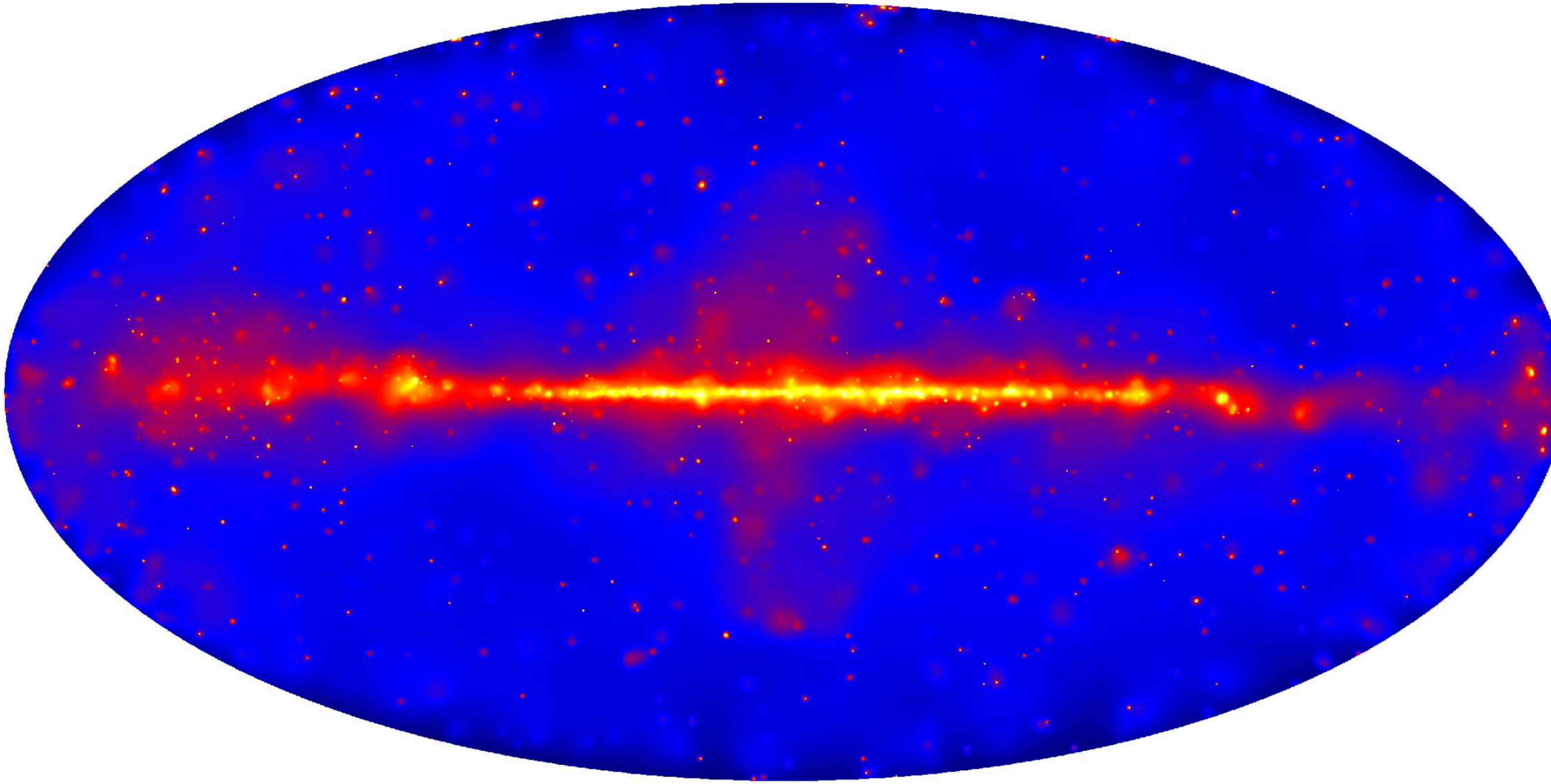
Hard Fermi-LAT Sources

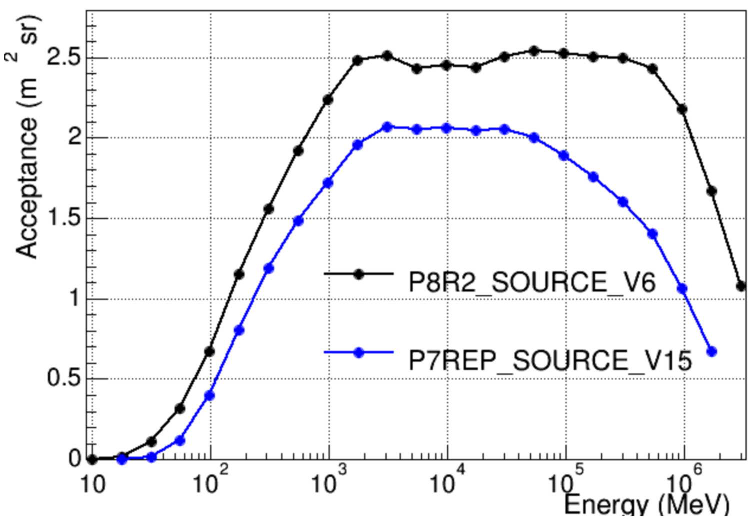


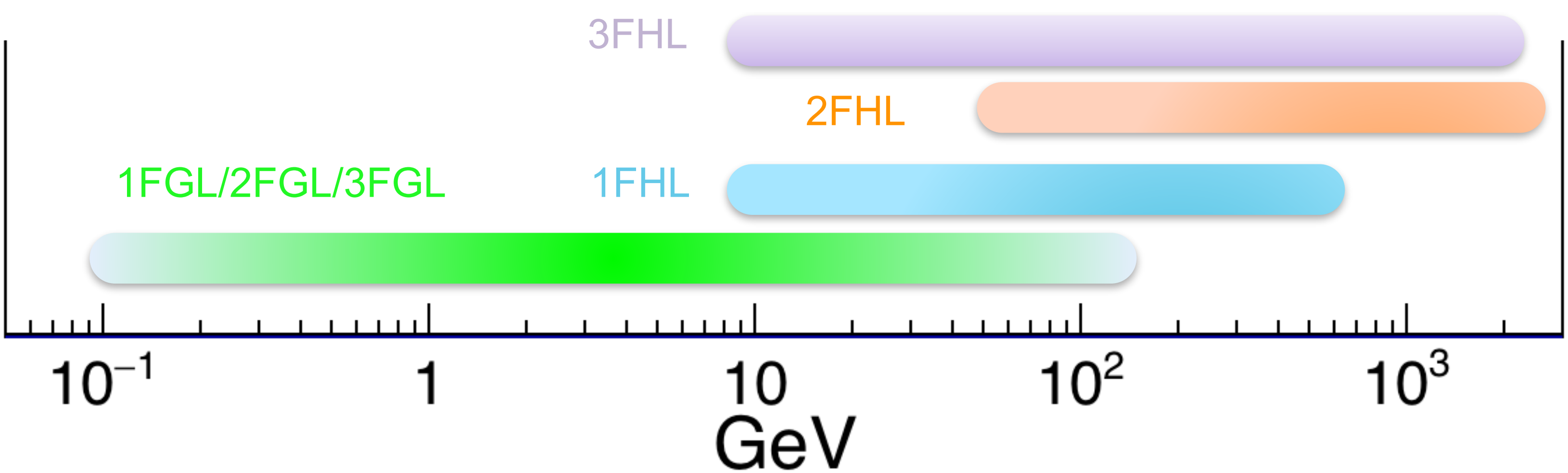
Sara Cutini,
Marco Ajello, Alberto Domínguez, Jamie Cohen and Dario Gasparrini

on behalf of the Fermi-LAT Collaboration

Fermi-LAT Catalogs

*n*FGL Catalogs detect and characterize sources in the ~0.1-100 GeV energy range
*n*FHL Catalogs explore the higher-energy sky





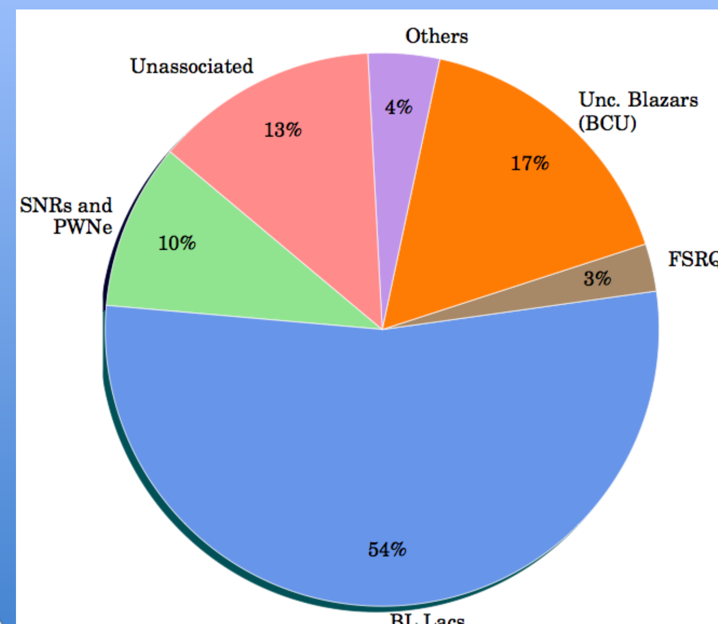
Analysis Details: 2FHL

- **Analysis details**
  - 50 GeV – 2 TeV
  - 80 months of data (till April 2015)
  - Pass 8 (source)
  - Unbinned likelihood

- **Detections**
  - 360 sources:
    - 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%) !

Associations



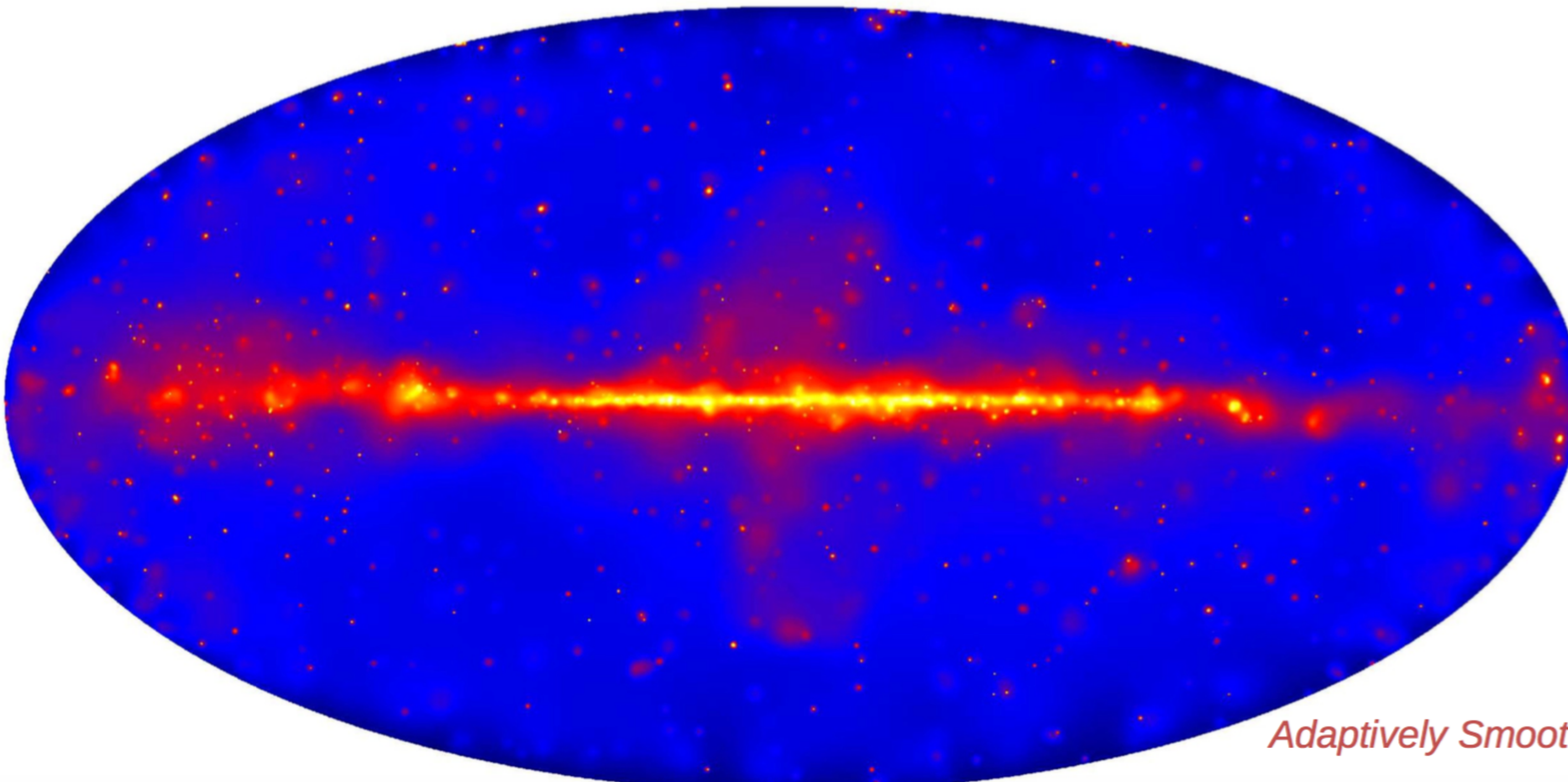
Bottom line: *plenty of sources for TeV telescopes*

The 2FHL sky: count map

80 months of P8 data (50 GeV – 2 TeV)

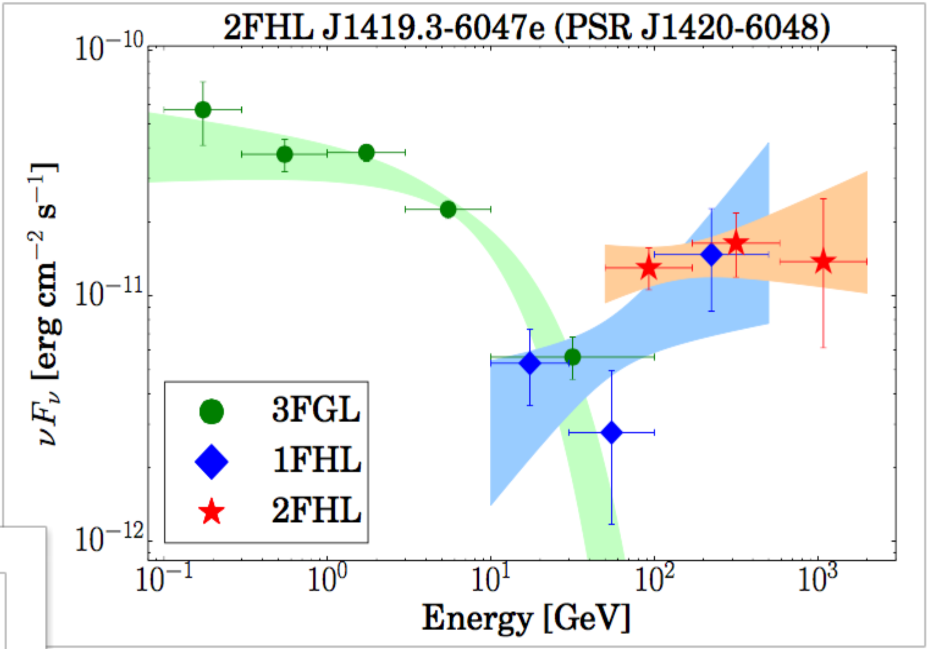
61,000 photons E > 50 GeV
22,100 photons E > 100 GeV
2,000 photons E > 500 GeV

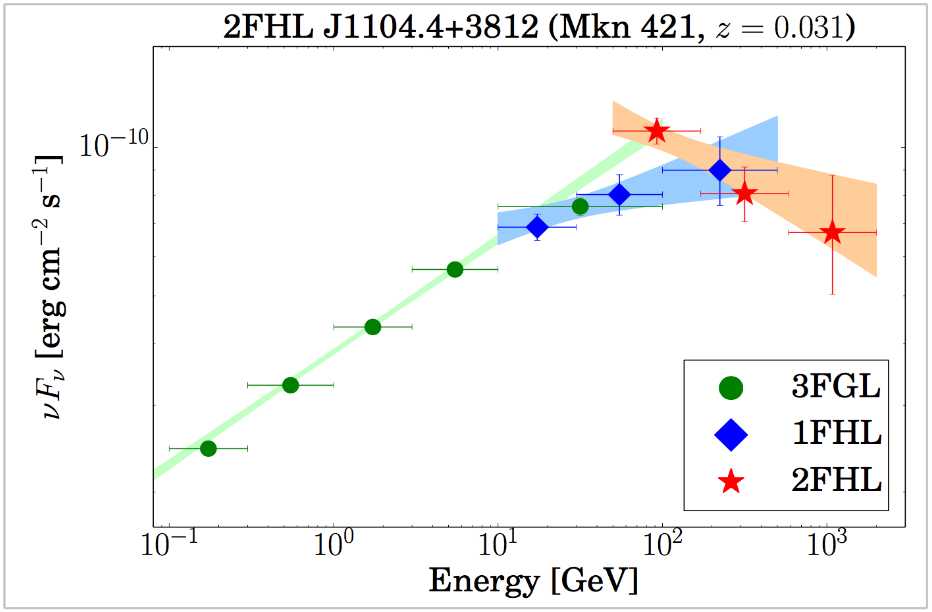
~1.5 photon every deg^2



Adaptively Smoothed

Spectral Energy Distributions

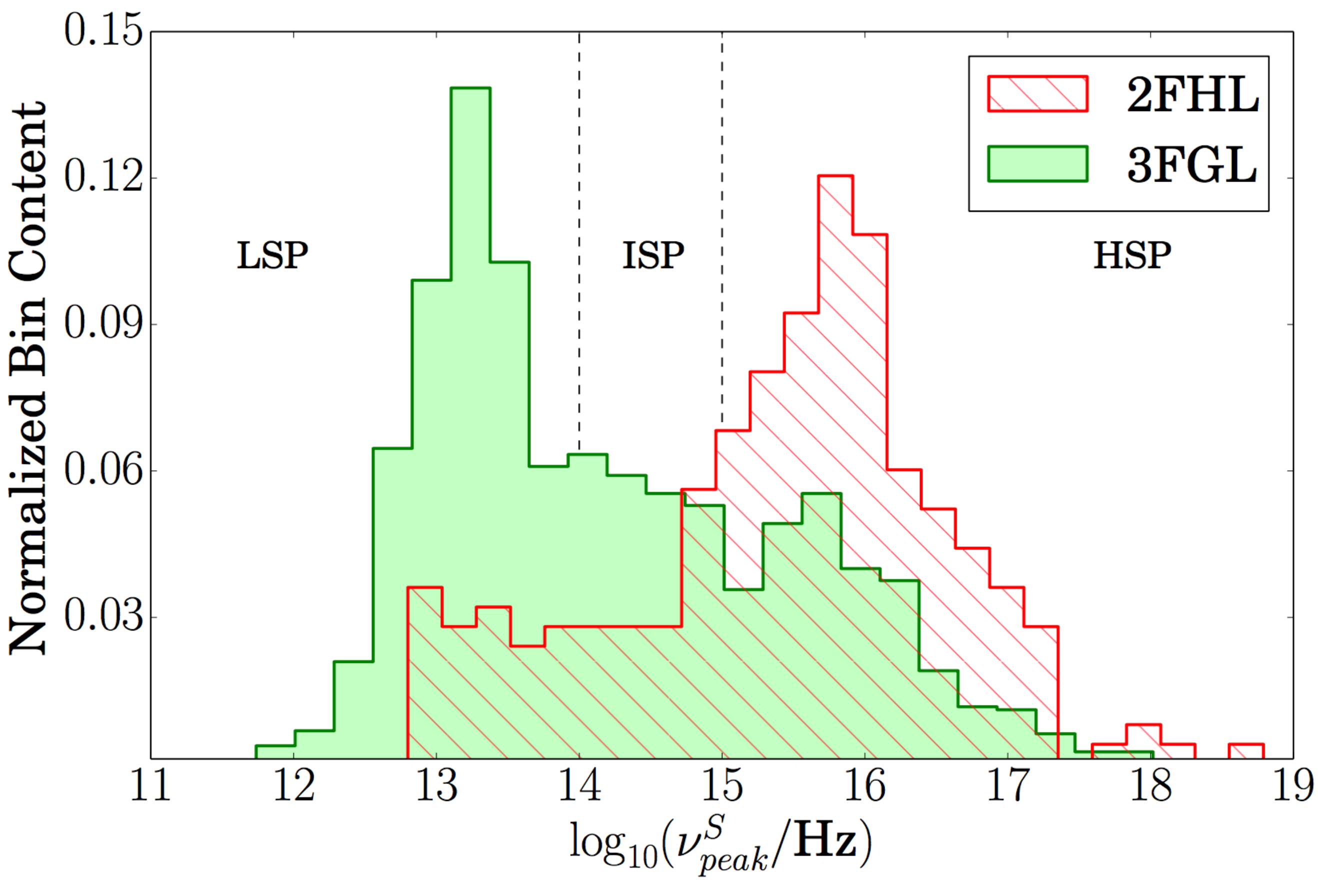




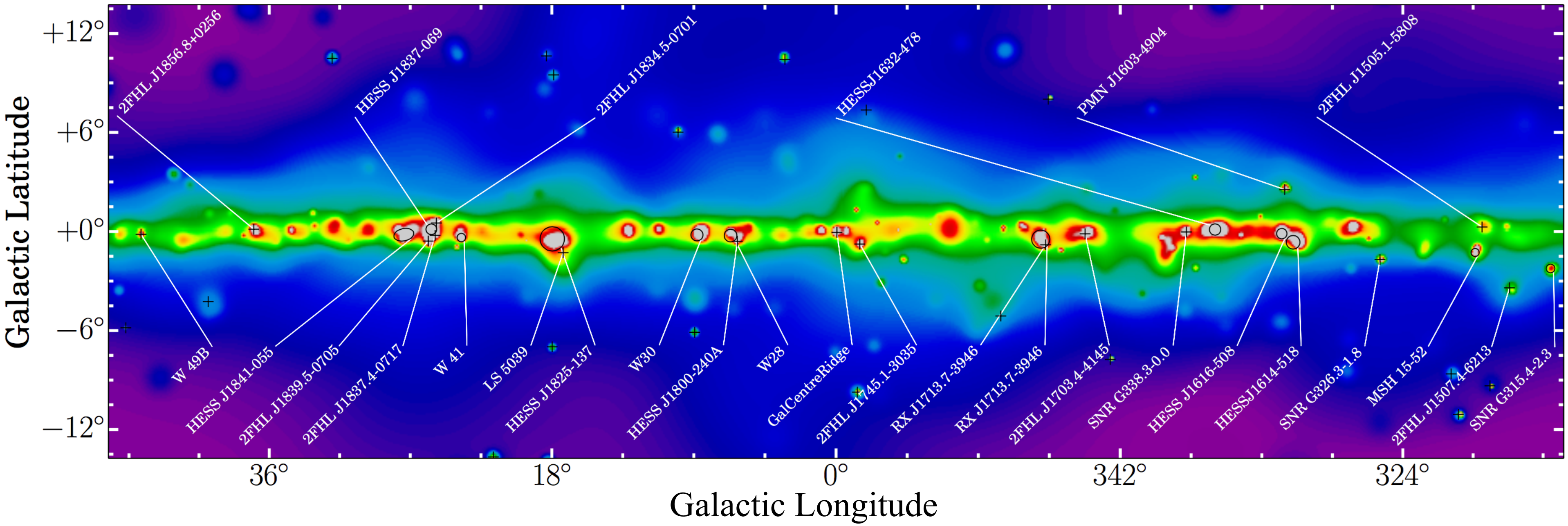
Available at:
http://fermi.gsfc.nasa.gov/ssc/data/access/lat/2FHL/

Blazars

- **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



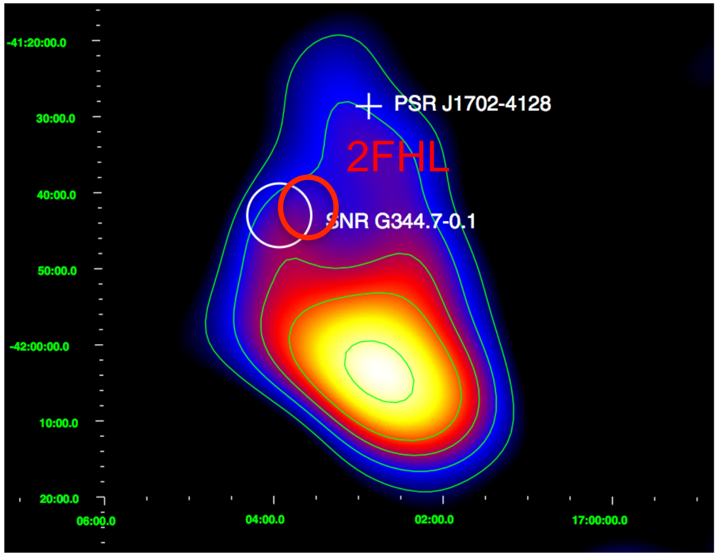
Galactic Sources



- **103 sources at |b|<10°**
  - 42 blazars, 39 Galactic objects, 13 unassociated and 9 Dark Acc.
  - PWNe/SNRs represent 87% of the Galactic population
  - Galactic sources are very hard
    - Median photon index of ~2, while for blazars is ~3
  - Half of the unassociated sources are hard and thus (likely) Galactic

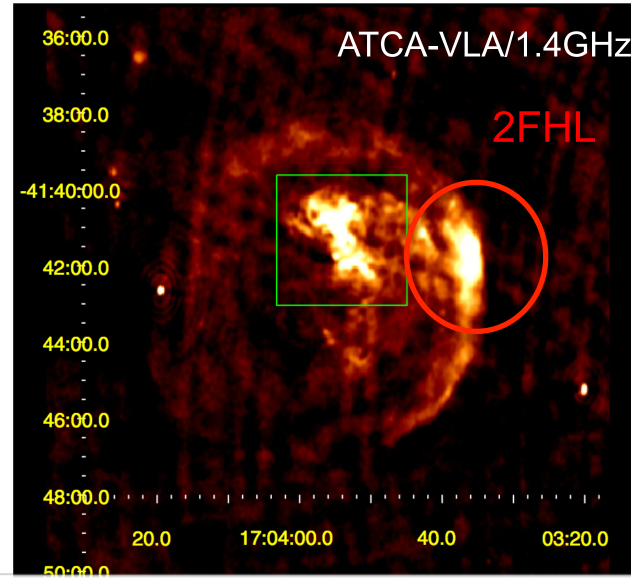
Example of a dark accelerator

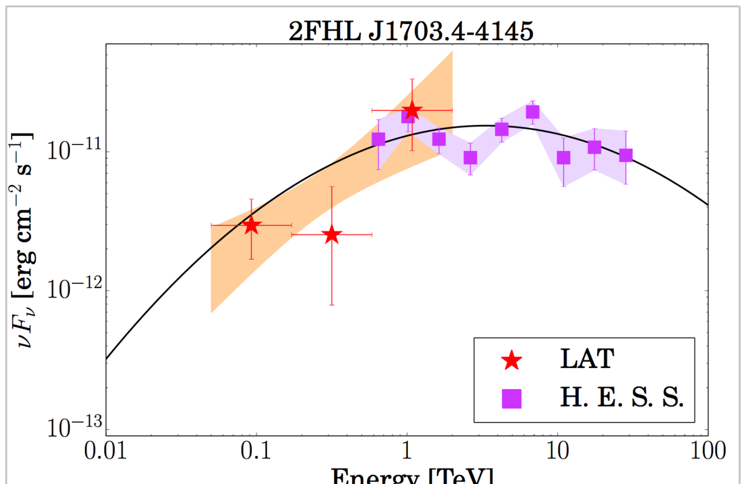
Aharonian+08



HESS J1702-420

Giacani et al.2011

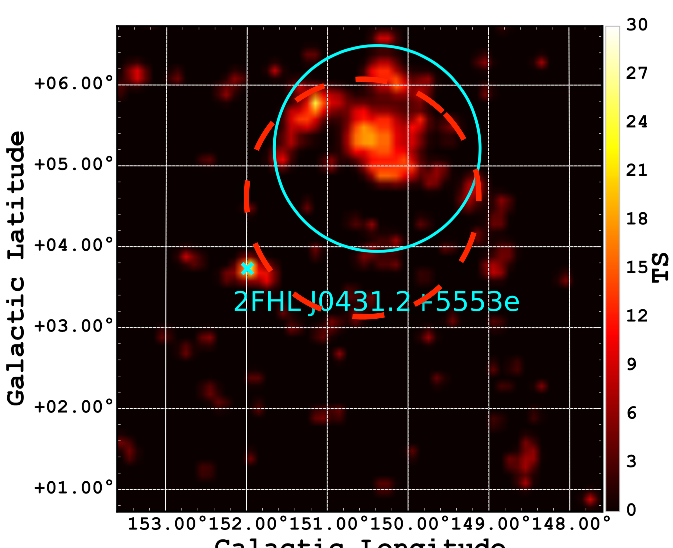




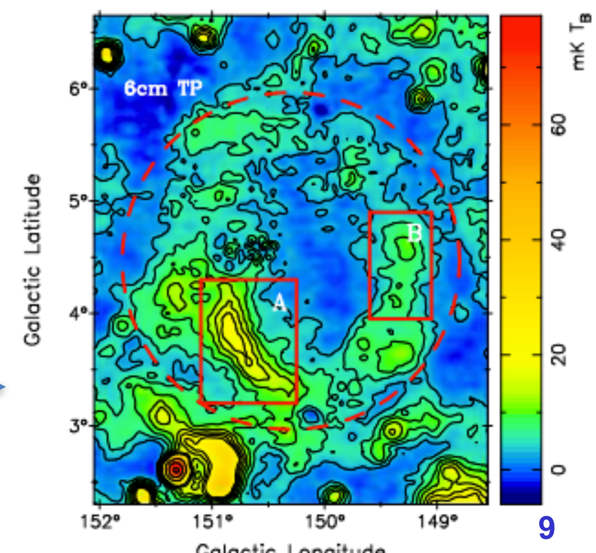
New Extended Sources

- **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 [deg]	b [deg]	TS	TS_{ext}	TS_{2pts}	F_{50}	ΔF_{50}	Γ	$\Delta\Gamma$	Association	Class	Radius [deg]
J0431.2+5553e	150.384	5.216	87.9	83.4	26.2	11.70	2.11	1.66	0.20	G 150.3+4.5	snr	1.27
J1112.4−6059e	291.222	-0.388	80.9	68.3	22.5	12.80	2.36	2.15	0.28	PSR J1112−6103	pwn	0.53
J1355.2−6430e	309.730	-2.484	82.3	31.8	12.9	9.59	1.95	1.56	0.22	PSR J1357−6429	pwn	0.57
J1419.2−6048e	313.432	0.260	109.3	49.1	15.6	17.60	2.80	1.87	0.19	PSR J1420−6048	pwn	0.36
J1443.2−6221e	315.505	-2.239	75.6	29.9	19.2	7.23	1.70	2.07	0.30	SNR G315.4−2.3	snr	0.27



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



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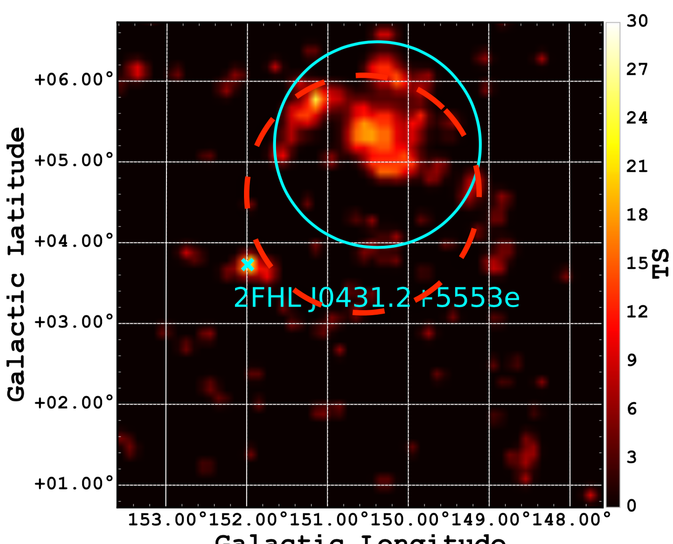

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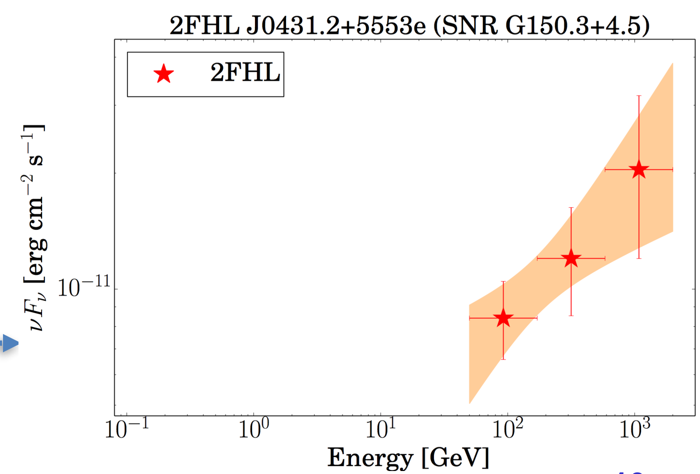
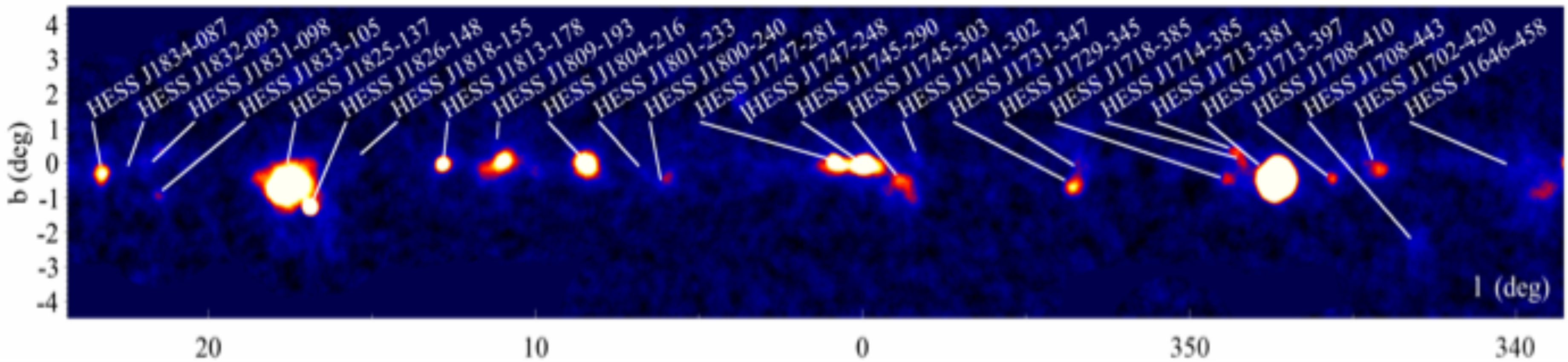


Comparison with the H.E.S.S. G.P. Survey

Fermi Gamma-ray Space Telescope

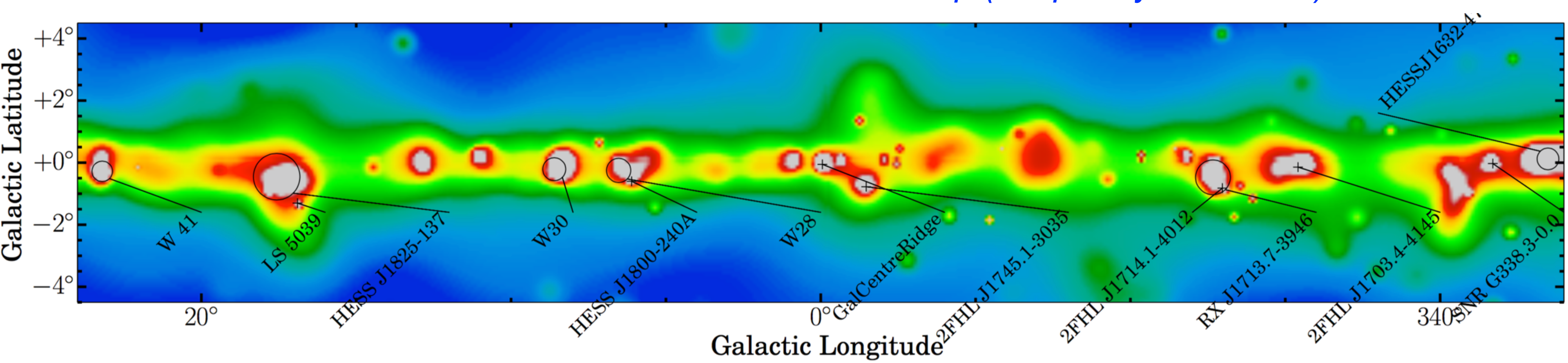
asdc ASI Science Data Center

Significance Map

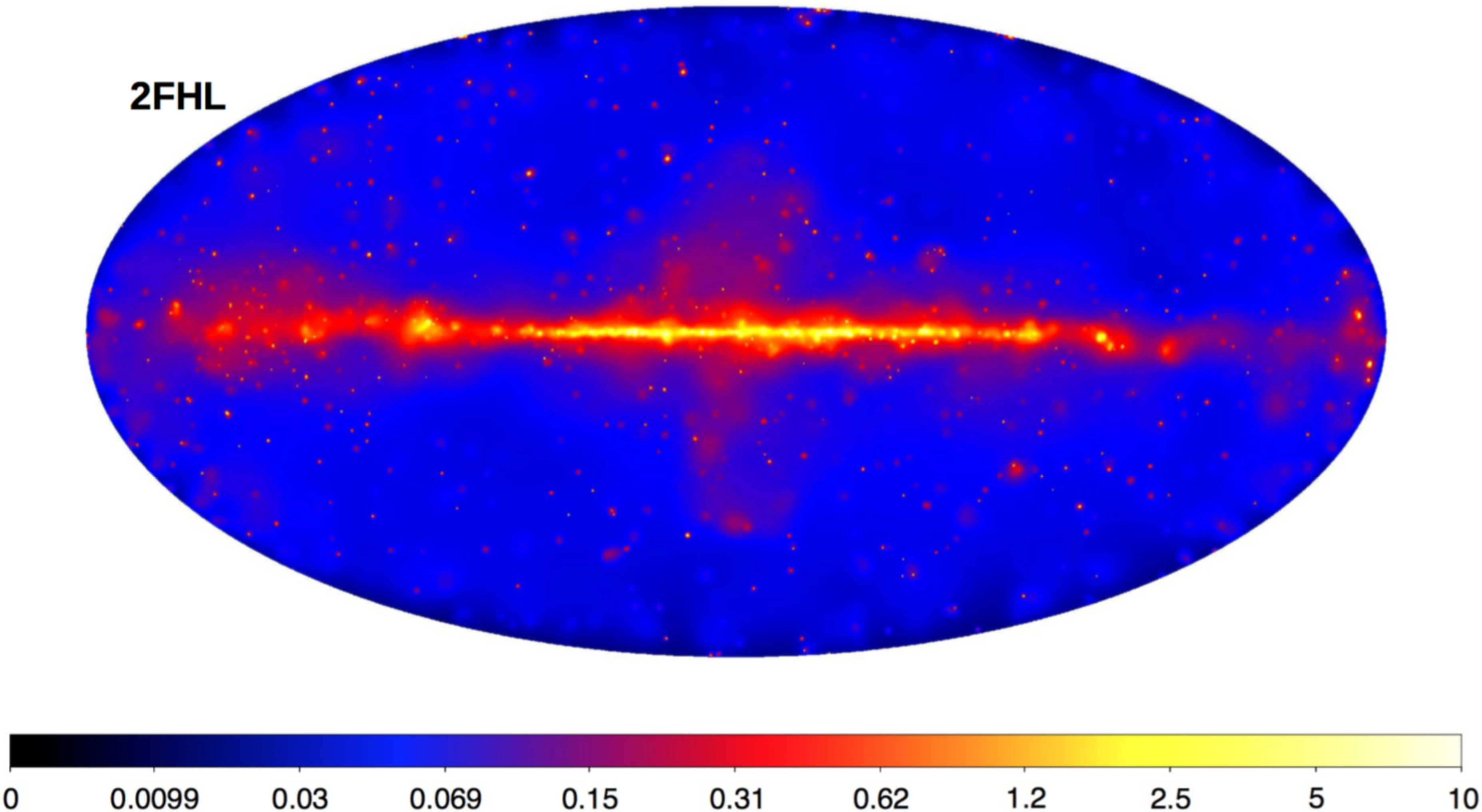


Aharonian et al. 2006, Carrigan et al. 2013

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



The future is bright: 3FHL



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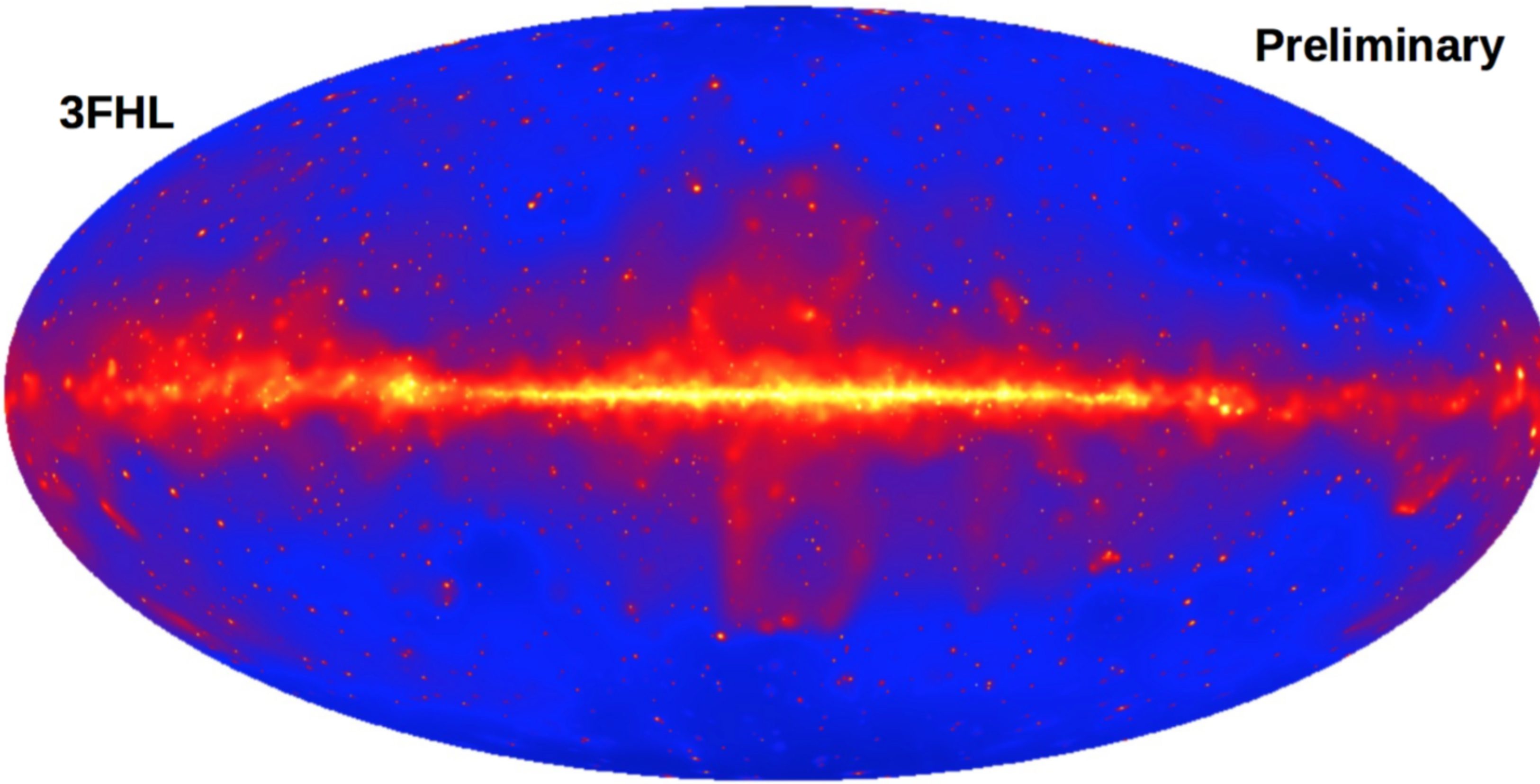
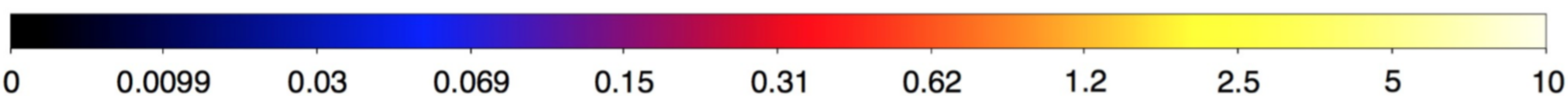


More than 1,700 sources at E>10 GeV in 84 months of *Fermi*-LAT data

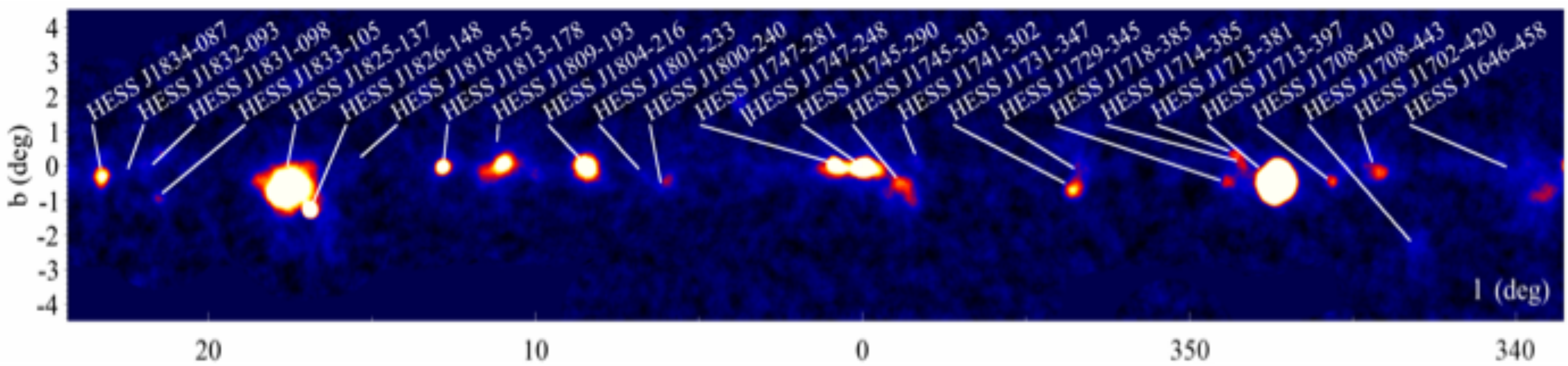


Conclusions

- *Fermi*-LAT has produced a new, sensitive, census of the >50 GeV sky
  - *It detected 360 sources, a lot of them new → only 25% in the TeVCat*
  - *It detected new extended sources*
  - *>80% of the sources are blazars (BL Lacs) detected up to z~2*
  - *It yielded interesting results for the:*
    - *EGB – LAT collaboration*
      - *Almost accounted by blazars*
    - *EBL – Dominguez & Ajello, ApJL, 2015, 813, 34*
      - *Clear signs of EBL attuenation (nothing else)*
    - *Neutrino background: - Bechtol et al.* arXiv:1511.00688

Backup slides

Comparison with the H.E.S.S. G.P. Survey

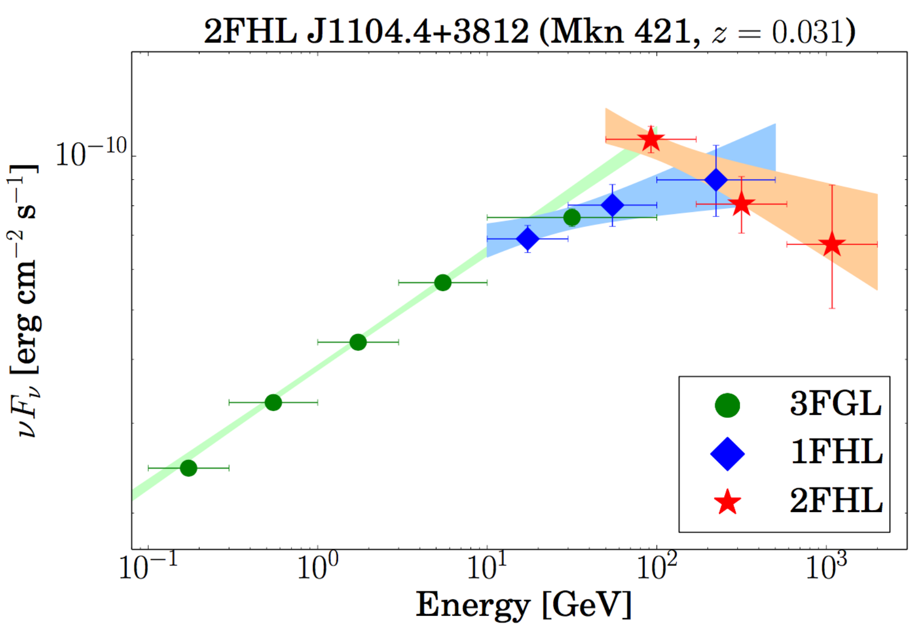


Aharonian et al. 2006, Carrigan et al. 2013

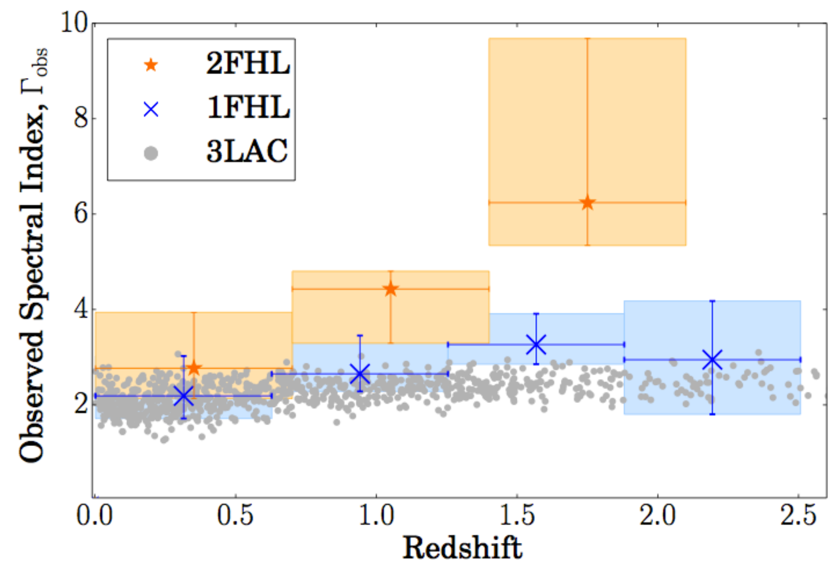
- H.E.S.S. reported the detection of 69 sources reaching a sensitivity of ~2% of the >1 TeV Crab Nebula flux
- The LAT detects (in 2FHL) 36 sources in the same region reaching an average sensitivity of 3-4% of the Crab Nebula flux
- The LAT detects an equal number of PWNe/SNRs while for H.E.S.S they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

Blazar Spectra

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



Photon index distribution vs redshift



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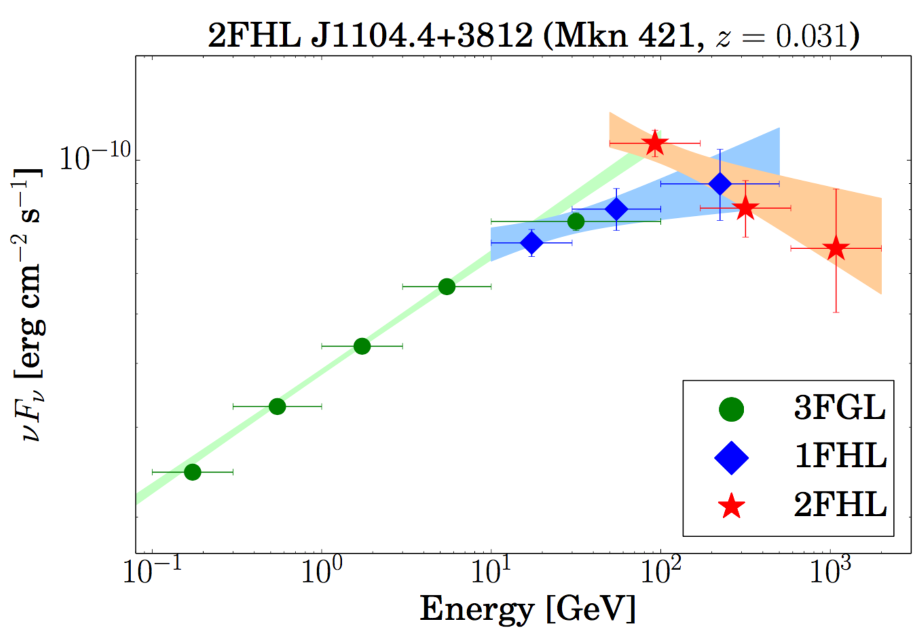
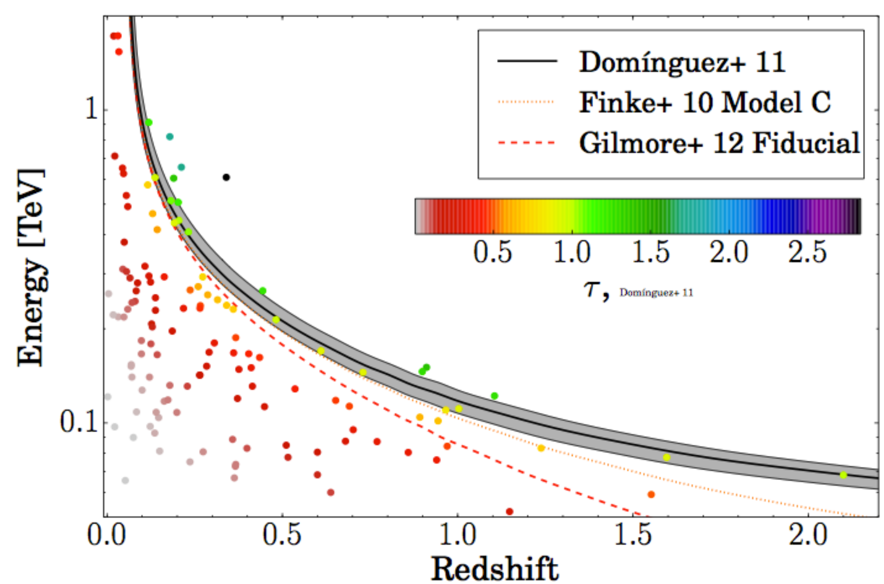
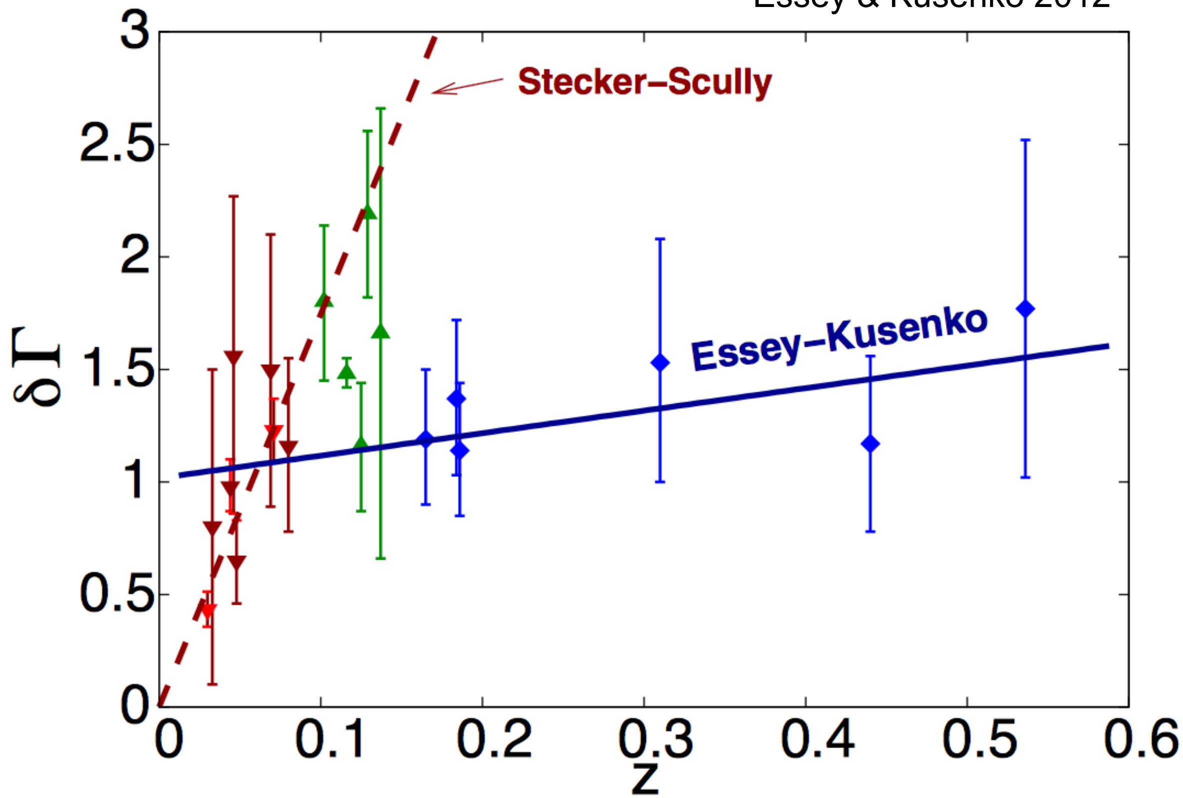




Extragalactic Background Light

- **Spectral breaks between the VHE and Fermi band have been used as diagnostic for/against the EBL** (Essey&Kusenko, Sanchez+13,etc)
  - **spectral flattening at high redshift has been interpreted as sign of interesting physics**

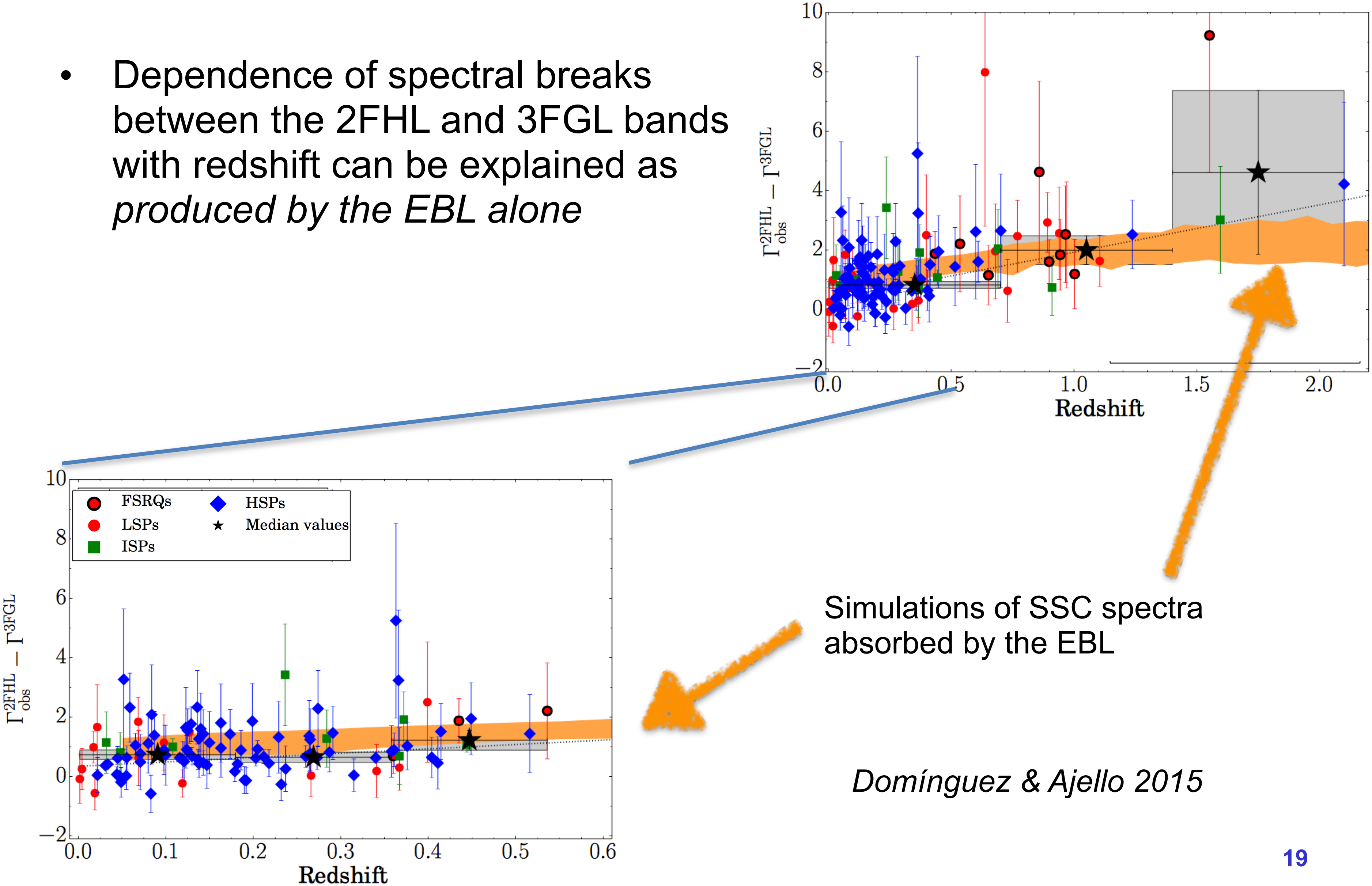
Essey & Kusenko 2012



$$\delta\Gamma = \Gamma_{\mathrm{TeV}} - \Gamma_{\mathrm{GeV}}$$

Extragalactic Background Light

- Dependence of spectral breaks between the 2FHL and 3FGL bands with redshift can be explained as *produced by the EBL alone*



Simulations of SSC spectra absorbed by the EBL

Domínguez & Ajello 2015

Summary

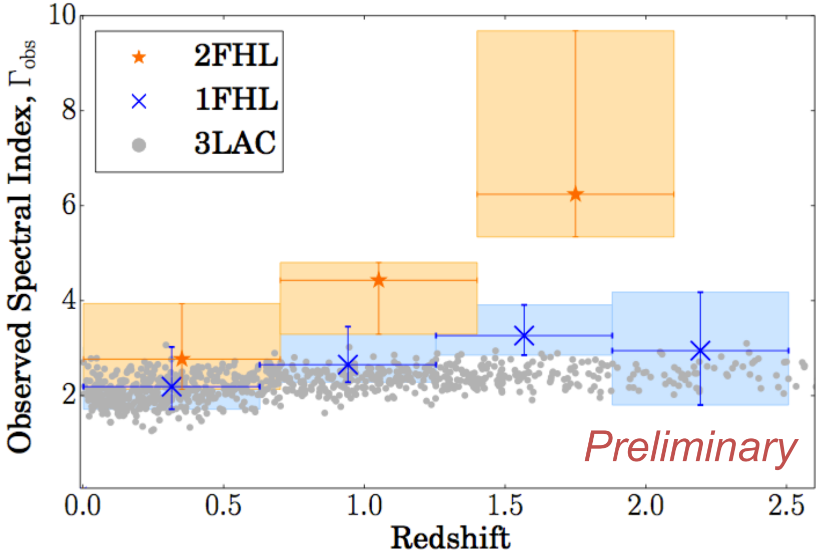
- 2FHL opens a new window on the high-energy sky
  - 360 sources detected between 50 GeV and 2 TeV
    - 75% blazars, 14% Galactic and 11 % unassociated
    - only 25% detected in TeVCat

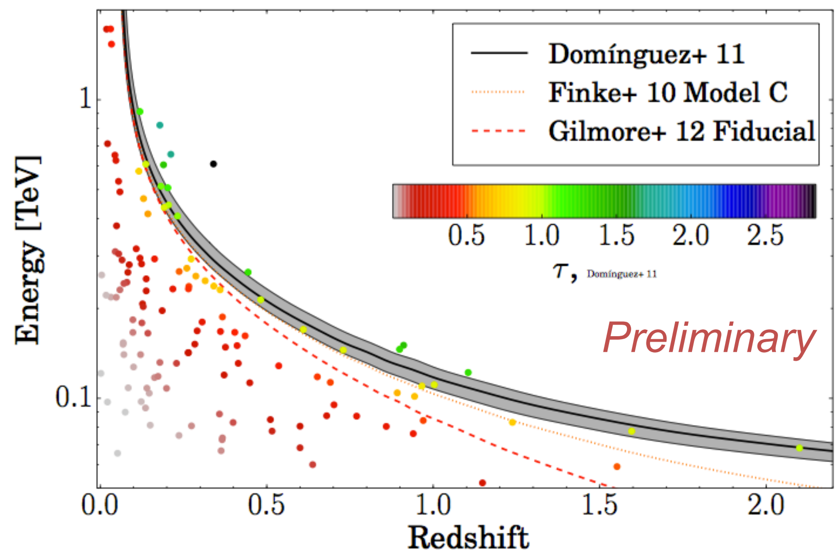
- **Galactic science:**
  - all display hard spectra, 87 % are PWNe/SNRs
  - 5 new extended sources and ~25 unassociated sources
  - good match to the H.E.S.S. Galactic plane survey

- **Extragalactic science:**
  - >80% of 2FHL sources are blazars (BL Lacs), detected up to z~2
  - Clear signs of EBL attenuation (and nothing else)

Best of All ? Sensitivity increases linearly with time, so stay tuned!

Extragalactic Background Light: 1

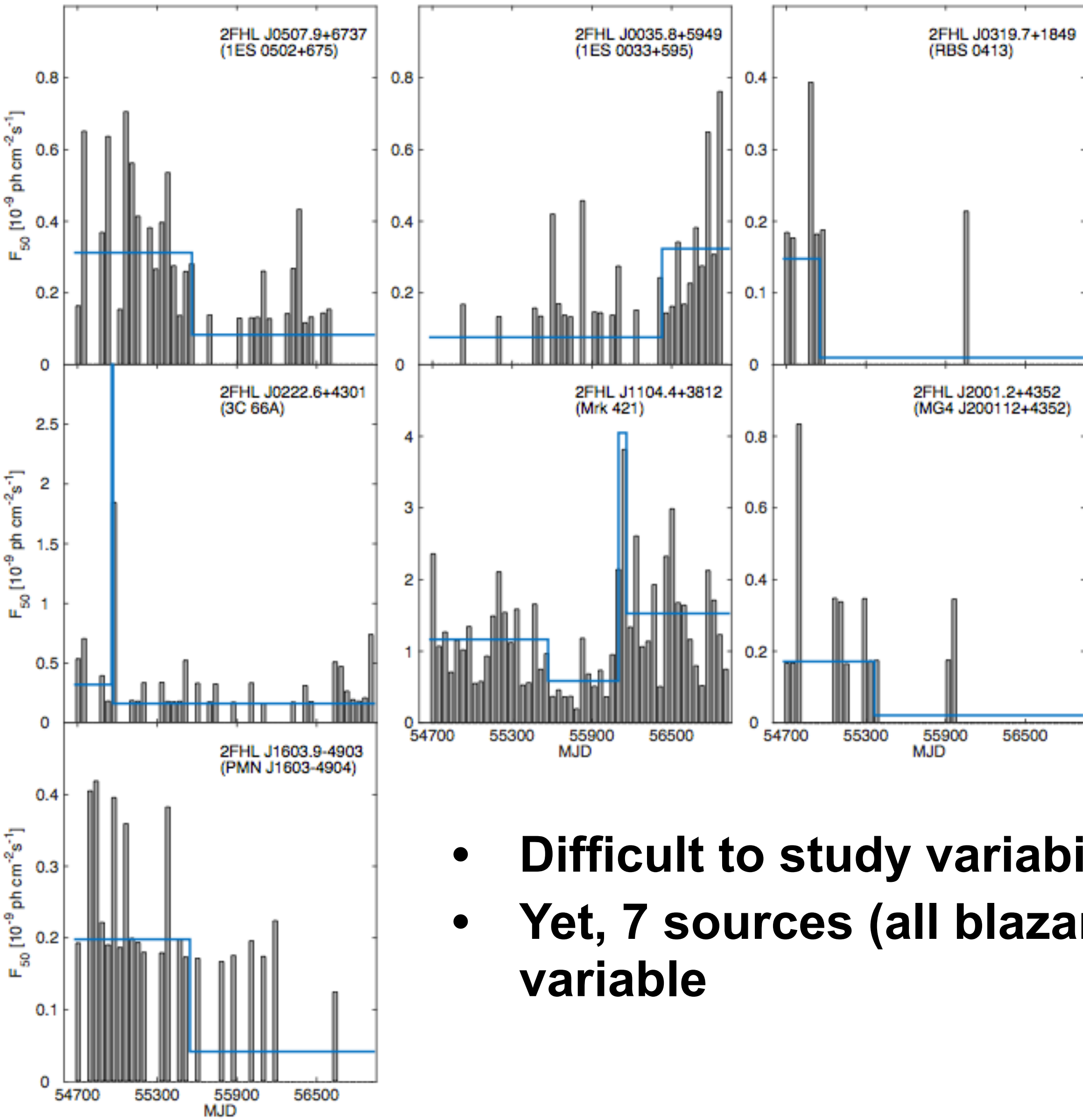




- **Evidence for strong softening of the 2FHL spectra with redshift**
  - Most likely due to EBL

- **Several photons detected beyond the horizon**
  - Very important to constrain the EBL

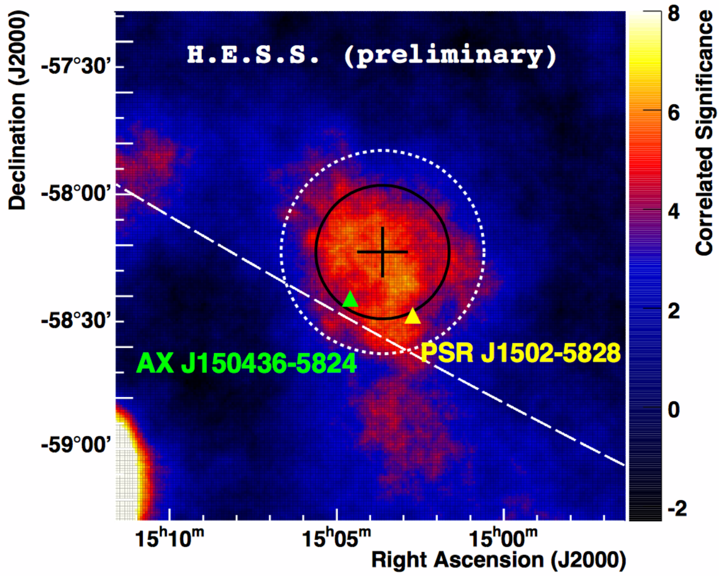
Variability

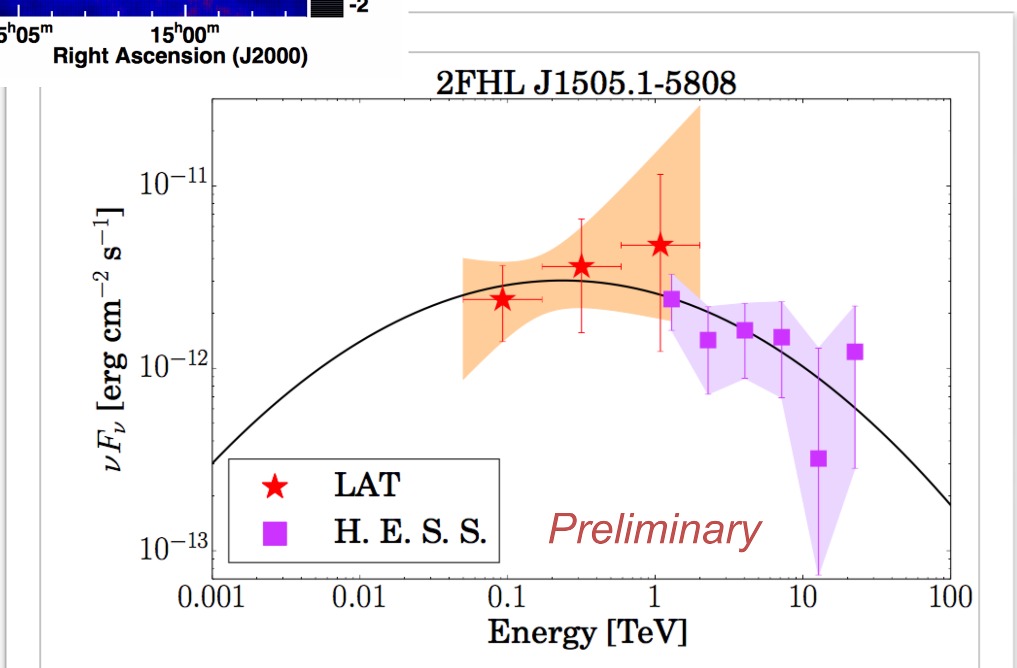


- **Difficult to study variability with few photons**
- **Yet, 7 sources (all blazars) are found to be variable**

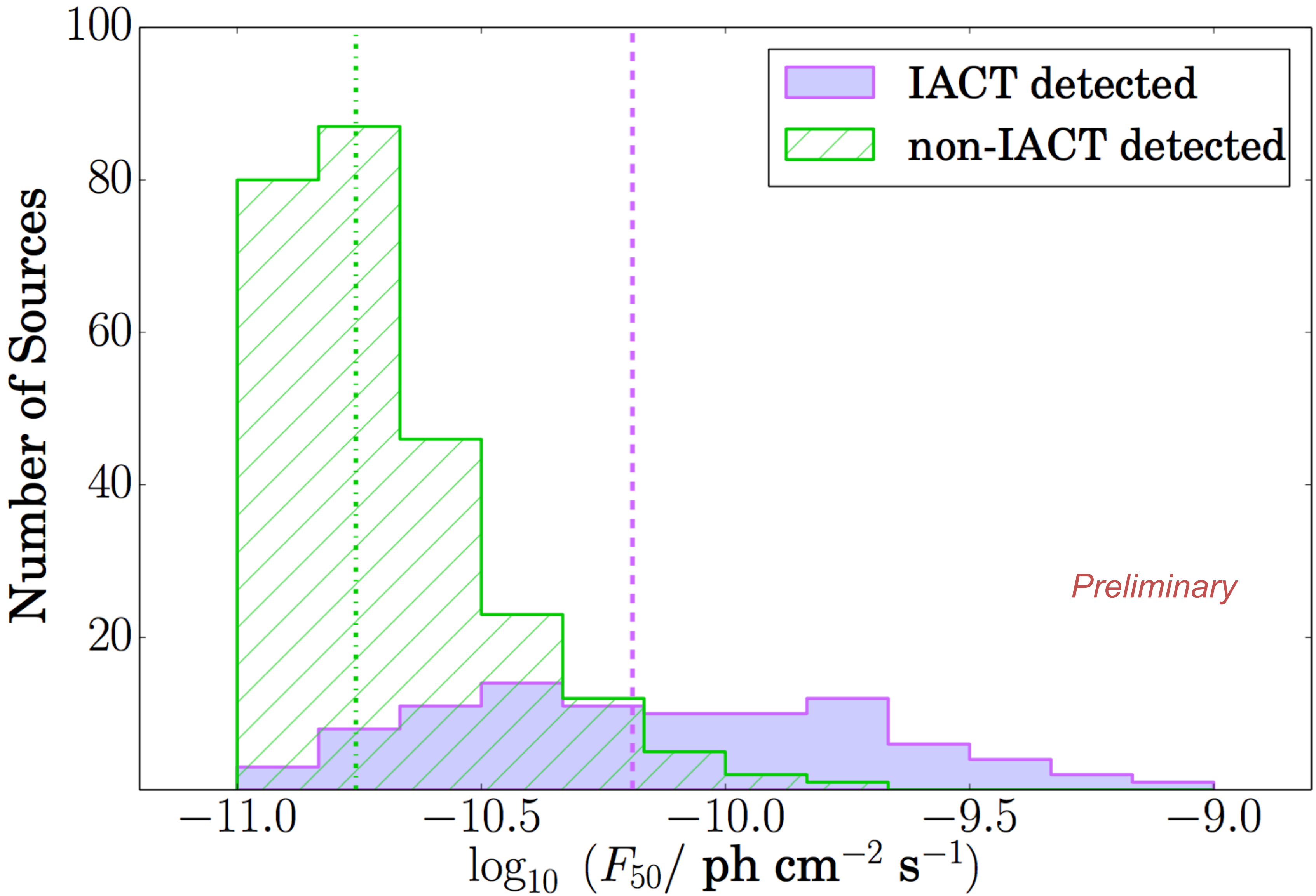
Example of a Dark Accelerator: 2

Renaud et al. 2008



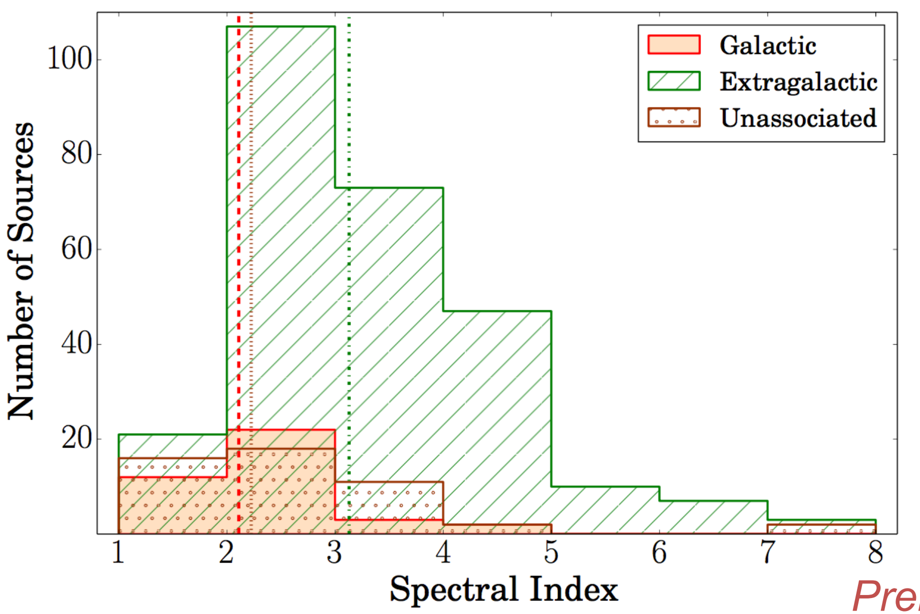


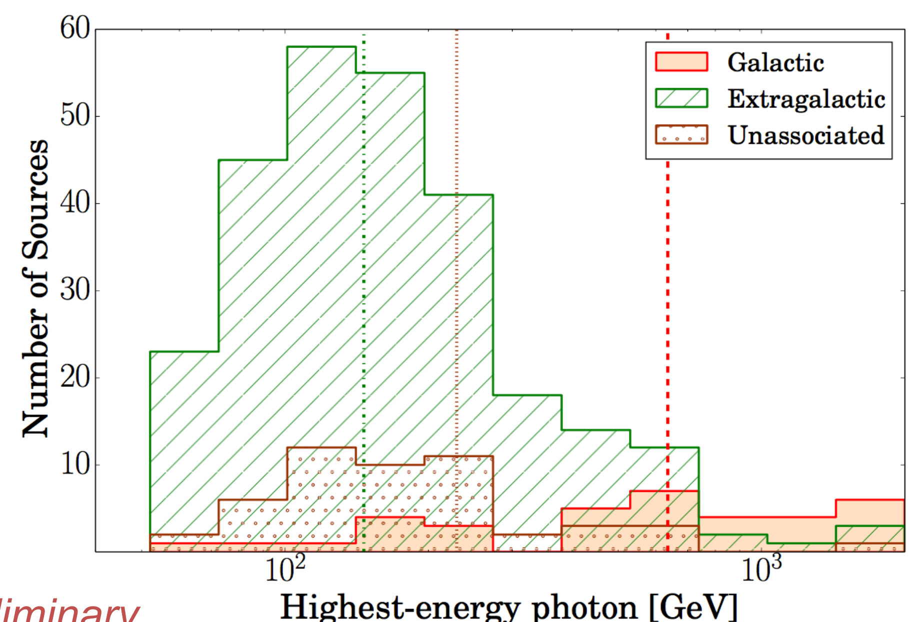
2FHL Sources detected at TeV energies



General Properties

- Galactic sources have much harder spectra than extragalactic ones
  - Median spectral index Γ=2 vs Γ=3
  - The EBL might be the culprit
  - Spectral index can be used to distinguish Galactic objects among the unassociated sources





Preliminary

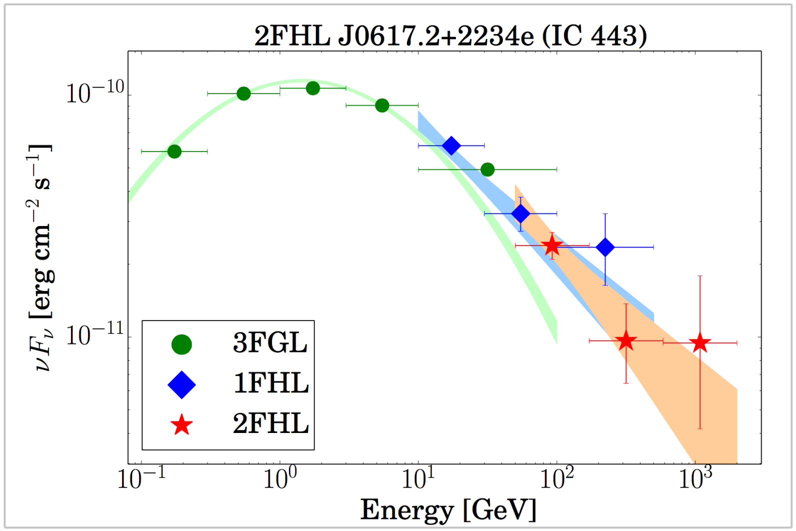
Search for Extended Sources

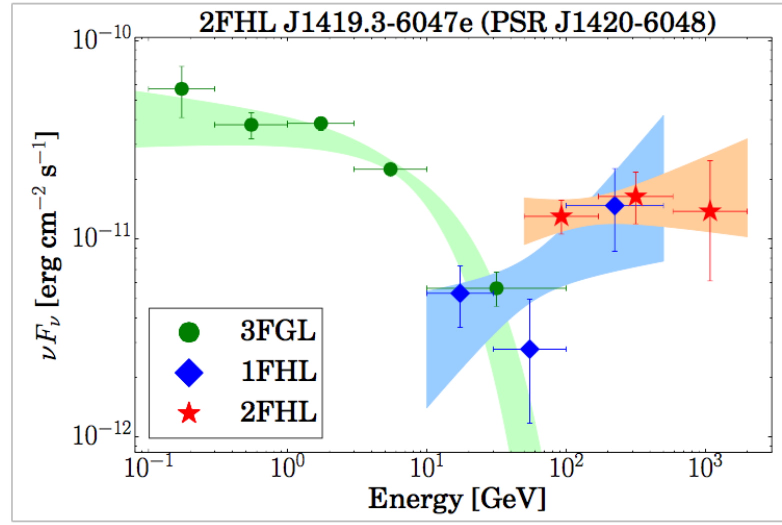
- **We used the extended templates of previously detected sources:**
  - 25 from 3FGL + W41
  - Of them 6 sources were not significantly detected:
    - SMC, S 147, Cen-A (lobes), W 44, HB 21, Cygnus loop

- **Blind search for new sources:**
  - 72 ROIs of 10°, devoid of sources, centered at $b=0$
  - Iteratively add disk source at most significant TS peak
  - Fit and choose extended source if $TS_{ext}>16$

- **It resulted in the detection of 5 new extended sources**

Spectral Energy Distributions





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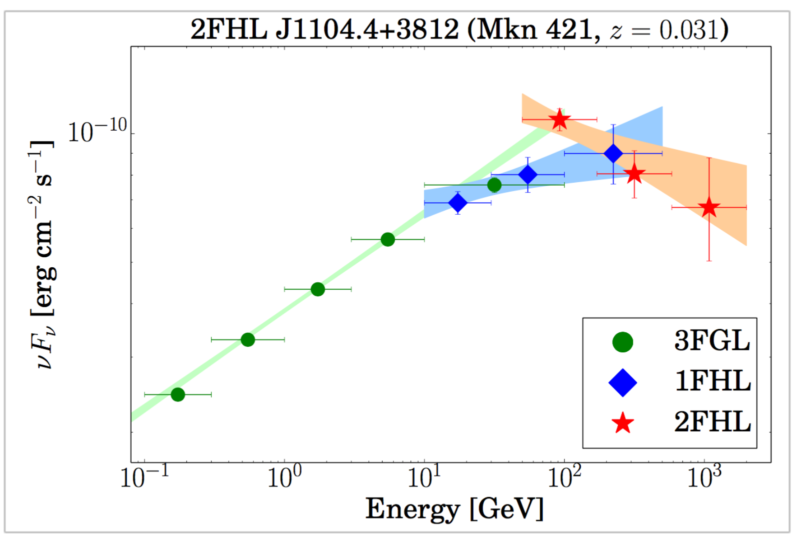
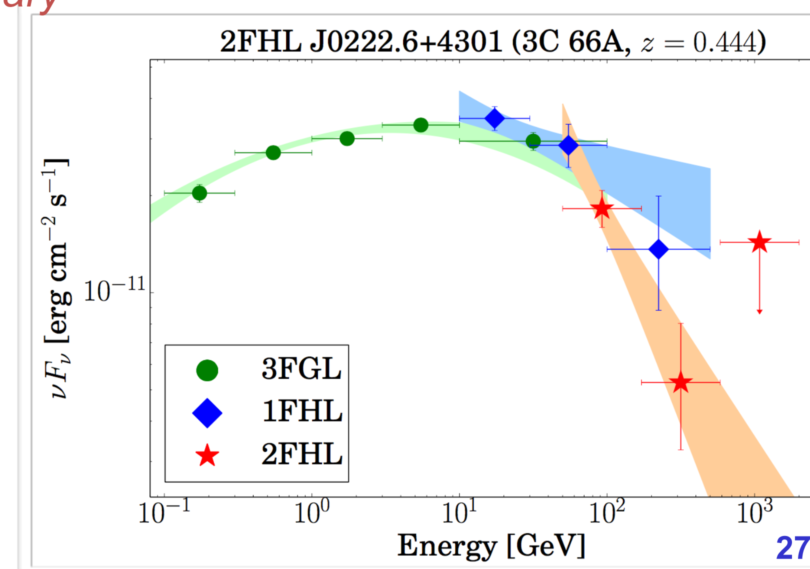
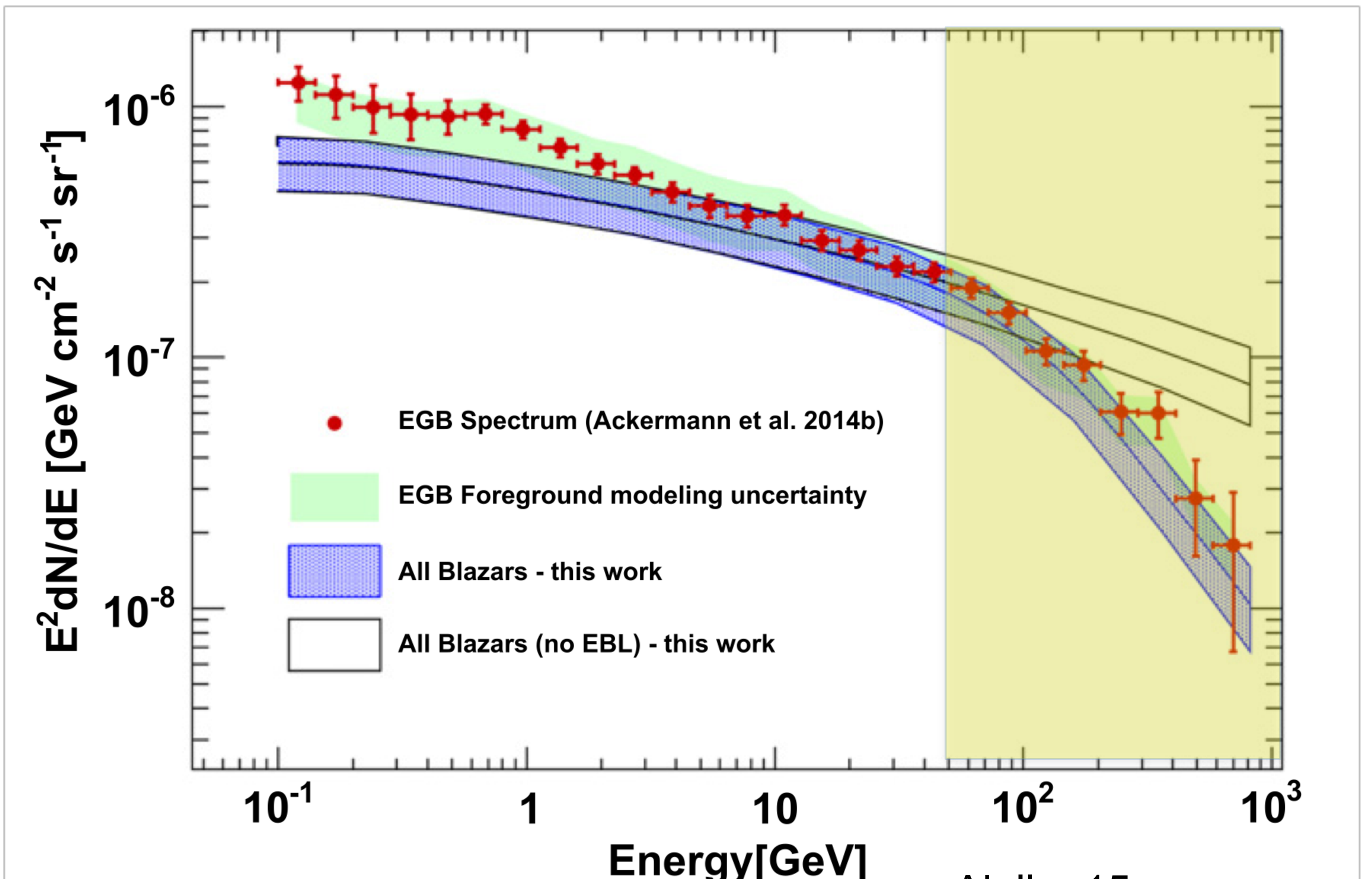




Extragalactic Gamma-ray Background

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

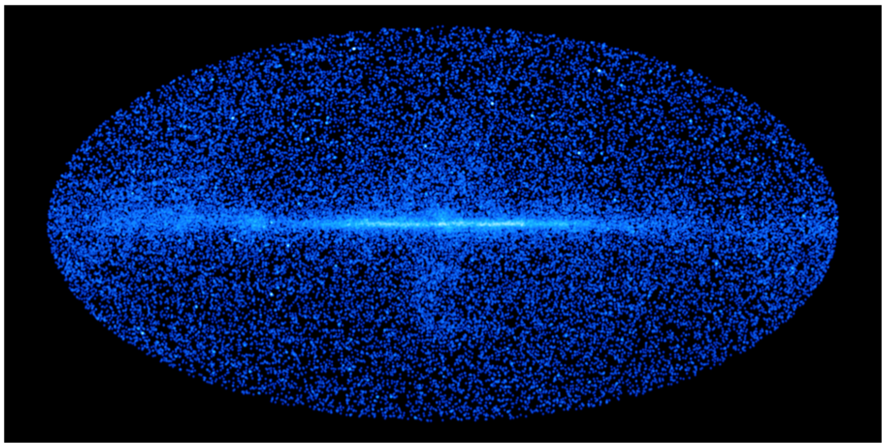
EGB: Ackermann et al. 2015, Models: Ajello+2015, Di Mauro+2015

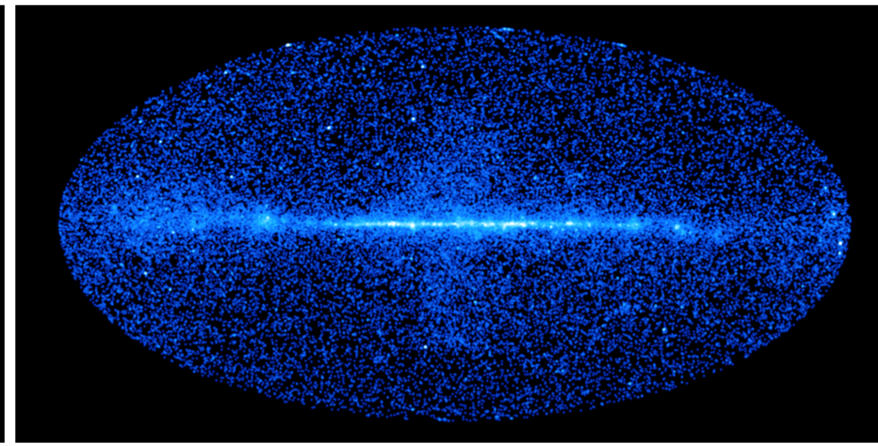


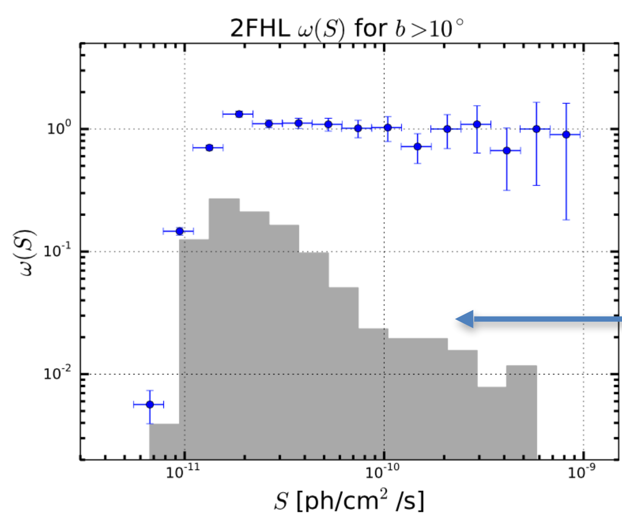
Ajello+15

Extragalactic Gamma-ray Background

- **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





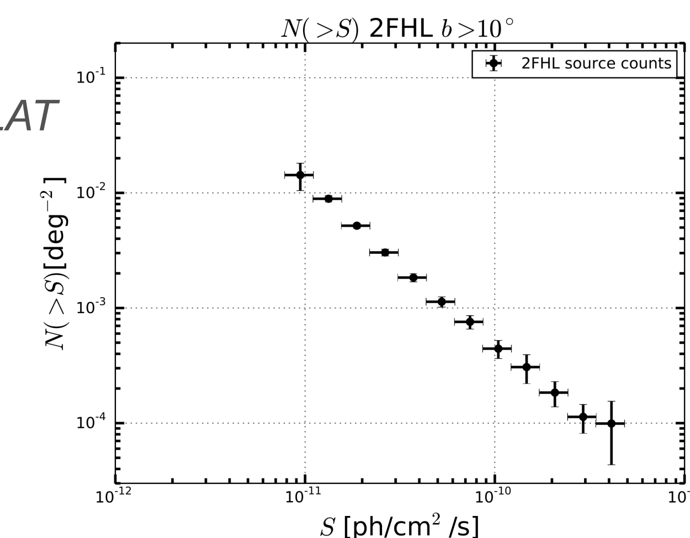


Di Mauro & Ajello

on behalf of the Fermi/LAT collaboration

Observed Flux distribution

Preliminary



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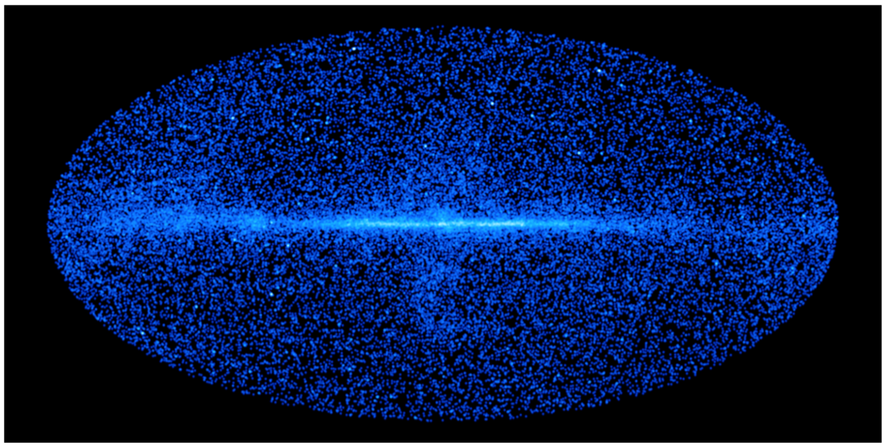

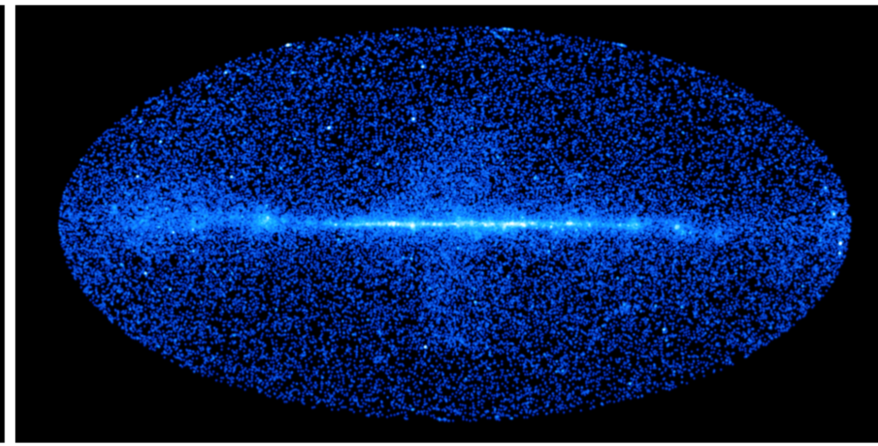

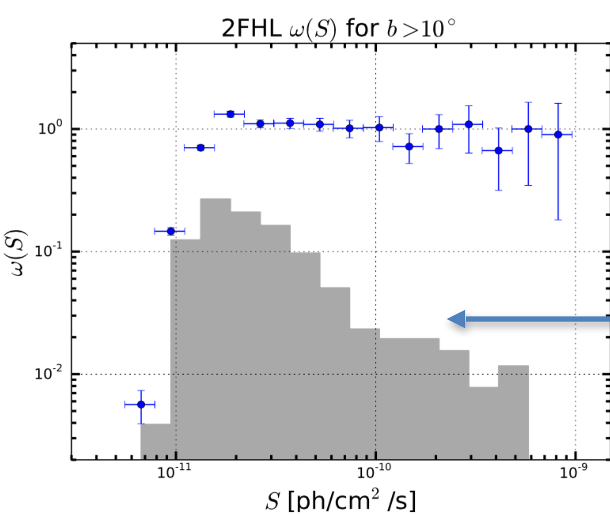

Di Mauro & Ajello
on behalf of the Fermi/LAT collaboration

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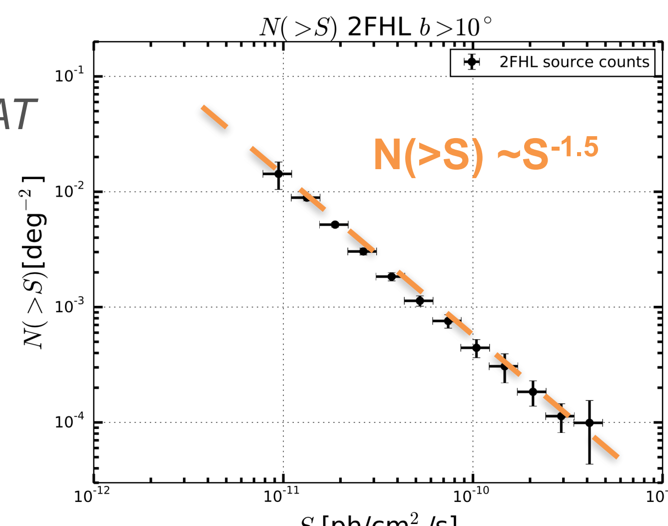
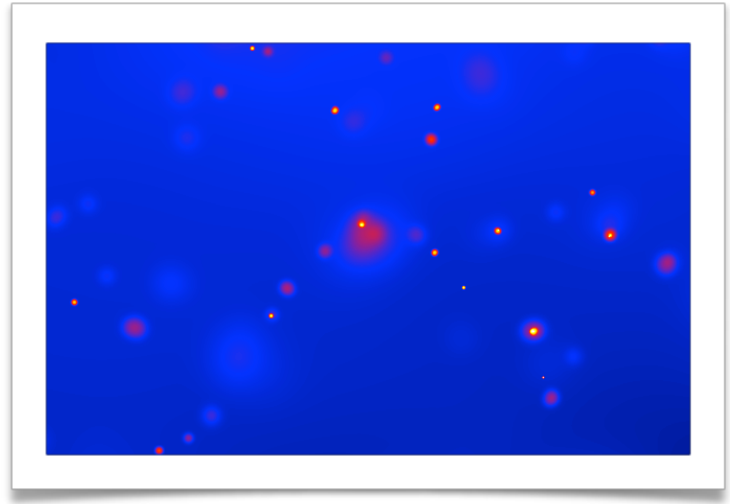
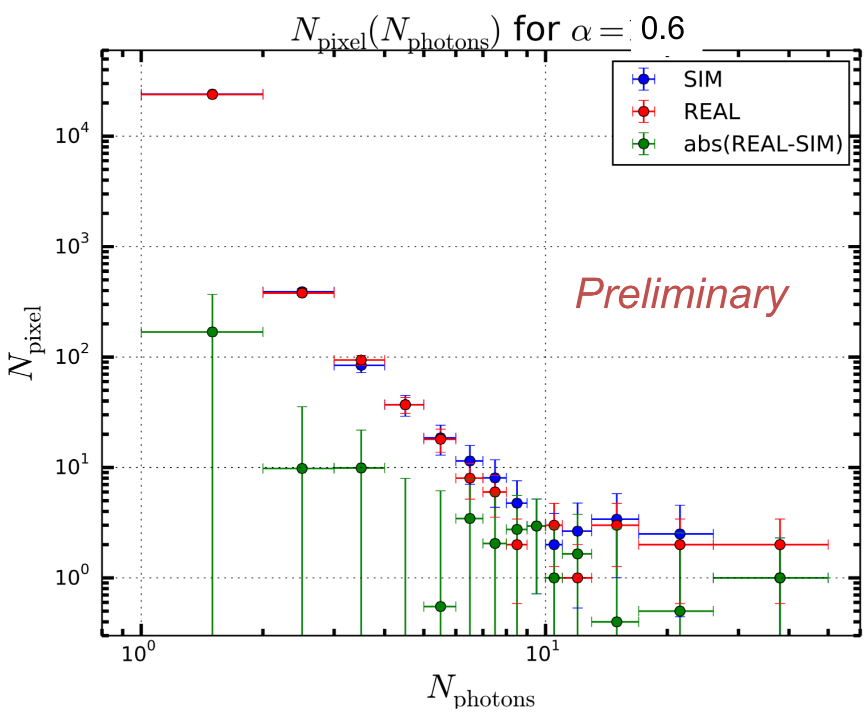


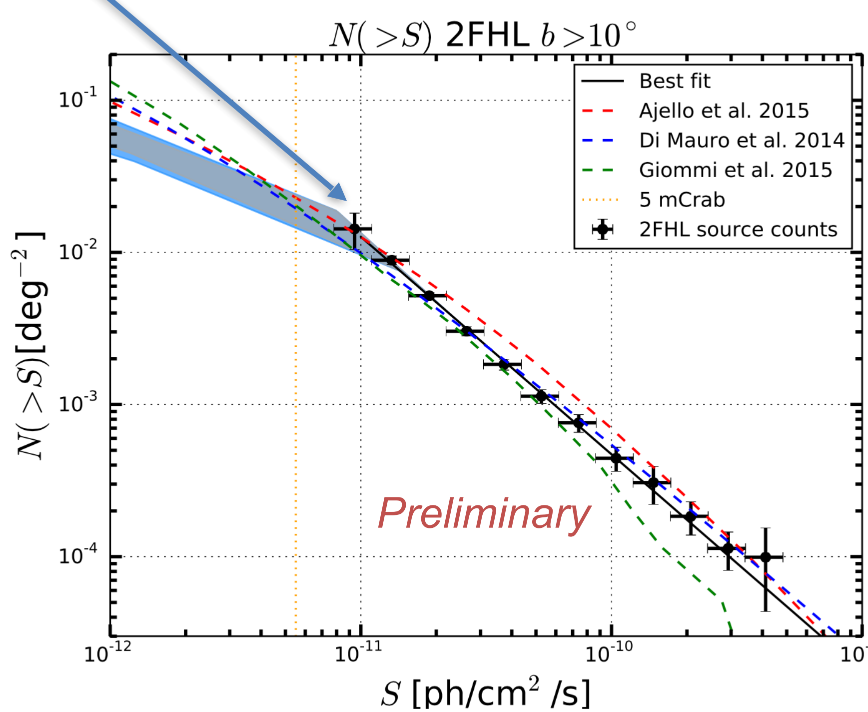
Photon Fluctuation Analysis

- **Fluctuations of the background depend also on the properties of the unresolved source population**



α = power law index below the break





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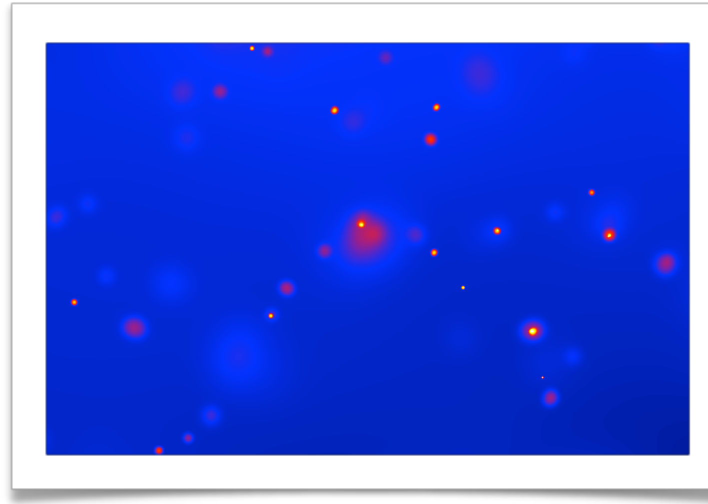
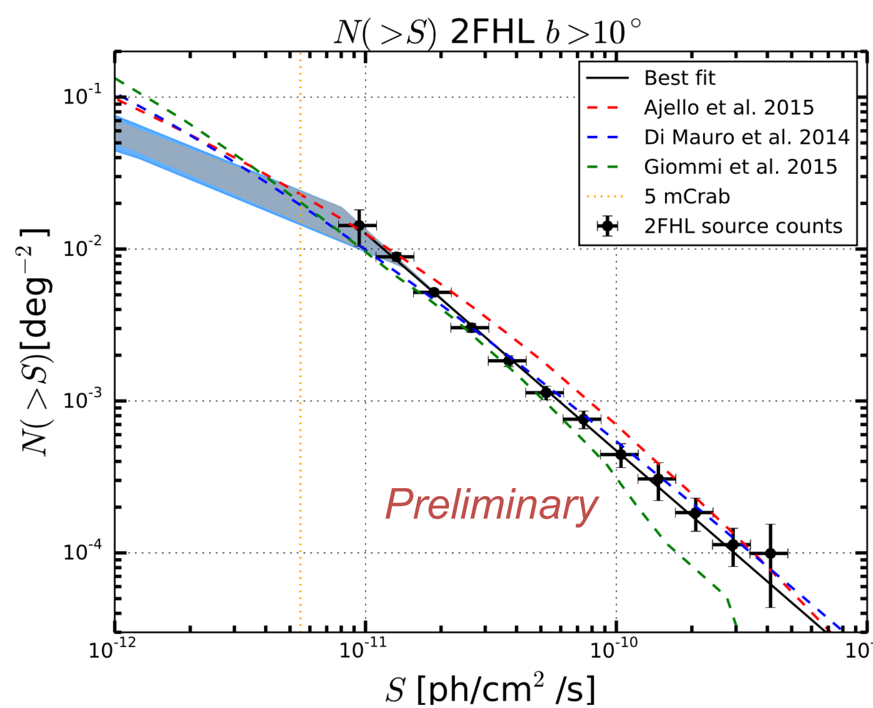


- The 2FHL LogN-LogS resolves 96(+15/-18)% of the IGRB



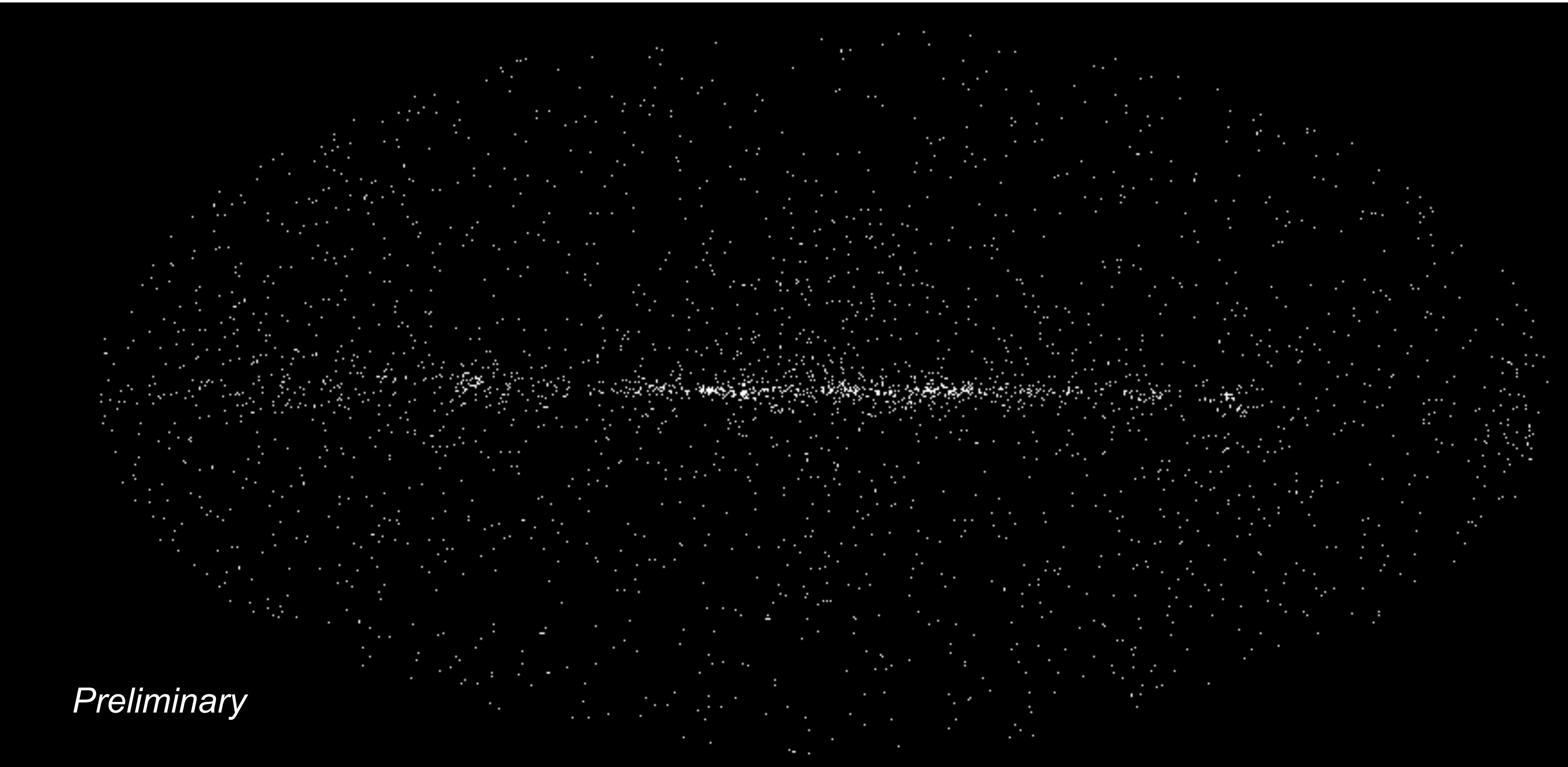
Nearly all the IGRB is produced by BL Lacs

Count Map

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



Extragalactic Background Light: 2

- **Measuring the intrinsic spectral index:** fitting an EBL-absorbed power law model to 129 2FHL blazars with a redshift
  - **the intrinsic spectra are much harder than the observed ones**

Domínguez & Ajello 2015 ApJL accepted