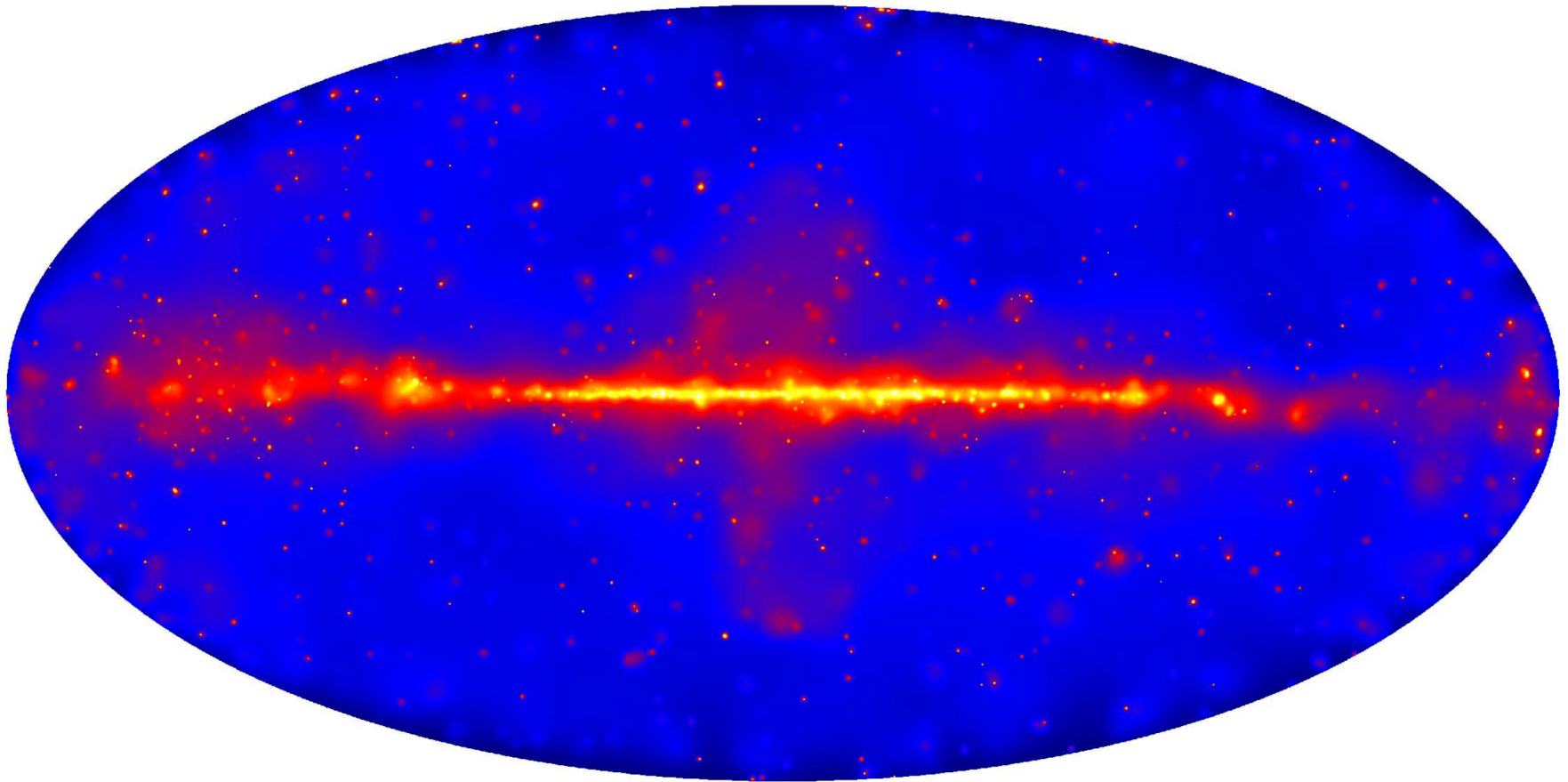


## 2FHL: The Second Catalog of Hard Fermi-LAT Sources



Marco Ajello, Alberto Domínguez, Jamie Cohen, Sara Cutini, Dario Gasparri

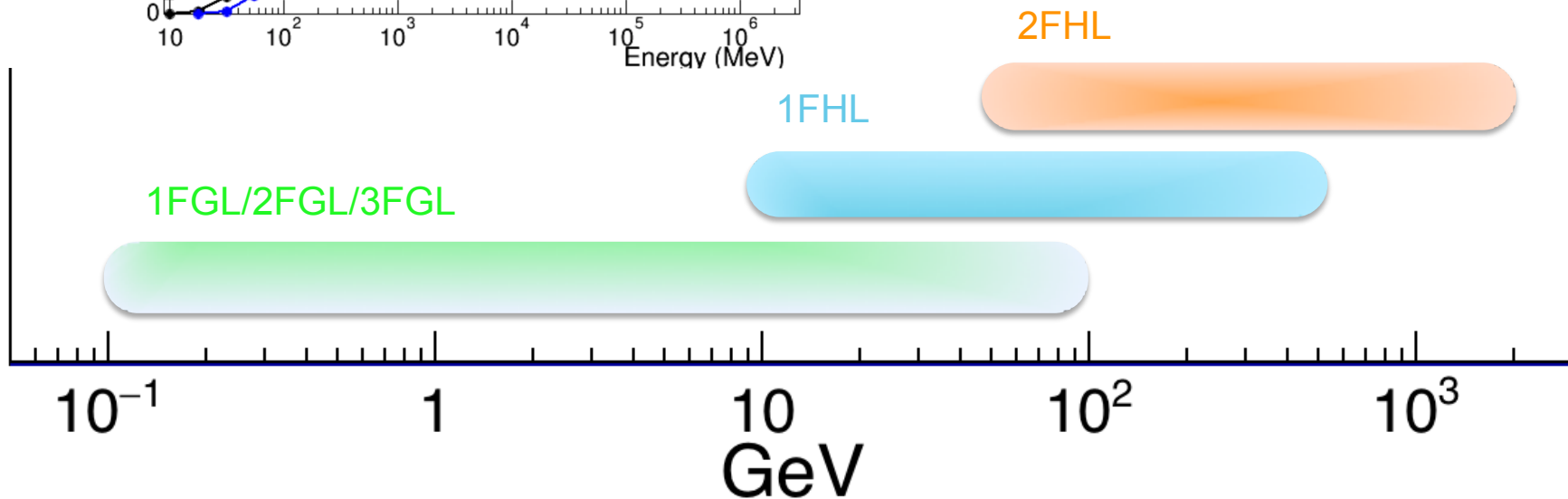
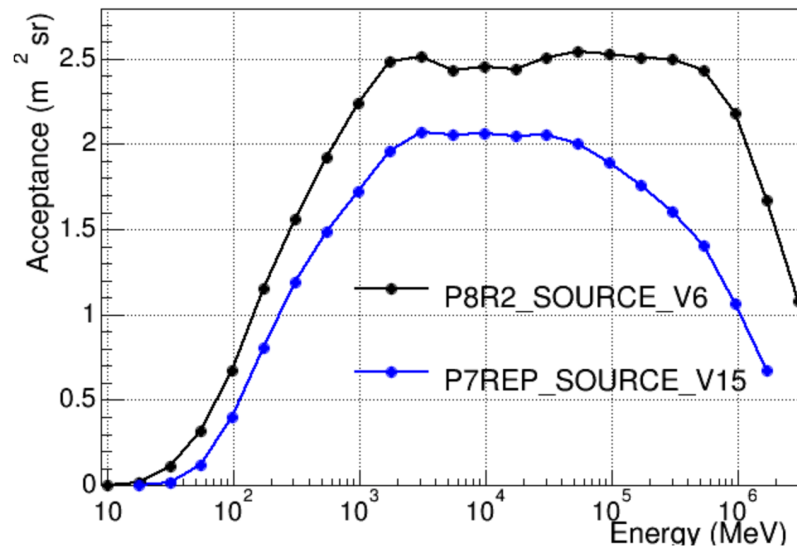
*on behalf of the Fermi-LAT Collaboration*

Accepted on ApJS: arXiv:1508.04449



**nFGL** Catalogs detect and characterize sources in the  $\sim 0.1$ -100 GeV energy range

**nFHL** Catalogs explore the higher-energy sky

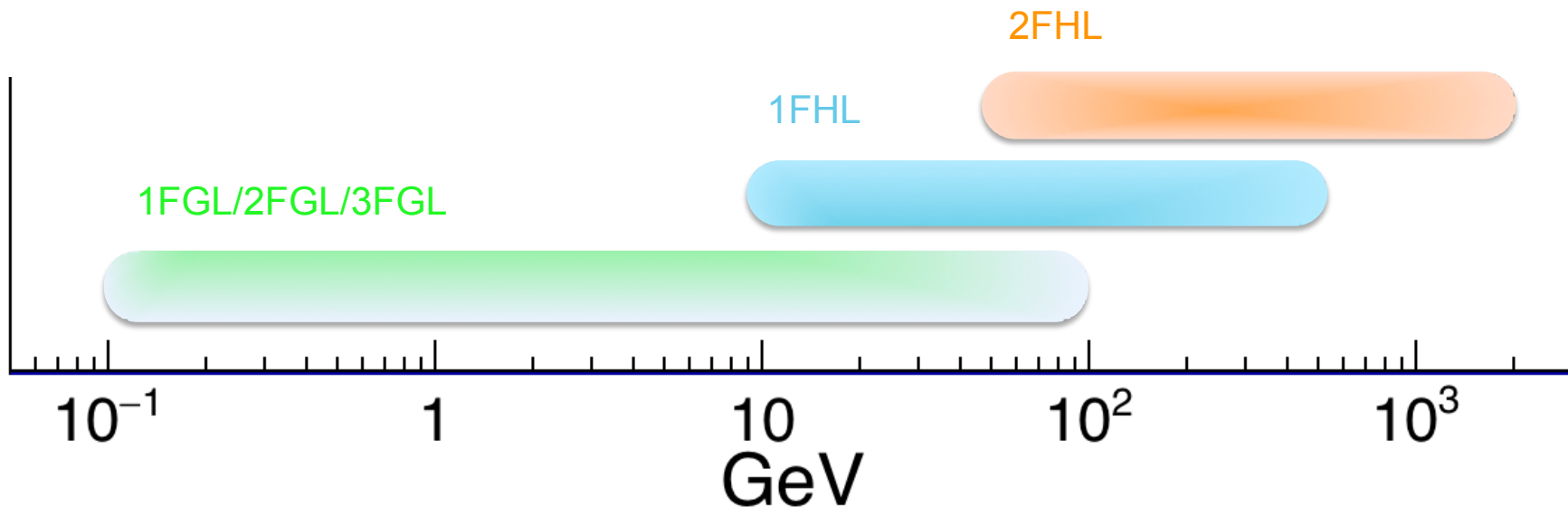




**nFGL** Catalogs detect and characterize sources in the 0.1-100 GeV energy range

**nFHL** Catalogs explore the higher-energy sky

**Why 2FHL ?** Improvement delivered by Pass 8 enables study of the EBL, EGB, Galactic plane, etc, and connects well to the TeV world



## Count Map



80 months of P8 data (50 GeV – 2 TeV)

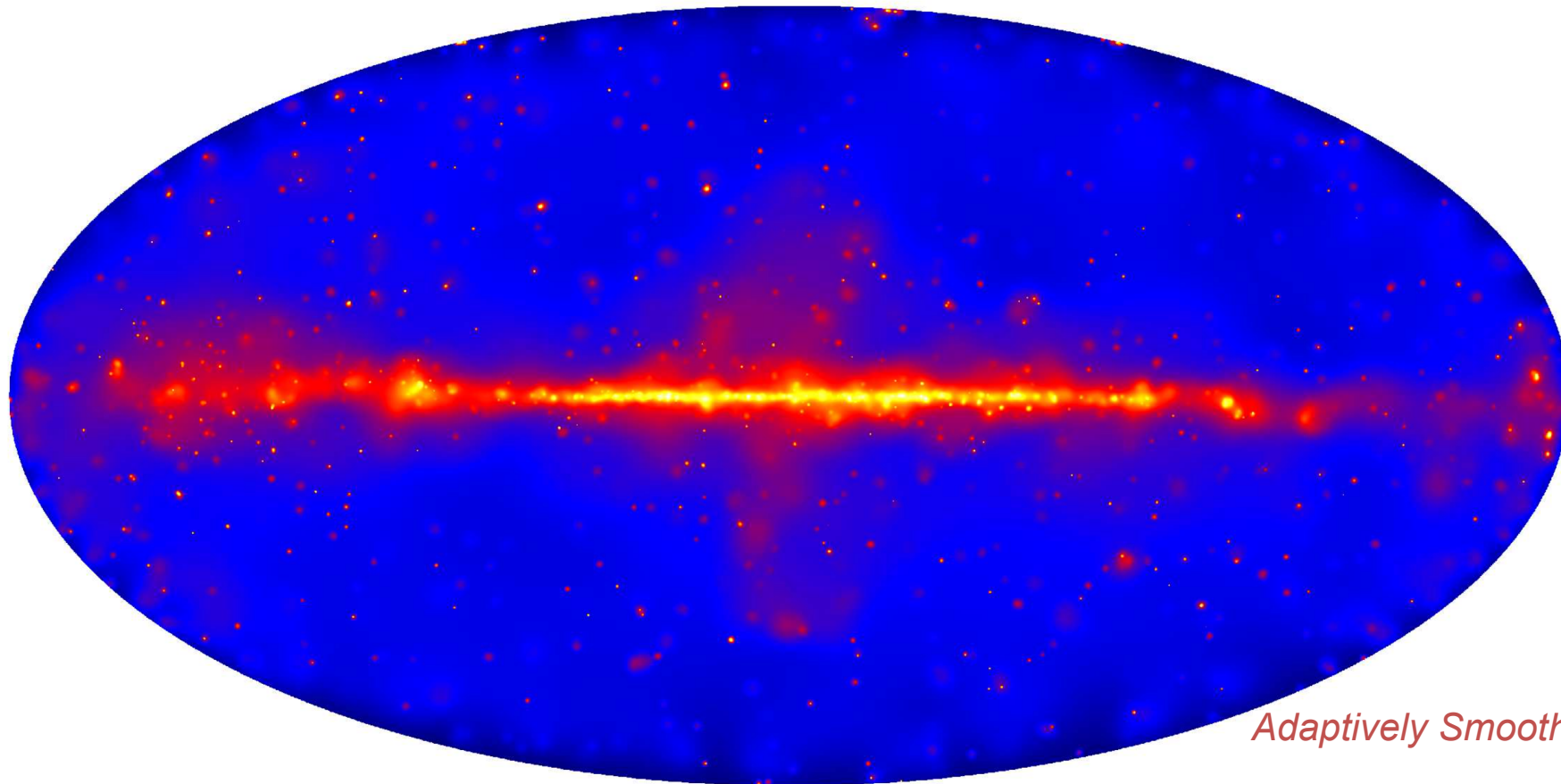
61,000 photons  $E > 50$  GeV

22,100 photons  $E > 100$  GeV

2,000 photons  $E > 500$  GeV



$\sim 1.5$  photon every  $\text{deg}^2$

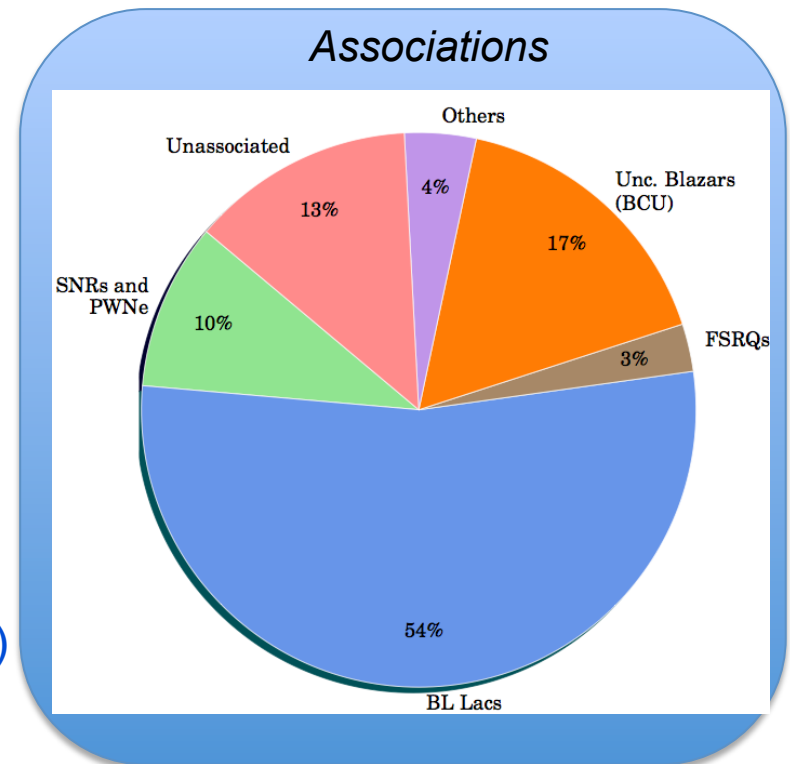


*Adaptively Smoothed*



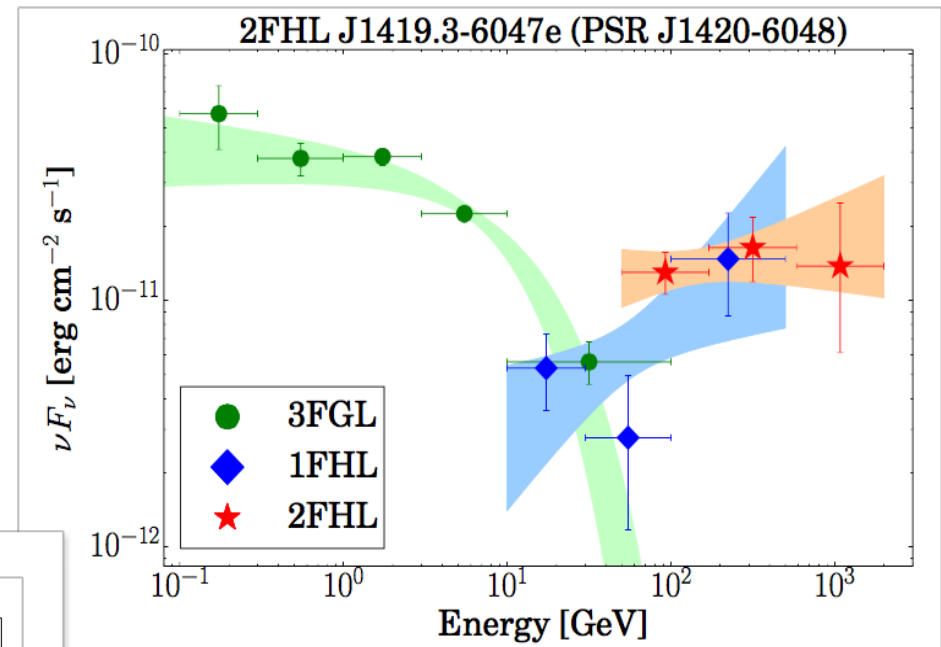
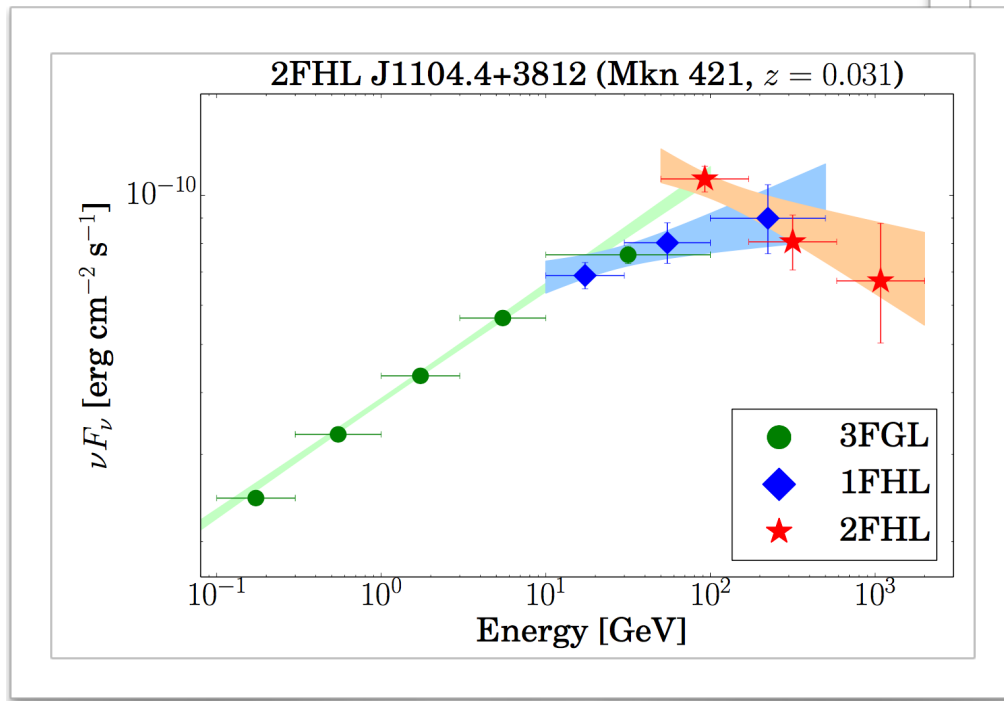
- **Analysis details**
  - 50 GeV – 2 TeV
  - 80 months of data (till April 2015)
  - Pass 8 (source)
  - Unbinned likelihood
- **Detections**
  - 360 sources:
    - 75% blazars, 11% Galactic sources, 14% unassociated
  - 78 detected by IACTs (TeVCat)
  - 230 detected in 1FHL
  - 303 detected in 3FGL
  - 57 brand new sources (not 1FHL/3FGL)

Median localization accuracy is 1.7 arcmin (68%) !

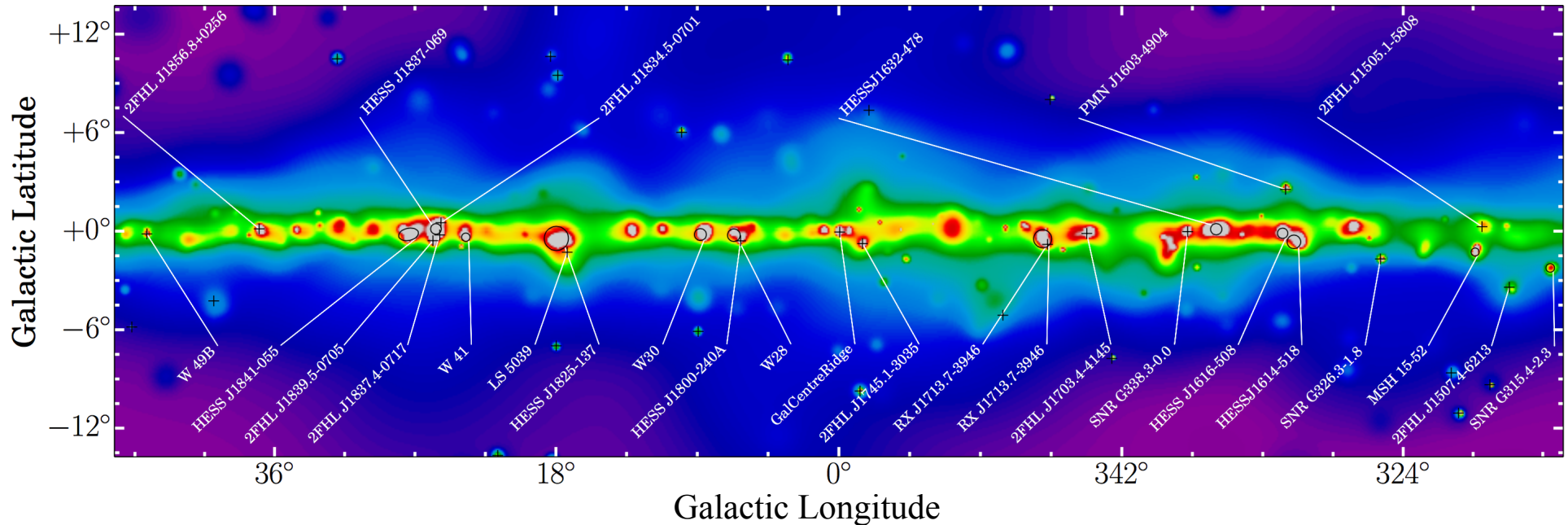


**Bottom line:** plenty of sources for TeV telescopes

# Spectral Energy Distributions



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

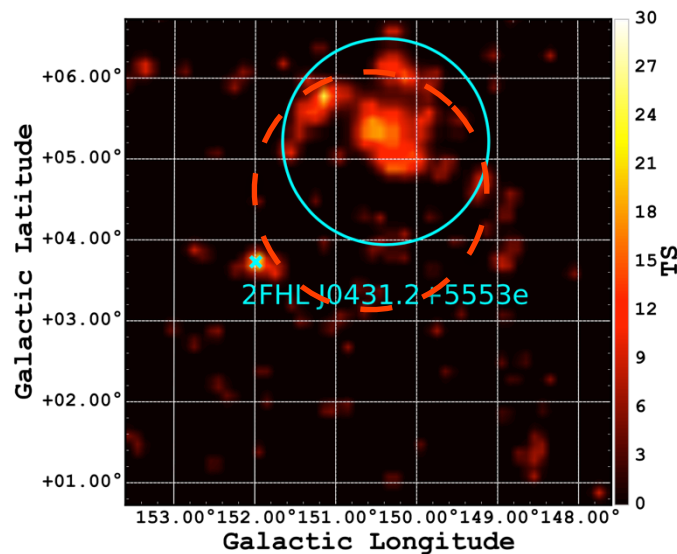


- **103 sources at  $|b| < 10^\circ$** 
  - 42 blazars, 39 Galactic objects, 13 unassociated and 9 Dark Acc.
  - PWNe/SNRs represent 87% of the Galactic population
  - Galactic sources are very hard
    - Median photon index of  $\sim 2$ , while for blazars is  $\sim 3$
  - Half of the unassociated sources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

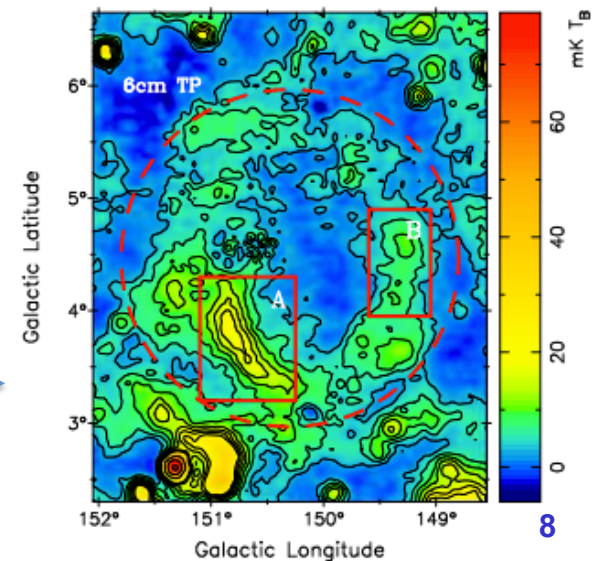


- **All new sources are significantly detected in 2FHL (TS>75)**
  - They are hard, and harder than the Galactic diffuse emission
  - They are associated to known (3) PWNe and (2) SNRs
  - Detailed characterization will be reported in future papers

2FHL Name	$l$ [deg]	$b$ [deg]	TS	$TS_{ext}$	$TS_{2pts}$	$F_{50}$	$\Delta F_{50}$	$\Gamma$	$\Delta\Gamma$	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

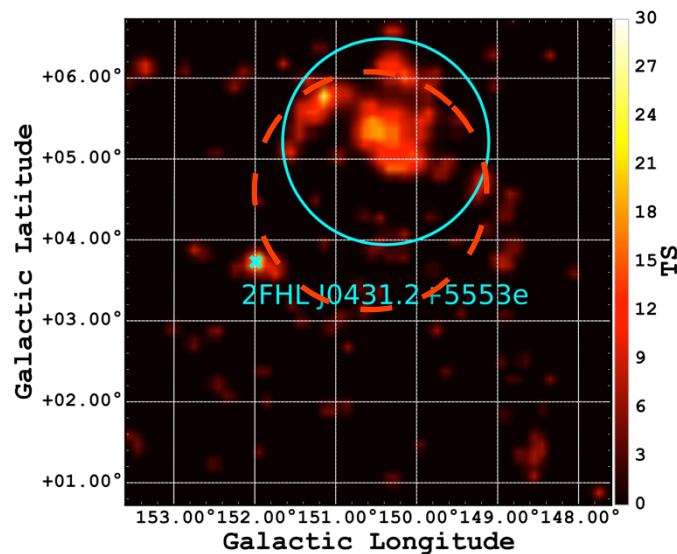




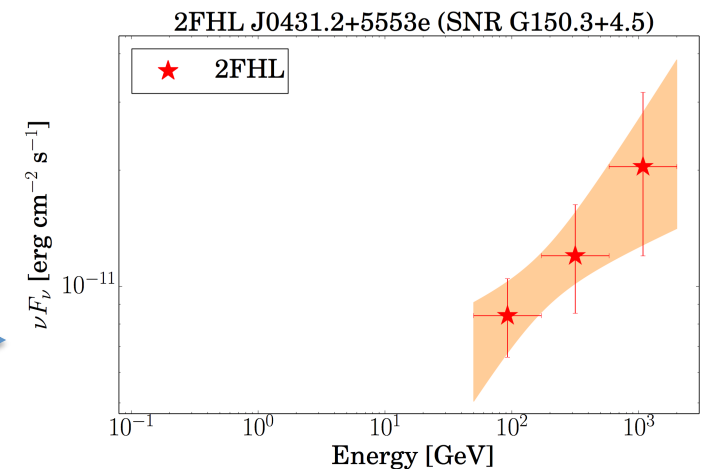


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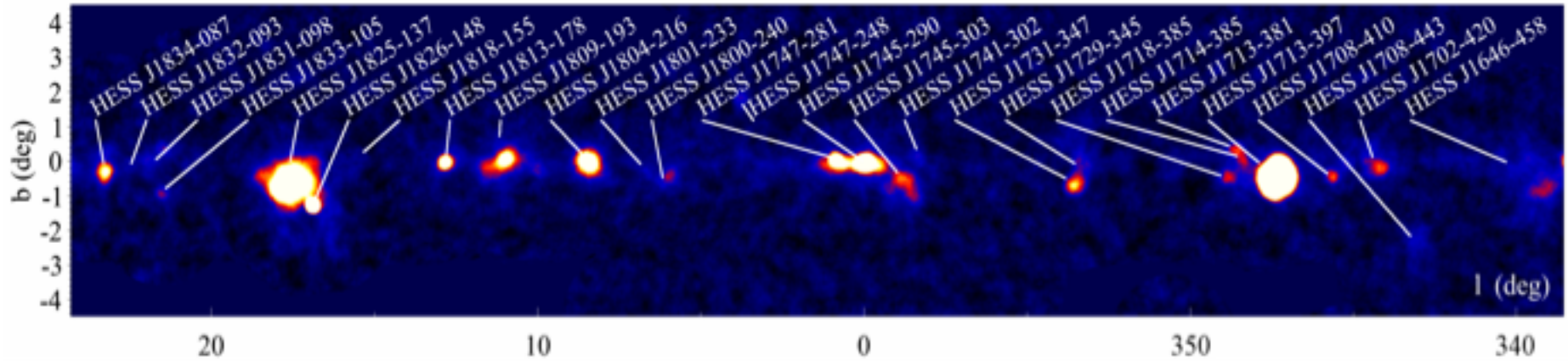


New SNR  
(G150.3+4.5)  
discovered by Gao &  
Han 2014



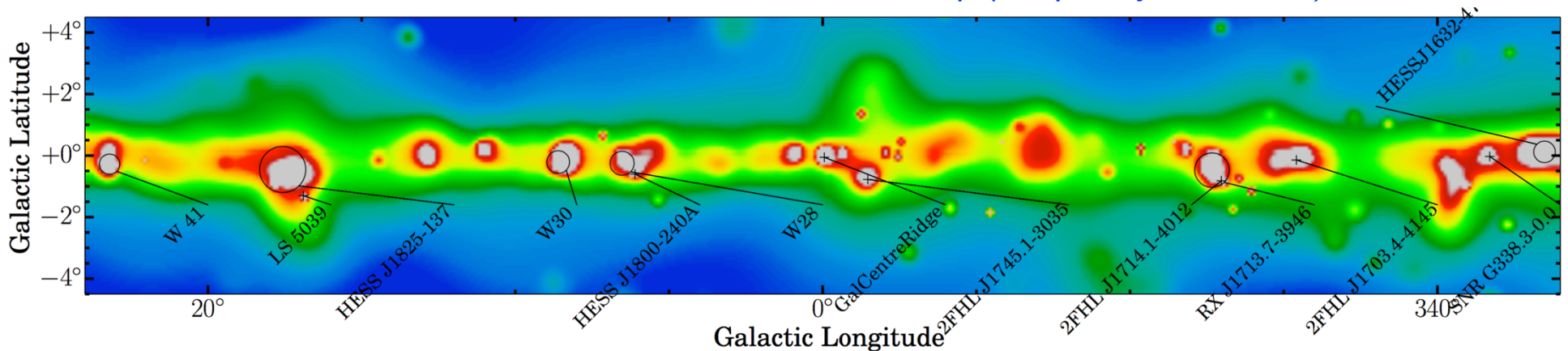


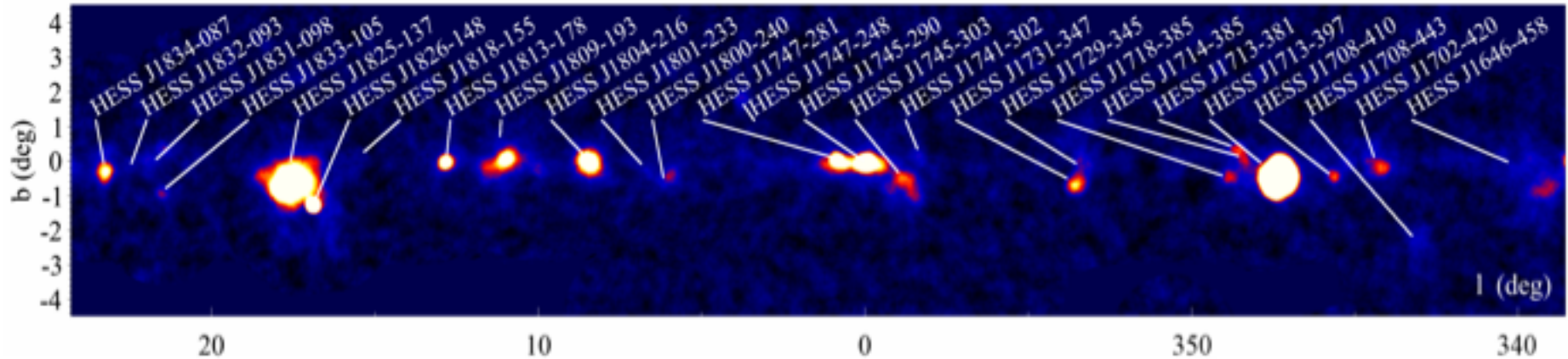
Significance Map



Aharonian et al. 2006, Carrigan et al. 2013

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





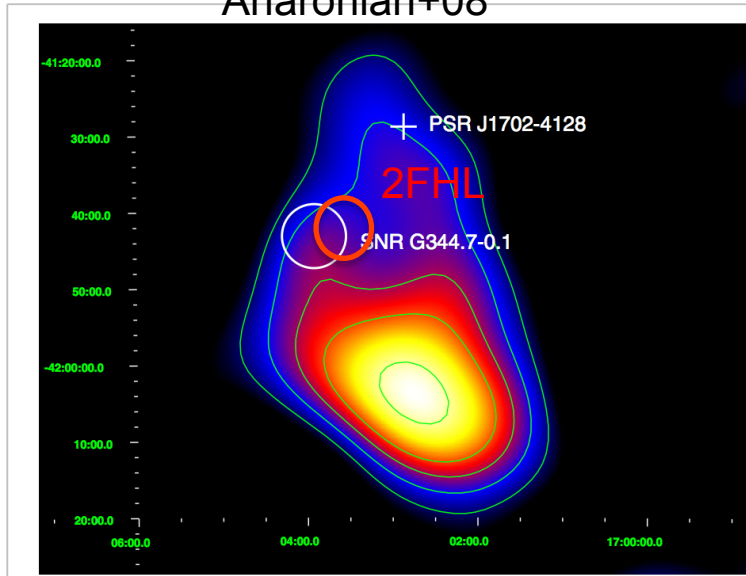
Aharonian et al. 2006, Carrigan et al. 2013

- H.E.S.S. reported the detection of 69 sources reaching a sensitivity of  $\sim 2\%$  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

# Example of a dark accelerator

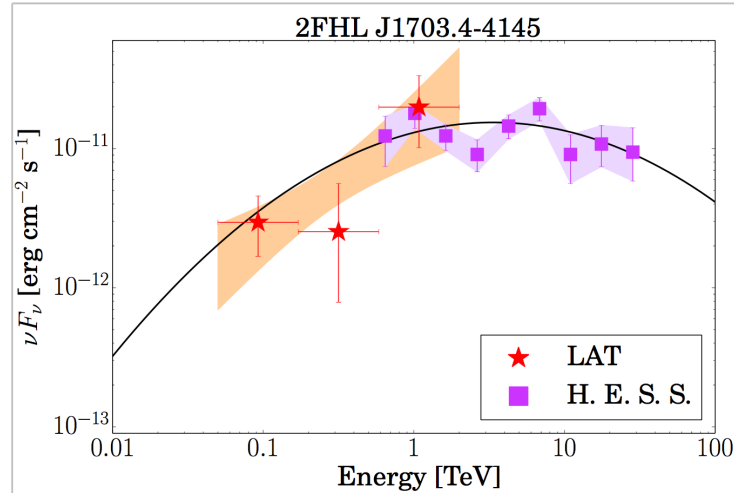
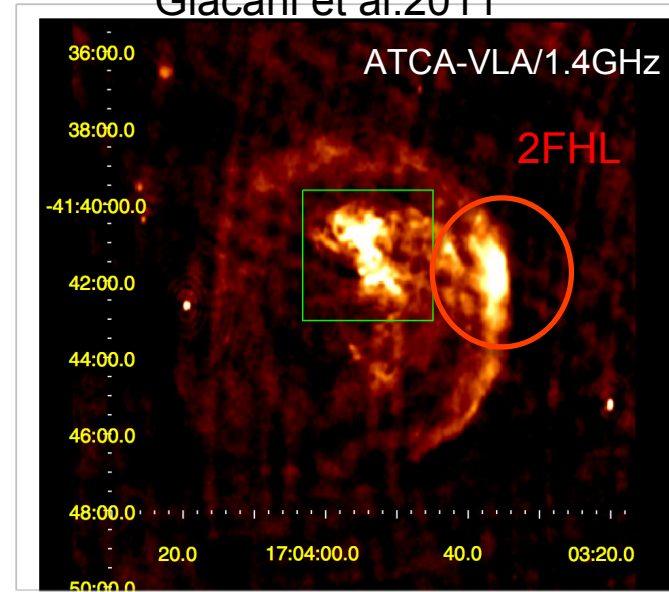


Aharonian+08



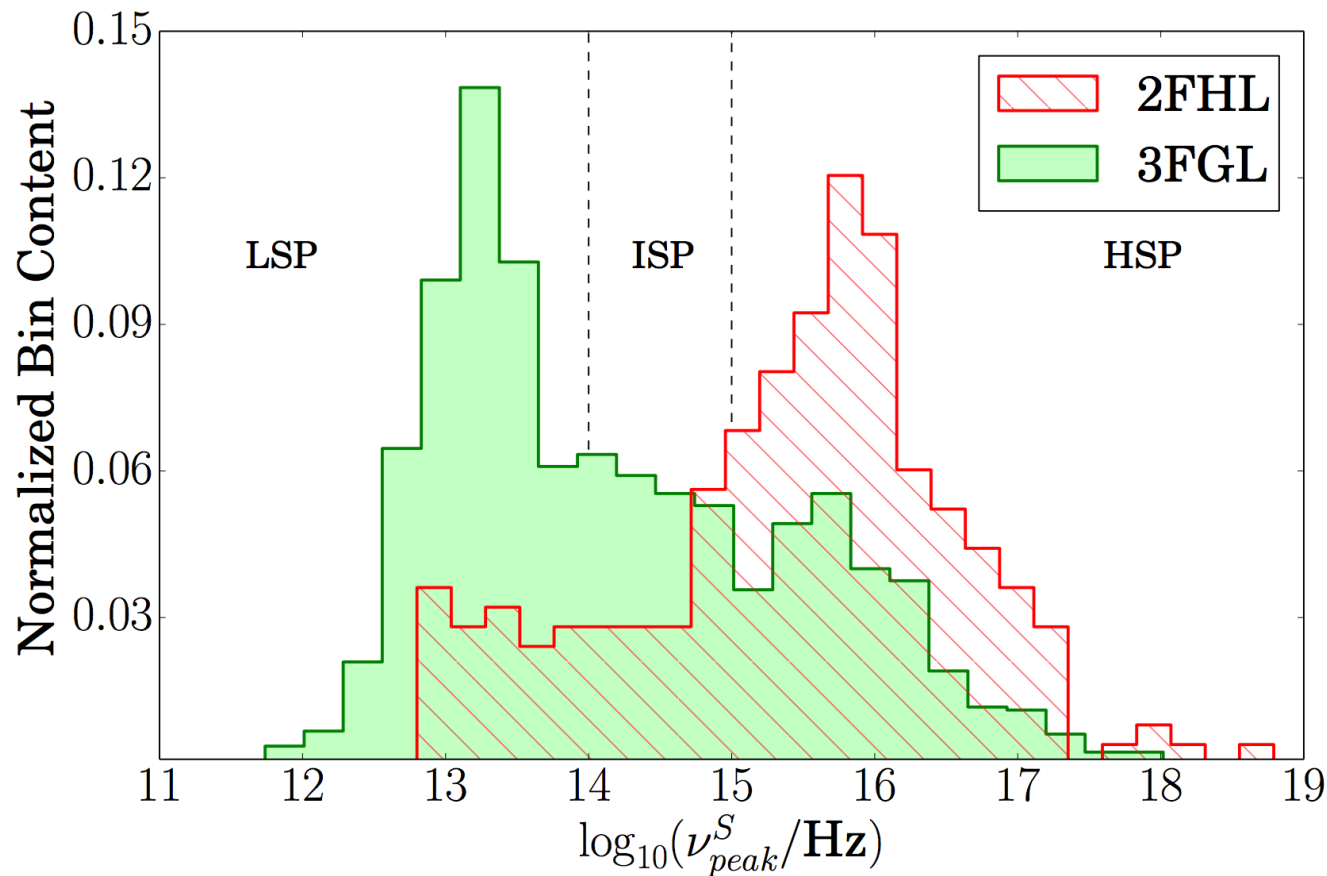
HESS J1702-420

Giacani et al.2011



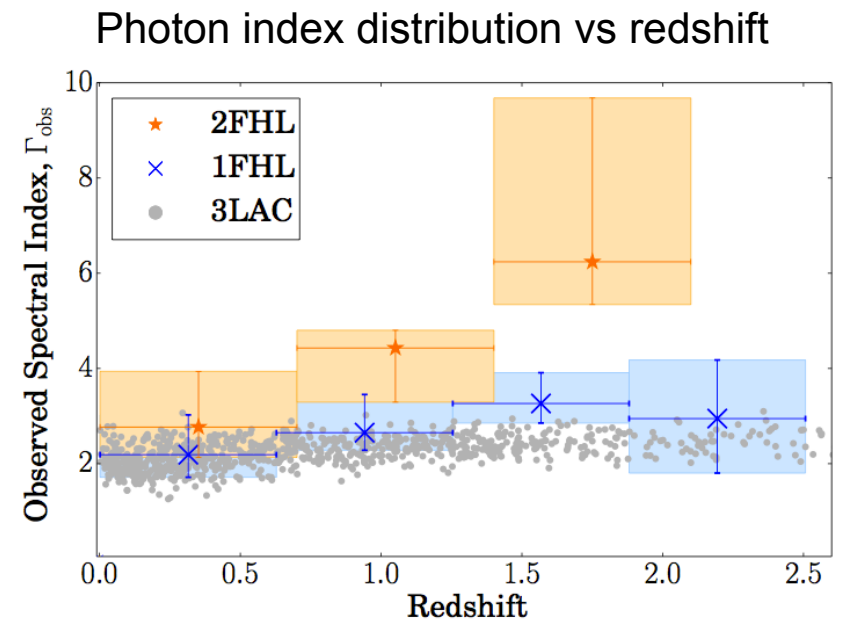
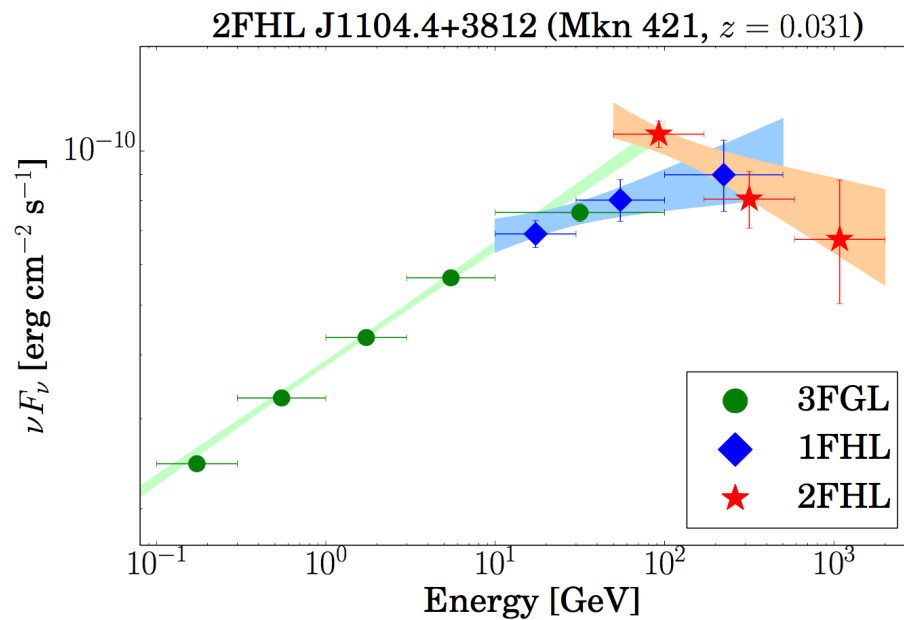


- **Blazar-like objects constitute >80% of the 2FHL Catalog**
  - Detected up to  $z \sim 2$
  - Most of them are BL Lacs, only 10 FSRQs
  - Different population than 3FGL



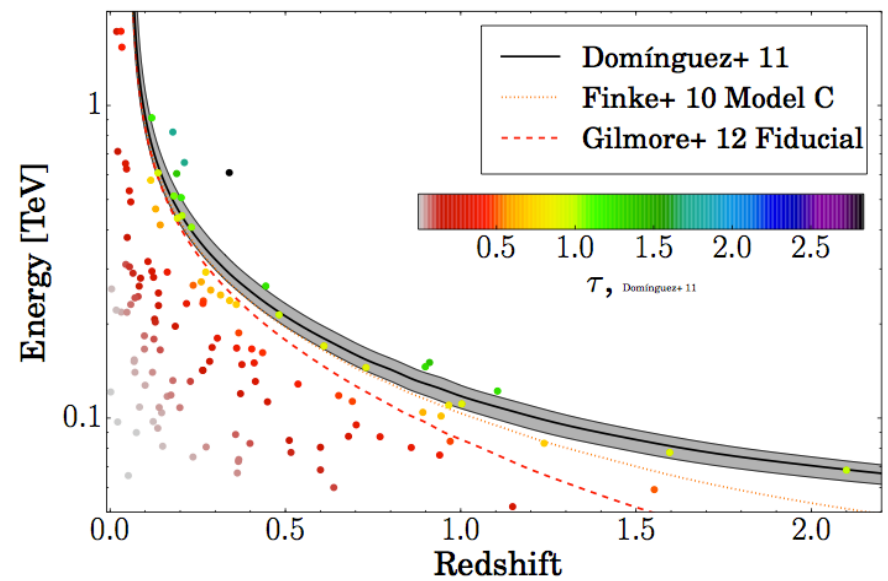
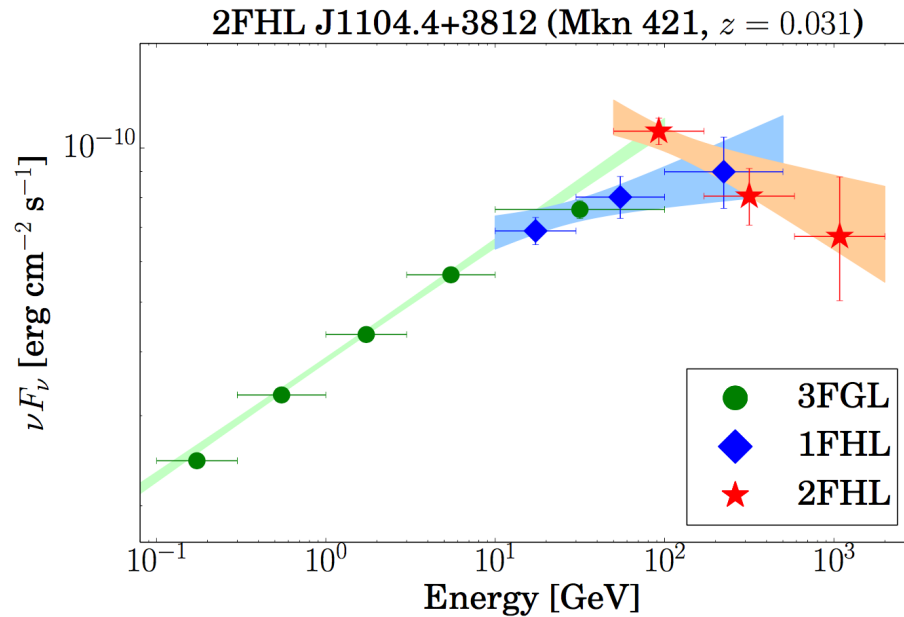


- Being sensitive over  $\sim 4$  decades in energy, the LAT resolves the high-energy peak
  - Sources become softer at higher energies
  - Sources becomes softer at high redshift



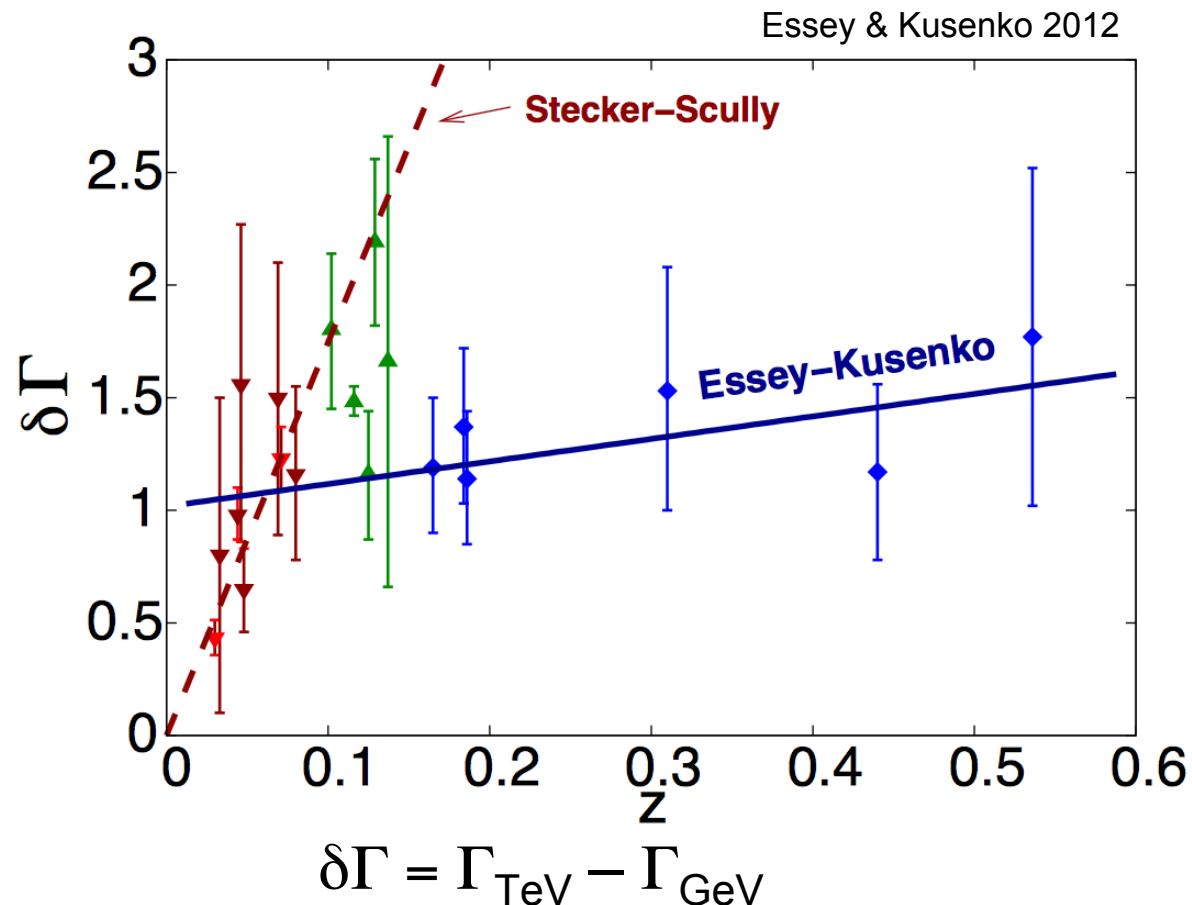


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- Spectral breaks between the VHE and Fermi band have been used as diagnostic for/against the EBL (Essey&Kusenko, Sanchez+13,etc)
  - spectral flattening at high redshift has been interpreted as sign of interesting physics

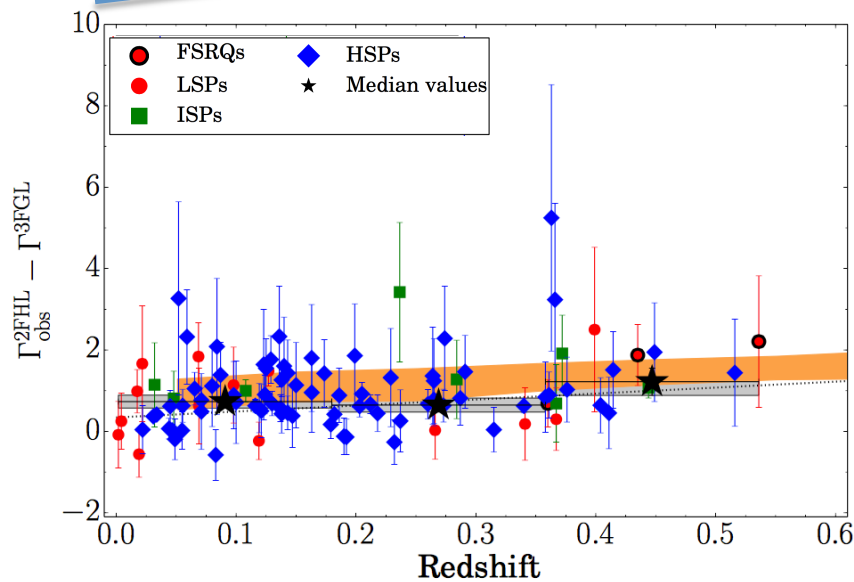
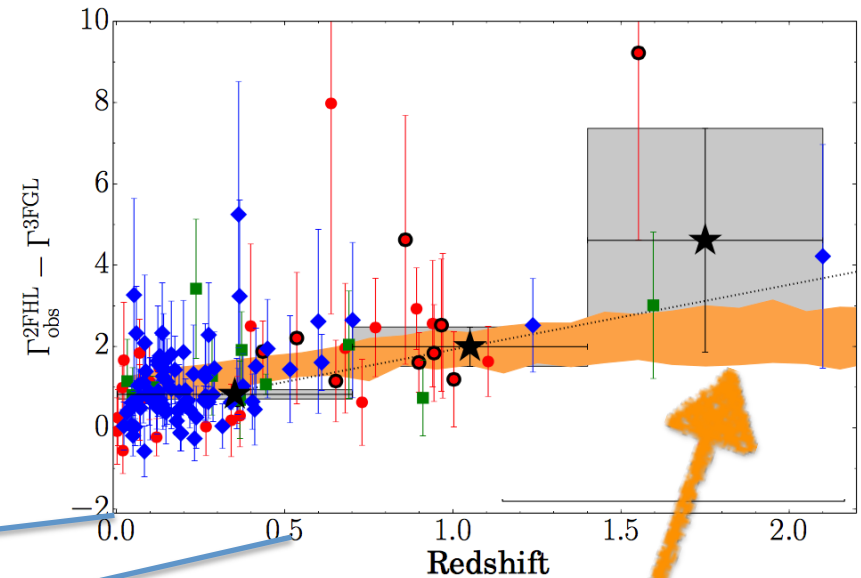




# Extragalactic Background Light



- 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*



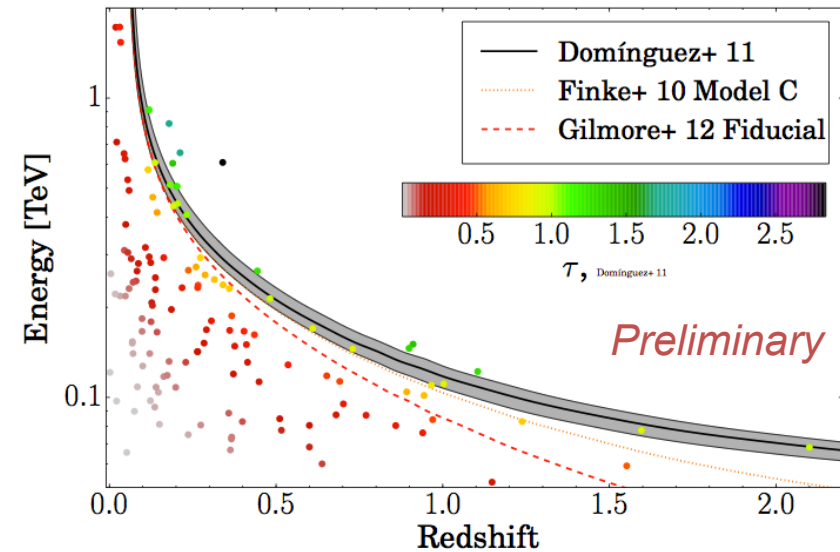
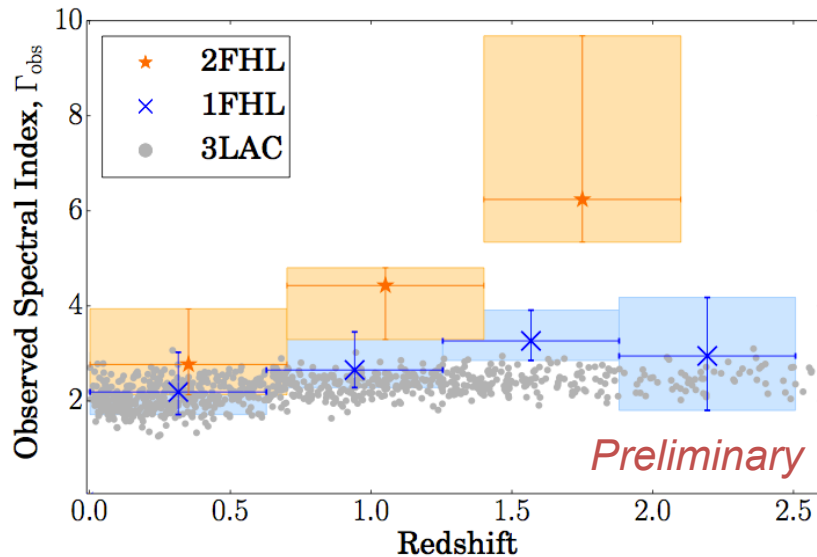
- 2FHL opens a new window on the high-energy sky
  - 360 sources detected between 50 GeV and 2 TeV
    - 75% blazars, 14% Galactic and 11 % unassociated
    - only 25% detected in TeVCat
  - **Galactic science:**
    - all display hard spectra, 87 % are PWNe/SNRs
    - 5 new extended sources and ~25 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  $z \sim 2$
    - Clear signs of EBL attenuation (and nothing else)
    - Results on the EGB in Mattia's Talk

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

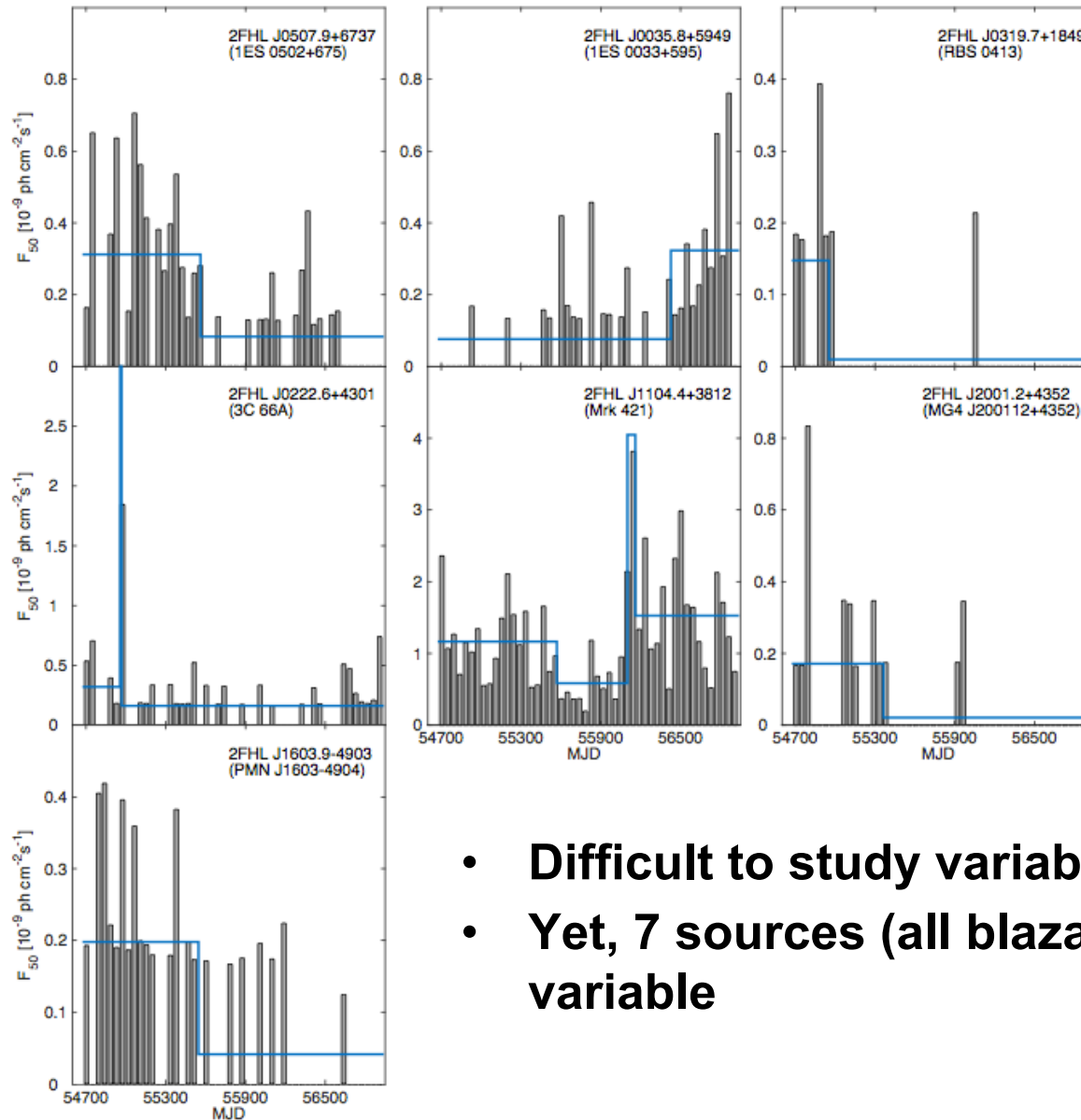


**End**

# 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

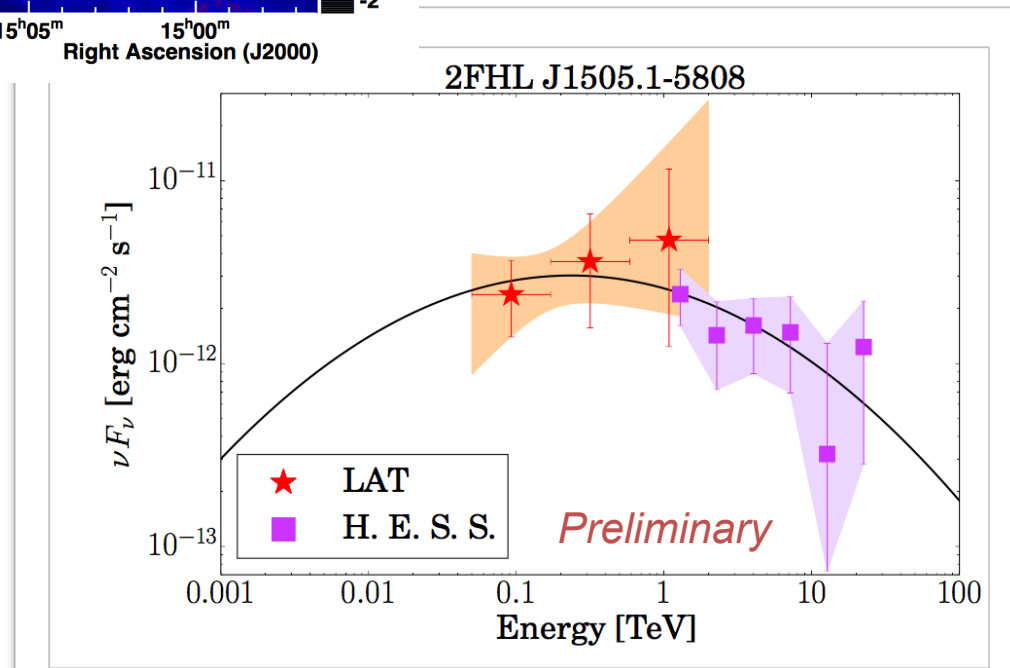
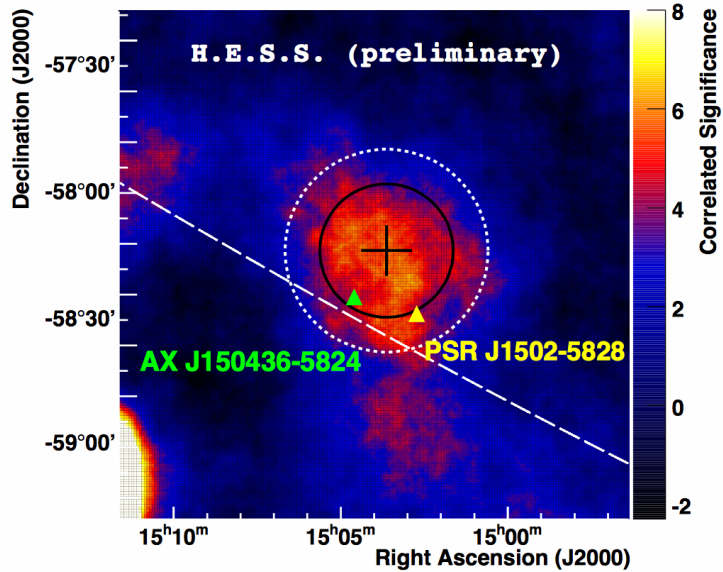


- **Difficult to study variability with few photons**
- **Yet, 7 sources (all blazars) are found to be variable**

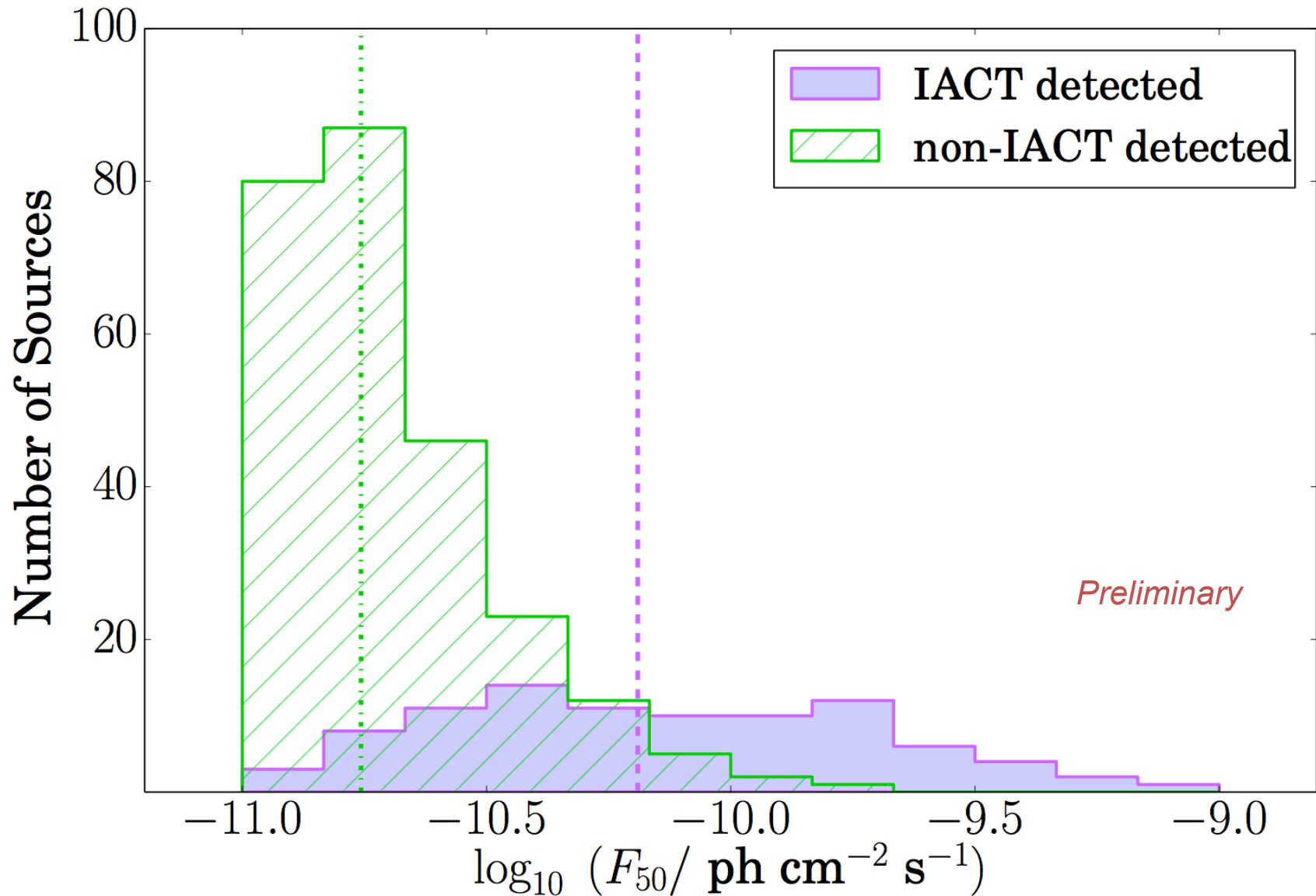
# Example of a Dark Accelerator: 2



Renaud et al. 2008

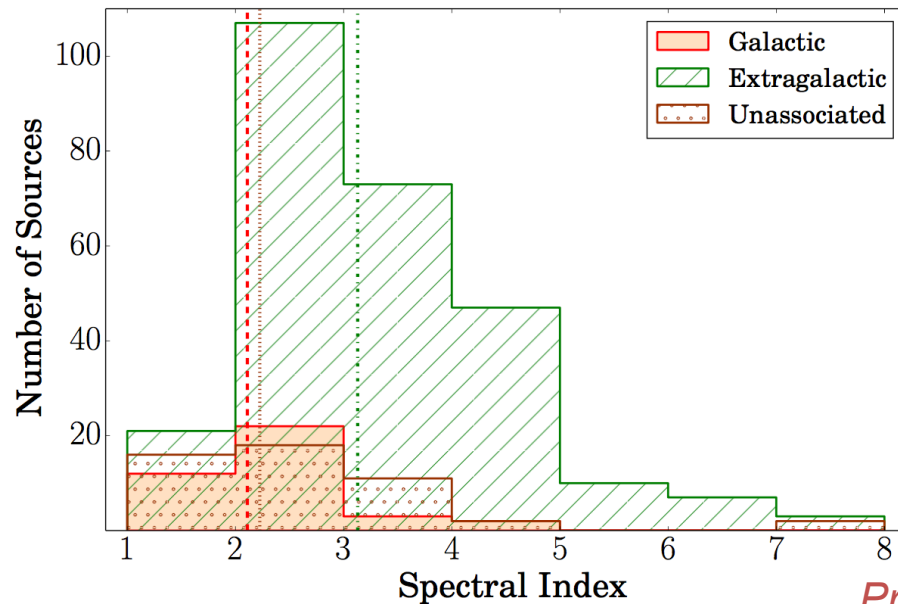


## 2FHL Sources detected at TeV energies

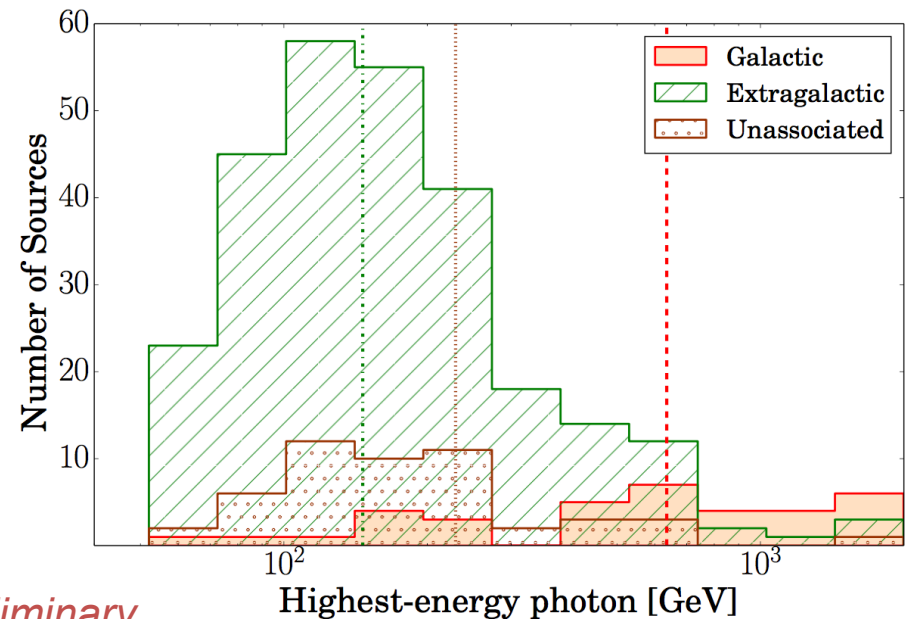




- Galactic sources have much harder spectra than extragalactic ones
  - Median spectral index  $\Gamma=2$  vs  $\Gamma=3$
  - The EBL might be the culprit
  - Spectral index can be used to distinguish Galactic objects among the unassociated sources



*Preliminary*

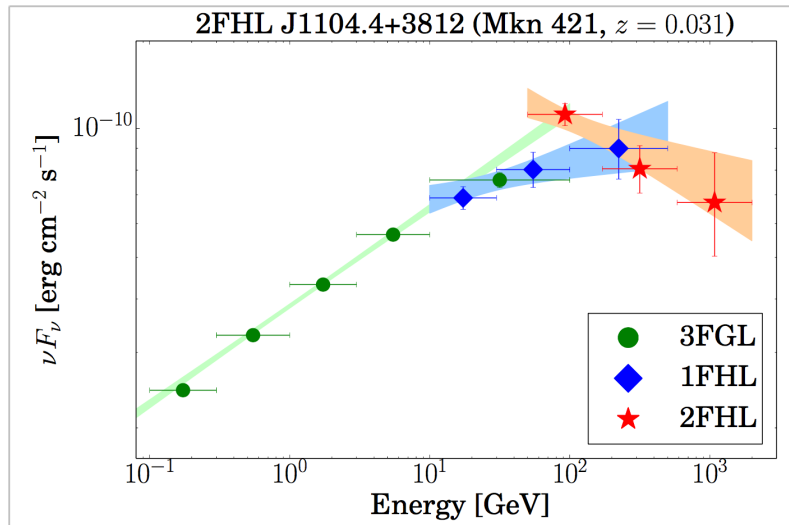
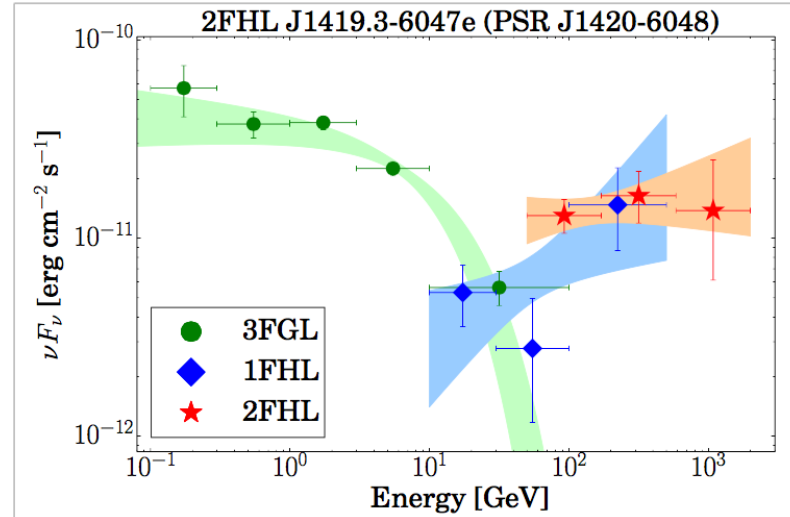
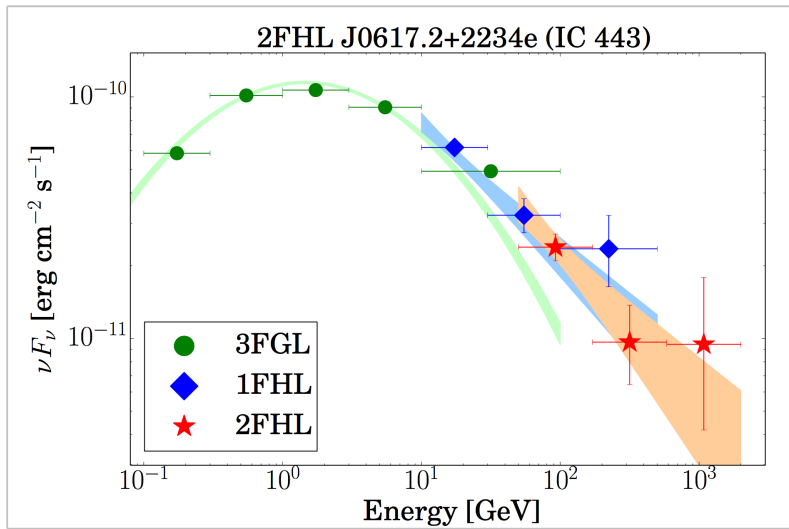




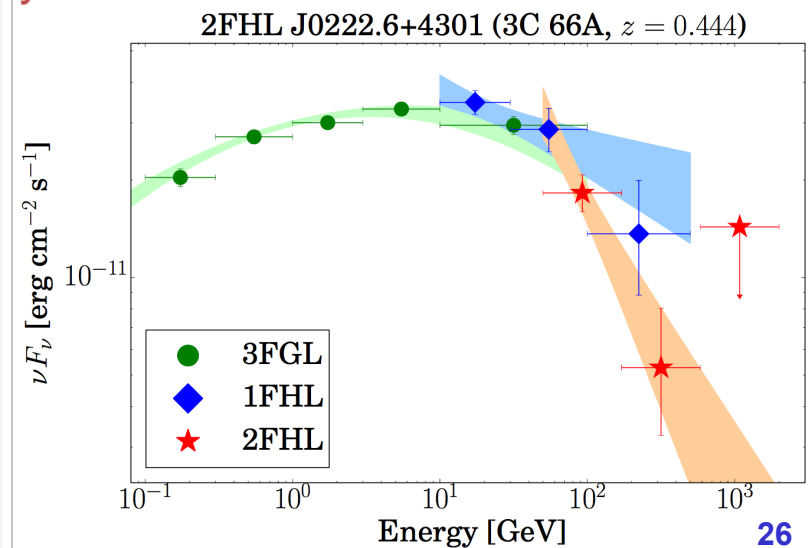


- **We used the extended templates of previously detected sources:**
  - 25 from 3FGL + W41
  - Of them 6 sources were not significantly detected:
    - SMC, S 147, Cen-A (lobes), W 44, HB 21, Cygnus loop
- **Blind search for new sources:**
  - 72 ROIs of  $10^\circ$ , devoid of sources, centered at  $b=0$
  - Iteratively add disk source at most significant TS peak
  - Fit and choose extended source if  $TS_{\text{ext}} > 16$
- **It resulted in the detection of 5 new extended sources**

# Spectral Energy Distributions



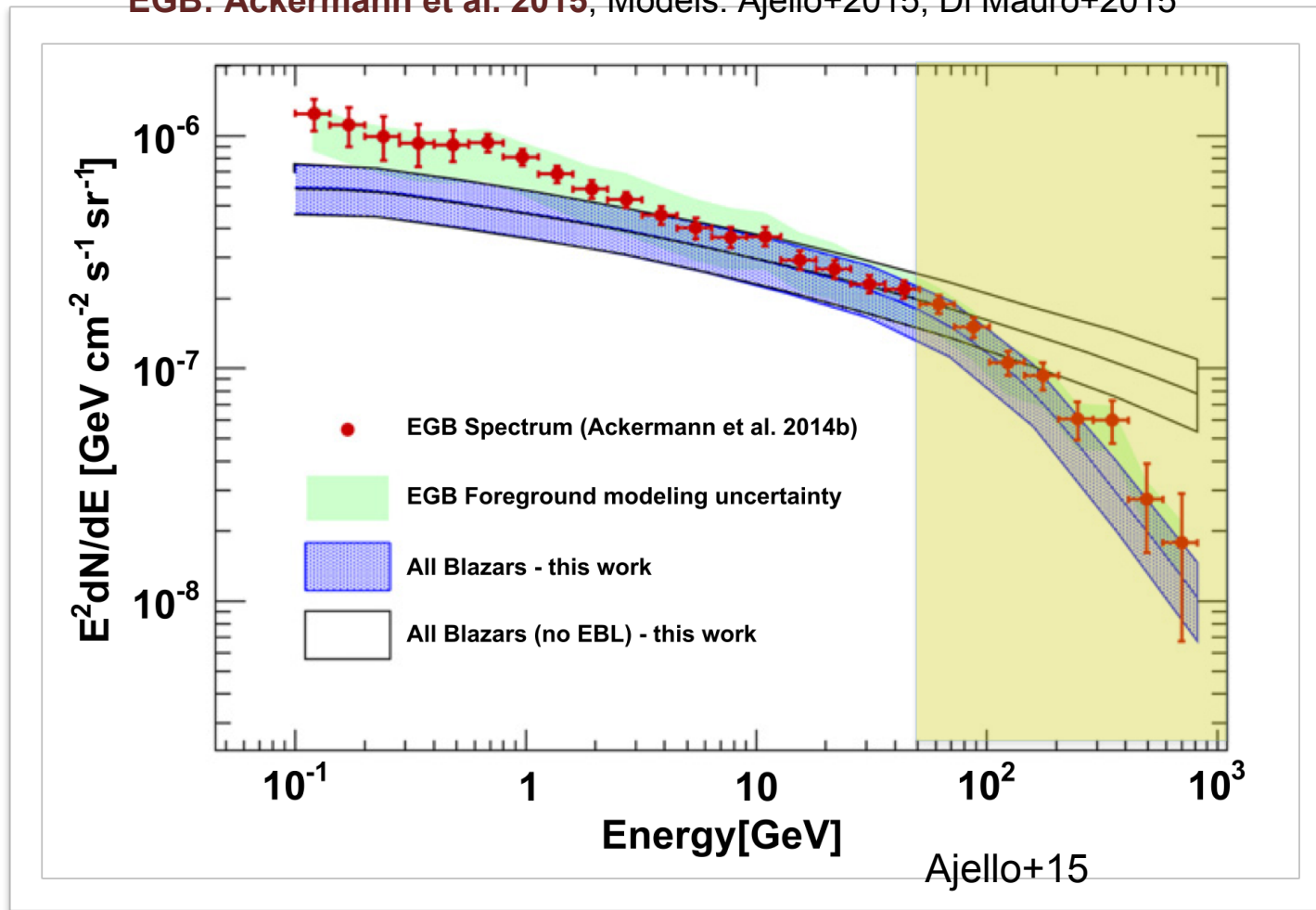
*Preliminary*





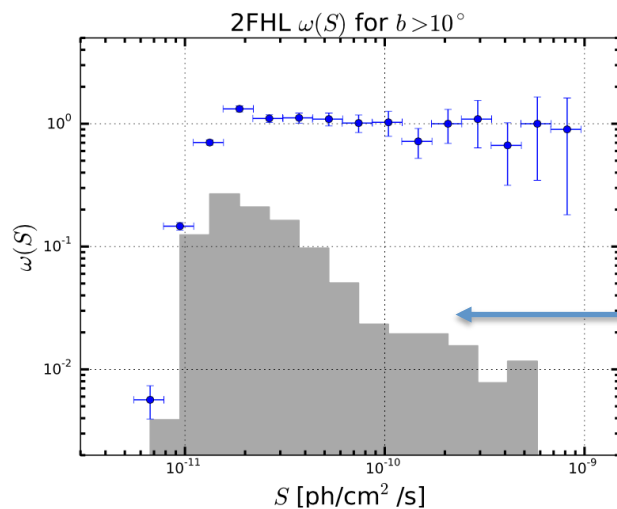
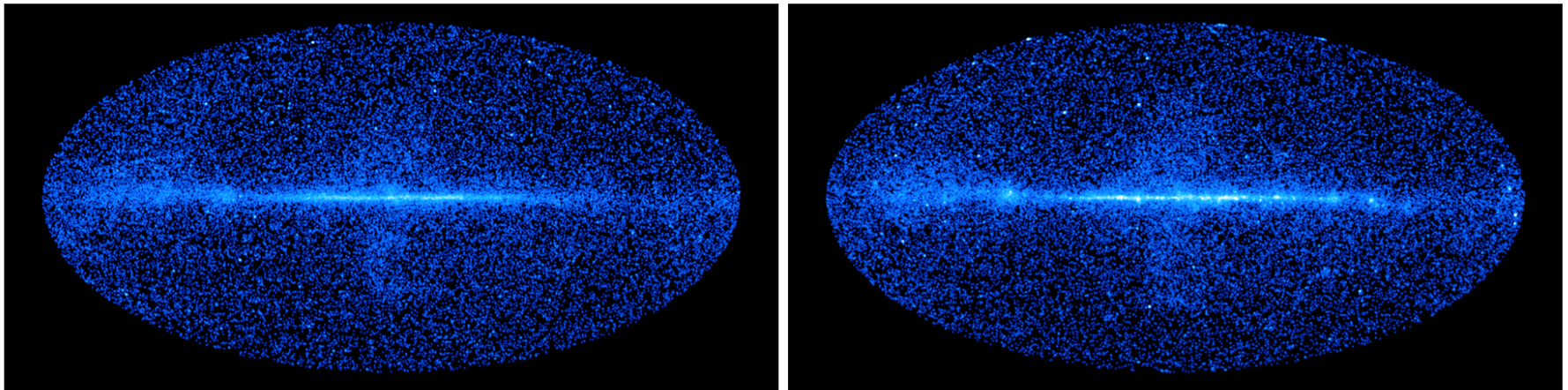
- Models predict that the  $>50$  GeV EGB is produced by blazars

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





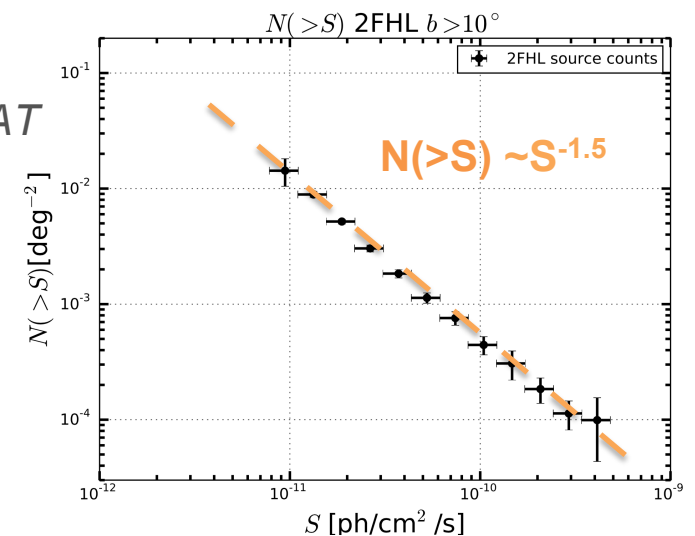
- Perform simulations of the  $> 50$  GeV sky to determine the detection efficiency
  - i.e. the probability to detect a source in 2FHL as a function of flux



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

Observed Flux  
distribution

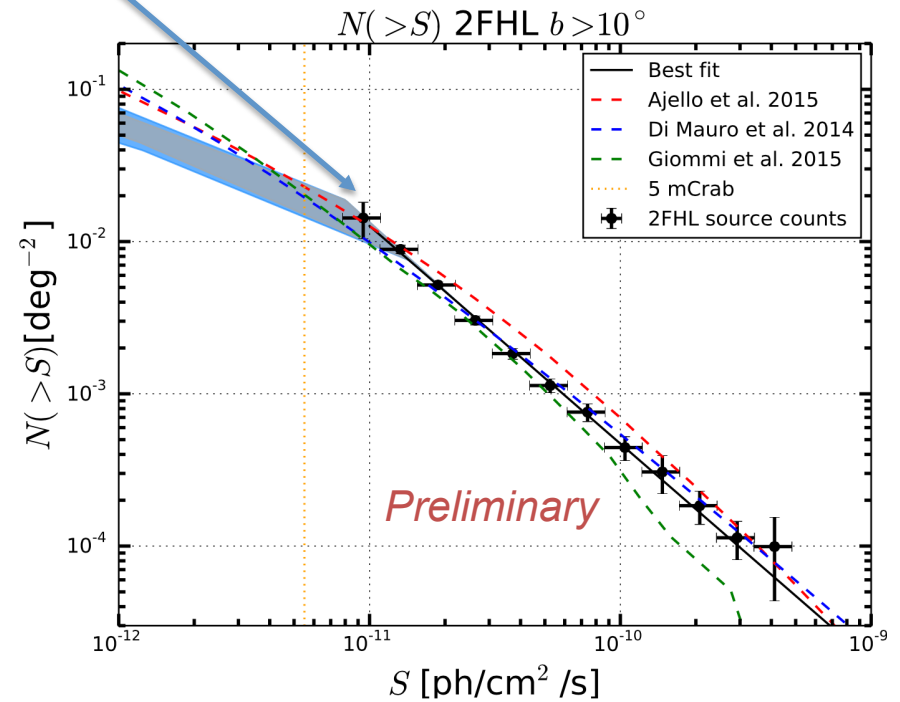
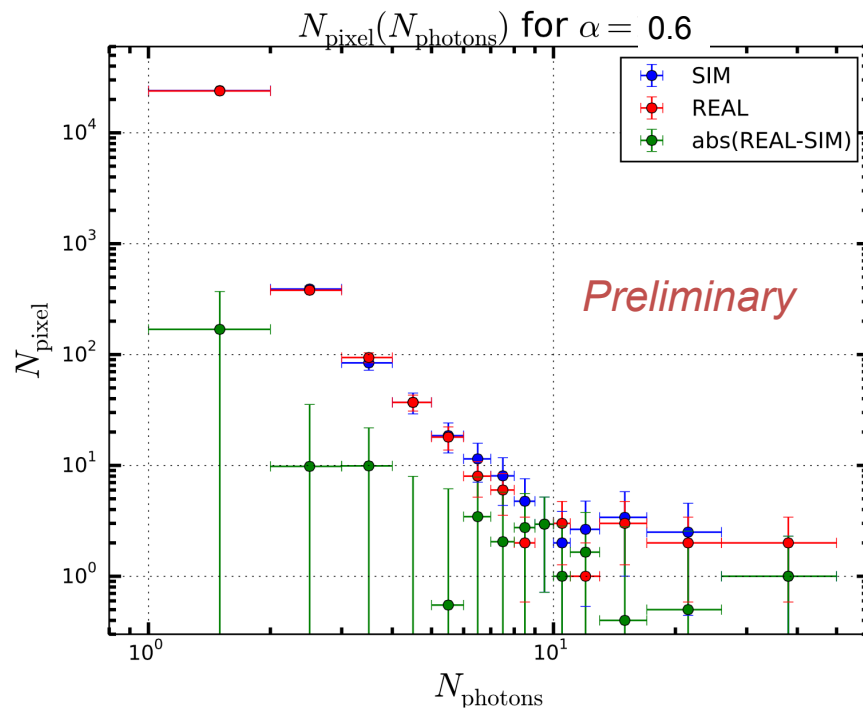
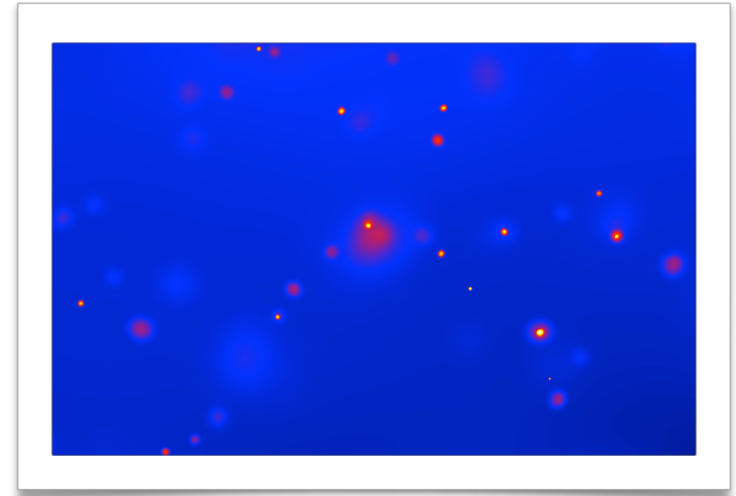
*Preliminary*





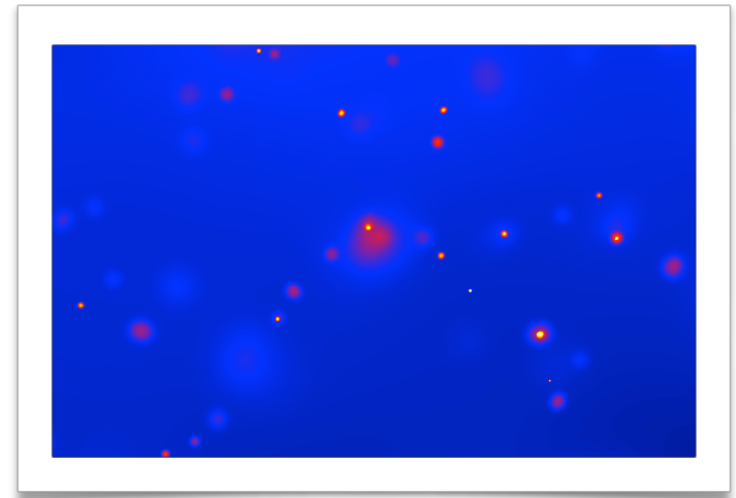
- Fluctuations of the background depend also on the properties of the unresolved source population

$\alpha$  = power law index below the break



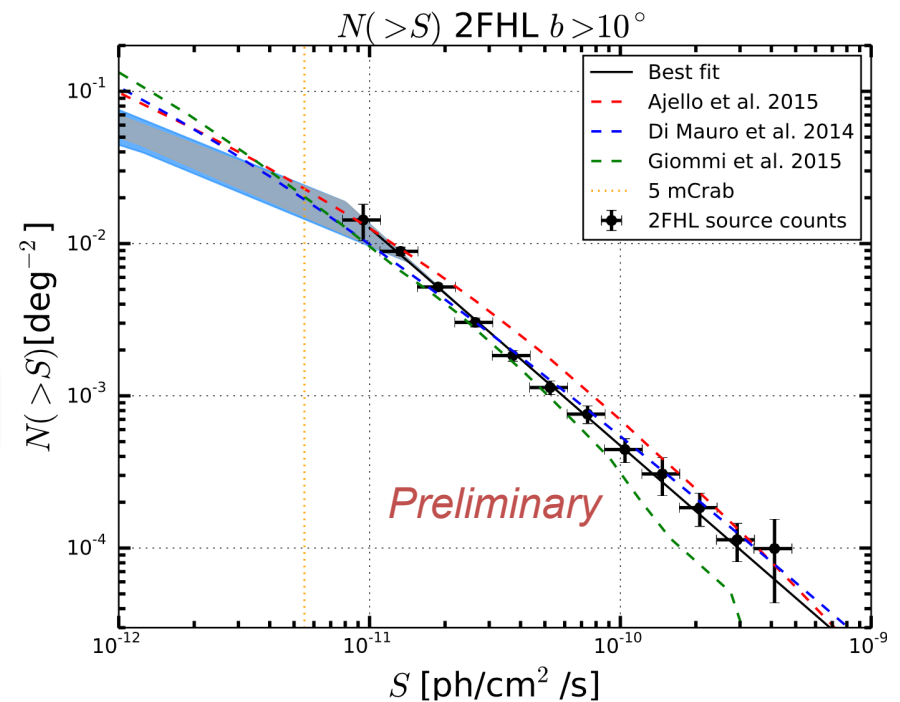


- Fluctuations of the background depend also on the properties of the unresolved source population



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

Nearly all the IGRB is produced by BL Lacs



# Count Map

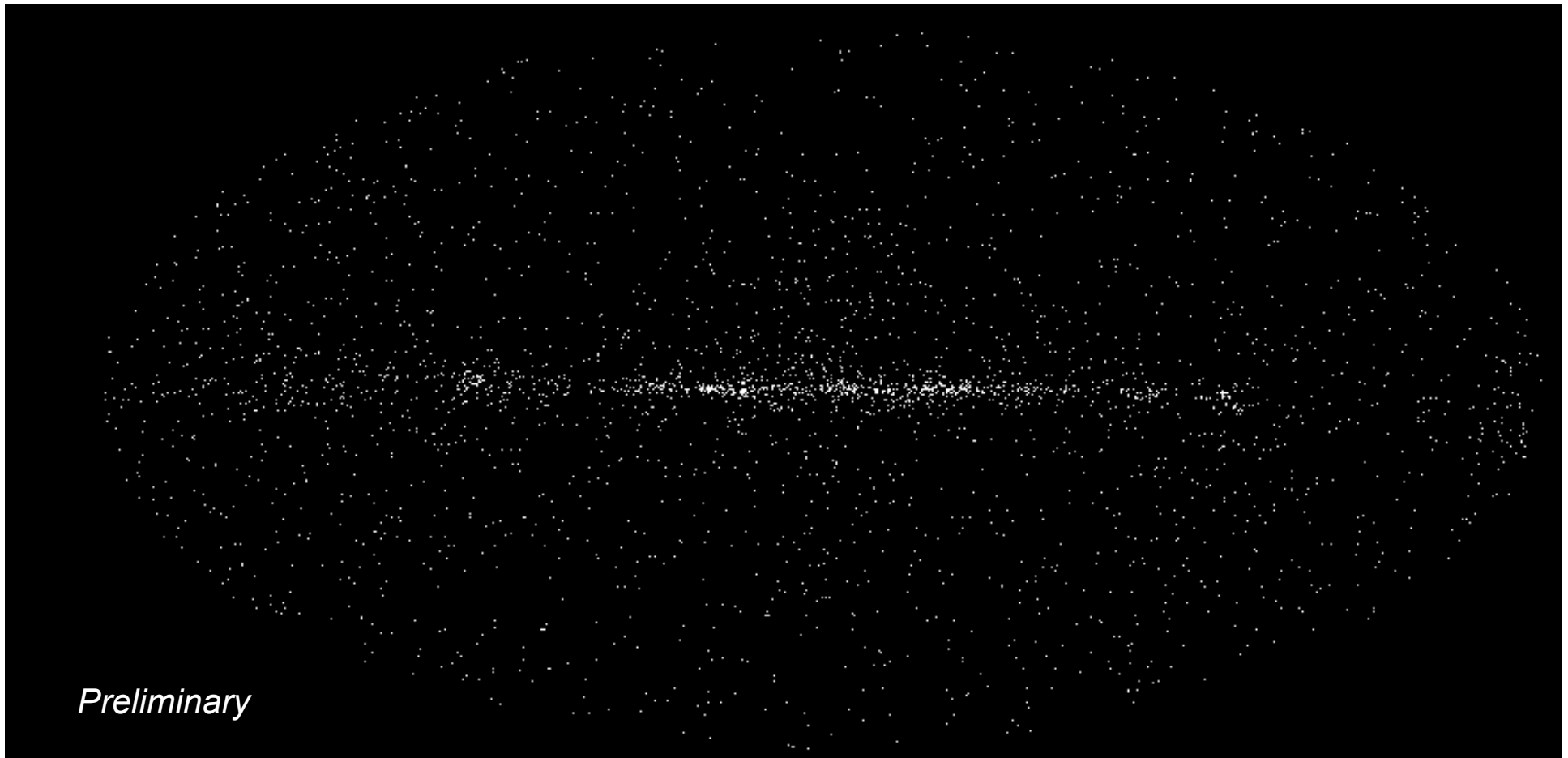


80 months of P8 data (50 GeV – 2 TeV)

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



~1.5 photon every  $\text{deg}^2$



*Preliminary*



- **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

