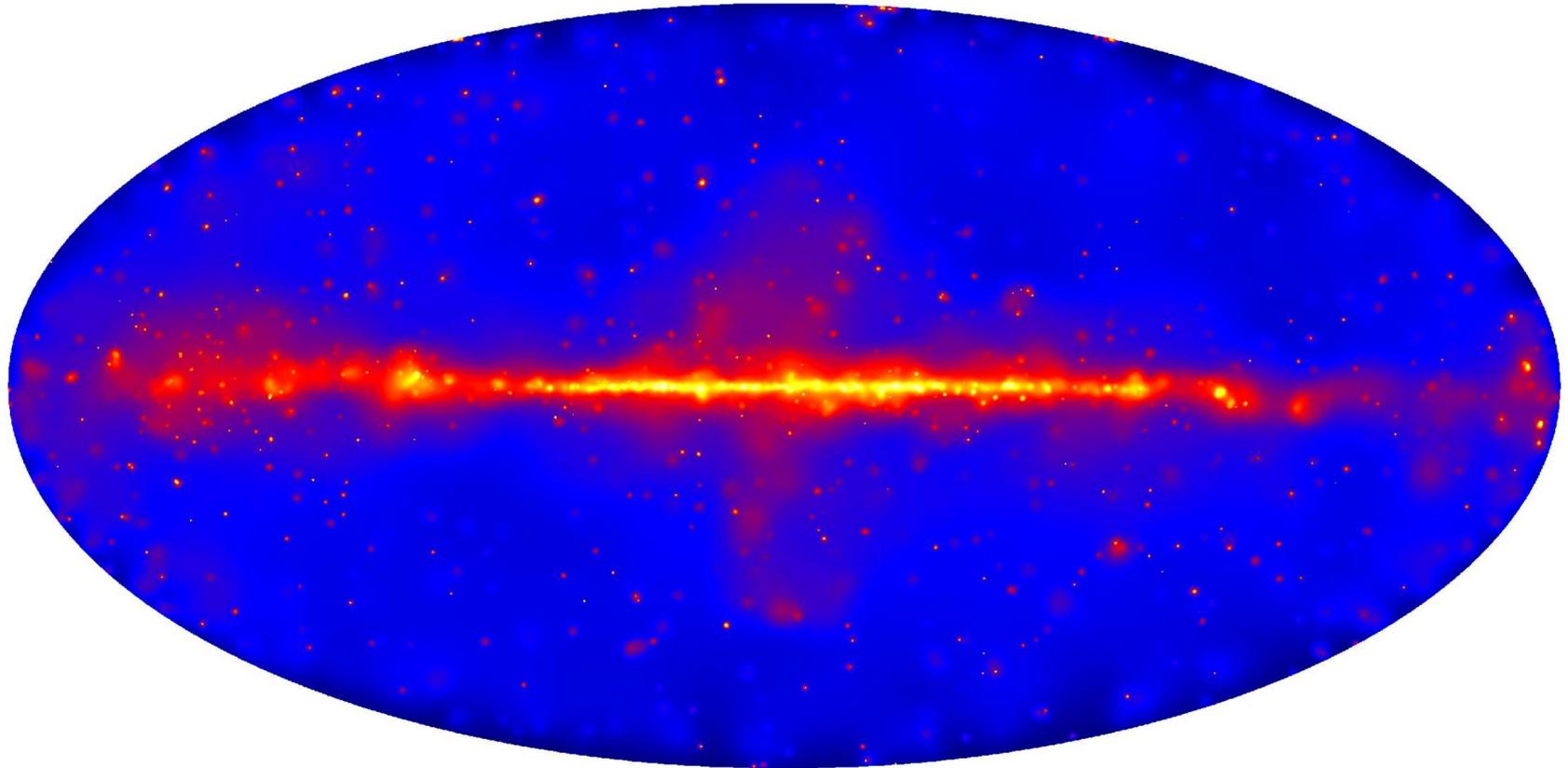
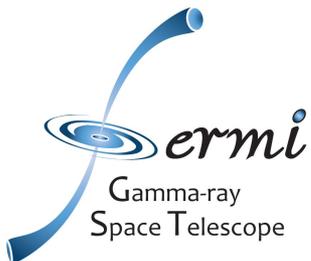


# Latest Fermi-LAT results on EBL gamma-ray attenuation



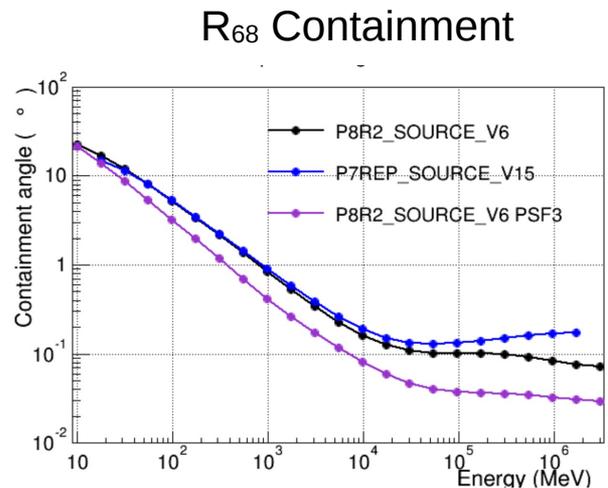
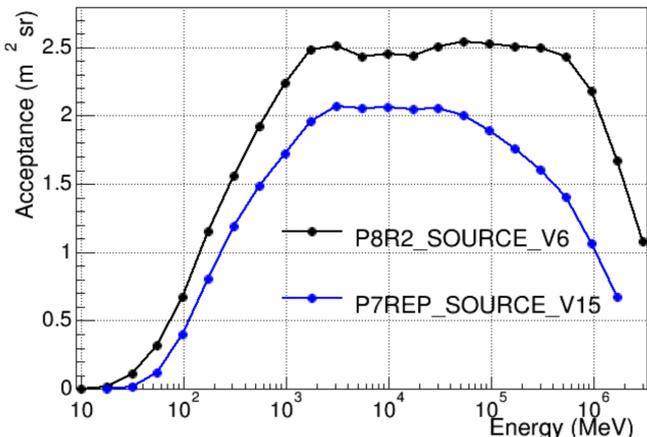
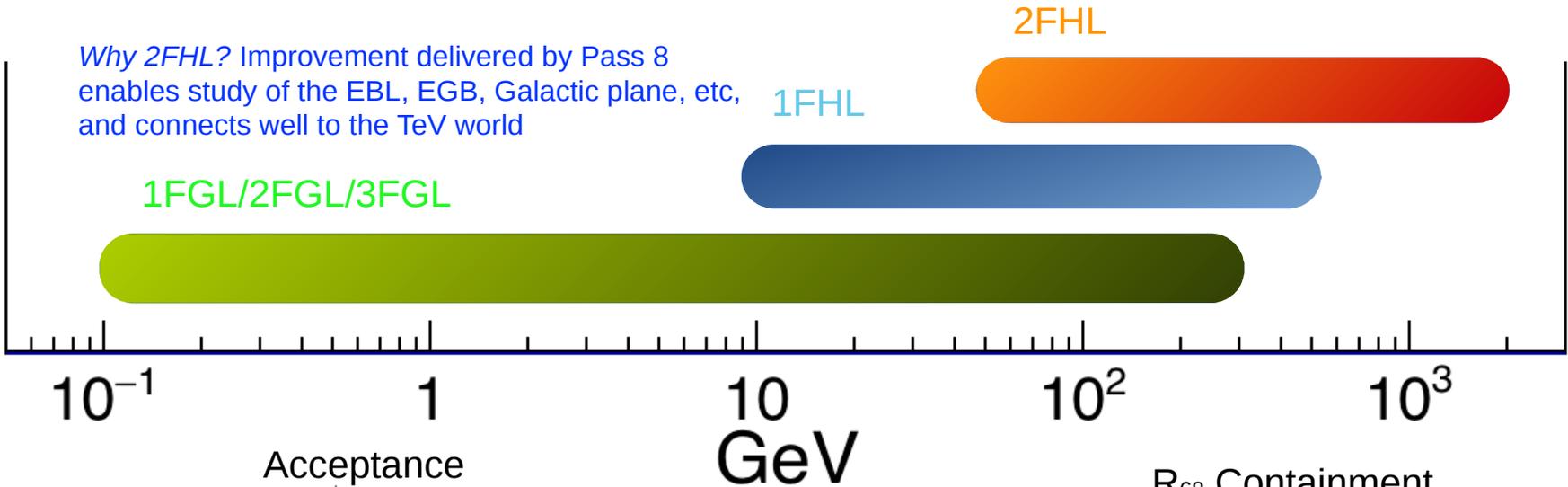
Alberto Domínguez (UC Madrid) & Marco Ajello (Clemson University)  
On behalf of the Fermi-LAT collaboration



# Fermi-LAT Catalogs

*n*FGL Catalogs detect and characterize sources in the ~0.1-300 GeV energy range  
*n*FHL 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



# The 2FHL sky: count map

80 months of P8 data (50 GeV – 2 TeV)

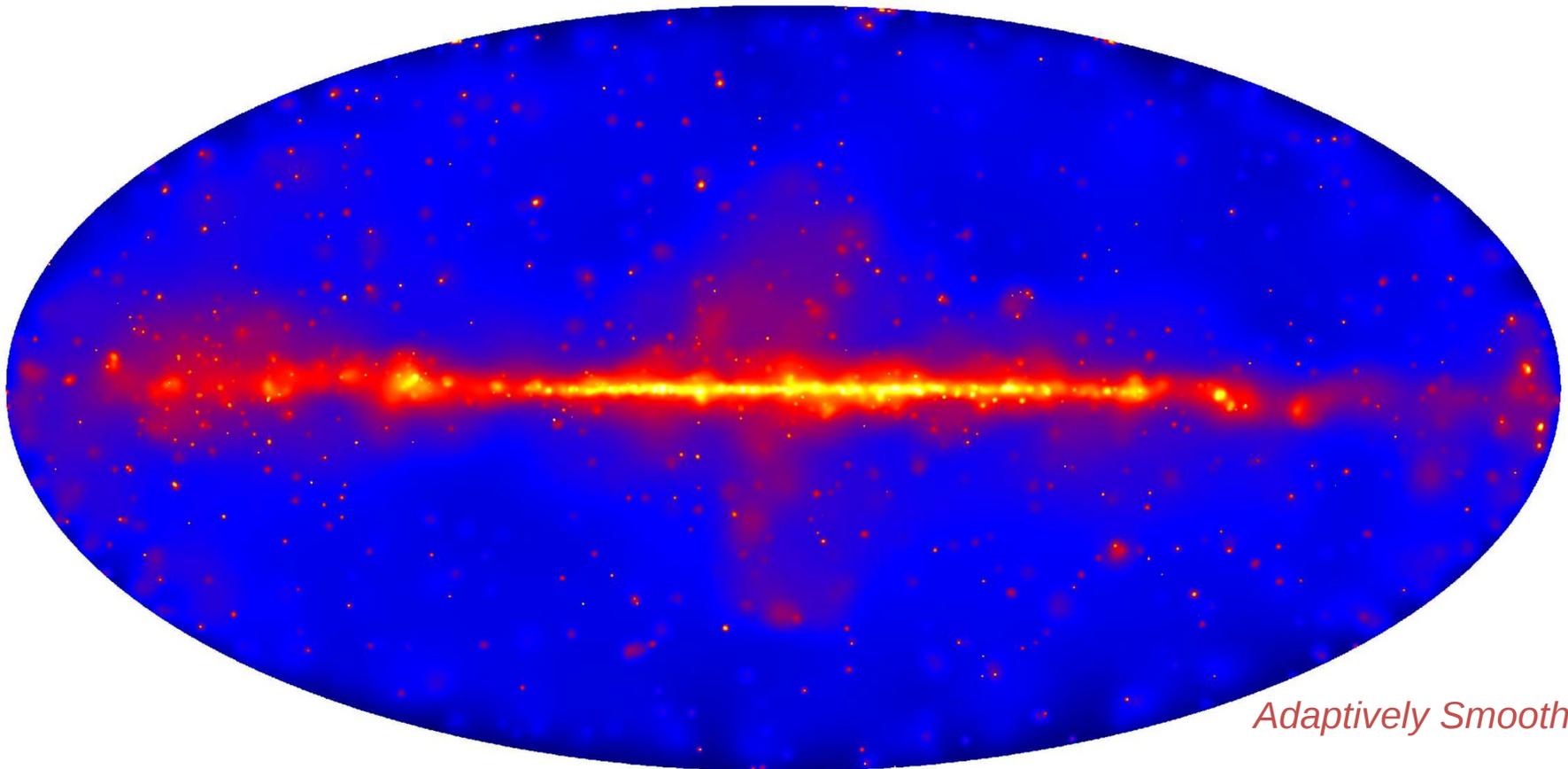
61,000 photons  $E > 50$  GeV

22,100 photons  $E > 100$  GeV

2,000 photons  $E > 500$  GeV



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



*Adaptively Smoothed*

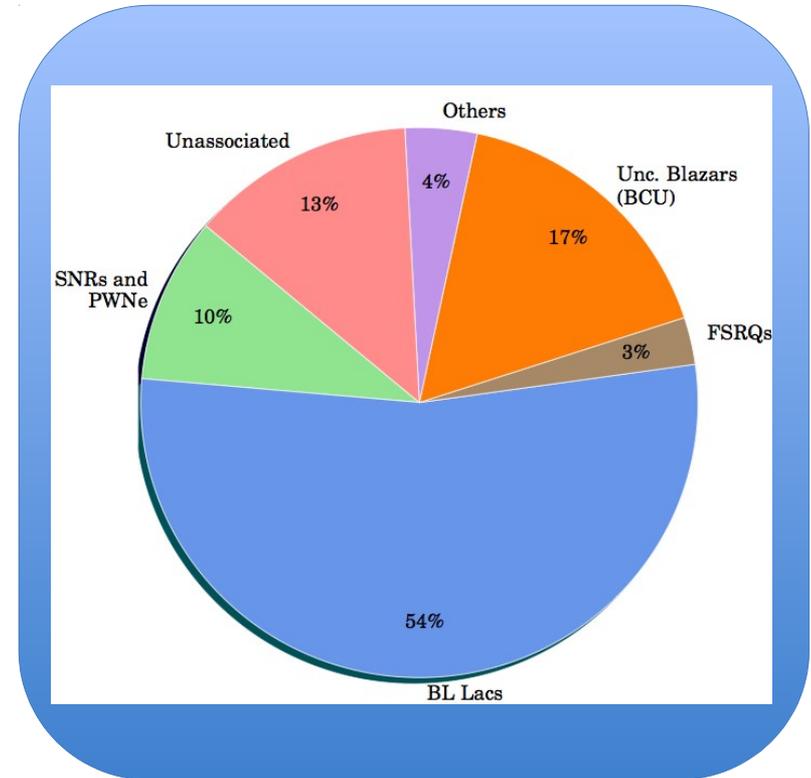
# Analysis Details of the 2FHL Catalog

- **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)

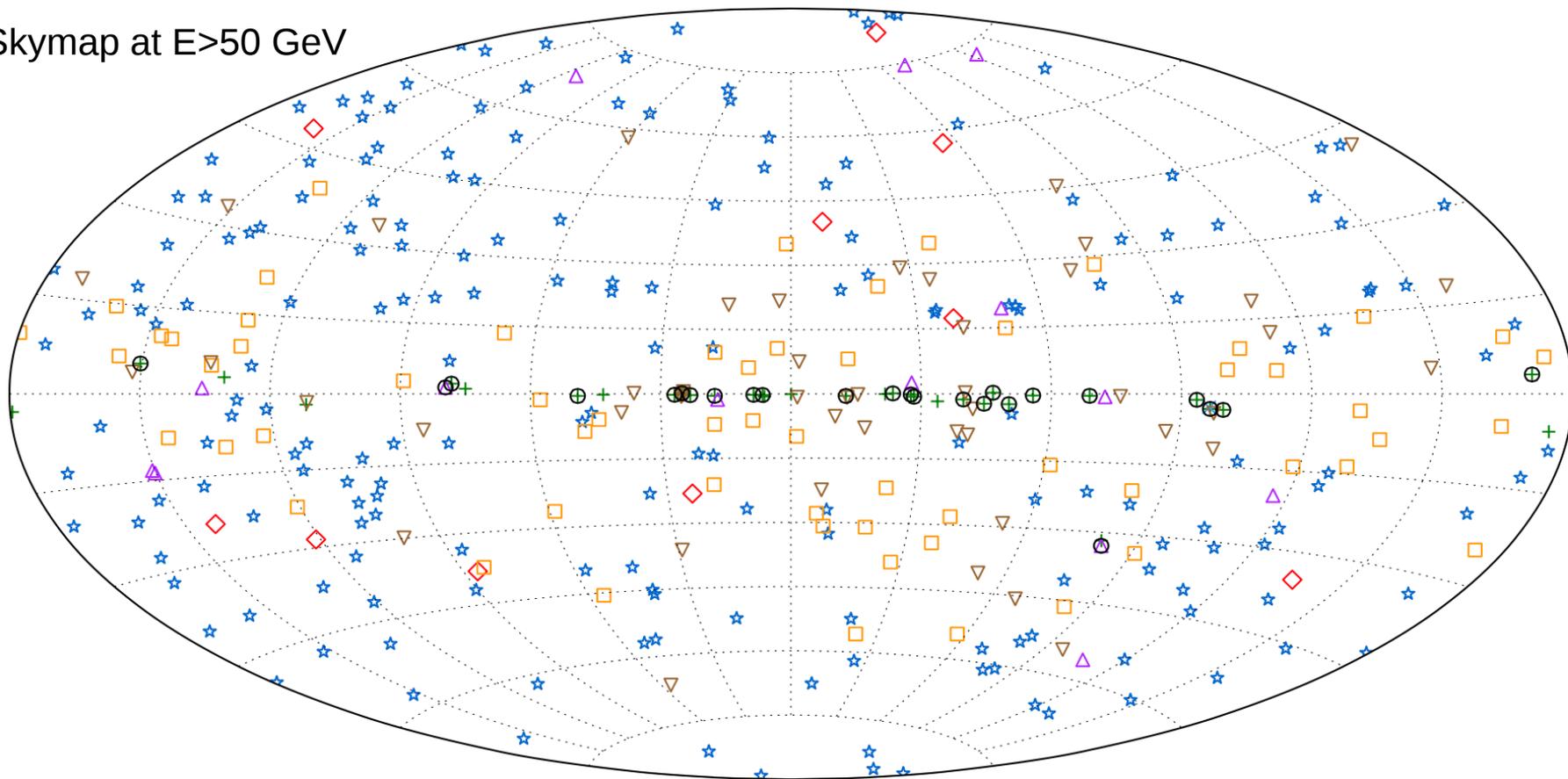


Median localization accuracy of 2.4 arcmin (68%)!

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

# Associations

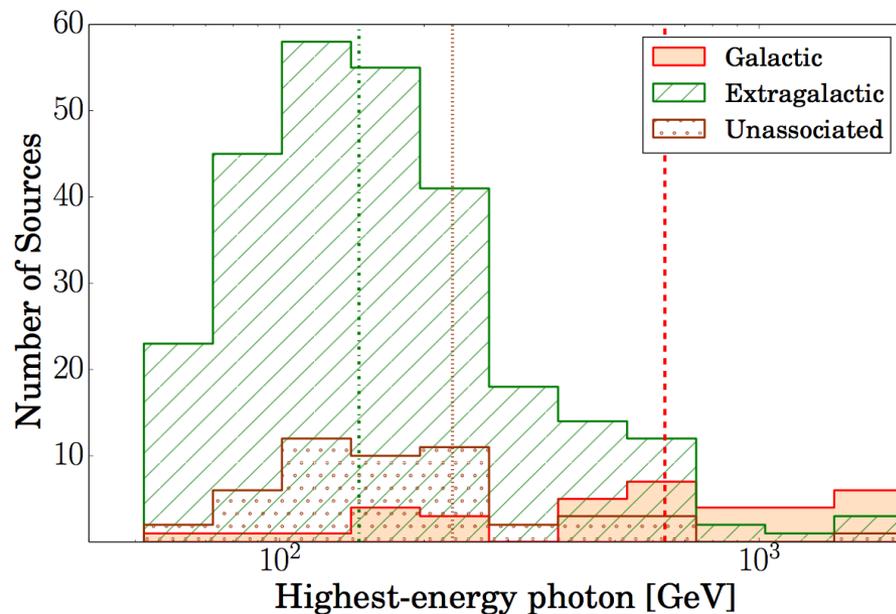
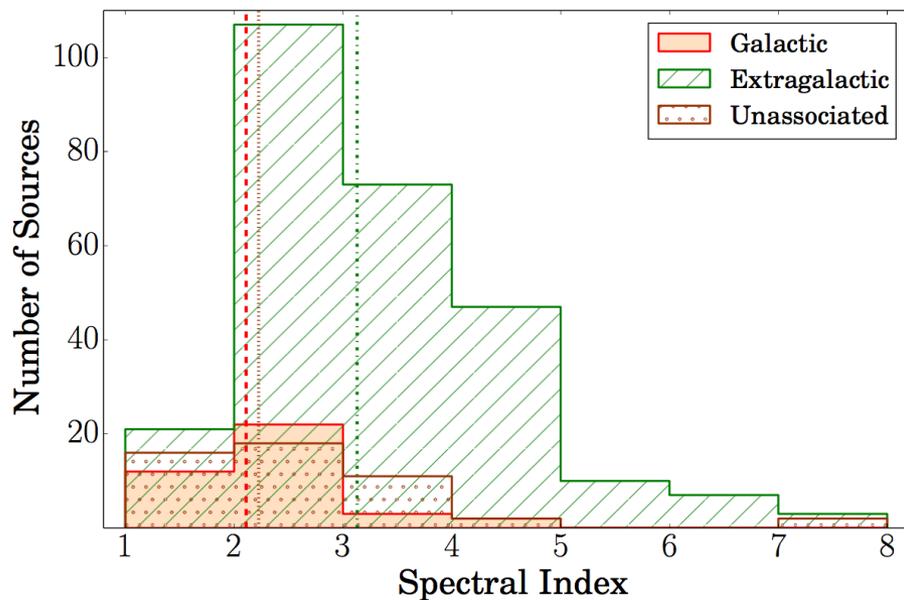
Skymap at  $E > 50$  GeV



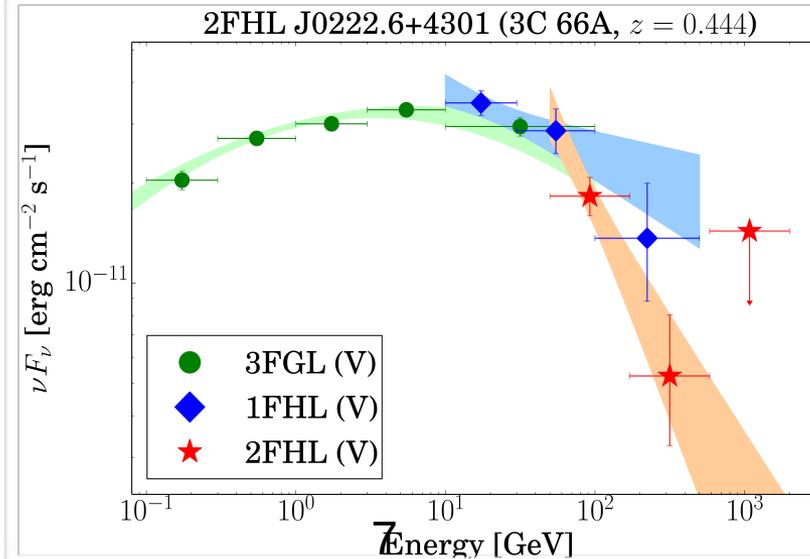
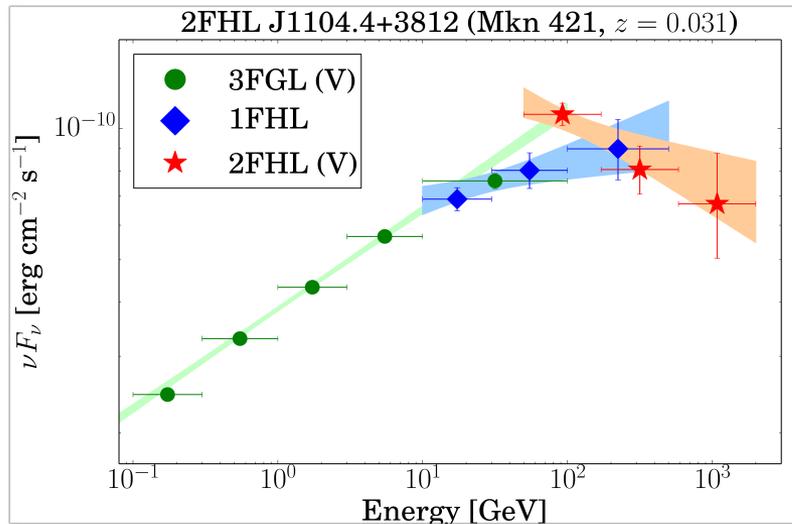
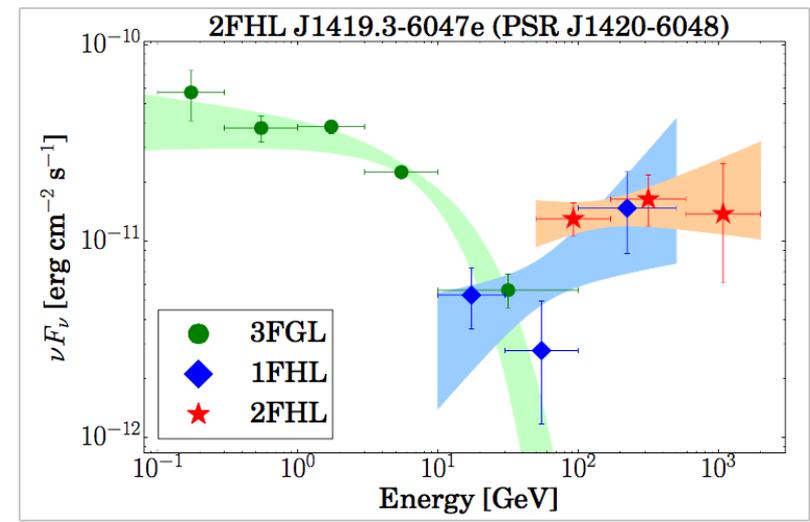
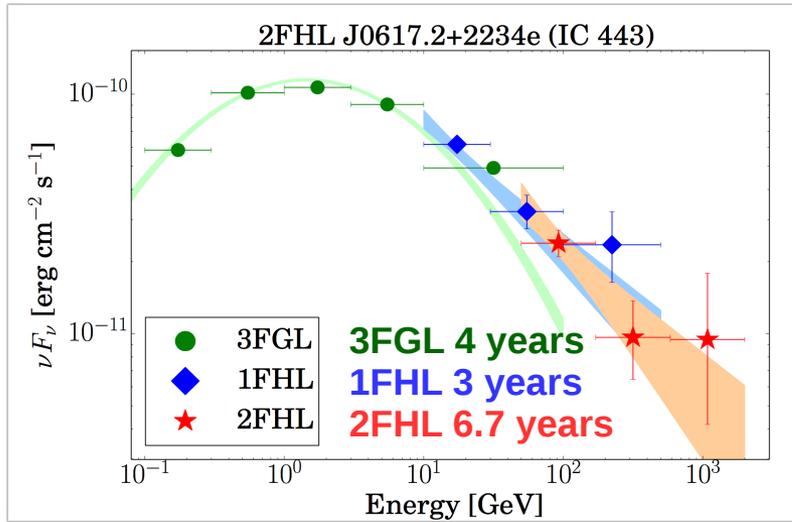
+	SNRs and PWNe	★	BL Lacs	□	Unc. Blazars	▽	Unassociated
×	Pulsars	◇	FSRQs	△	Others	○	Extended



- 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

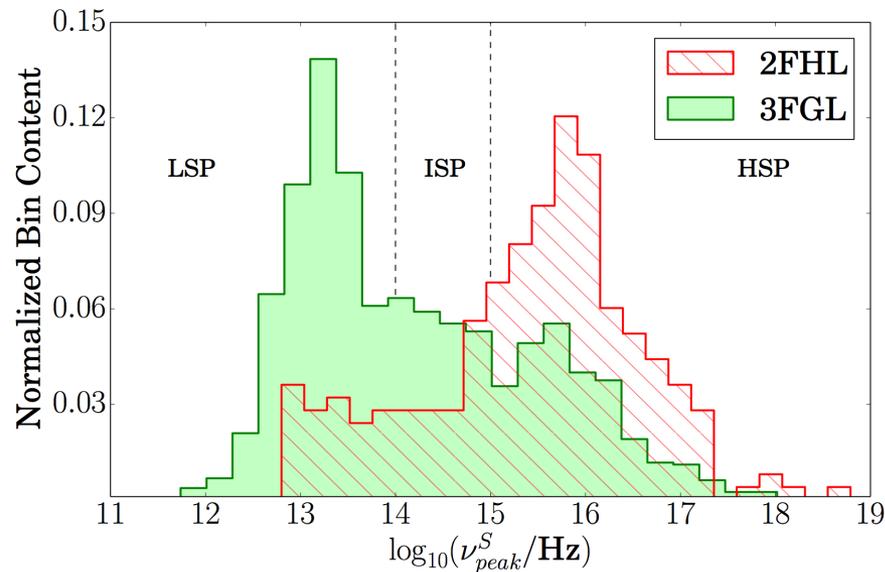


# Spectral Energy Distributions: publicly available at the Fermi Science Support Center

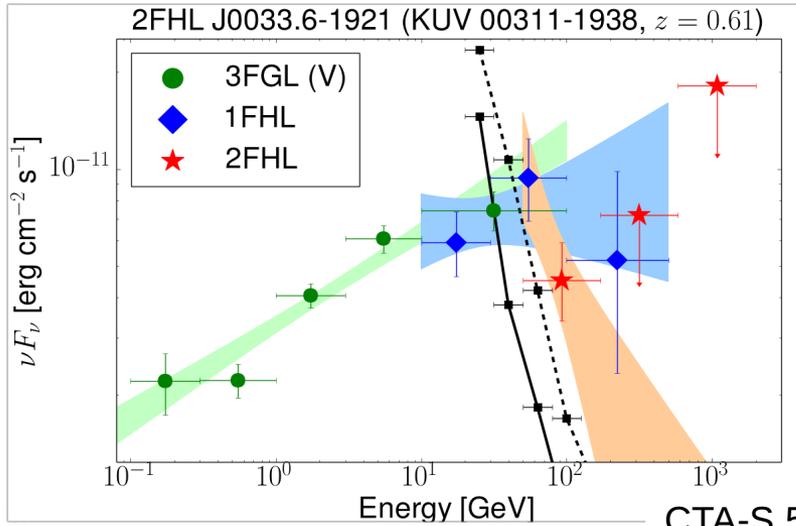


# Extragalactic Sources

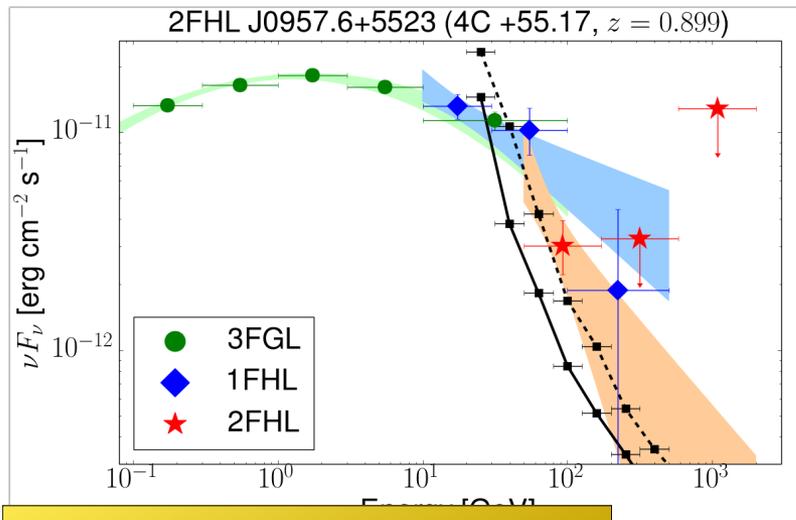
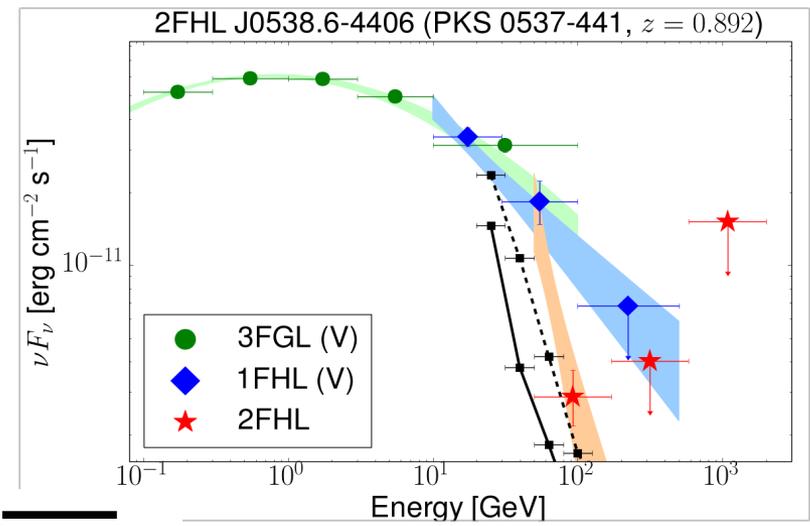
- **Blazar-like objects constitute >80% of the 2FHL Catalog**
  - Detected up to  $z \sim 2$
  - Most of them are BL Lacs, only 10 FSRQs
  - Different population than 3FGL



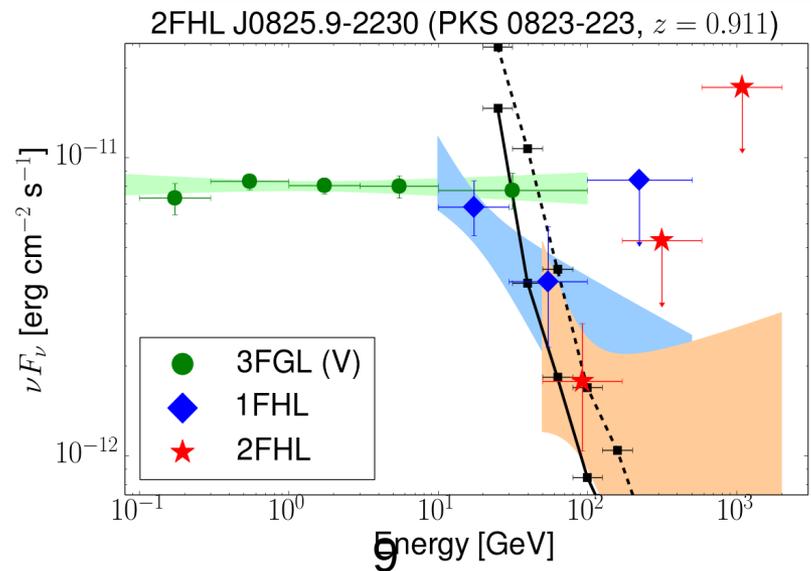
# Blazars at intermediate redshift, $0.6 < z < 1$ (16 in 2FHL)



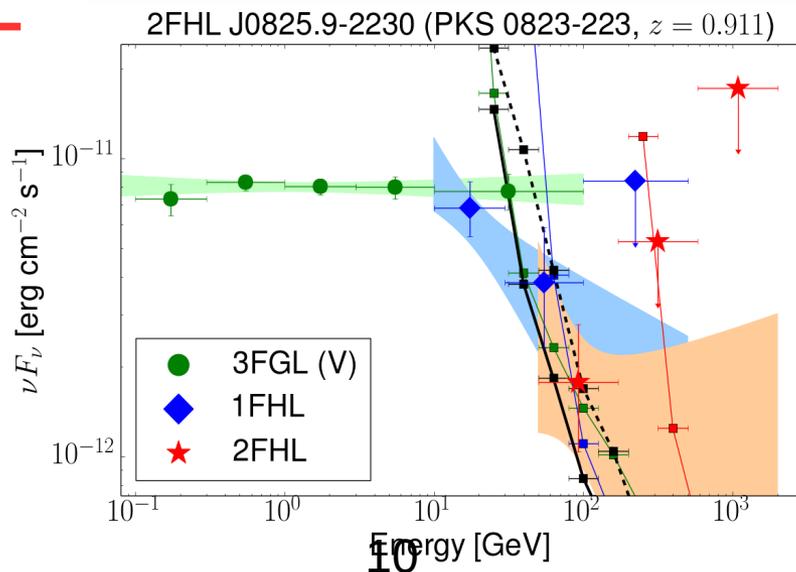
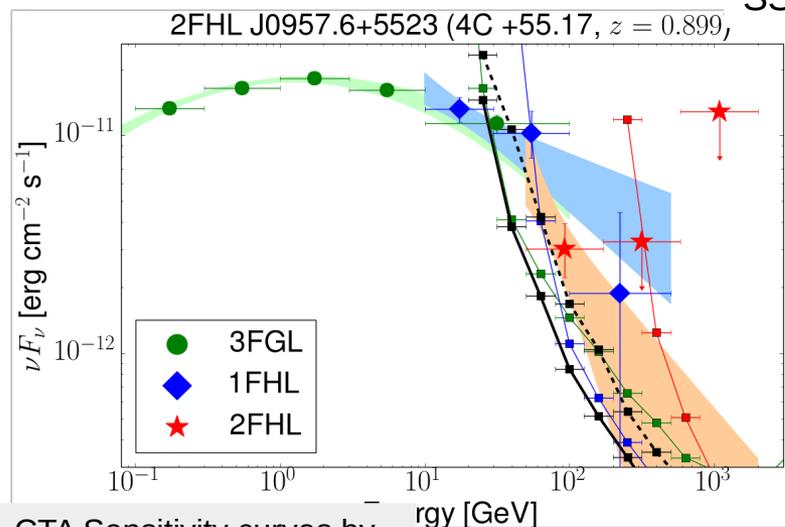
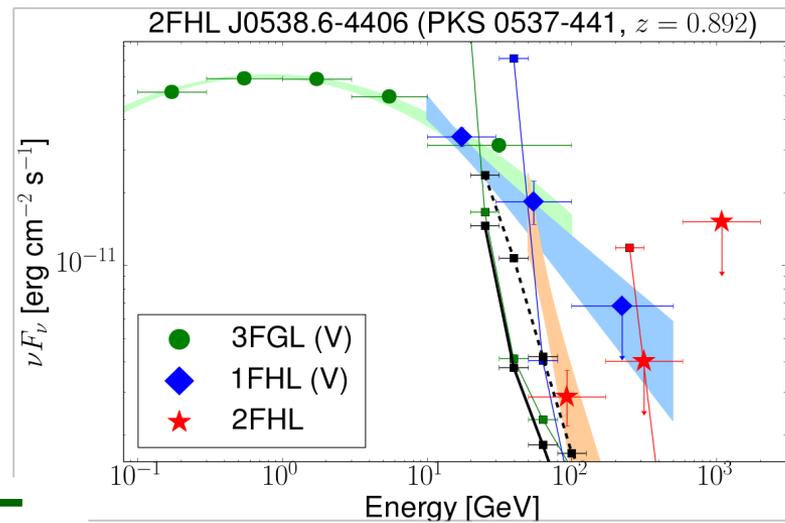
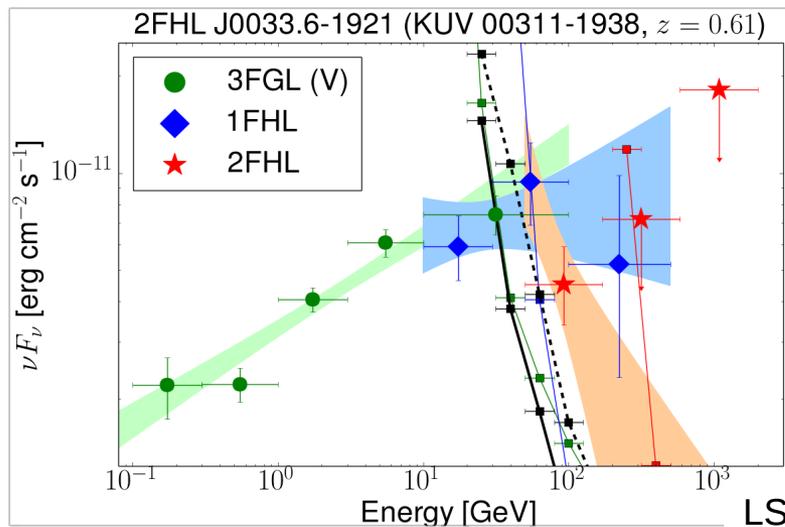
— CTA-S  $5\sigma$  in 50 h  
 - - - CTA-N  $5\sigma$  in 50 h



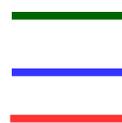
Not considering visibility from site!



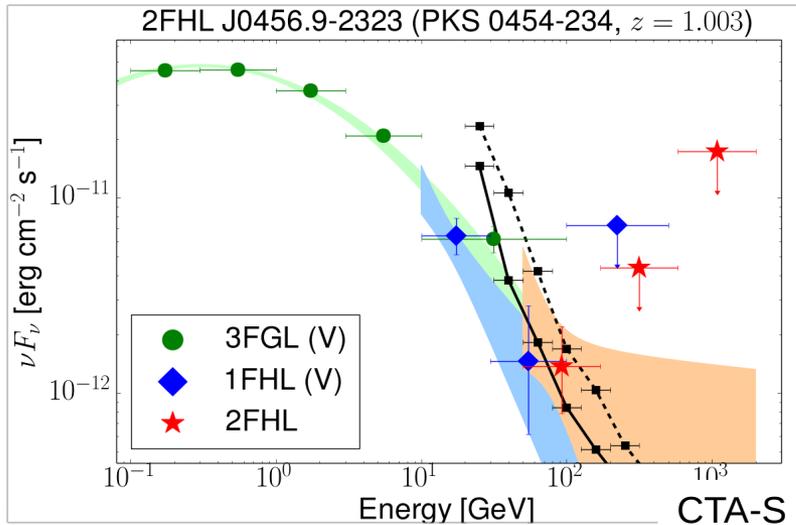
# Blazars at intermediate redshift, $0.6 < z < 1$ (16 in 2FHL)



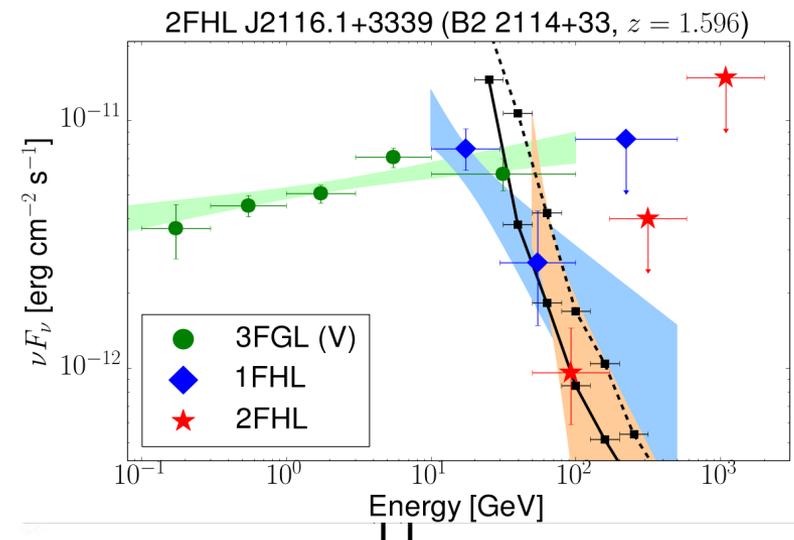
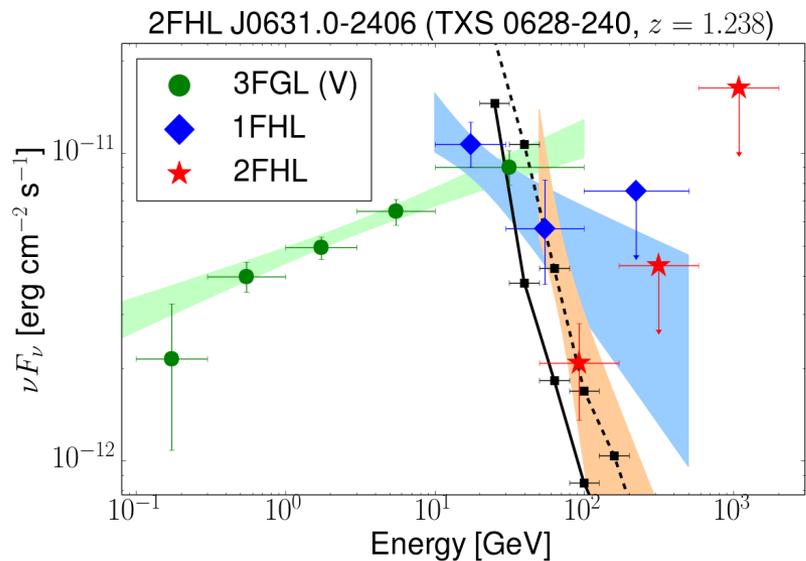
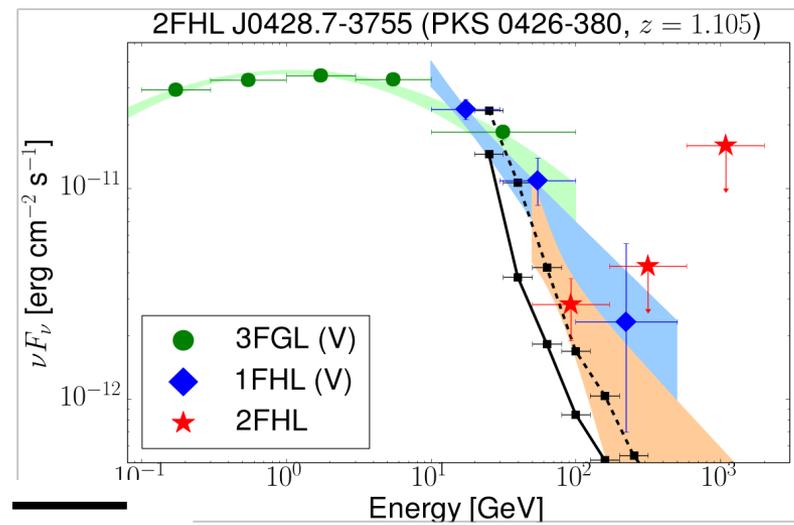
LSTs  
MSTs  
SSTs



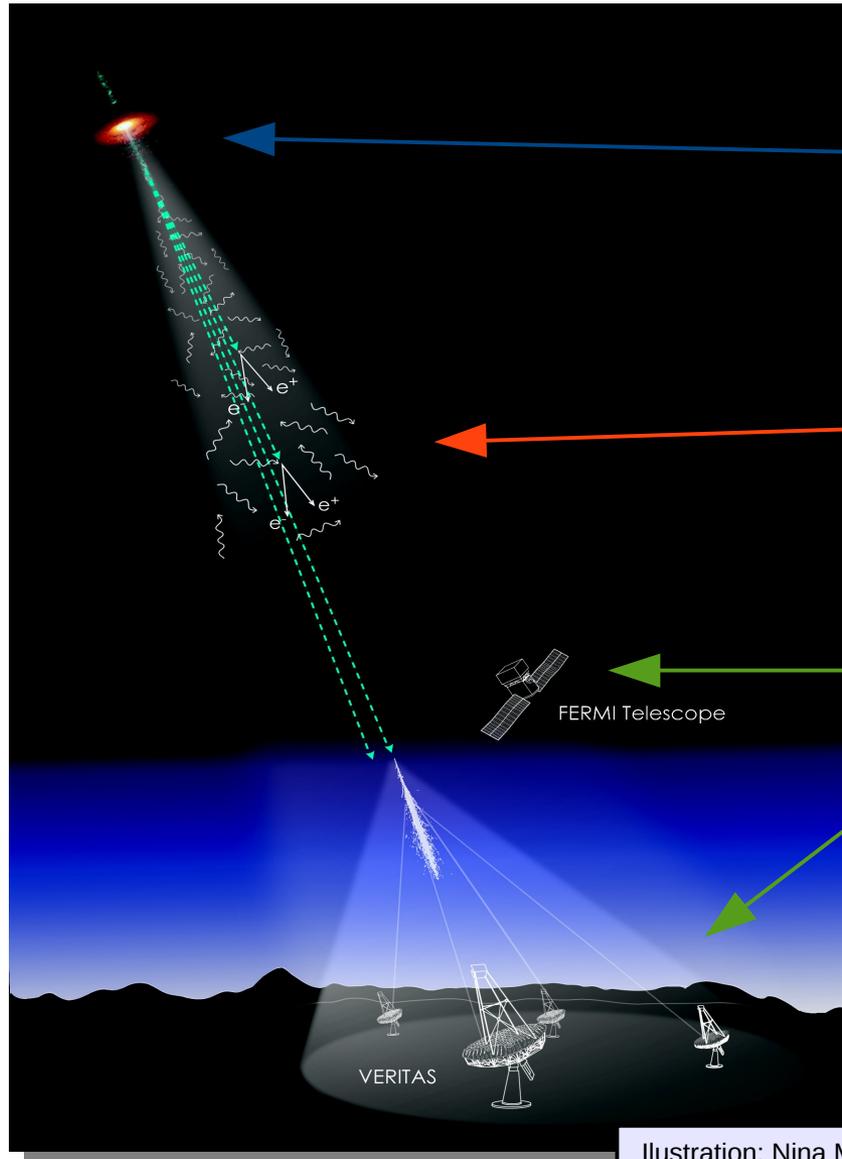
# Blazars at high redshift, $z > 1$ (7 in 2FHL)



CTA-S 5 $\sigma$  in 50 h  
CTA-N 5 $\sigma$  in 50 h



# Extragalactic Background Light



Extragalactic source:  
e.g. Blazar

**Blazars: AGNs emitting at all wavelength  
with energetic jets pointing towards us.**

**Pair-production interaction**

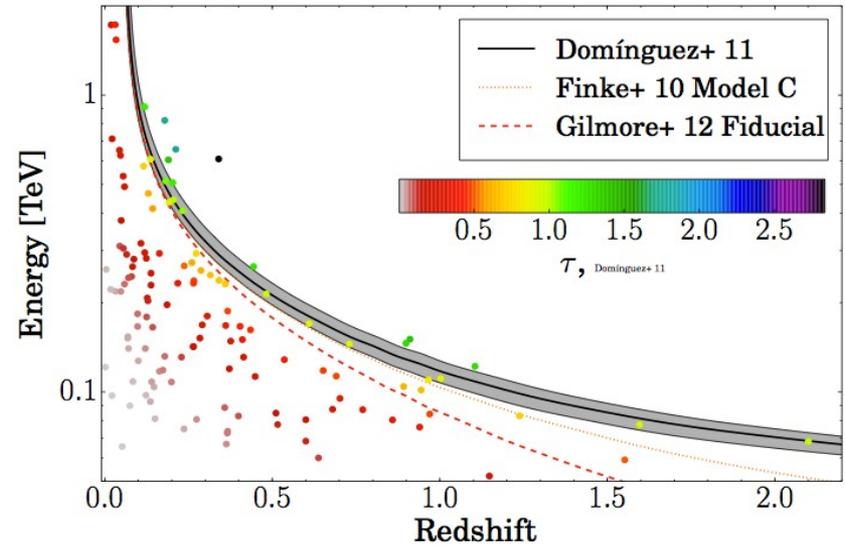
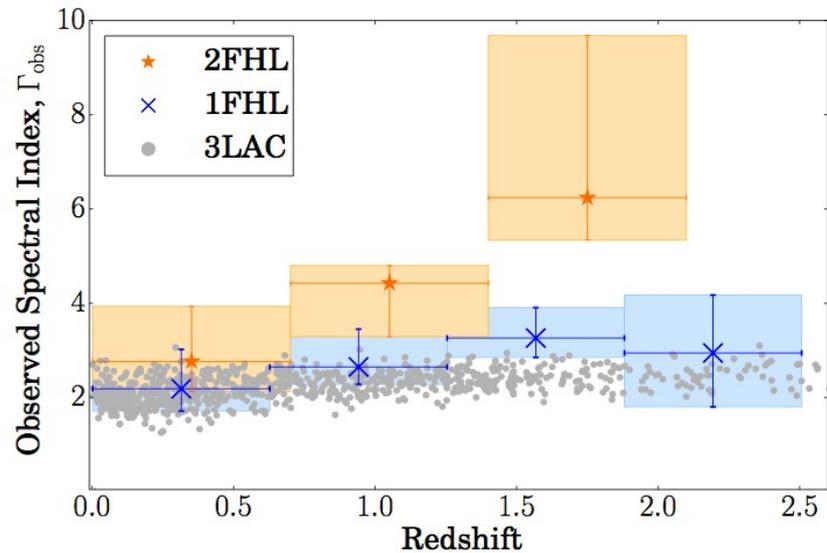
**Reverse of most known electron-positron  
annihilation process**

Telescopes: Fermi-LAT and  
Imaging Atmospheric  
Cherenkov Telescopes  
(IACTs)

$$\left. \frac{dN}{dE} \right|_{obs} = \left. \frac{dN}{dE} \right|_{int} \exp[-\tau(E, z)]$$

Illustration: Nina McCurdy & Joel Primack

# Extragalactic Background Light

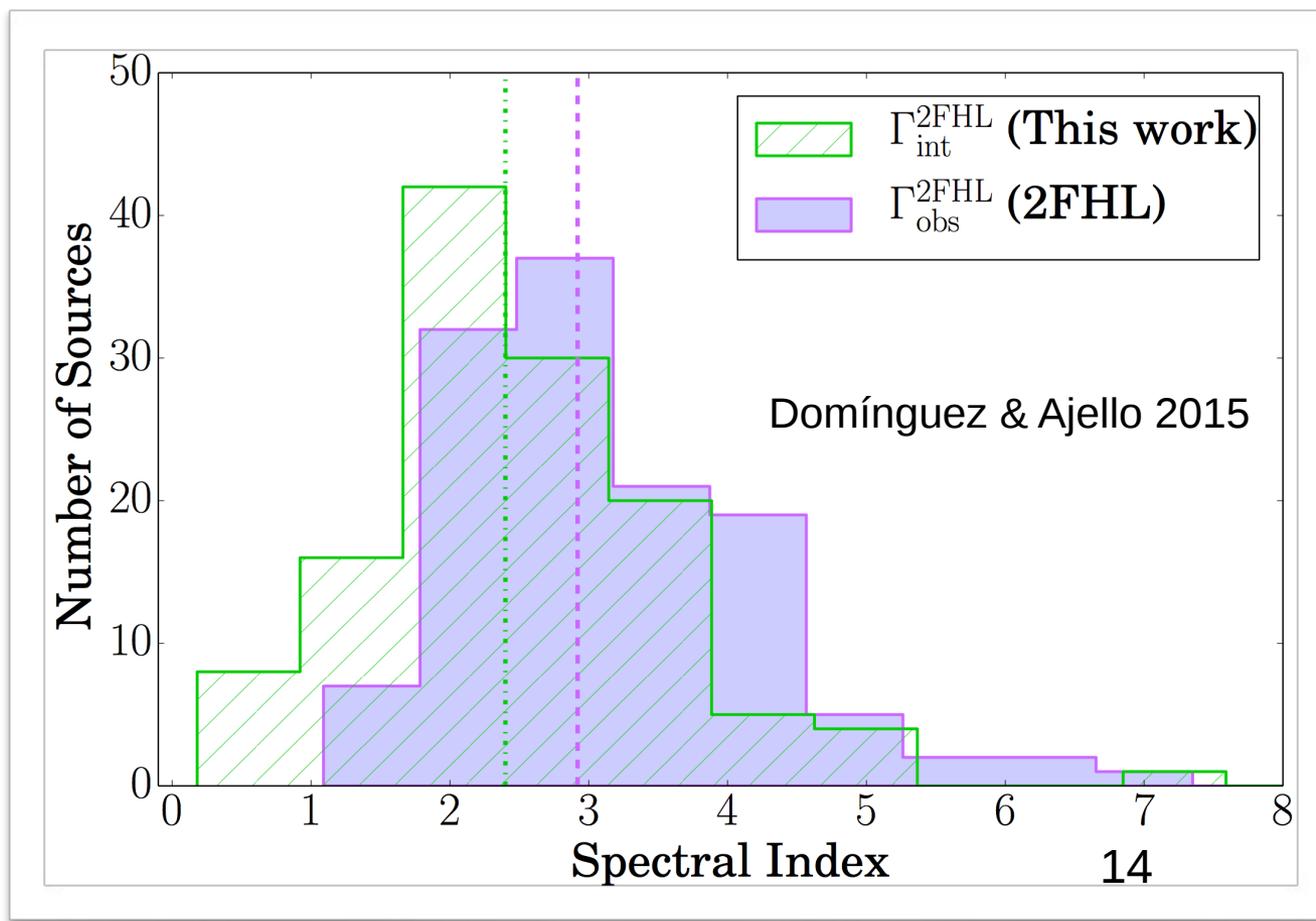


See also Domínguez+ 13 on the CGRH

- 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

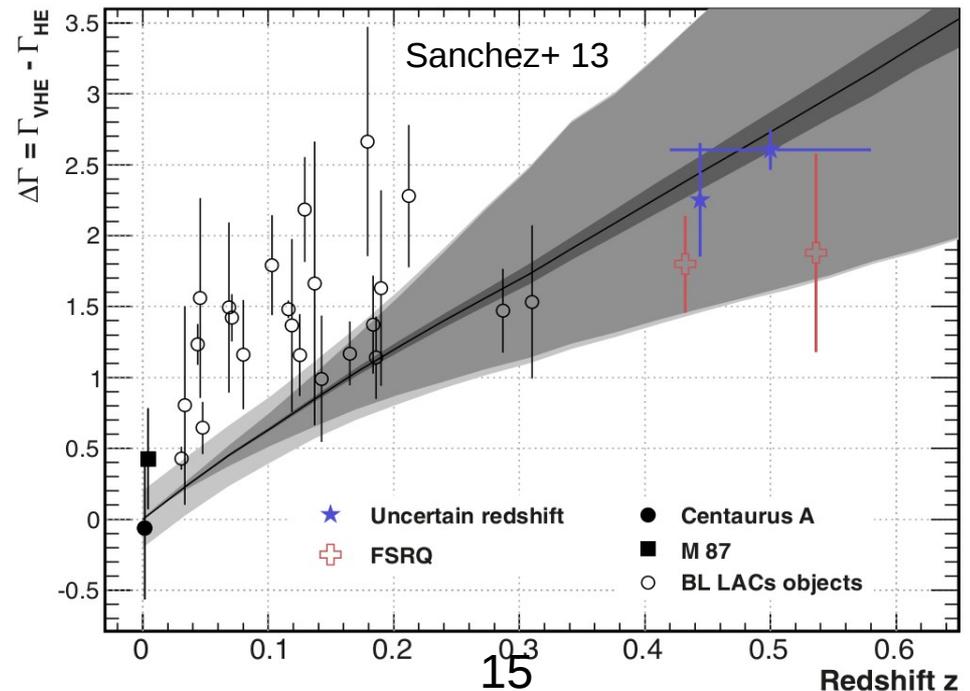
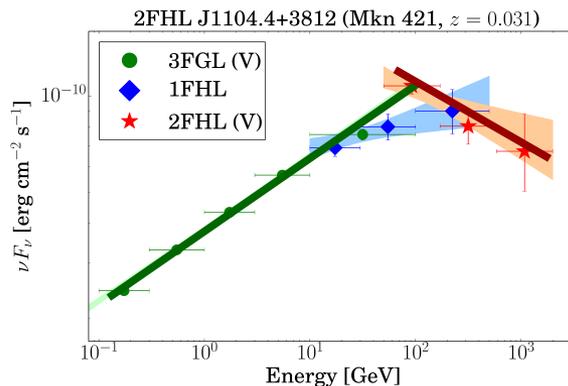
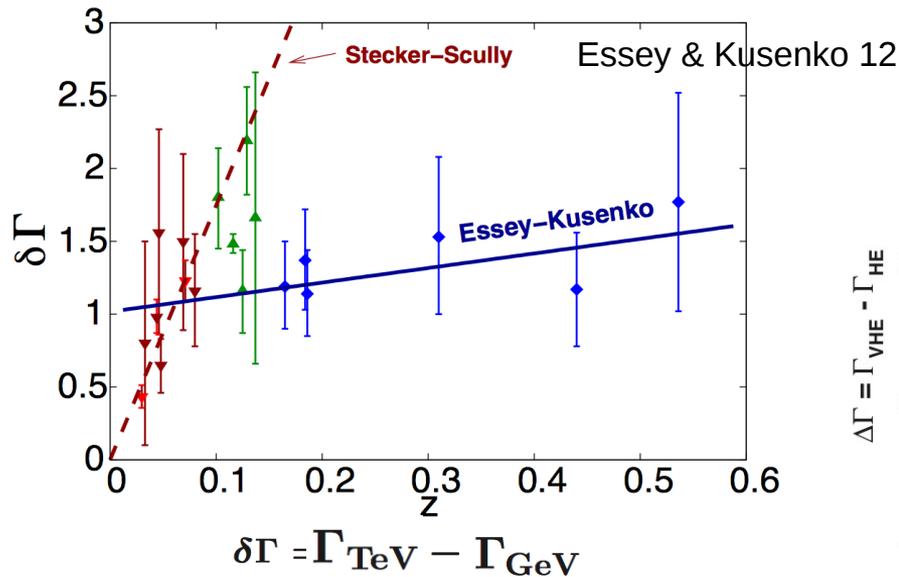
## Extragalactic Background Light: 2

- **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**



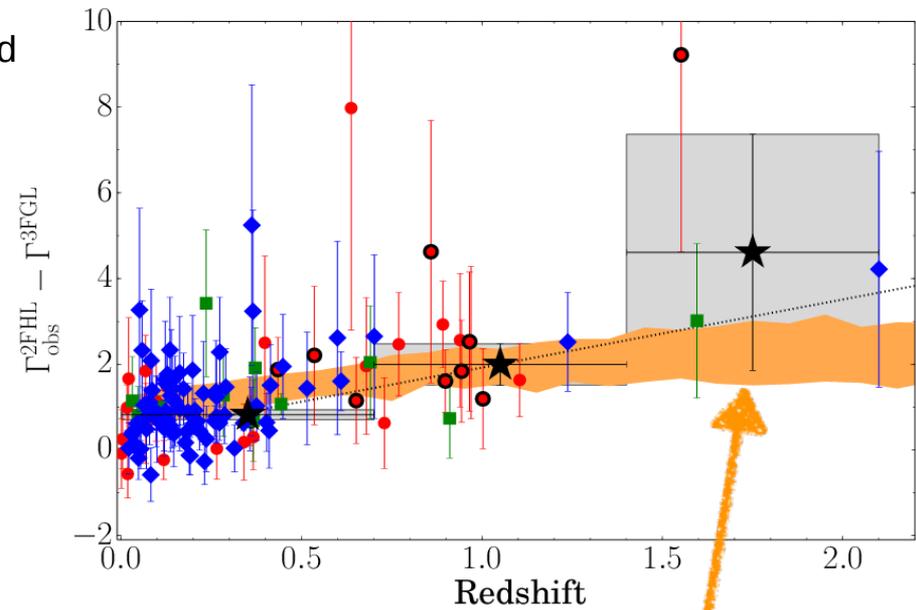
# Extragalactic Background Light: 3

- Spectral breaks between the VHE and Fermi band have been used as diagnostic for/against the EBL (Essey&Kusenko 12, Sanchez+13, Galanti+15)
  - spectral flattening at high redshift has been interpreted as sign of interesting physics

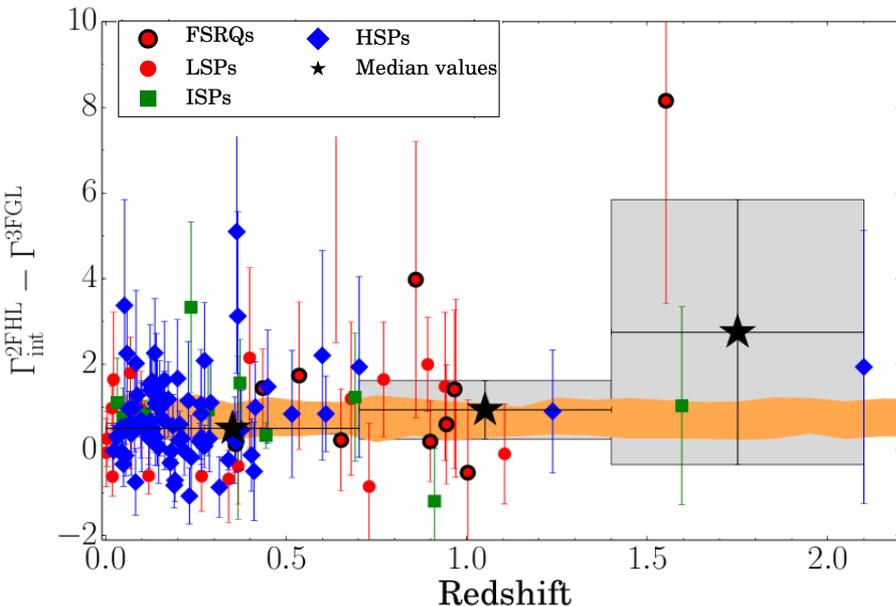


# Extragalactic Background Light: 4

- Spectral break of 122 blazars, up to  $z \sim 2$ , all measured with the same instrument and averaged over long periods of time, thus reducing systematics.
- 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.



Simulations of SSC spectra absorbed by the EBL

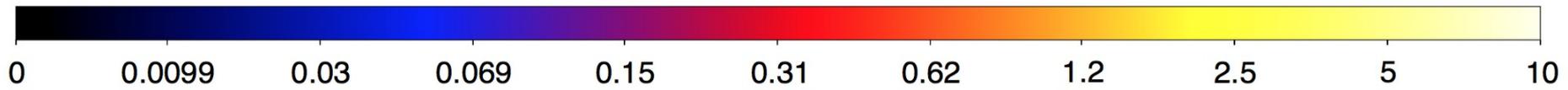
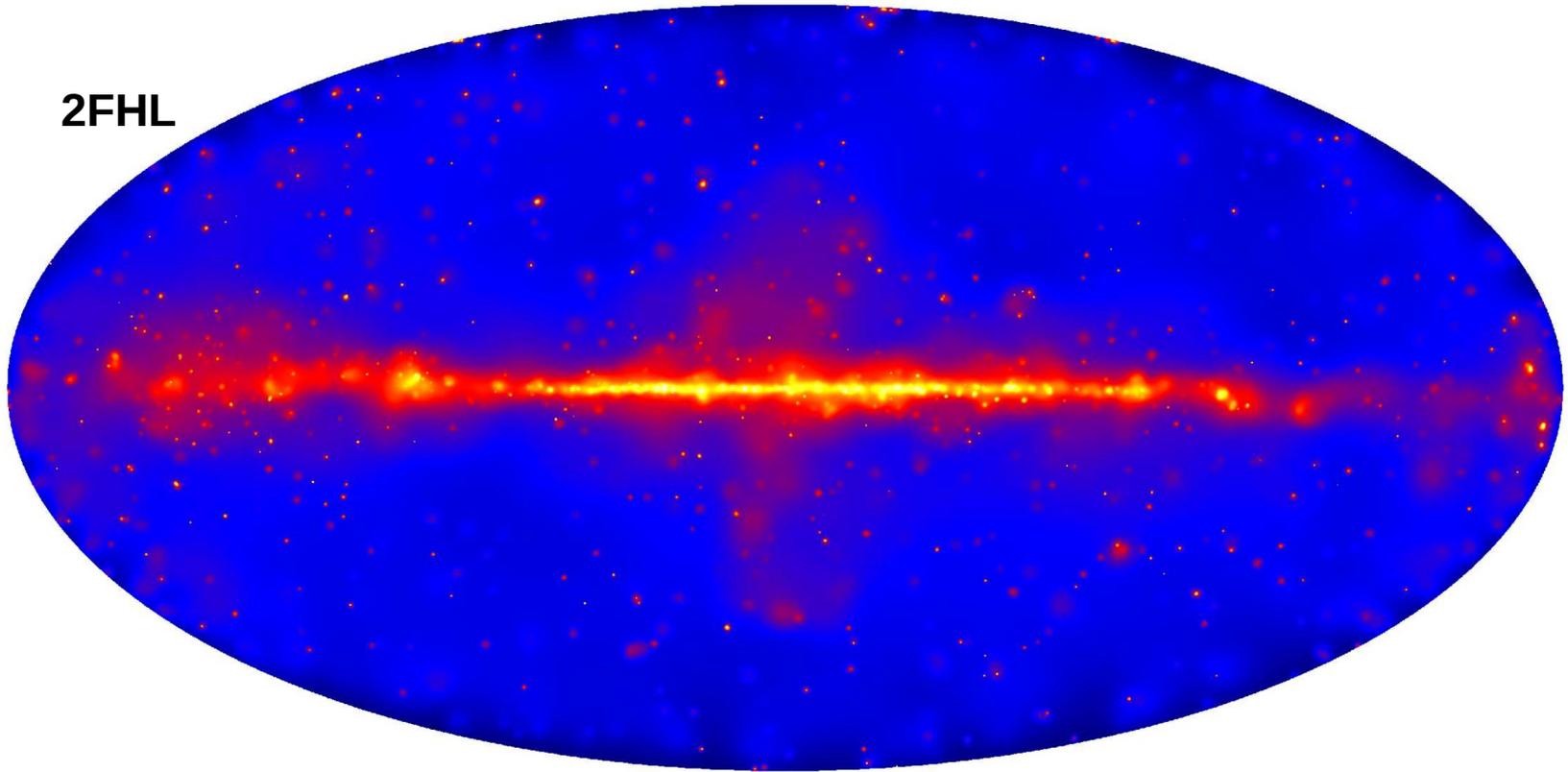


Simulations of SSC spectra

Domínguez & Ajello 15

# The future is bright: 3FHL

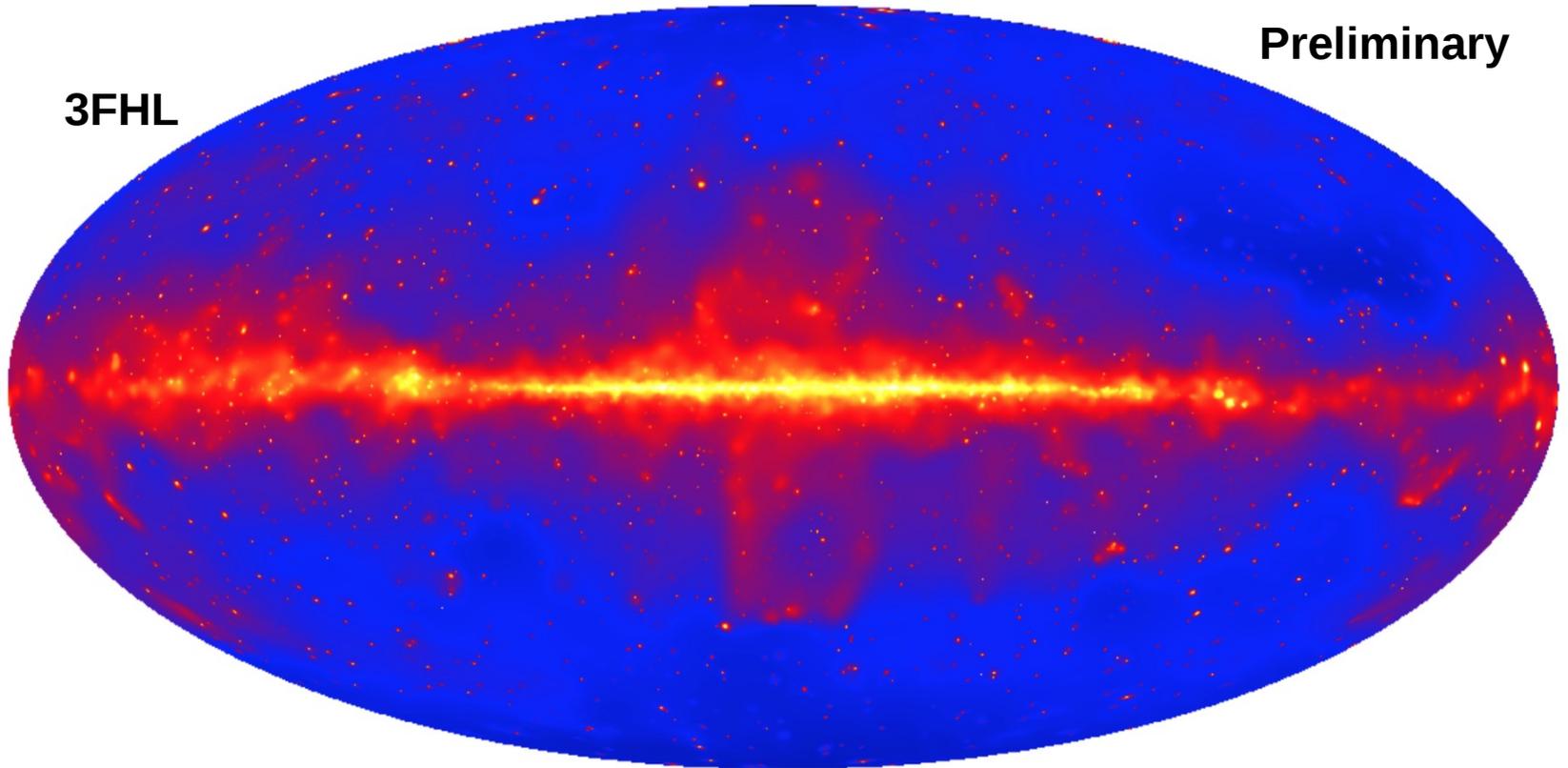
2FHL



# The future is bright: 3FHL

Preliminary

3FHL



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



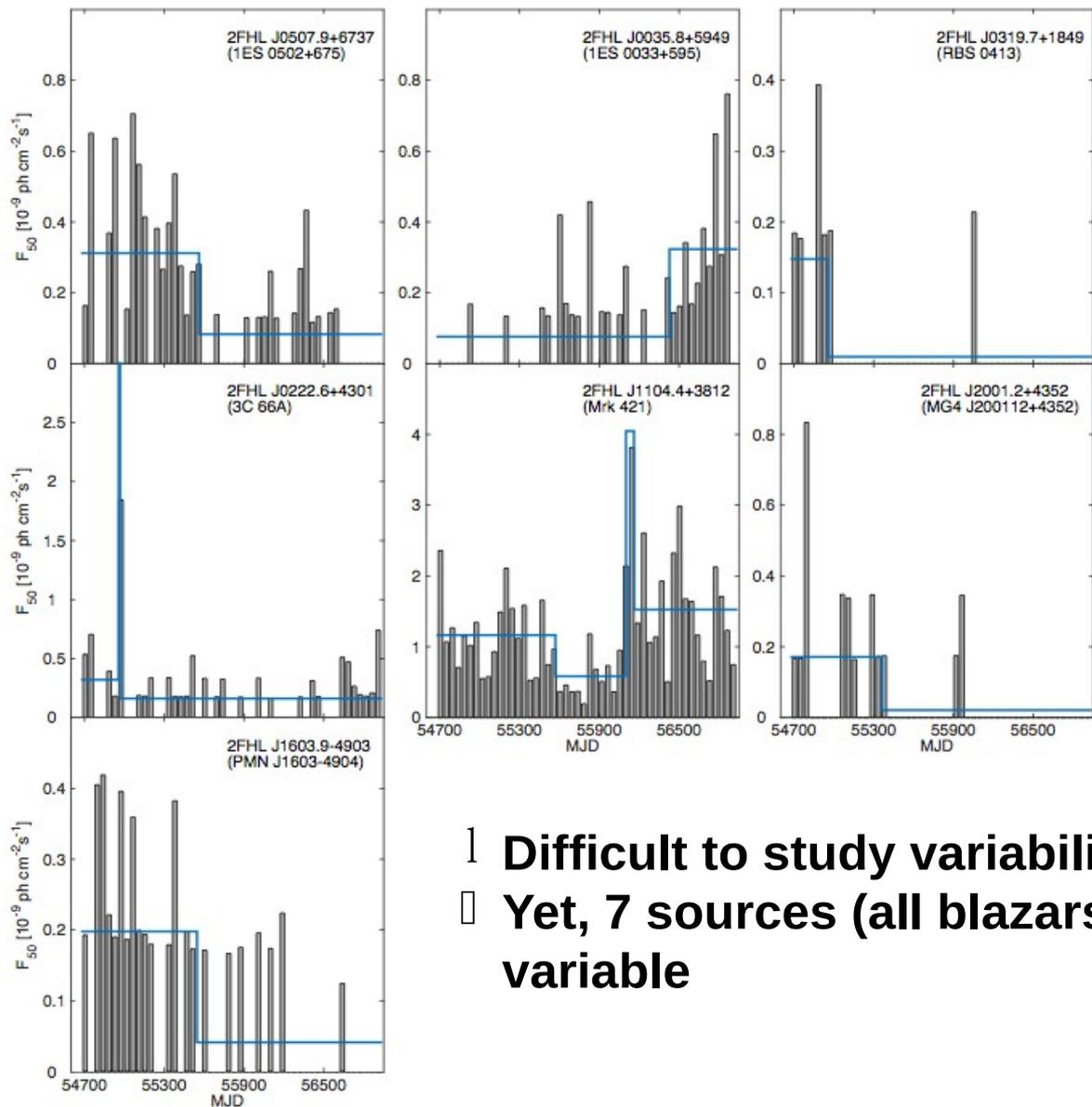


- 2FHL opens a new window on the high-energy sky
  - 360 sources detected between 50 GeV and 2 TeV
    - 75% blazars, 14% Galactic and 11 % unassociated
    - only 25% detected in TeVCat
- **Extragalactic science:**
  - >80% of 2FHL sources are blazars (BL Lacs), detected up to  $z \sim 2$
  - Clear signs of EBL attenuation (and nothing else)
  - HSP blazars are excellent probes of the EBL (see Domínguez & Ajello 2016)
  - Almost all the IGRB is accounted for by blazars (Ackermann et al. 2015, led by Mattia Di Mauro & Marco Ajello)

**The future of gamma-ray astronomy is very bright,  
So stay tuned!**



# Backup



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



## Analysis

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

## Detections

- ~350 sources
- 84 detected by ACTs (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

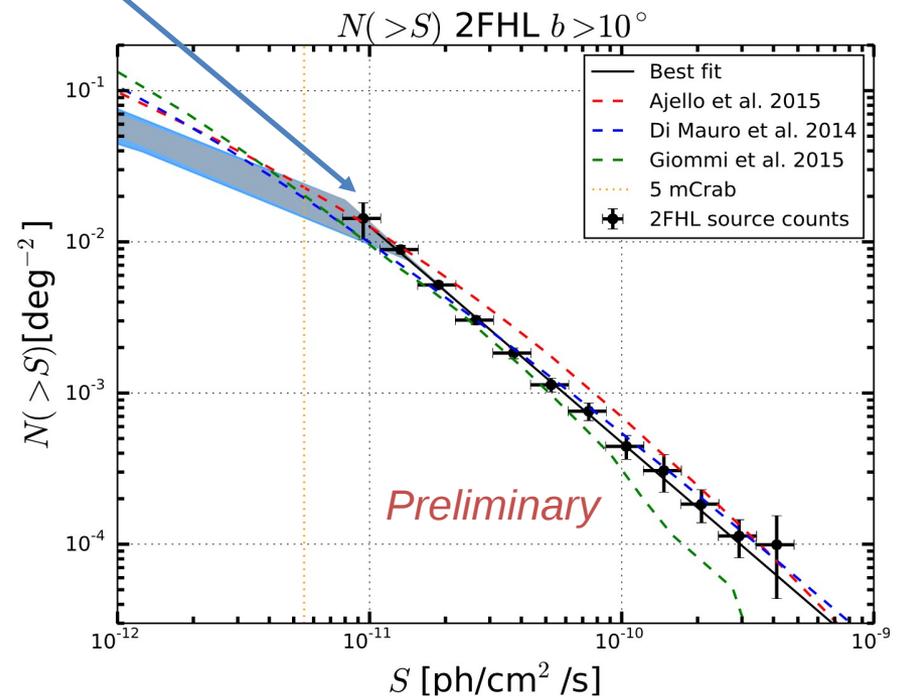
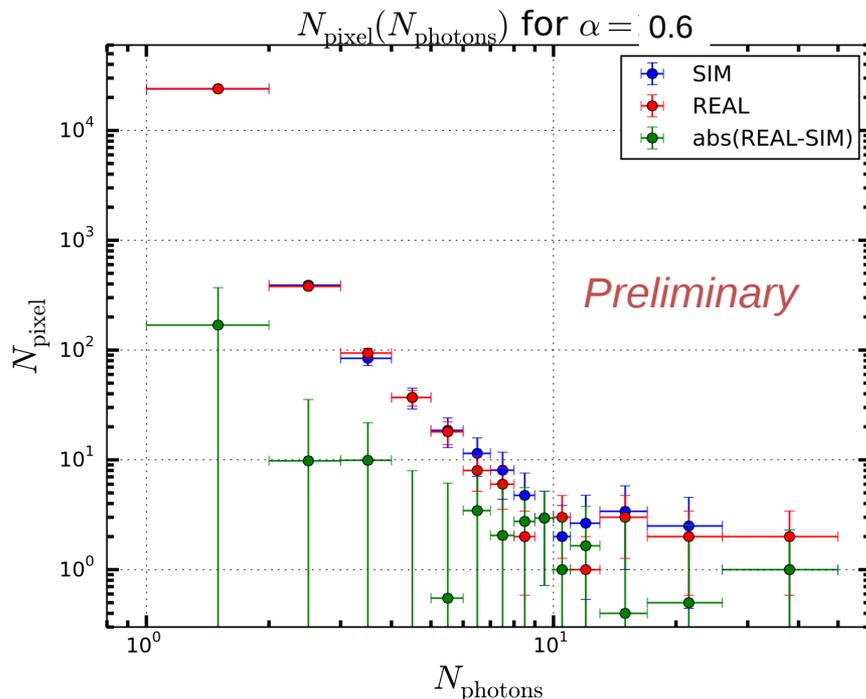
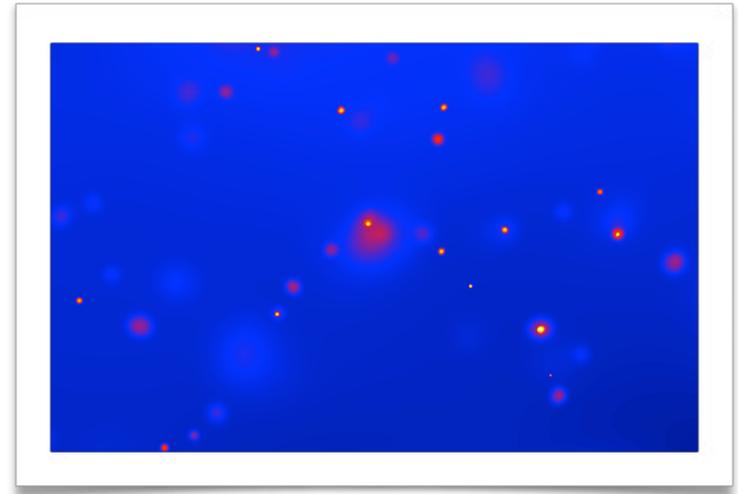
- 227 sources
- Main difference is at high  $|b|$
- Better PSF, less background  
=improved sensitivity
- 160(P7) vs 250(P8) sources

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



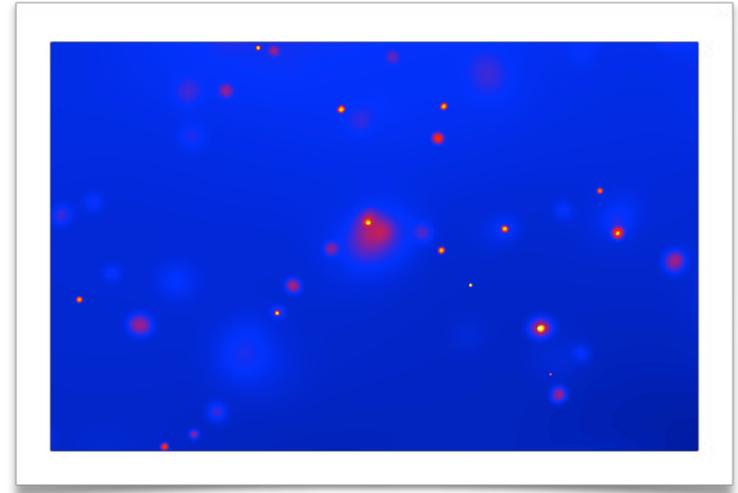
- Fluctuations of the background depend also on the properties of the unresolved source population

$\alpha$  = power law index below the break



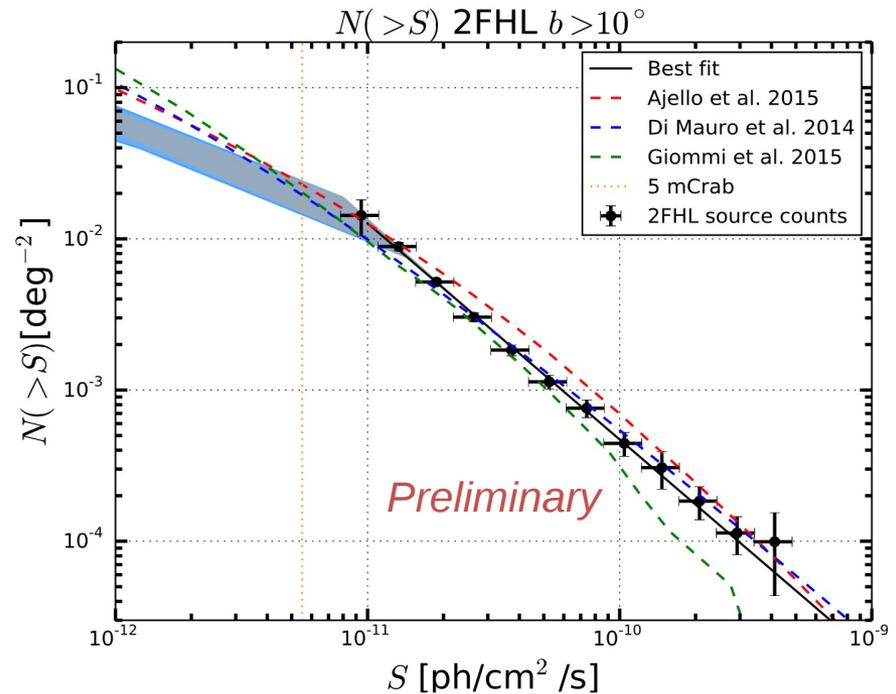


Fluctuations of the background depend also on the properties of the unresolved source population



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

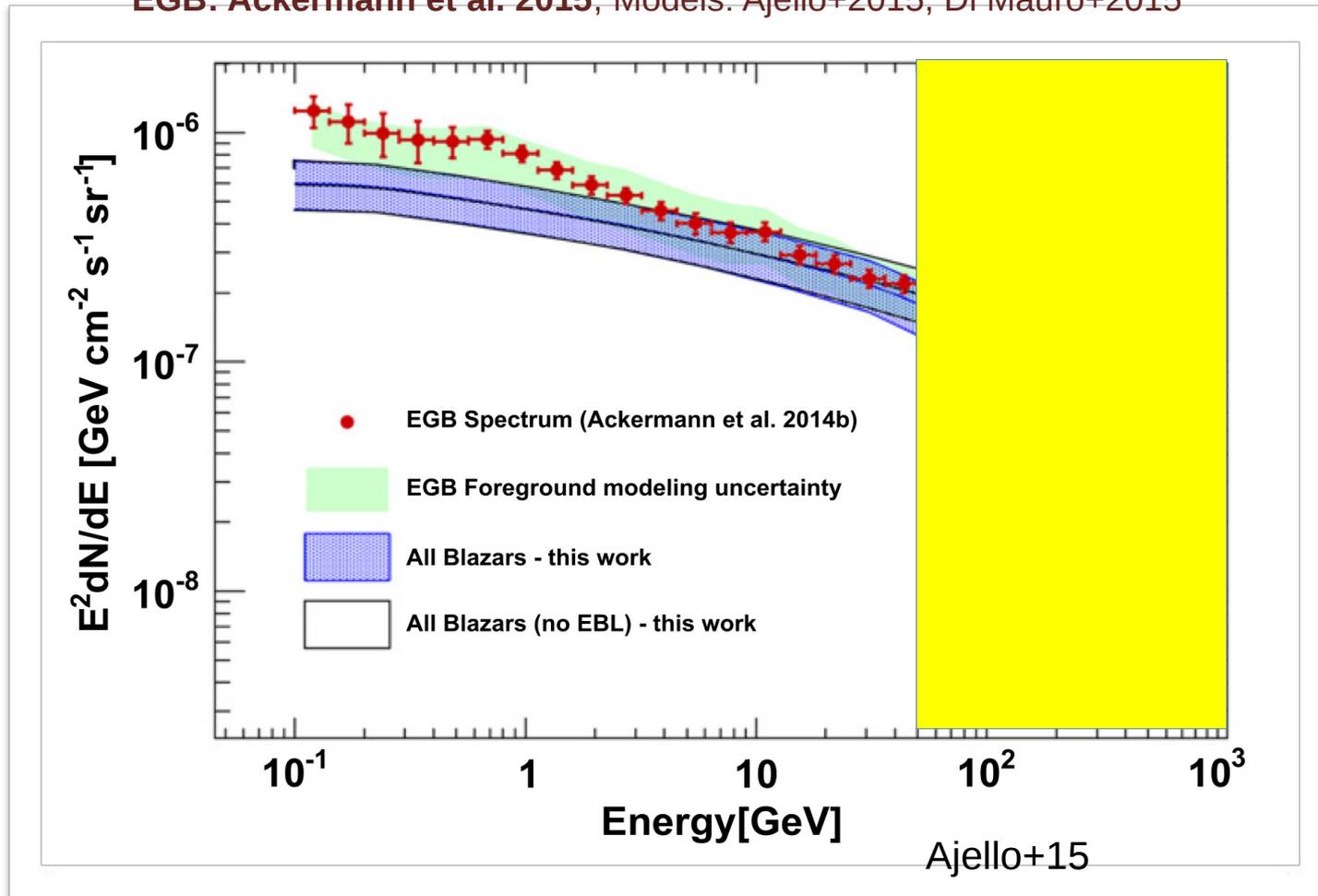
Nearly all the IGRB is produced by BL Lacs





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

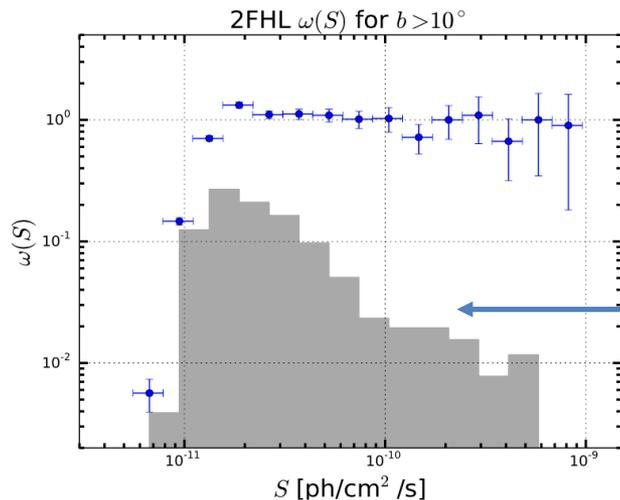
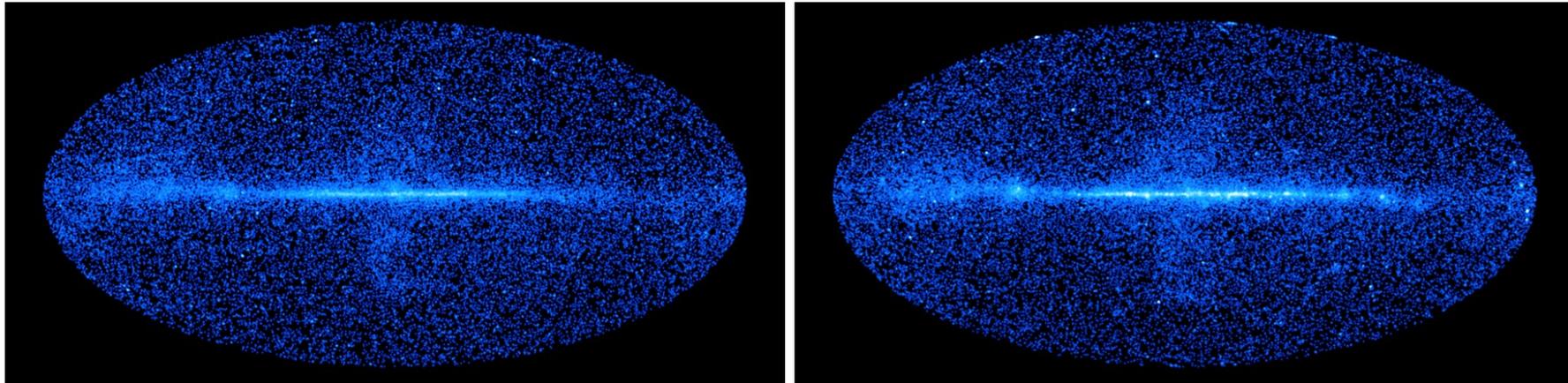
EGB: Ackermann et al. 2015, Models: Ajello+2015, Di Mauro+2015





□ 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*

