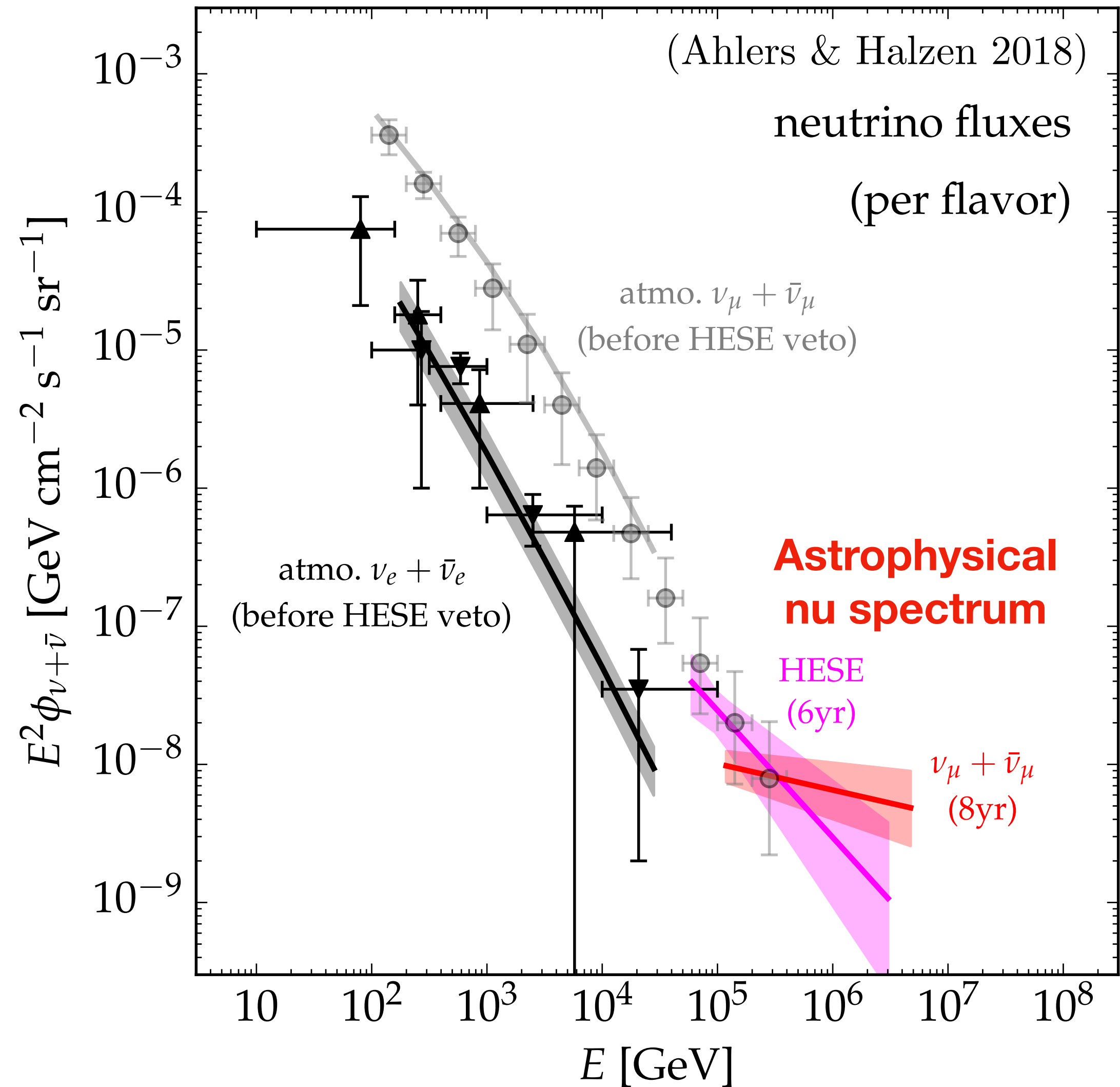# Identifying multiwavelength counterparts to astrophysical neutrino events

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Tenth International Fermi Symposium 2022

HIGH-ENERGY ASTROPHYSICAL NEUTRINOS

(Ahlers & Halzen 2018)
neutrino fluxes
(per flavor)

atmo. $\nu_\mu + \bar\nu_\mu$
(before HESE veto)

atmo. $\nu_e + \bar\nu_e$
(before HESE veto)

**Astrophysical
nu spectrum**

HESE
(6yr)

$\nu_\mu + \bar\nu_\mu$
(8yr)

- **Astrophysical neutrino flux detected by the IceCube neutrino observatory in the 10 TeV - 10 PeV energy range.**

- Atmospheric origin excluded at >8σ.

- Flux > 200 TeV consistent with a power-law spectrum with index ~ 2.2-2.8.

- Astrophysical flux dominates above ~200 TeV.

ASTROPHYSICAL NEUTRINOS – SKY DISTRIBUTION

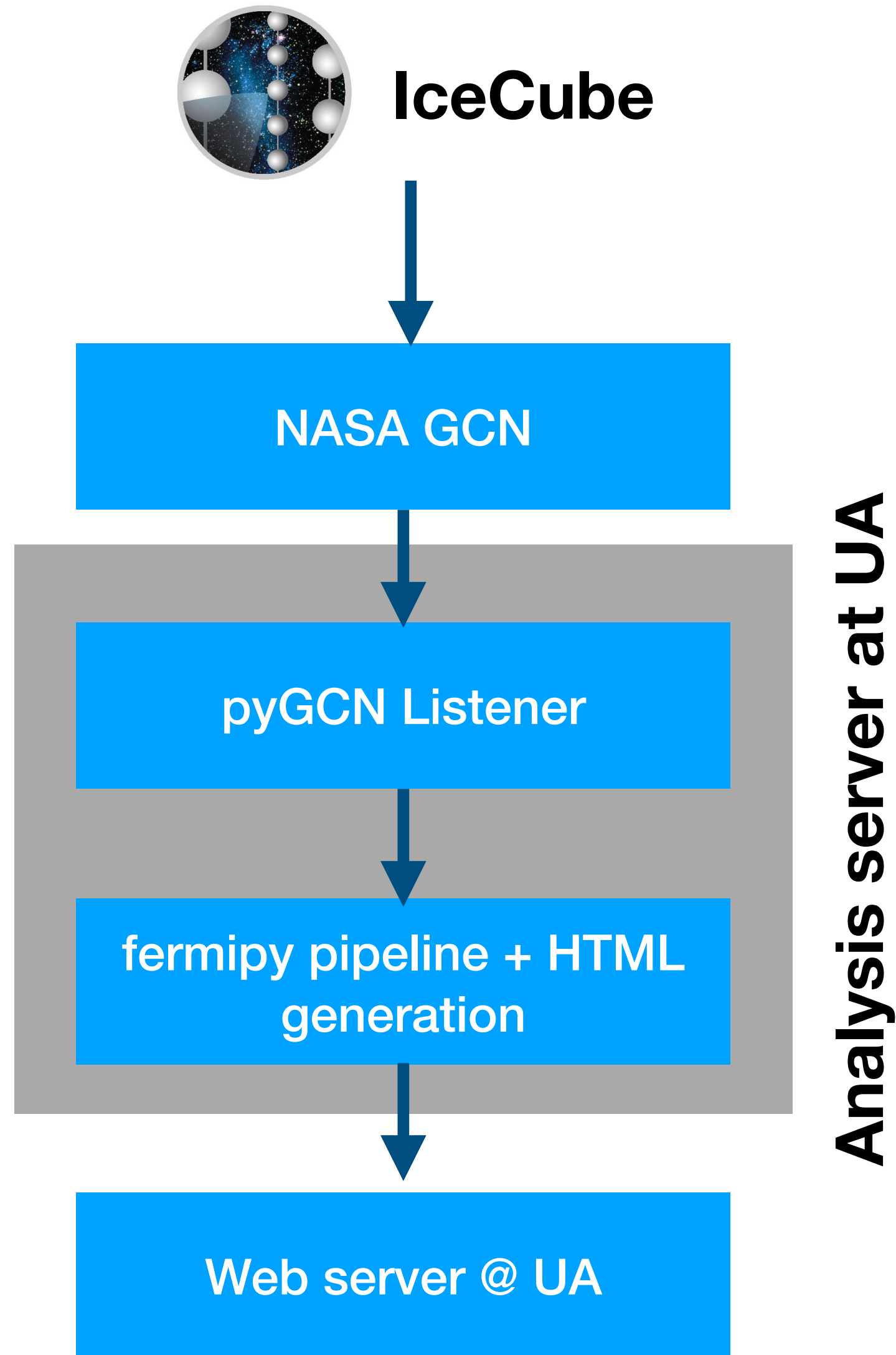
Arrival directions of most energetic neutrino events

IceCube-Gen2 arXiv/2008.04323
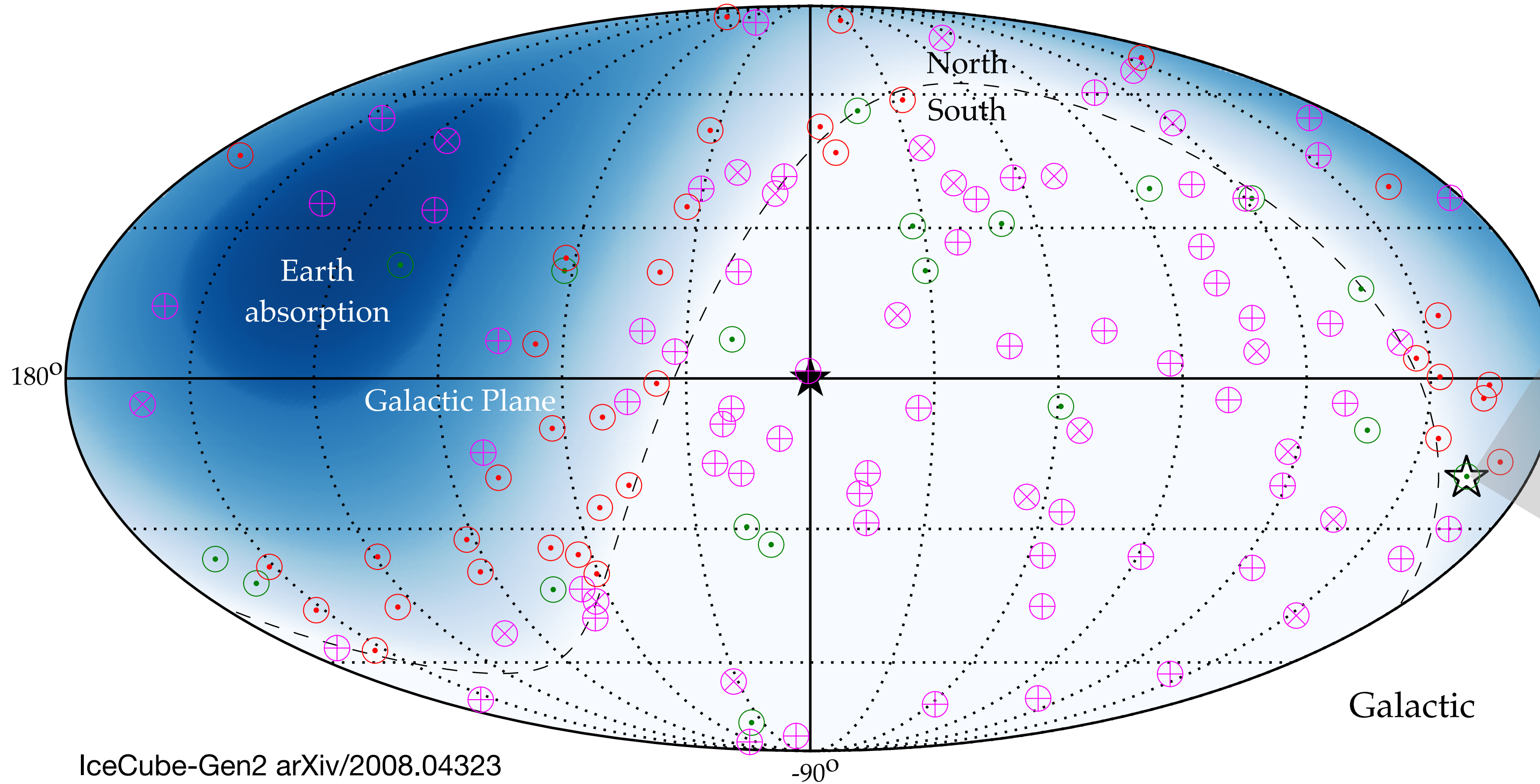
- **Low event rate (~O(10) /year above 100 TeV).**

- Events are localized to ~1°. Enables searches for EM counterparts.

- Challenge: IceCube 4π sensitivity requires ToO observations and/or wide-field EM coverage.

NEUTRINO FOLLOW-UP PLANNING TOOL

- **Main goal is to address three questions:**

  - What's in the area of the neutrino event?

  - Is the region observable from your observatory?

  - **Anything interesting going on at that location?**

- **Main components of the tool:**

  - Perform automatic Fermi-LAT analysis of the neutrino ROI (see talk by Simone Garrappa on Tuesday) on multiple time scales (e.g. 1 month, 1 year, full mission).

  - Calculate visibilities for common follow-up instruments.

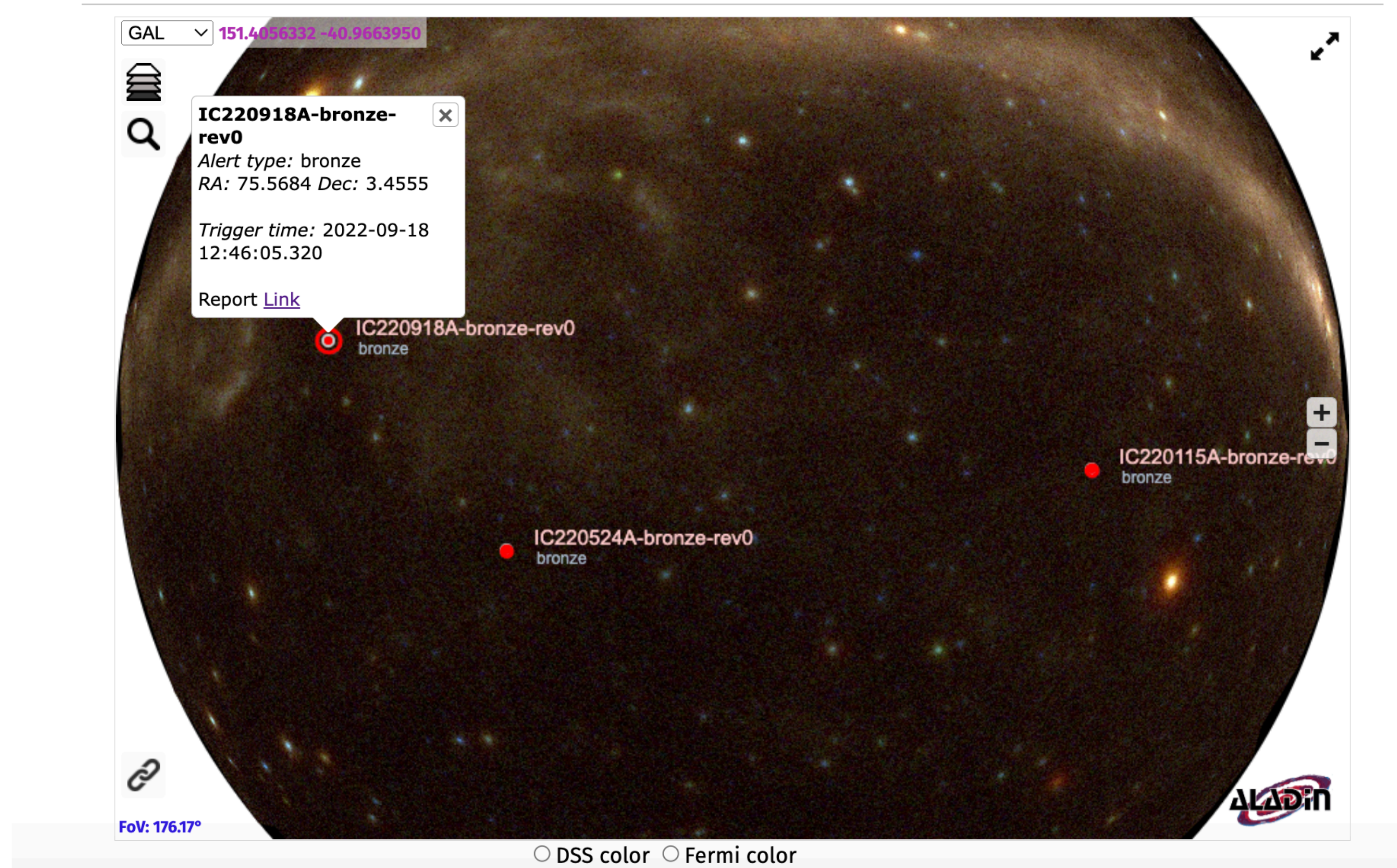 - Collect MWL archival data sources for known sources in the region.

PROCESSING PIPELINE

IceCube

Analysis server at UA

NASA GCN

pyGCN Listener

fermipy pipeline + HTML generation

Web server @ UA

- Listen for IceCube Gold/Bronze alerts coming through GCN (pygcn).

- Launch a fermipy automatic analysis pipeline. Python wrapper library provides HTML generation, visibility calculations (astropy).

- Results (HTML, FITS, images, etc) are mirrored to a web server, currently under testing.

Fermi-LAT follow-up of IceCube realtime alerts

http://multimessenger.ua.edu/fermi   Development version! (No release yet)

ALERT SUMMARY

IceCube realtime alert: IC220918A-bronze-rev0

Report generated (UTC):   2022-10-14 05:49:26
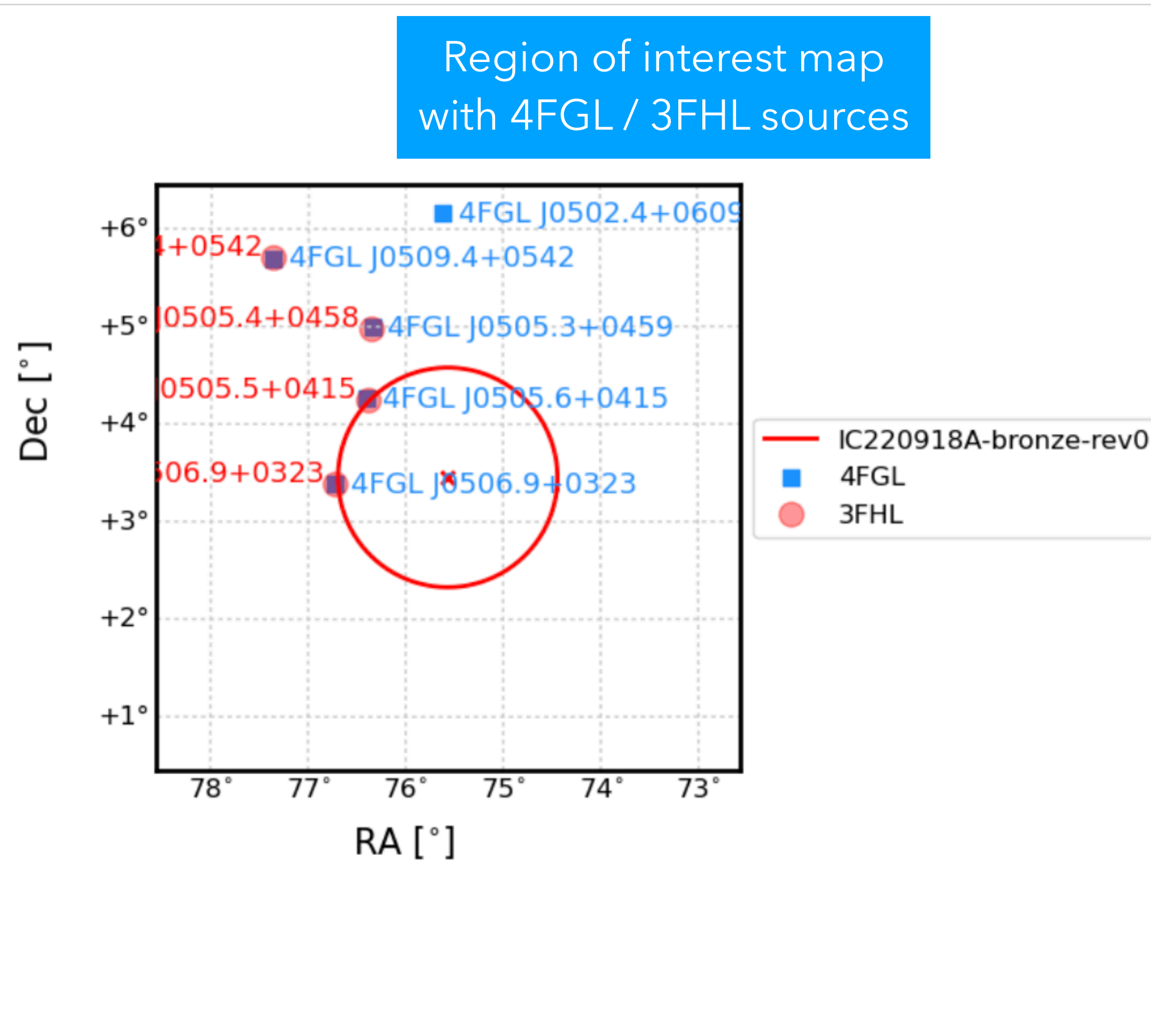Current time (UTC):   2022-10-14 06:13:36
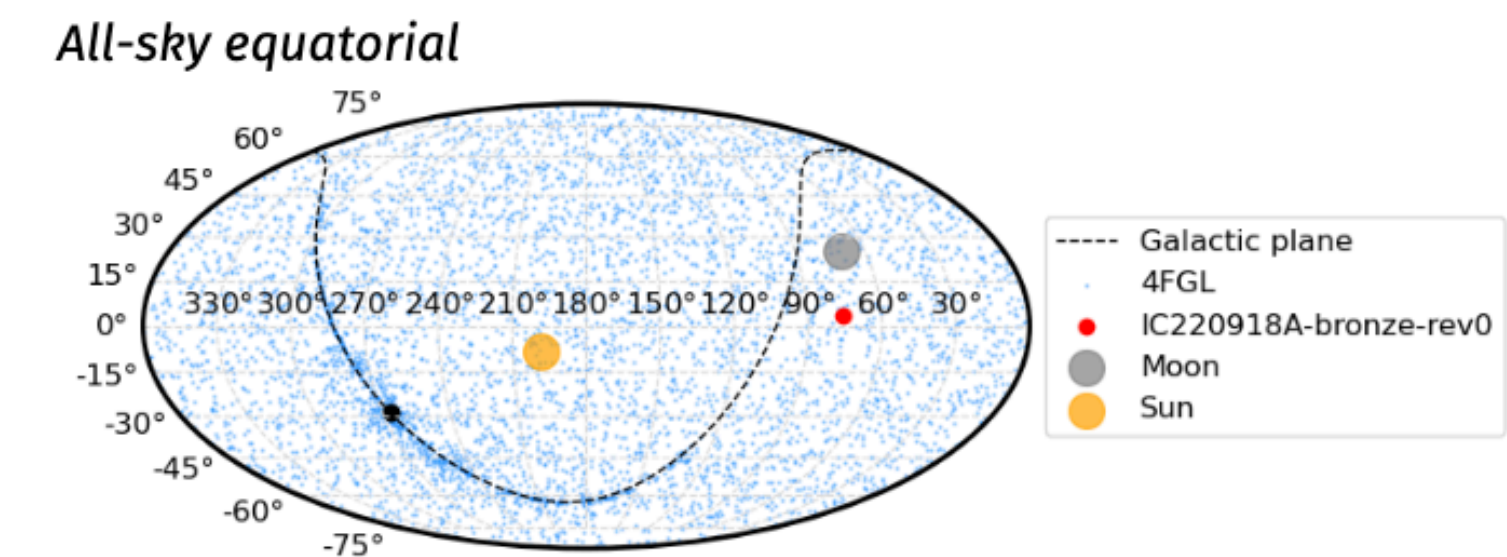
[Back to all alerts](#)

Alert properties

Event type:	bronze alert
RA (J2000) [deg]:	75.5684
Dec (J2000) [deg]:	3.4555
Error radius [deg]:	1.13
Trigger time:	2022-09-18 12:46:05.320
Run ID:	137065
Event ID:	22012496
GCN Notice:	[Link](#)

STATIC SKYMAPS

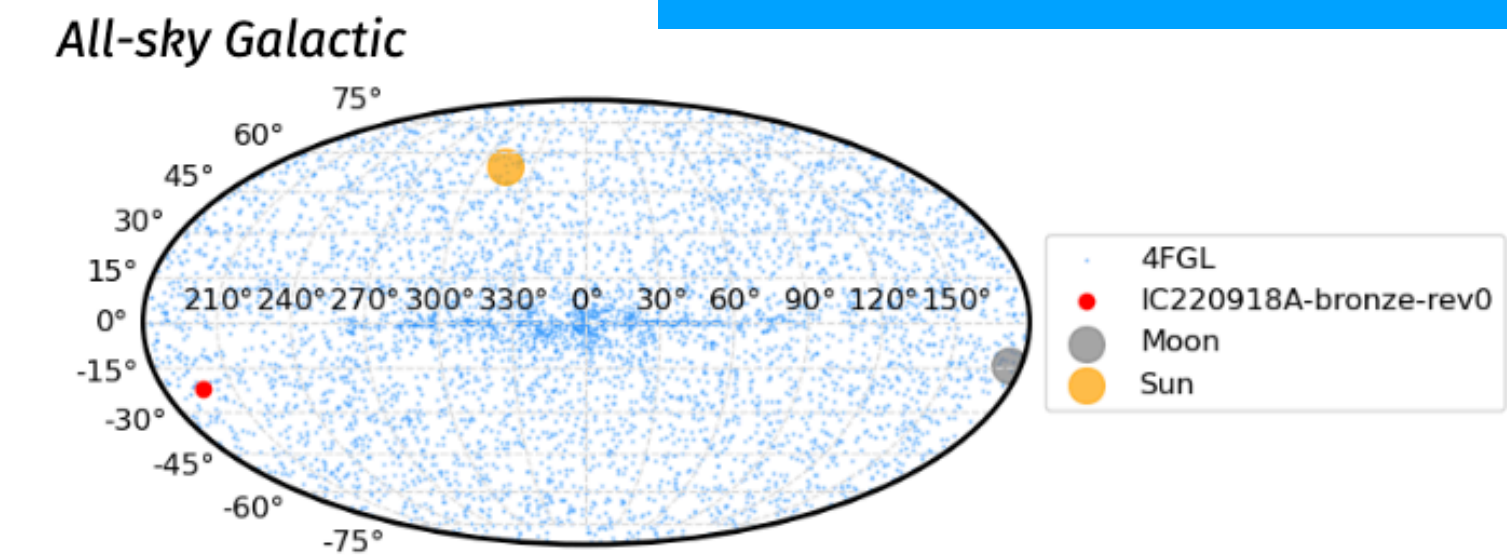## Skymaps

Region of interest map with 4FGL / 3FHL sources

All-sky equatorial map with Moon / Sun

All-sky Galactic map with Moon / Sun

NEARBY FERMI CATALOGUED SOURCES (4FGL-DR3, 3FHL)
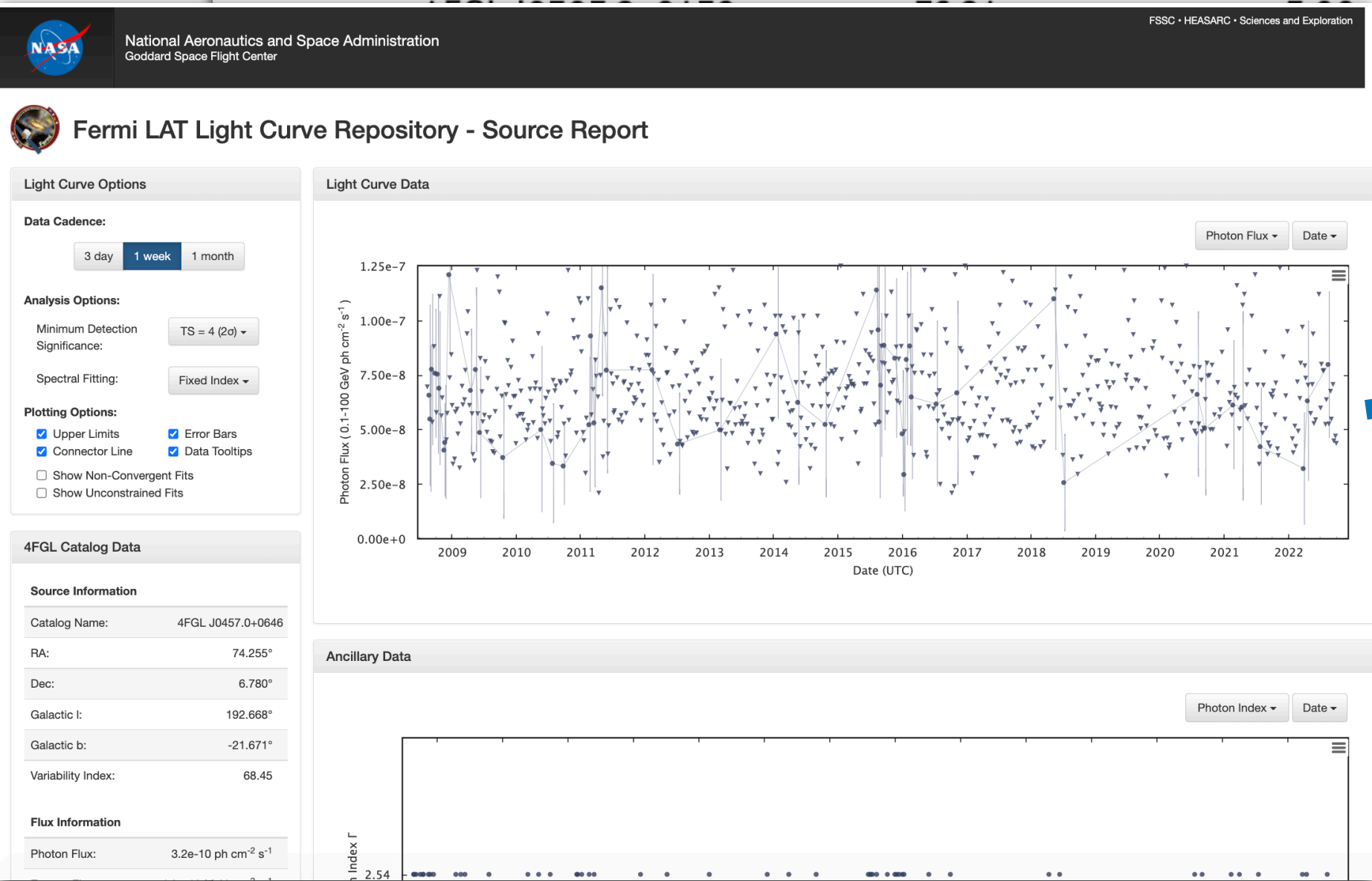

Nearby 4FGL sources

Fermi sources are shown within a 5 deg radius from the alert best-fit position. Sources contained within the error circle of the alert are highlighted in color. For sources with a known association, "Search Simbad" returns an identifier query using the association name listed (note that in many cases the association name is not resolved by Simbad). If no association is listed, return a radial search 0.3 deg around the Fermi source position.

Name	RA [deg]	Dec [deg]	Association	Search	Distance [deg]	MWL
4FGL J0505.6+0415	76.40	4.27	MG1 J050533+0415	Search Simbad	1.16	LCR FAVA DX
4FGL J0506.9+0323	76.73	3.39	2MASS J05065014+0323587	Search Simbad	1.16	LCR FAVA DX
			PKS 0502+049	Search Simbad	1.73	LCR FAVA DX
			PKS 0459+060	Search Simbad	2.71	LCR FAVA DX
			TXS 0506+056	Search Simbad	2.87	LCR FAVA DX
			4C +06.21	Search Simbad	3.57	LCR FAVA DX

Cone search in Simbad

Links to the **Light Curve Repository**, **FAVA**, and the **ASI SSDC Data Explorer**

fit position. Sources contained within the error circle of the alert are highlighted in color. For sources with a ing the association name listed (note that in many cases the association ermi source position.

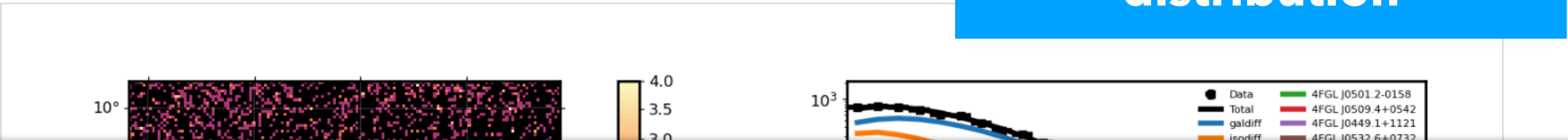|	Association	Search	Distance [d	
	MG1 J050533+0415	Search Simbad	1.15	
		Search Simbad	1.16	
	PKS 0502+049	Search Simbad	1.72	LCR FAVA DX
	TXS 0506+056	Search Simbad	2.88	LCR FAVA DX
3FHL J0509.4+0542	77.36	5.71		

FERMI-LAT ANALYSIS RESULTS

Fermi-LAT prompt analysis

Fermi-LAT analysis of the alert over two different timescales of one month and the full mission.

One month results

Counts map and energy distribution

TS map

Results per source

Best-fit values for known sources. Analysis result files

Fermi sources with a TS > 9 are included in this list. Links are provided for the spectral fits results as a plot, and in FITS and npy format.

| Name	RA [deg]	Dec [deg]	Distance [deg]	Spectrum type	TS	Flux [>100 MeV]	Result files
4FGL J0509.4+0542	77.36	5.70	2.87	LogParabola	131.29	5.406e-08	Spectrum plot FITS file npy file
4FGL J0501.2-0158	75.30	-1.97	5.44	LogParabola	106.98	1.709e-07	Spectrum plot FITS file npy file
4FGL J0449.1+1121	72.28	11.36	8.55	LogParabola	17.90	1.702e-07	Spectrum plot FITS file npy file
4FGL J0532.6+0732	83.17	7.55	8.60	LogParabola	11.23	4.329e-08	Spectrum plot FITS file npy file
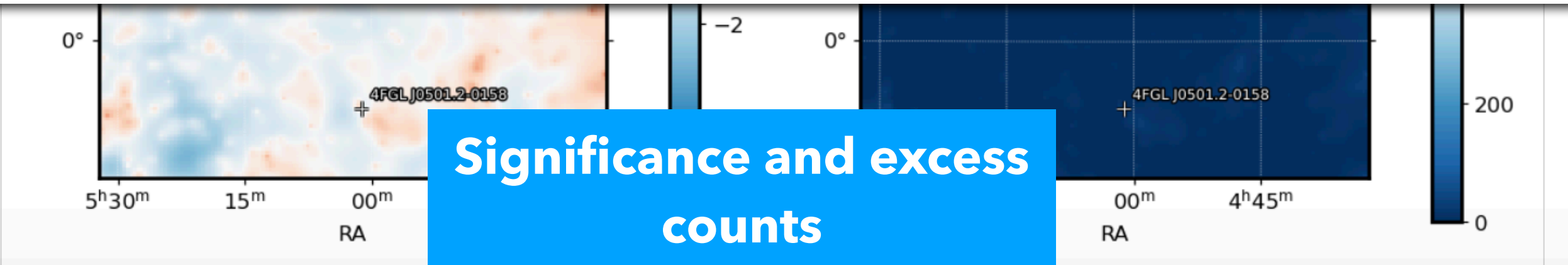
Significance and excess counts
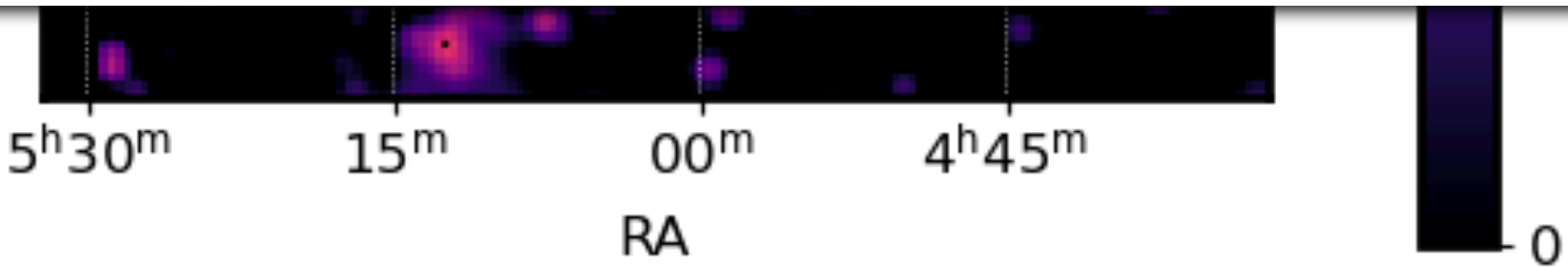
GEV PHOTONS

Fermi-LAT GeV photons

GeV photons observed from the direction of the alert over the last month
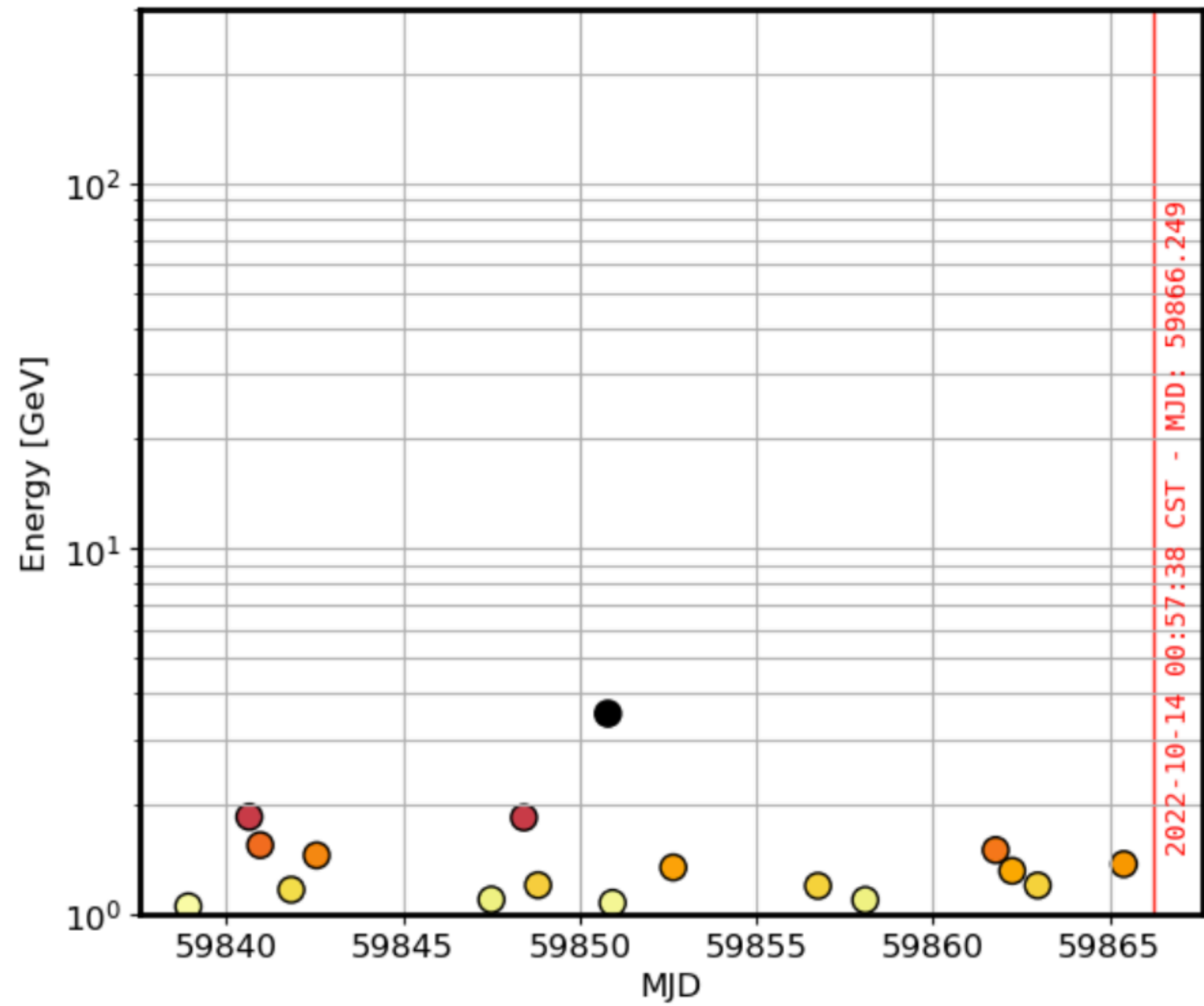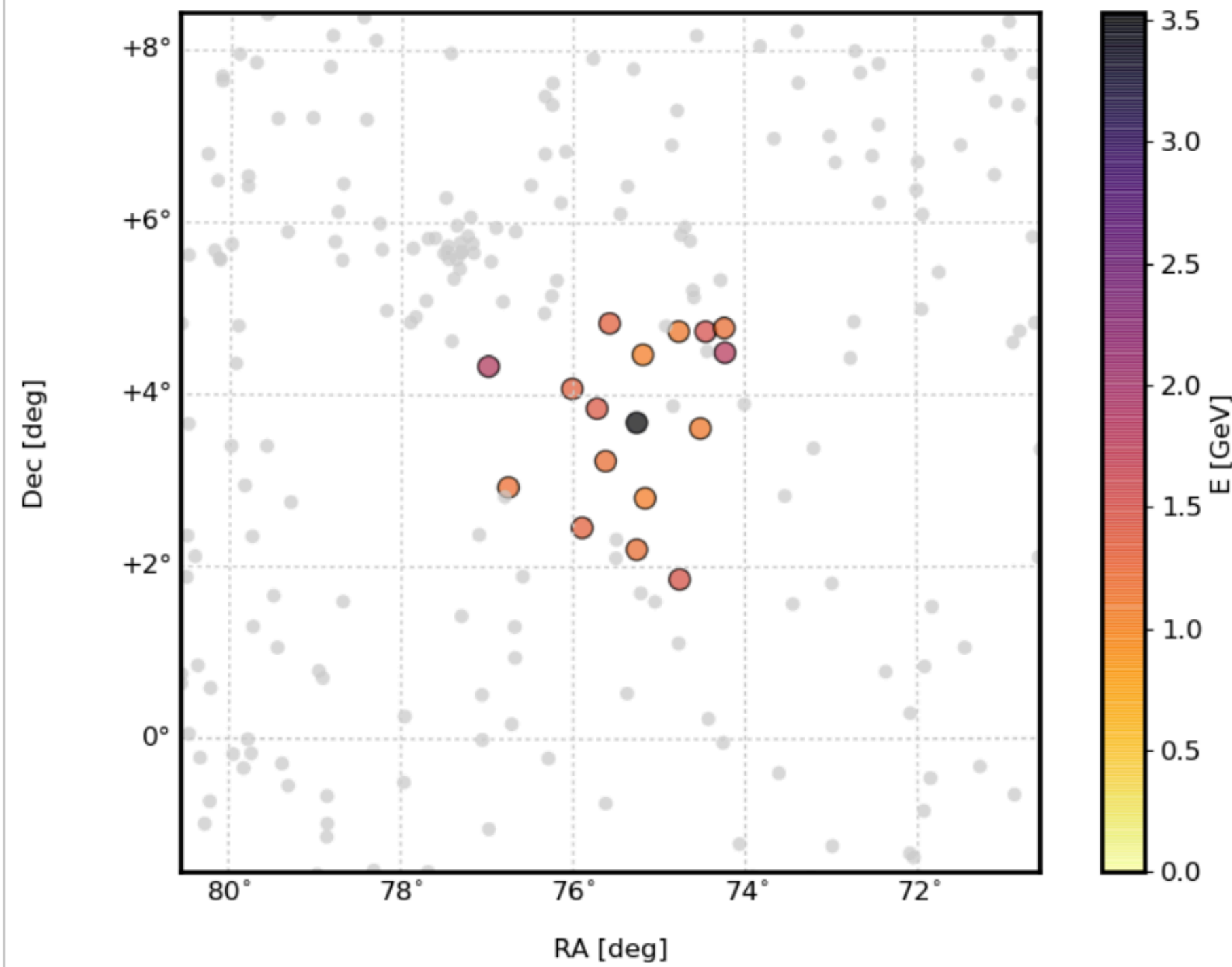
Photons positionally coincident with the best-fit alert position at 95% coincidence level.
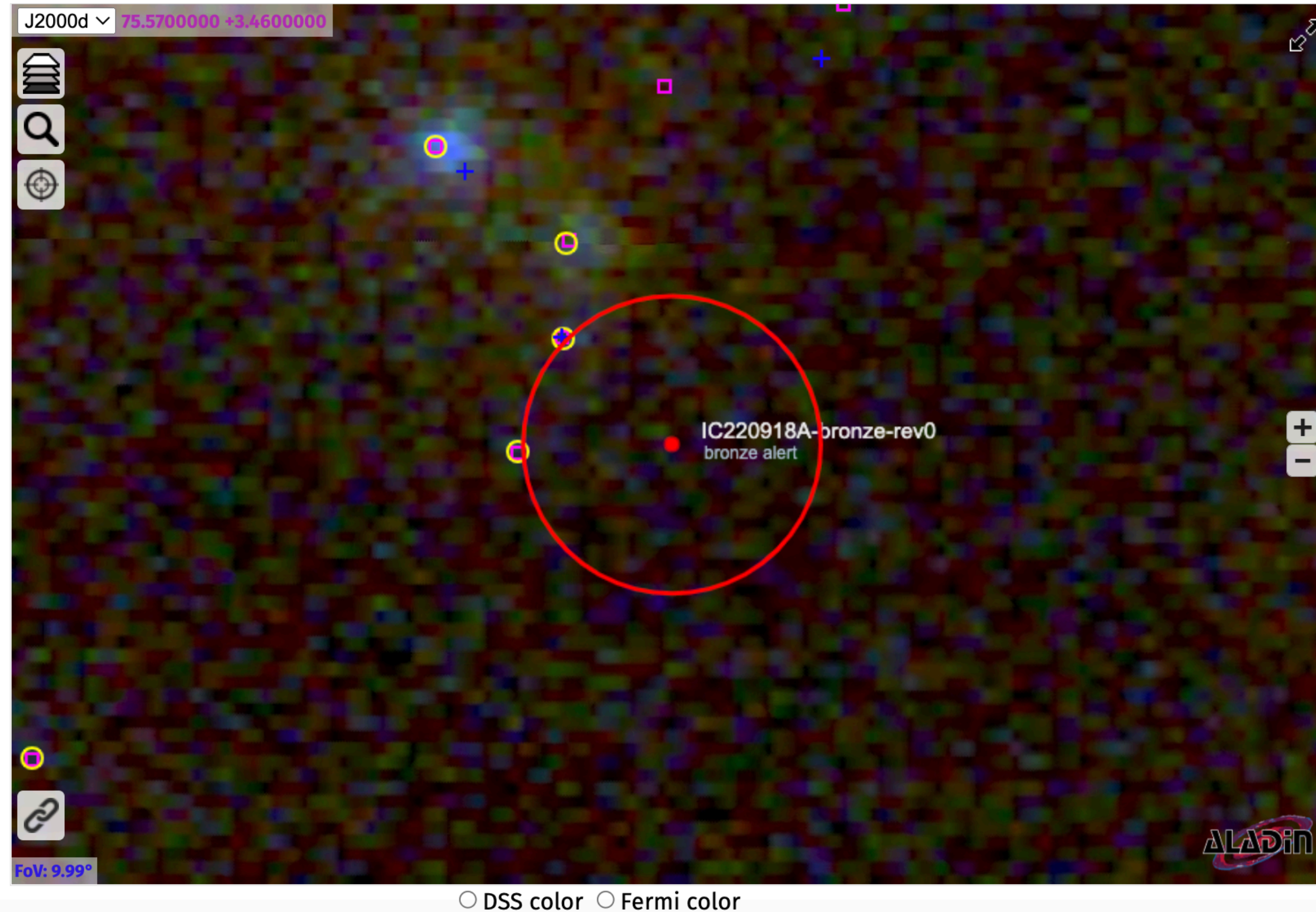
INTERACTIVE SKYMAP

INTERACTIVE SKYMAP

Image layer (MWL)

Sun/Moon (current)
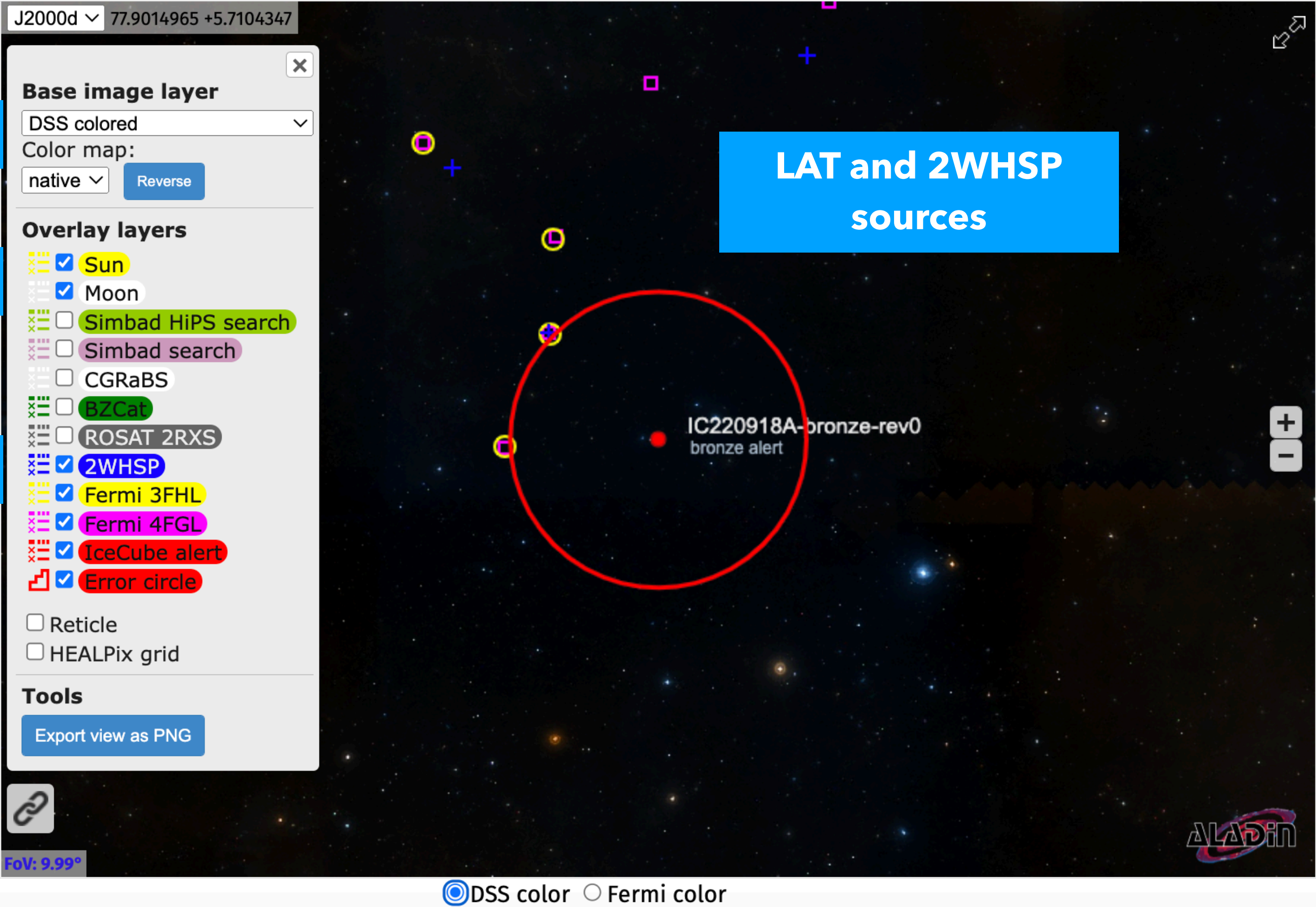
Selected catalogs
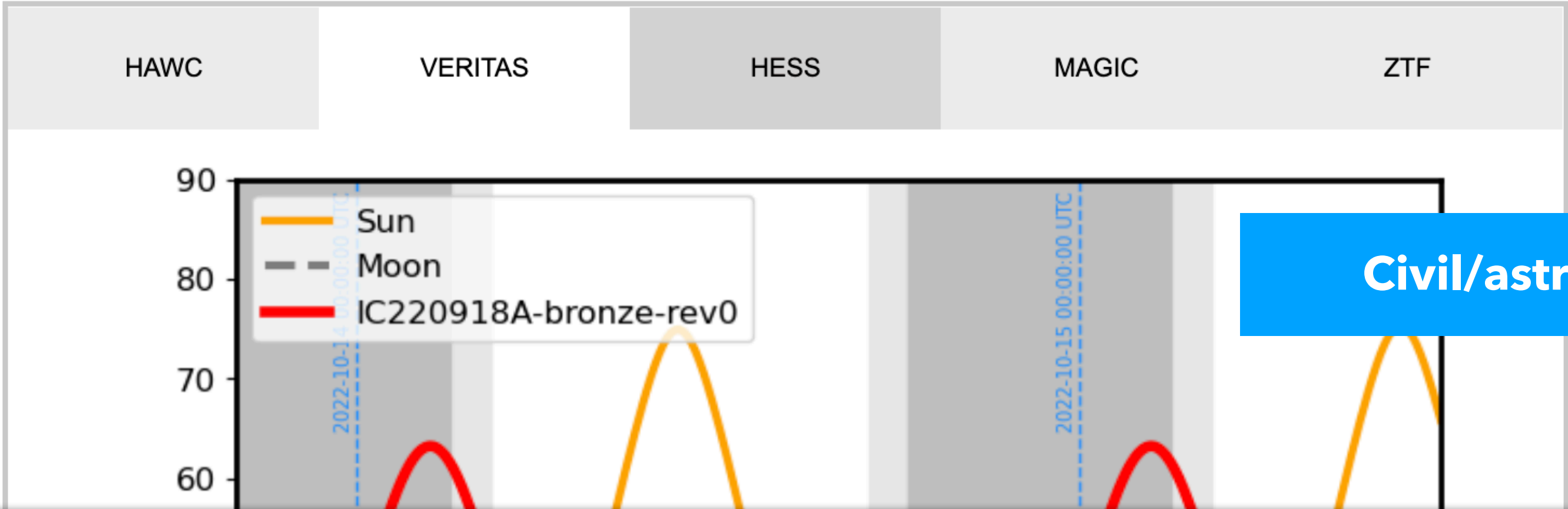
VISIBILITY

Visibility

Visibility plots (elevation vs time) for four ground-based instruments over the next hours for the alert. Dark (light) bands indicate civil (astronomical) twilights for each site. Moon and sun elevations are also shown.

| HAWC | VERITAS | HESS | MAGIC | ZTF |

Legend:
- Sun
- Moon
- IC220918A-bronze-rev0

Alert, Sun and Moon

Civil/astronomical twilight

Swift visibility

Visibility conditions for Swift at the time of the report generation based on the distance of the alert position to the Sun and Moon. Red or green colors indicate if the position is observable (>23 deg away from the Moon and >47 away from the Sun).

| Sun separation [deg] | 123.5 deg |
| Moon separation [deg] | 21.9 deg |

UTC Time
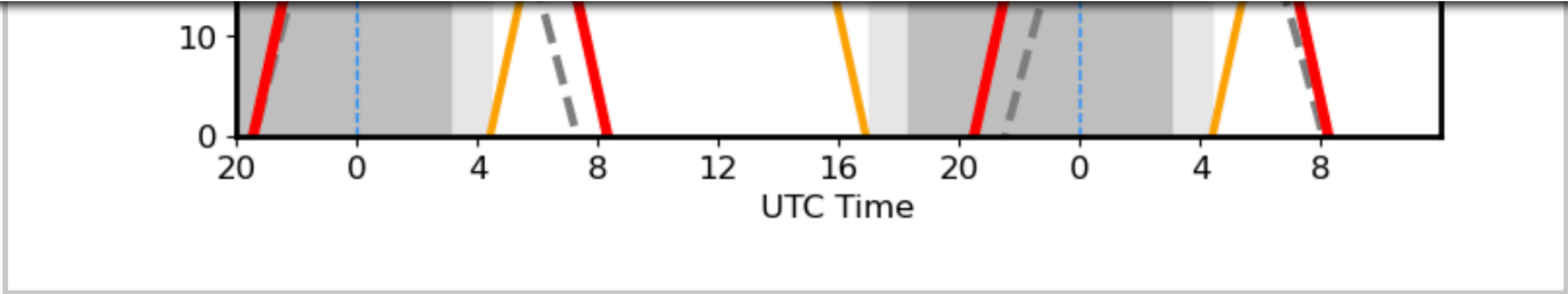
NEXT STEPS

- Include the 1 year and full-mission analysis (multi-threading support).

- Gather additional MWL data (e.g. from NED) and SED construction.

- Reanalysis of all existing alerts for IceCube.

- Release of first working version expected by January 2023.

- **Supported through Fermi GI grant 80NSSC20K1587**