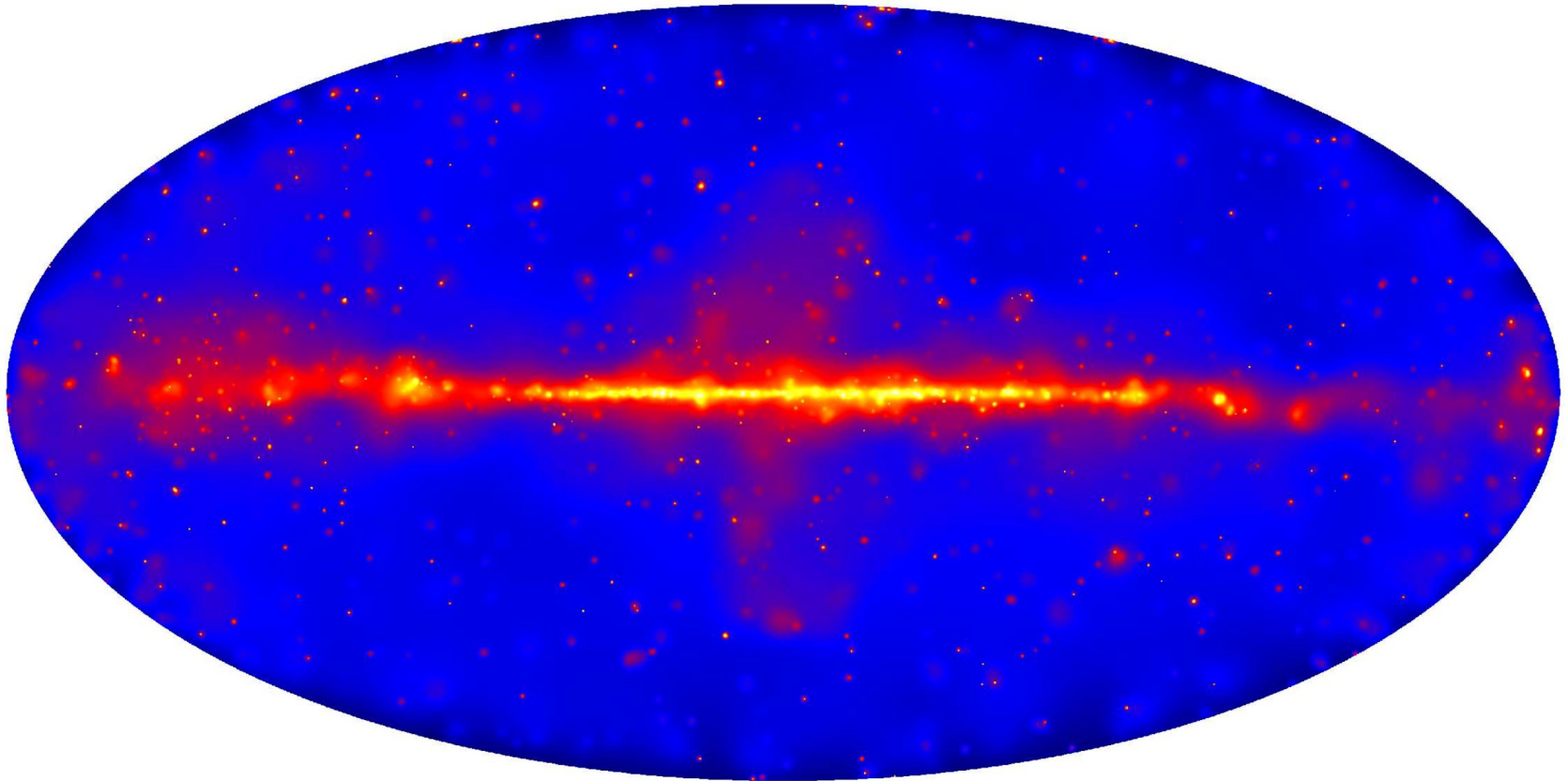
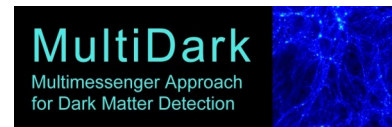
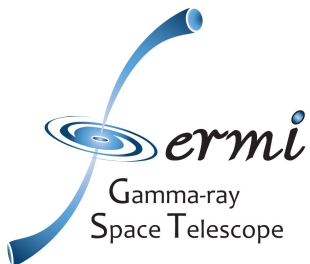


Latest Fermi-LAT results on EBL gamma-ray attenuation

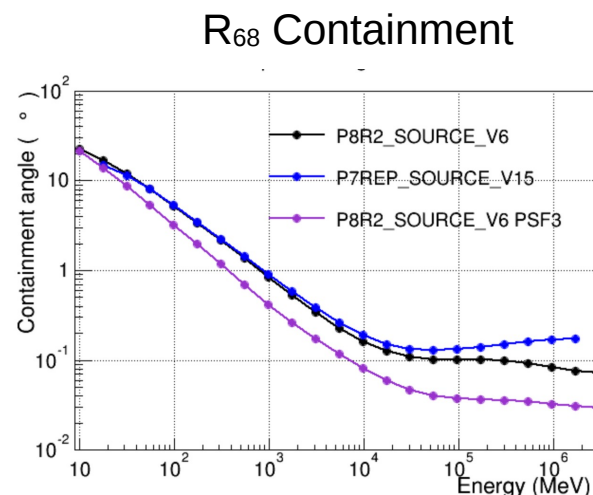
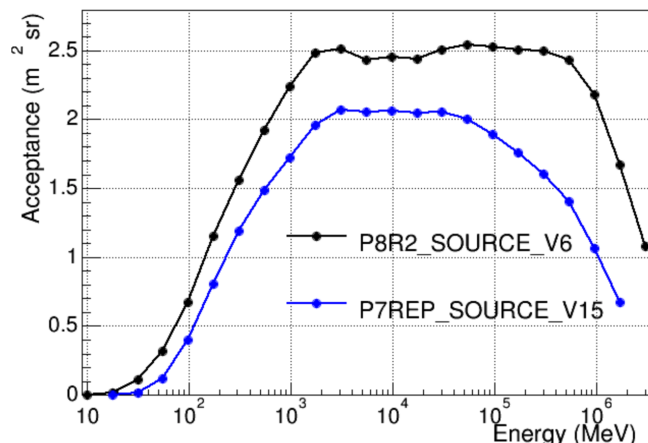
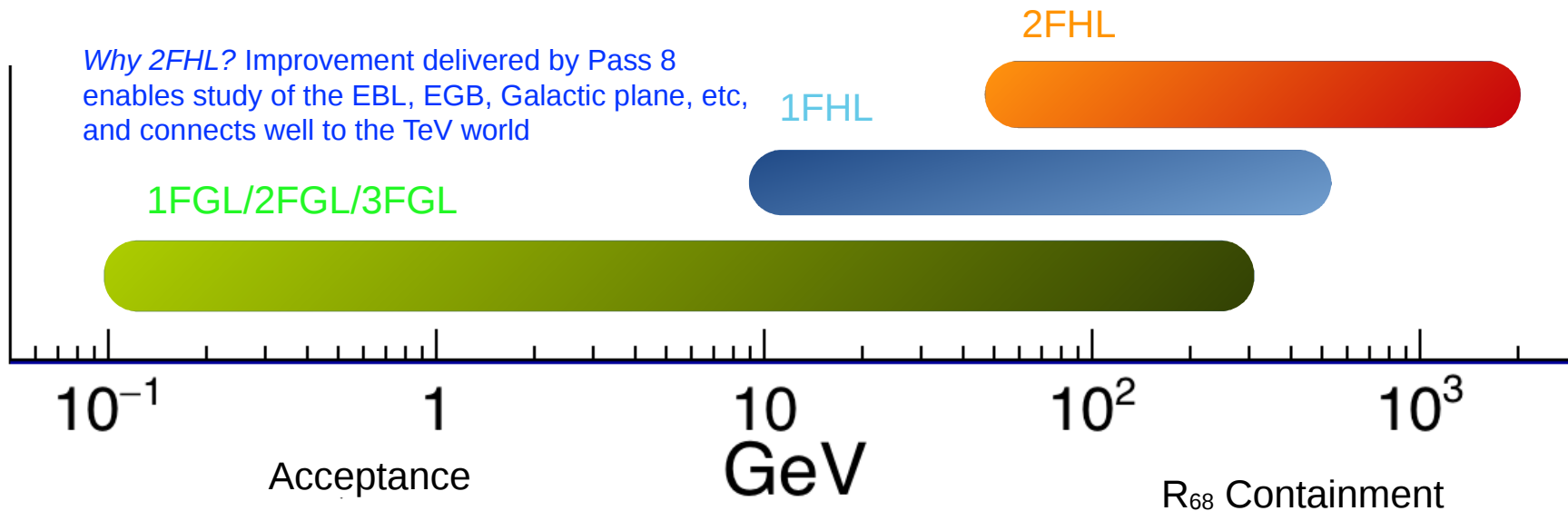


Alberto Domínguez (UC Madrid) & Marco Ajello (Clemson University)
On behalf of the Fermi-LAT collaboration



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



The 2FHL sky: count map

80 months of P8 data (50 GeV – 2 TeV)

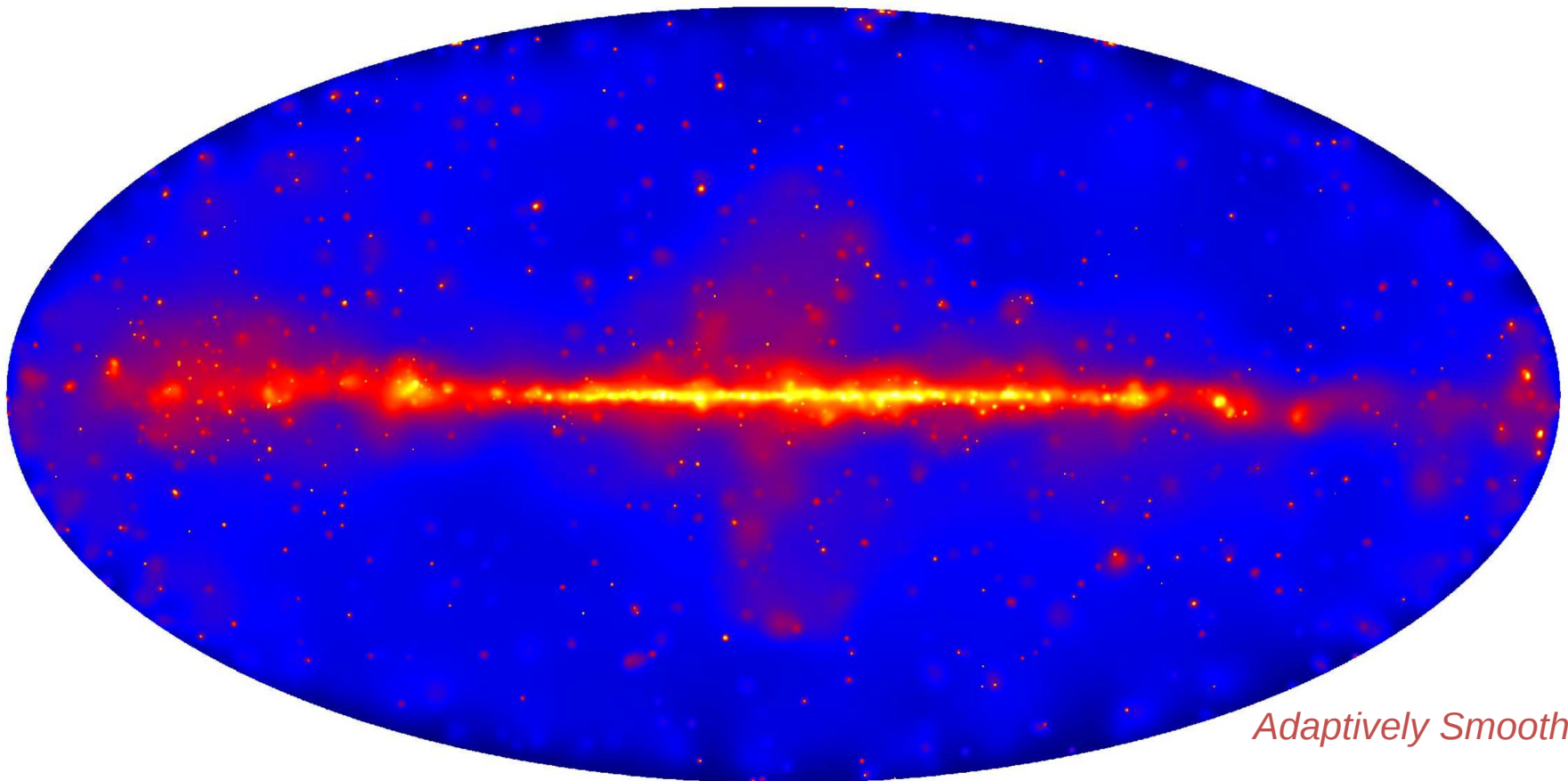
61,000 photons $E > 50$ GeV

22,100 photons $E > 100$ GeV

2,000 photons $E > 500$ GeV



~ 1.5 photon every deg^2



Adaptively Smoothed

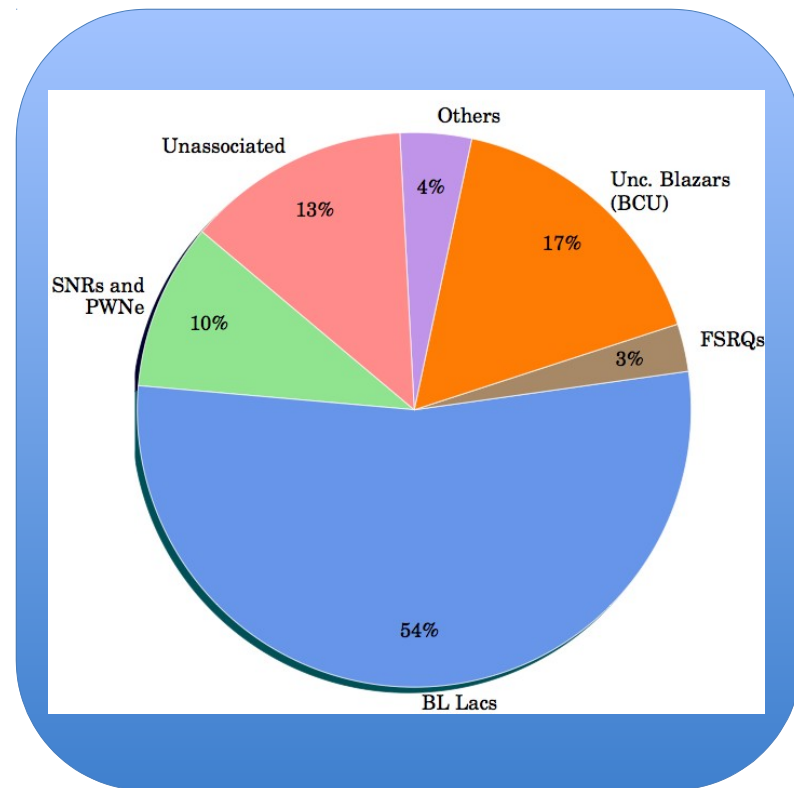
Analysis Details of the 2FHL Catalog

- **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)

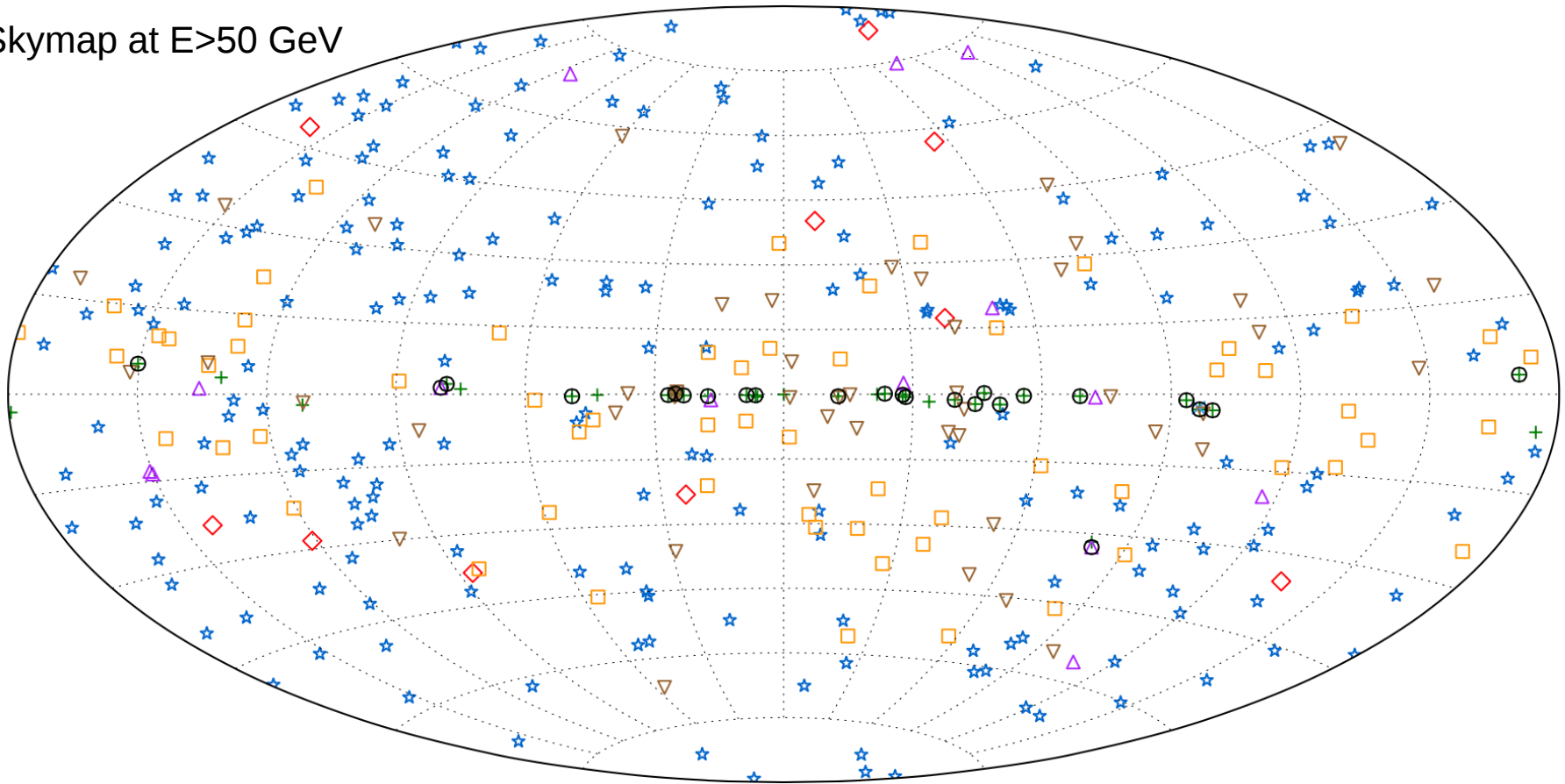


Median localization accuracy of 2.4 arcmin (68%)!

Bottom line: plenty of sources for TeV telescopes

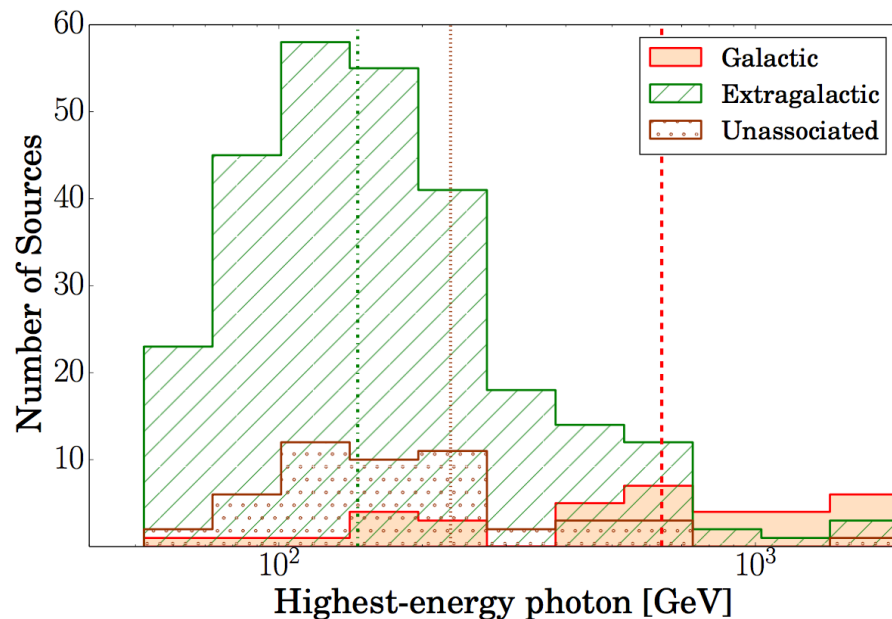
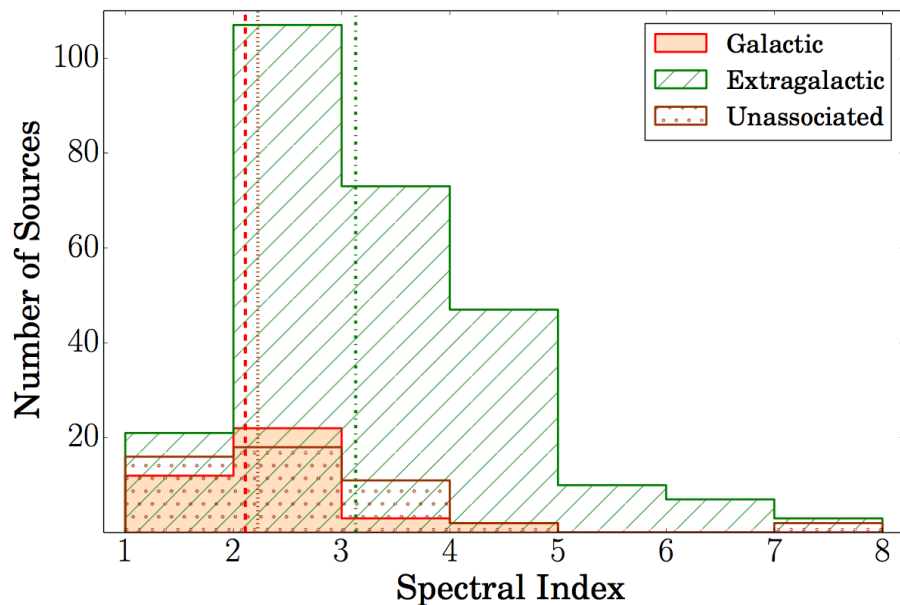
Associations

Skymap at $E > 50$ GeV

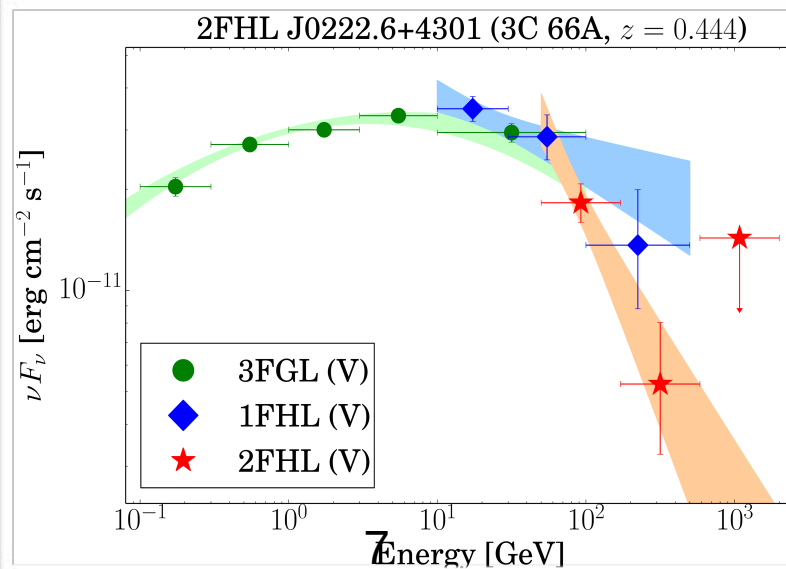
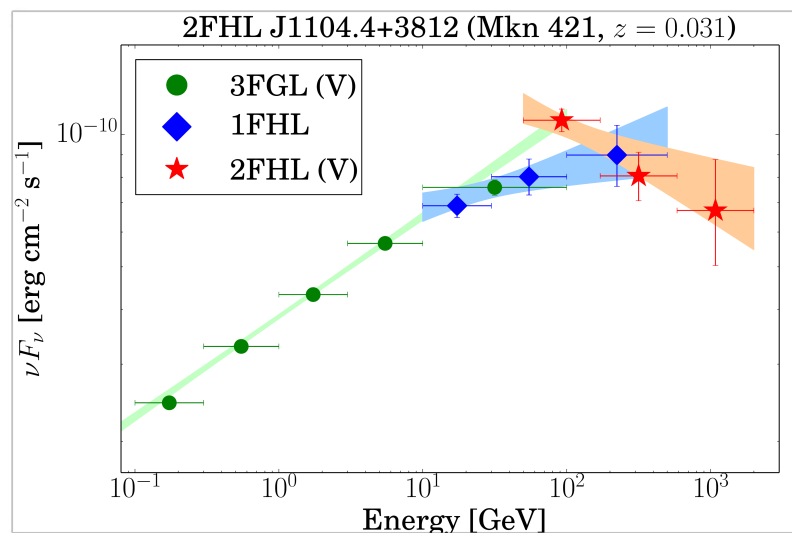
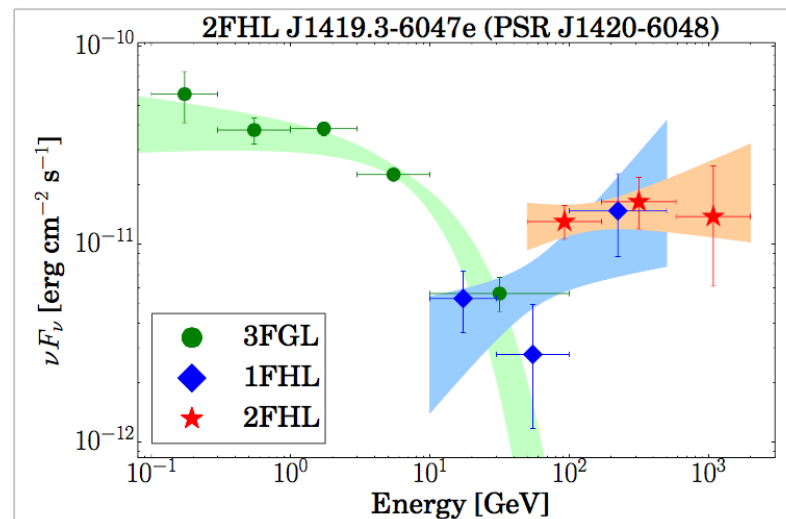
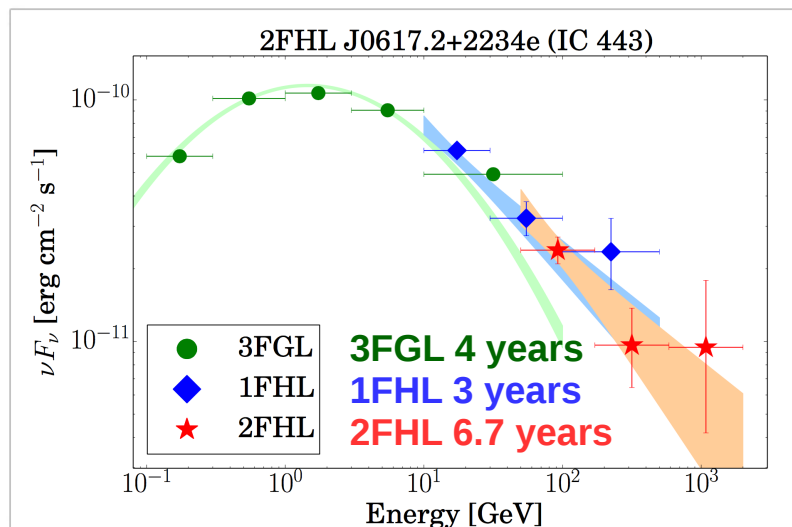


+	SNRs and PWNe	★	BL Lacs	□	Unc. Blazars	▽	Unassociated
×	Pulsars	◇	FSRQs	△	Others	○	Extended

- 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

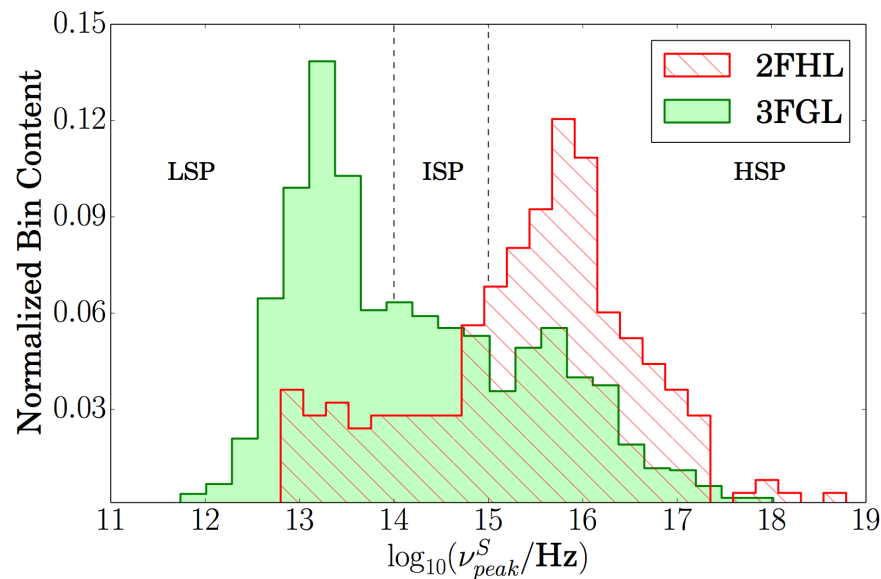


Spectral Energy Distributions: publicly available at the Fermi Science Support Center

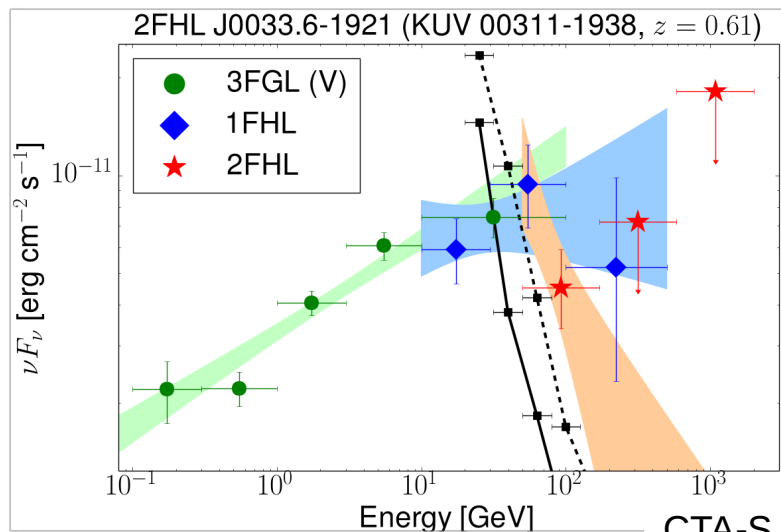


Extragalactic Sources

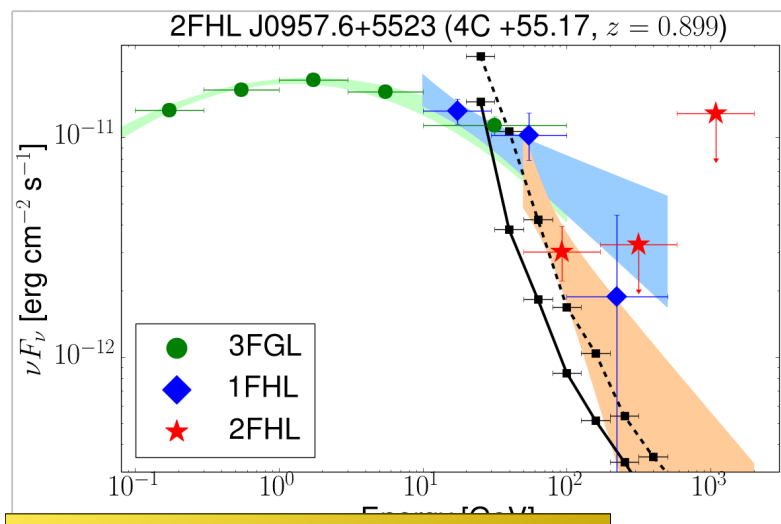
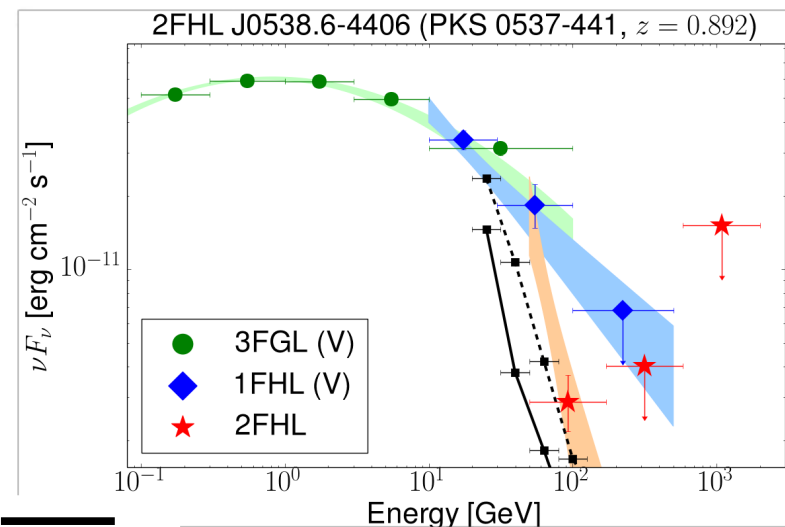
- **Blazar-like objects constitute >80% of the 2FHL Catalog**
 - Detected up to $z \sim 2$
 - Most of them are BL Lacs, only 10 FSRQs
 - Different population than 3FGL



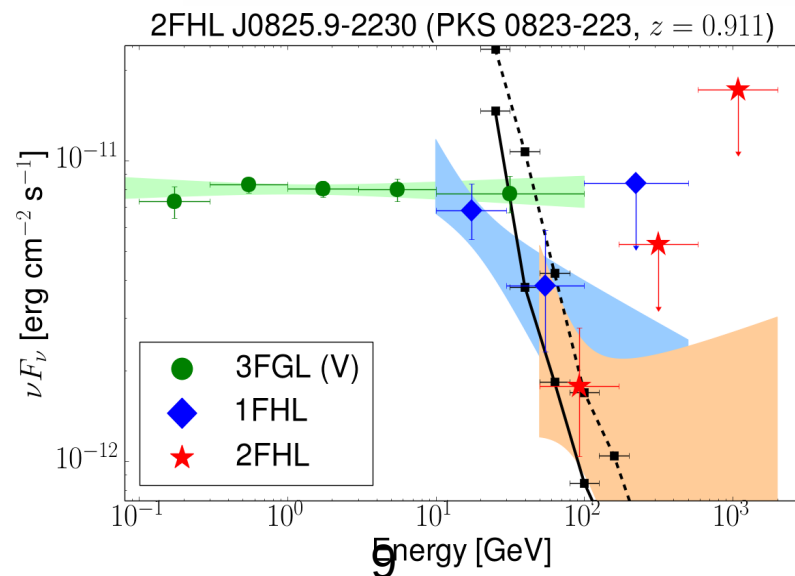
Blazars at intermediate redshift, $0.6 < z < 1$ (16 in 2FHL)



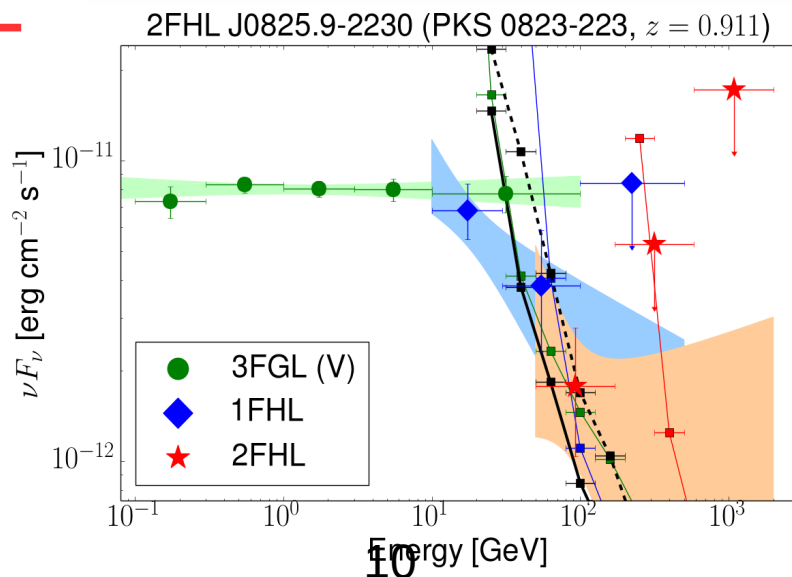
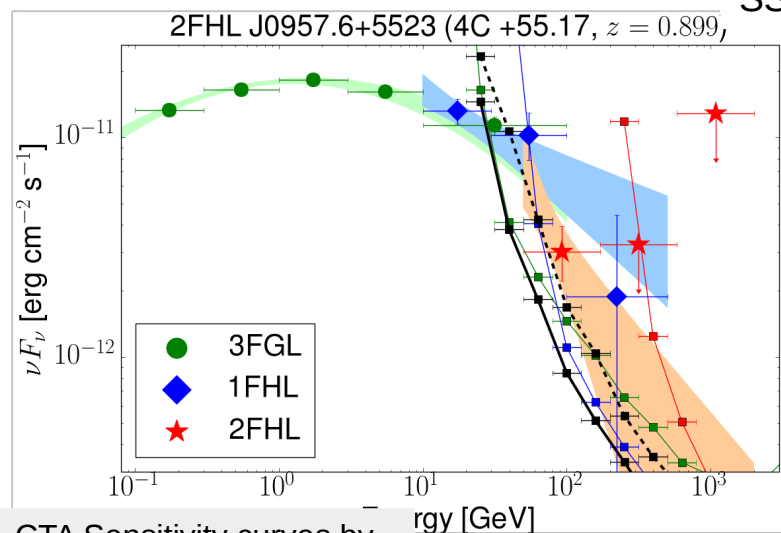
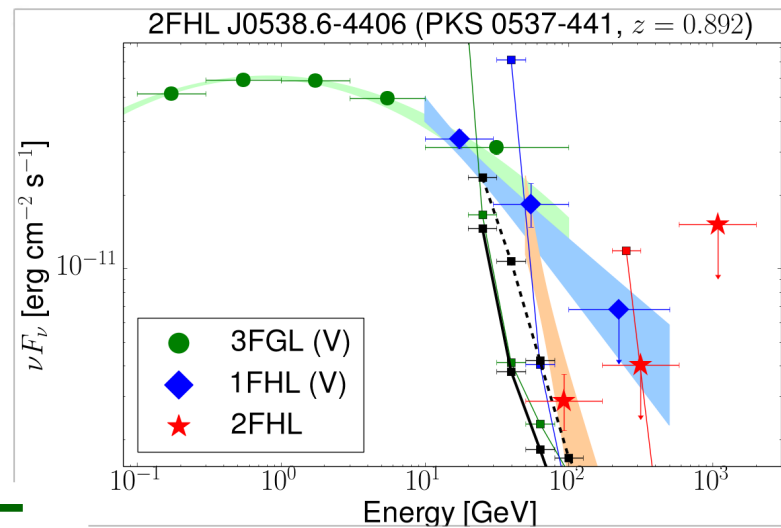
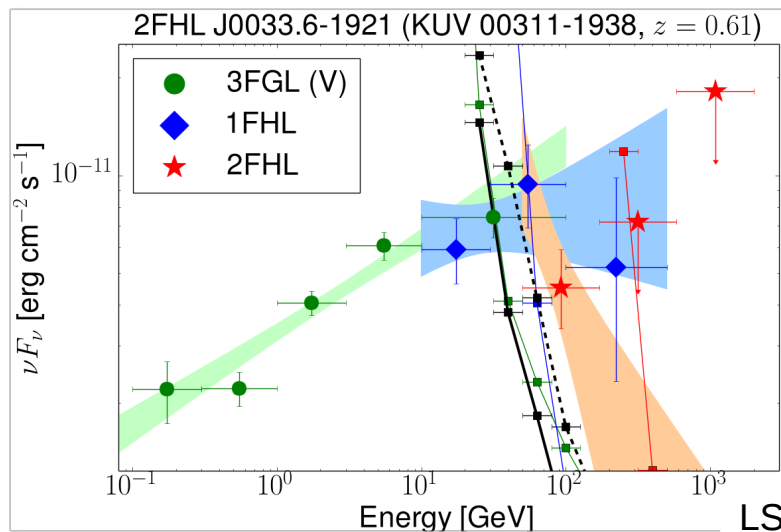
CTA-S 5 σ in 50 h
 CTA-N 5 σ in 50 h



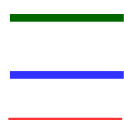
Not considering visibility from site!



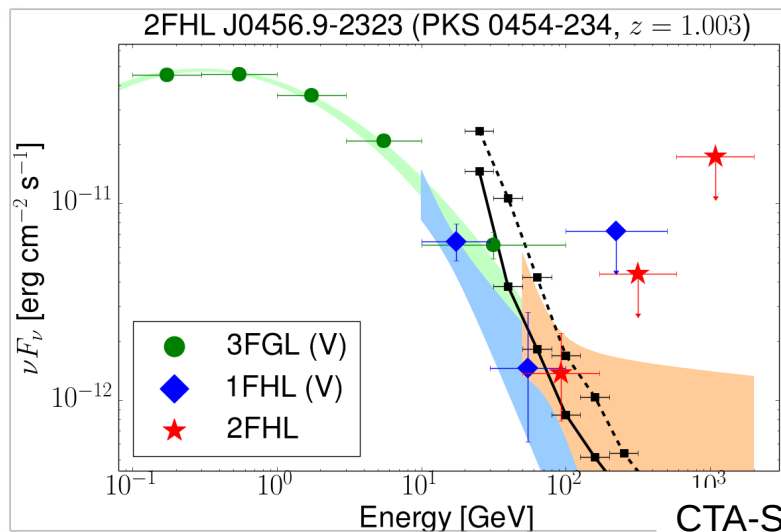
Blazars at intermediate redshift, $0.6 < z < 1$ (16 in 2FHL)



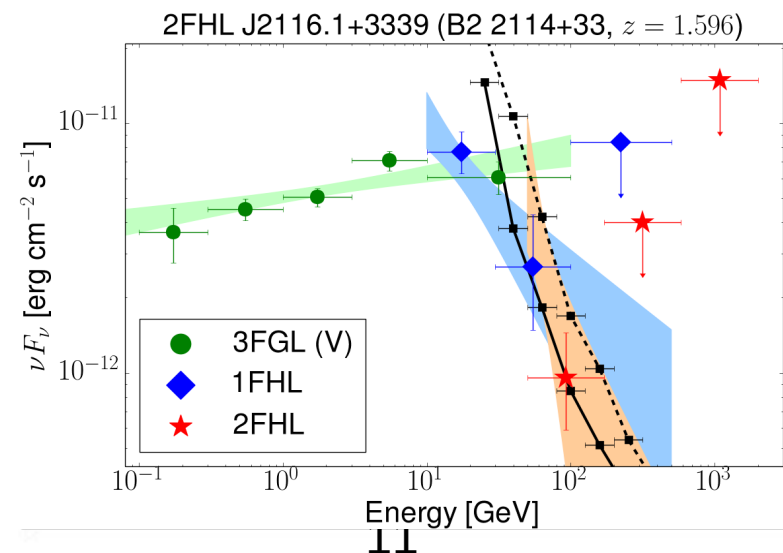
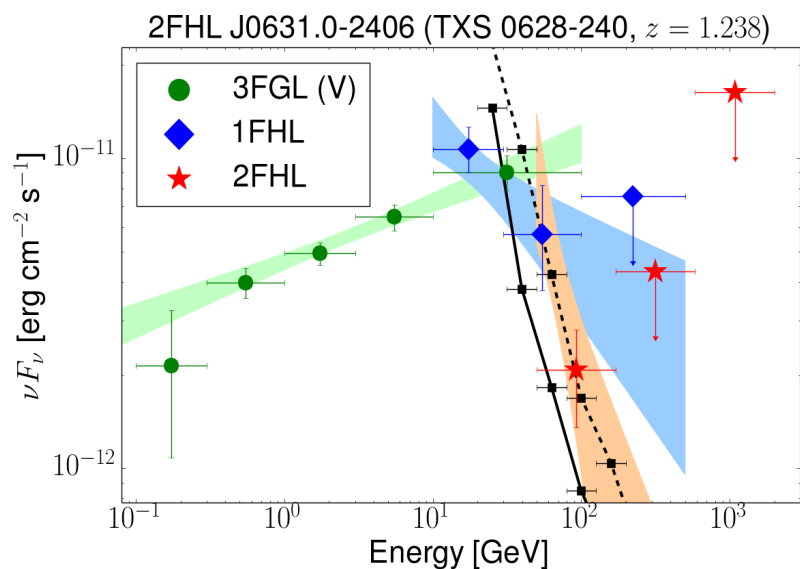
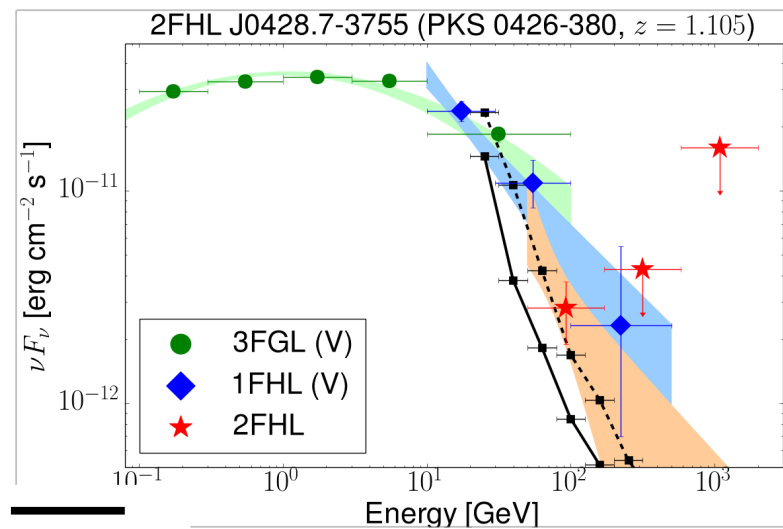
LSTs
MSTs
SSTs



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



CTA-S 5 σ in 50 h
CTA-N 5 σ 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)

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

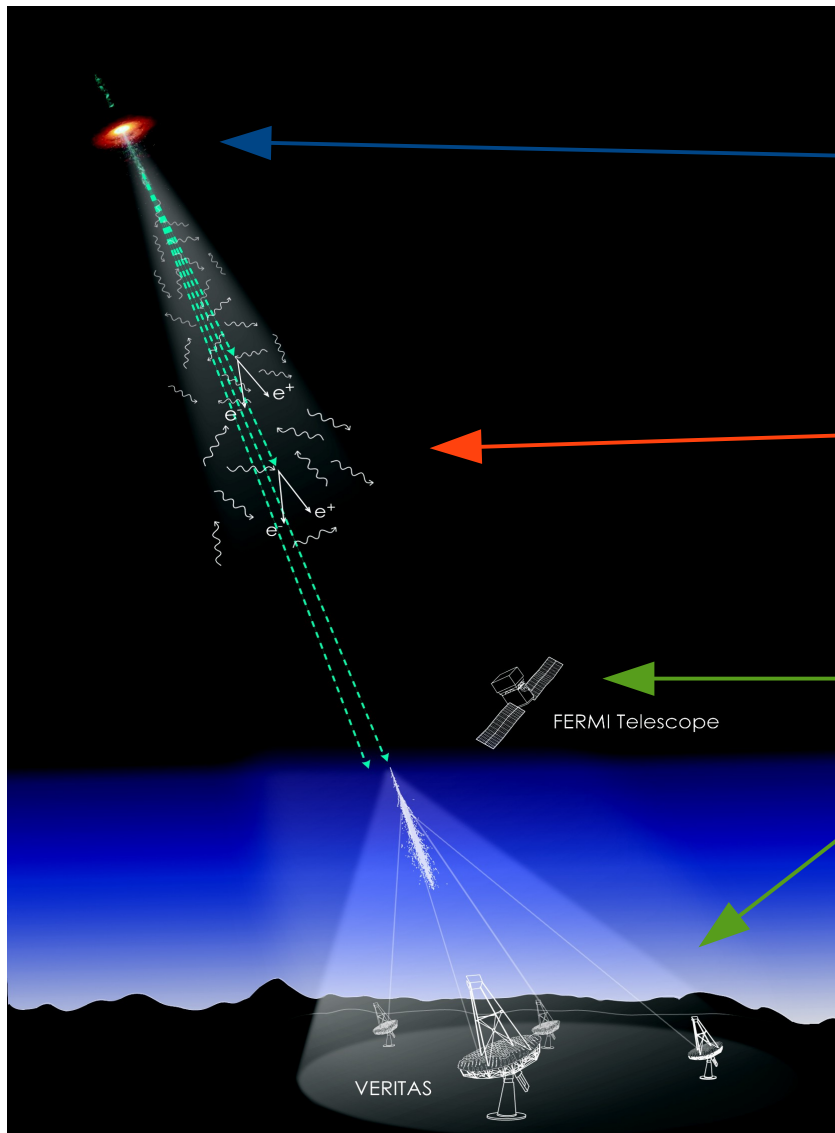
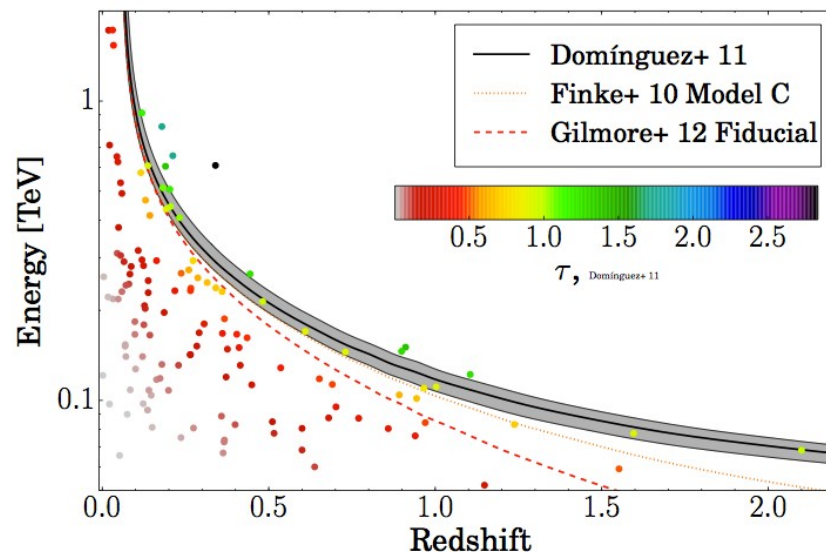
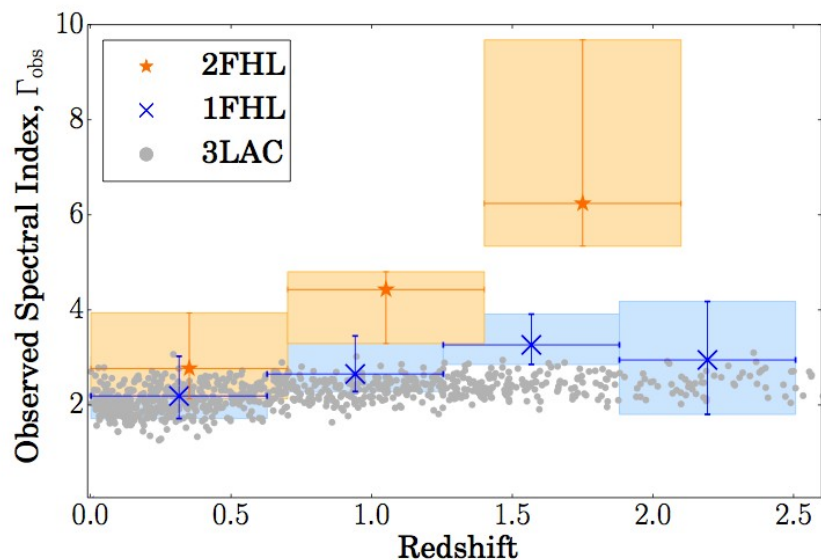


Illustration: Nina McCurdy & Joel Primack

Extragalactic Background Light

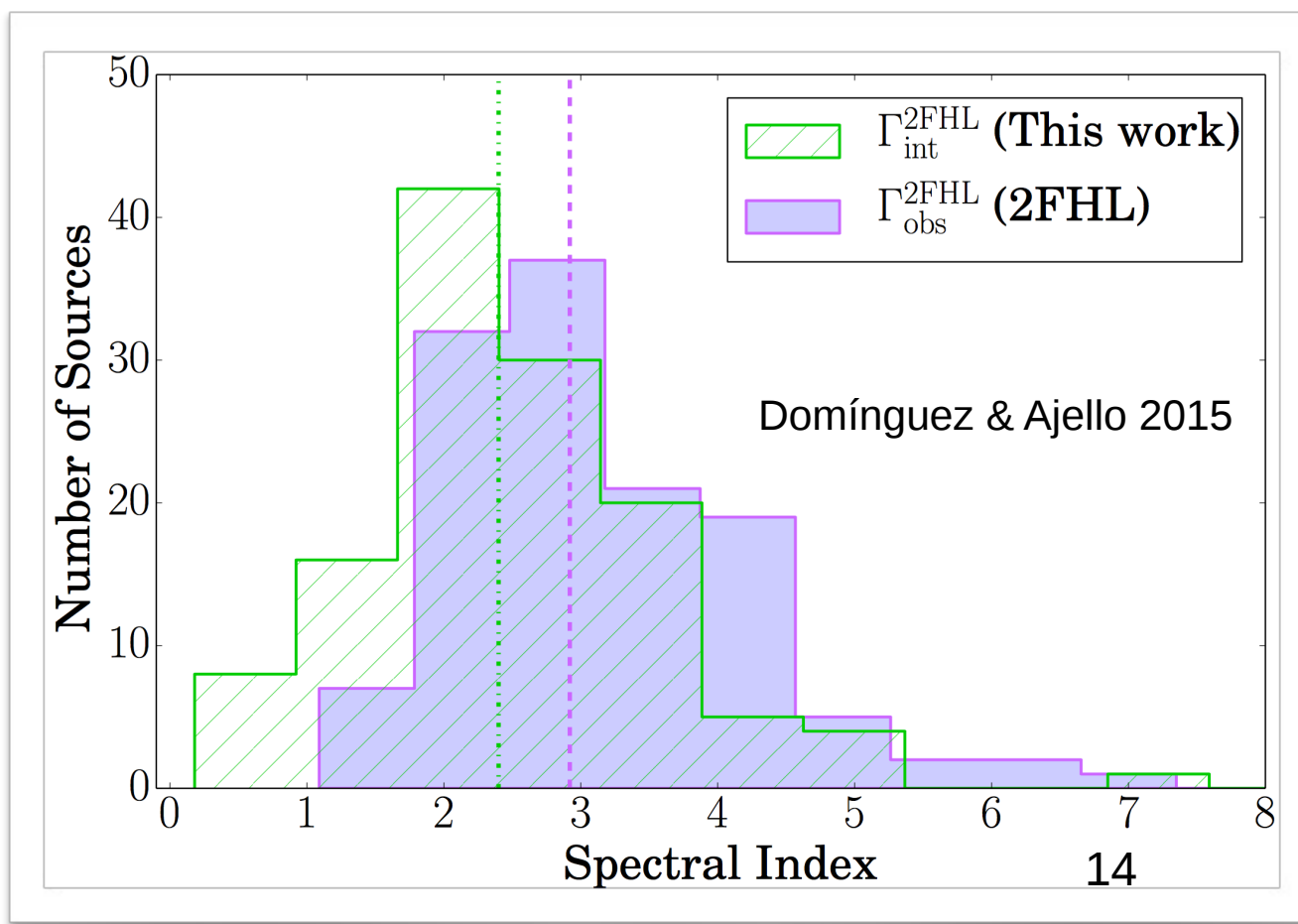


See also Domínguez+ 13 on the CGRH

- 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

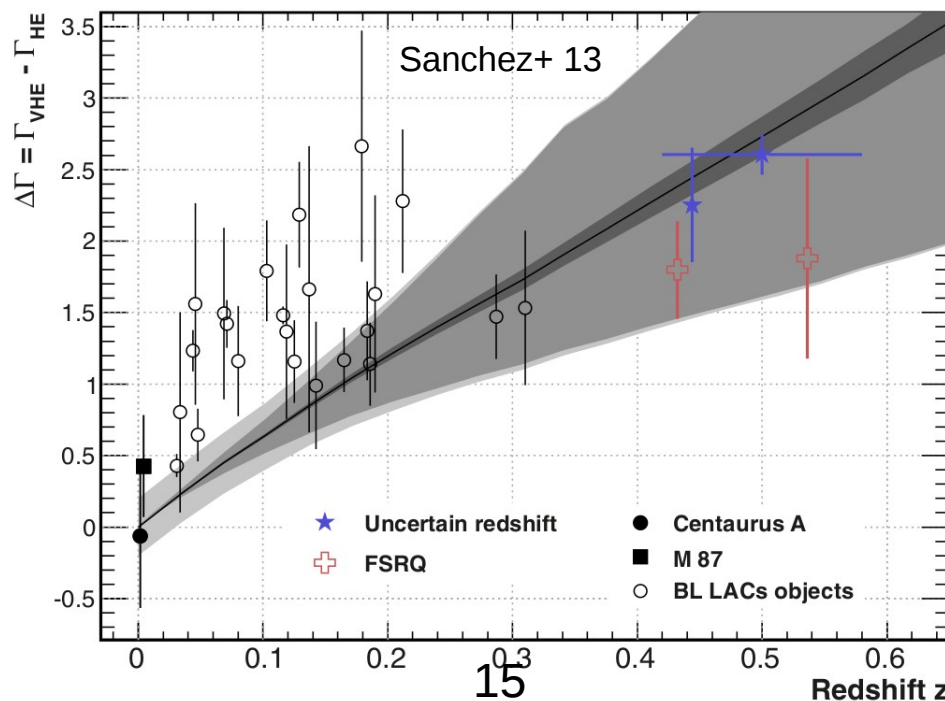
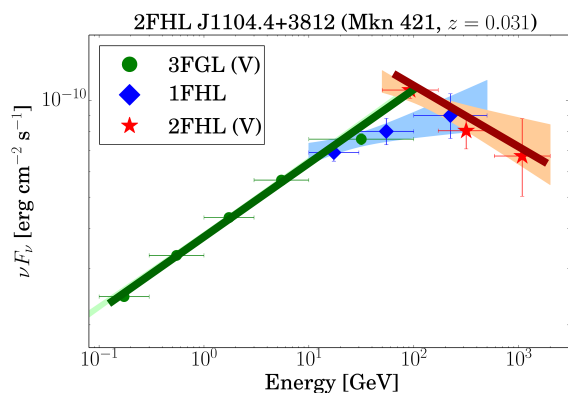
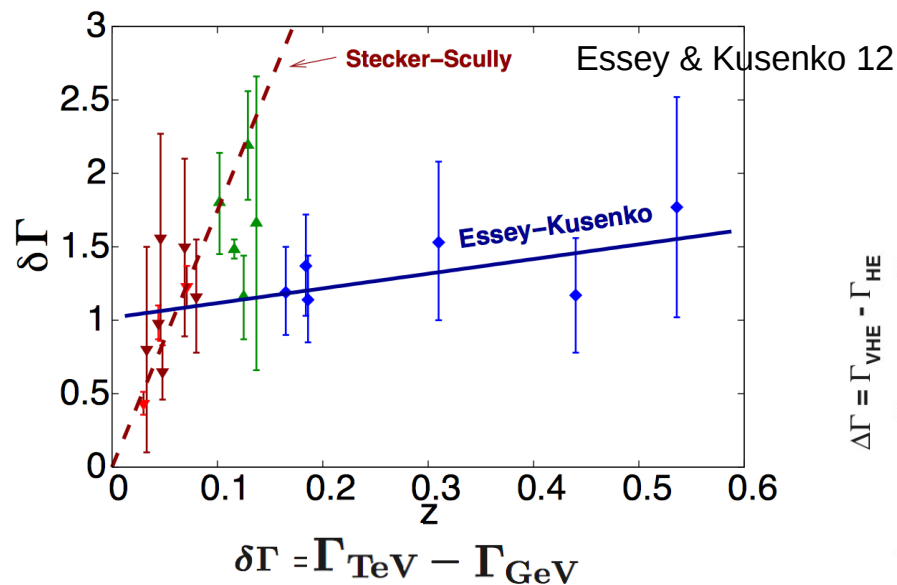
Extragalactic Background Light: 2

- **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



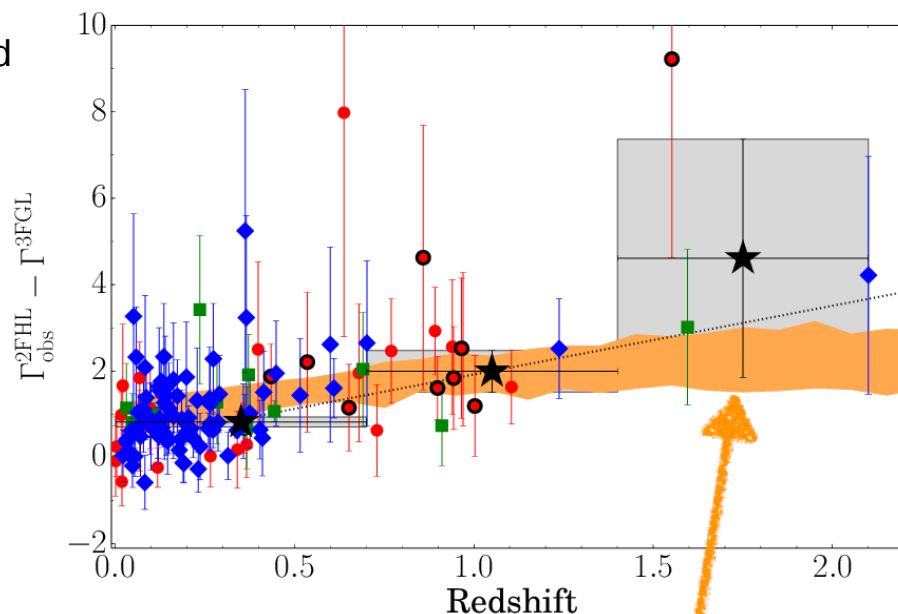
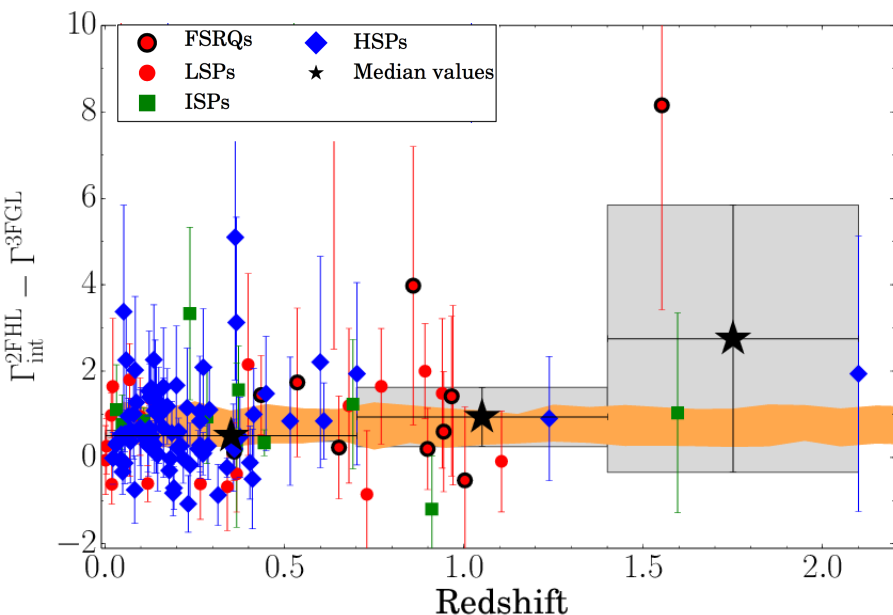
Extragalactic Background Light: 3

- 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.



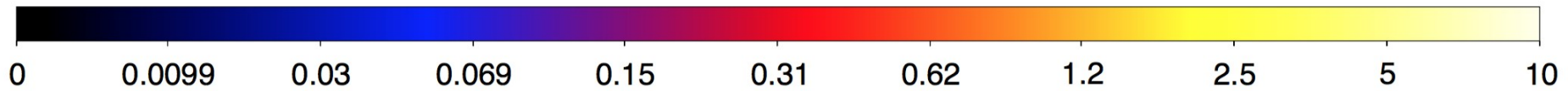
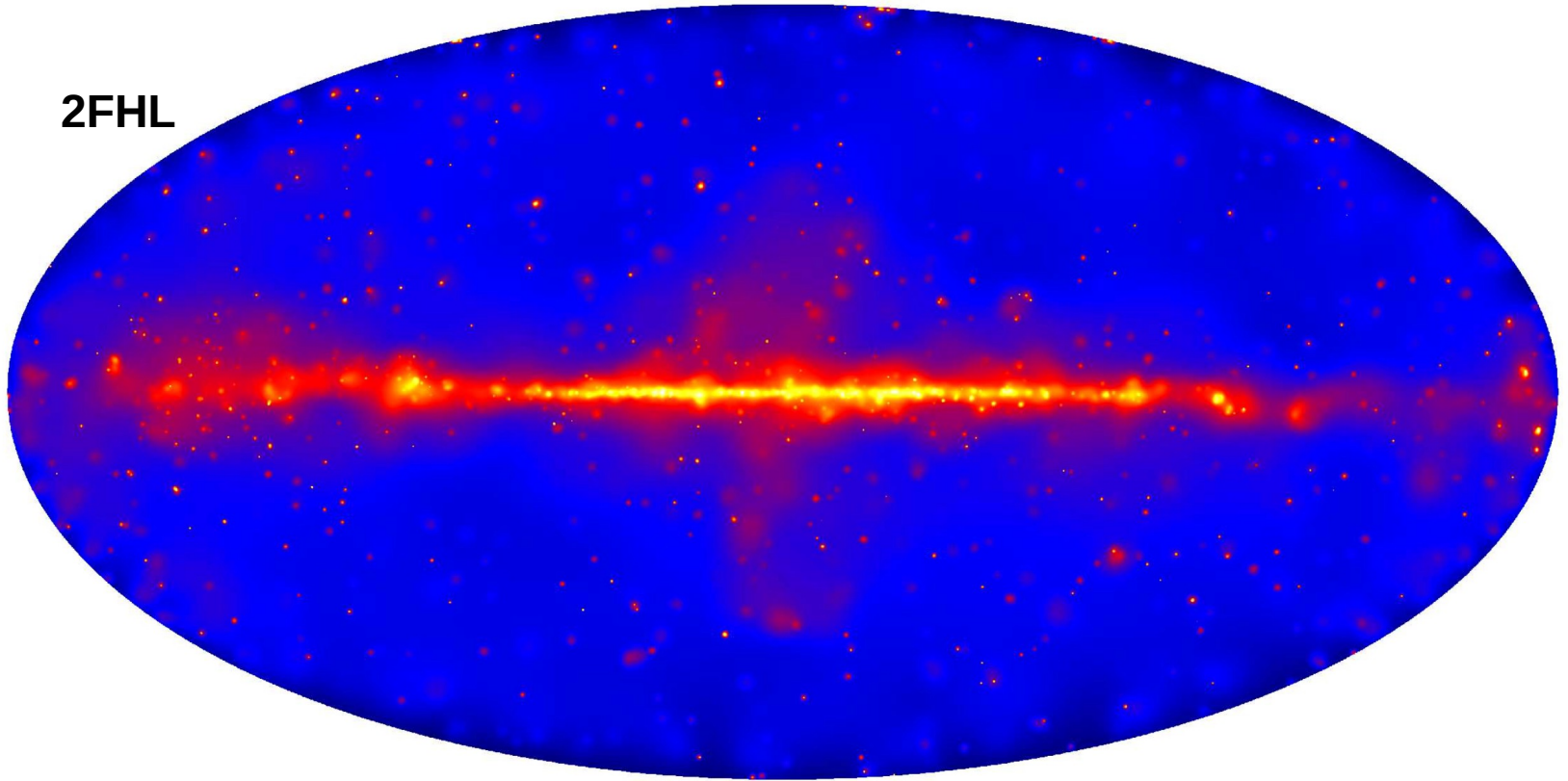
Simulations of SSC spectra absorbed by the EBL

Simulations of SSC spectra

Domínguez & Ajello 15

The future is bright: 3FHL

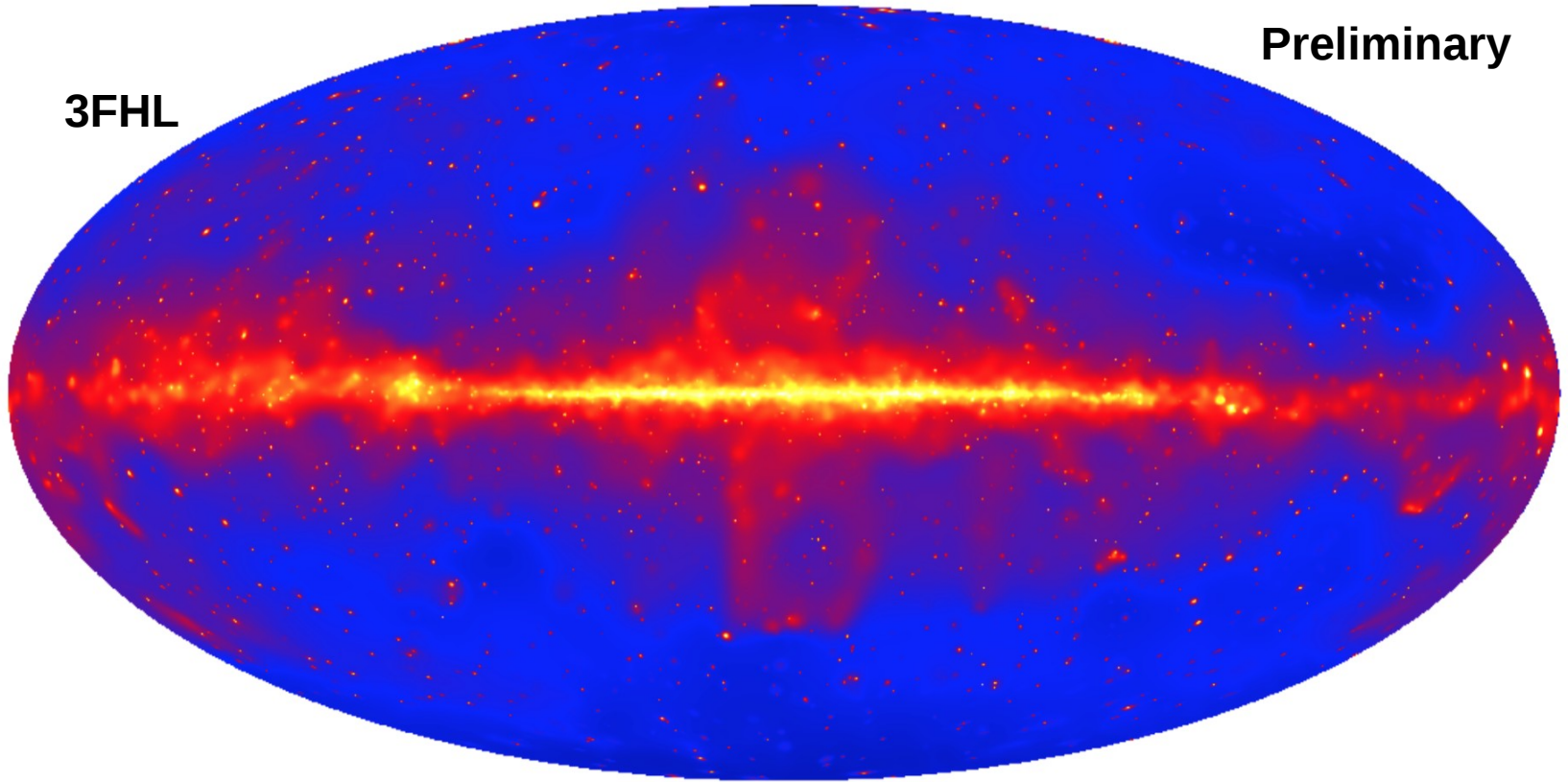
2FHL



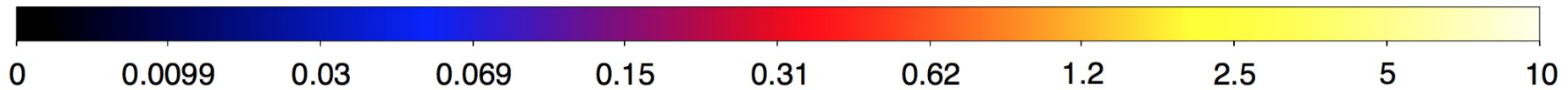
The future is bright: 3FHL

Preliminary

3FHL



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

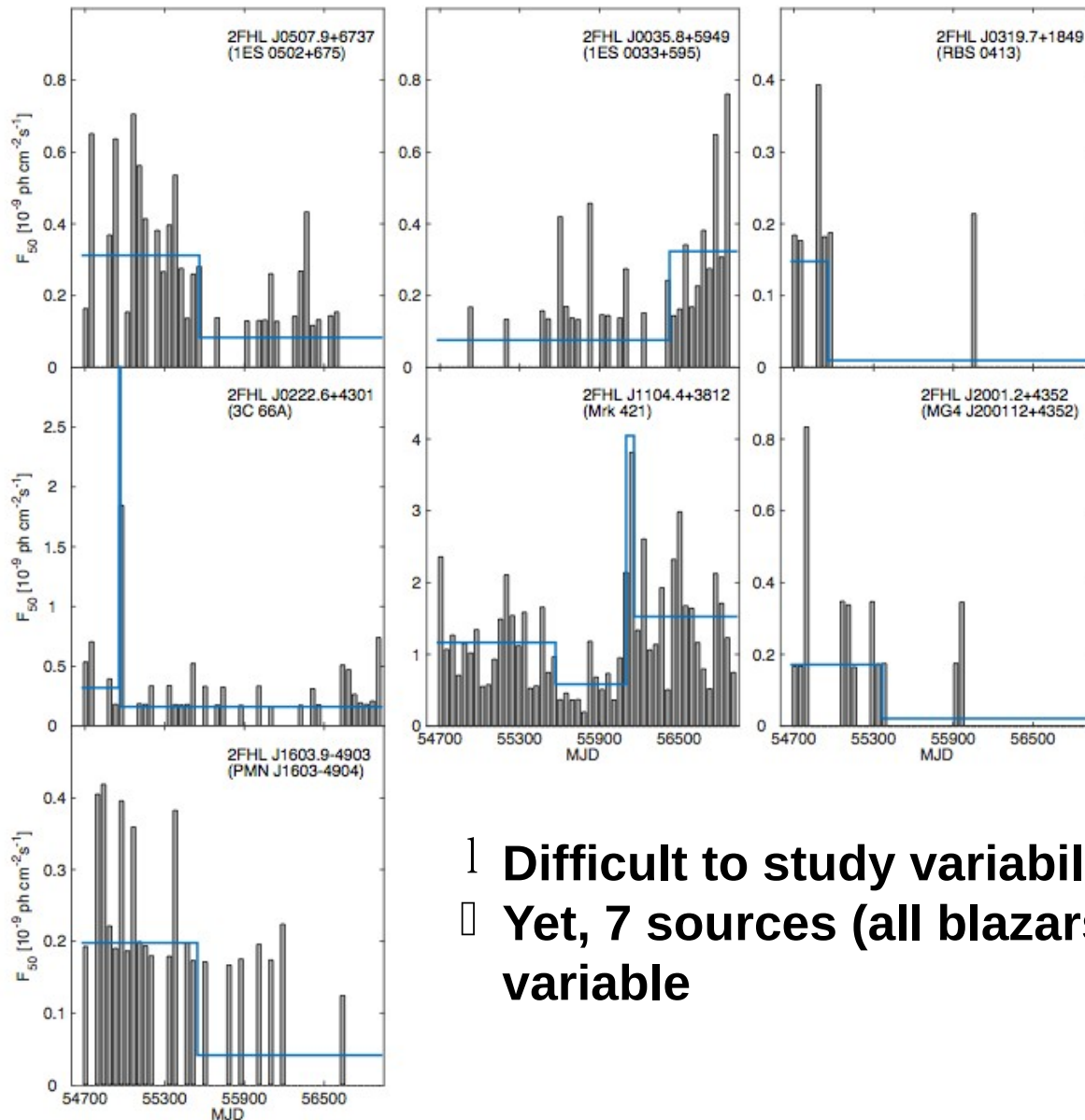




- 2FHL opens a new window on the high-energy sky
 - 360 sources detected between 50 GeV and 2 TeV
 - 75% blazars, 14% Galactic and 11 % unassociated
 - only 25% detected in TeVCat
- **Extragalactic science:**
 - >80% of 2FHL sources are blazars (BL Lacs), detected up to $z \sim 2$
 - Clear signs of EBL 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



- 1 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)

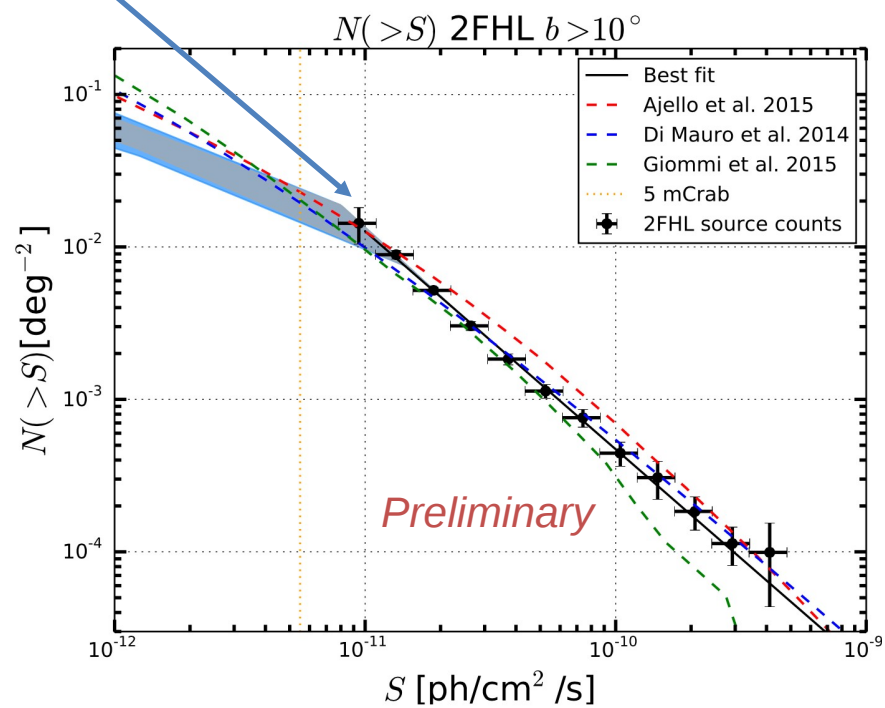
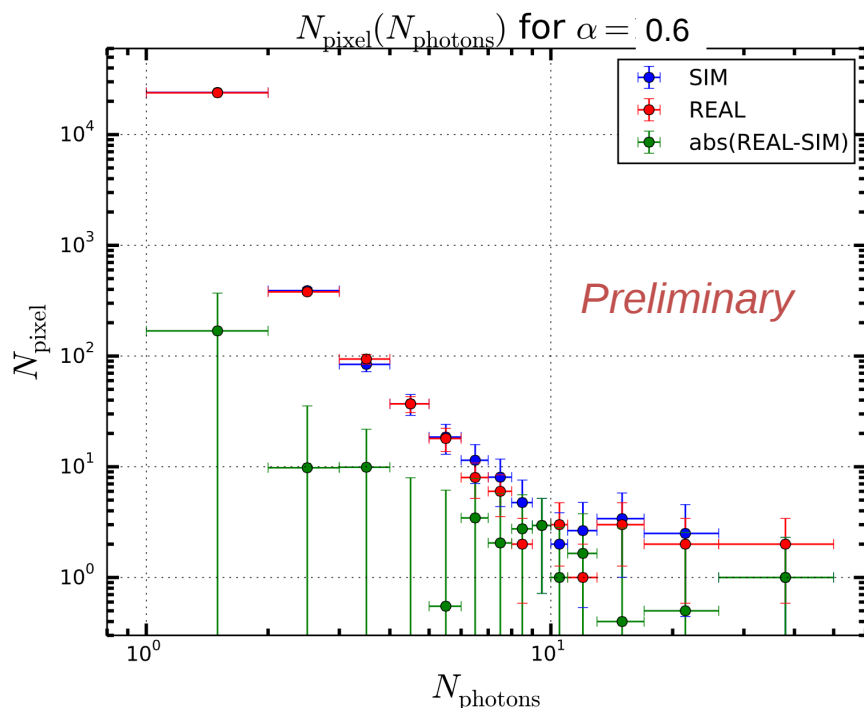
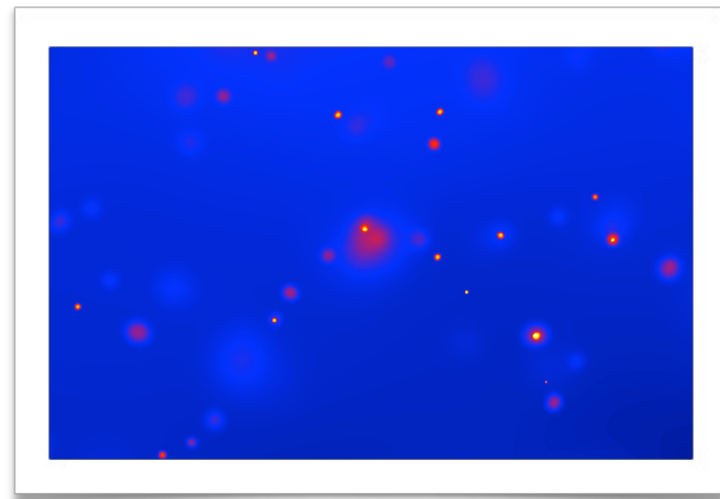
Detections in P7

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

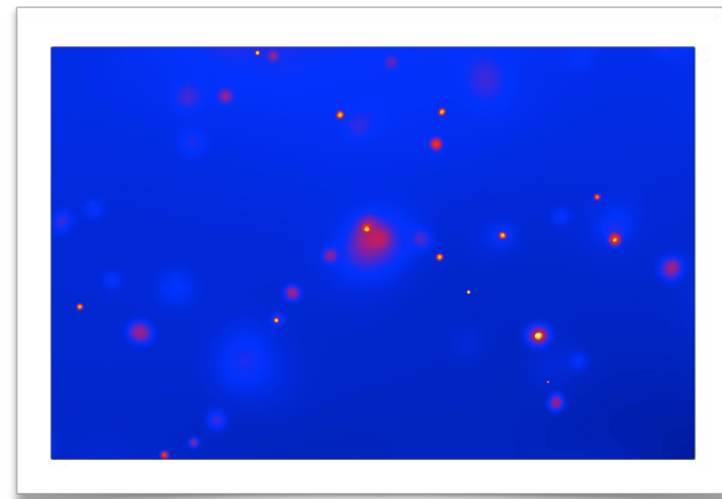
Bottom line: ~130 sources not in 1FHL and ~250 not in TeVCat, 60 not in 3FGL

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

α = power law index below the break

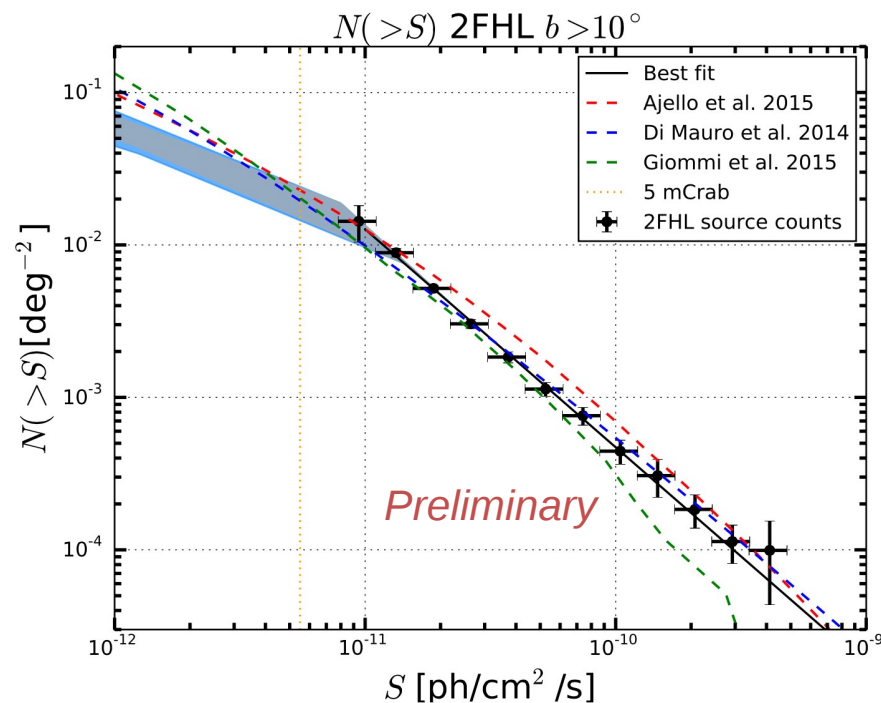


Fluctuations of the background depend also on the properties of the unresolved source population



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

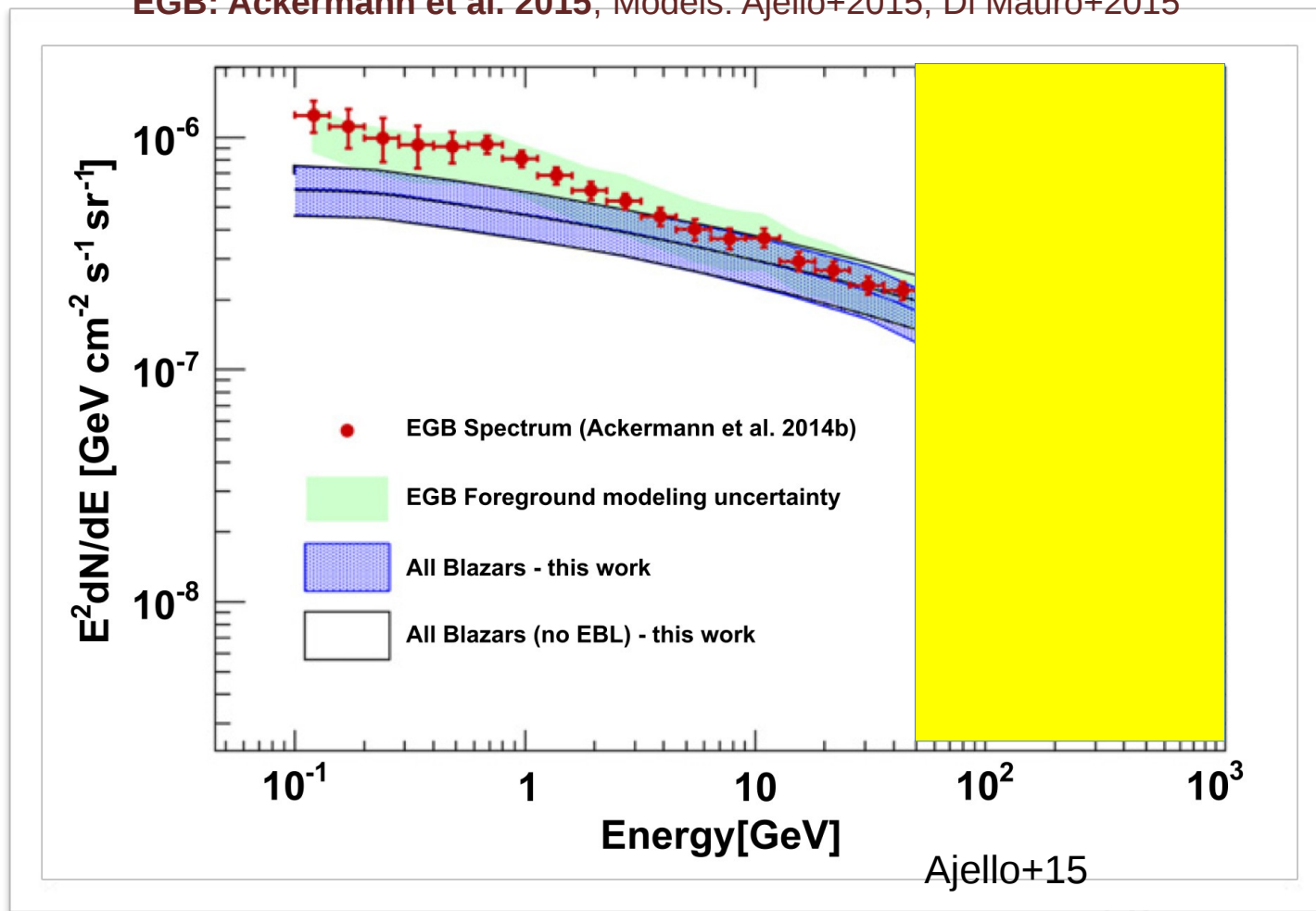
Nearly all the IGRB is produced by BL Lacs





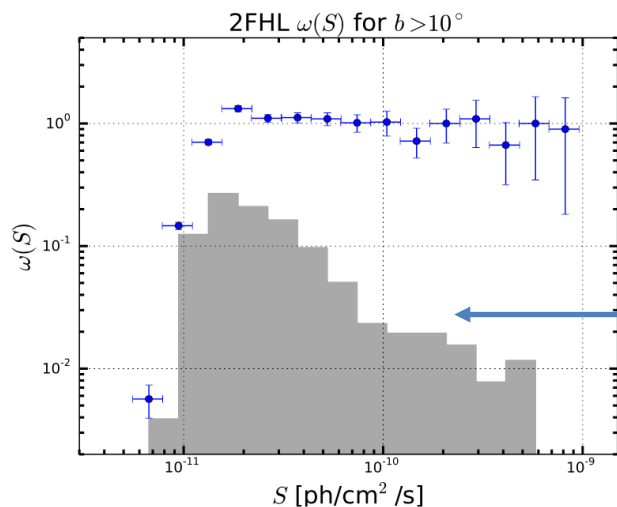
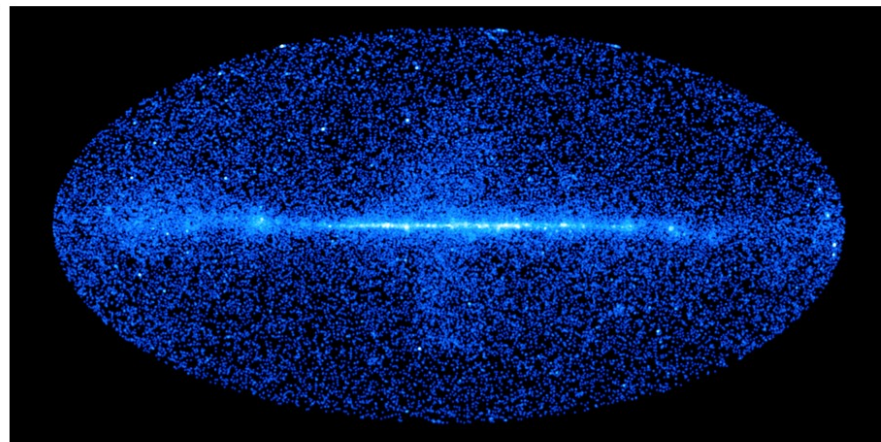
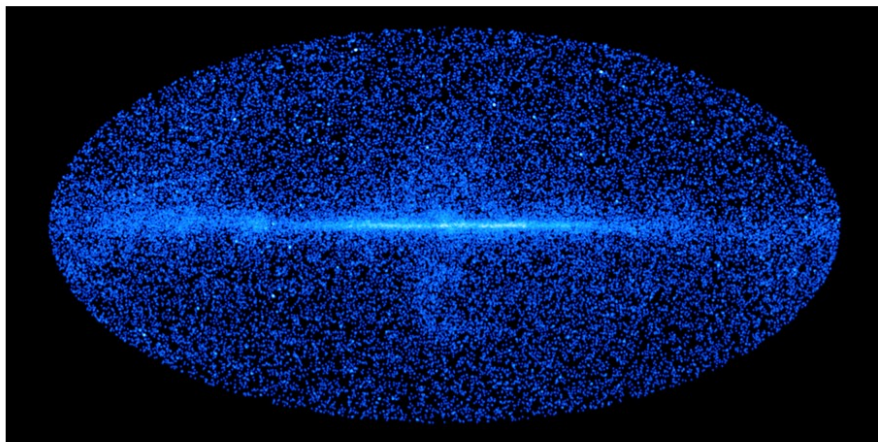
- Models predict that the >50 GeV EGB is produced by blazars

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



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

1 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

