2FHL: The Second Catalog of Hard Fermi-LAT Sources





Alberto Domínguez (Clemson University & UC Madrid), Marco Ajello, Jamie Cohen, Sara Cutini, Dario Gasparrini

on behalf of the Fermi-LAT Collaboration



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S:





80 months of P8 data (50 GeV - 2 TeV)

61,000 photons E > 50 GeV 22,100 photons E > 100 GeV 2,000 photons E > 500 GeV

~1.5 photon every deg²







80 months of P8 data (50 GeV - 2 TeV)

61,000 photons E > 50 GeV 22,100 photons E > 100 GeV 2,000 photons E > 500 GeV

~1.5 photon every deg^2

Preliminary

Adaptively Smoothed



1 Analysis details

- □ 50 GeV 2 TeV
- ⁰ 80 months of data (till April 2015)
- Pass 8 (source)
- Unbinned likelihood

Detections

- 360 sources:
 - ¹ 75% blazars, 11% Galactic sources, 14% unassociated
- □ 78 detected by IACTs (TeVCat)
- 230 detected in 1FHL
- 303 detected in 3FGL
- 57 brand new sources (not 1FHL/3FGL)

Median localization accuracy is 1.7 arcmin (68%) !



Bottom line: plenty of sources for TeV telescopes



Gamma-ray Space Telescope







y:

Galactic sources have much harder spectra than extragalactic ones

- I Median spectral index $\Gamma=2$ vs $\Gamma=3$
- ¹ The EBL might be the culprit
- Spectral index can be used to distinguish Galactic objects among the unassociated sources



Gamma-ray Spectral Energy Distributions





sermi Galactic Sources

Gamma-ray





103 sources at |b|<10°

- 42 blazars, 39 Galactic objects, 13 unassociated and 9 Dark Acc.
- PWNe/SNRs represent 87% of the Galactic population
- I Half of the unassociated sources are hard and thus (likely) Galactic





We used the extended templates of previously detected sources:

- 25 from 3FGL + W41
- Of them 6 sources were not significantly detected:
 - ^I SMC, S 147, Cen-A (lobes), W 44, HB 21, Cygnus loop

Blind search for new sources:

- □ 72 ROIs of 10°, devoid of sources, centered at b=0
- I Iteratively add disk source at most significant TS peak
- \square Fit and choose extended source if TS_{ext}>16

It resulted in the detection of 5 new extended sources





All new sources are significantly detected in 2FHL (TS>75)
 They are hard, and harder than the Galactic diffuse emission
 They are associated to known (3) PWNe and (2) SNRs
 Detailed characterization will be reported in future papers

| 2FHL Name | l [m deg] | b [deg] | \mathbf{TS} | TS_{ext} | TS_{2pts} | F_{50} | ΔF_{50} | Г | $\Delta\Gamma$ | Association | Class | Radius [deg] |
|--------------------------------|--------------------|---------------|---------------|---------------------|----------------------|------------------|-----------------|----------------|----------------|-------------------------------|---------------------------------|----------------|
| J0431.2+5553e J1112.4-6059e | 150.384 291.222 | 5.216 - 0.388 | 87.9 80.9 | $83.4 \\ 68.3$ | 26.2 22.5 | $11.70 \\ 12.80$ | 2.11 2.36 | $1.66 \\ 2.15$ | $0.20 \\ 0.28$ | G 150.3+4.5 PSB J1112-6103 | snr | 1.27 0.53 |
| J1355.2-6430e | 309.730 | -2.484 | 82.3 | 31.8 | 12.9 | 9.59 | 1.95 | 1.56 | 0.20 | PSR J1357-6429 | pwn | 0.57 |
| J1443.2-6048e | 313.432 315.505 | -2.239 | 109.3 75.6 | $\frac{49.1}{29.9}$ | 15.6 19.2 | 17.60 7.23 | $2.80 \\ 1.70$ | 1.87 2.07 | $0.19 \\ 0.30$ | SNR G315.4-2.3 | $\frac{\text{pwn}}{\text{snr}}$ | $0.36 \\ 0.27$ |



New SNR (G150.3+4.5) discovered by Gao & Han 2014

Preliminary







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|---|---|--|---------------------------------------|--------------------------------------|--------------------------------------|---|--------------------------------------|--------------------------------------|---|---|--------------------------|--|
| J0431.2+5553e J1112.4-6059e J1355.2-6430e J1419.2-6048e I1443.2-6221e | $150.384 \\ 291.222 \\ 309.730 \\ 313.432 \\ 315.505$ | 5.216 -0.388 -2.484 0.260 -2.239 | 87.9 80.9 82.3 109.3 75.6 | 83.4 68.3 31.8 49.1 29.9 | 26.2 22.5 12.9 15.6 19.2 | $11.70 \\ 12.80 \\ 9.59 \\ 17.60 \\ 7.23$ | 2.11 2.36 1.95 2.80 1.70 | 1.66 2.15 1.56 1.87 2.07 | $\begin{array}{c} 0.20 \\ 0.28 \\ 0.22 \\ 0.19 \\ 0.30 \end{array}$ | G 150.3+4.5 PSR J1112-6103 PSR J1357-6429 PSR J1420-6048 SNB G315 4-2 3 | snr pwn pwn pwn | $1.27 \\ 0.53 \\ 0.57 \\ 0.36 \\ 0.27$ |



Gamma-ray Comparison with the H.E.S.S. G.P. Survey

Space Telescope



Significance Map



Fermi-LAT >50 GeV Count Map (adaptively smoothed)





- ¹ H.E.S.S. reported the detection of 69 sources reaching a sensitivity of ~2% of the >1 TeV Crab Nebula flux
- The LAT detects (in 2FHL) 36 sources in the same region reaching an average sensitivity of 3-4% of the Crab Nebula flux
- ¹ The LAT detects an equal number of PWNe/SNRs while for H.E.S.S they are in a 1.5:1 ratio
- ^I Within the H.E.S.S. footprint there are:
 - I 7 unassociated sources
 - ⁰ 6 objects coincident with dark accelerators

sermi Example of a dark accelerator











Blazar-like objects constitute >80% of the 2FHL Catalog

- Detected up to z~2
- Most of them are BL Lacs, only 10 FSRQs
- Different population than 3FGL







- Being sensitive over ~4 decades in energy, the LAT resolves the high-energy peak
 - Sources become softer at higher energies



Sermi Extragalactic Background Light: 1

Space Telescope





- Evidence for strong softening of the 2FHL spectra with redshift
 Most likely due to EBL
- Several photons detected beyond the horizon
 Very important to constrain the EBI
 - Very important to constrain the EBL



- S.
- Measuring the intrinsic spectral index: fitting an EBL-absorbed power law model to 128 2FHL blazars with a redshift
 the intrinsic spectra are much harder than the observed ones





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Spectral breaks between the VHE and Fermi band have been used as diagnostic for/against the EBL (Essey&Kusenko, Sanchez+13,etc)

¹ spectral flattening at high redshift has been interpreted as sign of interesting physics



Extragalactic Background Light: 4



- Dependence of spectral breaks between the 2FHL and 3FGL bands with redshift can be explained as *produced by the EBL alone.*
- There is no evolution of the physics that drives the photon emission in HSP blazars => excellent probes of the EBL.







Models predict that the >50 GeV EGB is produced by blazars





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Perform simulations of the > 50 GeV sky to determine the detection efficiency

i.e. the probability to detect a source in 2FHL as a function of flux









- 2FHL opens a new window on the high-energy sky
 - 360 sources detected between 50 GeV and 2 TeV
 - 75% blazars, 14% Galactic and 11 % unassociated
 - only 25% detected in TeVCat

- Galactic science:

- all display hard spectra
- 5 new extended sources, 9 dark accelerators, 87% of PWNe/SNRs
- good match to the H.E.S.S. Galactic plane survey

- Extragalactic science:

- >80% of 2FHL sources are blazars (BL Lacs), detected up to z~2
- Clear signs of EBL attenuation (and nothing else)
- HSP blazars are excellent probes of the EBL
- Almost all the IGRB is accounted for by blazars





Backup

Detection Pipeline



NB: all source spectra are modeled as simple power laws

Gamma-ray Space Telescope





Sermi 2FHL Some Numbers



Analysis

ace Telescope

- □ **50 GeV 2 TeV**
- ~74 months of data
- **Pass 8 (source)**
- Unbinned likelihood

Detections

- 2 ~350 sources
- □ <u>84 detected by ACTs</u> (TeVCat)
- 238 detected in 1FHL
- **234 detected in 3FGL**
- □ ~60 brand new sources

Analysis
50 GeV – 2 TeV
~74 months of data
Pass 7 (source)

- Detections in P7
 227 sources
- Main difference is at high [b]
- Better PSF, less background =improved sensitivity
- 160(P7) vs 250(P8) sources

Bottom line: ~130 sources not in 1FHL and ~250 not in TeVCat, 60 not in 3FGL





Fermi-LAT (1FGL, 2FGL, 3FGL) catalogs do an excellent job in characterizing variability and energetics of sources detected in the 0.1-100 GeV band*



*3FGL goes up to 300 GeV



- Pass 8 opens a new window on the >50 GeV sky: 1. Improve PSF and Acceptance (factor of 0.5-2 in P8)
 - 2. Low background and good (constant) PSF (0.1 deg at 68%)
 - 3. All-sky exposure
- Why a catalog of sources detected at >50 GeV ?
 - **I**. Allows study of the EBL, EGB, Galactic plane etc.
 - **I.** Continues our effort to characterize sources at high energies
 - \mathbb{I}_{\cdot} Connects well to IACTs, HAWC and the upcoming CTA

Gamma-ray Example of a Dark Accelerator: 2

Space Telescope



Renaud et al. 2008 8 Declination (J2000) **Correlated Significance** H.E.S.S. (preliminary) -57°30' 6 -58°00' 4 2 -58°30' SR J1502-5828 AX J150436-5824 0 -59°00' -2 15^h10^m 15^h05^m 15^h00^m Right Ascension (J2000) 2FHL J1505.1-5808 10^{-11} $u F_{
u}$ [erg cm $^{-2}$ s $^{-1}$] 10^{-12} LAT \star H. E. S. S. Preliminary 10^{-13} 0.001 0.01 0.1 10 100 Energy [TeV]





The 2FHL LogN-LogS resolves 96(+15/-18)% of the IGRB

Nearly all the IGRB is produced by BL Lacs







