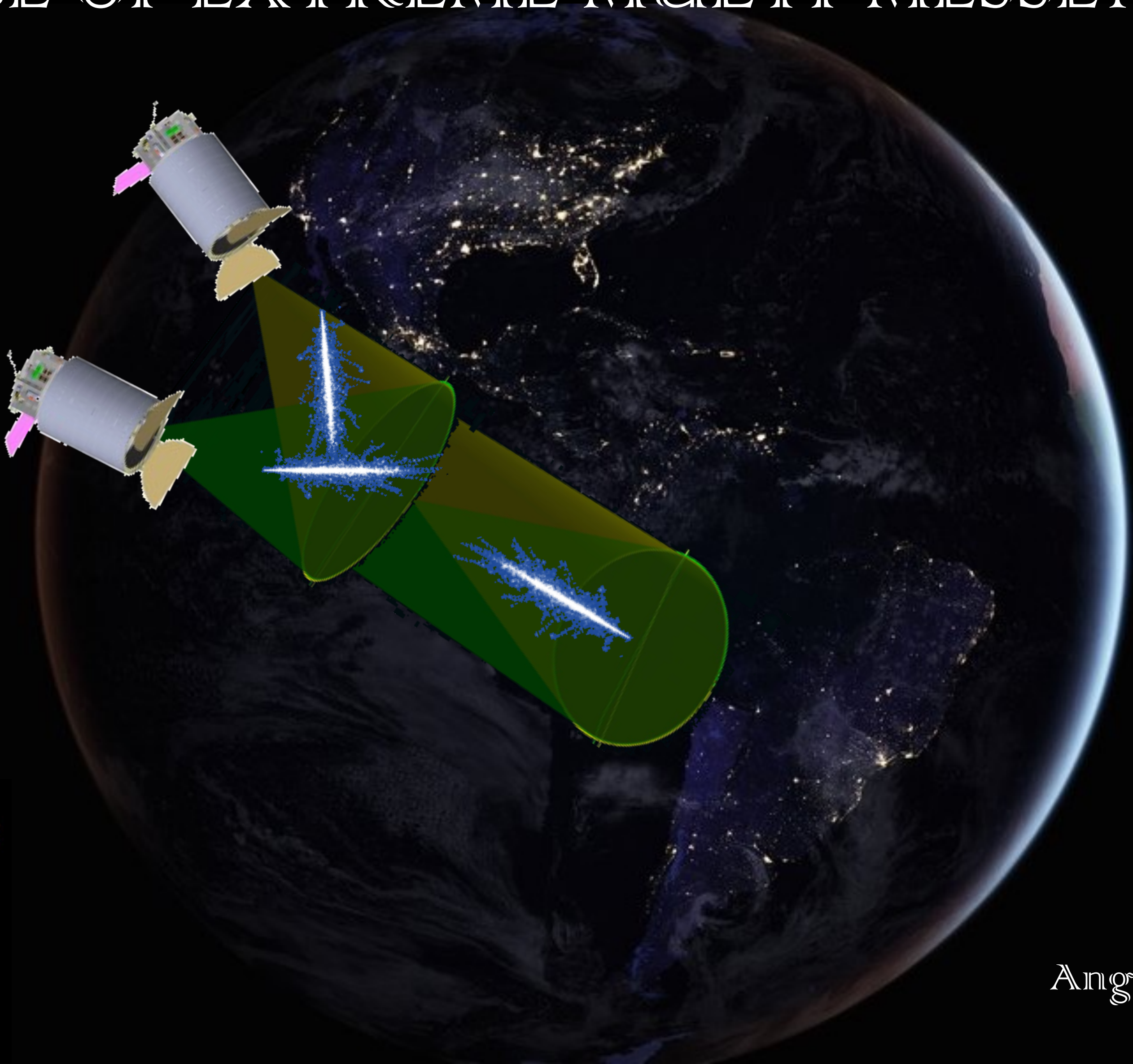
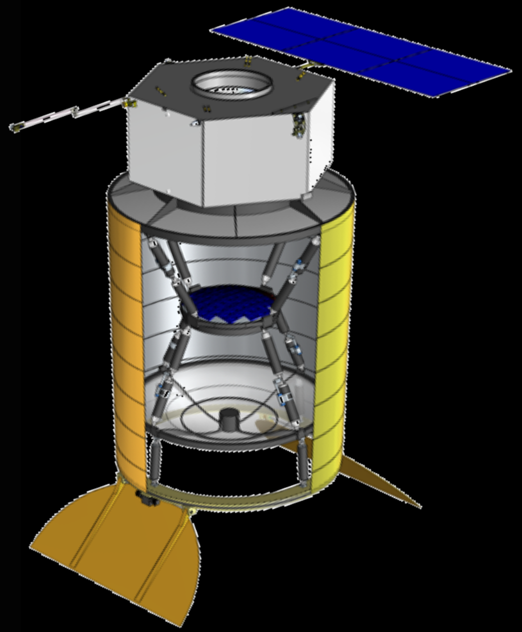
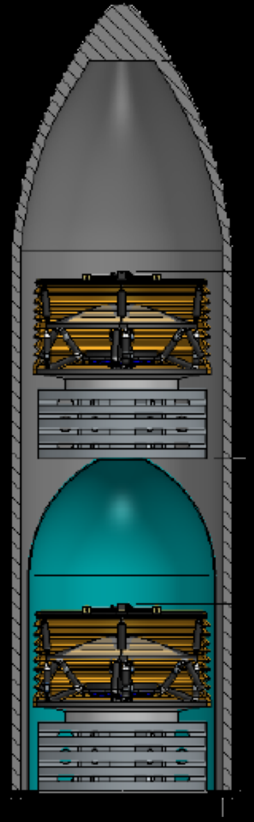
The POEMMA Observatory

PROBE OF EXTREME MULTI-MESSENGER ASTROPHYSICS







Angela V. Olinto

THE UNIVERSITY OF CHICAGO

POEMMA Collaboration

USA: University of Chicago: *A. V. Olinto (PI),* S. S. Meyer, J. Eser, R. Diesing; **NASA/GSFC:** J. F. Krizmanic (deputy PI), 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; **Colorado School of Mines**: F. Sarazin, L. Wiencke, G. Filippatos, V. Kungel, K.-D. Merenda; **University of Alabama, Huntsville**: J. Adams, E. Kuznetsov, P. Reardon, **University of Utah:** D. R. Bergman; University of Maryland: C. Guepin; **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: **Palacký University:** K. Cerny, **Czech Academy of Sciences**: D. Mandát, M. Pech, P. Schovánek

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JAPAN: RIKEN: M. Casolino,, Y. Takizawa

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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

76 scientists from 38 institutions and 13 countries
OWL, JEM-EUSO, Auger, TA, Veritas, CTA, Fermi, Theory

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

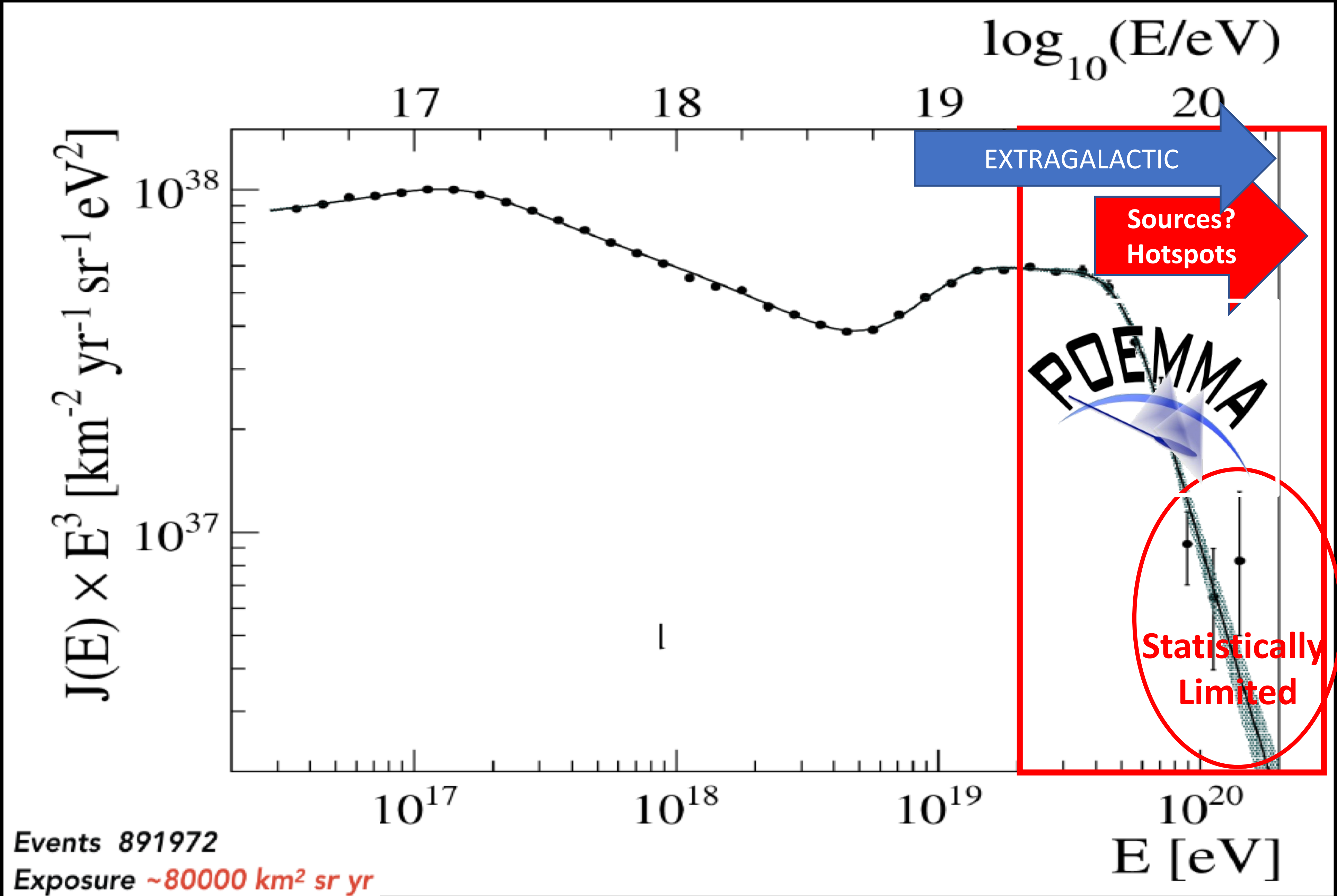
What are the sources of **Astrophysical Neutrinos**?

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

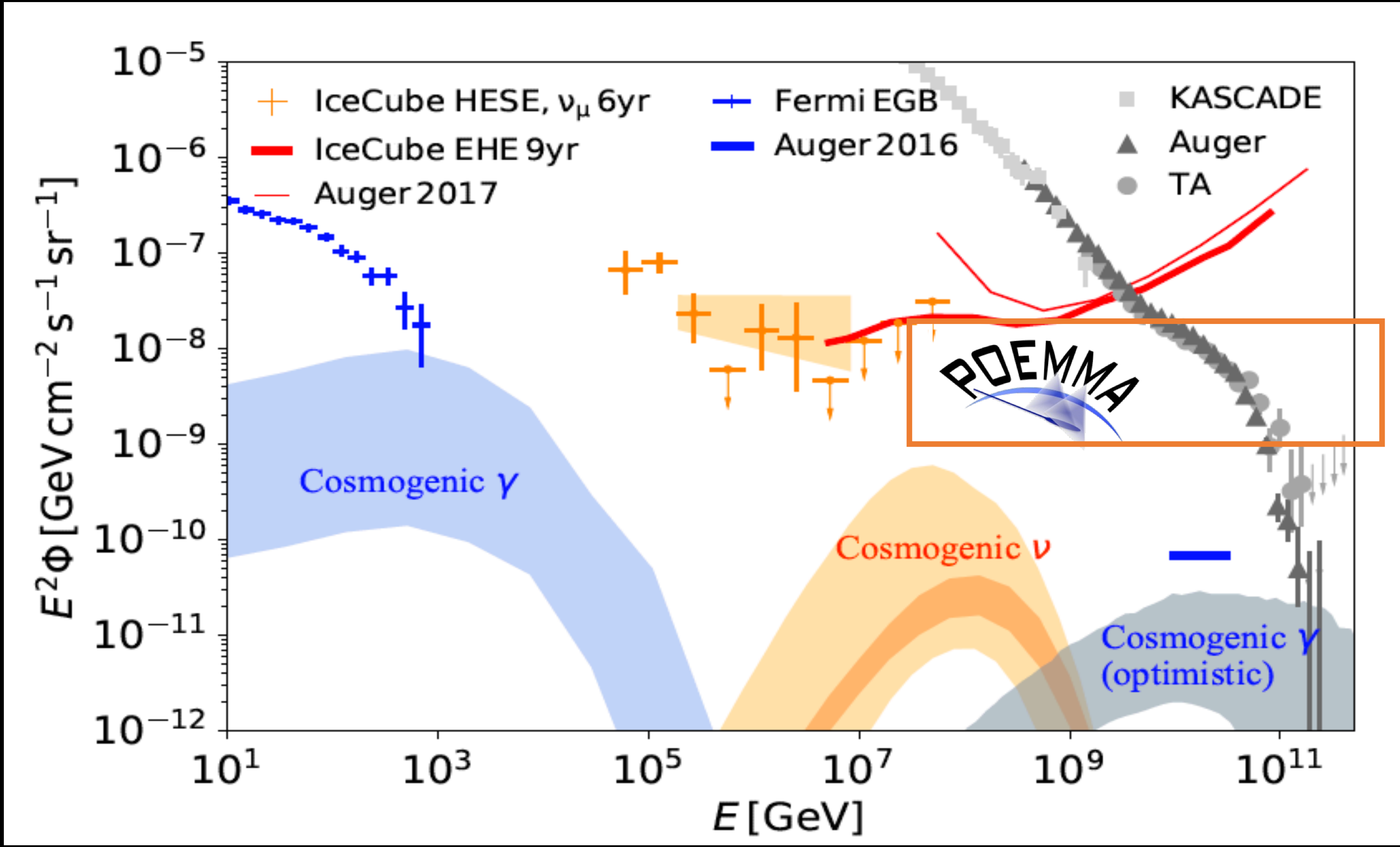
What is the physics and astrophysics at energies >> "ground-based" accelerators? Are there New Interactions or Dark Matter signatures (e.g., Secret Neutrino Interactions, Extra-Dimensions, Supermassive Dark Matter, Macroscopic Dark Matter)?

arXiv:2012.07945 arXiv:1907.03694 arXiv:1906.07209 arXiv:2104.05131

Auger Spectrum ICRC 2019



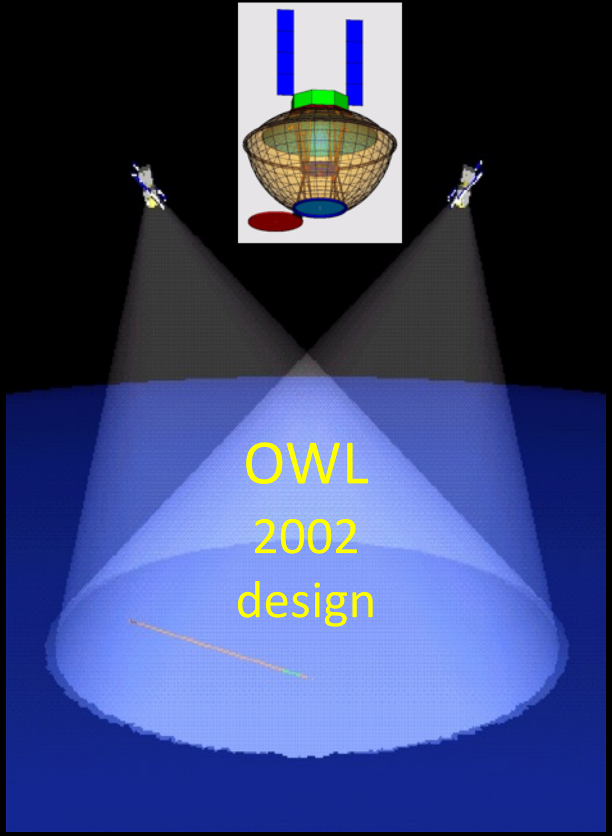
Cosmogenic and Astrophysical neutrinos



Batista et al, arXiv:1903.06714.pdf

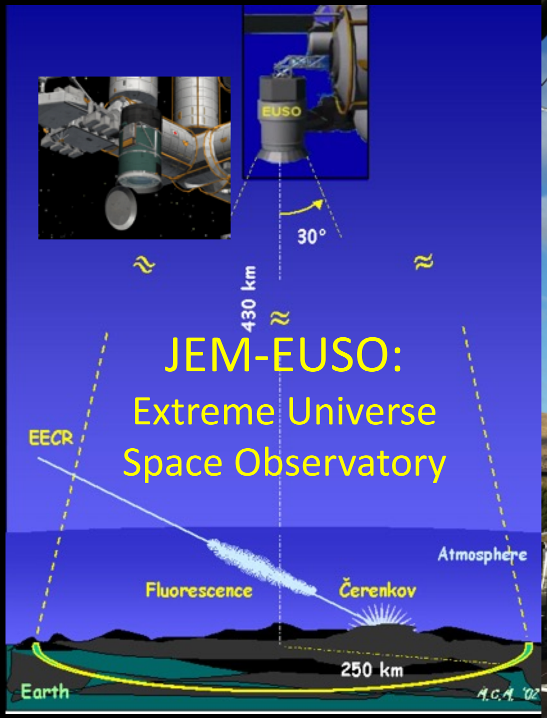
POEMMA Predecessors

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



Orbiting Wide-angle Light-collectors

TUS, KLYPVE-EUSO

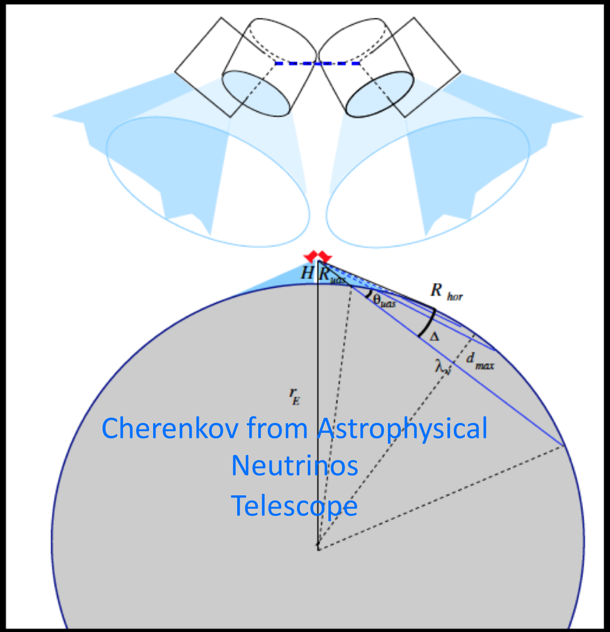


EUSO-Balloon
EUSO@TA
Mini-EUSO

EUSO-SPB1

EUSO-SPB2

CHANT



JEM-EUSO program

Joint Experiment Missions
Extreme Universe Space Observatory

EUSO-TA (2013-)

EUSO-Balloon (2014)

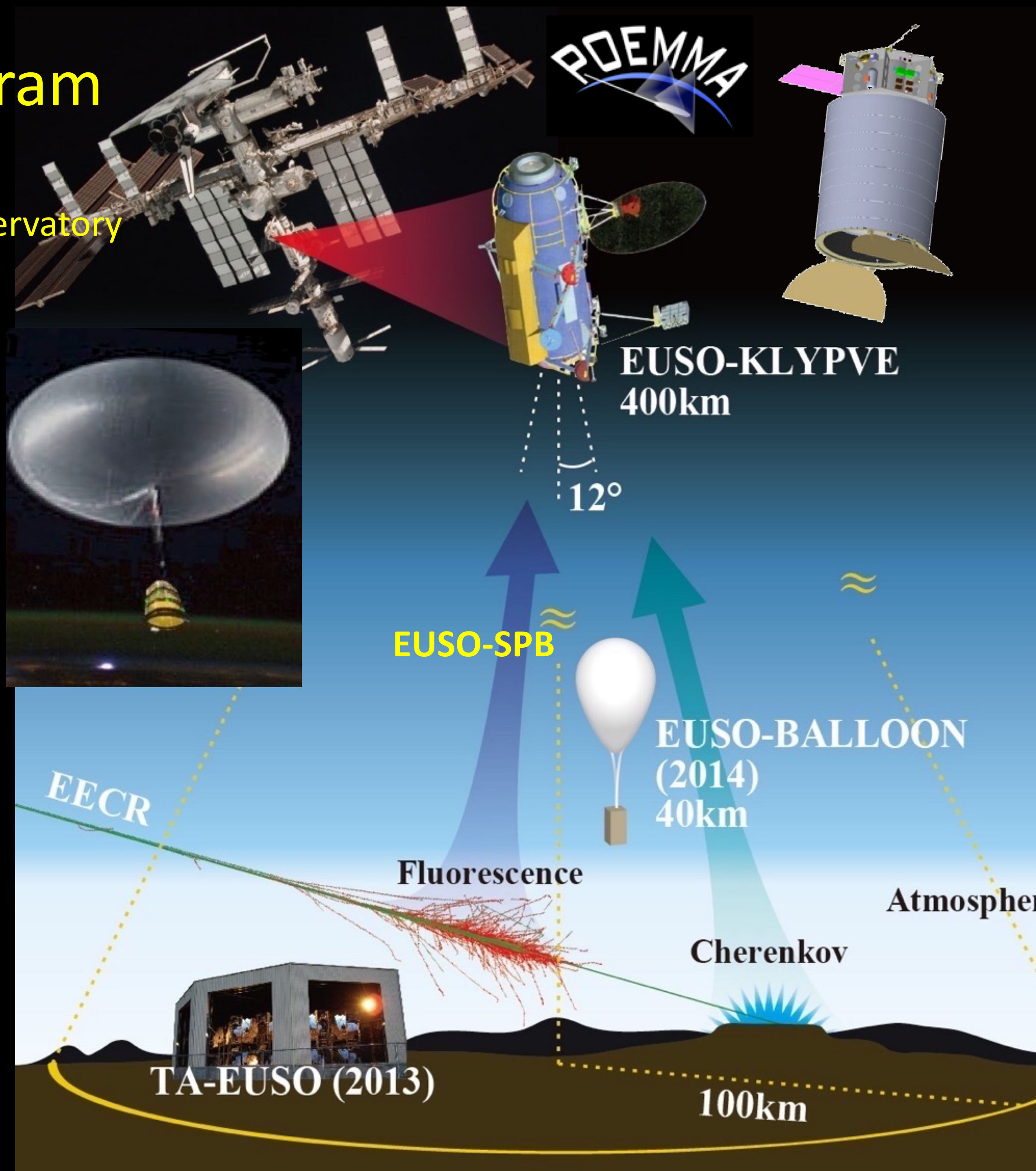
EUSO-SPB1 (2017)

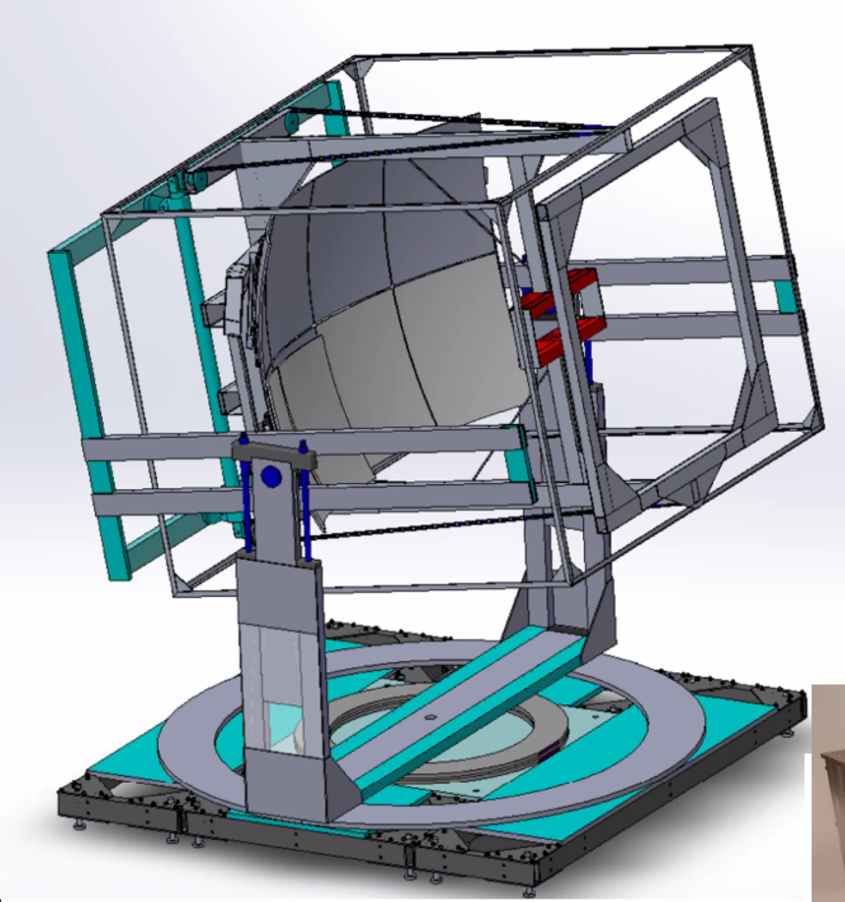
Mini-EUSO (2019)

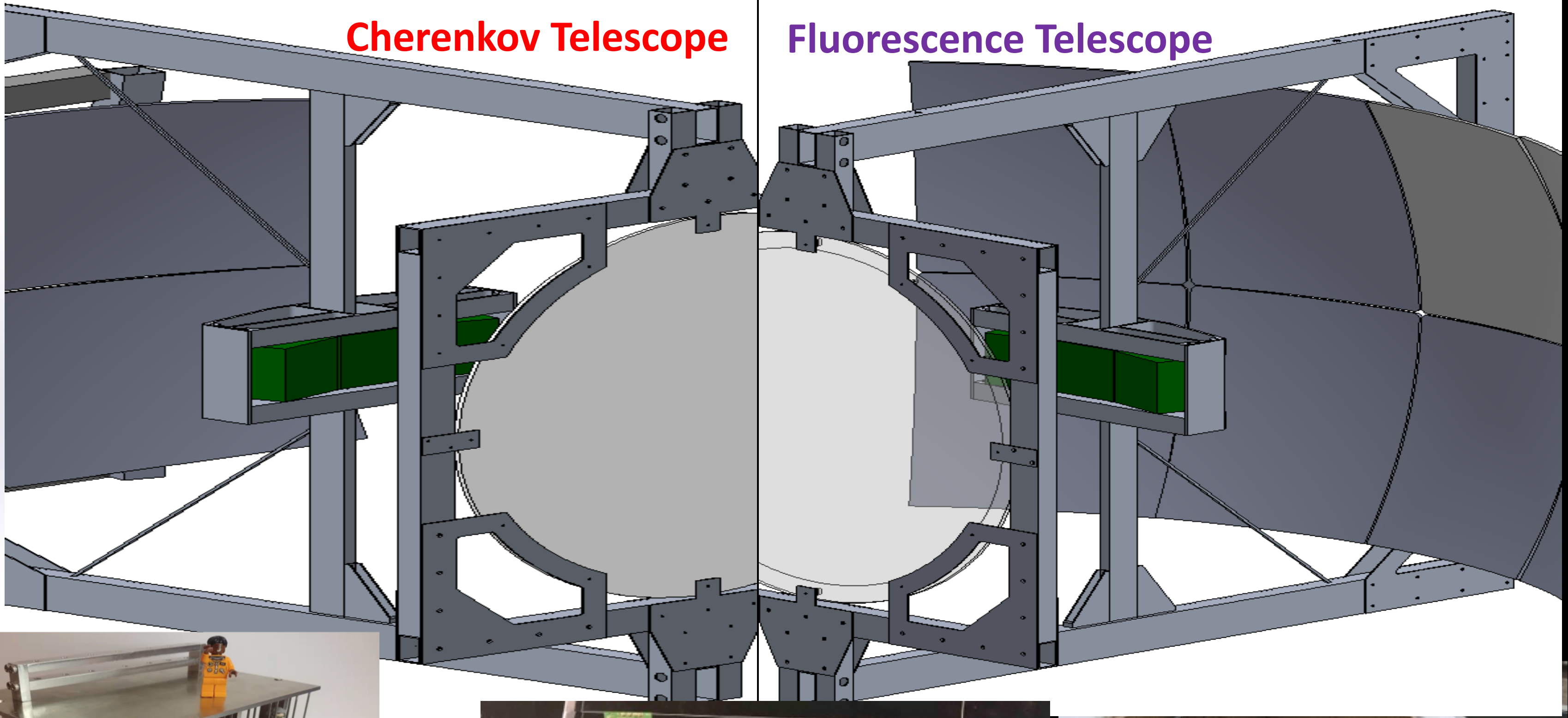
EUSO-SPB2 (2023)

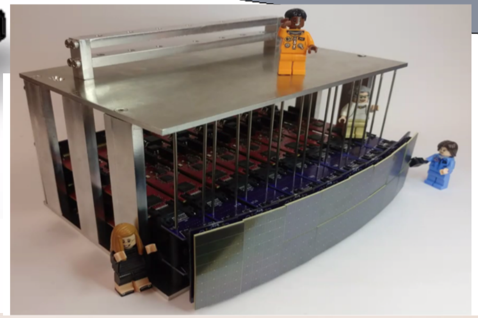
K-EUSO (2024+)

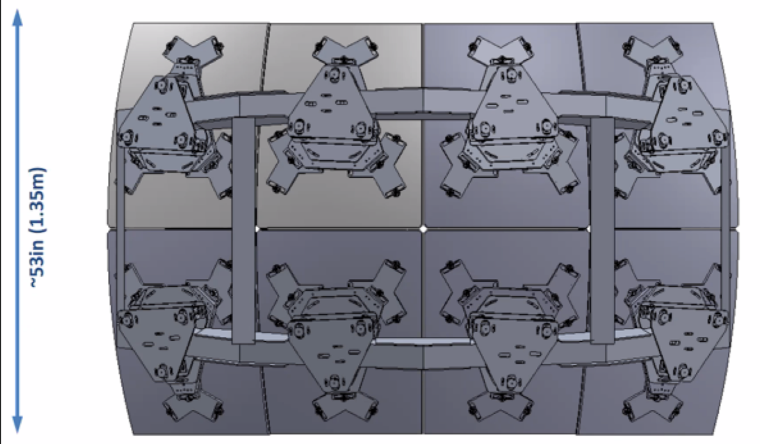
POEMMA (2028+)

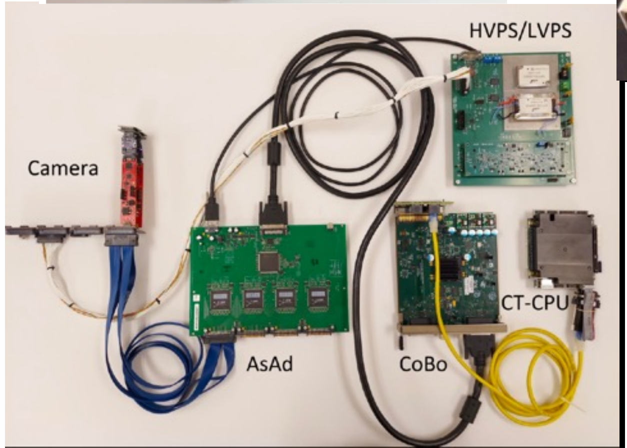


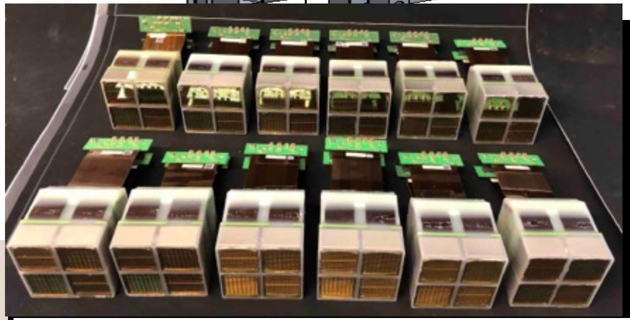


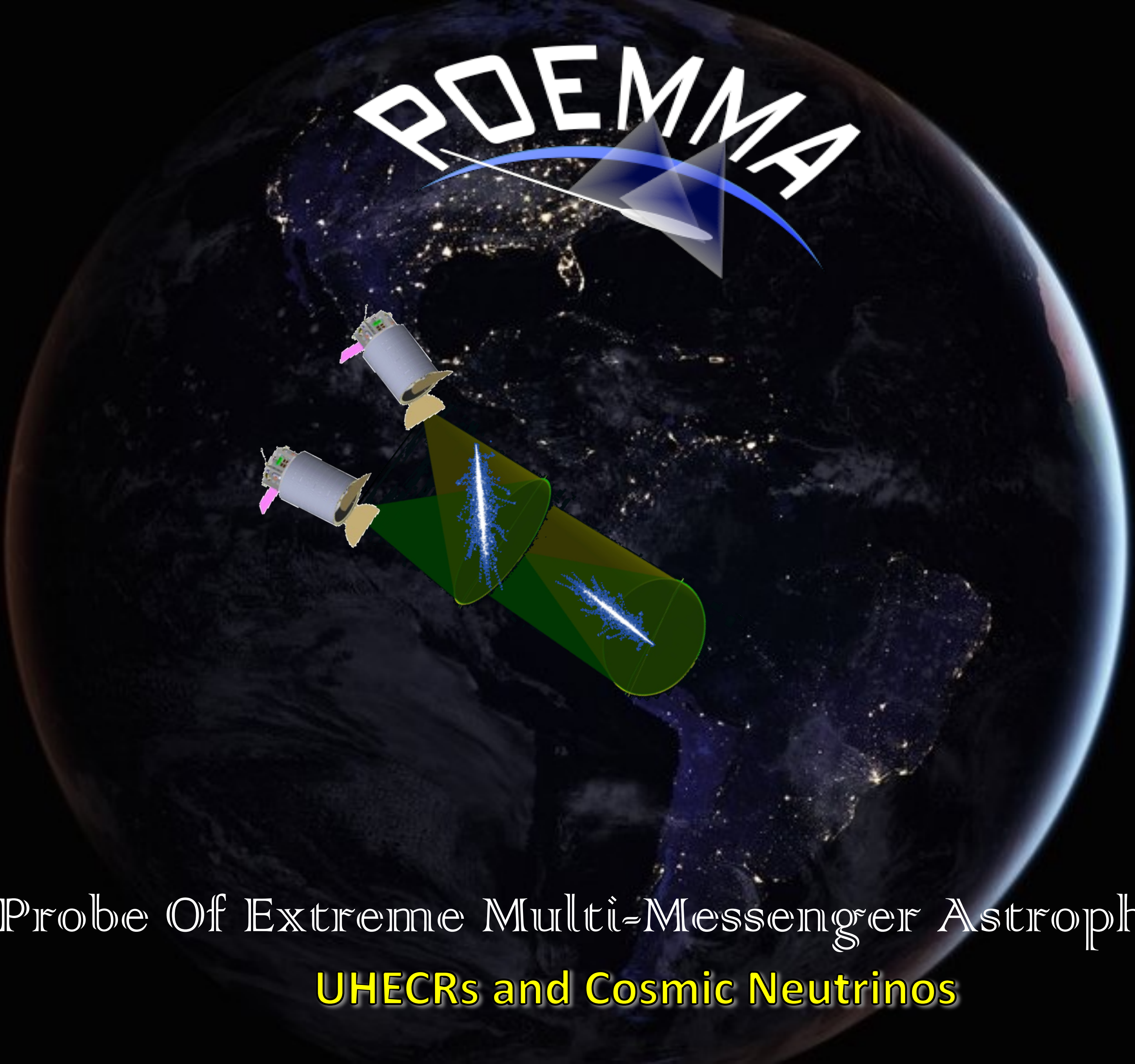

Cherenkov Telescope
Fluorescence Telescope




~53in (1.35m)

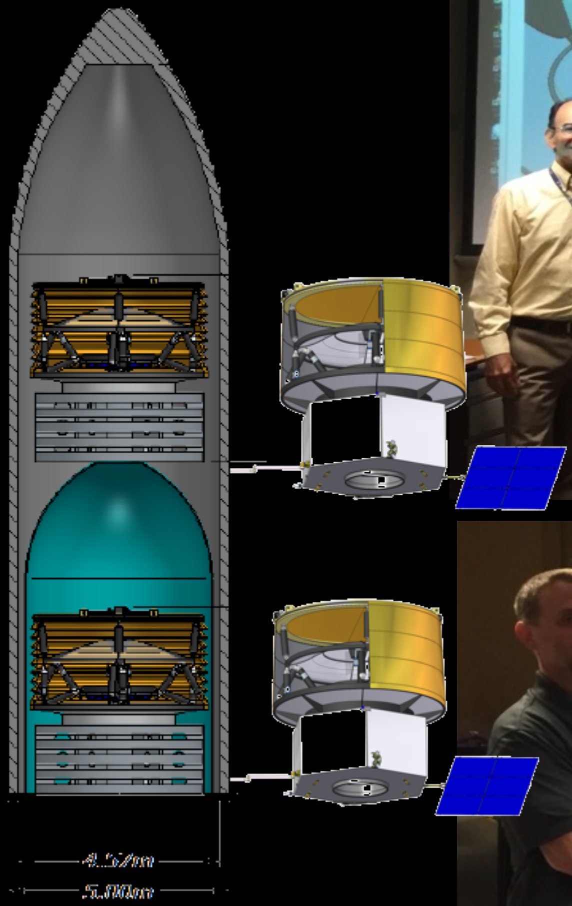

HVPS/LVPS
Camera
CT-CPU
AsAd
CoBo

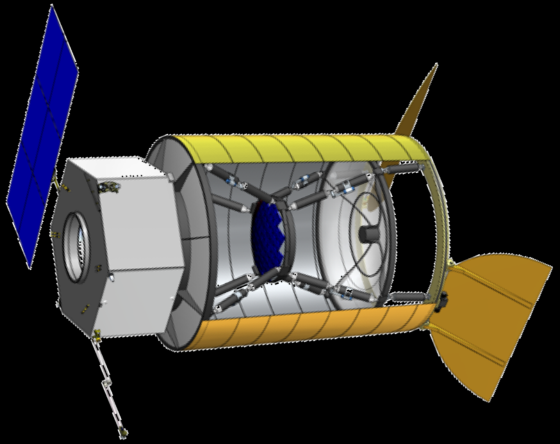


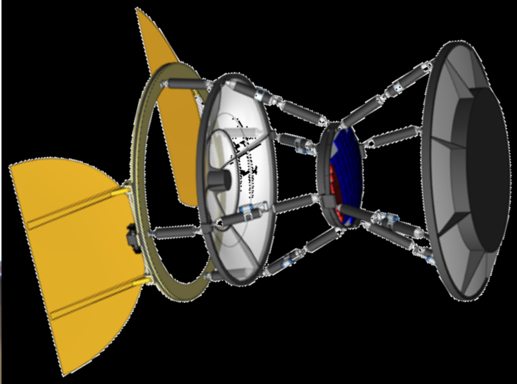

POEMMA
NASA
Probe Of Extreme Multi-Messenger Astrophysics
UHECRs and Cosmic Neutrinos

POEMMA at NASA-GSFC

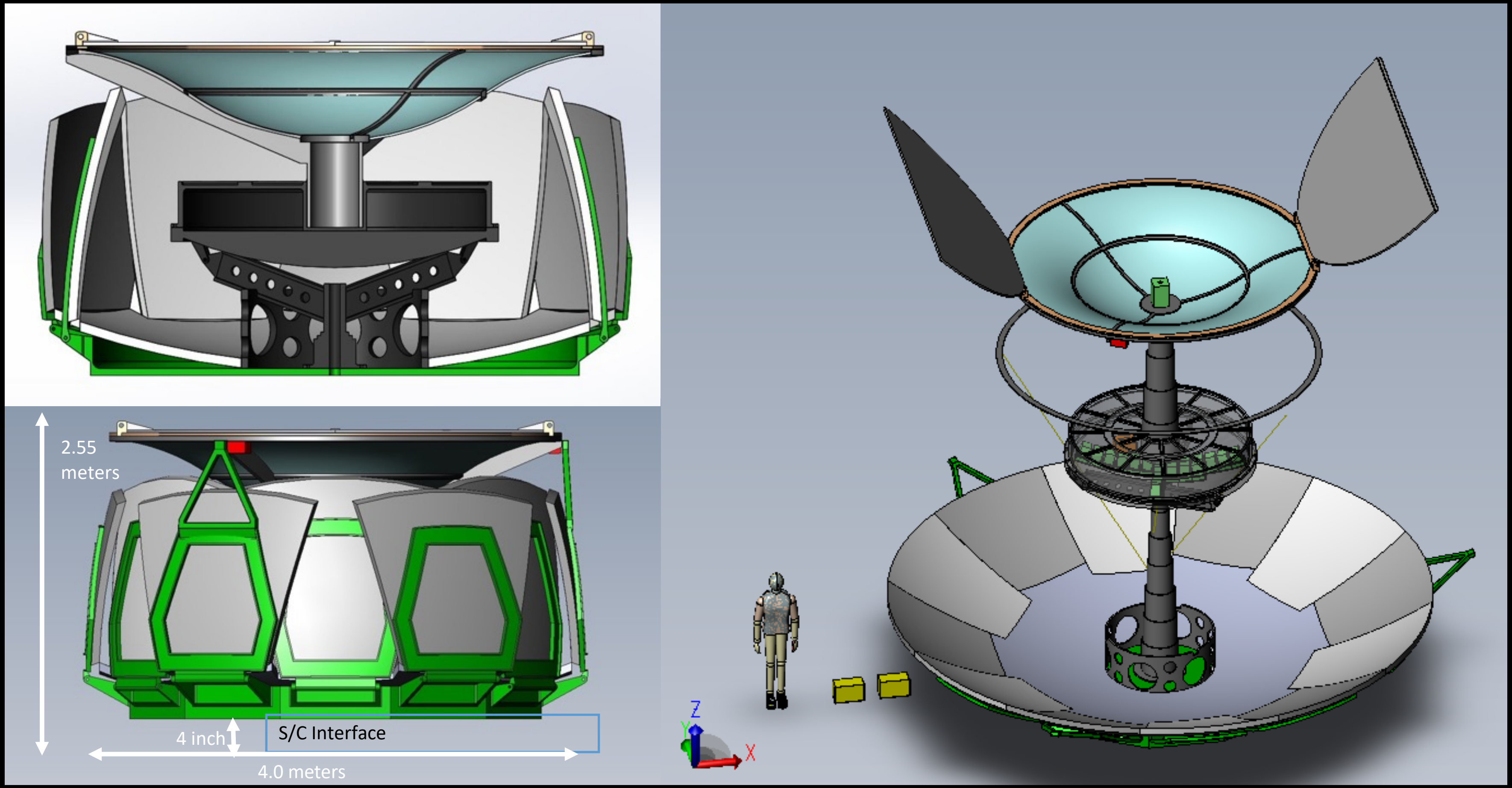
Instrument Design Lab: Jul 31-Aug 4, 2017
Mission Design Lab: Oct 30-Nov 3, 2017







Pre-IDL Design



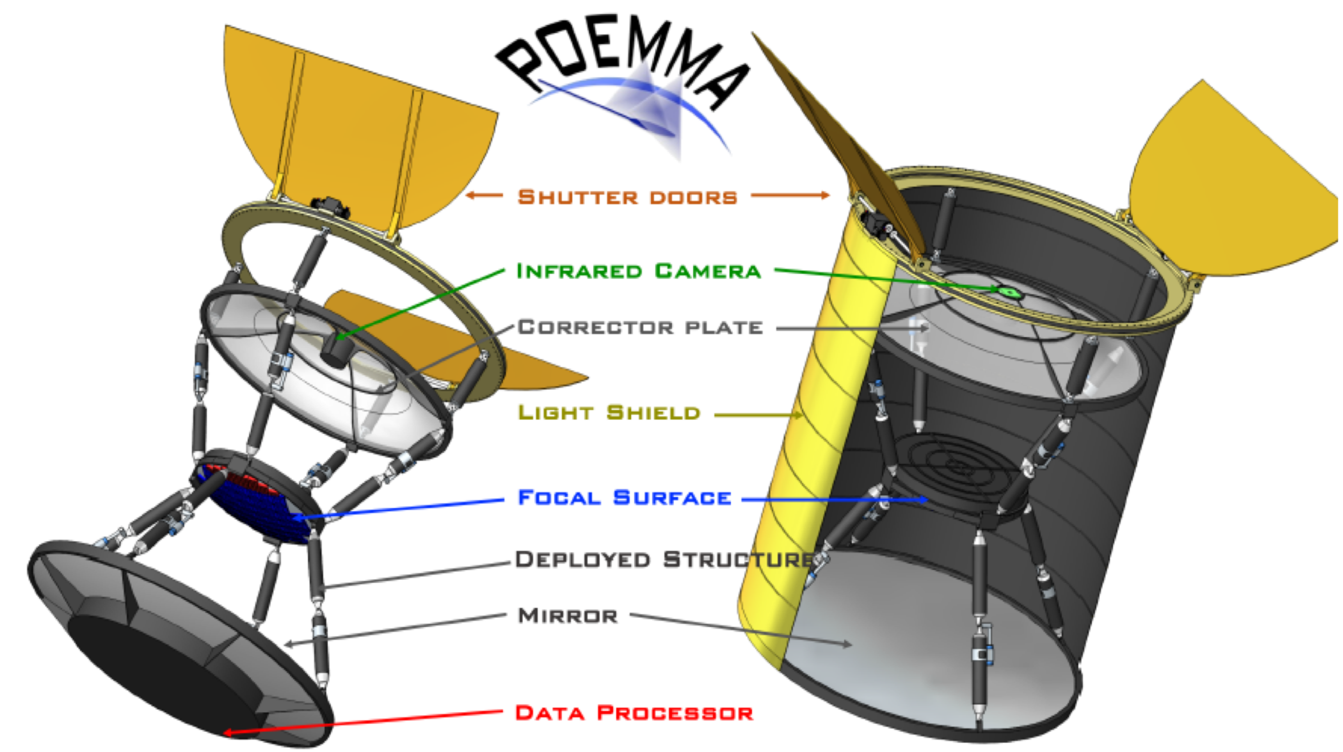
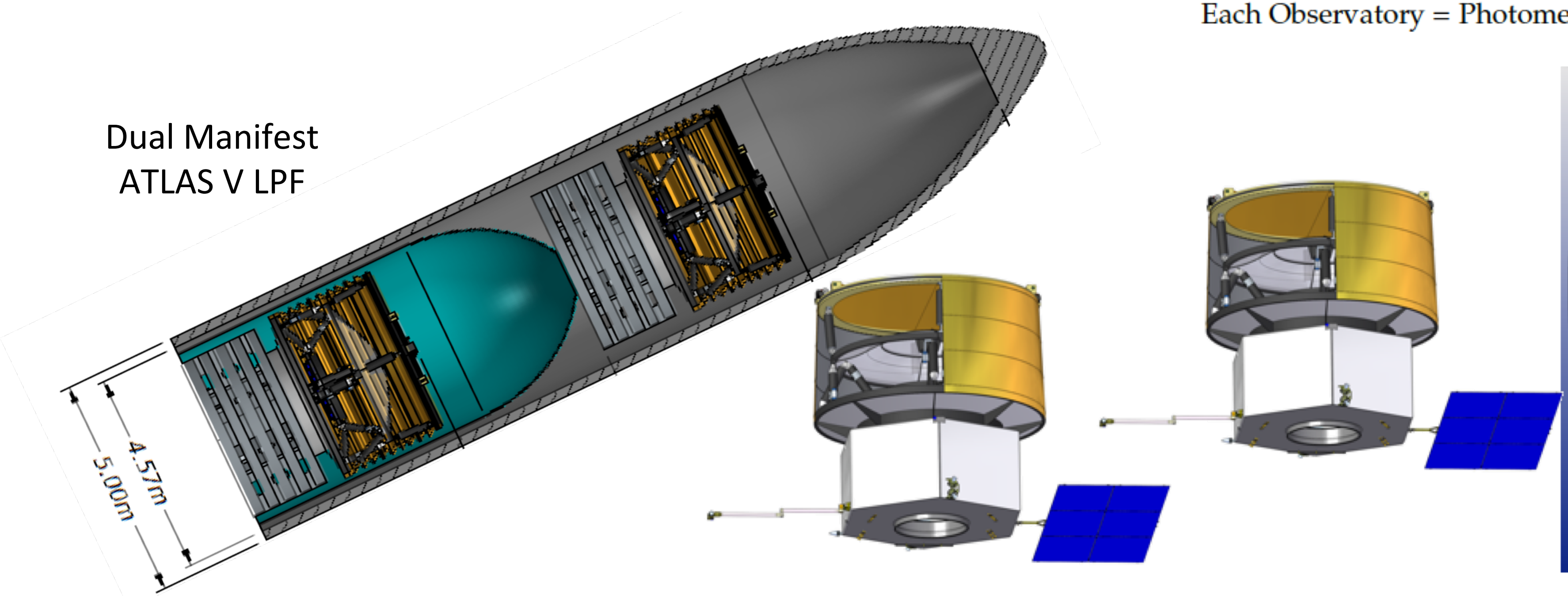
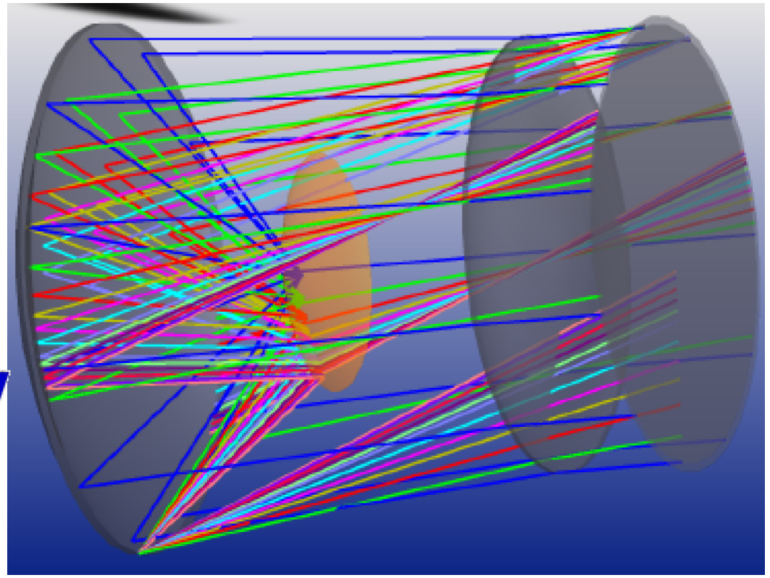


TABLE I: POEMMA Specifications:

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

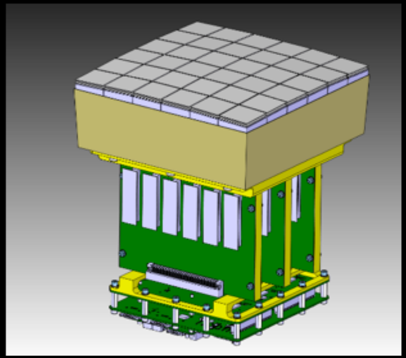


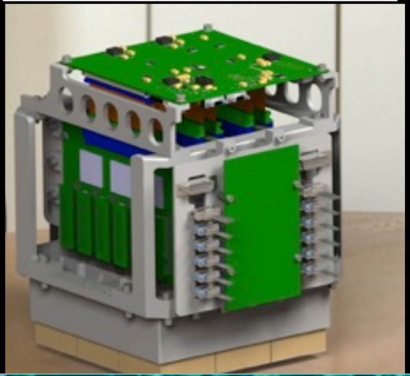


POEMMA

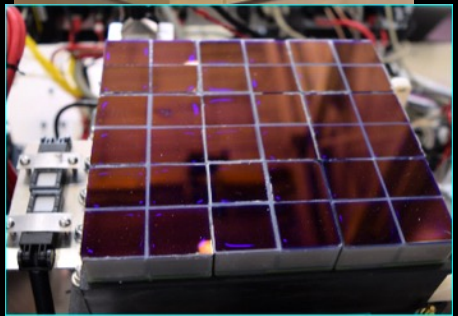
Hybrid Focal Surface

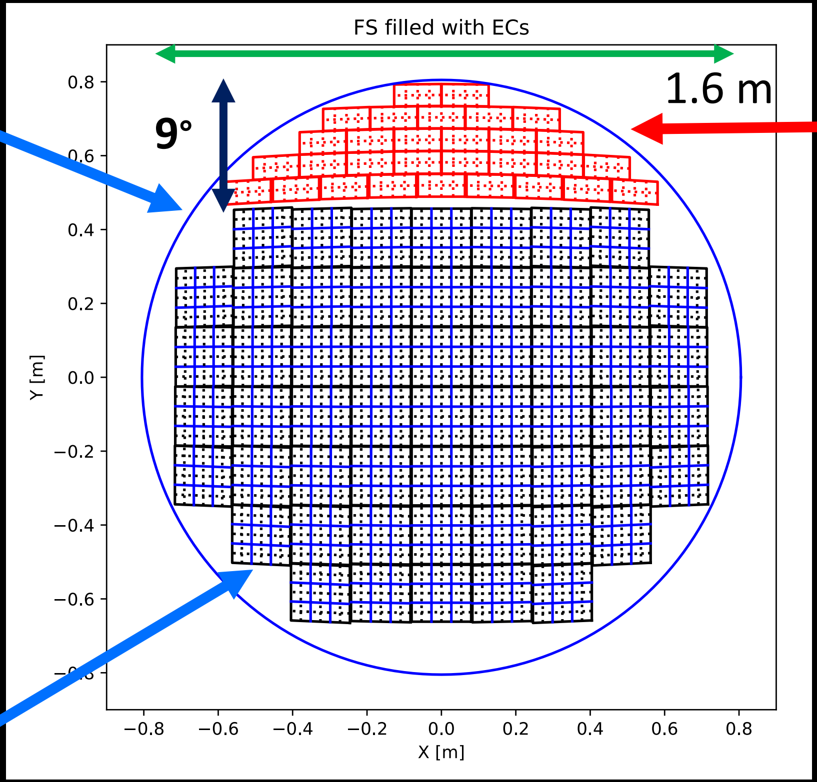
UV Fluorescence
MAPMTs with BG3 filter:
1 usec sampling





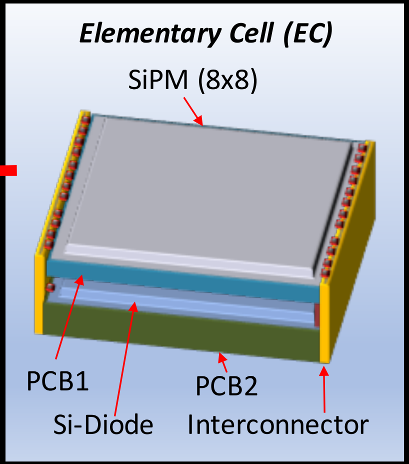
EUSO-SPB2
3 PDMs



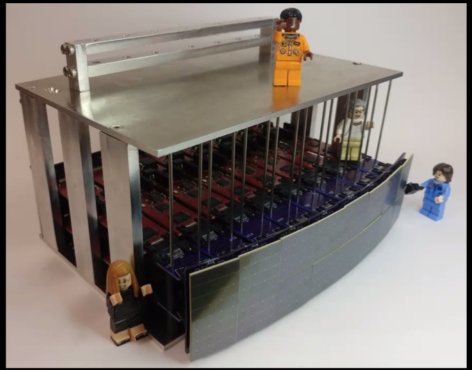


55 Photo Detector Modules (PDMs)
TOTAL 126,720 pixels
(1 PDM = 36 MAPMTs = 2,304 pixels)

Cherenkov Detection
SiPMs:
20 nsec sampling



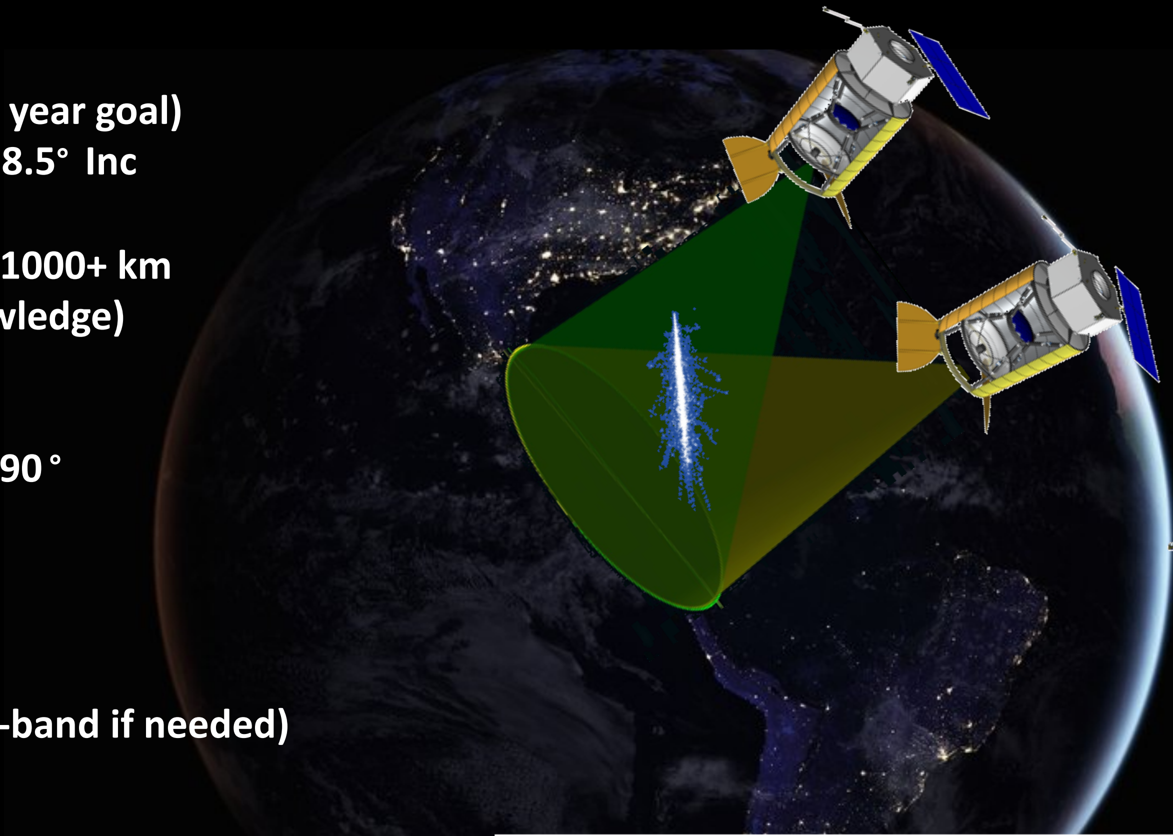
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)



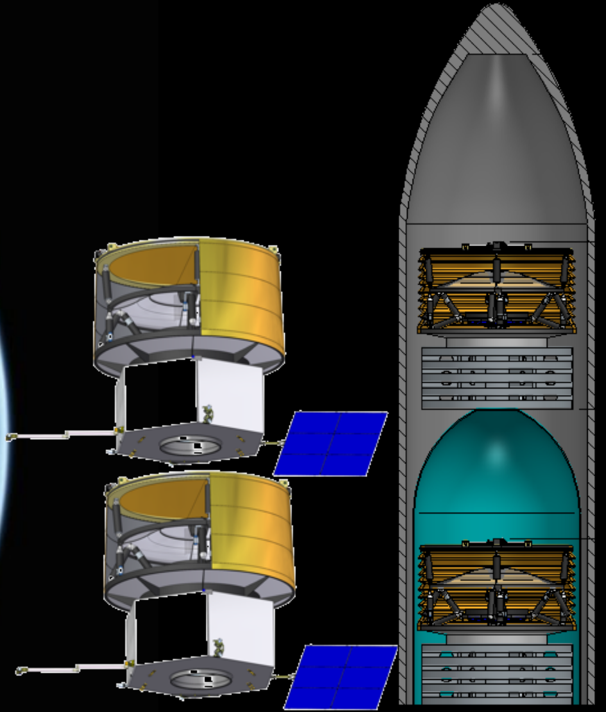
EUSO-SPB2
Cherenkov
Camera

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



Dual Manifest
ATLAS V LPF

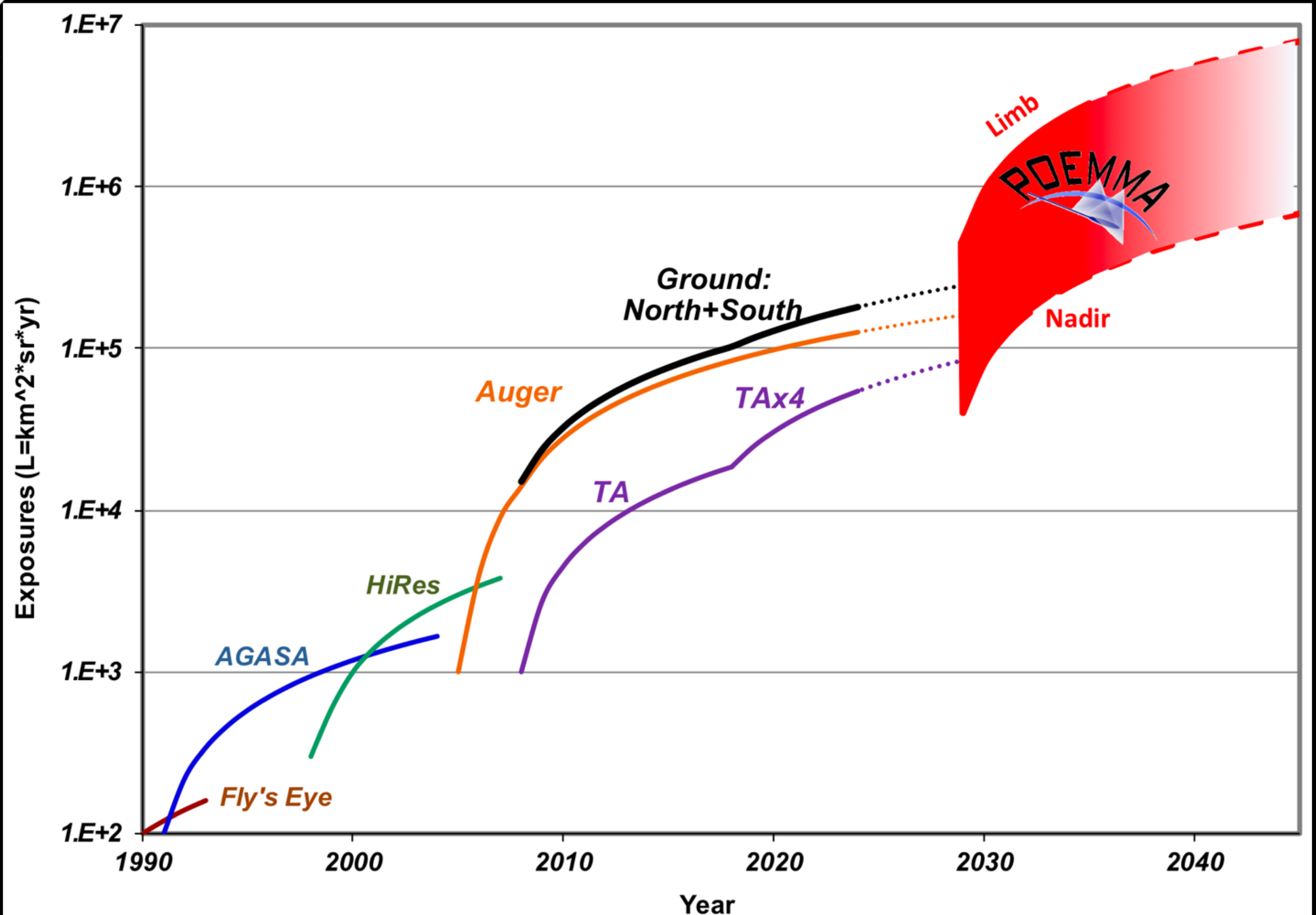


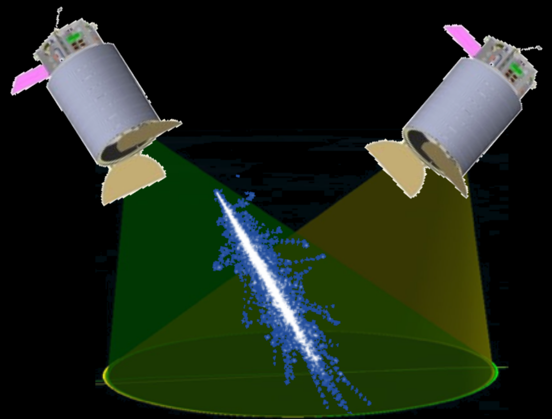
Operations:

- 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

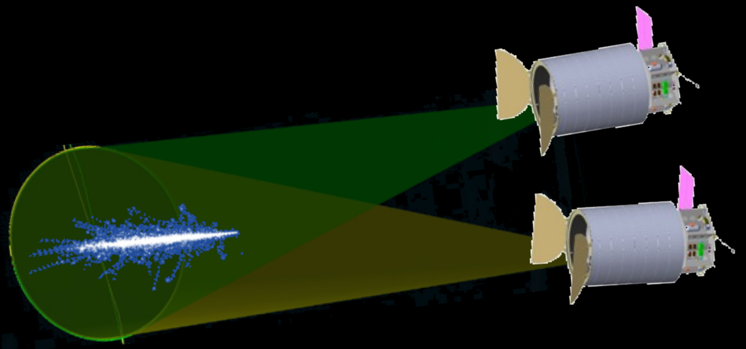
Observation Modes	Telescope Separation	Pointing	Science Goals (section)
POEMMA-Stereo (mode-2)	~300 km	down close to Nadir; overlapping atmospheric volumes	**UHECR fluorescence** (2.2, 2.3) precision stereo reconstruction UHECR lower energies 10s EeVs
POEMMA-Limb (mode-3)	~25 km	towards the Limb; azimuth follows ToO target overlapping volume at Limb	**Neutrino Cherenkov** (2.4, 2.5, 2.6) **ToO-stereo**
		towards the Limb; overlapping volume nearby non-overlapping at Limb	**UHECR fluorescence** (2.2, 2.3) stereo reconstruction 10s EeV monocular for 100s EeVs
	~300 km	fast slew towards the Limb from POEMMA-Stereo mode azimuth follows ToO target	**Neutrino Cherenkov** (2.4, 2.5, 2.6) **ToO-dual**

POEMMA UHECR Exposure



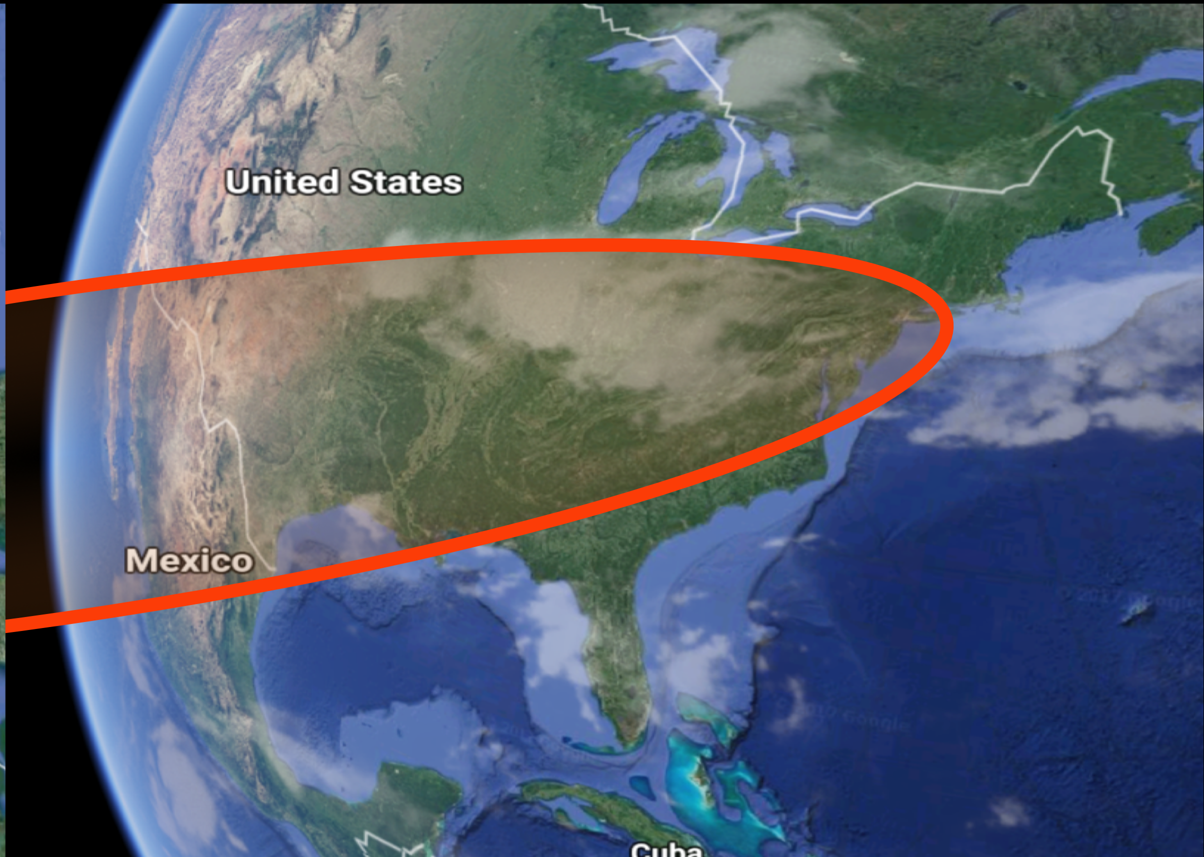


Observing Modes

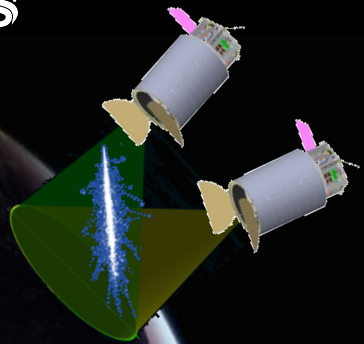


Nadir for UHECR: Radius 200-400 km

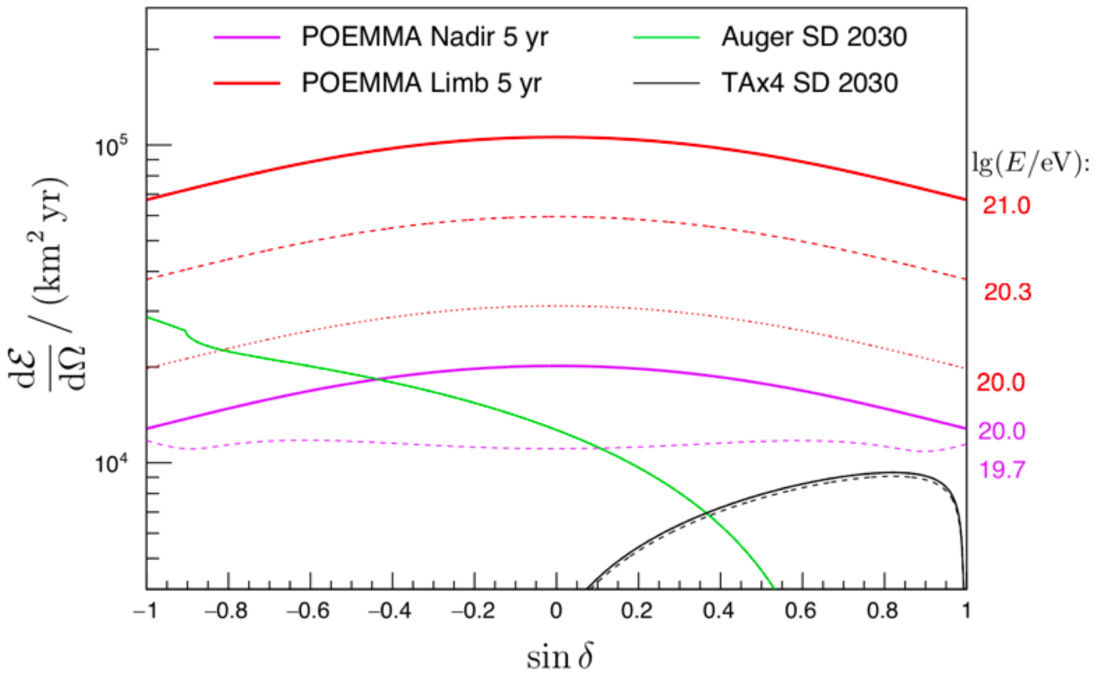
Limb for Neutrinos & UHECRs: Radius 3 10^3 km



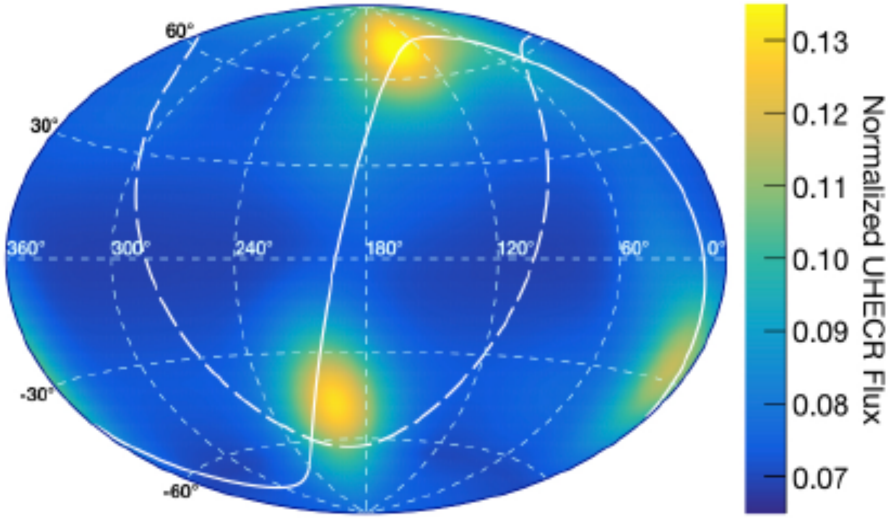
POEMMA: UHECRs



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



nearby Starburst Galaxies Fermi-LAT



POEMMA probability density

Anchordoqui et al. arXiv:1907.03694

AVO et al. arXiv:2012.0794

Fluorescence Capabilities

Angular Resolution:

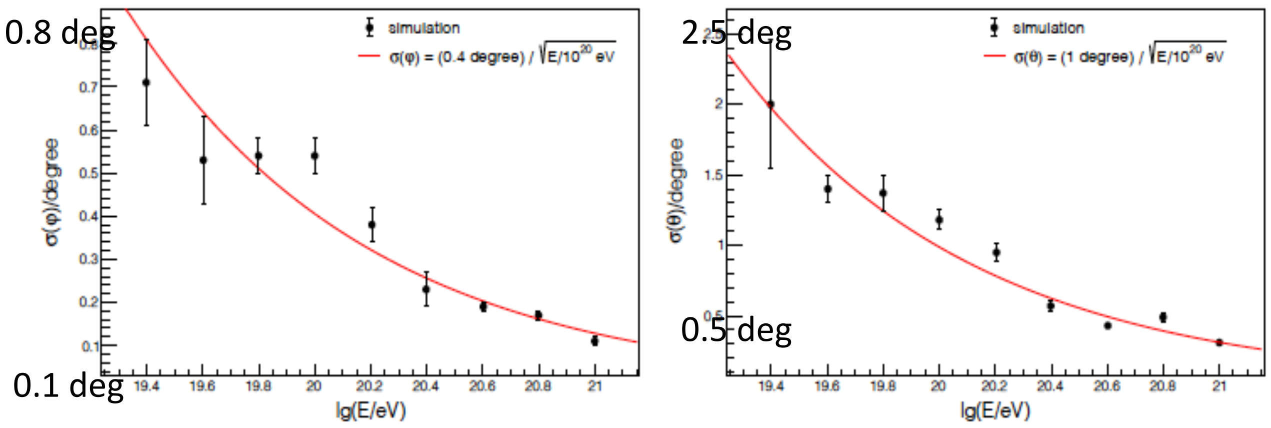


FIG. 5: POEMMA's simulated stereo-reconstructed angular resolution versus UHECR energy. Left: Azimuth angle, right: zenith angle.

Xmax Resolution:

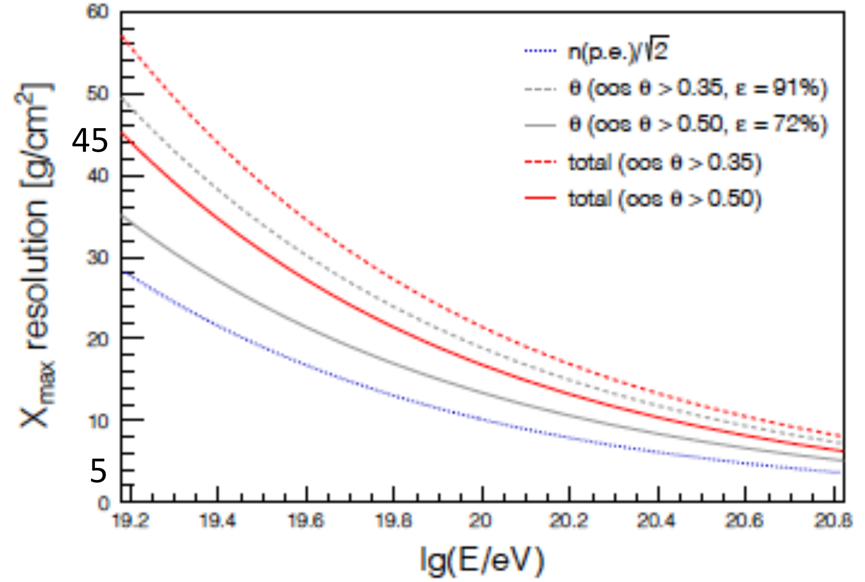


FIG. 17: Preliminary estimate of the X_{max} resolution of POEMMA in stereo mode. The contributions from the photo-electron statistics and angular resolution are shown in blue and gray respectively. The total resolution, obtained by adding both contributions in quadrature is shown in red for two cuts on the maximum zenith angle.

Energy Resolution:

1 eye: 26% and 24% at 50 and 100 EeV;
2 eyes: 18% and 17% at 50 and 100 EeV

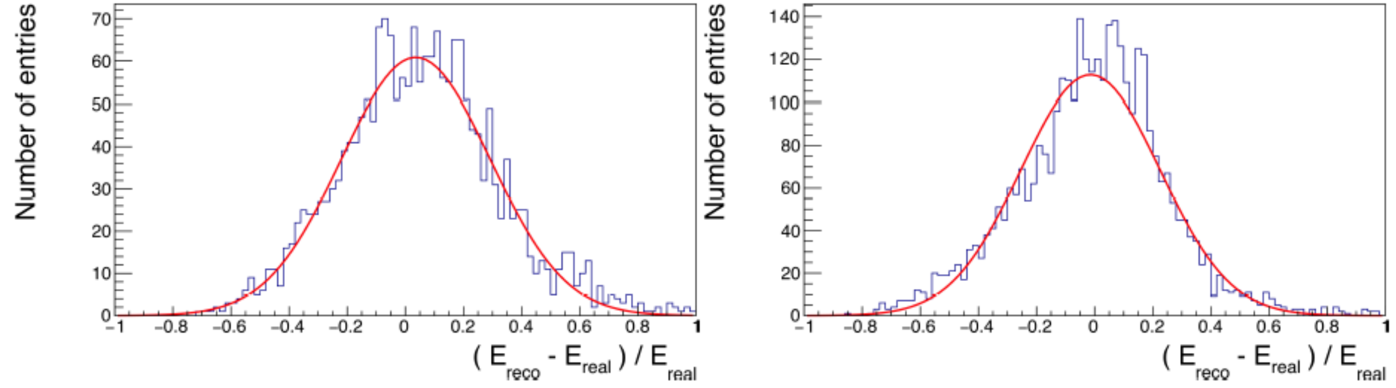
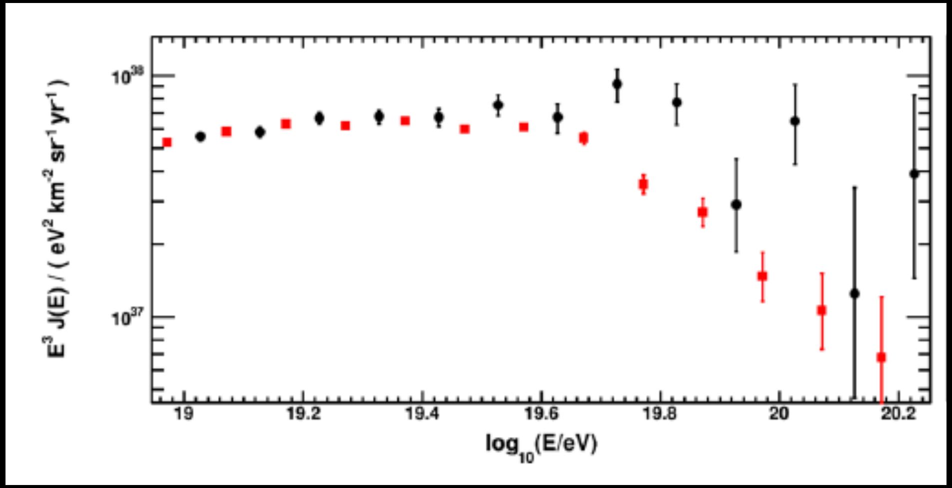


FIG. 36: ESAF simulated energy resolution assuming 1° zenith and azimuth angular resolution. Left: 50 EeV results, right: 100 EeV results.

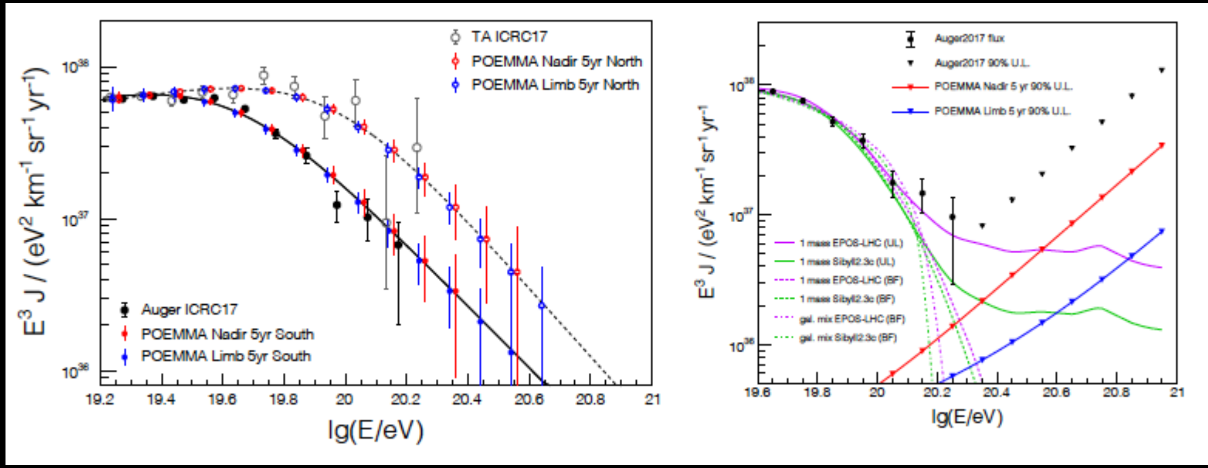
Anchordoqui et al., arxiv.1907.03694

Current (2019) & POEMMA Observations

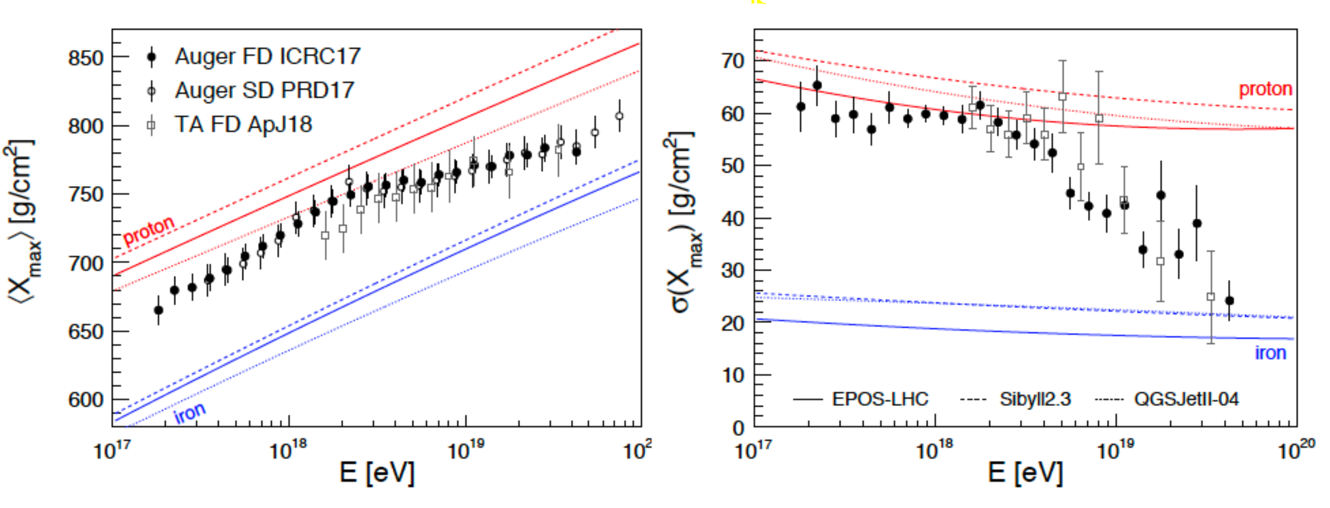
Current UHECR Spectrum



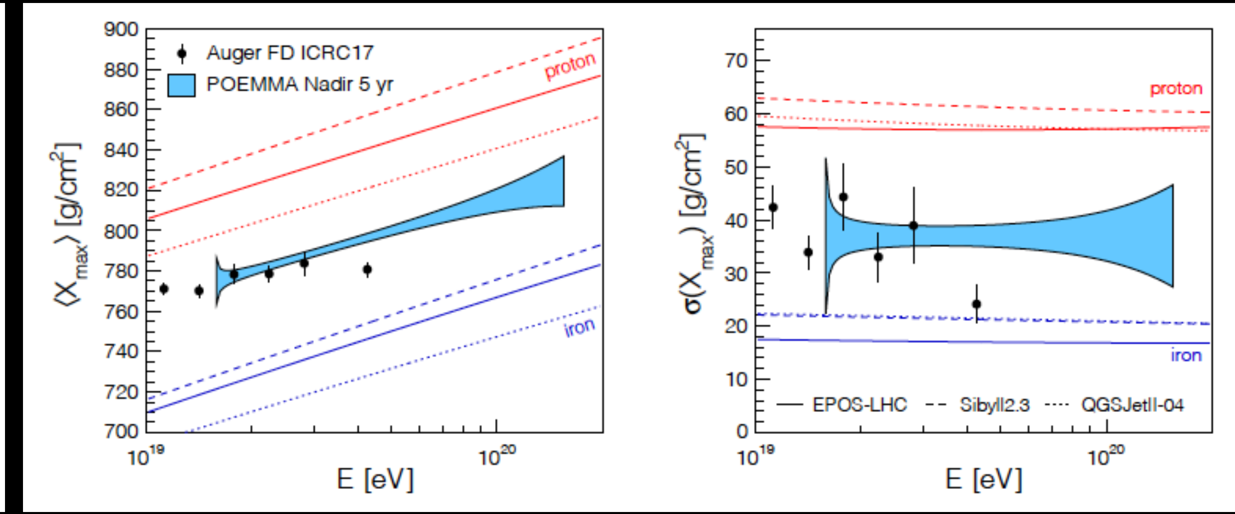
POEMMA UHECR Spectrum



Current UHECR Composition



POEMMA UHECR Composition

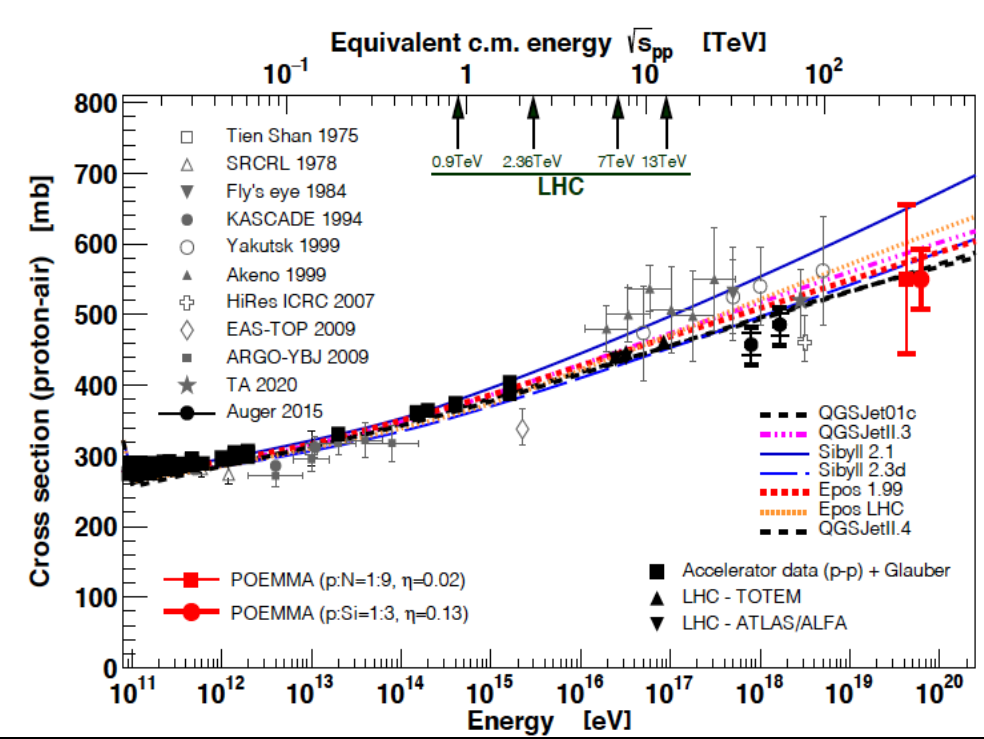


Batista et al., 2019: arxiv:1903.06714

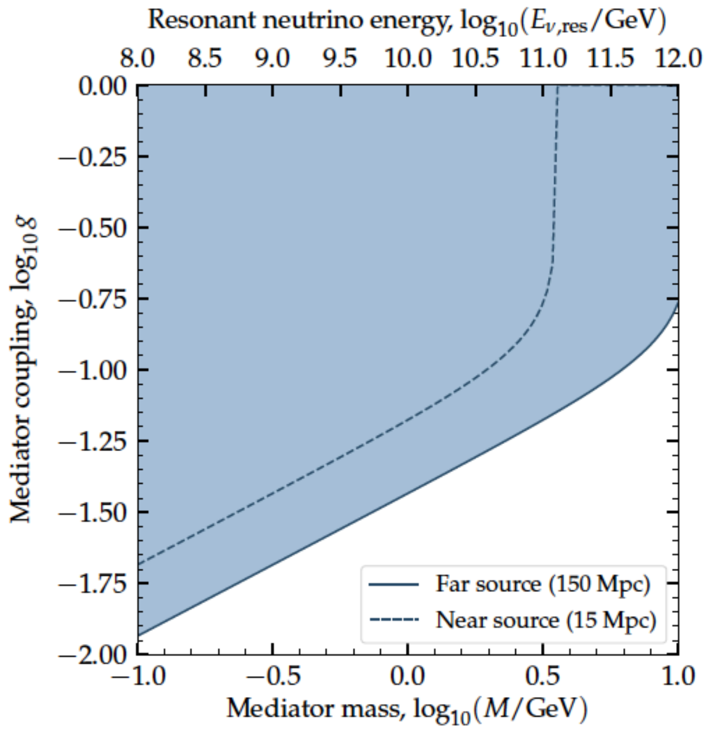
Anchordoqui et al., arxiv.1907.03694

Particle Physics with POEMMA

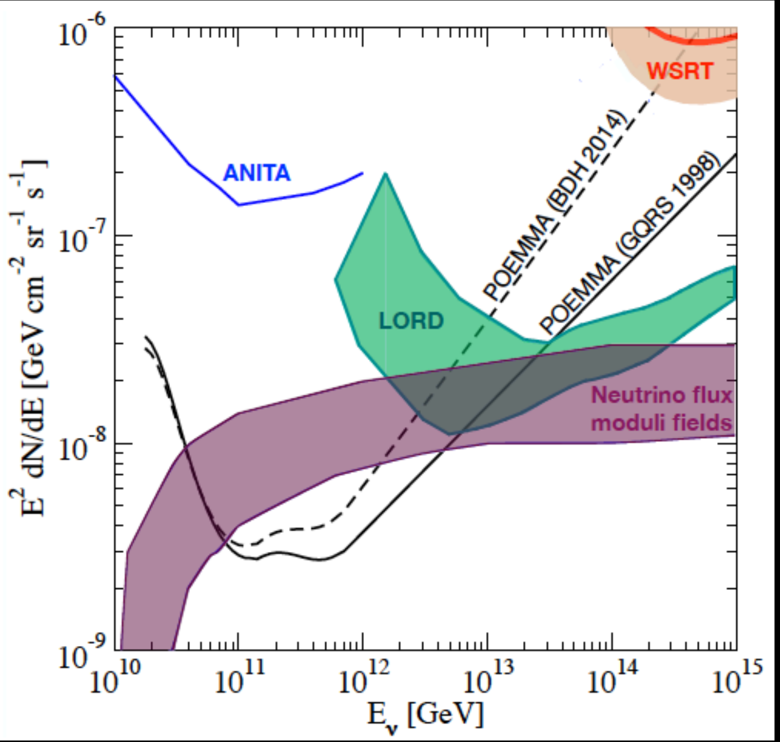
UHE proton-air cross section



Sensitivity Secret Neutrino Interactions with Cherenkov



Sensitivity UHE fluorescence from all three neutrino flavors



AVO et al. arXiv:2012.0794

POEMMA: Neutrinos

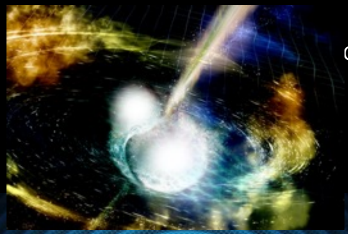
POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of tau decays.

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

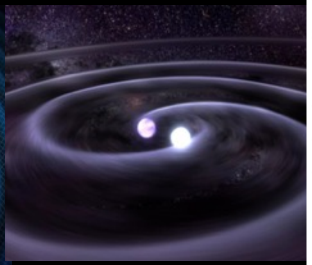
POEMMA: Neutrino Target of Opportunity

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.



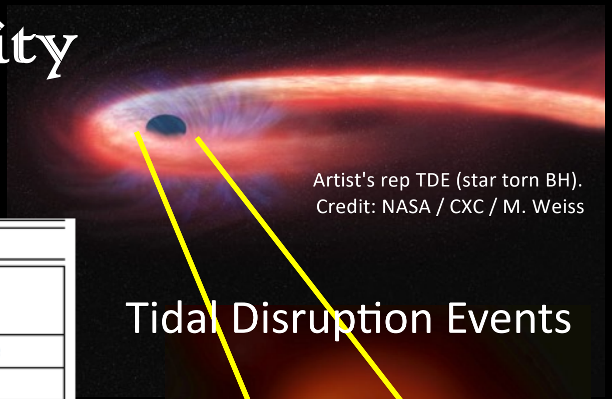
Artist's rep WD-WD merger
Credit: Ars Technica

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] $M_{SMBH} = 5 \times 10^6 M_\odot$ 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]

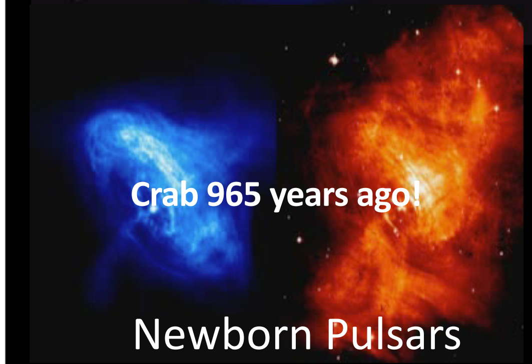
(*) Not applicable due to a lack of known blazars within 100 Mpc.



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

Tidal Disruption Events

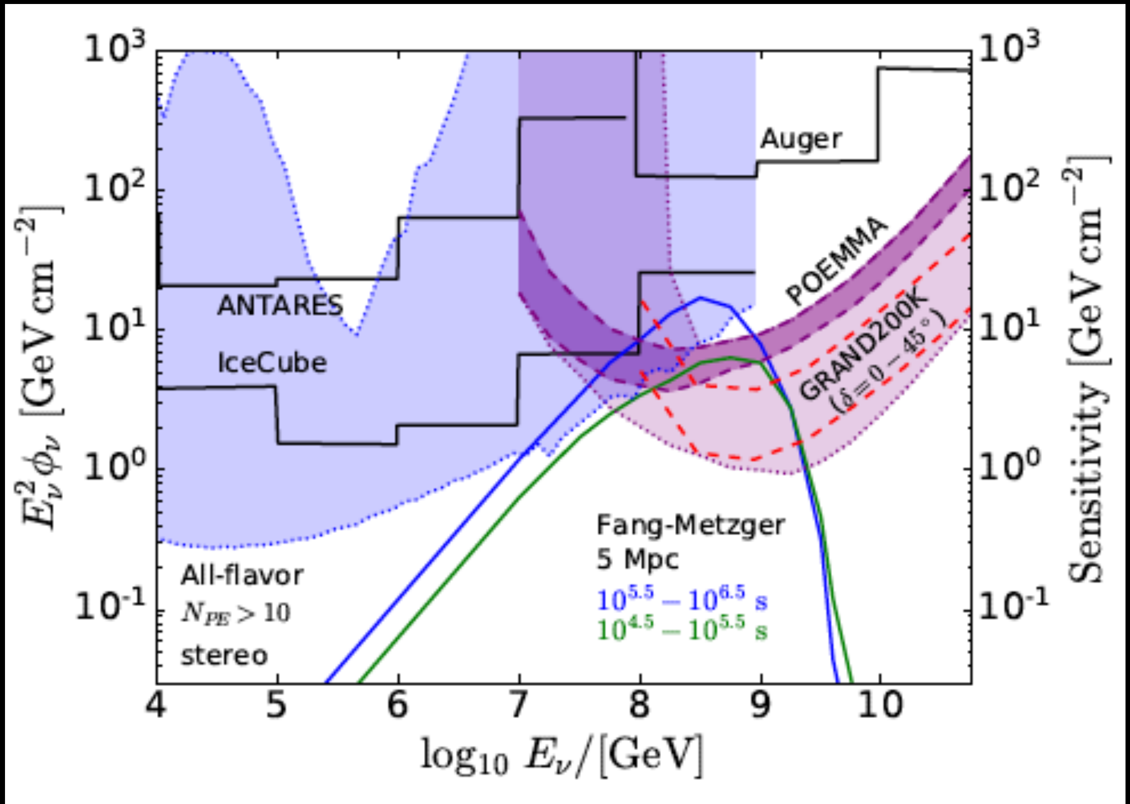
EVENT HORIZON TELESCOPE
COLLABORATION/MAUNAKEA
OBSERVATORIES/ASSOCIATED PRESS



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

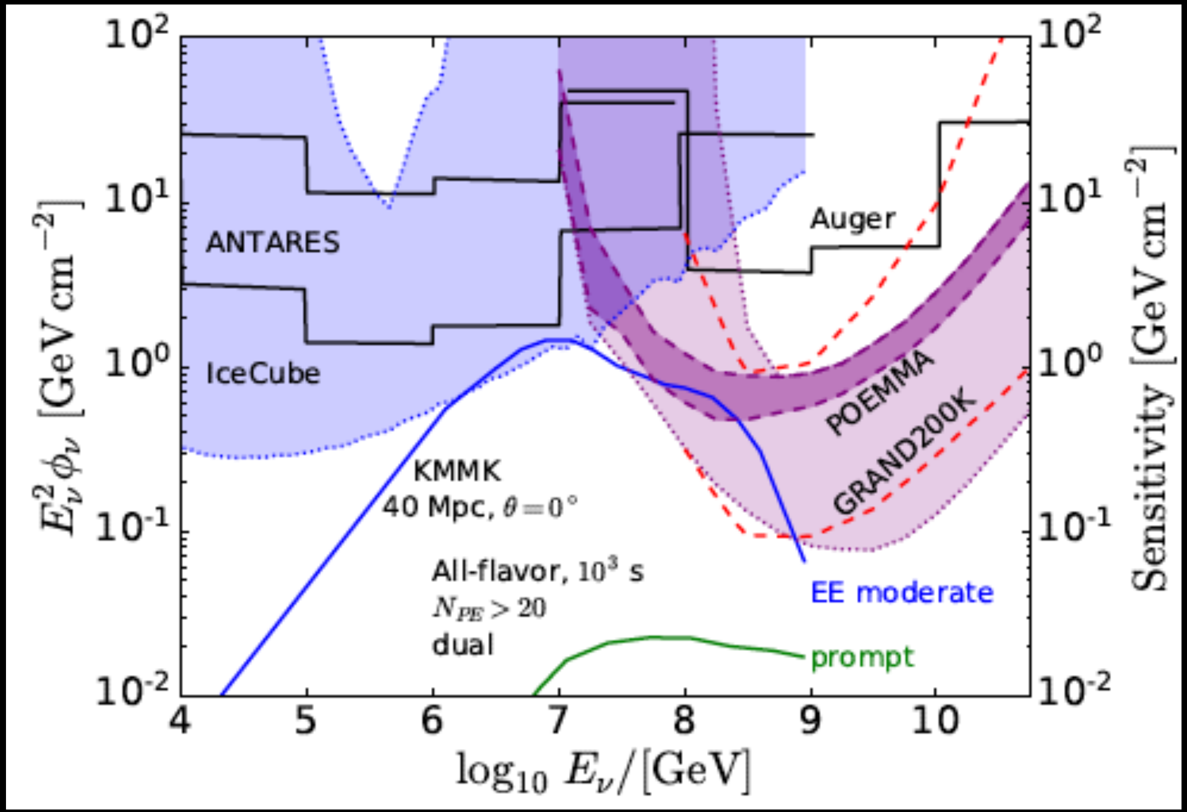
Transient Neutrino Point Source Sensitivity

Long Bursts



Fang & Metzger, arXiv:1707.04263

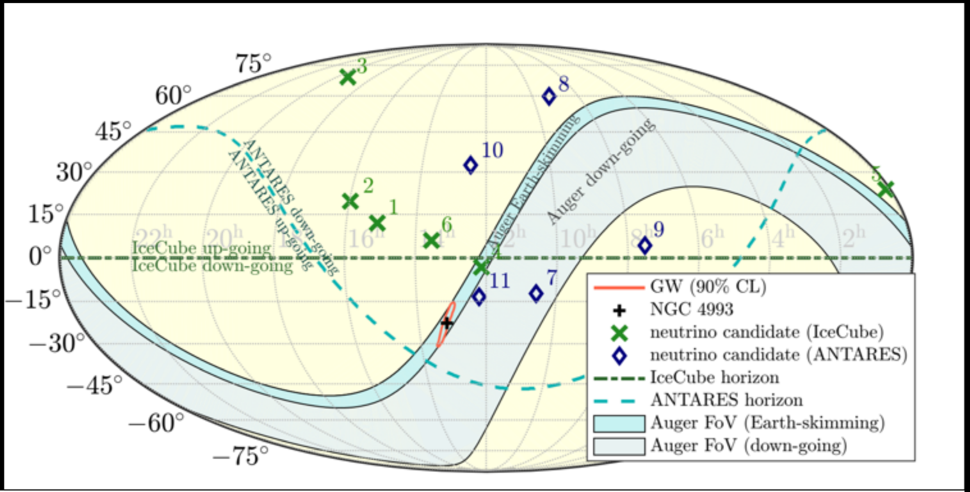
Short Bursts (<100 s)



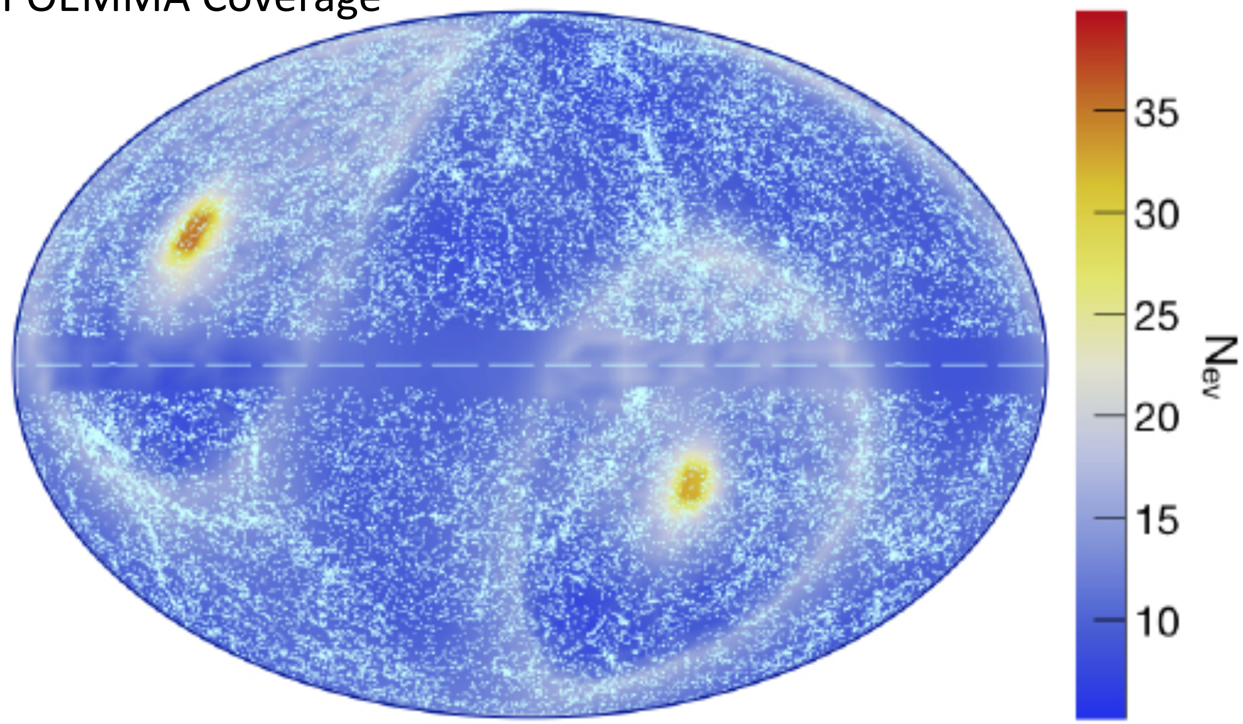
Kimura et al, arXiv:1708.07075

Venters et al. arXiv:1906.07209 and AVO et al. arXiv:2012.0794

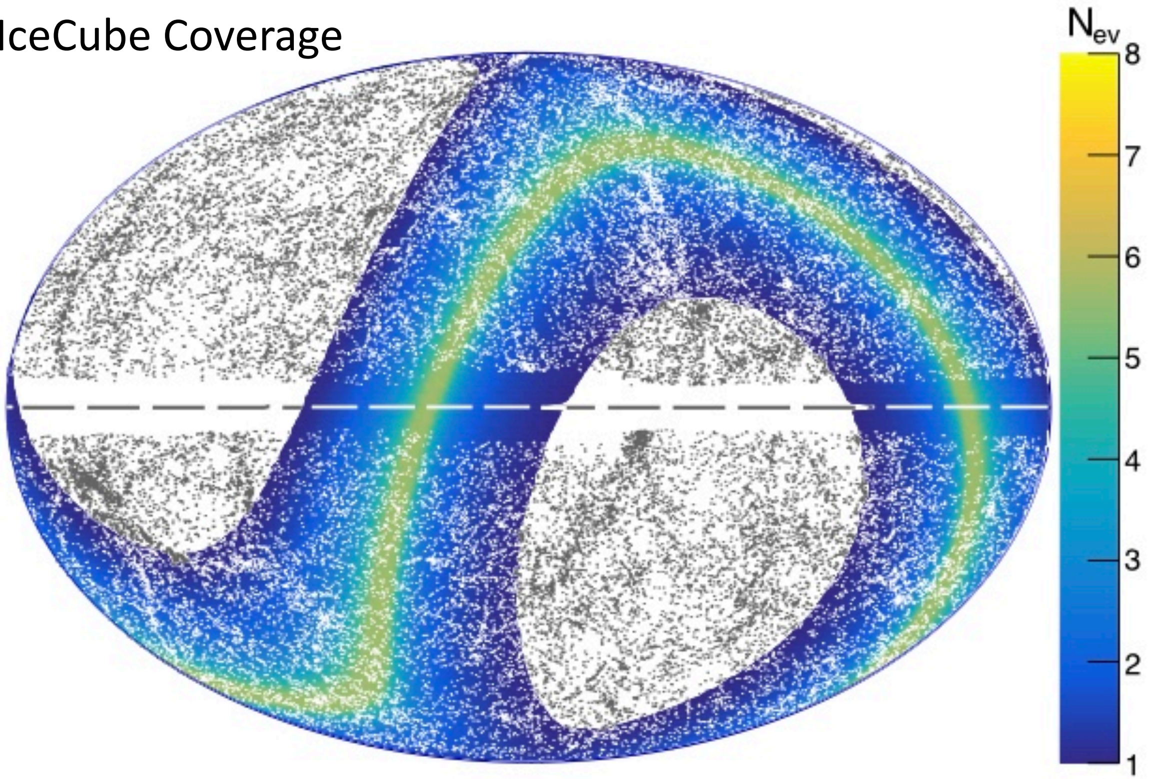
Full Sky Coverage
HE-UHE Neutrinos



POEMMA Coverage



IceCube Coverage



Venters et al arXiv:1906.07209

POEMMA

UHECR and Neutrino Observations

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