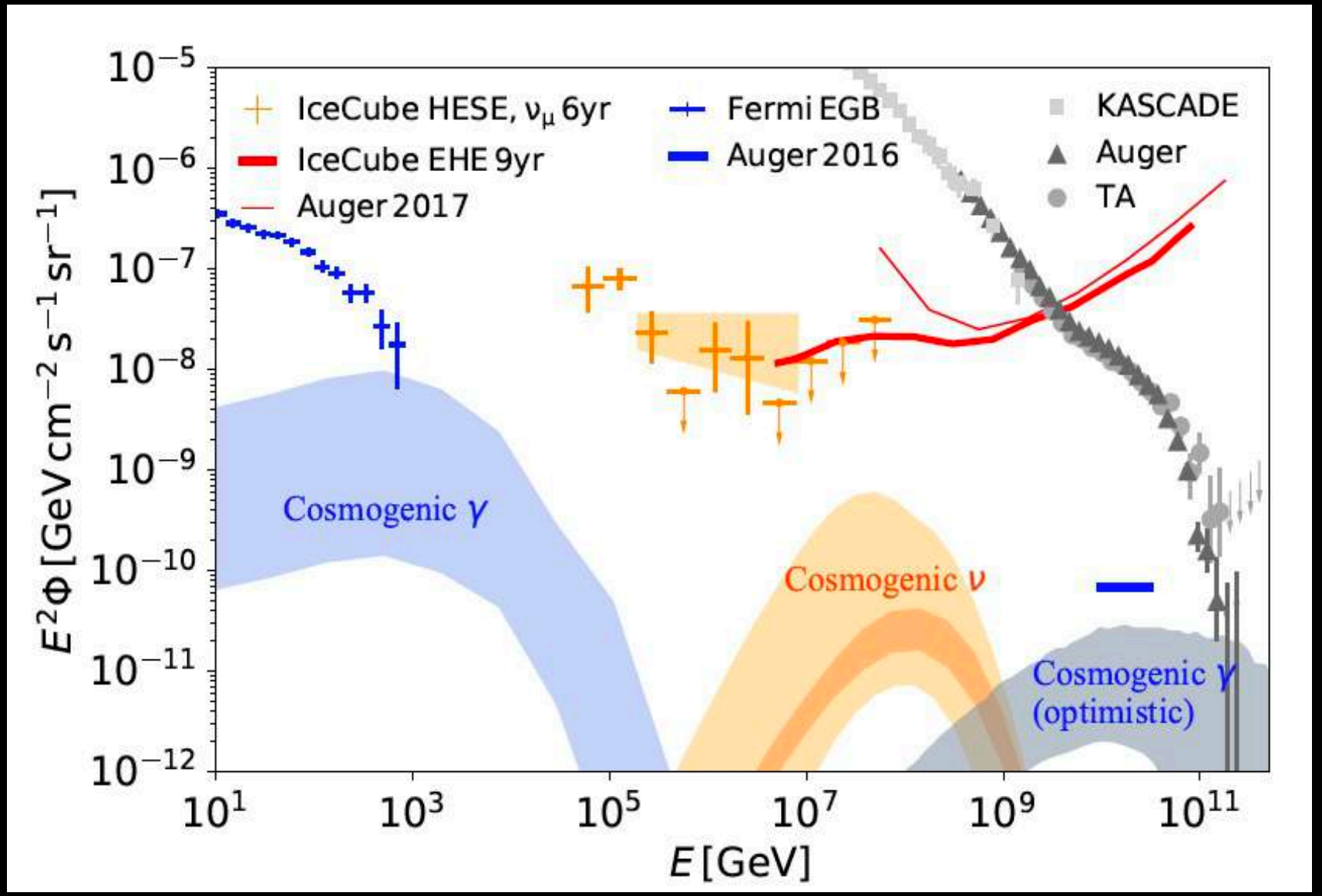
Cosmic Neutrino Spectra





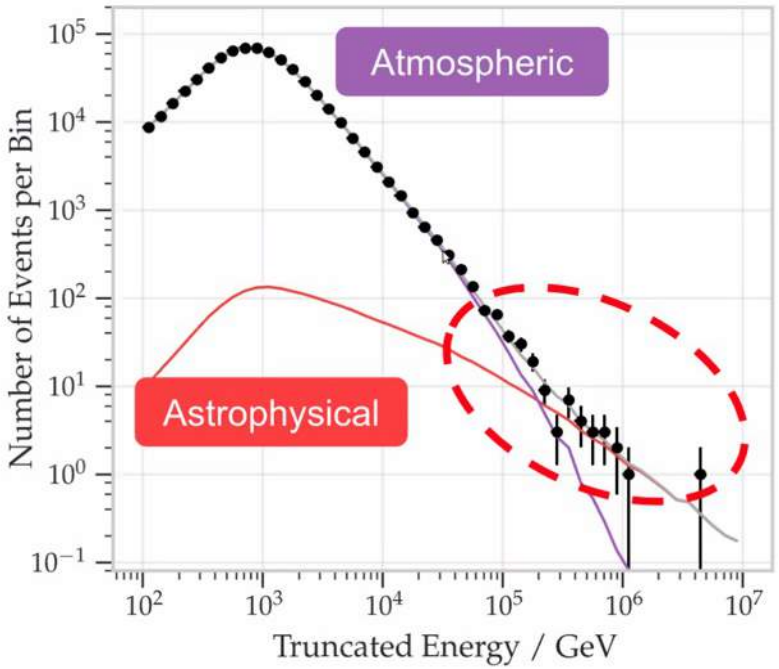


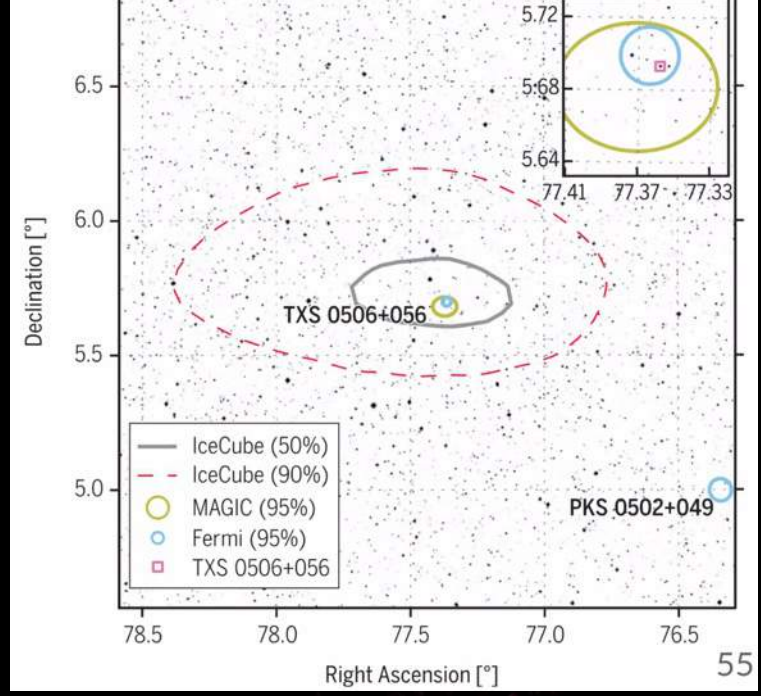
Cosmogenic Messengers

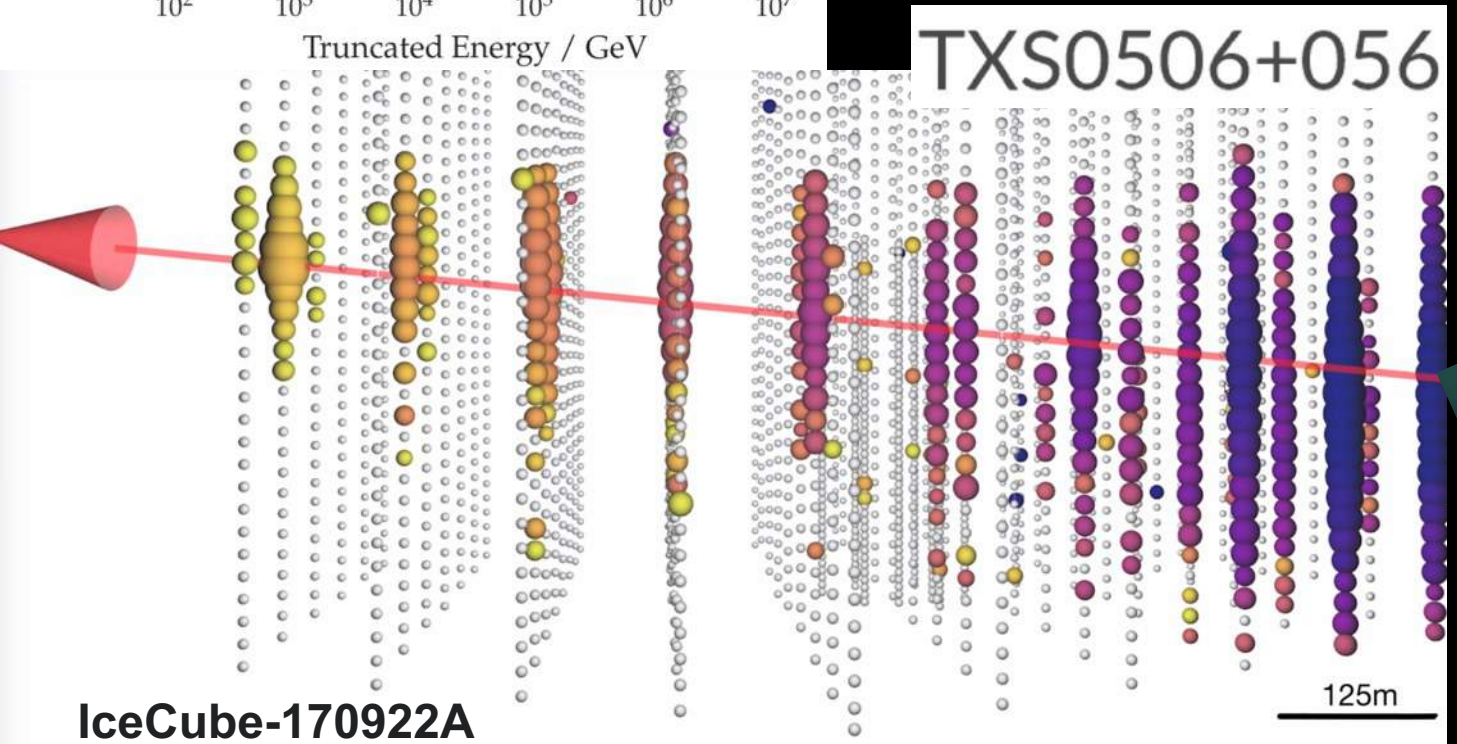


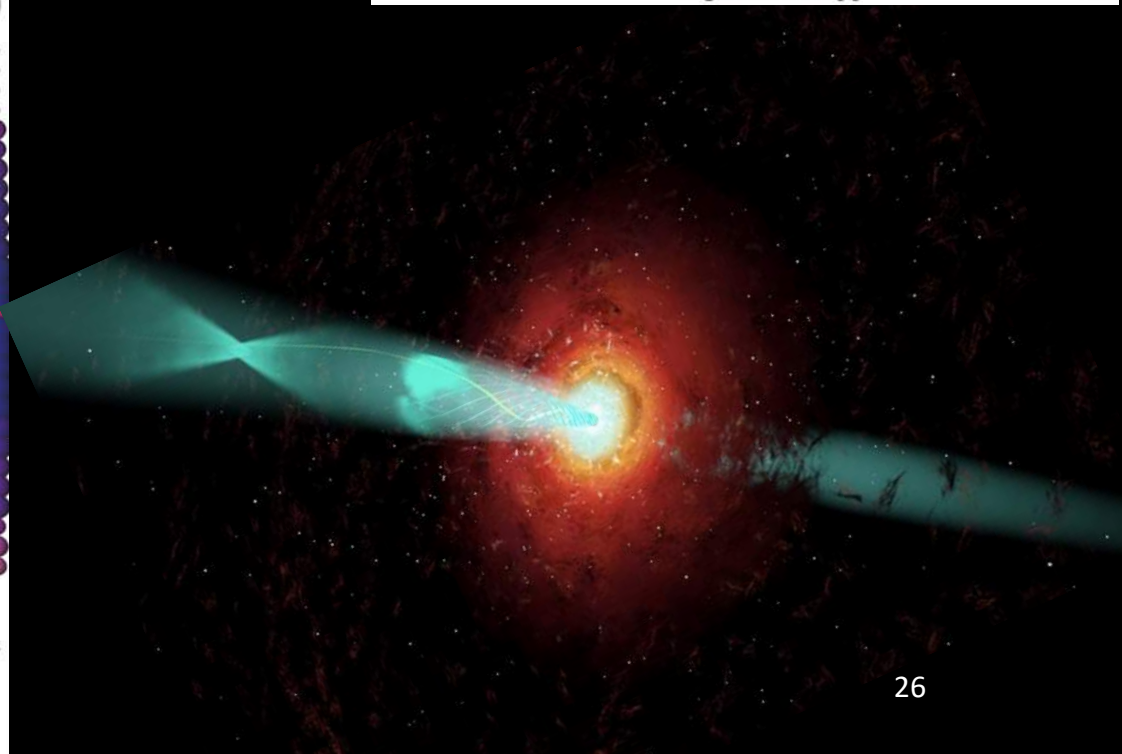
Batista et al, arXiv:1903.06714.pdf

Astrophysical Neutrinos



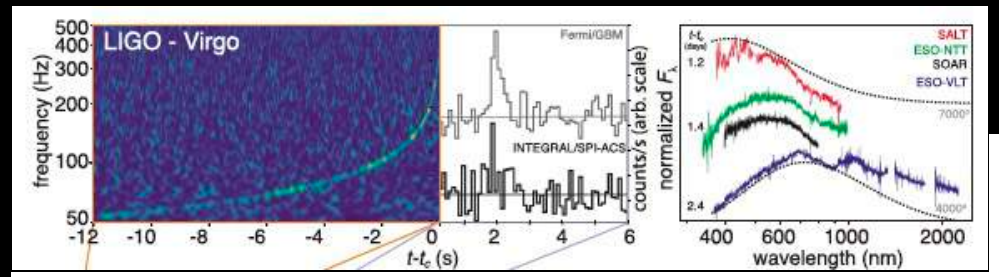


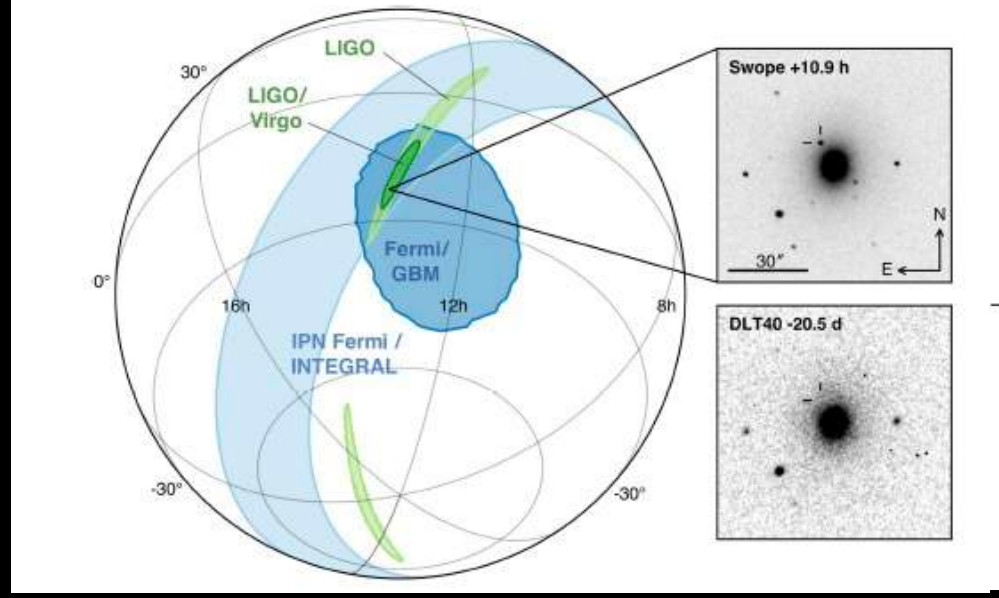




GW170817

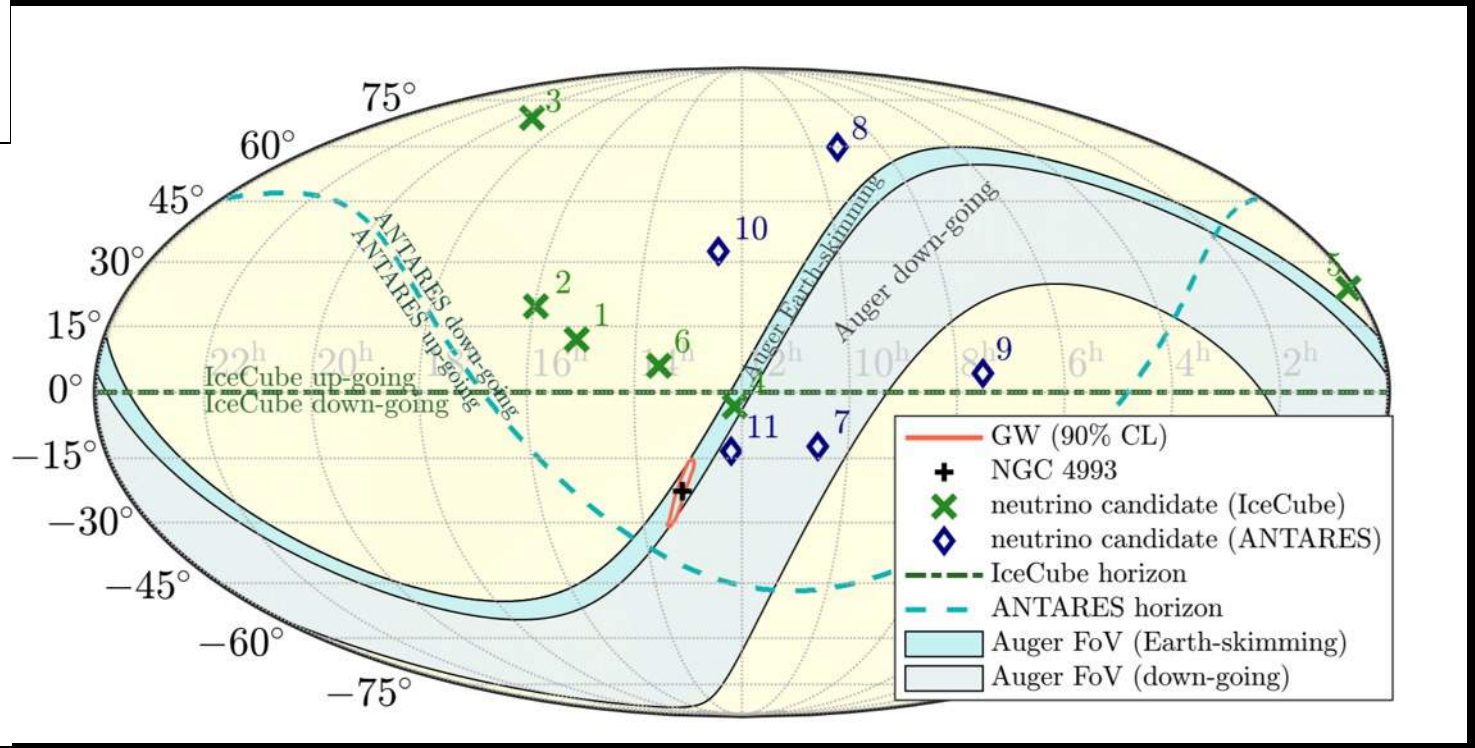
Neutron Star- Neutron Star Merger





LIGO et al ApJL, arXiv:1710.05833

No Neutrinos Yet



Albert et al, arXiv:1710.05839

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Are there Extra-Dimensions, Supermassive Dark Matter, Topological Defects?

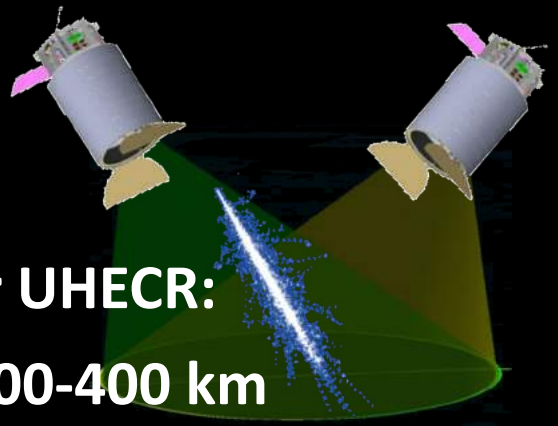
Probe Of Extreme Multi-Messenger Astrophysics

UHECRs and Cosmic Neutrinos

POEMMA: study collaboration

USA: University of Chicago: *A. V. Olinto (PI),* S. S. Meyer, J. Eser, R. Diesing
NASA/GSFC: J. F. Krizmanic (deputy PI), C. Guepin, E. Hays , J. McEnery, J. W. Mitchell, J. S Perkins, F. Stecker, T. M. Venters
NASA/MSFC: P. Bertone, M.J. Christl, R. M. Young,
University of Alabama, Huntsville: J. Adams, E. Kuznetsov, P. Reardon,
University of Utah: D. R. Bergman
Colorado School of Mines: F. Sarazin, L. Wiencke, G. Filippatos, V. Kungel, K.-D. Merenda
City University of New York, Lehman College: L. Anchordoqu, T. C. Paul, J. F. Soriano
Georgia Institute of Technology: A. N. Otte, M. Bagheri, E. Gazda, O. Romero Matamala
Space Sciences Laboratory, University of California, Berkeley: E. Judd
University of Iowa: M. H. Reno, Y. Onel, J. Nachtman, D. Winn
KIPAC, Stanford: K. Fang
CZECH Rep: K. Cerny, D. Mandát, M. Pech, P. Schovánek
DENMARK: NBI: M. Bustamante
FRANCE: APC Univerite de Paris 7: E. Parizot, G. Prevot; IAP, Paris: C. Guepin
GERMANY: KIT: R. Engel, A. Haungs, R. Ulrich, M. Unger;
ITALY: Universita di Torino: M. E. Bertaina, D. Barghini, M. Battisti, F. Bisconti, F. Fenu, H. Miyamoto, Z. Plebaniak; Gran Sasso Science Institute: R. Aloisio, A. L. Cummings, I. De Mitri; INFN Frascati: M. Ricci, INFN Tor Vergata: M. Casolino, L. Marceli, U. of Rome Tor Vergata: P. Picozza
JAPAN: RIKEN: M. Casolino,, Y. Takizawa
MEXICO: , G. Medina Tanco
NORWAY: NTNU: F. Oikonomou
POLAND: University of Warsaw: L. W. Piotrowski; NCNR, Lodz: K. Shinozaki
RUSSIA: MSU: P. Klimov, M. Zotov
SLOVAKIA: IEP, Slovak Academy of Science: S. Mackovjak
SWITZERLAND: University of Geneva: A. Neronov

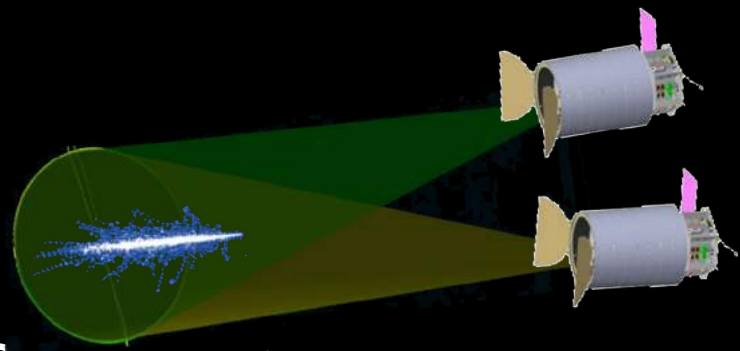
70 scientists from 32 institutions and 13 countries
OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory



Nadir for UHECR:

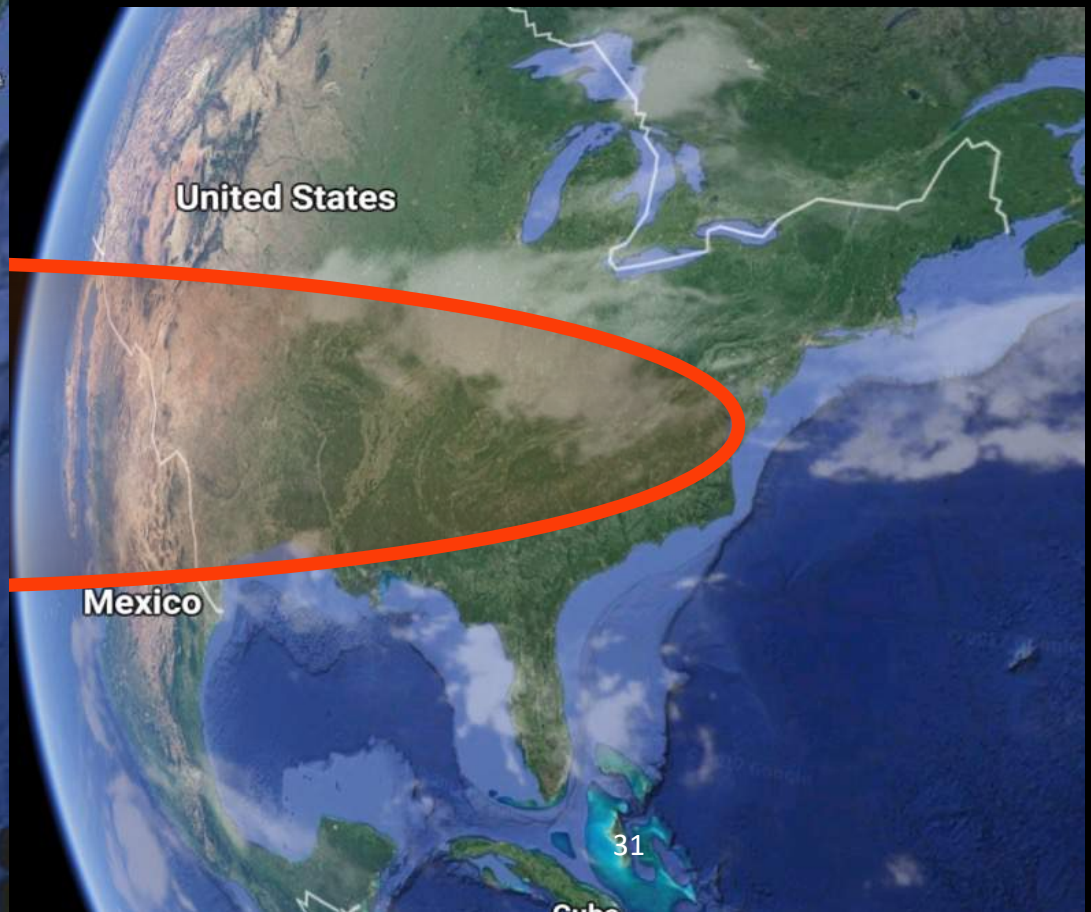
Radius 200-400 km

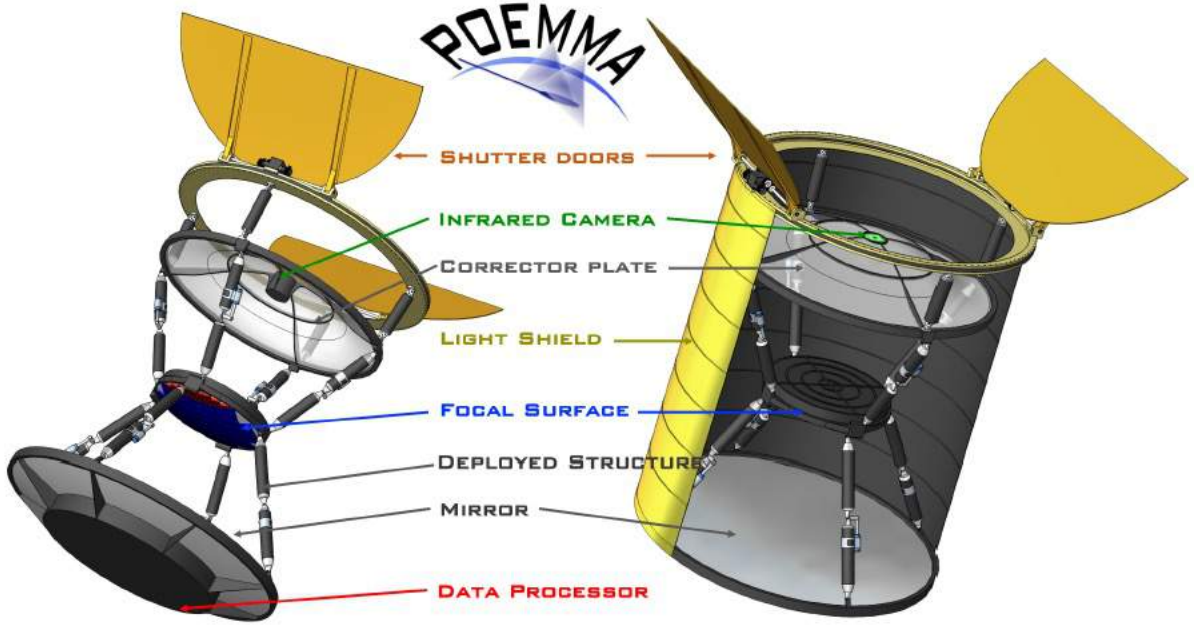
Observing Modes



Limb for Neutrinos & UHECRs

Radius 2.6-3.7 10^3 km





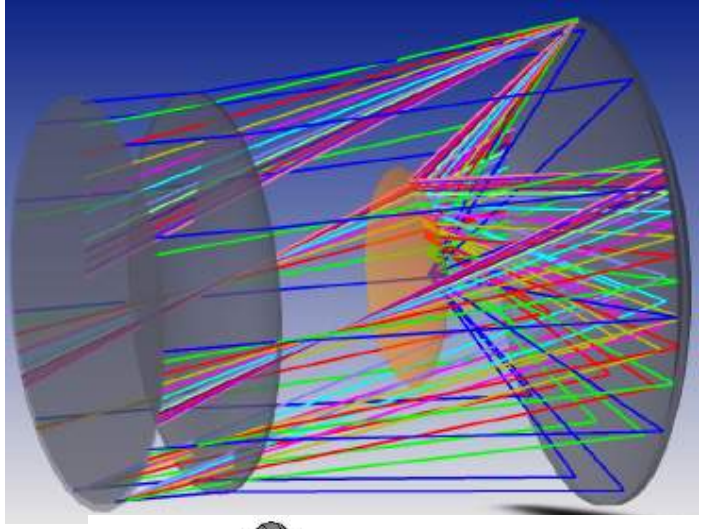
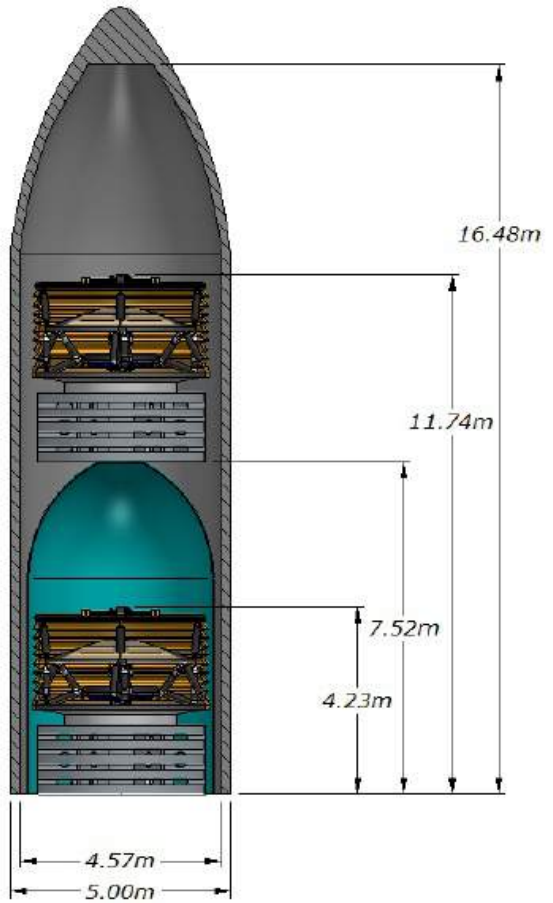


TABLE I: POEMMA Specifications:

Photometer	Components		Spacecraft	
Optics	Schmidt	45° full FoV	Slew rate	90° in 8 min
	Primary Mirror	4 m diam.	Pointing Res.	0.1°
	Corrector Lens	3.3 m diam.	Pointing Know.	0.01°
	Focal Surface	1.6 m diam.	Clock synch.	10 nsec
	Pixel Size	3×3 mm^2	Data Storage	7 days
	Pixel FoV	0.084°	Communication	S-band
PFC	MAPMT (1μs)	126,720 pixels	Wet Mass	3,450 kg
PCC	SiPM (20 ns)	15,360 pixels	Total Power	880 W
Photometer	(One)		Mission	(2 Observatories)
	Mass	1,550 kg	Lifetime	3 year (5 year goal)
	Power	590 W	Orbit	525 km, 28.5° Inc
	Data	< 1 GB/day	Orbit Period	95 min
			Observatory Sep.	~25 - 1000+ km

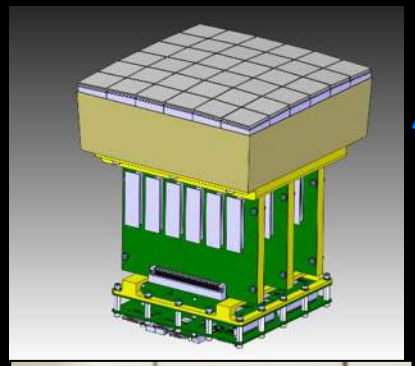
Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

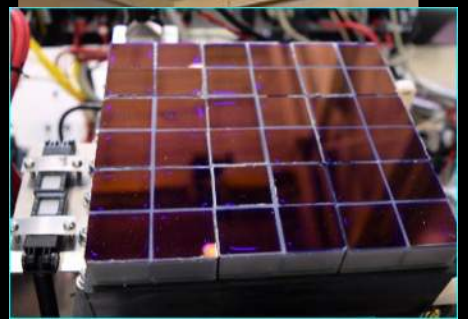


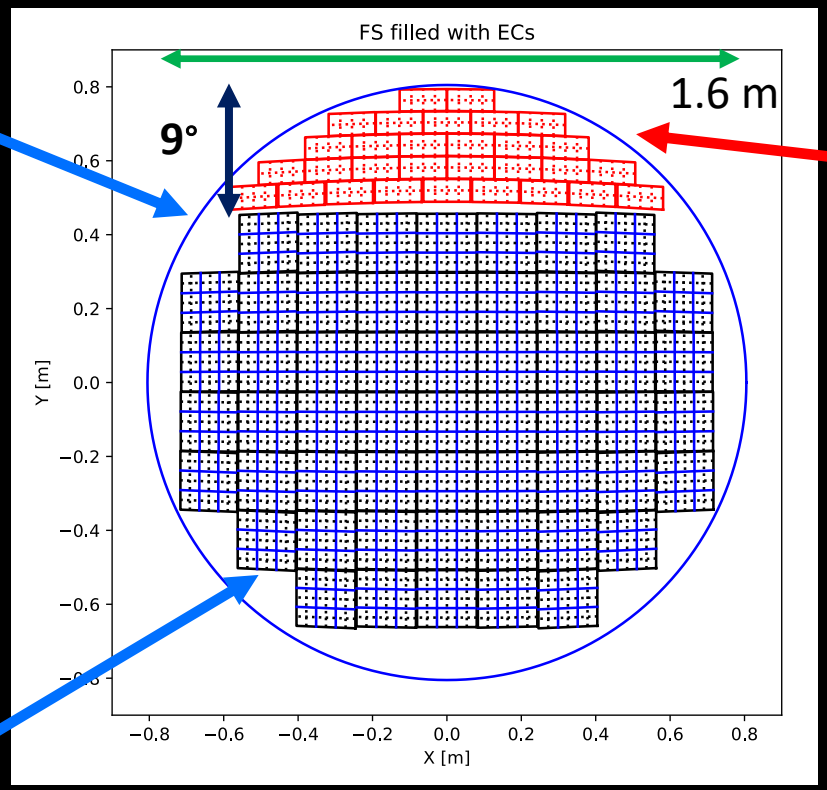
POEMMA

Hybrid Focal Surface

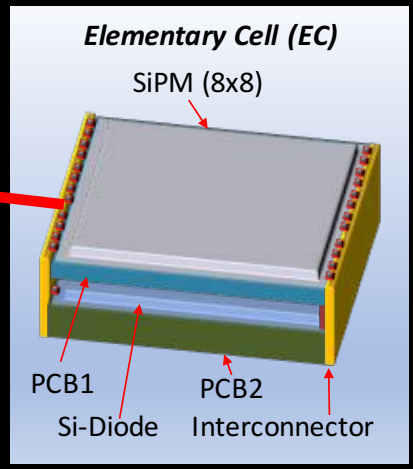
UV Fluorescence
MAPMTs with BG3 filter:
1 usec sampling







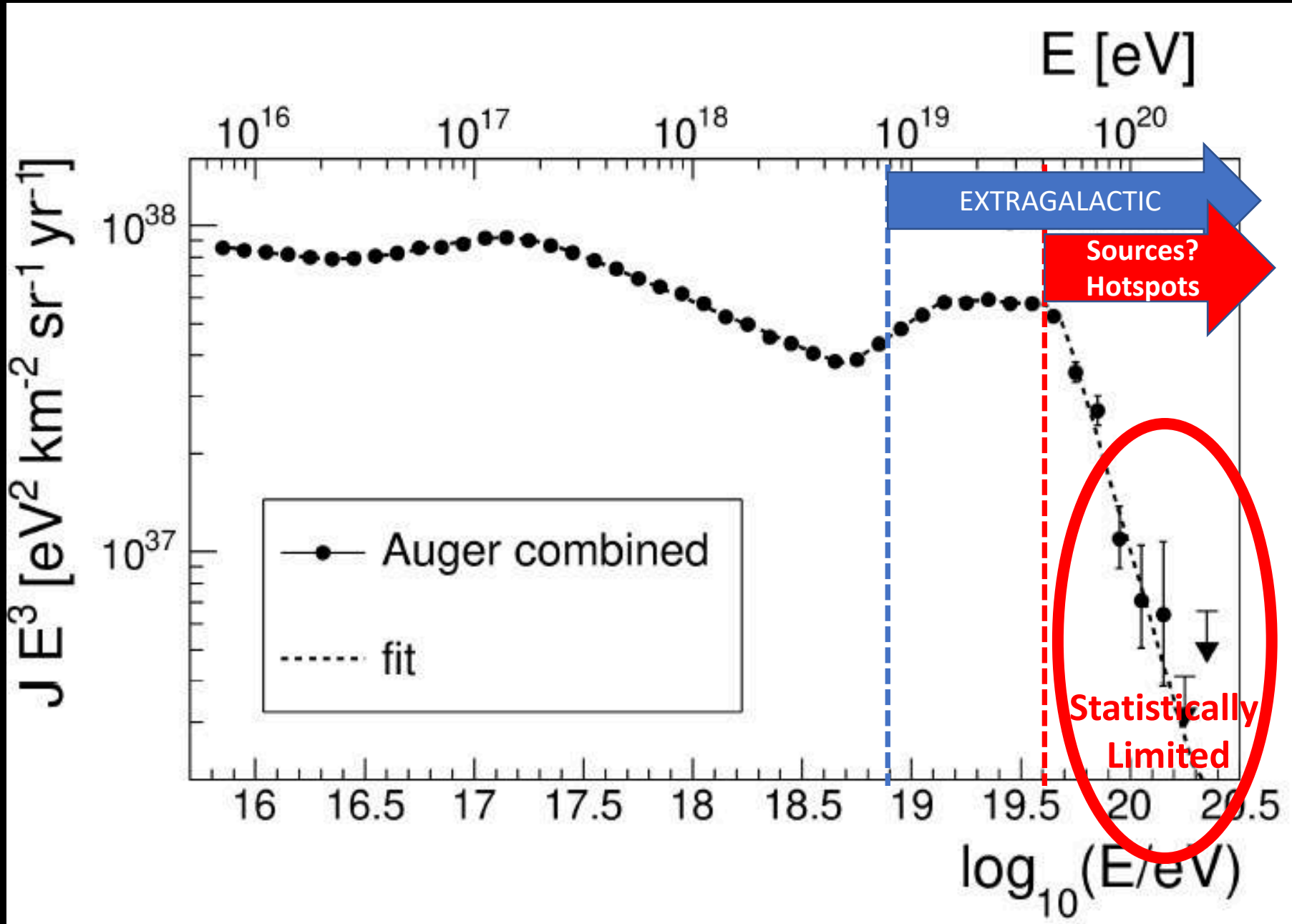
Cherenkov Detection
SiPMs:
20 nsec sampling



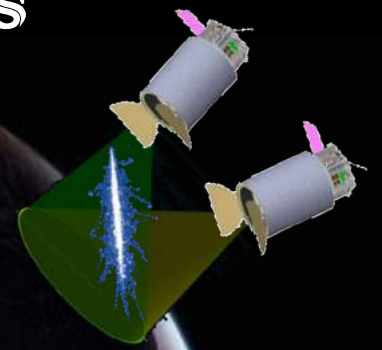
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)

55 Photo Detector Modules (PDMs)= TOTAL 126,720 pixels
(1 PDM = 36 MAPMTs = 2,304 pixels)

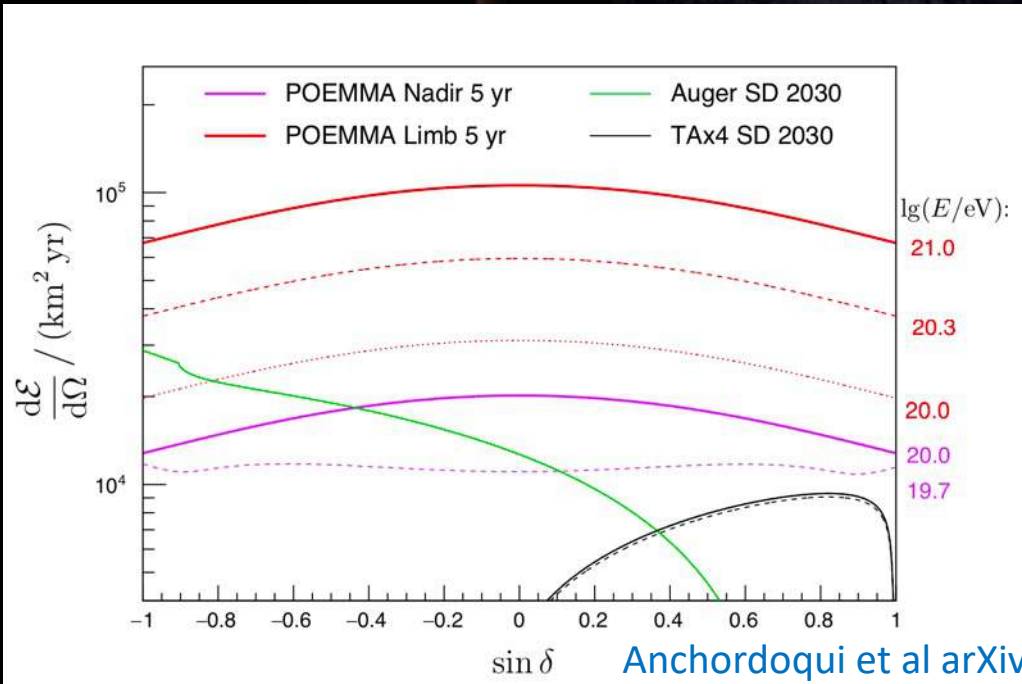
Auger Spectrum ICRC 2021



POEMMA: UHECRs

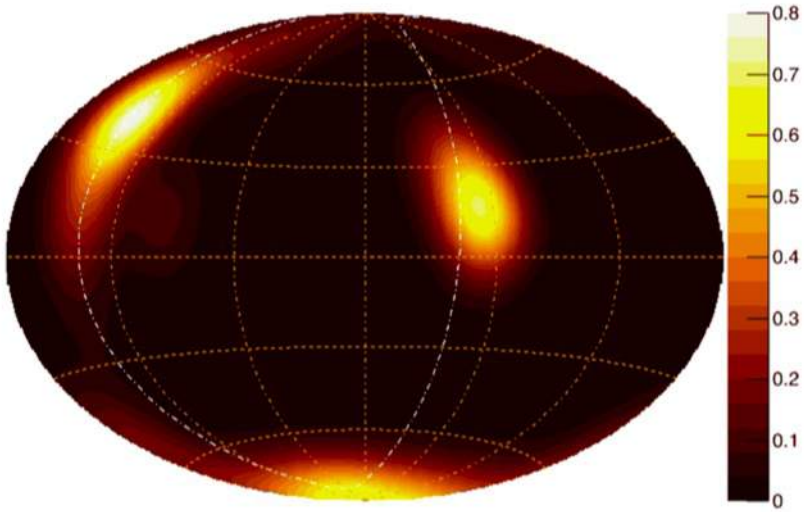


significant increase in exposure E >50 EeV
good energy, angular, and shower maximum resolutions,
accurately measure **Composition, Spectrum, Anisotropies**
Uniform sky coverage
to **guarantee the discovery of UHECR sources**



Anchordoqui et al arXiv:1907.03694

nearby Starburst Galaxies Fermi-LAT



POEMMA probability density

POEMMA: Neutrinos

POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of tau decays.

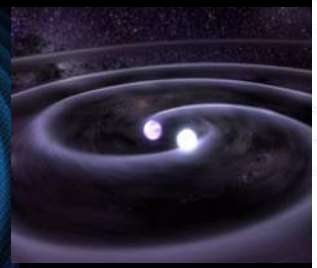
High-Energy Astrophysical Events generates neutrinos (ν_e,ν_μ) and 3 neutrino flavors reach Earth (Oscillations). Tau neutrinos generate tau leptons on their way out of the Earth's surface which decay producing up-going showers, detected by POEMMA

POEMMA: Neutrino Target of Opportunity

arXiv:1906.07209

Venters et al 2019 **Transient Events - 10s neutrinos/event from 10s of Mpc**

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



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

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

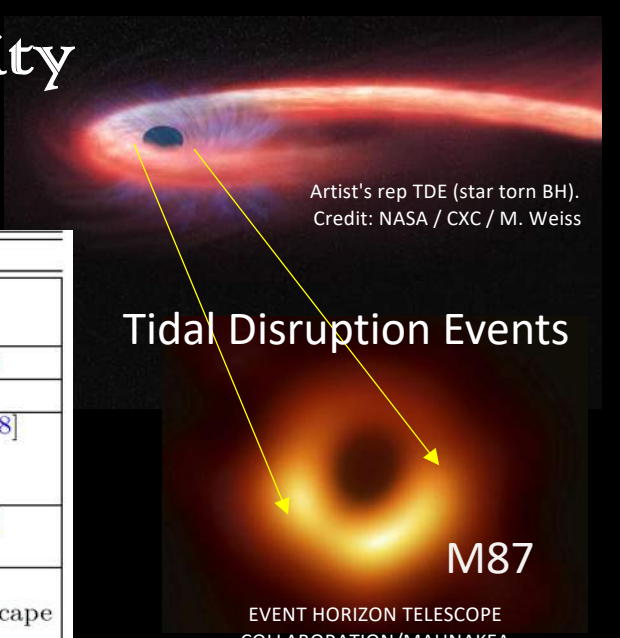
Long Bursts

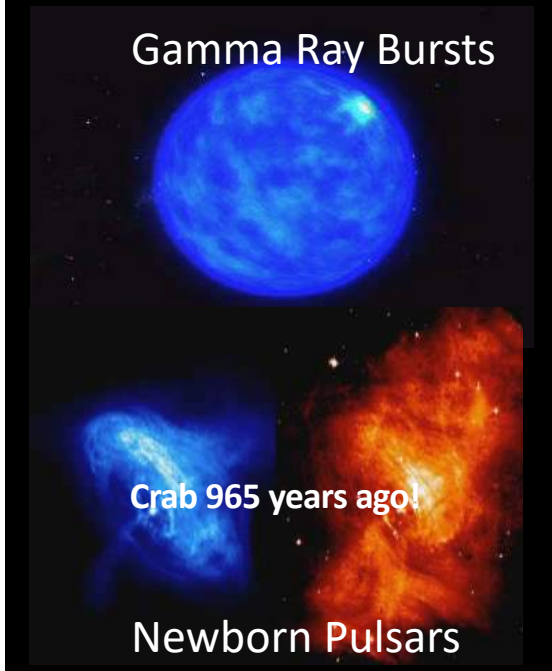
Source Class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest Distance for 1.0 ν per event	Model Reference
TDEs	1.1×10^5	0.8	3 Mpc	Dai and Fang [17] average
TDEs	5.6×10^5	3.9	6 Mpc	Dai and Fang [17] bright
TDEs	$\mathbf{2.2 \times 10^8}$	$\mathbf{1.4 \times 10^3}$	**115 Mpc**	**Lunardini and Winter [18] $M_{\rm SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling Model**
TDEs	6.3×10^7	*396*	*62 Mpc*	*Lunardini and Winter [18] Base Scenario*
Blazar Flares	NA*	NA*	43 Mpc	RFGBW [19] – FSRQ proton-dominated advective escape model
lGRB Reverse Shock (ISM)	9.9×10^4	0.7	2 Mpc	Murase [15]
lGRB Reverse Shock (wind)	2.0×10^7	144	37 Mpc	Murase [15]
BH-BH merger	$\mathbf{2.3 \times 10^7}$	**160**	**39 Mpc**	**Kotera and Silk [20] (rescaled) Low Fluence**
BH-BH merger	$\mathbf{2.4 \times 10^8}$	$\mathbf{1.7 \times 10^3}$	**119 Mpc**	**Kotera and Silk [20] (rescaled) High Fluence**
NS-NS merger	$\mathbf{3.6 \times 10^6}$	**24.8**	**13 Mpc**	**Fang and Metzger [21]**
WD-WD merger	20.0	0	33 kpc	XMMD [22]
Newly-born Crab-like pulsars (p)	1.6×10^2	1.1×10^{-3}	98 kpc	Fang [23]
Newly-born magnetars (p)	2.1×10^4	0.1	1 Mpc	Fang [23]
Newly-born magnetars (Fe)	4.1×10^4	0.3	2 Mpc	Fang [23]

Short Bursts

Source Class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest Distance for 1.0 ν per event	Model Reference
sGRB Extended Emission (moderate)	9.0×10^7	6.5×10^2	81 Mpc	KMMK [16]

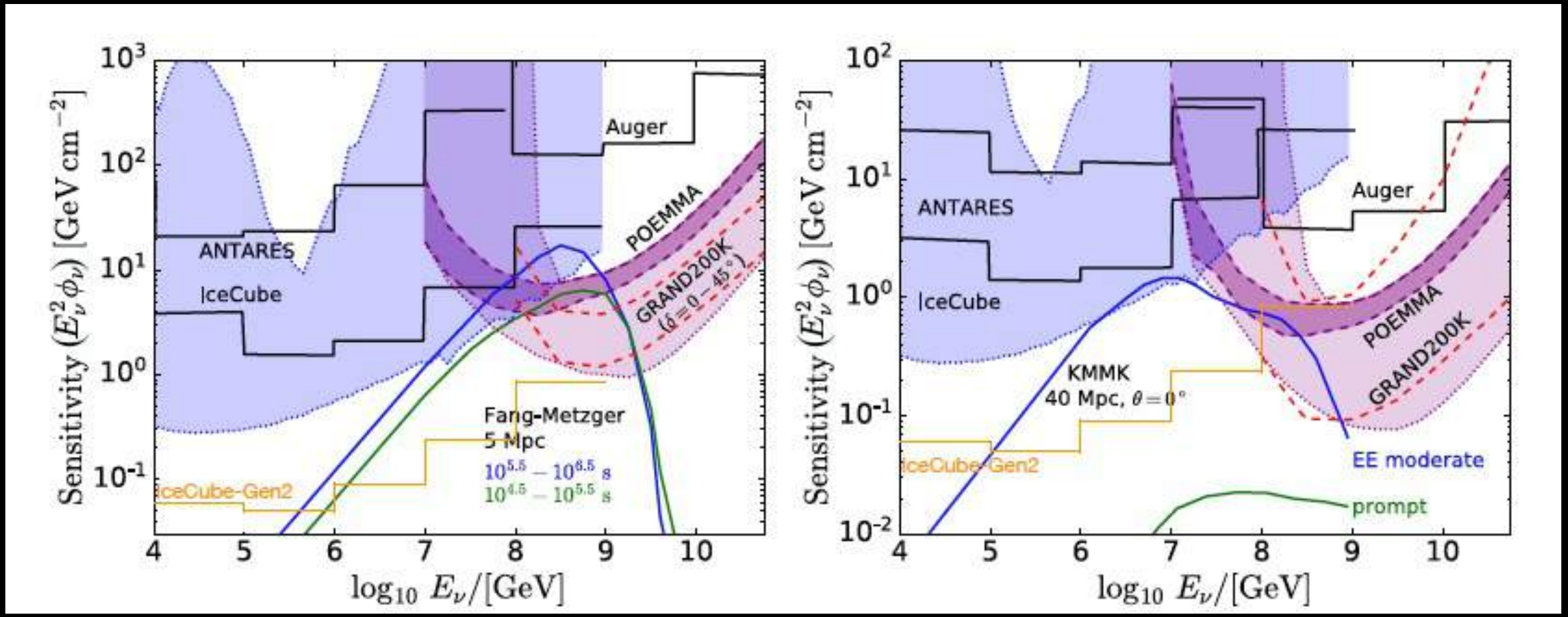
(*) Not applicable due to a lack of known blazars within 100 Mpc.





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

Transient Neutrino Point Source Sensitivity



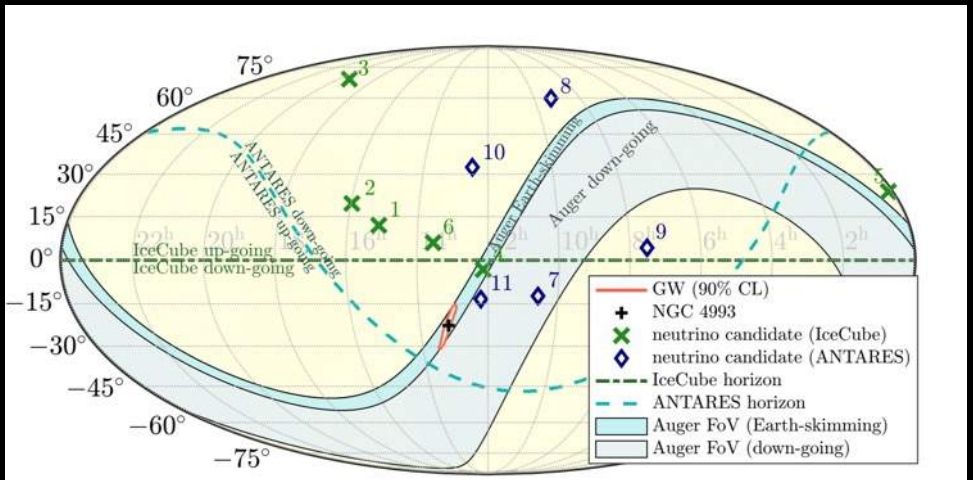
Fang & Metzger, arXiv:1707.04263

Kimura et al, arXiv:1708.07075

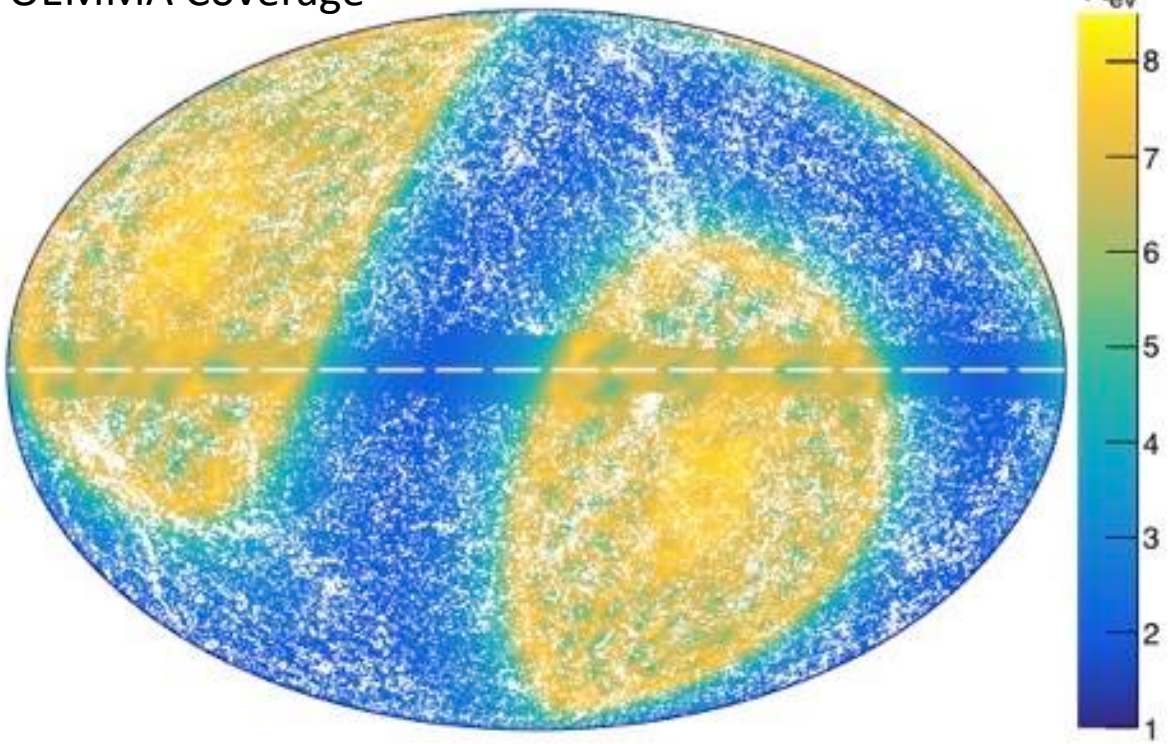
Venters et al, Snowmass2021, LOI, (2020)

Sky Coverage HE-UHE Neutrinos

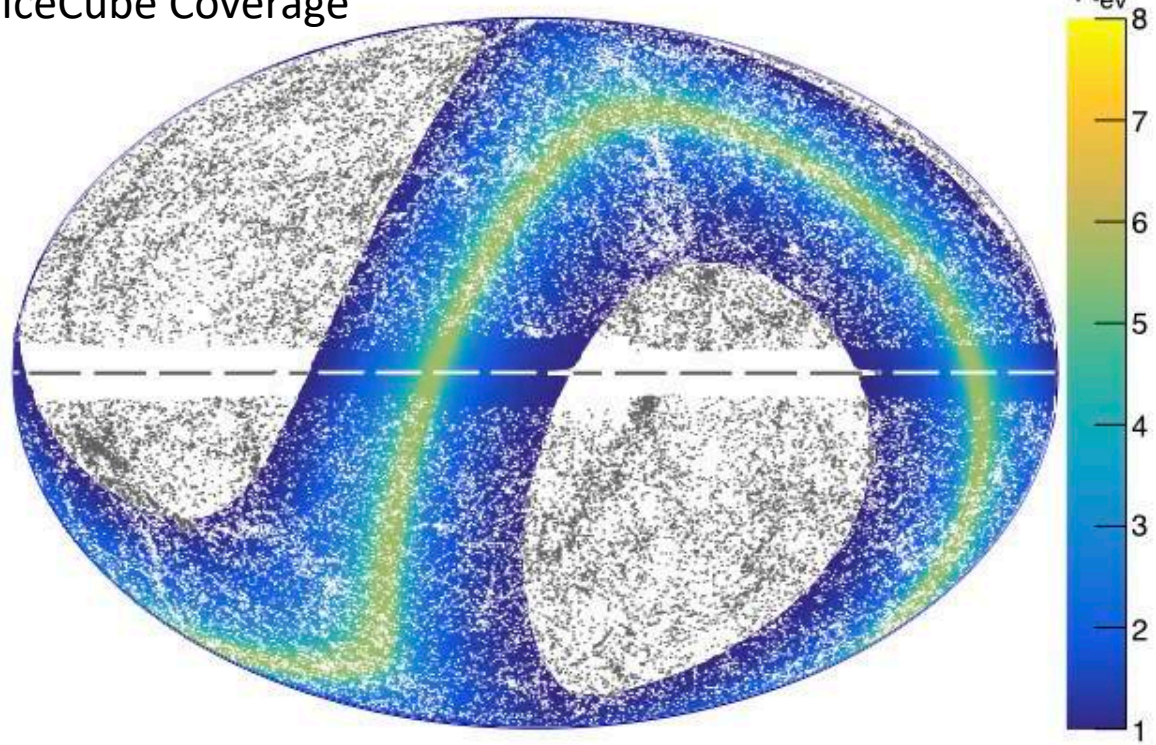
Complementary



POEMMA Coverage

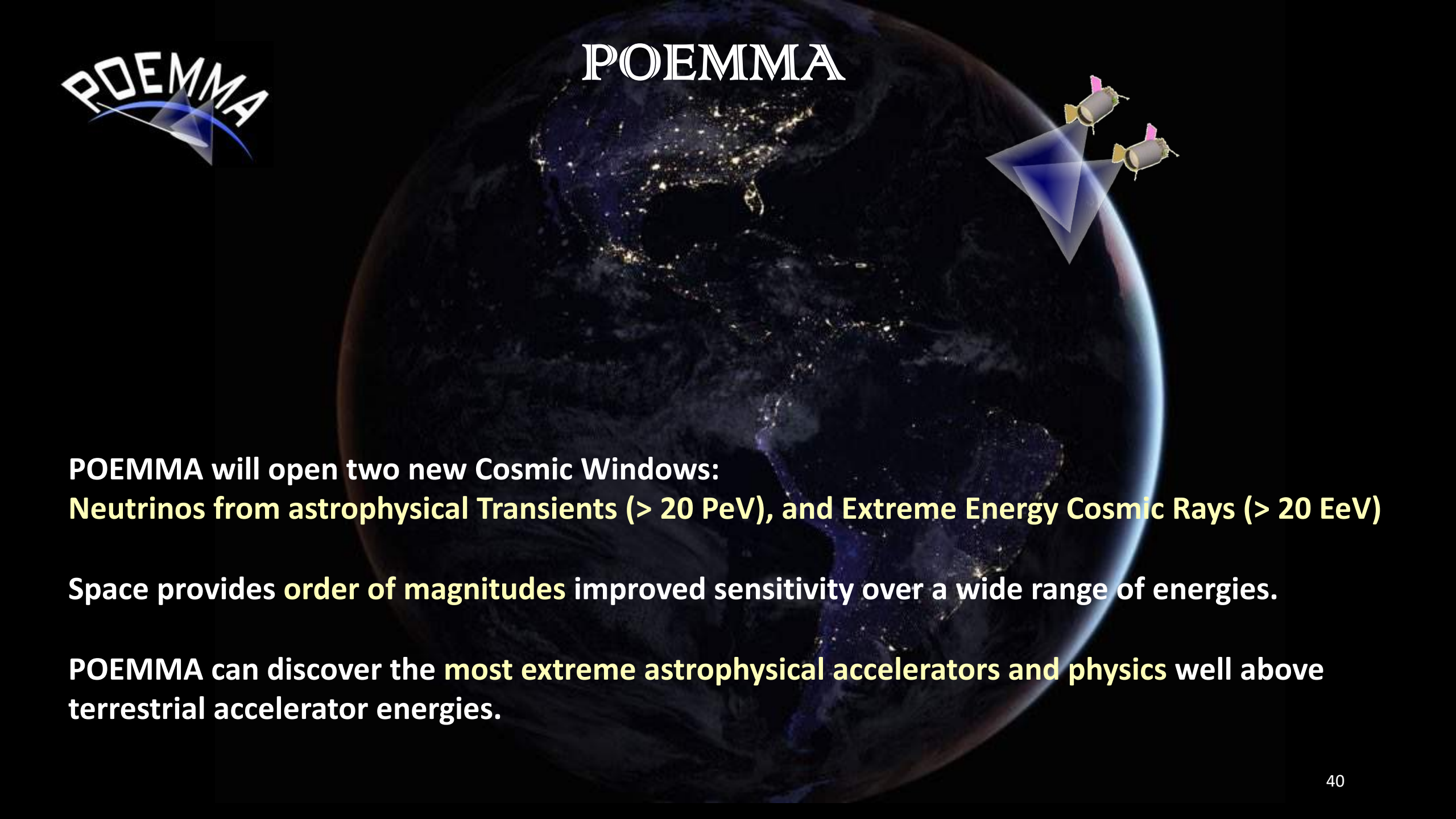


IceCube Coverage



Venters et al arXiv:1906.07209

POEMMA



POEMMA will open two new Cosmic Windows:
Neutrinos from astrophysical Transients (> 20 PeV), and Extreme Energy Cosmic Rays (> 20 EeV)

Space provides order of magnitudes improved sensitivity over a wide range of energies.

POEMMA can discover the most extreme astrophysical accelerators and physics well above terrestrial accelerator energies.

JEM-EUSO program

Joint Experiment Missions
Extreme Universe Space Observatory

EUSO-TA (2013-)

EUSO-Balloon (2014)

EUSO-SPB1 (2017)

Mini-EUSO (2019)

EUSO-SPB2 (2023)

K-EUSO (2024+)

POEMMA (2028+)

EUSO-SPB1

Extreme Universe Space Observatory on a Super Pressure Balloon

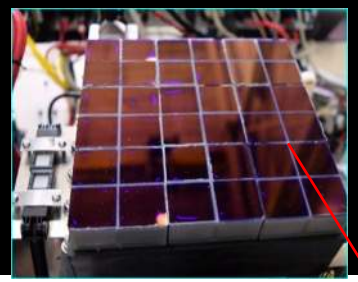
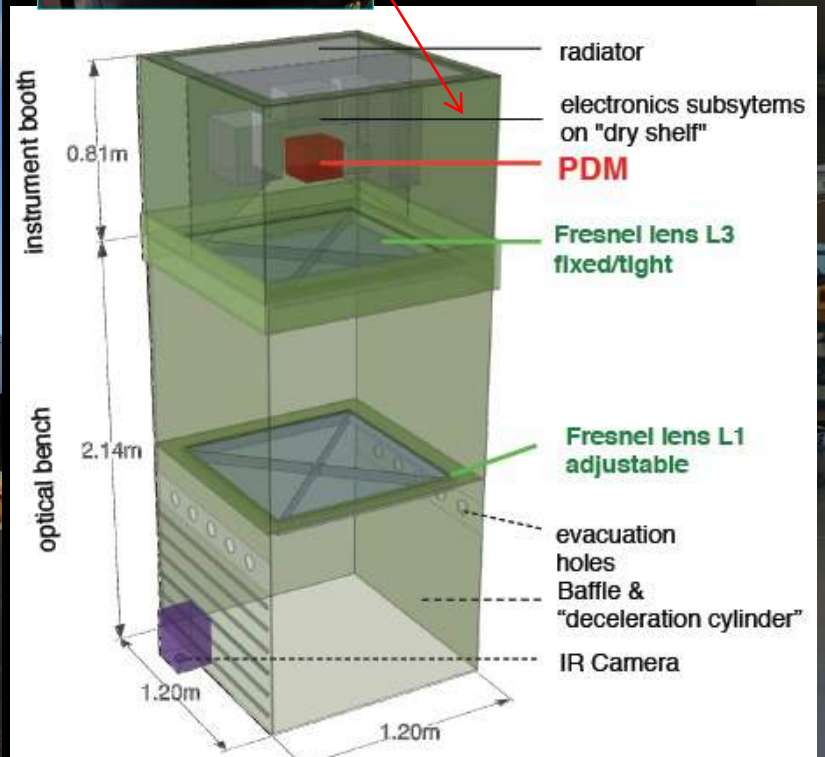
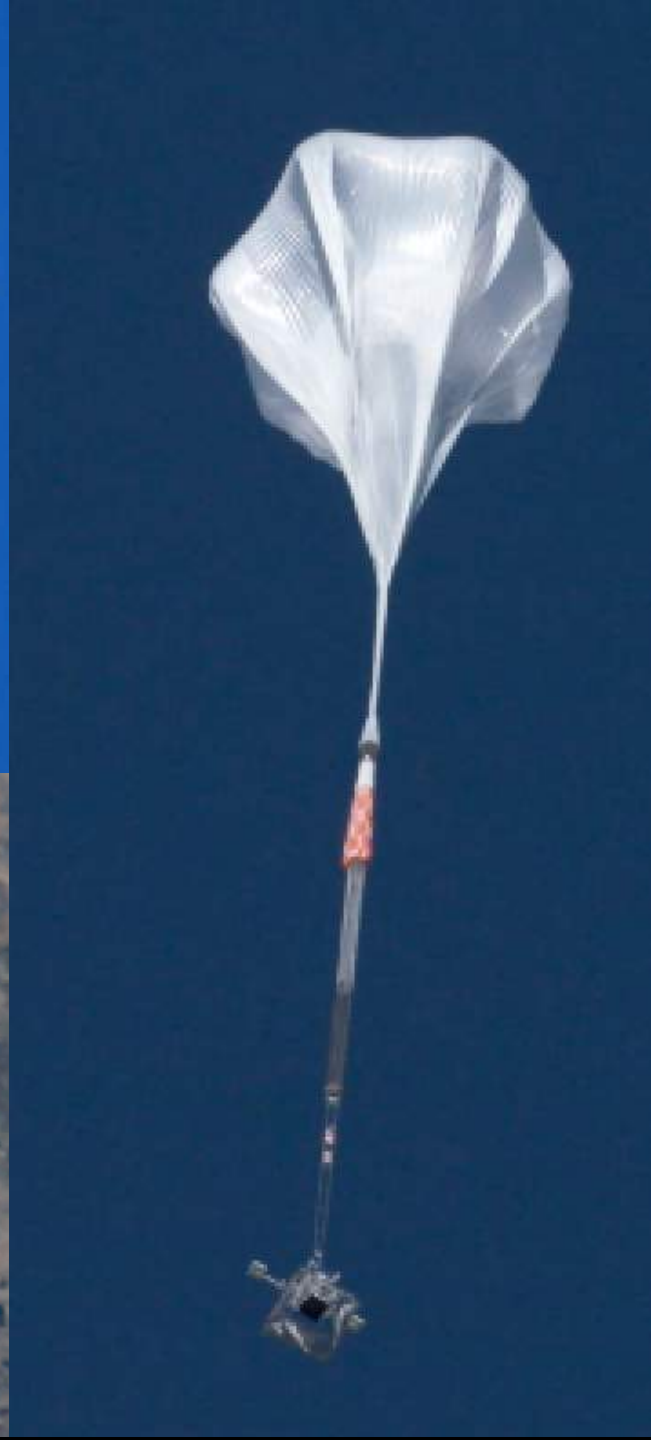


Photo-Detector Module (PDM)
3x3 ECs =
36 MAPMTS
2,304 pixels



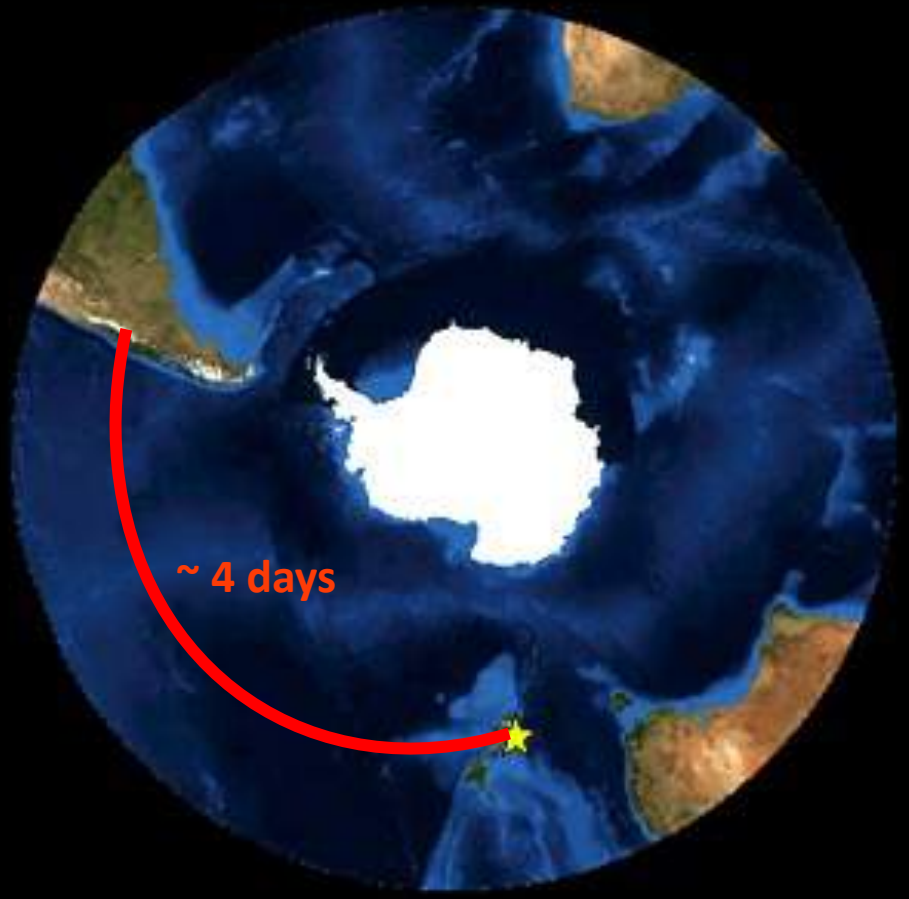


EUSO-SPB 1

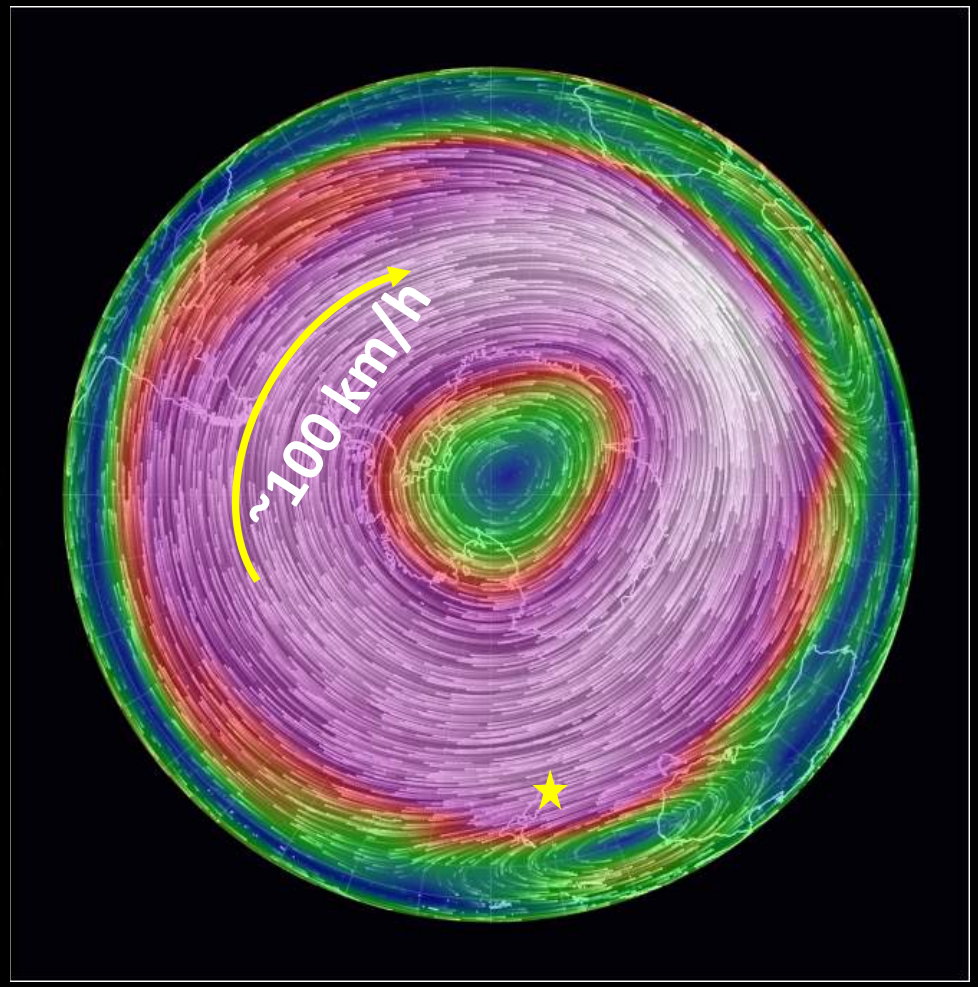
launch, April 24, 2017

23:51 UTC

Why New Zealand?



Wanaka
South Island
New Zealand

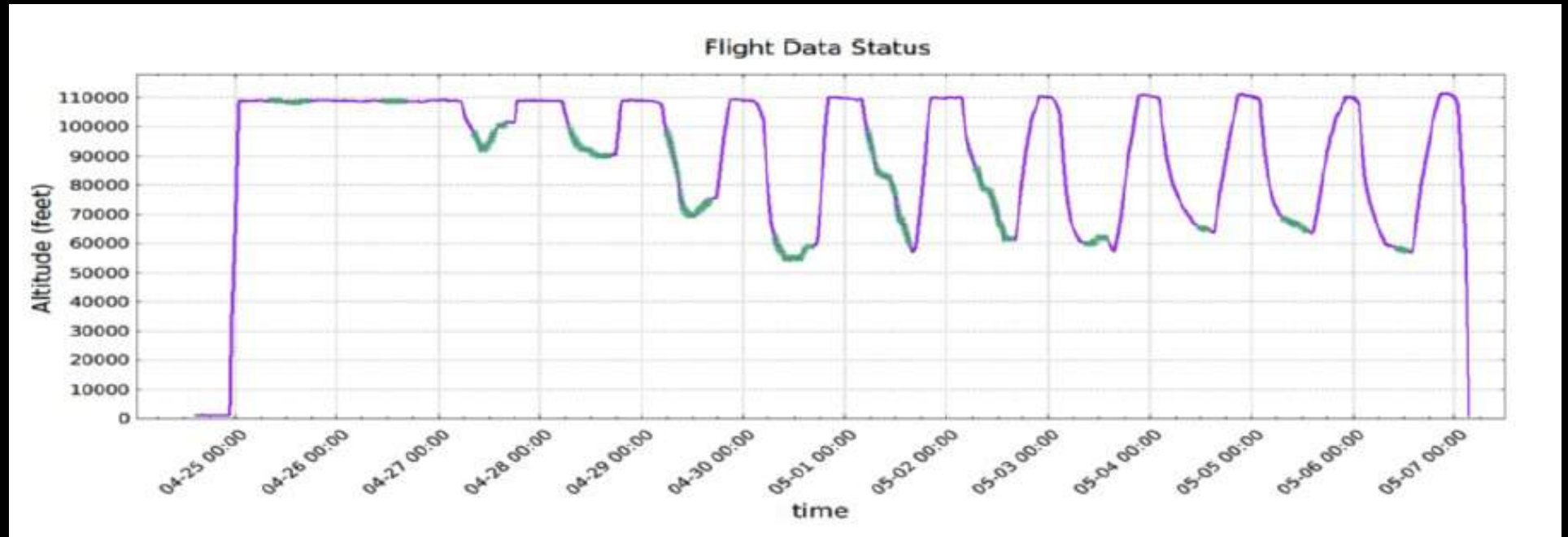


air flow at ~30 km June 9th 2017

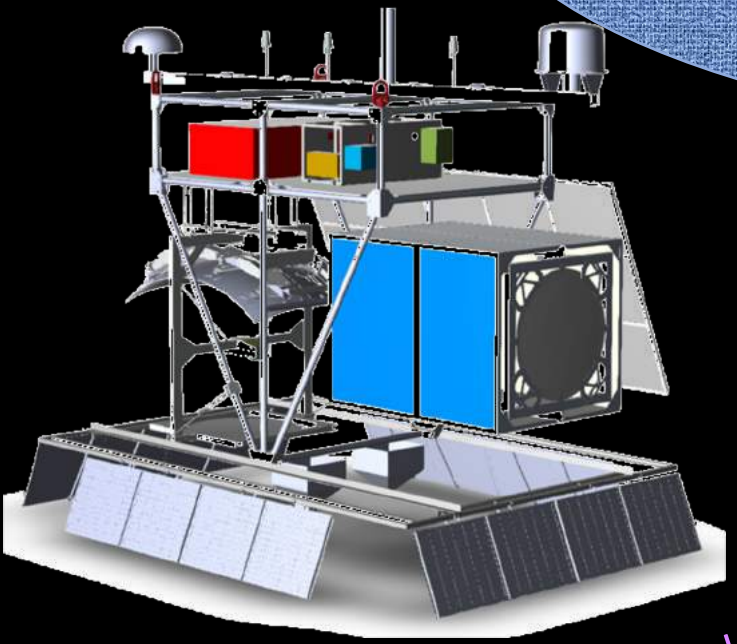
https://earth.nullschool.net/#current/wind/isobaric/10hPa/orthographic=180,-90,300

Cameron Beccario

NASA completed its third mid-latitude Super Pressure Balloon (SPB) flight at May 7 3:40 UTC, after 12 days, 4 hours and 34 minutes aloft.

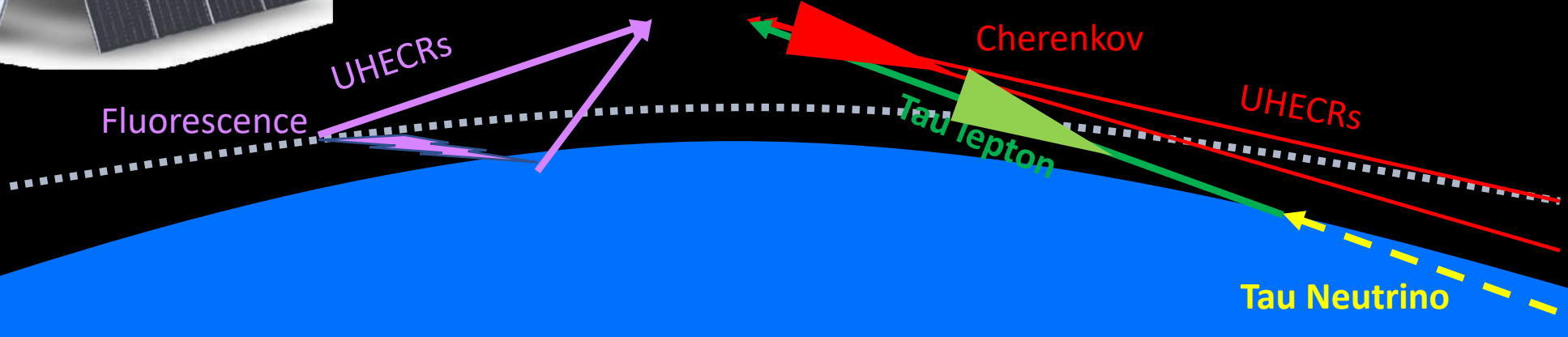


EUSO-SPB2

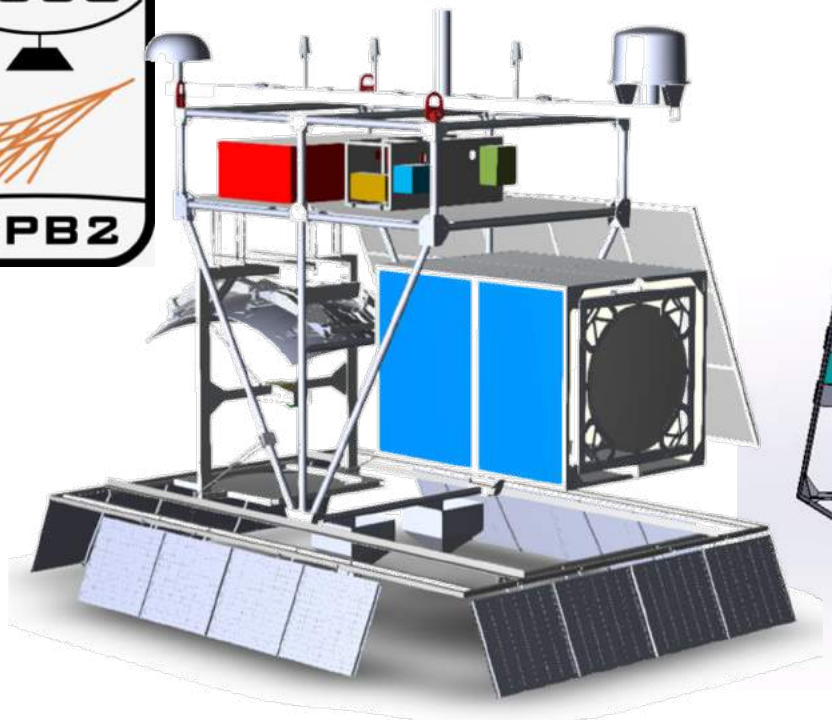


Cherenkov Emission from UHECRs

Fluorescence from UHECRS

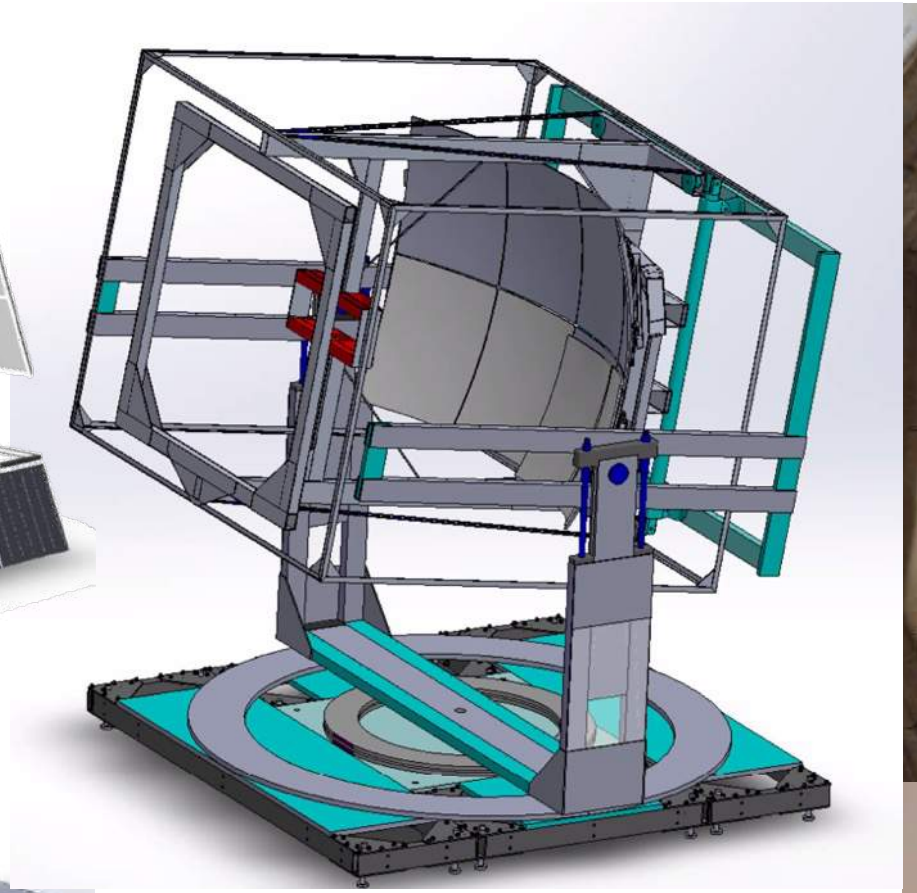


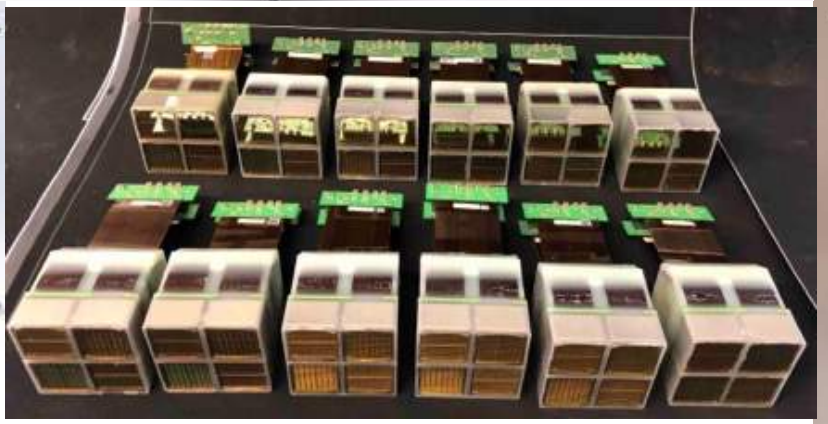
EUSO-SPB2



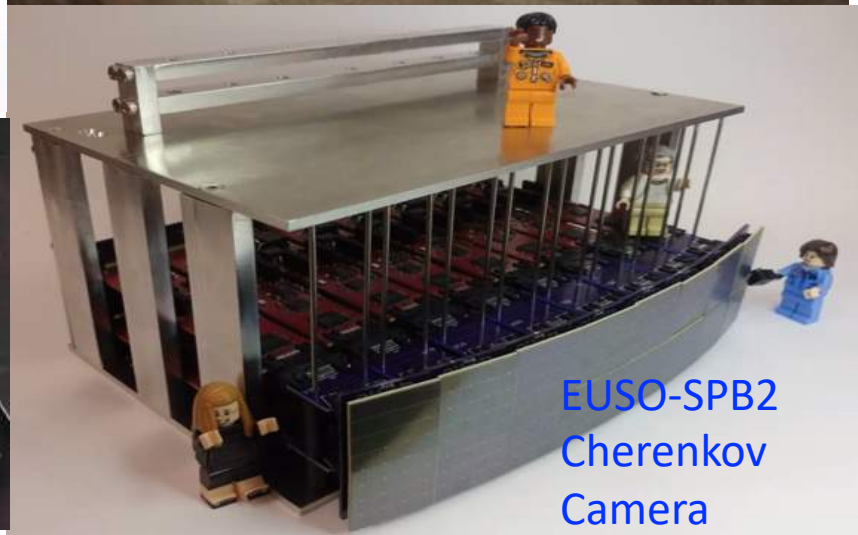
Fluorescence camera
MAPMs

Launch target Spring 2023





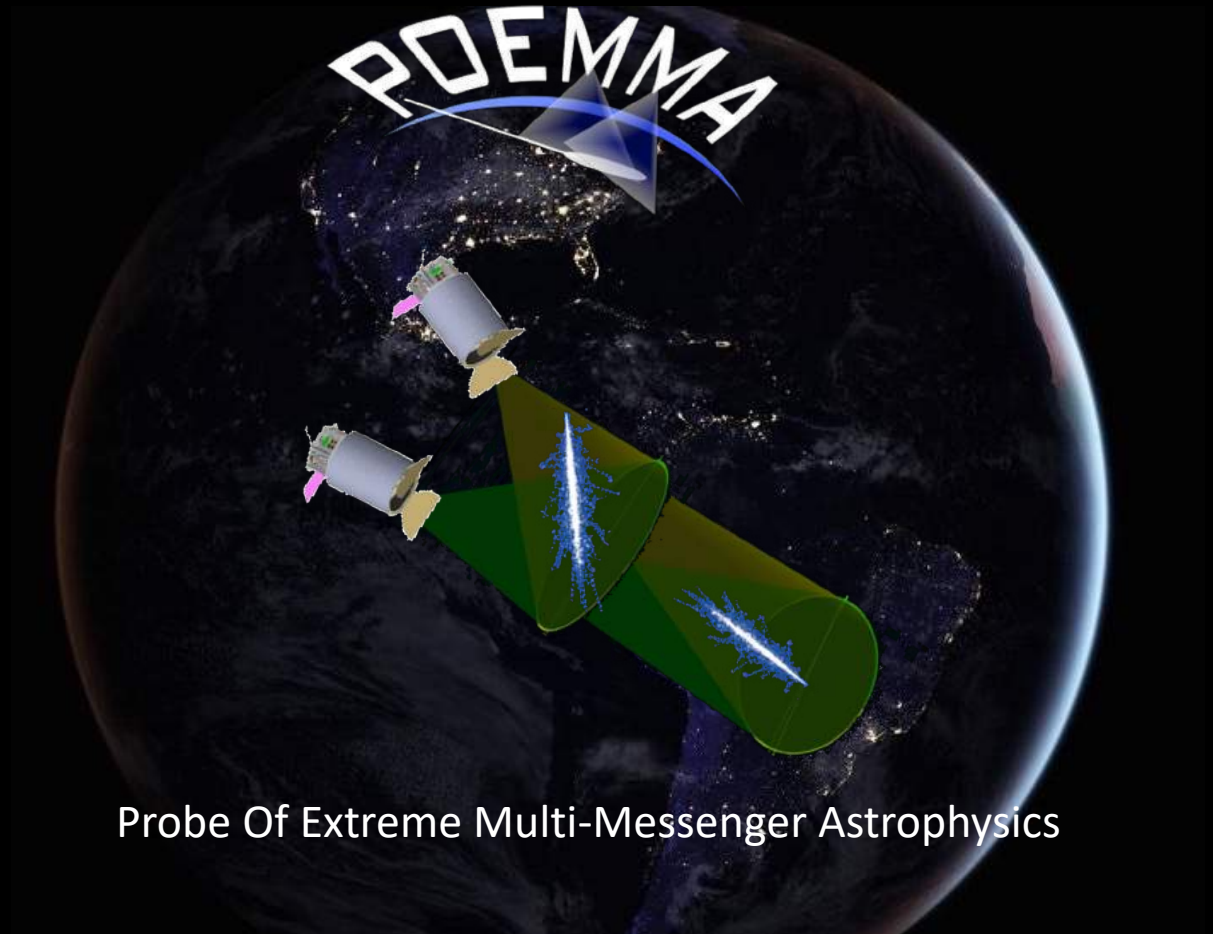
Mirror Element



EUSO-SPB2
Cherenkov
Camera

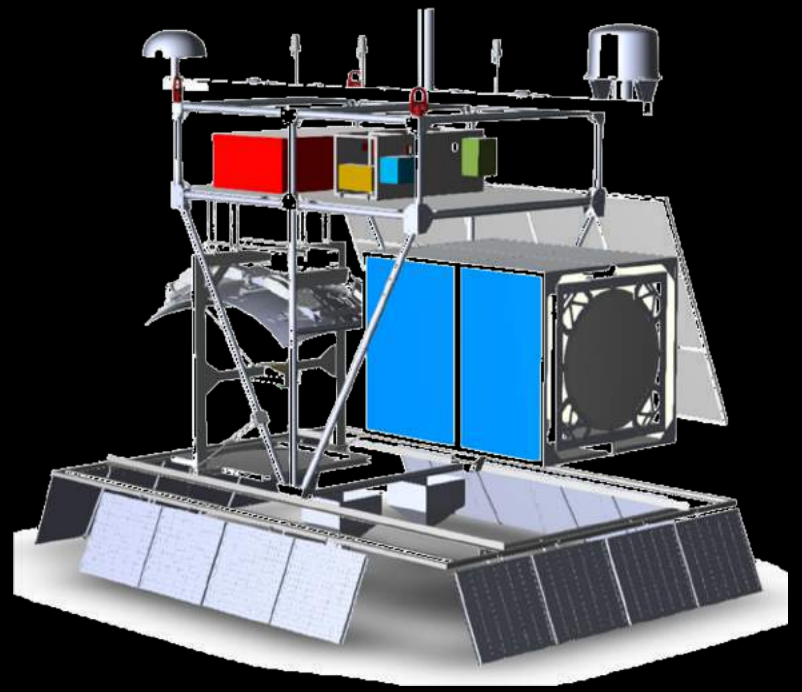
POEMMA & EUSO-SPB2

Earth's Atmosphere = Particle Observatory :
Discover the Origin of the Highest Energy Cosmic Rays ($E>10^{19}$ eV) and
Observe High Energy Neutrino Emission ($E>10^{16}$ eV) from Astrophysical Events
Study New Astro/Physics



Probe Of Extreme Multi-Messenger Astrophysics

EUSO-SPB2



Extreme Universe Space Observatory
on a Super Pressure Balloon

EUSO-SPB1 Launch from Wanaka, NZ
April 24, 2017