Neutrino Target-of-Opportunity Observations with Space-based and Suborbital Optical Cherenkov Detectors

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Background

- Many candidate astrophysical neutrino sources associated with transient events
- Space and suborbital Cherenkov expts. detect up-going ν_τ air showers:
  - ν_τ enters Earth → charged current interaction → τ emerges from ground → τ decays → air shower → Cherenkov signal
- In space: T_{orb} (~ 95mins.) + slewing → Access to large parts of sky
  - ➢ *Space missions uniquely suited for transient follow-up*
- POEMMA is a proposed space-based mission featuring an optical Cherenkov camera for detecting very-high energy neutrinos.
- EUSO-SPB2 is a balloon-borne experiment and is a pathfinder mission for POEMMA.
  - Launch expected in Spring 2023 from Wanaka, New Zealand.

Method

Scenarios

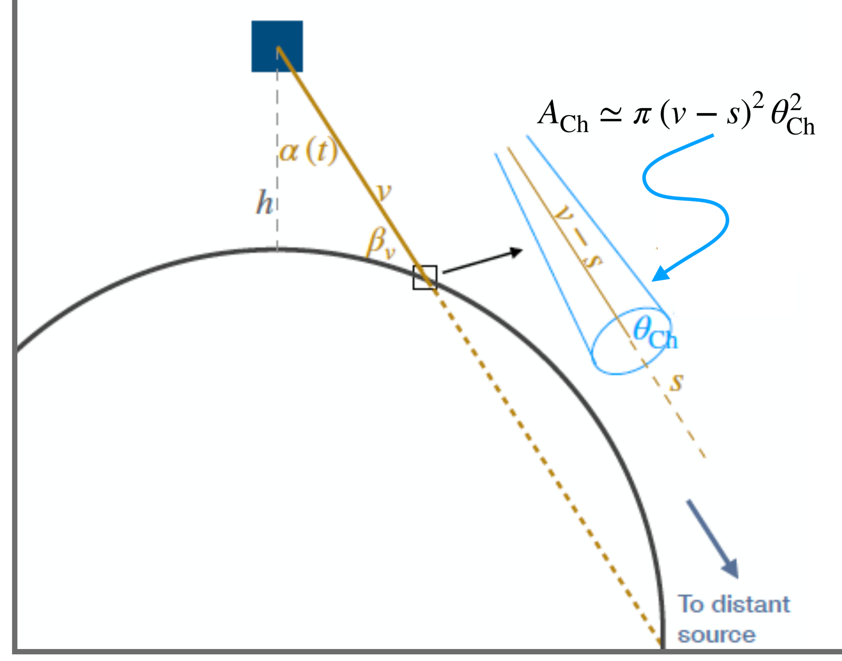
Long Burst

- Event duration ≥ 1 day
- POEMMA satellite separation ~ 50 km (lower E threshold)
- duty cycle (f_t) determined by Sun and Moon constraints

Short Burst

- Event duration ~ 1000 sec.
- POEMMA satellite separation ~ 300 km (higher E threshold)
  - Satellites observe indep.
- Ignoring Sun and Moon ($f_t = 1$)
- Assume best-case scenario:
  - Source dips below limb at t_0

Calculations



Instantaneous Acceptance:

$$A\left(\alpha(t), E_{\nu_\tau}\right) \simeq \int dP_{obs}\left(E_{\nu_\tau}, \beta_\nu, s\right) A_{Ch}(s)$$

Average over Observ. Time:

$$\left\langle A\left(E_{\nu_\tau}\right)\right\rangle_{T_{obs}} = \frac{1}{T_{obs}} \int_{t_0}^{t_0+T_{obs}} A\left(\alpha(t), E_{\nu_\tau}\right) dt$$

All-flavor Sensitivity:

$$\frac{2.44}{\ln(10)} \times \frac{\left(N_{fl} = 3\right) E_\nu}{f_t \left\langle A(E_\nu)\right\rangle_{T_{obs}}}$$

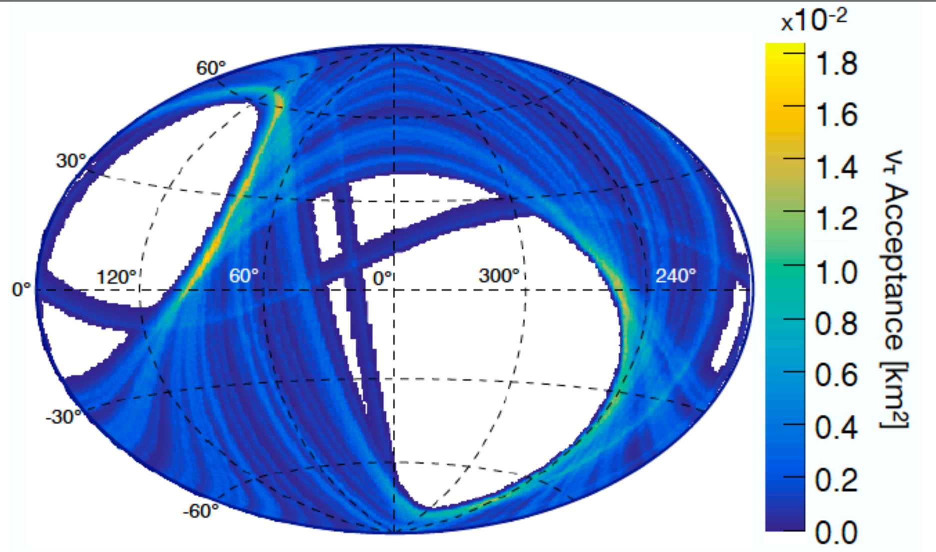
Number Events:

$$N_{ev} = \int_{\Delta E_\nu} \phi_\nu\left(E_\nu, z\right) \left\langle A\left(E_\nu\right)\right\rangle_{T_{obs}} dE_\nu ,$$

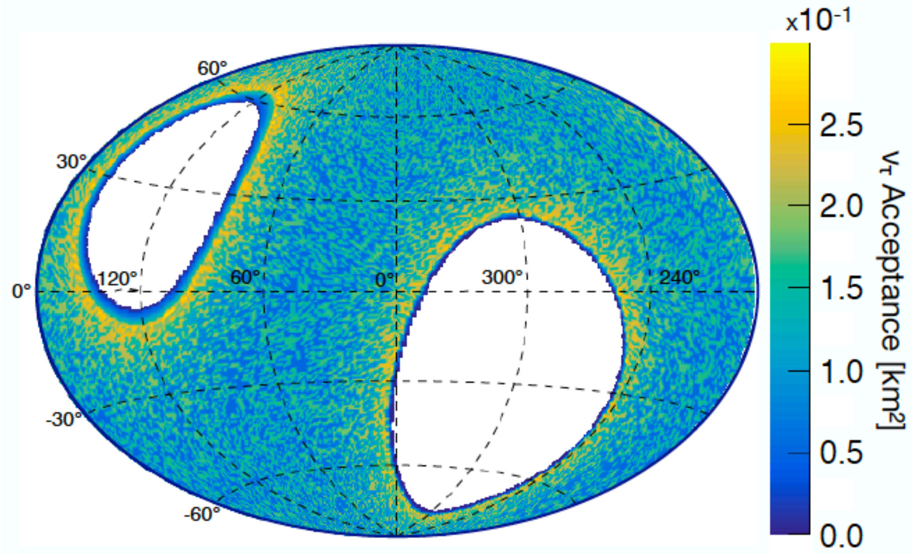
$\phi_\nu\left(E_\nu, z\right)$ = at-Earth ν fluence

Results

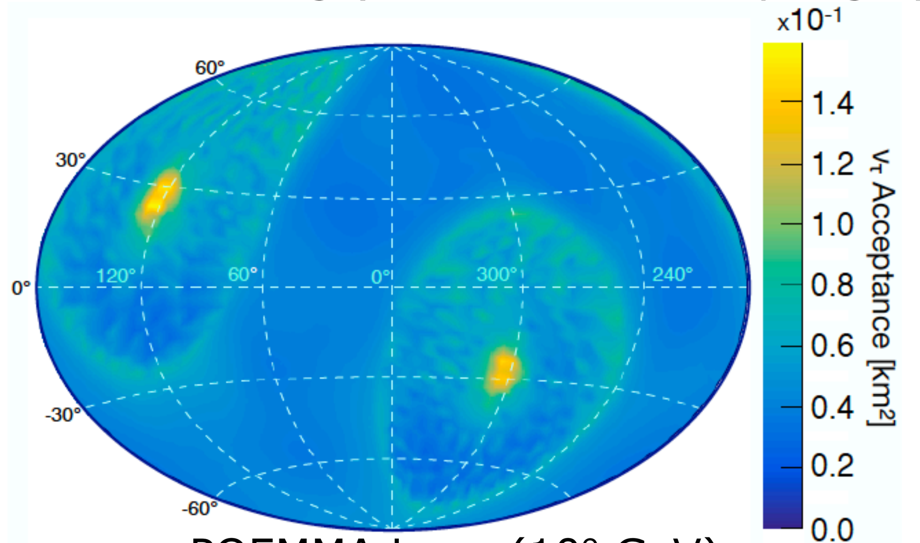
Acceptance Sky Plots



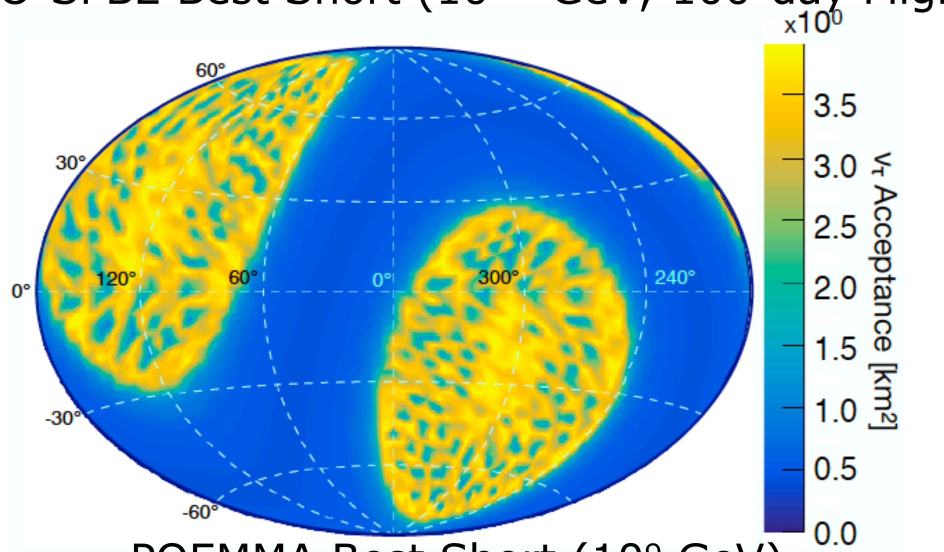
EUSO-SPB2 Long ($10^{8.5}$ GeV; 100-day Flight)



EUSO-SPB2 Best Short ($10^{8.5}$ GeV; 100-day Flight)

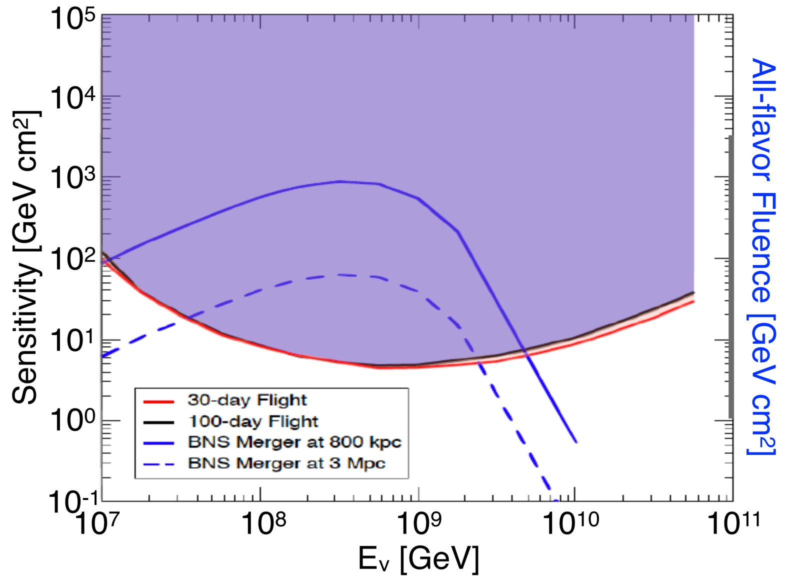


POEMMA Long (10^9 GeV)



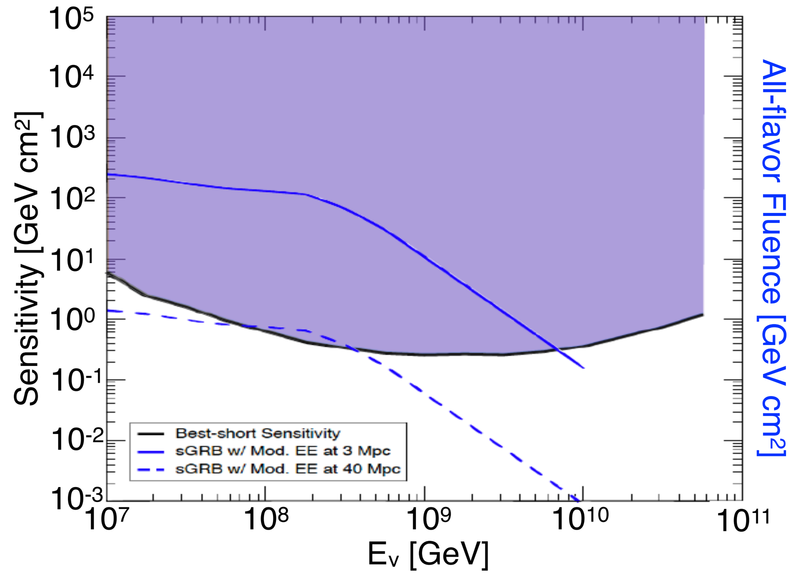
POEMMA Best Short (10^9 GeV)

Transient Sensitivity

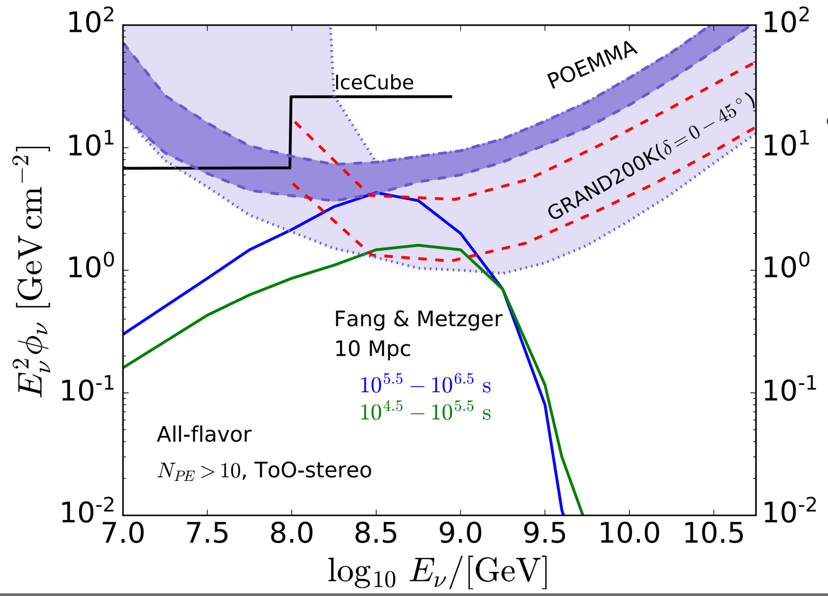


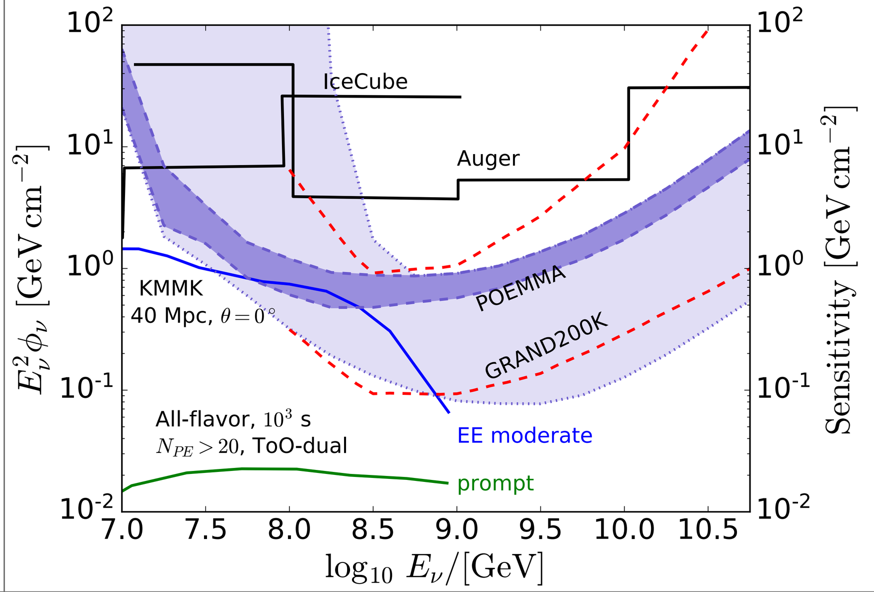
EUSO-SPB2 Long

EUSO-SPB2 Best Short



POEMMA Long





POEMMA Best Short

Results (cont.)

Prospects for ToO Detection

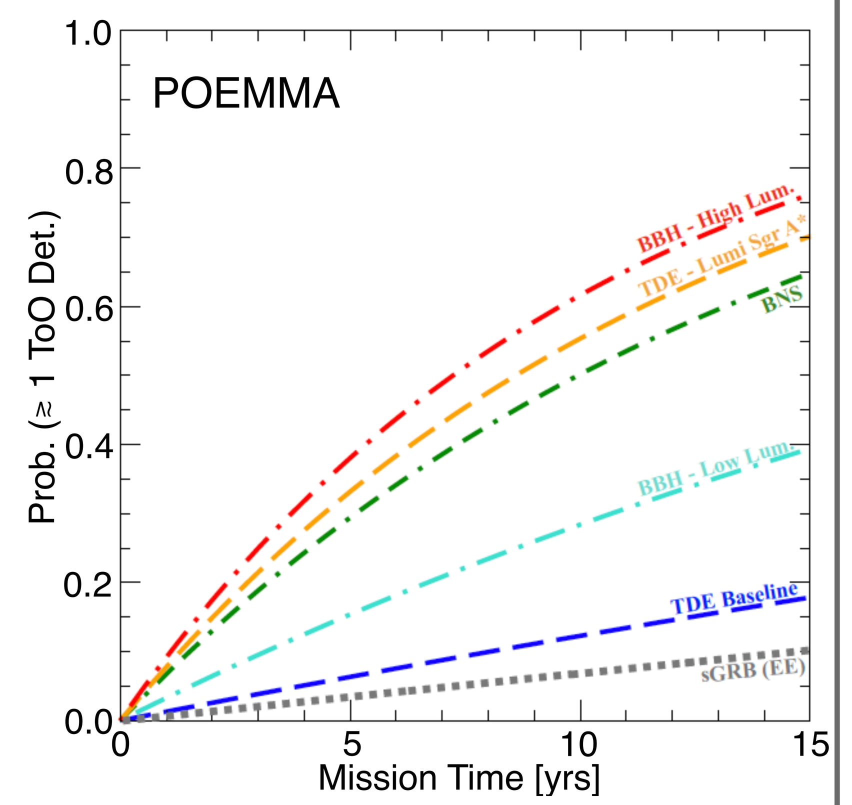
Source Class	EUSO-SPB2 ν Horizon Distance	POEMMA ν Horizon Distance	Model Reference
TDE $M_{SMBH} = 5 \times 10^6 M_\odot$	9 Mpc	128 Mpc	Lunardini & Winter (2017)
TDE Base Scenario	4.5 Mpc	69 Mpc	Lunardini & Winter (2017)
BBH merger – Low Fluence	6 Mpc	43 Mpc	Kotera & Silk (2016)
BBH merger – High Fluence	19 Mpc	137 Mpc	Kotera & Silk (2016)
BNS merger	2.3 Mpc	16 Mpc	Fang & Metzger (2017)
sGRB w/ Mod. Extended Emission	25 Mpc	90 Mpc	Kimura et al. (2017)

Horizon Distances for Detecting at Least 1 Neutrino

⊗

Cosmol. Event Rate

➡



Poisson Detection Probabilities Over Mission Lifetime

Conclusions

- Most promising candidate astrophysical neutrino sources are tidal disruption events (TDEs), binary neutron star (BNS) mergers, and binary black hole (BBH) mergers.
- Both POEMMA and EUSO-SPB2 will be able to detect these sources out to well beyond the Galaxy.
- Prospects for detecting a ToO are promising for POEMMA.
- ToO studies to be included in νSpaceSim neutrino simulation package.

References

[1] The POEMMA Collab., 2021, JCAP, 06, 007
[2] Eser, J., Olinto, A. V., & Wiencke, L., et al., 2021, PoS (ICRC21), 404
[3] Reno, M. H., Venters, T. M., & Krizmanic, J. F., et al., 2021, PoS (ICRC21), 1201
[4] Krizmanic, J. F., et al., 2021, PoS (ICRC21), 1205
[5] Venters, T. M., et al., 2020, PRD, 102, 123013
[6] Reno, M. H., Venters, T. M., & Krizmanic, J. F., 2019, 100, 063010

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