The Targets of Opportunity Source Catalog for the EUSO-SPB2 Mission

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Introduction

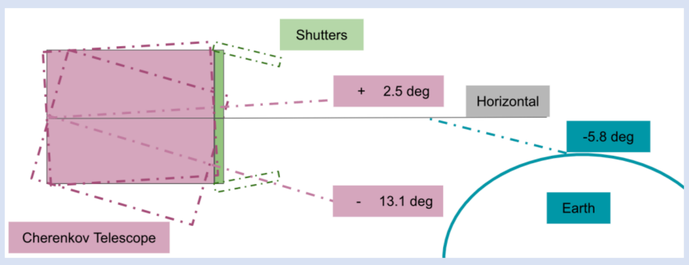
The Extreme Universe Space Observatory on a Super Pressure Balloon 2 (EUSO-SPB2) searched for ultra high energy cosmic rays and very high energy (VHE) neutrinos from suborbital space with two telescopes[1]

The Fluorescence Telescope (FT)[2]:
- Points down
- Records fluorescence light from cosmic ray EASs with energies >1EeV

The Cherenkov Telescope (CT)[2,3]:
- Points near the Earth's limb
- Below the limb, follows up on Targets of Opportunity (ToOs) from astrophysical transient sources by searching for upwards-going Cherenkov emission from PeV-scale extensive air showers (EASs) induced by tau neutrinos

EUSO-SPB2 Benefits

Ground-based Detectors Vs **Suborbital and Space-based Detectors**
- At PeV energies, much of the sky becomes inaccessible to ground-based detectors because of Earth attenuation effects
- EUSO-SPB2 pioneers a solution to the attenuation problem
- Overcomes a restricted field of view
- Has the ability to respond to alerts of potential neutrino alerts throughout



The CT utilizes a tilt and rotation system to follow up on ToOs. The CT achieves a field of view of 6.4 degrees in altitude and 12.8 degrees in azimuth. The entire payload can be rotated 360 degrees in azimuth and the CT can be tilted over a range of 15.6 degrees

Astrophysical Sources of Interest

ToO sources of interest for EUSO-SPB2:
- galactic and extra-galactic supernovae
- binary neutron star mergers
- neutron star-black hole mergers
- nearby tidal disruption events
- flaring blazars
- gamma-ray bursts
- other transients

ToO Catalog for EUSO-SPB2

Goal: to optimize the scientific reach of the ToO program within the operational parameters of the EUSO-SPB2 mission

A catalog of sources was developed from the three preexisting alert systems broadcast from various observatories and instruments:
- Gamma-ray Coordination Network (GCN) - sorted by a python script
- Transient Name Server (TNS) - sorted by a python script
- Astronomer's Telegram (ATel) - sorted by hand

The catalog also includes a list of steady sources

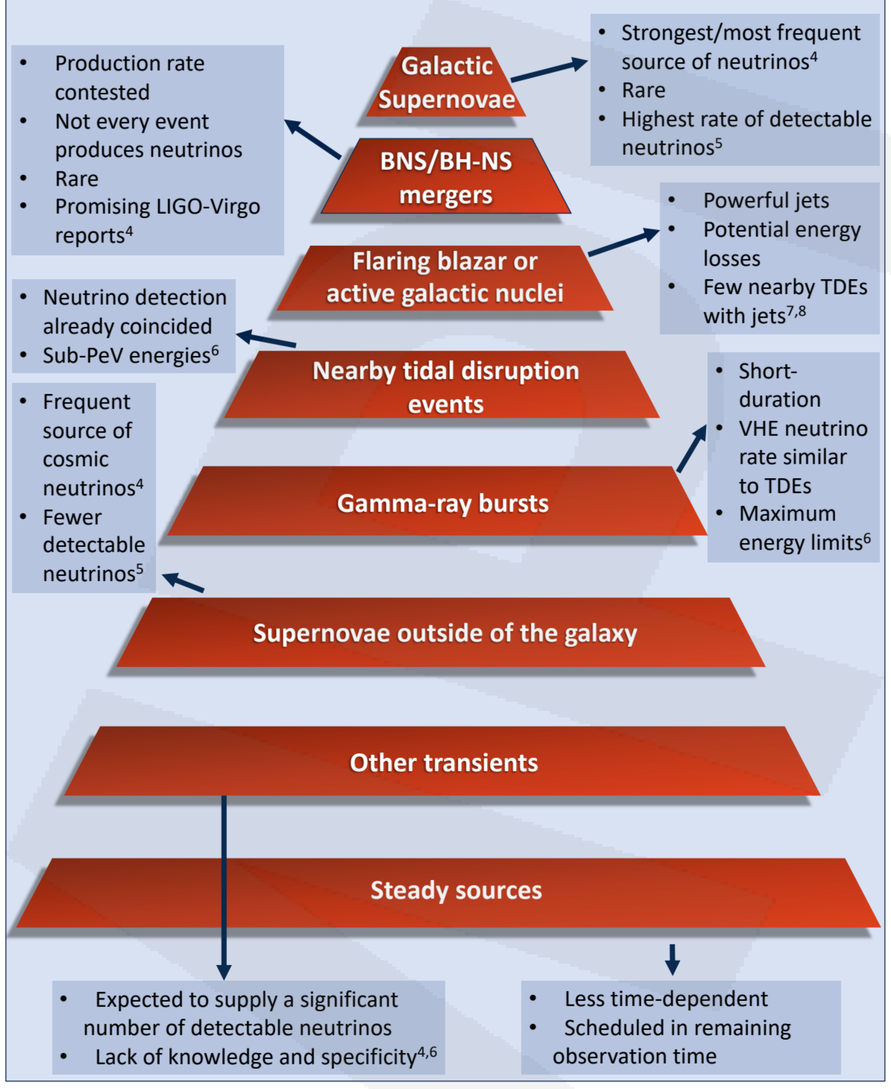
Catalog Entries:
- Reported observation time
- Reported observation coordinates
- Redshift (if available)
- Priority value

User interface: used to manually enter new source alert information at the time of observation

Steady HBL	Steady Hotspot	Steady HBL	Steady HBL
PKS 0548-322	Old TA Hotspot	RX J0648	H 1722+119
(-9.00, 221.58)	(-9.00, 130.12)	(-9.00, 282.20)	(-9.00, 81.59)
Steady HBL	**Steady Seyfert**	**Steady HBL**	**Steady HBL**
1ES 0347-121	NGC 253	HESS J1943-213	SHBL J001355.9-18540
(-9.00, 249.35)	(-9.00, 130.12)	(-9.00, 70.46)	(-9.00, 120.82)
Steady HBL	**Steady Blazar**	**Steady HBL**	**Steady HBL**
1ES 1011+496	Mrk 421	1ES 1215+303	H 2356-309
(-9.00, 324.05)	(-9.00, 310.25	(-9.00, 301.54)	(-9.00, 135.74
Steady HBL	**Steady Blazar**	**Steady HBL**	**Steady HBL**
1ES 0806+524	Mrk 501	1ES 1741+196	PKS 0301-243
(-9.00, 328.00)	(-9.00, 48.15)	(-9.00, 72.53)	(-9.00, 234.45)
Steady HBL	**Steady Blazar**	**Steady HBL**	**Steady HBL**
RGB J0710+591	BL Lacertae	1ES 1727+502	PKS 0447-439
(-9.00, 335.61)	(-9.00, 44.36)	(-9.00,c34.65)	(-9.00, 199.47)
Steady HBL	**Steady HBL**	**Steady HBL**	**Steady HBL**
1ES 0414+009	PKS 2155-304	KUV 00311-1938	1ES 1218+304
(-9.00, 265.72)	(-9.00, 135.28)	(-9.00, 123.38)	(-9.00, 302.11)

ToO Prioritization for EUSO-SPB2

- Source catalog typically contains ~150 ToOs
- Each night, it is possible for more than 10 of these ToOs to fulfill observability criteria
- CT can only repoint to 4-5 sources each night

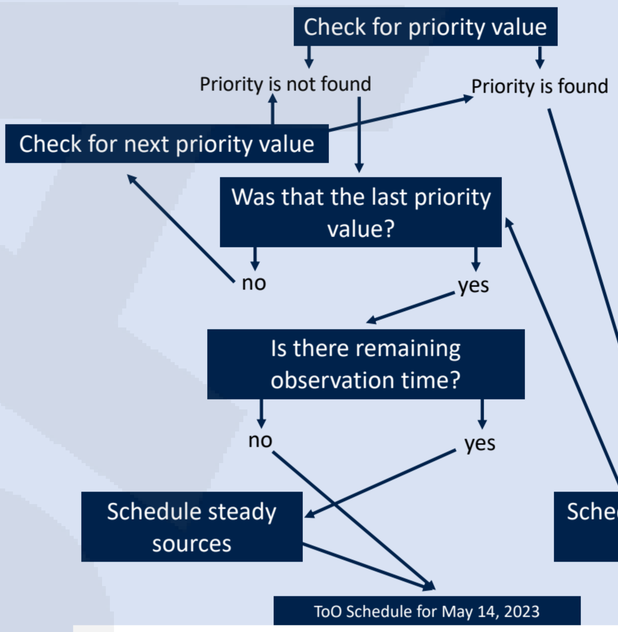


ToO Scheduler

- Takes entries from the ToO catalog
- Compares their daily trajectories with the CT trajectory
- Calculates the time and location of when the ToO will cross the detector's field of view

Out of the tens of sources that cross into the detector's field of view during a nightly observation run (4-5 hours), only 4-5 may be scheduled

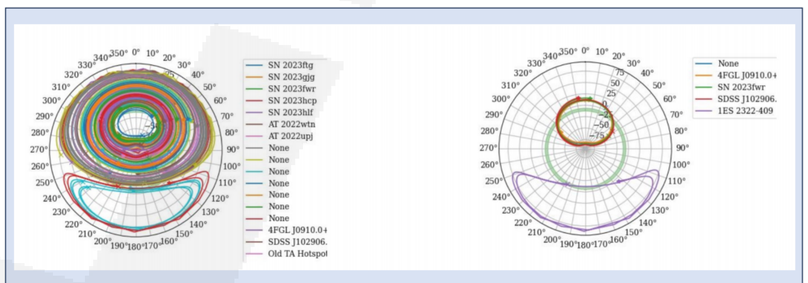
The prioritization scheme is used to trim down the observable ToOs to fit the observation run schedule



ToO Schedule for May 14, 2023

Source type, name	Pointing (az)	Move time	Start time	End time
AGN, SDSS J102906.69+555625.2	47.19°	05:00	05:10	05:30
Steady FRB, FRB 20181119A	6.23°	05:30	05:40	06:10
SN II, SN 2023ftg	81.76°	06:10	06:20	06:50
AGN, 4FGL J0910.0+4257	315.96°	07:50	08:00	08:40
GRB, GRB230503A	187.66°	09:10	09:20	10:40

Results



The EUSO-SPB2 flew with a live prioritized catalog of potential neutrino sources to point the CT at. On the left: An example of the trajectories of ToOs in the EUSO-SPB2 Cherenkov detector field of view before prioritization on May 14, 2023. On the right: the trajectories of ToOs in the EUSO-SPB2 Cherenkov detector field of view after prioritization on May 14, 2023. The green circle on each of these plots represents the field of view, and the radius represents the altitude

Future Applications

- Useful application of the many alert systems from successful detectors
- Can be used for various missions aimed at observing VHE neutrinos - including a follow-up balloon mission to EUSO-SPB2
- Application to the trajectory of Mini-EUSO[9]
- Other balloon missions such as PUEO[10]
- Satellite missions such as Terzina[11] and POEMMA[12]

After the software is finalized and documented, it will be open source and available via GitHub.

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Related Posters and Talks

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