EAS Optical Cherenkov signatures of tau neutrinos for space and suborbital detectors

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Up-going air showers from $\nu_\tau \rightarrow \tau$, τ decay

- Neutrinos from transients (ToO), diffuse flux, from UHECR interactions with background radiation.
- Part of a multi-messenger astrophysics program.

Tidal Disruption Event (TDE)

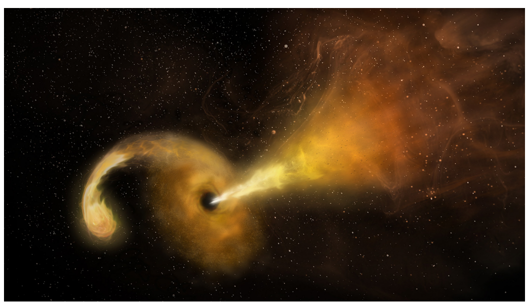


Figure from nasa.gov/Credits: Sophia Dagnello, NRAO/AUI/NSF

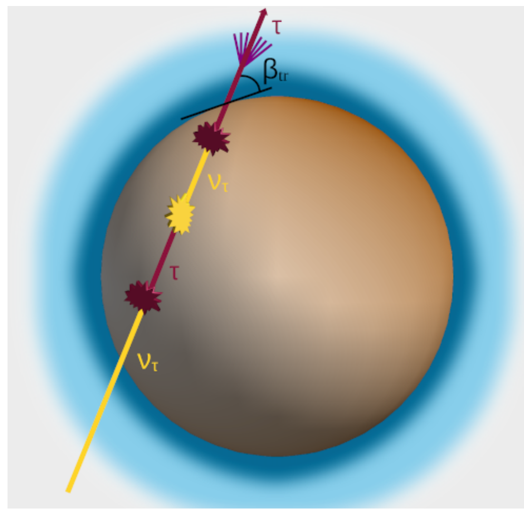
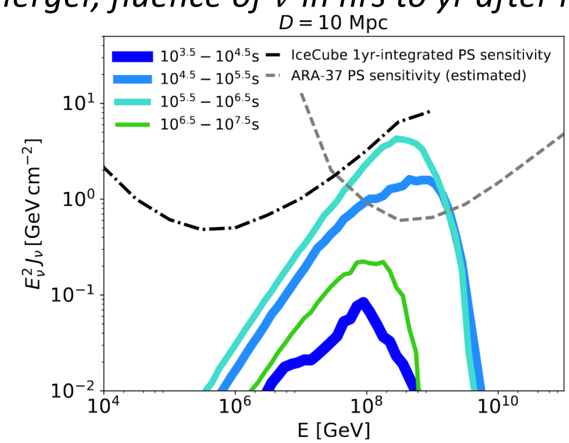


Figure courtesy of S. Patel.

- Astrophysical/cosmic neutrinos oscillate and arrive with 3 flavors.
- $\nu_\tau \rightarrow \tau$, τ decays to create EAS, optical Cherenkov signal.

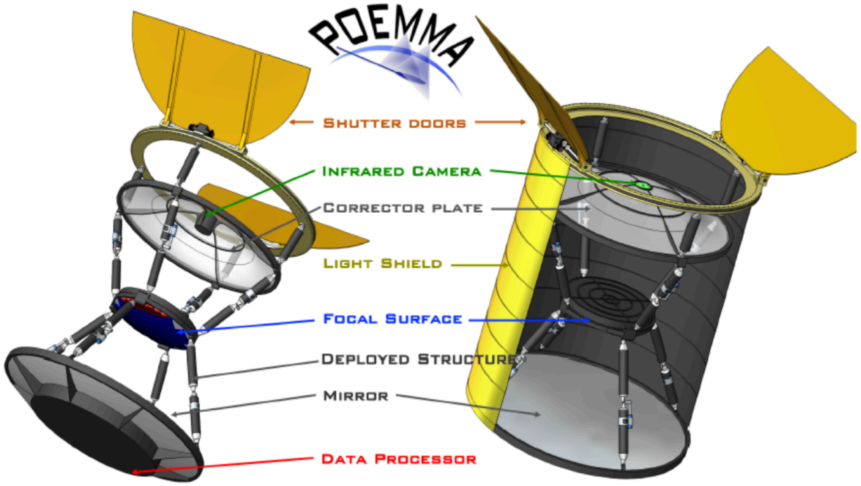
Millisec magnetar remnant from NS-NS merger, fluence of ν in hrs to yr after merger.



Fang & Metzger, Ap J 849 (2017) 153

Optical Cherenkov telescopes (plus fluorescence telescopes)

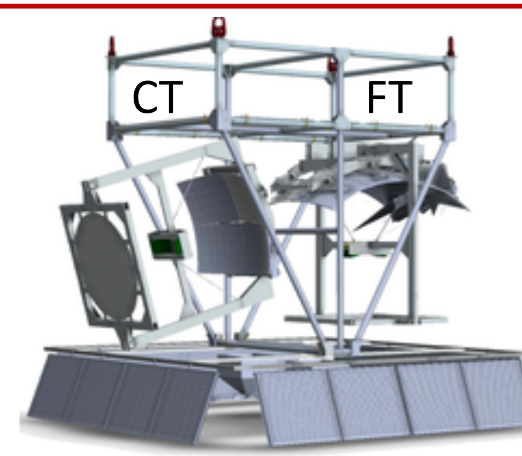
POEMMA satellite, proposed for 2028+



- Hybrid focal surface: Cherenkov and fluorescence.
- Pair of satellites at 525 km altitude, 5 year mission.
- Limb viewing mode for neutrino-induced air showers.
- A = 2.5 m^2 photon collecting area for Cherenkov.

#863 Olinto

EUSO-SPB2 balloon launch May 2023



- Launch from Wanaka, NZ.
- Potential for 100 days orbiting at 33 km altitude.
- Search for neutrino events and measure optical backgrounds.
- A = 0.35 m^2 photon collecting area.

#235 Eser

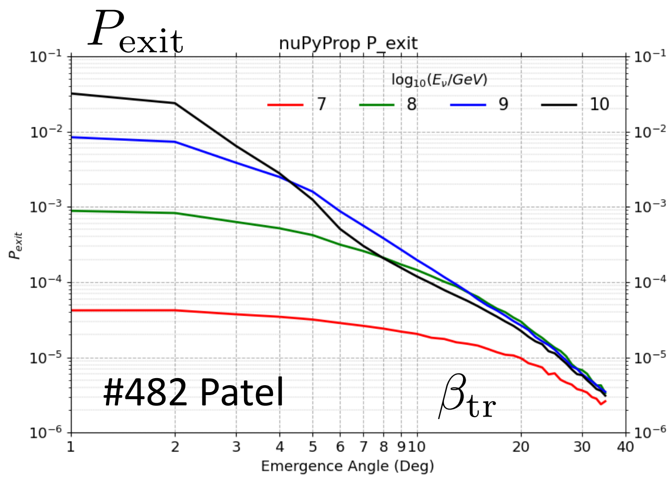
Outline

- Diffuse neutrino projected sensitivity.
  POEMMA with 360^o azimuthal coverage needed to be competitive.
- Point source detection (ToO), sky coverage and projected sensitivity.
  Strength of both instruments, EUSO-SPB2 will be a pathfinder instrument.
- Uncertainties and backgrounds.
- Summary.

Details: see MHR et al., Phys. Rev. D 100 (2019) 963010; Venters et al., Phys. Rev. D 102 (2020) 123013; Olinto et al. [POEMMA], JCAP 06 (2021) 007; V. Scotti et al. [JEM-EUSO], NIM A 958 (2020) 162164

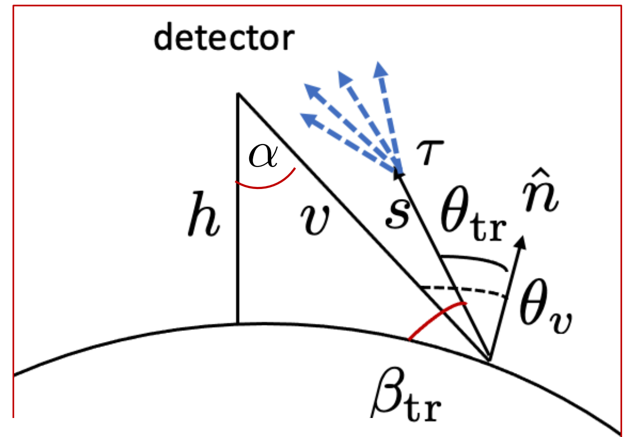
ICRC 2021: 1337 Venters; 1025 Krizmanic; 1091 Bagheri; 235 Eser; 863 Olinto; 482 Patel and others.

Sensitivity to diffuse neutrino flux



Greisen parameterization of showers, composite atmosphere model.

Photoelectron thresholds set to limit night sky air glow backgrounds to <1%.



POEMMA Stereo:

$$N_{\rm PE} > 10,\ \ \rho_{\rm th} = \frac{20\ \gamma}{\rm m^2}$$

POEMMA Dual:

$$N_{\rm PE} > 20,\ \ \rho_{\rm th} = \frac{40\ \gamma}{\rm m^2}$$

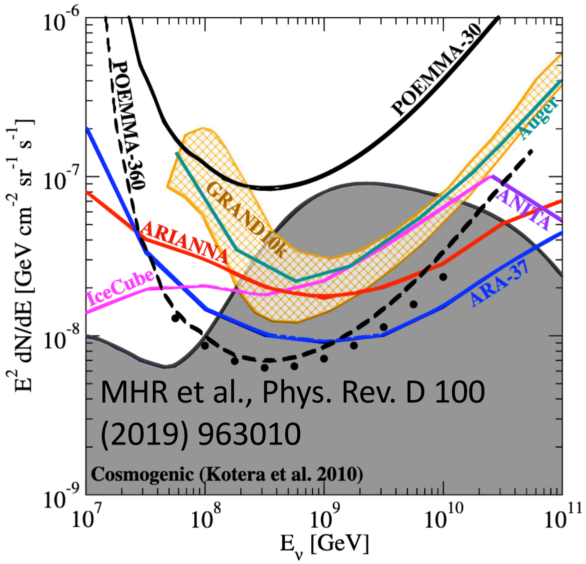
EUSO-SPB2:

$$N_{\rm PE} > 14,\ \ \rho_{\rm th} = \frac{200\ \gamma}{\rm m^2}$$

Mission	POEMMA Stereo (Dual)	EUSO-SPB2
h	525 km	33 km
$\Delta\alpha$	7°	6.4°
$\Delta\phi$	30°	12.8°
$\rho_\gamma^{\rm min}$	20 (40) $\gamma/{\rm m}^2$	200 $\gamma/{\rm m}^2$
$\beta_{\rm tr}^{\rm max}$	19.6°	10.8°

Diffuse flux sensitivity (all flavor)

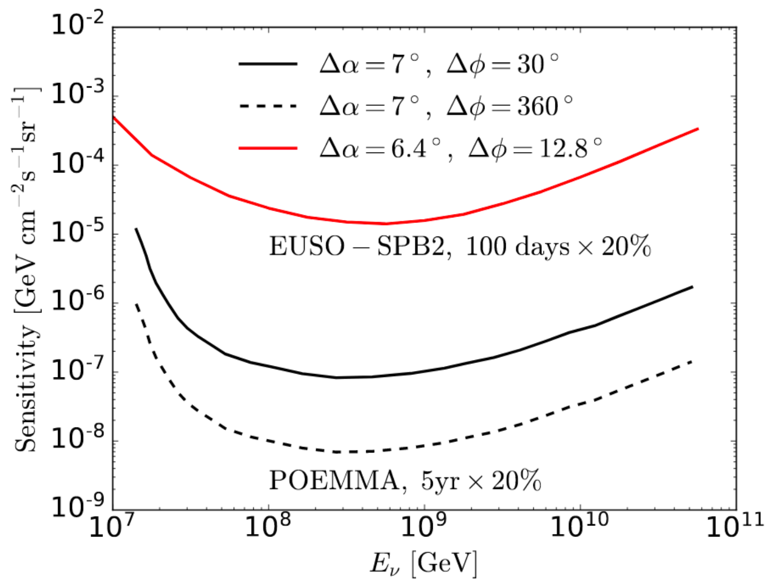
POEMMA – 360° would improve sensitivity, air glow leads to higher backgrounds.



used f_t = (0.30) for POEMMA

Cummings et al (CAK), PRD 103 (2021) 043017: tails of EAS profiles at high altitudes make some improvements (factor close to 10 for 10^{11} GeV). See also muon detection.

SPB2: t_{obs}=1/18 of 5 years



closer to the shower

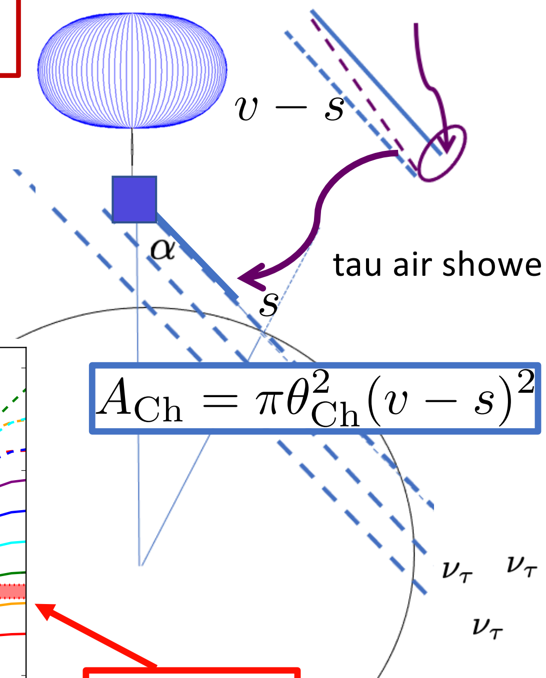
$$\text{Sensitivity} = E_\nu \frac{2.44}{\ln(10)} \frac{3}{\langle A\Omega\rangle t_{\rm obs}(0.20)}$$

$$\langle A\Omega\rangle = \int_{S(\Delta\phi)} \int_{\Delta\Omega_{\rm tr}} P_{\rm obs} \times \hat{r}\cdot\hat{n}\, dS\ d\Omega_{\rm tr}$$

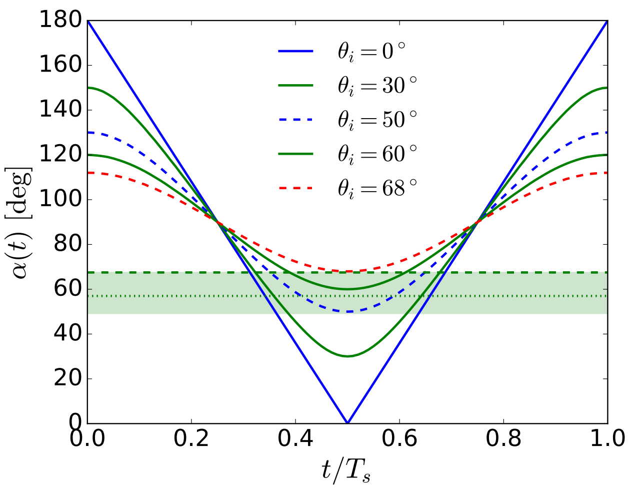
Effective area for point source detection

Time averaged instantaneous effective area depends on neutrino source location, time source dips below the horizon (but not too far).

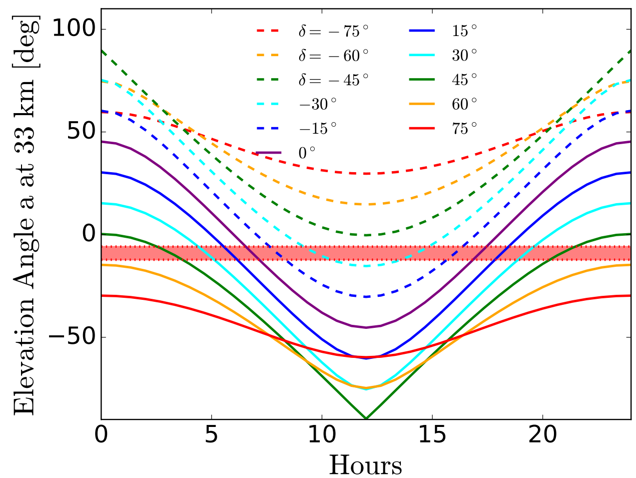
$$\langle A \rangle = \frac{1}{T_0}\int_{t_0}^{t_0+T_0} dt \int dP_{\rm obs}(E_\nu, \beta_v(t), s) A_{\rm Ch}(s)$$



POEMMA: orbital period 90 min



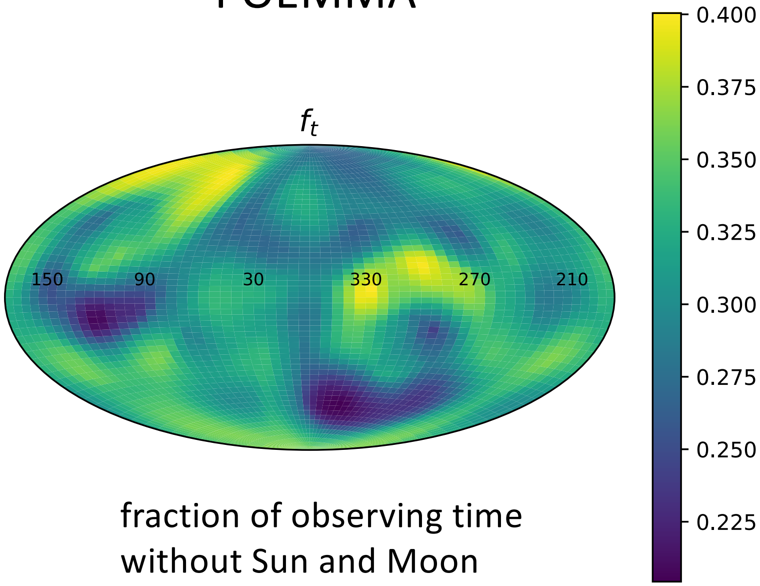
EUSO SPB2: day



red band: observable

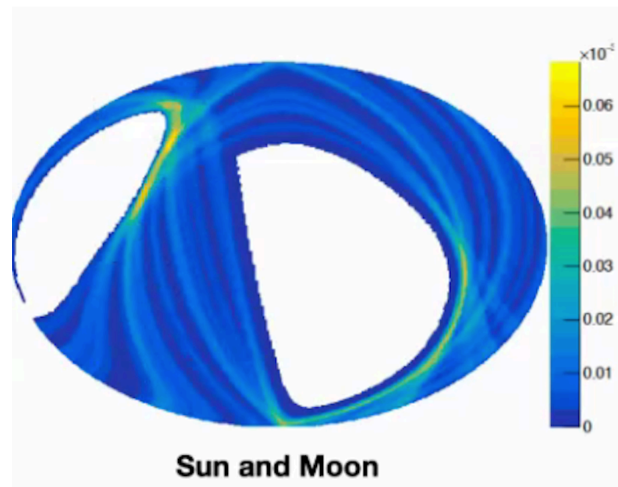
Point source sky coverage

POEMMA



fraction of observing time
without Sun and Moon

EUSO-SPB 2



30 day effective area for 10 PeV neutrinos,
Sun and Moon over full period included.

full sky coverage (here 380 day avg)

more focused sky coverage

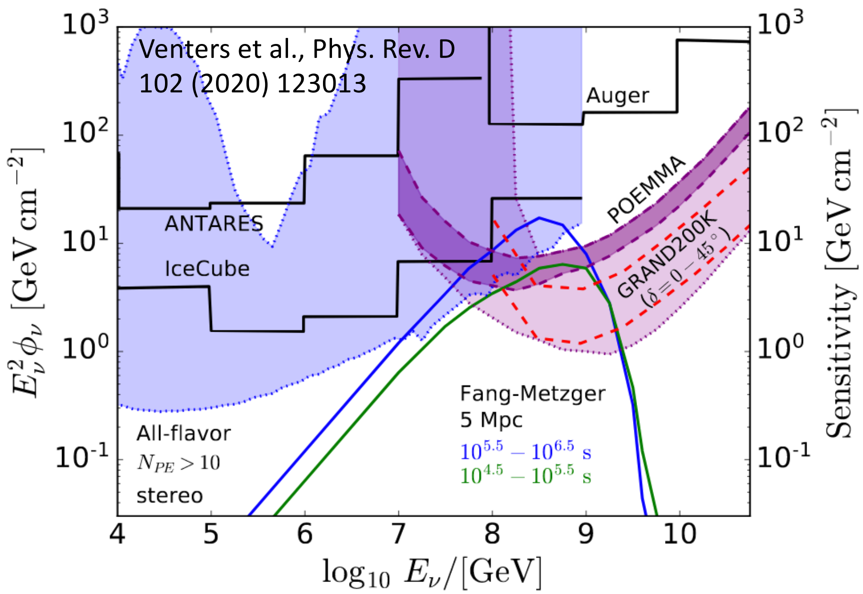
#1337 Venters

Sensitivity to long-burst transients

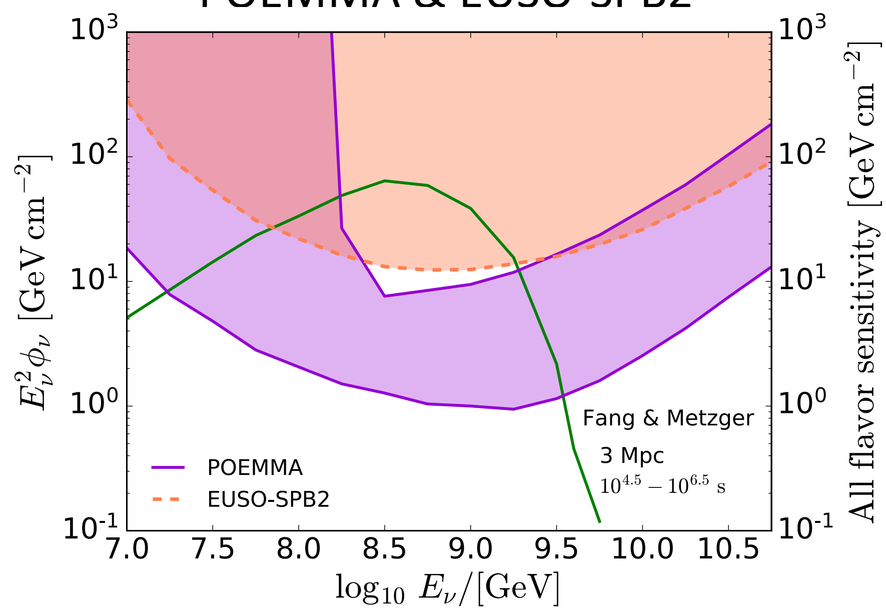
Per decade, all flavor, no muons.
10^6 s neutrino burst (~2 weeks)

Sensitivity to long neutrino bursts of 30 day duration assuming 20% duty cycle, azimuthal slewing.

POEMMA



POEMMA & EUSO-SPB2



Fang & Metzger, Ap J 849 (2017) 153

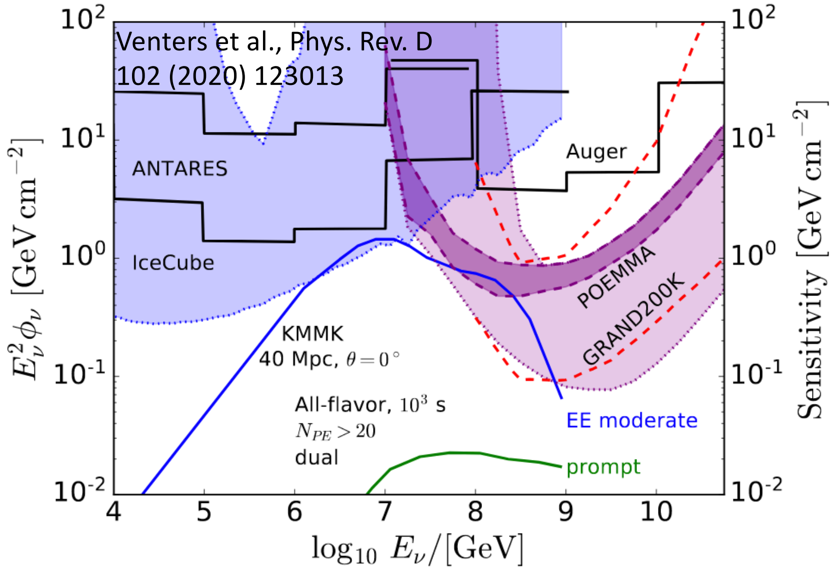
#1337 Venters

Sensitivity to short-burst transients

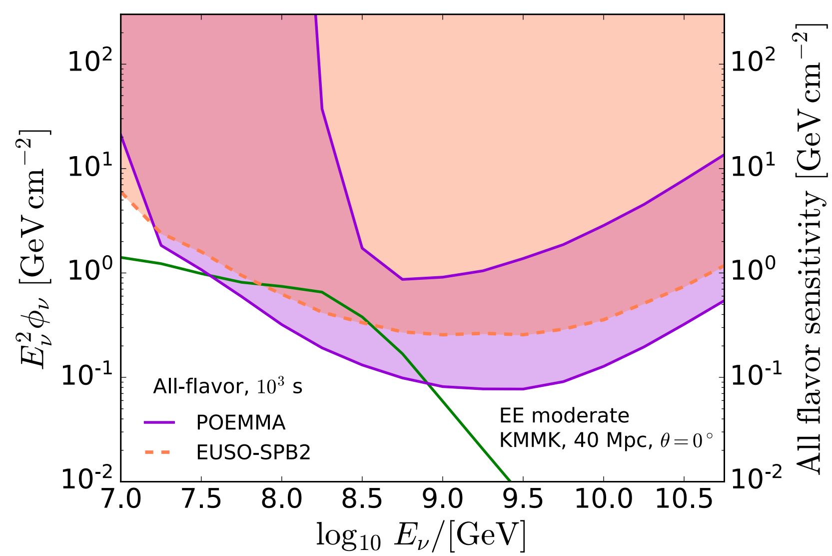
Best short-burst neutrino transients for 1,000 s burst, on axis viewing for short GRB.

No Sun and Moon, and burst occurs when viewable (part of "best").

POEMMA



POEMMA & EUSO-SPB2



KMMK: Kimura, Murase, Meszaros, Kiuchi, Ap. J. 848 (2017) L4.

#1337 Venters

Modeling uncertainties and backgrounds

Backgrounds:

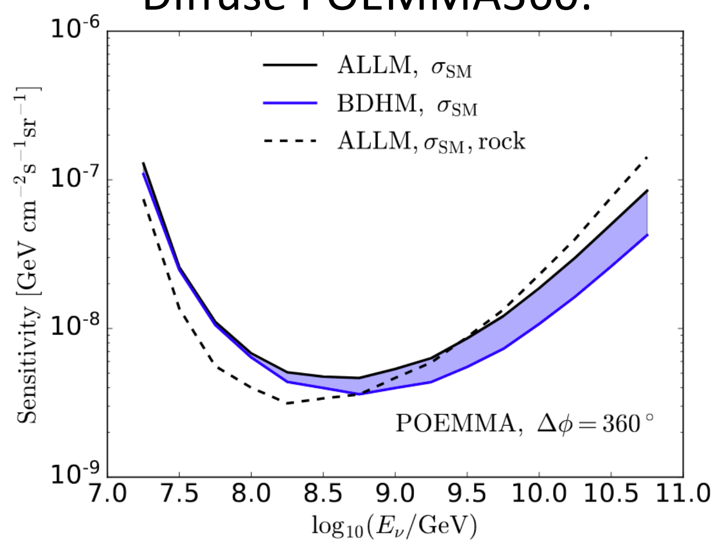
- Thresholds are set to limit interference of night sky air glow background so that the fake neutrino probability is <1%. EUSO-SPB2 will measure air glow.
- The diffuse neutrino flux is not an important background to point source measurements.
- UHECR signals reflected off the ground have the wrong timing: reflection time is large at these angles.
- Cherenkov signals from UHECR showers in the atmosphere above the limb come from a very narrow angular range.

See background discussion for ToO in Venters et al., Phys. Rev. D 102 (2020) 123013.

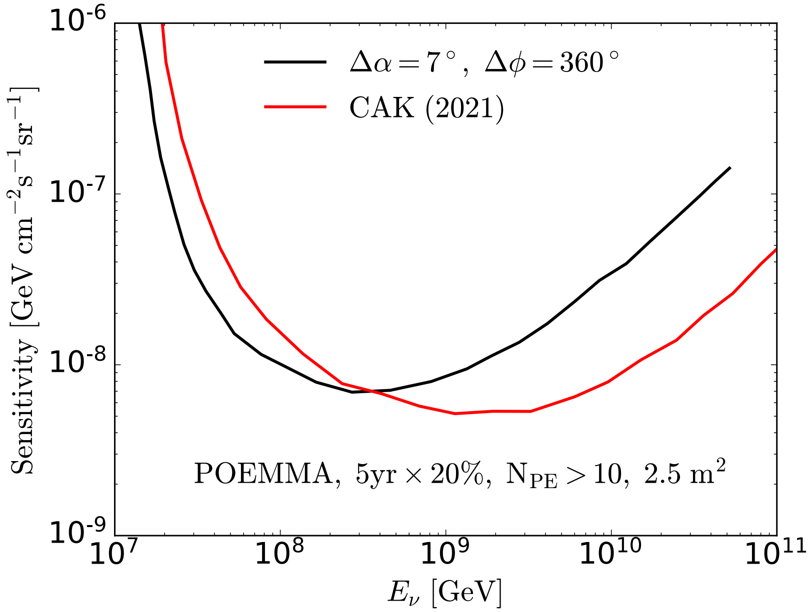
Uncertainties include:

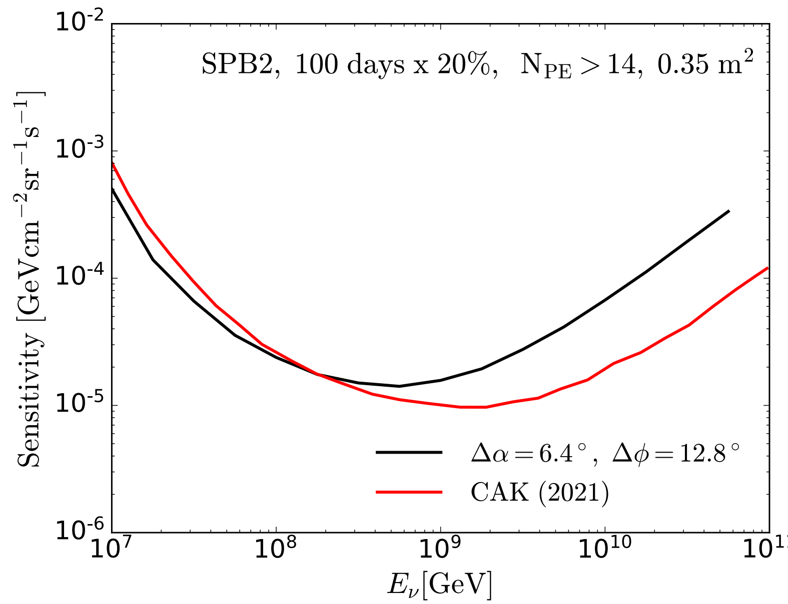
- Neutrino cross section
- Tau energy loss
- Water or rock in final layer?

Diffuse POEMMA360:



Modeling the showers





Cummings et al. (2021) air shower modeling with tails (CORSIKA, upward) compared to Greisen parameterization and simple scaling of 100 PeV air shower with distance from shower max to detector. Improves UHE sensitivity.

Cummings et al (CAK), PRD 103 (2021) 043017

Summary for Cherenkov telescope ToO detection

POEMMA satellite, proposed for 2028+

- Mono- and dual-telescope viewing.
- *With external (GCN) alerts, best sensitivity to all-flavor neutrino fluences from transient sources 0.1-1 GeV/cm^2 if source in the field of in view.*
- *All sky coverage over the course of a year.*
- *Five years of viewing.*

EUSO-SPB2 balloon launch May 2023

- Pathfinder instrument to POEMMA-like space-based instrument.
- *With GCN alerts, sensitivity to all-flavor neutrino fluences from transient sources as good as 1-10 GeV/cm^2 if source can be put in the field of in view.*
- *There is, in principle sensitivity, to events in nearby galaxies.*