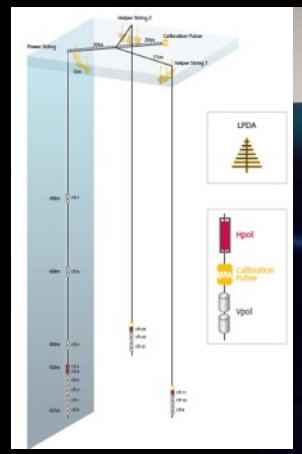
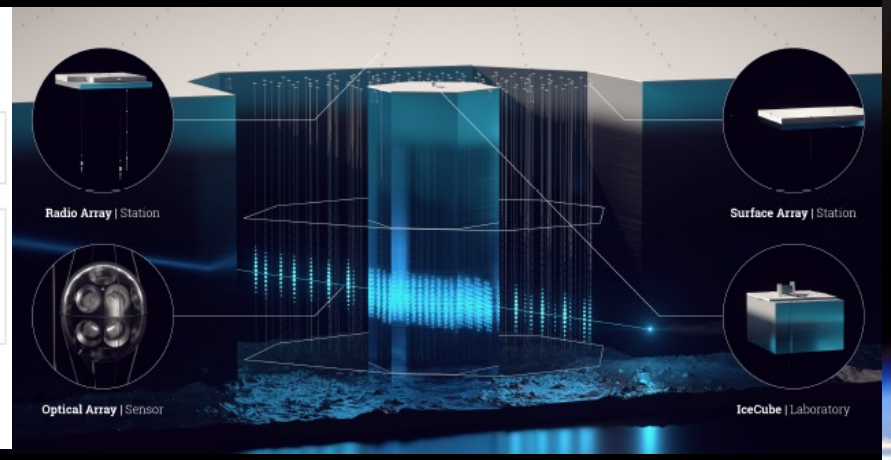
(High to) Ultrahigh Energy Neutrinos

Snowmass Blue Sky Neutrino Frontier

RNO-G



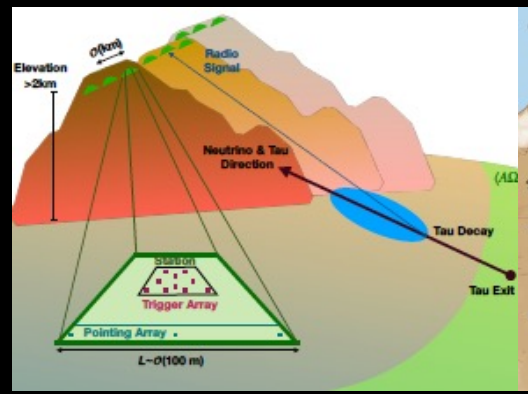
IceCube-Gen-2



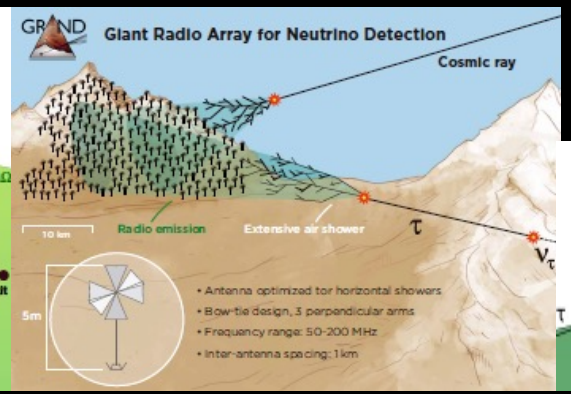
PUEO

EUSO-SPB2

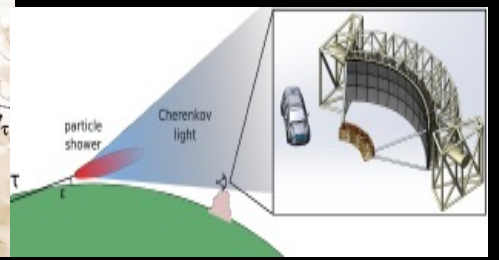
BEACOM



GRAND



Trinity

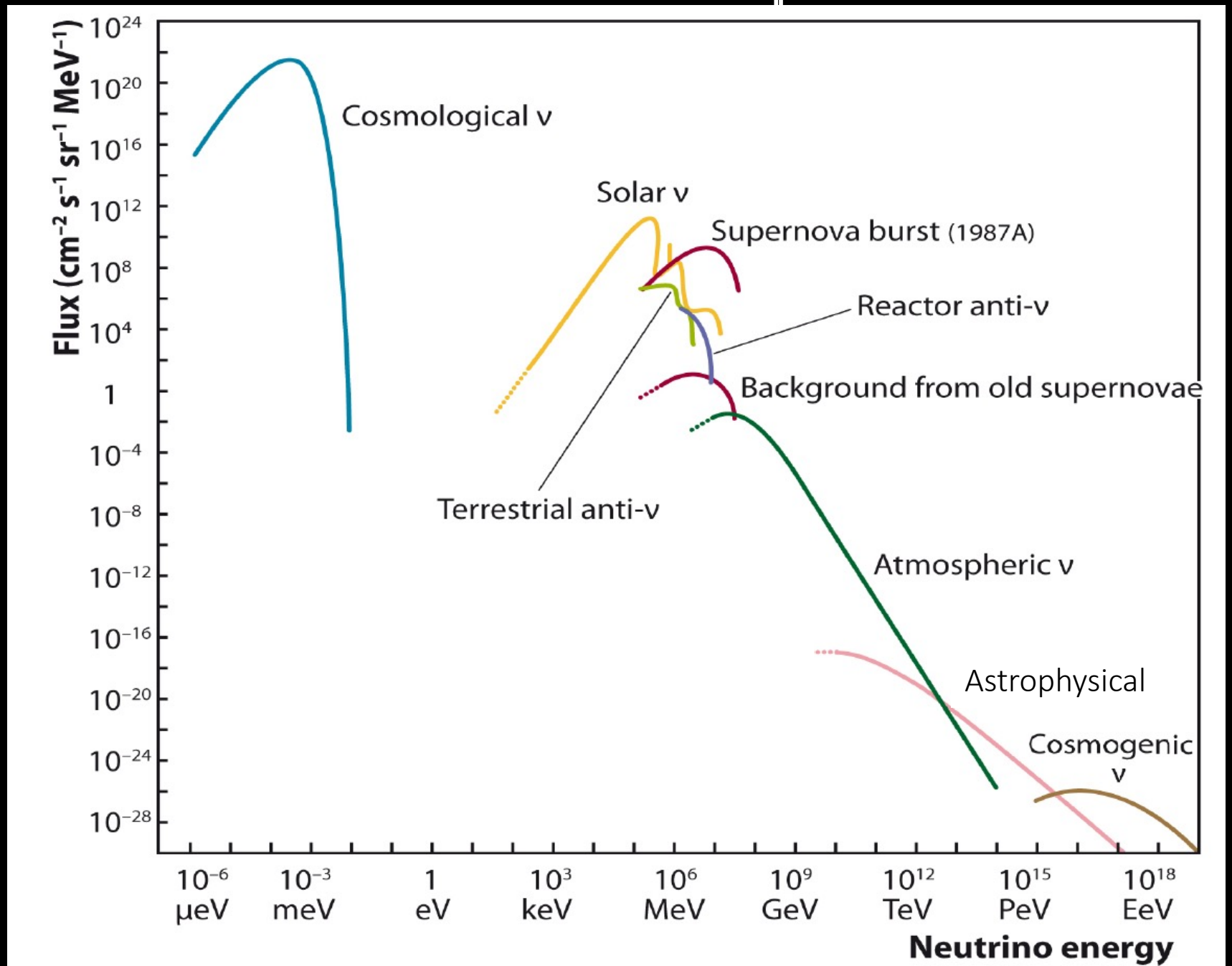


July 21, 2022

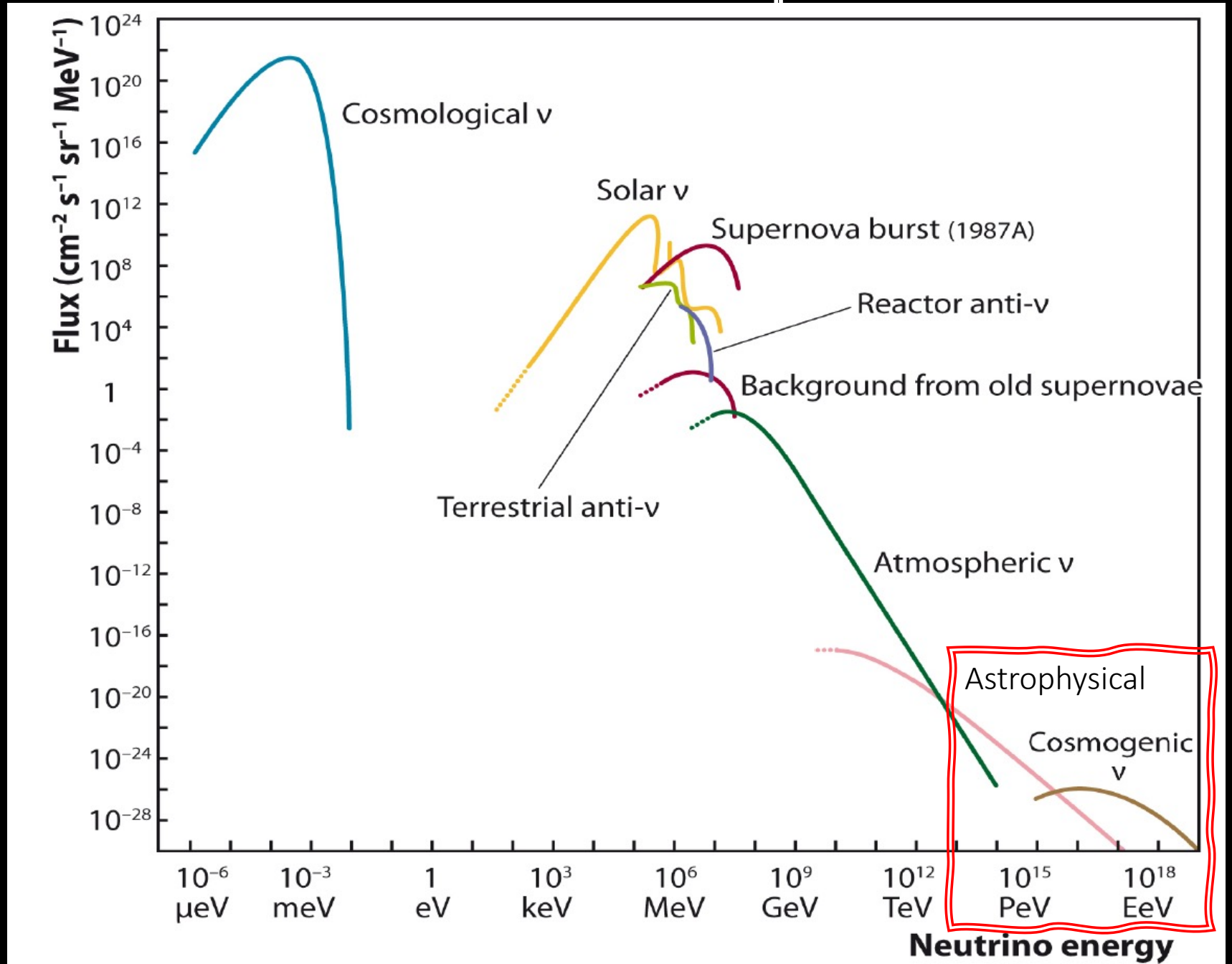
Angela V. Olinto

THE UNIVERSITY OF CHICAGO

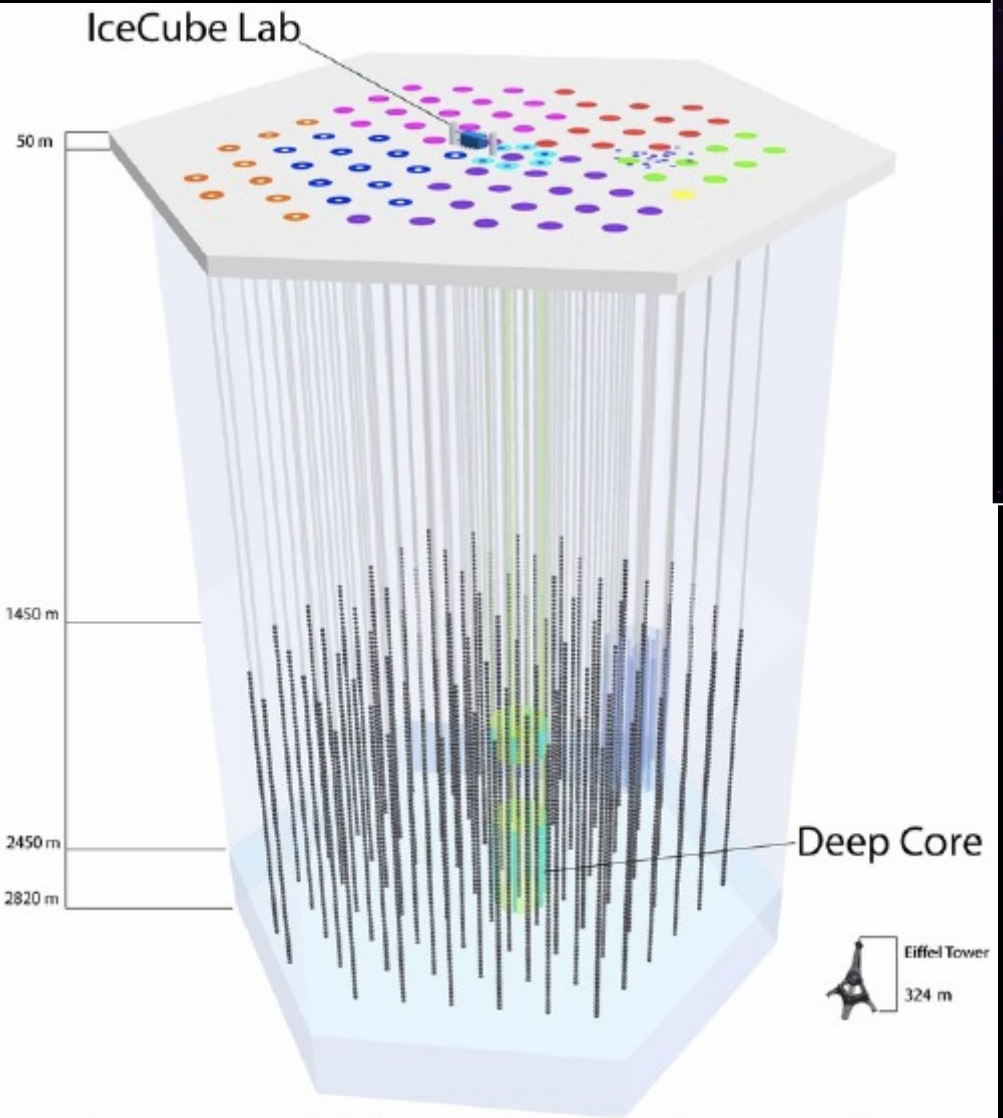
Cosmic Neutrino Spectra



Cosmic Neutrino Spectra: HE UHE



IceCube@SouthPole
Data taken since 2010



https://icecube.wisc.edu

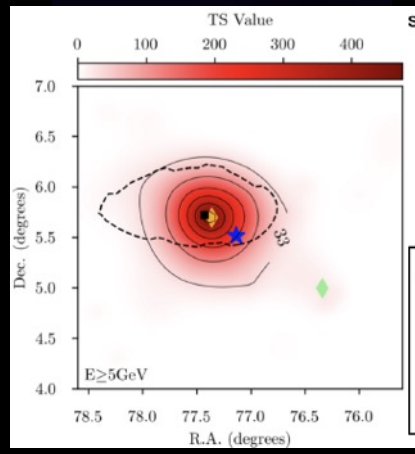
HE Neutrino Astronomy is here

Elisa Resconi

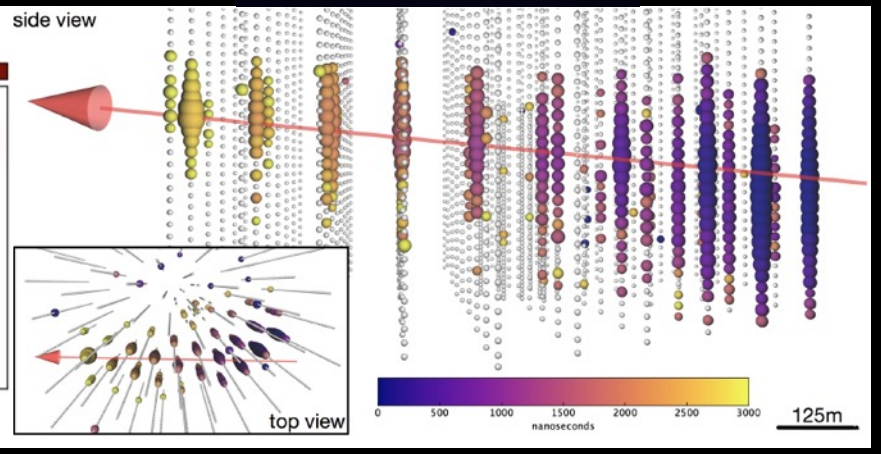
γ-2022

- Diffuse flux of high energy cosmic neutrinos
- Potential associations:
  - Jetted AGN: TXS0506+056 as template source, other tentative associations published;
  - Non-Jetted AGN: a new scenario emerging;
  - Promising: Galactic component as guaranteed flux.

TXS0506+056



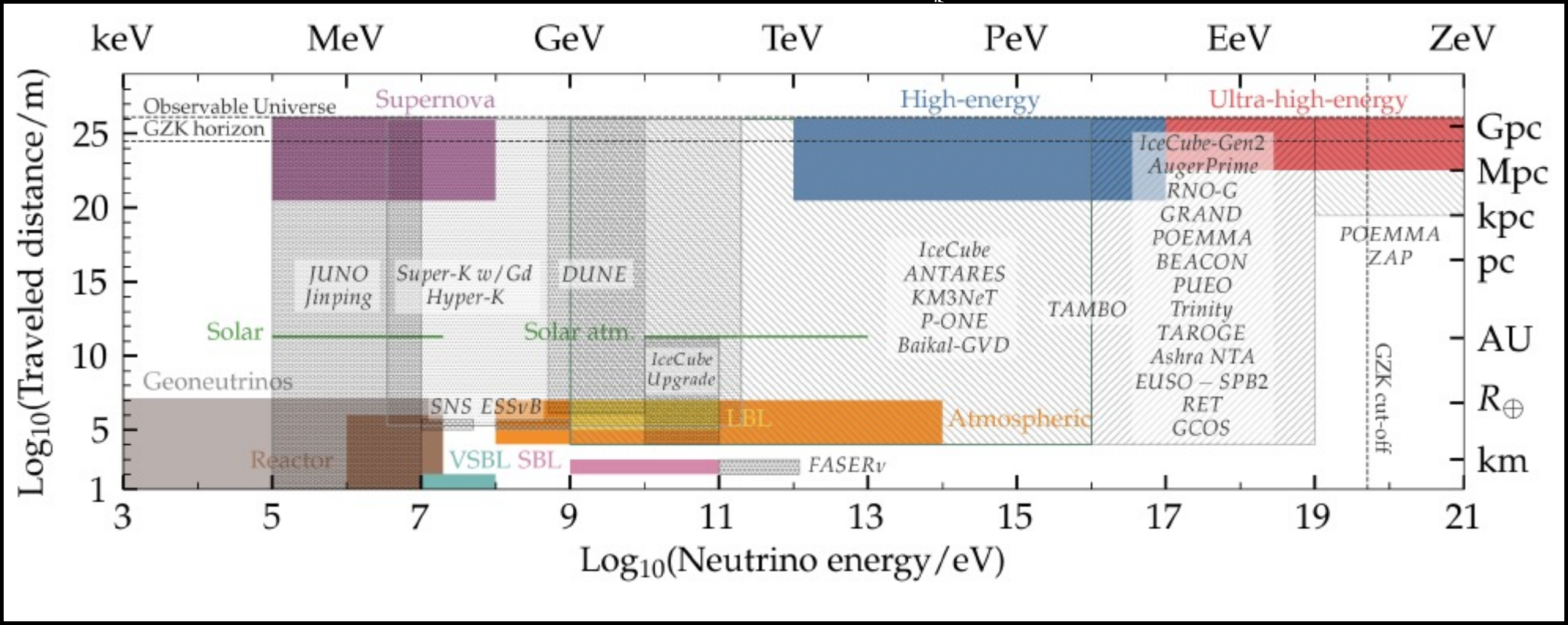
IceCube-170922



"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A", The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. *Science* 361, 2018

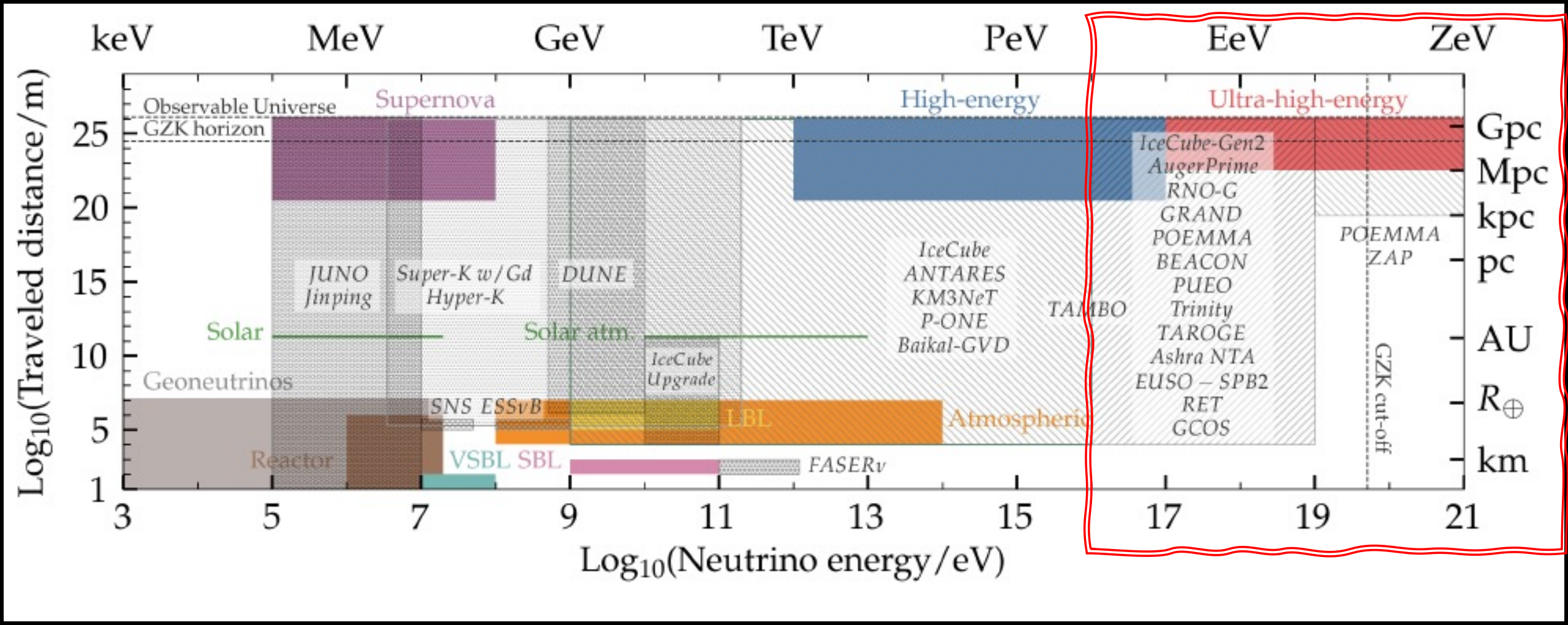
High-Energy and Ultra-High-Energy Neutrinos

A Snowmass White Paper



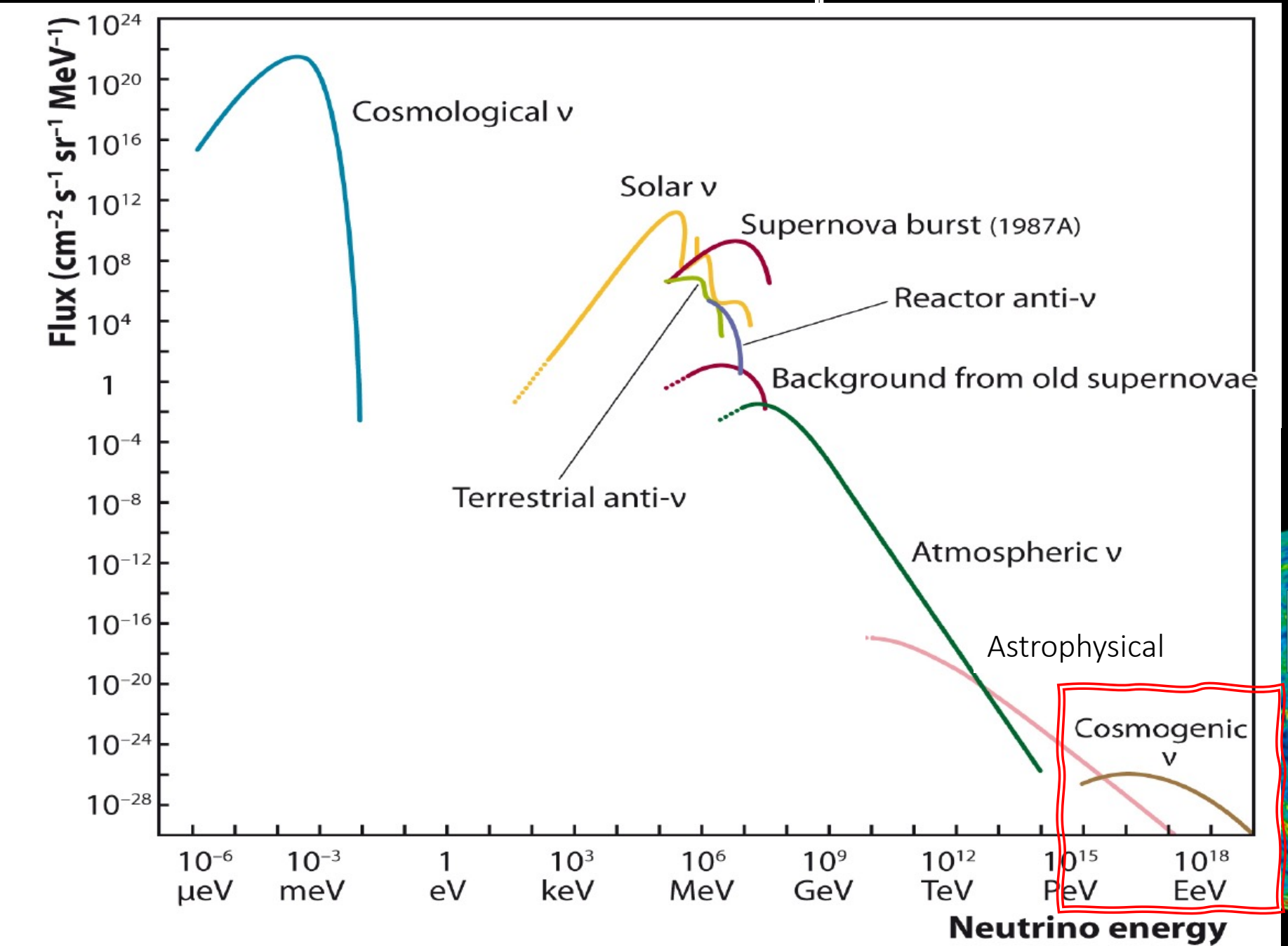
Ackermann et al, arXiv:2203.08096

High- + Ultrahigh-Energy Neutrinos

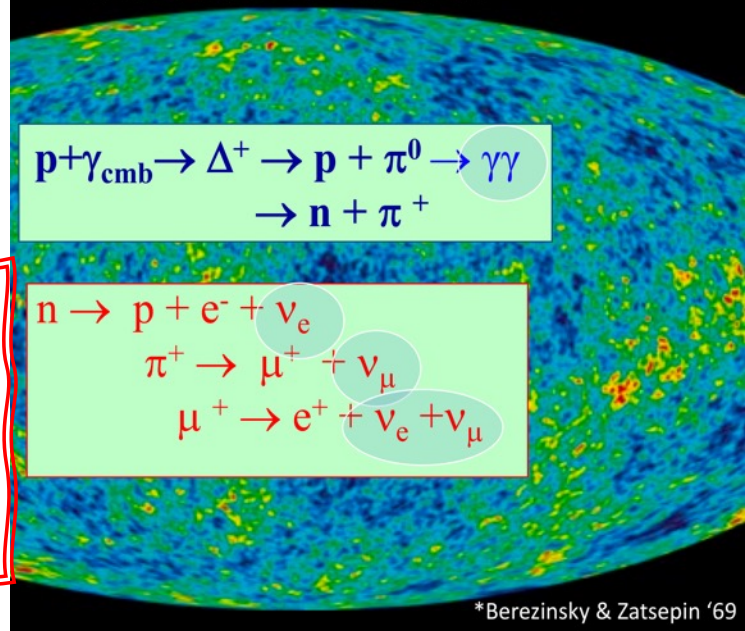


Ackermann et al, arXiv:2203.08096

Cosmic Neutrino Spectra



Cosmogenic (GZK, BZ*)
Neutrinos & Photons

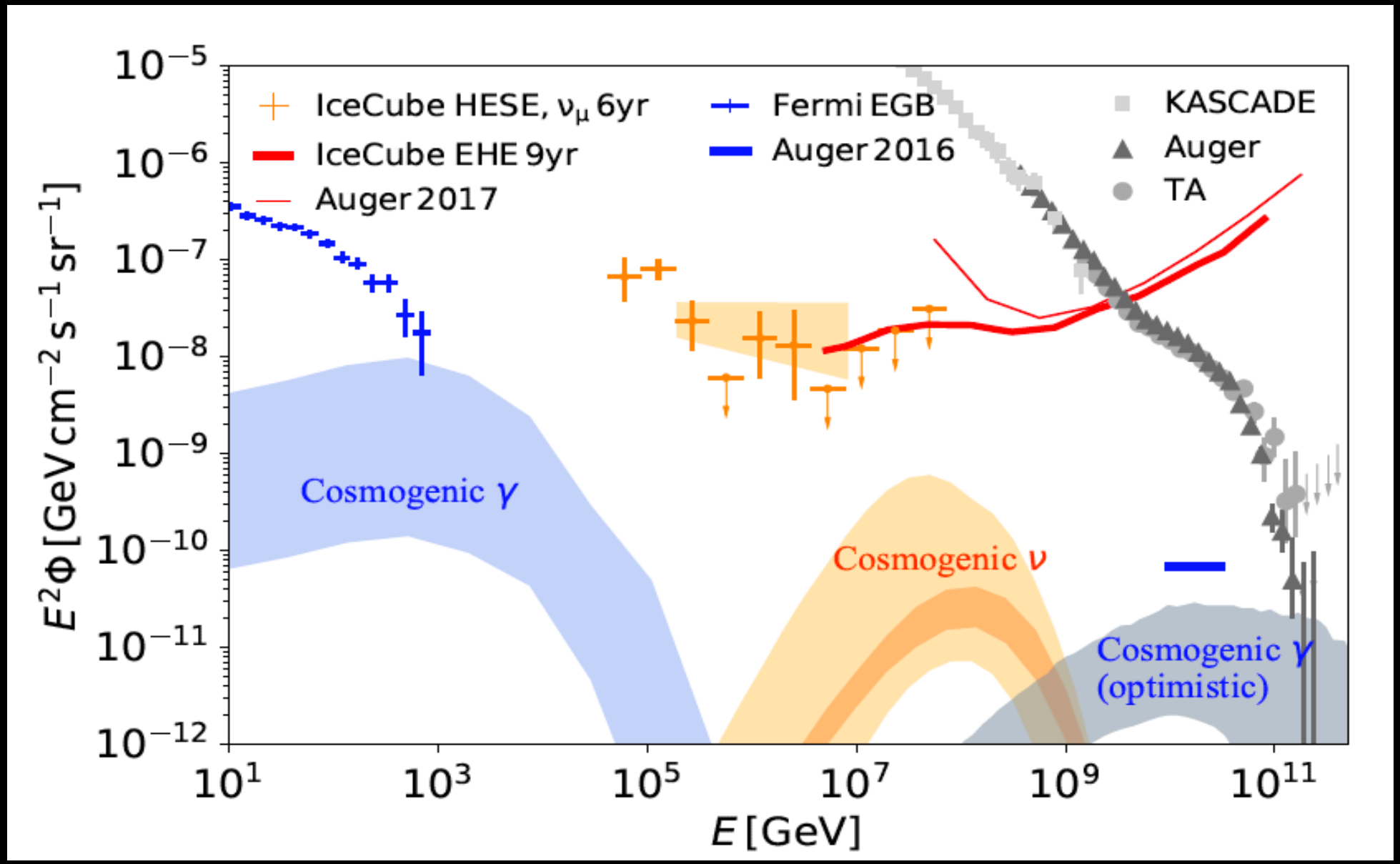


$p + \gamma_{cmb} \rightarrow \Delta^+ \rightarrow p + \pi^0 \rightarrow \gamma\gamma$
$\rightarrow n + \pi^+$

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

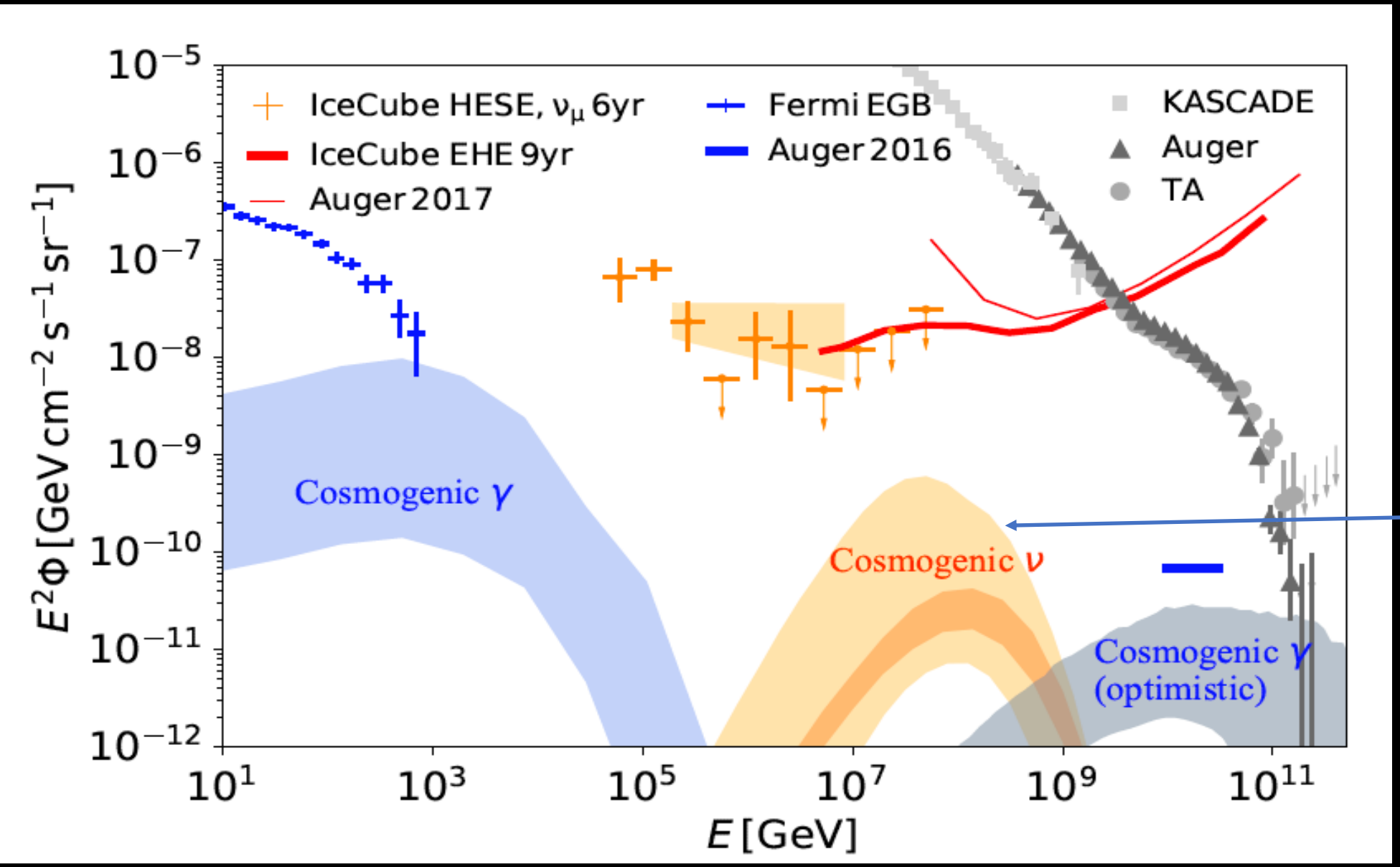
*Berezinsky & Zatsepin '69

Cosmogenic Messengers



Batista et al, arXiv:1903.06714.pdf

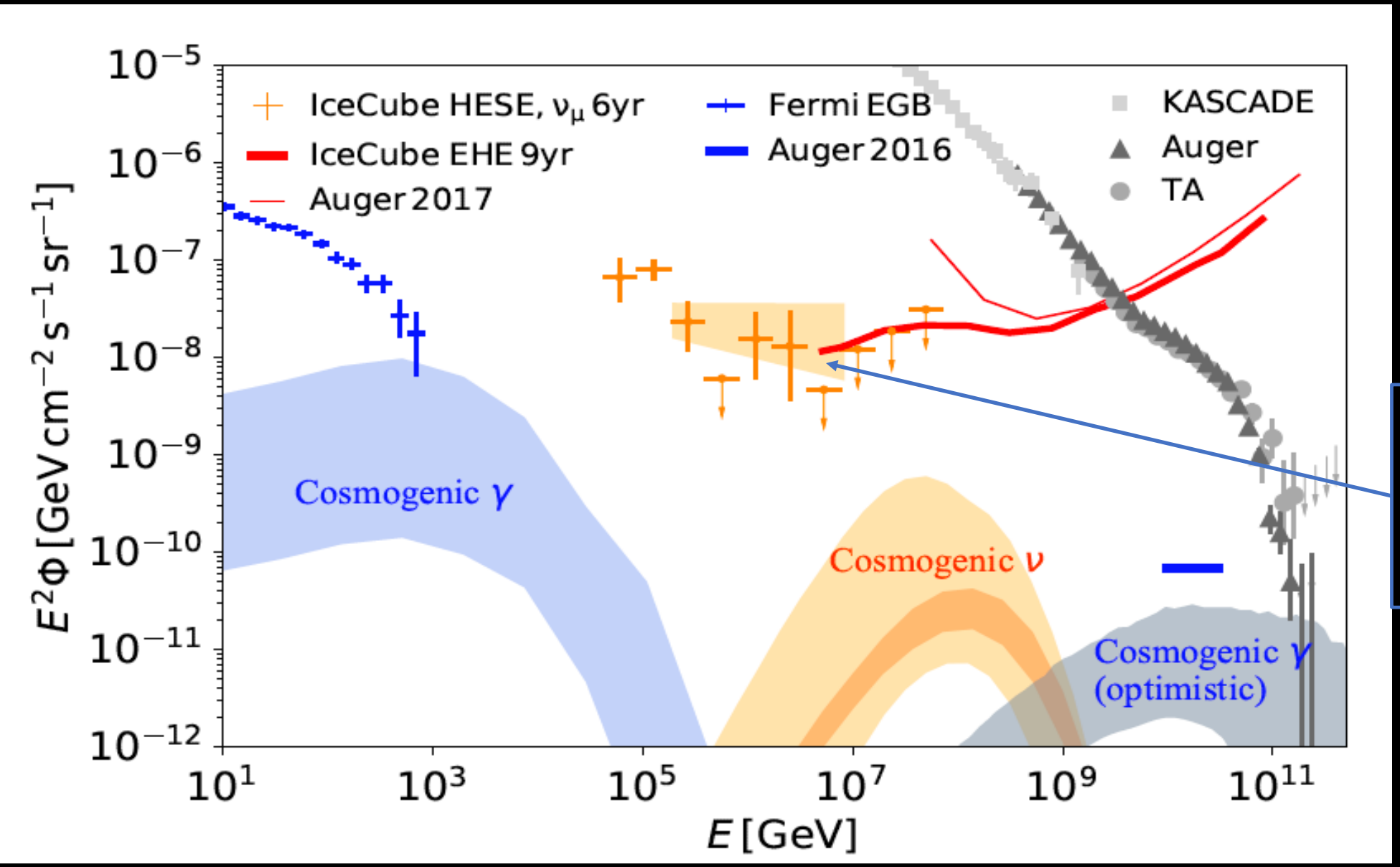
Cosmogenic Messengers



Cosmogenic Neutrino Flux much lower due to mixed composition of UHECRs above 10s EeV Observed by the Pierre Auger Experiment

Batista et al, arXiv:1903.06714.pdf

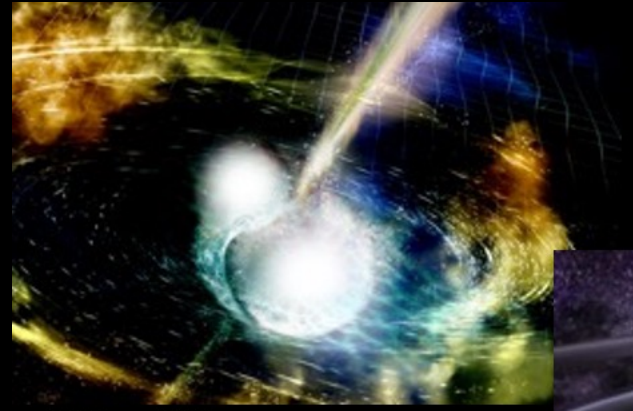
Cosmogenic Messengers



Astrophysical Neutrinos observed by IceCube. Possible sources (multi-messenger transients) can reach > 10s of PeV

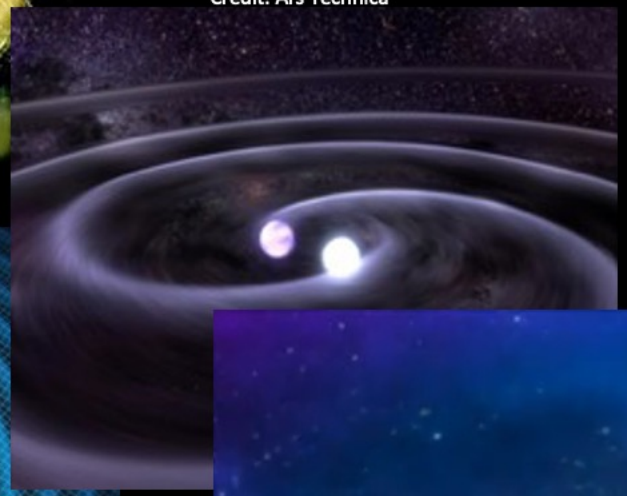
Batista et al, arXiv:1903.06714.pdf

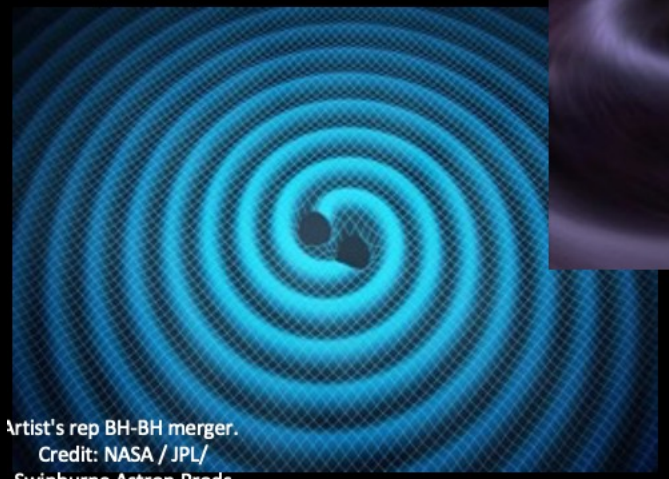
Astrophysical Neutrino Transients



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

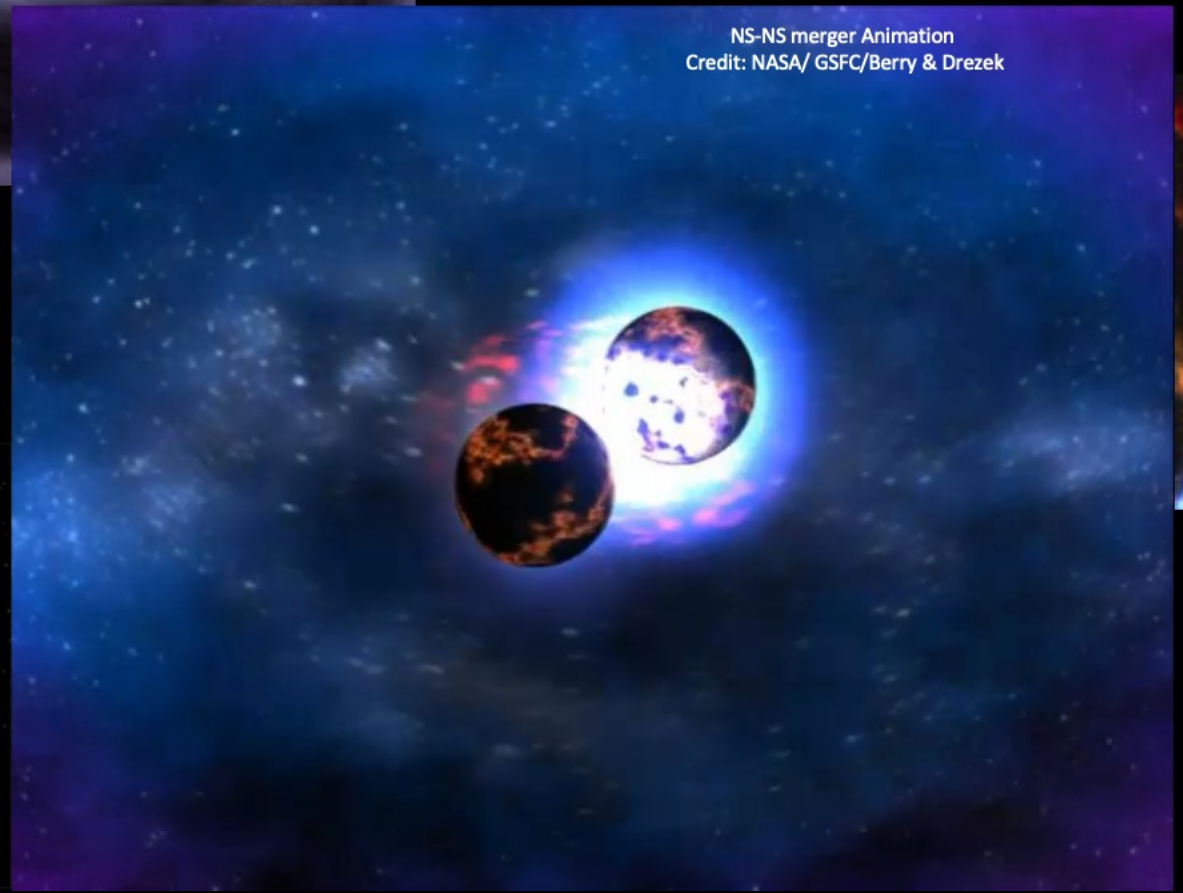
Artist's rep WD-WD merger
Credit: Ars Technica





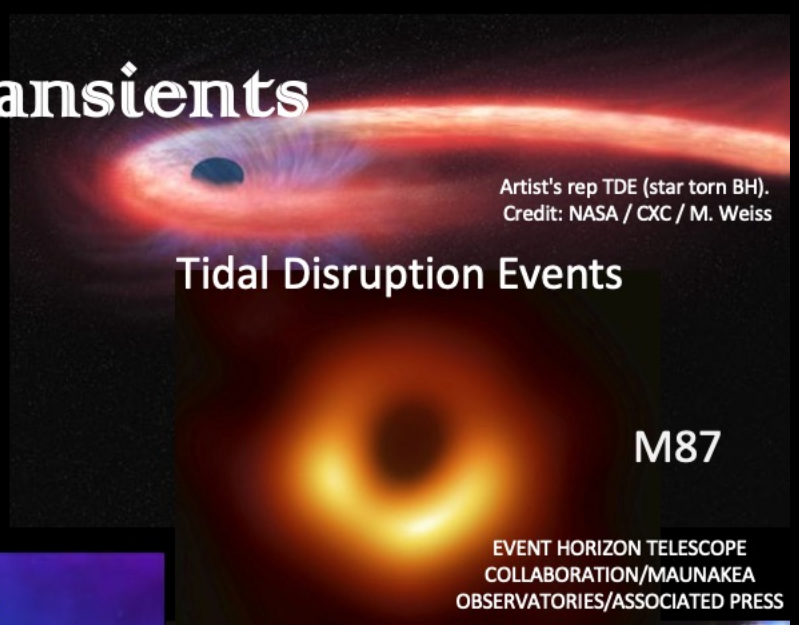
Artist's rep BH-BH merger.
Credit: NASA / JPL/
Swinburne Astron.Prods

Binary Coalescence



NS-NS merger Animation
Credit: NASA/ GSFC/Berry & Drezek

Blazar Flares



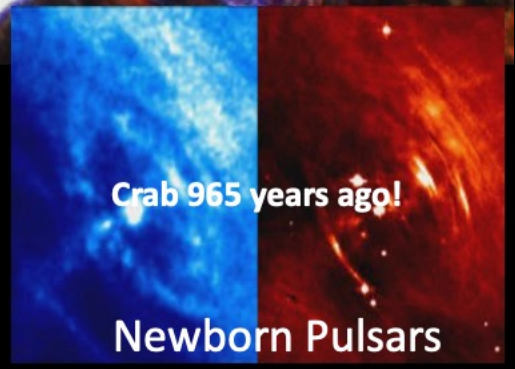
Artist's rep TDE (star torn BH).
Credit: NASA / CXC / M. Weiss

Tidal Disruption Events

M87

EVENT HORIZON TELESCOPE
COLLABORATION/MAUNAKEA
OBSERVATORIES/ASSOCIATED PRESS

Gamma Ray Bursts



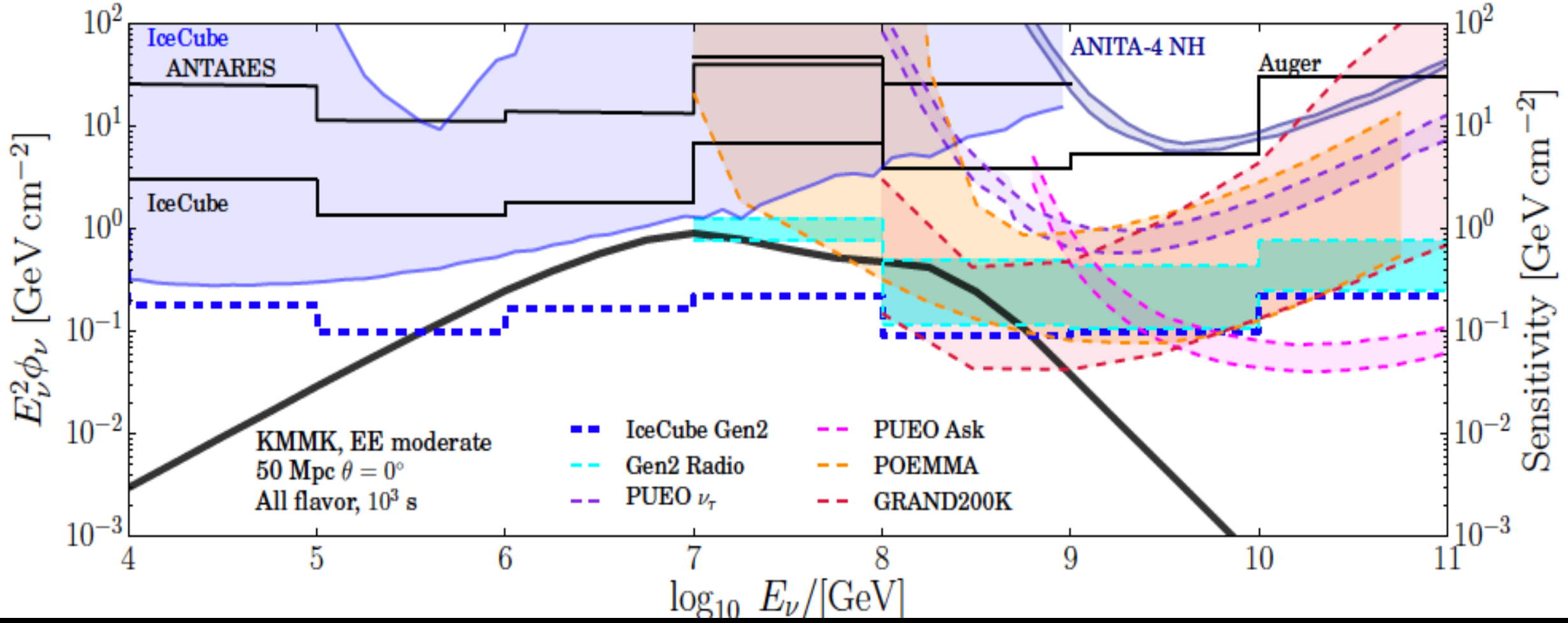
Crab 965 years ago!

Newborn Pulsars

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

Astrophysical Neutrino Transients:

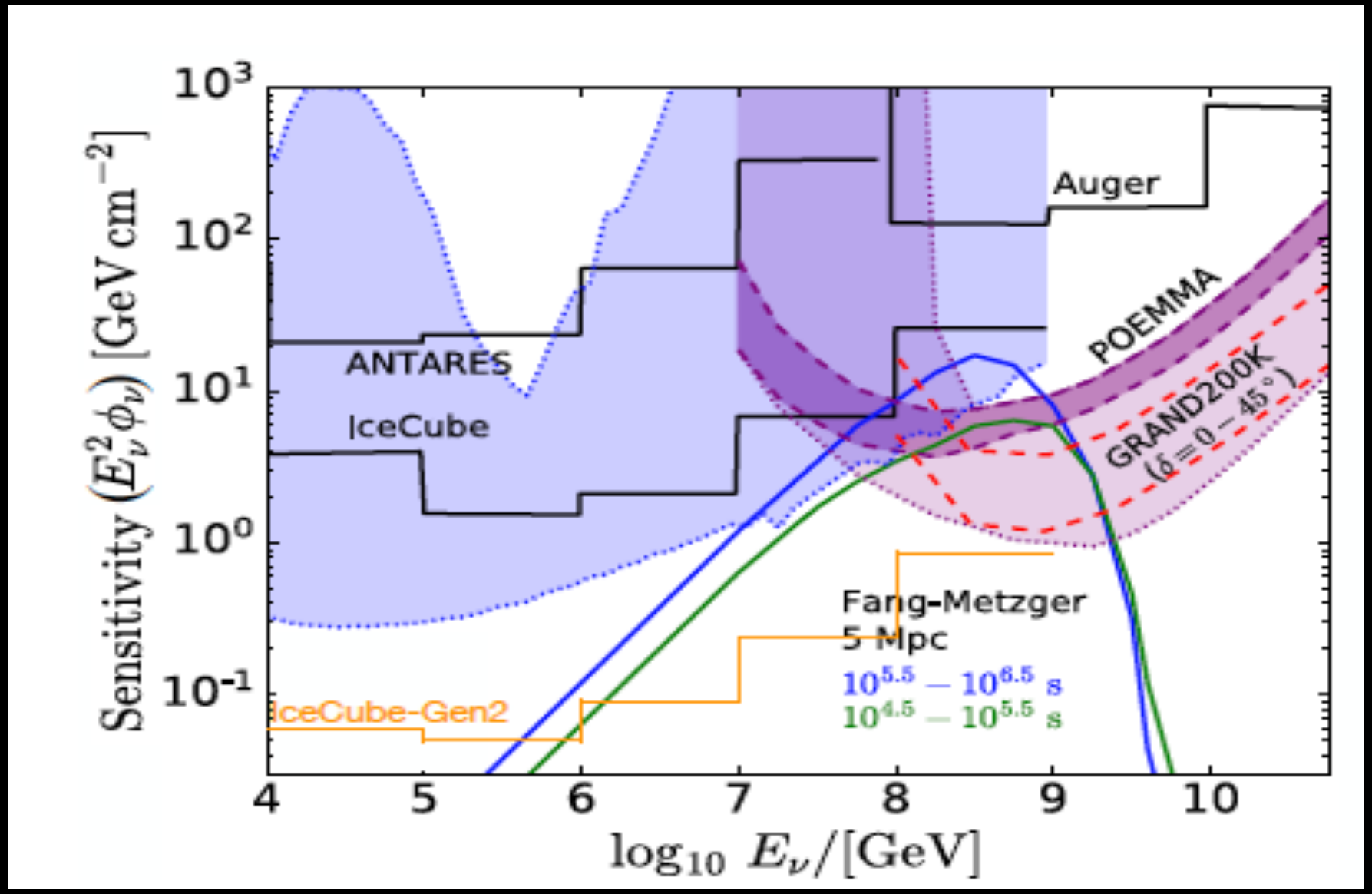
Short Gamma-Ray Bursts



Ackermann et al, arXiv:2203.08096

Kimura et al, arXiv:1708.07075

Astrophysical Neutrino Transients: Binary Neutron Star Mergers



Venters et al, Snowmass2021, LOI, (2020)

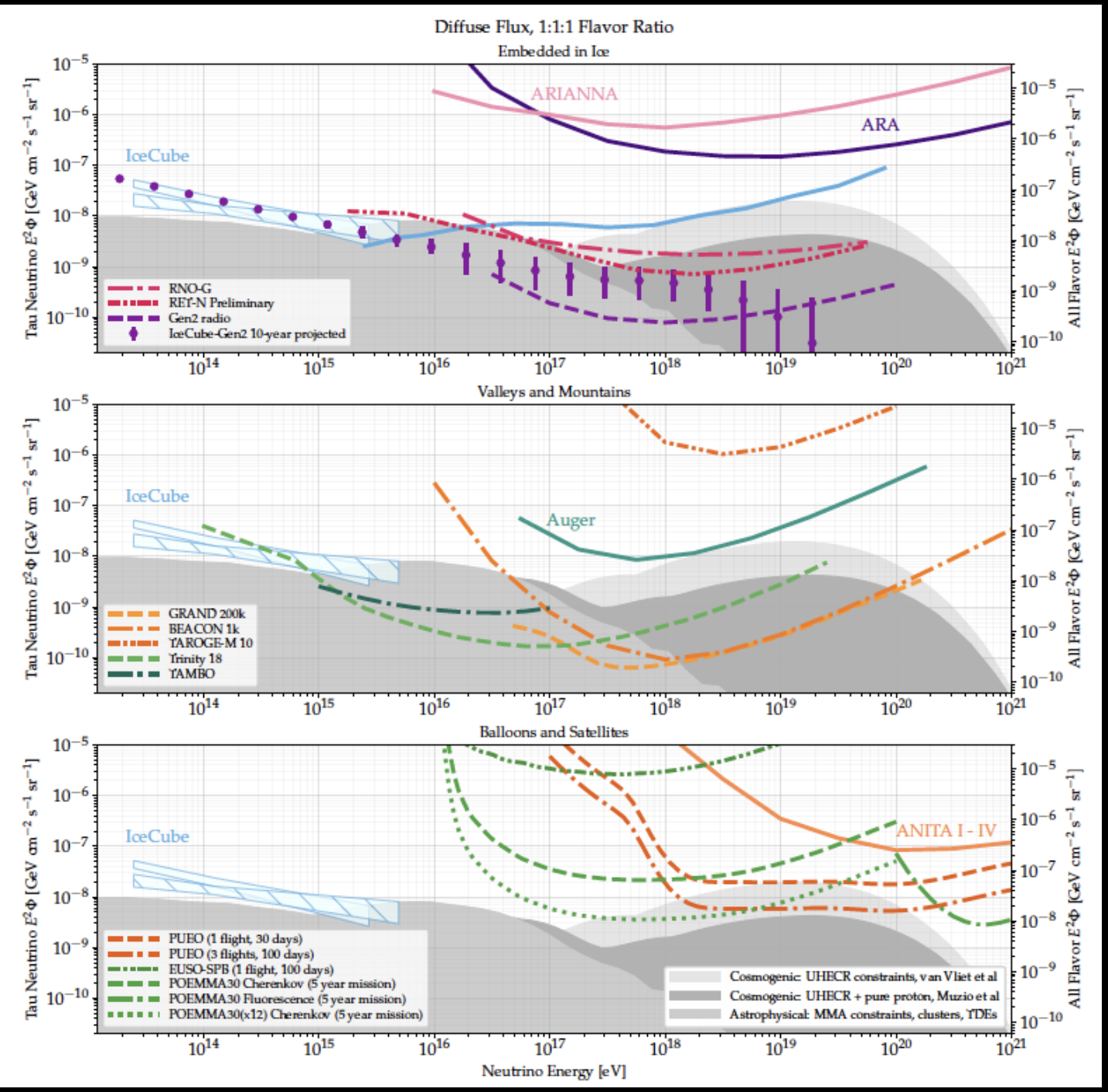
Fang & Metzger, arXiv:1707.04263

Tau Neutrinos in the Next Decade: from GeV to EeV

				Flavor		Technique			Neutrino Target					Geometry					
Experiments	Phase & Online Date	Energy Range	Site	Tau	All Flavor	Optical / UV	Radio	Showers	H_2O	Atmosphere	Earth's limb	Topography	Lunar Regolith	Embedded	Planar Arrays	Valley	Mountains	Balloon	Satellite
IceCube	2010	TeV-EeV	South Pole		✓	✓			✓					✓					
KM3NeT	2021	TeV-PeV	Mediteranean		✓	✓			✓					✓					
Baikal-GVD	2021	TeV-PeV	Lake Baikal		✓	✓			✓					✓					
P-ONE	2020	TeV-PeV	Pacific Ocean		✓	✓			✓					✓					
IceCube-Gen2	2030+	TeV-EeV	South Pole		✓	✓	✓		✓					✓					
ARIANNA	2014	>30 PeV	Moore's Bay		✓		✓		✓					✓					
ARA	2011	>30 PeV	South Pole		✓		✓		✓					✓					
RNO-G	2021	>30 PeV	Greenland		✓		✓		✓					✓					
RET-N	2024	PeV-EeV	Antarctica		✓		✓		✓					✓					
ANITA	2008,2014,2016	EeV	Antarctica	✓	✓		✓		✓		✓							✓	
PUEO	2024	EeV	Antarctica	✓	✓		✓		✓		✓							✓	
GRAND	2020	EeV	China / Worldwide	✓			✓			✓	✓	✓			✓		✓		
BEACON	2018	EeV	CA, USA/ Worldwide	✓			✓				✓	✓					✓		
TAROGE-M	2018	EeV	Antarctica	✓			✓				✓	✓					✓		
SKA	2029	>100 EeV	Australia		✓		✓						✓		✓				
Trinity	2022	PeV-EeV	Utah, USA	✓		✓					✓						✓		
POEMMA		>20 PeV	Satellite	✓	✓	✓				✓	✓								✓
EUSO-SPB	2022	EeV	New Zealand	✓		✓					✓							✓	
Pierre Auger	2008	EeV	Argentina	✓	✓			✓		✓	✓	✓			✓				
AugerPrime	2022	EeV	Argentina	✓	✓		✓	✓		✓	✓	✓			✓				
Telescope Array	2008	EeV	Utah, USA	✓	✓			✓		✓					✓				
TAx4		EeV	Utah, USA	✓	✓			✓											
TAMBO	2025-2026	PeV-EeV	Peru	✓				✓				✓				✓			

Operational		Date full operations began
Prototype		Date protoype operations began or begin
Planning		Projected full operations

Abraham et al
arXiv:2203.05591



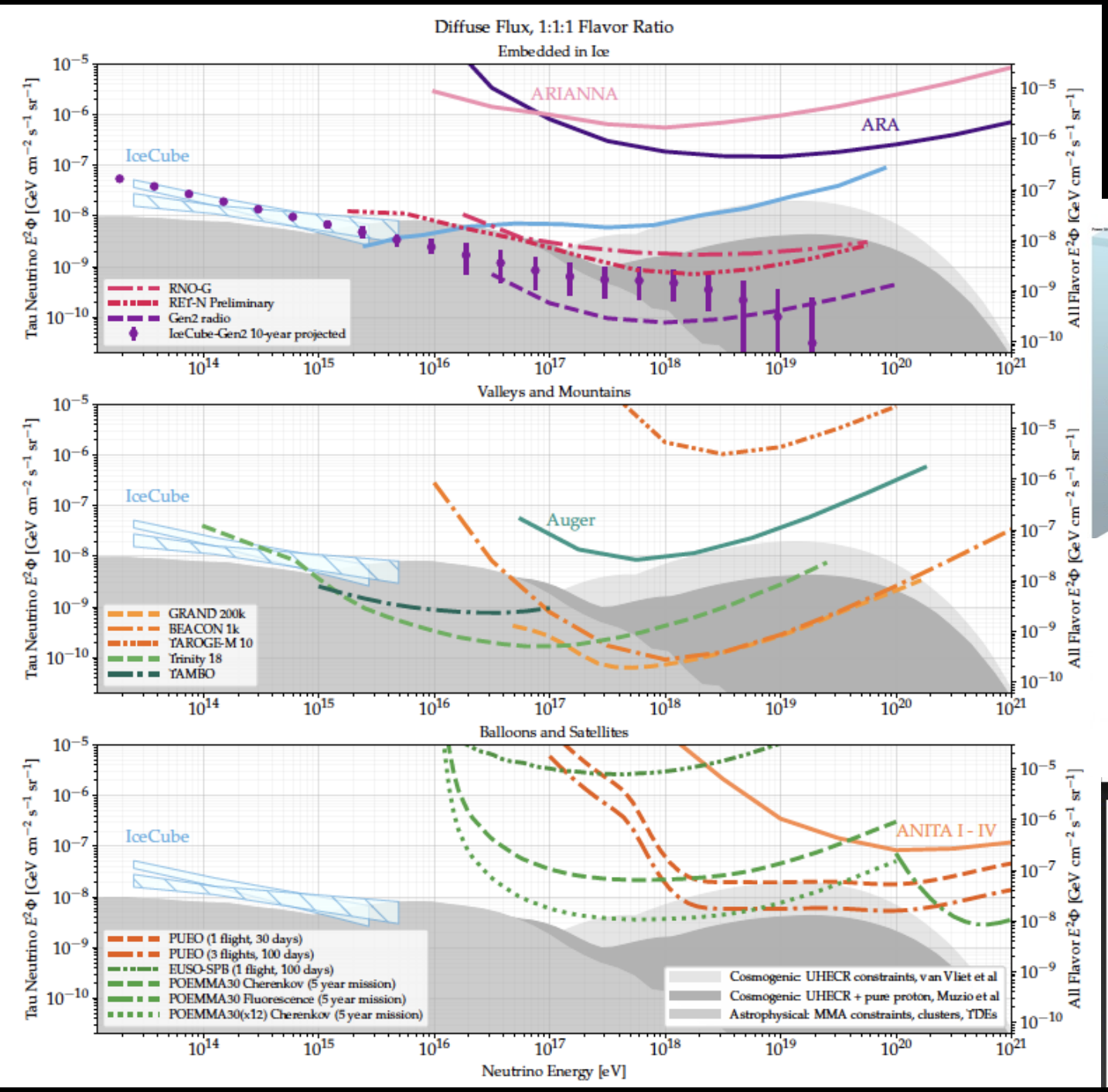
Water and Ice

Ground Arrays, Mountains, Valleys

Balloon-Borne experiments and Satellites

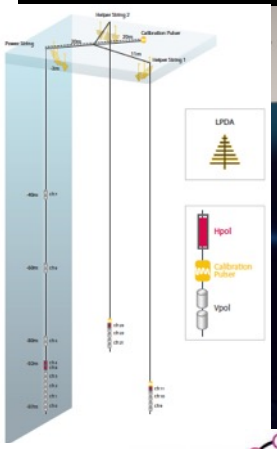
Abraham et al
arXiv:2203.05591

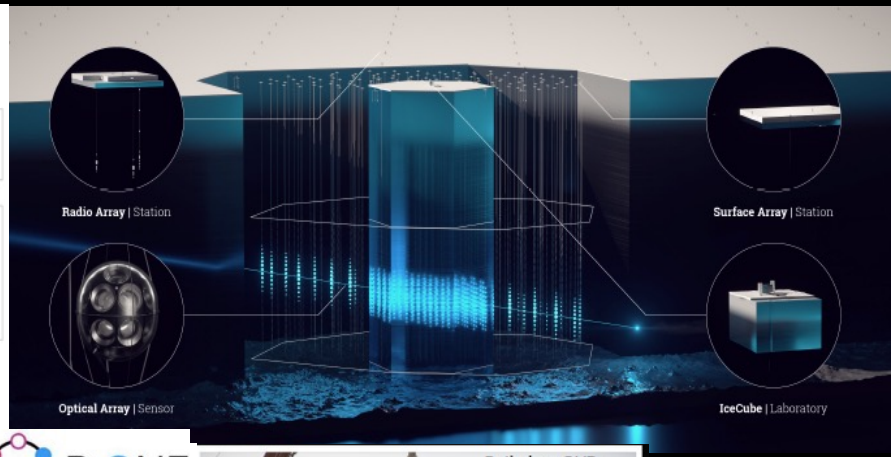
Water and Ice

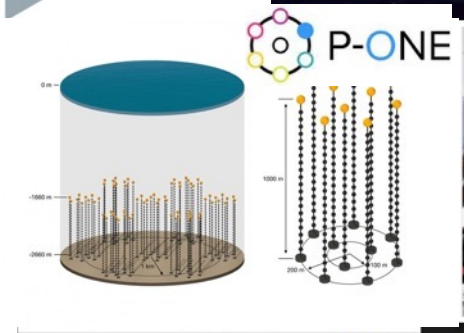


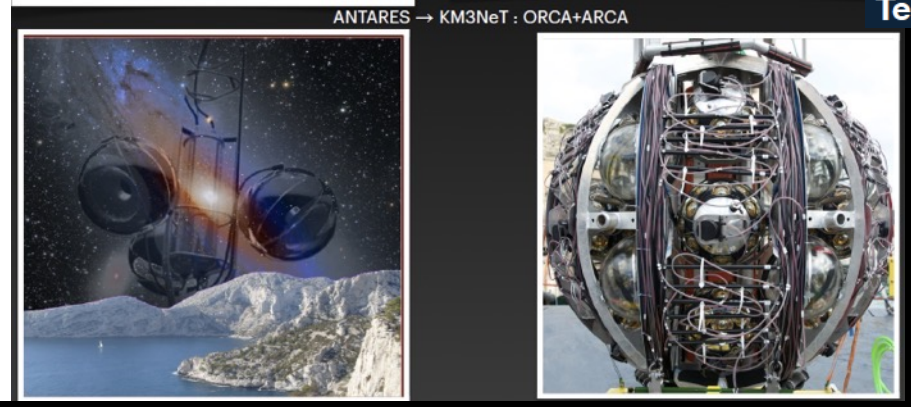
RNO-G

IceCube-Gen-2



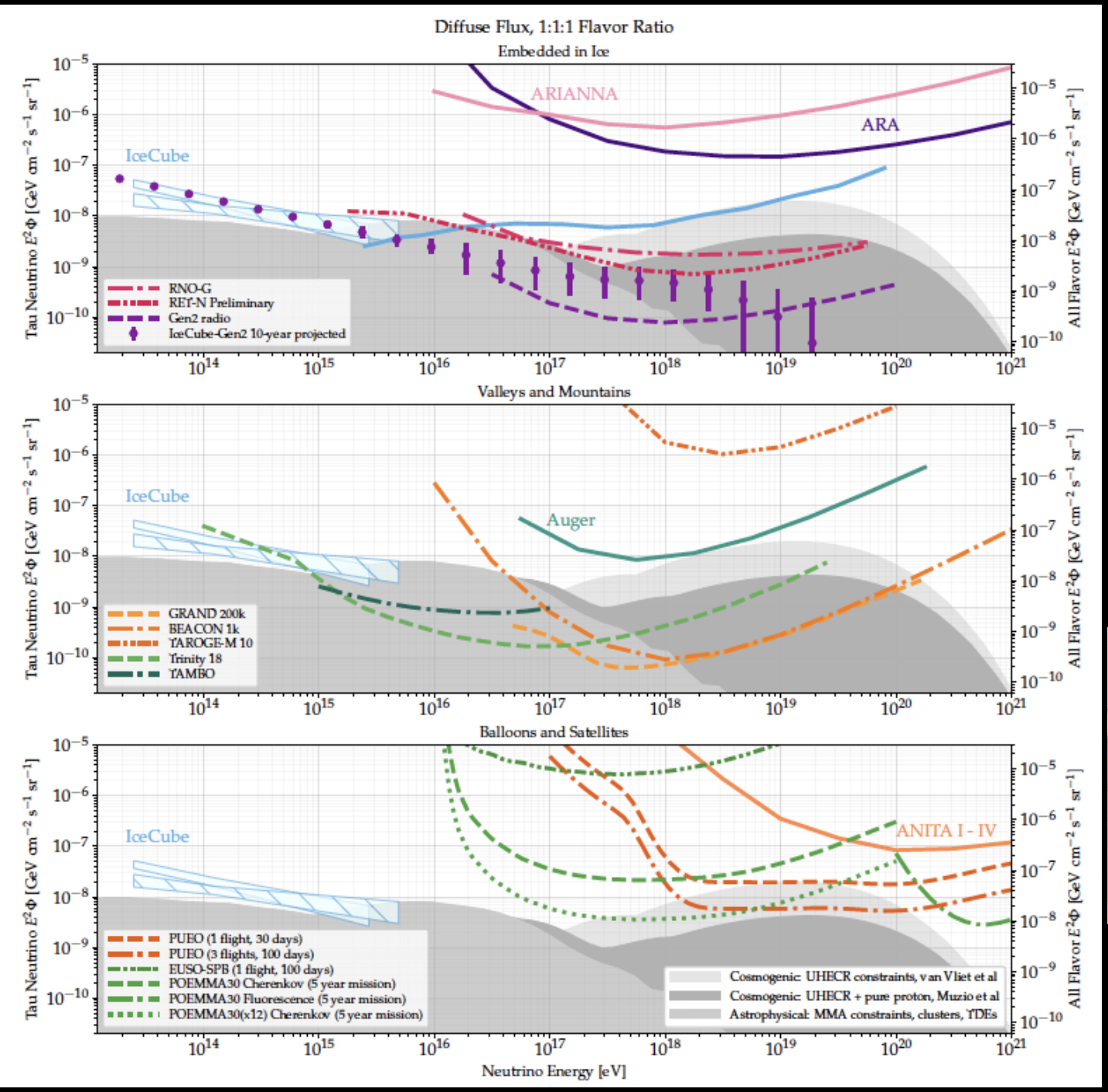






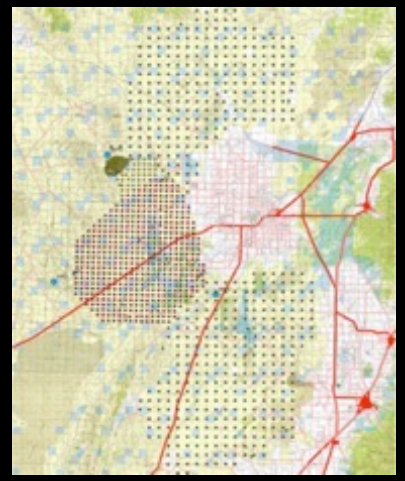
Teresa Montaruli

γ 2022 7th Heidelberg International Symposium on High Energy Gamma-Ray Astronomy Barcelona, July 4-8 2022



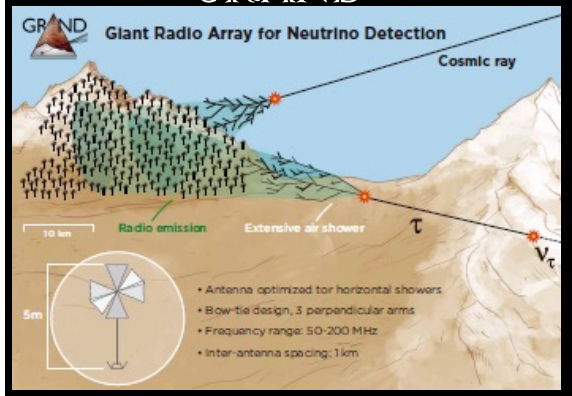
Auger (Prime)

TAx4

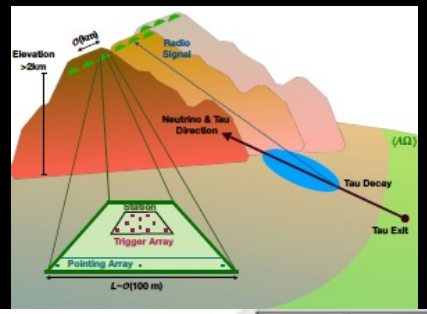


Ground Arrays, Mountains, Valleys

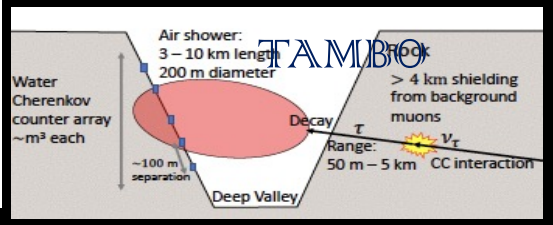
GRAND



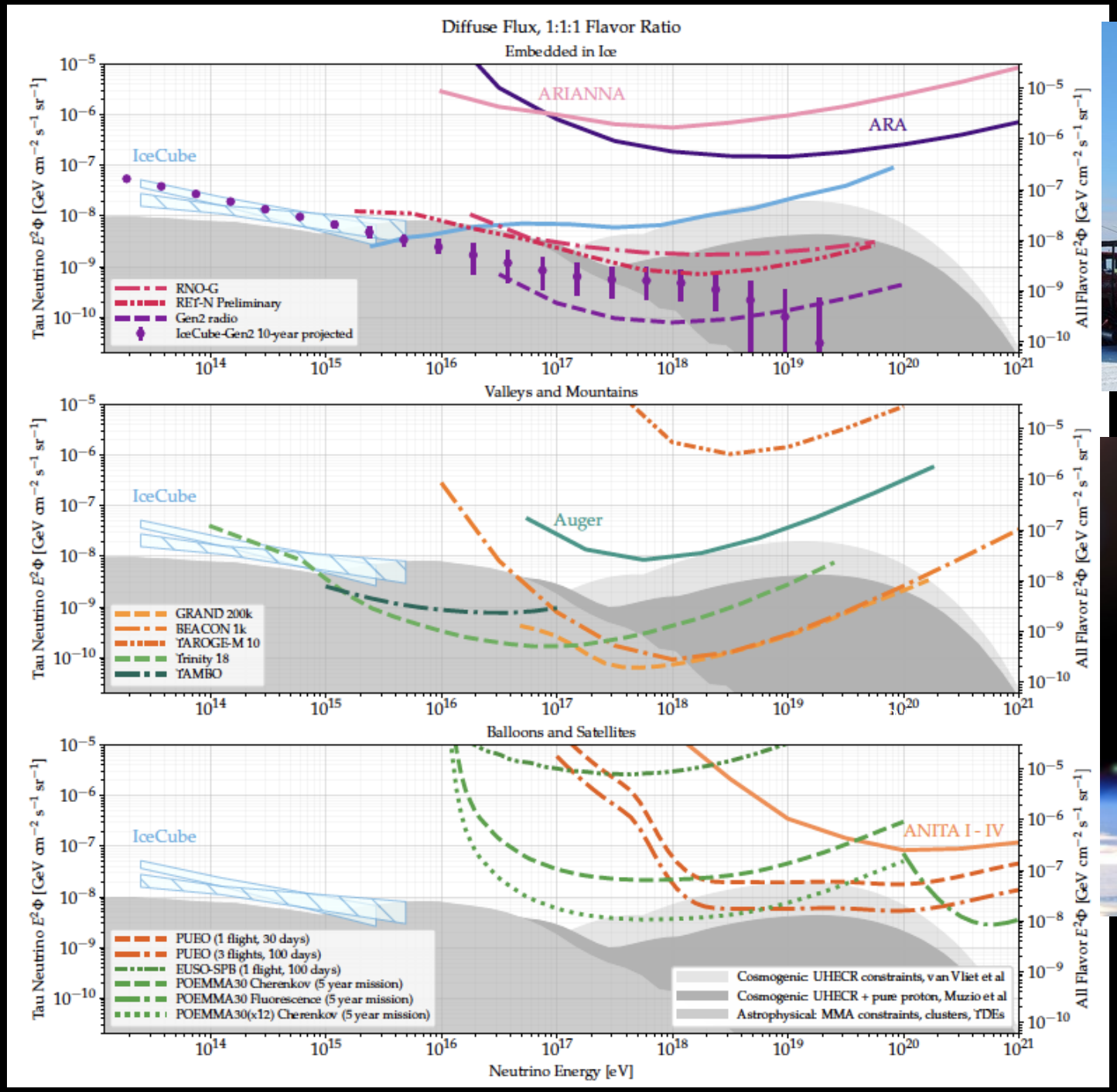
BEACOM

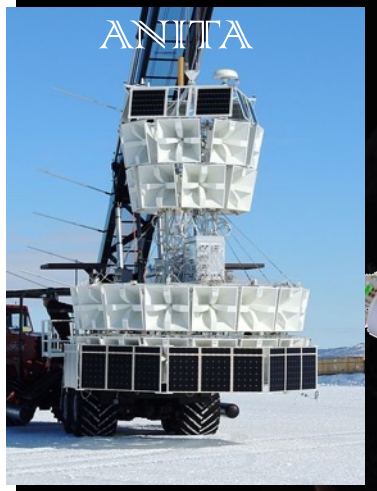


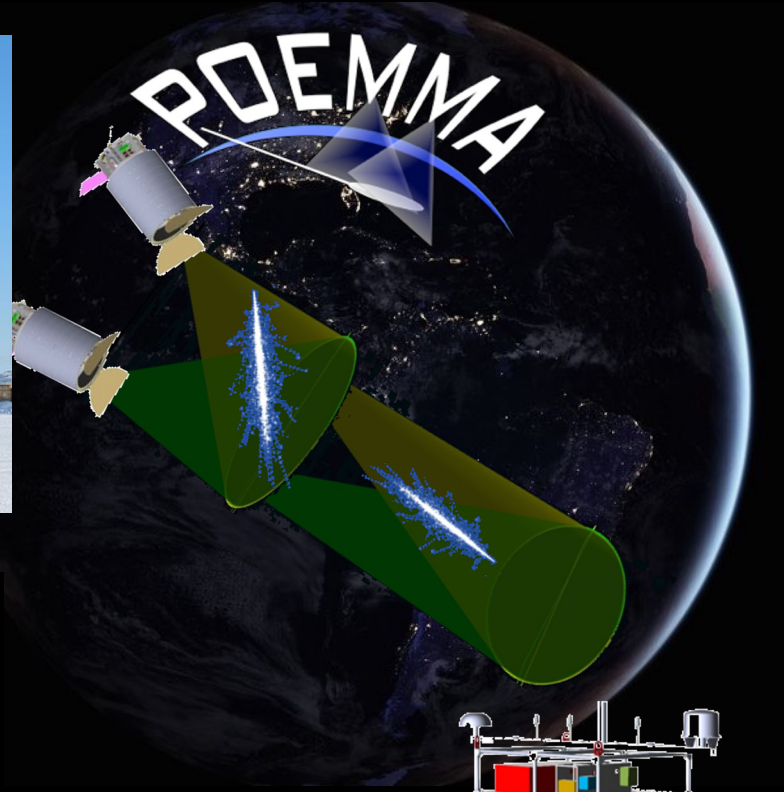
TAMBO

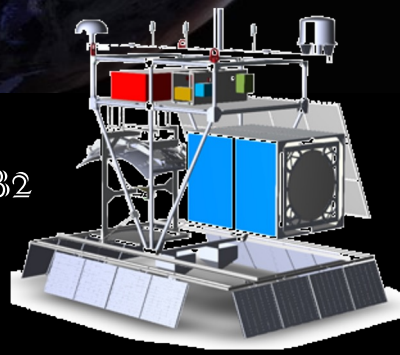


Trinity







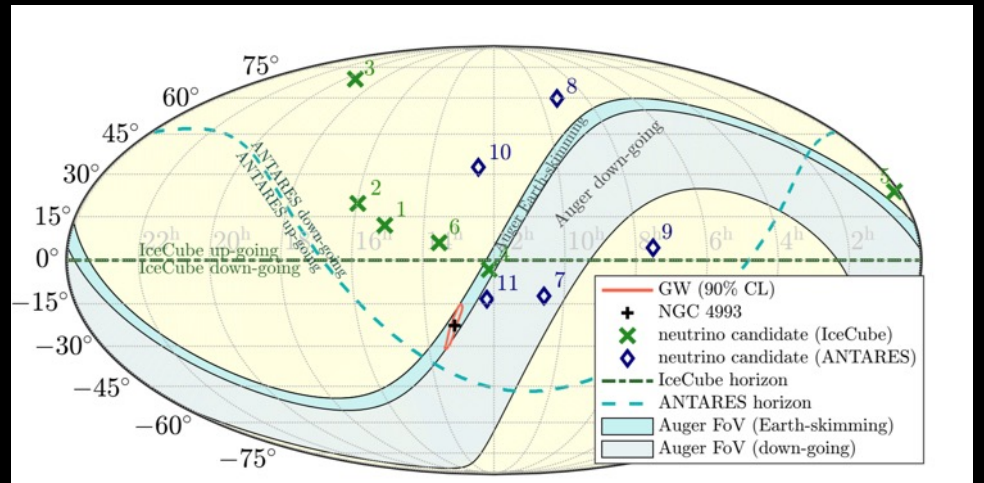


Balloon-Borne experiments and Satellites

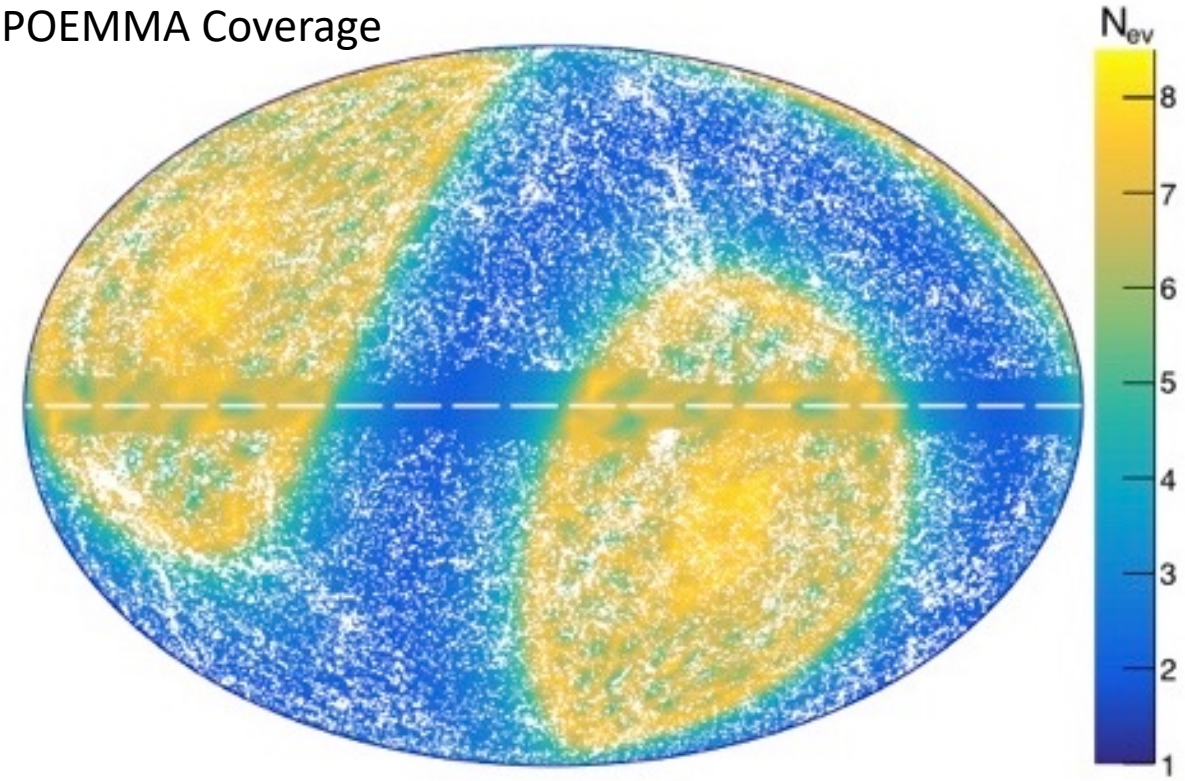
Abraham et al arXiv:2203.05591

Sky Coverage HE-UHE Neutrinos

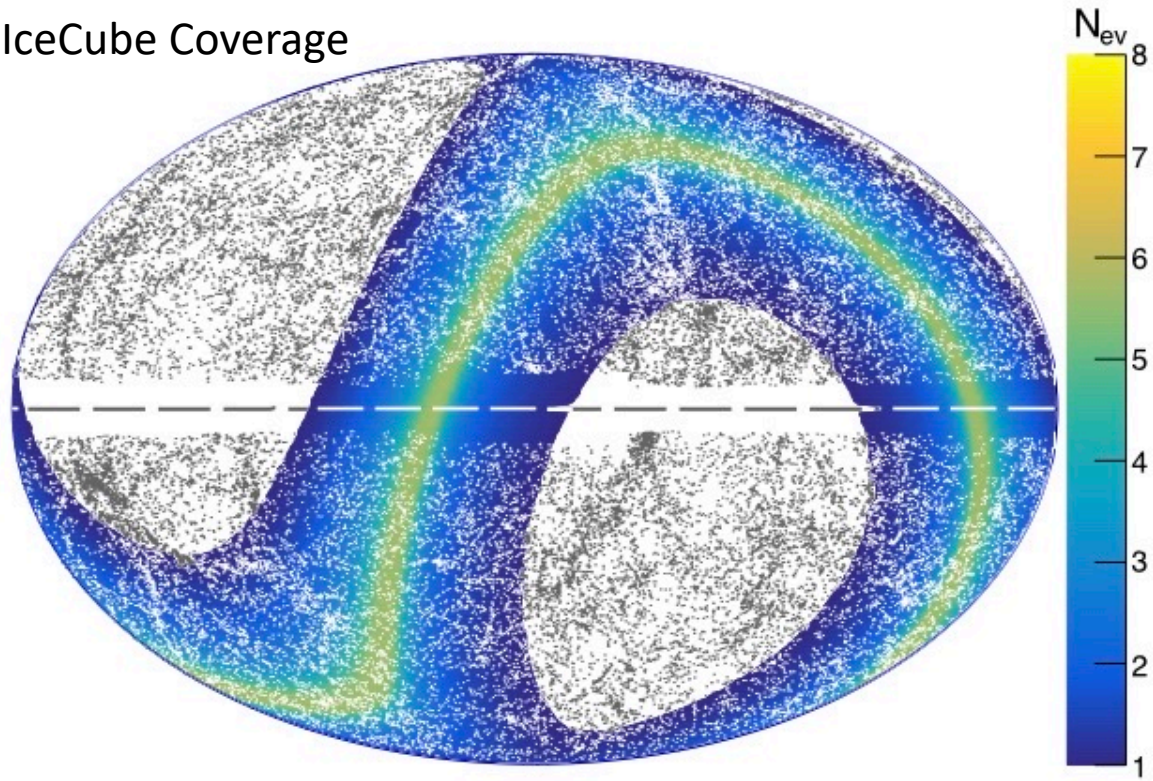
Complementary



POEMMA Coverage



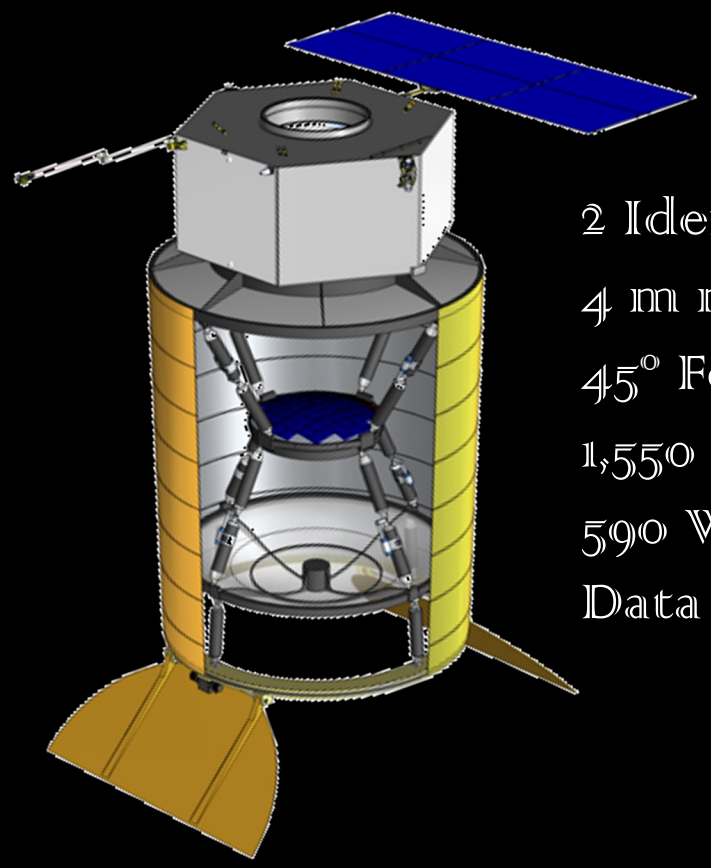
IceCube Coverage



Venters et al arXiv:1906.07209

POEMMA

Probe Of Extreme Multi-Messenger Astrophysics



2 Identical Telescopes

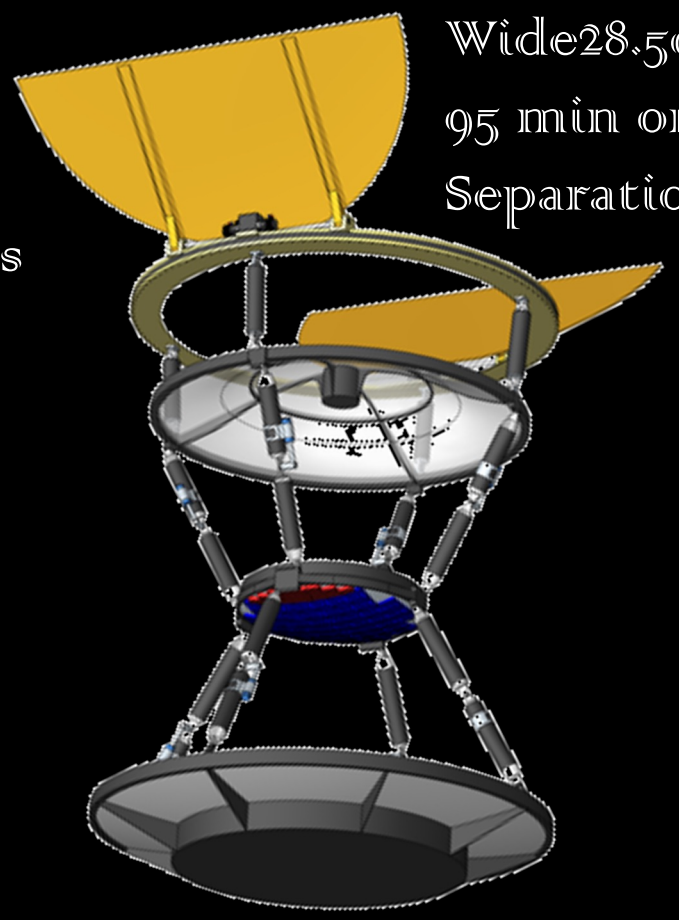
4 m mirror

45° FoV Schmidt Optics

1,550 kg mass

590 W power

Data 1 GB/day



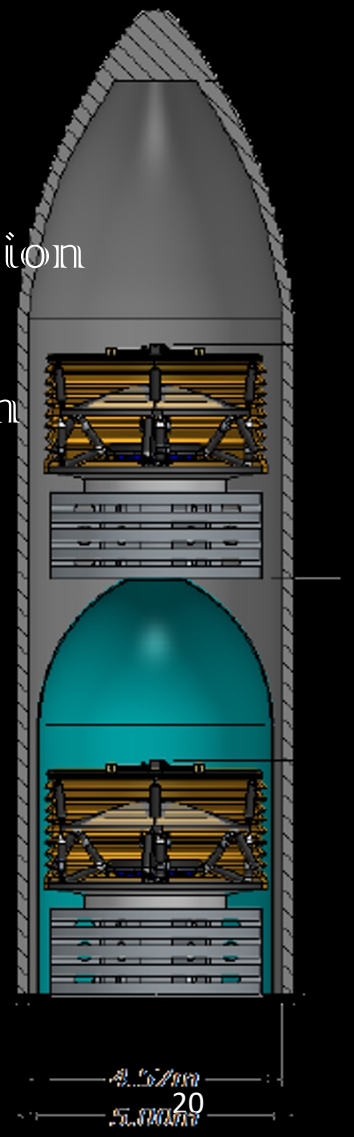
5yr Mission

Alt 525 km

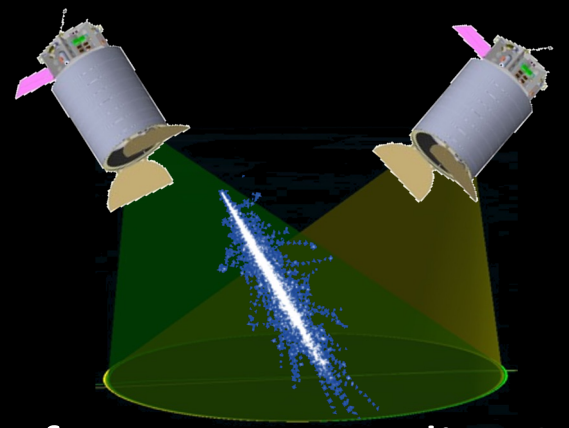
Wide28.50 Inclination

95 min orbits

Separation 100s km

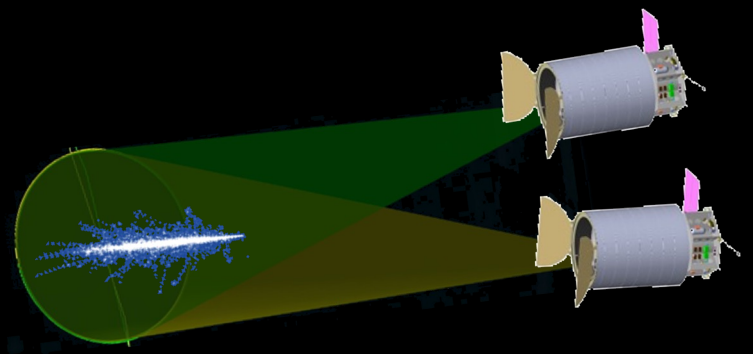


Instrument and Mission Design for
Astro 2020 Probe Class Missions (2017-2019)

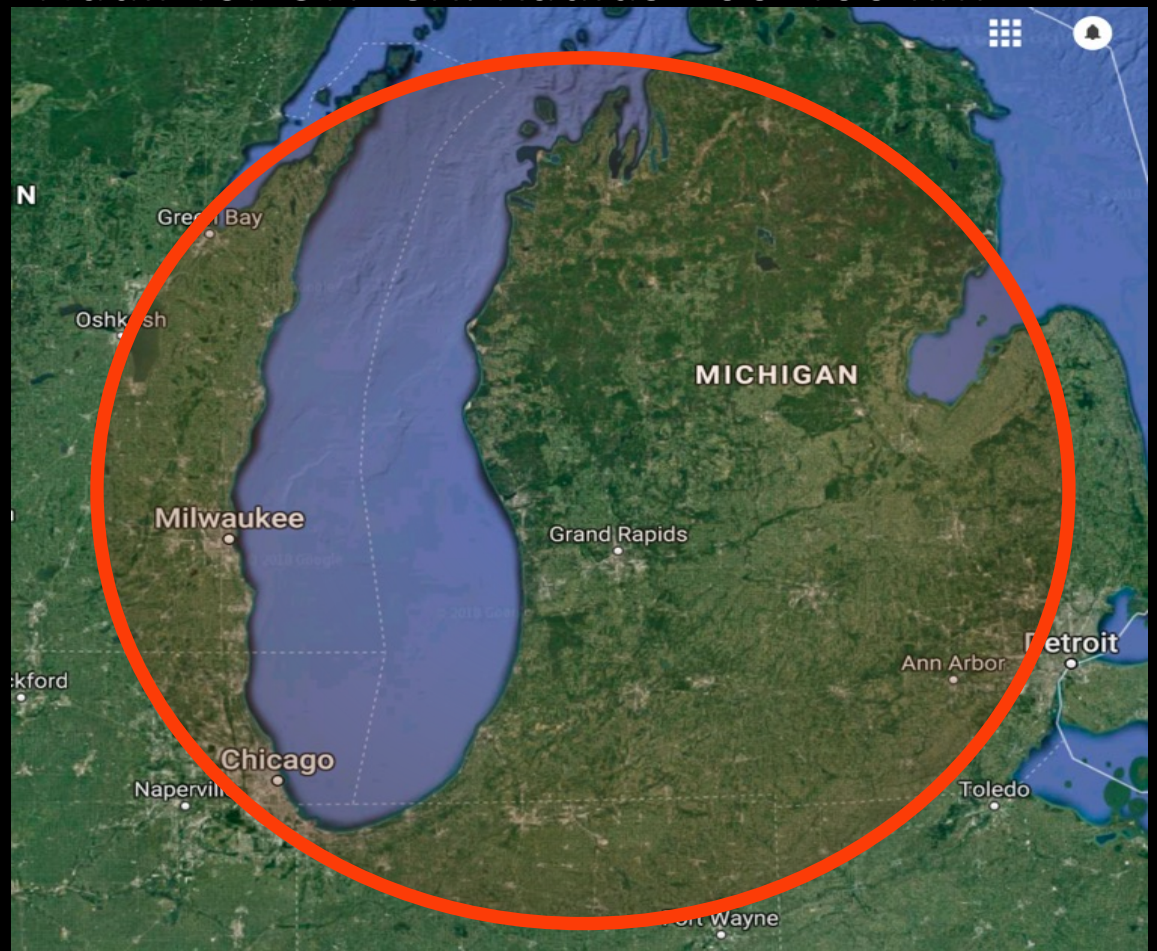


POEMMA

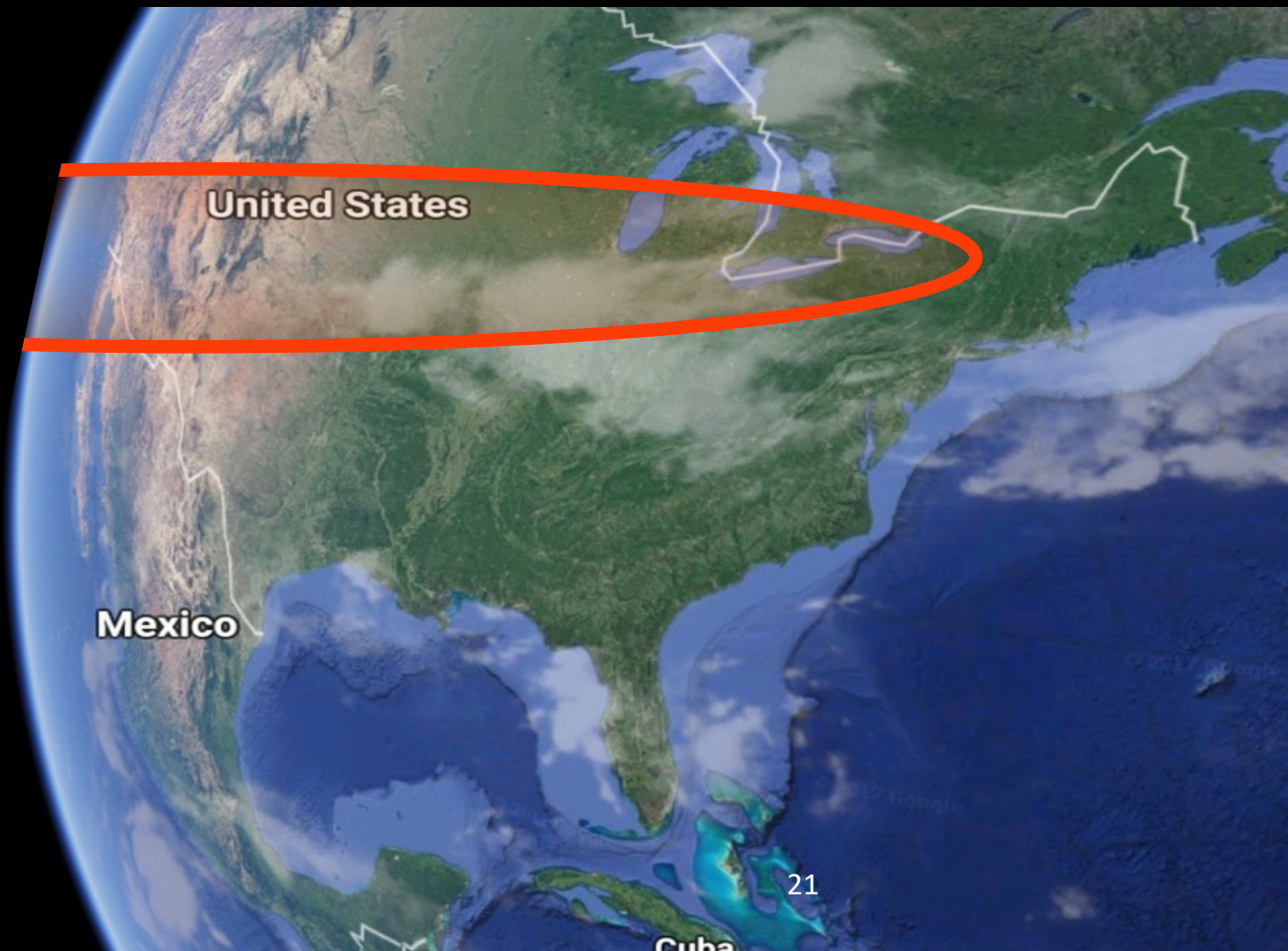
Observing Modes



Nadir for UHECR: Radius 200-400 km



Limb for Neutrinos UHECR: 2-4 10^3 km



EUSO-SPB2

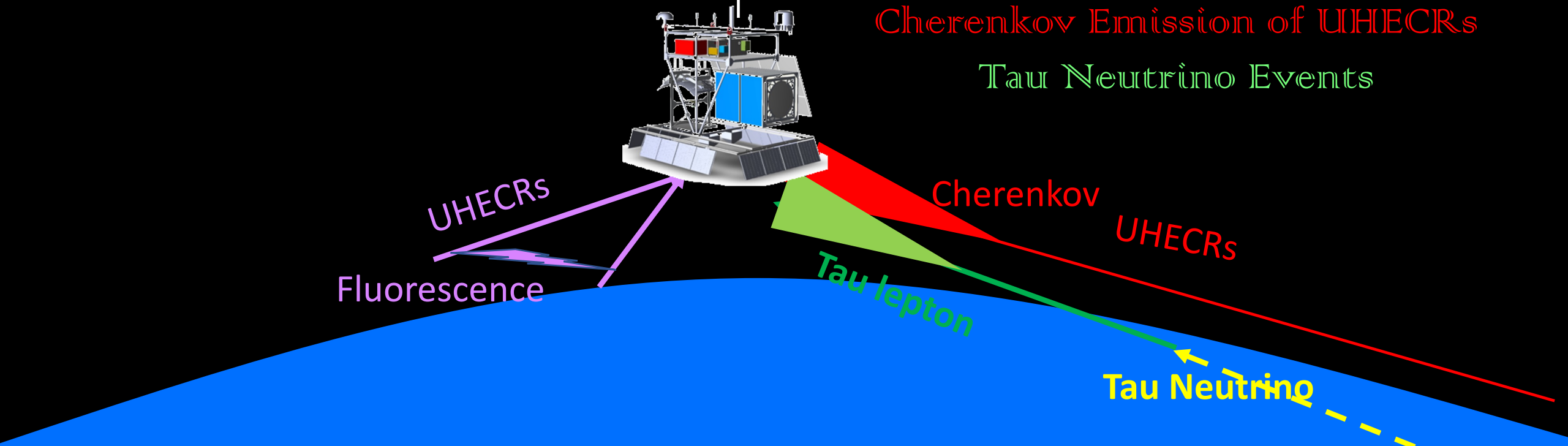
Extreme Universe Space Observatory on a Super Pressure Balloon 2

2023 flight

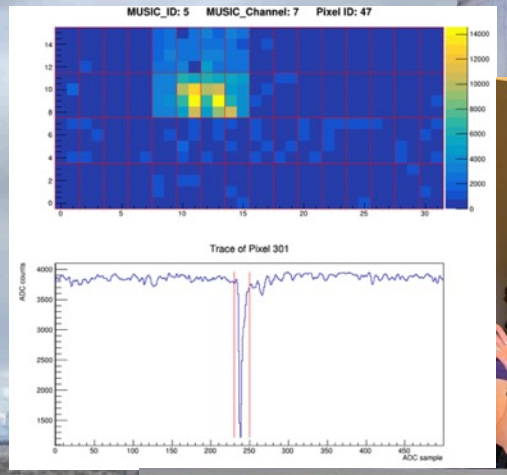
Fluorescence from UHECRS

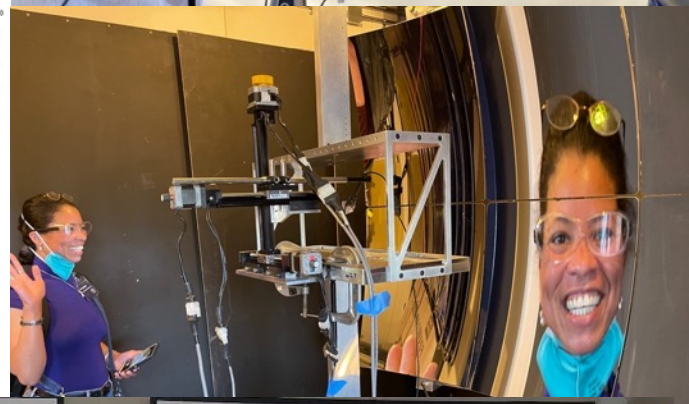
Cherenkov Emission of UHECRs

Tau Neutrino Events



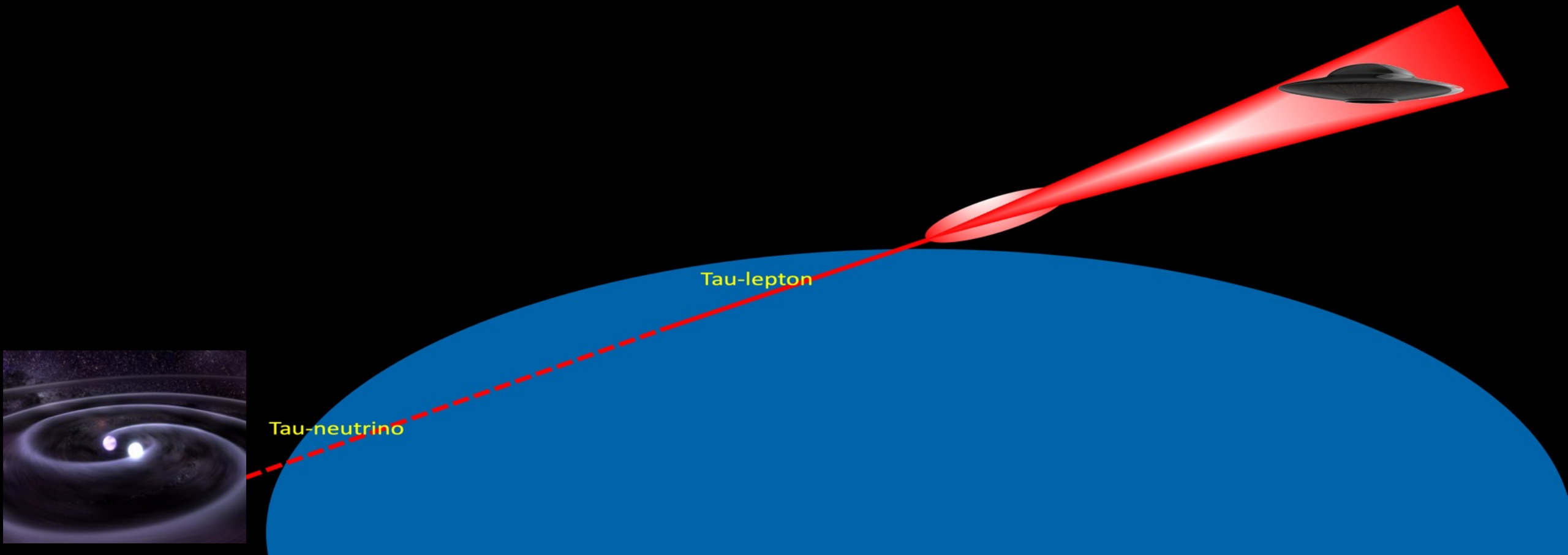
Field Test of the Cherenkov Telescope
Telescope Array site in Utah
March 2022





Concept of Neutrino Surveyor (POEMMA 360)

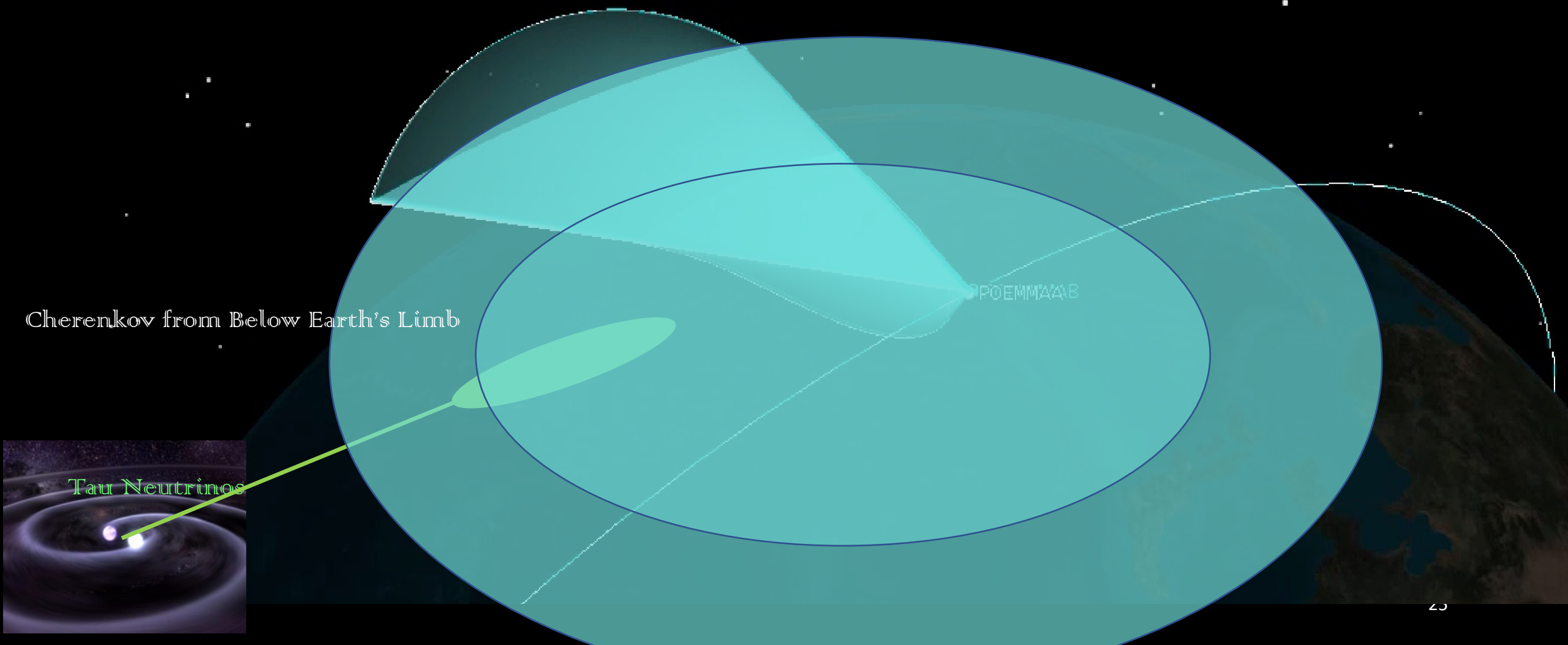
- to observe 360° azimuth and 15° below limb
- Design based on EUSO-SPB2 Cherenkov Telescope
- Radio component (PUEO)



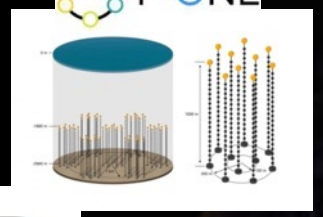
Neutrino Surveyor in Space

Observe Neutrino "Light"curves of MMA transients

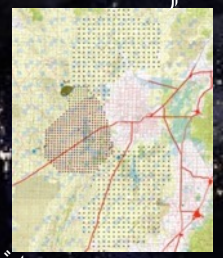
Expand Supernoave-type studies to HE and UHEs



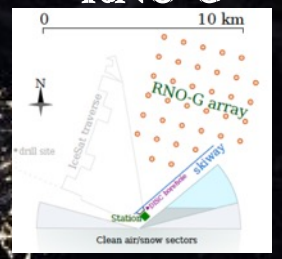
Future detectors of UHE Neutrinos



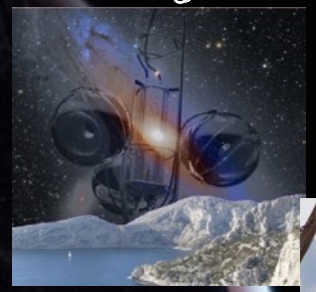
TAx4



RNO-G

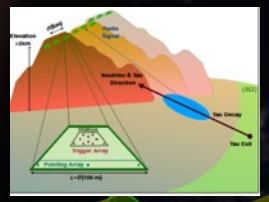


KM3Net

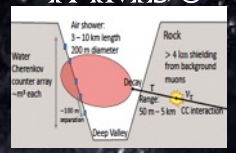


GVD

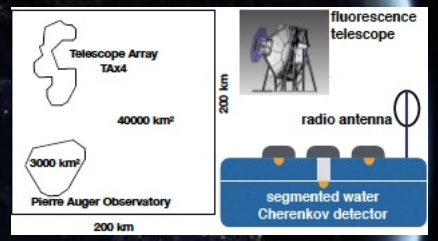
BEACON, Trinity,
AshraNTA, TAROGE

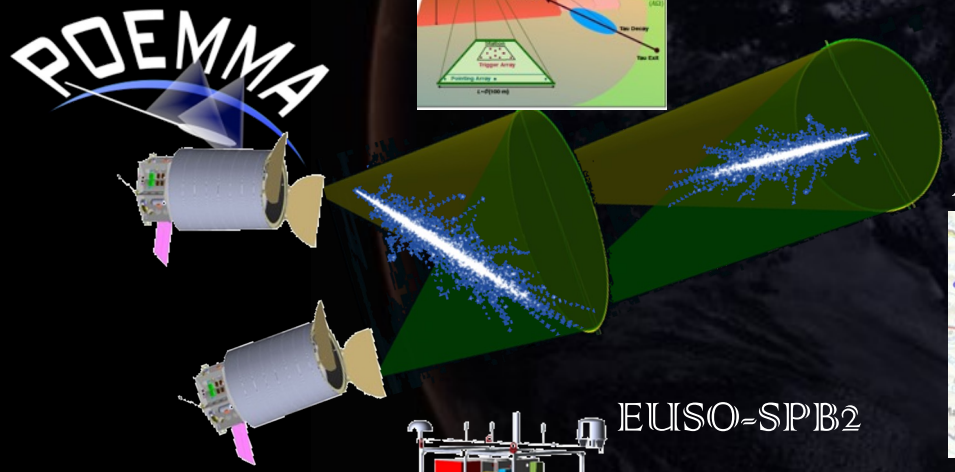


TAMBO



GCRO

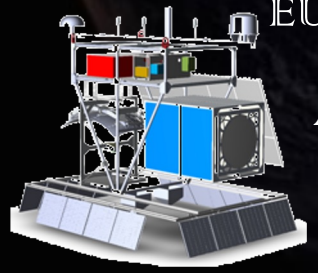




Auger (Prime)

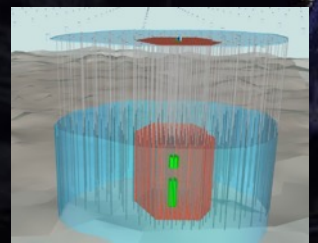
PUEO

EUSO-SPB2



ARIANNA

IceCube-Gen2



Future Looks
Very Bright
In Neutrinos!