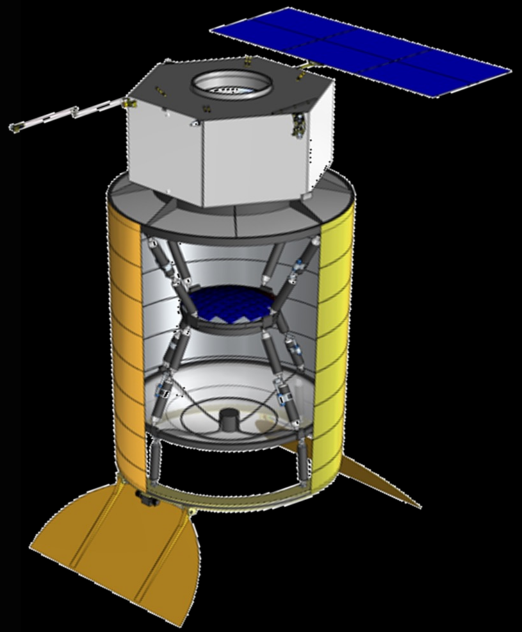
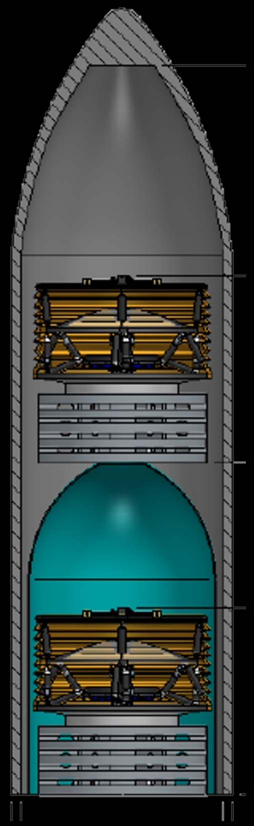
Update on the Roadmap to POEMMA

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

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;

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

MEXICO: **UNAM:** 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

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

POEMMA & EUSO APS Talks

Saturday, April 9, 2022
E15.00006 : nuSpaceSim, John F Krizmanic, et al

Monday, April 11, 2022
W03.00001: EUSO-SPB2 Status and Science, Angela V. Olinto, et al.
W03.00002: Development of the Cherenkov Telescope for EUSO-SPB2, Eliza Gazda et al.
W03.00003: EUSO-SPB2 Telescope Optics and Testing, Viktoria Kungel et al.

Tuesday, April 12, 2022
Z03.00004 Observing UHECRs and cosmic neutrinos with POEMMA, Claire Guepin et al,

Astroparticle Physics Questions:

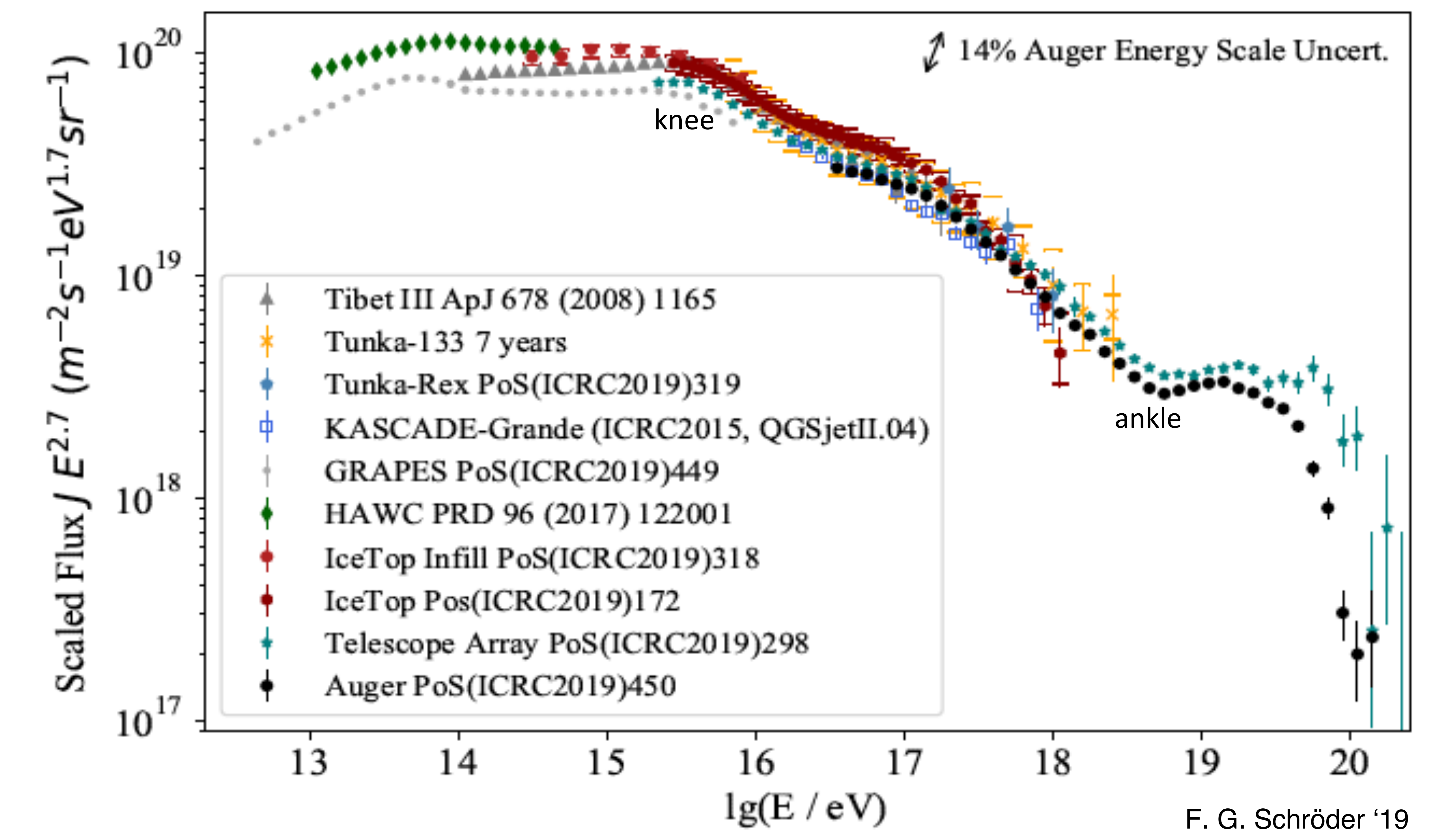
What are the sources of the **Ultra-High Energy Cosmic Rays** (UHECRs)?

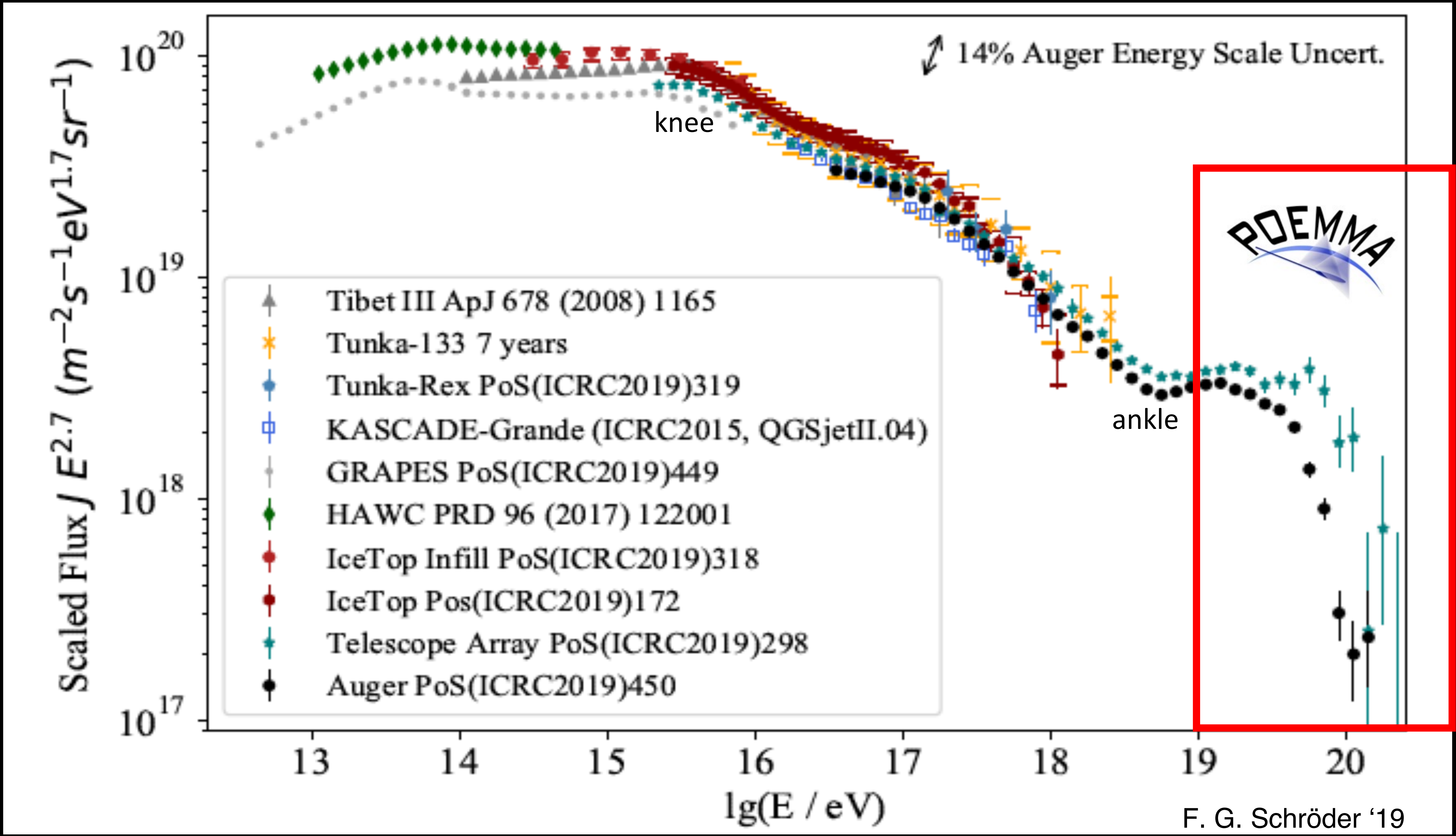
Measure Spectrum, Composition, Anisotropies **$E>10^{19}$ eV = 10 EeV**

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?


14% Auger Energy Scale Uncert.
knee
ankle
Tibet III ApJ 678 (2008) 1165
Tunka-133 7 years
Tunka-Rex PoS(ICRC2019)319
KASCADE-Grande (ICRC2015, QGSjetII.04)
GRAPES PoS(ICRC2019)449
HAWC PRD 96 (2017) 122001
IceTop Infill PoS(ICRC2019)318
IceTop Pos(ICRC2019)172
Telescope Array PoS(ICRC2019)298
Auger PoS(ICRC2019)450
Scaled Flux $J\,E^{2.7}$ $(m^{-2}s^{-1}eV^{1.7}sr^{-1})$
10^{20}
10^{19}
10^{18}
10^{17}
13
14
15
16
17
18
19
20
lg(E / eV)
F. G. Schröder '19



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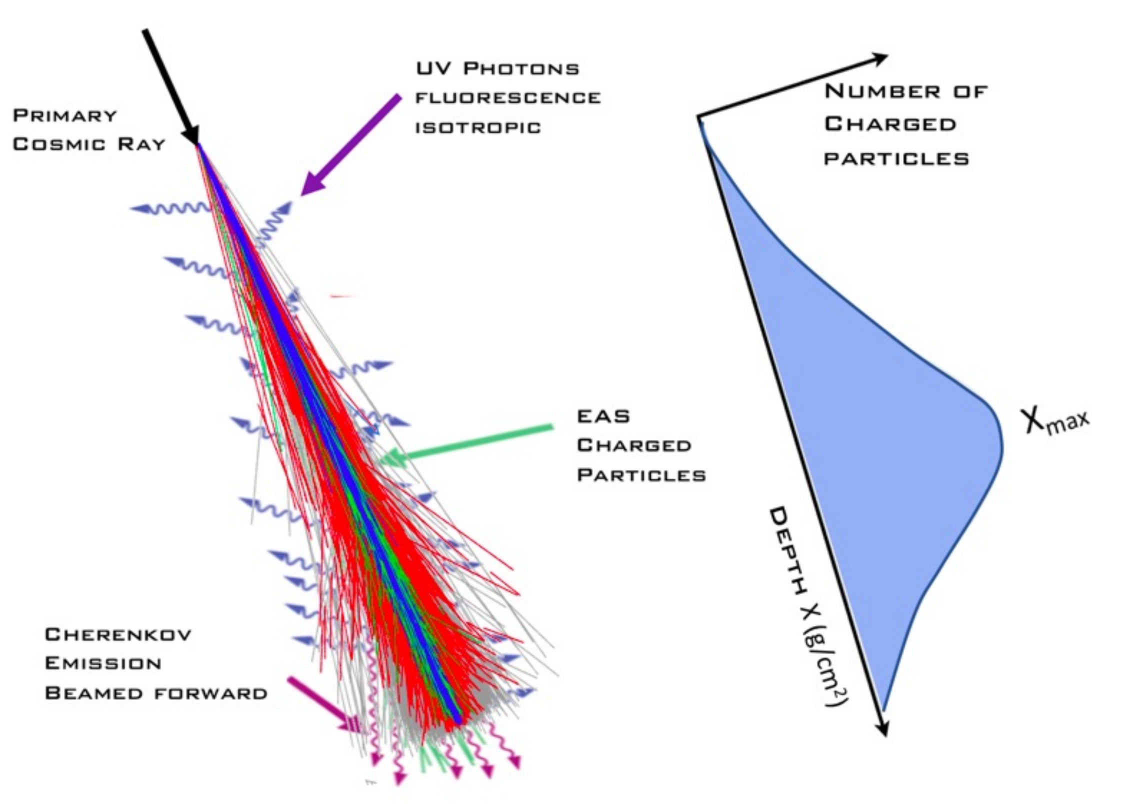
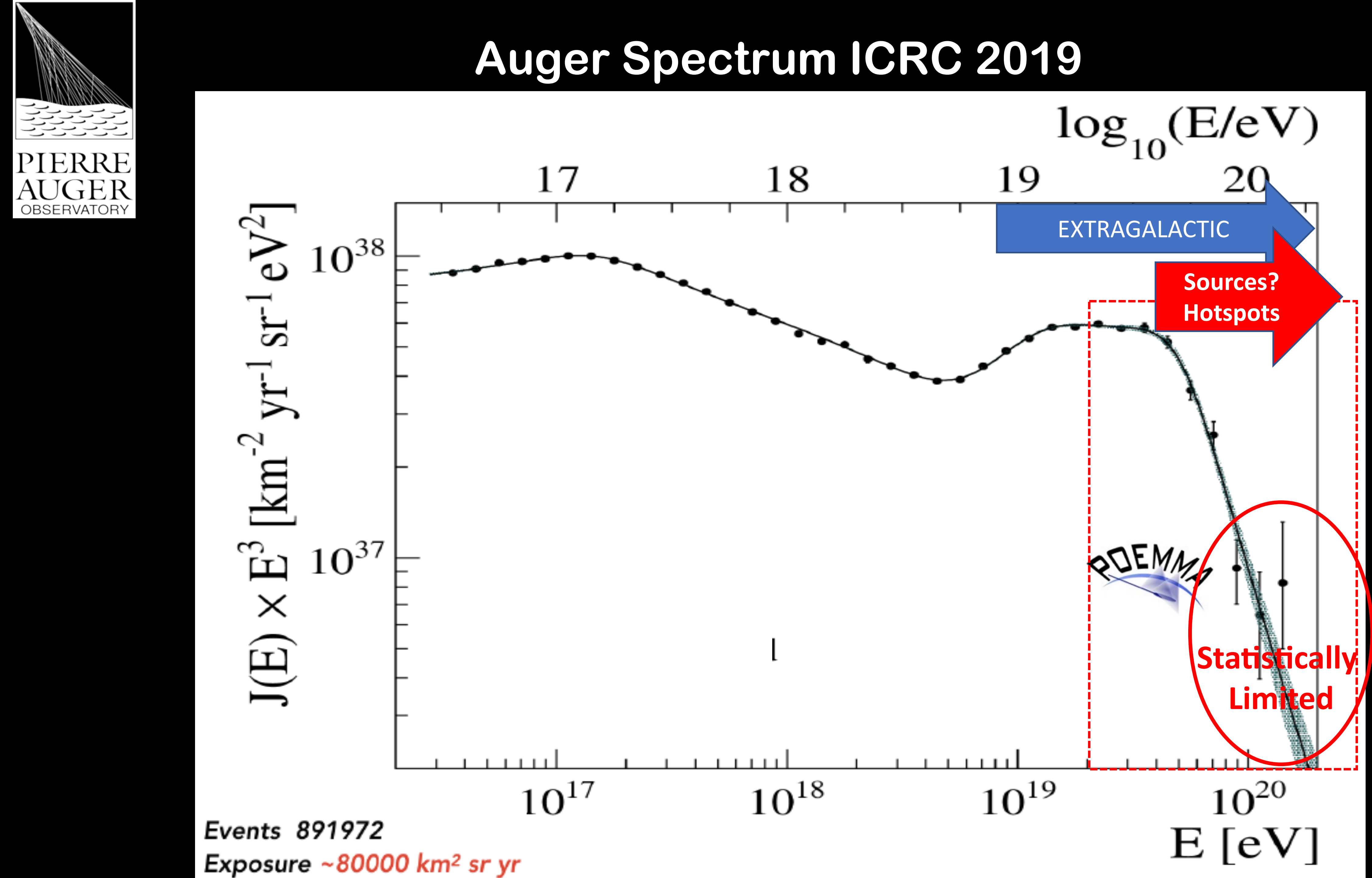
Scaled Flux J E^2.7 (m^-2 s^-1 eV^1.7 sr^-1)
lg(E / eV)
F. G. Schröder '19

Extensive Air Showers



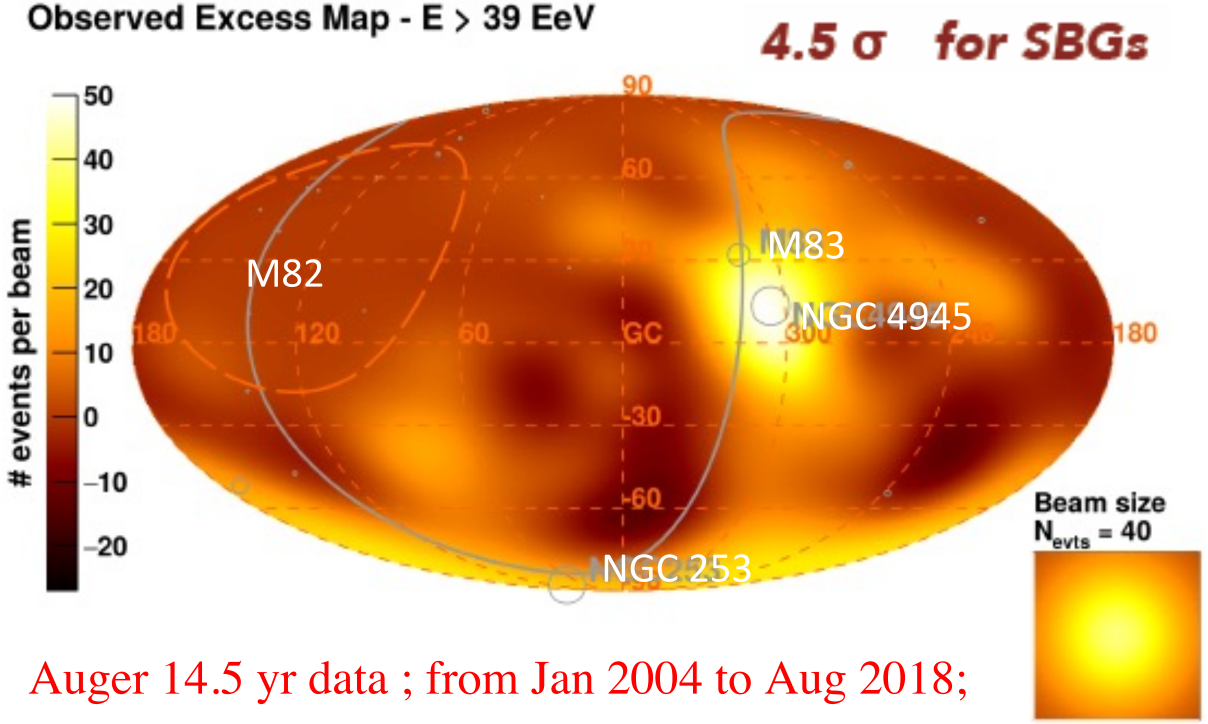
Auger Spectrum ICRC 2019



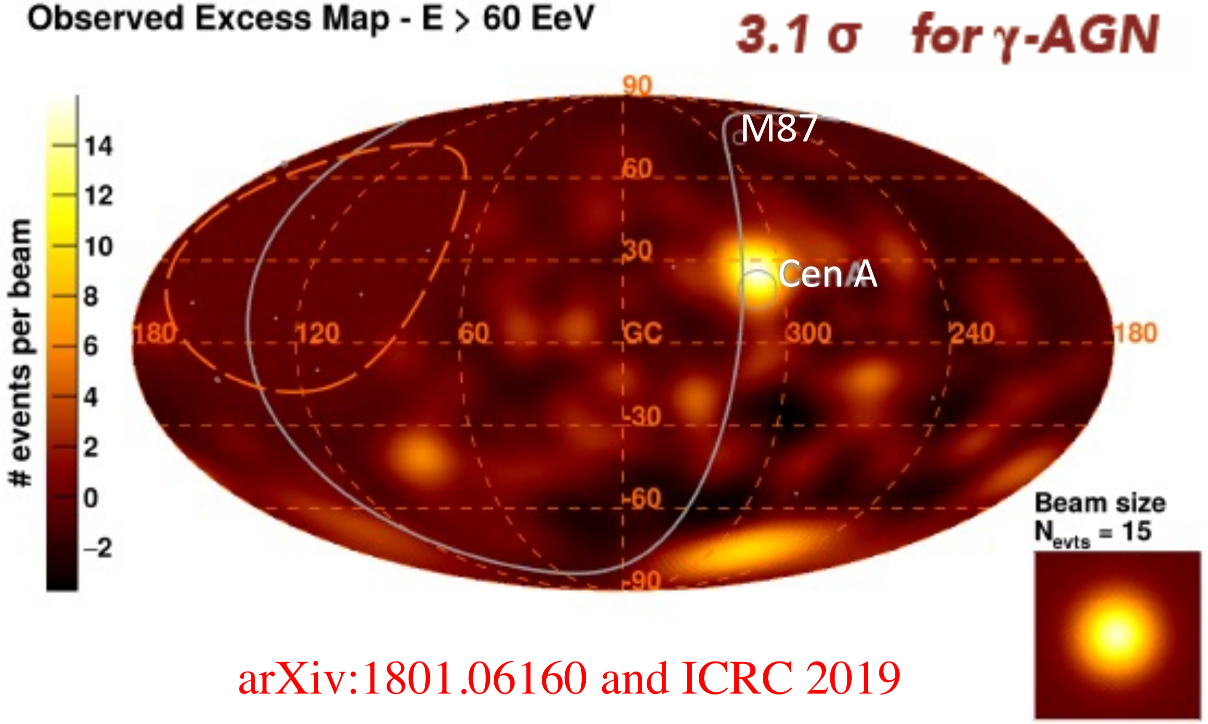
Auger (and TA) Anisotropy Hints > 40 EeV

Starbursts Galaxies (SBGs) or Active Galactic Nuclei (AGN)?

4.5 σ for SBGs



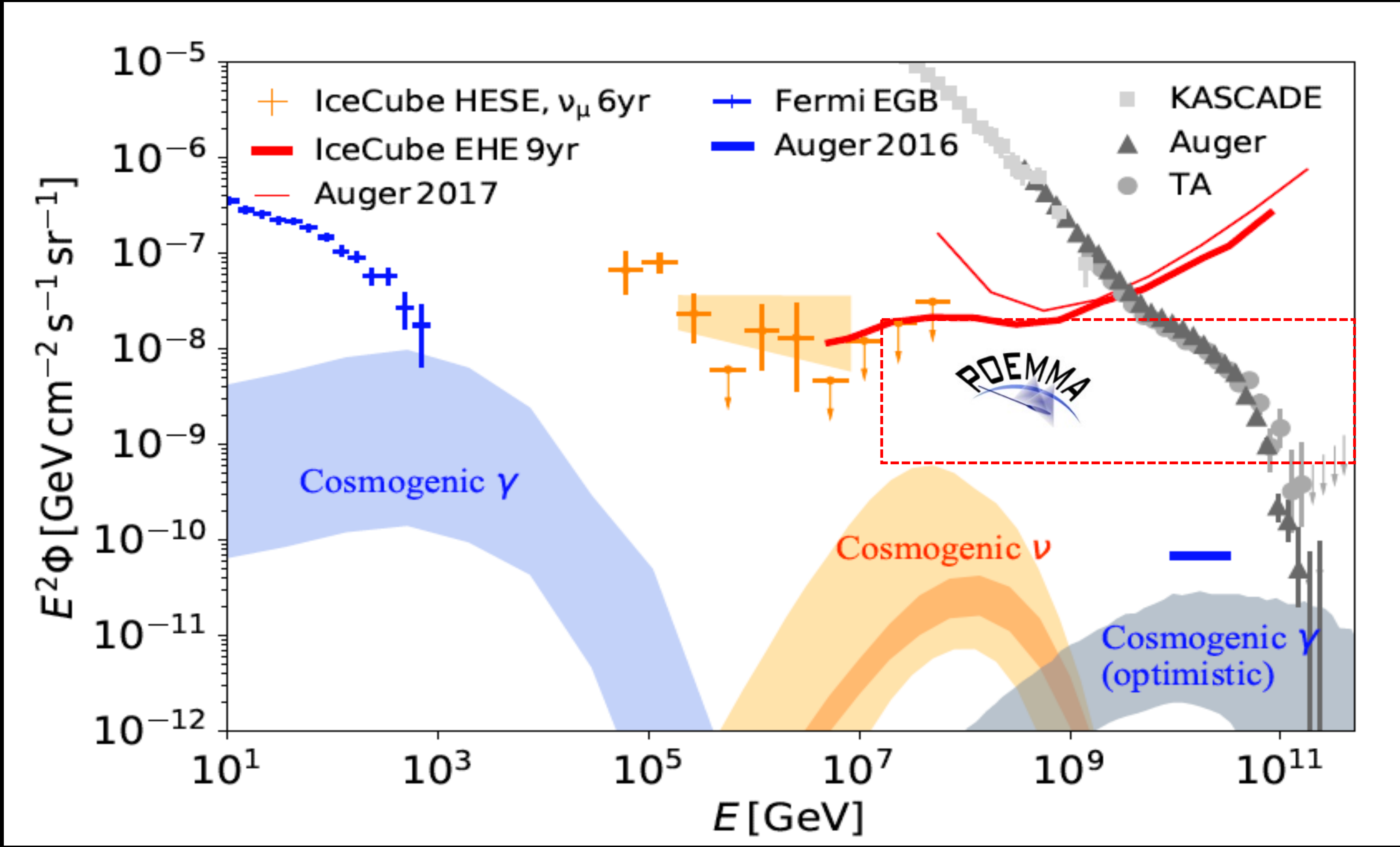
3.1 σ for γ-AGN



Auger 14.5 yr data ; from Jan 2004 to Aug 2018;

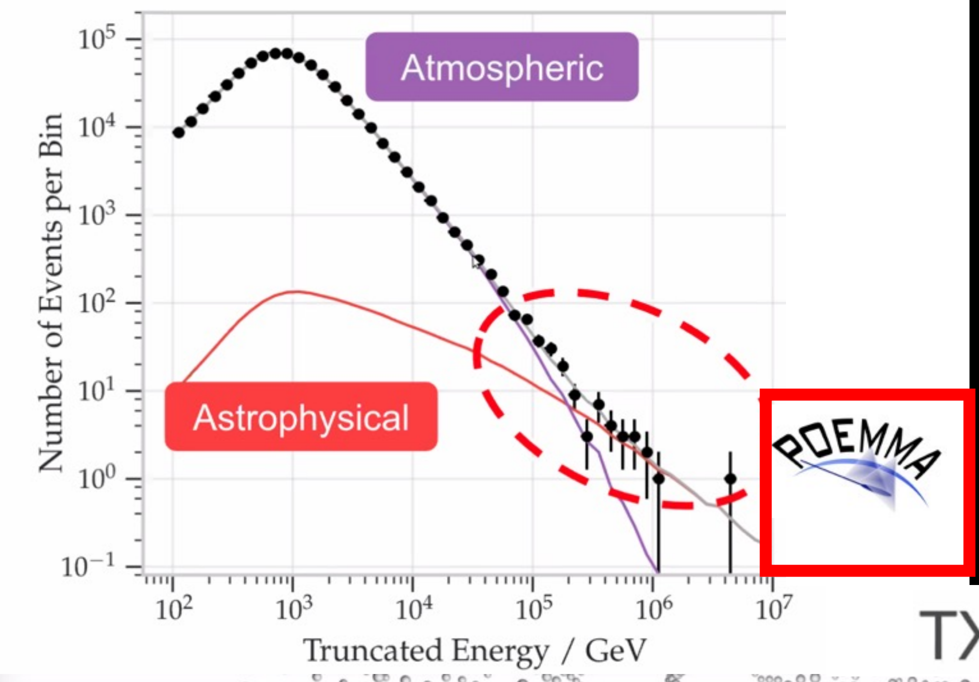
arXiv:1801.06160 and ICRC 2019

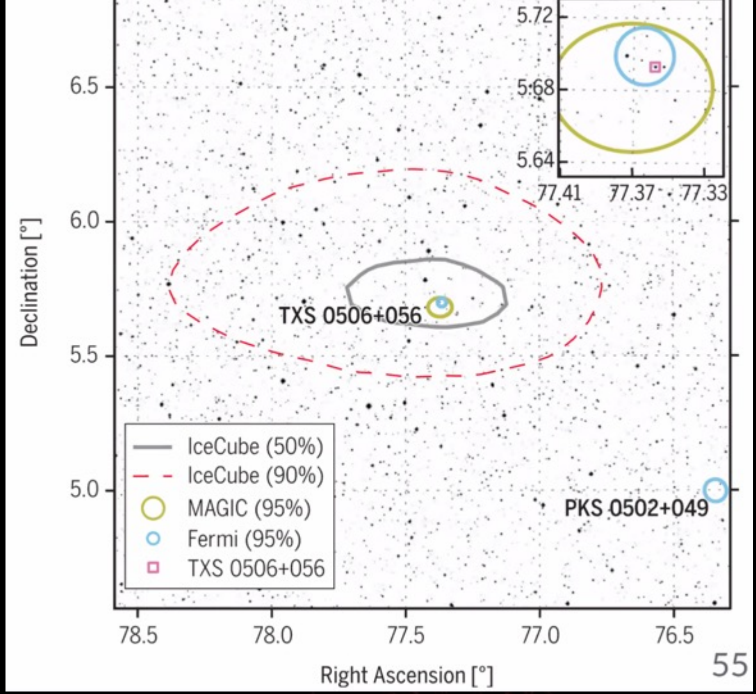
Cosmogenic & Astrophysical Messengers



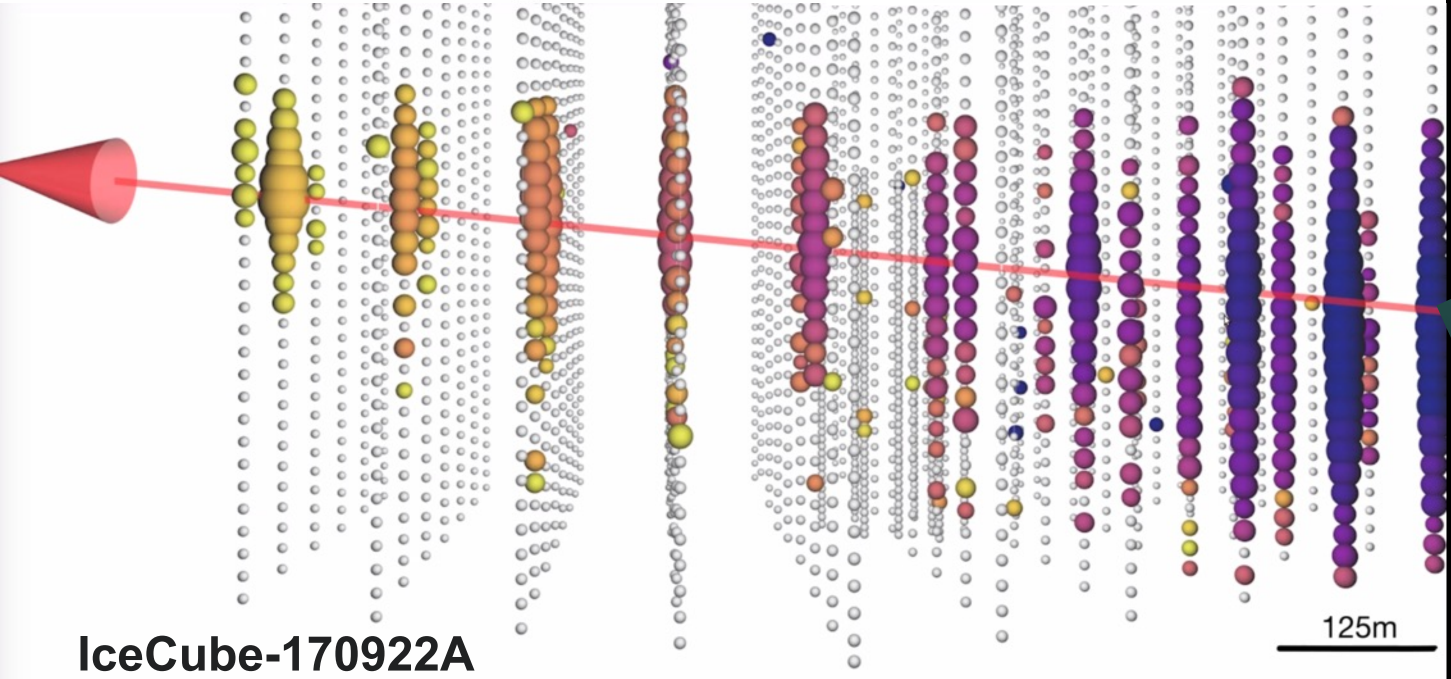
Batista et al, arXiv:1903.06714.pdf

Astrophysical Neutrinos



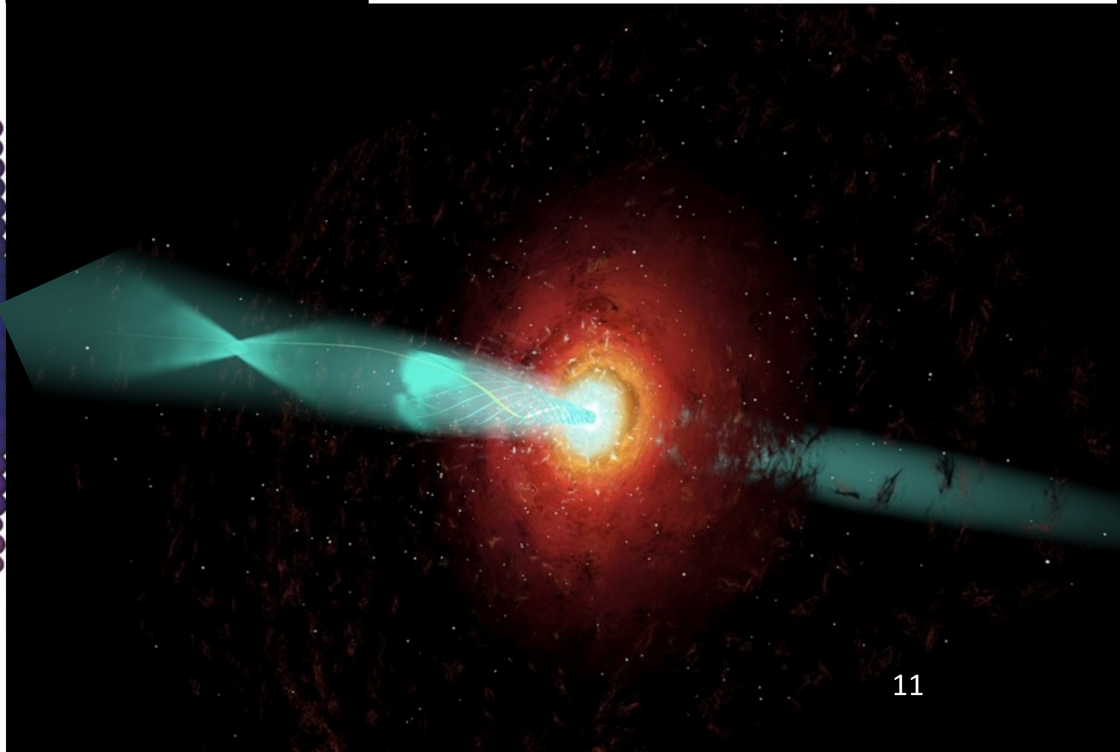


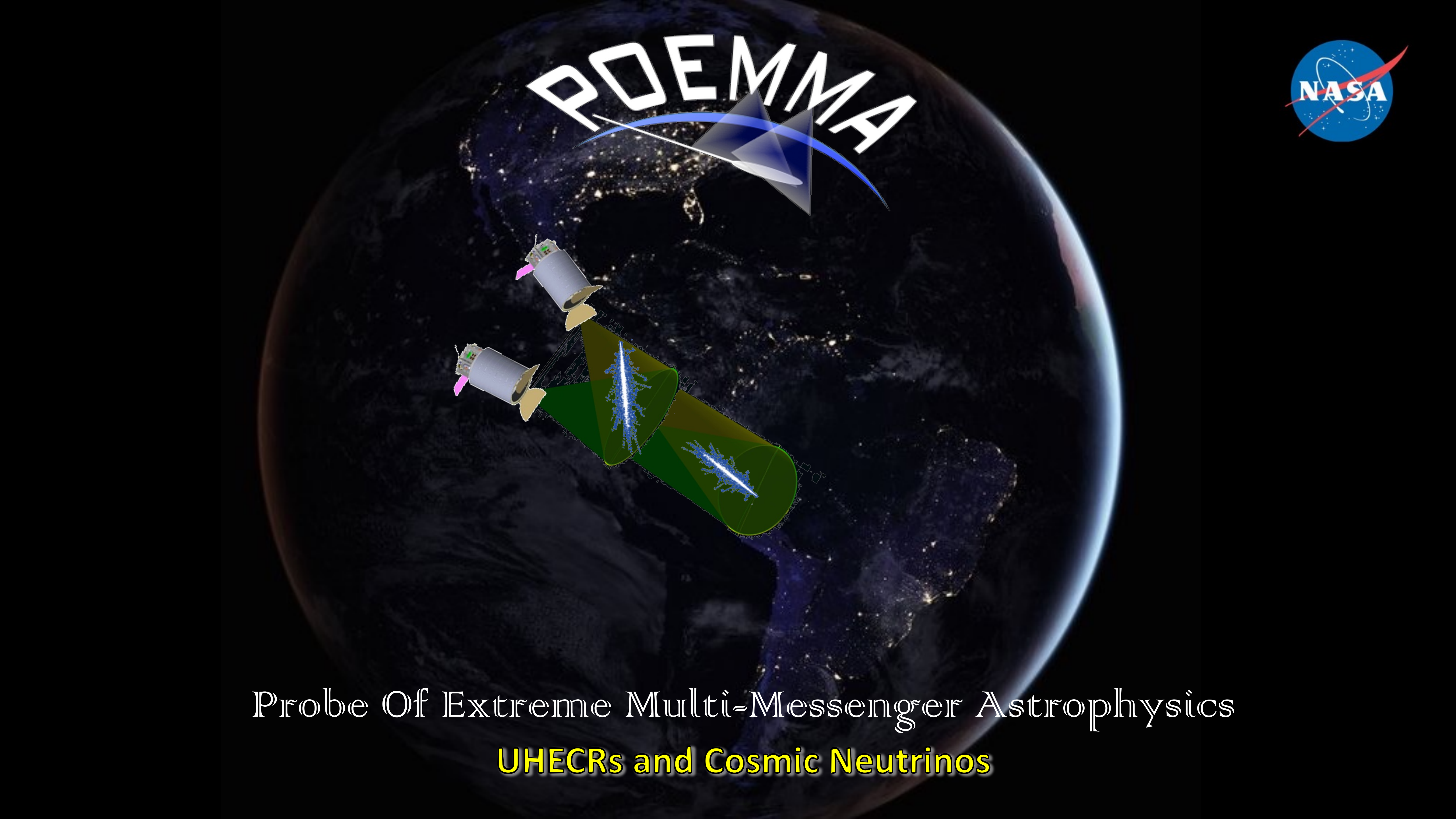
TXS0506+056



IceCube-170922A

estimated neutrino energy of 300TeV




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

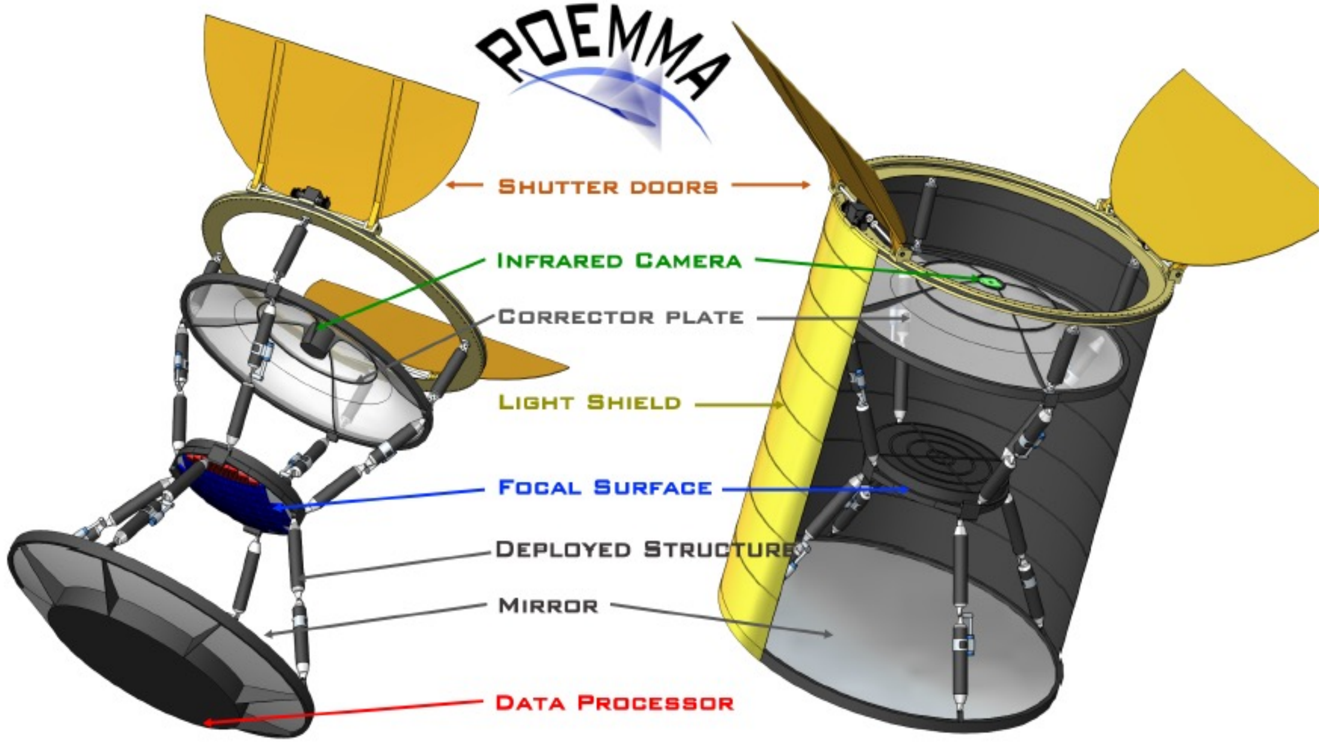
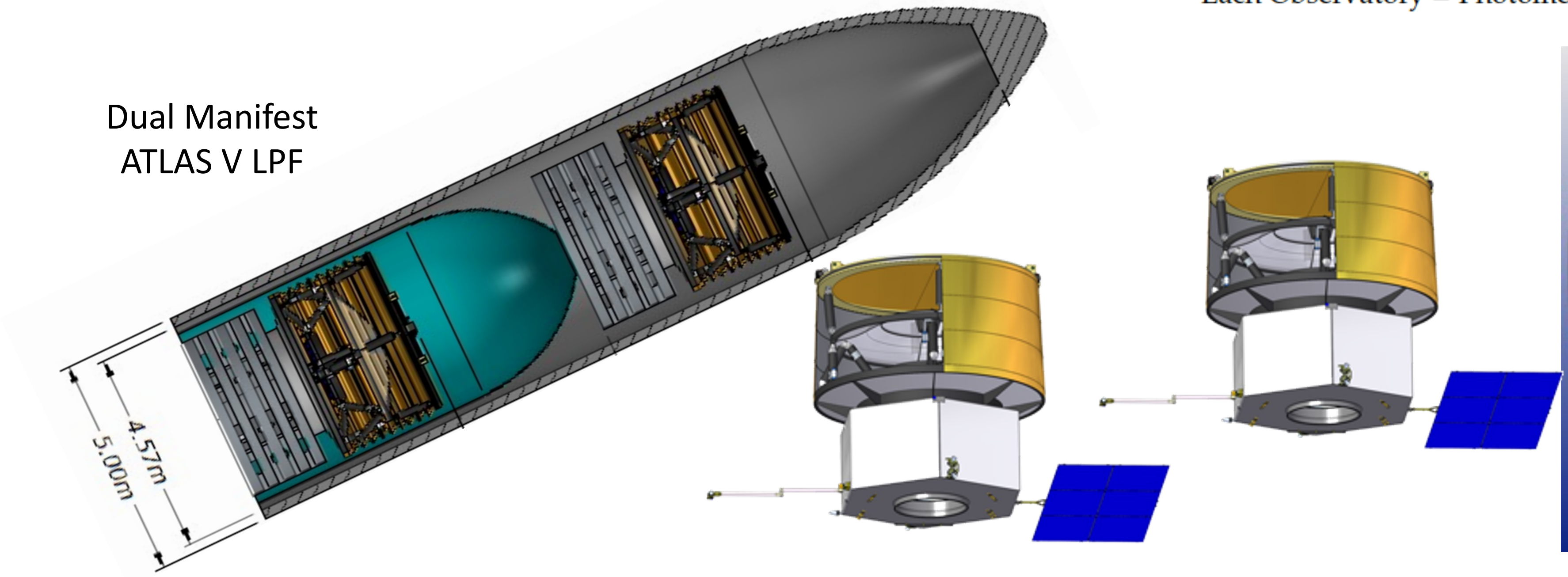
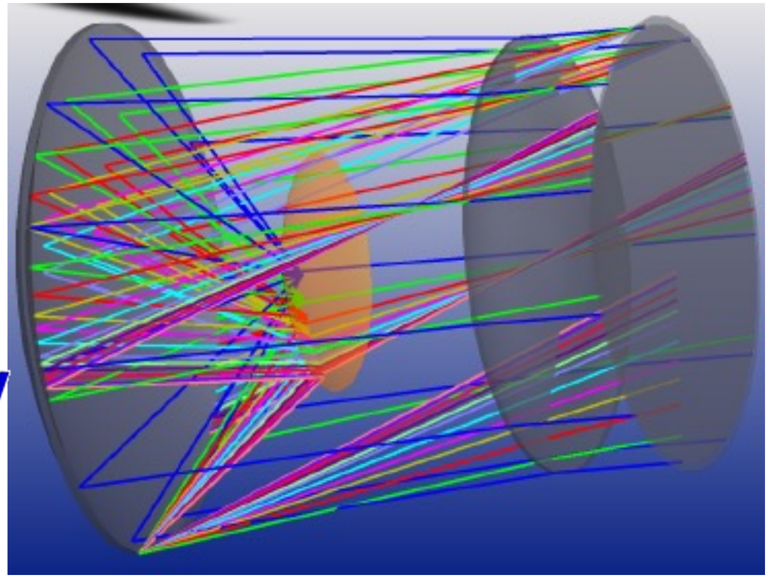


TABLE I: POEMMA Specifications:

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

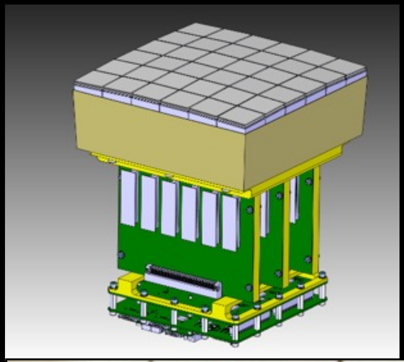


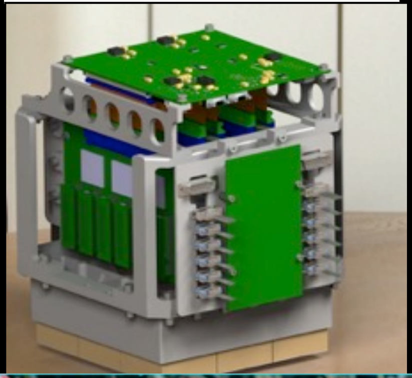


POEMMA

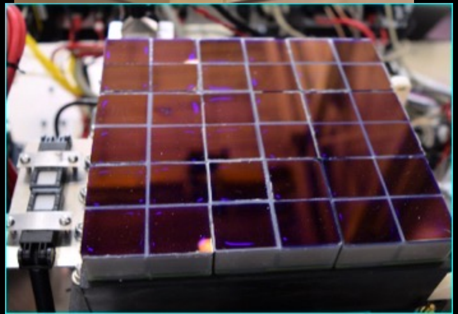
Hybrid Focal Surface

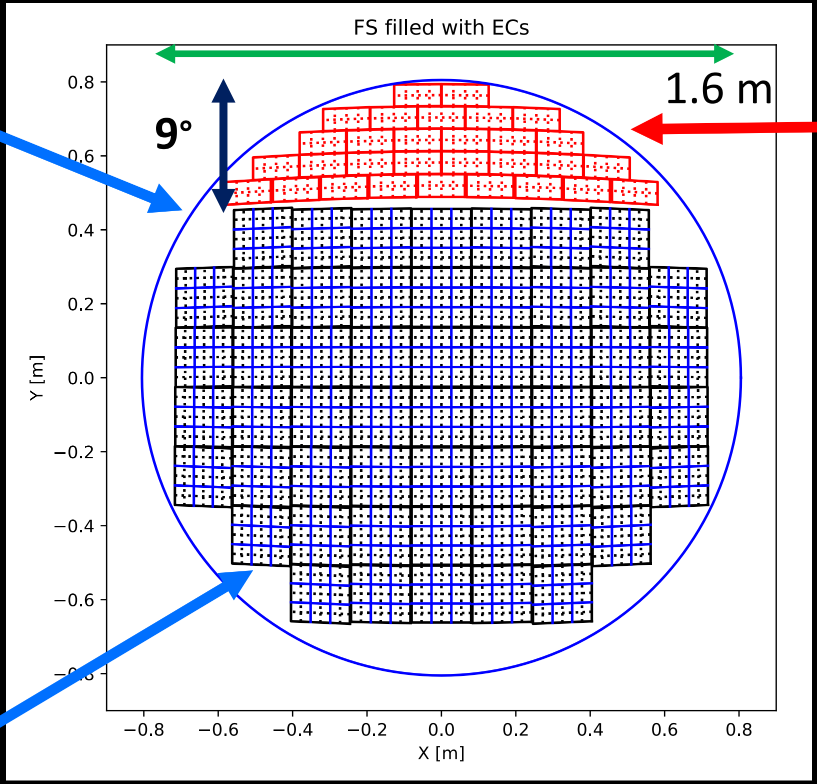
UV Fluorescence
MAPMTs with BG3 filter:
1 usec sampling





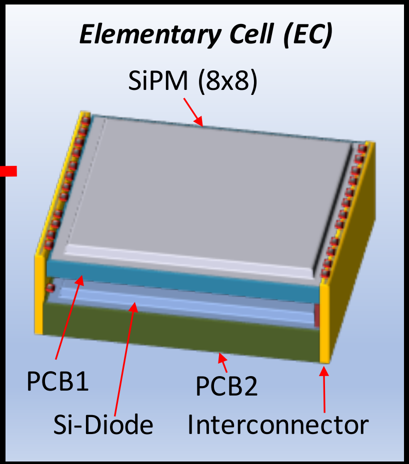
EUSO-SPB2
3 PDMs



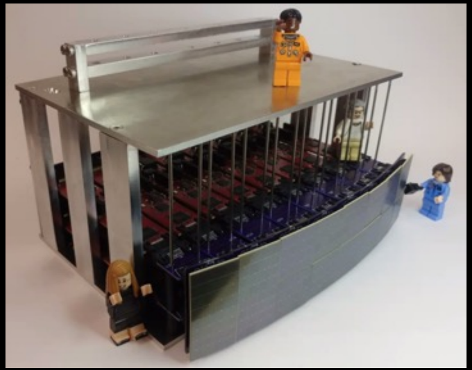


55 Photo Detector Modules (PDMs)
TOTAL 126,720 pixels
(1 PDM = 36 MAPMTs = 2,304 pixels)

Cherenkov Detection
SiPMs:
20 nsec sampling



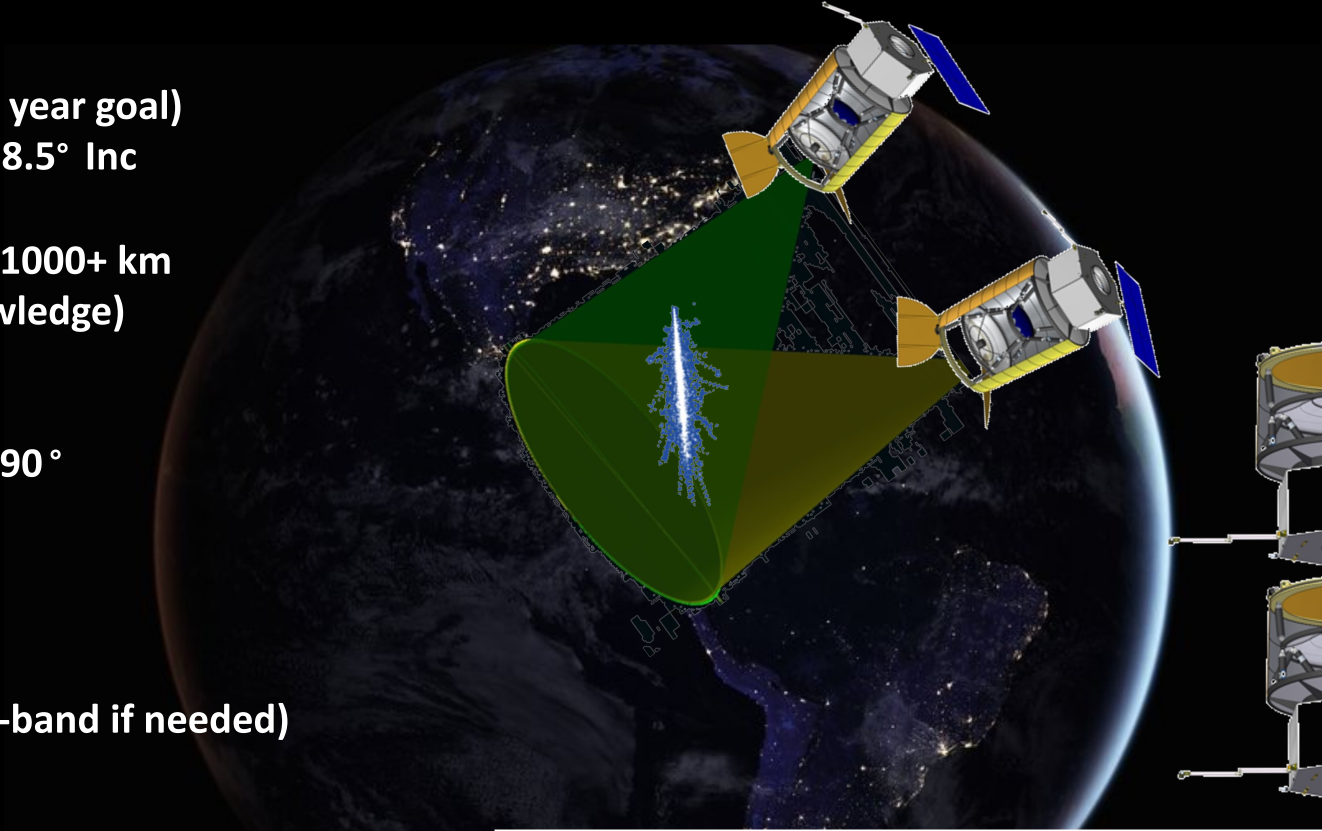
30 SiPM focal surface units
Total 15,360 pixels
512 pixels per FSU (64x4x2)



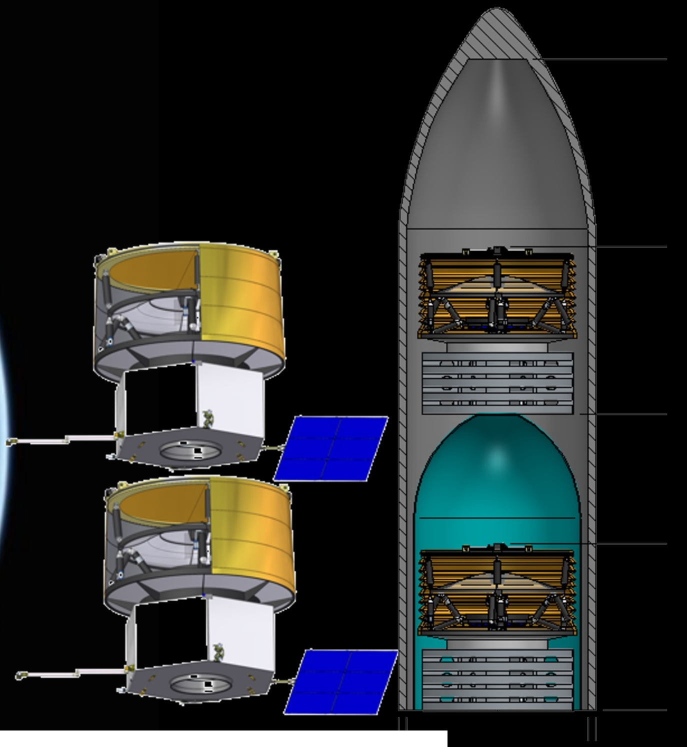
EUSO-SPB2
Cherenkov
Camera

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



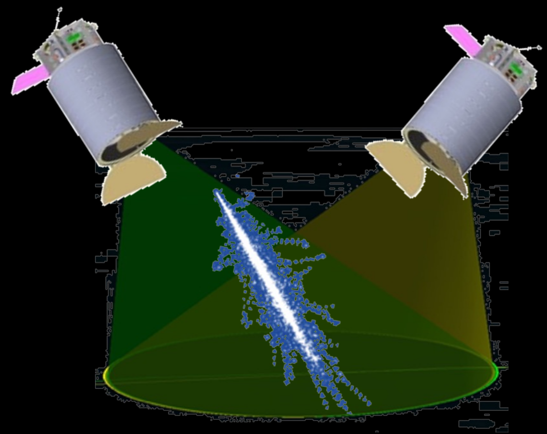
Operations:

- 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

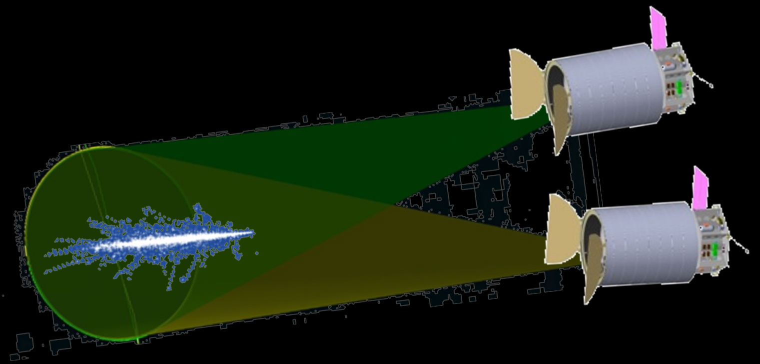
Observation Modes	Telescope Separation	Pointing	Science Goals (section)
POEMMA-Stereo (mode-2)	~300 km	down close to Nadir; overlapping atmospheric volumes	**UHECR fluorescence** (2.2, 2.3) precision stereo reconstruction UHECR lower energies 10s EeVs
POEMMA-Limb (mode-3)	~25 km	towards the Limb; azimuth 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

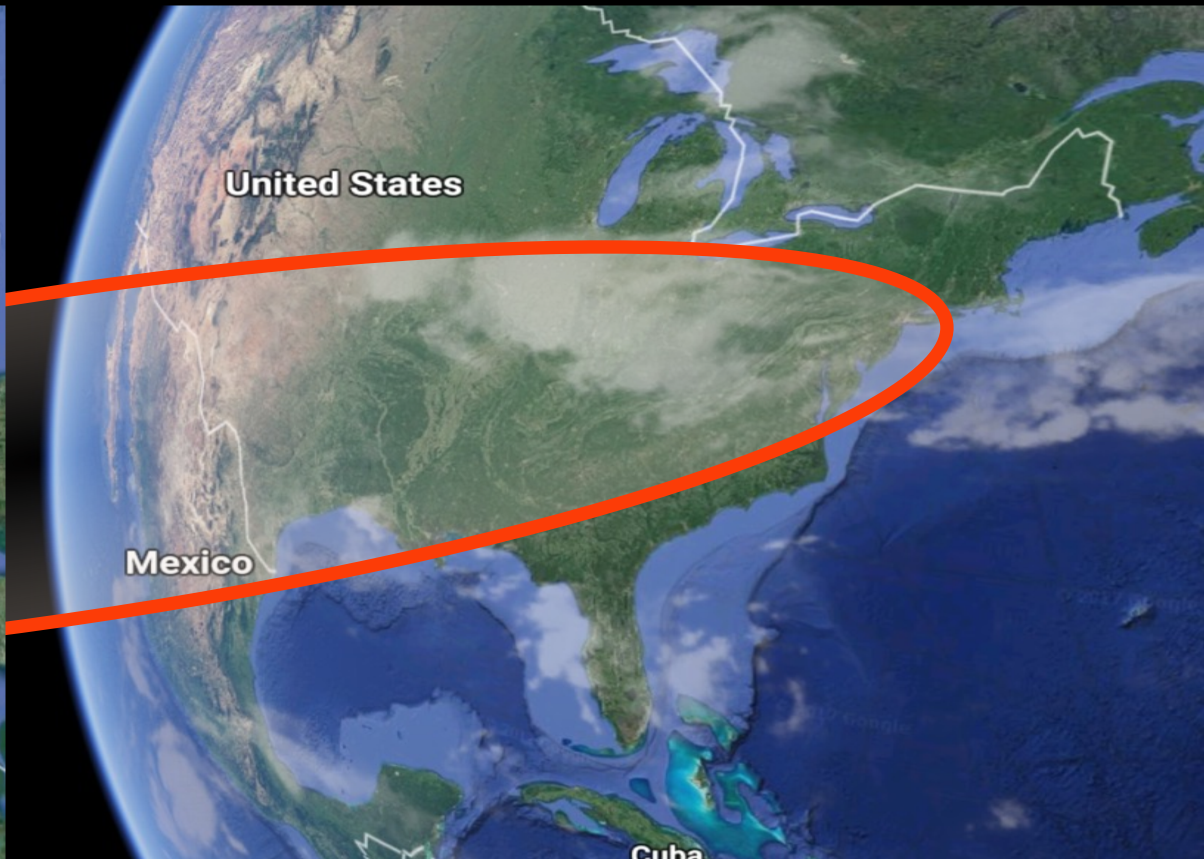
Observing Modes



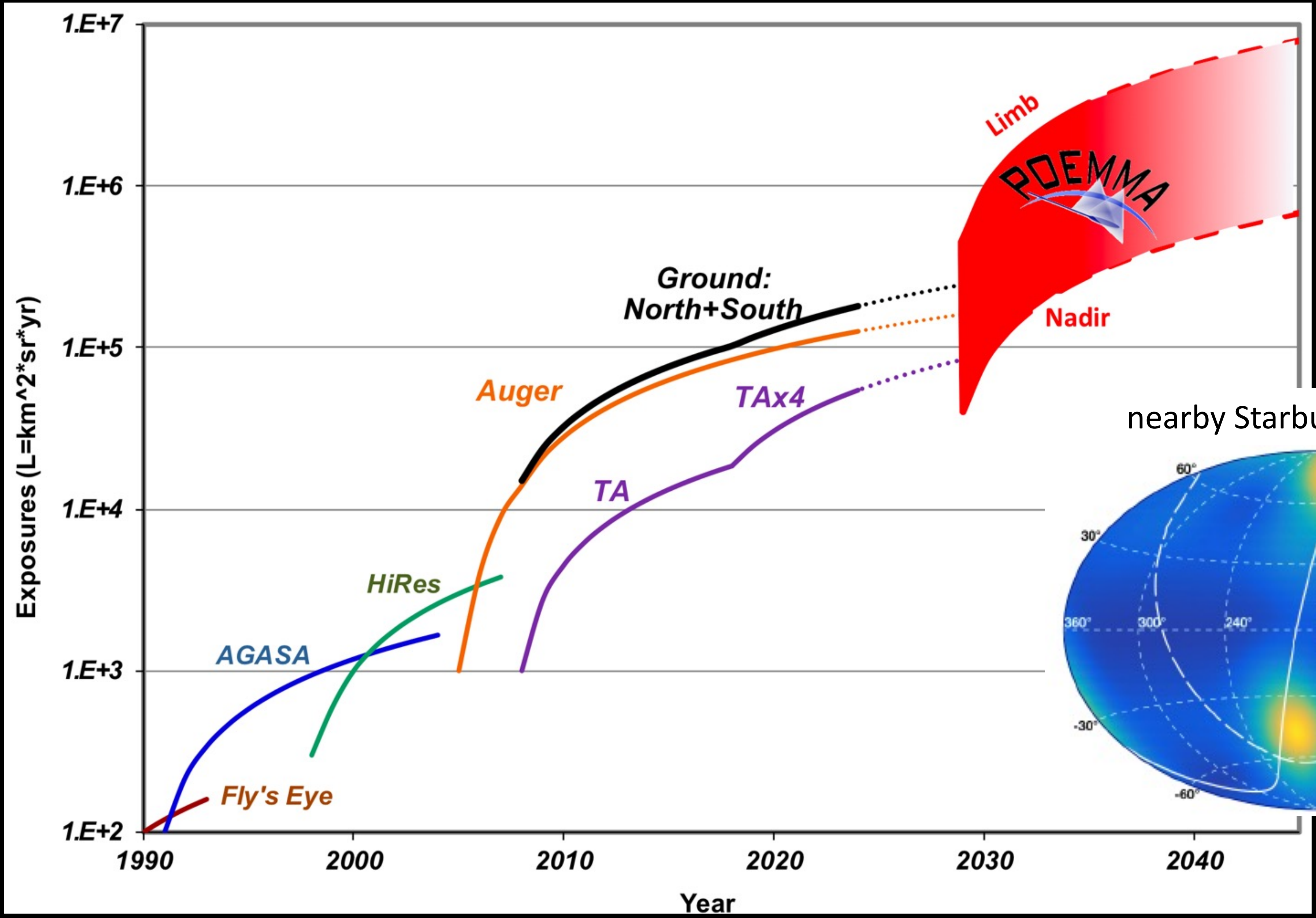
Nadir for UHECR: Radius 200-400 km



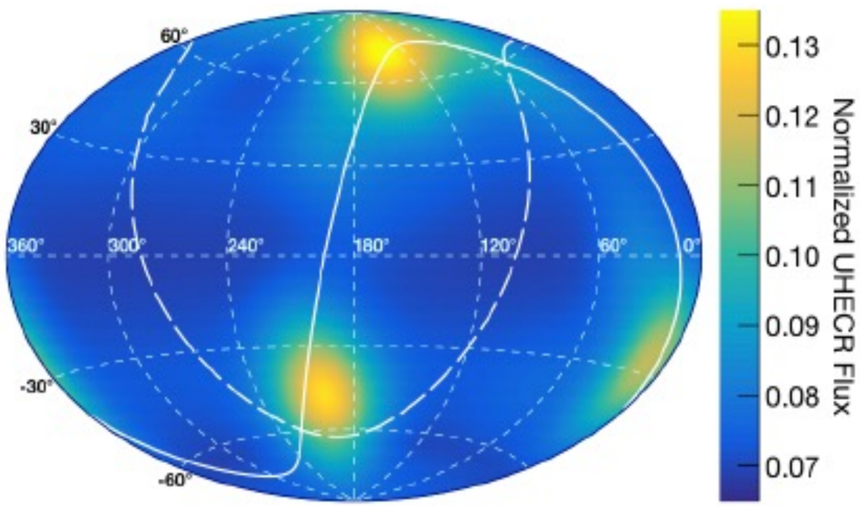
Limb for Neutrinos & UHECRs: Radius 3 10^3 km



POEMMA UHECR Exposure



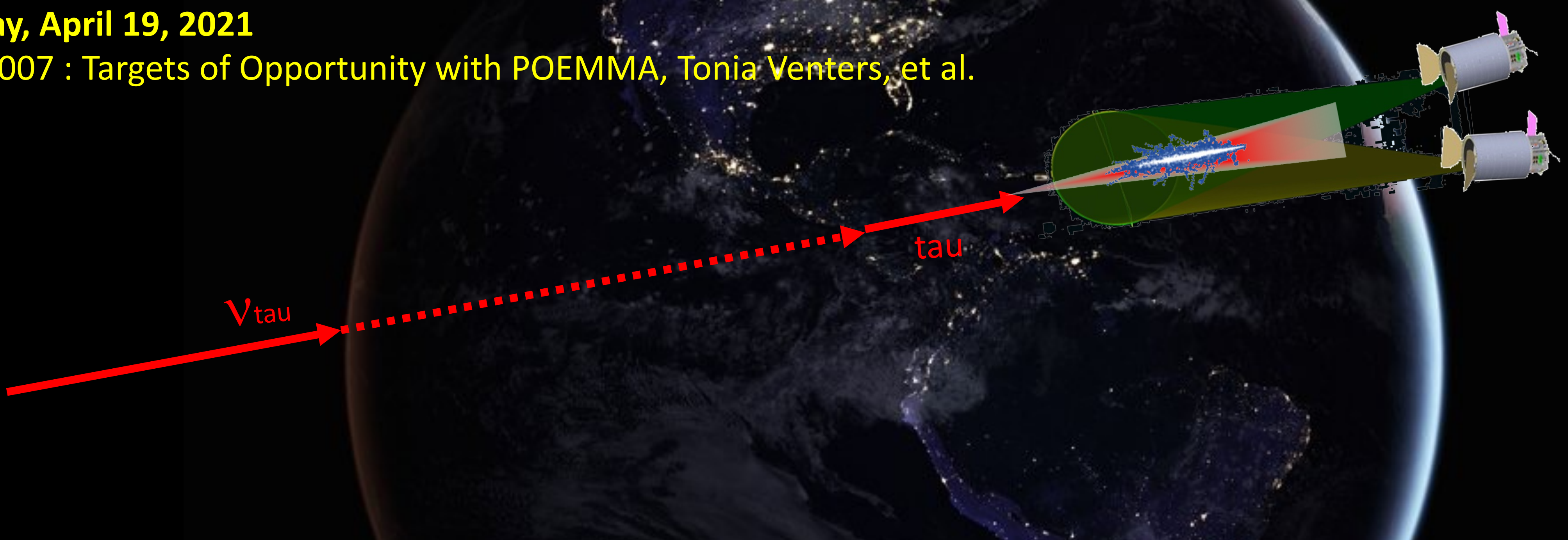
nearby Starburst Galaxies Fermi-LAT



POEMMA: Neutrinos

Monday, April 19, 2021

S10.00007 : Targets of Opportunity with POEMMA, Tonia Venters, et al.

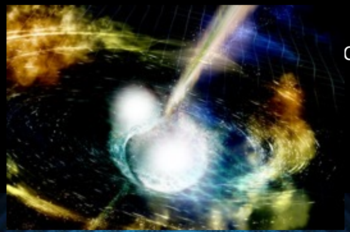


POEMMA designed to observe neutrinos with E > 20 PeV through Cherenkov signal of tau decays.

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

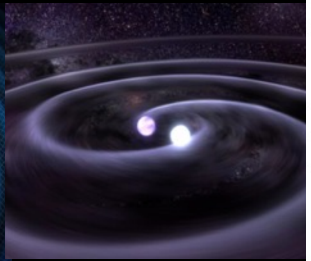
POEMMA: Neutrino Target of Opportunity

arXiv:1906.07209



Artist's rep NS-NS merger.
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

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

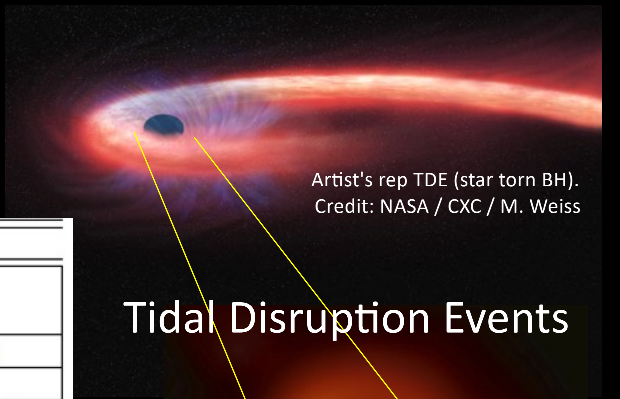
Long Bursts

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.



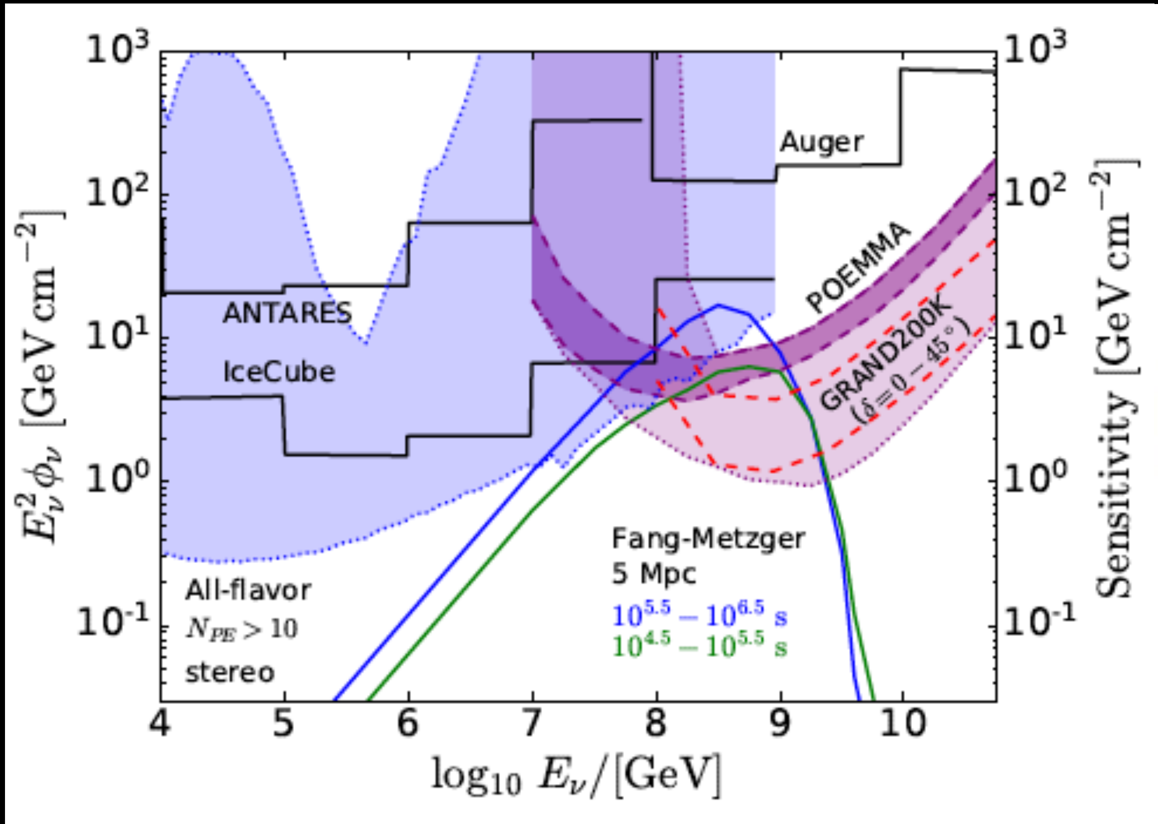
Artist's rep TDE (star torn BH).
Credit: NASA / CXC / M. Weiss

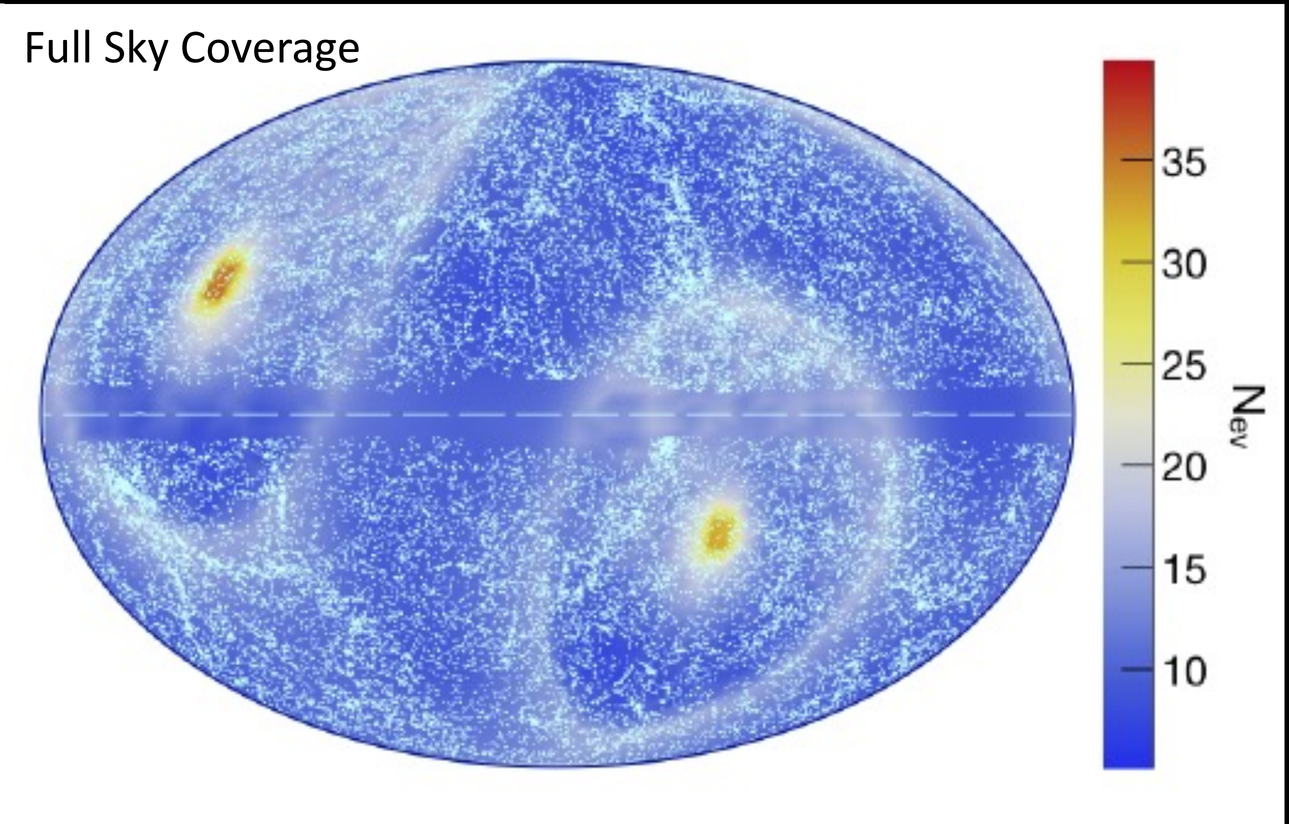
EVENT HORIZON TELESCOPE
COLLABORATION/MAUNAKEA
OBSERVATORIES/ASSOCIATED PRESS

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



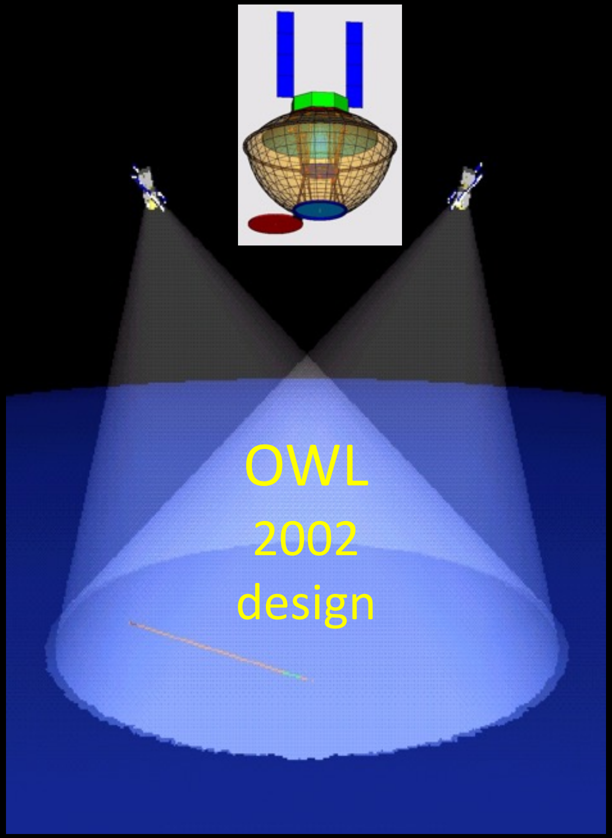


Fang & Metzger, arXiv:1707.04263

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

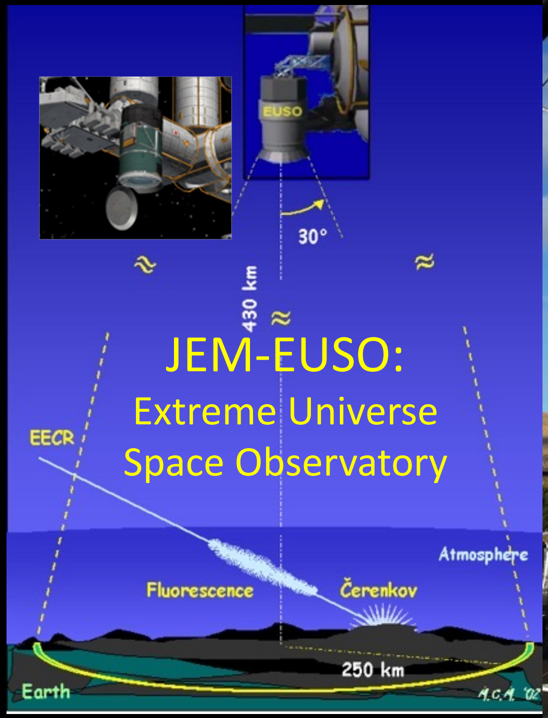
POEMMA Predecessors

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



Orbiting Wide-angle Light-collectors

TUS, KLYPVE-EUSO

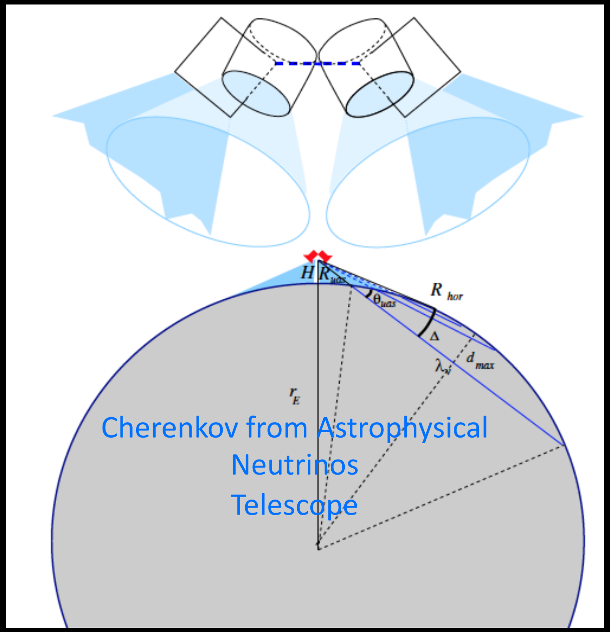


EUSO-Balloon
EUSO@TA
Mini-EUSO

EUSO-SPB1

EUSO-SPB2

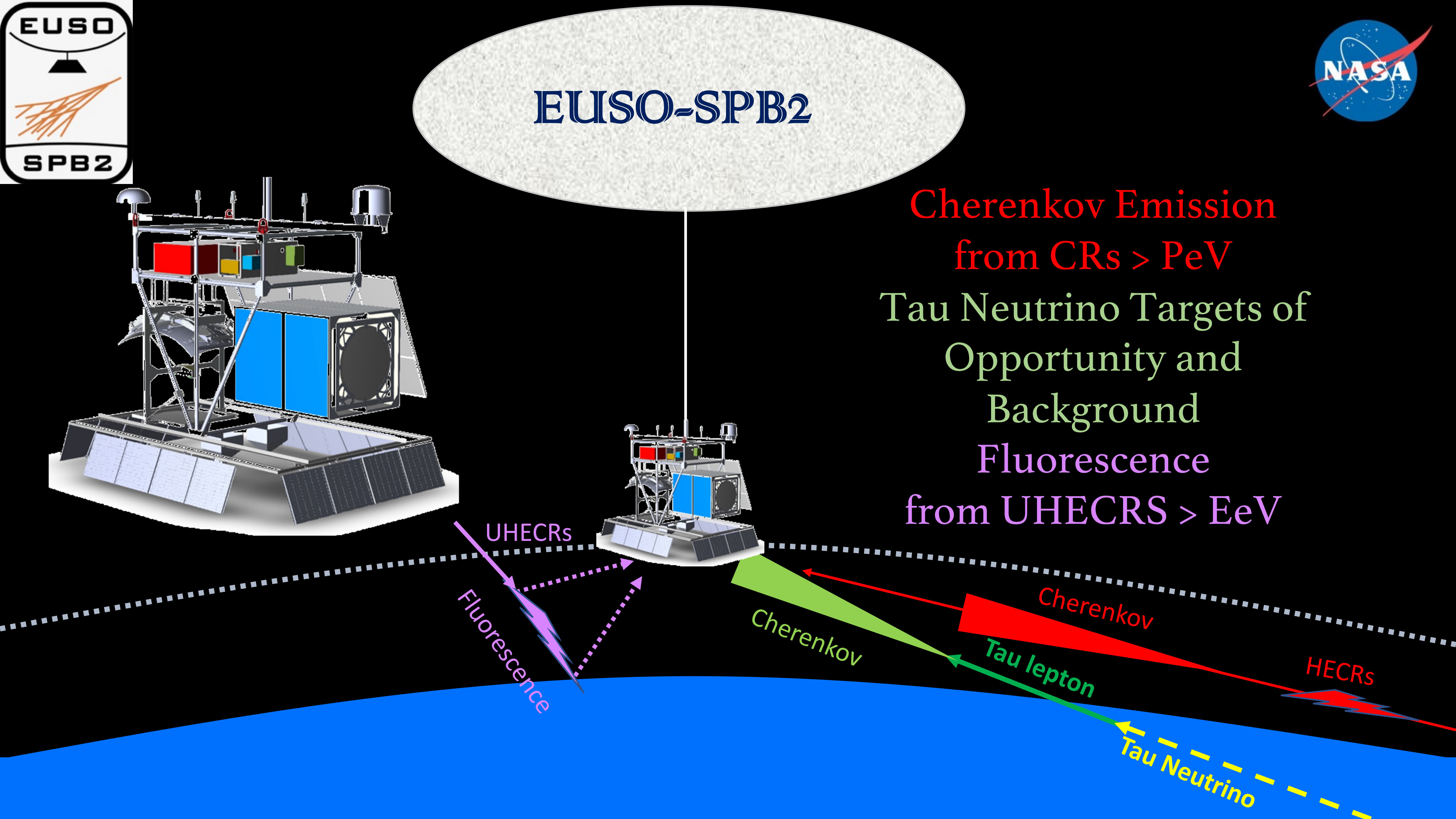
CHANT



EUSO-SPB Extreme Universe Space Observatory on a Super Pressure Balloon


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

Планета Королёва — «УФ атмосфера»


EUSO
SPB2
EUSO-SPB2
NASA
Cherenkov Emission
from CRs > PeV
Tau Neutrino Targets of
Opportunity and
Background
Fluorescence
from UHECRS > EeV
UHECRs
Fluorescence
Cherenkov
Cherenkov
Tau lepton
HECRs
Tau Neutrino

EUSO-SPB2

Extreme Universe Space Observatory on NASA Super Pressure Balloon

Altitude of ~ 33km, from Wanaka, NZ around the Southern Ocean

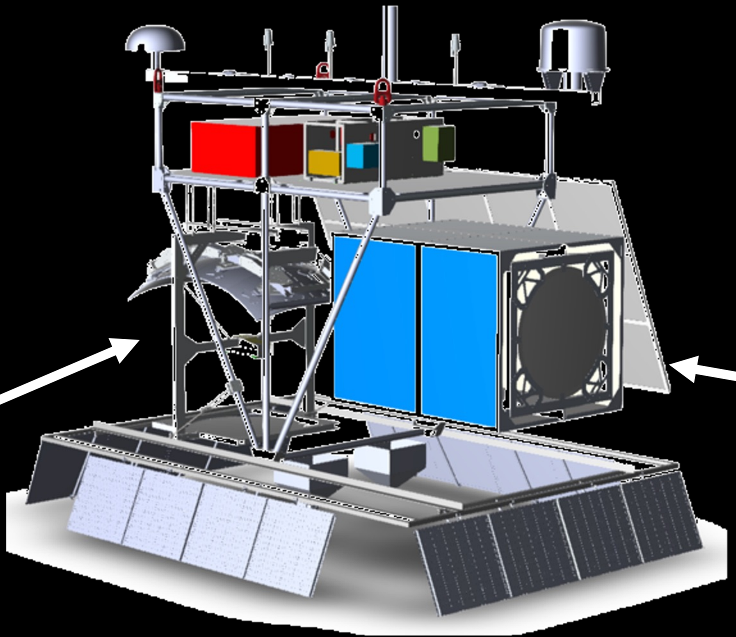
EUSO-SPB2 objectives:

1. observe **1st extensive air showers with fluorescence** from suborbital space;

2. observe **Cherenkov light from extensive air showers** initiated by cosmic rays;

3. measure the **background for the detection of neutr**ino induced upward going air showers;

4. **search for neutrinos from astrophysical transient** events (e.g., binary neutron star mergers).

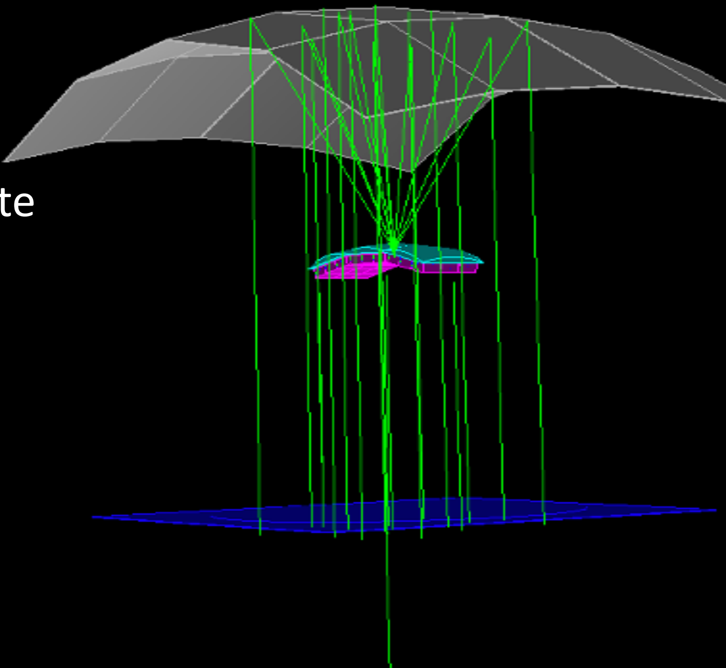


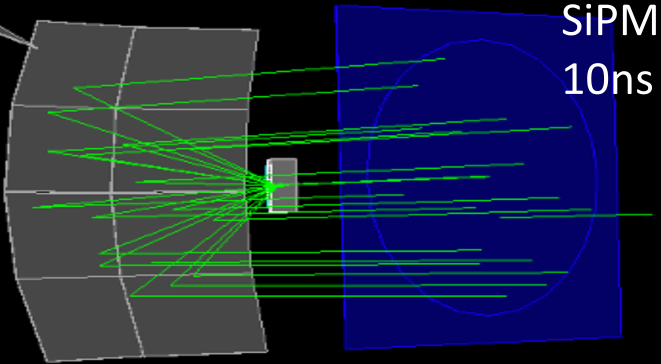
Fluorescence Telescope

points down
Schmidt Optics,
37.4° x 11.4° FoV
MAPMT camera,
6,912 pixels
1 μs integration rate

Cherenkov Telescope

points +- 5 deg below/above limb of the Earth
Schmidt Optics, FoV:
6.4° zenith 12.8 ° azimuth
SiPM camera, 512 pixels
10ns picture rate



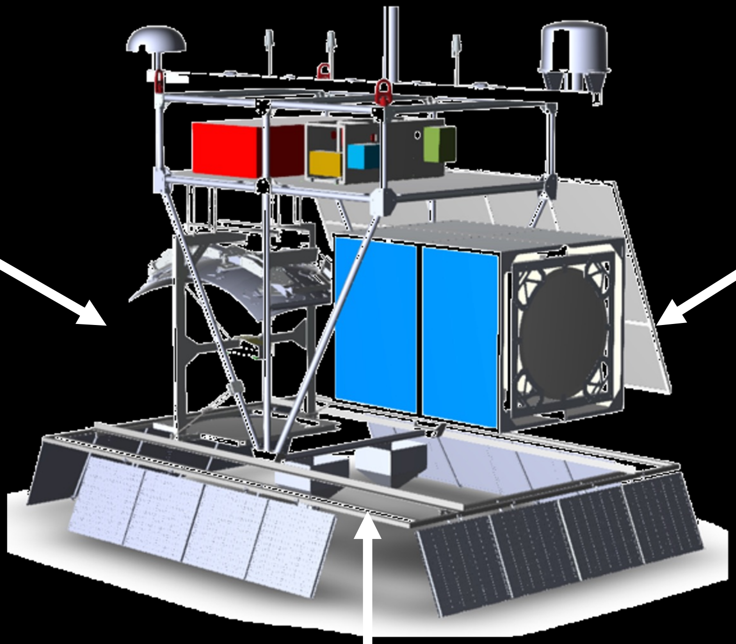


Geant4 of Optics

EUSO-SPB2

Fluorescence Telescope

points down
Schmidt Optics,
37.4° x 11.4° FoV
MAPMT camera,
6,912 pixels
1 μs integration rate



Cherenkov Telescope

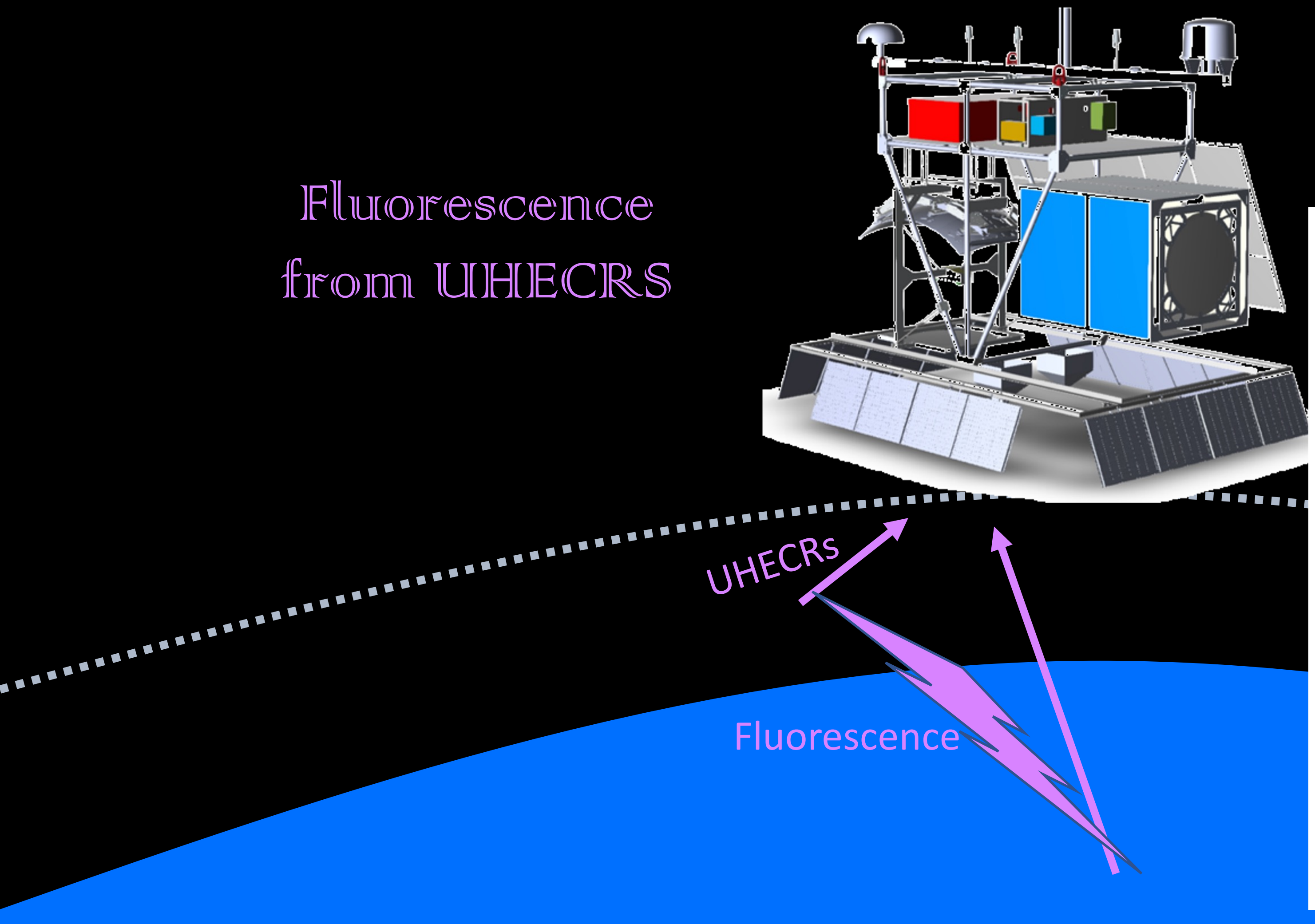
points +- 5 deg below/above limb of the Earth
Schmidt Optics, FoV:
6.4° zenith 12.8° azimuth
SiPM camera, 512 pixels
10ns picture rate

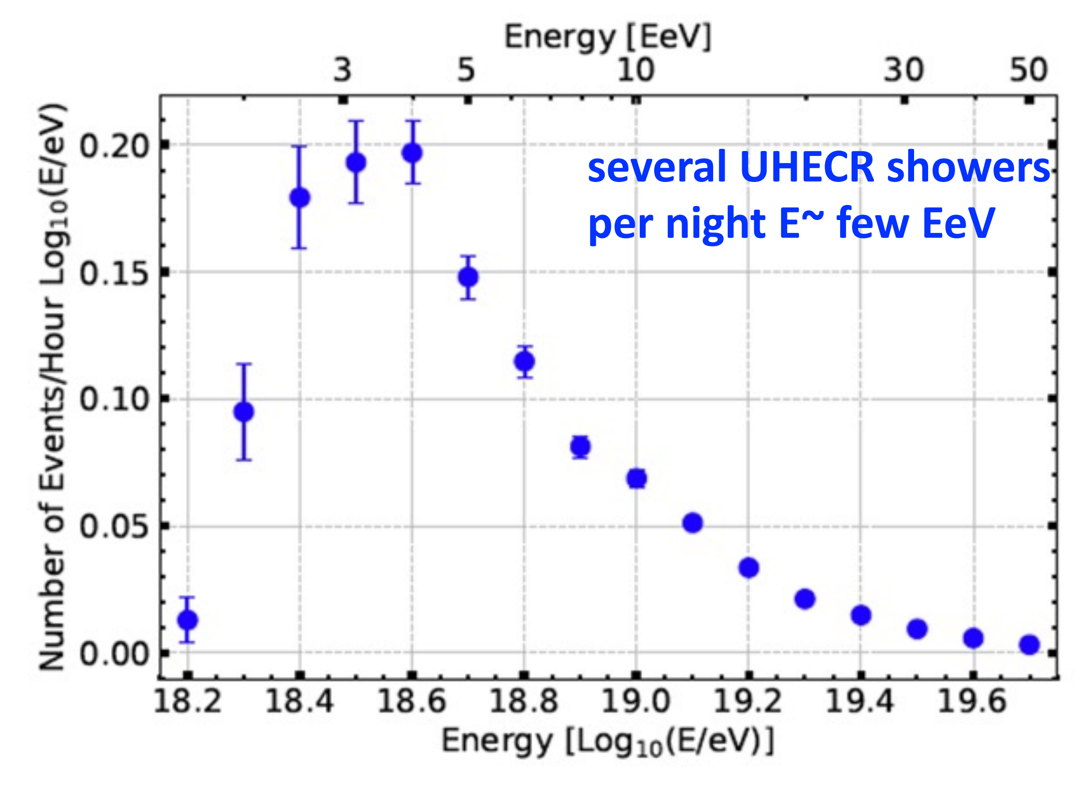
Infrared Camera

Observes cloud coverage
70° x 53° FOV, 640 x 480 pixels
9.7-11.3μm and 11.6-12.7μm
1 image every 2 mins

EUSO-SPB2

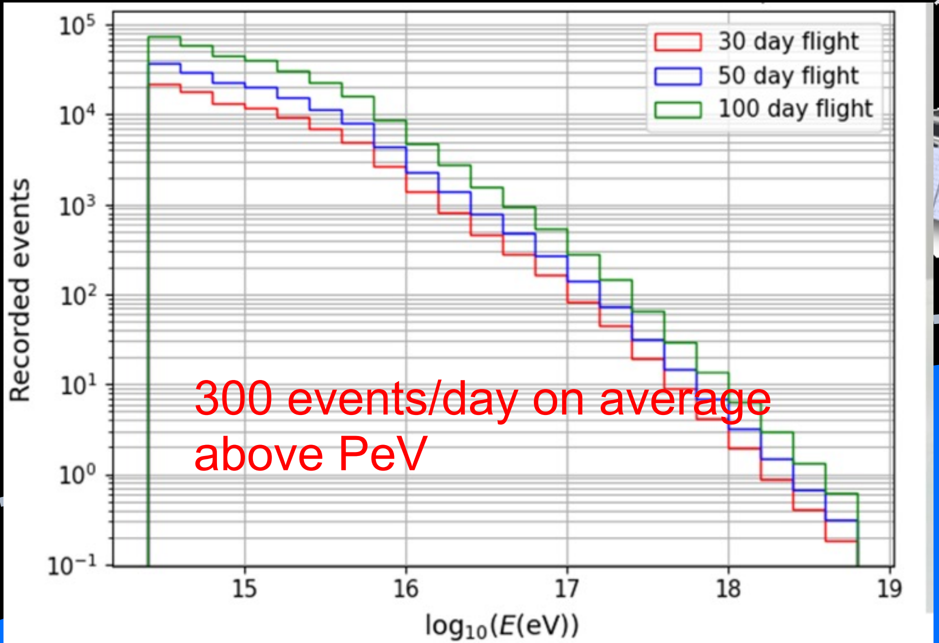
Fluorescence
from UHECRS

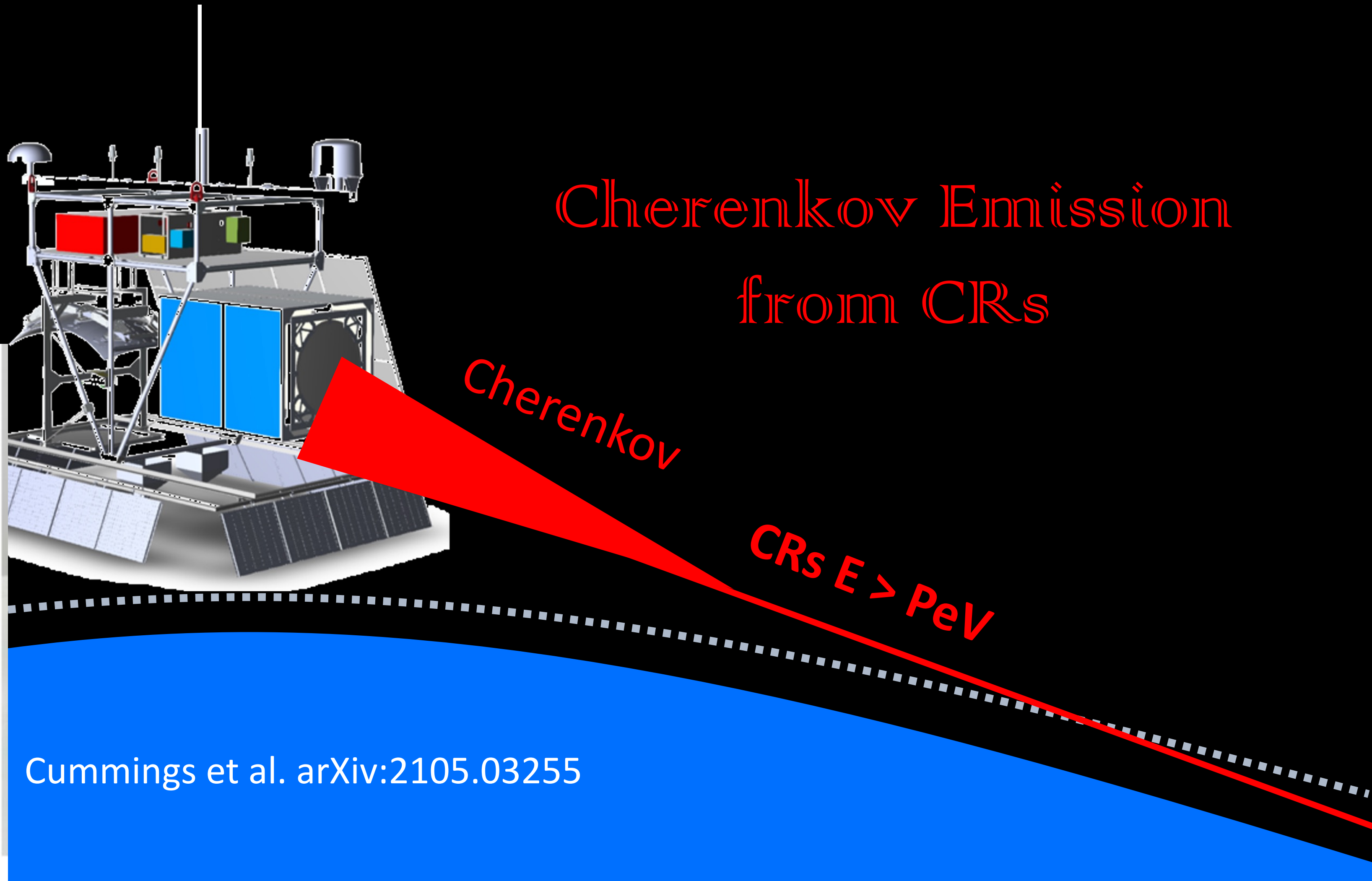




EUSO-SPB2

Cherenkov Emission from CRs

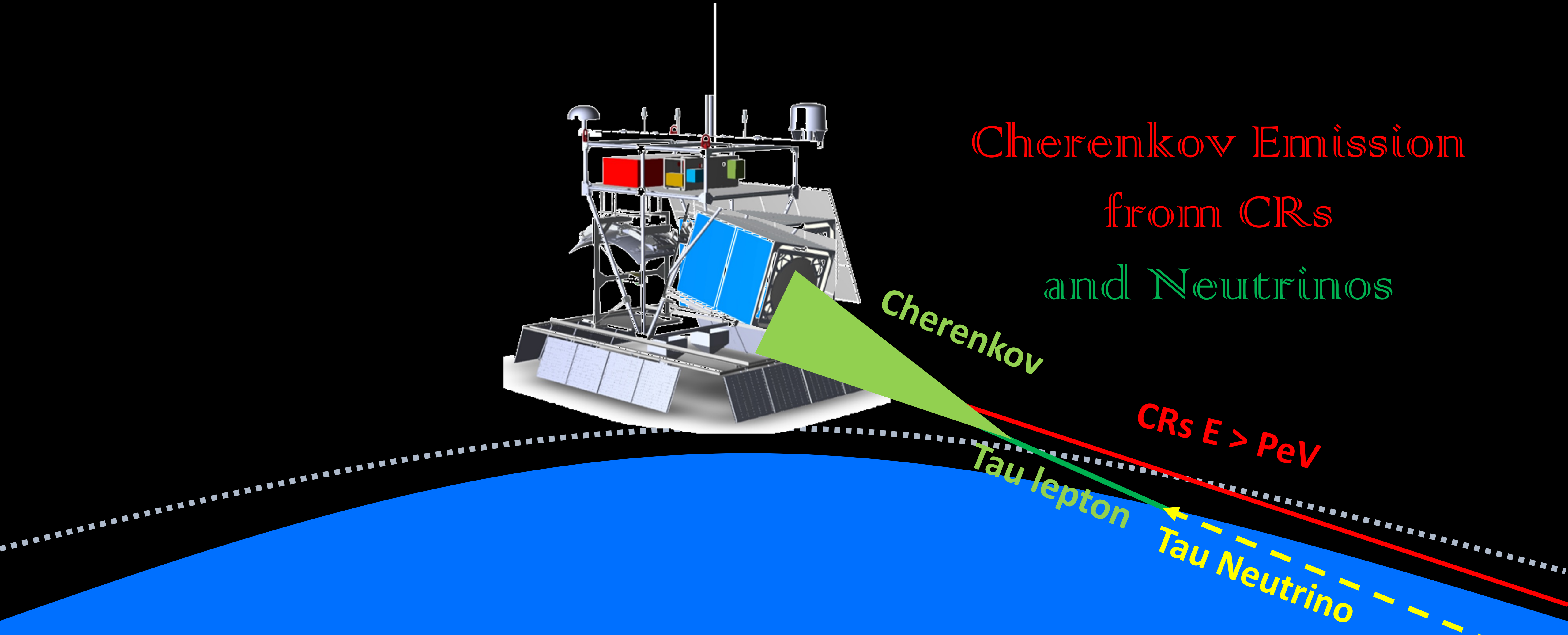




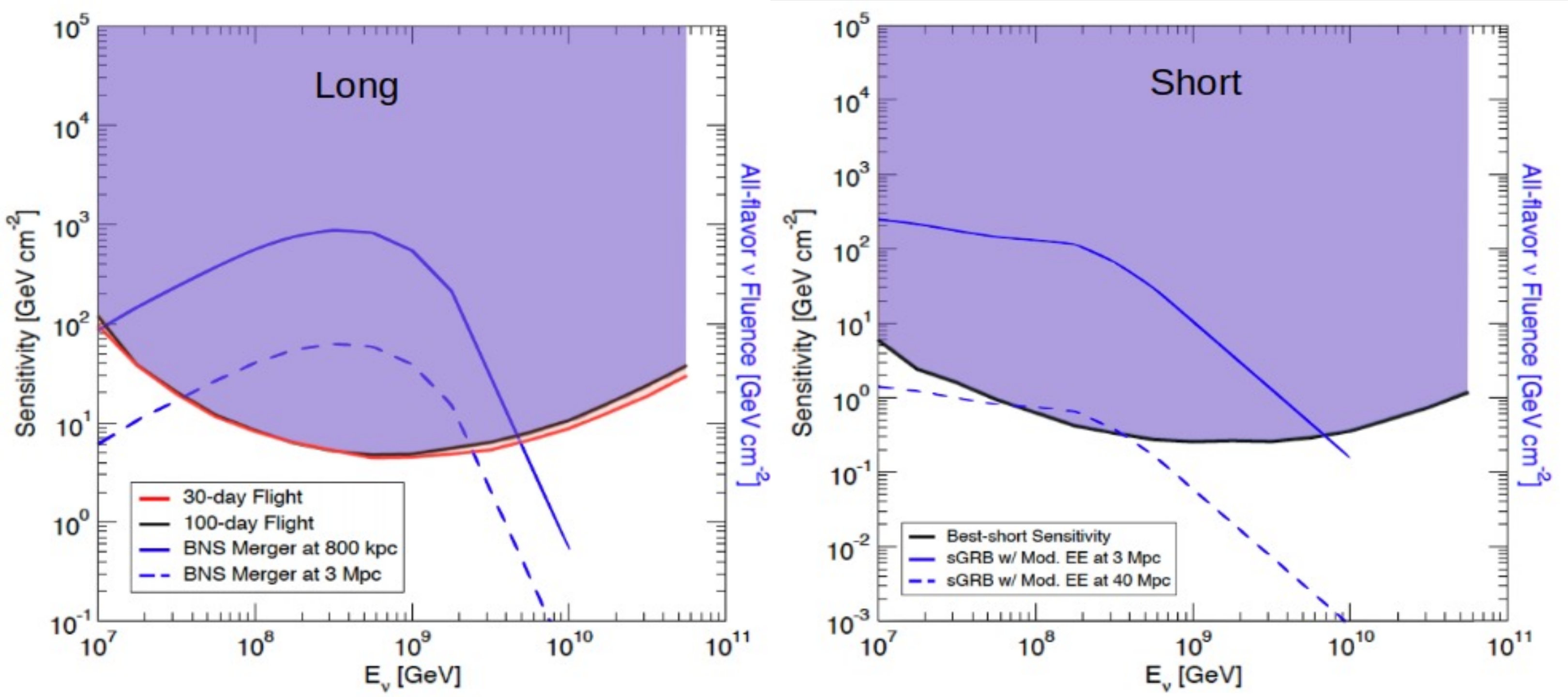
Cummings et al. arXiv:2105.03255

EUSO-SPB2

Cherenkov Emission
from CRs
and Neutrinos



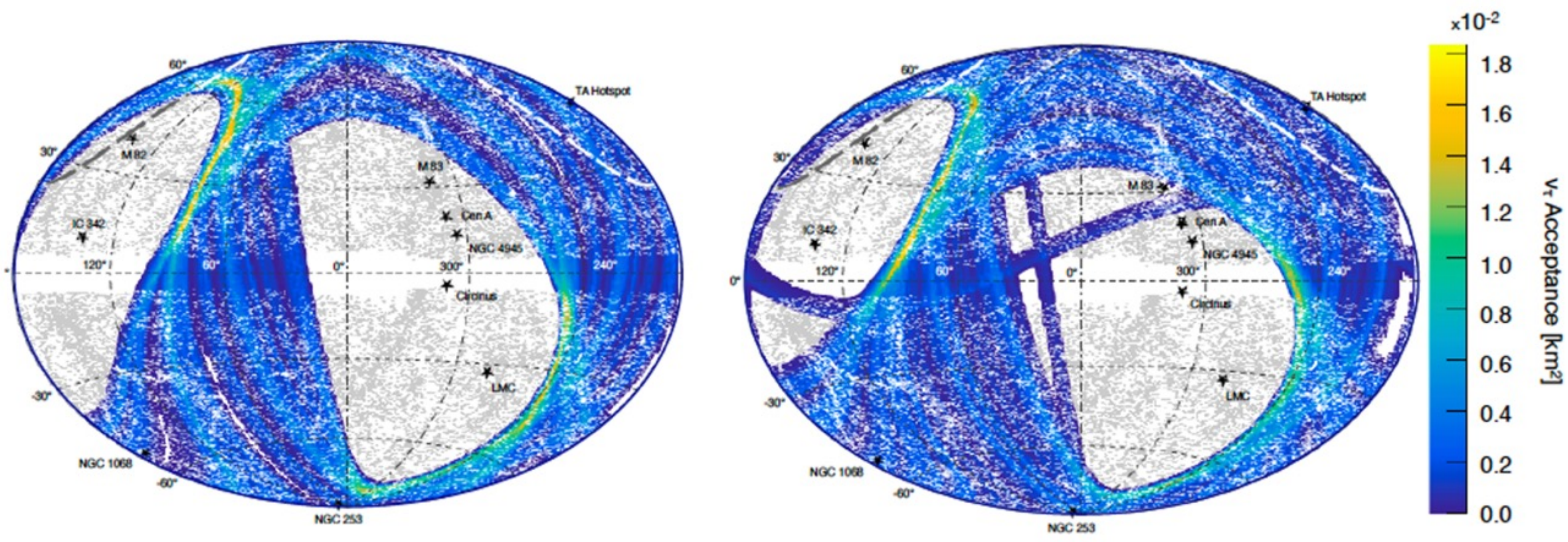
Target of Opportunity Neutrino Searches



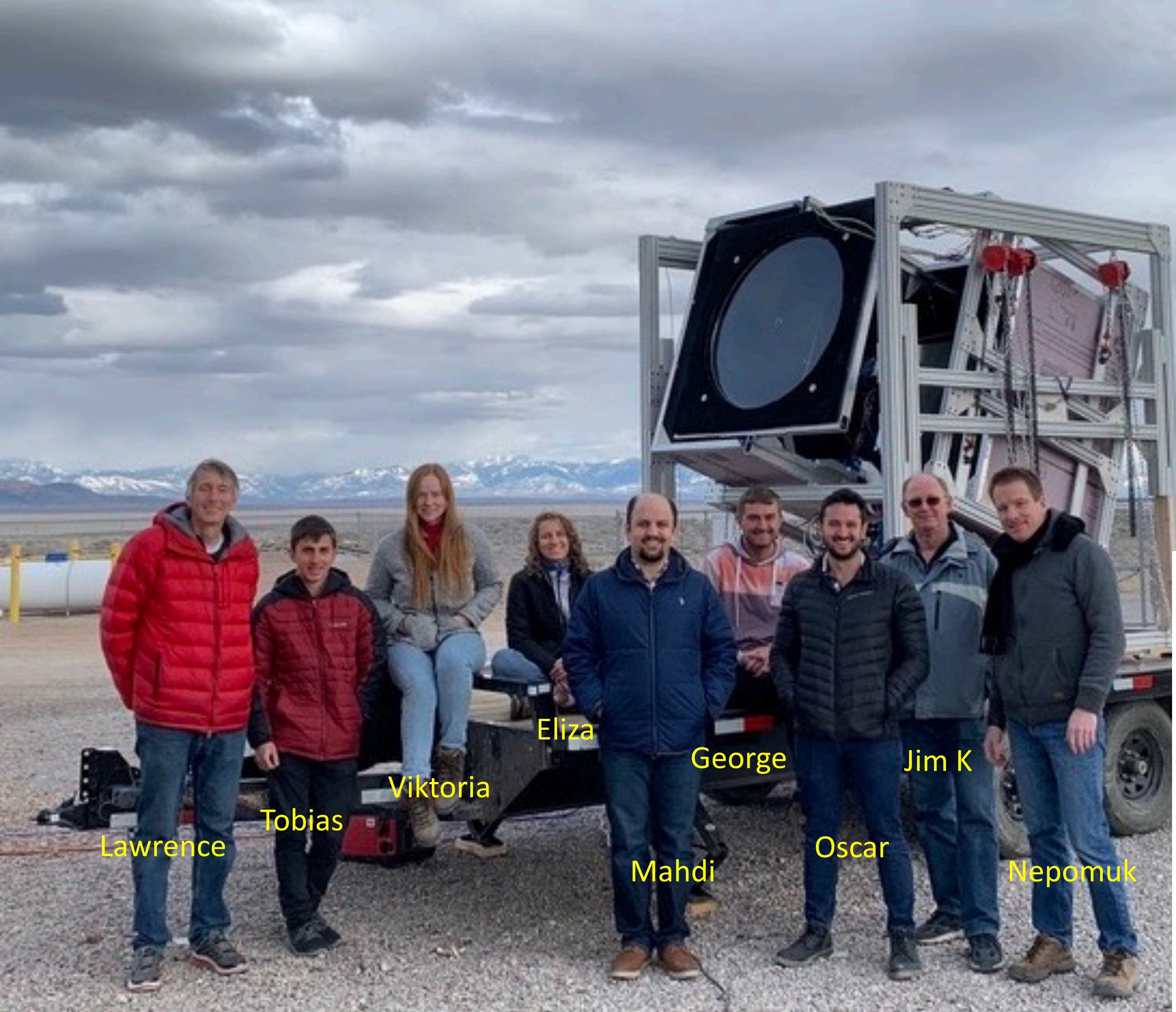
Sky Map of acceptance to tau-neutrino 30-day (left) and 100-day (right) flights

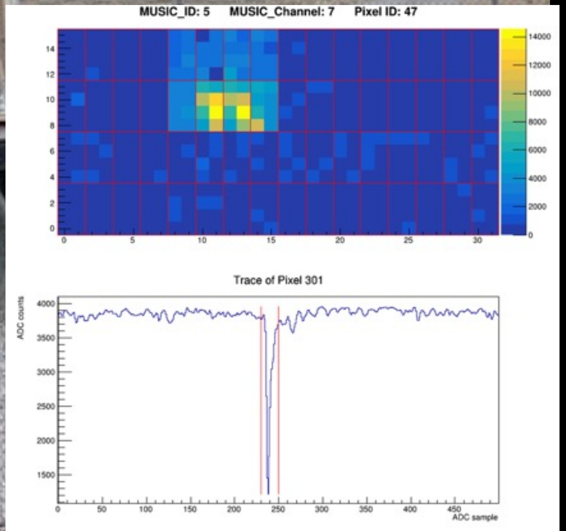
Sensitivity to ToO neutrino flux per decade in energy, for long and a short emitters (all-flavor)

Venters, et al,
PoS(ICRC2021), 977 (2021).



Field Test of the Cherenkov Telescope
Telescope Array site in Utah
March 2022





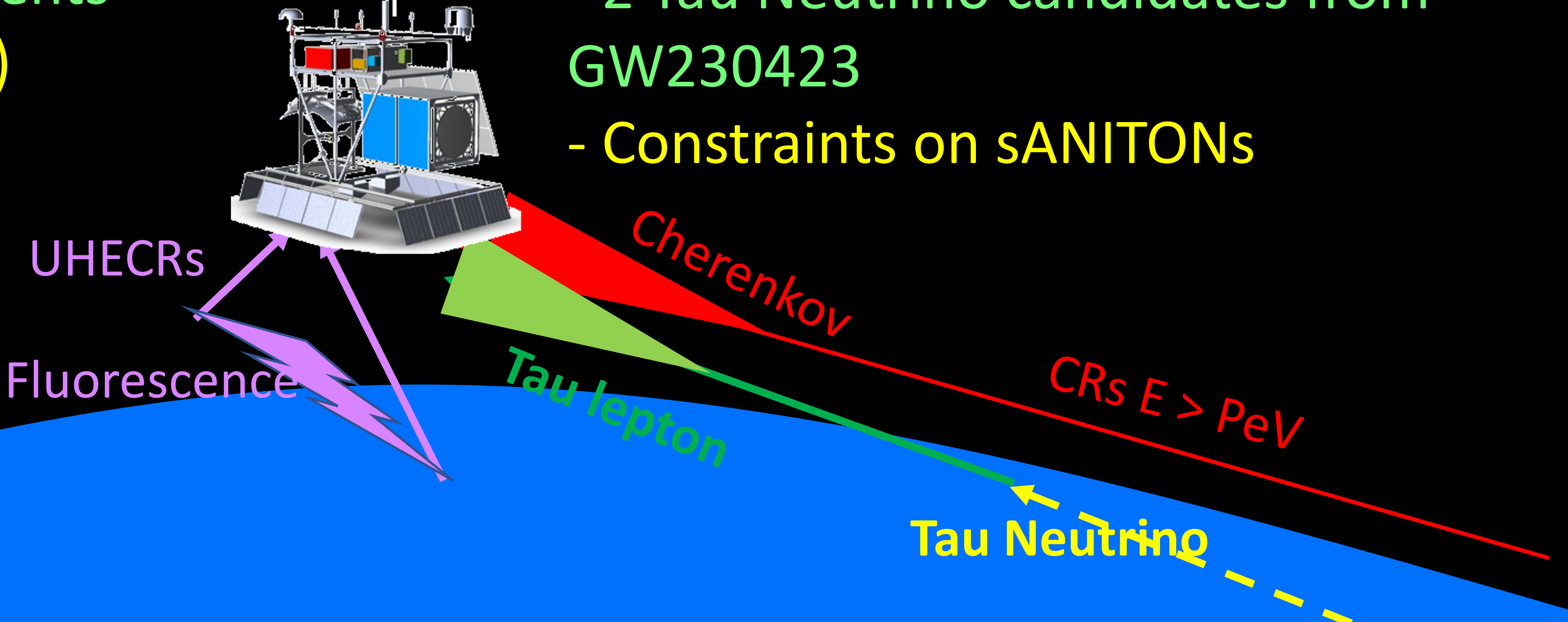
ThermoVac Test of Fluorescence Camera
ThermoVac Test of Infrared Camera

EUSO-SPB2
2023 flight

Fluorescence from UHECRS
Cherenkov Emission from UHECRs
Tau Neutrino Events
(ANITONS?!)

Science Results:

- Fluorescence from ~30 UHECRS
- CR spectrum from 10^{15} eV to **10^{17}eV**
- 2 Tau Neutrino candidates from GW230423
- Constraints on sANITONs



POEMMA

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?

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