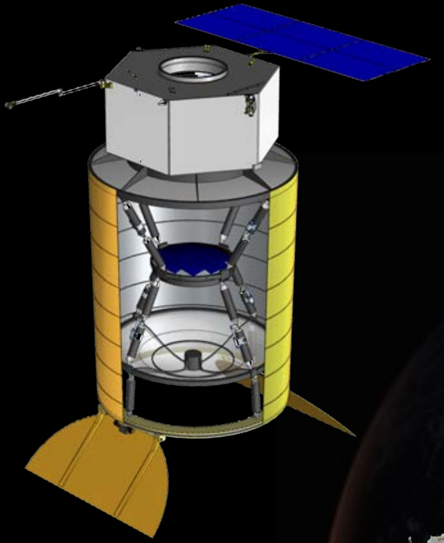


POEMMA

Probe Of Extreme Multi-Messenger Astrophysics

UHECRs and Cosmic Neutrinos

Angela V. Olinto

THE UNIVERSITY OF CHICAGO

POEMMA: study collaboration

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

NASA/MSFC: Mark J. Christl (deputy PI), Roy M. Young, Peter Bertone

University of Alabama, Huntsville: James Adams, Patrick Reardon, Evgeny Kuznetsov,

NASA/GSFC: John W. Mitchell, John Krizmanic, Jeremy S Perkins, Julie McEnery, Elizabeth Hays, Floyd Stecker, Tonia Venters

University of Utah: Doug Bergman

Colorado School of Mines: Lawrence Wiencke, Frederic Sarazin, J. Eser

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

Georgia Institute of Technology: A. Nepomuk Otte

Space Sciences Laboratory, University of California, Berkeley: Eleanor Judd

University of Iowa: Mary Hall Reno

ITALY: Universita di Torino: Mario Edoardo Bertaina, Francesco Fenu, Kenji Shinozaki; INFN Torion: F. Bisconti; Gran Sasso Science Institute: Roberto Aloisio, A. L. Cummings, I. De Mitri; INFN Frascati: Marco Ricci

FRANCE: APC Univerite de Paris 7: Etienne Parizot, Guillaume Prevot; IAP, Paris: C. Guepin

SWITZERLAND: University of Geneva: Andrii Neronov

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

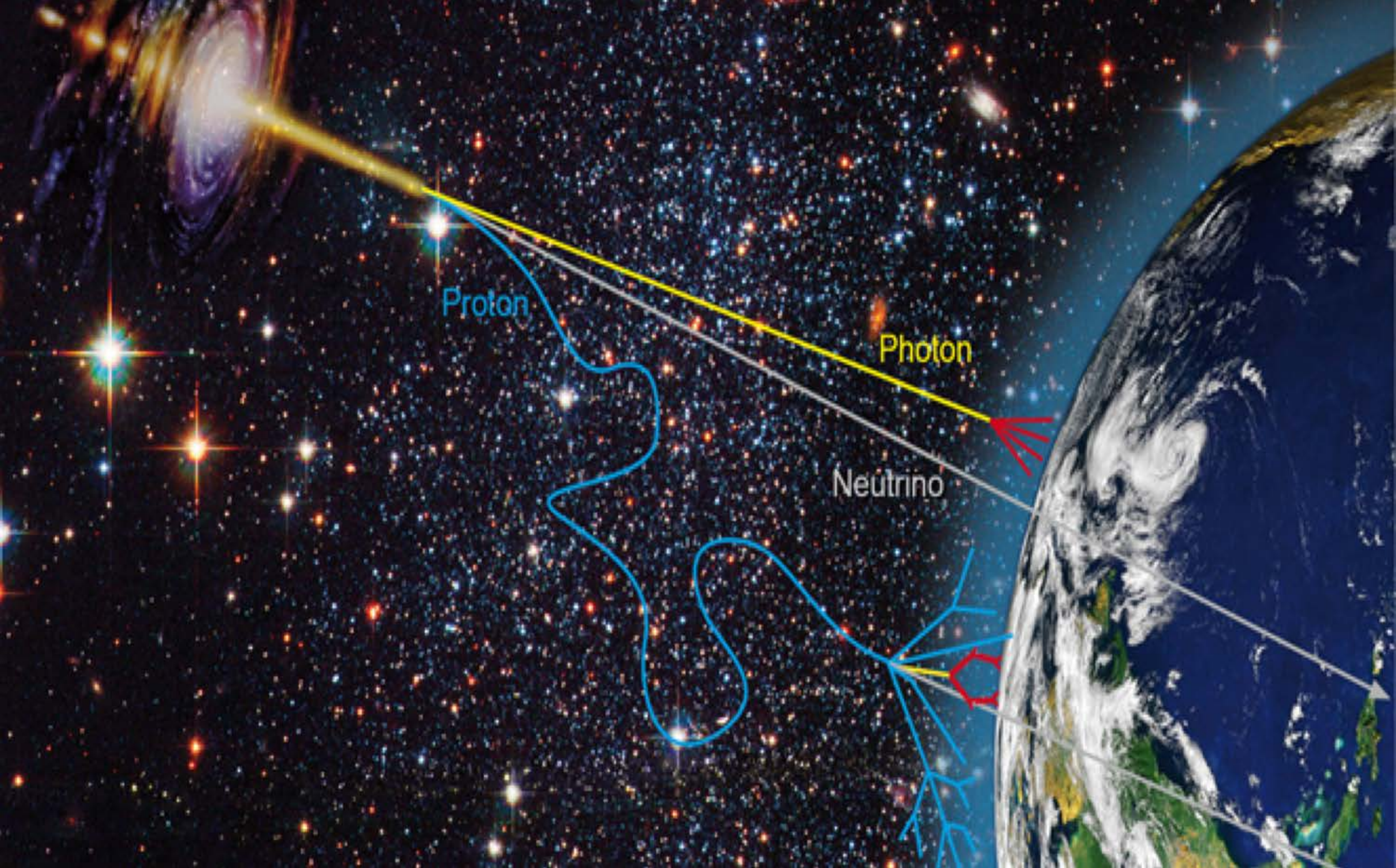
JAPAN: RIKEN: M. Casolino

GERMANY: KIT: M. Unger; ESO: F. Oikonomou

Scientists from 16+ institutions from

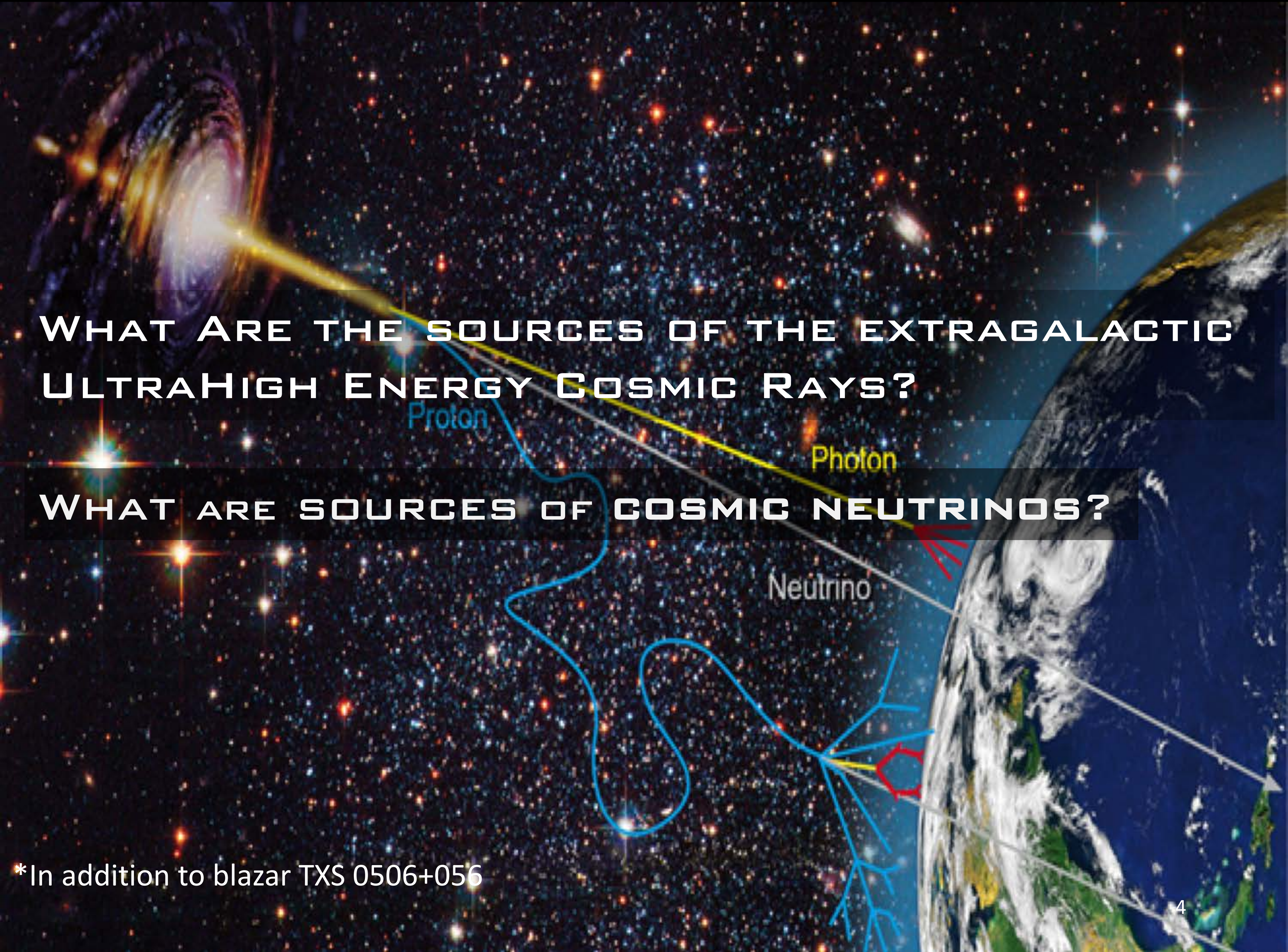
OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

The Earth Atmosphere as a Sub-Atomic Particle Detector



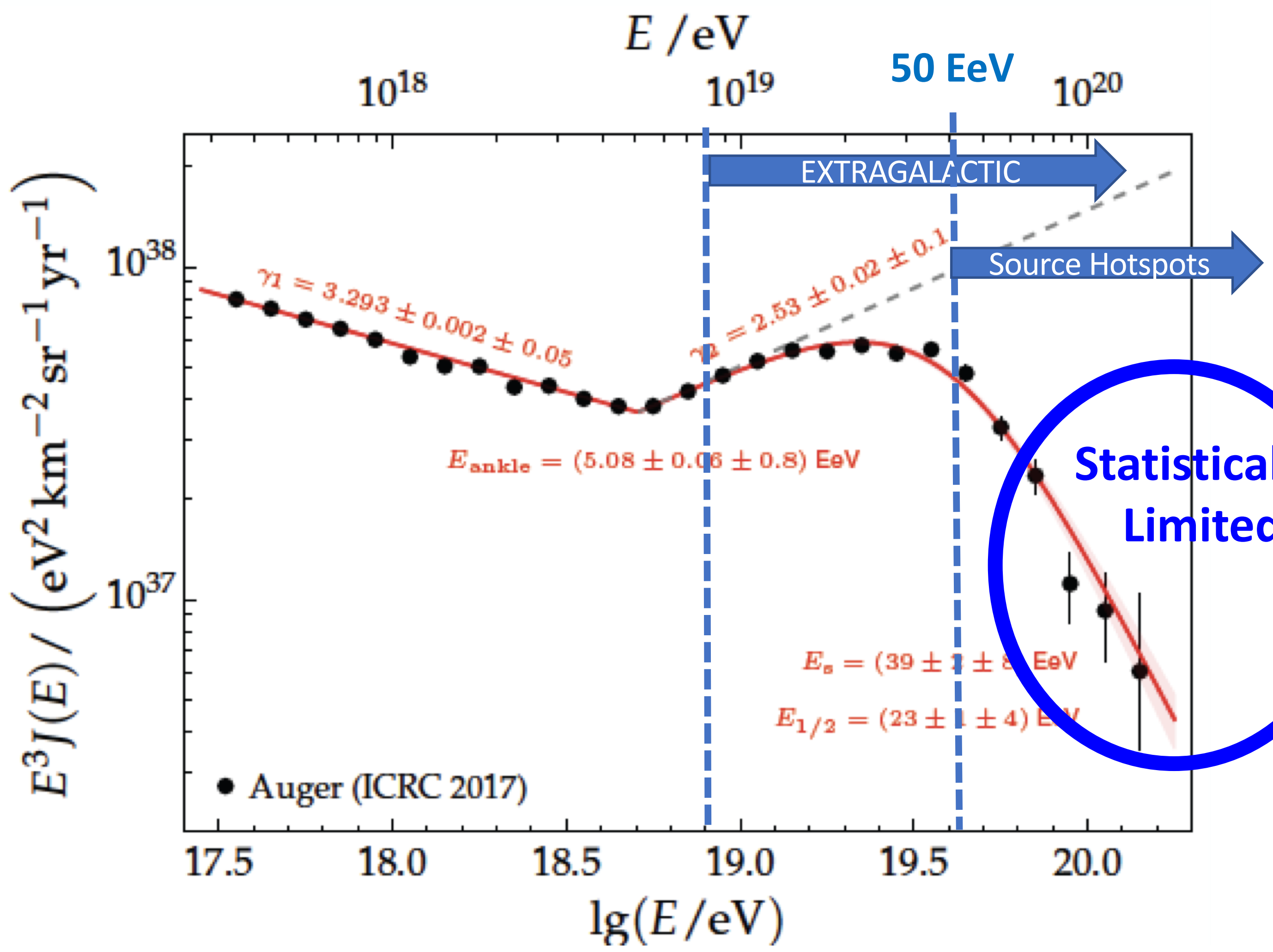
What Are the sources of the extragalactic UltraHigh Energy Cosmic Rays?

What are sources of cosmic neutrinos?



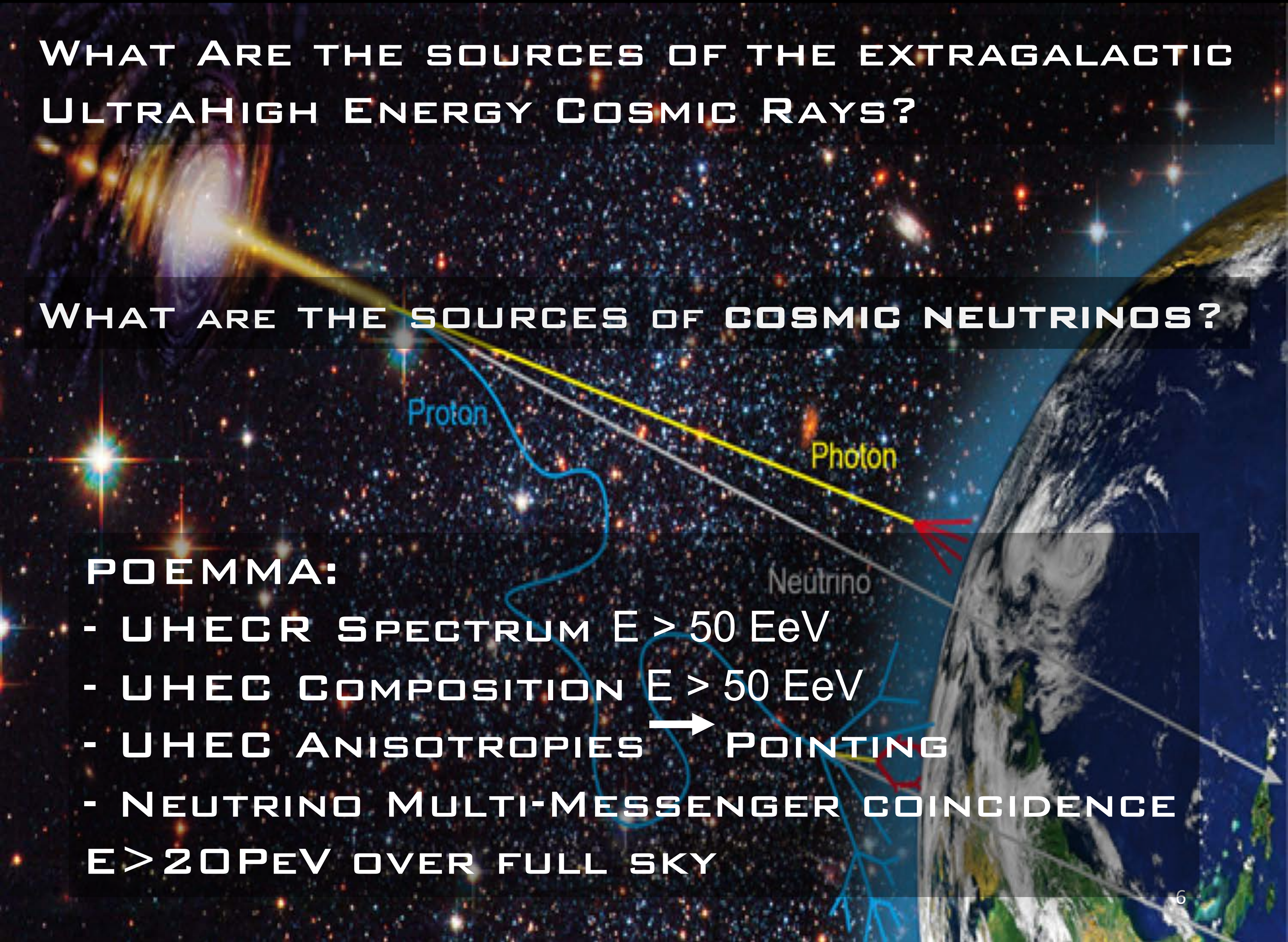
*In addition to blazar TXS 0506+056

UHECR Challenge



What Are the sources of the extragalactic UltraHigh Energy Cosmic Rays?

What are the sources of cosmic neutrinos?



POEMMA:

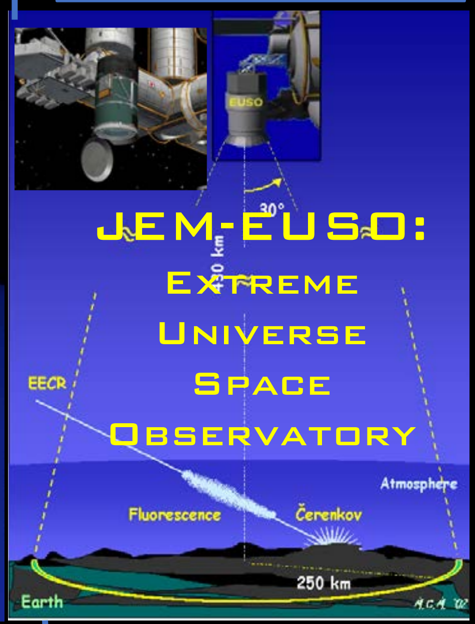
- UHECR Spectrum E > 50 EeV
- UHEC Composition E > 50 EeV
- UHEC Anisotropies → Pointing
- Neutrino Multi-Messenger coincidence E>20PeV over full sky

POEMMA: Probe of Extreme Multi-Messenger Astrophysics

Based on OWL 2002 study, JEM-EUSO, EUSO balloon & SPB experience, and CHANT proposal

Orbiting Wide-angle Light-collectors

TUS, KLYPVE-EUSO

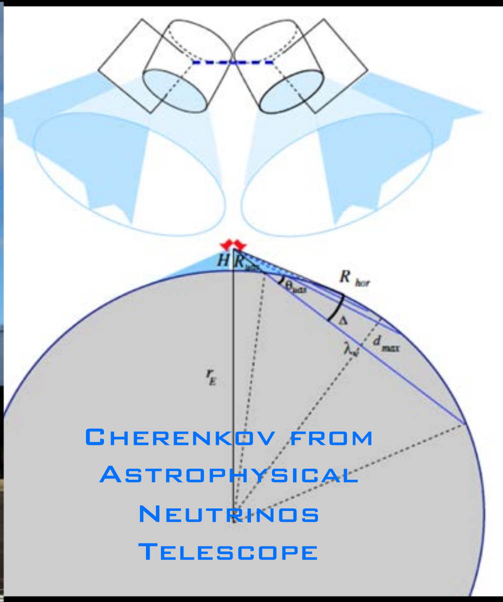


EUSO-Balloon
EUSO@TA
Mini-EUSO

EUSO-SPB1

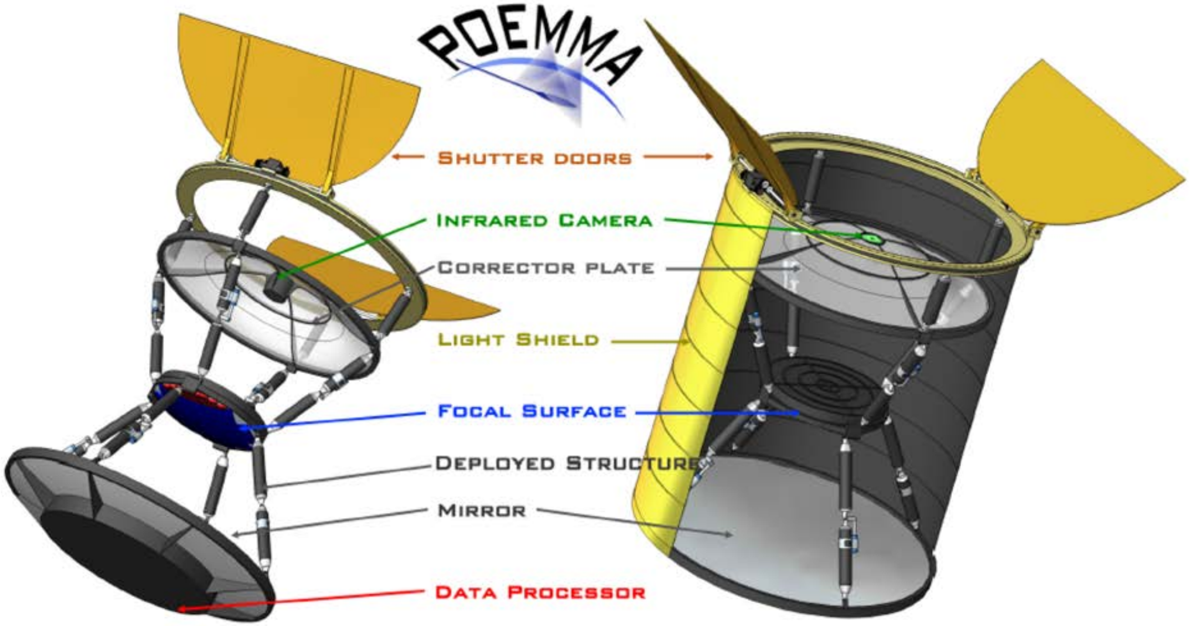
EUSO-SPB2

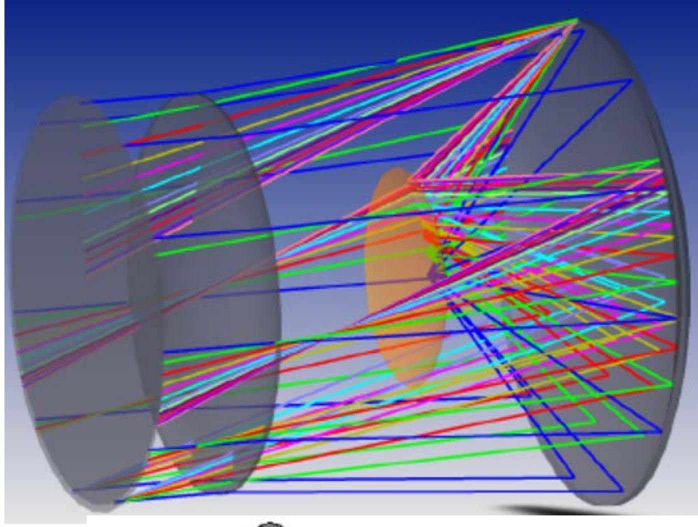
CHANT



POEMMA IDL MDL at GSFC IDC

IDL Jul 31-aug 4, 2017
MDL Oct 30-Nov 3, 2017





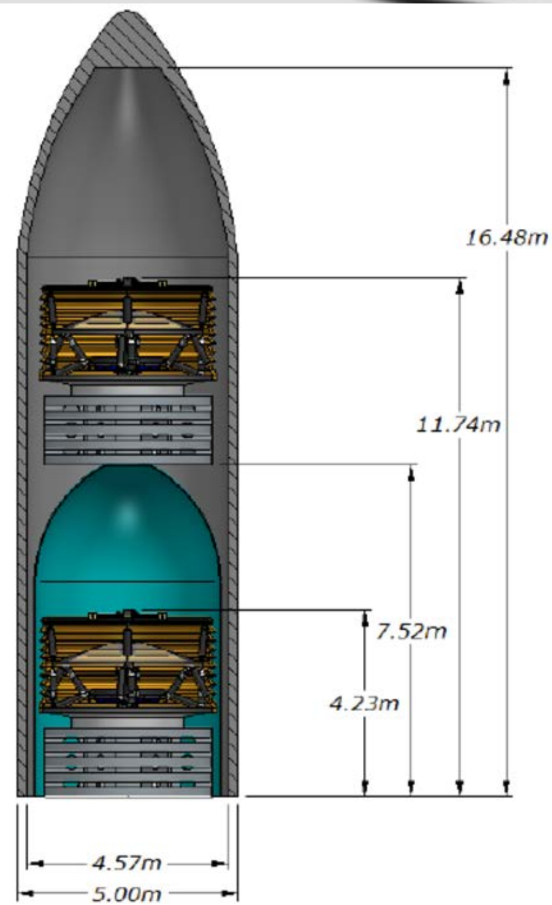


TABLE I: POEMMA Specifications:

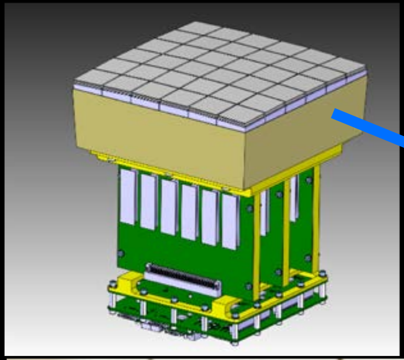
Photometer	Components		Spacecraft	
Optics	Schmidt	45° full FoV	Slew rate	90° in 8 min
	Primary Mirror	4 m diam.	Pointing Res.	0.1°
	Corrector Lens	3.3 m diam.	Pointing Know.	0.01°
	Focal Surface	1.6 m diam.	Clock synch.	10 nsec
	Pixel Size	3×3 mm^2	Data Storage	7 days
	Pixel FoV	0.084°	Communication	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

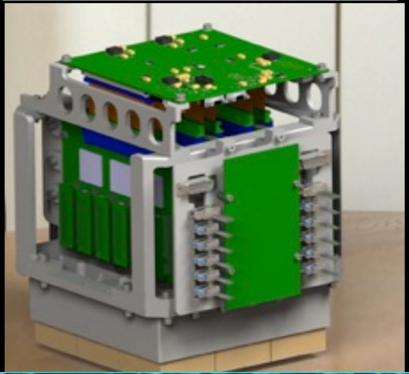
Each Observatory = Photometer + Spacecraft; POEMMA Mission = 2 Observatories

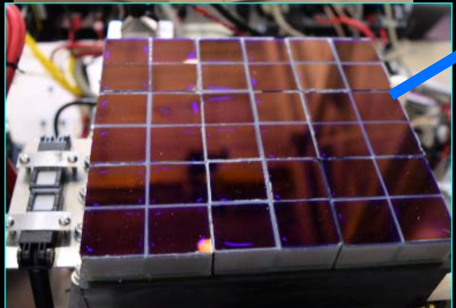
POEMMA

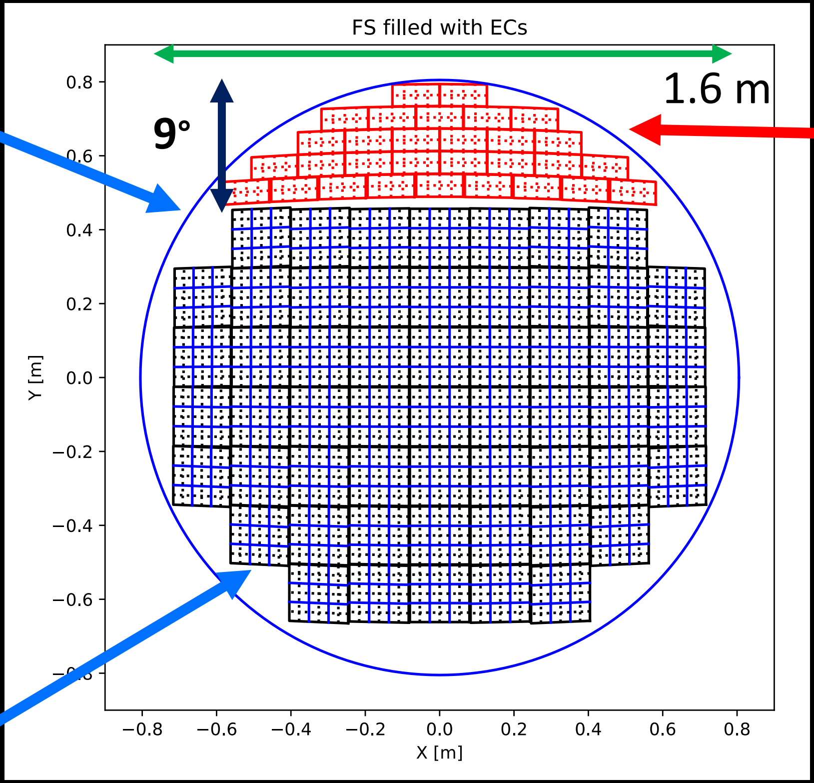
Hybrid MM Focal Surface

UV Fluorescence
MAPMTs with BG3 filter:
JEM-EUSO: 1 usec sampling

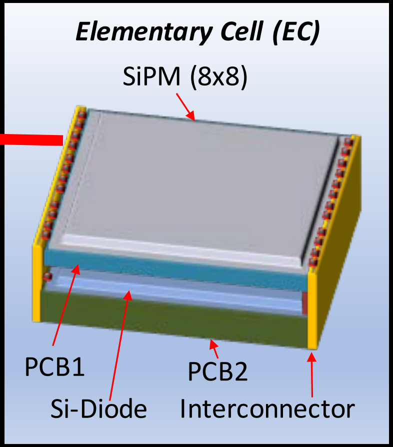








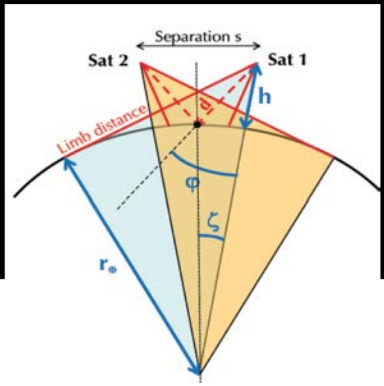
Cherenkov Detection with SiPMs:
20 nsec sampling

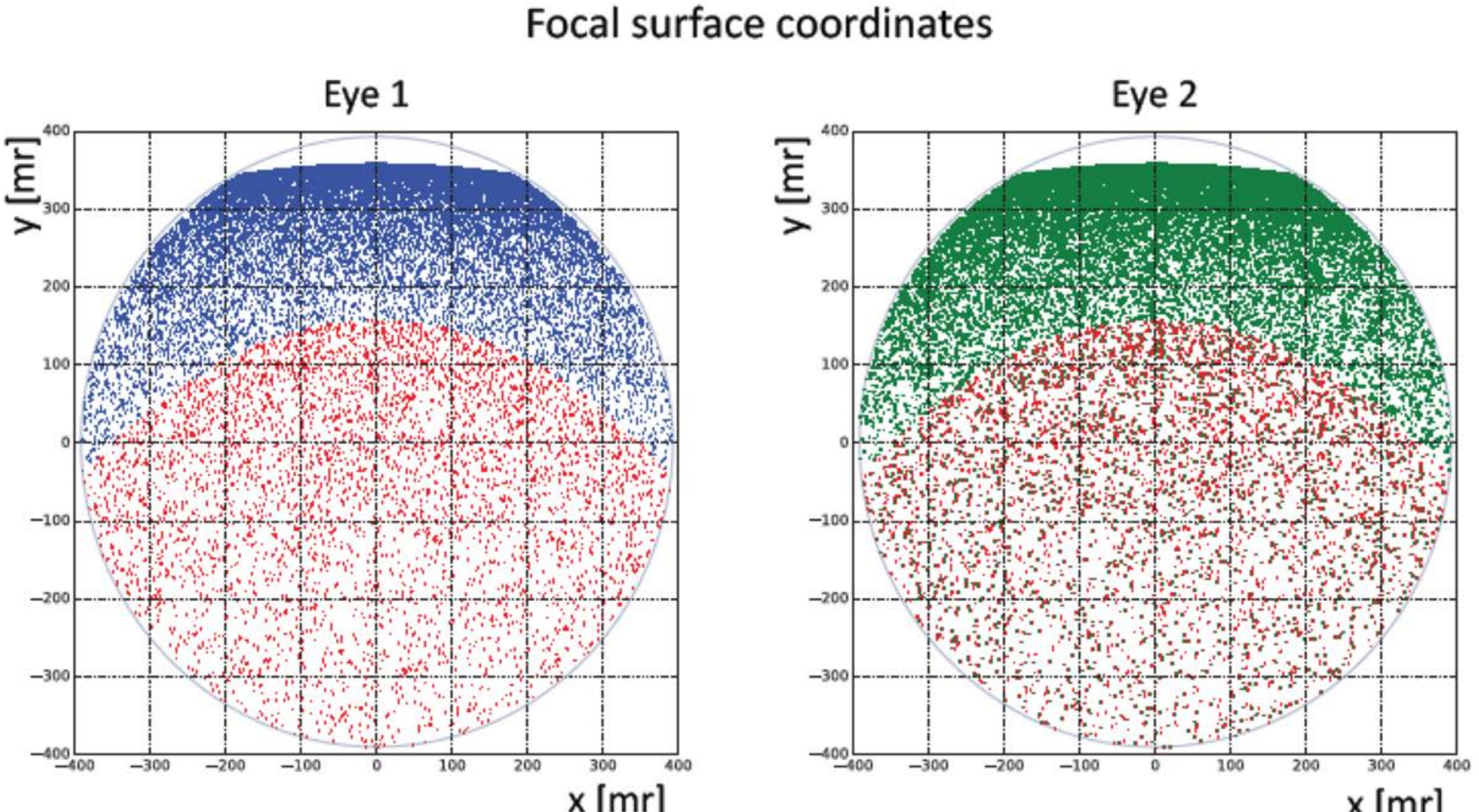


30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)
Si-Diode for LEO radiation backgrounds rejection

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

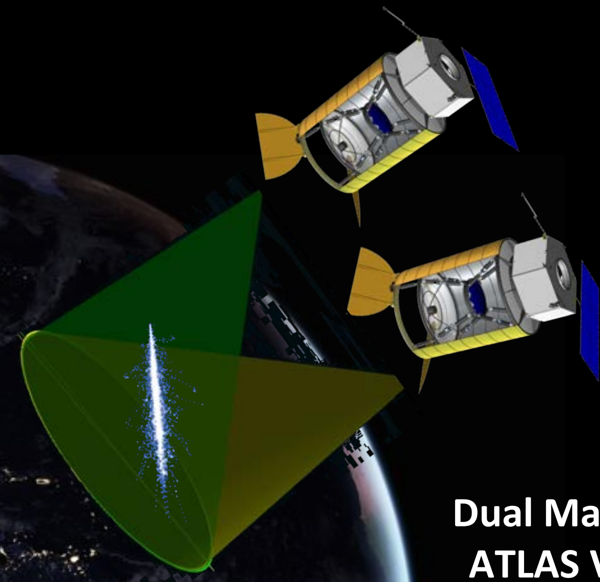
FOV 2˚ above limb





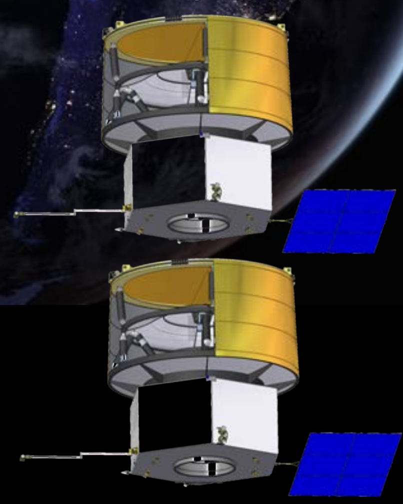
POEMMA MISSION

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

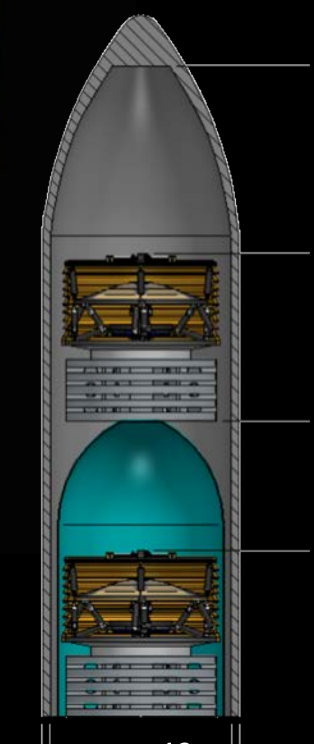


Operations:

- 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

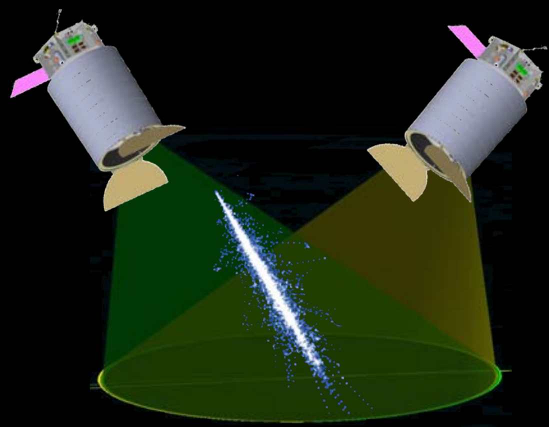


Dual Manifest
ATLAS V LPF



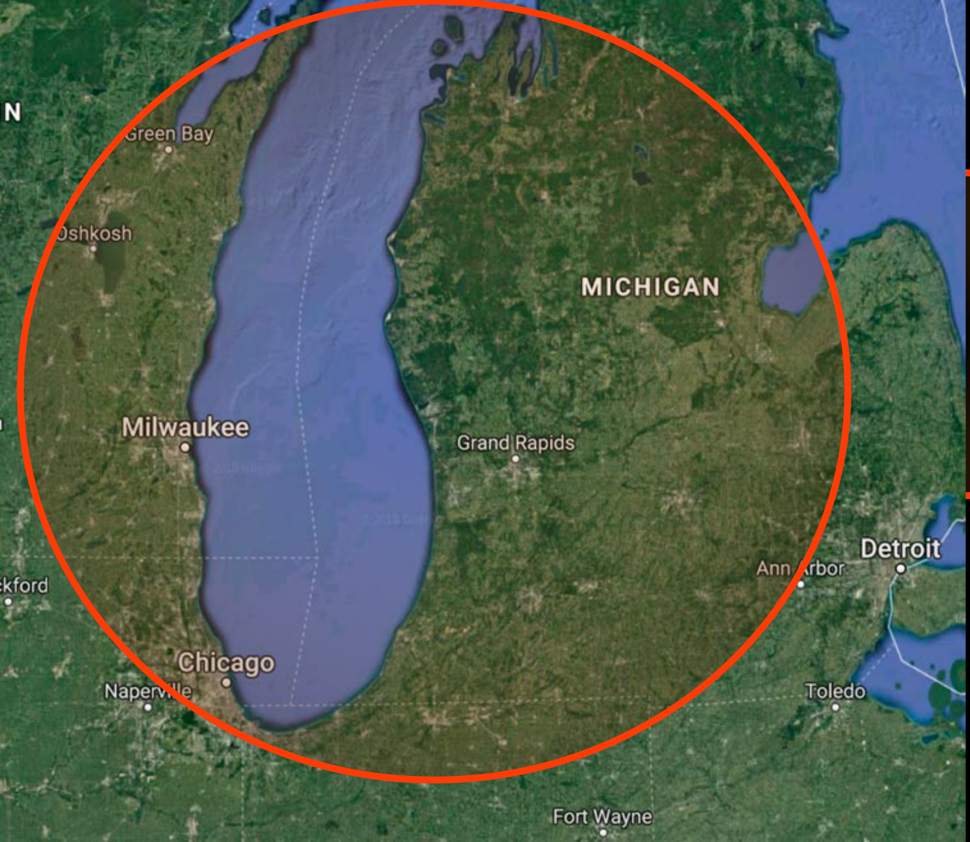
POEMMA

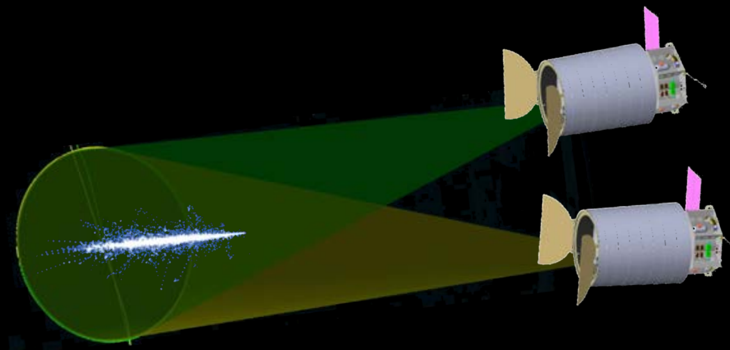
Observing Modes



Nadir for UHECR:

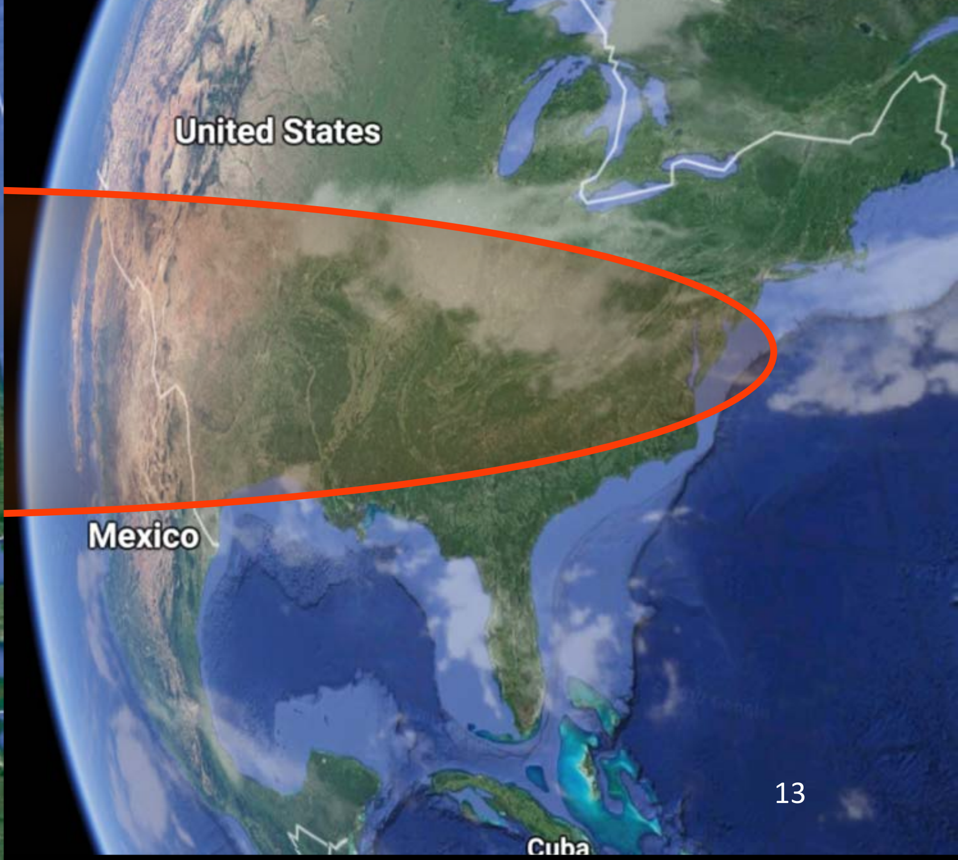
Radius 200-400 km



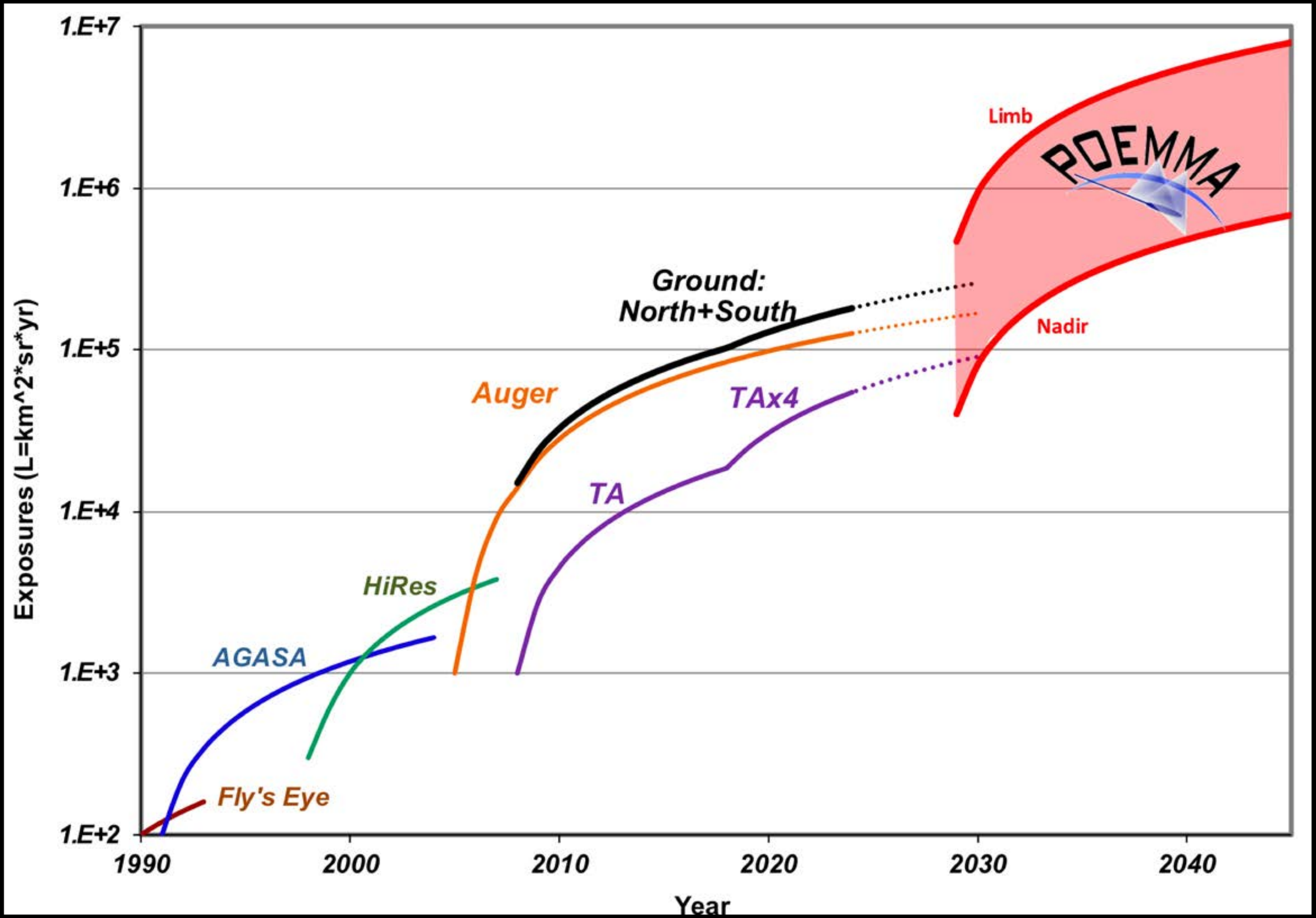


Limb for Neutrinos & UHECRs

Radius 2.6-3.7 10^3 km

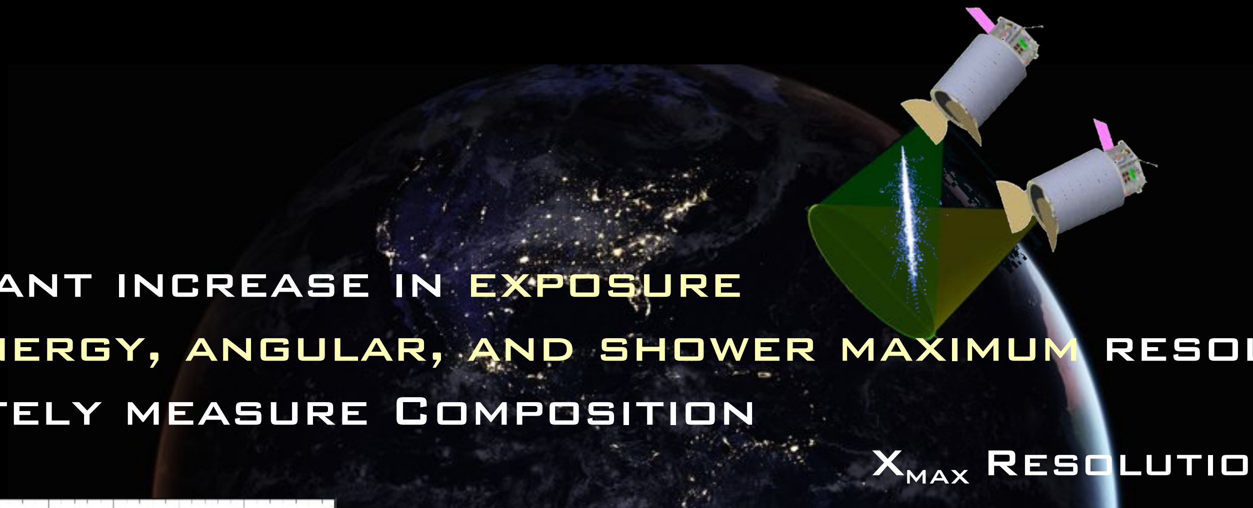


POEMMA: Exposure History



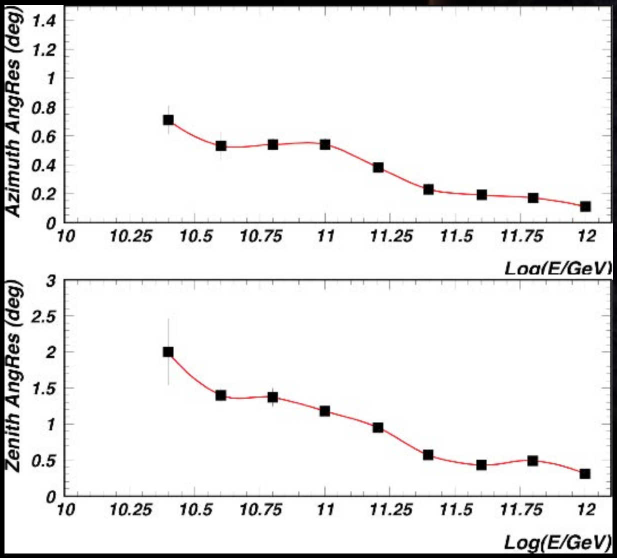
POEMMA UHECRs

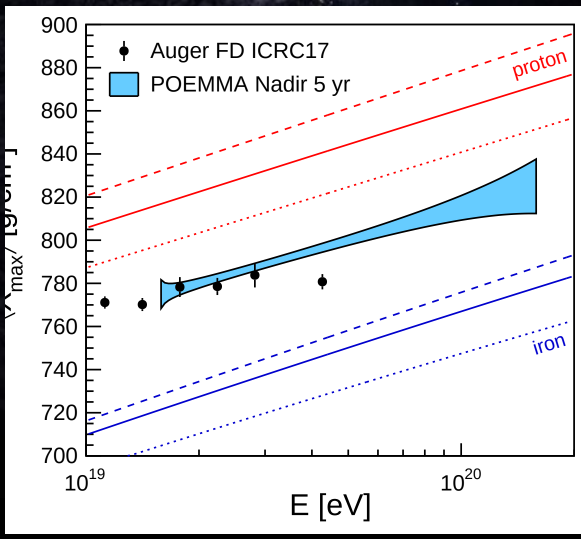
Performance

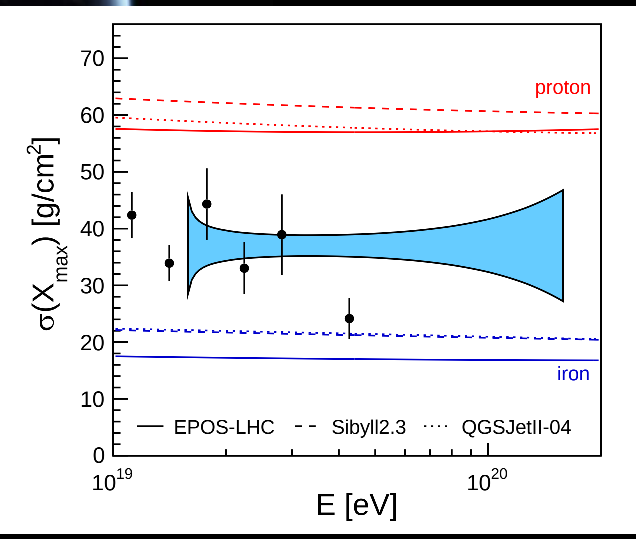


- Significant increase in **exposure**
- Good **energy, angular, and shower maximum** resolutions,
- Accurately measure Composition

X_{MAX} Resolution ~ 30 g/cm^2



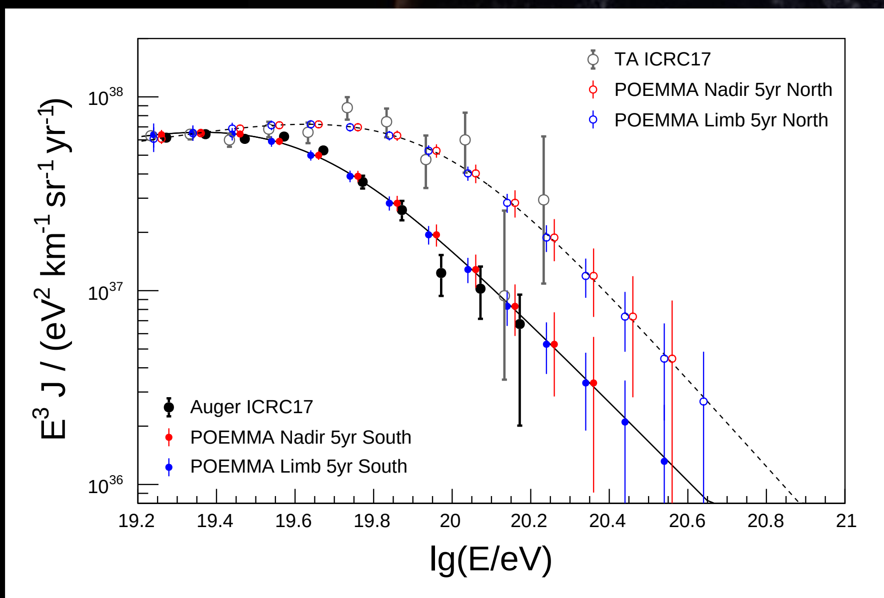


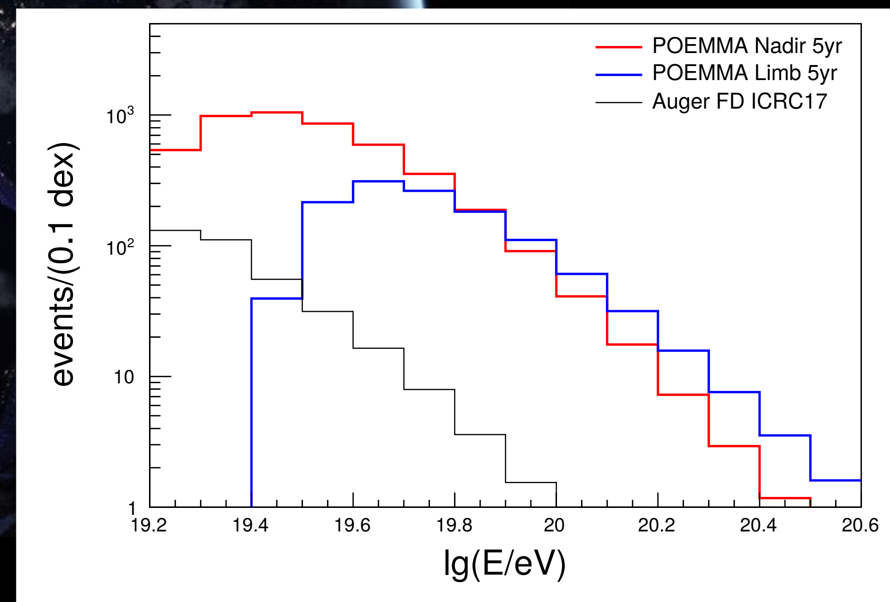


POEMMA UHECRs

Performance

- Significant increase in exposure
- Good energy, angular, and shower maximum resolutions,
- accurately measure Composition, Spectrum





POEMMA UHECRs

Performance

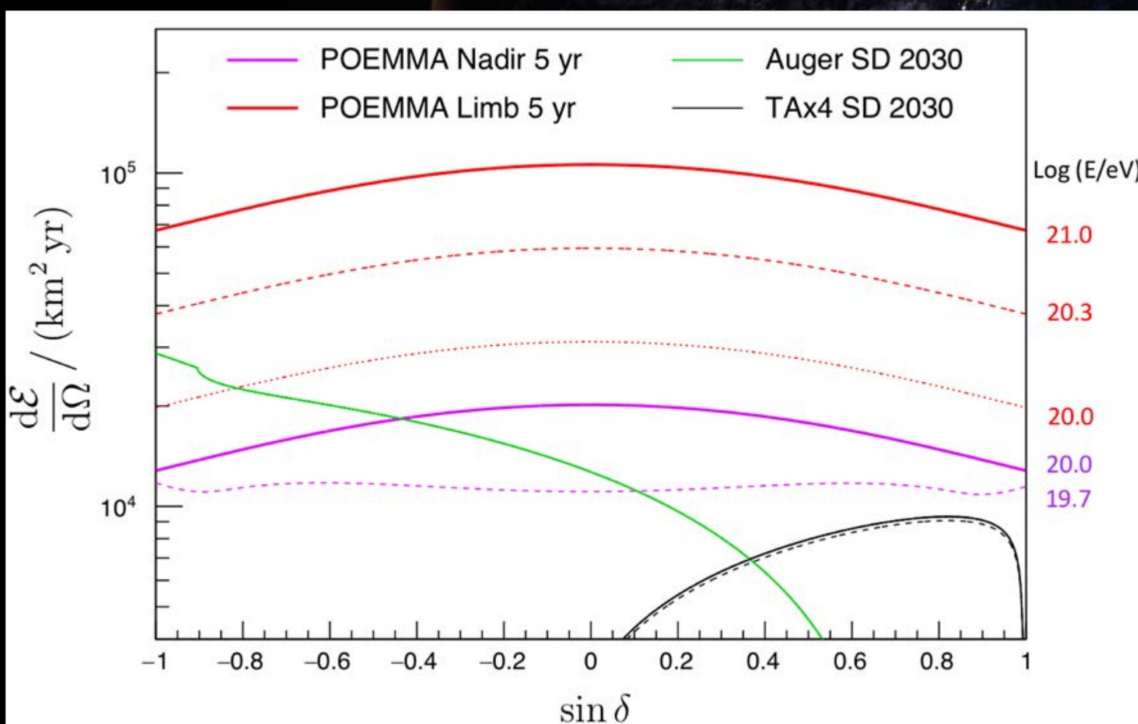
significant increase in exposure E >50 EeV

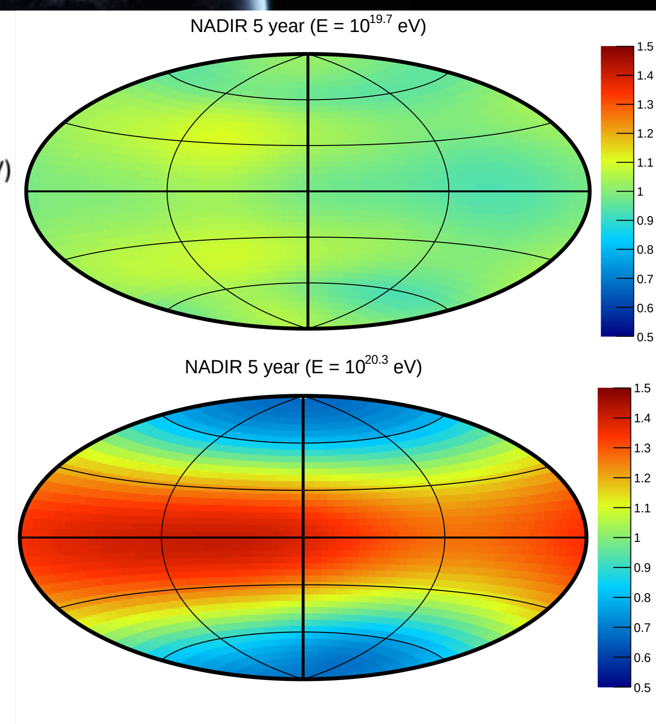
good energy, angular, and shower maximum resolutions,

accurately measure Composition, Spectrum, Anisotropies

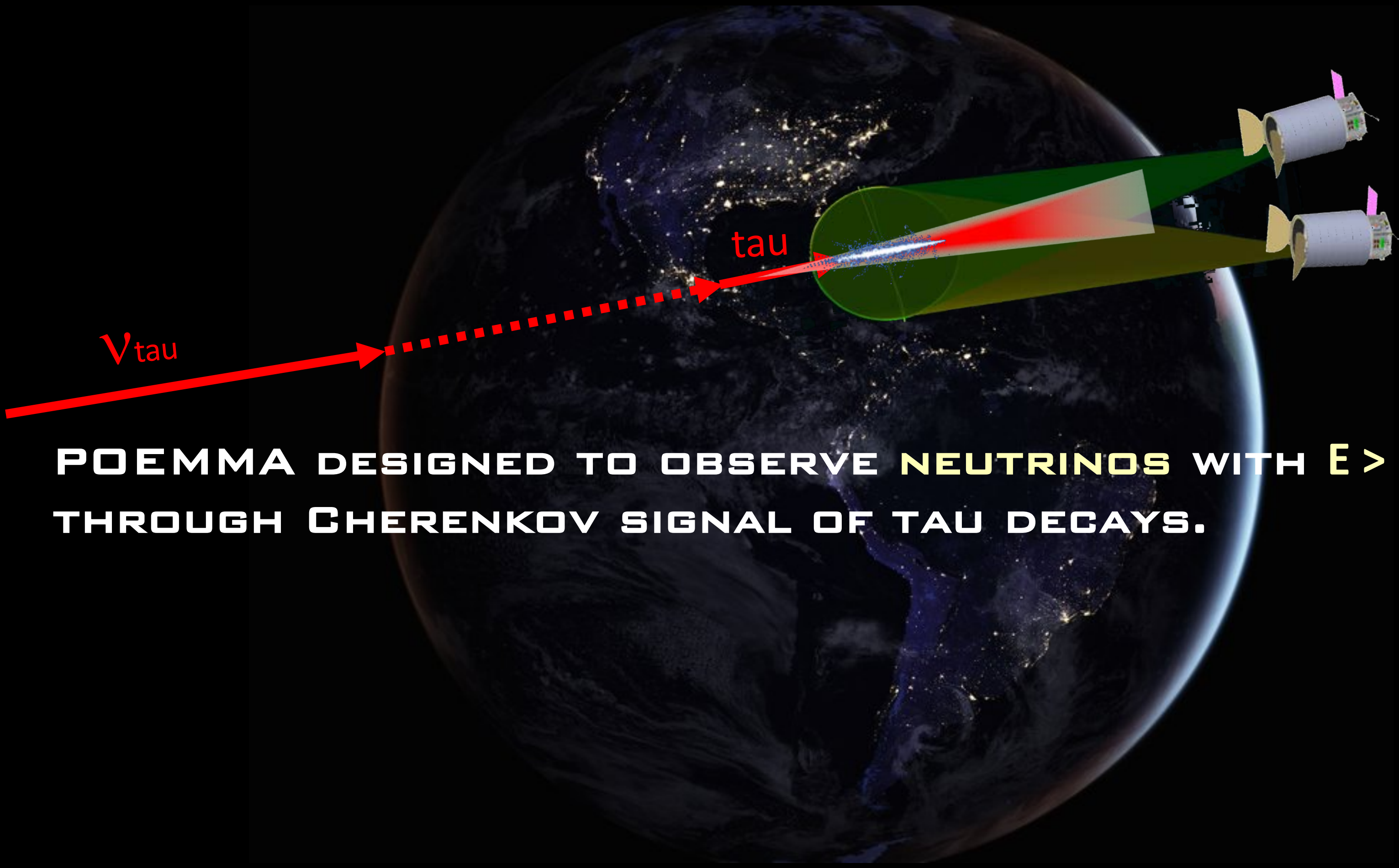
Uniform sky coverage

to guarantee the discovery of UHECR sources



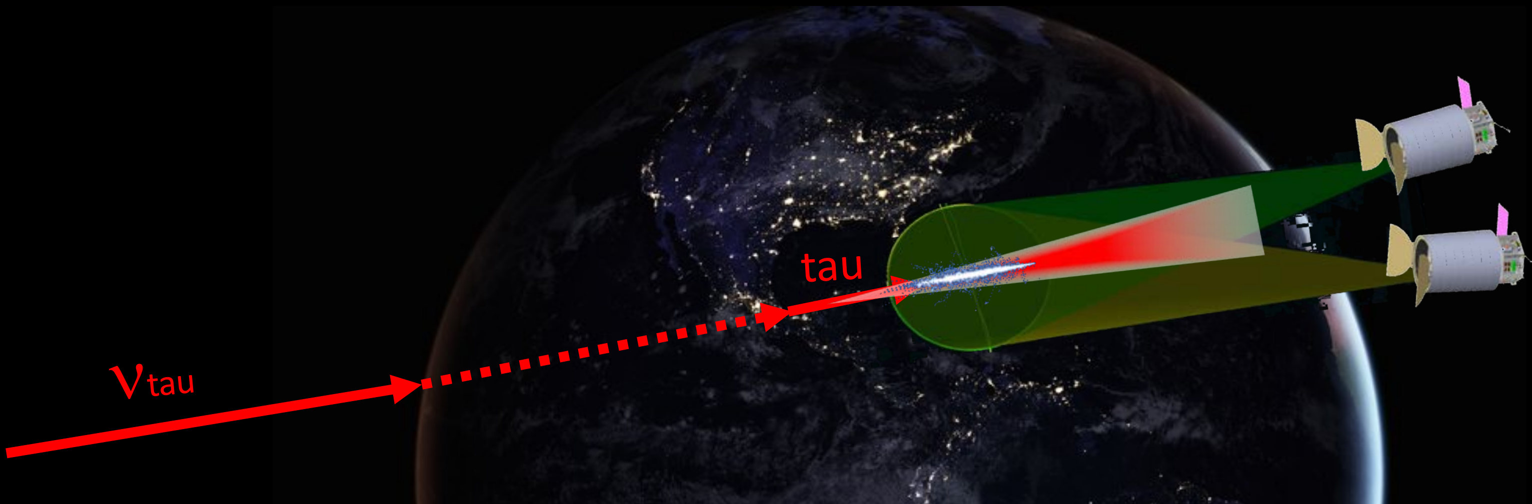


POEMMA Neutrinos



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

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 TOO

(Targets of Opportunity)

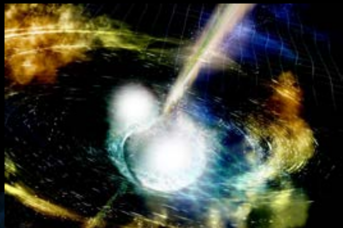
Venters et al 2019

Transient Events

few to 100 Million neutrinos/event

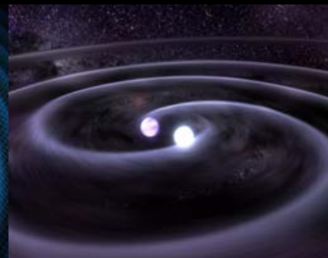
10 neutrinos up to 120 Mpc!

arXiv:1906.07209

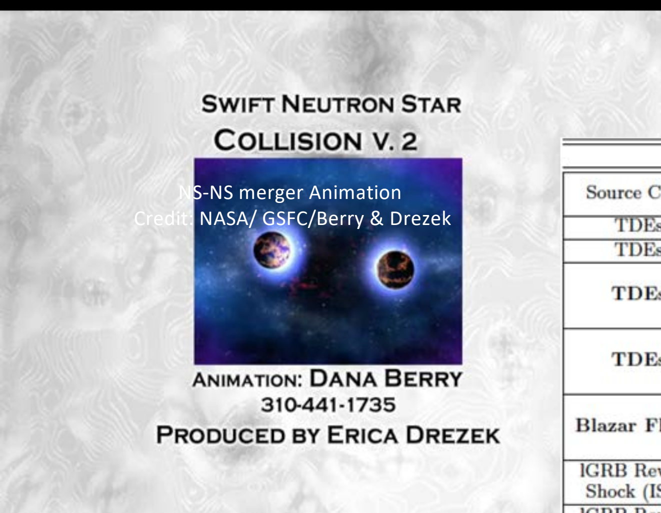


Artist's rep NS-NS merger.
Credit: Credit: NSF/LIGO/
SSU/A. Simonnet.

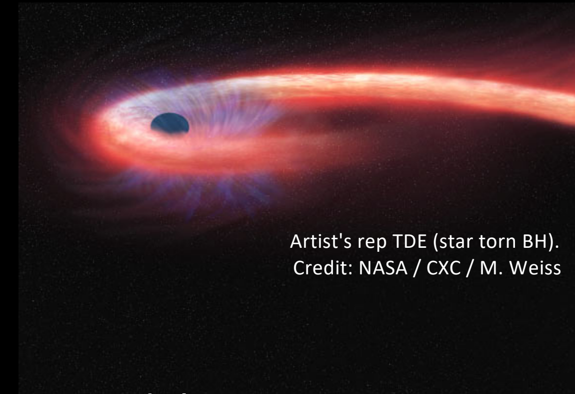
Artist's rep BH-BH merger.
Credit: NASA / JPL/
Swinburne Astron.Prods



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



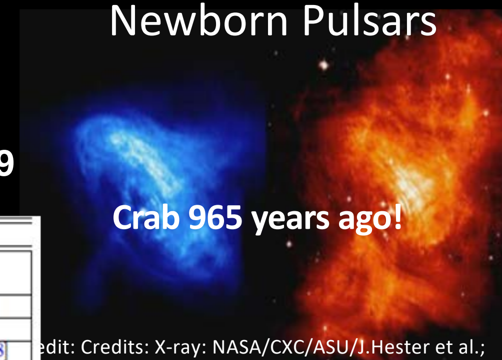
Binary Coalescence



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

Tidal Disruption Events

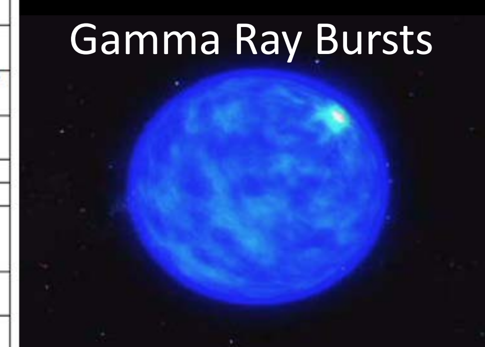
Newborn Pulsars



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

Blazar Flares

Gamma Ray Bursts

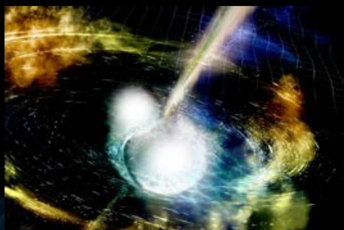


Long Bursts

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	1.12×10^5	0.77	2.64 Mpc	Dai and Fang [17] average
TDEs	5.62×10^5	3.88	5.91 Mpc	Dai and Fang [17] bright
TDEs	$\mathbf{2.23 \times 10^8}$	$\mathbf{1.44 \times 10^3}$	**115.20 Mpc**	**Lunardini and Winter [18] $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling Case**
TDEs	**NA***	$\mathbf{1.07 \times 10^3}$	**100.03 Mpc**	**Lunardini and Winter [18] $M_{SMBH} = 1 \times 10^5 M_\odot$ Strong Scaling Case**
Blazar Flares	**NA***	$\mathbf{1.91 \times 10^2}$	**42.96 Mpc**	**RFGBW [19] – FSRQ proton-dominated advective escape model**
lGRB Reverse Shock (ISM)	9.88×10^4	0.69	2.49 Mpc	Murase [15]
lGRB Reverse Shock (wind)	2.05×10^7	143.75	37.36 Mpc	Murase [15]
BH-BH merger	6.94×10^6	47.84	20.75 Mpc	Kotera and Silk [20] – $t_{dur} \sim 10^4$ s
BH-BH merger	$\mathbf{3.48 \times 10^9}$	$\mathbf{2.4 \times 10^4}$	**477.8 Mpc**	**Kotera and Silk [20] – $t_{dur} \sim 10^{6.7}$ s**
NS-NS merger	$\mathbf{3.58 \times 10^6}$	**24.75**	**12.76 Mpc**	**Fang and Metzger [21]**
WD-WD merger	20.06	0	33.46 kpc	XMMD [22]
Newly-born Crab-like pulsars (p)	1.56×10^2	1.07×10^{-3}	98.27 kpc	Fang [23]
Newly-born magnetars (p)	2.1×10^4	0.13	1.1 Mpc	Fang [23]
Newly-born magnetars (Fe)	4.07×10^4	0.26	1.53 Mpc	Fang [23]

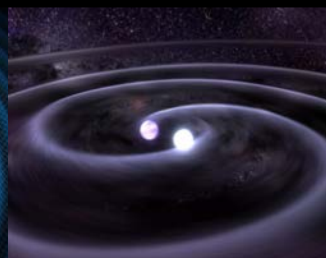
GW170817 follow up w ANTARES, ICECUBE, AUGER

arXiv:1710.05839

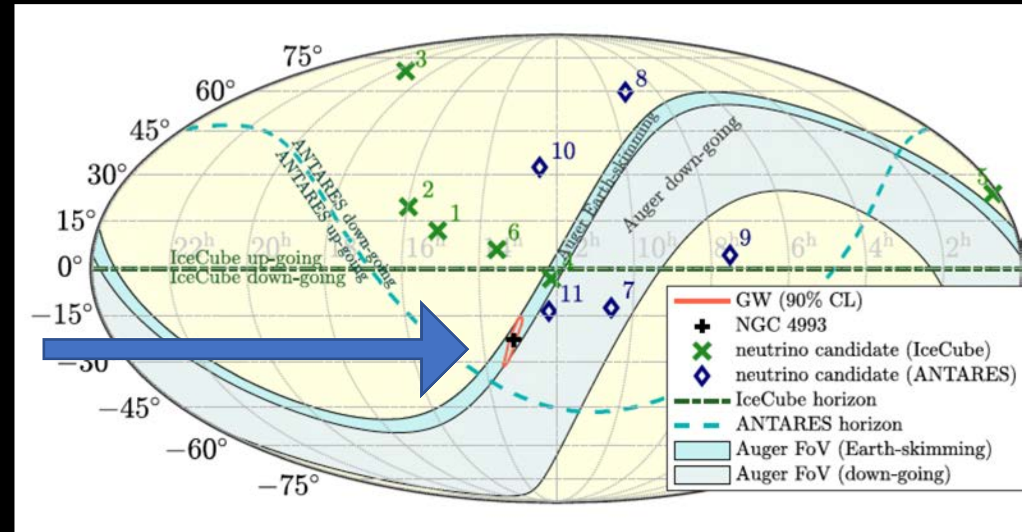


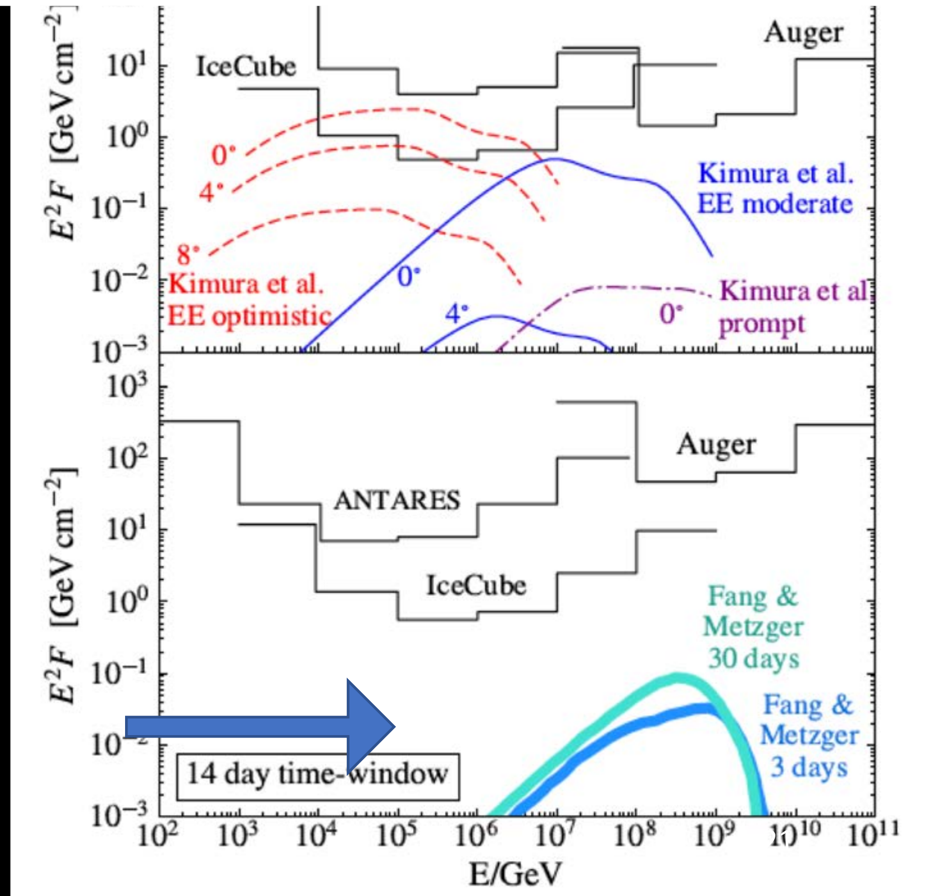
Artist's rep NS-NS merger. Credit: Credit: NSF/LIGO/ SSU/A. Simonnet.

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

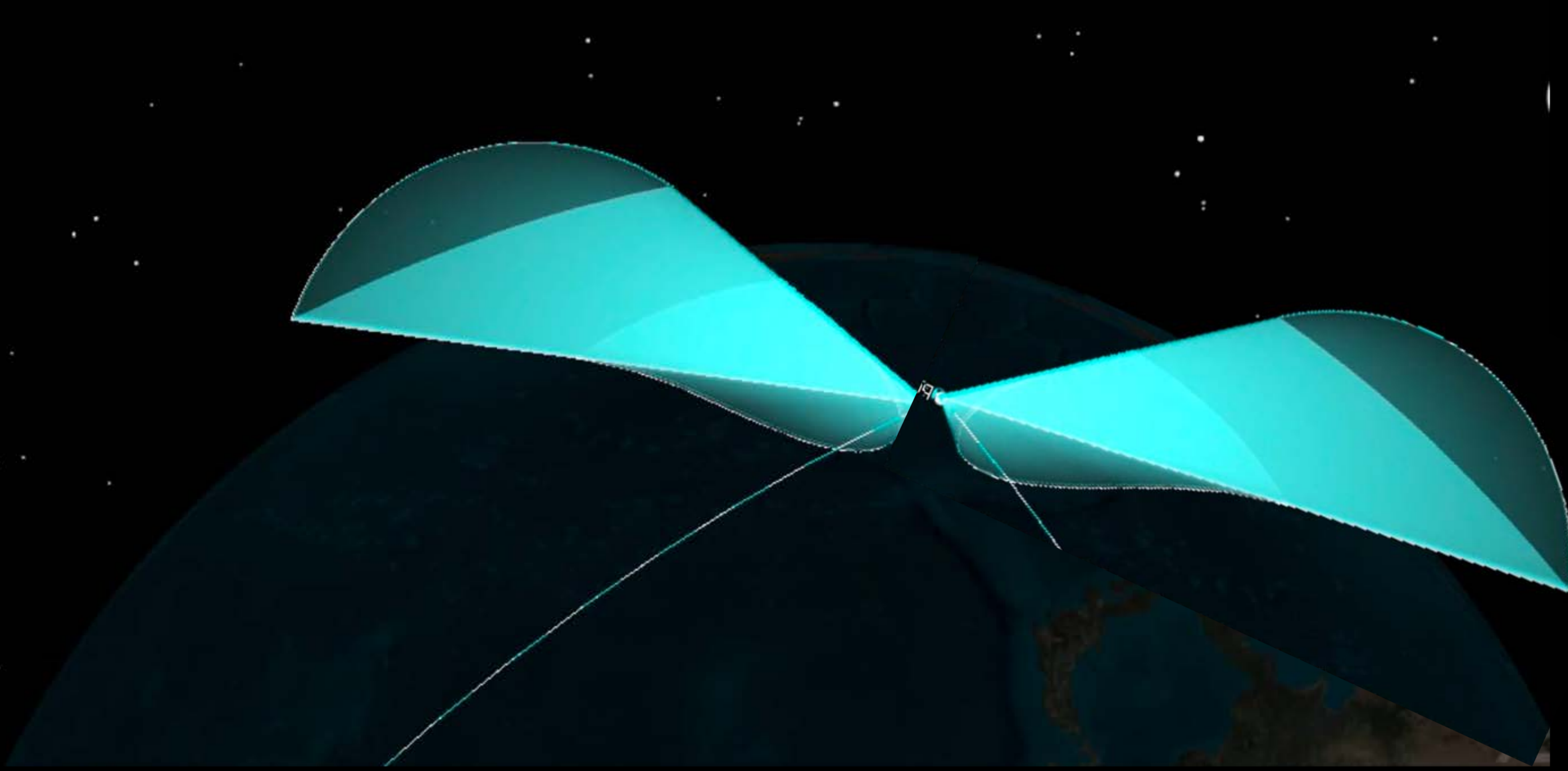


Artist's rep WD-WD merger Credit: Ars Technica

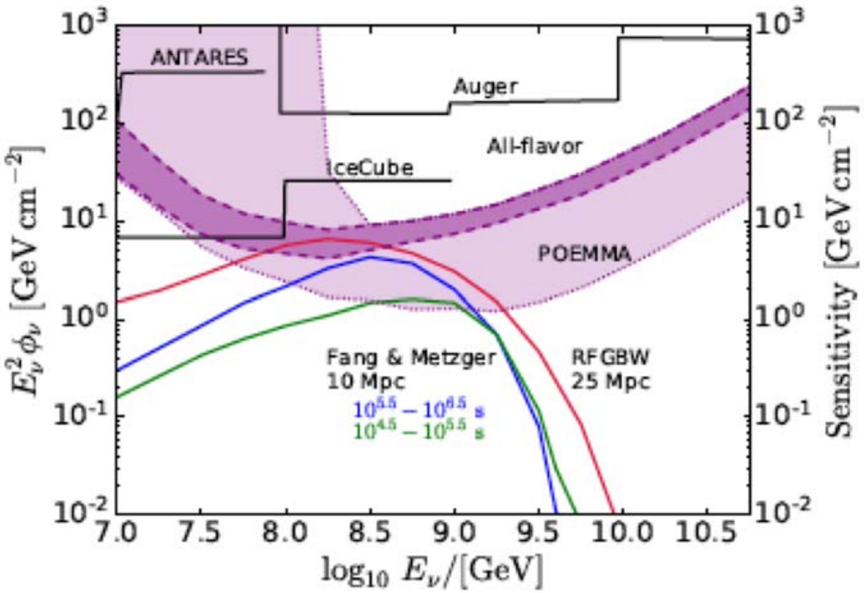


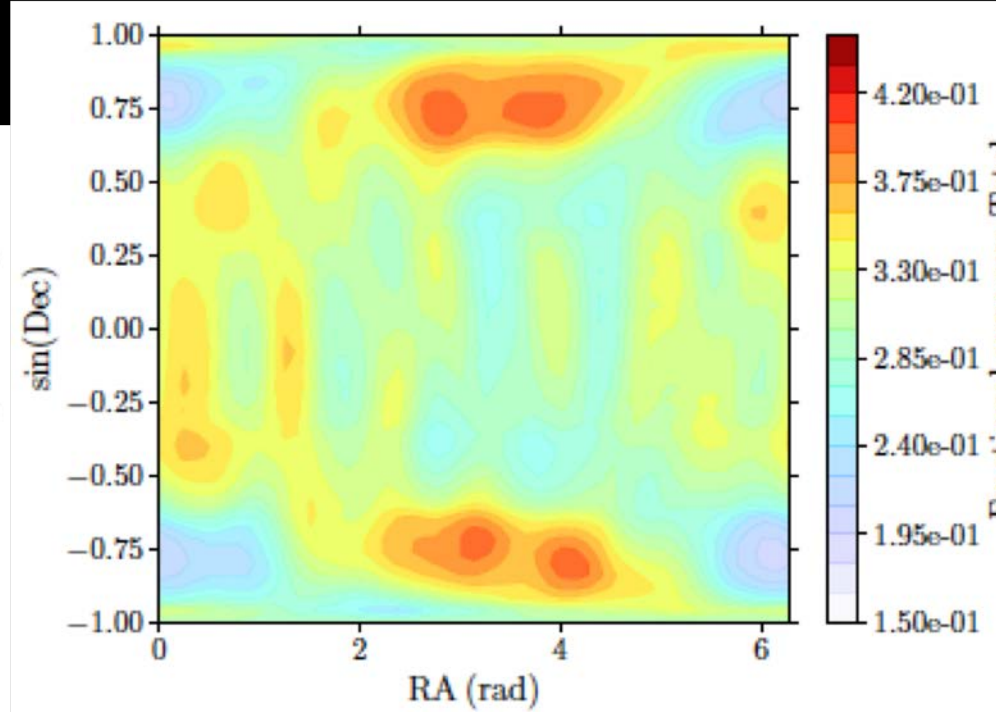


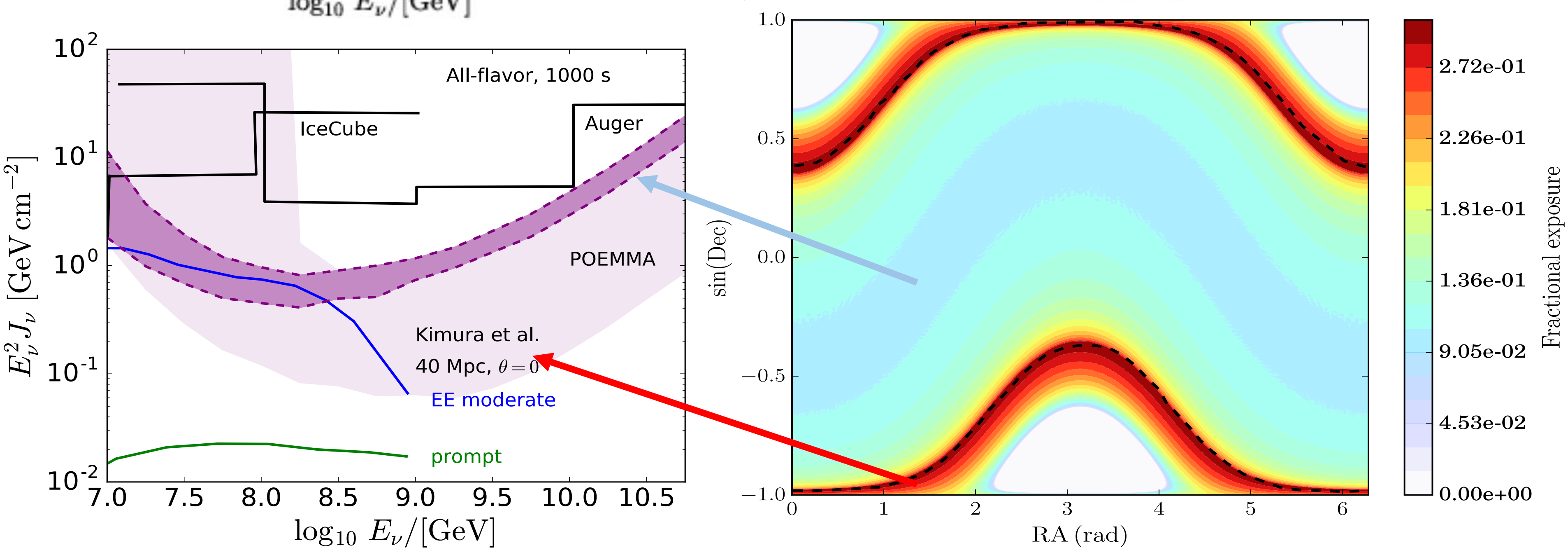
POEMMA



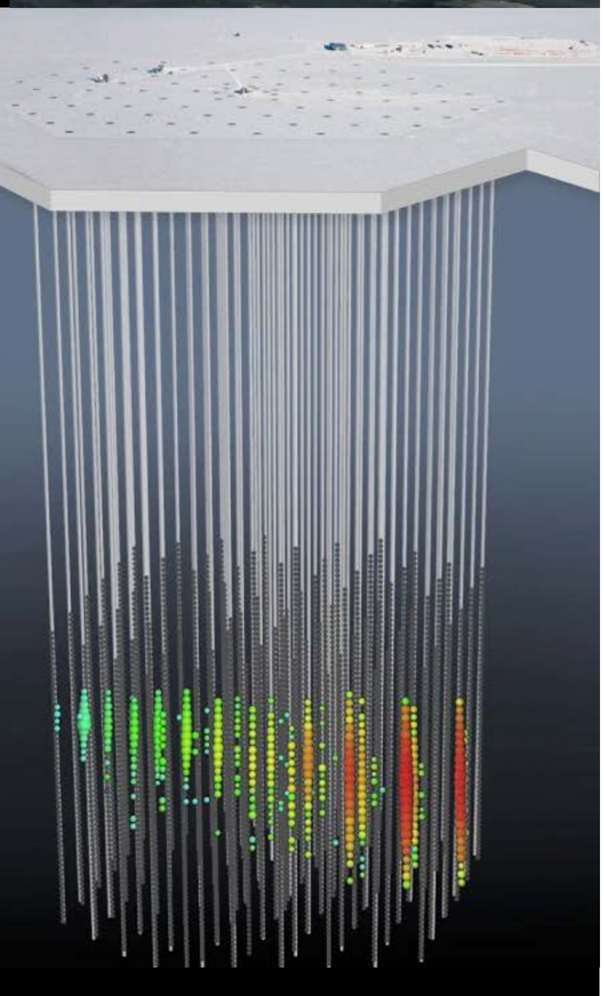
GW170817 follow up w POEMMA arXiv:1906.07209



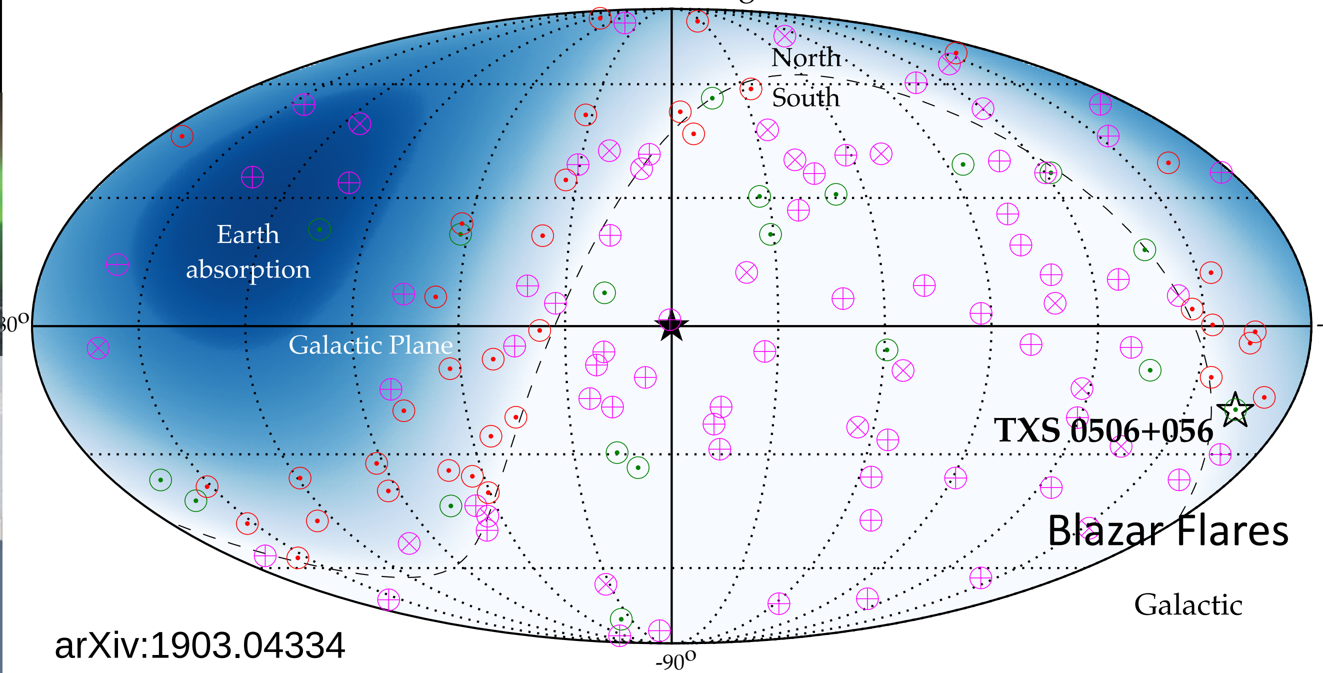




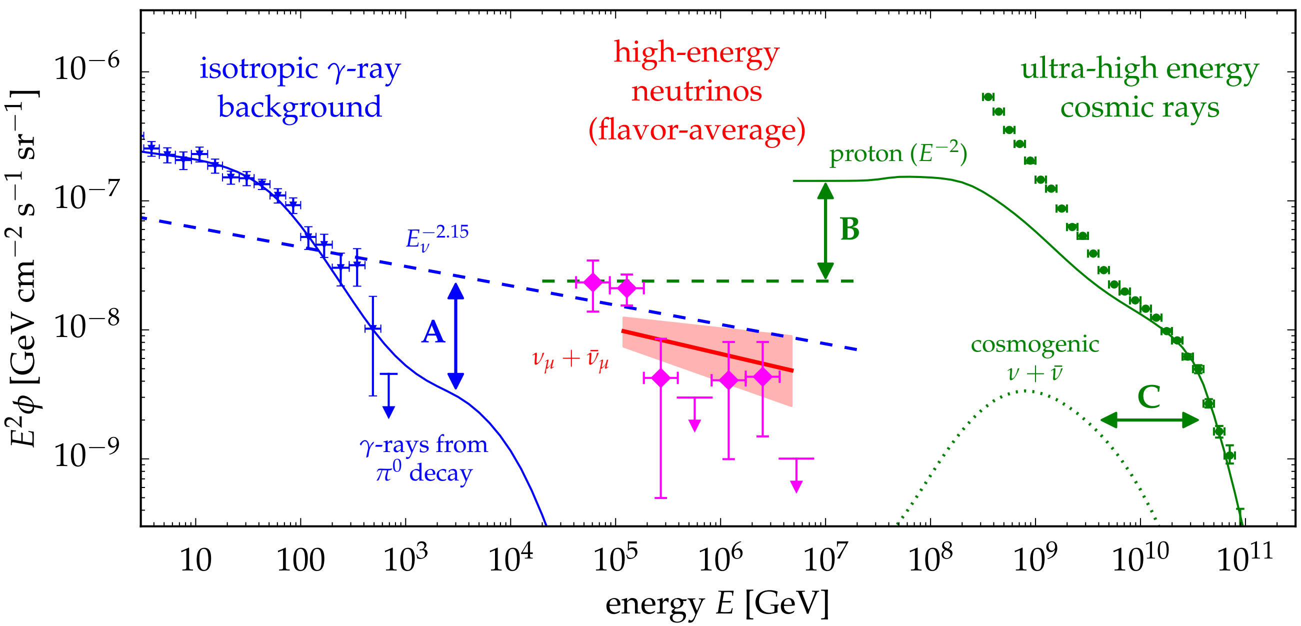
IceCube



Arrival directions of most energetic neutrino events



arXiv:1903.04334



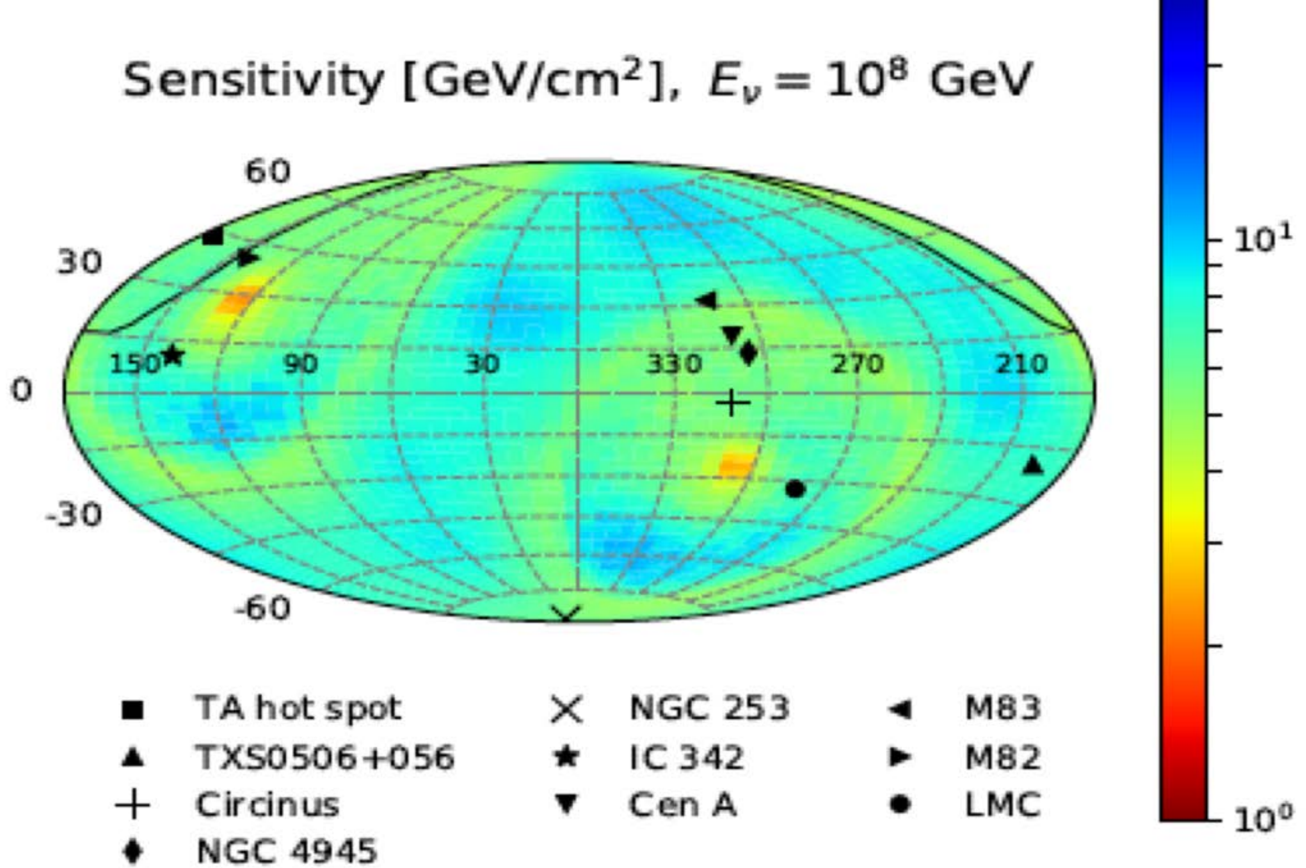
POEMMA

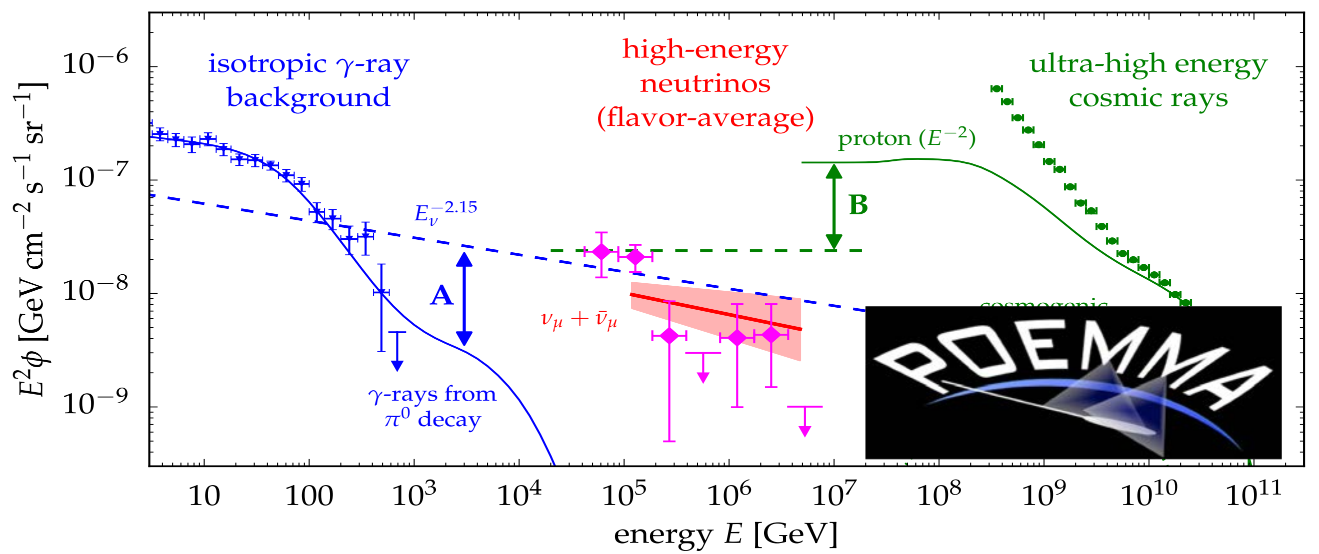
Observe

beyond 20 PeV

Full Sky Coverage

arXiv:1906.07209





POEMMA

Neutrino TOO

(Targets of Opportunity)

Venters et al 2019

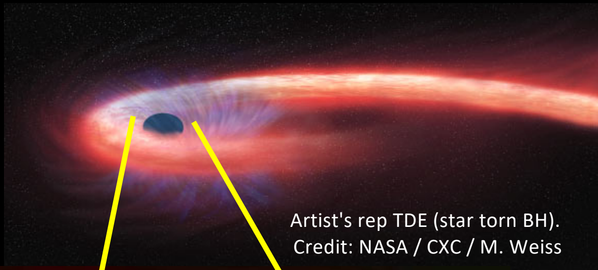
Transient Events

few to 100 Million neutrinos/event

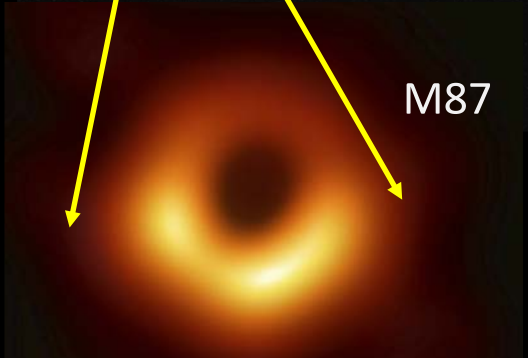
arXiv:1906.07209

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	1.12×10^5	0.77	2.64 Mpc	Dai and Fang [17] average
TDEs	5.62×10^5	3.88	5.91 Mpc	Dai and Fang [17] bright
TDEs	$\mathbf{2.23 \times 10^8}$	$\mathbf{1.44 \times 10^3}$	**115.20 Mpc**	**Lunardini and Winter [18] $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling Case**
TDEs	**NA***	$\mathbf{1.07 \times 10^3}$	**100.03 Mpc**	**Lunardini and Winter [18] $M_{SMBH} = 1 \times 10^5 M_\odot$ Strong Scaling Case**
Blazar Flares	**NA***	$\mathbf{1.91 \times 10^2}$	**42.96 Mpc**	**RFGBW [19] – FSRQ proton-dominated advective escape model**
lGRB Reverse Shock (ISM)	9.88×10^4	0.69	2.49 Mpc	Murase [15]
lGRB Reverse Shock (wind)	2.05×10^7	143.75	37.36 Mpc	Murase [15]
BH-BH merger	6.94×10^6	47.84	20.75 Mpc	Kotera and Silk [20] – $t_{dur} \sim 10^4$ s
BH-BH merger	$\mathbf{3.48 \times 10^9}$	$\mathbf{2.4 \times 10^4}$	**477.8 Mpc**	**Kotera and Silk [20] – $t_{dur} \sim 10^{6.7}$ s**
NS-NS merger	$\mathbf{3.58 \times 10^6}$	**24.75**	**12.76 Mpc**	**Fang and Metzger [21]**
WD-WD merger	20.06	0	33.46 kpc	XMMD [22]
Newly-born Crab-like pulsars (p)	1.56×10^2	1.07×10^{-3}	98.27 kpc	Fang [23]
Newly-born magnetars (p)	2.1×10^4	0.13	1.1 Mpc	Fang [23]
Newly-born magnetars (Fe)	4.07×10^4	0.26	1.53 Mpc	Fang [23]

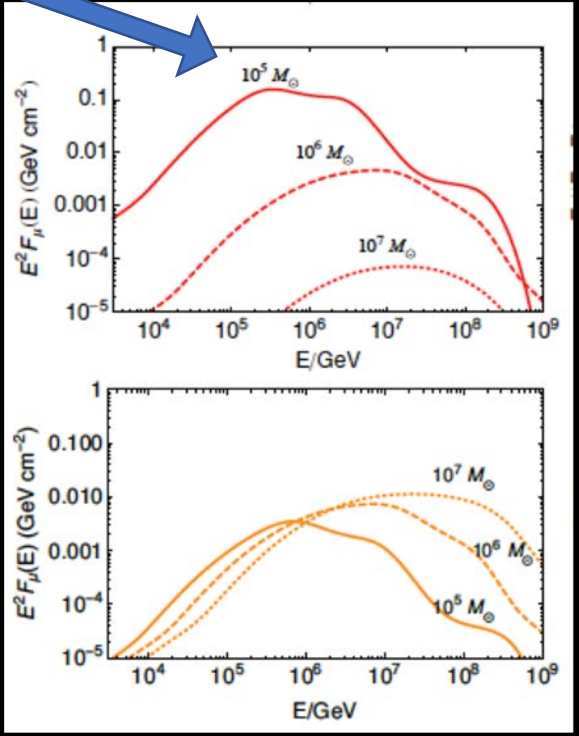
Short Bursts				
Source Class	No. of ν's at GC	No. of ν's at 3 Mpc	Largest Distance for 1.0 ν per event	Model Reference
sGRB Extended Emission (moderate)	2.23×10^8	1.55×10^3	117.44 Mpc	KMMK [16]
sGRB Prompt	8.10×10^6	69.19	26.66 Mpc	KMMK [16]



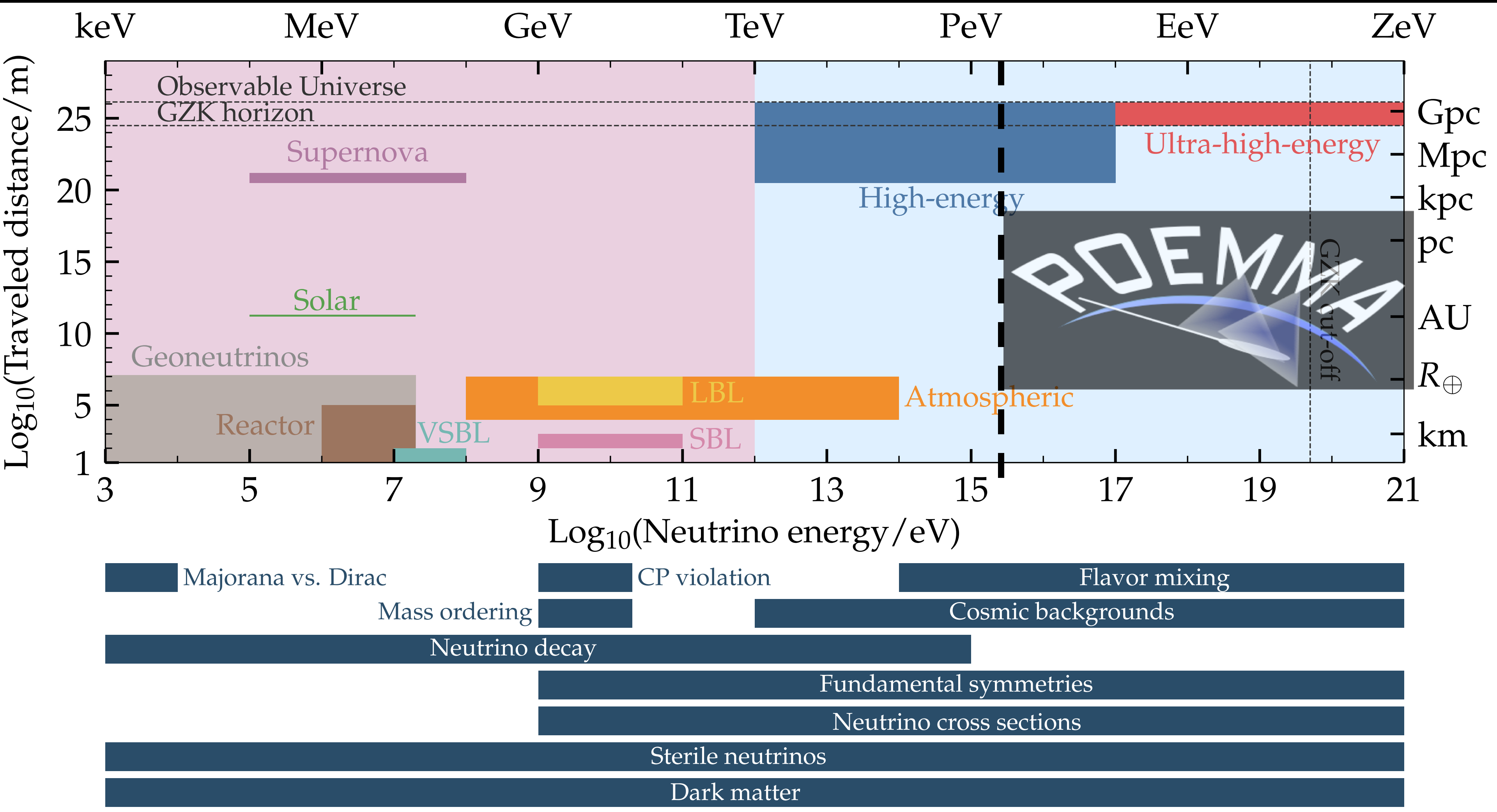
Artist's rep TDE (star torn BH). Credit: NASA / CXC / M. Weiss



EVENT HORIZON TELESCOPE COLLABORATION/MAUNAKEA OBSERVATORIES/ASSOCIATED PRESS



Fundamental Physics with High-Energy Cosmic Neutrinos



arXiv:1903.04333

JEM-EUSO PROGRAM

Joint Experiment Missions
Extreme Universe Space
Observatory

EUSO-TA (2013-)

EUSO-Balloon (2014)

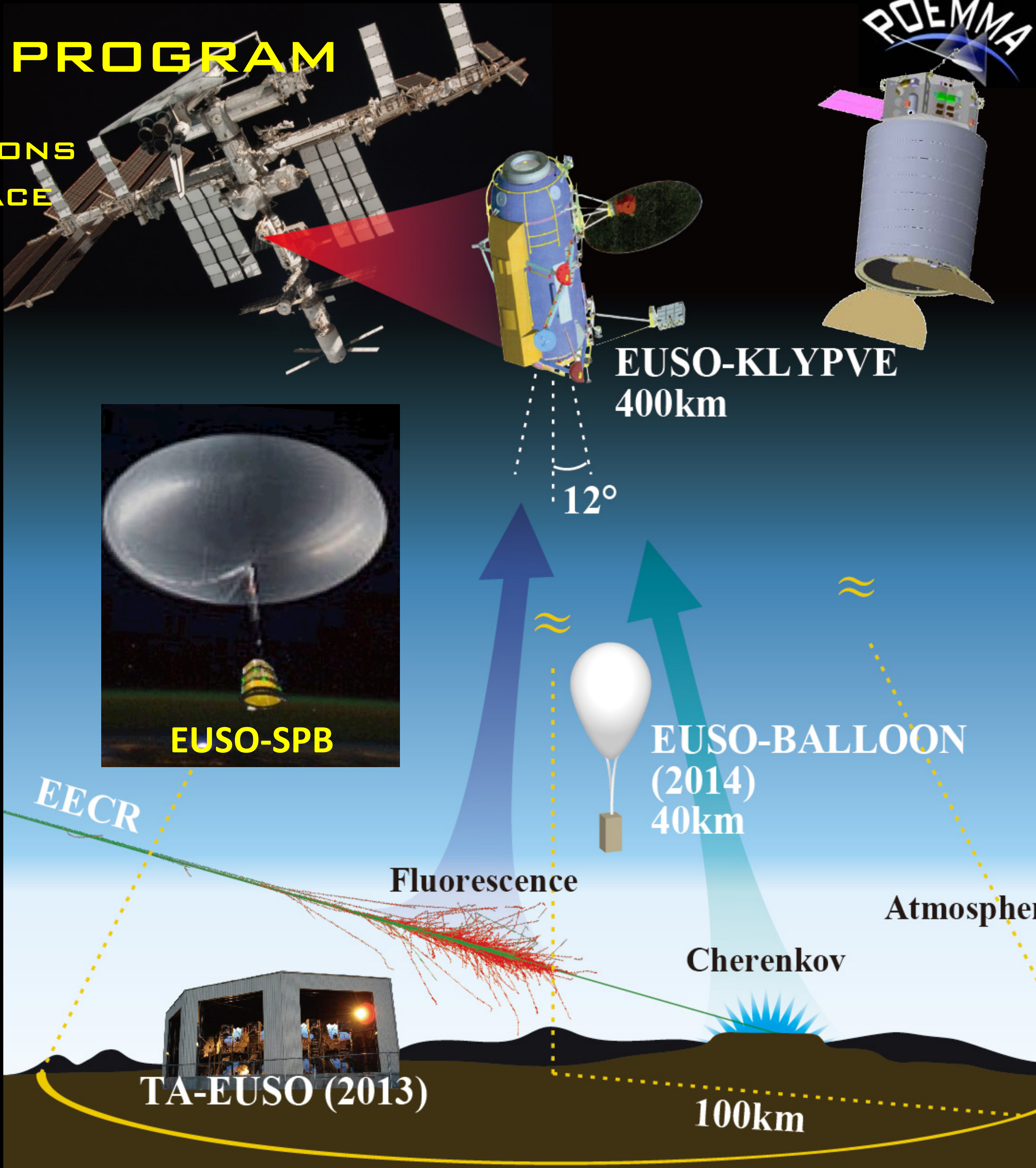
EUSO-SPB1 (2017)

Mini-EUSO (20119)

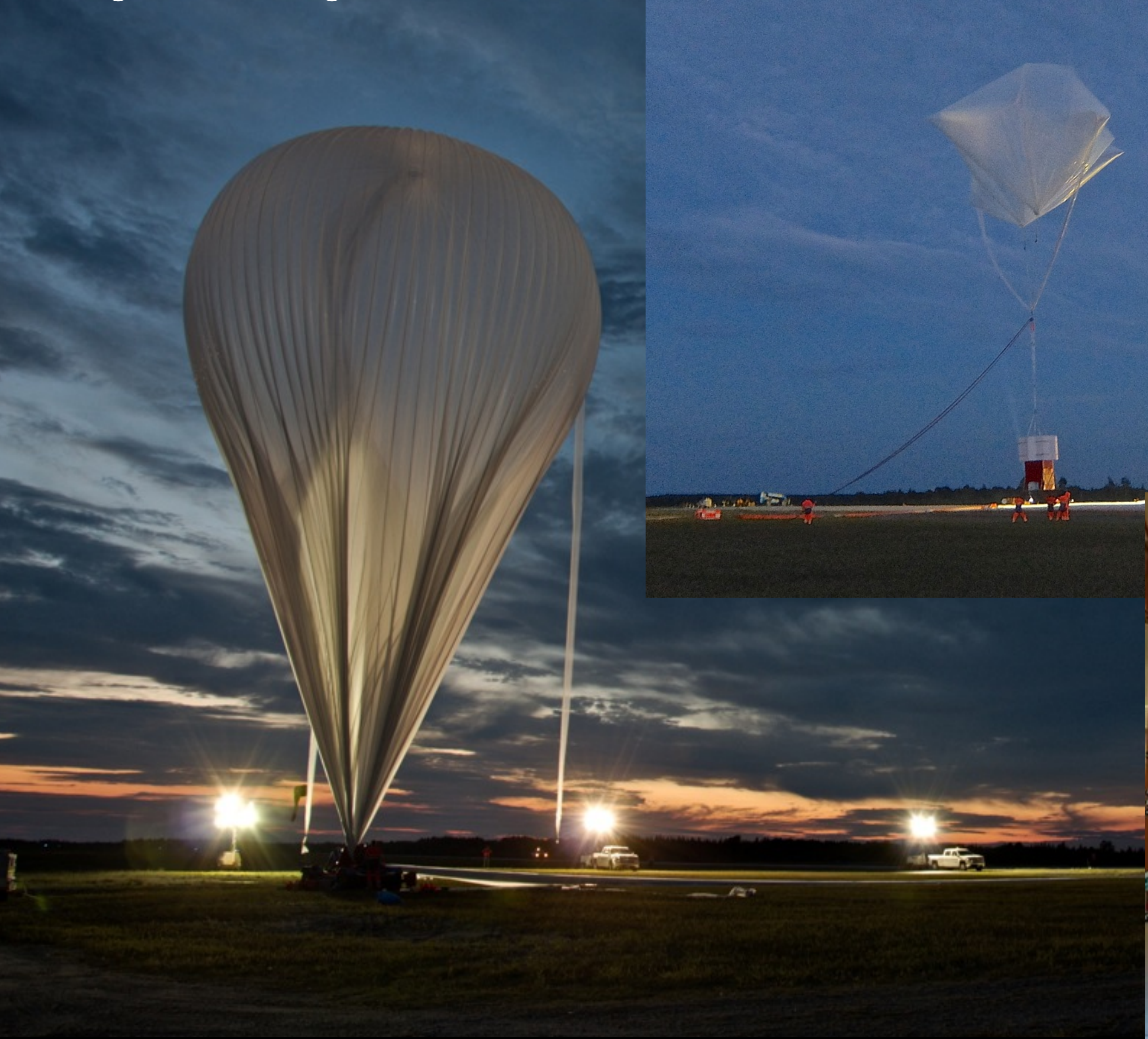
EUSO-SPB2 (2021-22)

K-EUSO (2023+)

POEMMA (2028+)

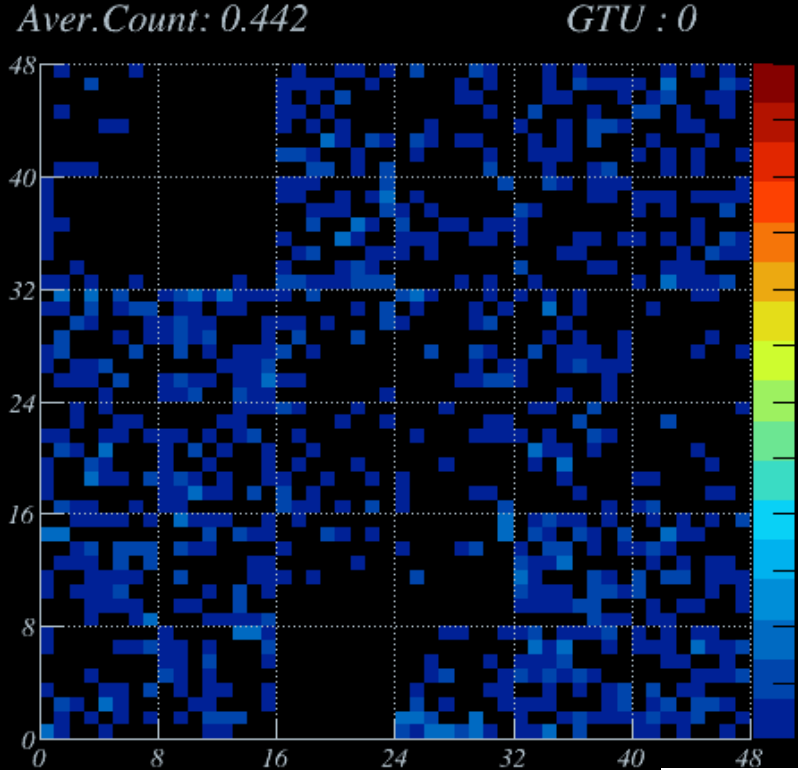


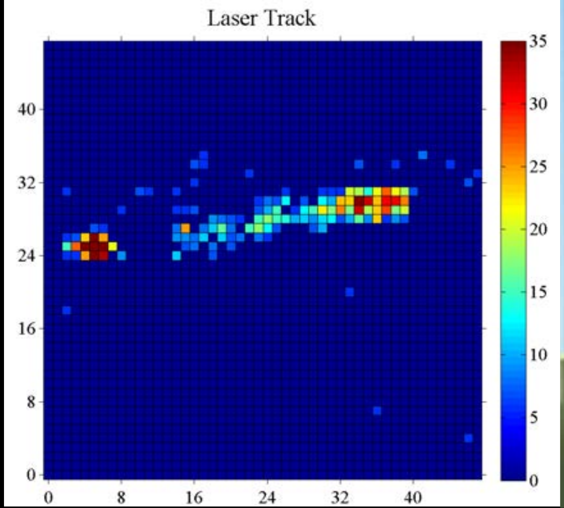
EUSO Balloon:
1st flight and first light on 24-25.8.2014



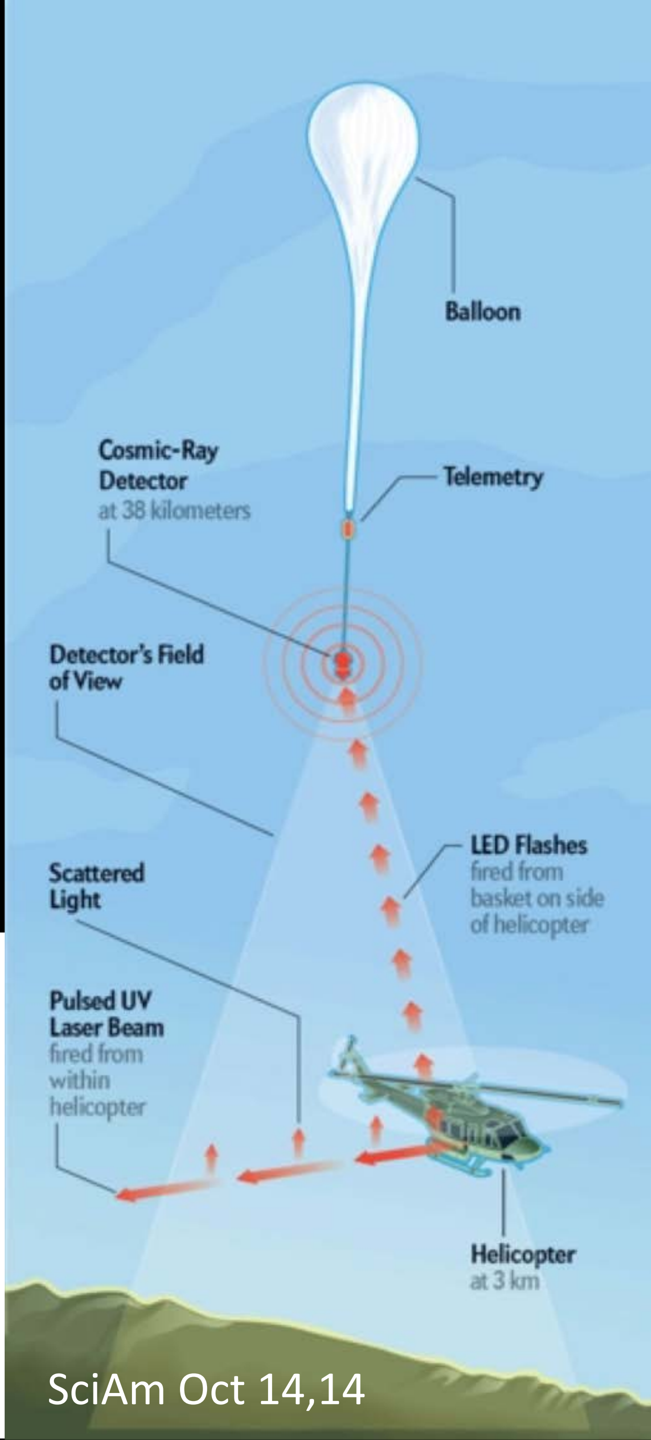
EUSO-Balloon 2014

Flasher & Laser events





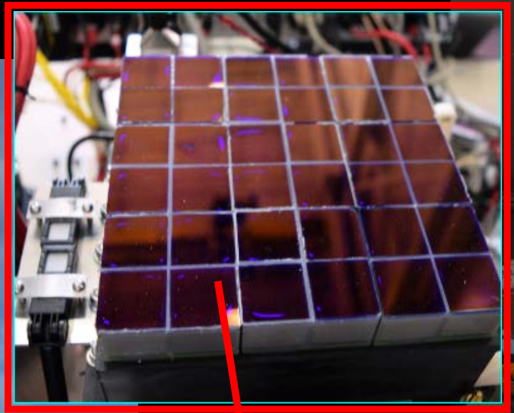
355nm Laser:
~10^{20} eV equivalent brightness

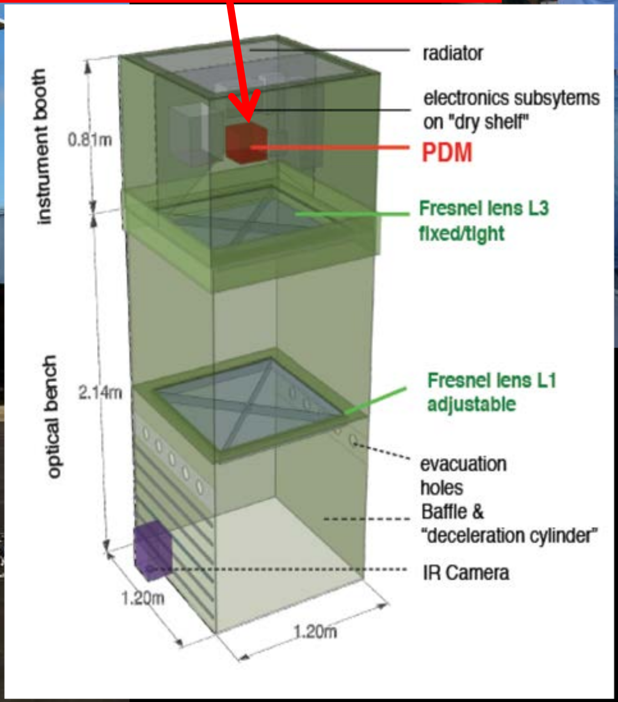


SciAm Oct 14,14

EUSO-SPB

Extreme Universe Space Observatory on a Super Pressure Balloon

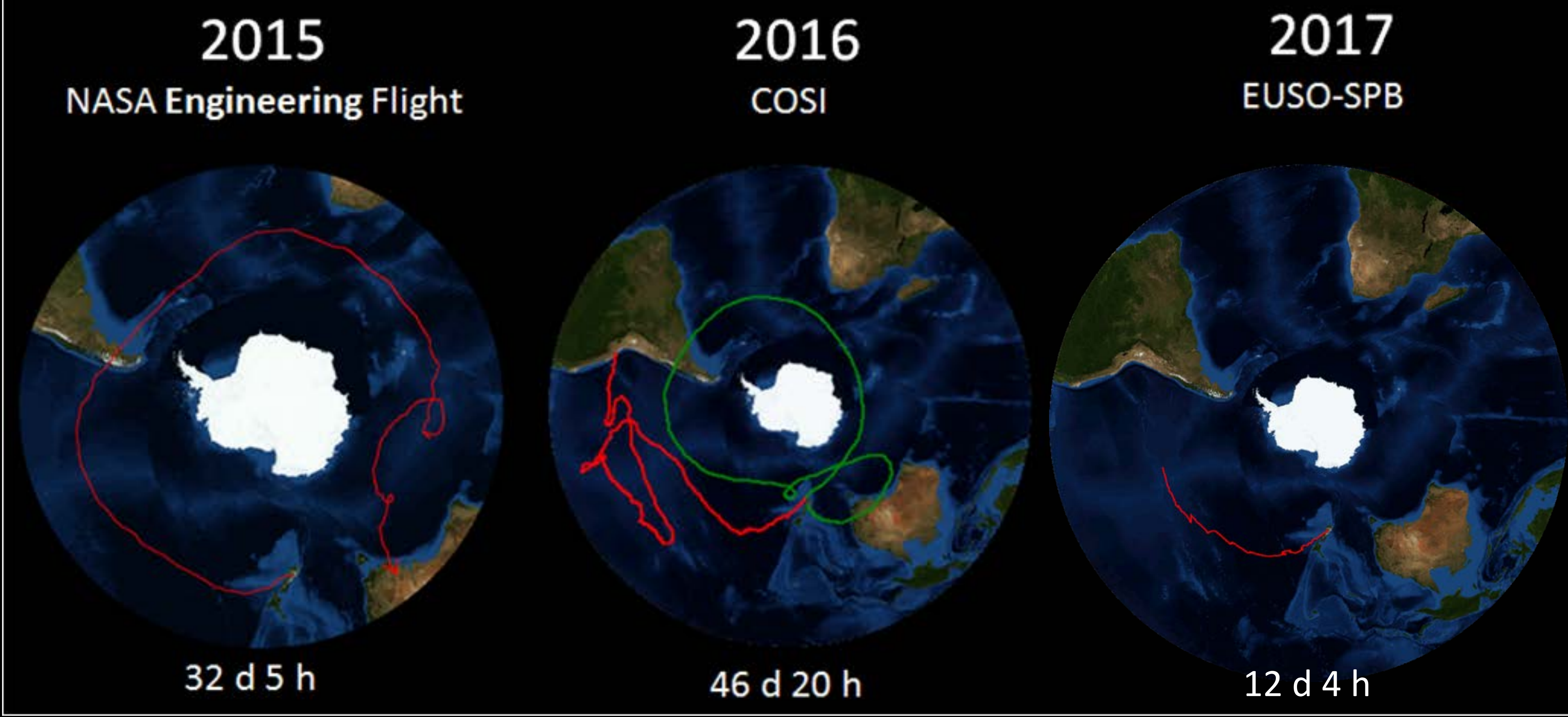




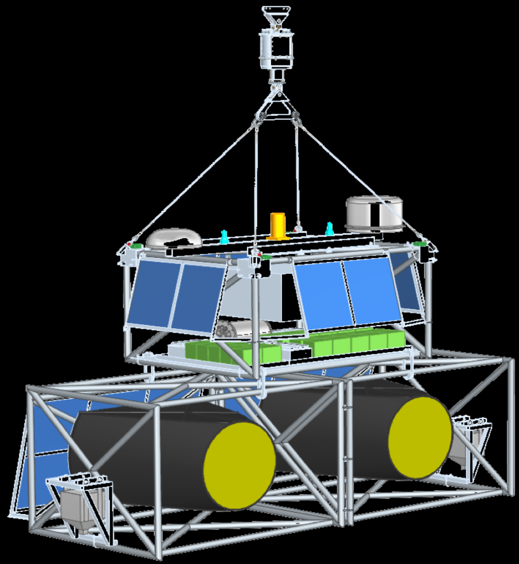
Ultrafast Camera:
Photo-Detector Module (PDM)
(3x3 ECs = 36 MAPMTS ; 2,304 pixels)


EUSO-SPB
LAUNCH,
APRIL 24,
2017
23:51 UTC

WANAKA 2017 Campaign
Super Pressure Balloon (SPB) EUSO mission



arXiv:1703.04513

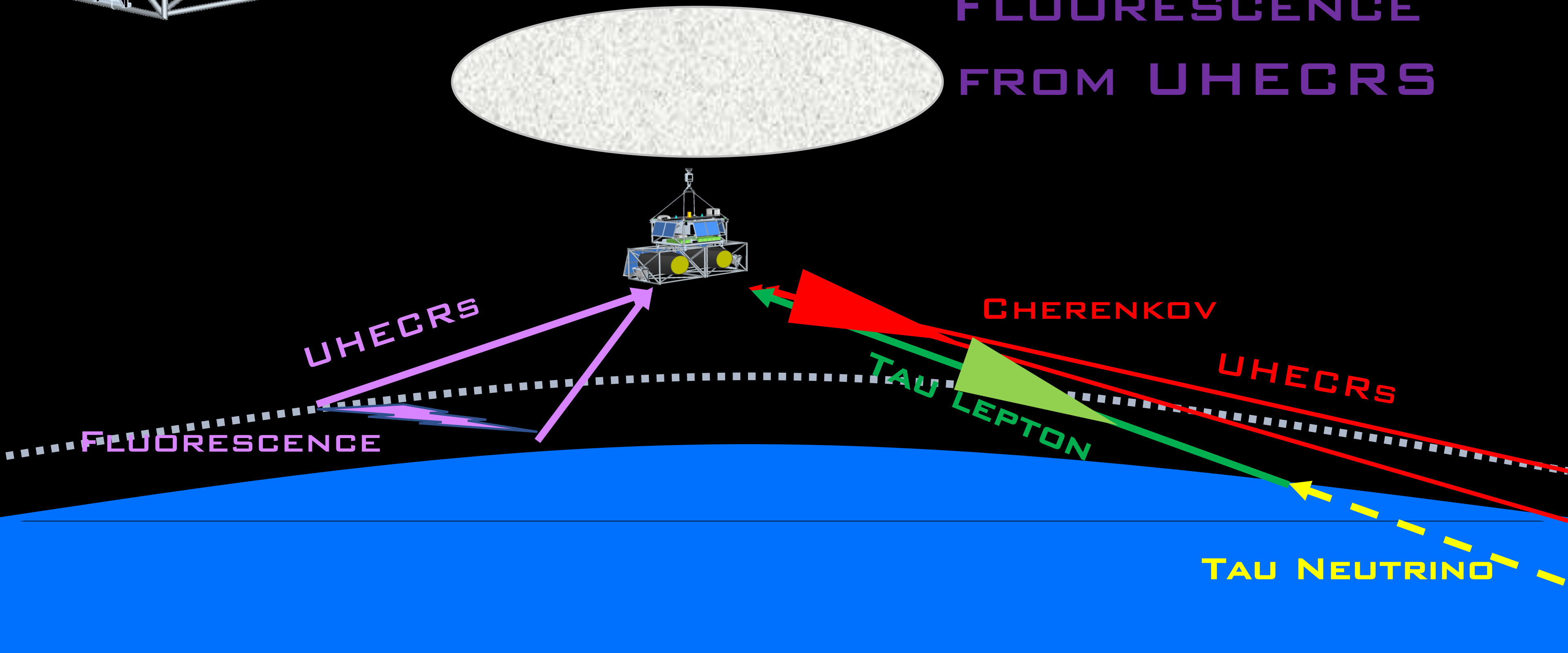


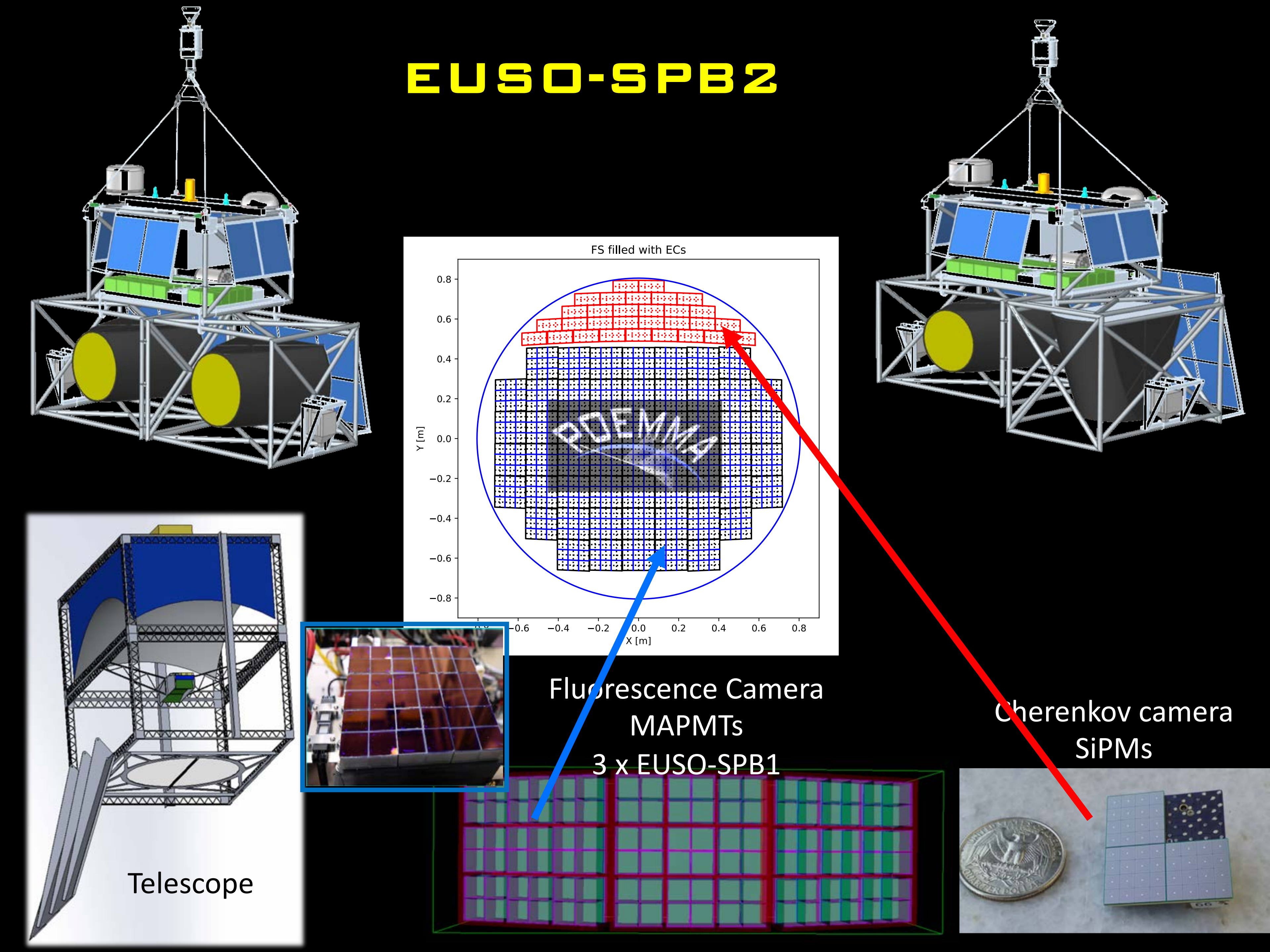
EUSO-SPB2

Cherenkov Emission from UHECRs

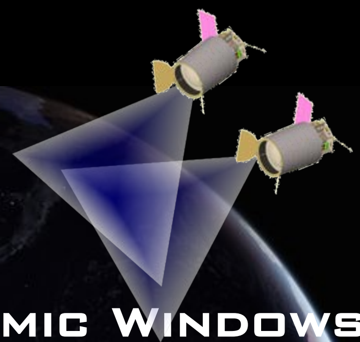
Tau Neutrino Background

Fluorescence from UHECRS




EUSO-SPB2
FS filled with ECs
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.8
Y [m]
−0.6 −0.4 −0.2 0.0 0.2 0.4 0.6 0.8
X [m]
POEMMA
Fluorescence Camera
MAPMTs
3 x EUSO-SPB1
Cherenkov camera
SiPMs
Telescope

POEMMA



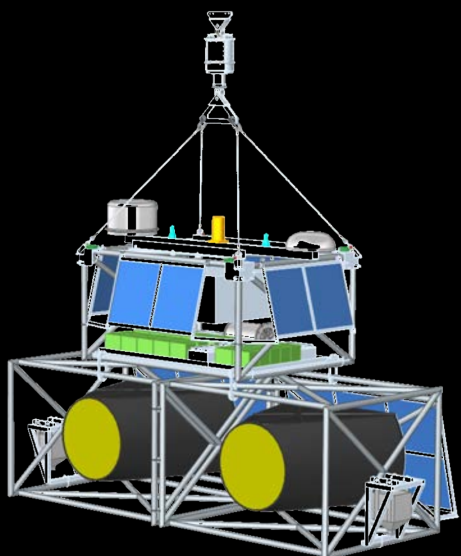
POEMMA will open two new Cosmic Windows:
neutrinos from astrophysical Transients (> 20 PeV), and
extreme energy cosmic ray (> 30 EeV)

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

POEMMA can rewrite the textbook on the most extreme astrophysical accelerators and fundamental physics interactions well above terrestrial accelerator energies.

Space Probes of the Highest Energy Particles:

EUSO-SPB2



the Earth's Atmosphere as an Extreme Energy Particle Observatory

POEMMA

UHECR and Neutrino Observations