Targets of Opportunity with POEMMA*

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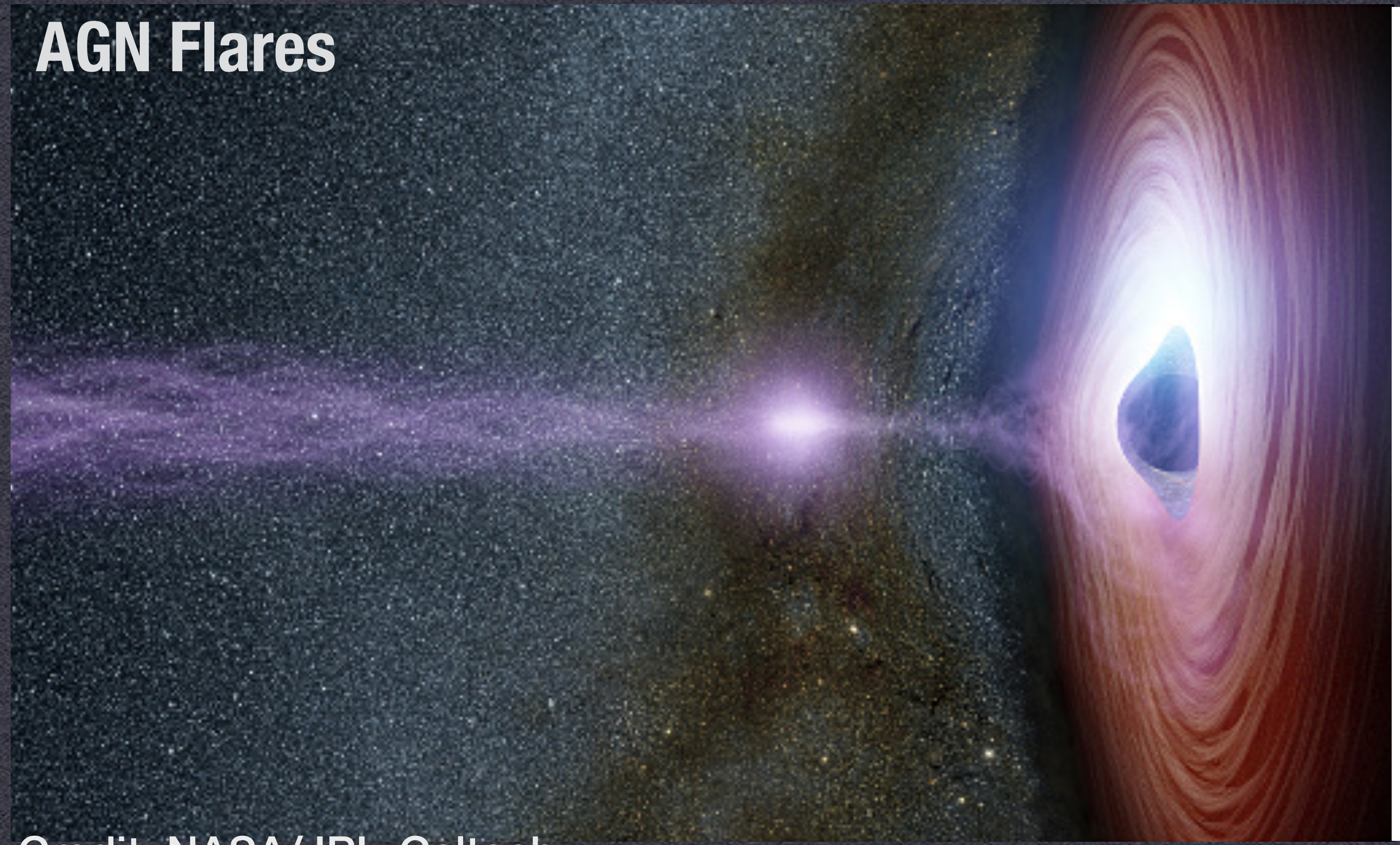
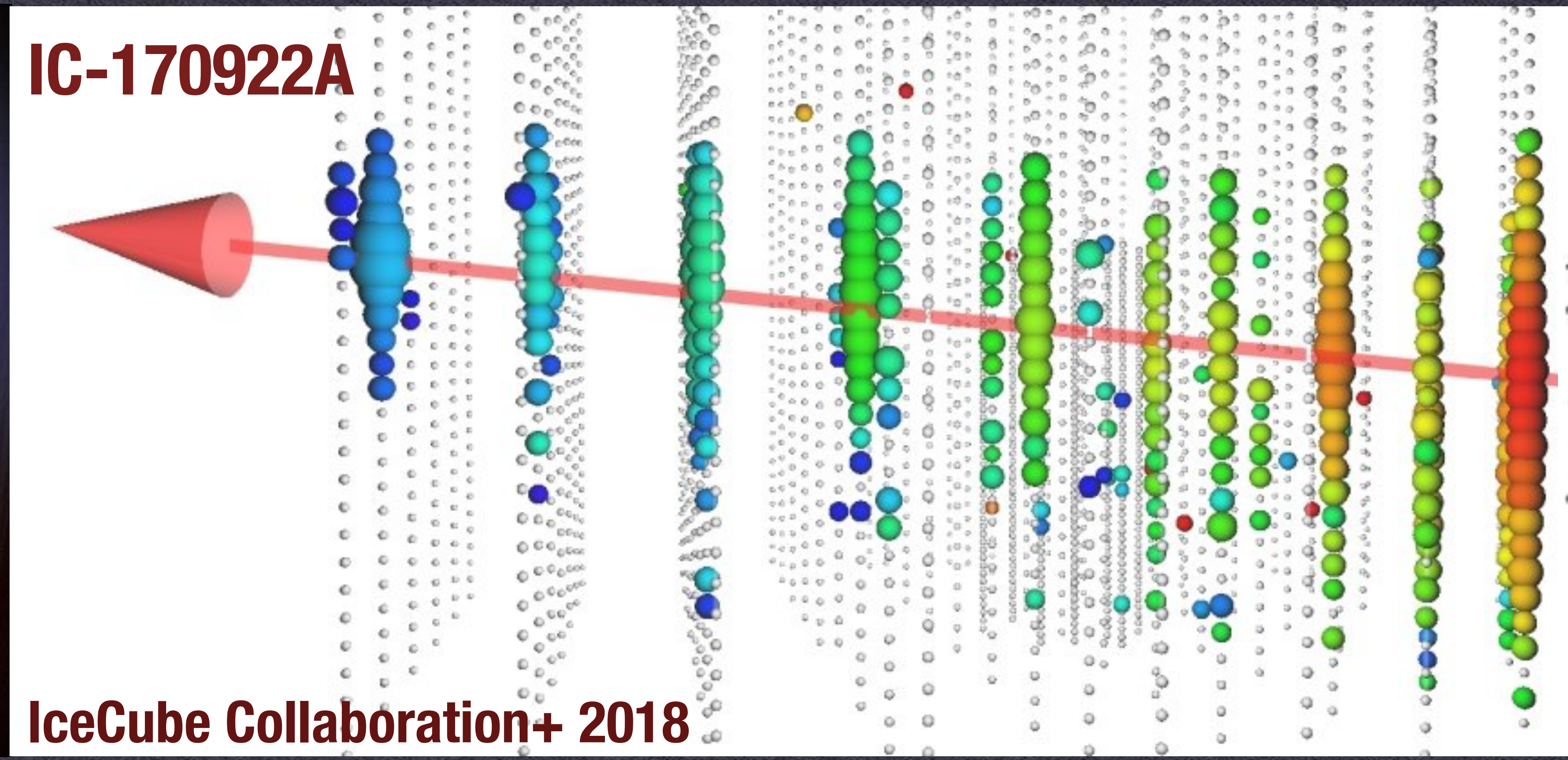
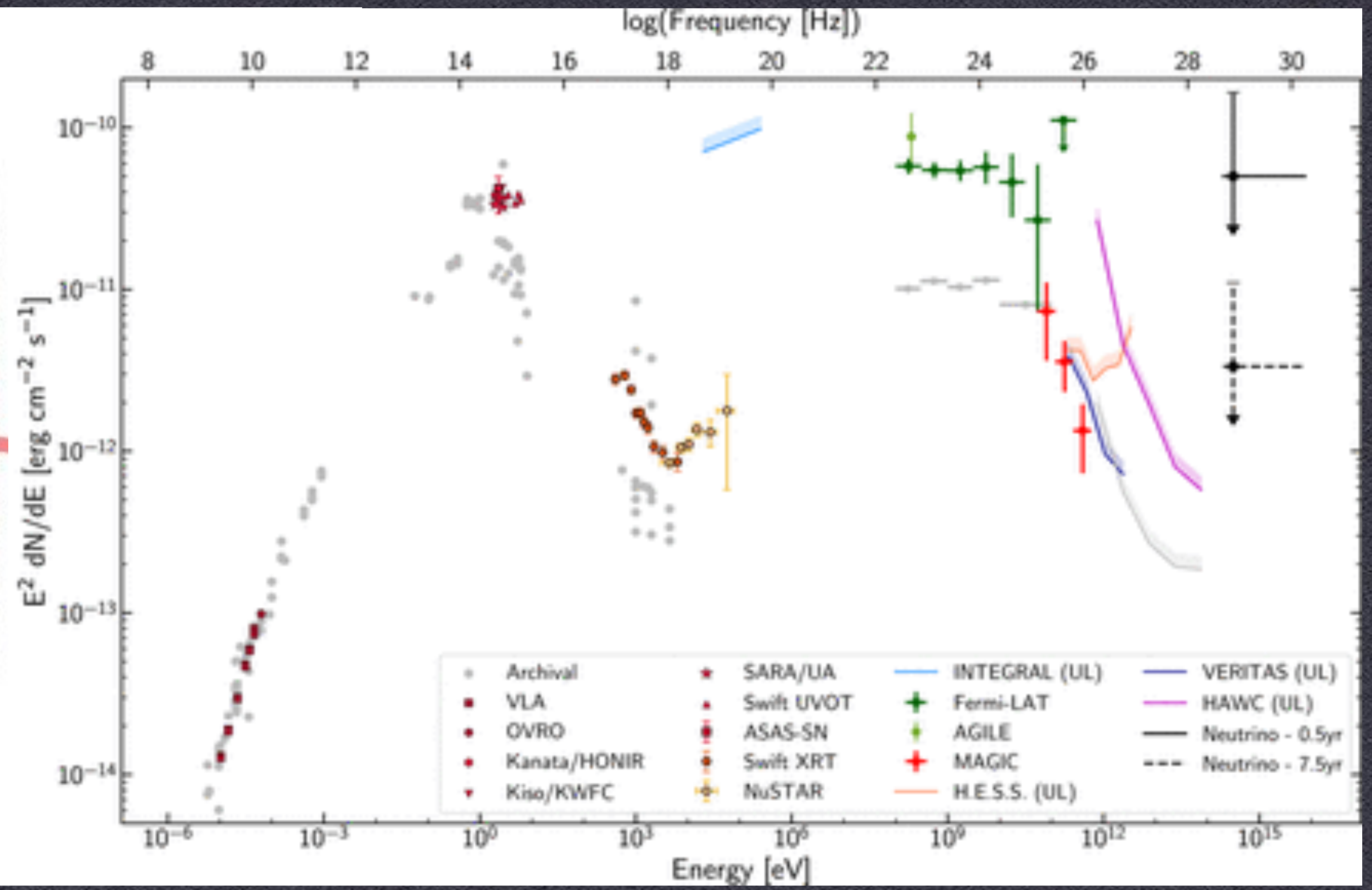
Background Image Credit: Google Earth

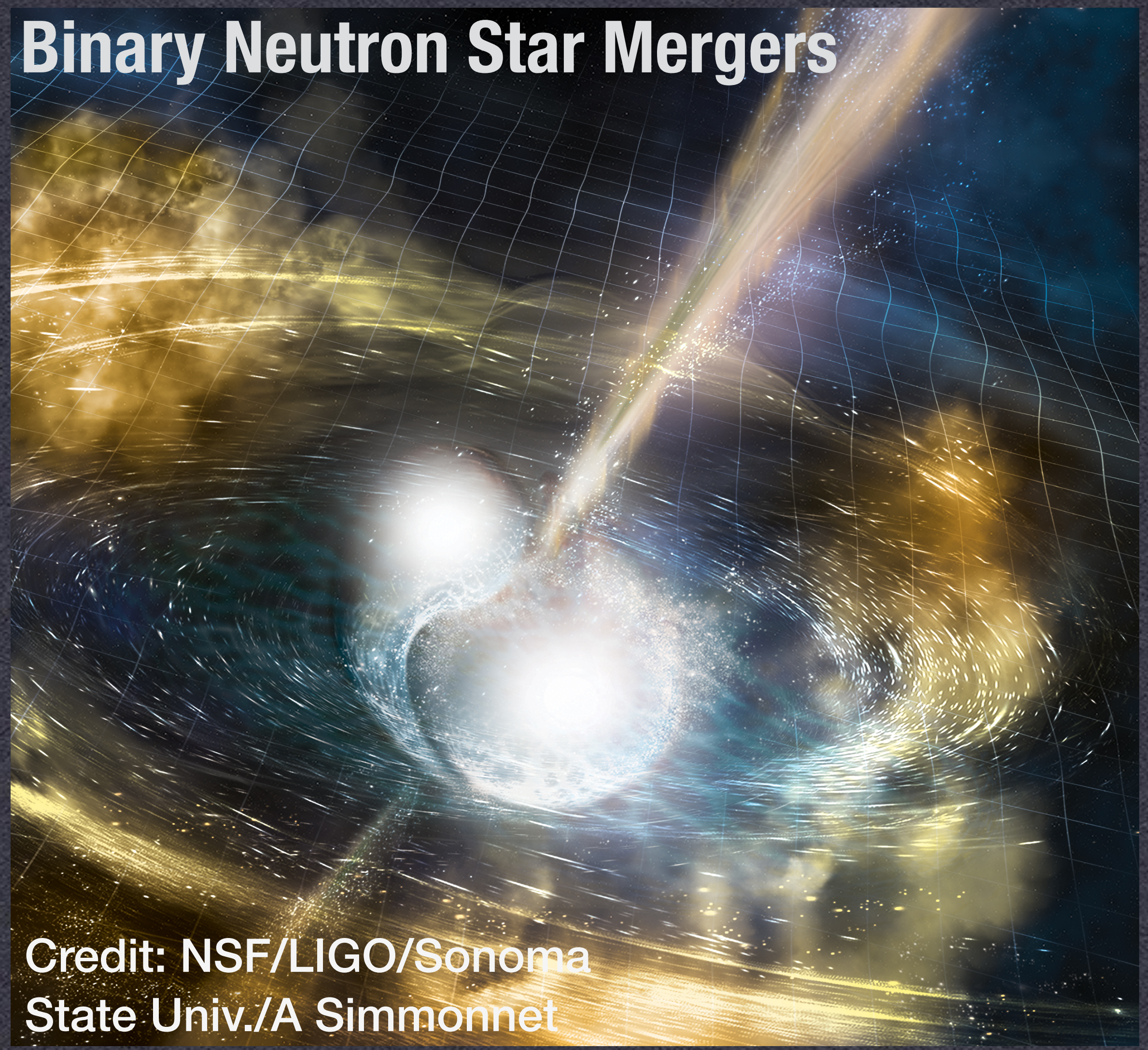
*Paper submitted to PRD (arXiv:1906.07209)

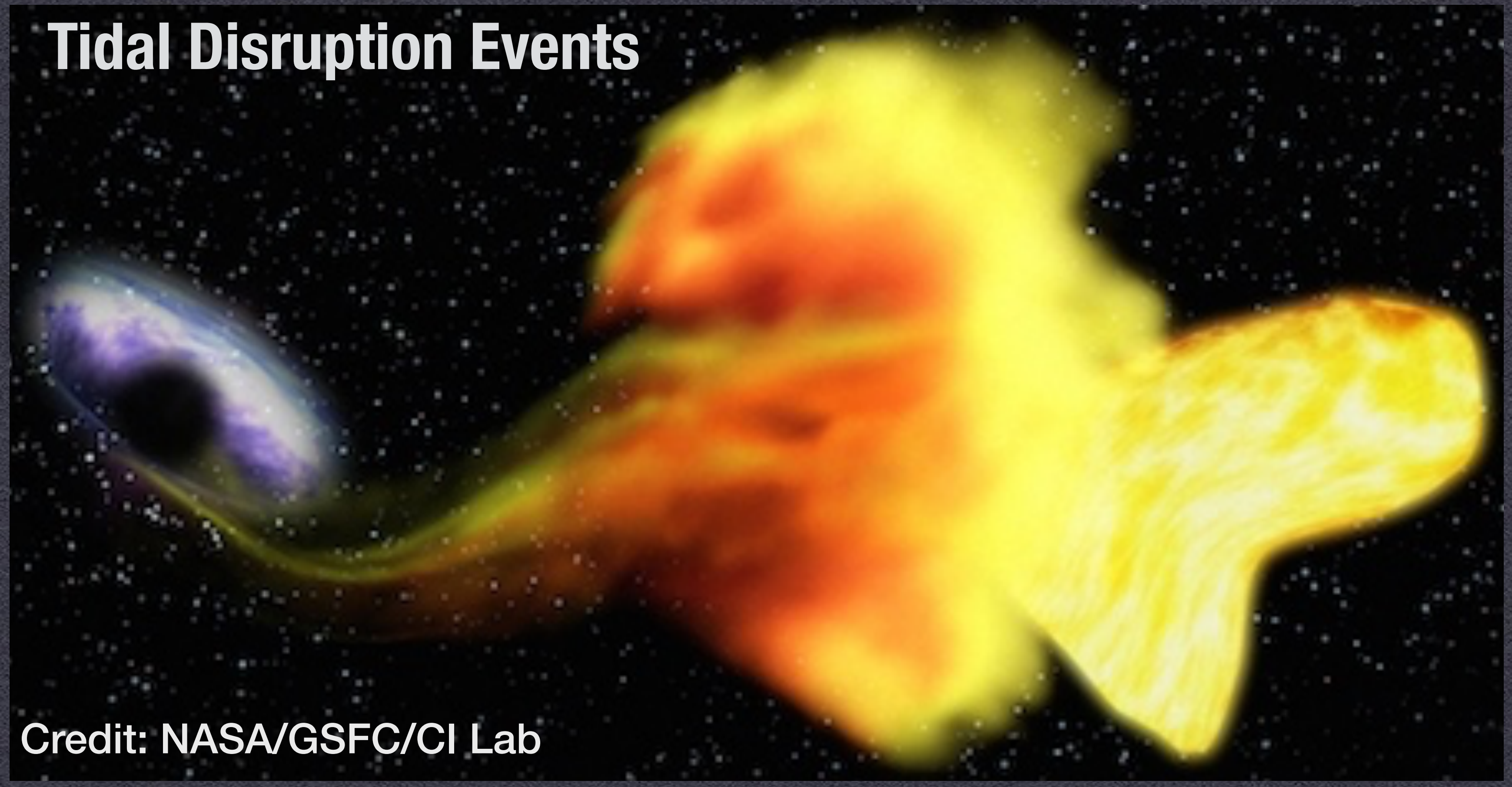
Transient Sources of Astrophysical Neutrinos

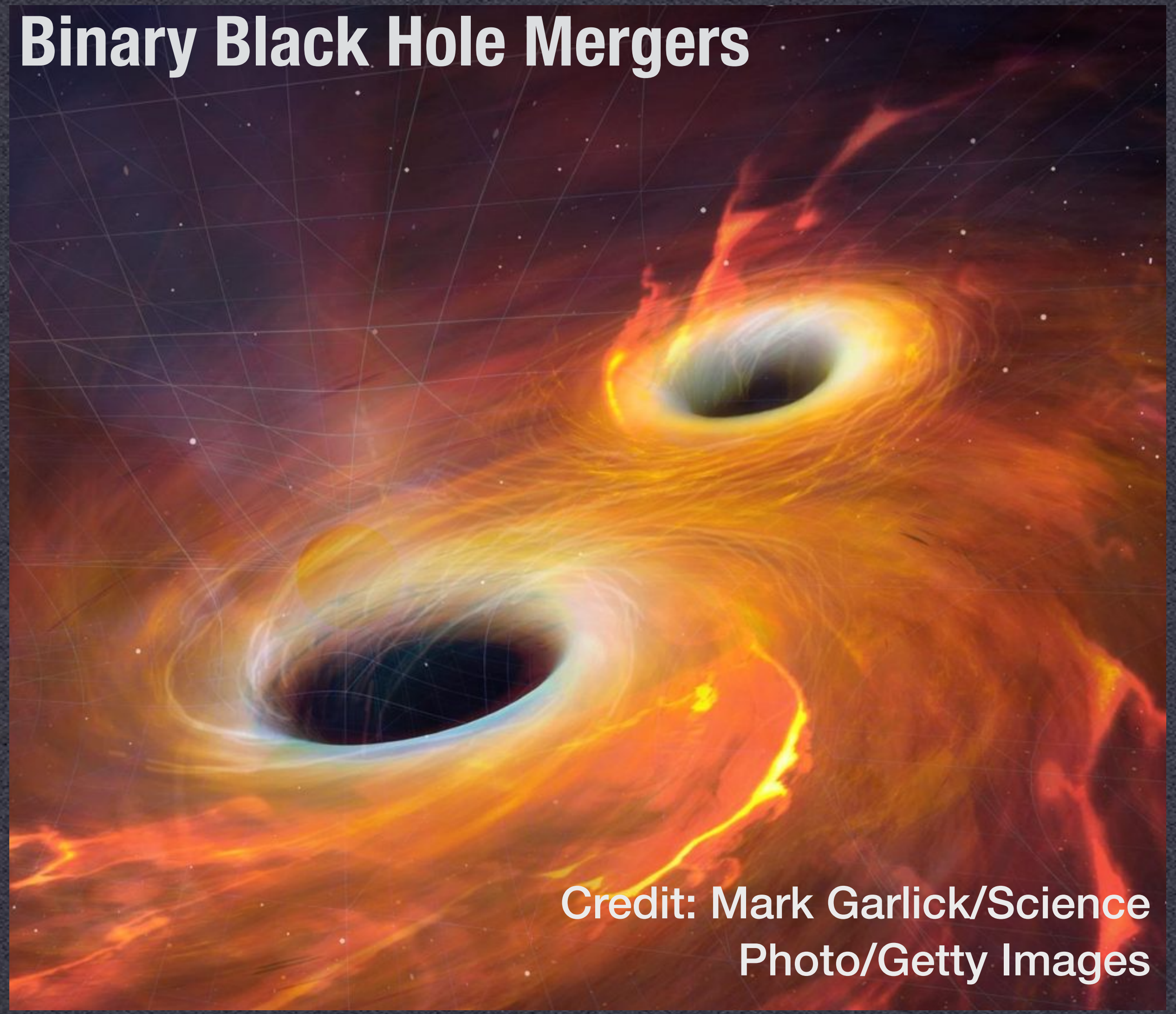








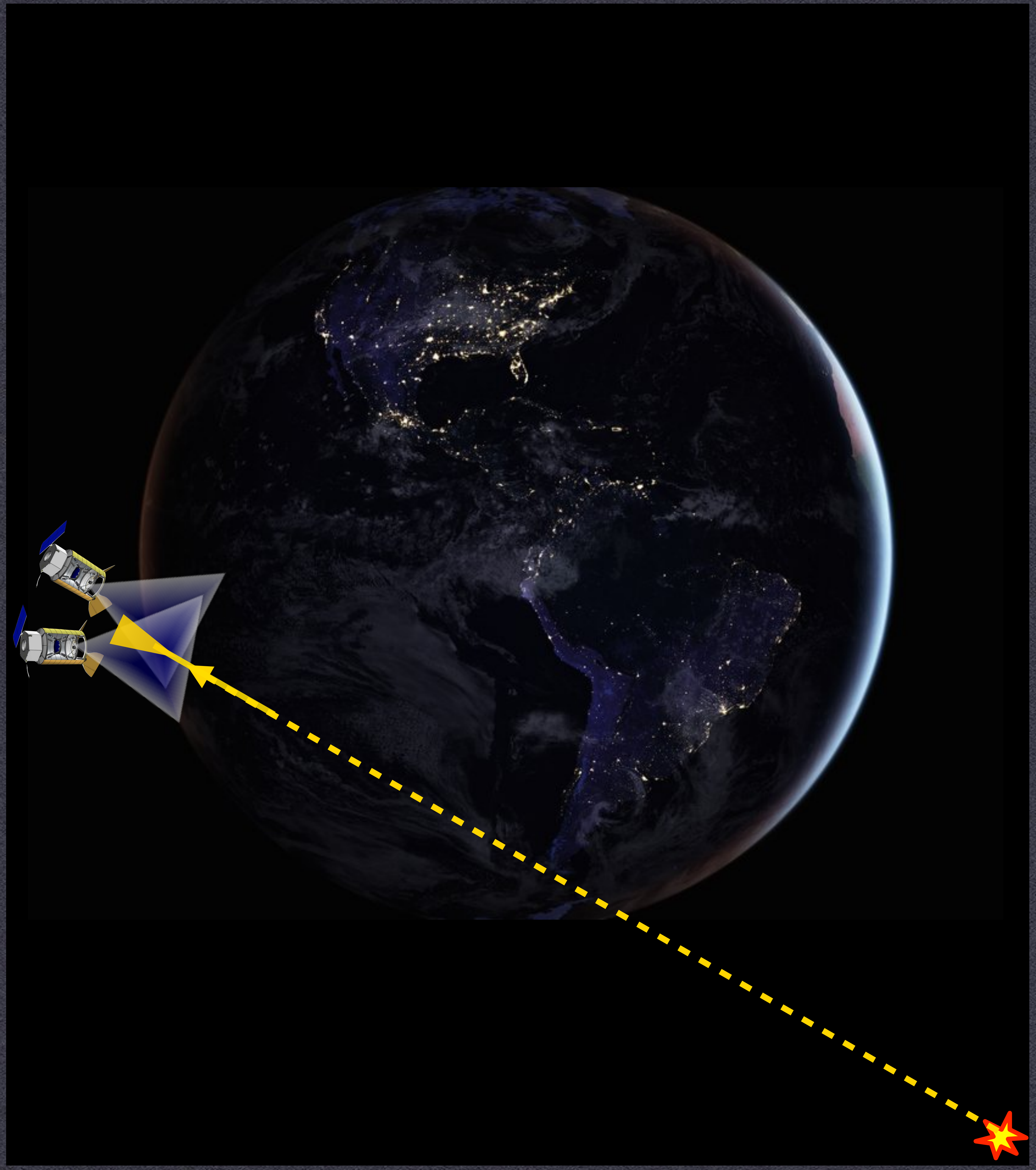




Flavor ratio at source — $\nu_e : \nu_\mu : \nu_\tau = 1 : 2 : 0$ ➡ *Flavor ratio at Earth — $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1$*

ToO Follow-up with POEMMA

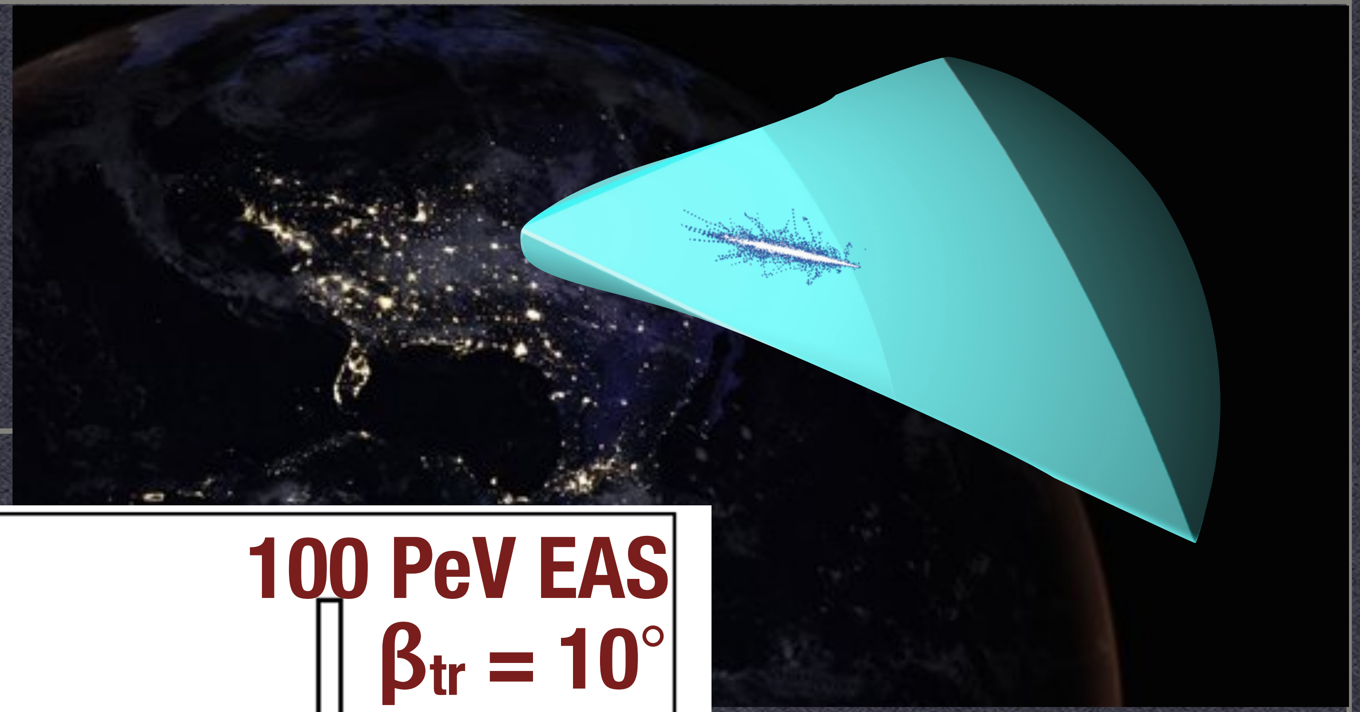
- Designed to detect optical Cherenkov from > 20 PeV ν_τ's
- Field of View: $30^\circ \times 9^\circ$
- Rapid slewing: ~ 90° in 500 s
- Orbital Characteristics
  - Inclination: 28.5°
  - Orbital Period: 95 min.
- Slew + Orbit + FoV ⟶ ~ 21%/37% of sky accessible in 500 s/1000 s
- Capability to maneuver satellites closer together ⟶ improve sensitivity at lower energies
  - ~ 40 times over the mission lifetime

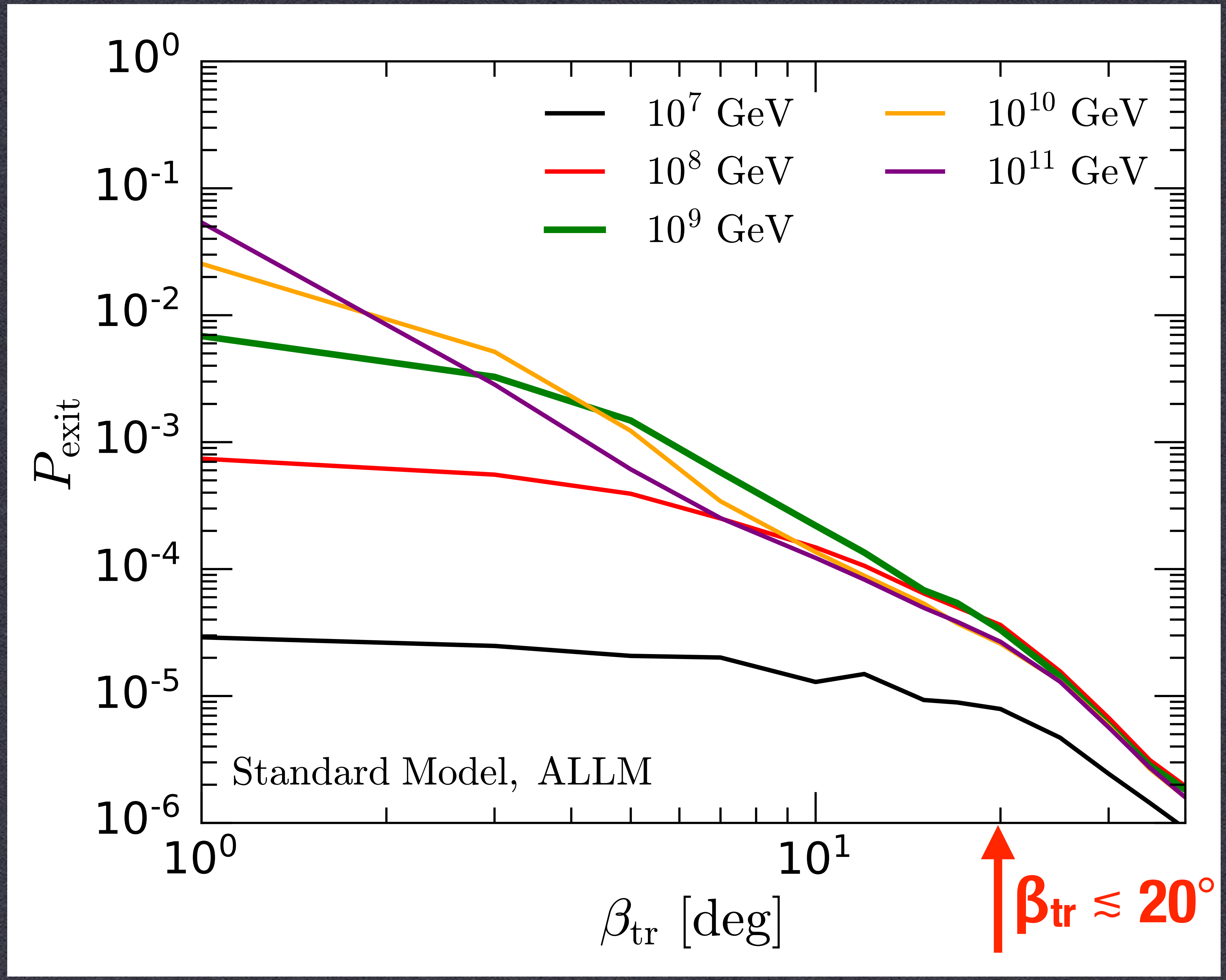


POEMMA uniquely suited for ToO follow-up at very-high energies and beyond!

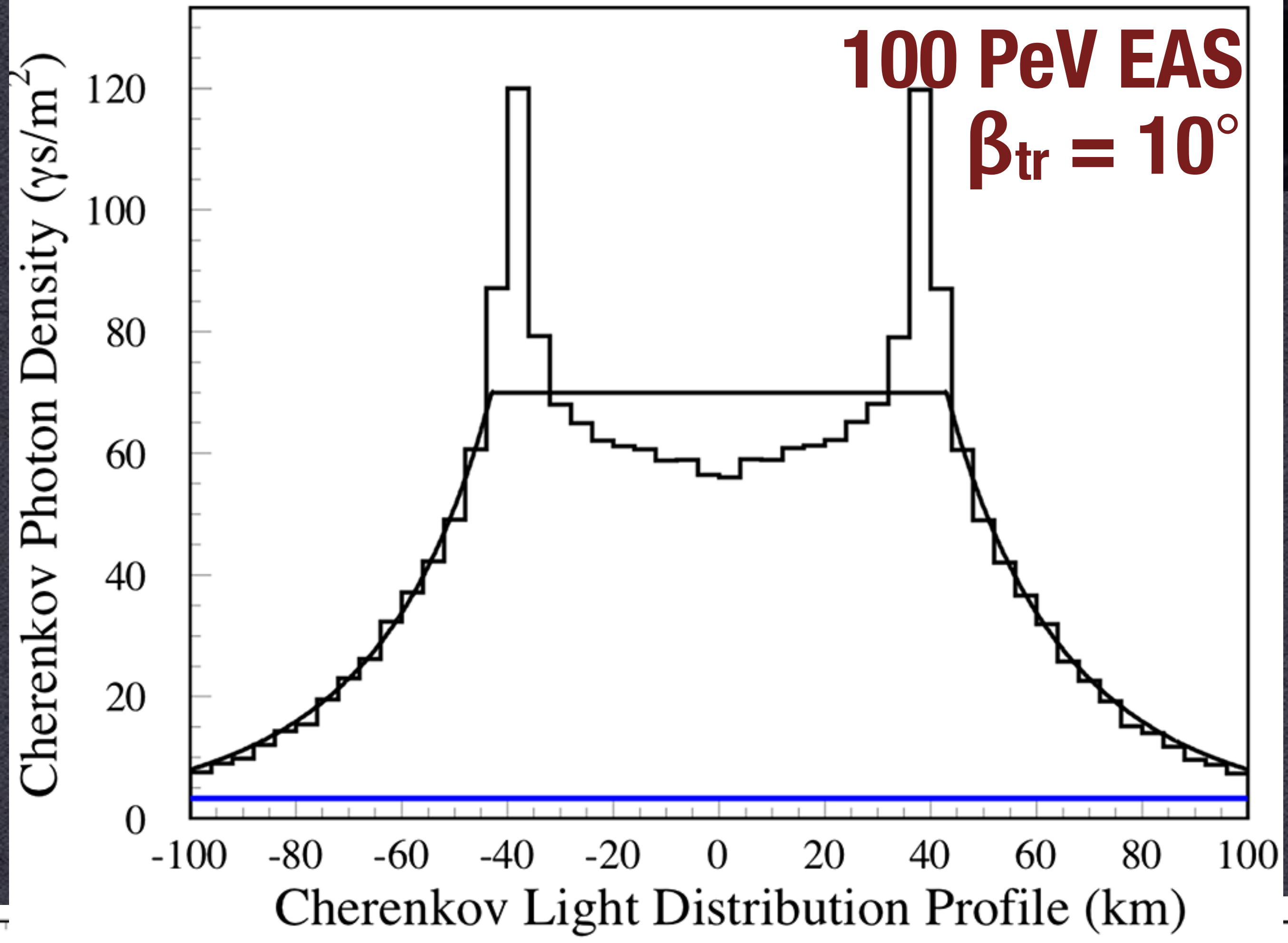
ν_τ Detection with POEMMA

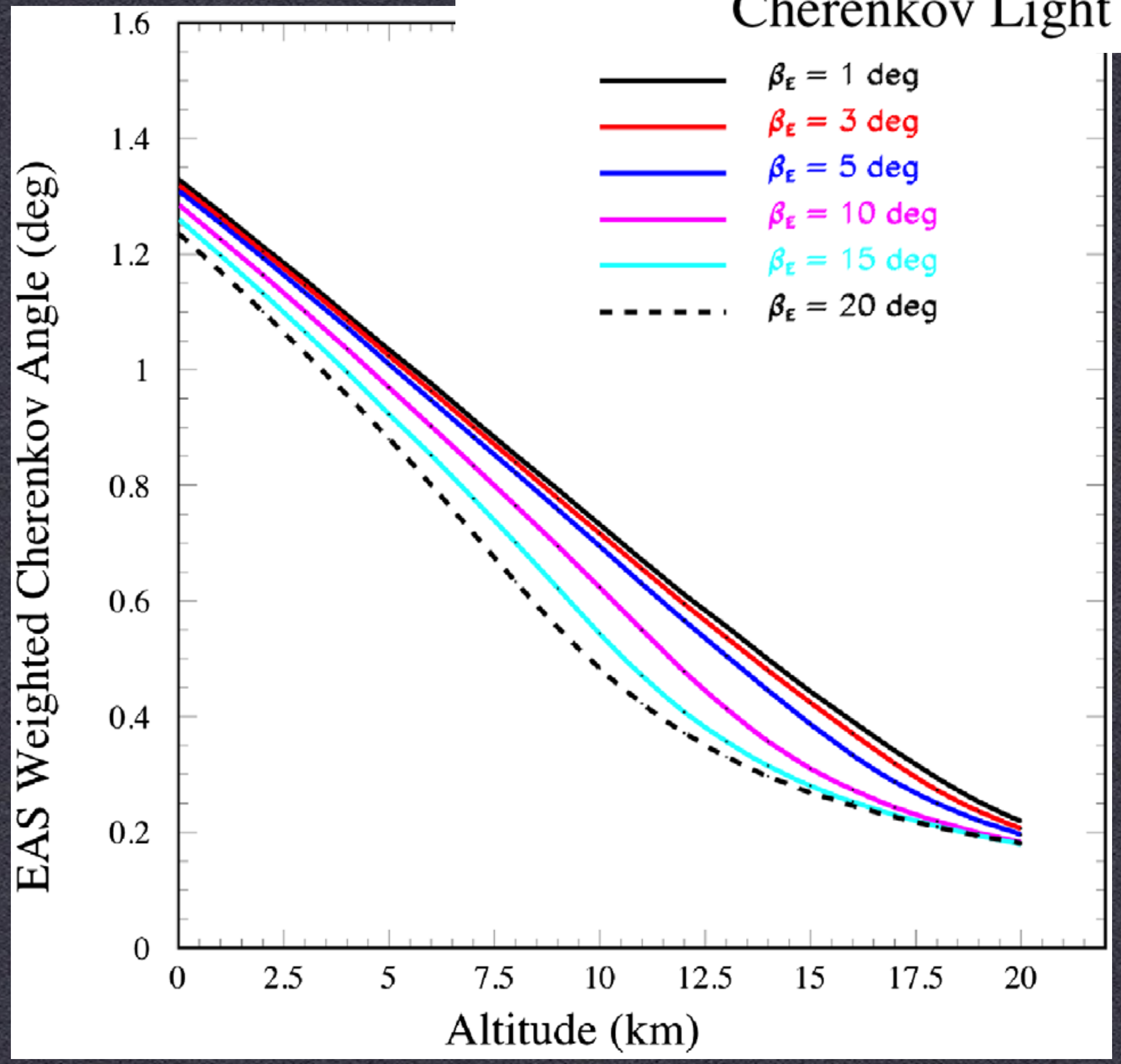
Limb-viewing Mode

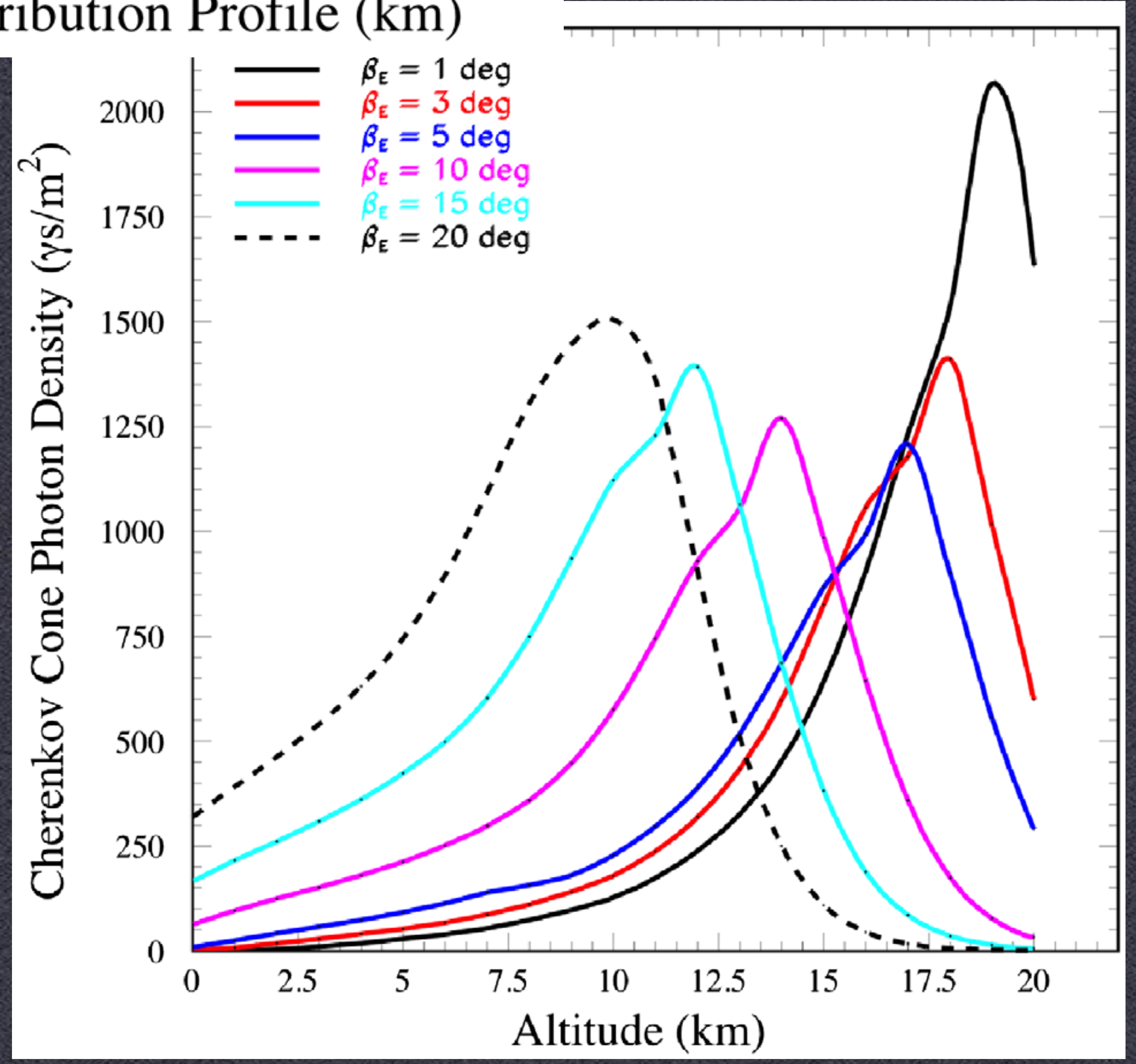




Tau lepton yield





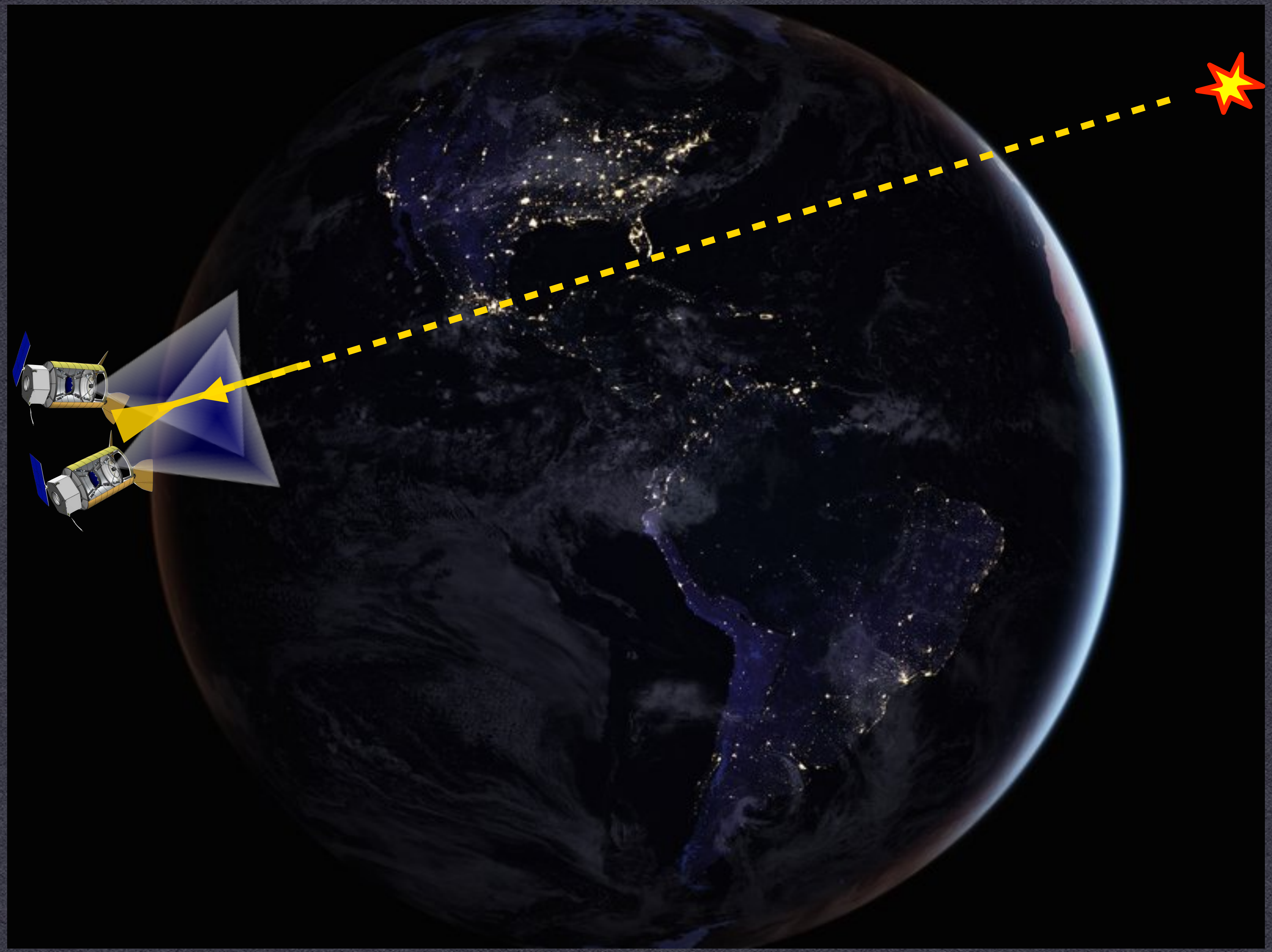


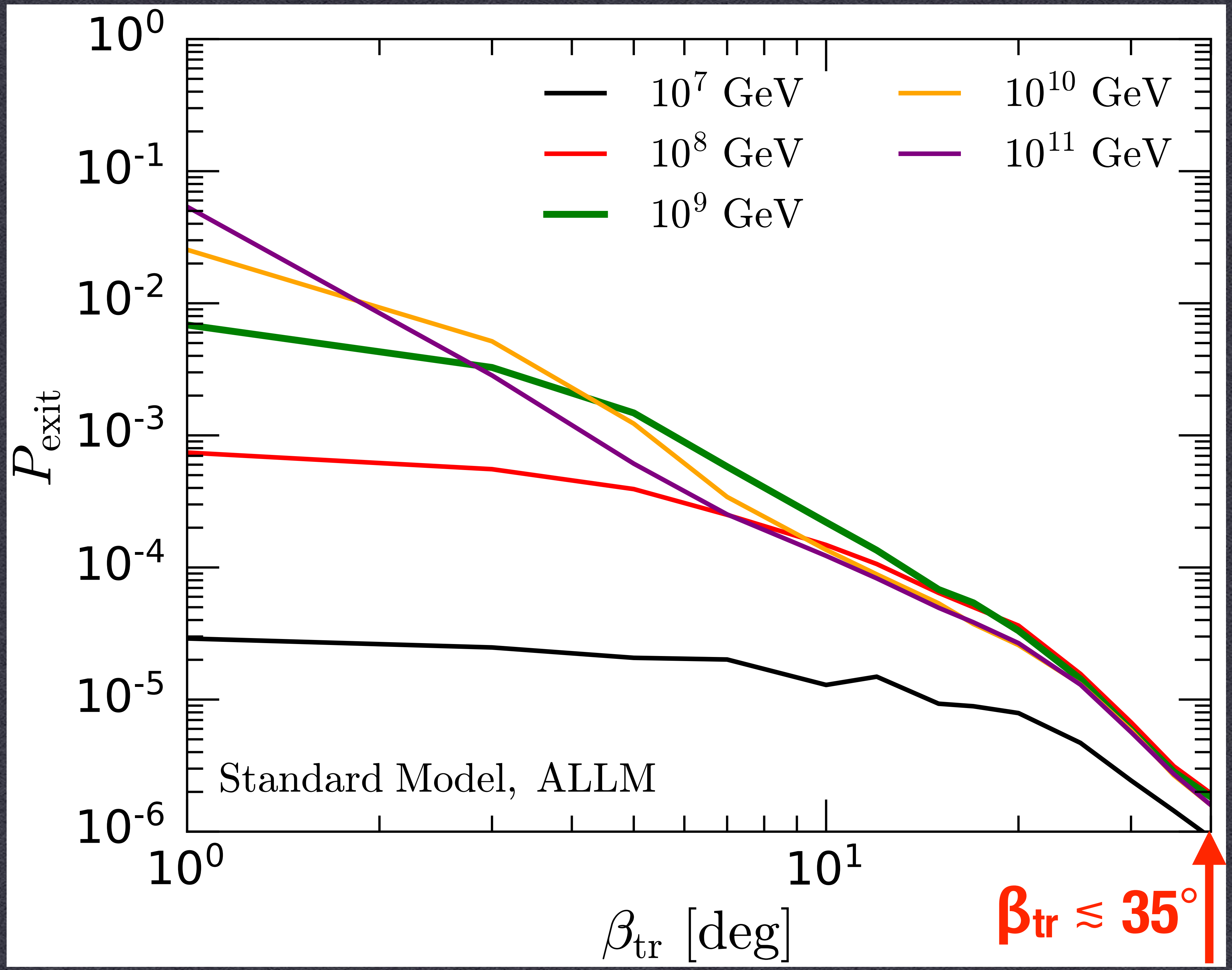
Cherenkov signal characteristics

Reno, Krizmanic, & TMV 2019

ν_τ Detection with POEMMA

ToO Mode

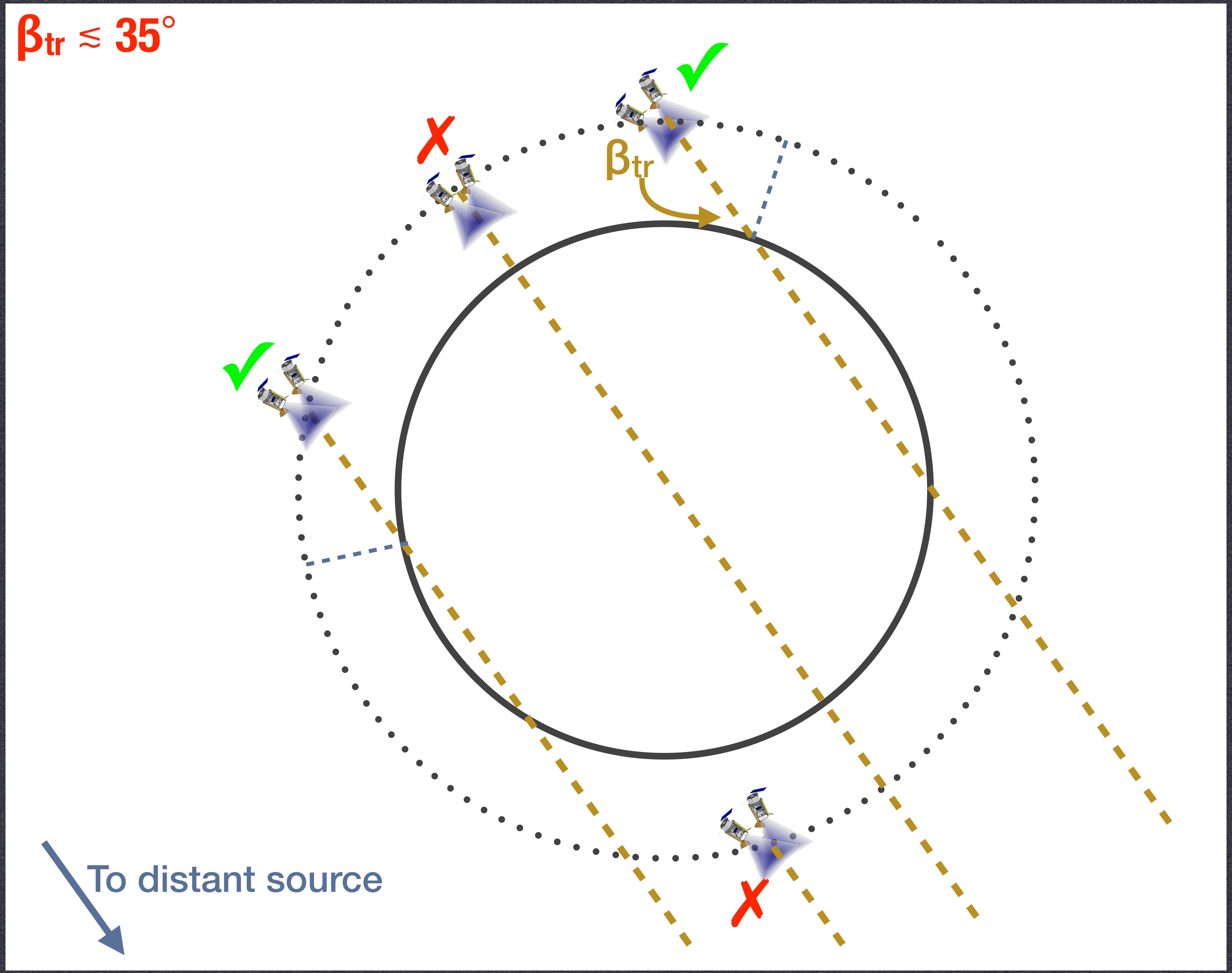


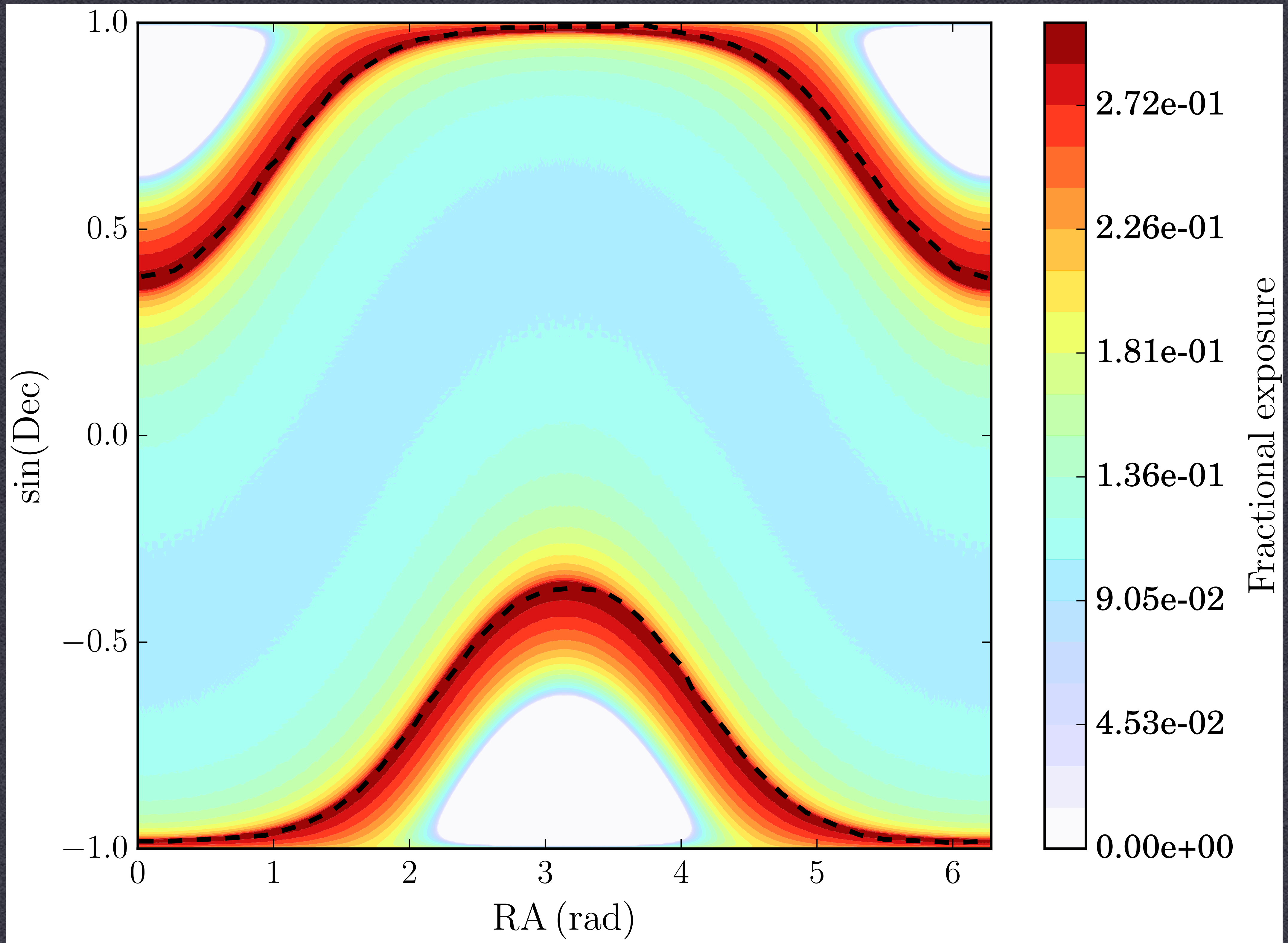


$\beta_{tr} \lesssim 35^\circ \longrightarrow$ viewing angle from Earth's limb ~ 18.3°

ν_τ Exposure for ToO Observations I

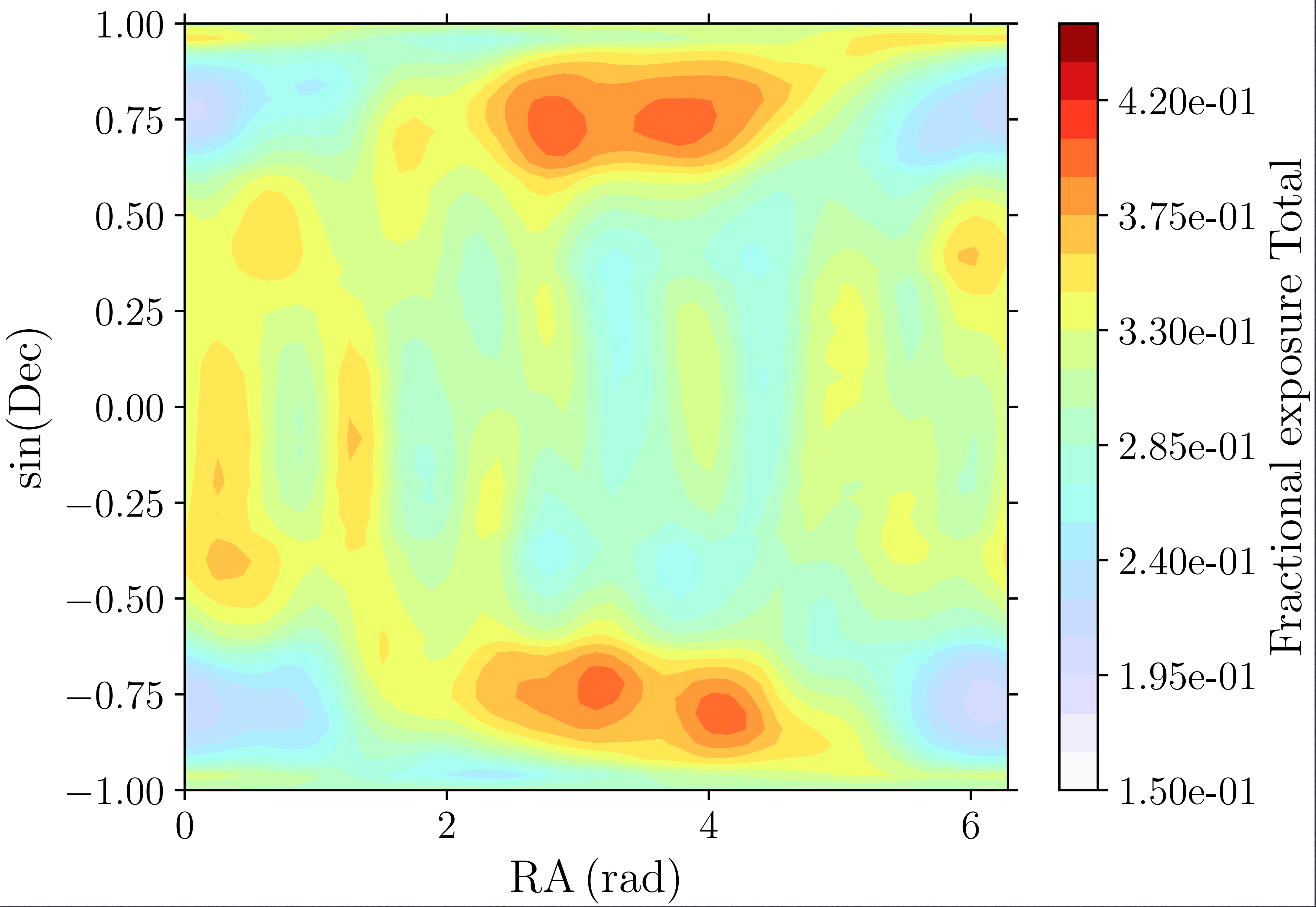
Tau Yield Constraint





ν_τ Exposure for ToO Observations II

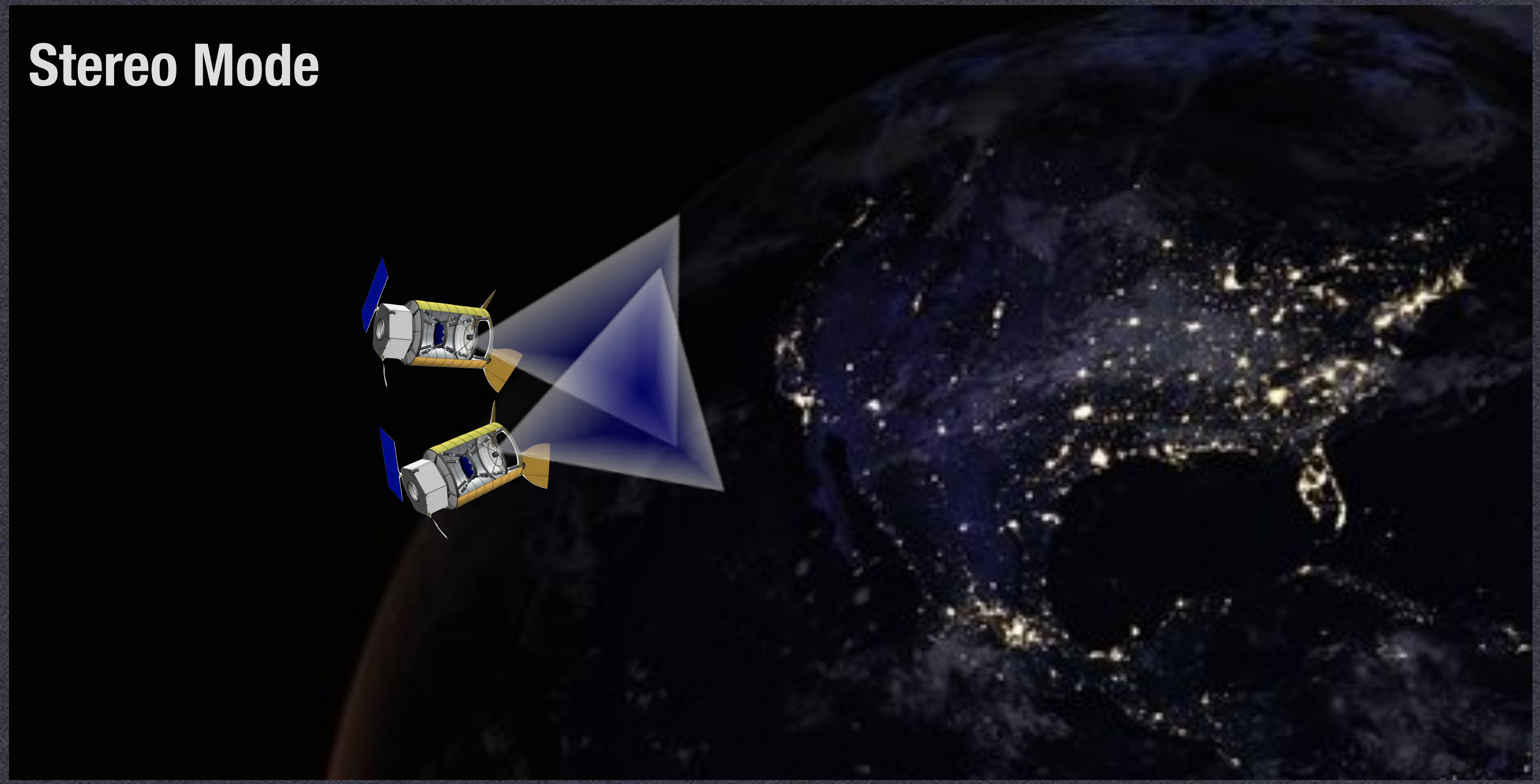
Sun and Moon Constraint



Averaged over 7 precession periods
(7 × 54.3 days ~ 380 days)

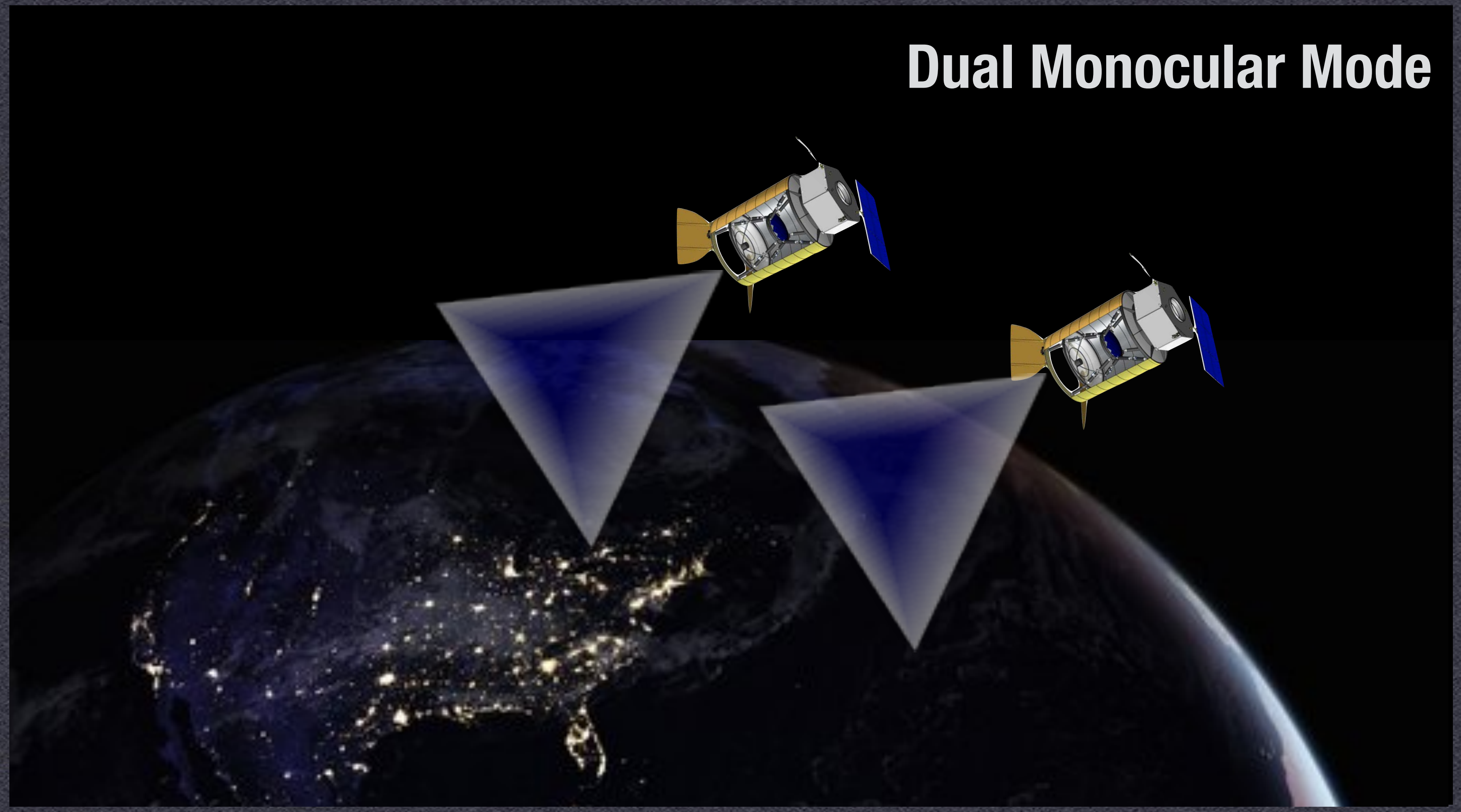
Two Transient Event Scenarios

Long Duration



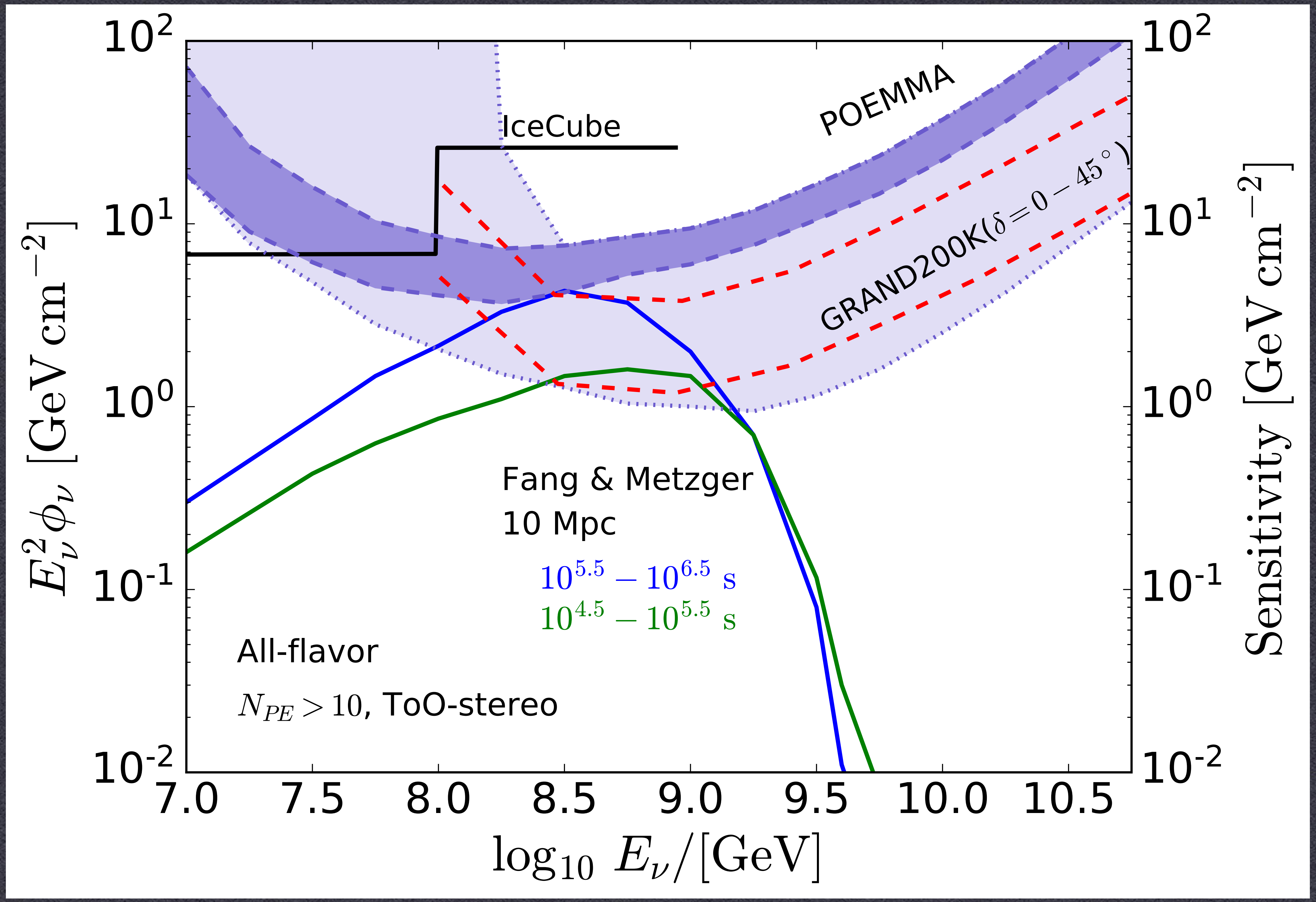
- Event duration: ≳ 1 day
- Stereo maneuver: ~ 1 day
- Average Sun or Moon effects
- Satellites in Stereo Mode
  - Separation ~ 50 km
- 10 PE threshold

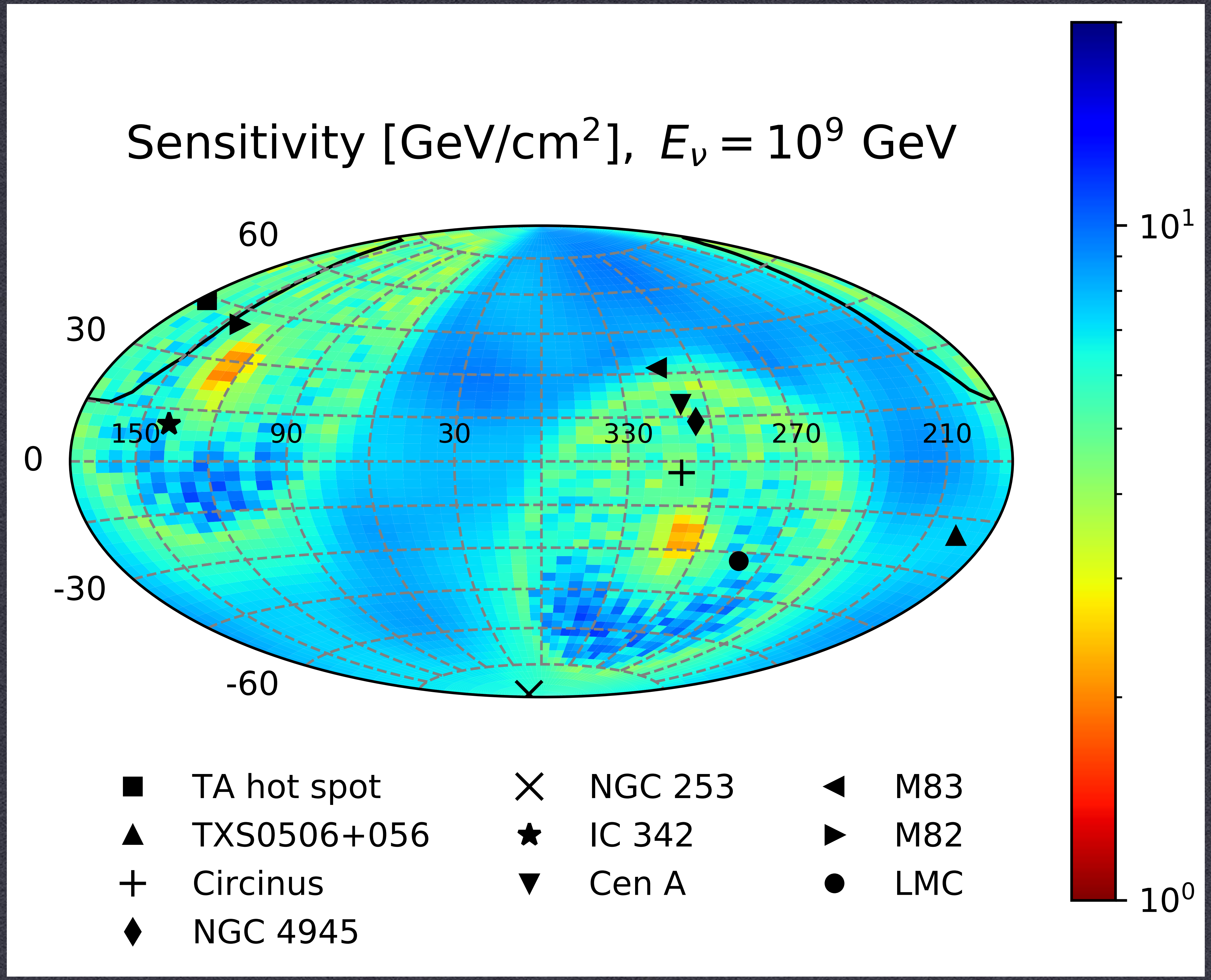
Short Duration



- Event duration: ~ 1000 s
- Slew time: ~ 500 s
- Optimal source location; no Sun or Moon effects
- Satellites in Dual Monocular Mode
  - Separation ~ 300 km
- 20 PE threshold

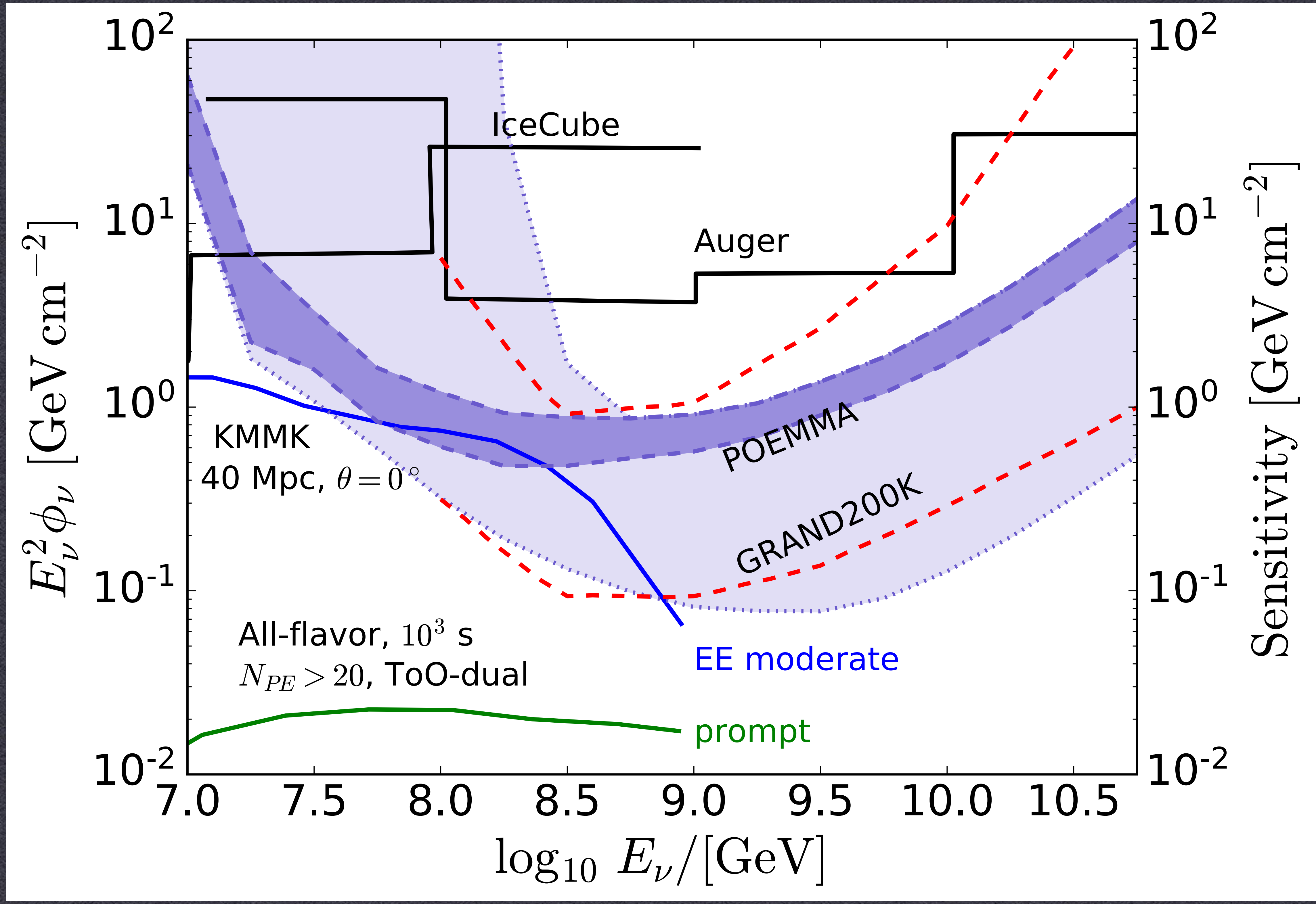
Example Long Duration Scenario

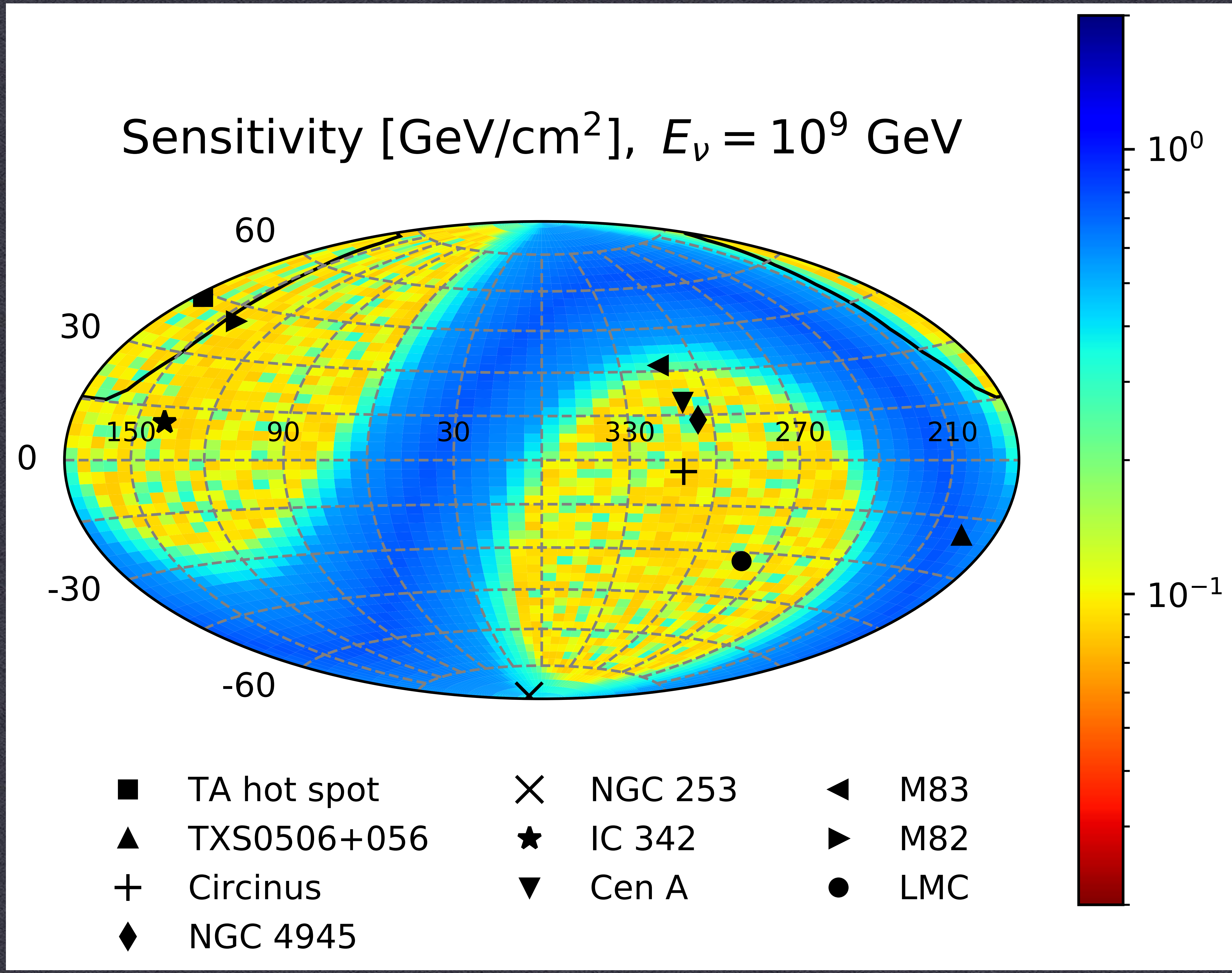




- Per decade all-flavor sensitivity
- 90% upper limit (2.44 events for background << 1)
- Muon showers excluded ($B_{shr} \simeq 83\%$)

Example Short Burst Scenario





- Per decade all-flavor sensitivity
- 90% upper limit (2.44 events for background << 1)
- Muon showers excluded ($B_{shr} \simeq 83\%$)

Potential Backgrounds

- Night-sky Air Glow:
  ≲ 1 × 10^{-5} events per long ToO obs.
- Diffuse Astrophysical Neutrino Flux:
  ≲ 2 × 10^{-4} events per long ToO obs. (based on IceCube limits)
- Total: ≲ 2.1 × 10^{-4} events per long ToO obs.
- W/ trials factor (100 obs.): ≲ 2.1 × 10^{-2} events
- Not counted in estimate:
  - Reflected Cherenkov from UHECRs —
    Pulse widths ~ hundreds of ns >> 20 ns
  - Above the limb UHECRs —
    Most significant at angles ≲ 1° below the limb

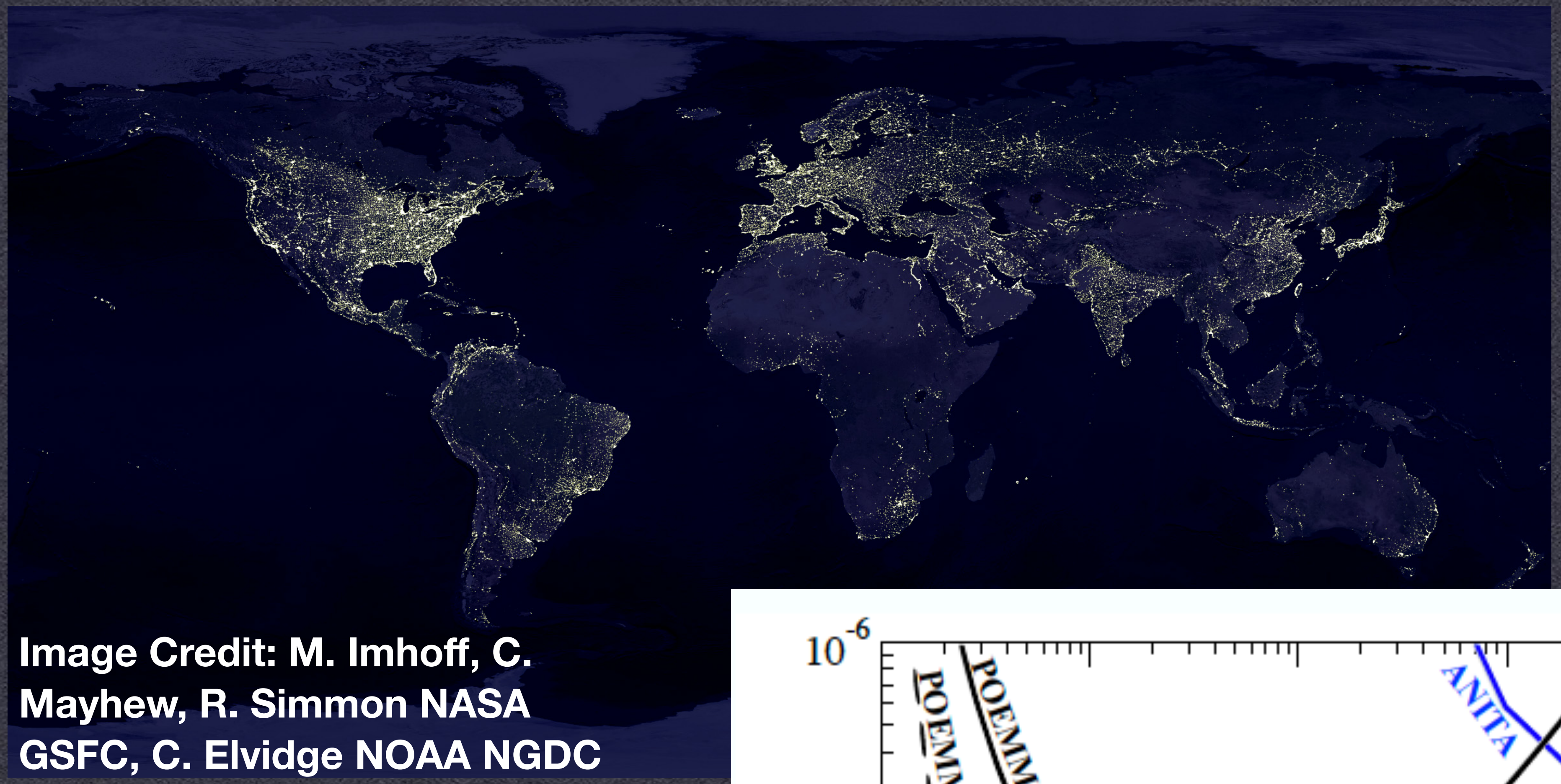
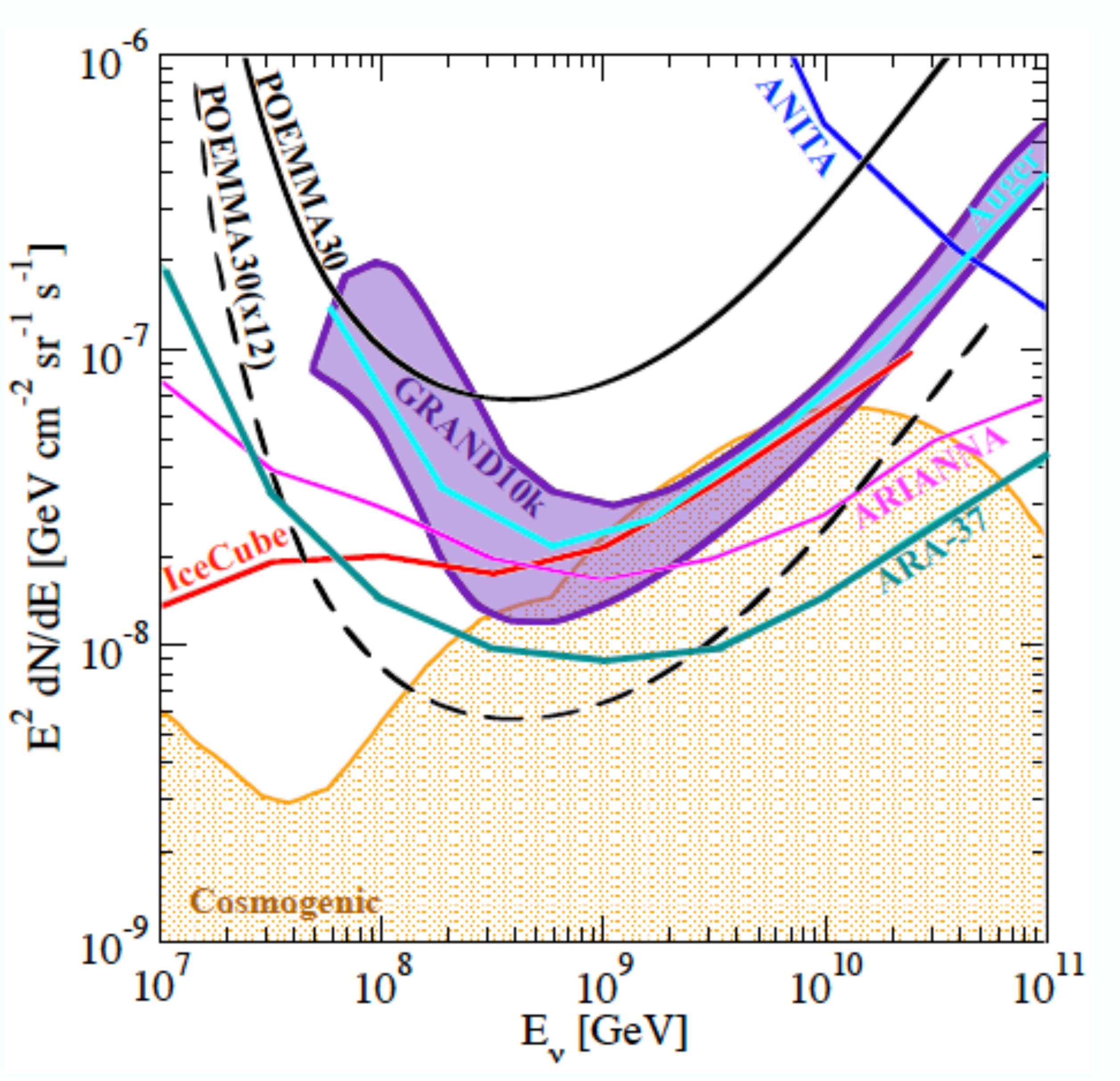


Image Credit: M. Imhoff, C. Mayhew, R. Simmon NASA GSFC, C. Elvidge NOAA NGDC

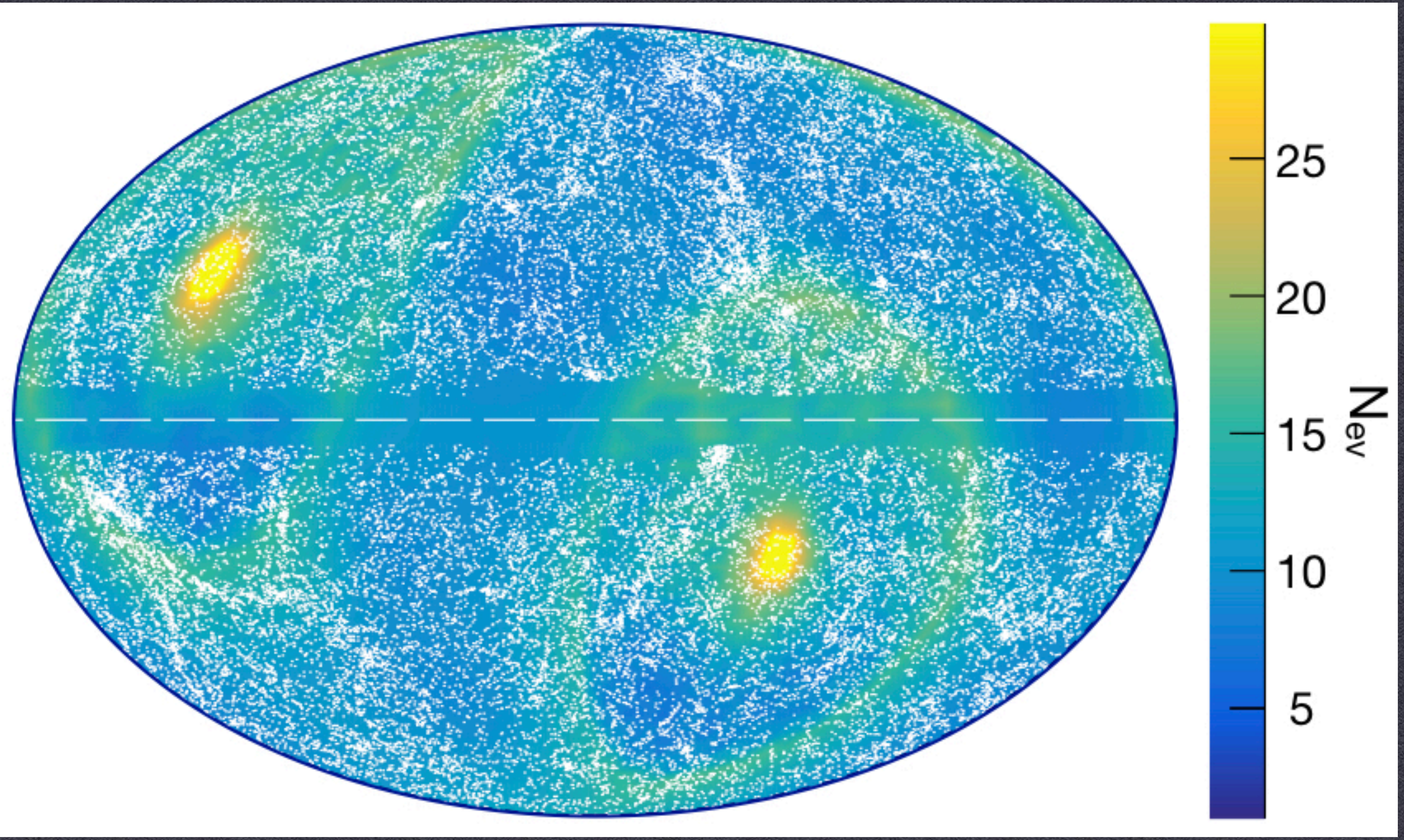


Reno, Krizmanic, & TMV 2019

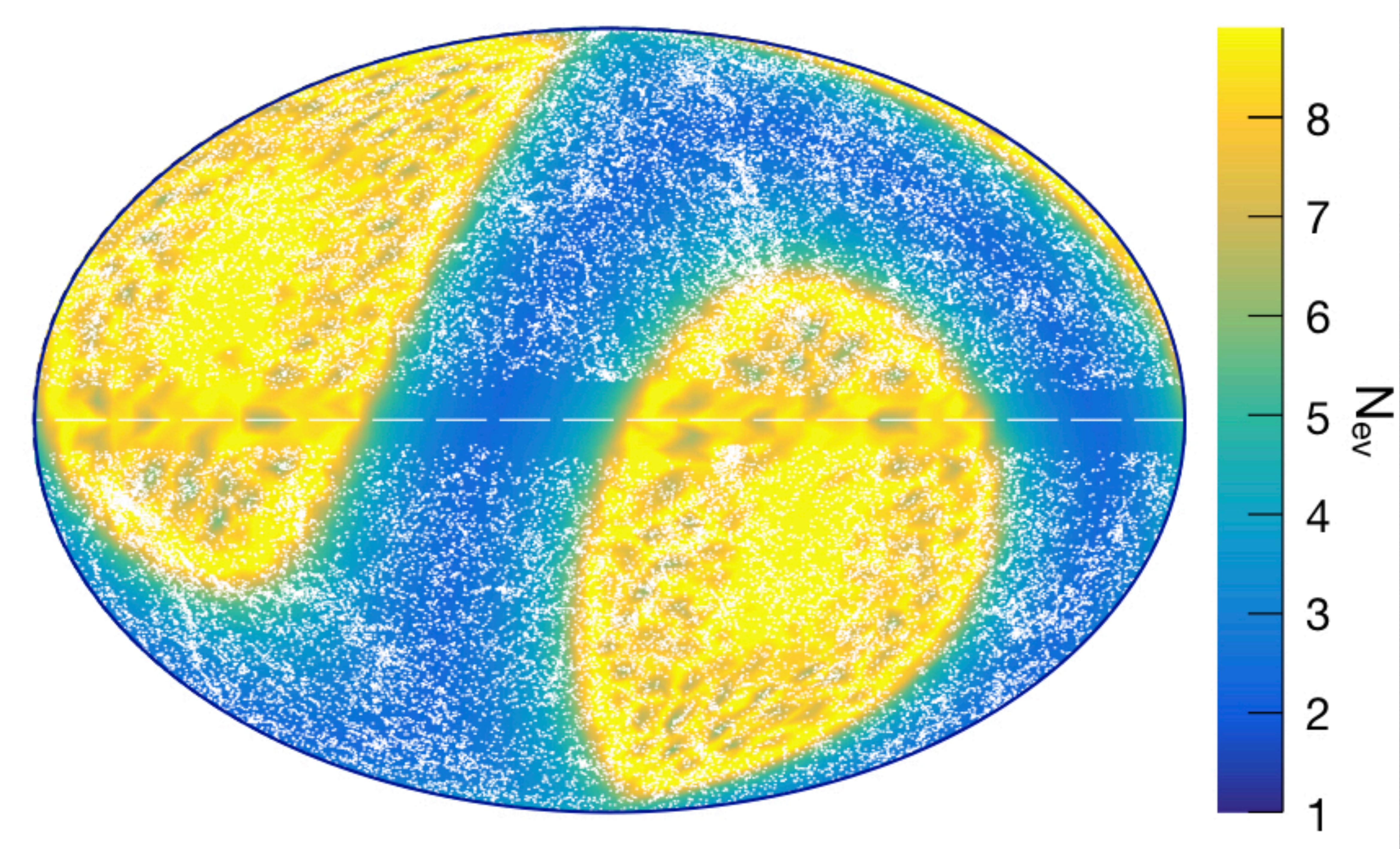
Need to detect 6 events to rule out background-only model at ≳ 5σ level.

Numbers of Events

Long Duration

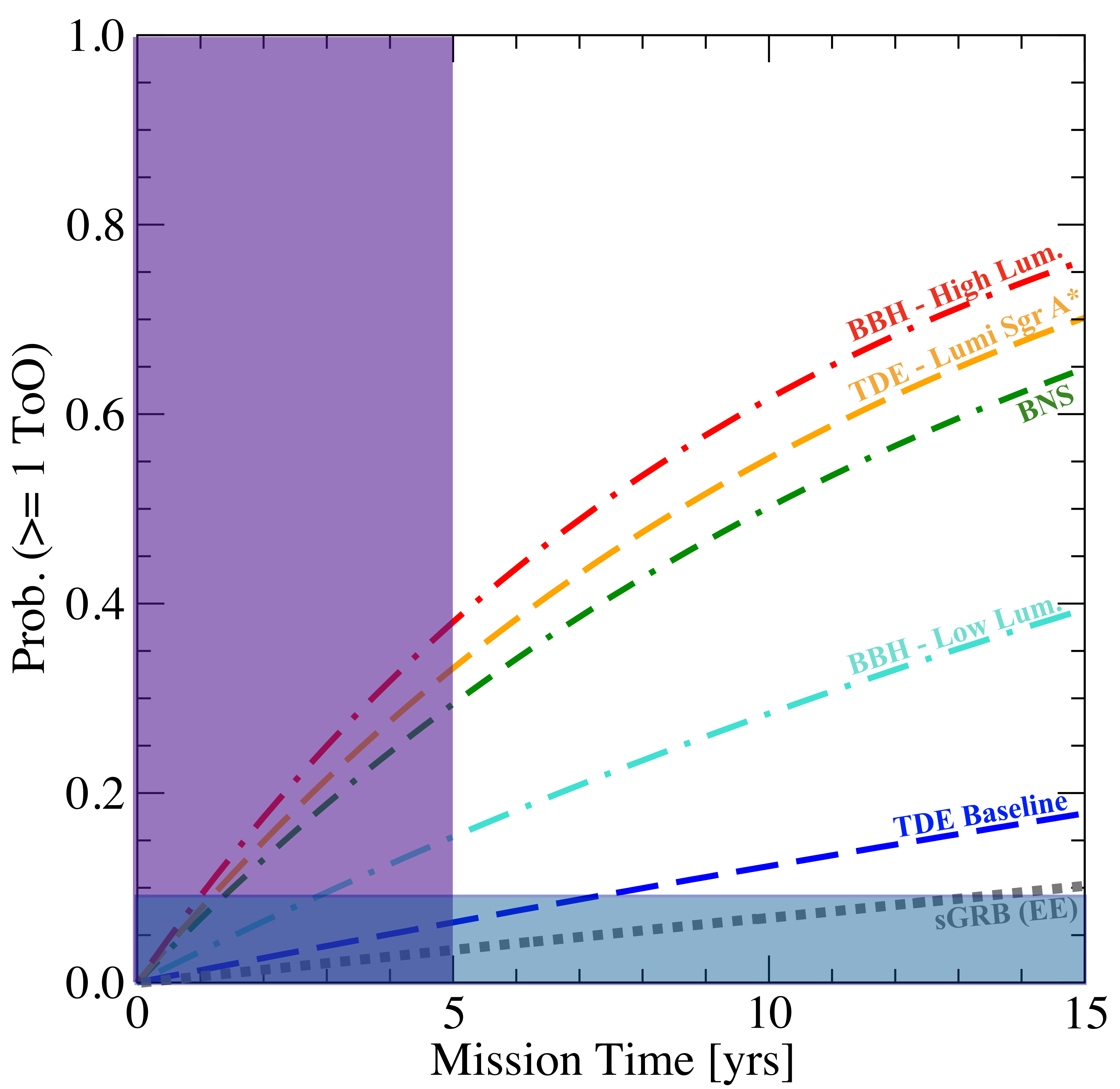


Short Duration



	POEMMA		IceCube		GRAND200k[a]	
Model	$1.0\nu_\tau$	$6.0\nu_\tau$	$1.0\nu_\mu$	$6.0\nu_\mu$	$1.0\nu_\tau$	$6.0\nu_\tau$
Fang and Metzger [22] BNS merger at 5 Mpc	100%	100%	70%	18%	82%	81%
KMMK [17] sGRB Mod. EE at 40 Mpc	100%	49%	50%	0%	81%	2%

Most Promising Source Classes



Poisson probability

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
Long Bursts				
TDEs	1.4×10^5	0.9	3 Mpc	Dai and Fang [18] average
TDEs	6.8×10^5	4.7	7 Mpc	Dai and Fang [18] bright
TDEs	$\mathbf{2.7 \times 10^8}$	$\mathbf{1.7 \times 10^3}$	**128 Mpc**	**Lunardini and Winter [19] $M_{SMBH} = 5 \times 10^6 M_\odot$ Lumi Scaling Model**
TDEs	7.7×10^7	*489*	*69 Mpc*	*Lunardini and Winter [19] Base Scenario*
Blazar Flares	NA*	NA*	47 Mpc	RFGBW [20] – FSRQ proton-dominated advective escape model
lGRB Reverse Shock (ISM)	1.2×10^5	0.8	3 Mpc	Murase [16]
lGRB Reverse Shock (wind)	2.5×10^7	174	41 Mpc	Murase [16]
BBH merger	$\mathbf{2.8 \times 10^7}$	**195**	**43 Mpc**	**Kotera and Silk [21] (rescaled) Low Fluence**
BBH merger	$\mathbf{2.9 \times 10^8}$	$\mathbf{2.0 \times 10^3}$	**137 Mpc**	**Kotera and Silk [21] (rescaled) High Fluence**
BNS merger	$\mathbf{4.3 \times 10^6}$	**30**	**16 Mpc**	**Fang and Metzger [22]**
BWD merger	25	0	38 kpc	XMMD [23]
Newly-born Crab-like pulsars (p)	190	0	109 kpc	Fang [24]
Newly-born magnetars (p)	2.5×10^4	0.2	1 Mpc	Fang [24]
Newly-born magnetars (Fe)	5.0×10^4	0.3	2 Mpc	Fang [24]
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)	1.1×10^8	800	90 Mpc	KMMK [17]

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

Summary and Future Work

* Space-based platform and rapid slewing capability make POEMMA uniquely suited for ToO follow-up at very-high and ultra-high energies.
* Large portion of sky available for short bursts (37% in $\lesssim$ 1000 s); quasi-uniform sky coverage for long bursts
* Most promising source classes for POEMMA include TDEs, BBH mergers, and BNS mergers.
* Monte Carlo simulations provide foundation for end-to-end neutrino simulation package for space-based and sub-orbital experiments ➢ νSpaceSim

Additional Details

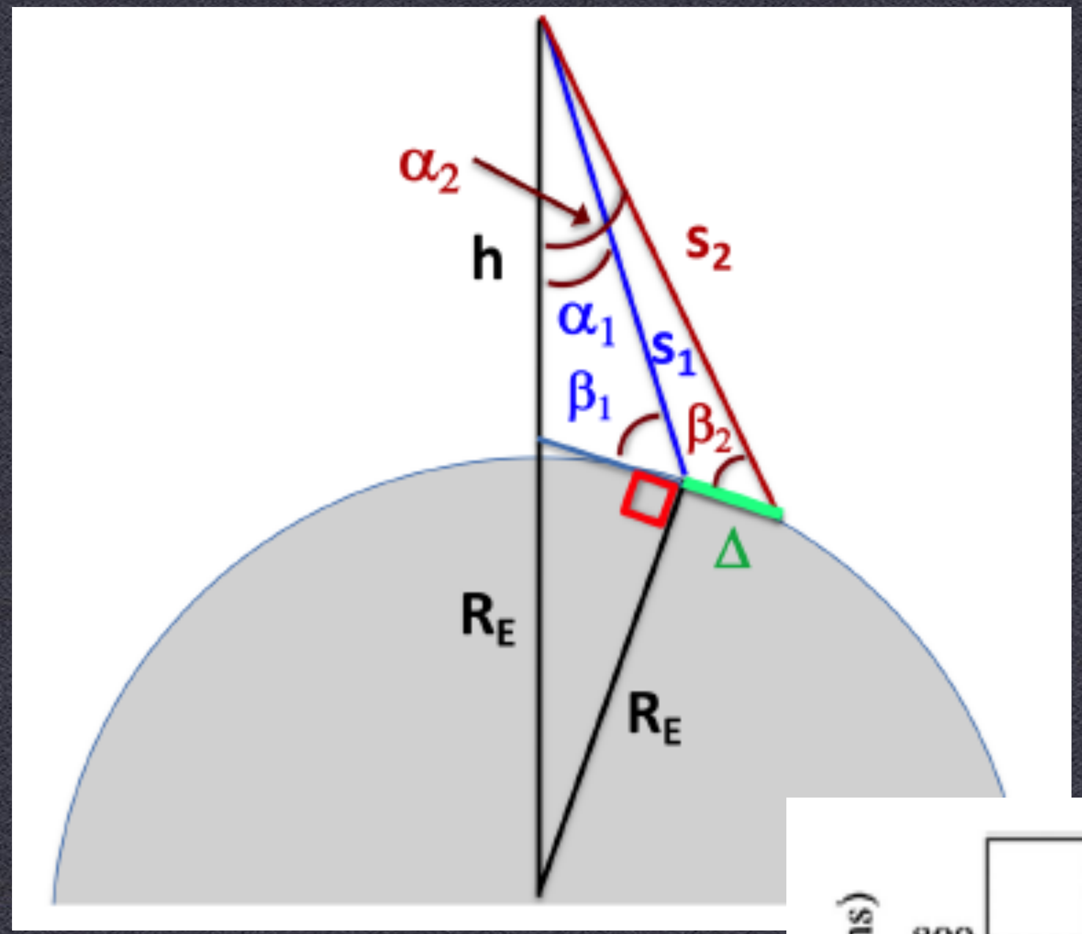
- ToO paper: Venters+ 2020, PRD, 102, 123013 (arXiv: 1906.07209)
- ν_τ Simulations and POEMMA Diffuse Neutrino Sensitivity: Reno, Krizmanic, TMV 2019, PRD, 100, 063010 (arXiv:1902.11287)
- POEMMA Exposure: Guépin+ 2019, JCAP, 3, 021 (arXiv:1812.07596)
- POEMMA Design:
  - POEMMA short report on https://science.nasa.gov/astrophysics/2020-decadal-survey-planning
  - POEMMA Mission paper: Olinto+, submitted to JCAP (arXiv: 2012.07945)

Thank you!

Backup Slides

Potential Backgrounds II

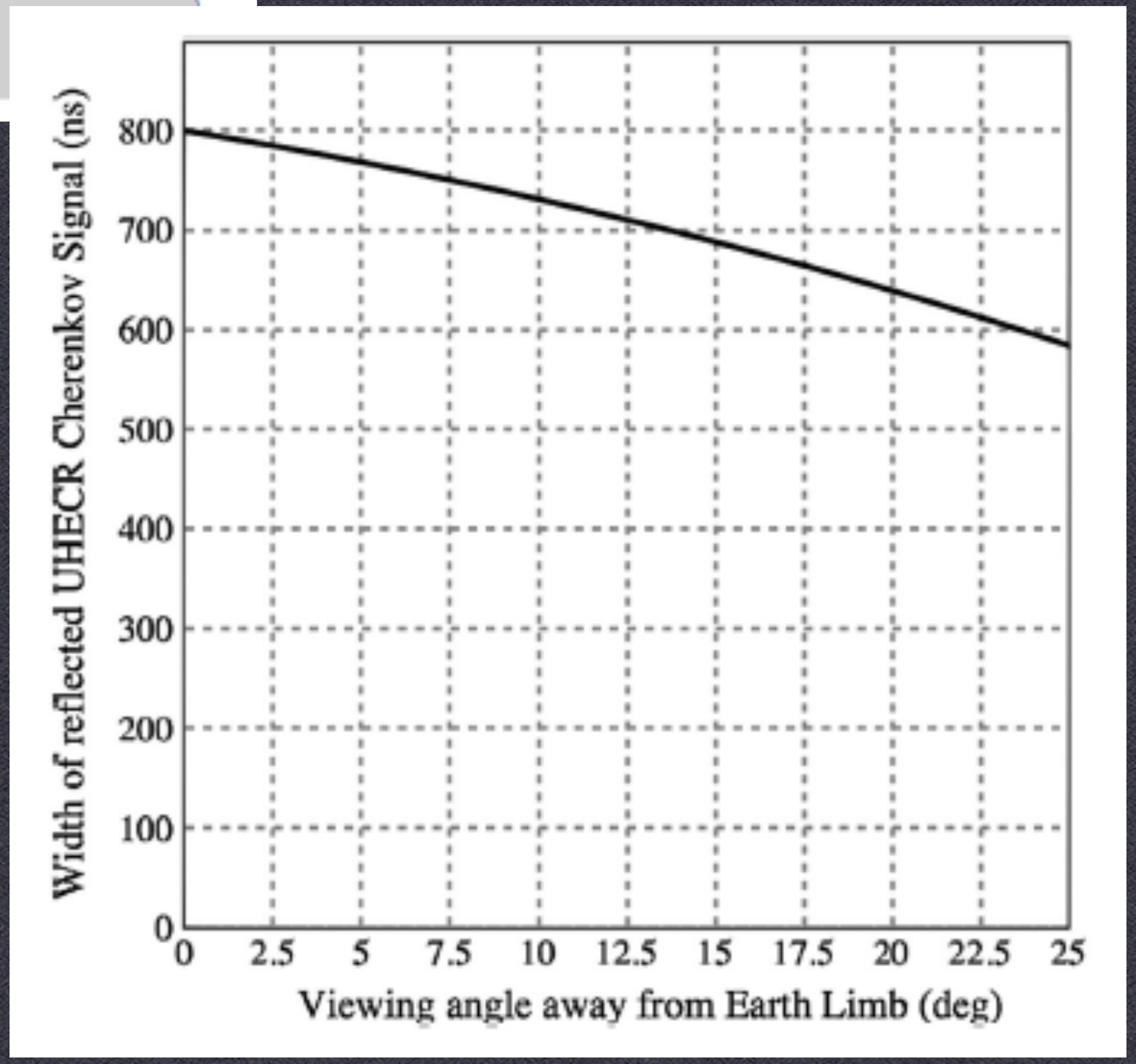
Reflected Cherenkov from UHECRs



Geometry

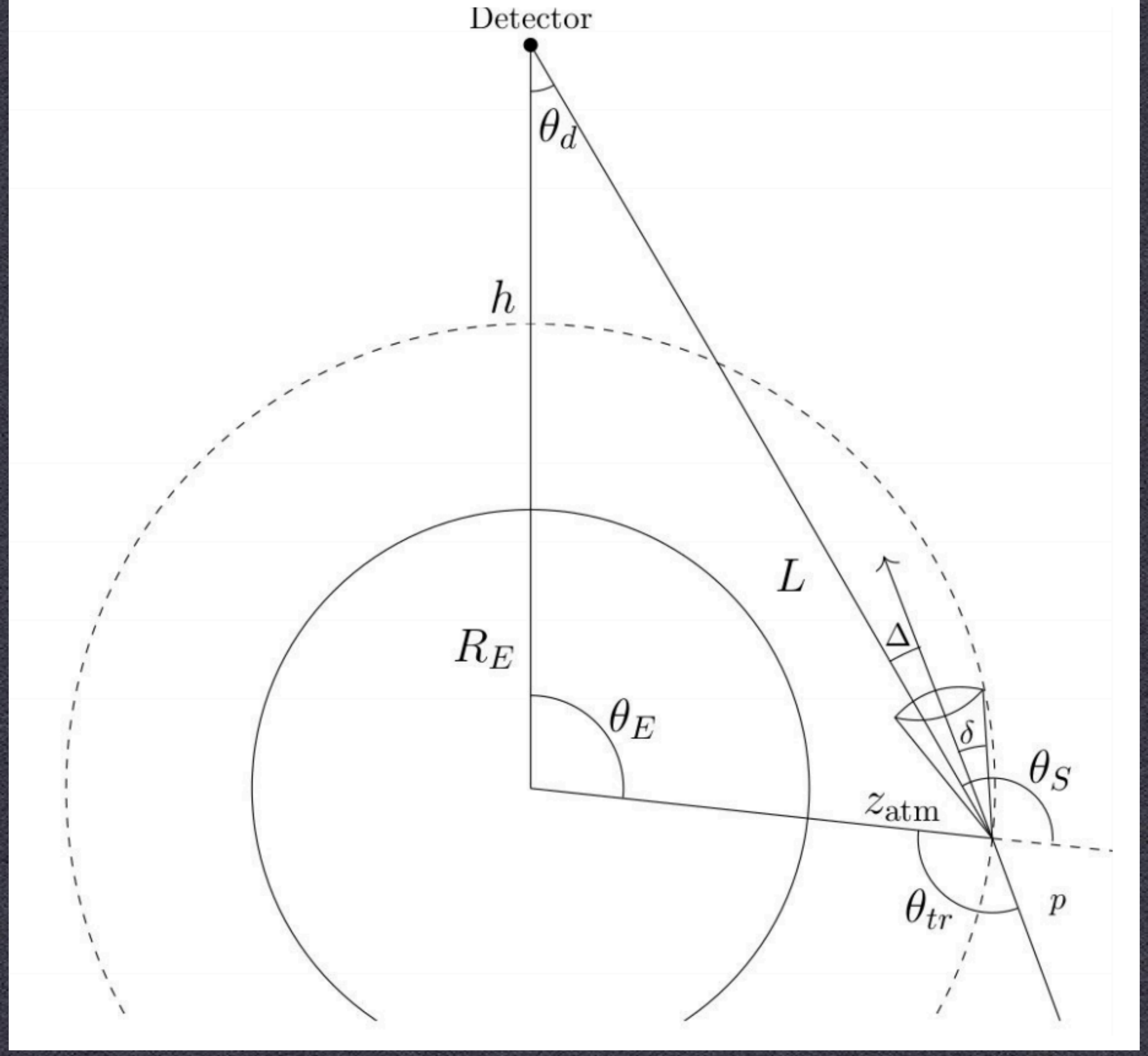
- **Ground:** pulse duration ~ hundreds ns (expected ν_τ pulse duration ~ 20 ns)
- **Clouds:** expect similar pulse durations
  - most probable hgts.: 3 and 15 km
  - shower max: ~ 6 km

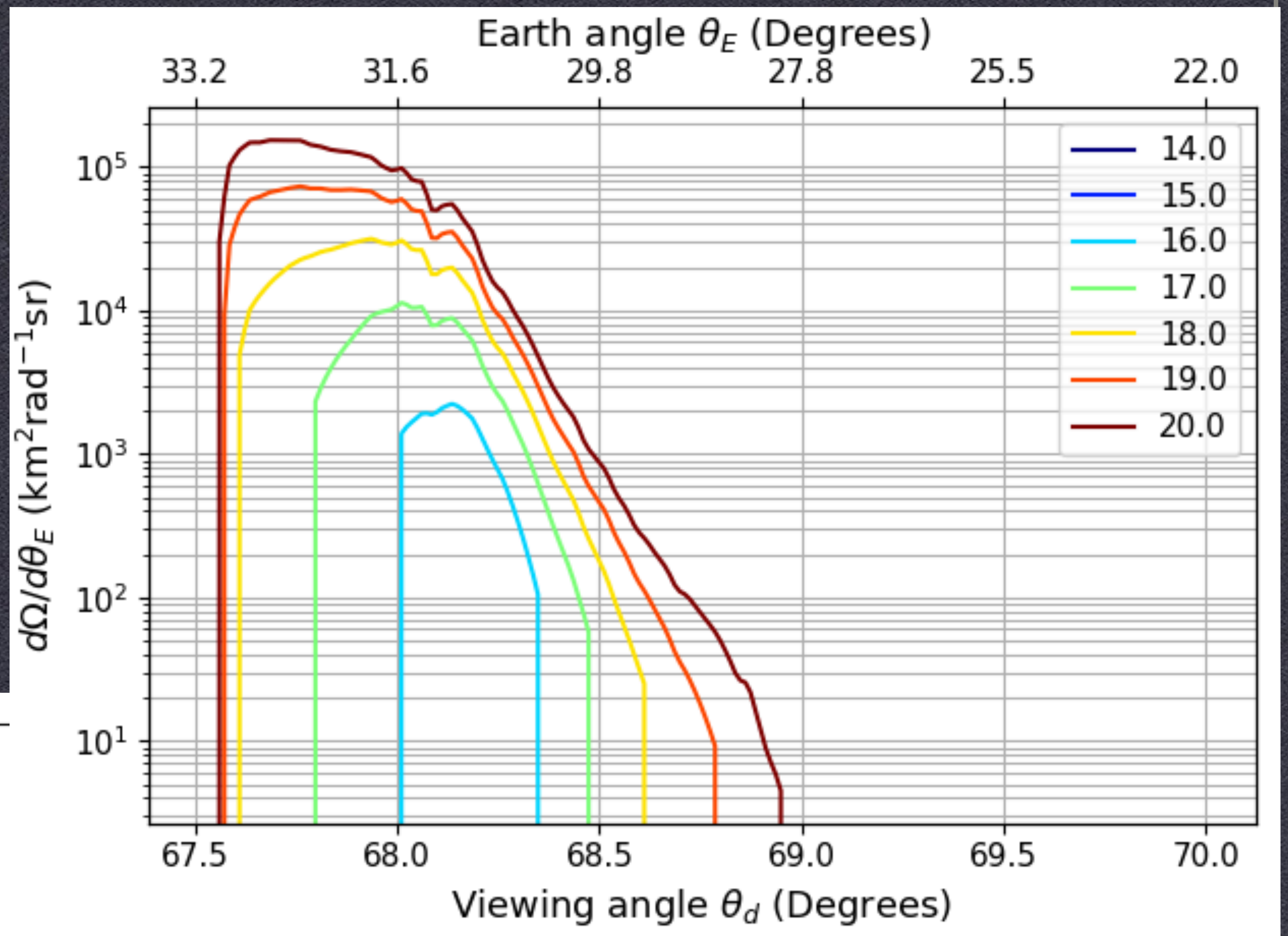
Pulse Width

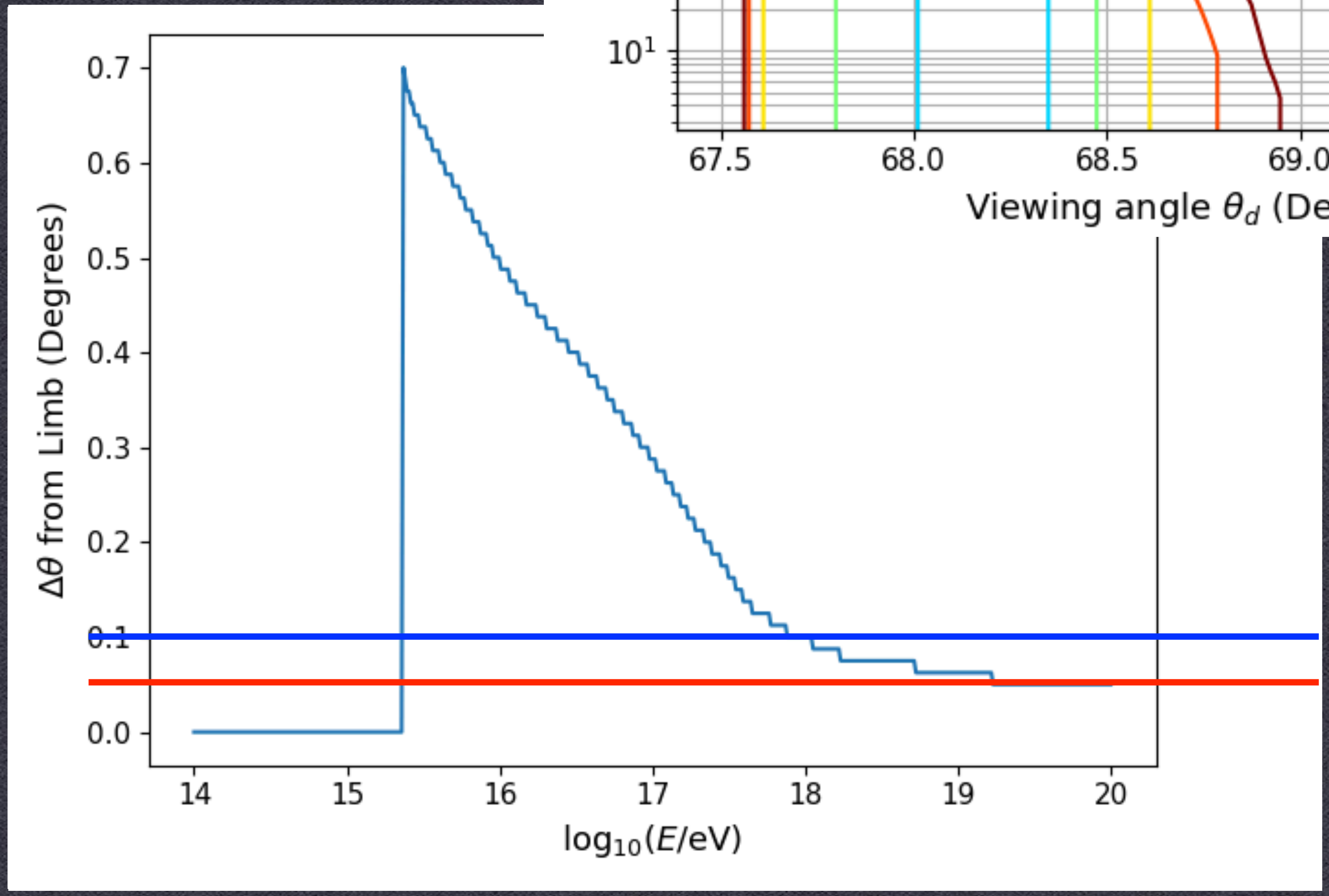


Potential Backgrounds III

Above-the-Limb UHECRs





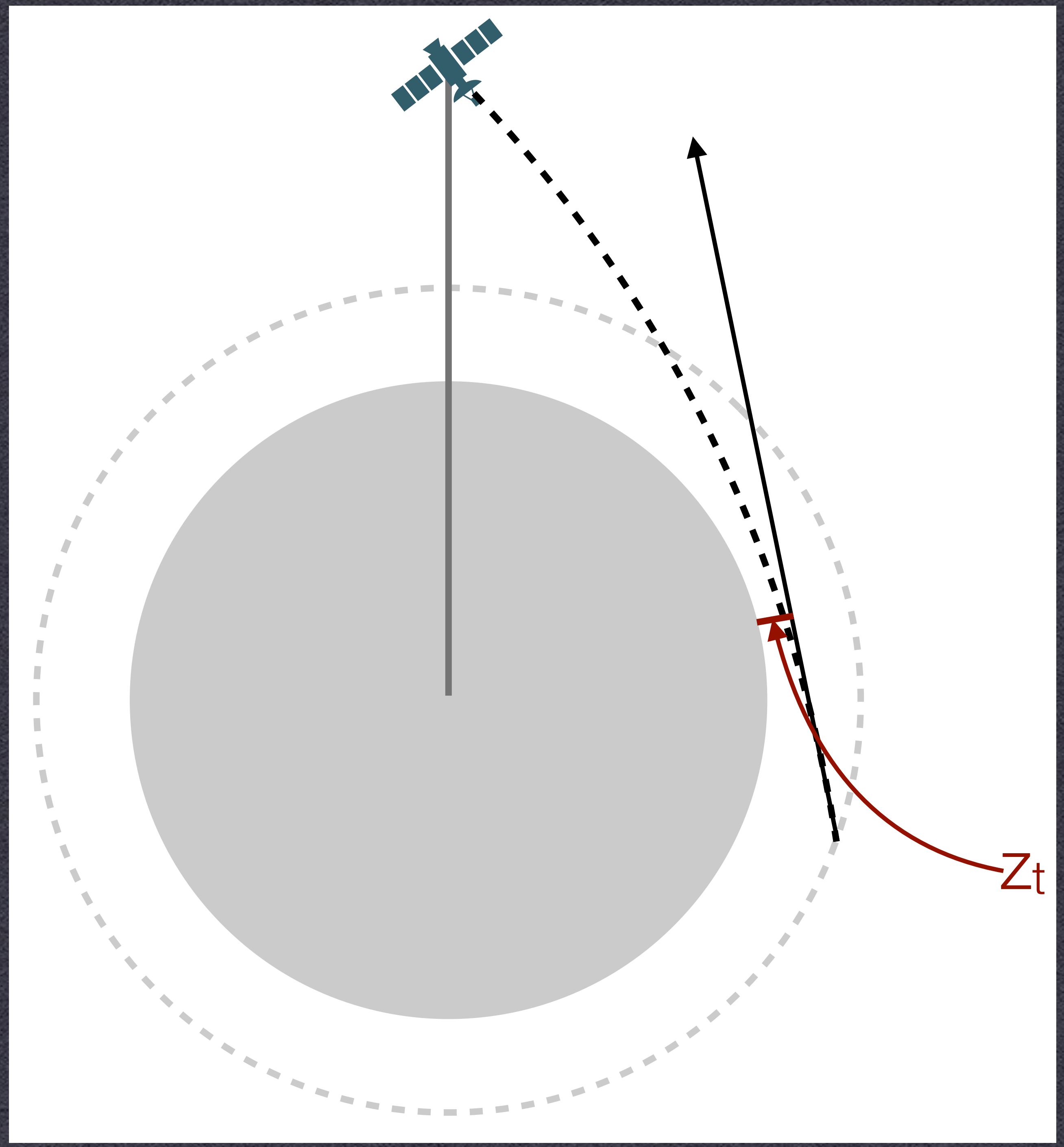


- "Zone of Acceptance" for ATL UHECRs
  - Below θ_{min}: Cher. signal attenuated below thres.
  - Above θ_{max}: rarified atm. ⇏ EASs

See Austin Cummings's Talk

Potential Backgrounds III

Above-the-Limb UHECRs



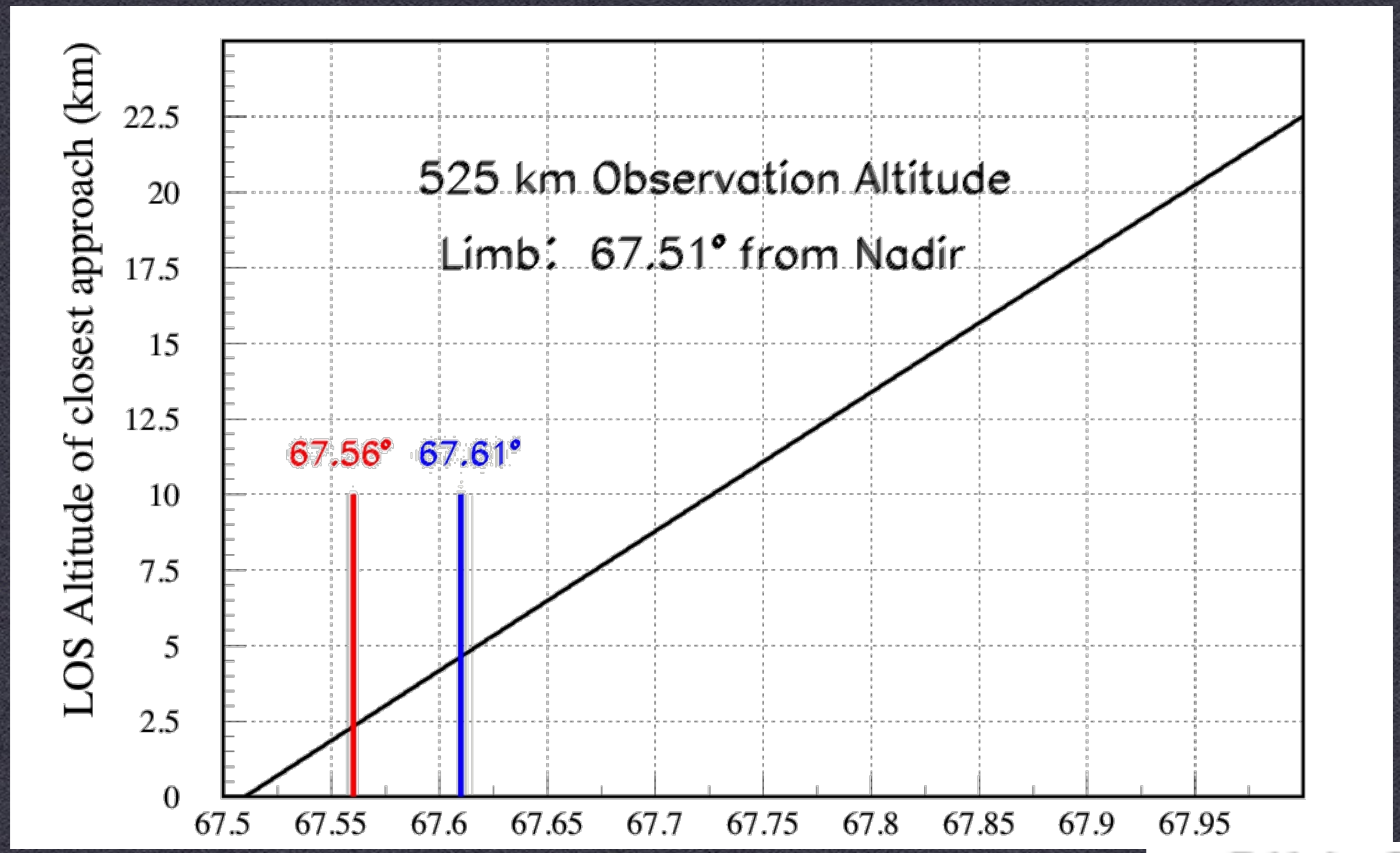


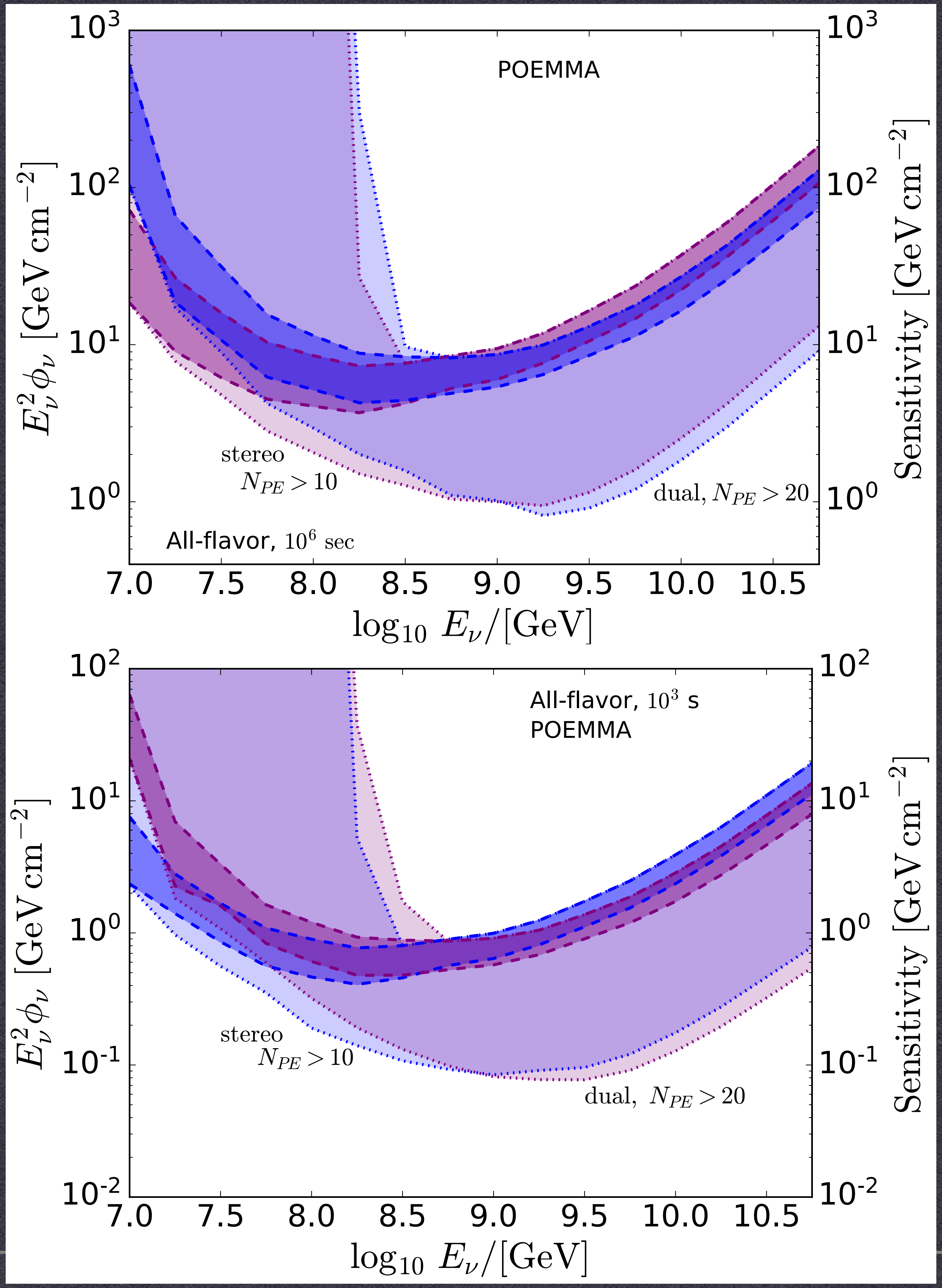
Table I. Comparison of Calculated Total Refraction Angles in Arc Minutes: (A) From Eq. (19); (B) From a Ray Trace Method; and (C) Their Difference

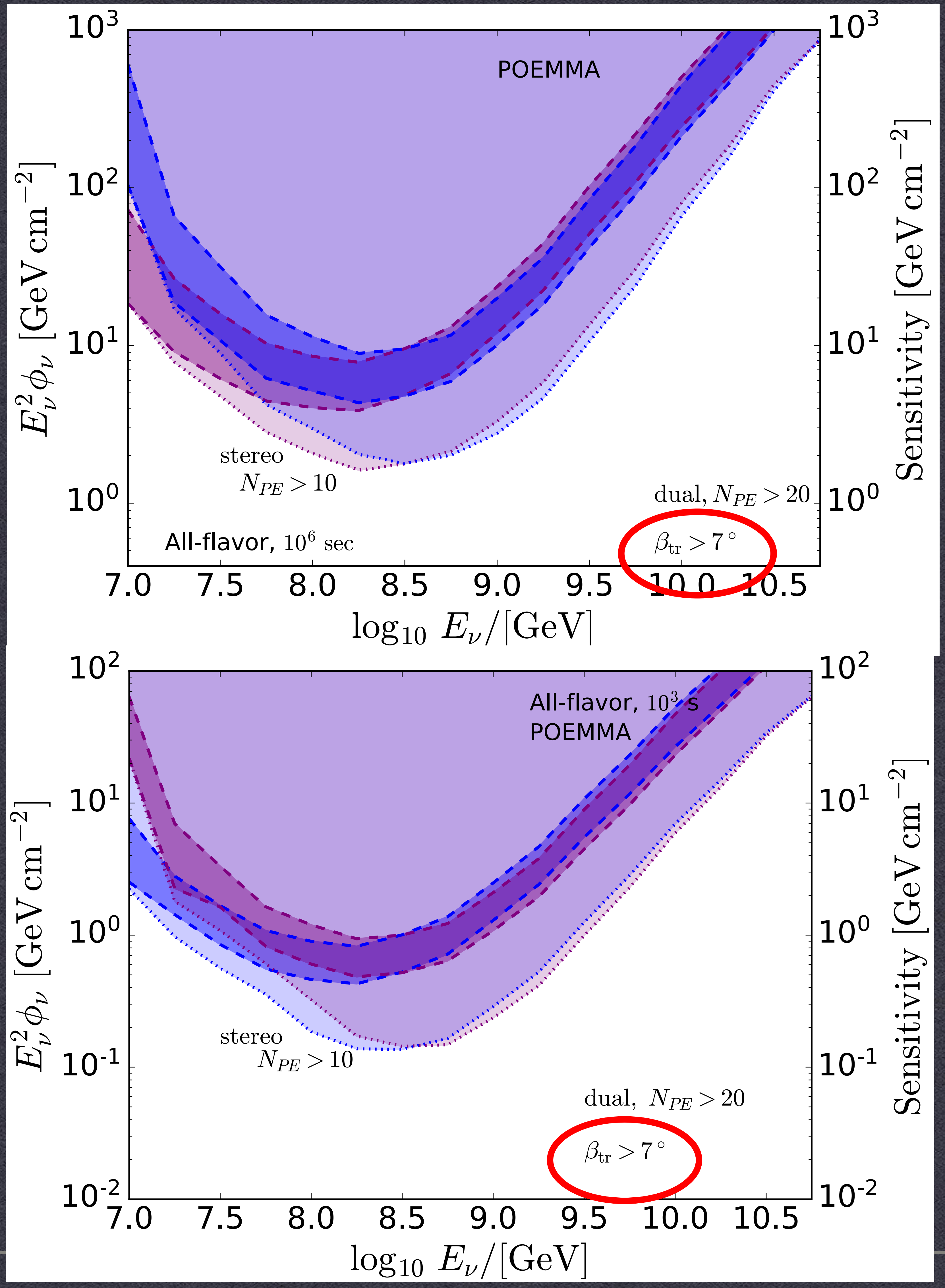
z_t(km)	A	B	C
0	66.147	66.242	−0.095
2	55.010	55.067	−0.057
4	45.445	45.481	−0.036
6	37.278	37.304	−0.026
8	30.378	30.399	−0.021
10	24.753	24.775	−0.022
12	19.858	19.883	−0.025
14	14.375	14.384	−0.009
16	10.429	10.432	−0.003
18	7.583	7.583	—
20	5.566	5.566	—
25	2.454	2.454	—
30	1.108	1.108	—
35	0.501	0.501	—
40	0.228	0.228	—
45	0.108	0.108	—

Chu (Applied Optics, 22, 5, 1983)

- ToO "Zone of Avoidance"
  - Atm. refraction: $\theta_{min} \rightarrow \theta_{max}$ for ToO
  - $\theta_{max} \sim 1°$ below the limb

Impact of Above-the-Limb Background





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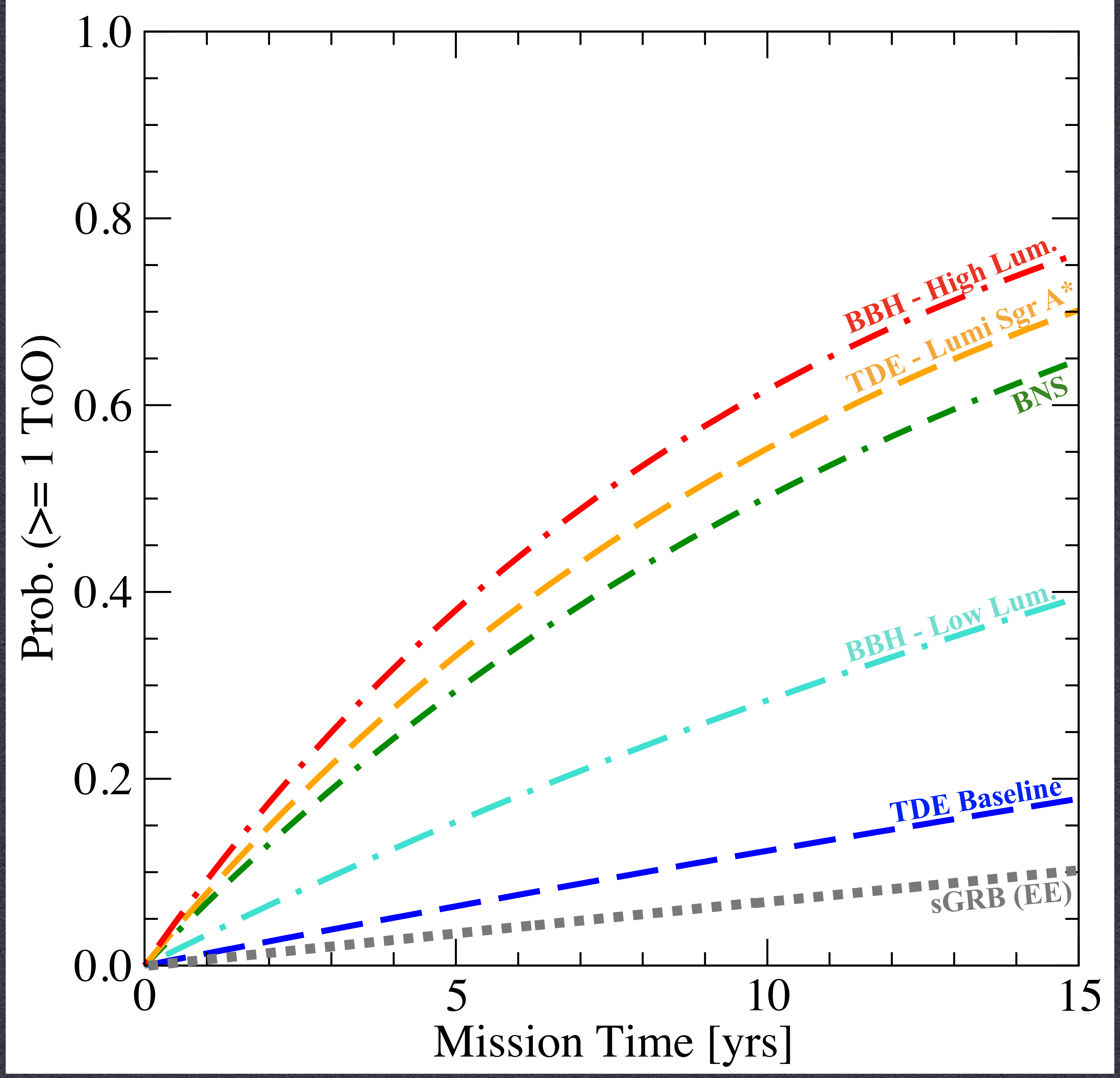
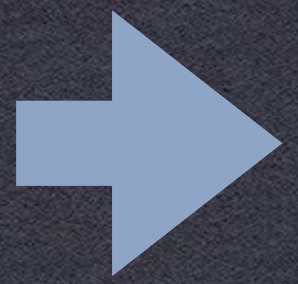
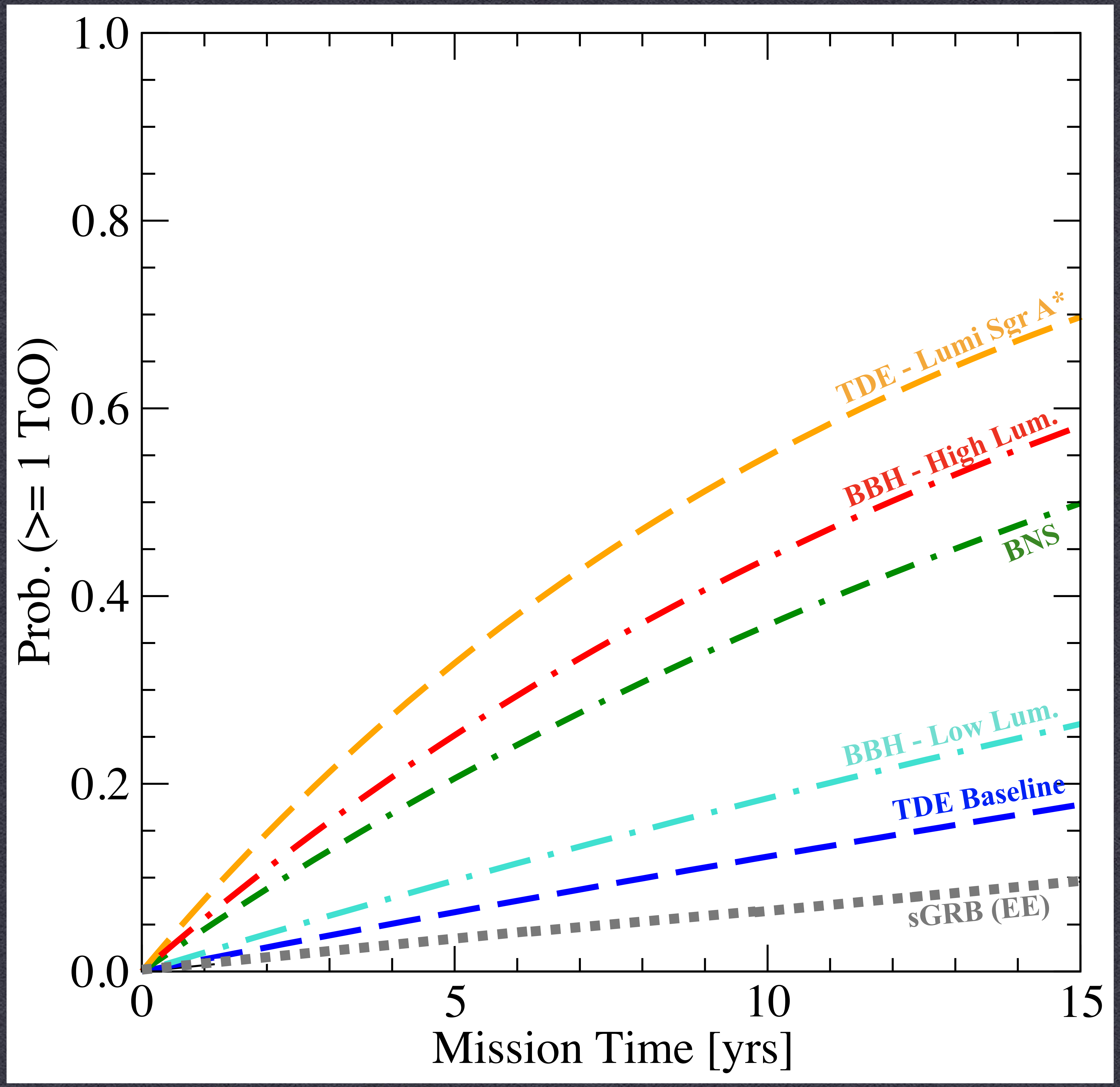


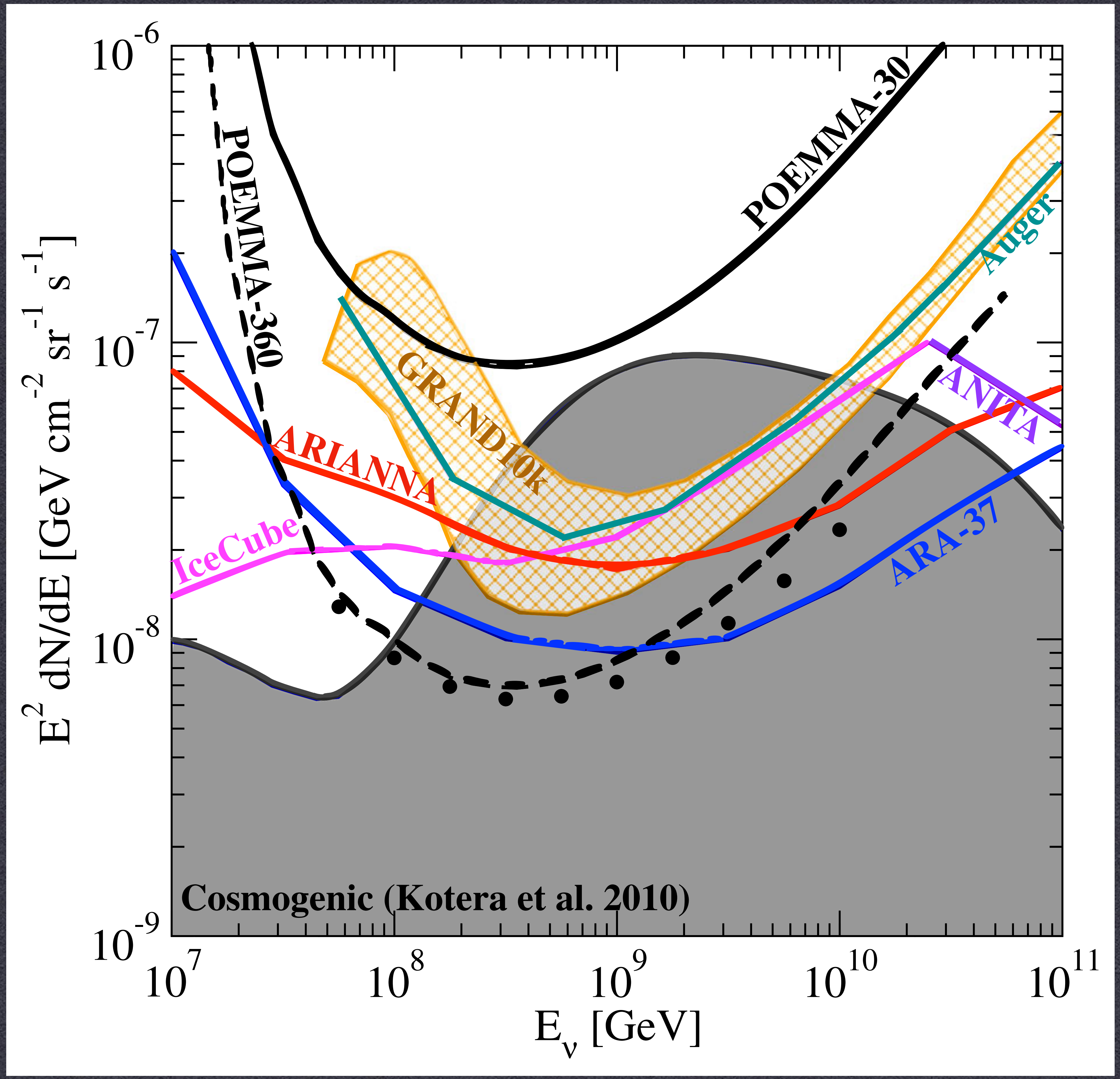




Reduction in ν events ~ few — 25%

Backgrounds

- Diffuse Astrophysical Neutrino Flux: $\lesssim 3 \times 10^{-4}$ events per ToO observation
- Reflected Cherenkov signals from UHECR EASs
  - Ground: pulse duration ~ hundreds ns (expected ν_τ pulse duration ~ 20 ns)
  - Clouds: real-time atmospheric monitoring will allow rejection
- Direct Cherenkov signals from over-the-horizon UHECR EASs —
  - Largest contribution when source is within ~ $2 \times \theta_{Ch}$ of the Earth's limb
  - Measurements from EUSO-SPB2 forthcoming
  - Simulation work in progress

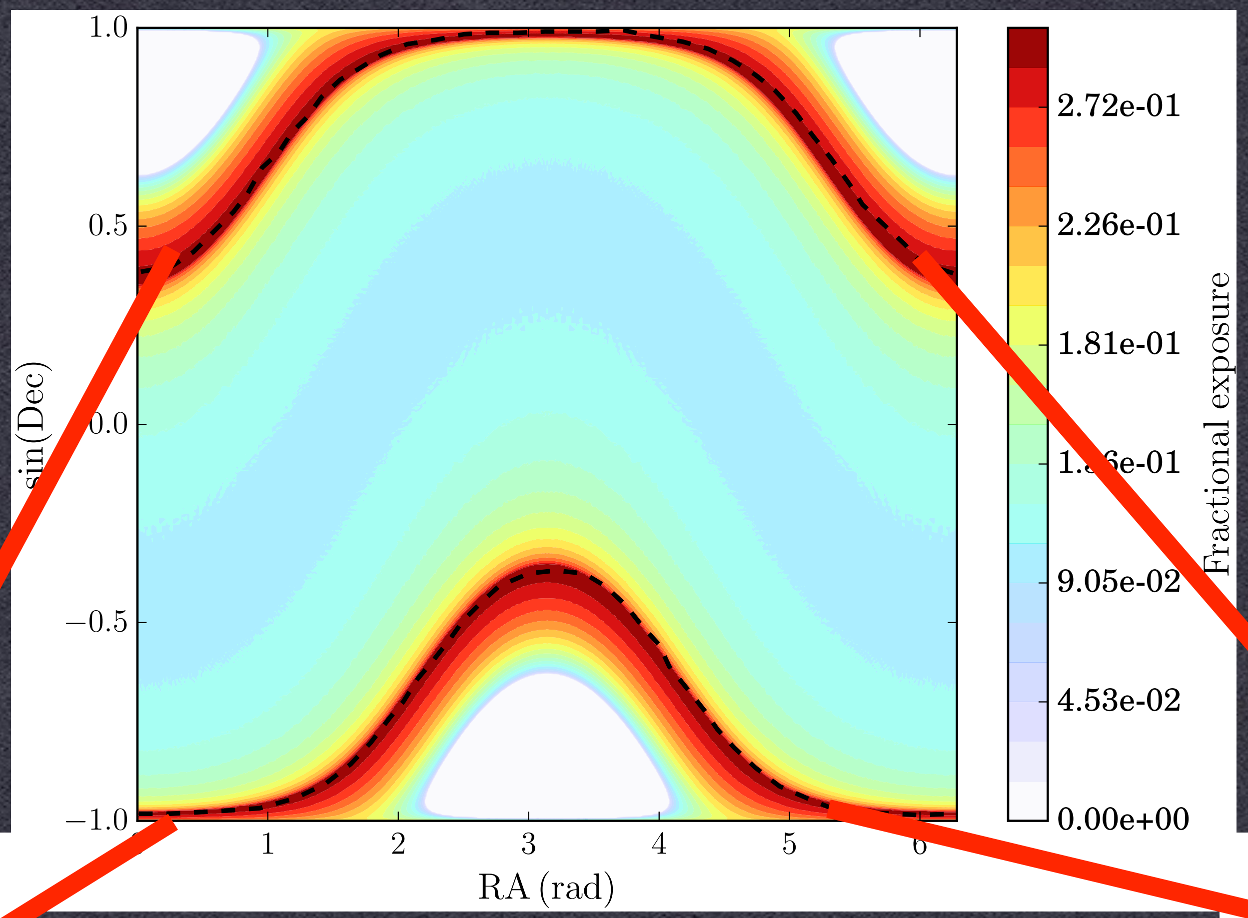


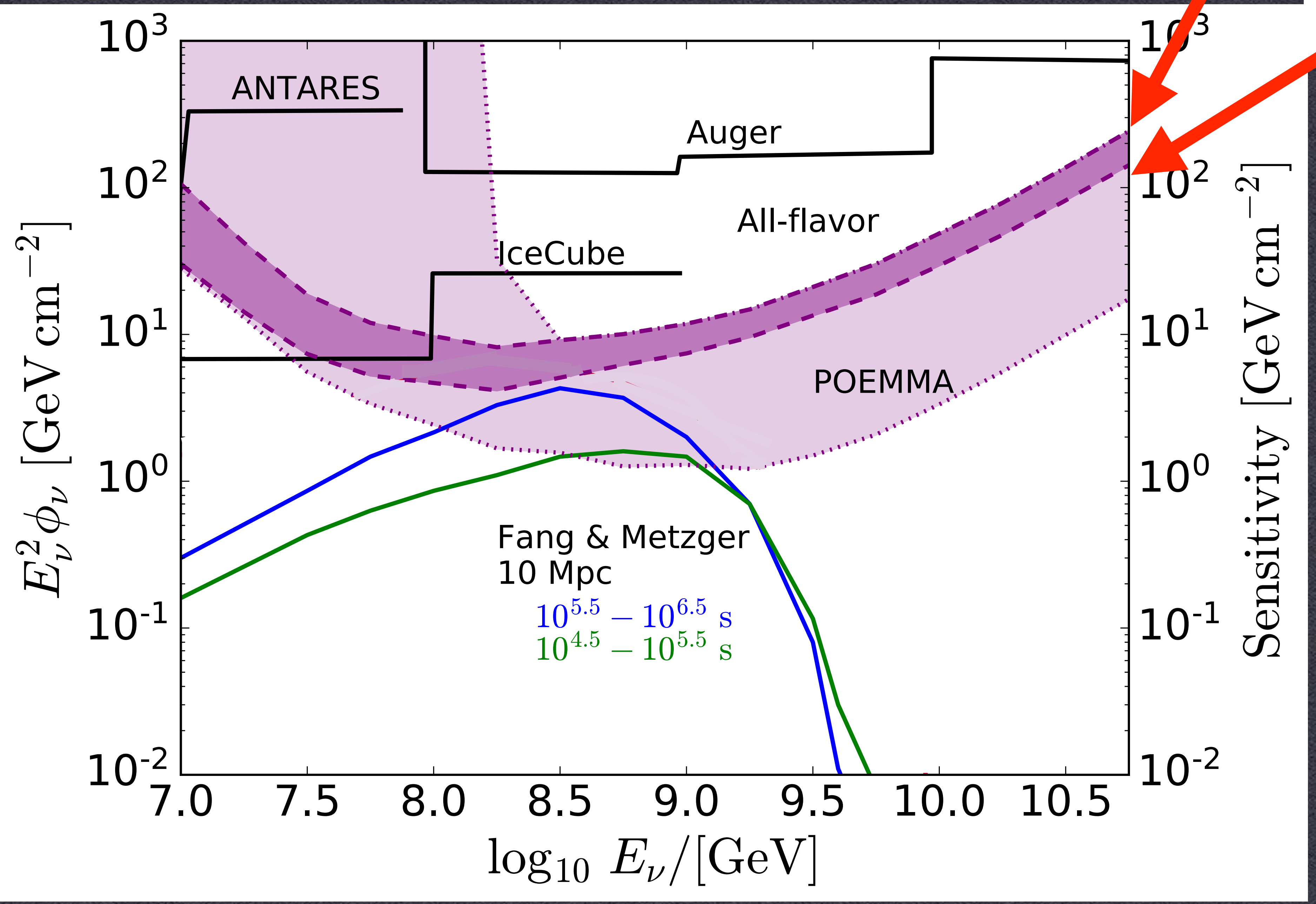
Reno, Krizmanic, & TMV 2019

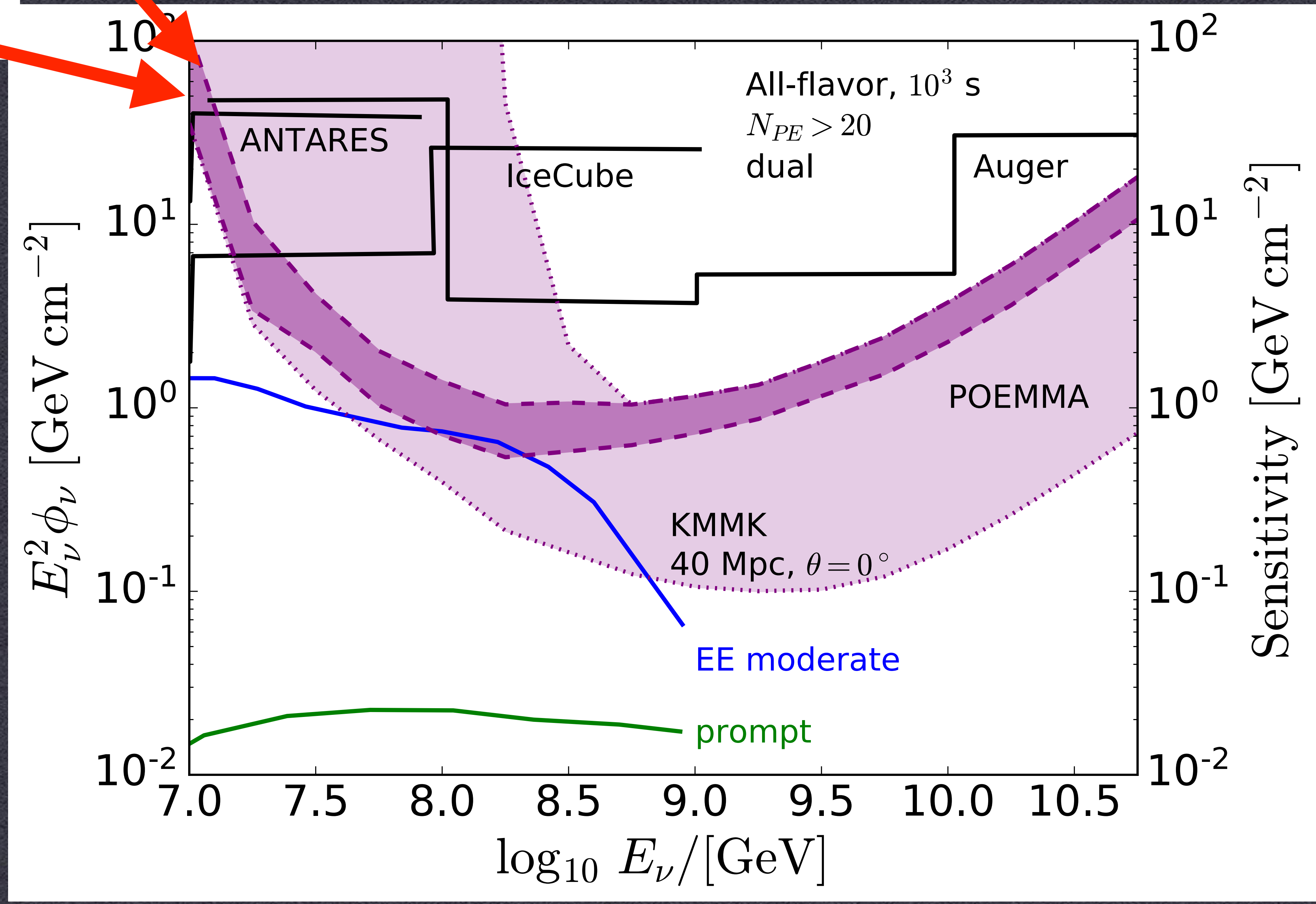
ToO Sensitivity

Long Duration

Short Duration

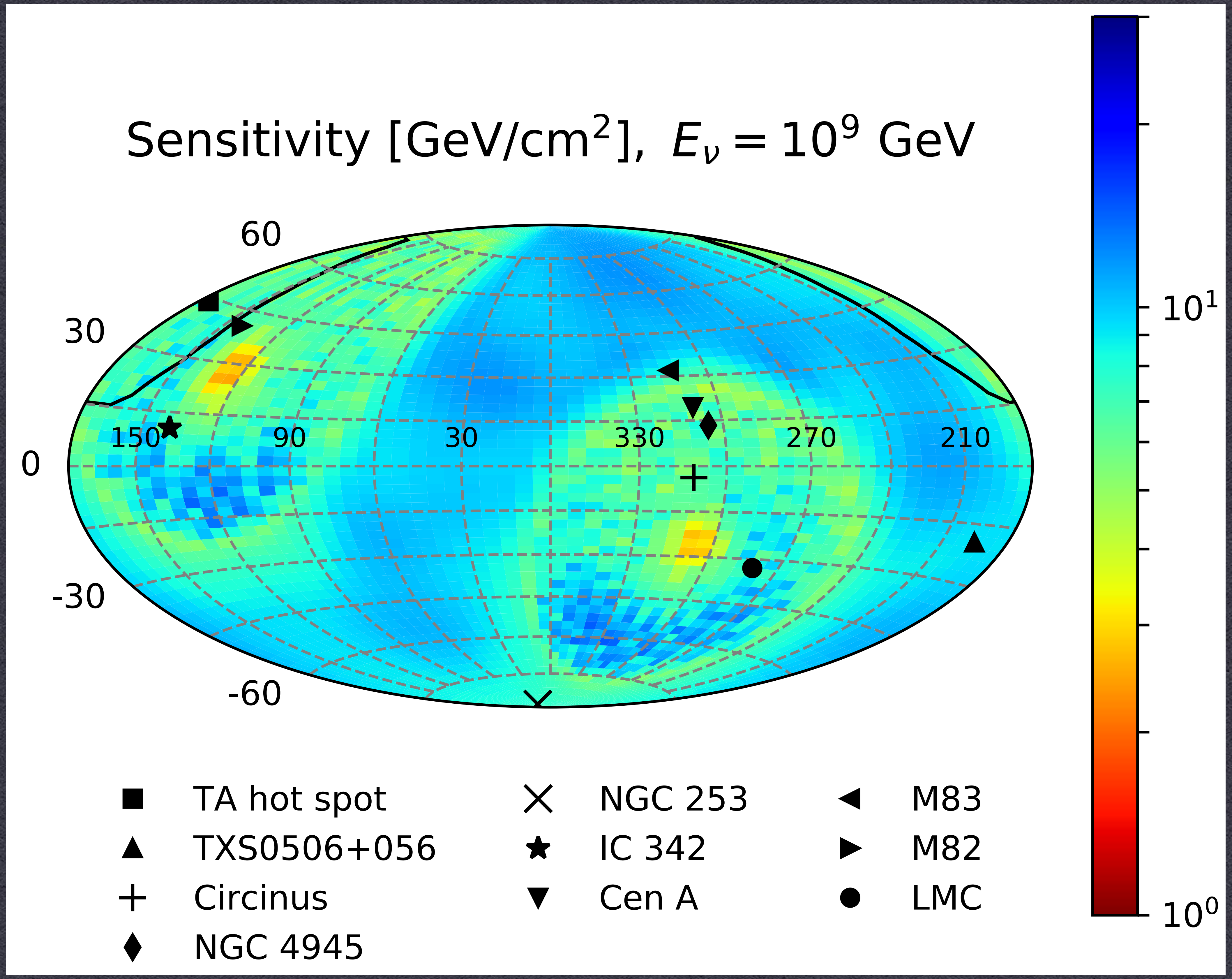




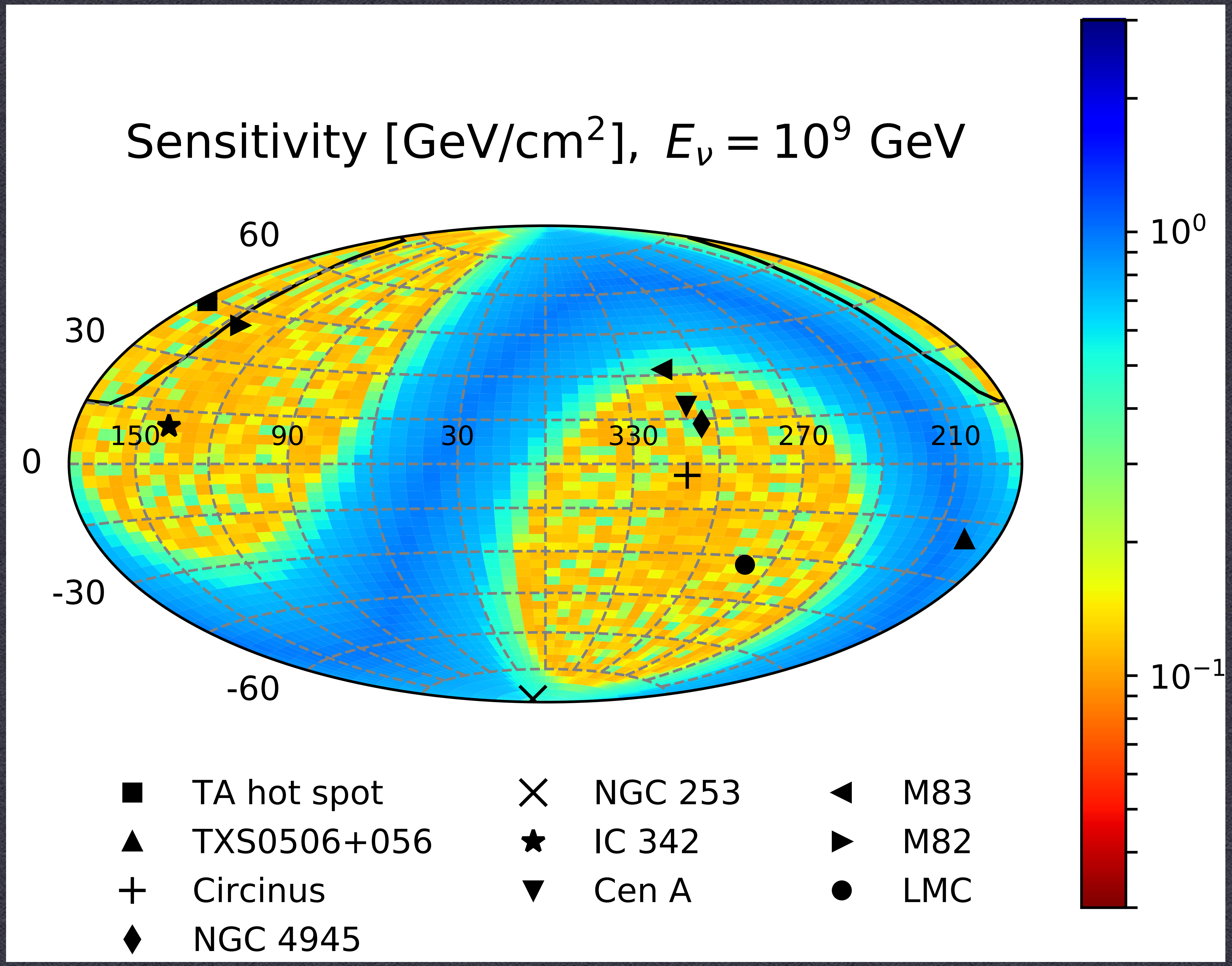


ToO Sensitivity Sky Plots

Long Duration

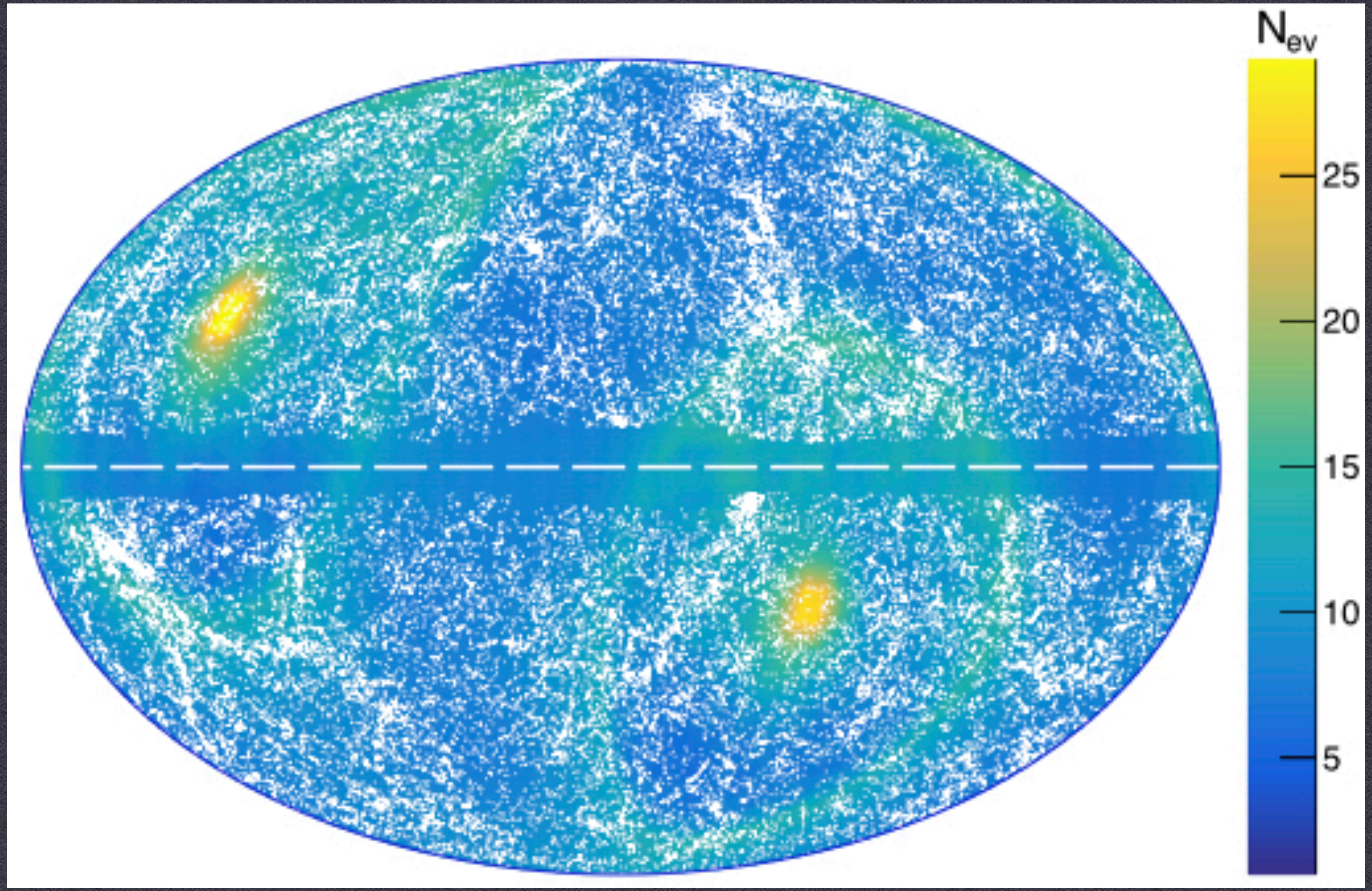


Short Duration



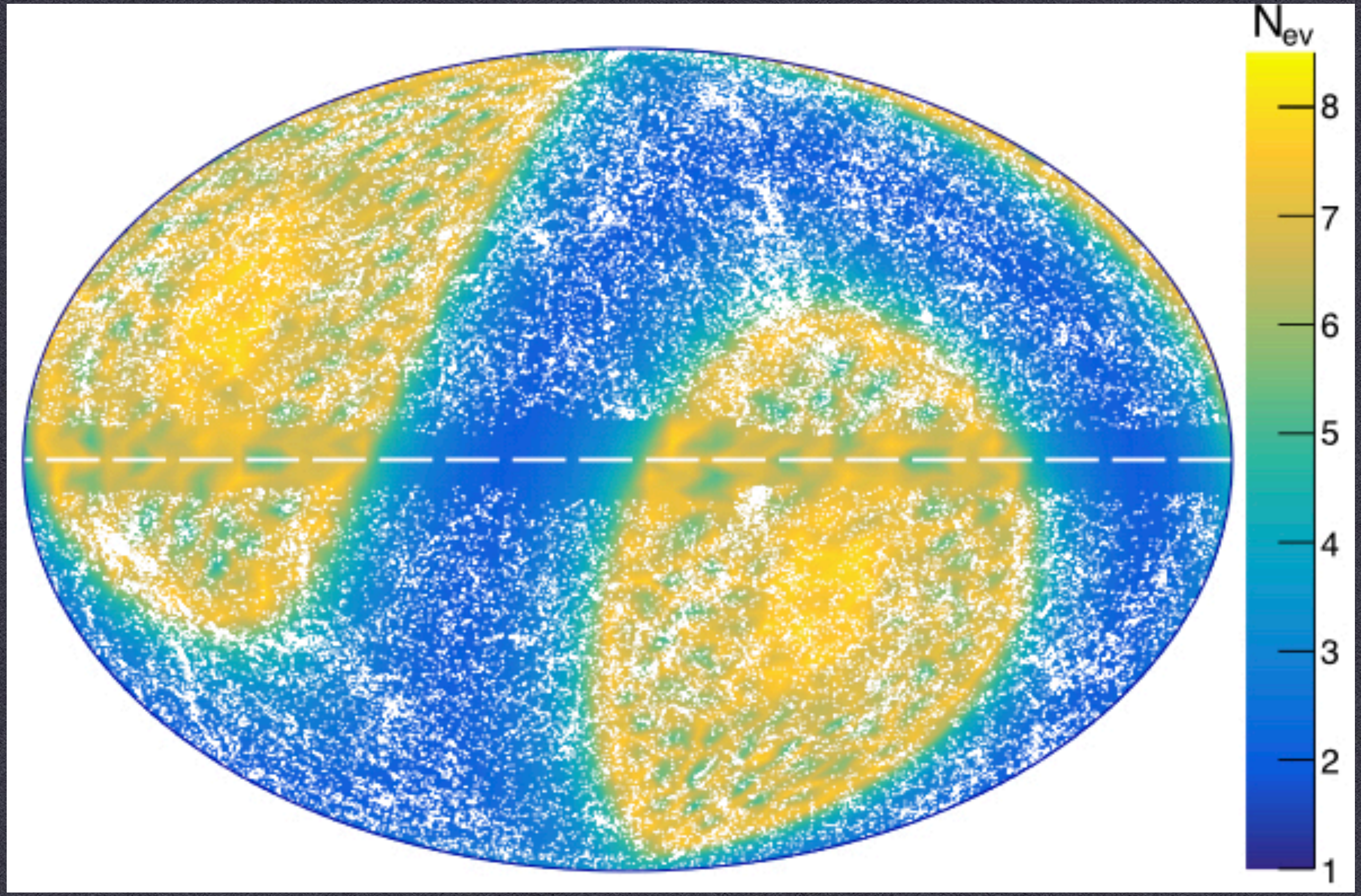
Numbers of Events

Long Duration



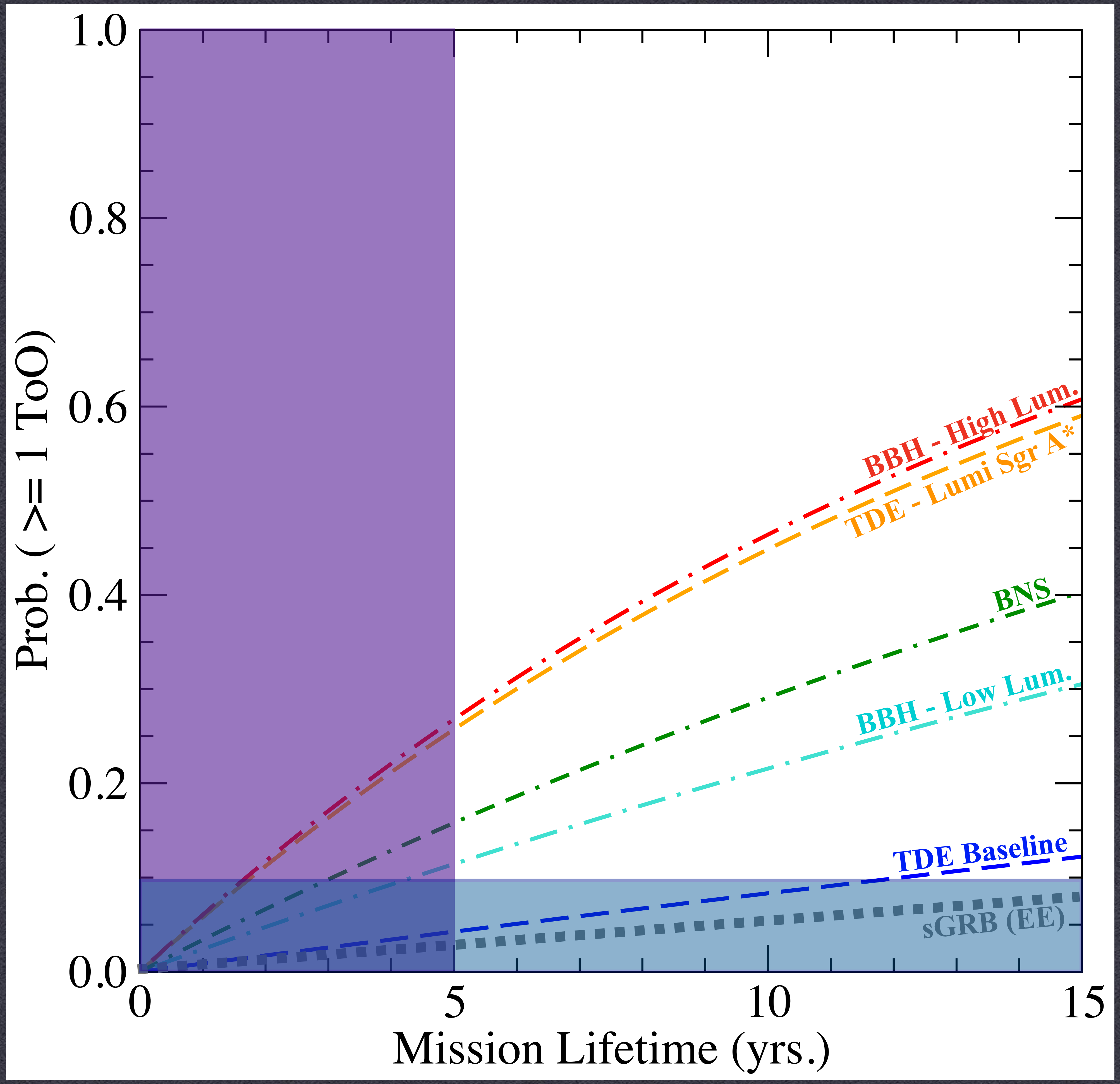
- Model: Fang & Metzger (2017) BNS Merger
- Source distance: 5 Mpc

Short Duration



- Model: Kimura+ (2017) sGRB w/ Mod. EE
- Source distance: 40 Mpc

Most Promising Source Classes



Poisson probability

Long Bursts

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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.