Pinpointing the sources of the *Fermi* Isotropic Gamma-ray Background using *Swift*

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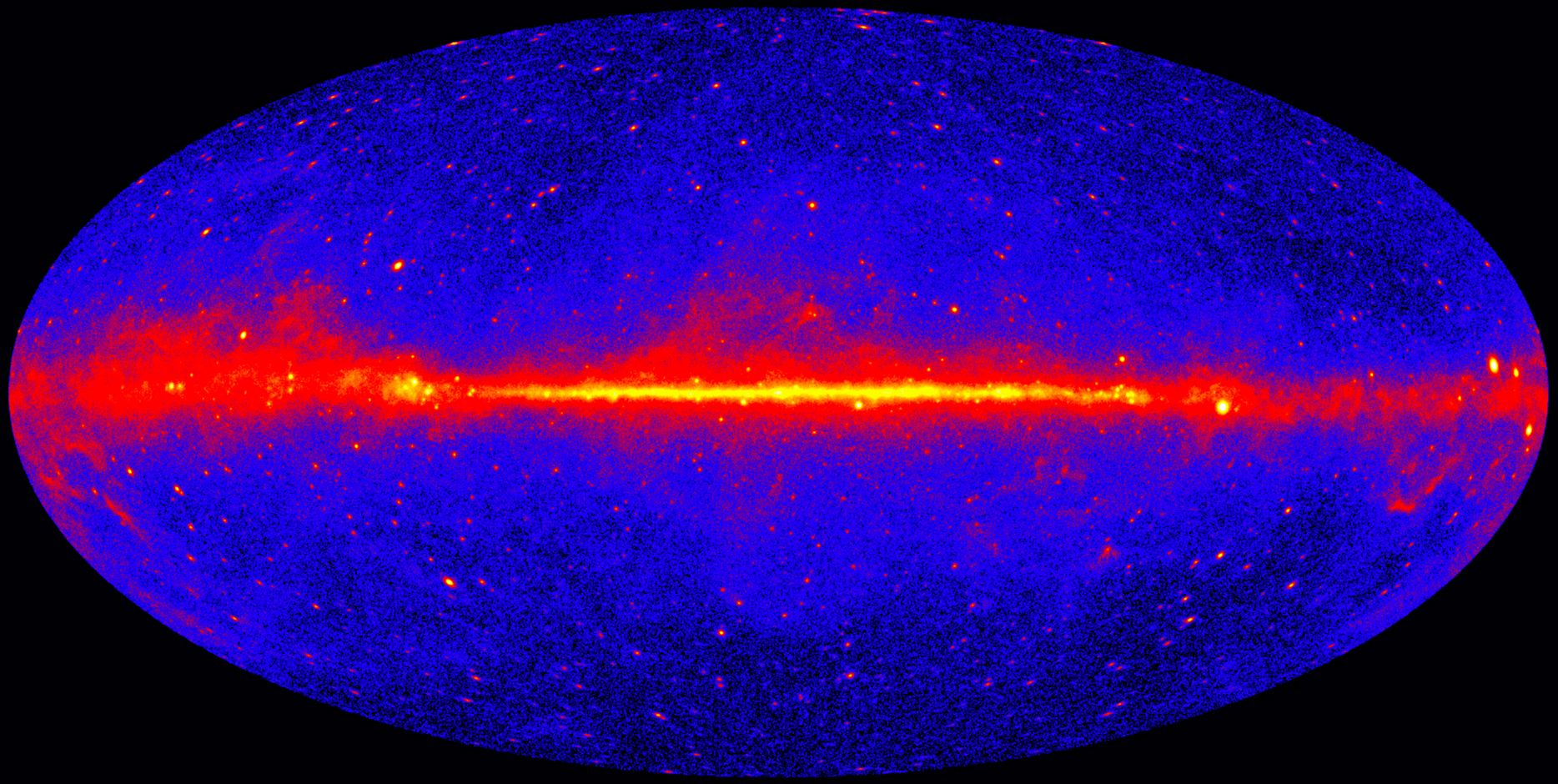
Ninth Fermi Symposium
April 2021

Composition of the *Fermi*-LAT sky



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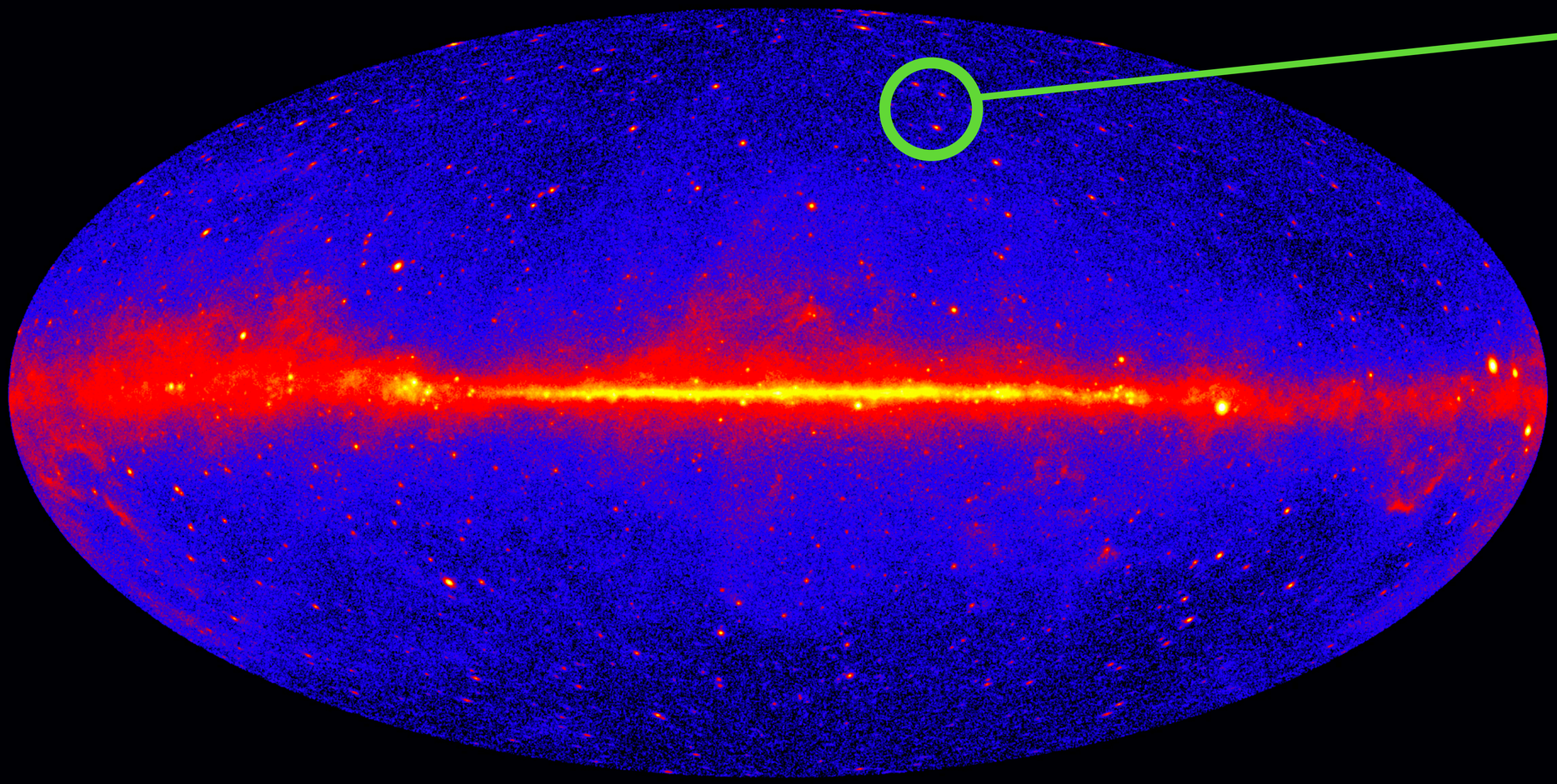

Point-like and extended sources

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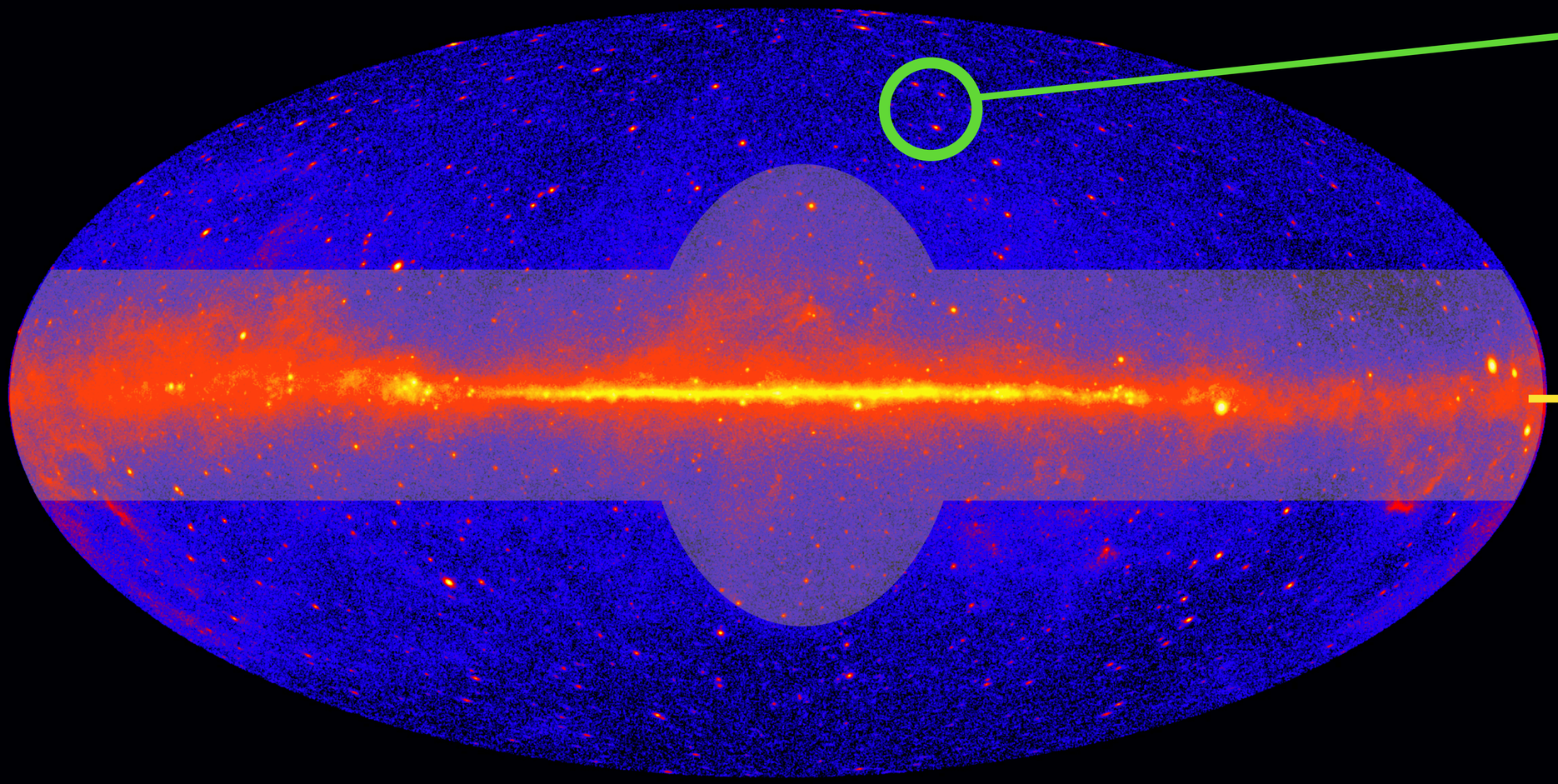
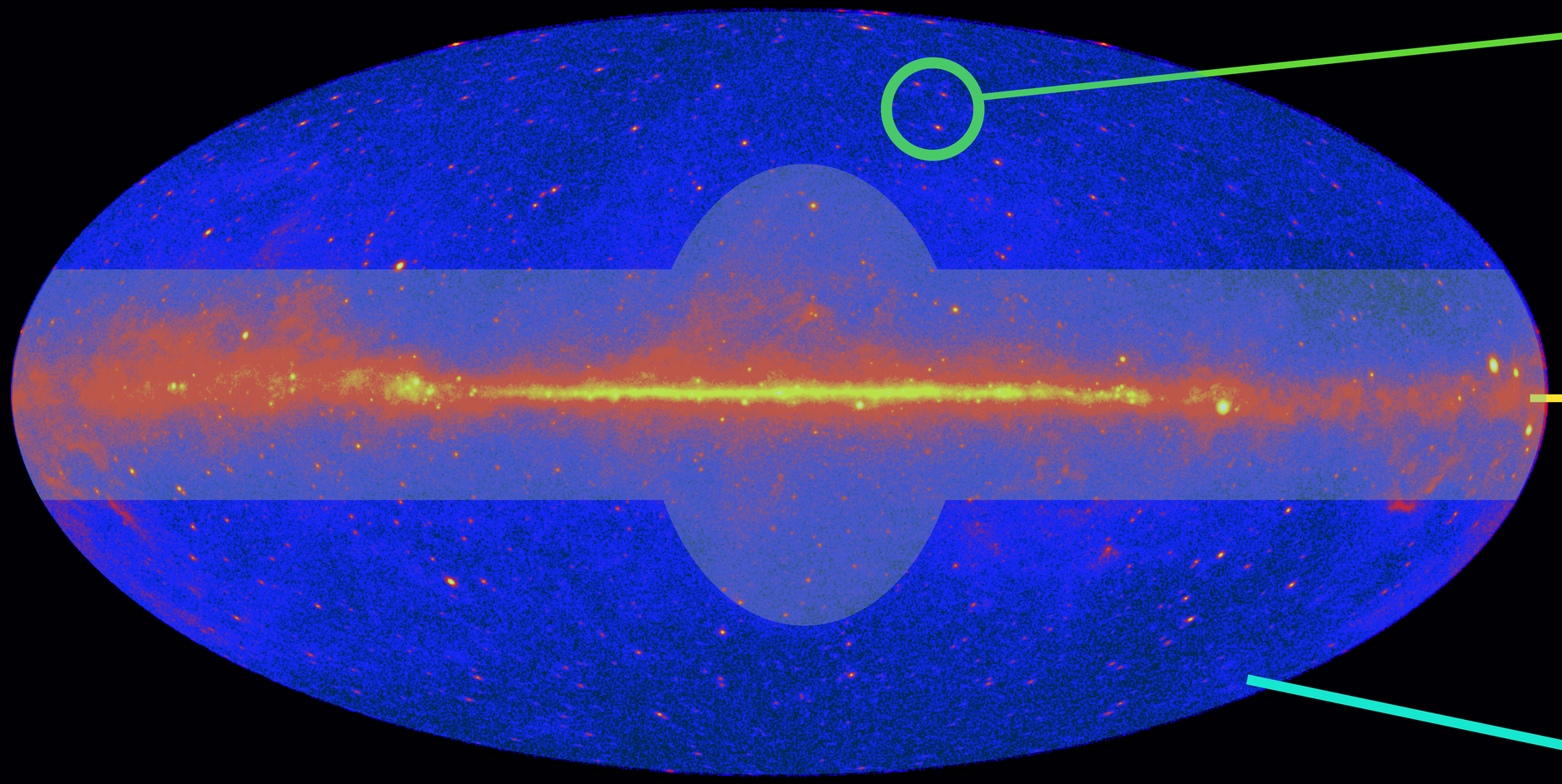


Point-like and extended sources

Galactic diffuse emission (+ bubbles)

Composition of the *Fermi*-LAT sky

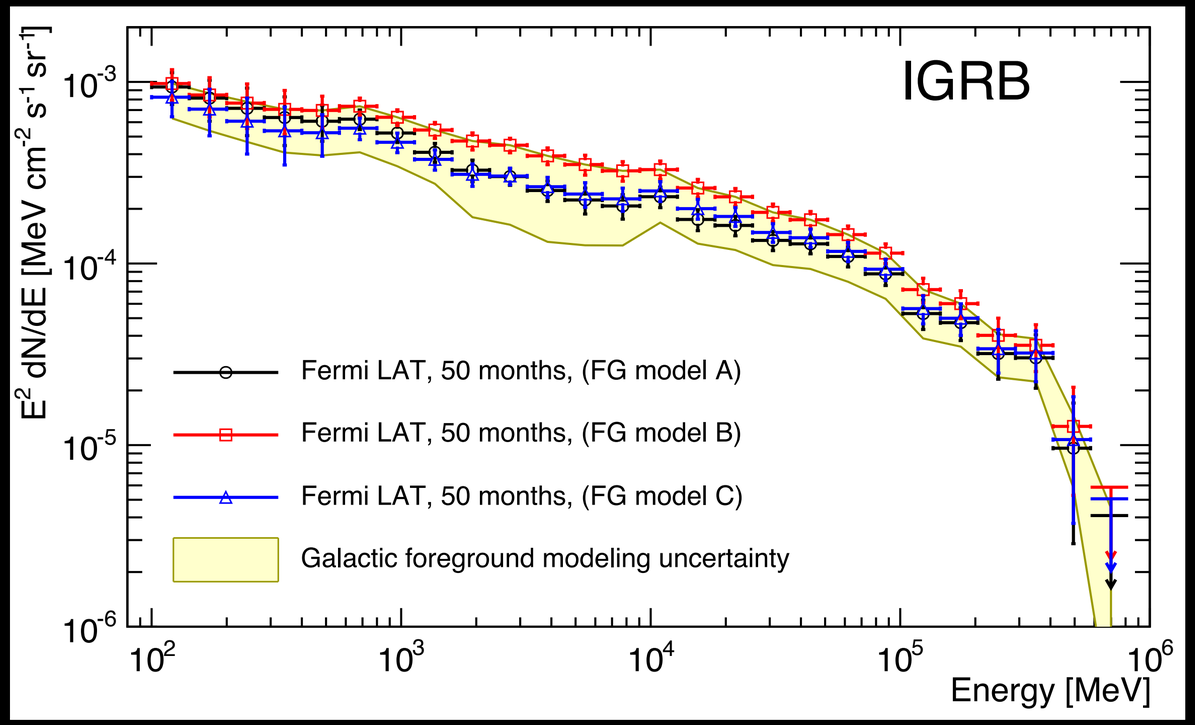


Point-like and extended sources

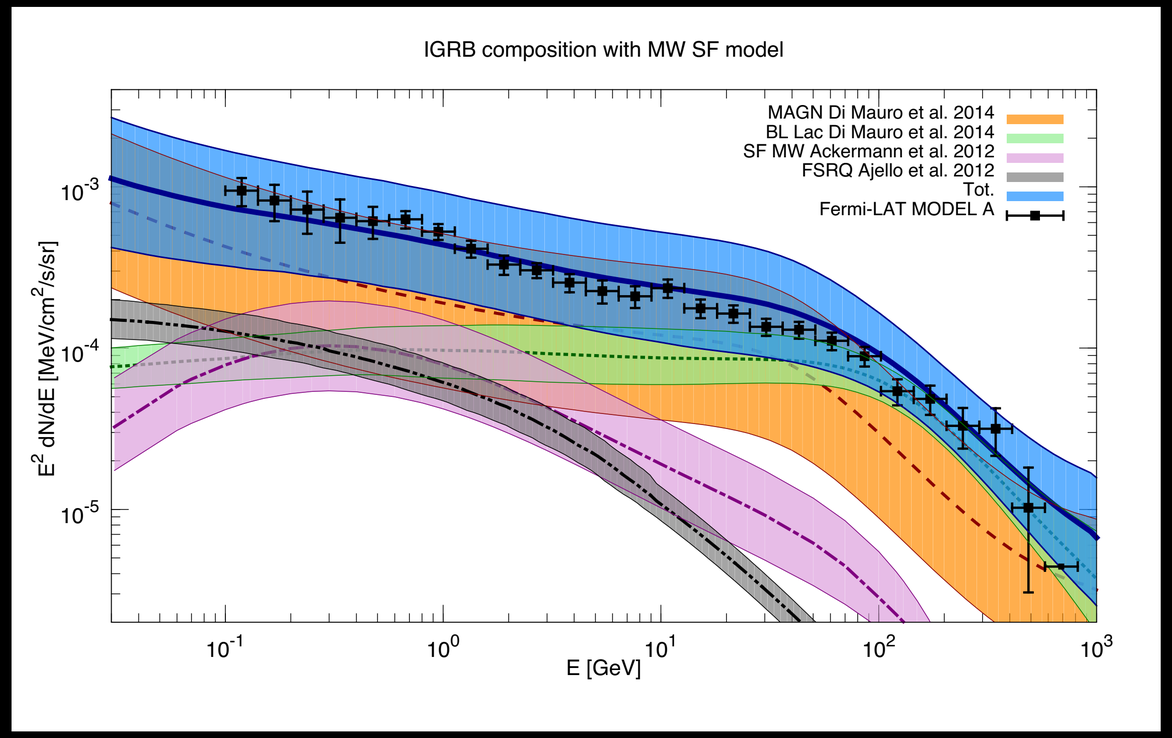
Galactic diffuse emission (+ bubbles)

Isotropic diffuse emission

The *Fermi* Isotropic Gamma-ray Background (IGRB)



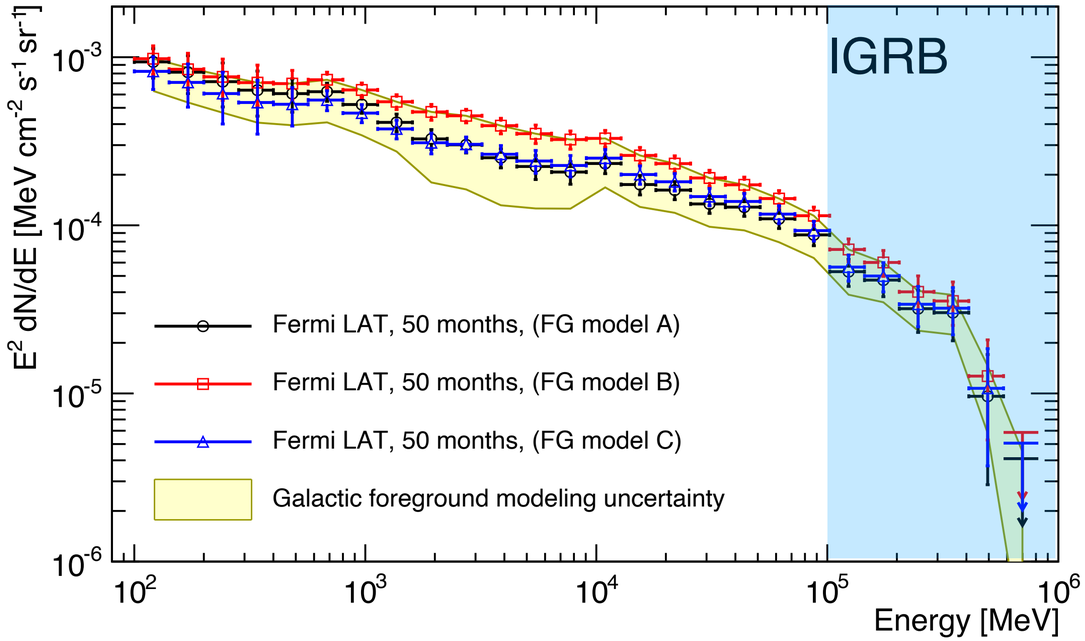
Ackermann et al. (Fermi-LAT) 2015 ApJ 799 86

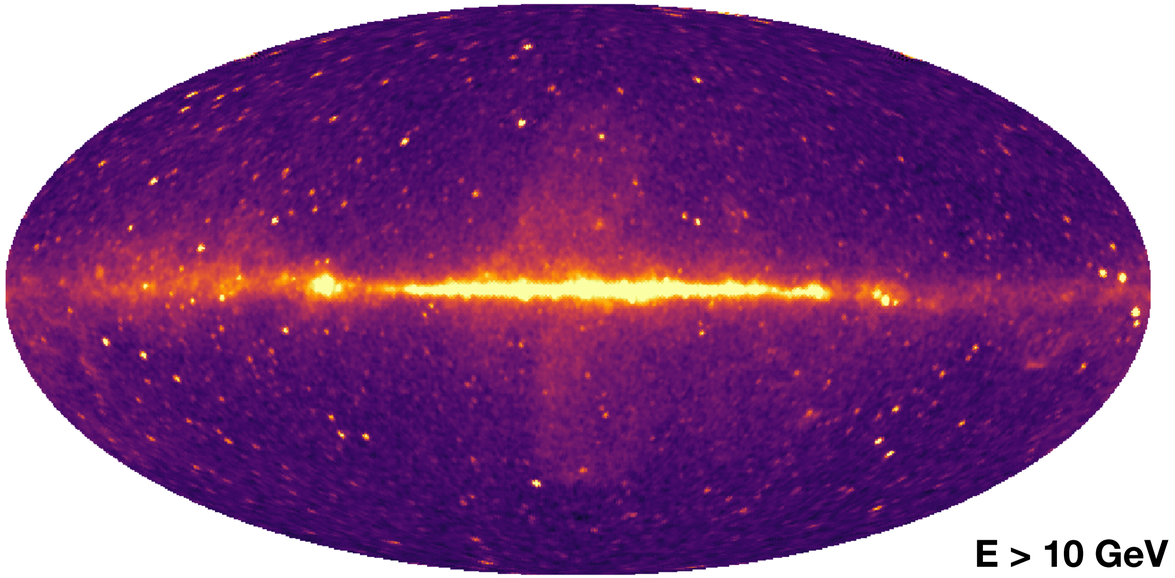


Di Mauro & Donato PRD 91 (2015) 123001

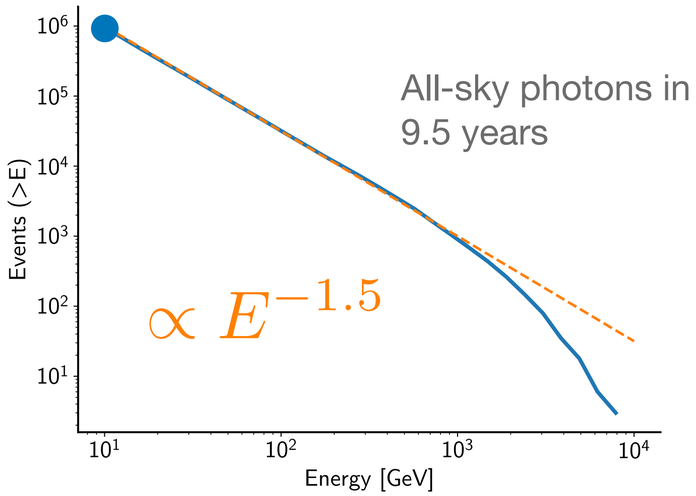
- Characterized by Fermi from 100 MeV to 820 GeV. Power law ($\Gamma \sim 2.3$) with a break at ~280 GeV.
- Contributions from sources too faint and numerous to be resolved, likely dominated by **blazars**.
- Composition has important consequences for other backgrounds (e.g. astrophysical neutrinos, DM constraints)

Pinpoint the sources of *Fermi* VHE photons

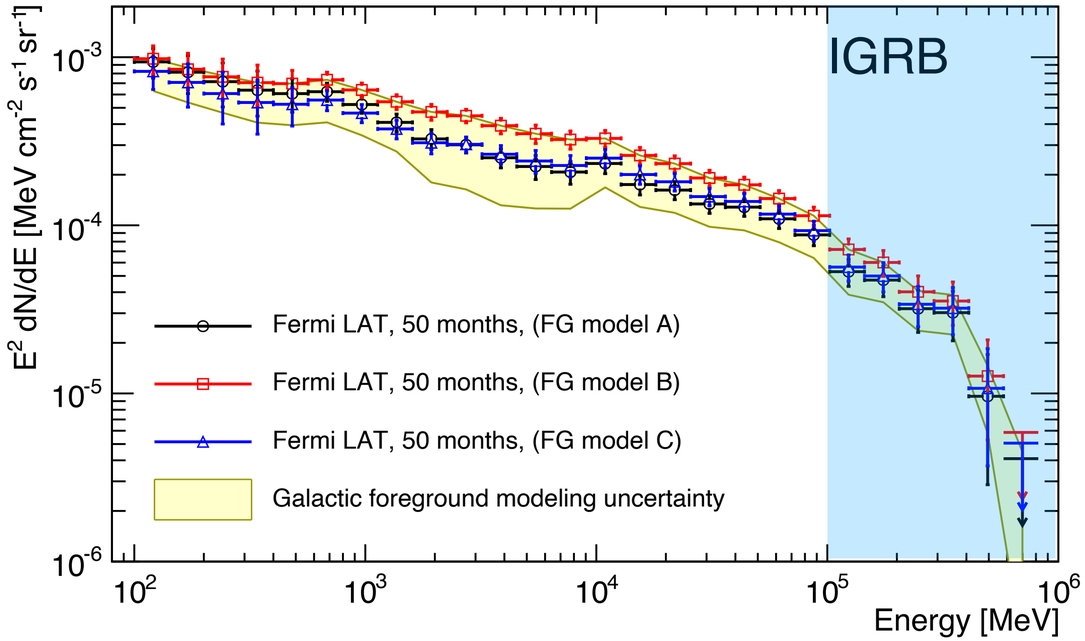


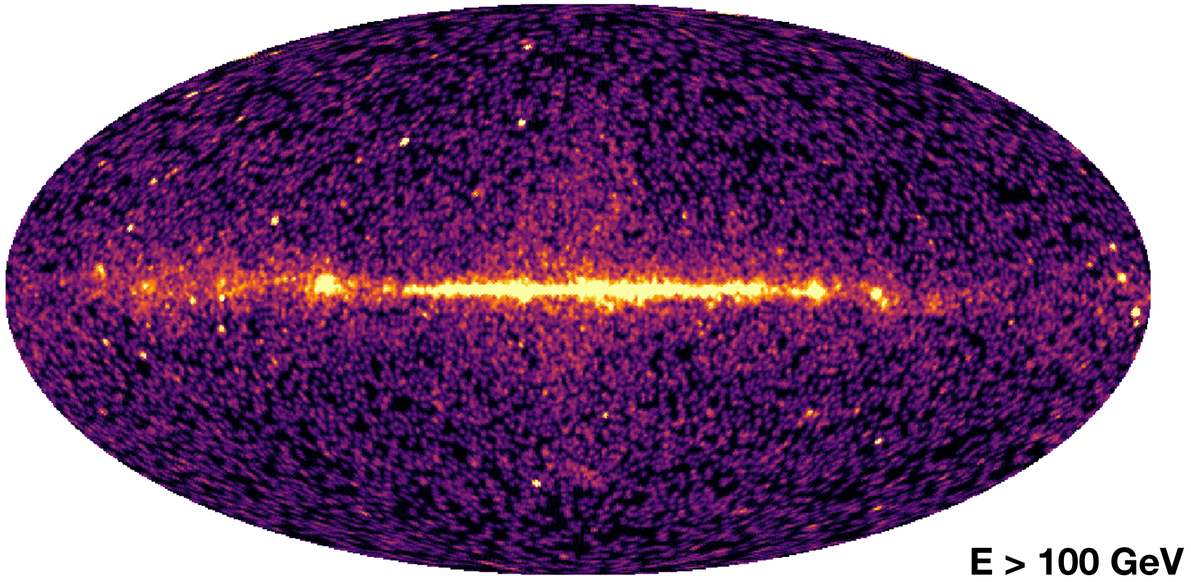


- **Goal**: identifying the sources of the IGRB, in particular in the very-high-energy range (E > 100 GeV).
  - Increase the catalog of VHE-detected sources and related studies (e.g. EBL)
  - Useful for current and future IACT follow-ups (e.g. CTA).
- **Challenge**: In this energy range LAT statistics per source are extremely low (~1 photon / deg^2 above 100 GeV in the entire dataset).



Pinpoint the sources of *Fermi* VHE photons





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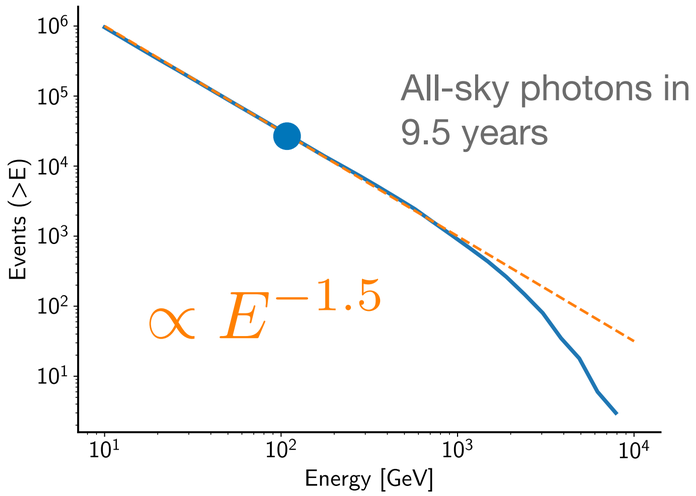

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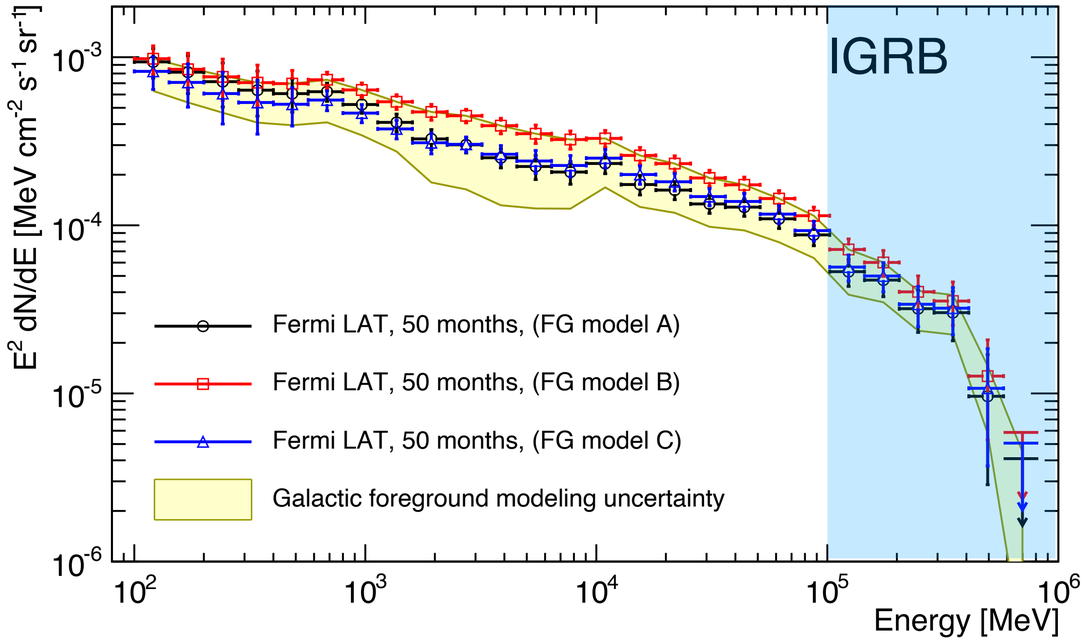

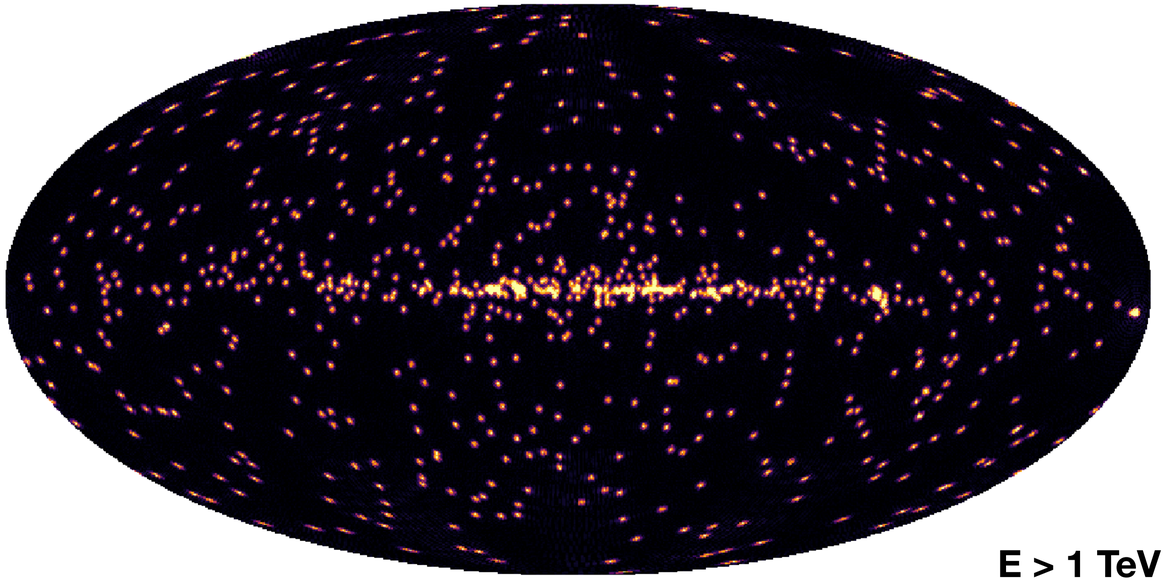

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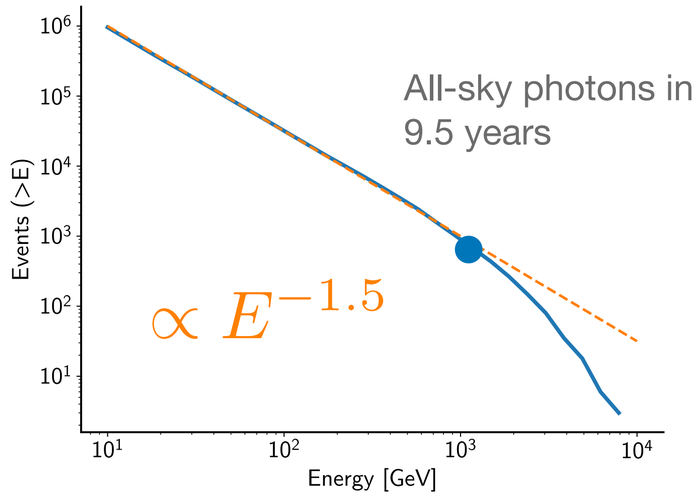
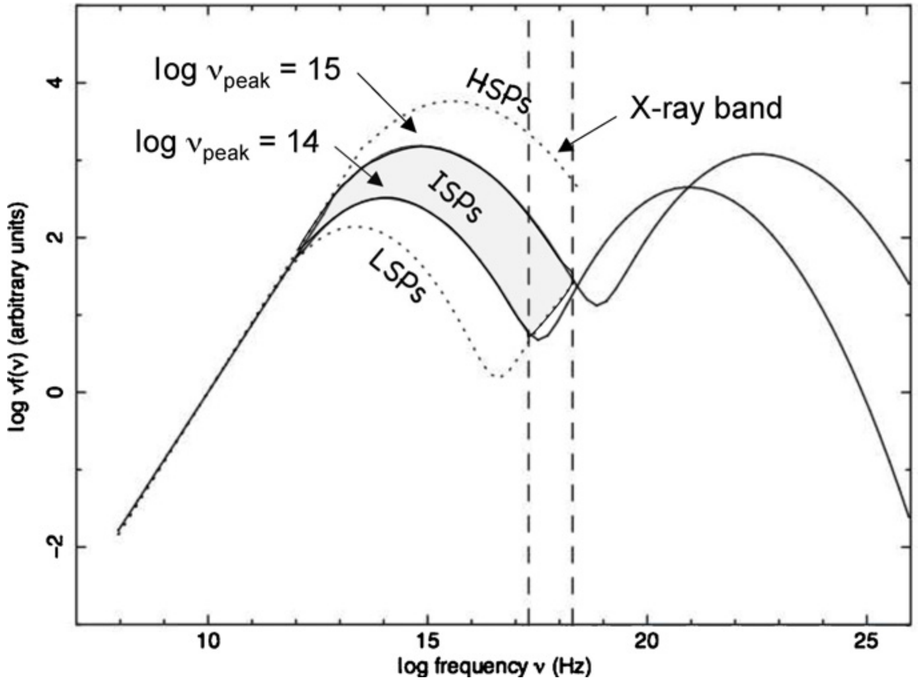
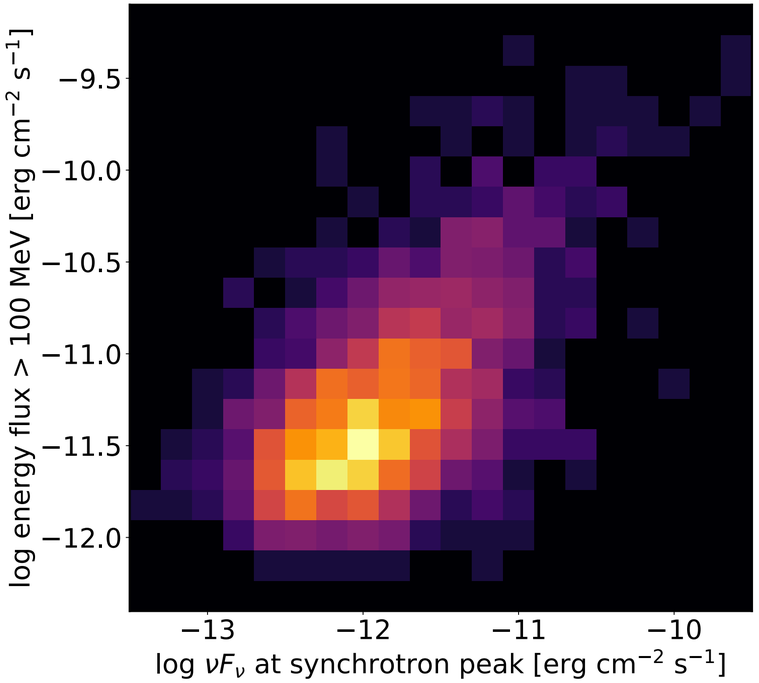


X-ray emission from gamma-ray blazars



Abdo et al. (Fermi-LAT) ApJ 716:30-70 2010



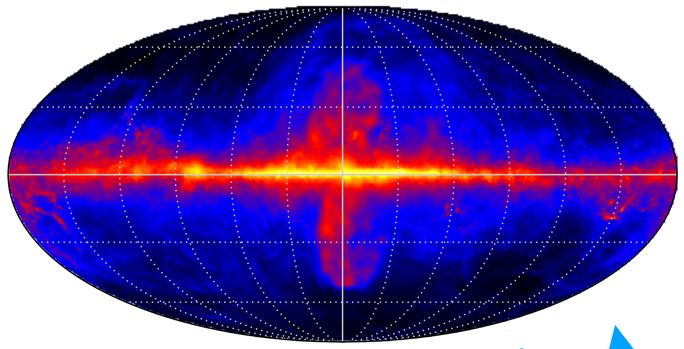
From 4LAC catalog (M. Ajello et al. 2020 ApJ 892 105)

Correlation between gamma-ray energy flux (>100 MeV) with synchrotron energy flux

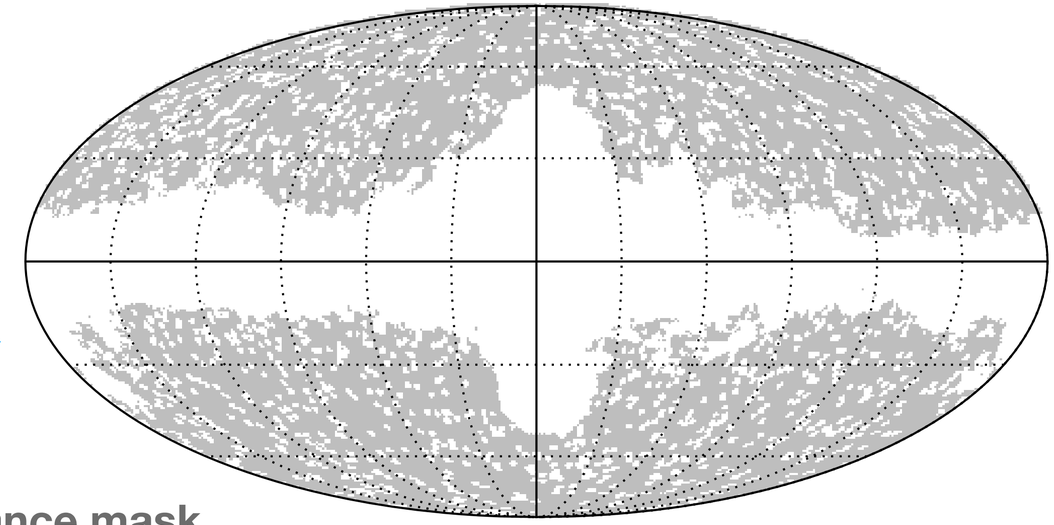
- Synchrotron emission from gamma-ray blazars observable in X-ray range.
- Correlated emission between the X-ray and gamma-ray band, typically seen in synchrotron self-Compton scenarios, provides an observational connection between both bands.

X-ray follow-up of *Fermi* VHE photons

- Search for X-ray emission from the direction of un-associated LAT VHE photons using *Swift*.
- Pilot program selected during *Swift* Cycle 15: Prompt follow-up of VHE photons (`P8R2_ULTRACLEANVETO` to minimize CR background), away from the Galactic plane and >1° distance from known 3FGL and TeVCat sources. 90° zenith cut to remove atmospheric gammas.
- Galactic diffuse mask uses `gll_iem_v06` model (107 - 147 GeV bin), thresholded at an intensity of $10^{-13.6}$ cm^{-2} s^{-1} sr^{-1} MeV^{-1} (selected to mask plane + bubbles)

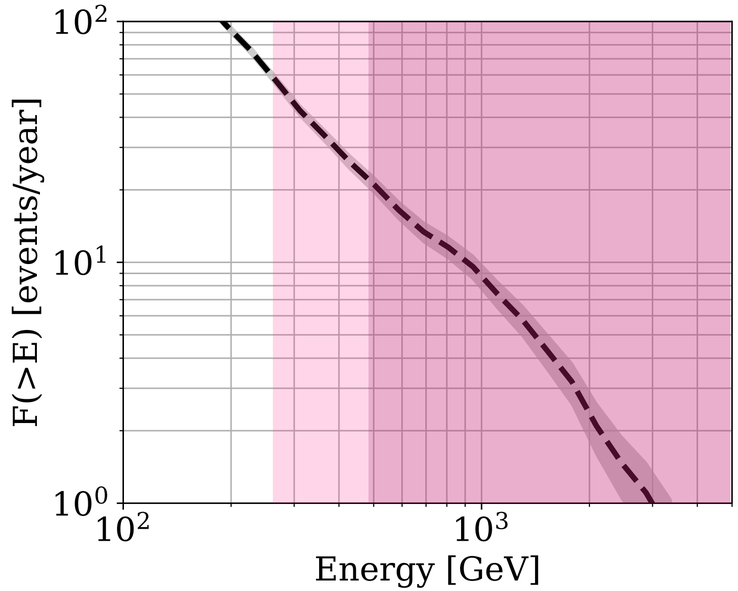


gll_em_v06
+
3FGL + TeVCat



Acceptance mask

Expected event rate before visibility constraints



VHE photon pipeline

Recent HE Fermi photons

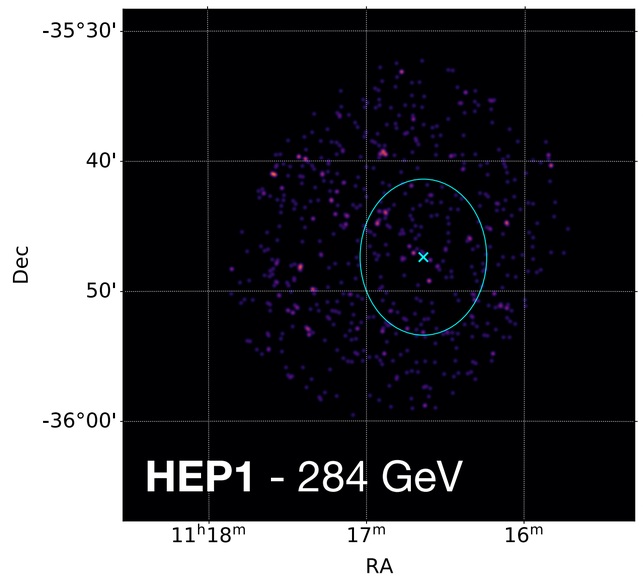
Generated: 2019-06-30 23:51:58.560
Current UTC time: 2021-04-14 01:38:54

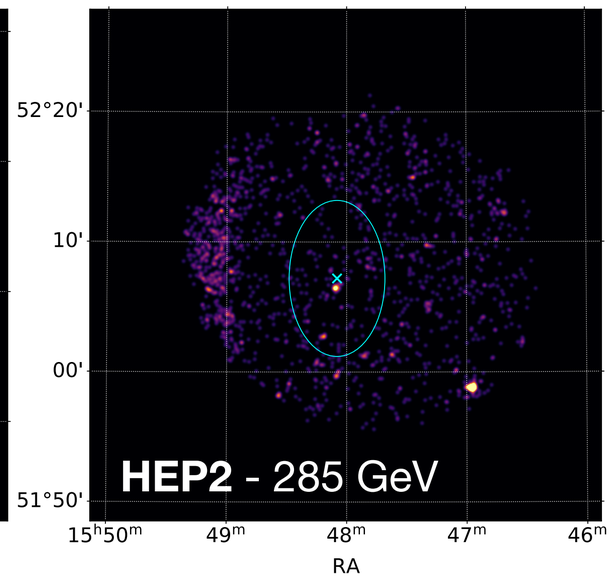
Energy [GeV]	RA [deg]	Dec [deg]	L [deg]	B [deg]	MJD	Time	Age [hours]	Run ID	Event ID	Moon dist [deg]	Sun dist [deg]	Search Cat
134.05	149.97	-56.36	280.78	-1.05	58506.73080	2019-01-23 17:32:21.200	3798.33	569955472	3997794	90	86	Search Simbad
203.83	274.37	-16.09	14.79	-0.00	58506.69198	2019-01-23 16:36:27.338	3799.26	569949571	8864231	9	166	Search Simbad
123.55	280.76	-3.64	28.73	0.21	58505.76395	2019-01-22 18:20:05.083	3821.53	569869878	8088194	20	160	Search Simbad
125.65	283.79	1.55	34.74	-0.12	58505.96260	2019-01-22 23:06:08.406	3816.76	569886797	10320739	25	156	Search Simbad
103.55	57.18	-27.85	224.57	-50.90	58505.39897	2019-01-22 09:34:31.185	3830.29	569840091	4782089	115	70	Search Simbad
281.18	147.14	37.98	185.20	50.39	58505.01293	2019-01-22 00:18:37.393	3839.56	569806923	5682197	137	37	Search Simbad
465.45	106.62	-10.17	223.68	-1.32	58504.35505	2019-01-21 08:31:16.659	3855.35	569748404	9272643	146	32	Search Simbad

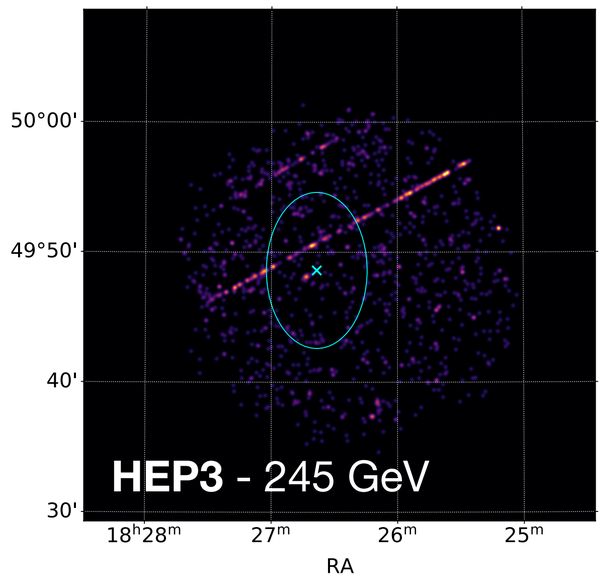
ID	Energy [GeV]	RA [°]	Dec [°]	Exposure [ks]
1	284	169.16	-35.79	2.0
2	285	237.02	52.12	4.1
3	245	276.66	49.81	4.1
4	952	36.72	37.74	4.0
5	328	118.51	6.91	4.0

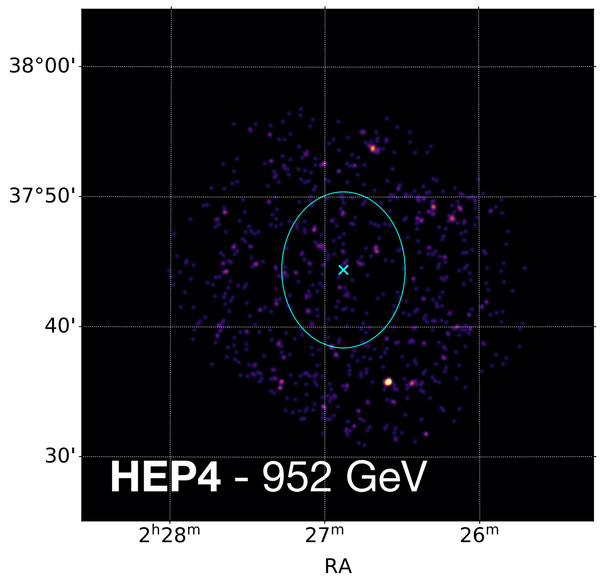
- Developed an automatic pipeline to run over the latest LAT photons (typically < 12 h age), selecting for those with VHE (white) that are in the **mask** (teal), and pass **energy selection** criteria.
- Checked for Swift **visibility** (distance to the Sun and Moon) and generated email alerts for those passing all cuts, which were used to trigger the *Swift* ToO requests.
- Two 2 ks exposures (~10^{-13} erg cm^{-2} s^{-1} sensitivity in the 0.3 - 10 keV band) separated by 24-48 hours to catch variability. Order of magnitude improvement over ROSAT all-sky survey.

Swift observations

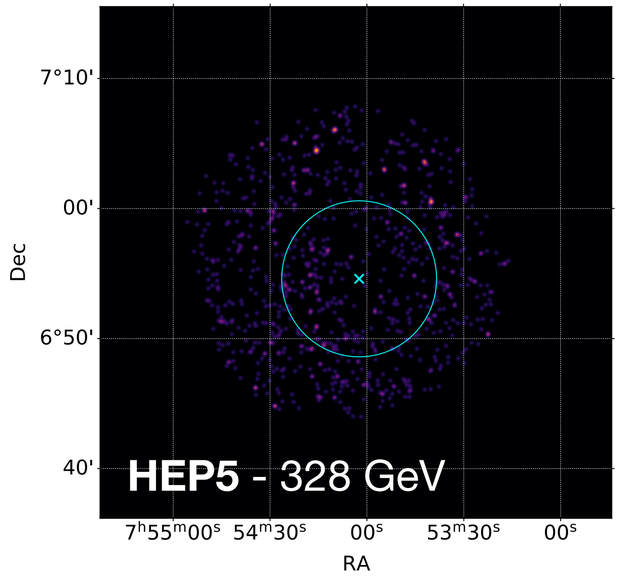




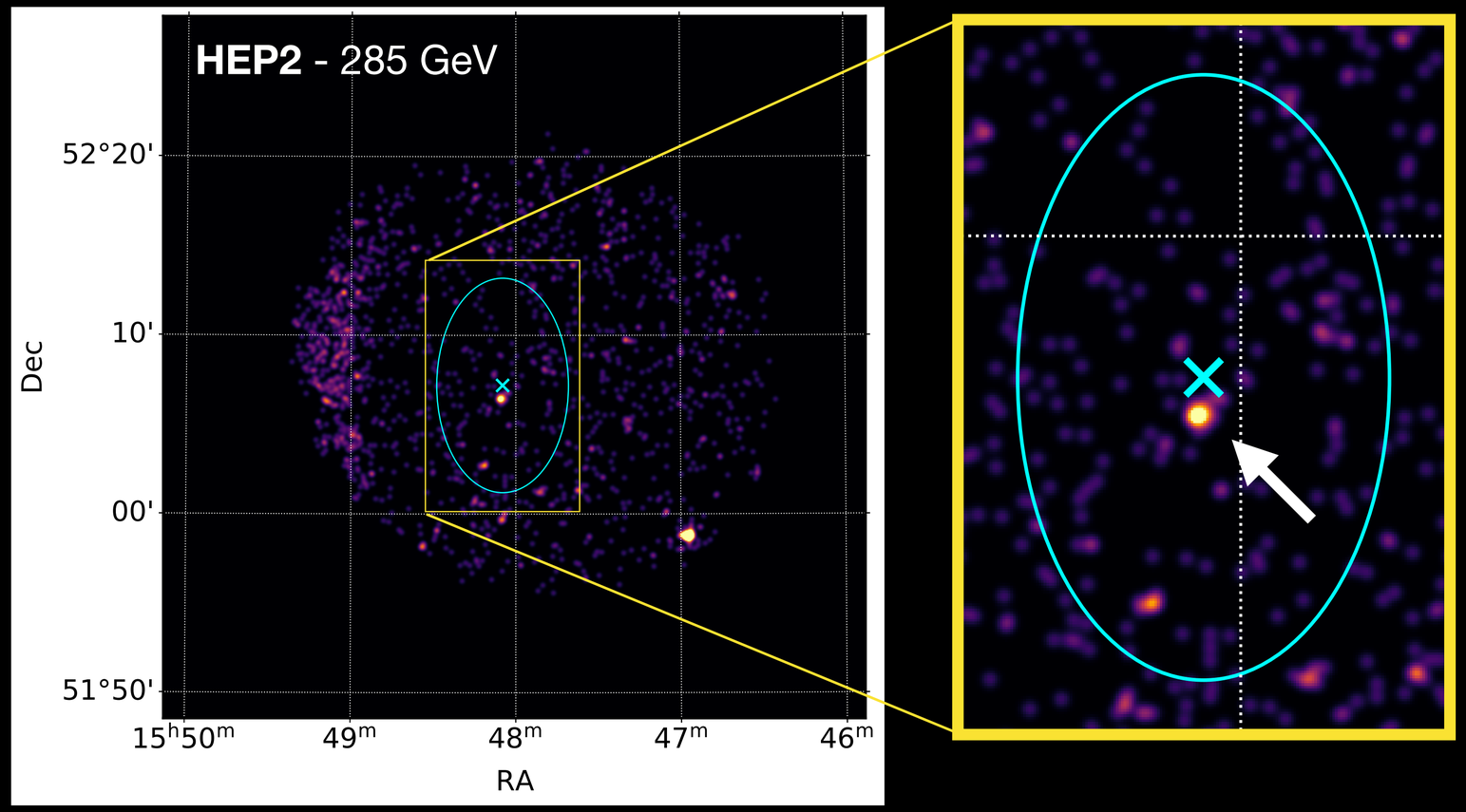




- Combined exposures from both 2 ks snapshots.
- *Swift* XRT observations of 5 LAT high energy photons (HEPs) reveal 2 sources within their 68% containment region at SNR > 3. Weak detection prevents a spectrum extraction.
- Other brighter sources in the FoV not contained in the HEP error regions.



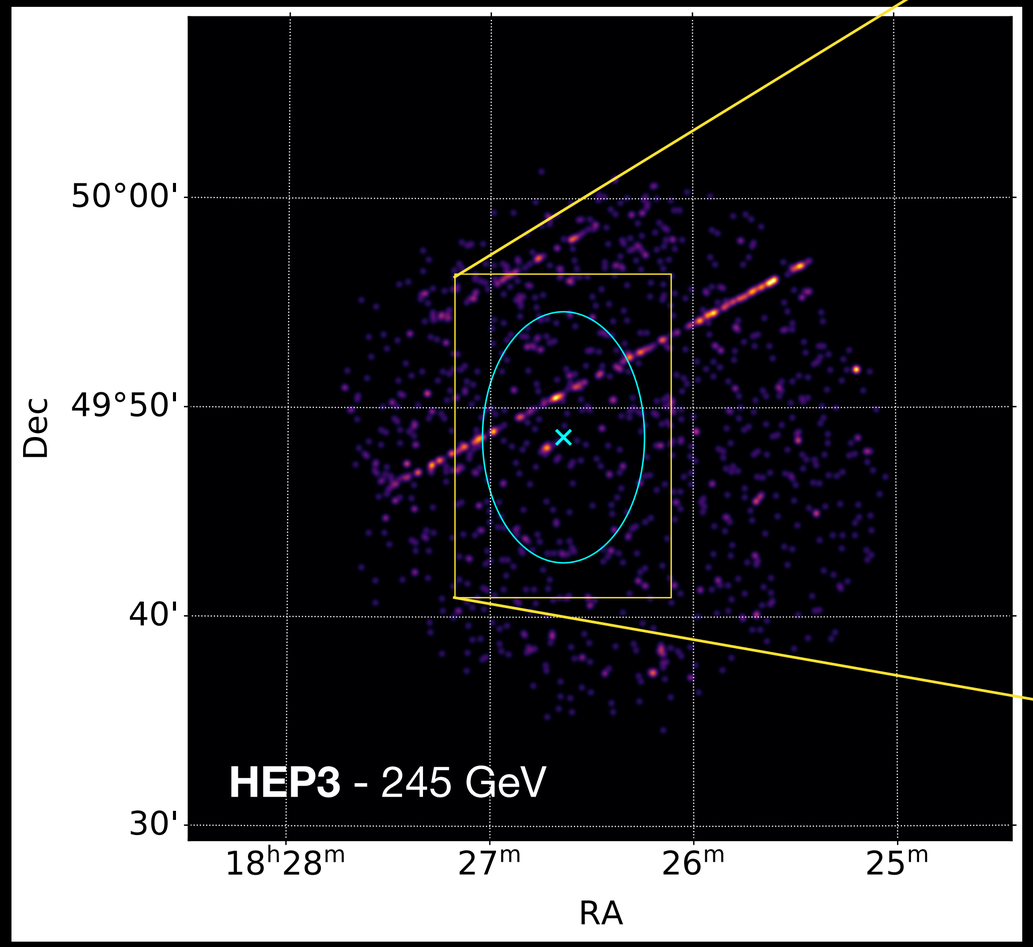
Swift observations

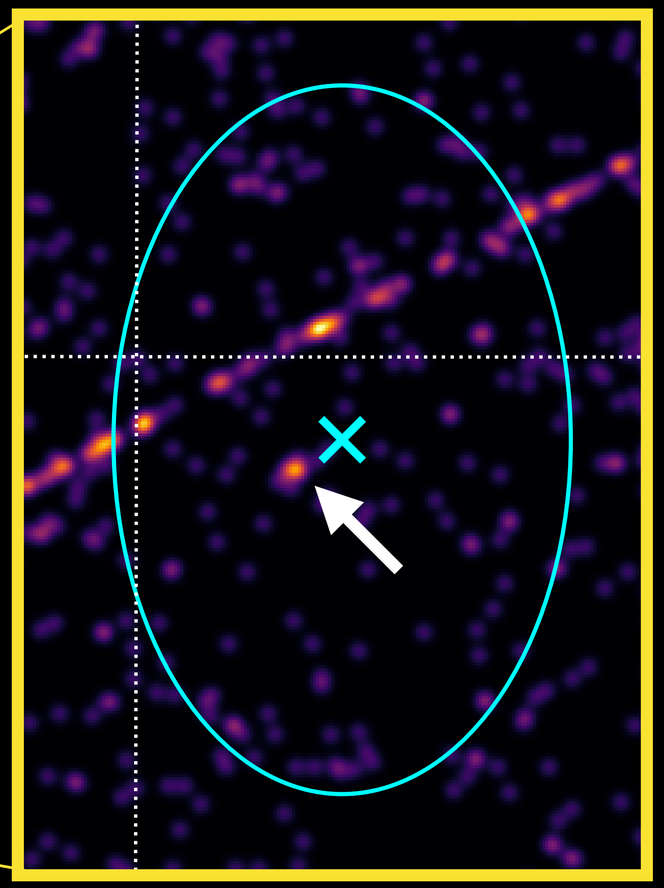


- Source catalogued in 1RXS as 1RXS J154805.4+520630
- Classified in SDSS as a QSO at redshift z = 0.615

- XRT count rate derived from ROSAT PSPC archival rate (WebPIMMS): 4.0 cts/ks
- Observed XRT count rate: 5.2 ± 1.2 cts/ks (~1σ excess wrt catalog)

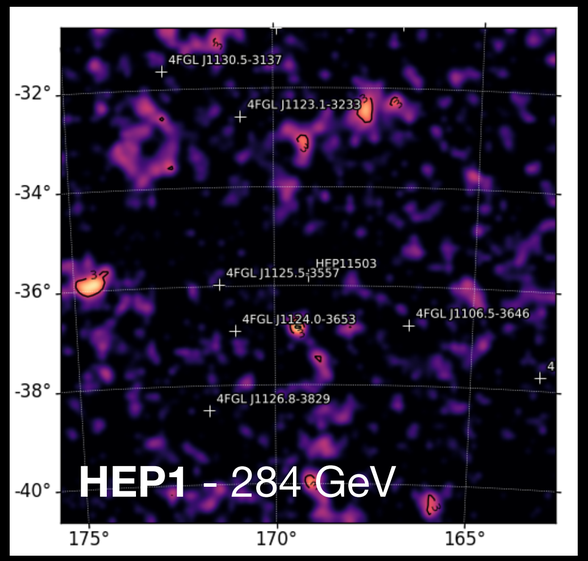
Swift observations

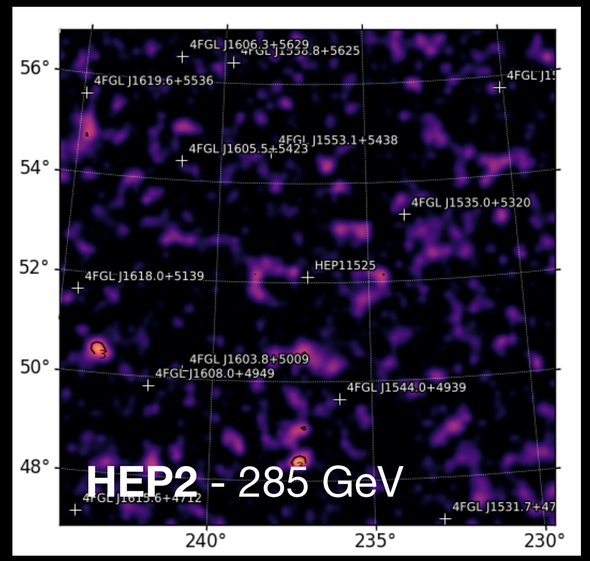


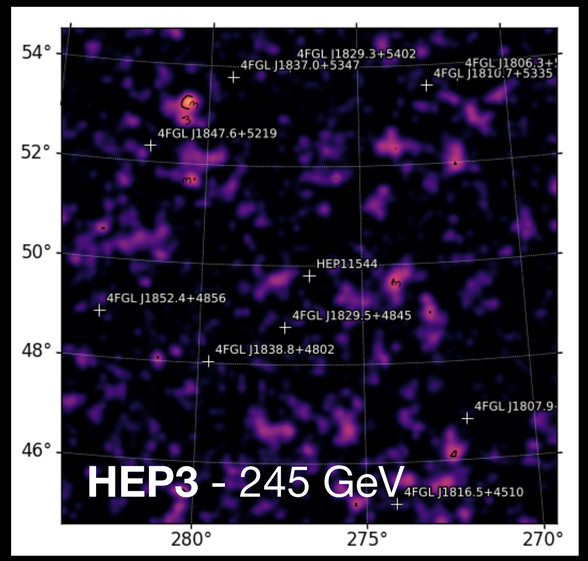


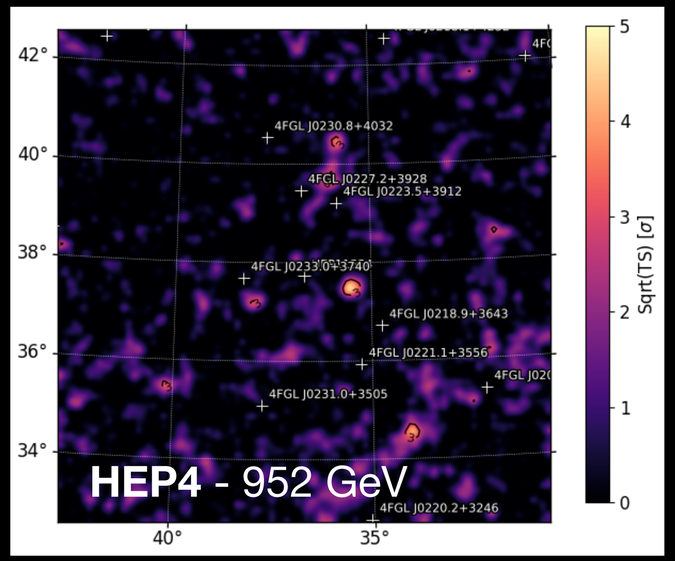
- Low SNR detection in XRT.
- No catalogued X-ray sources at that location. No clear multiwavelength counterpart (one WISEA, 2MASS source within 10”)

Fermi-LAT analyses of HEP ROIs

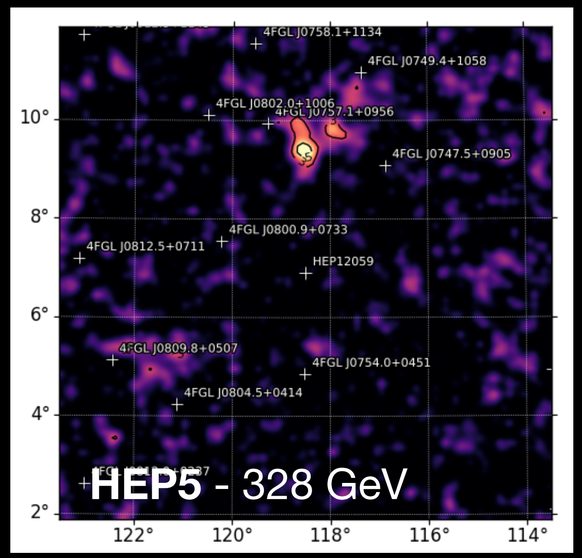








- Searching for additional GeV emission associated with the HEP.
- Standard analysis in the 1-500 GeV range on two time scales: full mission, and +/- 15 days around the HEP detection. No new sources detected at the HEP position for any of these targets.



Conclusions and outlook

- Pilot Swift program to identify counterparts to unassociated VHE *Fermi*-LAT photons
- Five triggers observed, one likely counterpart identified (HEP #2).
- No evidence of emission at lower LAT energies.
- Based on experience we will look at expanding this search for counterparts even if no XRT observations exist.
- Data from current and future X-ray surveys (e.g. eROSITA) would be useful in pinpointing the sources of the IGRB.