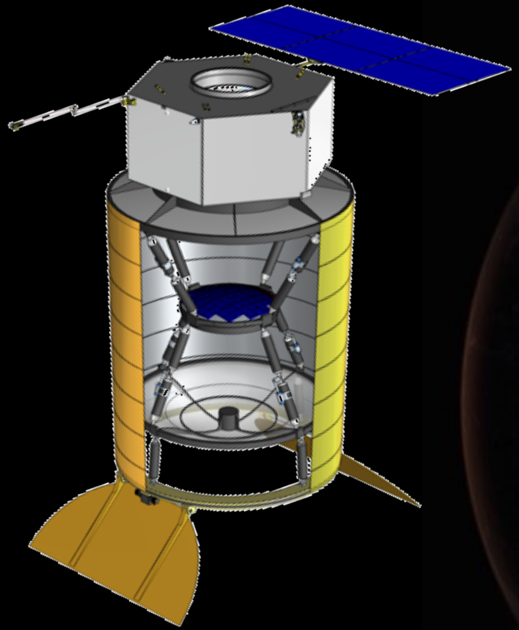
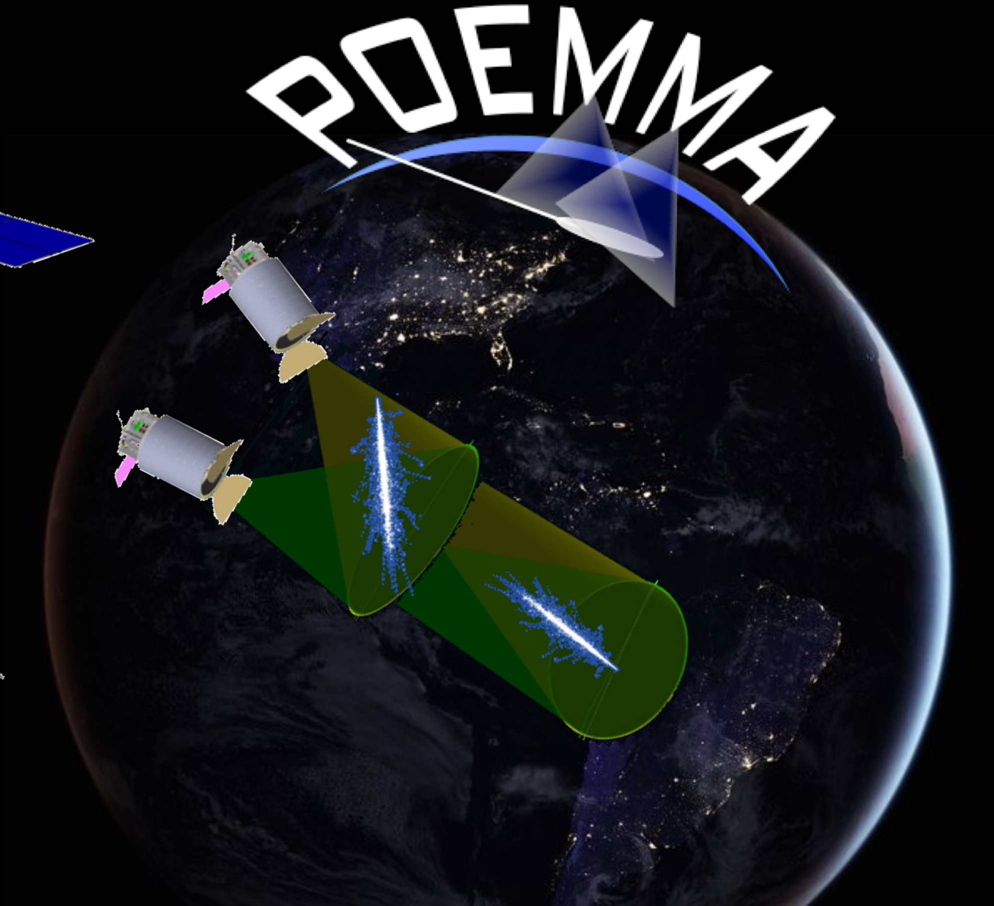
Space Observatories of the Highest Energy Particles: POEMMA & EUSO-SPB

EUSO-SPB1

EUSO-SPB2





23 November 2020

Angela V. Olinto

THE UNIVERSITY OF CHICAGO

Astroparticle Physics Questions:

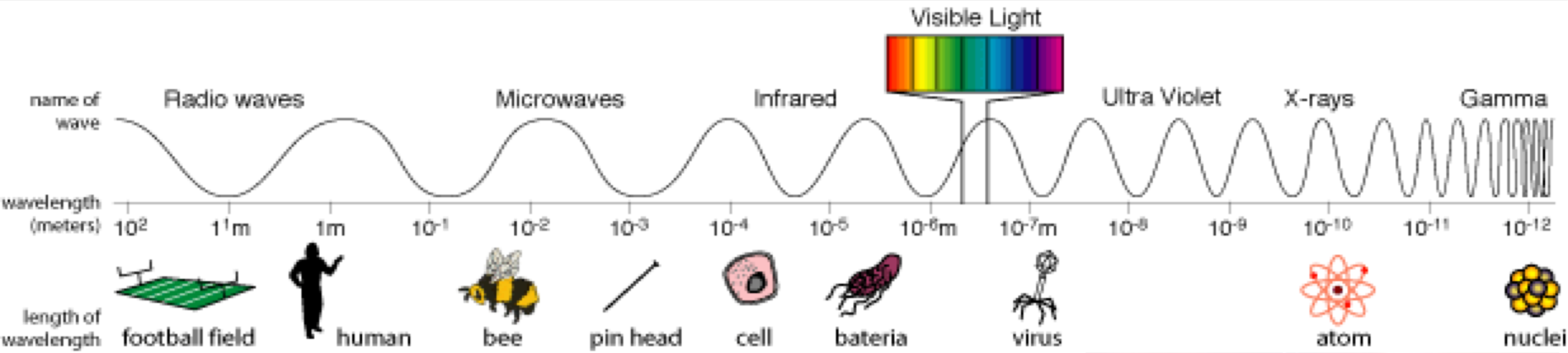
What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

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

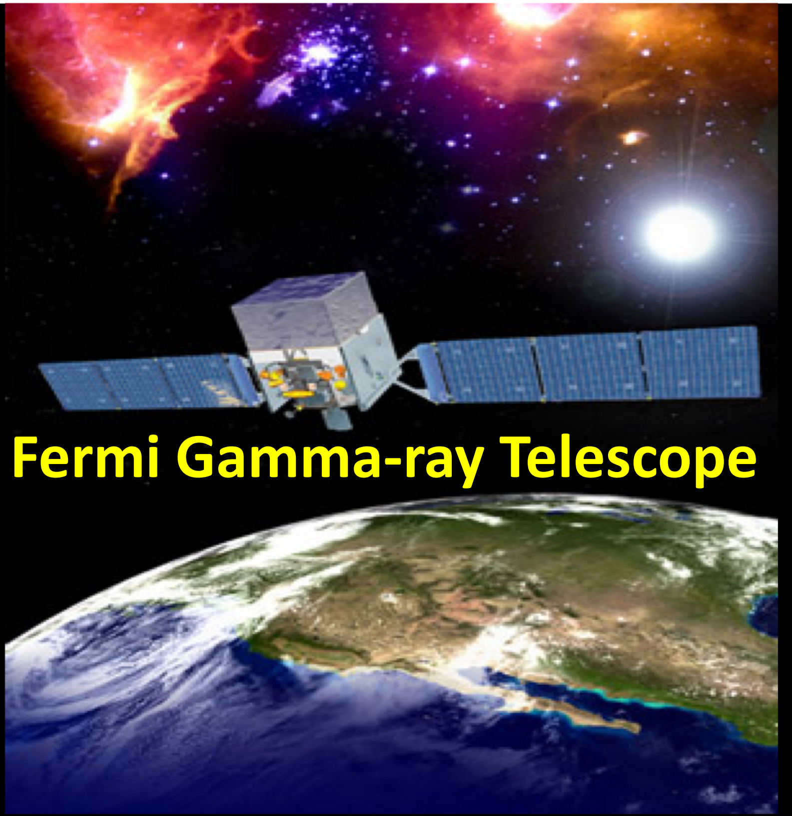
What are the sources of **Astrophysical Neutrinos**?

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

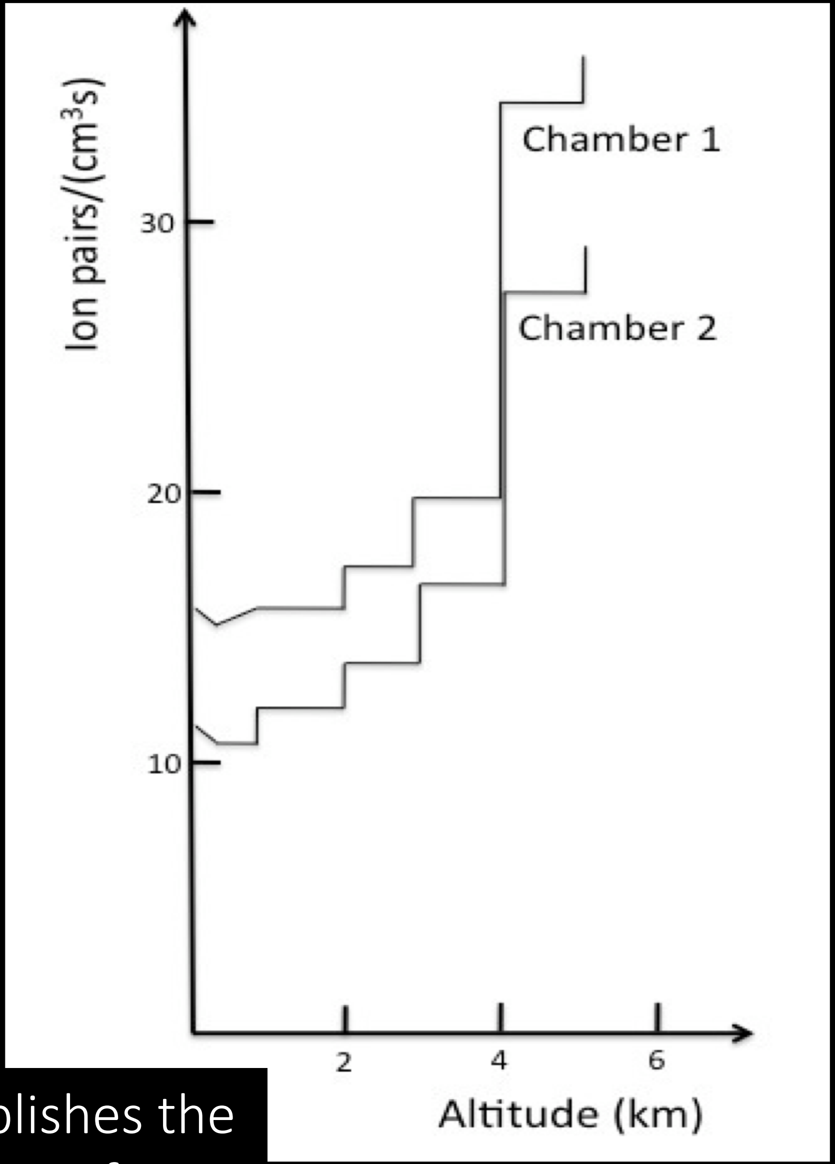
What is the physics and astrophysics at energies >> "ground-based" accelerators?
Are there Extra-Dimensions, Supermassive Dark Matter, Topological Defects?



Astronomy: 14 orders of magnitude



1912 Cosmic Rays

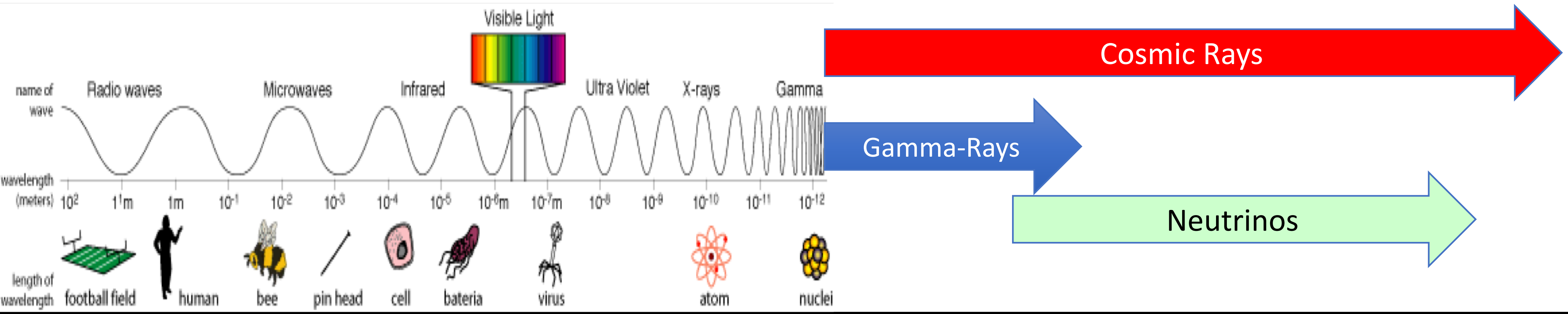


Victor Hess establishes the cosmic nature of ionizing radiation

Cosmic Particles

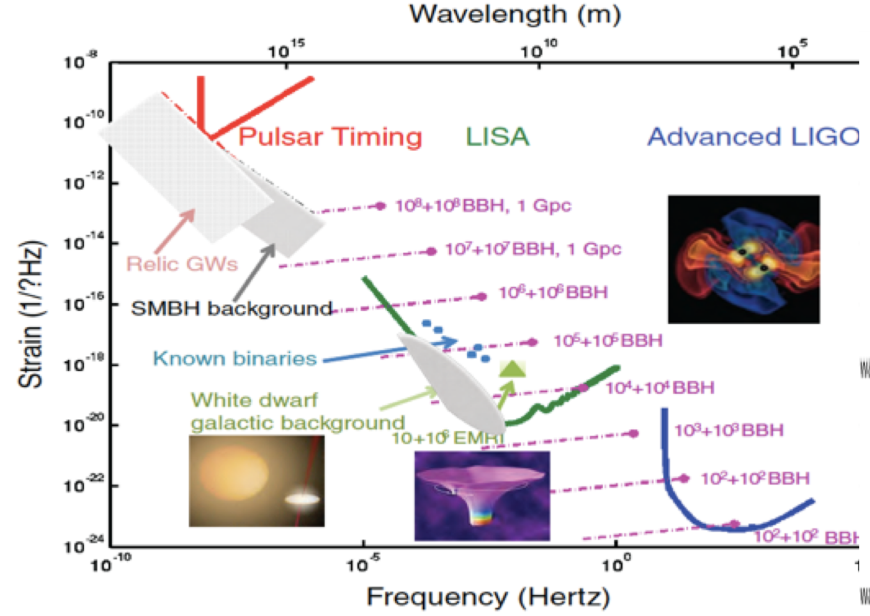
Cosmic Rays = relativistic atomic nuclei: Hydrogen (protons), He, heavier elements

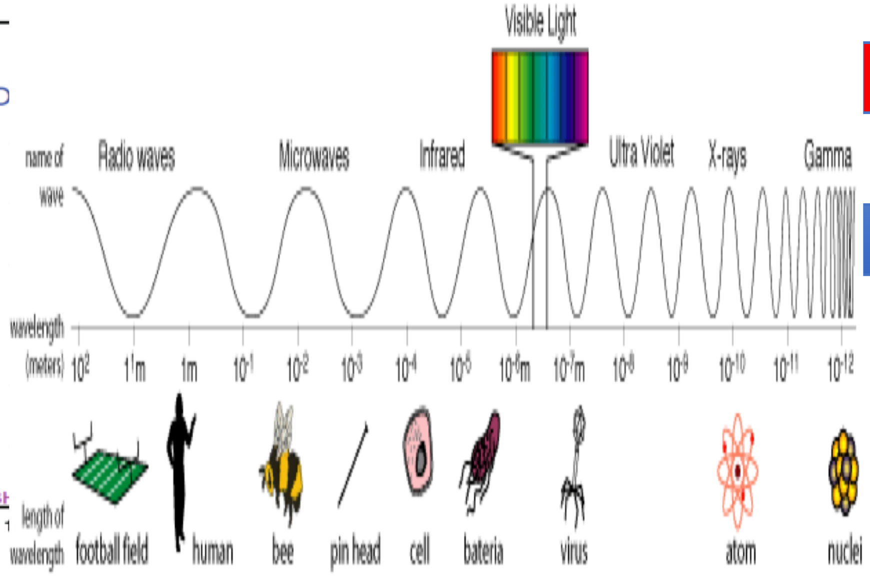
~ double the energy range for Astrophysics



Multi-Messengers

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



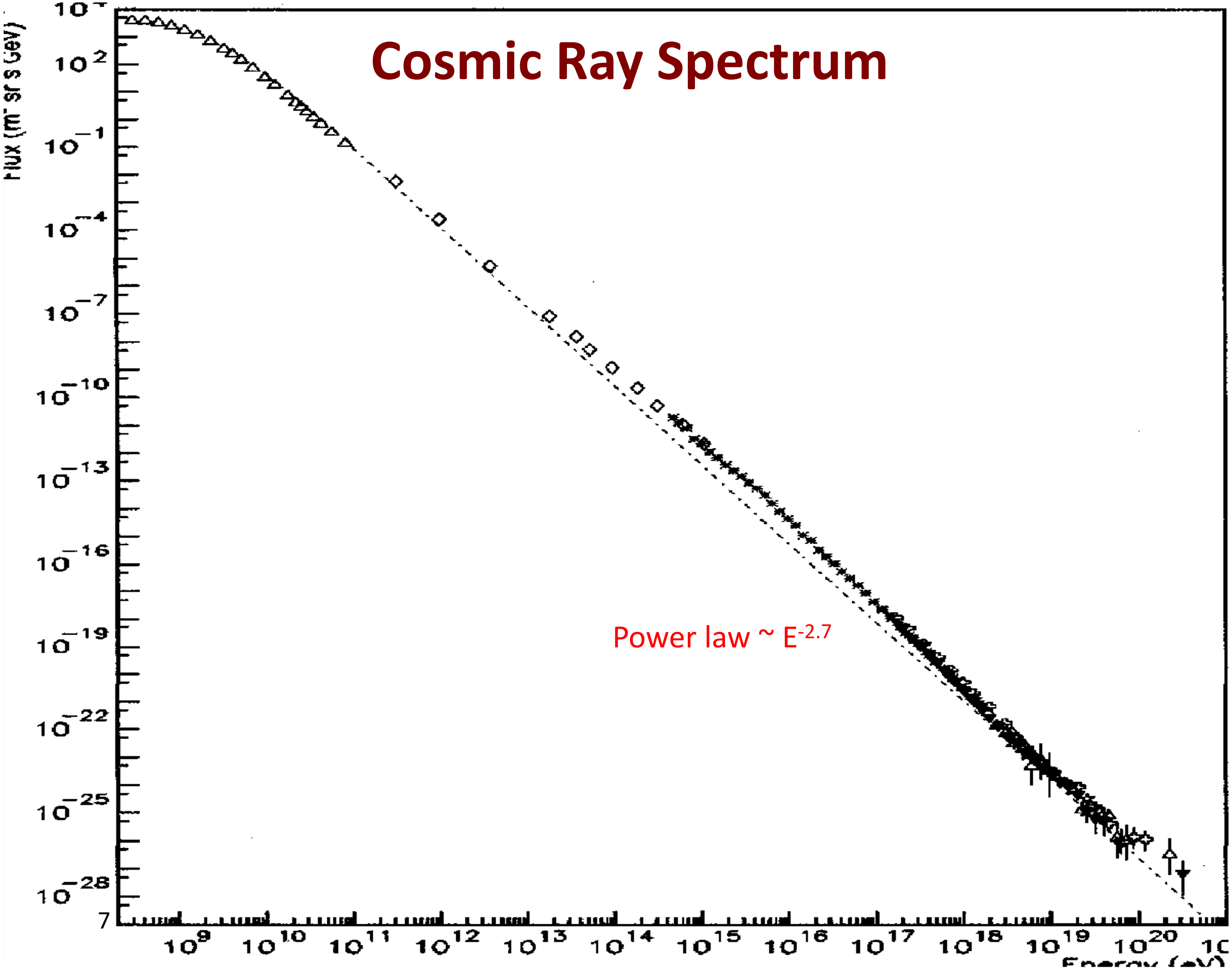


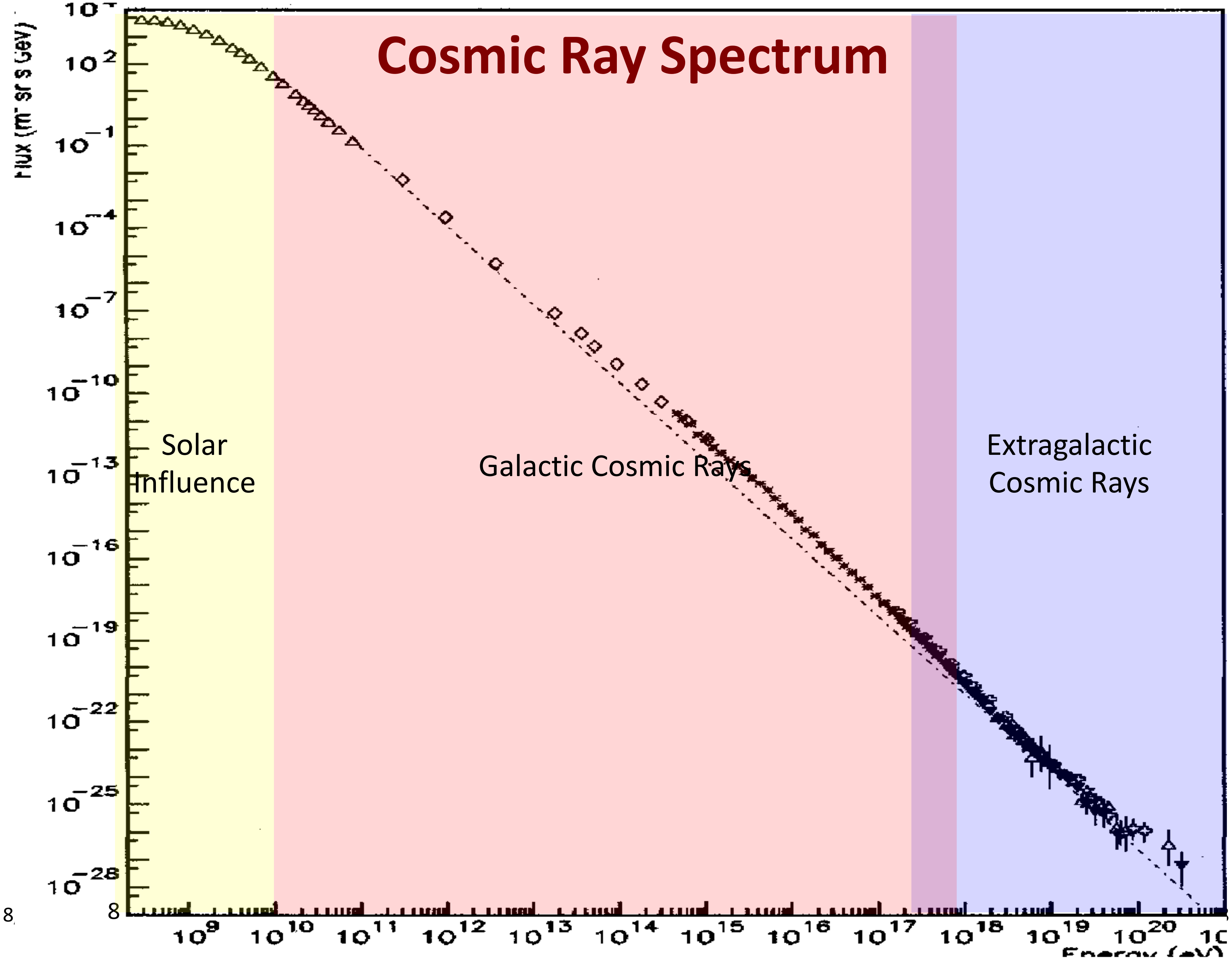
Cosmic Rays

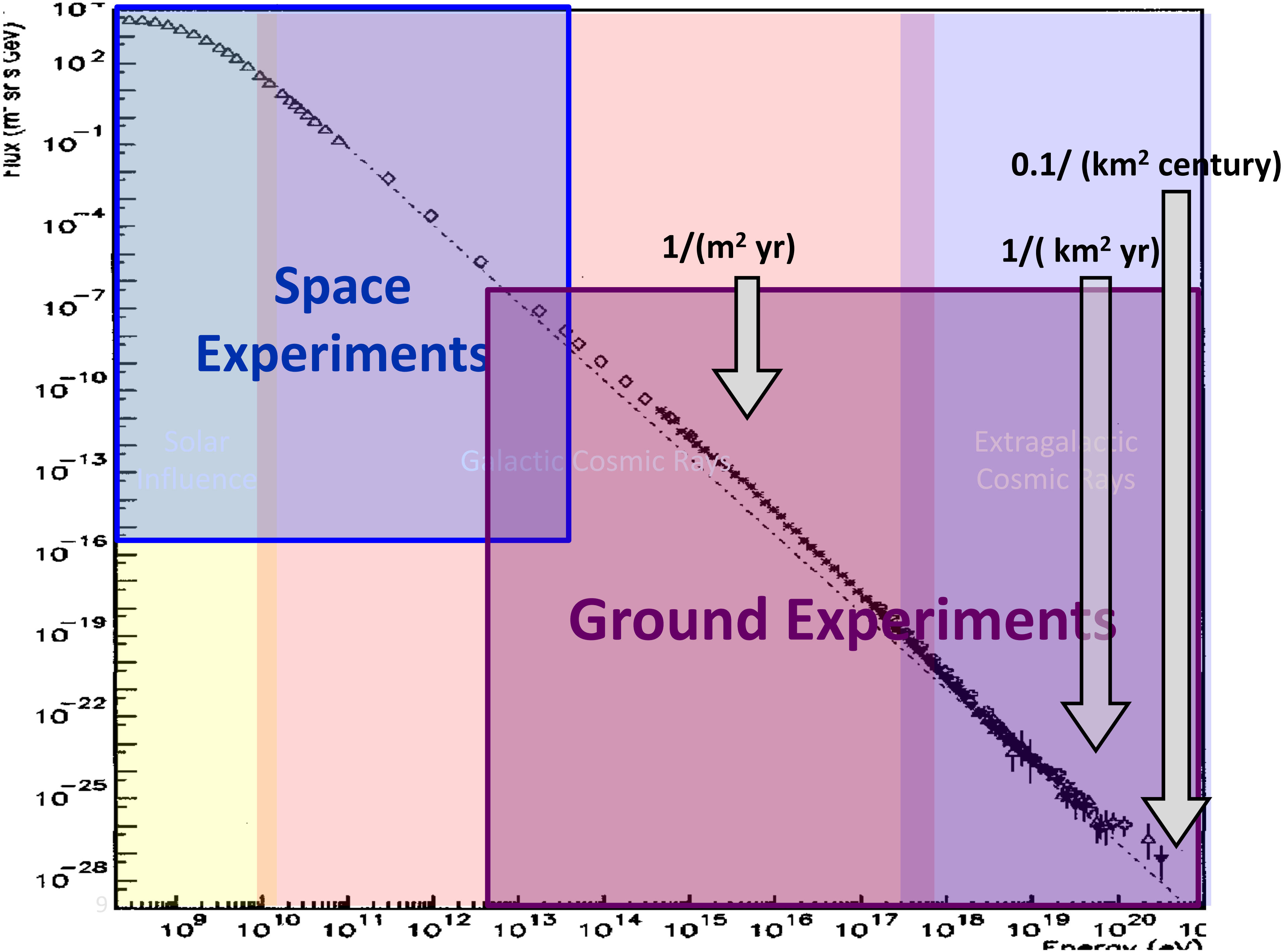
Gamma Rays

Neutrinos

Cosmic Ray Spectrum




Cosmic Ray Spectrum
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays
10^{2}
10^{-1}
10^{-4}
10^{-7}
10^{-10}
10^{-13}
10^{-16}
10^{-19}
10^{-22}
10^{-25}
10^{-28}
10^{9} 10^{10} 10^{11} 10^{12} 10^{13} 10^{14} 10^{15} 10^{16} 10^{17} 10^{18} 10^{19} 10^{20}



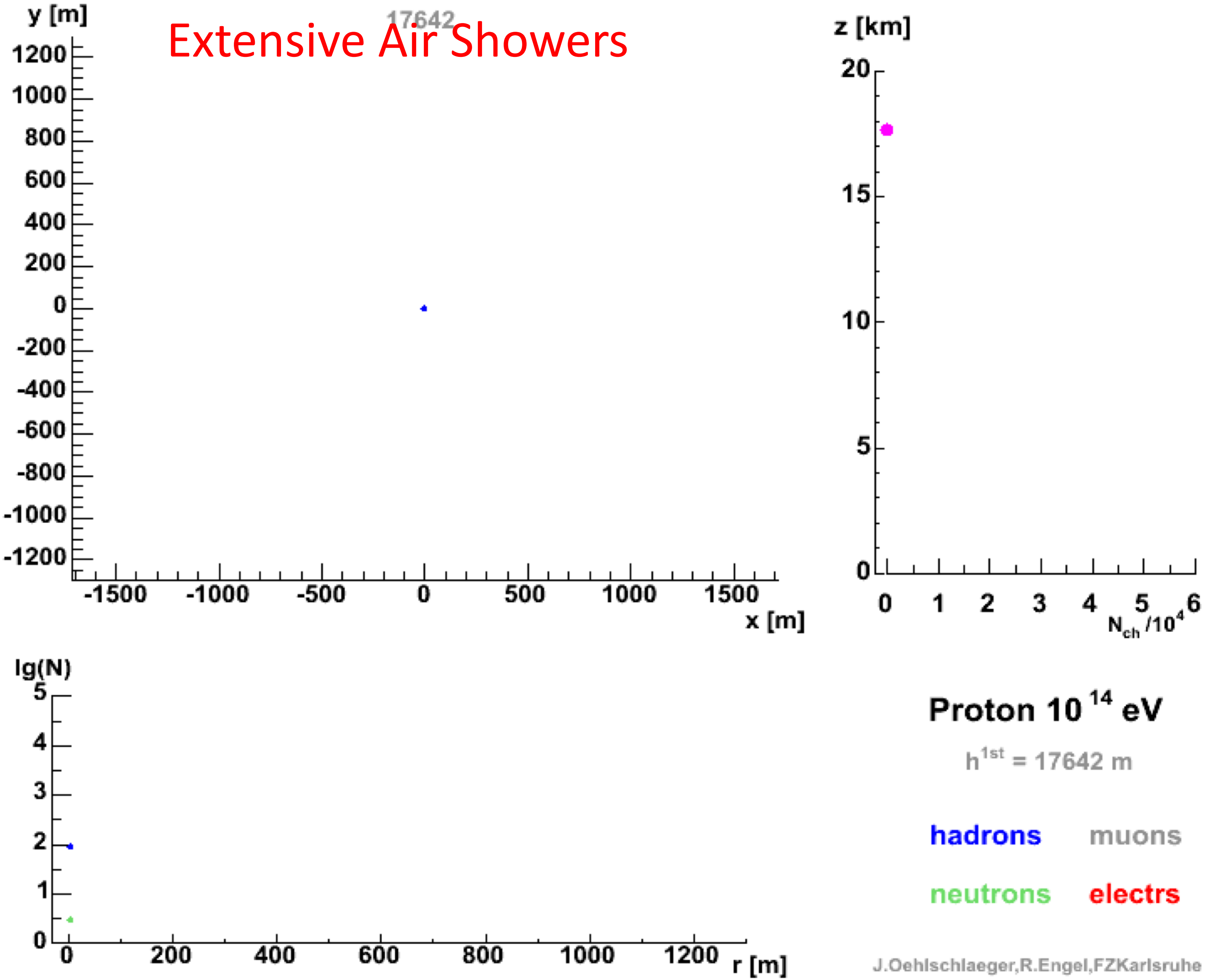
Space Experiments
Ground Experiments
1/(m2 yr)
1/(km2 yr)
0.1/ (km2 century)
Solar Influence
Galactic Cosmic Rays
Extragalactic Cosmic Rays

Extensive Air Showers

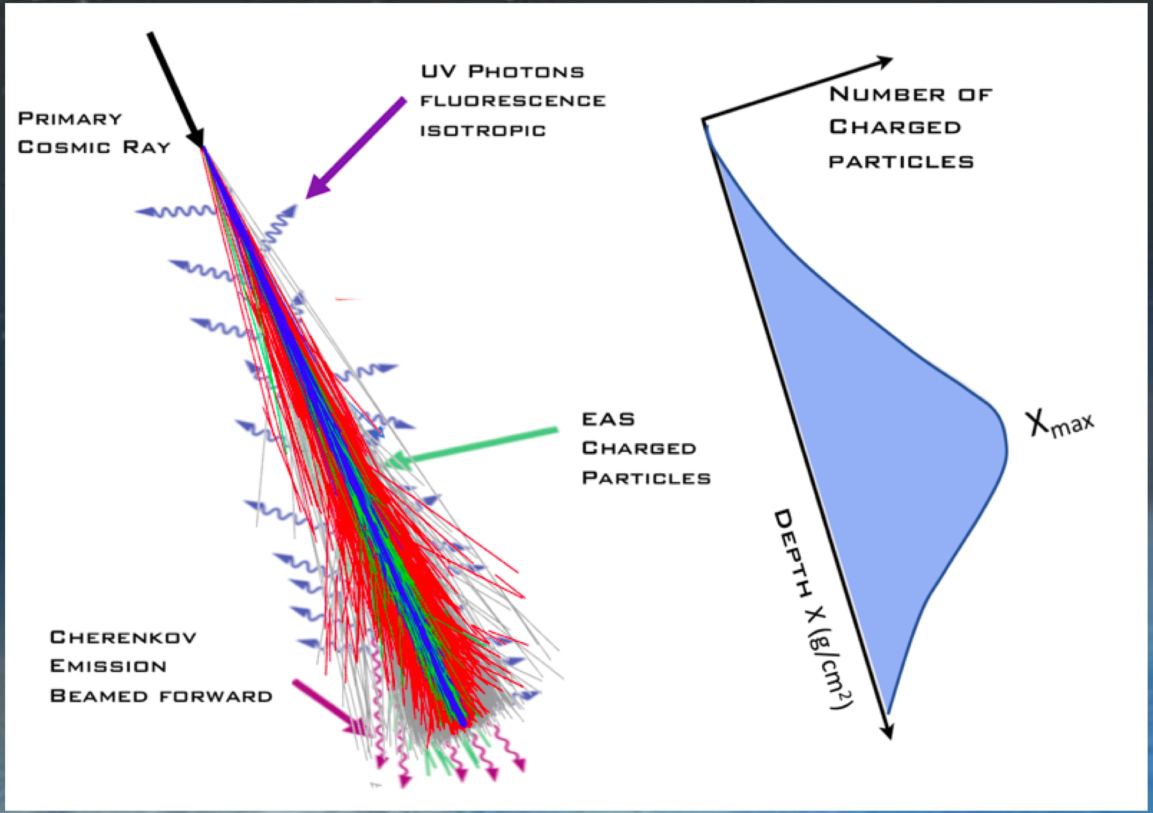
1937: Pierre Auger

~ 10^{15} eV

Extensive Air Showers



Extensive Air Showers



Leading Observatories of Ultrahigh Energy Cosmic Rays

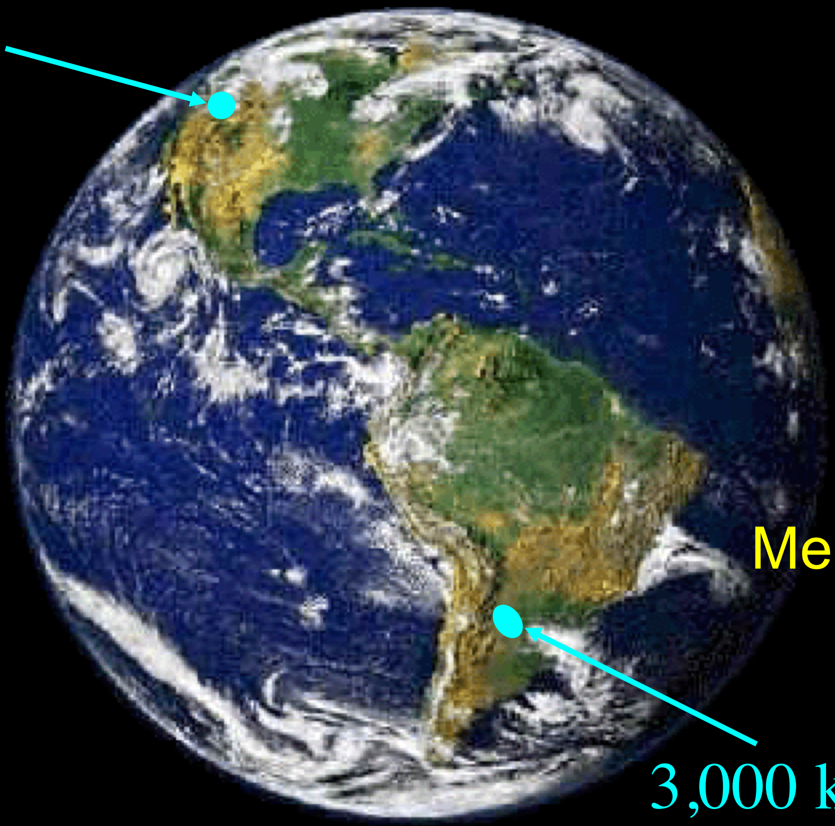
Telescope Array

Utah, USA

(5 country collaboration)

700 km^2 array

3 fluorescence telescopes



Pierre Auger Observatory

Mendoza, Argentina

(19 country collaboration)

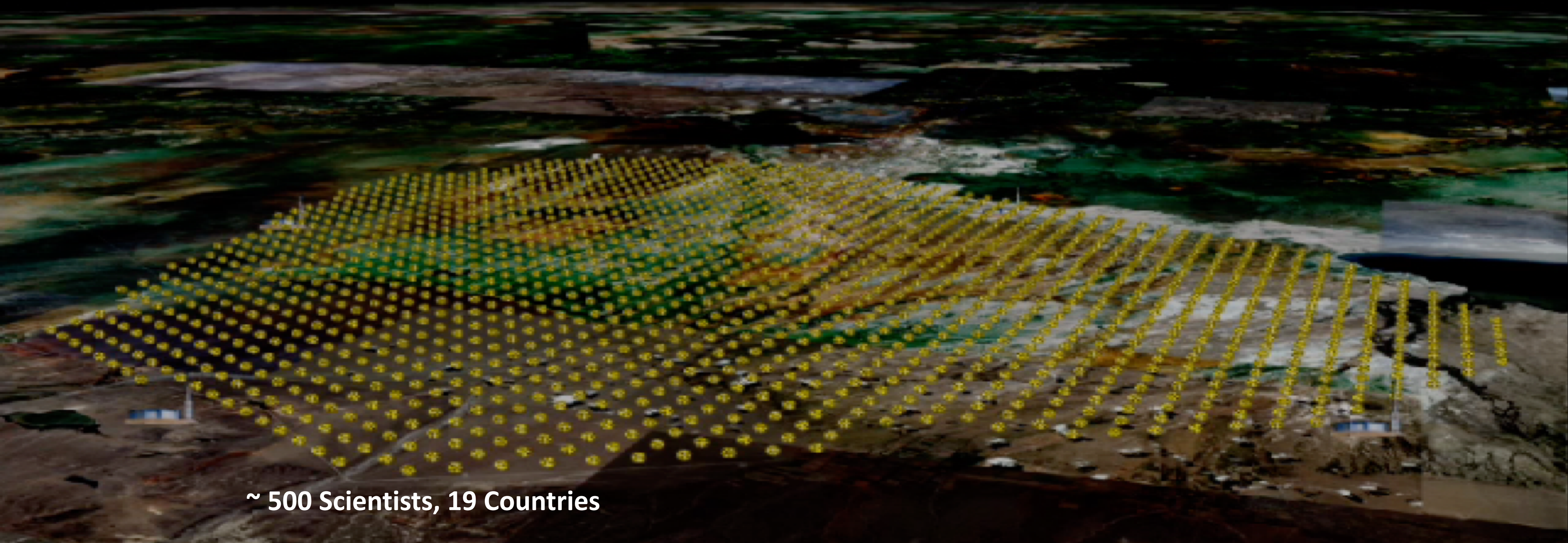
3,000 km^2 array

4 fluorescence telescopes

Pierre Auger Observatory

3,000 km^2 water cherenkov detectors array

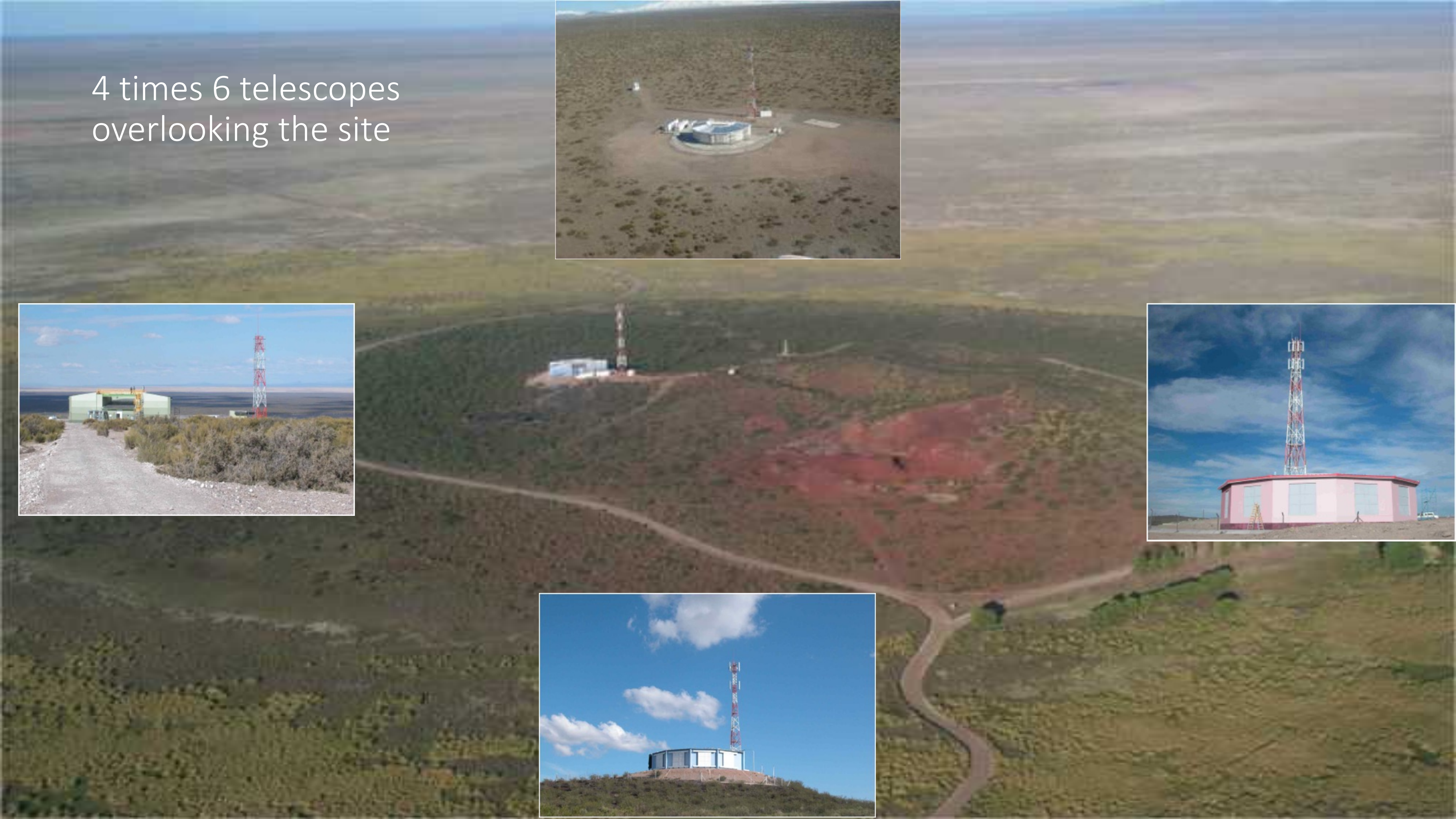
4 fluorescence Telescopes, Malargue, Argentina

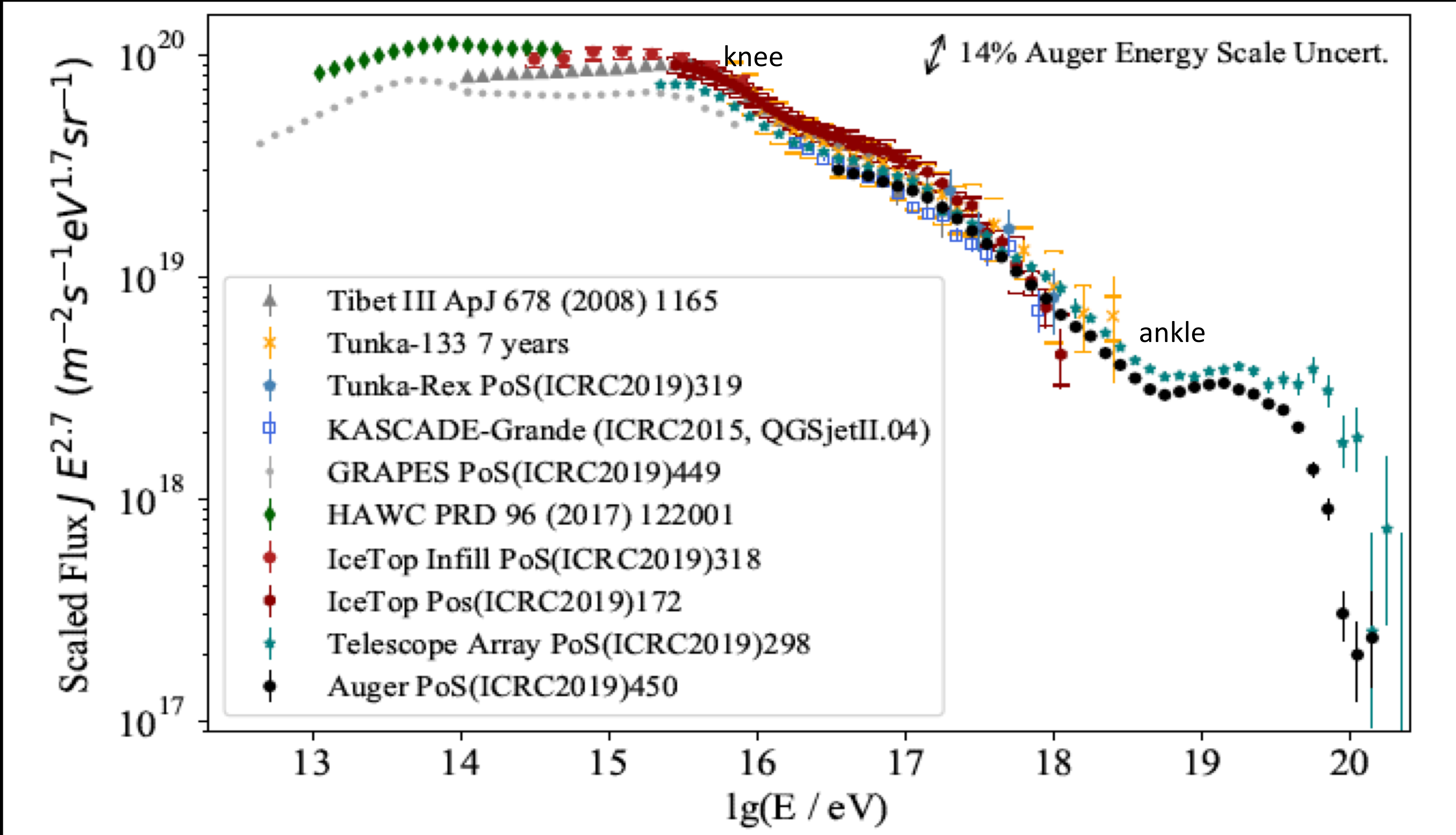


~ 500 Scientists, 19 Countries


array of tanks

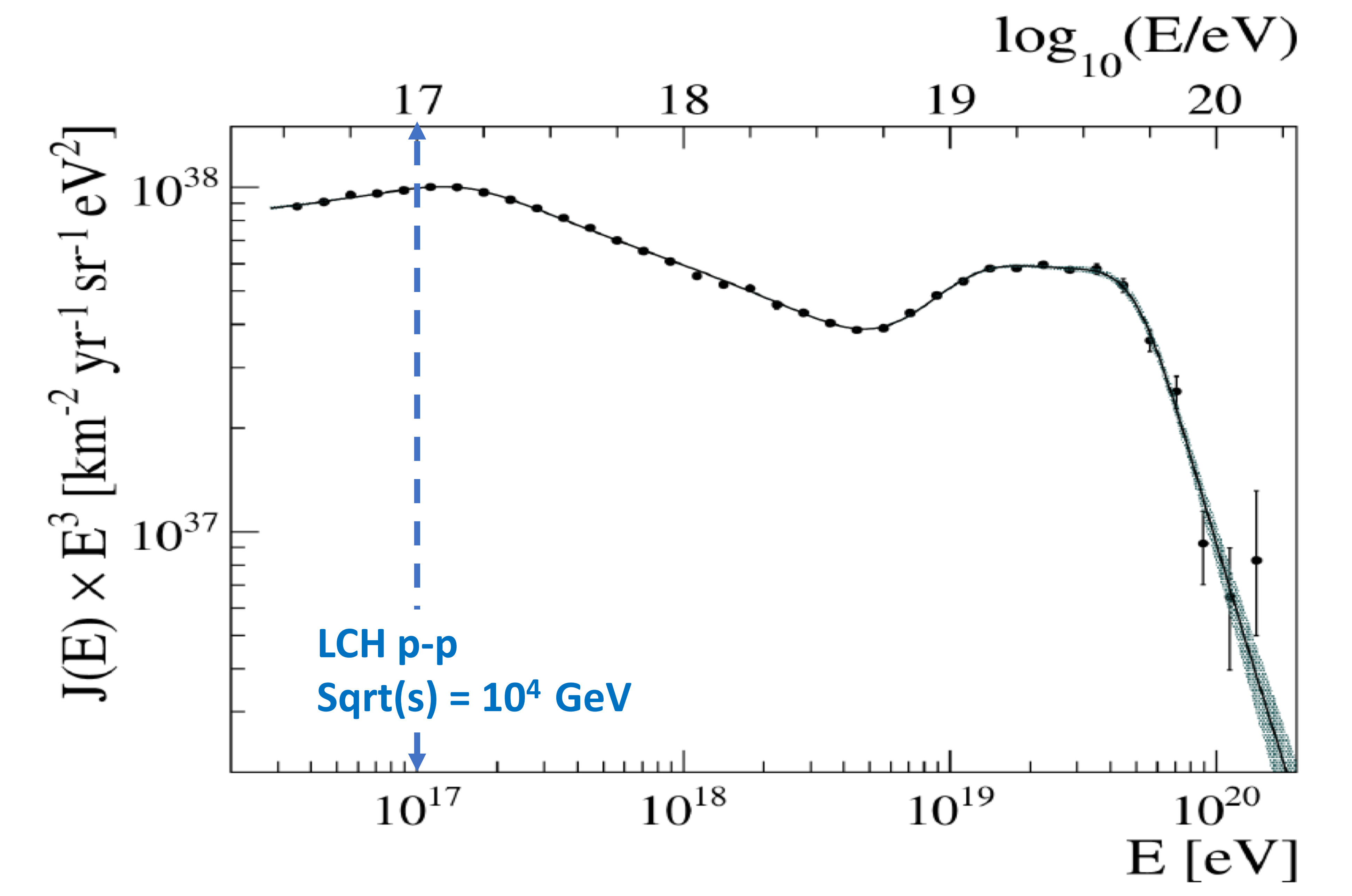
4 times 6 telescopes overlooking the site



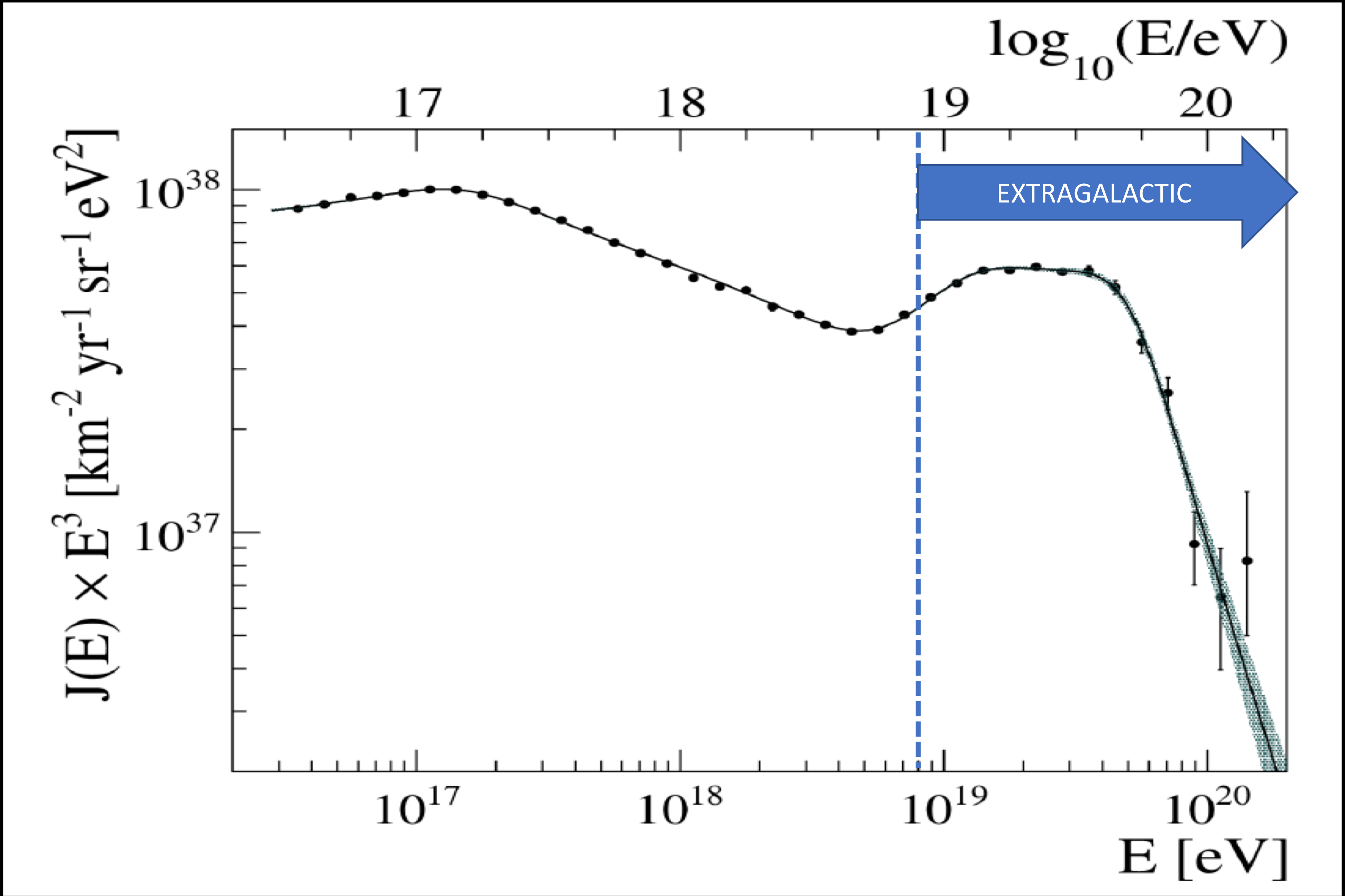


F. G. Schröder '19

Auger Spectrum ICRC 2019

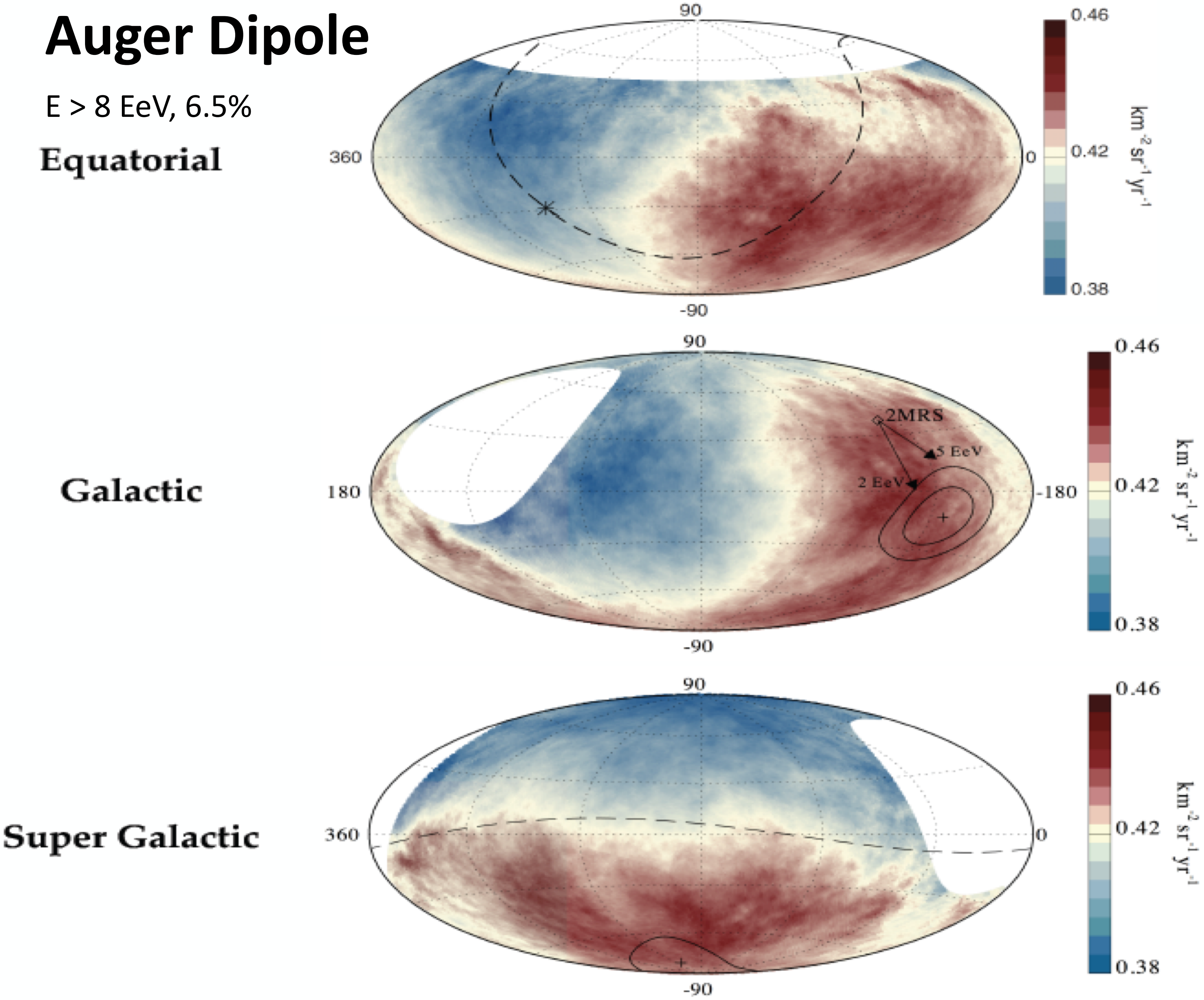


Auger Spectrum ICRC 2019

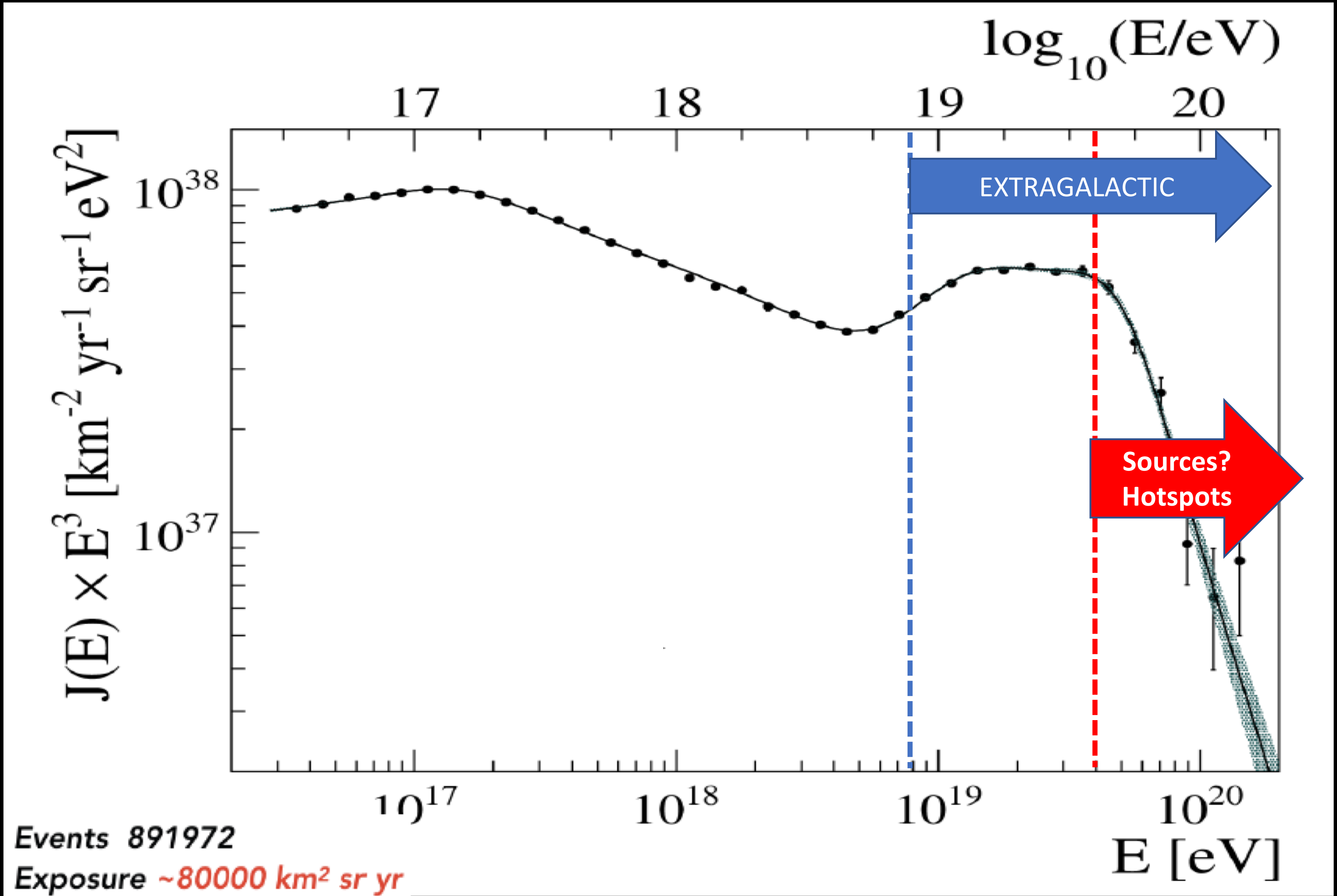


Auger Dipole

E > 8 EeV, 6.5%



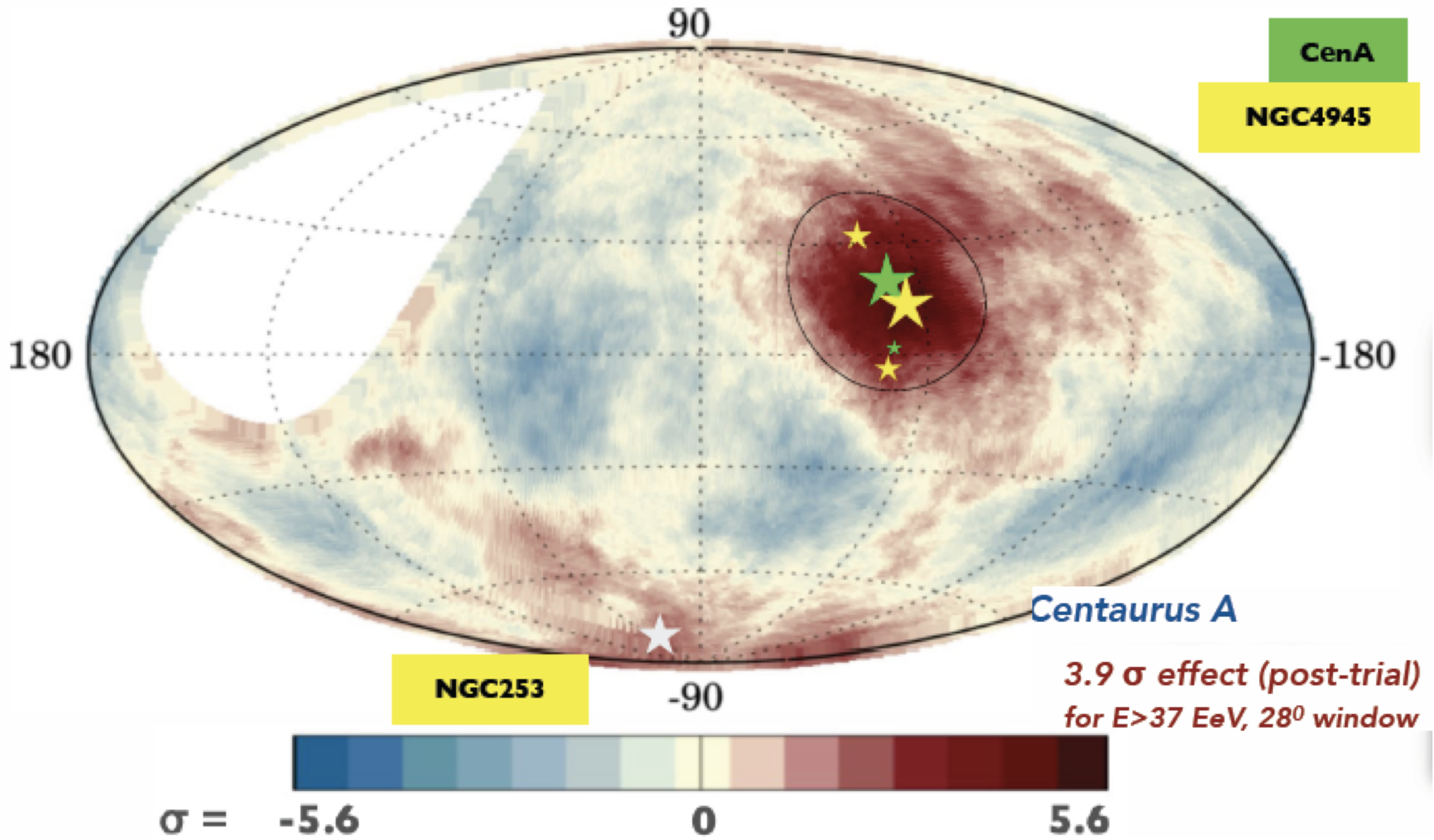
Auger Spectrum ICRC 2019



Anisotropy Hints > 40 EeV

Total SD events with E>32 EeV : 2157

Total exposure 101,400 km² sr yr



ICRC2019 *[Jan 2004-Aug 2018]*

4.5 σ for SBGs

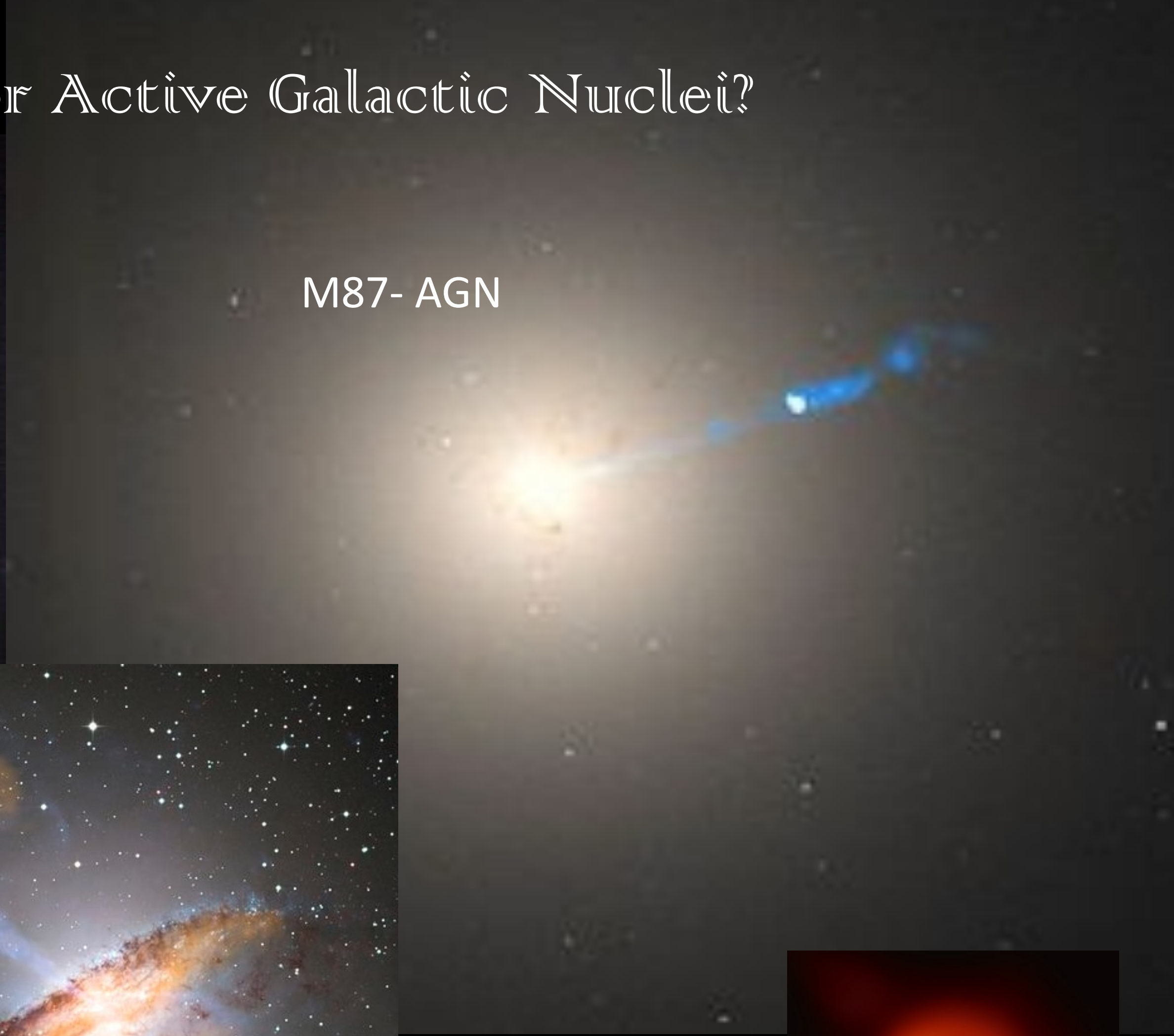
3.1 σ for γ-AGN

SBG: StarBurst Galaxies

AGN: Active Galactic Nuclei

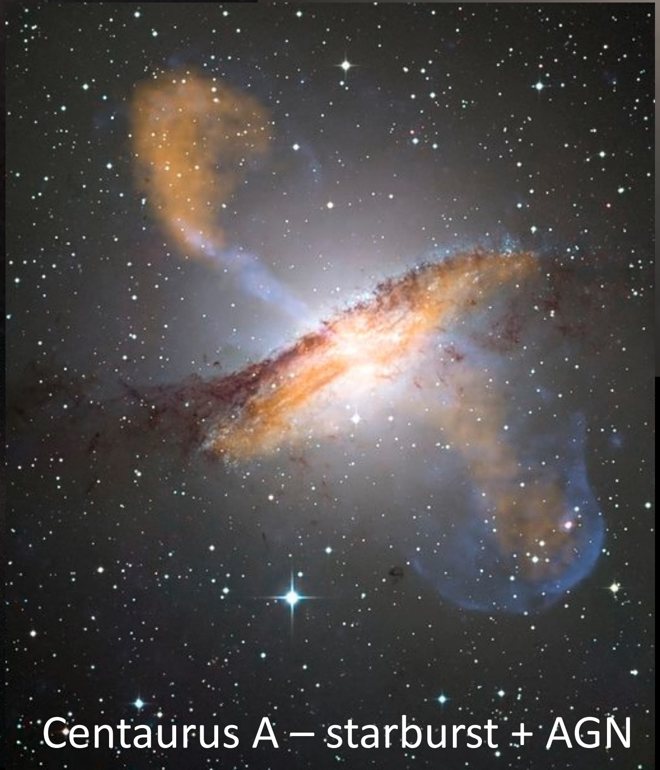
Starbursts Galaxies or Active Galactic Nuclei?

M82 – Starburst Galaxy



M87- AGN

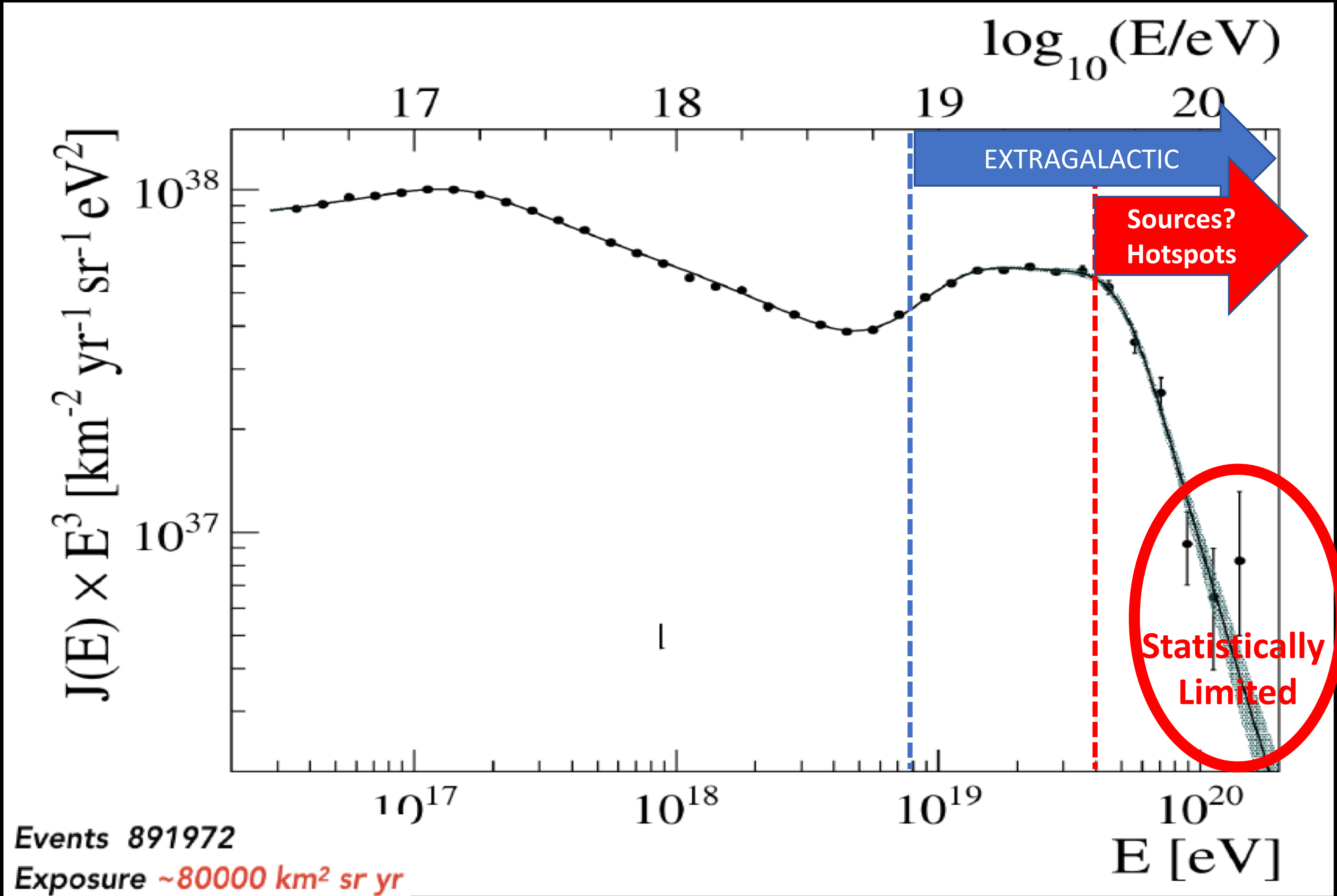
Sculptor Galaxy NGC 253



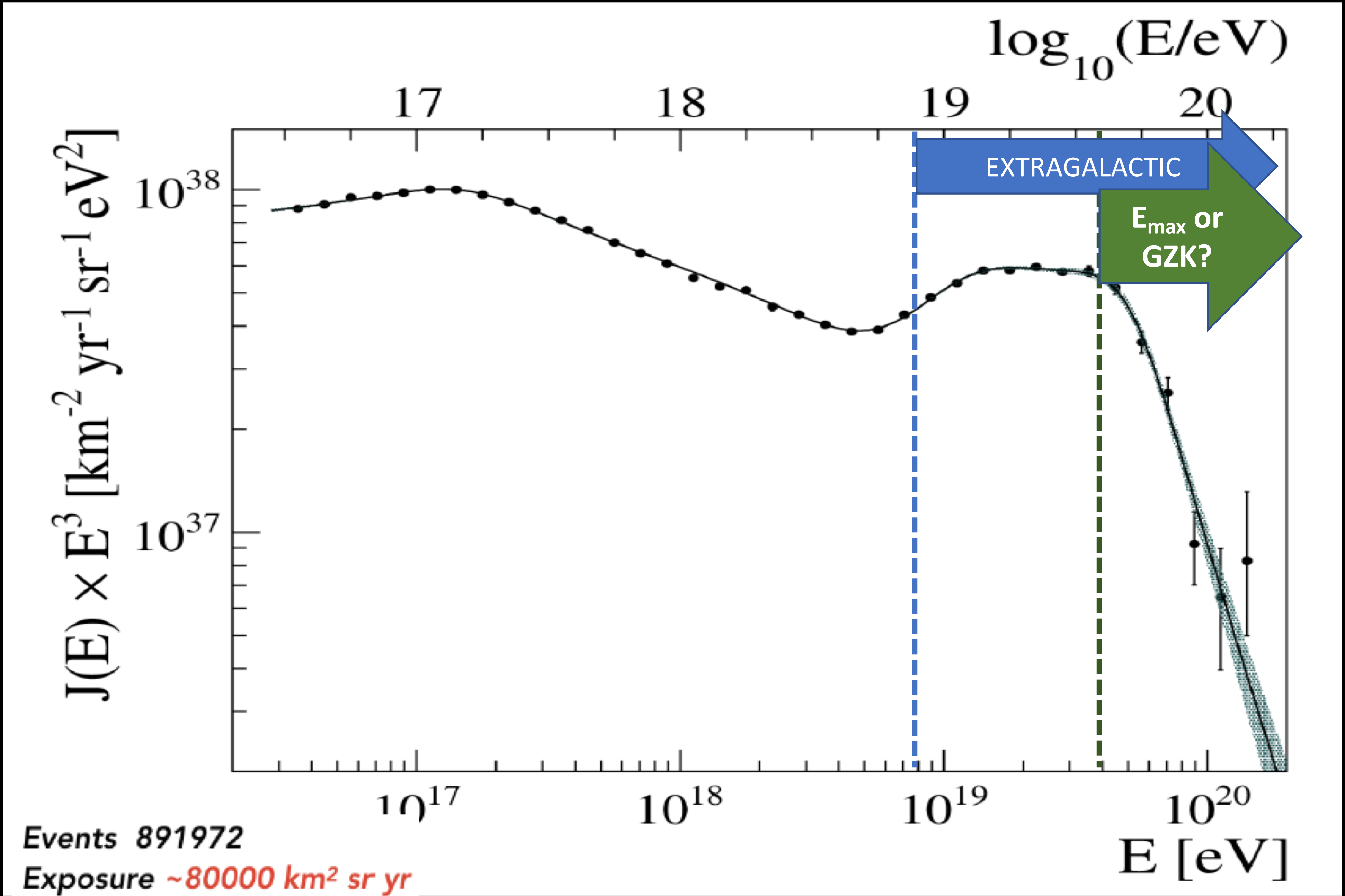
Centaurus A – starburst + AGN

Event Horizon Telescope
Image of M87

Auger Spectrum ICRC 2019

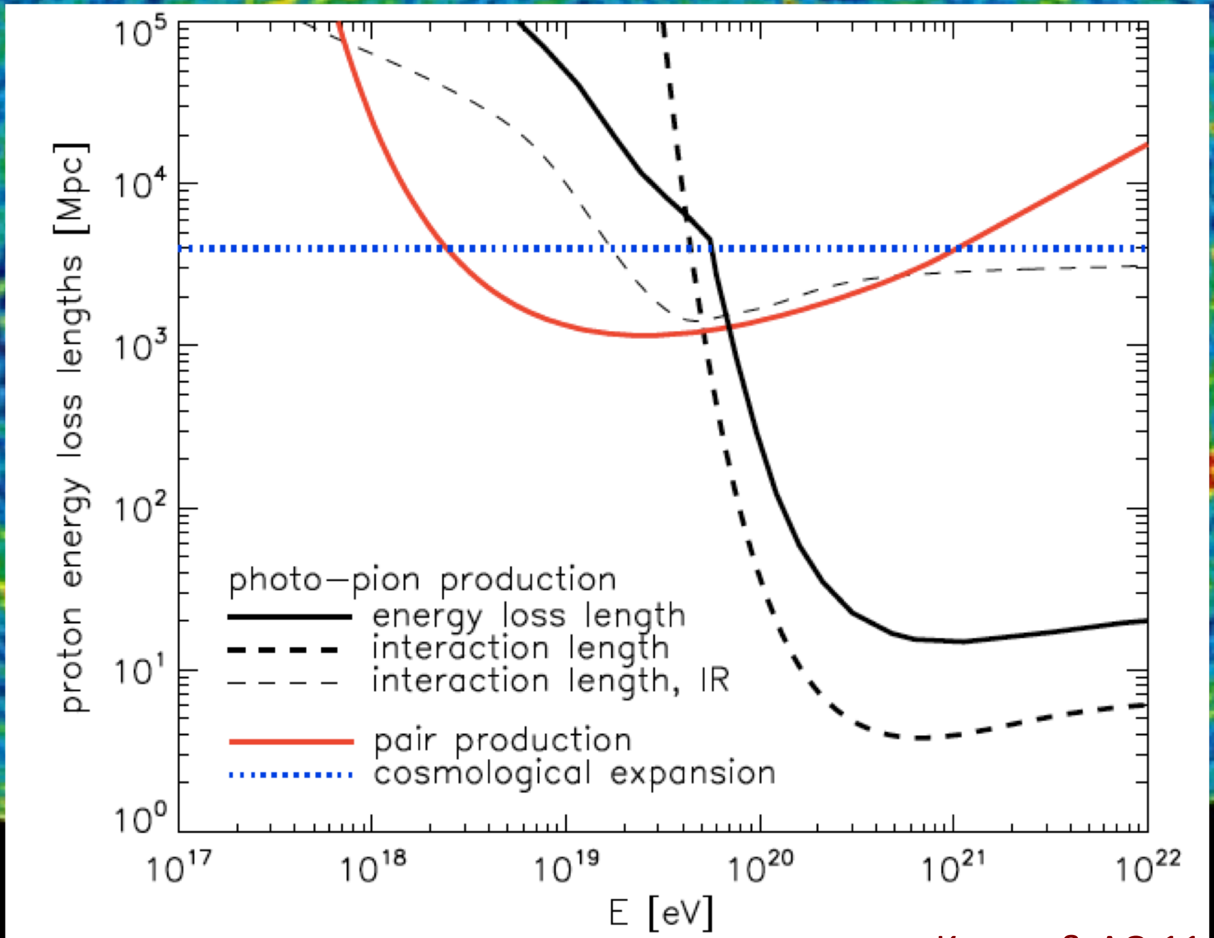


Auger Spectrum ICRC 2019



Greisen-Zatsepin-Kuzmin Effect

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



Kotera & AO 11

GZK Cutoff
Greisen,
Zatsepin, Kuzmin
1966

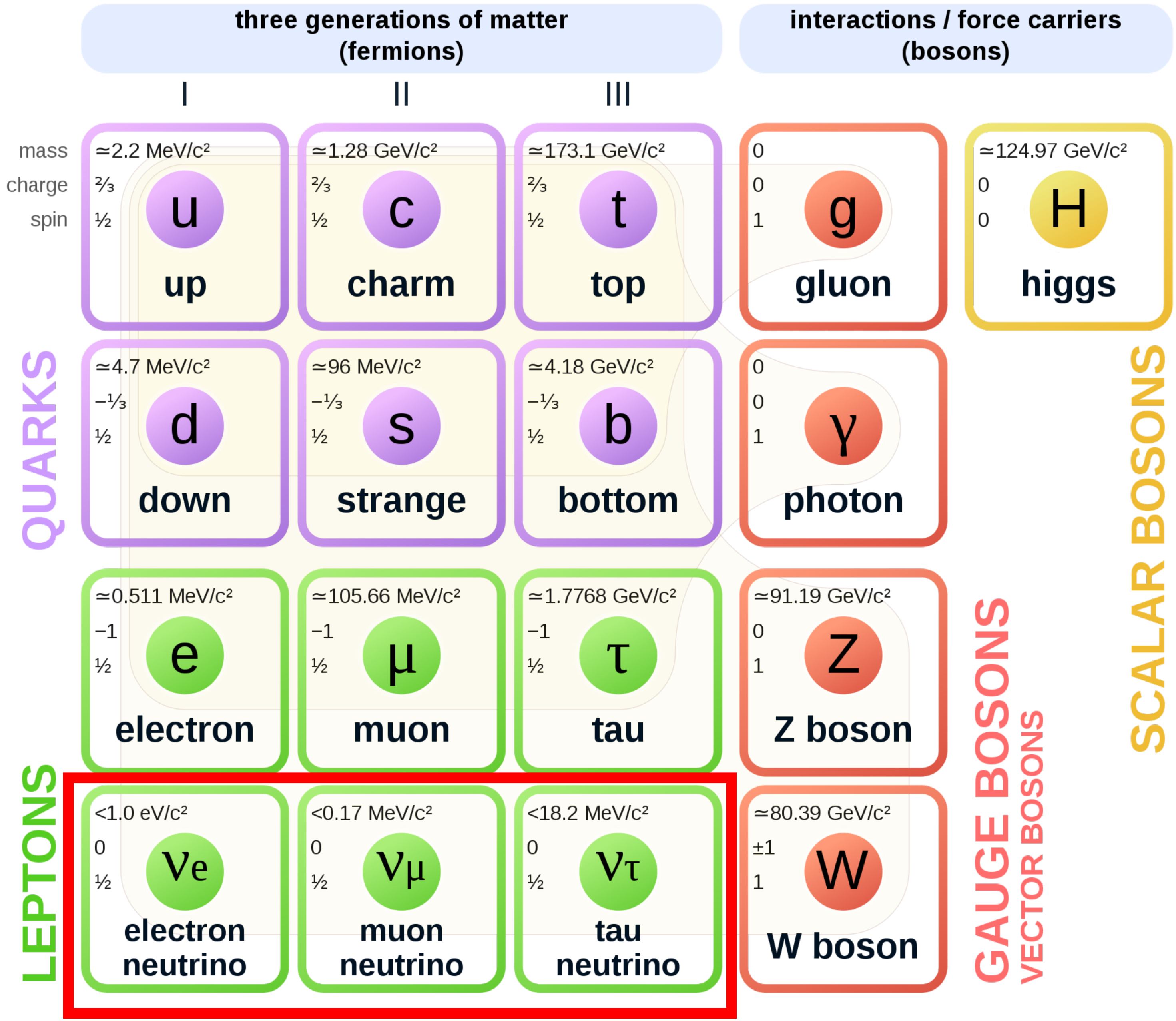
Cosmogenic (GZK, BZ*) Neutrinos & Photons

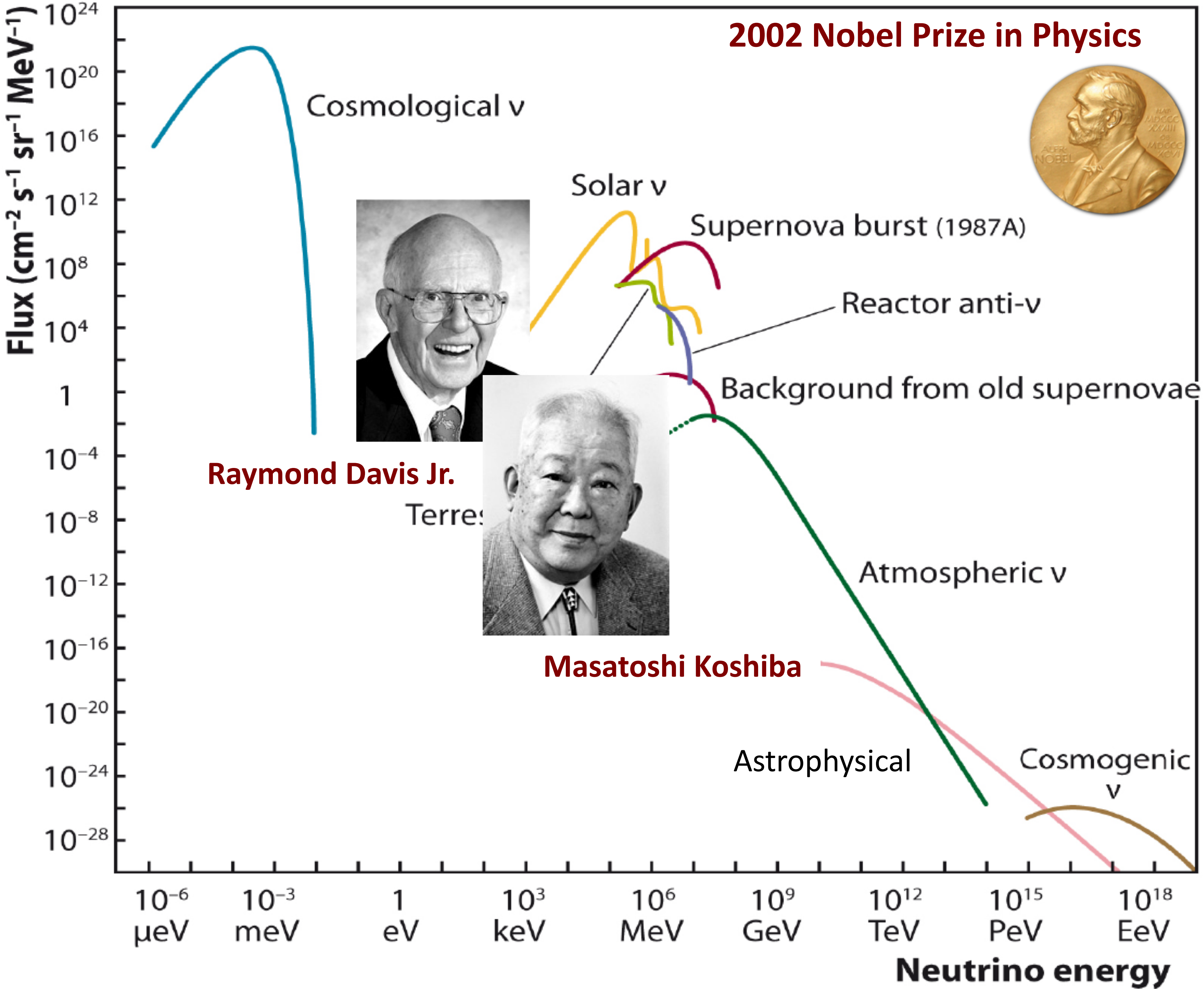
$$p+\gamma_{cmb} \rightarrow \Delta^+ \rightarrow p + \pi^0 \rightarrow \gamma\gamma$$
$$\rightarrow n + \pi^+$$

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

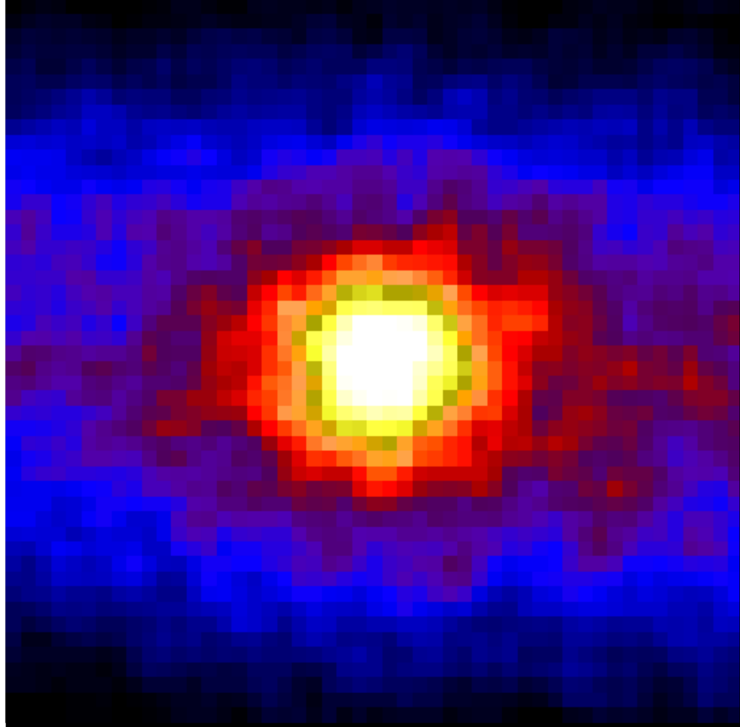
*Berezinsky & Zatsepin ‘69

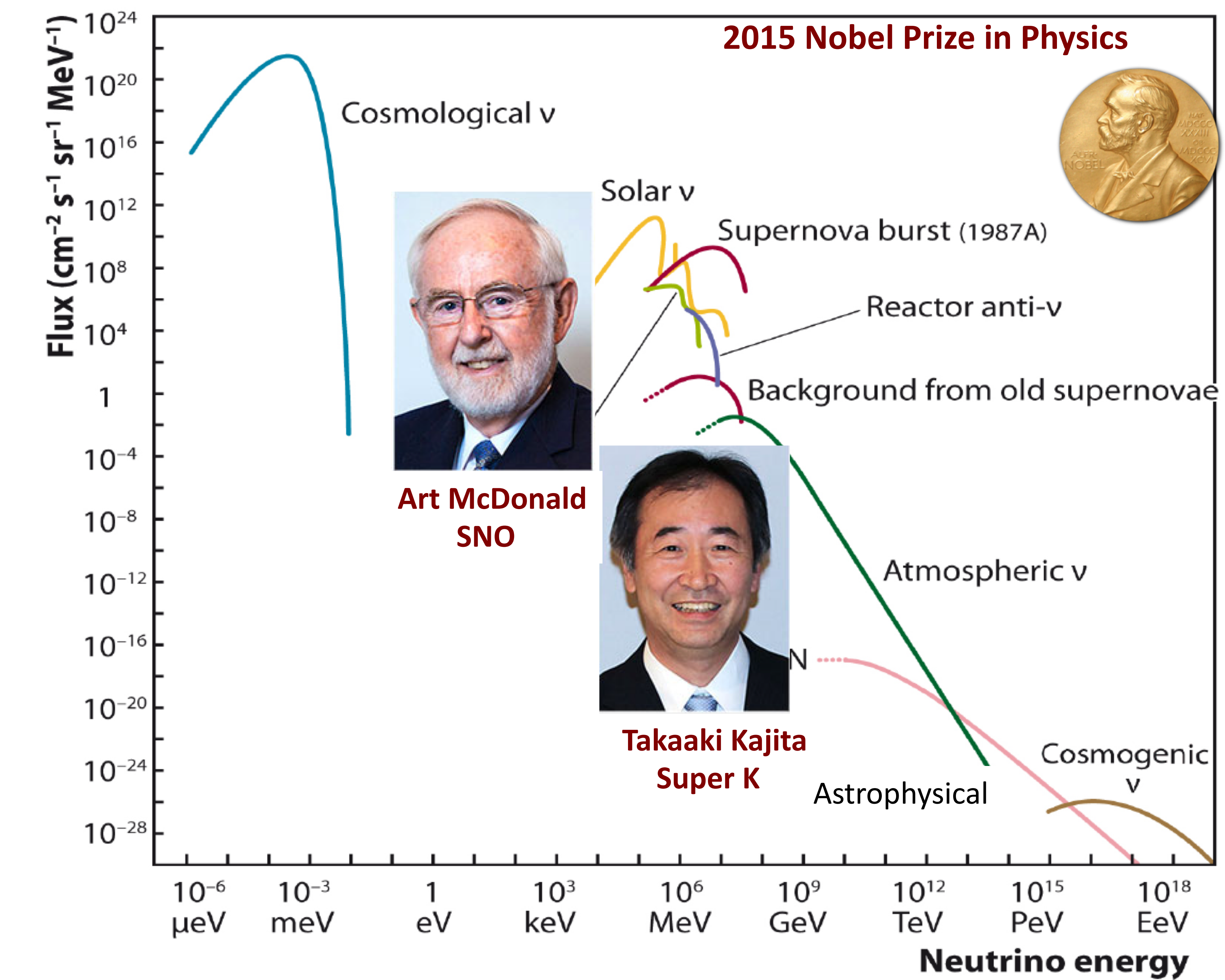
Standard Model of Elementary Particles



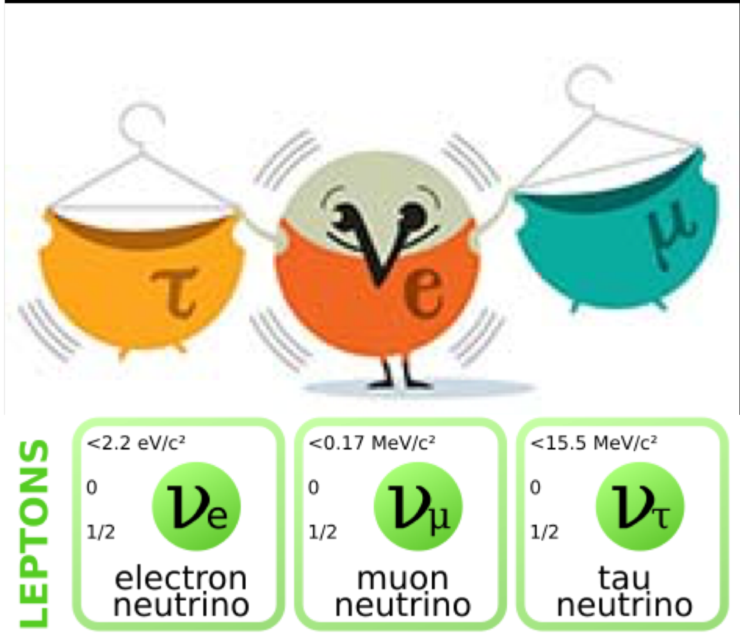


The Sun in Neutrinos

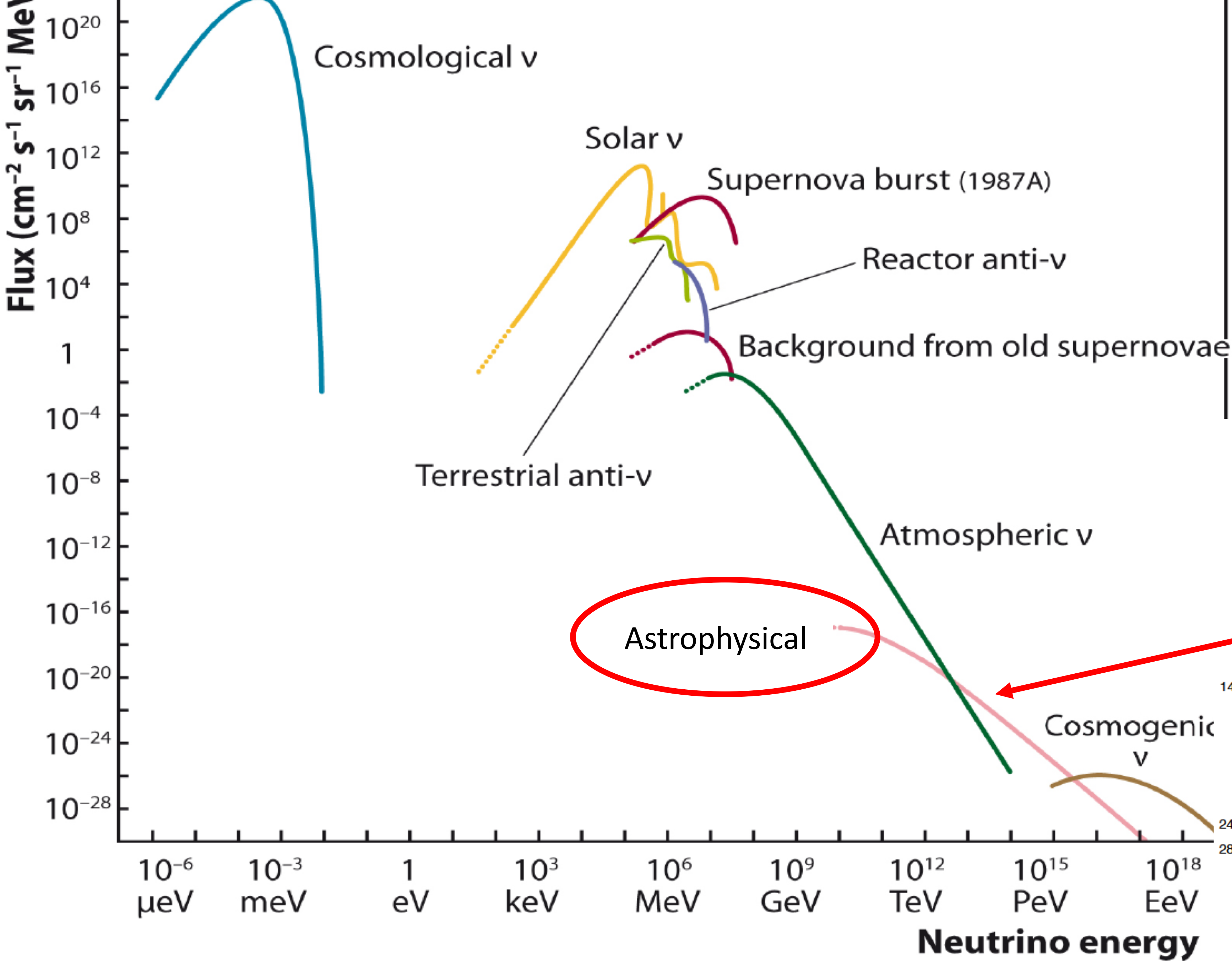




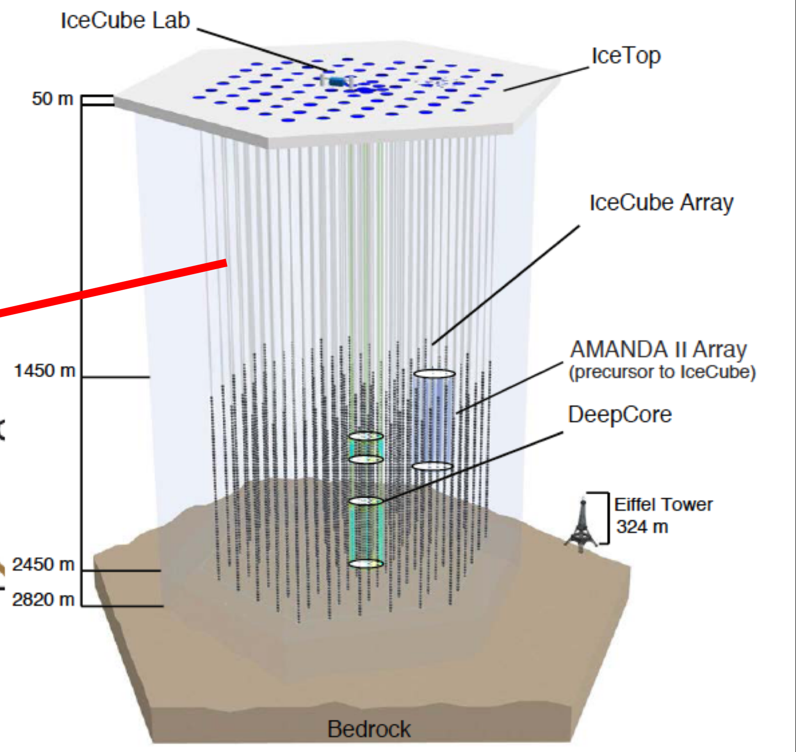
Discovery of Neutrino Oscillations



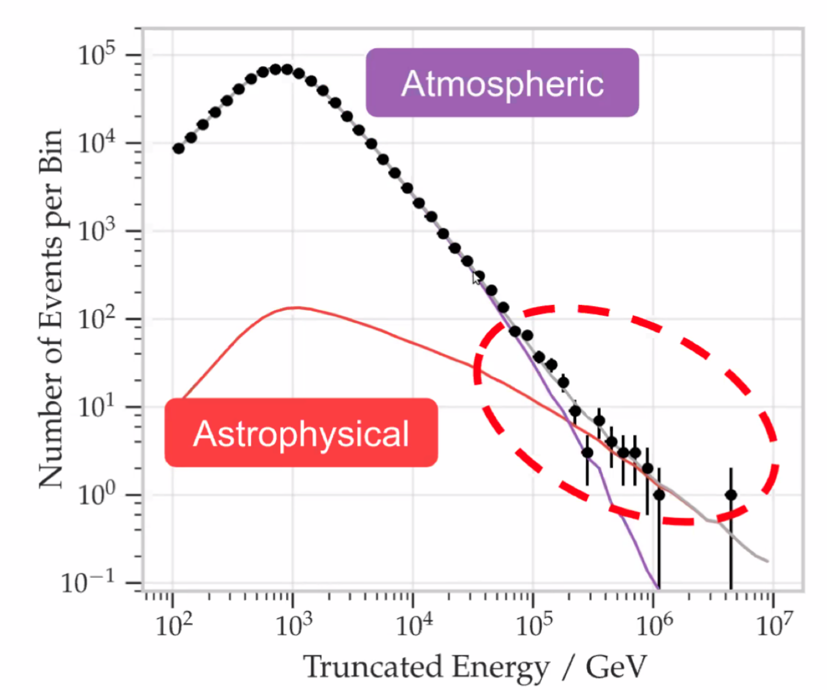
Cosmic Neutrino Spectra

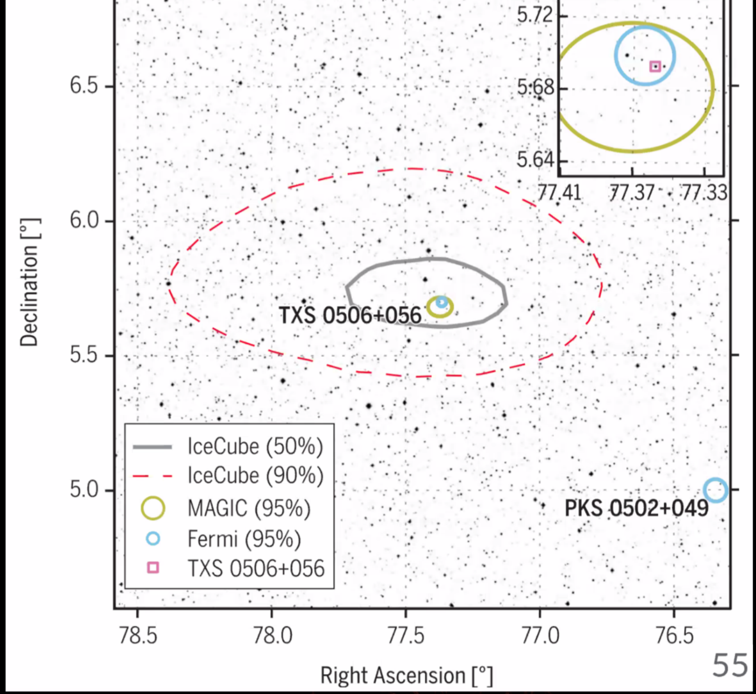


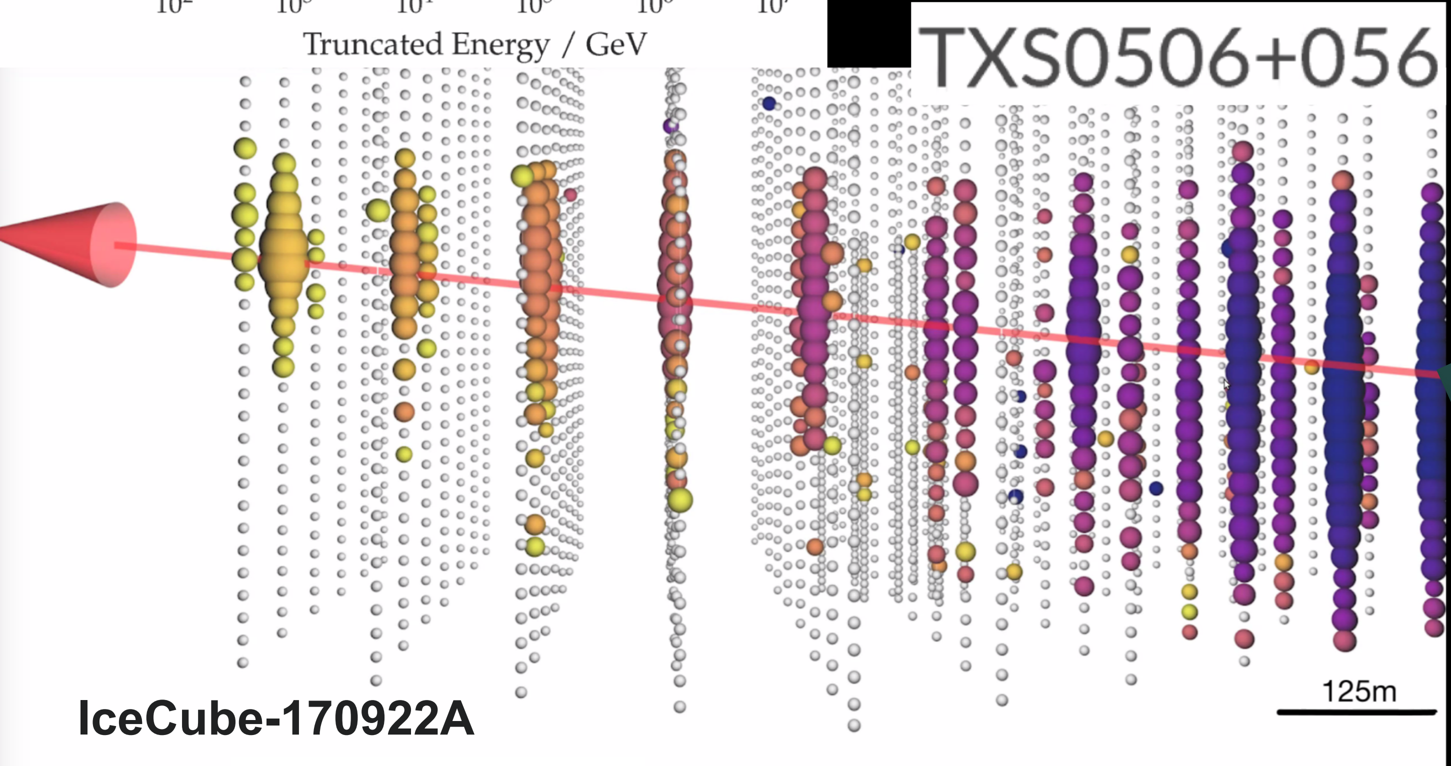
IceCube

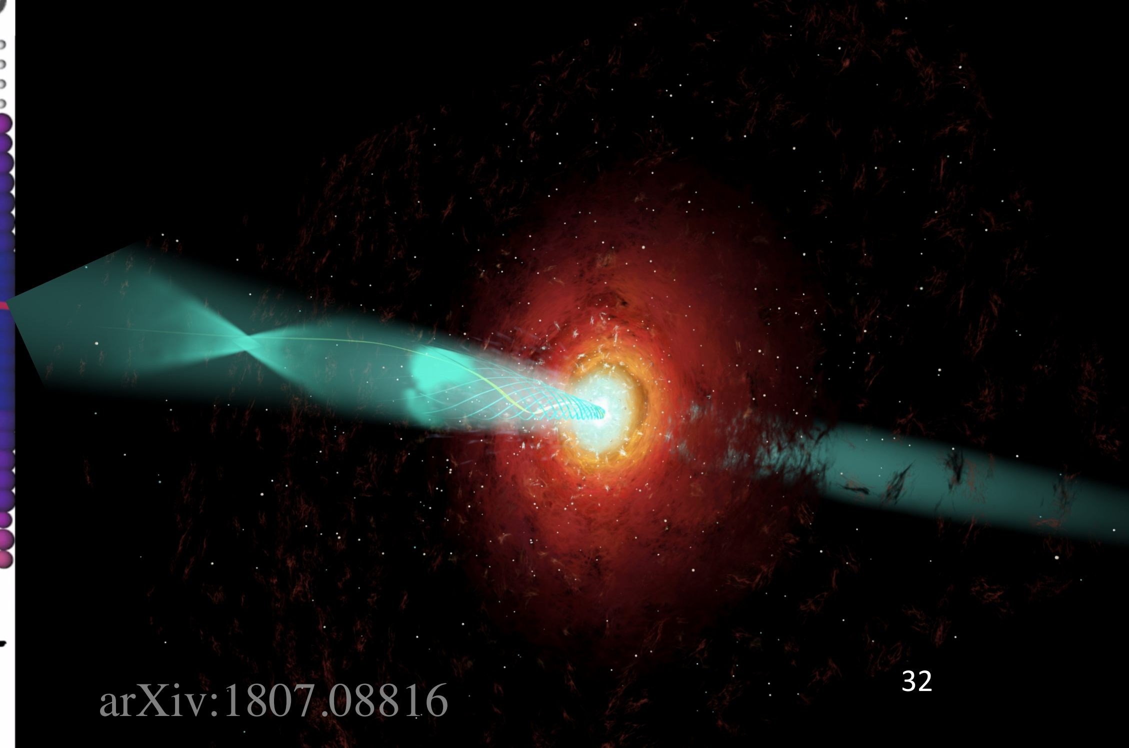


Astrophysical Neutrinos





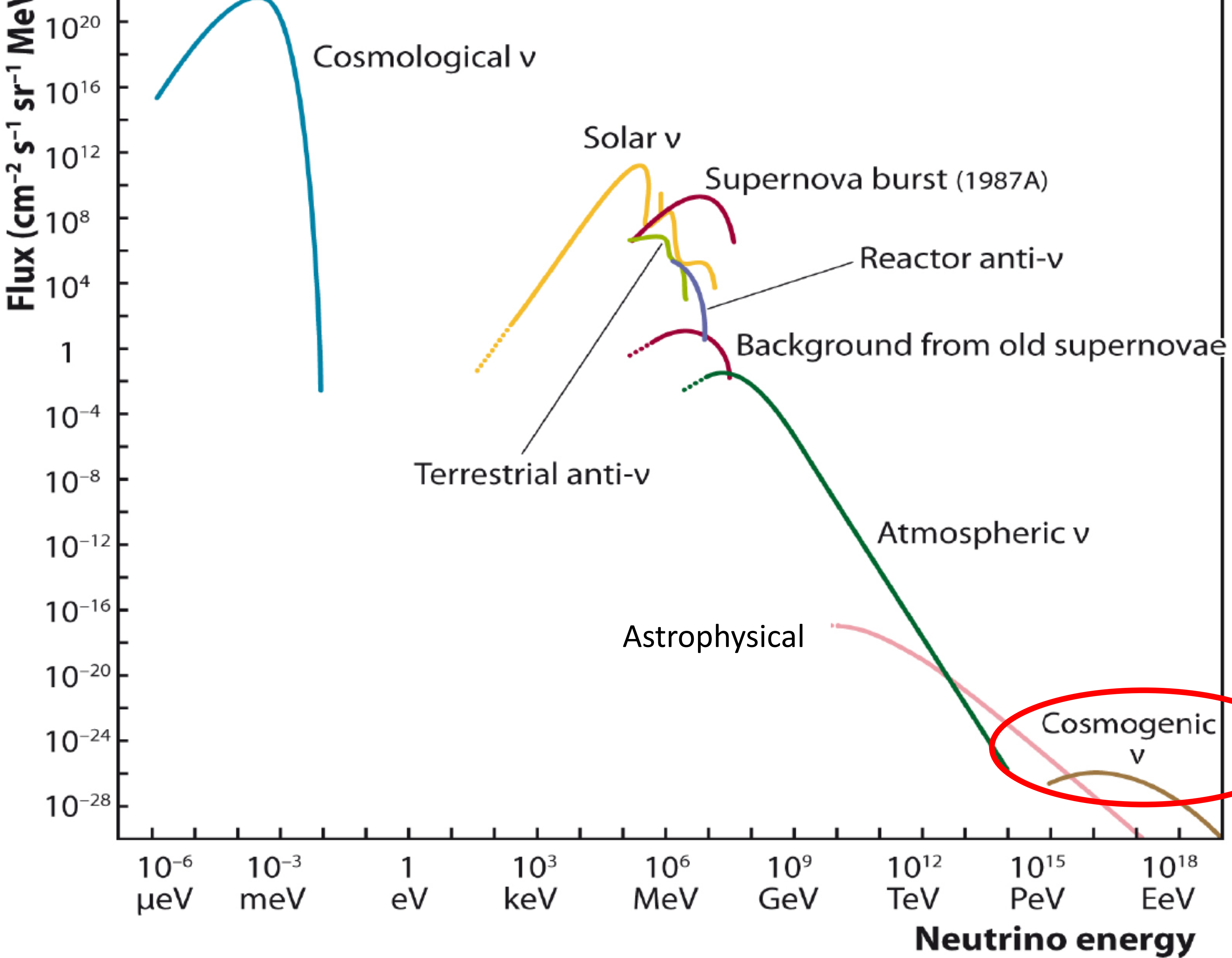




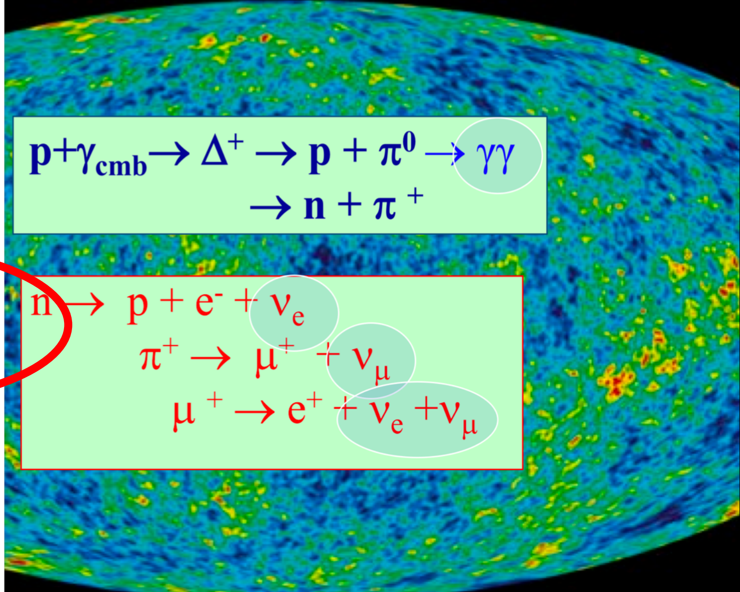
estimated neutrino energy of 300TeV

arXiv:1807.08816

Cosmic Neutrino Spectra

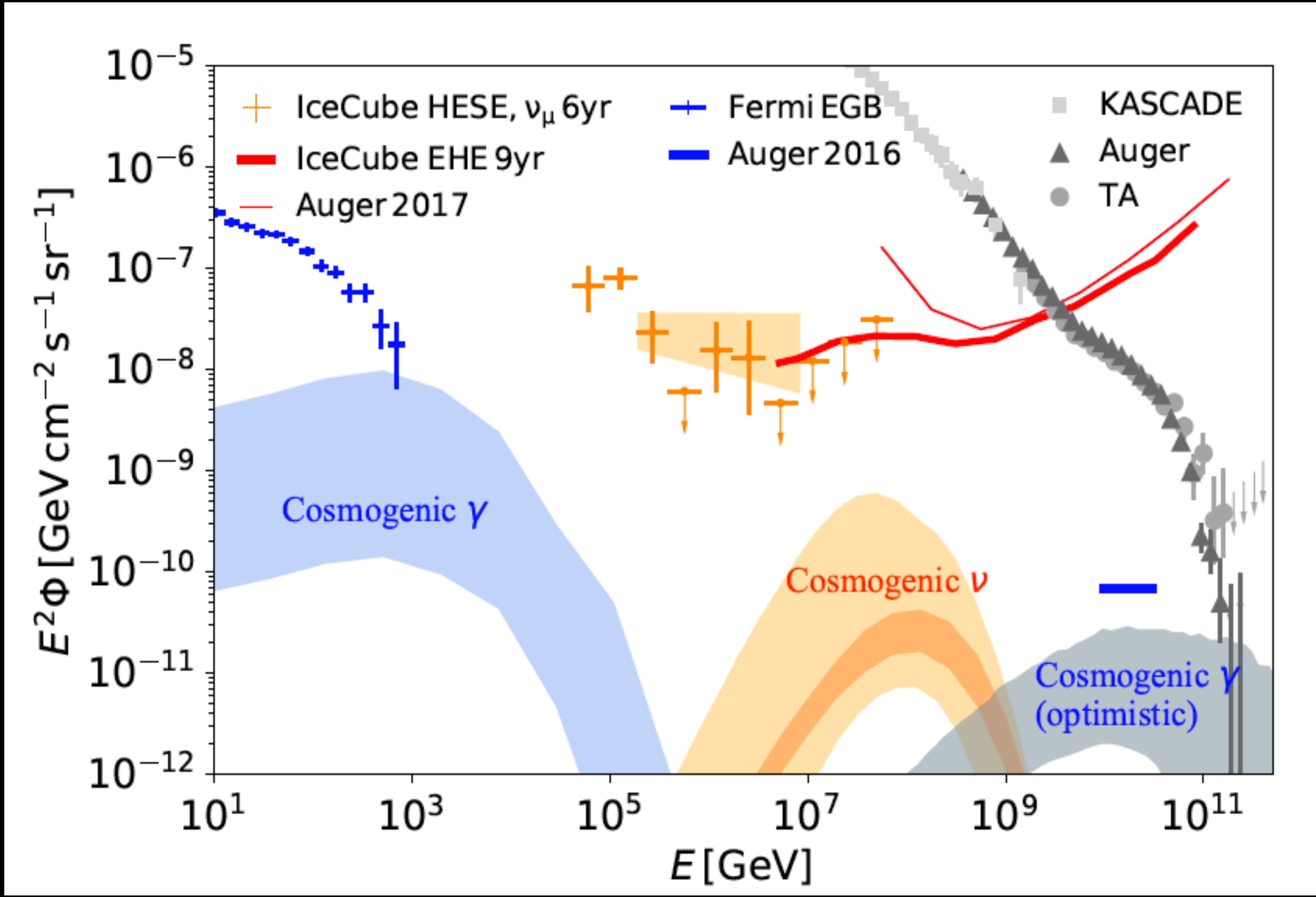


Cosmogenic (GZK, BZ*)
Neutrinos & Photons



*Berezinsky & Zatsepin '69

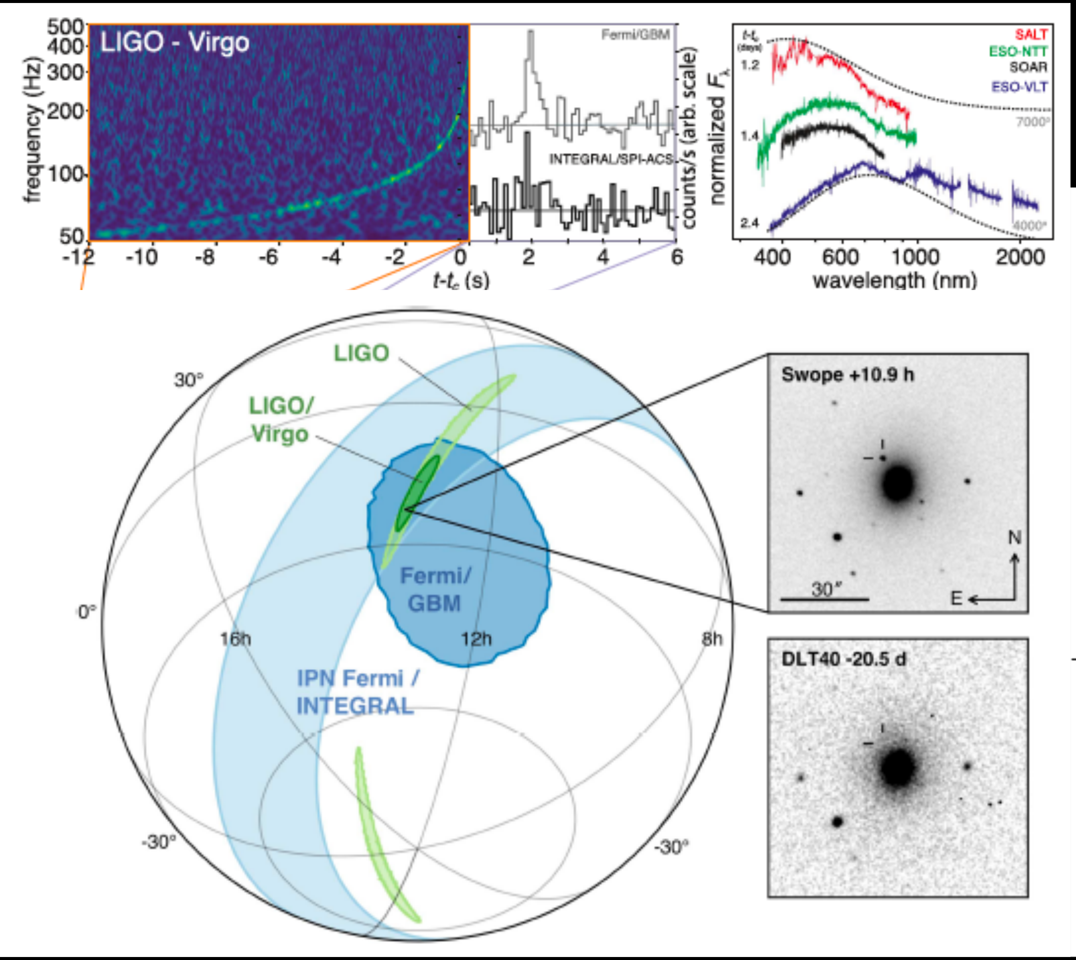
Cosmogenic Messengers



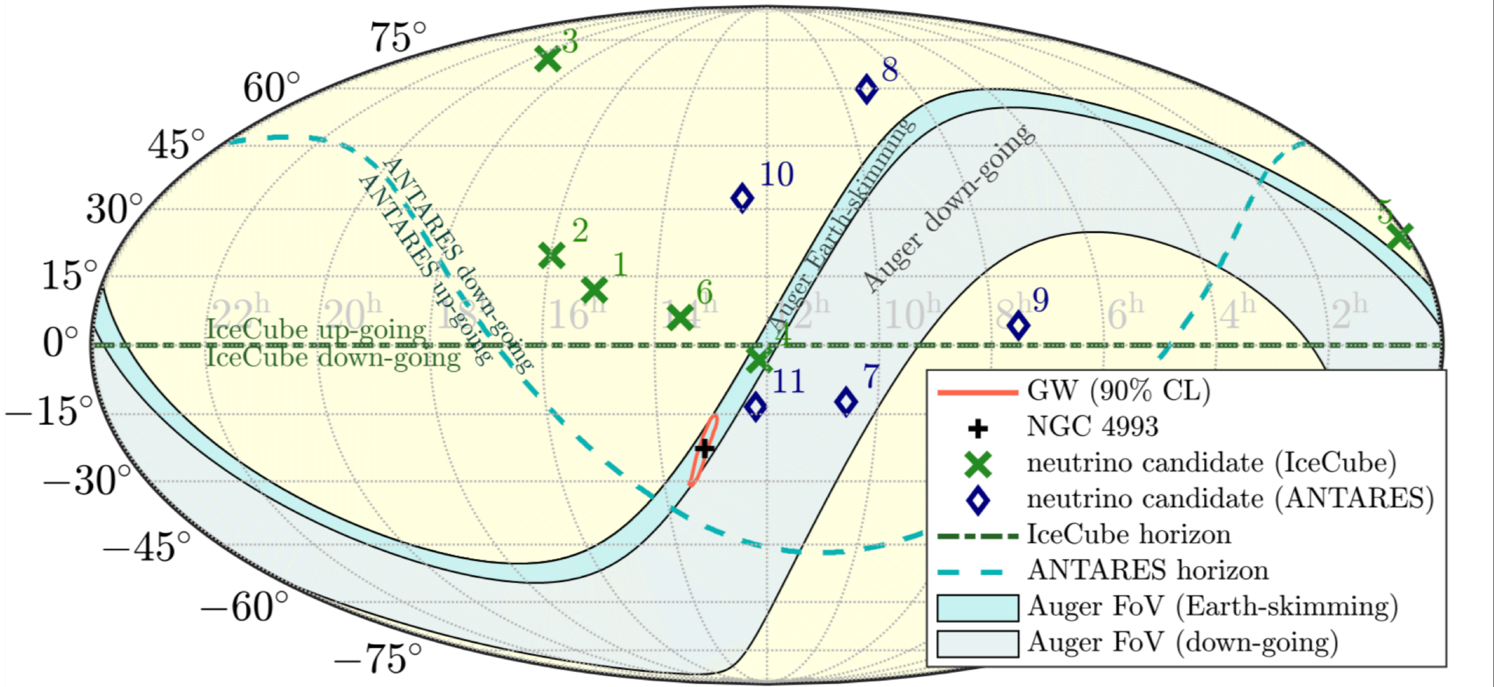
Batista et al, arXiv:1903.06714.pdf

GW170817

LIGO Virgo observation of Binary Neutron Star Coalescence – 70 electromagnetic observatories – NGC4993
GRB 170817A – Fermi and Integral 1.7s after



No Neutrinos Yet



LIGO et al ApJL, arXiv:1710.05833

Albert et al, arXiv:1710.05839

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What is the physics and astrophysics at energies >> "ground-based" accelerators?

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: *Angela V. Olinto (PI),* R. Diesing

NASA/GSFC: John 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: J. Eser, F. Sarazin, L. Wiencke,

City University of New York, Lehman College: L. Anchordoqu, T. C. Paul, J. F. Soriano

Georgia Institute of Technology: A. N. Otte

Space Sciences Laboratory, University of California, Berkeley: E. Judd

University of Iowa: M. H. Reno, Y. Onel, J. Nachtman, D. Winn

CZECH Rep: IP-CAS, K. Cerny

DENMARK: NBI: M. Bustamante

FRANCE: APC Univerite de Paris 7: E. Parizot, G. Prevot; IAP, Paris: C. Guepin

GERMANY: KIT: R. Ulrich, M. Unger;

ITALY: Universita di Torino: M. E. Bertaina, F. Bisconti, F. Fenu, A. Liberatore, K. Shinozaki: Gran Sasso Science Institute: R. Aloisio, A. L. Cummings, I. De Mitri; INFN Frascati: M. Ricci, INFN Tor Vergata: L. Marceli, U. of Rome Tor Vergata: P. Picozza

JAPAN: RIKEN: M. Casolino, L. W. Piotrowski, Y. Takizawa

MEXICO: UNAM, G. Medina-Tanco

NORWAY: NTNU, F. Oikonomou

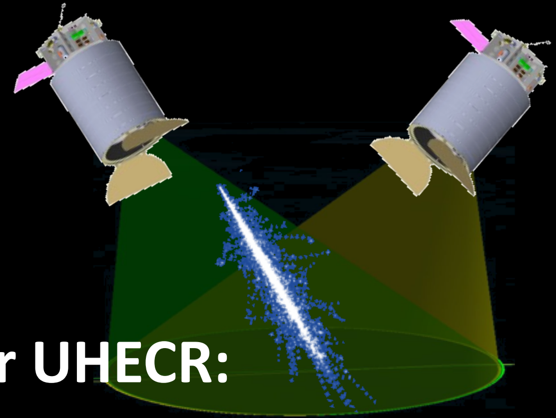
SLOVAKIA: IEP, Slovak Academy of Science: S. Mackovjak

SWITZERLAND: University of Geneva: A. Neronov

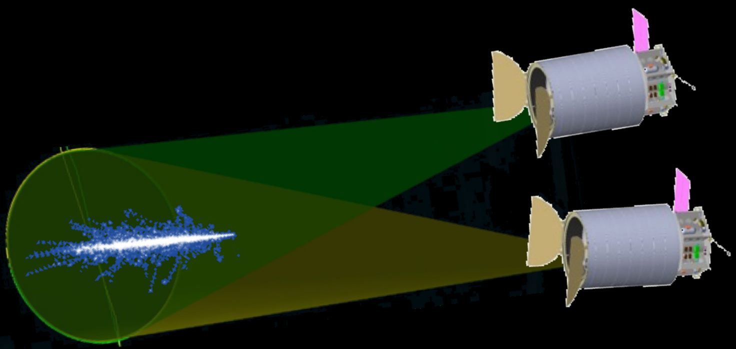
50+ scientists from 25+ institutions (11 countries)

OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

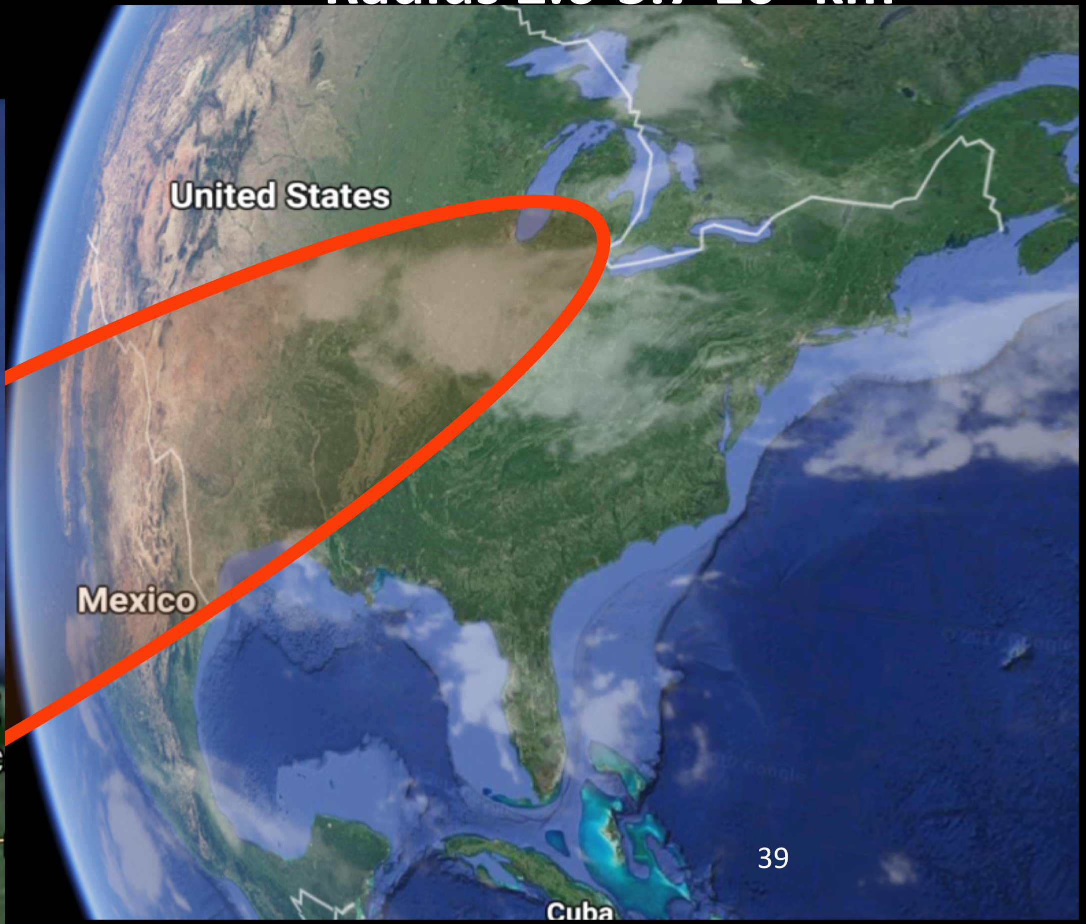
Observing Modes



Nadir for UHECR:
Radius 200-400 km

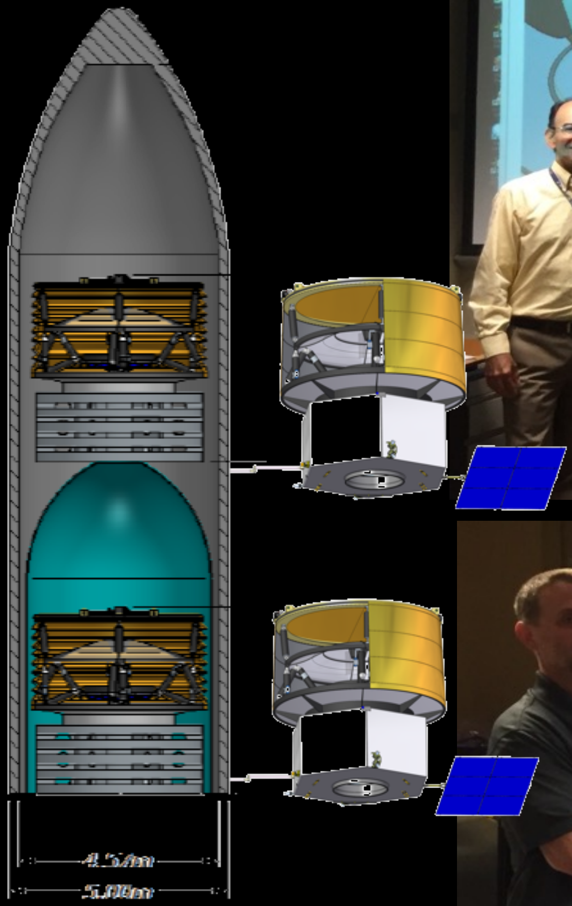


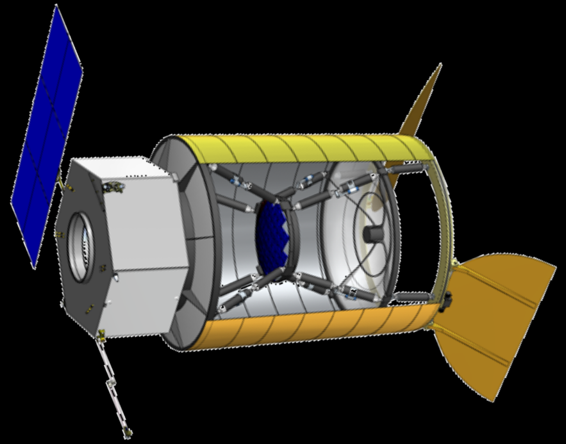
Limb for Neutrinos & UHECRs
Radius 2.6-3.7 10^3 km

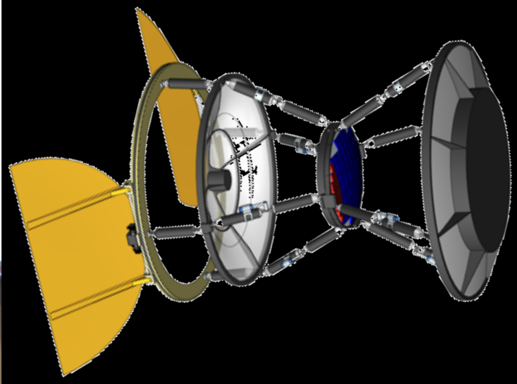


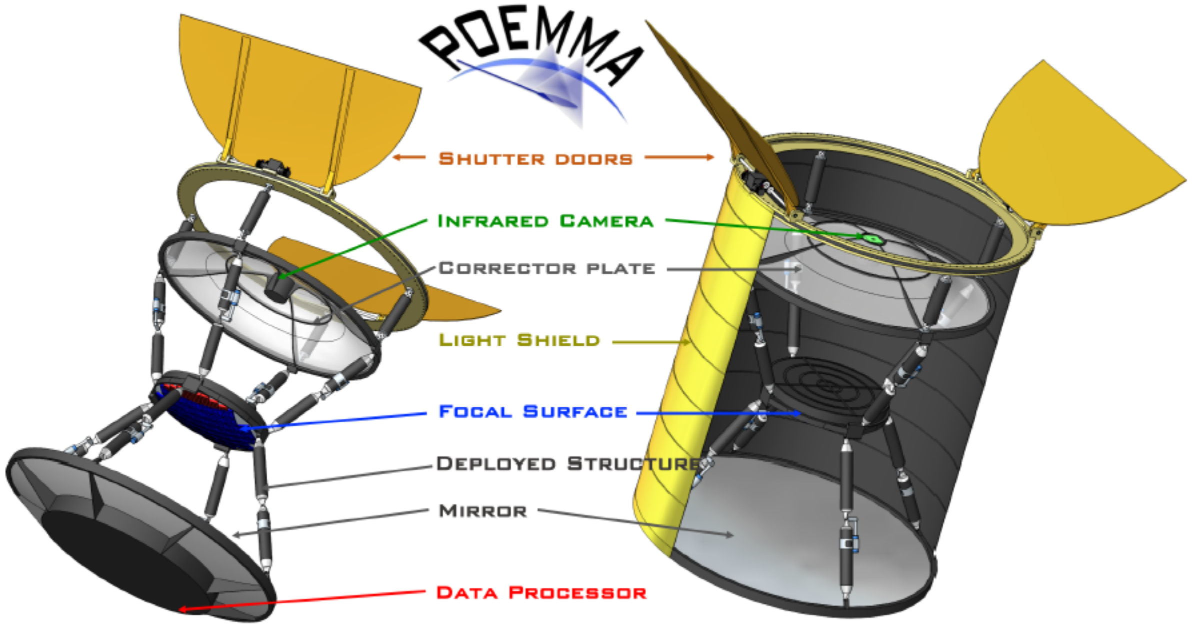
POEMMA at NASA-GSFC

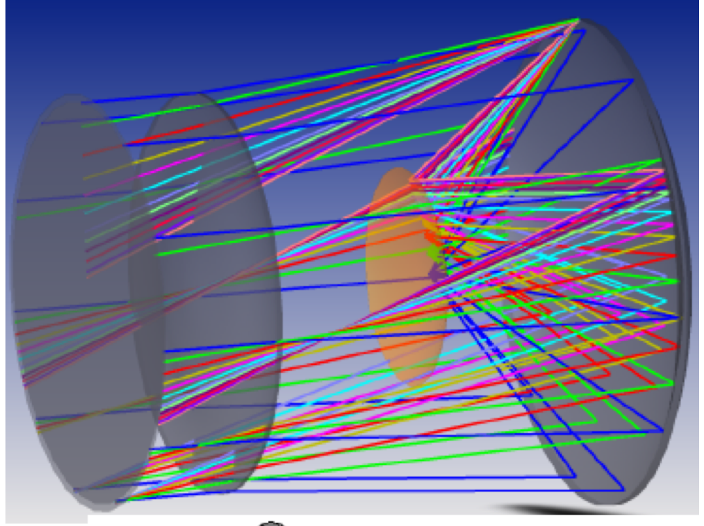
Instrument Design Lab: Jul 31-Aug 4, 2017
Mission Design Lab: Oct 30-Nov 3, 2017











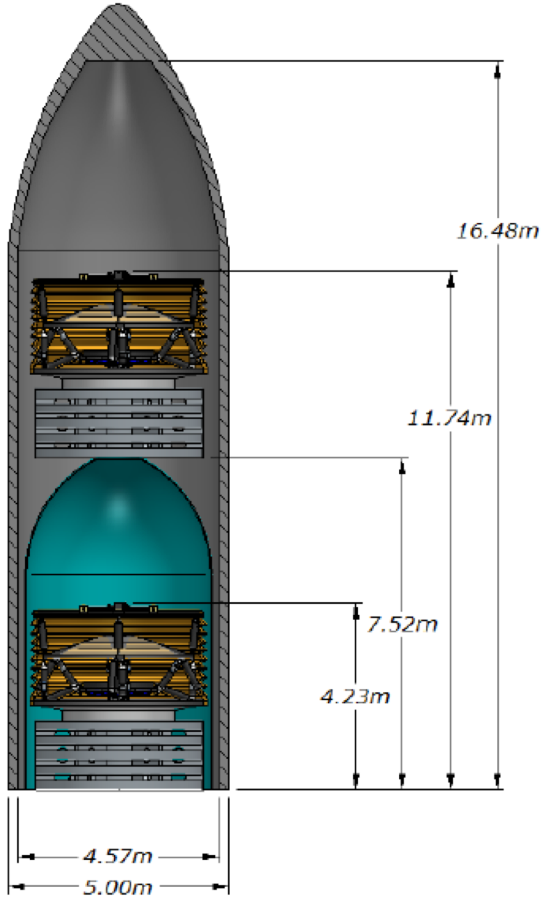


TABLE I: POEMMA Specifications:

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

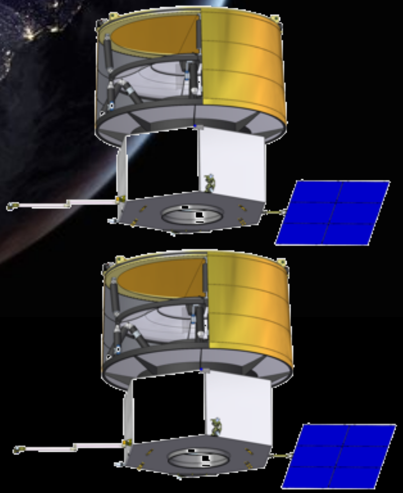
Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

POEMMA Mission

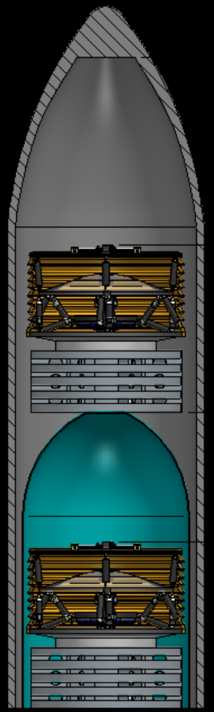
Mission Lifetime:	3 years (5 year goal)
Orbits:	525 km, 28.5° Inc
Orbit Period:	95 min
Satellite Separation:	~25 km – 1000+ km
Satellite Position:	1 m (knowledge)
Pointing Resolution:	0.1°
Pointing Knowledge:	0.01°
Slew Rate:	8 min for 90°
Satellite Wet Mass:	3860 kg
Power:	2030 W
Data:	1 GB/day
Data Storage:	7 days
Communication:	S-band (X-band if needed)
Clock synch (timing):	10 nsec

Operations:

- Each satellite collects data autonomously
- Coincidences analyzed on the ground
- View the Earth at near-moonless nights, charge in day and telemeter data to ground
- ToO Mode: dedicated com uplink to re-orient satellites if desired



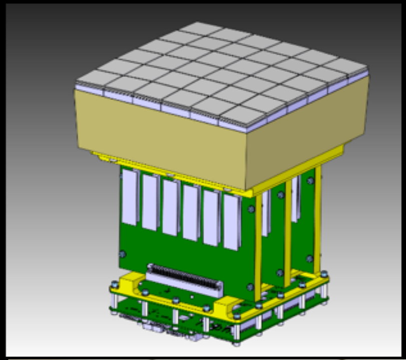
Dual Manifest
ATLAS V LPF

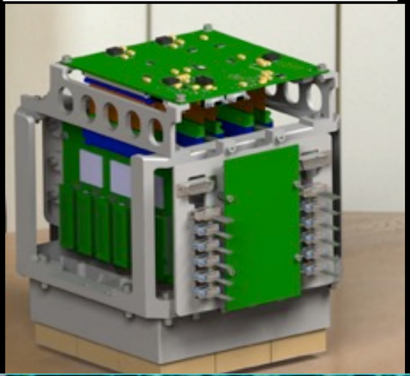


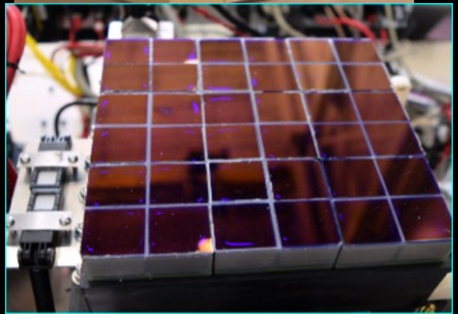
POEMMA

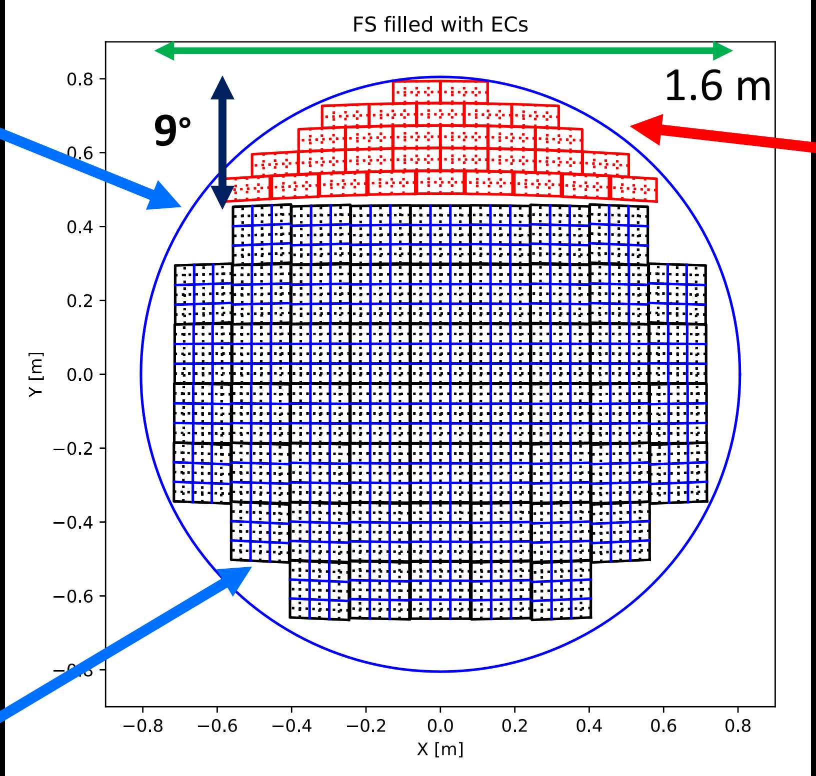
Hybrid Focal Surface

UV Fluorescence
MAPMTs with BG3 filter:
1 usec sampling

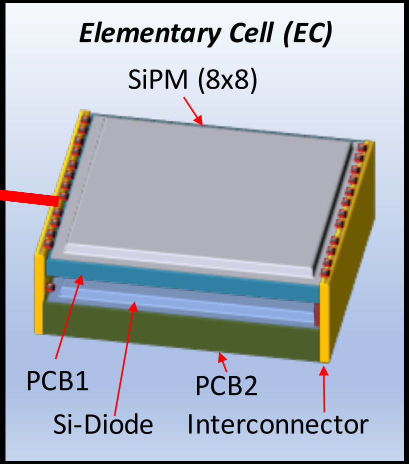








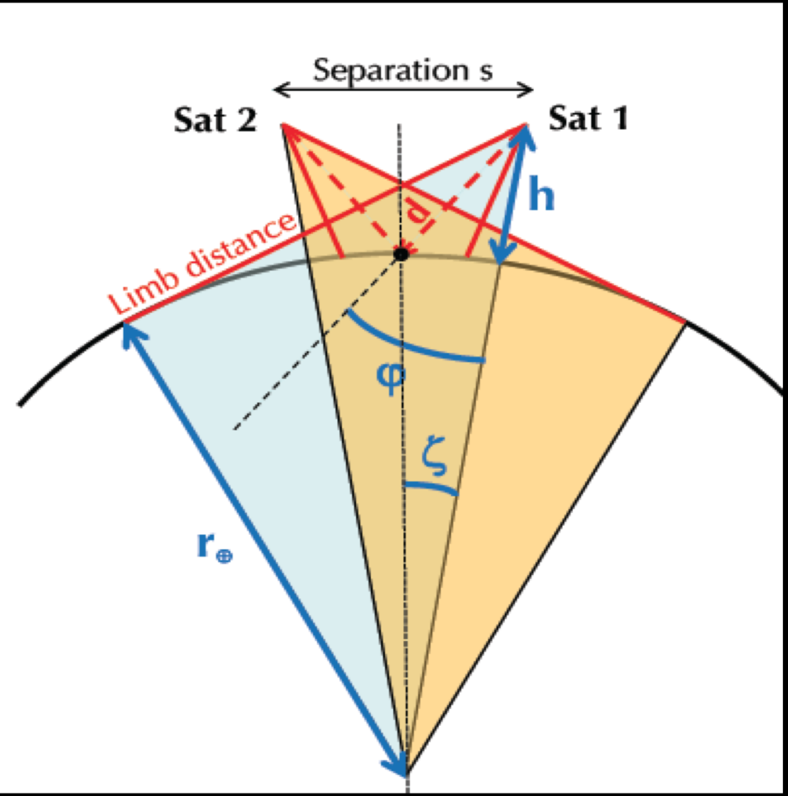
Cherenkov Detection
SiPMs:
20 nsec sampling

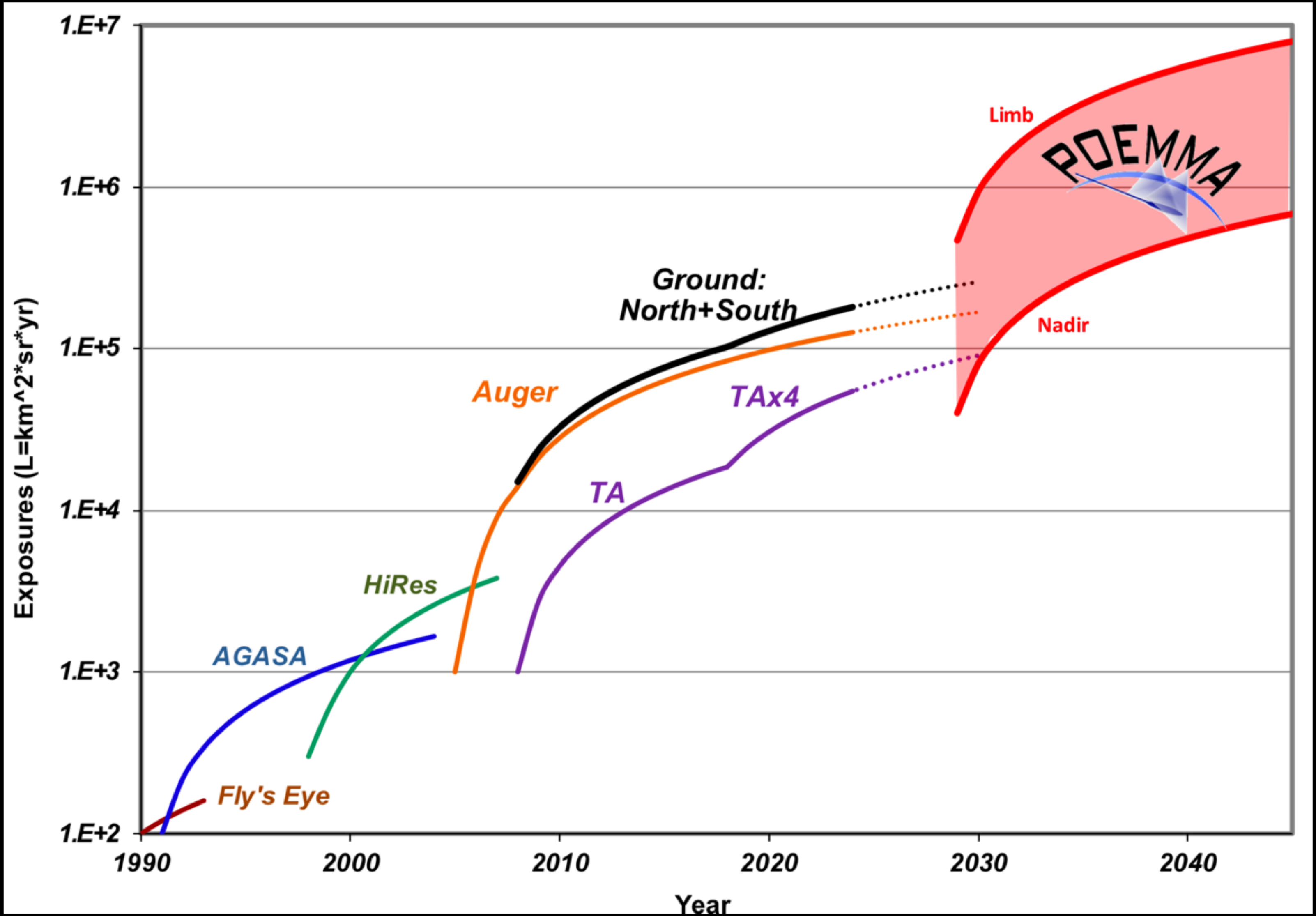


30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)

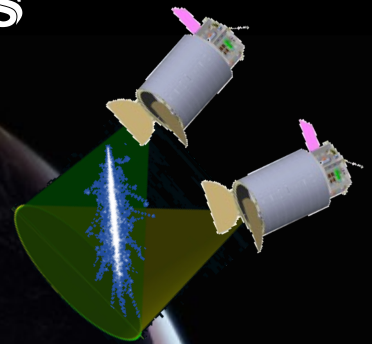
55 Photo Detector Modules (PDMs)= TOTAL 126,720 pixels
(1 PDM = 36 MAPMTs = 2,304 pixels)

POEMMA UHECR Exposure

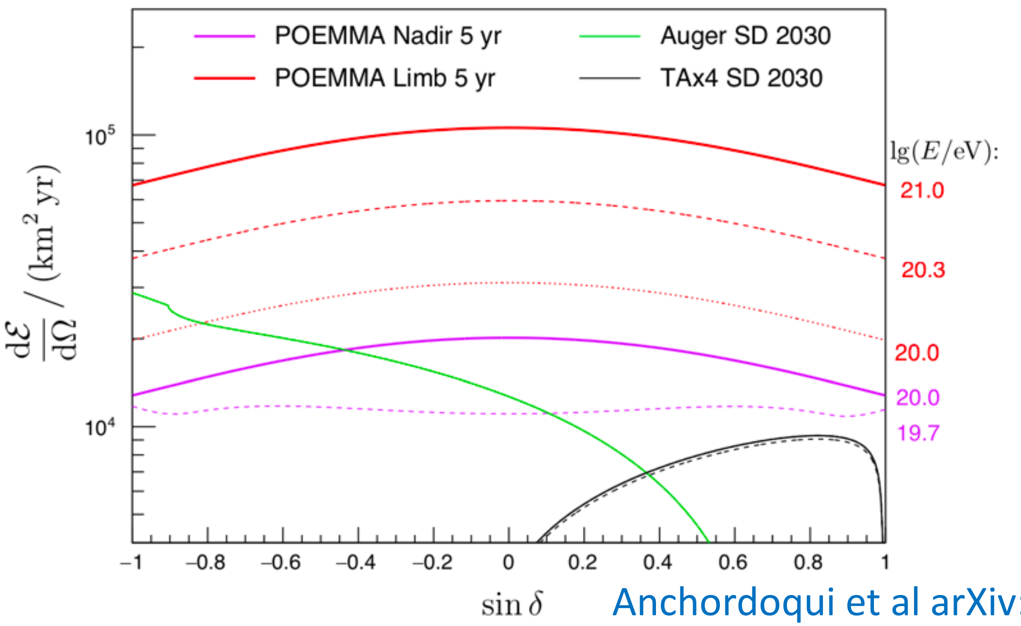




POEMMA: UHECRs

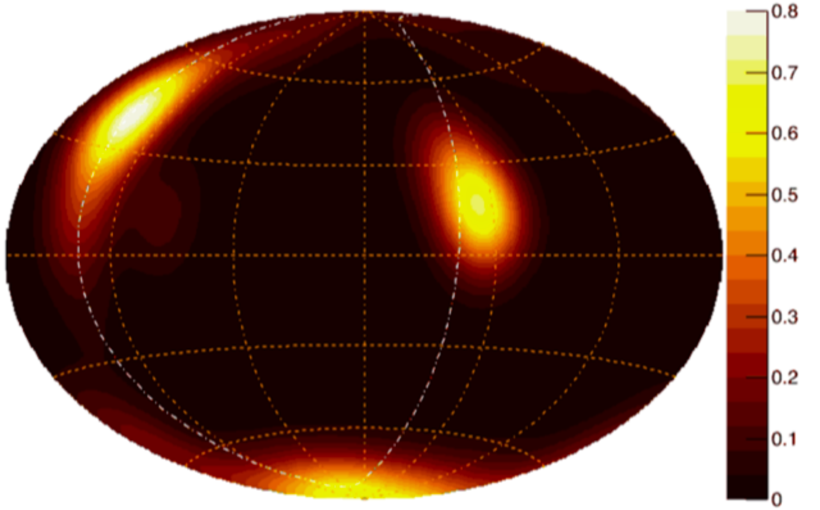


significant increase in exposure E >50 EeV
good energy, angular, and shower maximum resolutions,
accurately measure **Composition, Spectrum, Anisotropies**
Uniform sky coverage
to **guarantee the discovery of UHECR sources**



Anchordoqui et al arXiv:1907.03694

nearby Starburst Galaxies Fermi-LAT



POEMMA probability density

POEMMA: Neutrinos

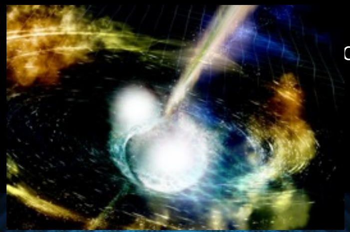
POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of tau decays.

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

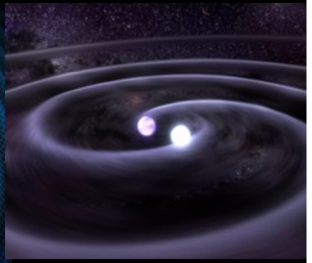
POEMMA: Neutrino Target of Opportunity

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.

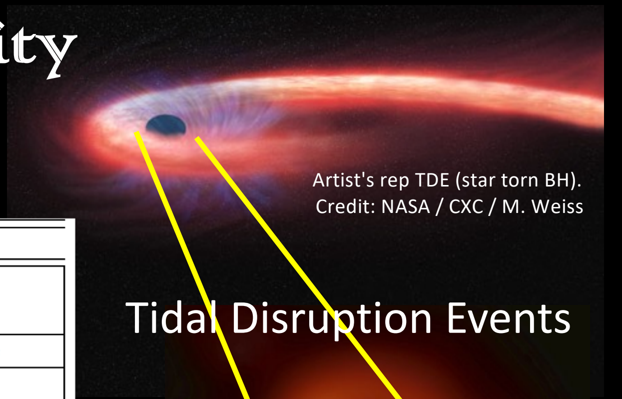


Artist's rep WD-WD merger
Credit: Ars Technica

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

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
Long Bursts				
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]

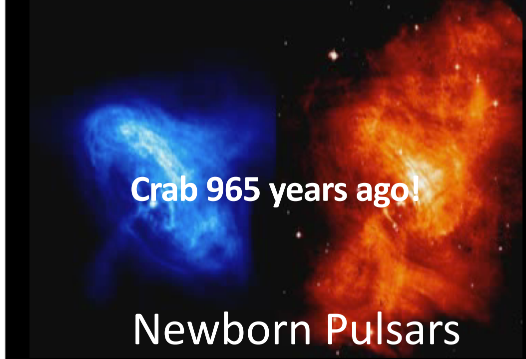
(*) Not applicable due to a lack of known blazars within 100 Mpc.



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

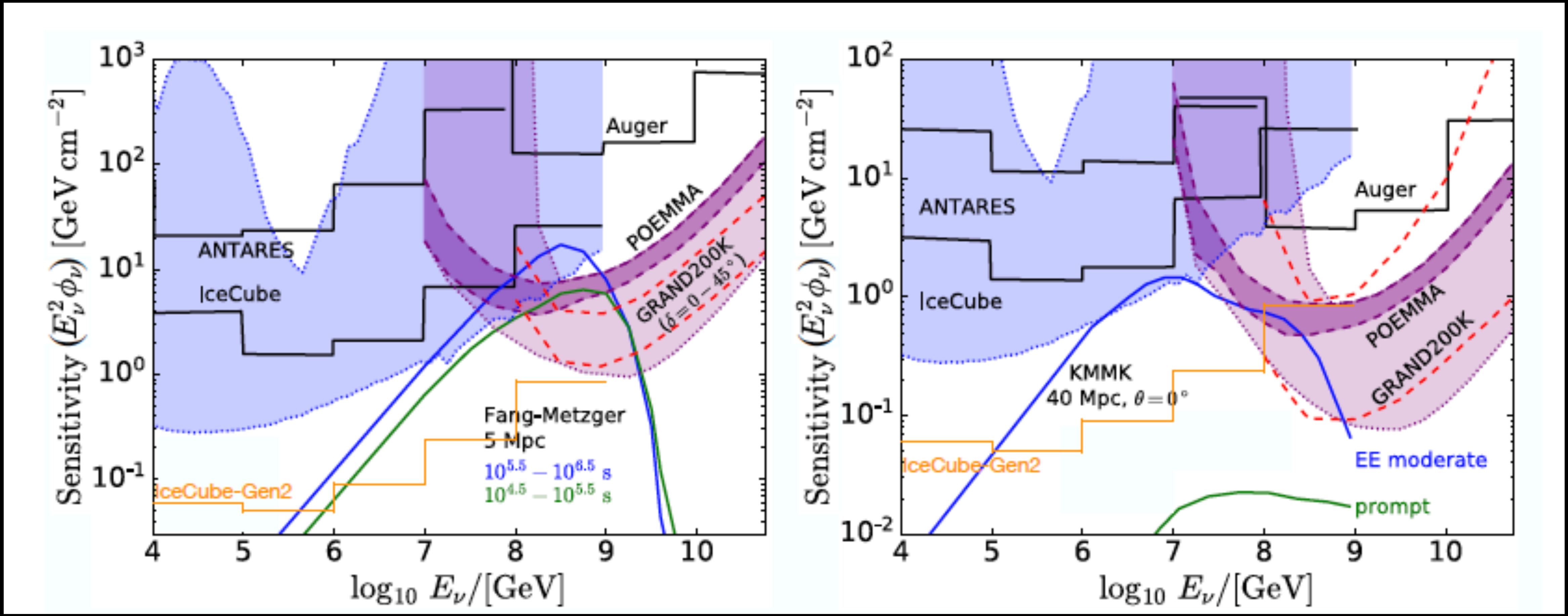
Tidal Disruption Events

EVENT HORIZON TELESCOPE
COLLABORATION/MAUNAKEA
OBSERVATORIES/ASSOCIATED PRESS



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

Transient Neutrino Point Source Sensitivity



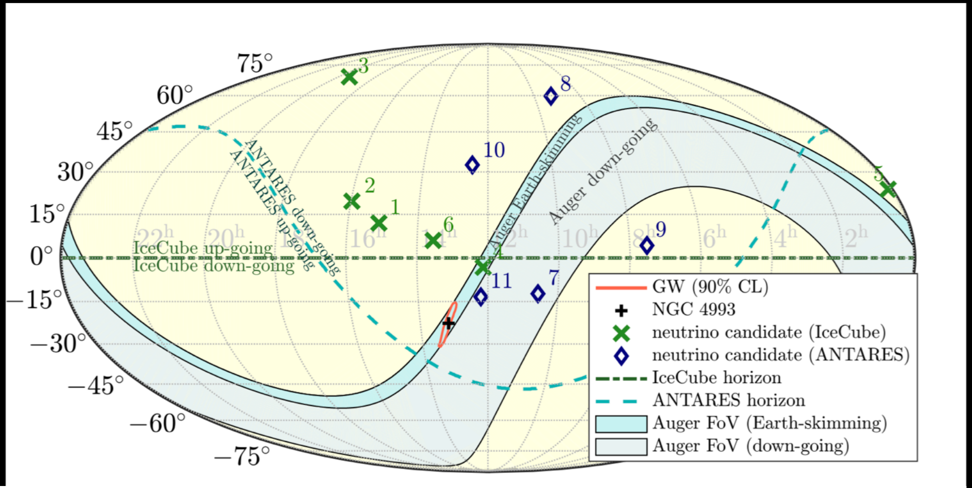
BNS coalescence or Kilonova: Fang & Metzger, arXiv:1707.04263

Short GRB: Kimura et al, arXiv:1708.07075

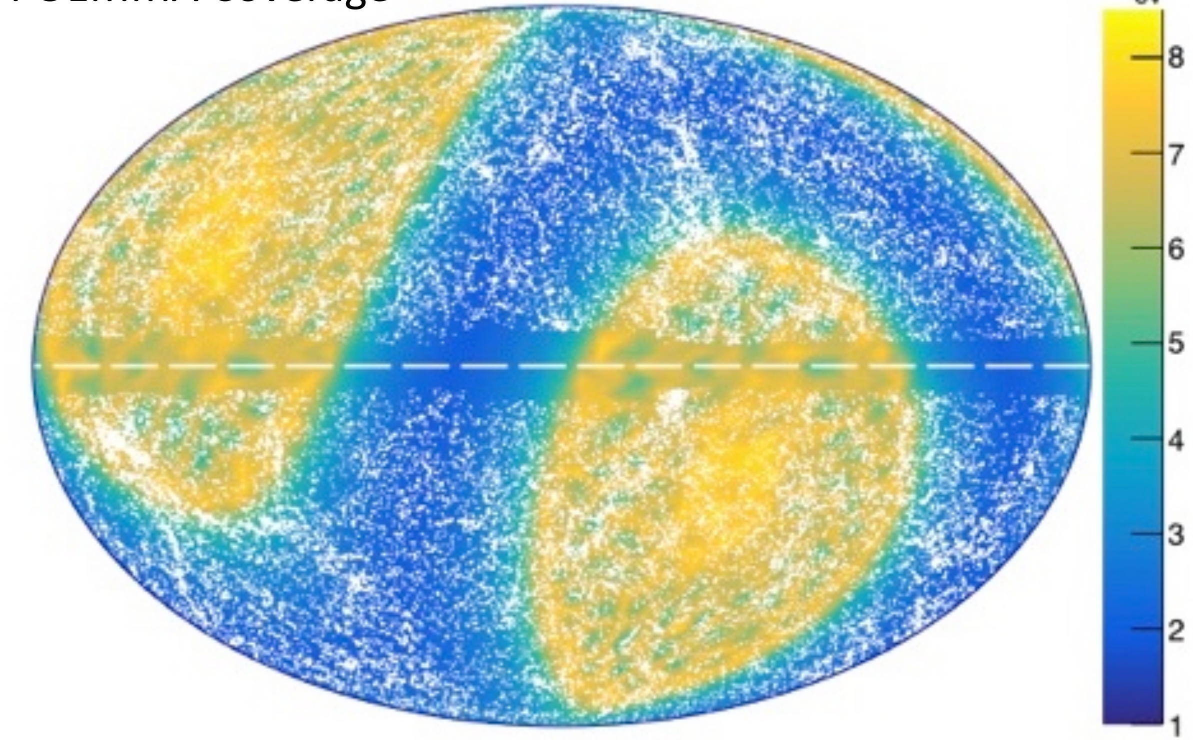
Venters et al, Snowmass2021, LOI, (2020), arXiv:1906.07209

Sky Coverage HE-UHE Neutrinos

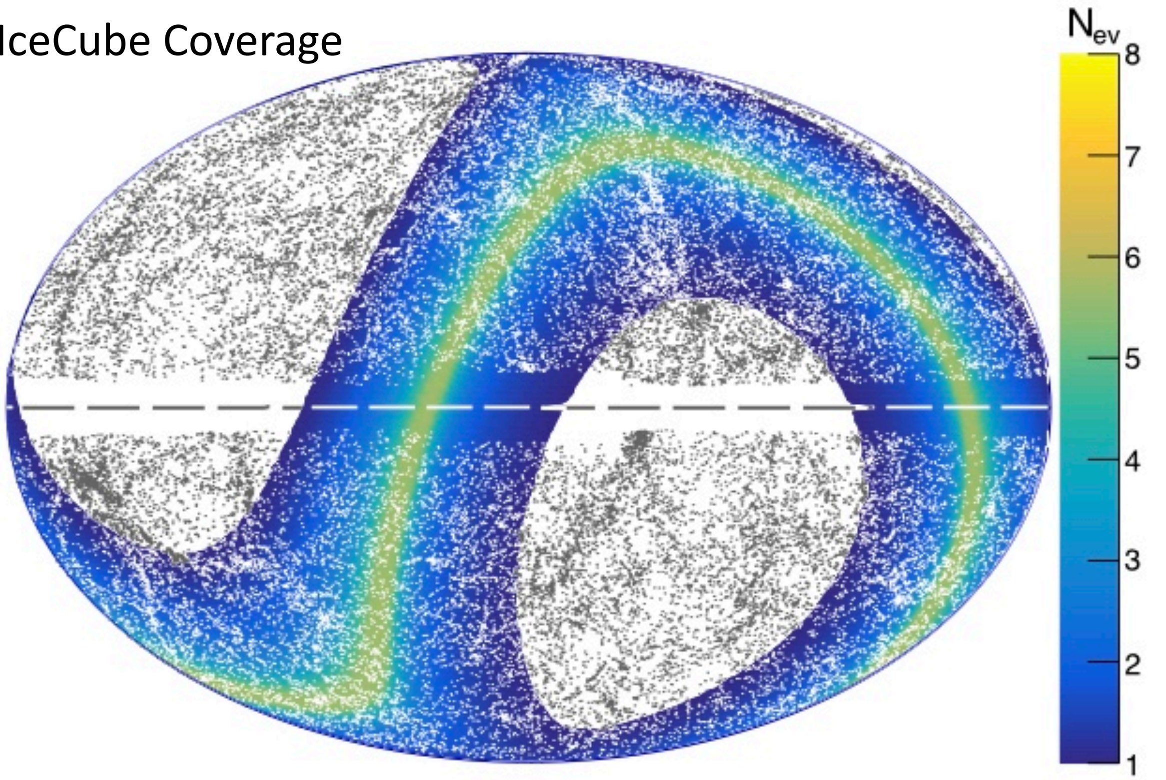
Complementary



POEMMA Coverage



IceCube Coverage

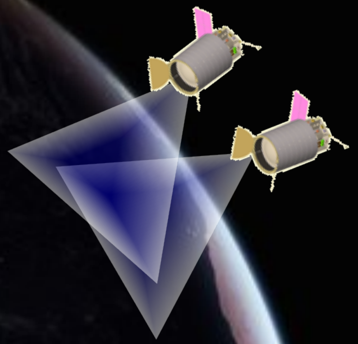


Venters et al arXiv:1906.07209

POEMMA

UHECR and Neutrino Observations

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)

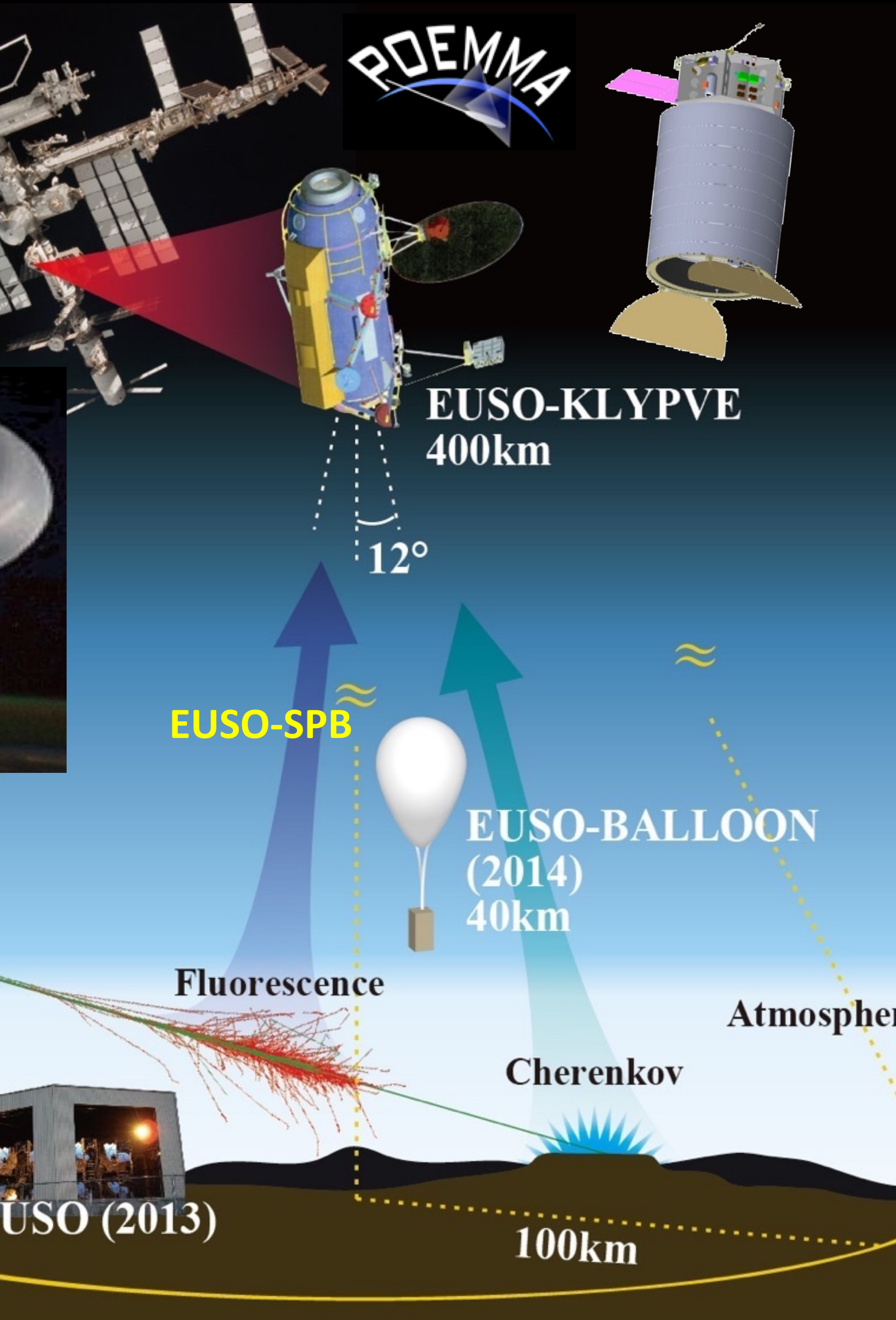
EUSO-SPB1 (2017)

Mini-EUSO (2019)

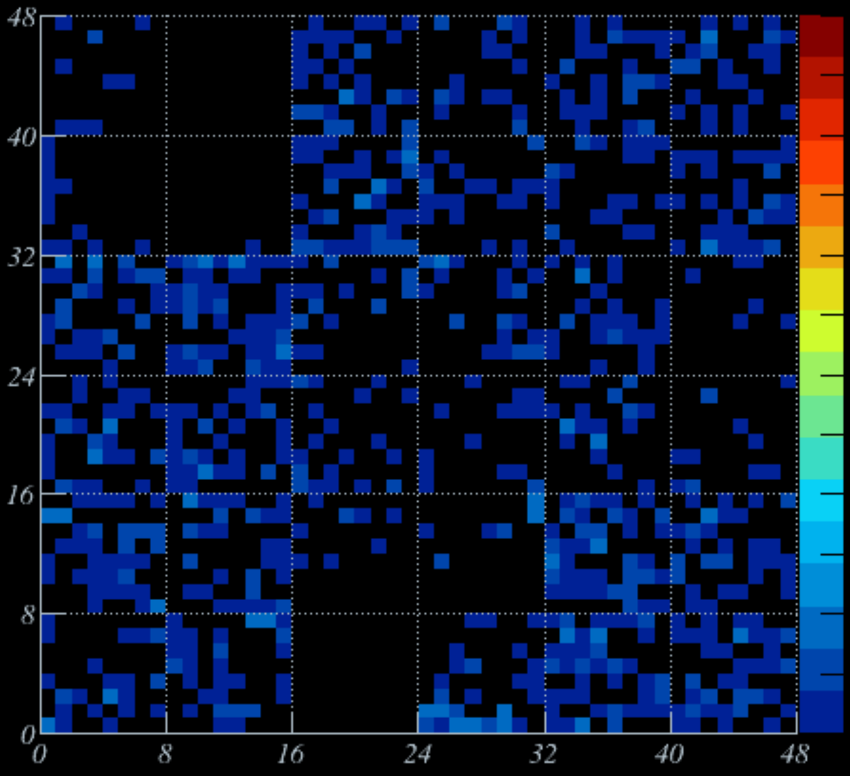
EUSO-SPB2 (2023)

K-EUSO (2024+)

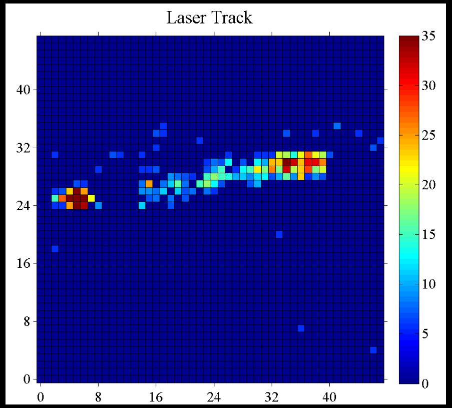
POEMMA (2028+)



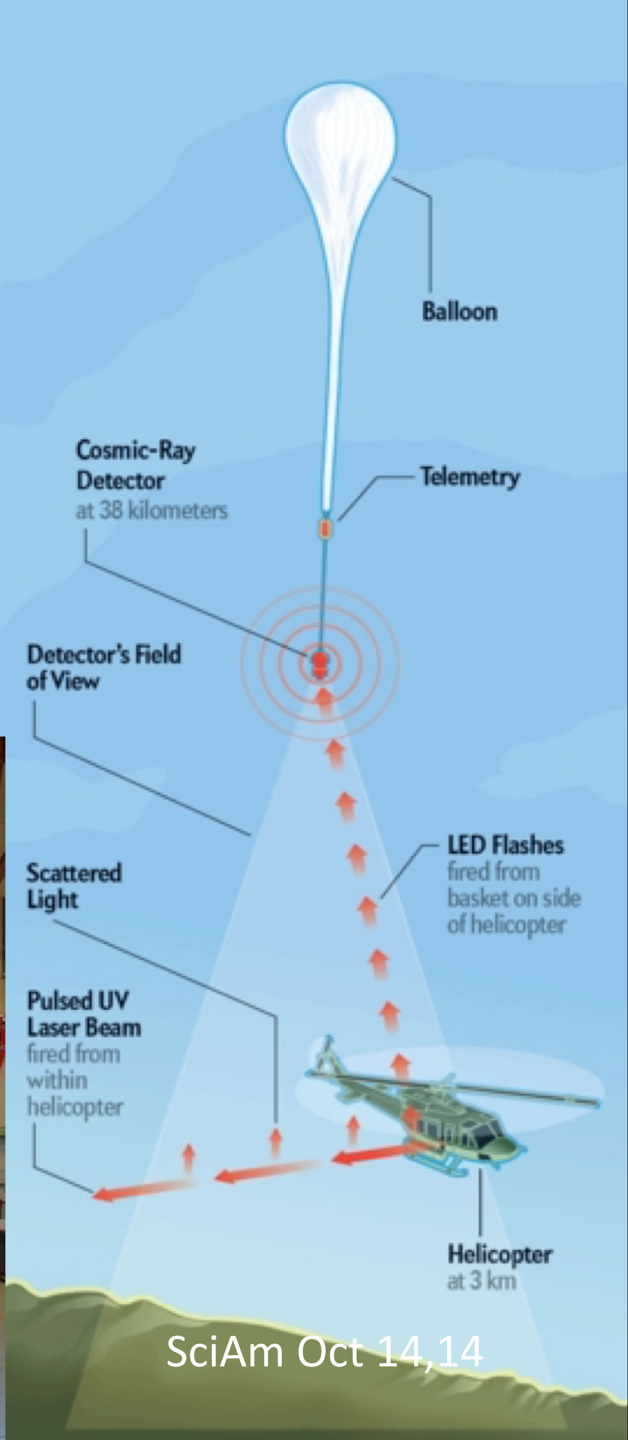
Flasher & Laser events



355nm Laser:
~10^{20} eV
equivalent brightness



EUSO Balloon:
1st flight on 24-25.8.2014



SciAm Oct 14,14

EUSO-SPB1

Extreme Universe Space Observatory on a Super Pressure Balloon

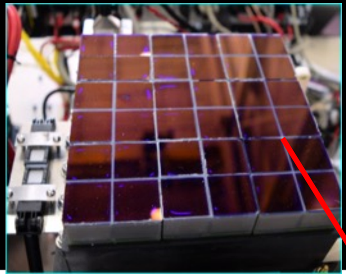
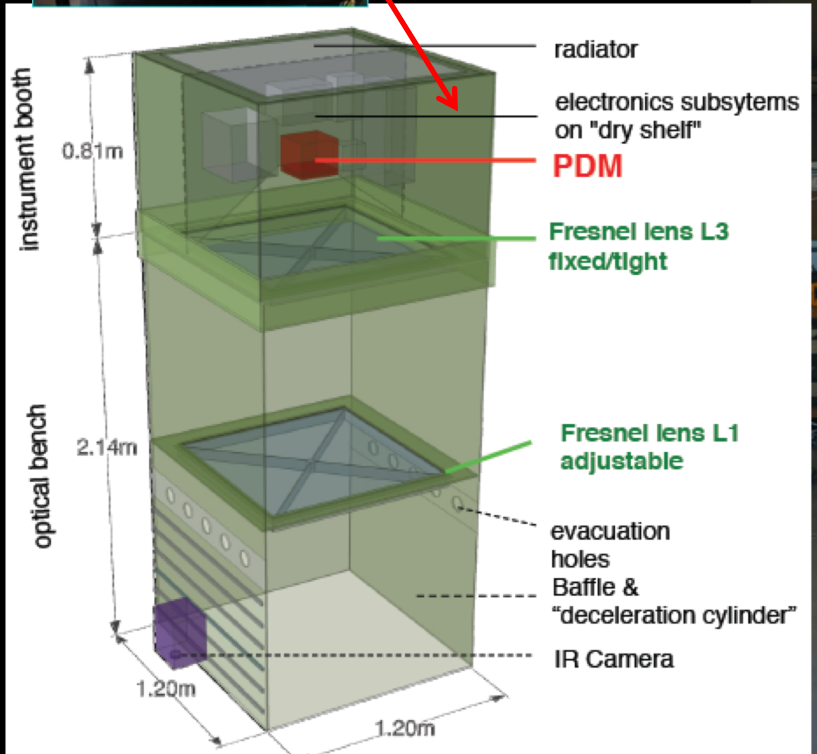
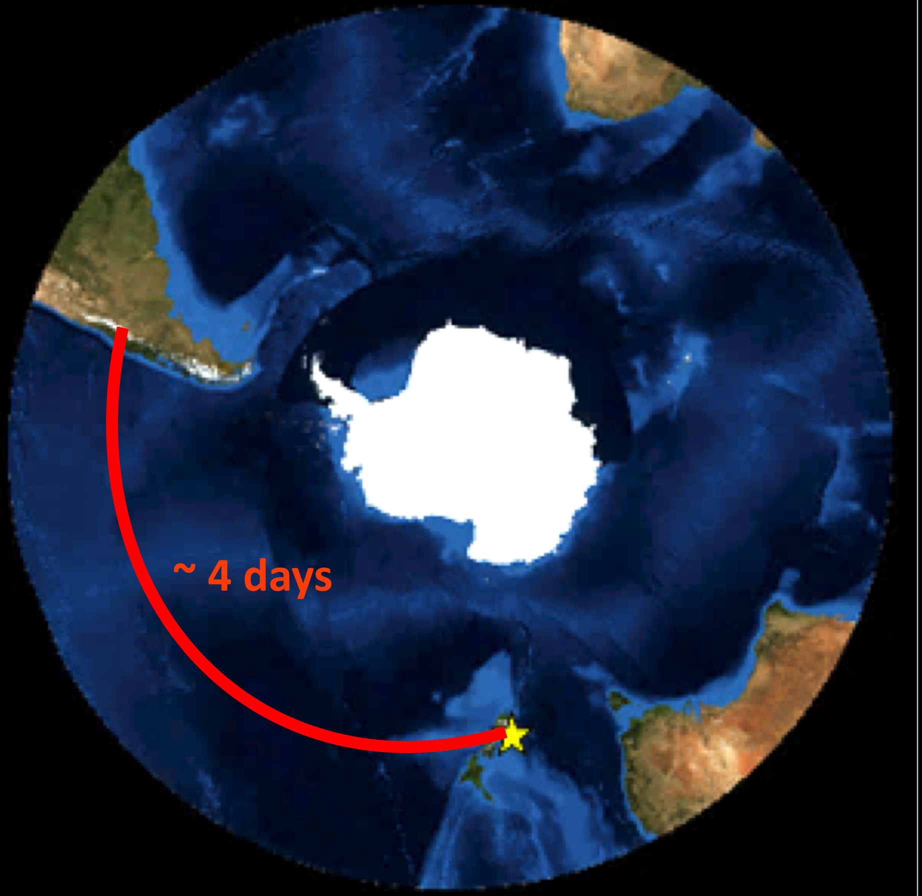


Photo-Detector Module (PDM)
3x3 ECs =
36 MAPMTS
2,304 pixels

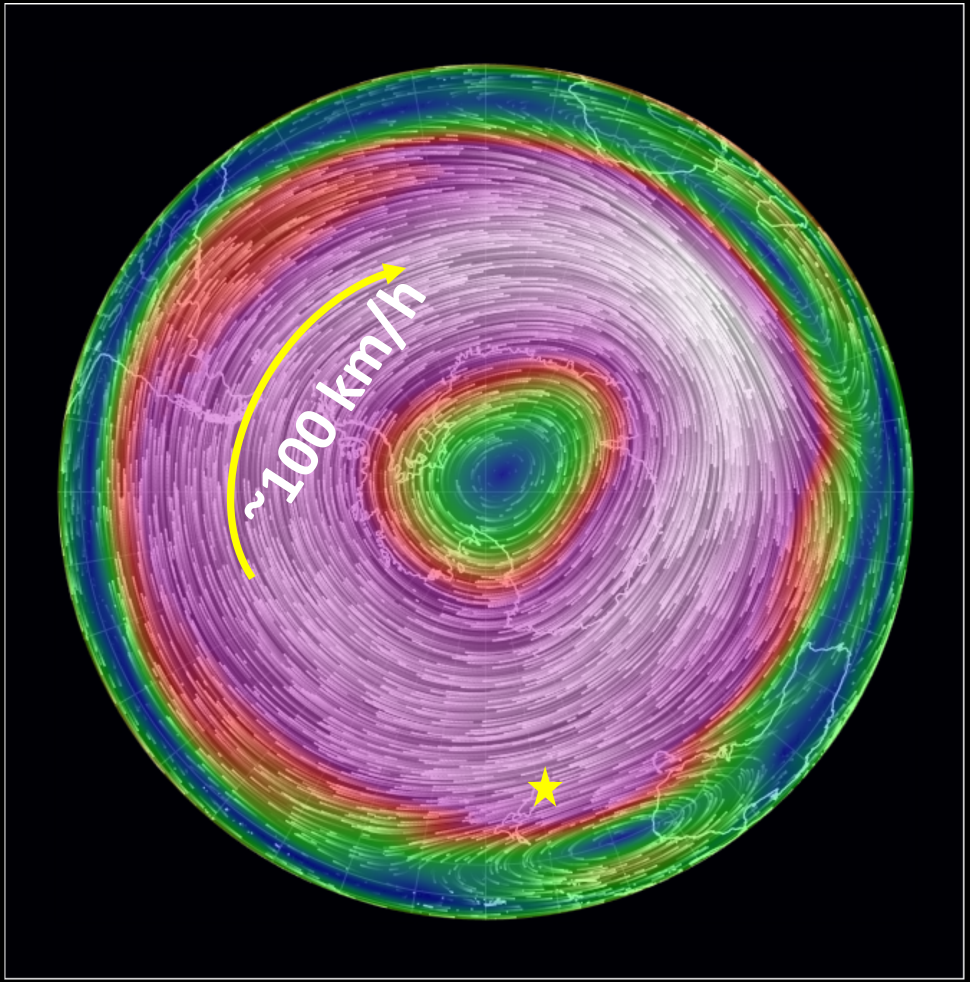



EUSO-SPB 1
launch, April 24, 2017
23:51 UTC

Why New Zealand?



Wanaka
South Island
New Zealand

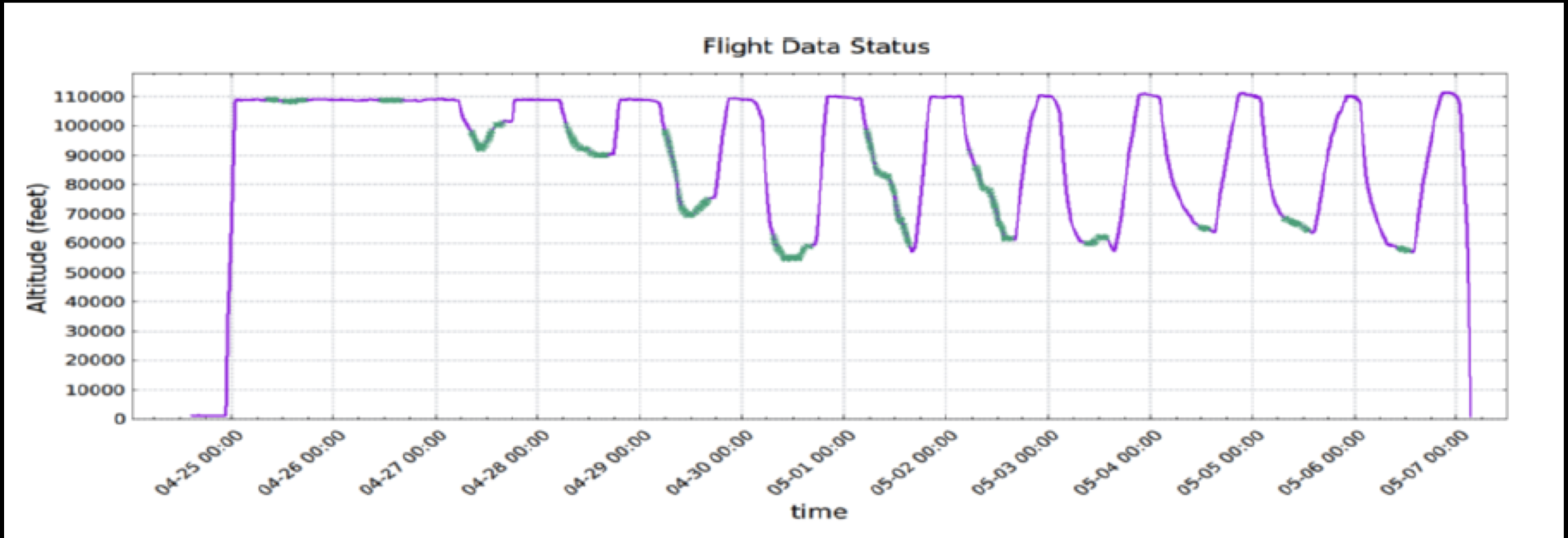


air flow at ~30 km June 9th 2017

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.

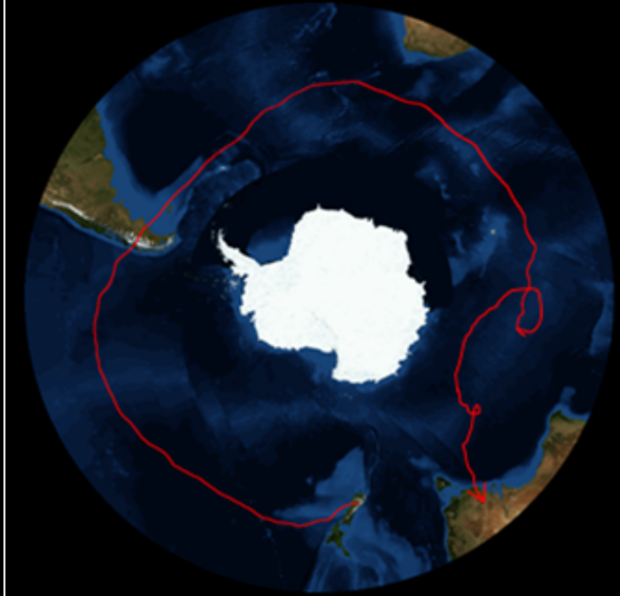


WANAKA 2017 Campaign

Super Pressure Balloon (SPB) EUSO mission

2015

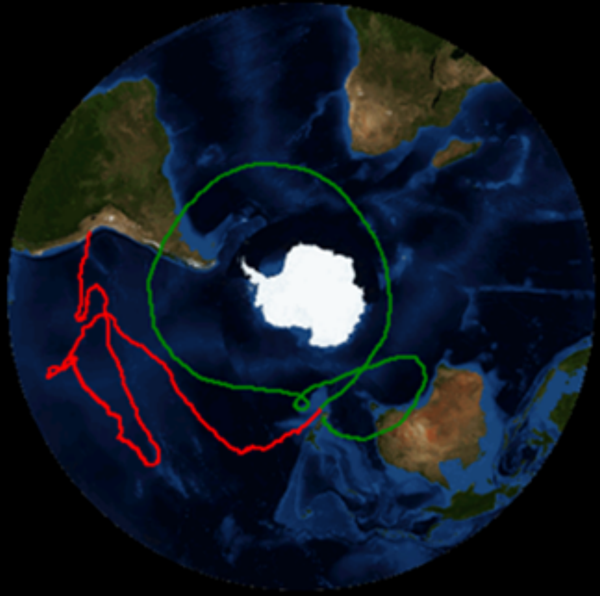
NASA **Engineering** Flight



32 d 5 h

2016

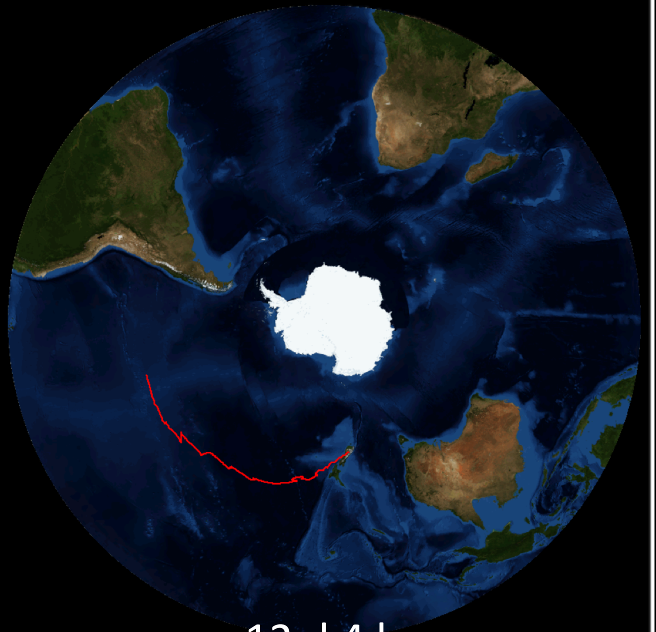
COSI



46 d 20 h

2017

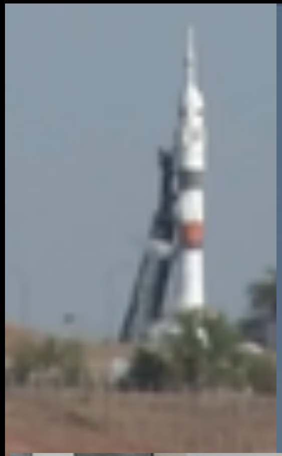
EUSO-SPB

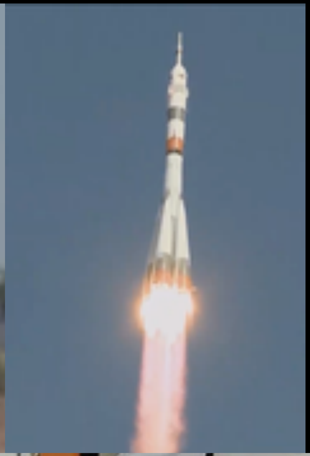


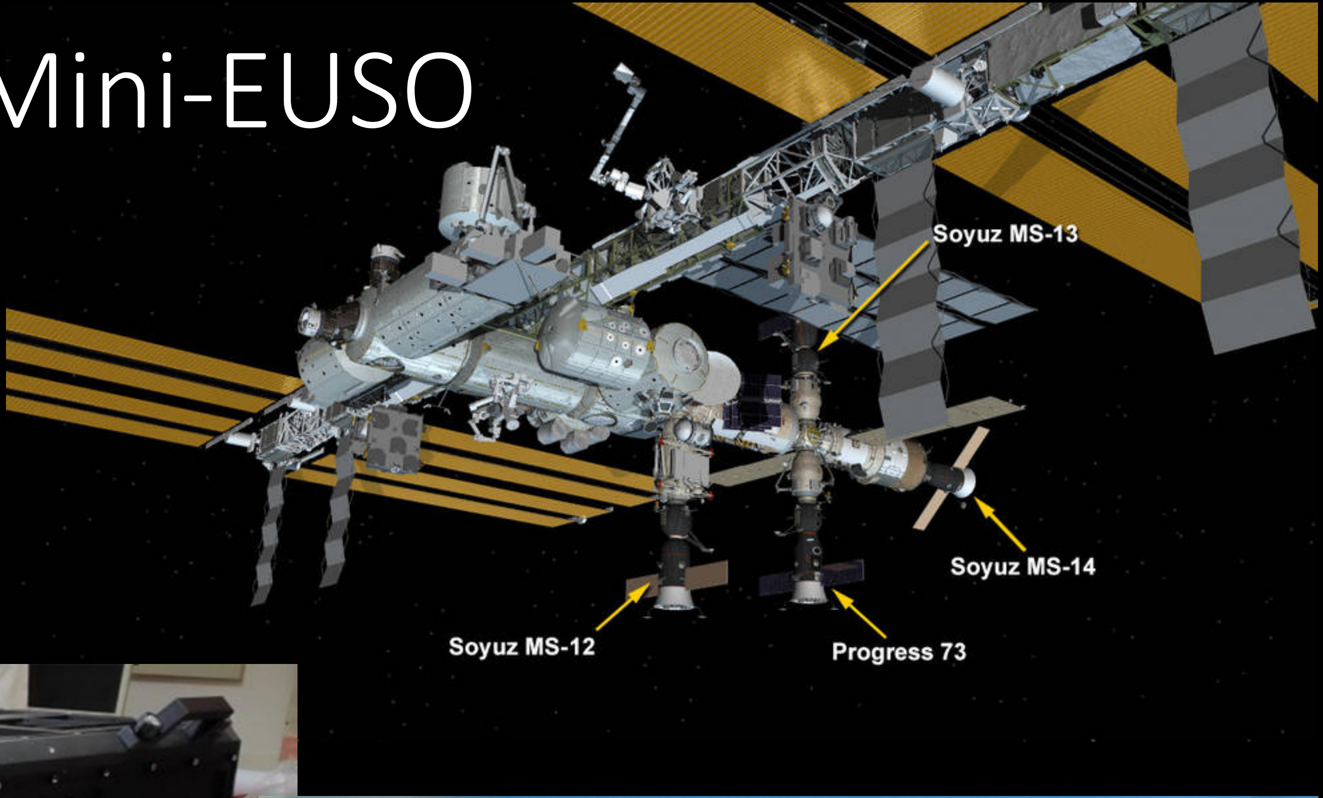
12 d 4 h

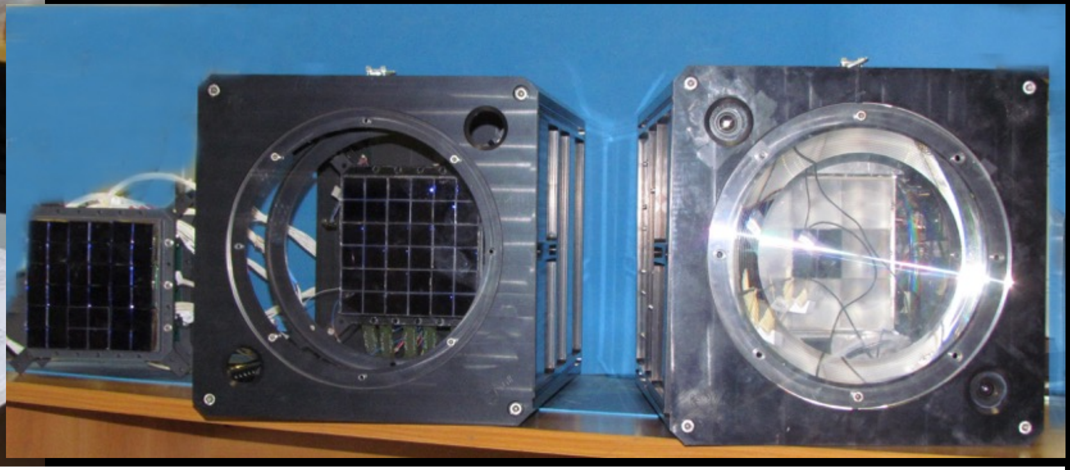
Mini-EUSO

Launch August 22, 2019







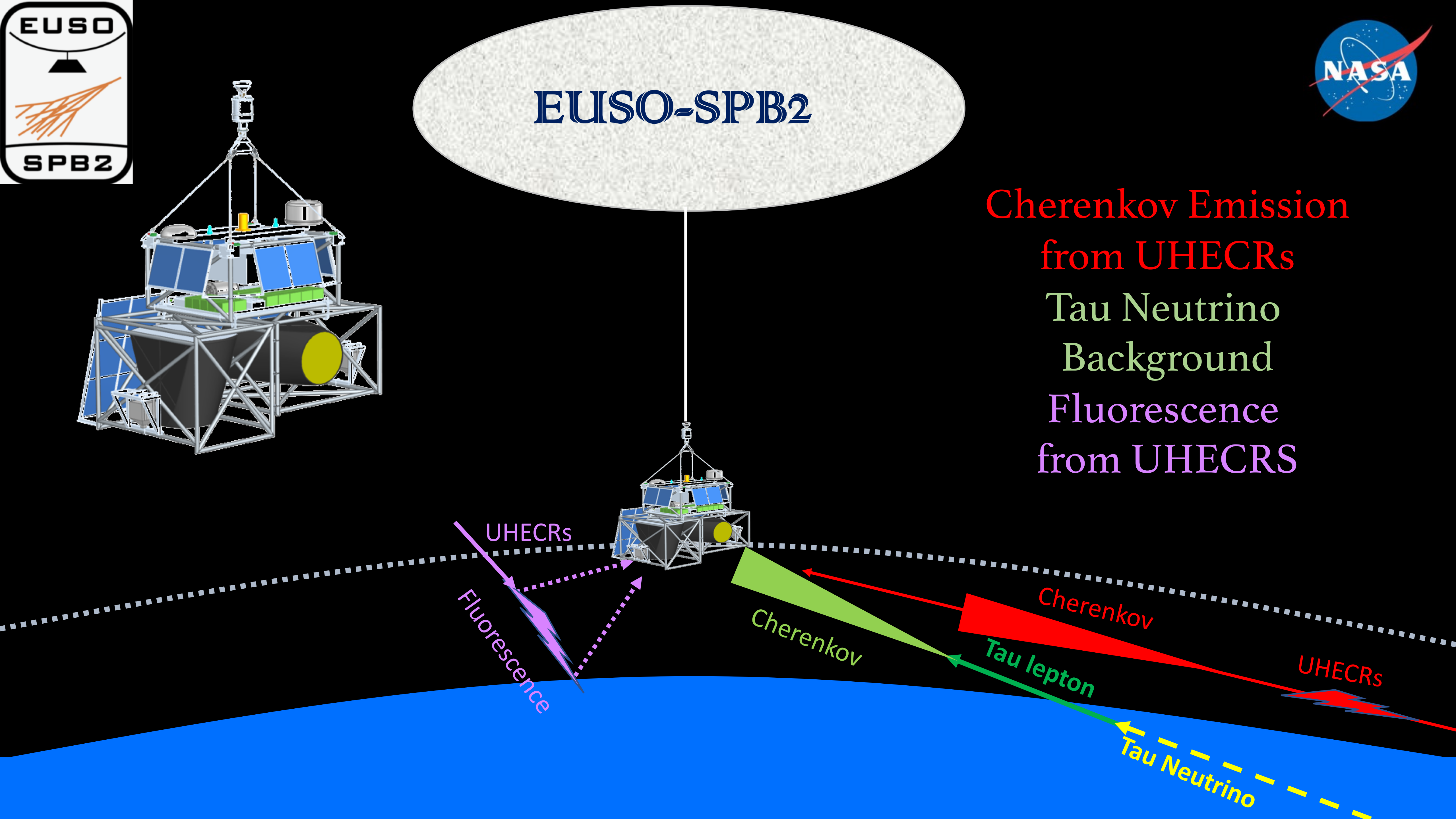


Soyuz MS-14 docked to the ISS

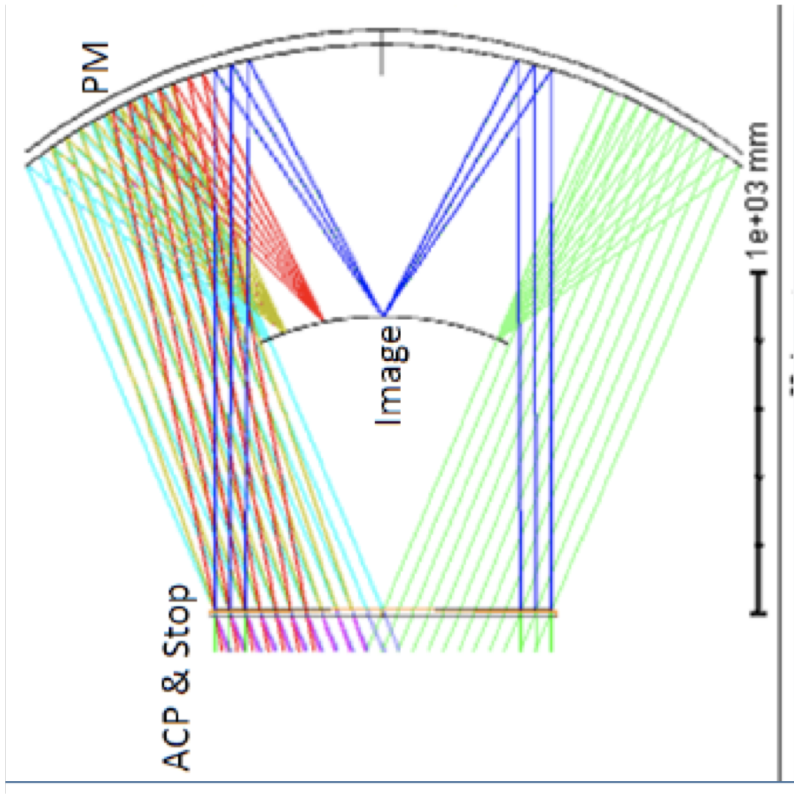
August 27, 2019, 03:10 GMT

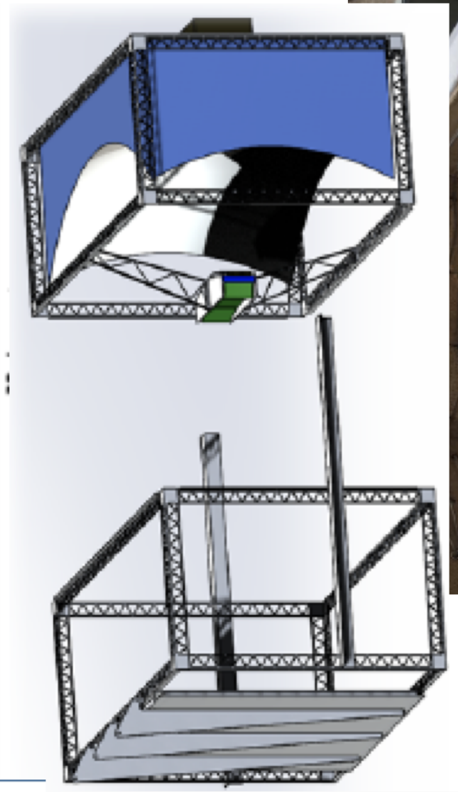
On August 27, 2019, the Soyuz MS-14 spacecraft docked to the Zvezda module of the International Space Station. The crew is now preparing to open the hatches.

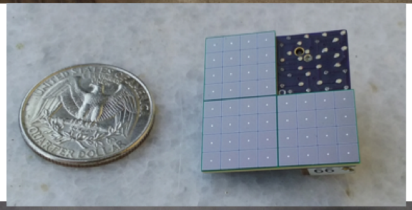
Планета Королёва — «УФ атмосфера»


EUSO
SPB2
EUSO-SPB2
NASA
Cherenkov Emission
from UHECRs
Tau Neutrino
Background
Fluorescence
from UHECRS
UHECRs
Fluorescence
Cherenkov
Cherenkov
Tau lepton
UHECRs
Tau Neutrino

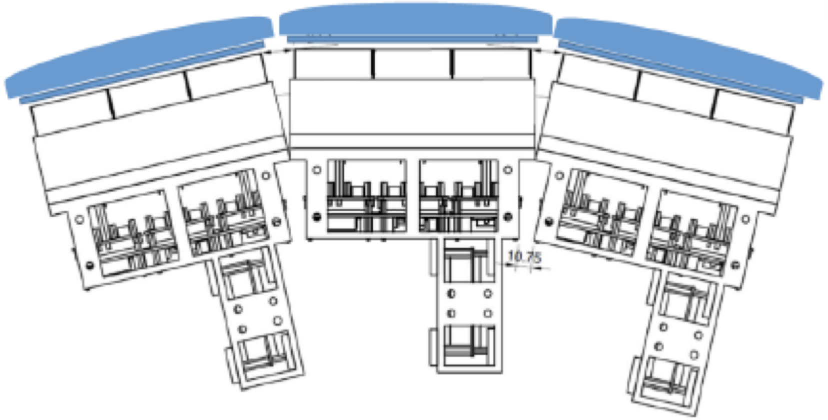
EUSO-SPB2



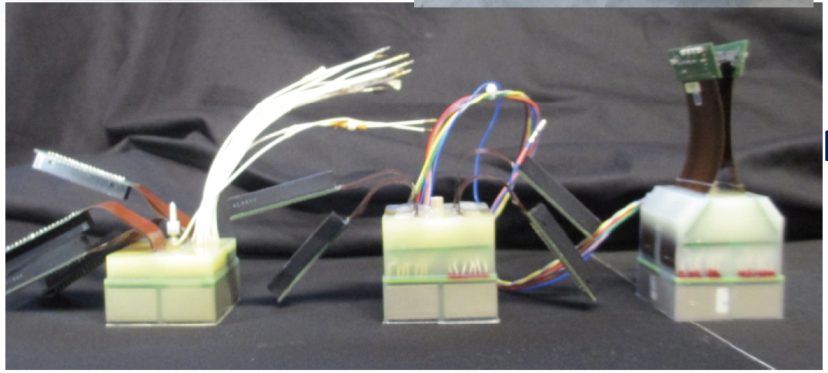




Cherenkov camera SiPMs



Launch target Spring 2022



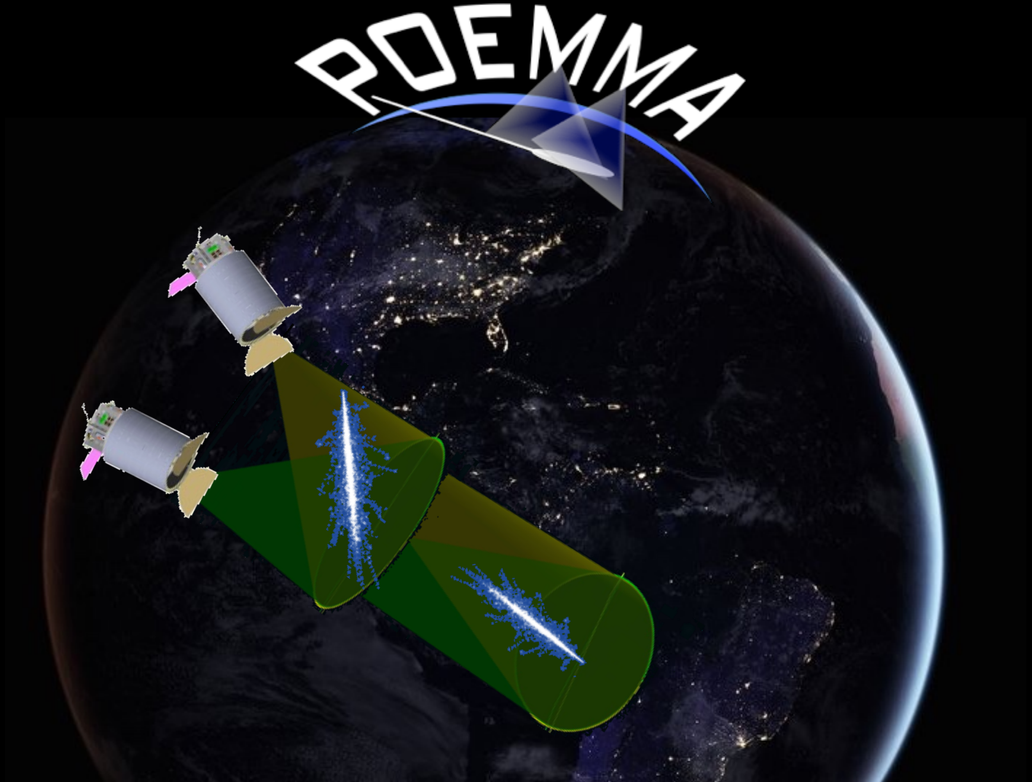
2014	2016	2018
4PMT	4PMT	4PMT
	+ CW board	+ CW board
		+ ASIC boards

Fluorescence camera MAPMs

POEMMA & EUSO-SPB2

Earth's Atmosphere = Particle Observatory :

- Discover the Origin of the Highest Energy Cosmic Rays ($E>10^{19}$ eV) and
- Discover 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