Title: The Fermi view of the (hard) blazar population

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Abstract:

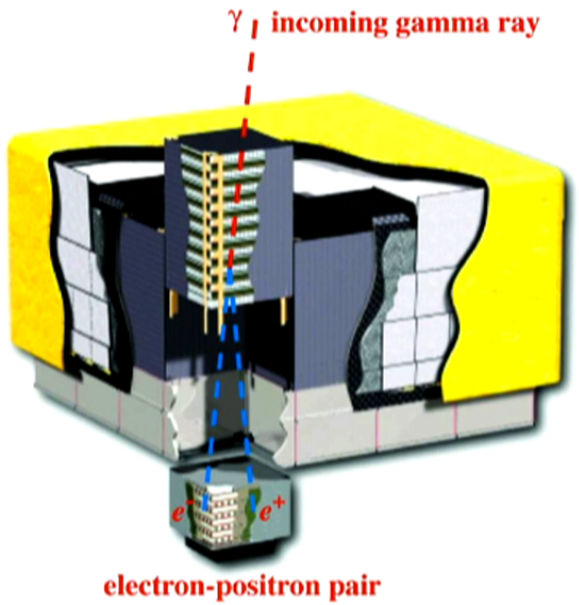
The *Fermi* view of the (hard) blazar population

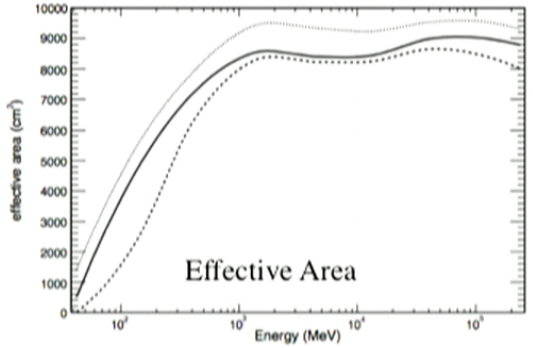
Clemson University

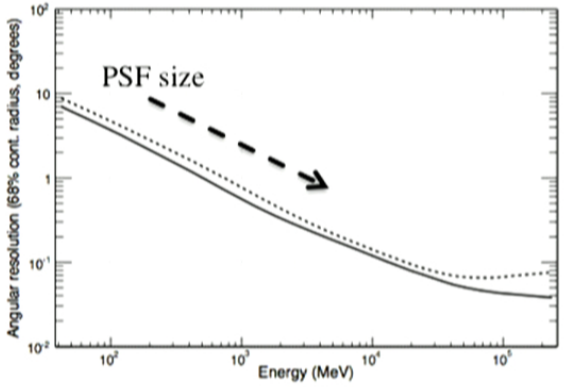
on behalf of the Fermi-LAT collaboration

Bigger, Sharper, Faster (*cit. M.Kerr*)

- *Fermi* is a pair conversion telescope with large effective area and good PSF







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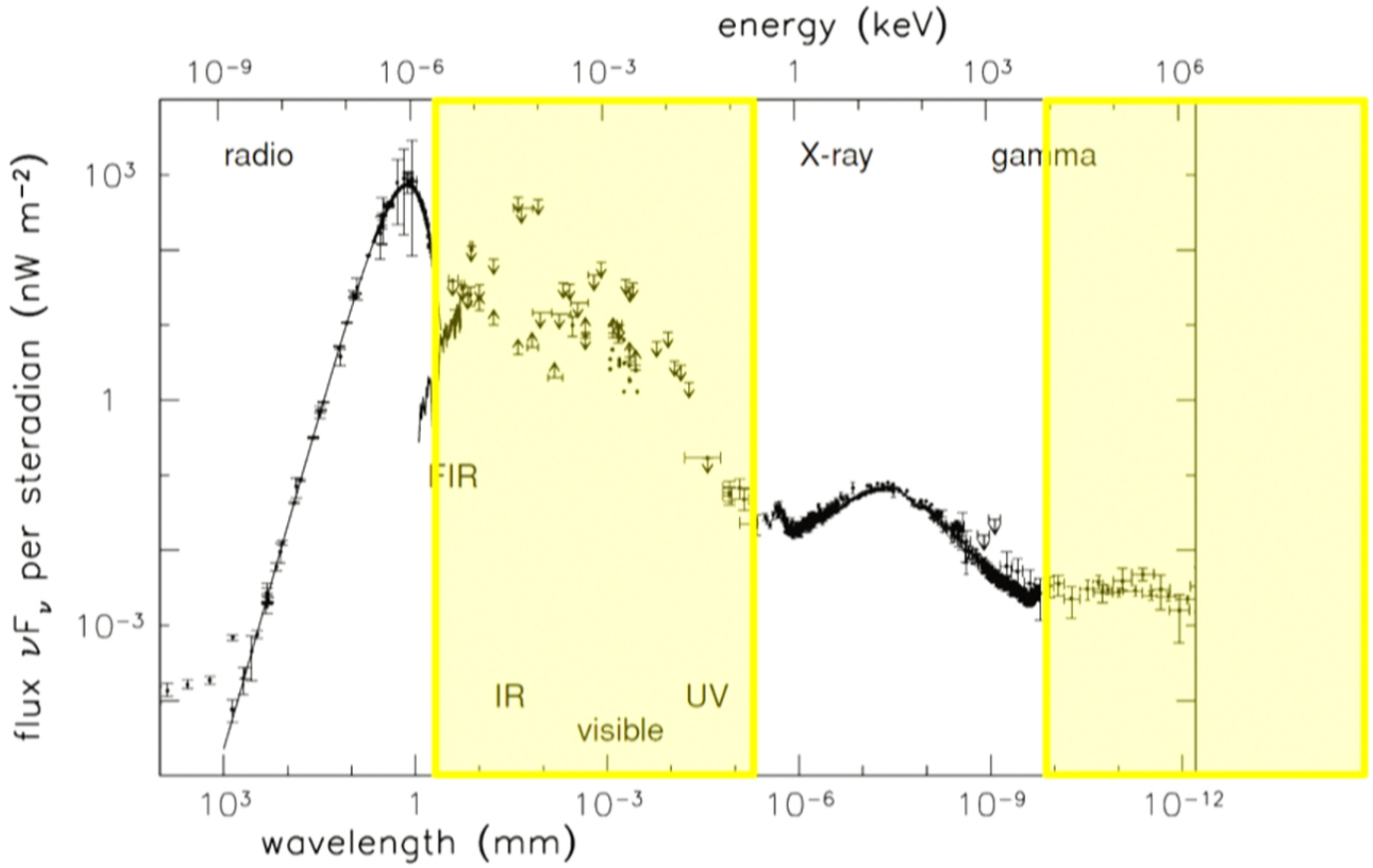
Cosmic Backgrounds



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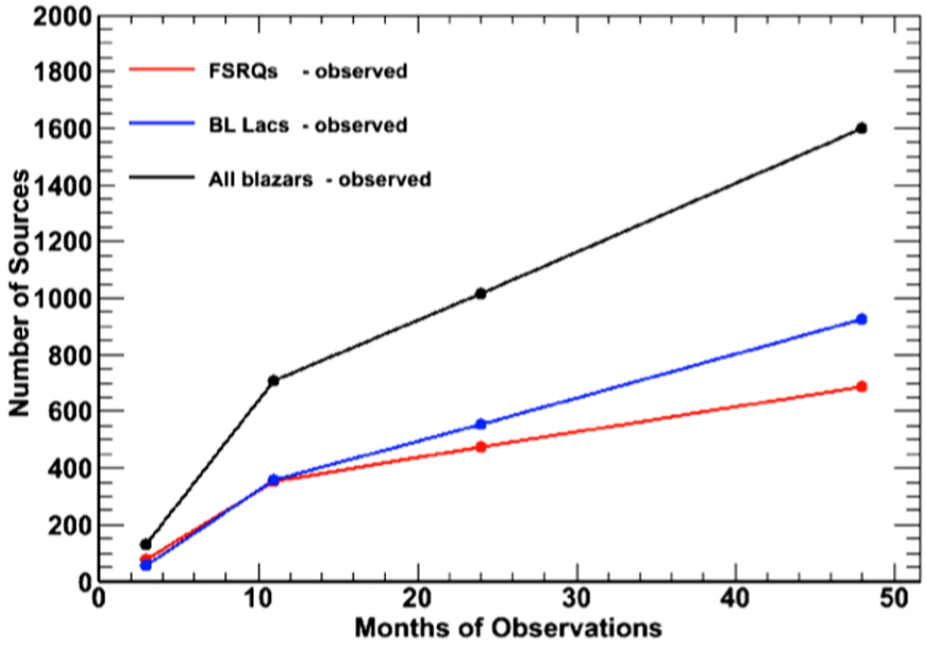
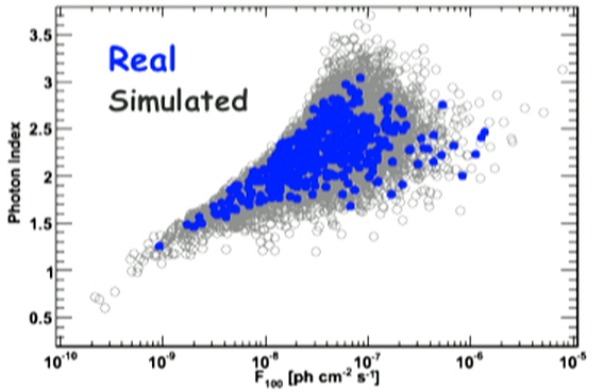
Blazars

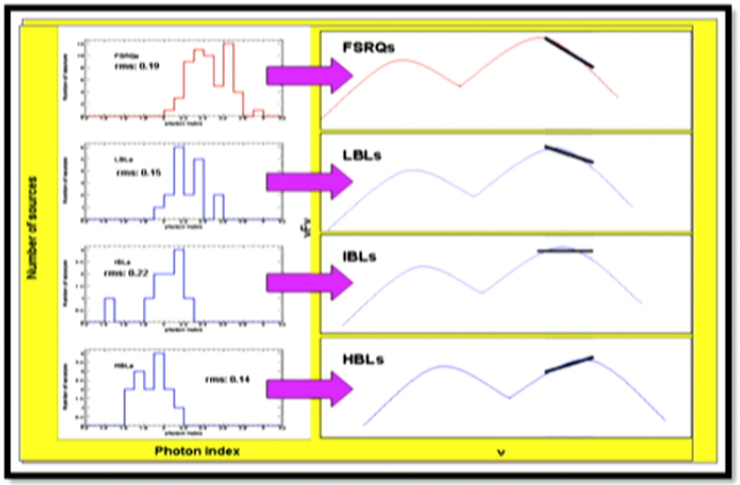
- Fermi is a blazar machine !
  - Blazars are (by far, >85%) the largest population of sources detected by *Fermi*
  - Numbers steadily increasing (BSL, 1LAC, 2LAC, 3LAC)
  - BL Lacs have taken over the FSRQs

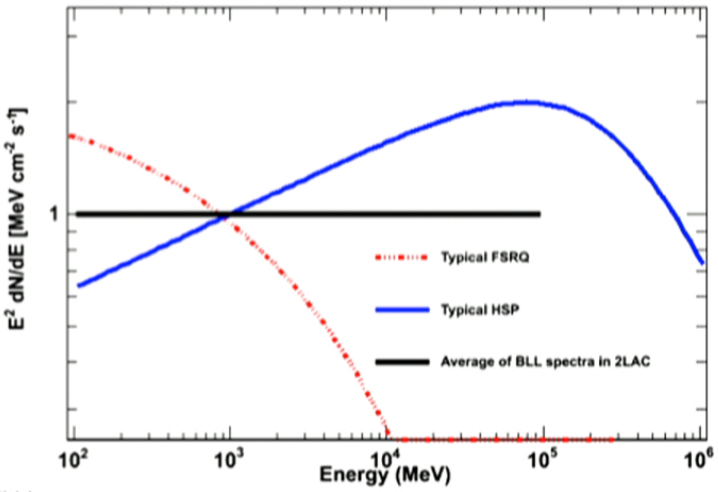


The Blazars Population

- Blazars potentially represent 85-95% of the high-latitude population
- FSRQs and BL Lac seem to segregate in the luminosity-index plane
- FSRQ and BL Lac have different photon index distributions







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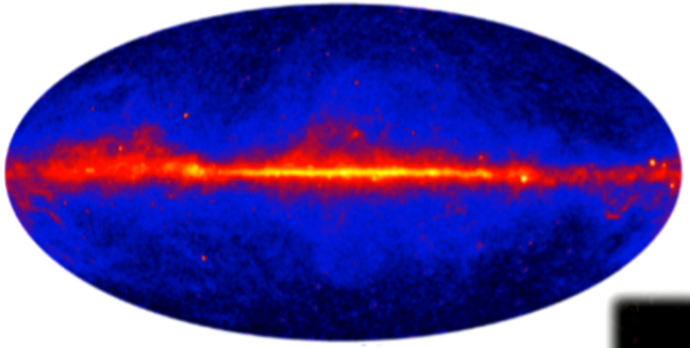
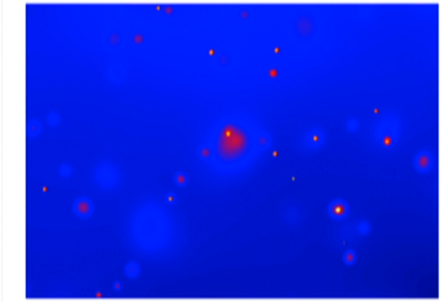
Finland 2...

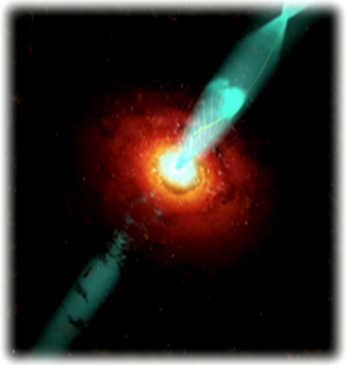
Well determined problem

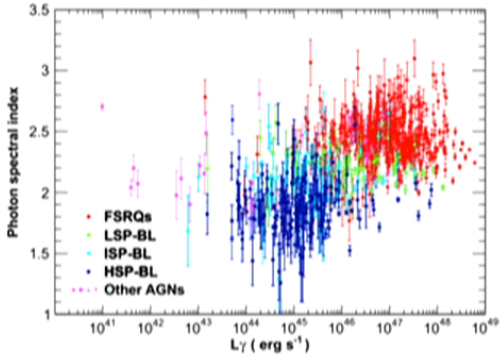
EGB

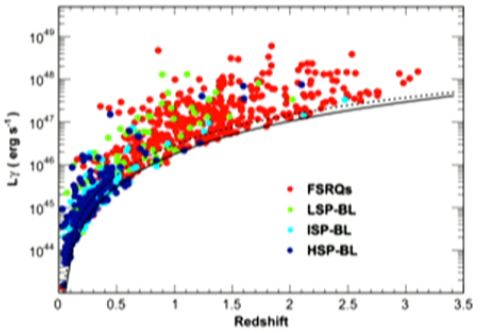


Fluctuations

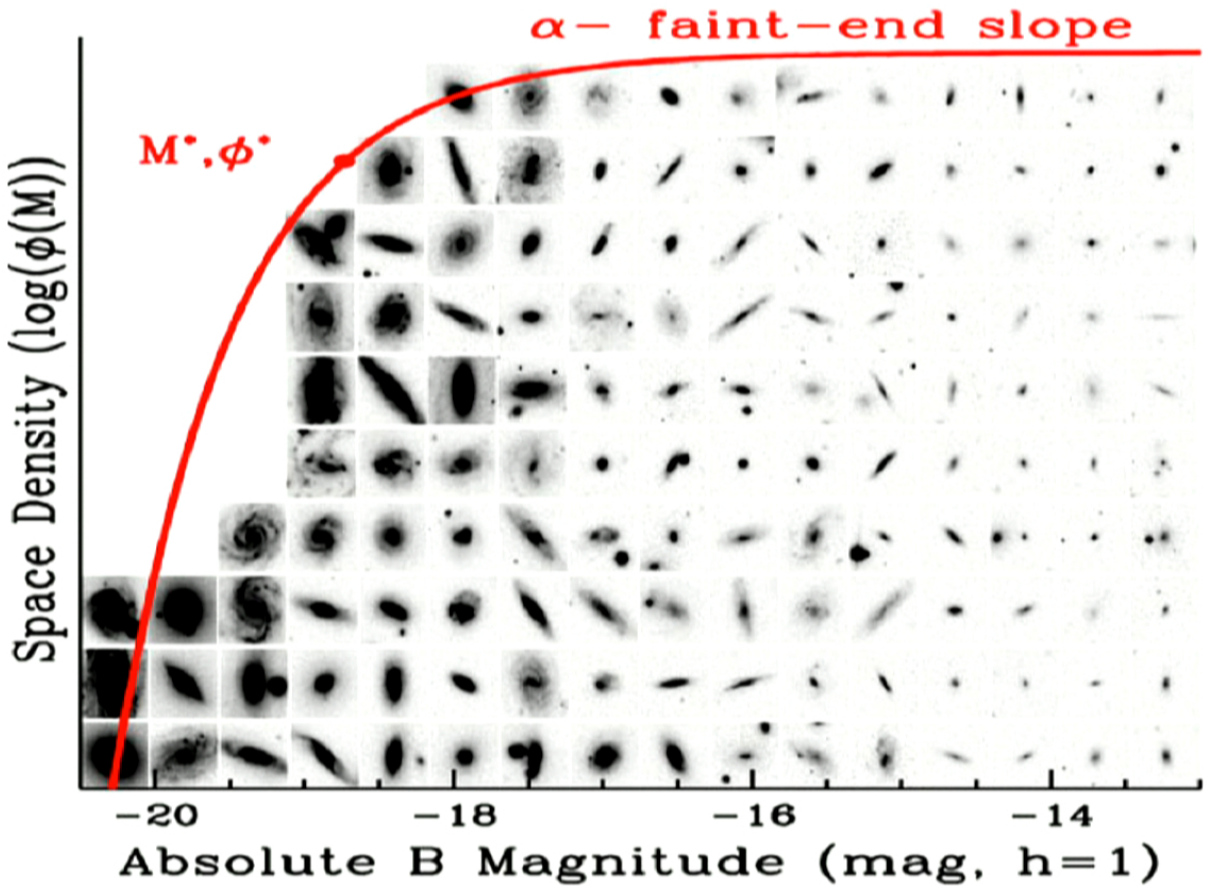








Luminosity function



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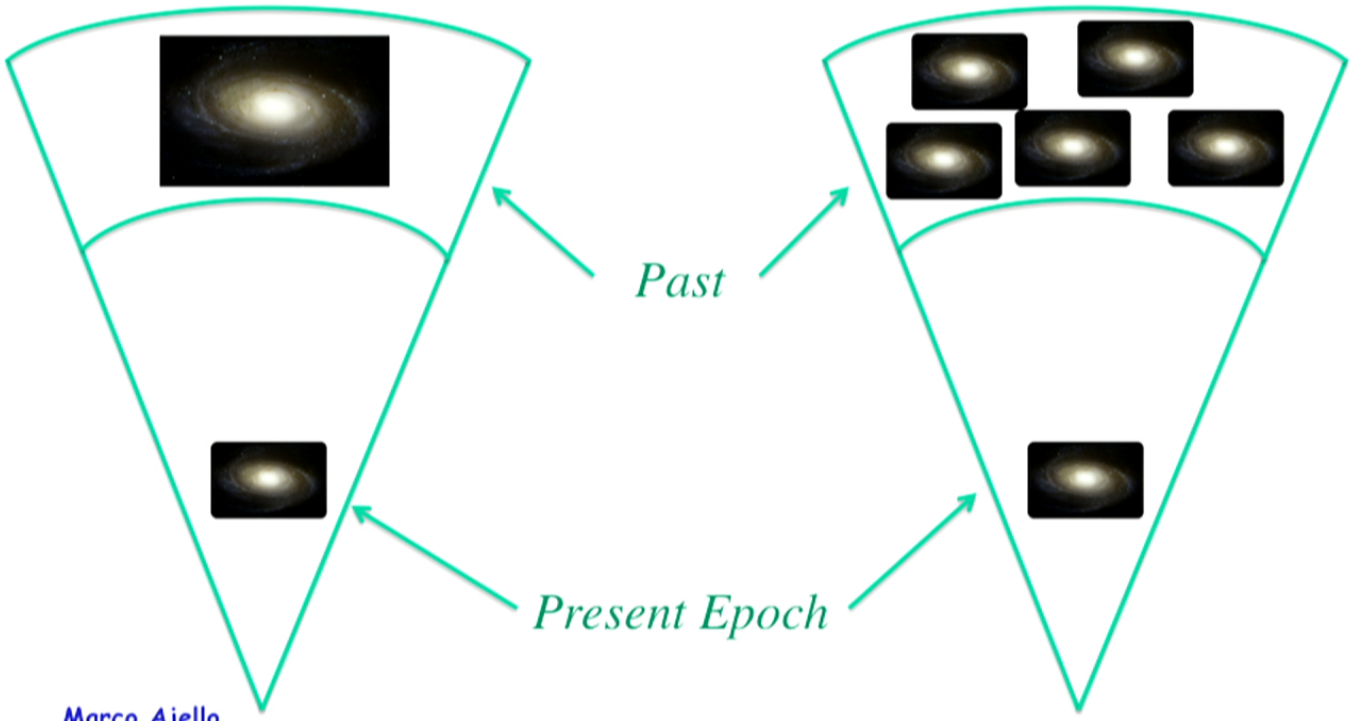
The Evolution of the LF

What you are asking is :

Were the objects more luminous or more numerous in the past ?



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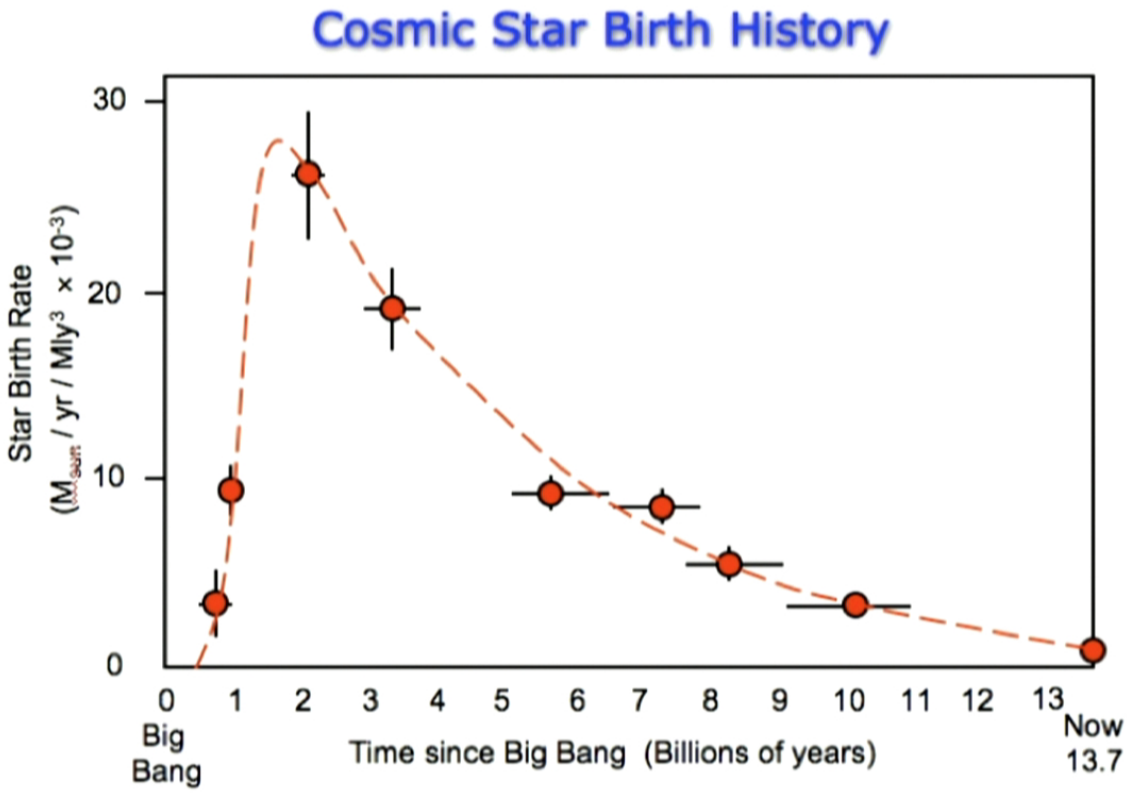
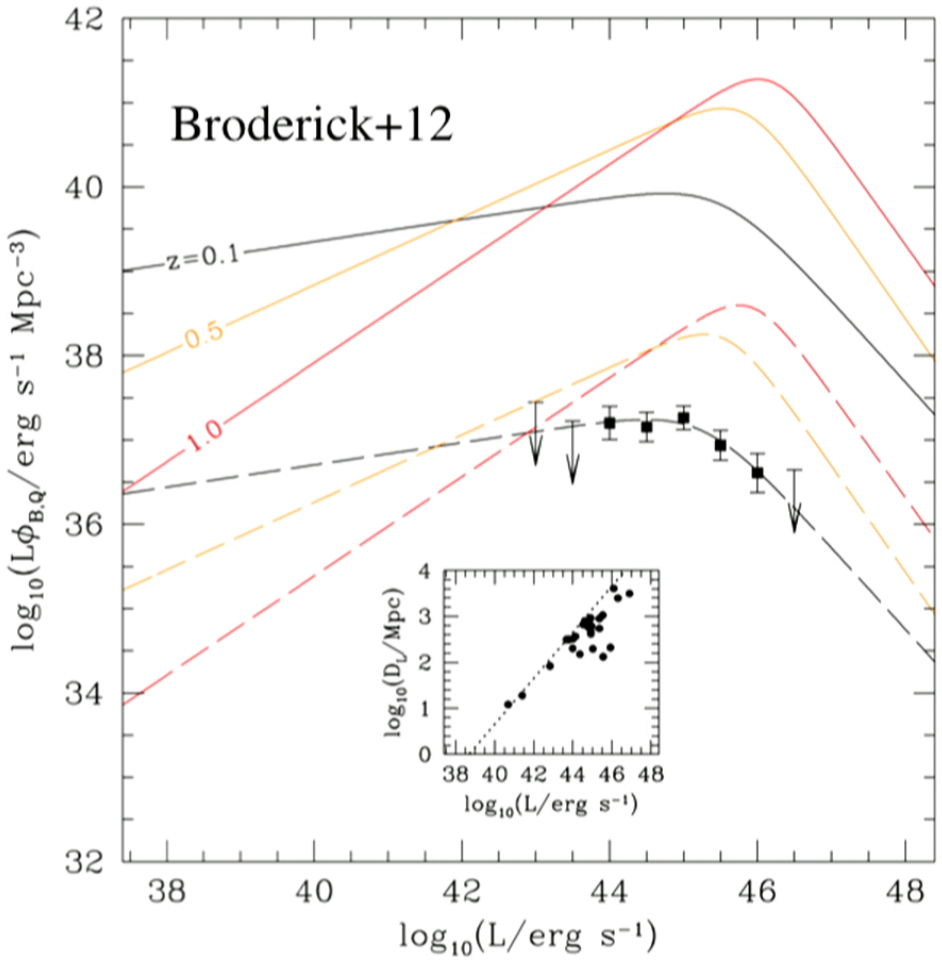
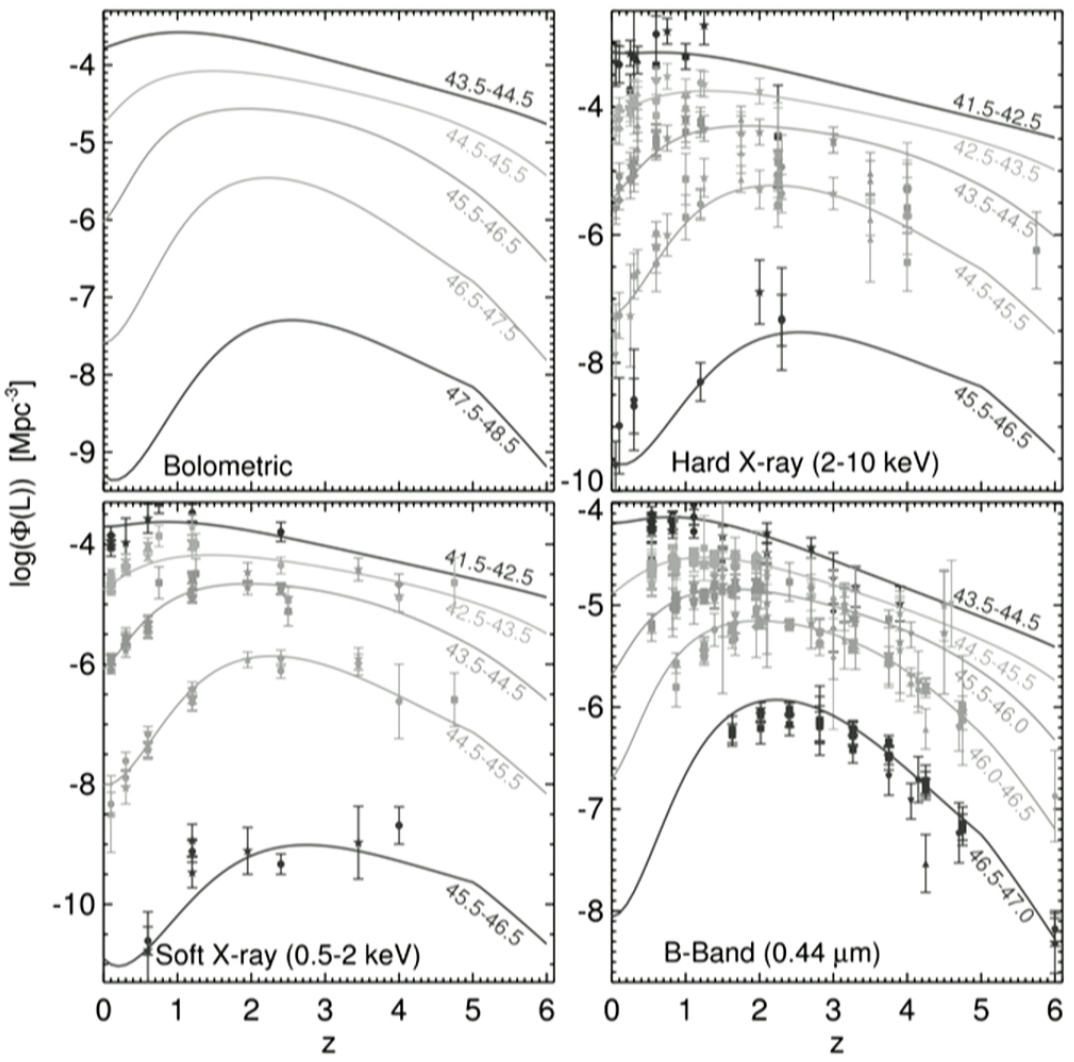
Evolution

- Positive evolution alone cannot exist

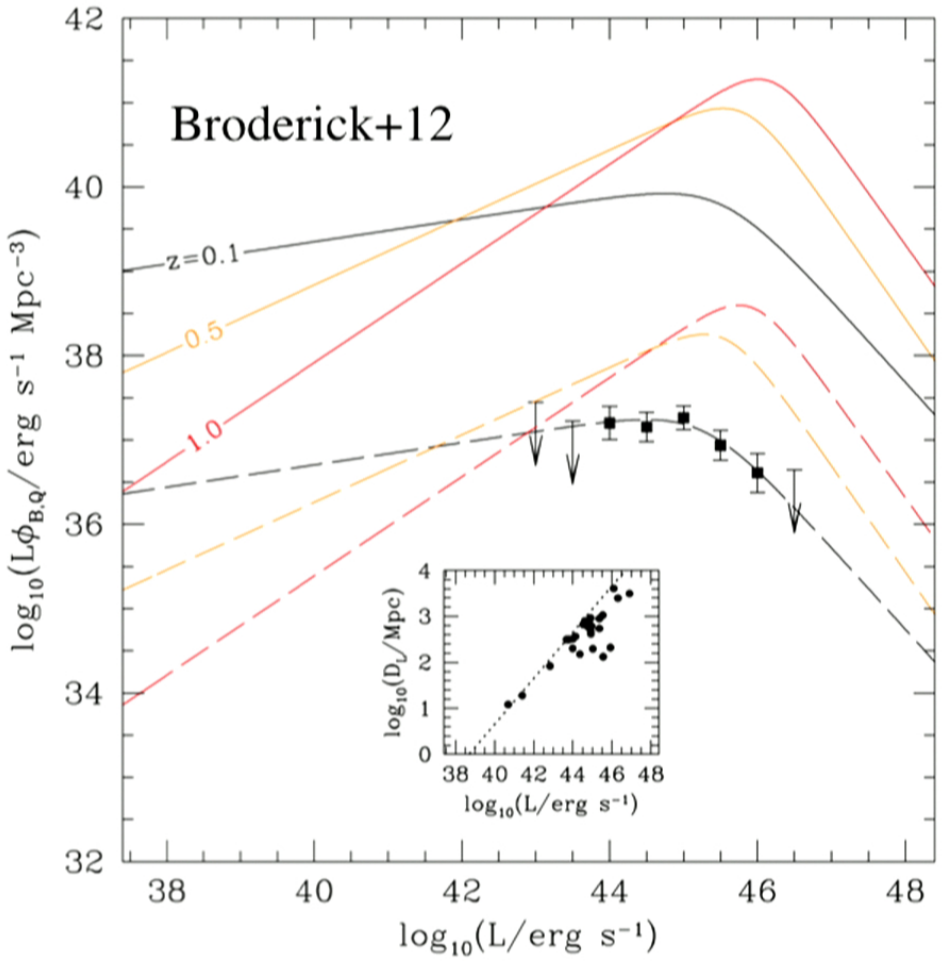


Scaling LF


Broderick+12
z=0.1
0.5
1.0
$\log_{10}(L\phi_{B,Q}/\mathrm{erg\ s^{-1}\ Mpc^{-3}})$
$\log_{10}(L/\mathrm{erg\ s^{-1}})$
$\log_{10}(D_L/\mathrm{Mpc})$
$\log_{10}(L/\mathrm{erg\ s^{-1}})$


log(Φ(L)) [Mpc^{-3}]
Bolometric
43.5-44.5
44.5-45.5
45.5-46.5
46.5-47.5
47.5-48.5
Hard X-ray (2-10 keV)
41.5-42.5
42.5-43.5
43.5-44.5
44.5-45.5
45.5-46.5
Soft X-ray (0.5-2 keV)
41.5-42.5
42.5-43.5
43.5-44.5
44.5-45.5
45.5-46.5
B-Band (0.44 μm)
43.5-44.5
44.5-45.5
45.5-46.0
46.0-46.5
46.5-47.0
z
z

Scaling LF


Broderick+12
z=0.1
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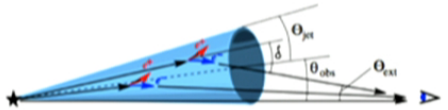
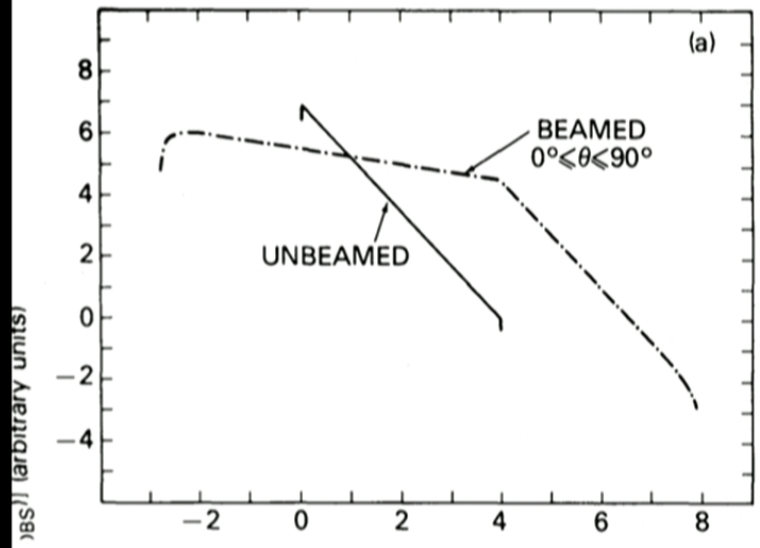
$\log_{10}(L\phi_{B,Q}/\mathrm{erg\ s^{-1}\ Mpc^{-3}})$
$\log_{10}(L/\mathrm{erg\ s^{-1}})$
$\log_{10}(D_L/\mathrm{Mpc})$
$\log_{10}(L/\mathrm{erg\ s^{-1}})$

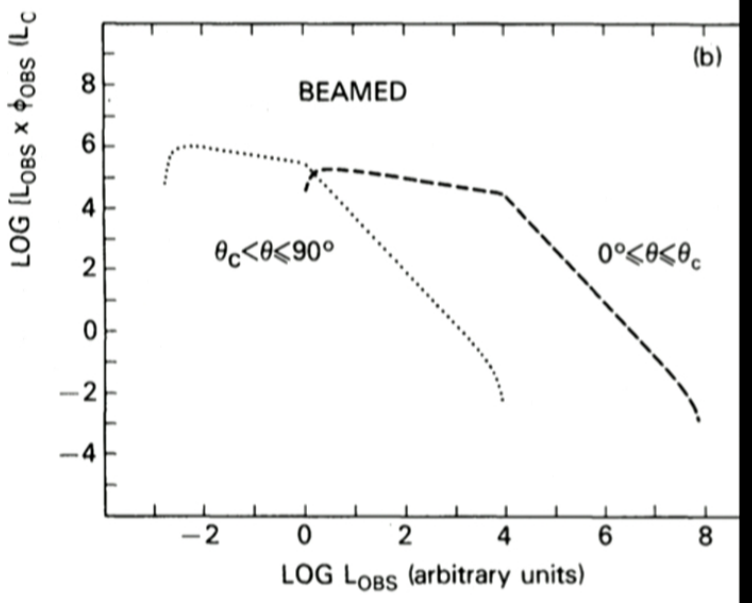
Beaming and the LF



Beaming is known to alter the shape of the luminosity function (Urry&Shafer84)
i.e. an intrinsic power-law LF can be transformed into a curved LF by beaming

Apparent luminosity $\longrightarrow$ $L = \delta^p \mathcal{L}$ $\longleftarrow$ *Real luminosity*

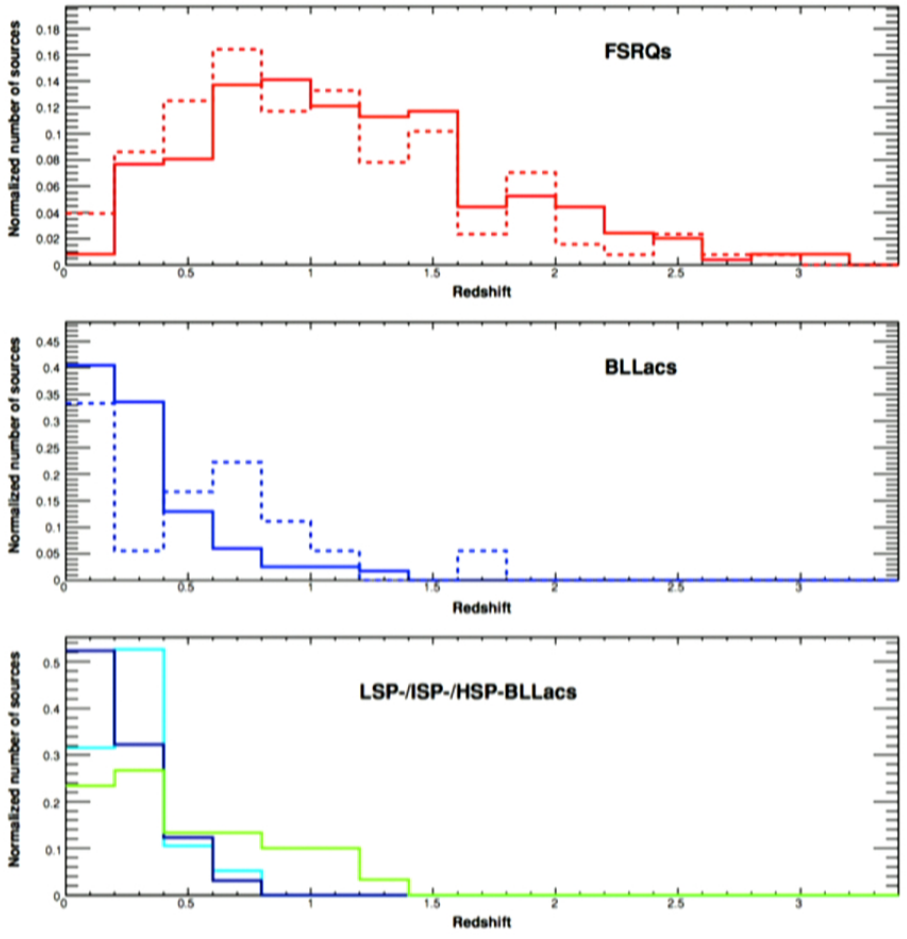




Redshift Distribution (pre-Fermi)

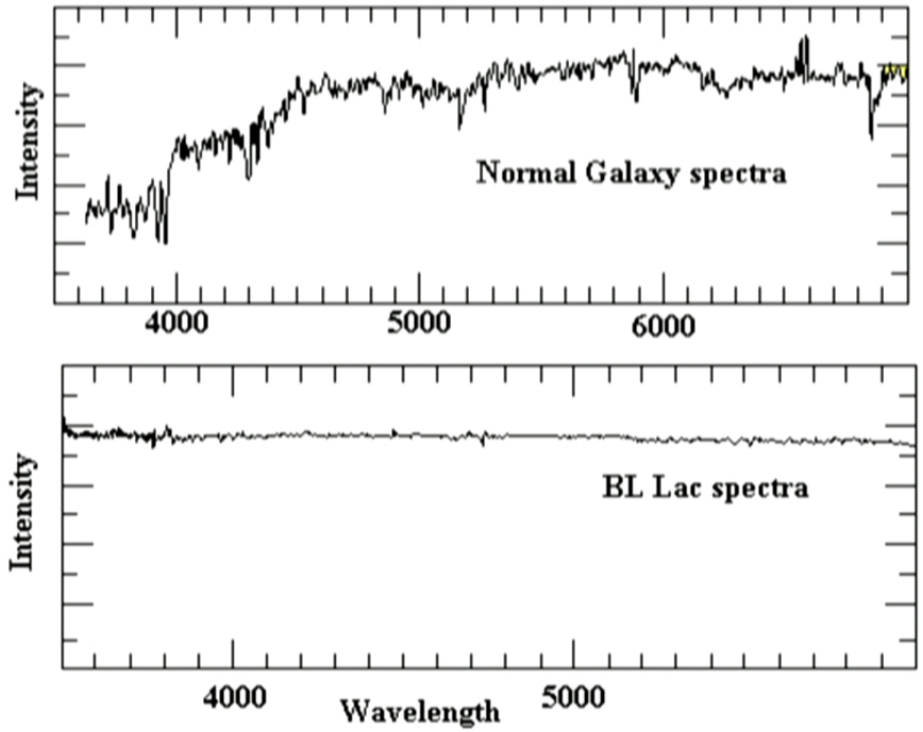
- ~50% of BL Lacs have no redshift
  - People tried already

Some refs. to previous works include : Urry+96, Rector+00, Beckmann +03, Marcha & Caccianiga 2013, Caccianiga+02, Padovani +07



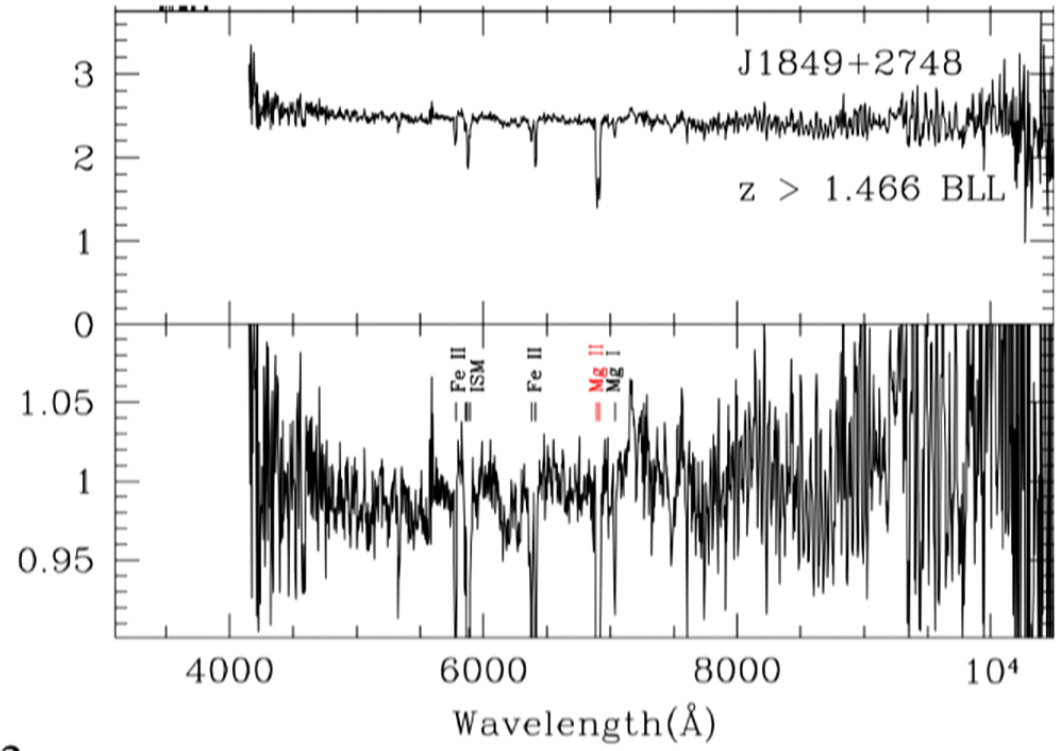
BL Lac spectra

- Featureless spectra:
  1. Swamped by jet continuum
  2. Weak/absent disk/BLR continuum (Giommi etc.)



Spectroscopic Lower limits

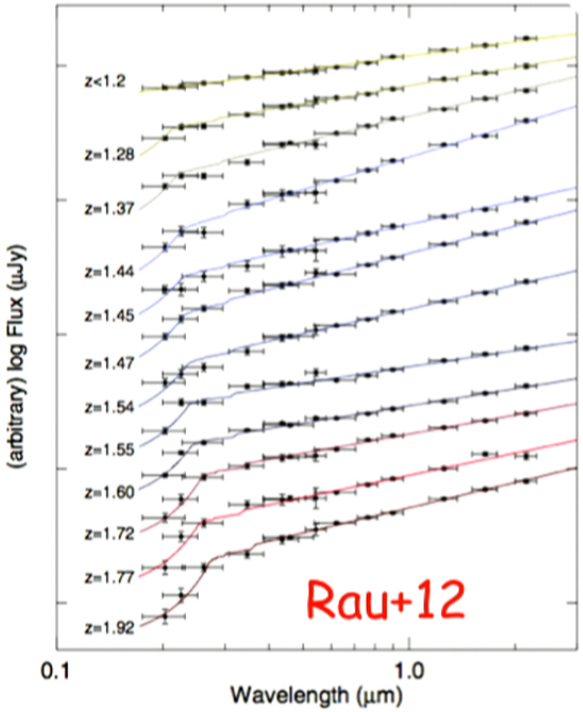
- Absorption lines in high resolution optical spectra due to intervening absorber along the line of sight

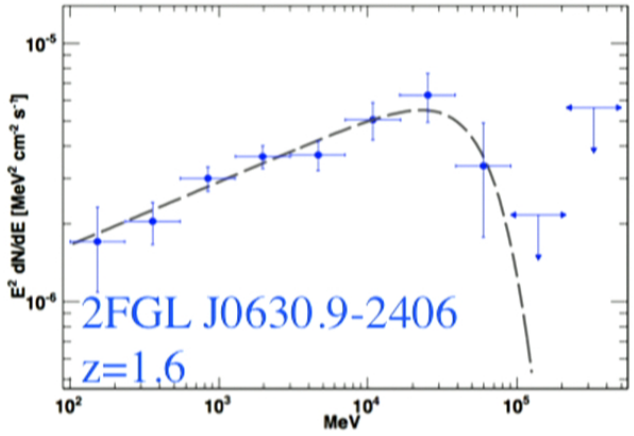


Shaw+12

Photometric redshift

- Drop out (mostly in UV/optical) due to Hydrogen along the line of sight
  - Relies on accurate photometry with Swift/UVOT and GROND





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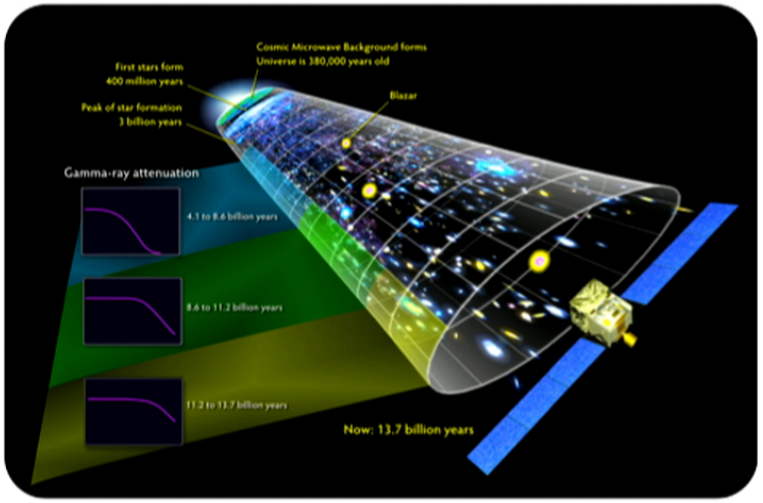
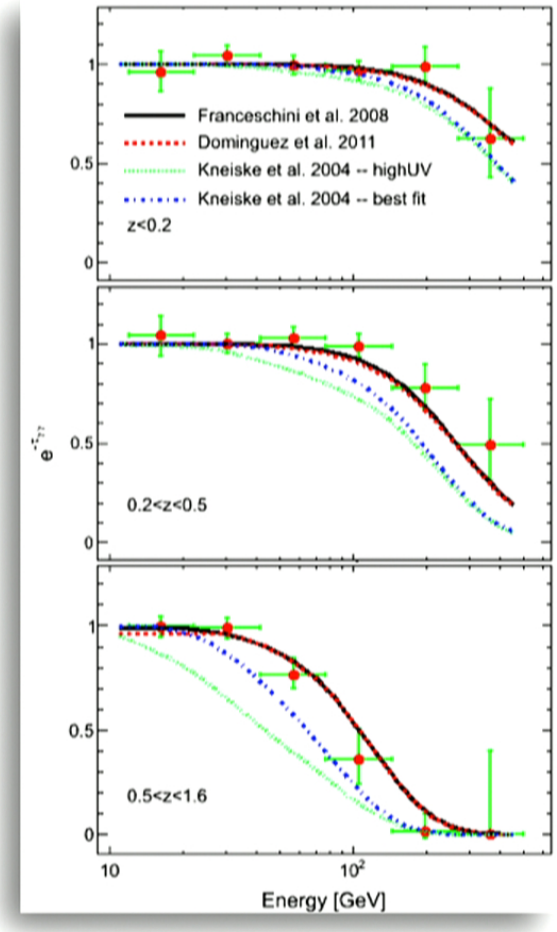
EBL Attenuation in LAT data

- First EBL detection (~6σ)
  (Ajello, Buehler & Reimer for the LAT-collaboration, 2012,Science, 338, 1190)
- The cut-off moves in z and Energy exactly as expected for EBL absorption
- EBL density at the lowest level: i.e. the amount of light that causes the absorption = amount of light from the galaxies we see

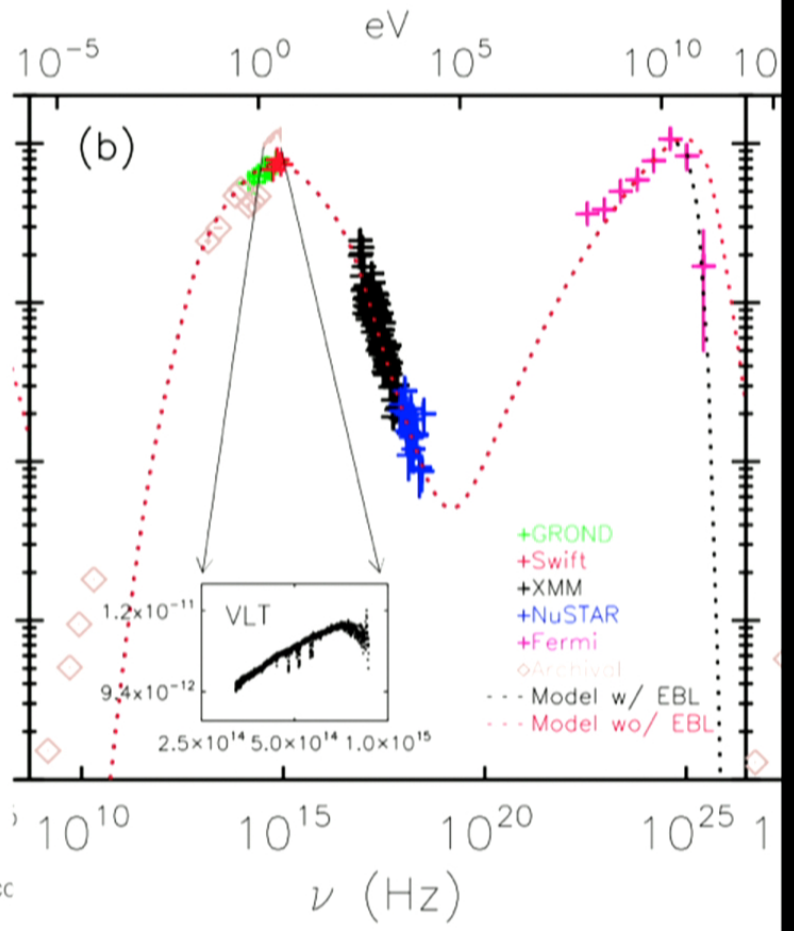




Do high-redshift BL Lacs exist ?

- Yes they do and they can be hard
- We all win
  - Cosmology with BL Lacs

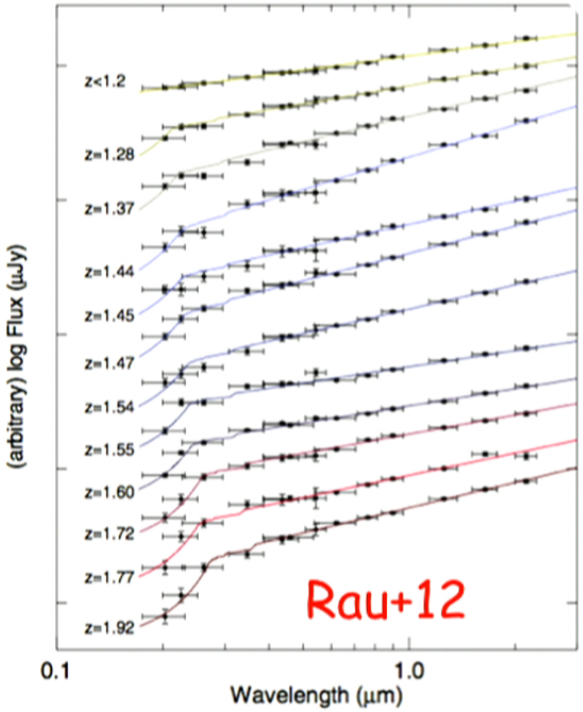
An, Romani, Ajello+ 2015



Marcc

Photometric upper limits

- Lack of the drop out (mostly in UV/optical) due to Hydrogen along the line of sight: implies z<1.2/1.3

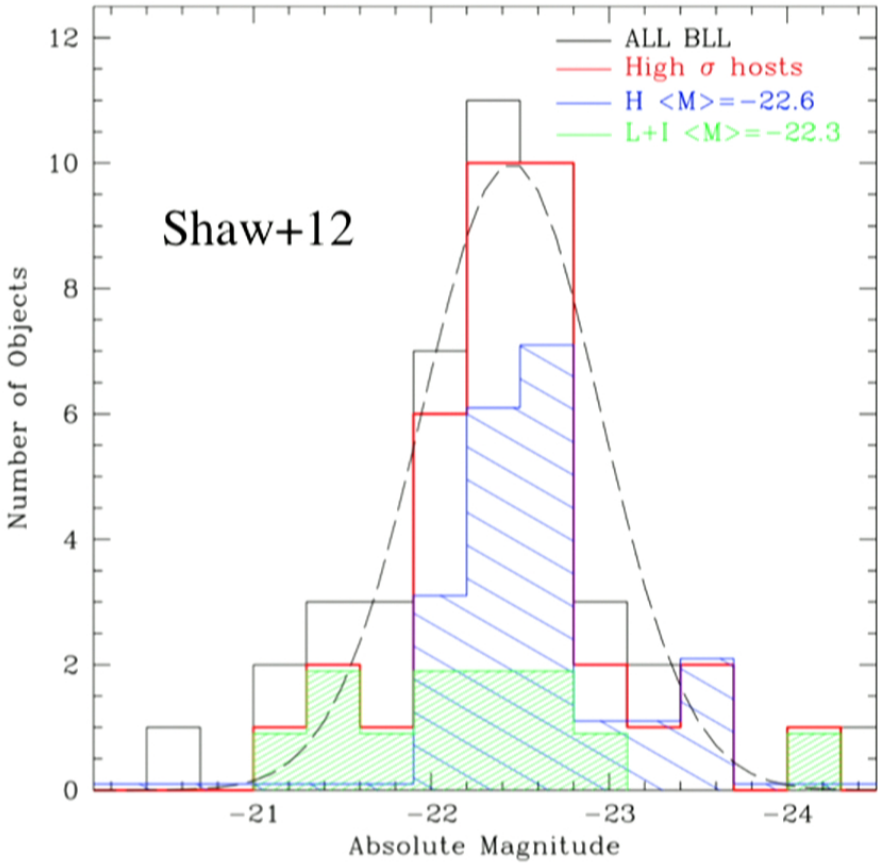


~90% of the BL Lacs (so originally w/o z) we targeted are at z<1.3

Host Galaxy Lower limits

- Proposed first by M. Urry
- BL Lac hosts are standard candle with M=-22.5

- Incredibly, it seems to hold
  - Tested by Sbarufatti+05, Shaw+12



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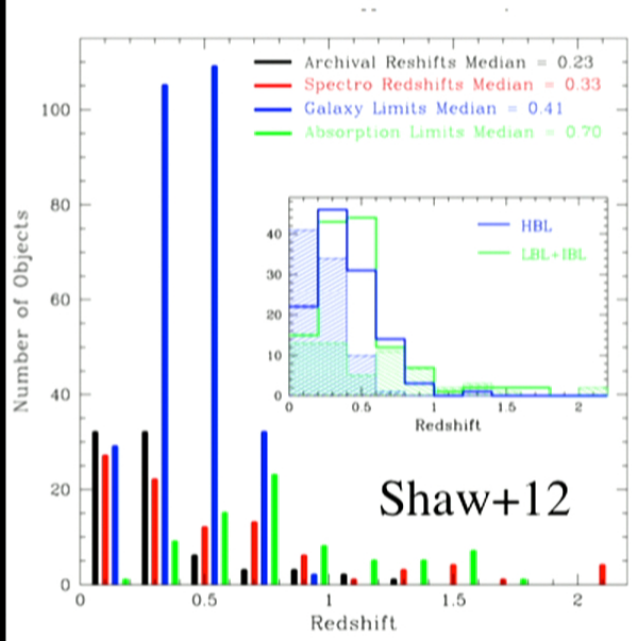
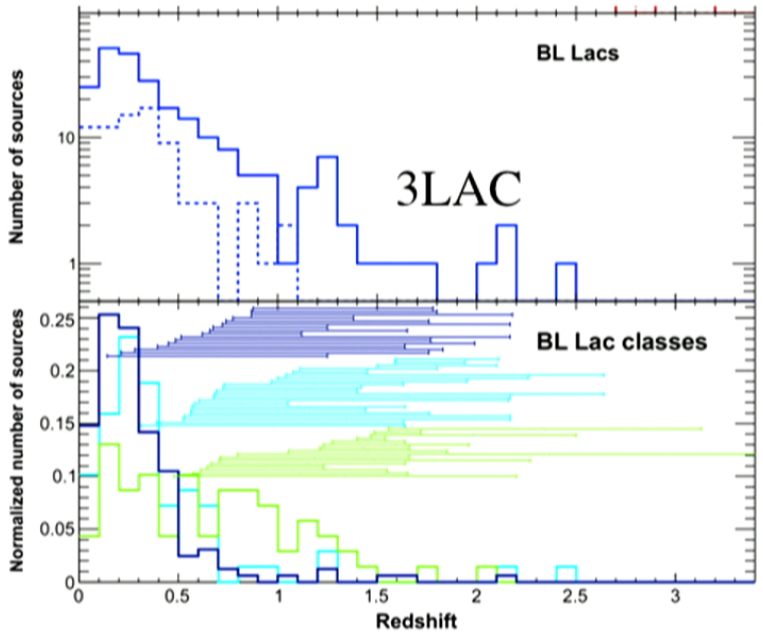
Putting everything together

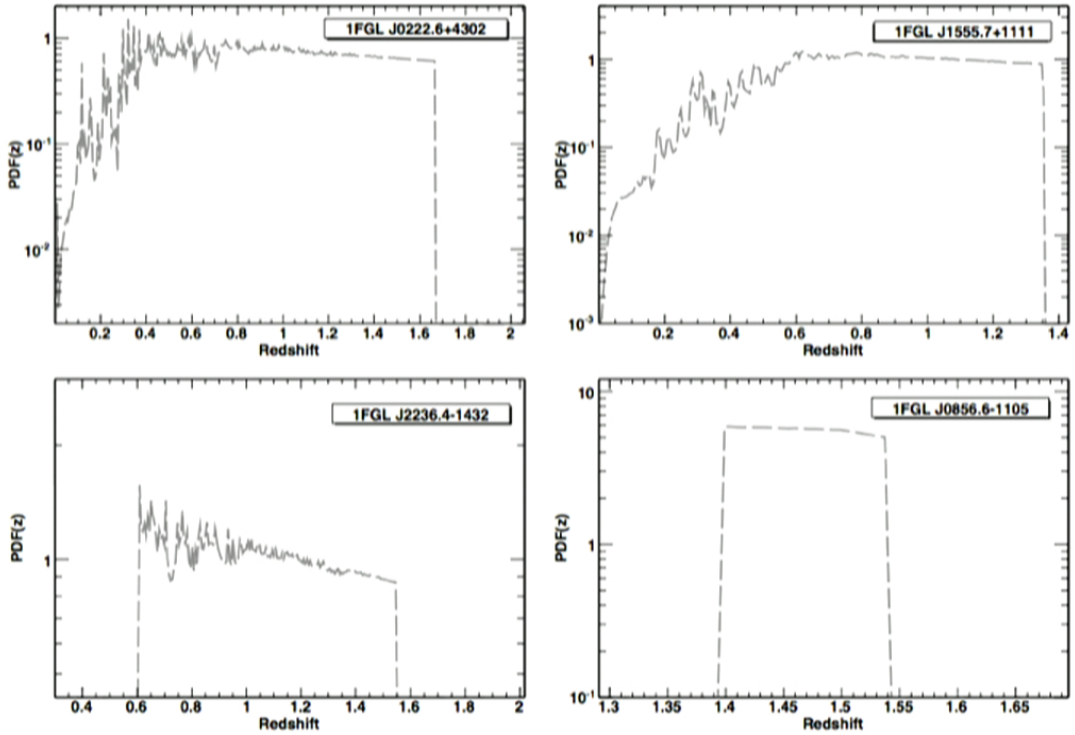
- Most BL Lacs w/o z lie *very likely* at higher z
- Sizable population of high-redshift (z>1) BL Lacs (also HSPs: hard TeV blazars)



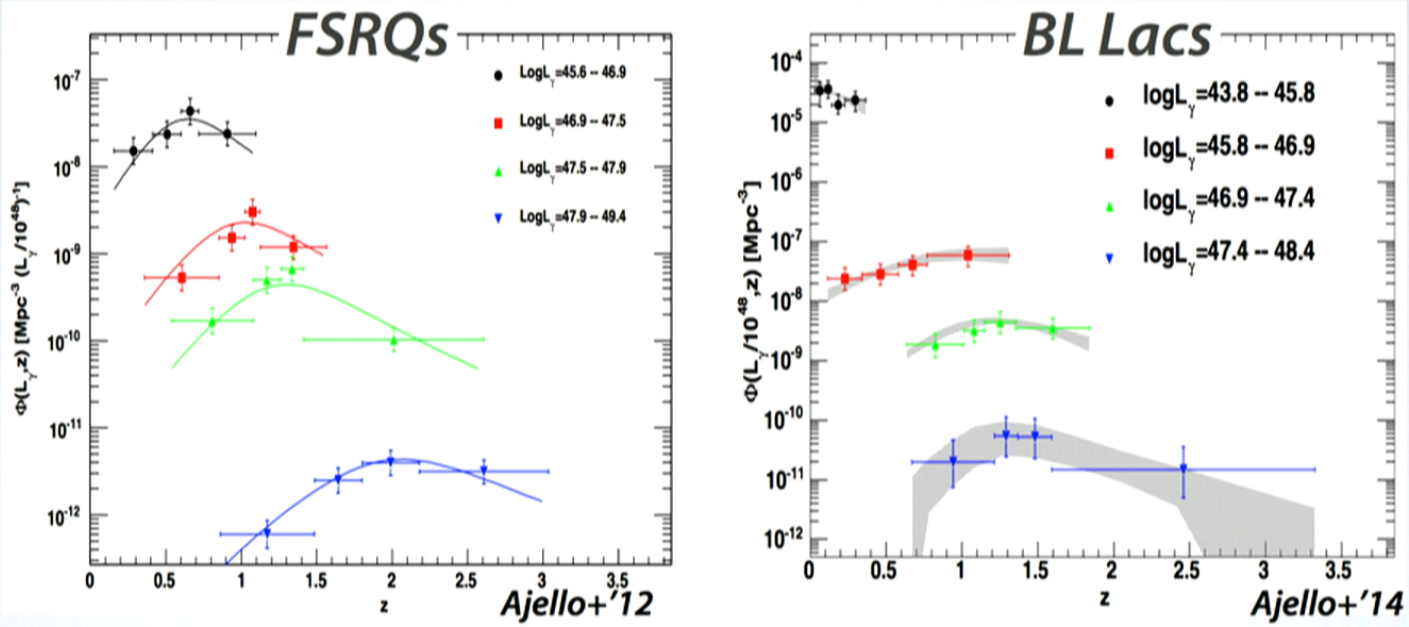


Some examples

- Some sources have a surprisingly well constrained redshift
  - First discovery: high-z (z>1) BL Lacs exist
  - They are not only LSPs (e.g. FSRQs in disguise), there is a non negligible fraction of HSPs out there !



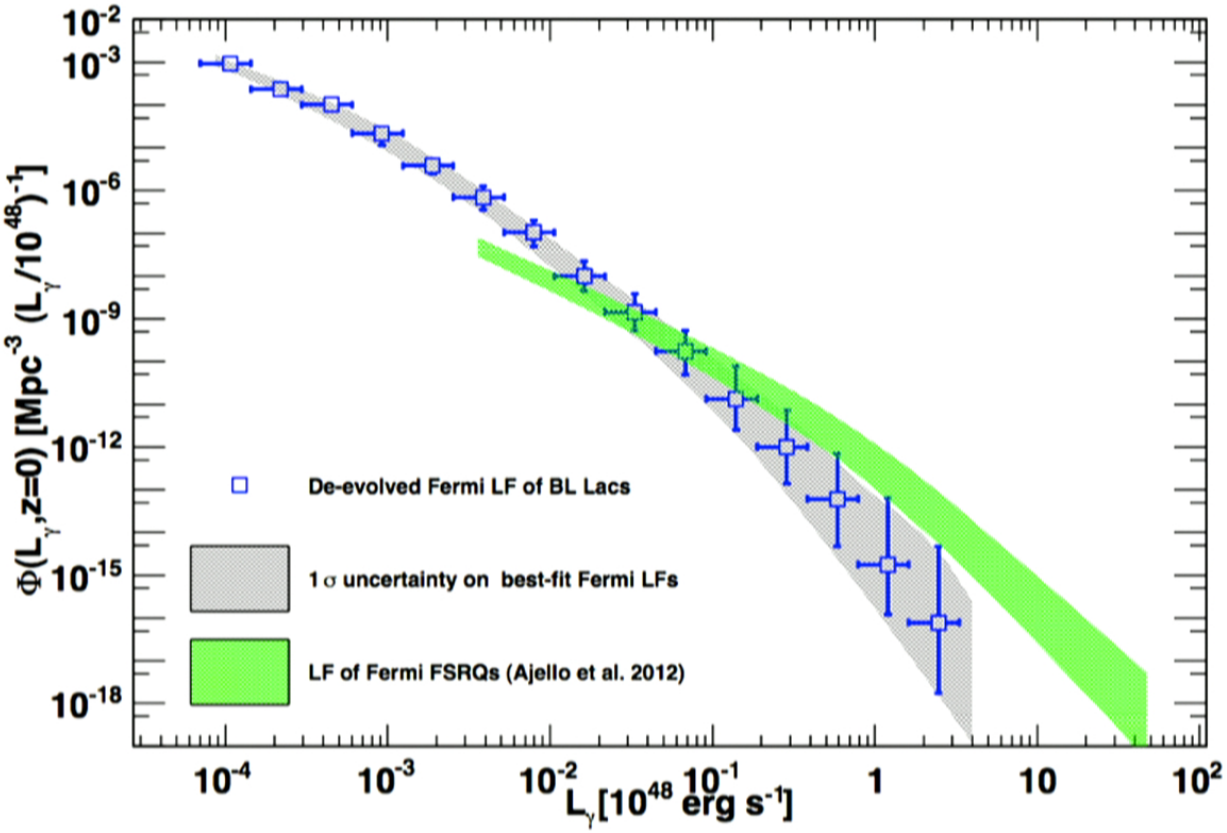
Cosmological Evolution of Blazars



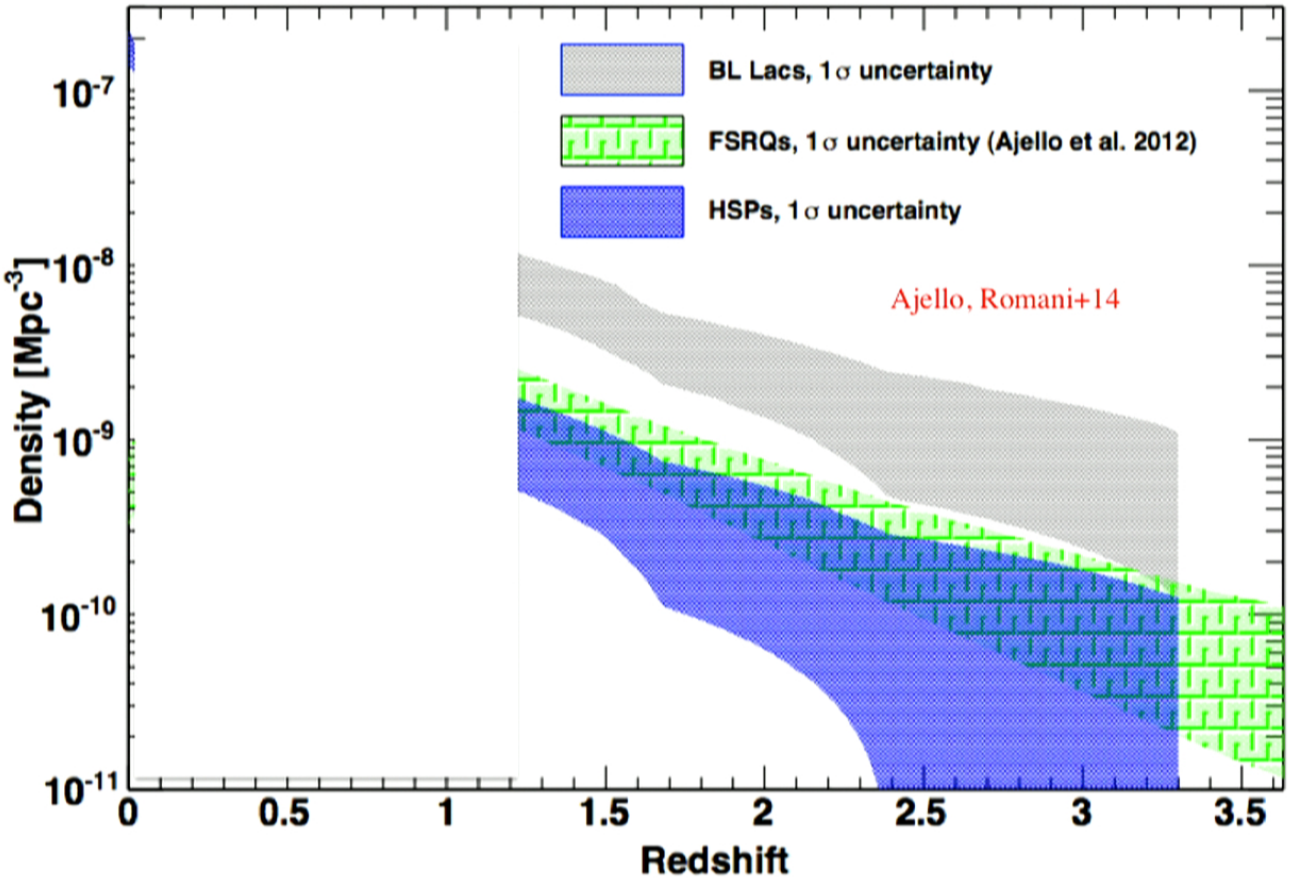
- FSRQs, LBLs, & IBLs show positive evolution.
- HBLs show negative evolution unlike other AGNs.

From Y. Inoue

LF at z~0


10^{-2}
10^{-3}
10^{-6}
10^{-9}
10^{-12}
10^{-15}
10^{-18}
$\Phi(L_\gamma,z=0)$ [Mpc^{-3} $(L_\gamma/10^{48})^{-1}$]
De-evolved Fermi LF of BL Lacs
1 σ uncertainty on best-fit Fermi LFs
LF of Fermi FSRQs (Ajello et al. 2012)
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
10^2
L_γ [10^{48} erg s^{-1}]

Space Density

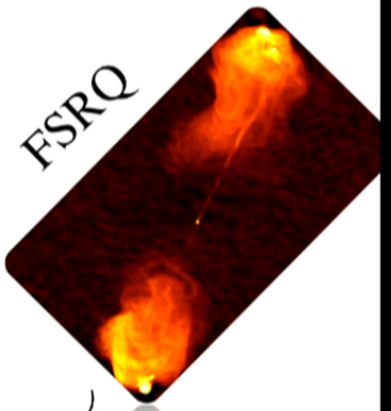


Genetic Link

Merging

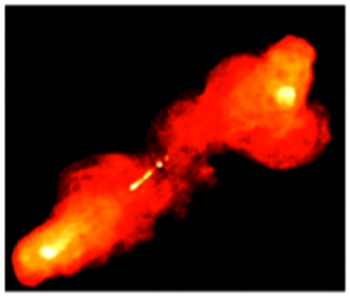
Cavaliere & D'Elia 2002
Böttcher & Dermer 2002

FSRQ



Gas poor elliptical galaxies

BL Lac



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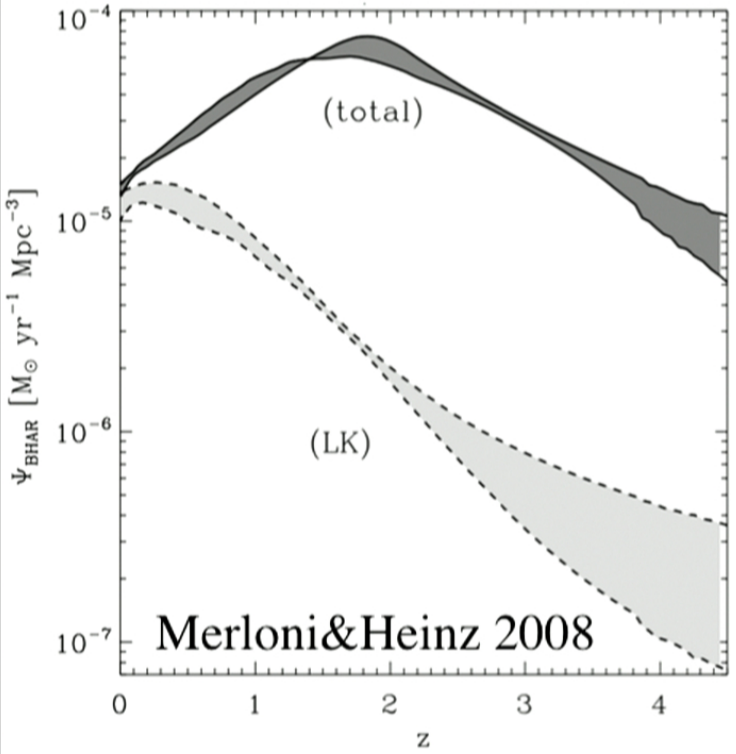
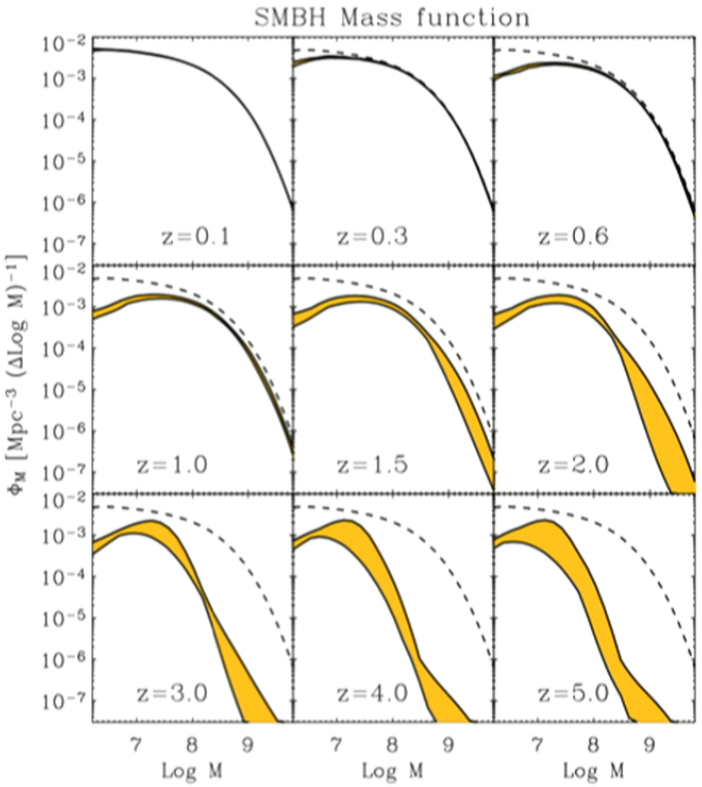
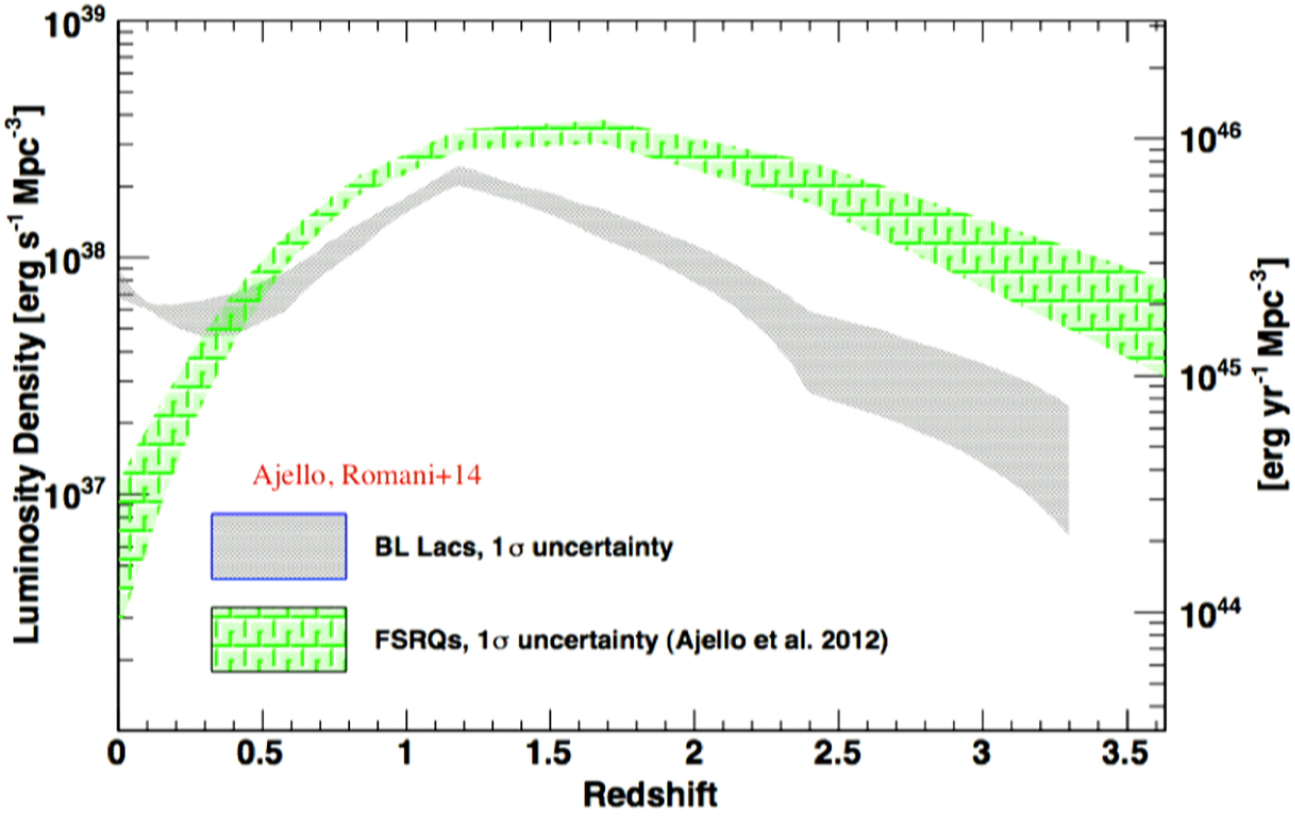
BH Mass function and accretion rate

- Space density of heavy (10^9) black holes changes slowly
- Inefficient accretors negatively evolve



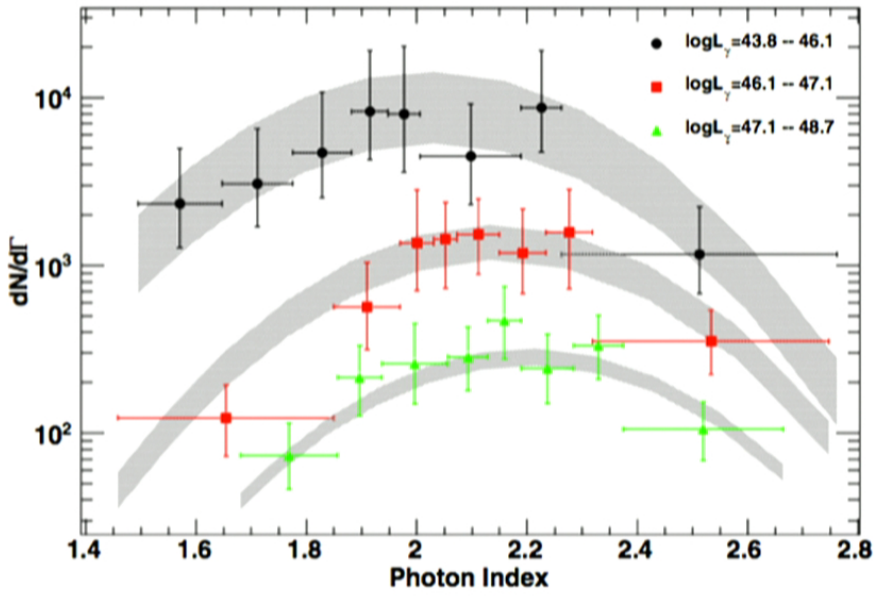


Luminosity Density

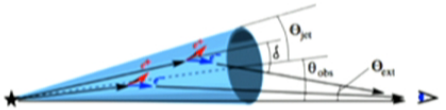


Blazar sequence?

- Softening of BL Lac spectra with Luminosity clearly detected
  - expected if particles cool faster in luminous objects (Fossati+98, Ghisellini+98, Finke 13)
  - might be produced by cascades as well (depending on IGMF strength)

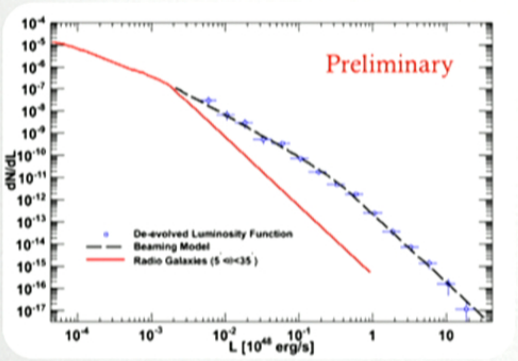


Beaming and the LF

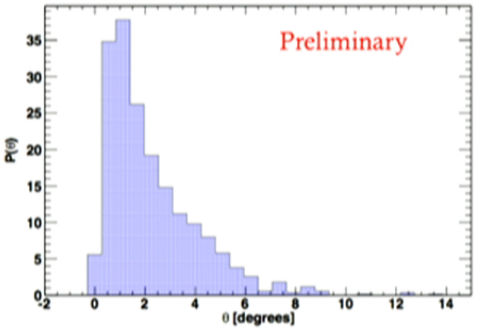


Beaming is known to alter the shape of the luminosity function (Urry&Shafer84)
i.e. an intrinsic power-law LF can be transformed into a curved LF by beaming

Apparent luminosity → $L = \delta^p \mathcal{L}$ ← *Real luminosity*



In agreement with MOJAVE (VLBA) results: *Lister+09, Savolainen+10*



1. *The average bulk Lorentz factor of Fermi FSQR is Γ=12-15*
2. *FSRQs are only 0.1-0.2% of their parent population*
3. *Most of the jets are seen within 5-6 degrees*
4. *The average angle is 2.9 degrees*

Beaming of BL Lacs

- BL Lacs have slower jets than FSRQs:
  - *Γ=6-8 vs Γ=12-15, but might reach higher Γ factors*
- Might be seen under larger angles
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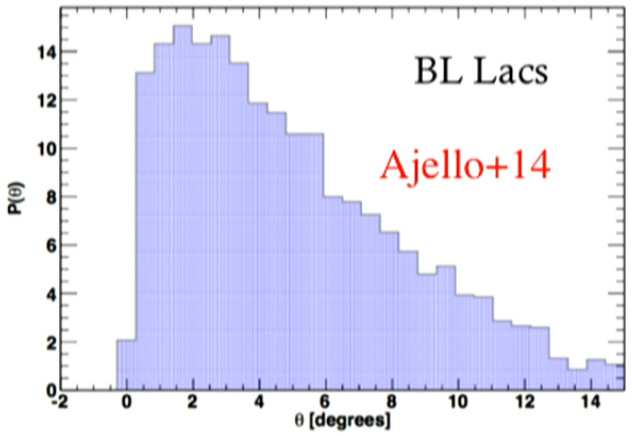
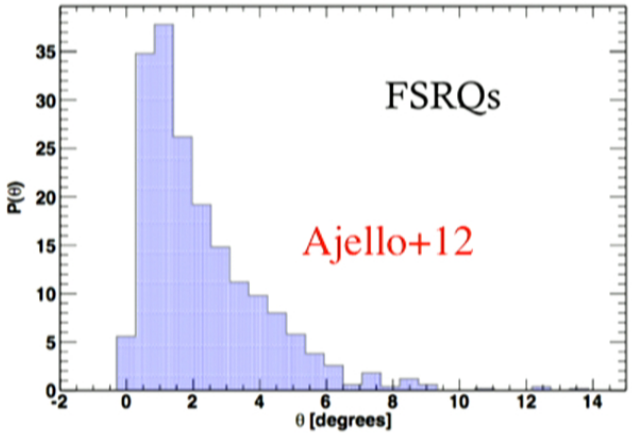
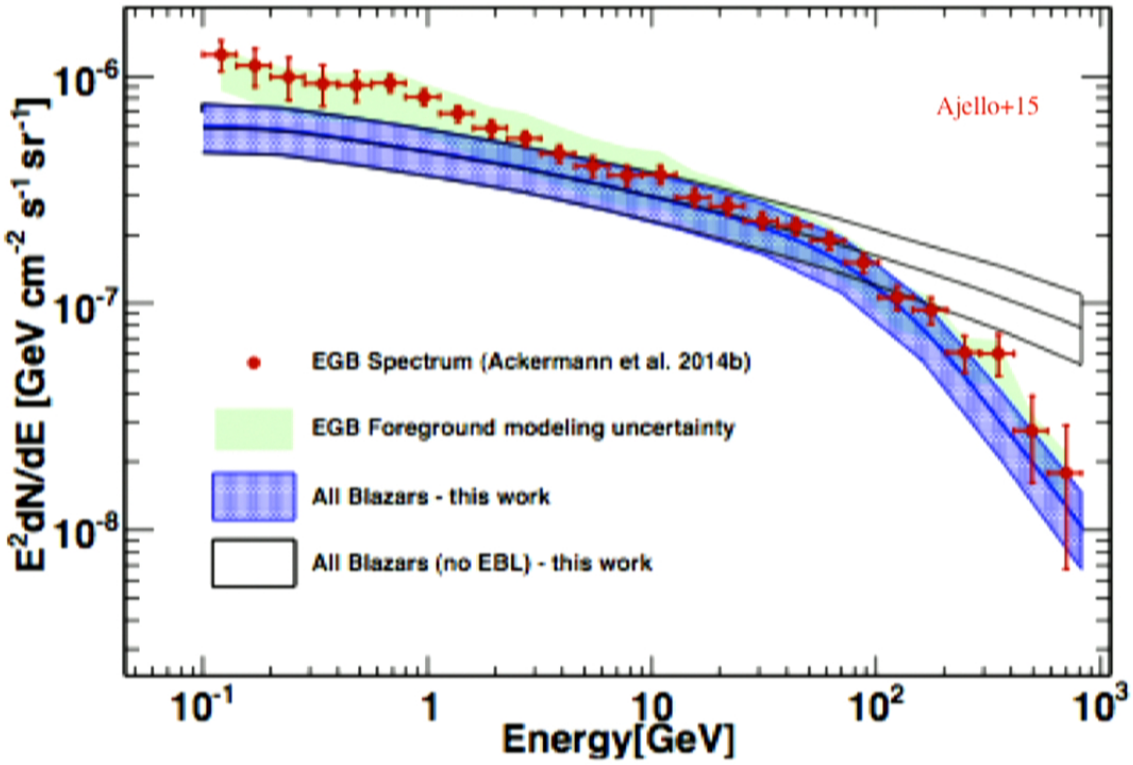


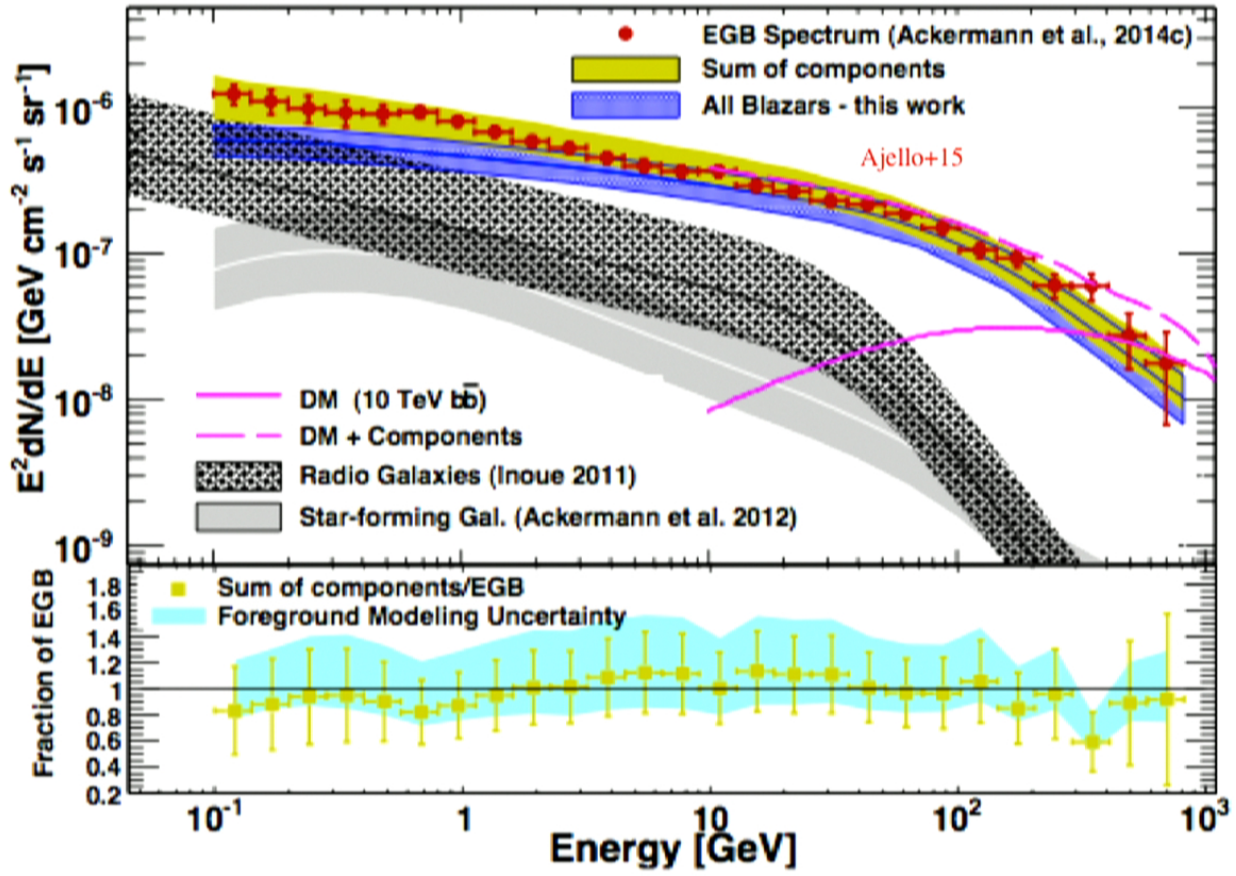


EGB

- Blazars contribute a grand-total of $(5\text{-}7)\times10^{-6}$ ph cm^{-2} s^{-1} sr^{-1}
  1. Blazars produce ~50% of the EGB: i.e. not all of it
  2. Blazars + EBL are responsible for the cut-off of the EGB spectrum

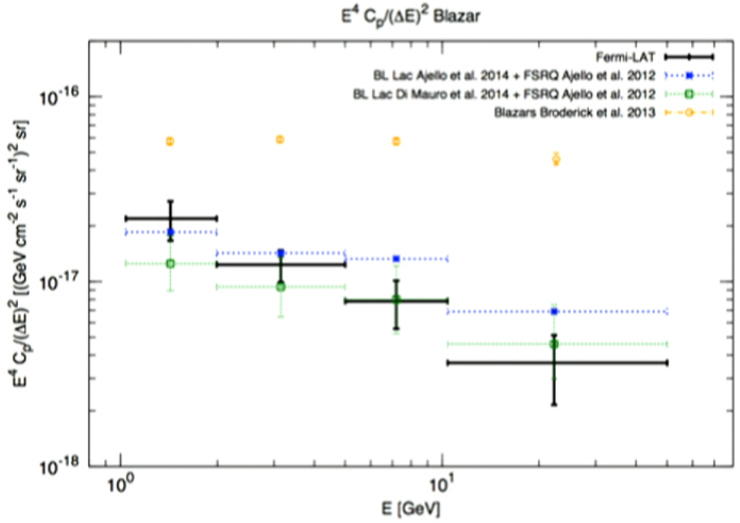


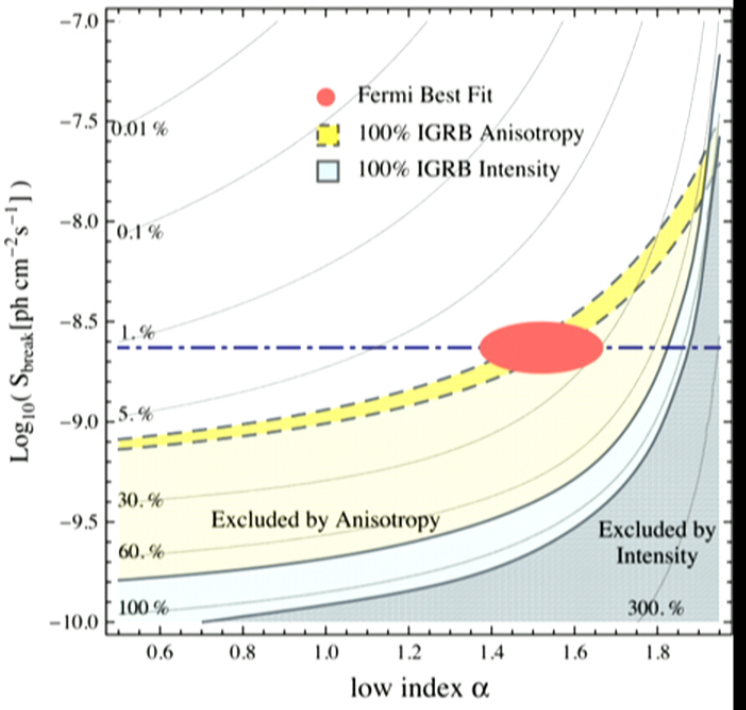
Summing Everything Up



Background Fluctuations

- Angular power consistent with being produced by blazars (Cuoco+12, Ackermann+12)





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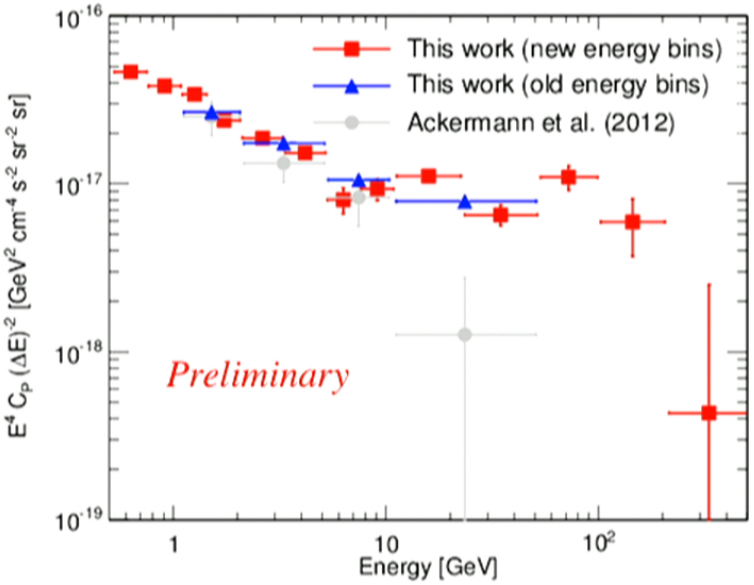
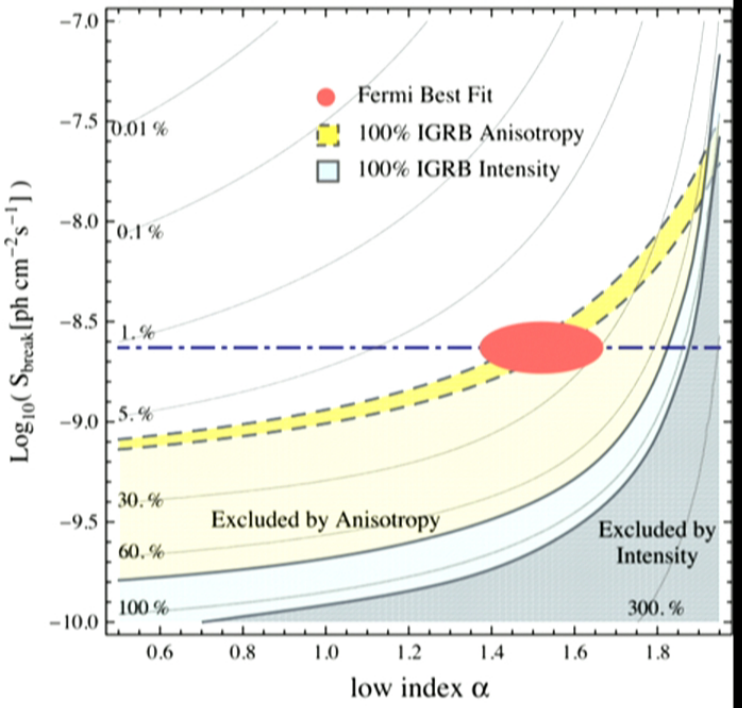
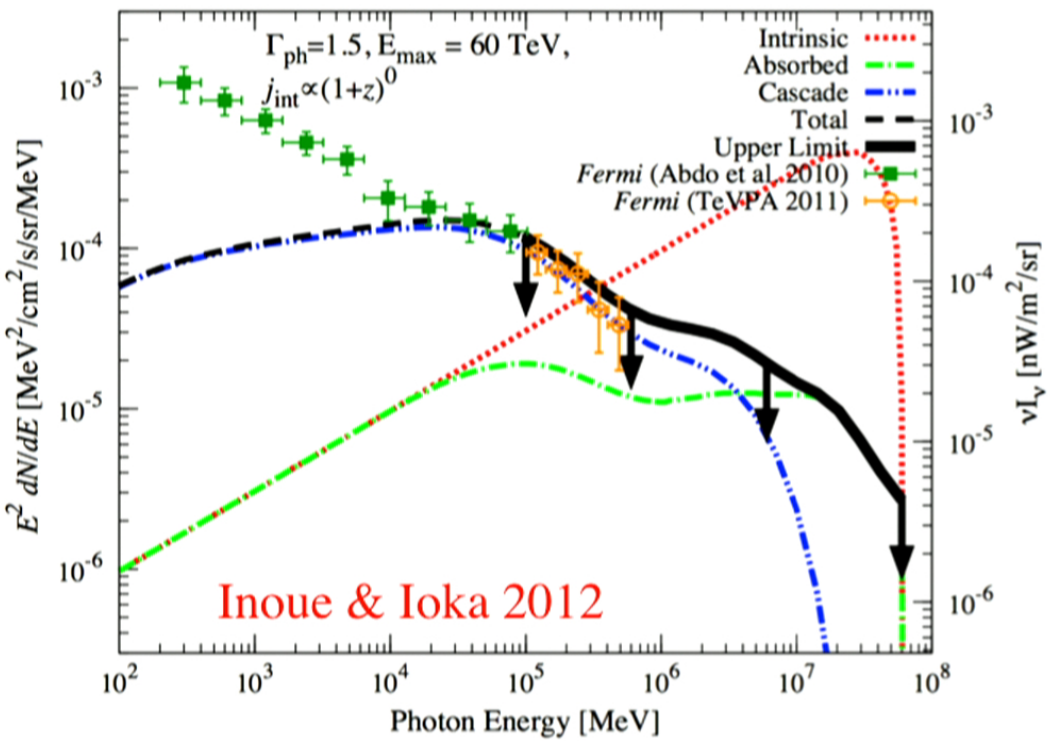




Upper Limit on the EGB



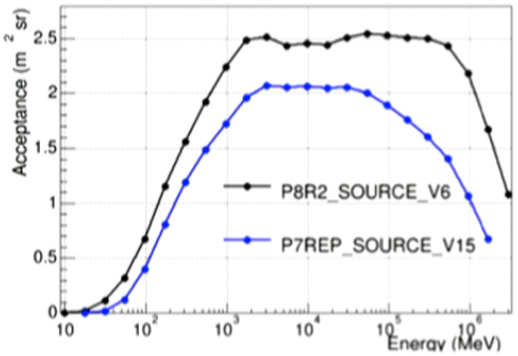
- Cascade component from reprocessed gamma rays cannot exceed the EGB spectrum itself
  - No or negative evolution is required

Happy 7th Birthday !!

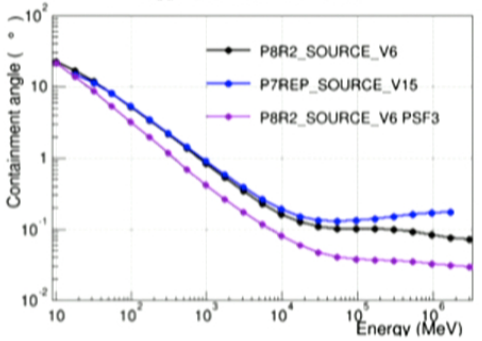
Fermi-LAT Catalogs

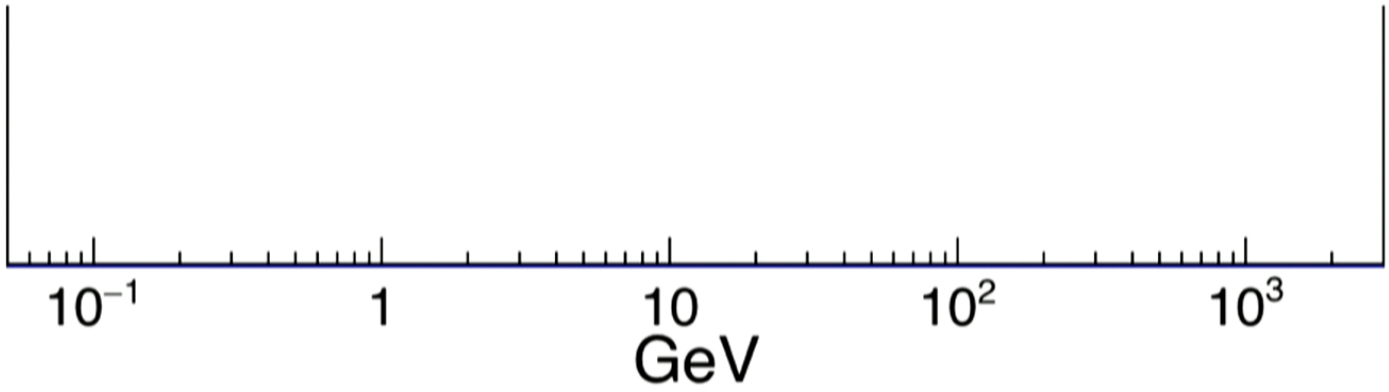
*n*FGL Catalogs detect and characterize sources in the ~0.1-100 GeV energy range

*n*FHL Catalogs explore the higher-energy sky



R68 Containment





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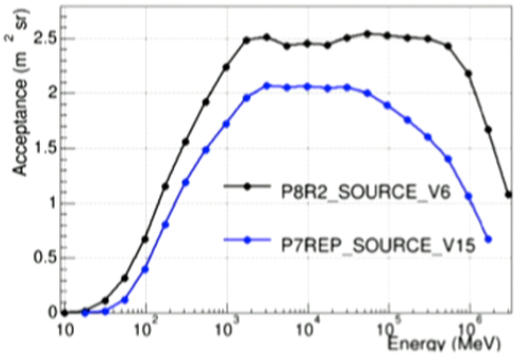
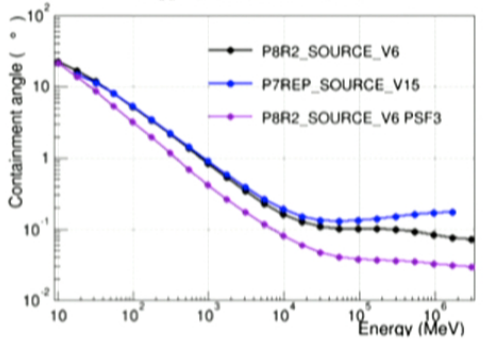
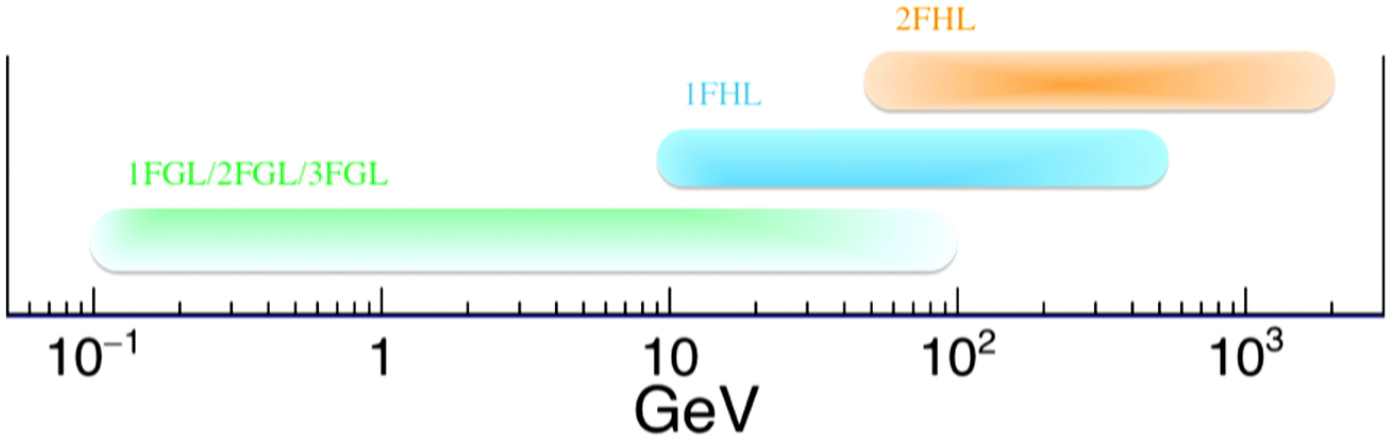


R68 Containment



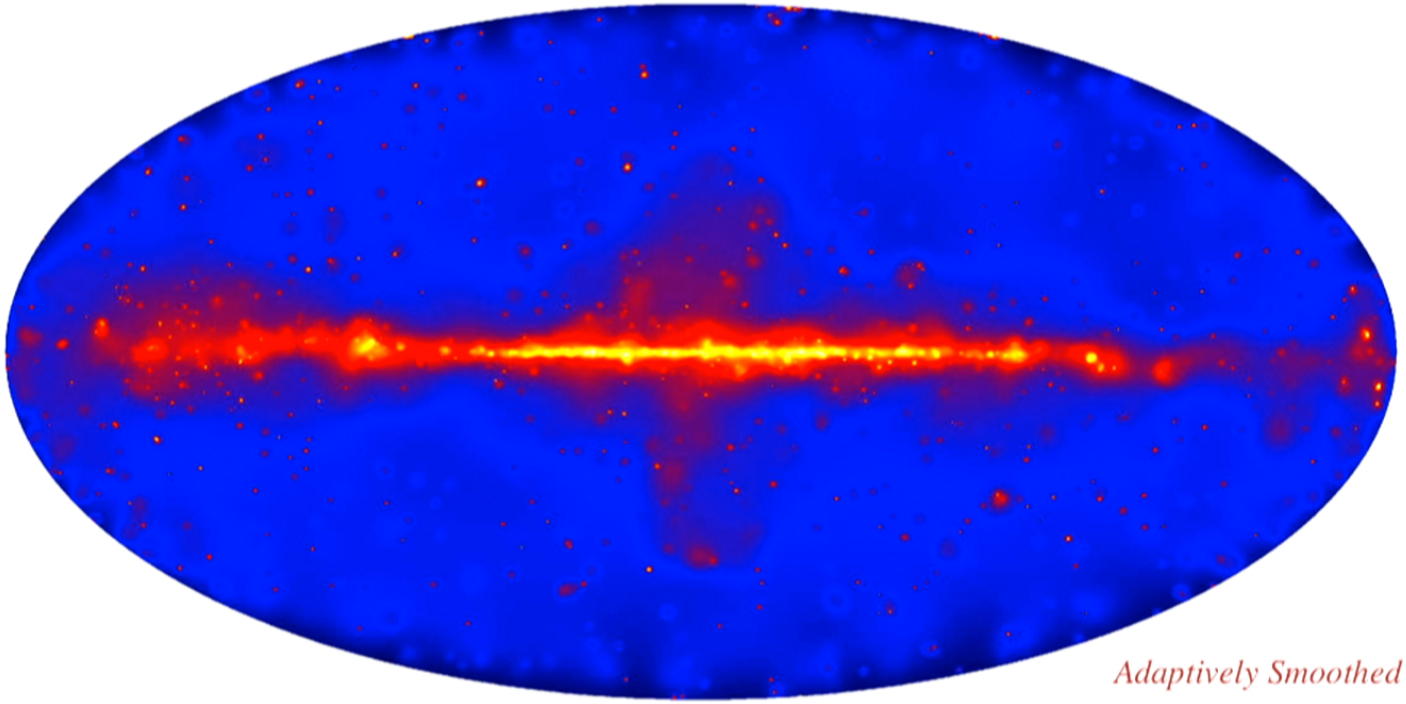


Count Map

80 months of P8 data (50 GeV – 2 TeV)

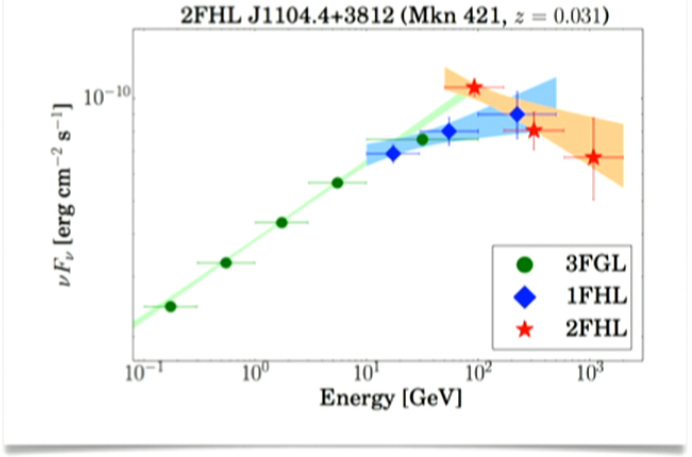
61,000 photons E > 50 GeV
22,100 photons E > 100 GeV
2,000 photons E > 500 GeV

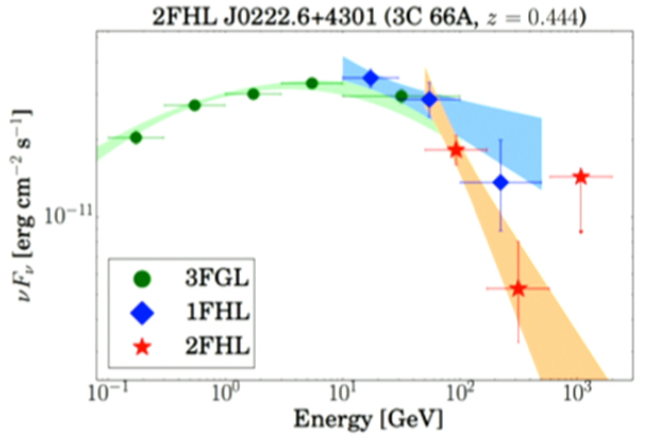
~1.5 photon every deg^2

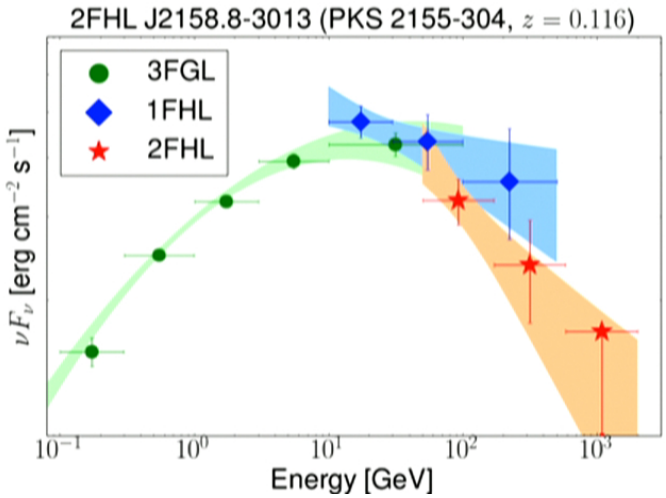


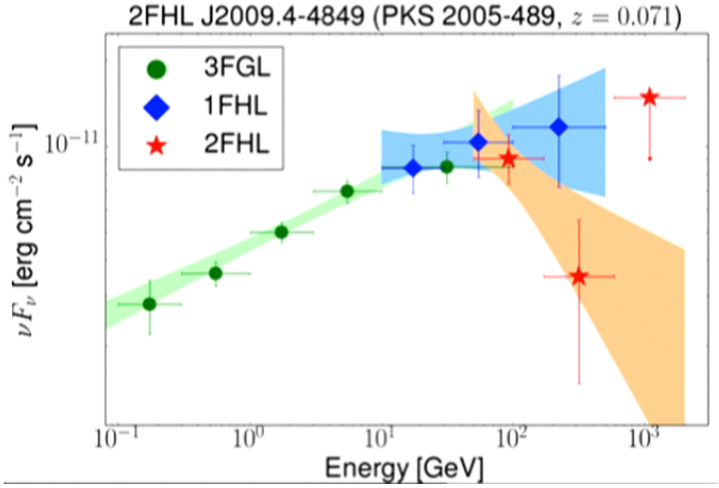
Adaptively Smoothed

Spectral Energy Distributions



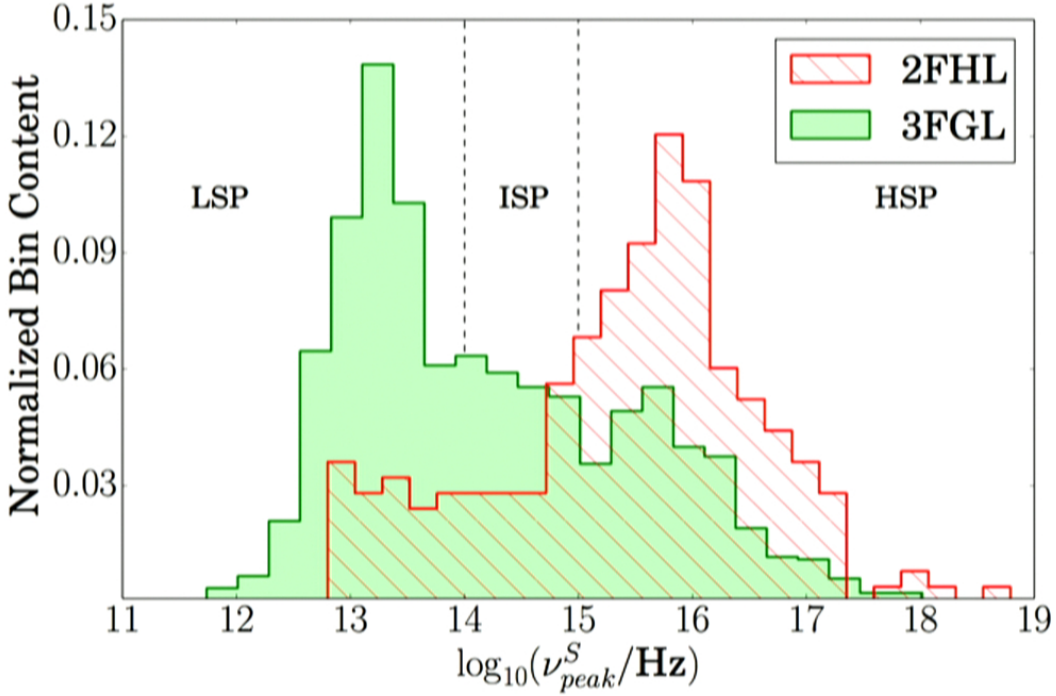




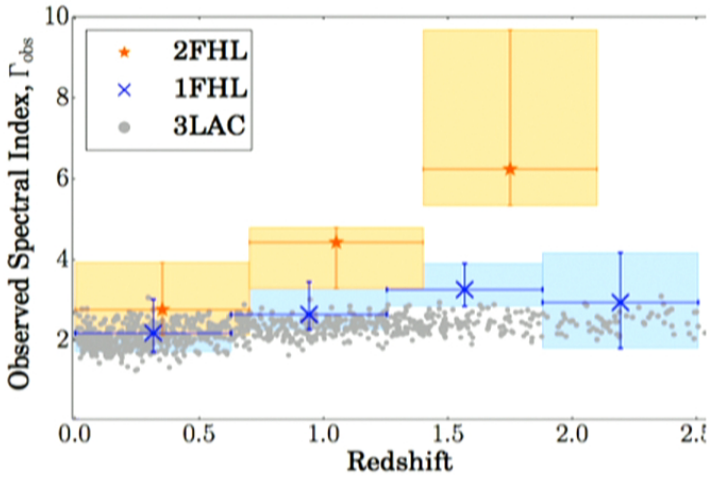


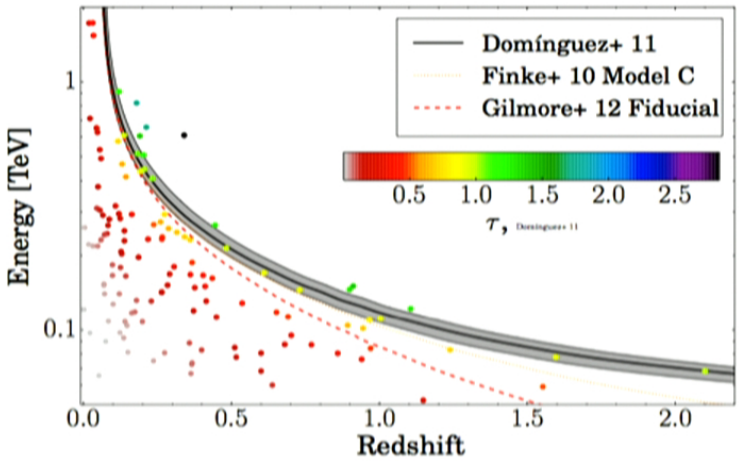
Blazars

- **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



Extragalactic Background Light: 1

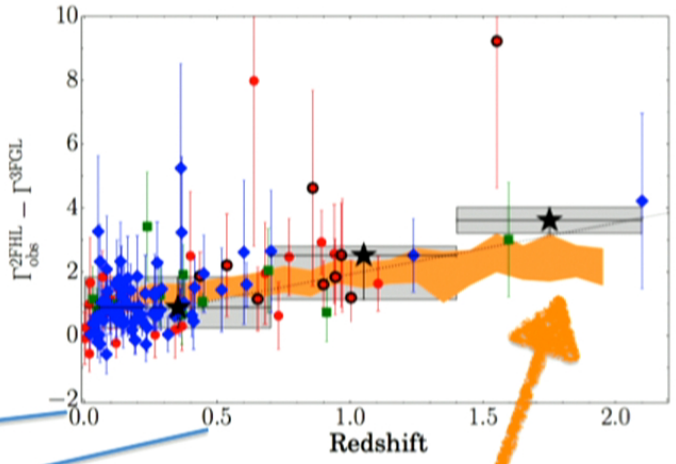


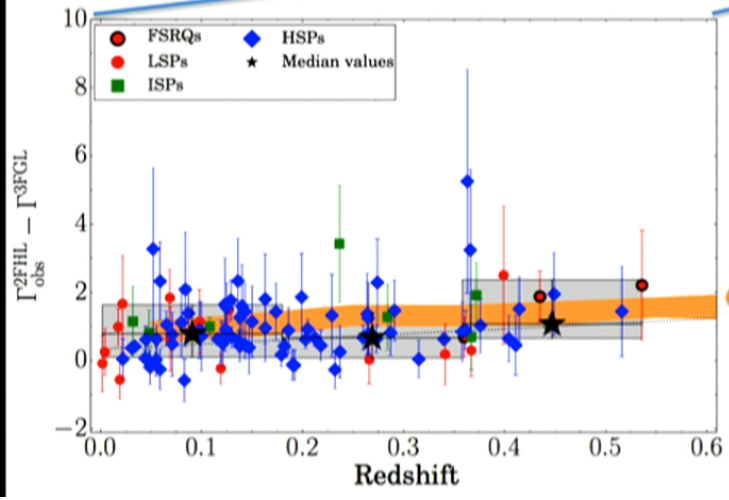


- **Evidence for strong softening of the 2FHL spectra with redshift**
  - Most likely due to EBL
- **Several photons detected beyond the horizon**
  - Very important to constrain the EBL

Extragalactic Background Light: 2

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



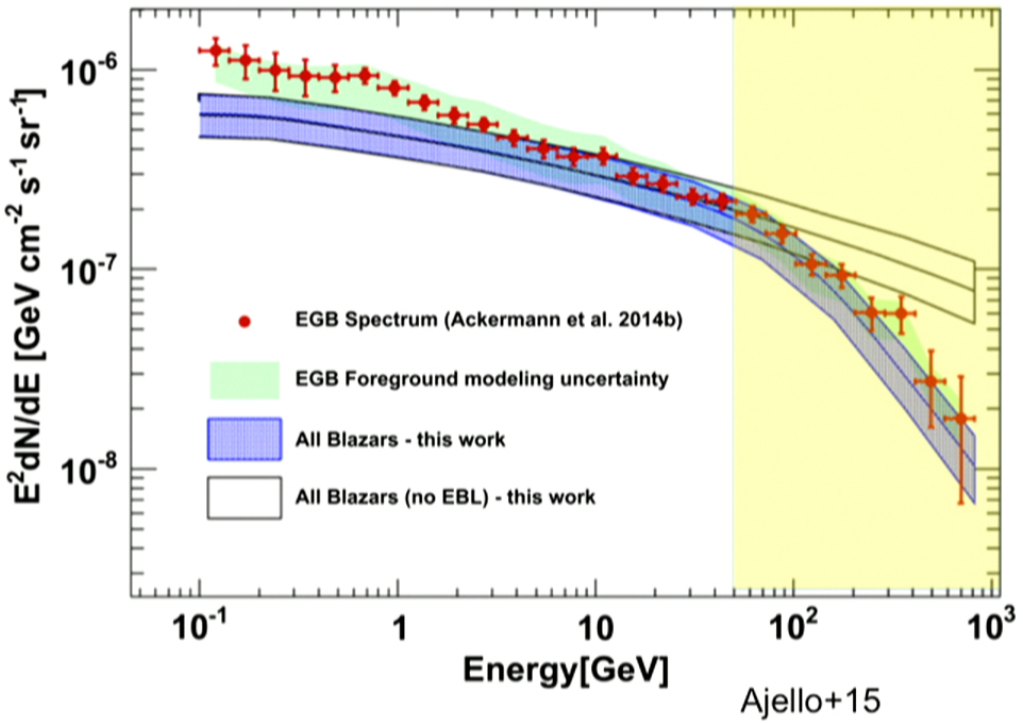


Simulations of SSC spectra absorbed by the EBL

Extragalactic Gamma-ray Background

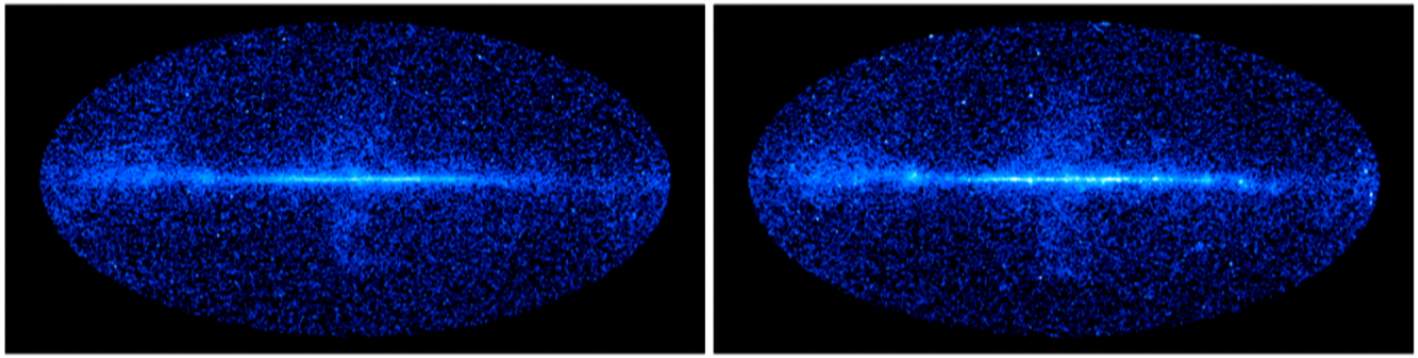
- **Models predict that the >50 GeV EGB is produced by blazars**

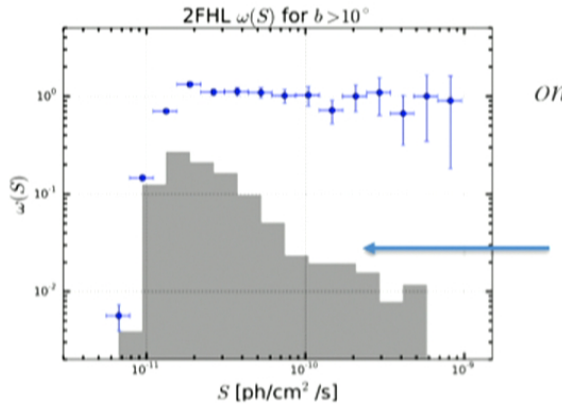
EGB: Ackermann et al. 2015, Models: Ajello+2015, Di Mauro+2015



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

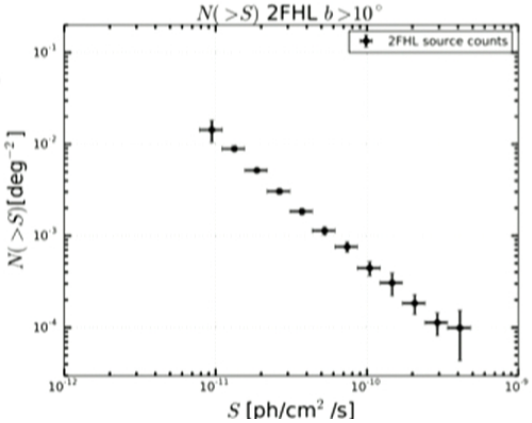




Di Mauro & Ajello
on behalf of the Fermi/LAT collaboration

Observed Flux distribution

PRL Accepted



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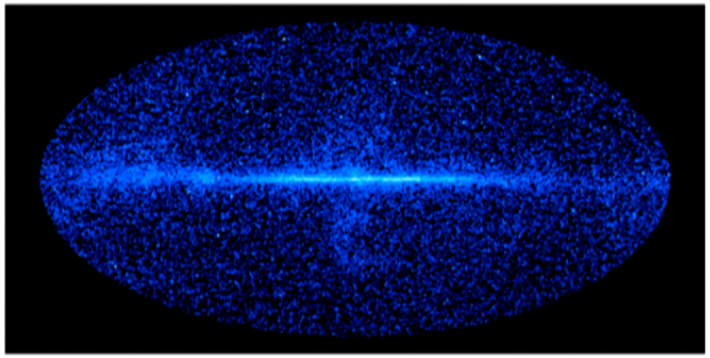

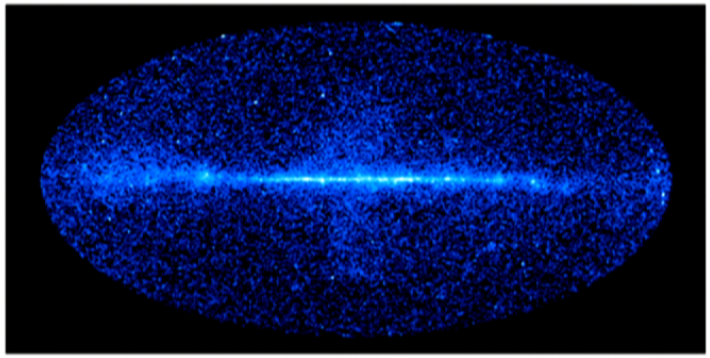

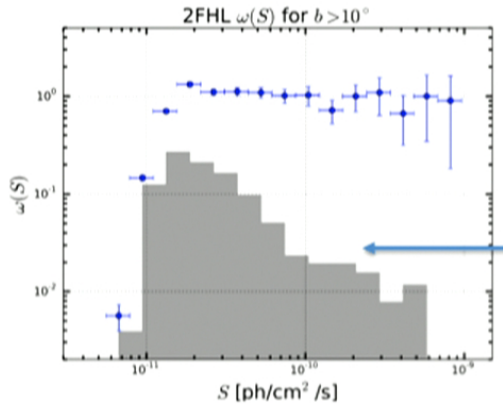

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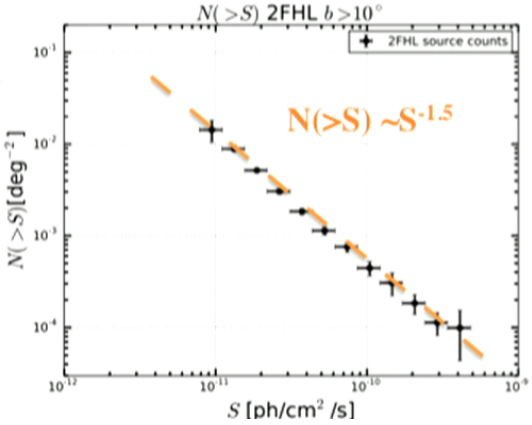
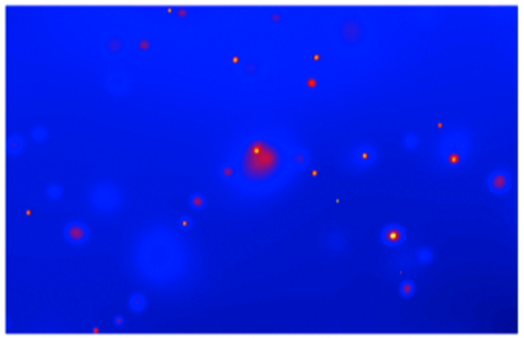
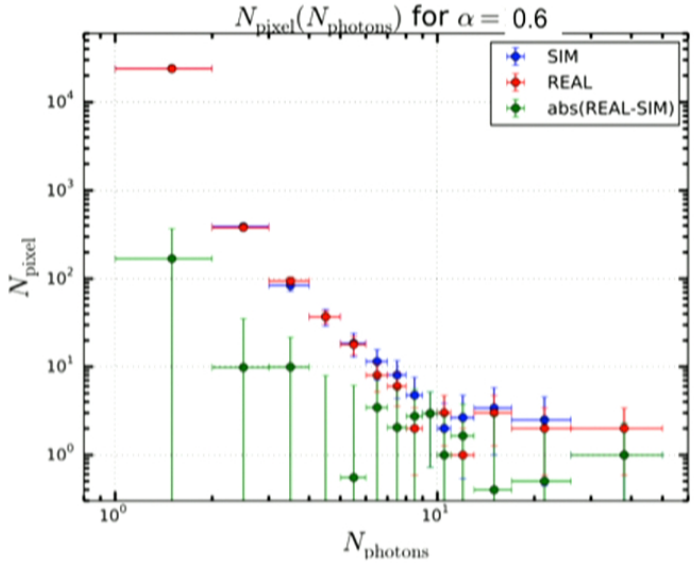


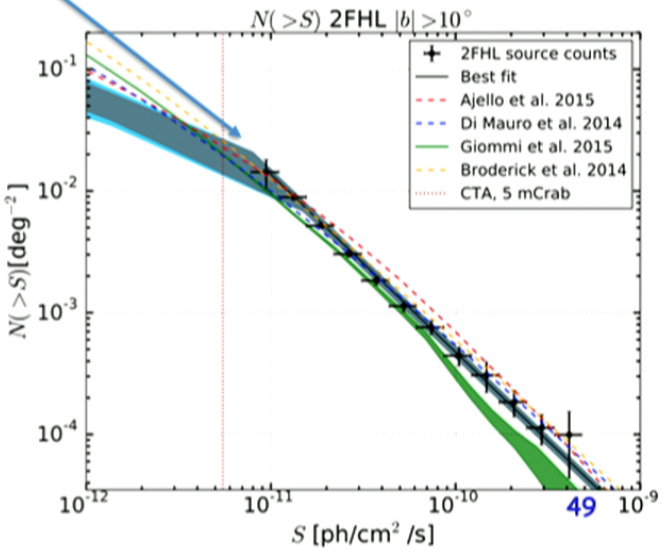
Photon Fluctuation Analysis

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



α = power law index below the break

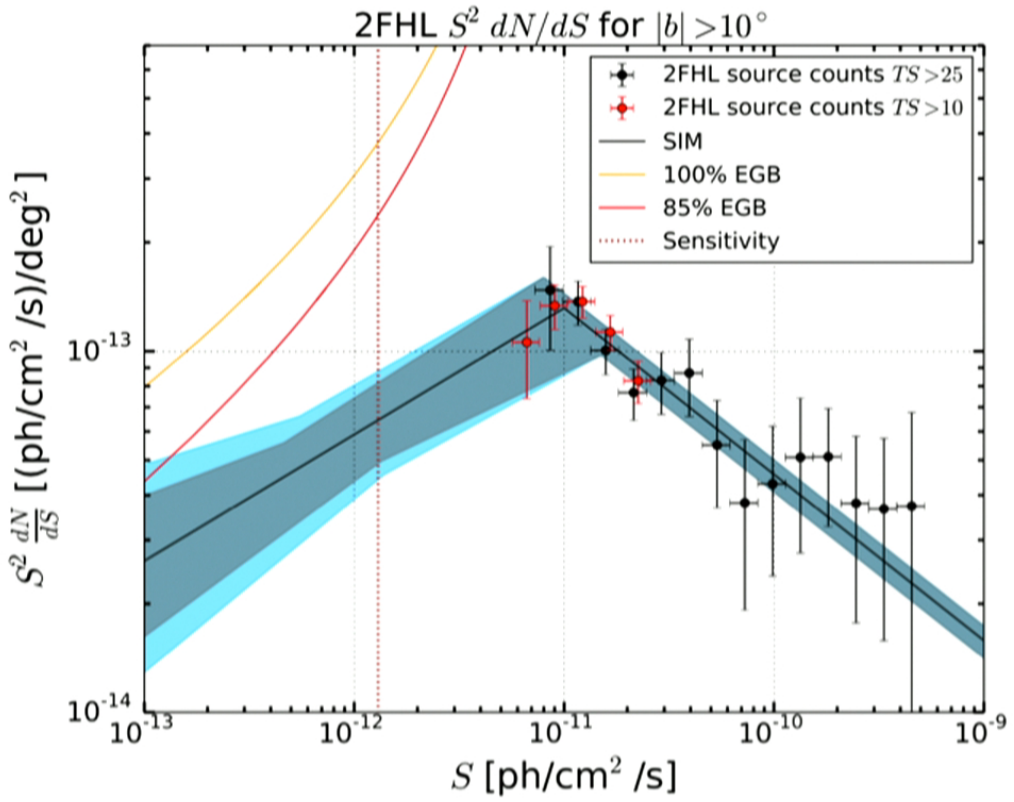




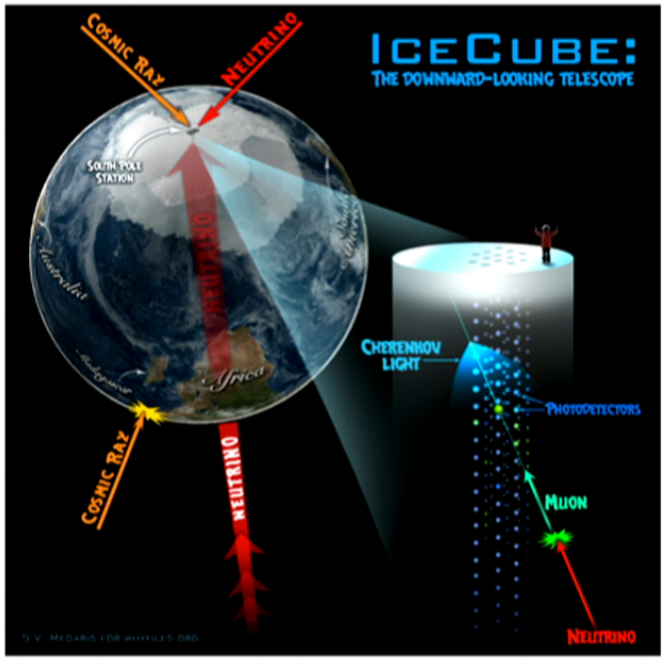
Results

- The 2FHL LogN-LogS resolves 86(+15/-18)% of the EGB

Nearly all the EGB is produced by BL Lacs

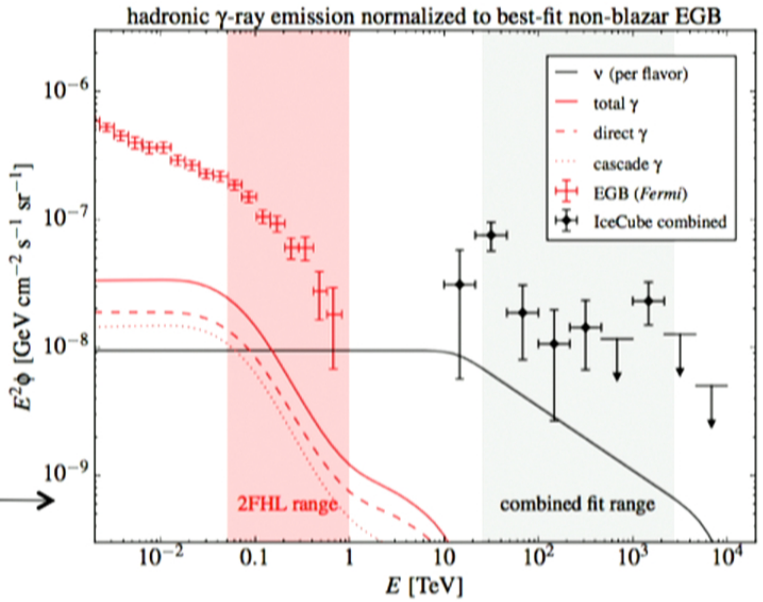


IceCube Neutrinos

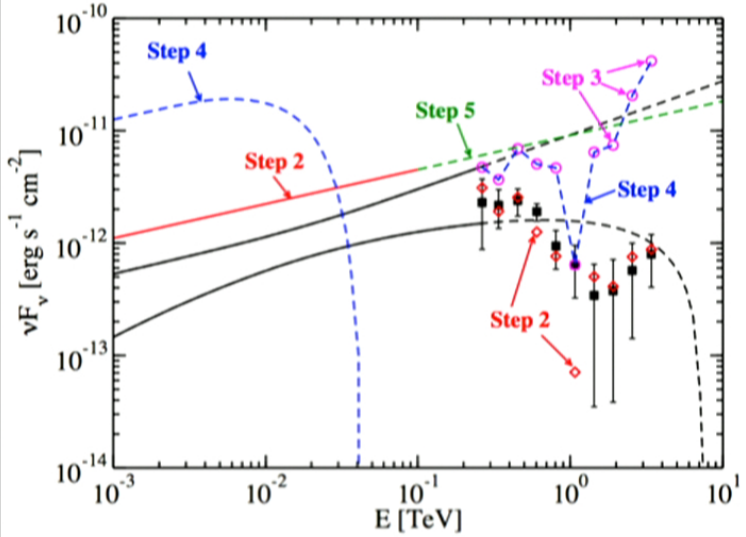


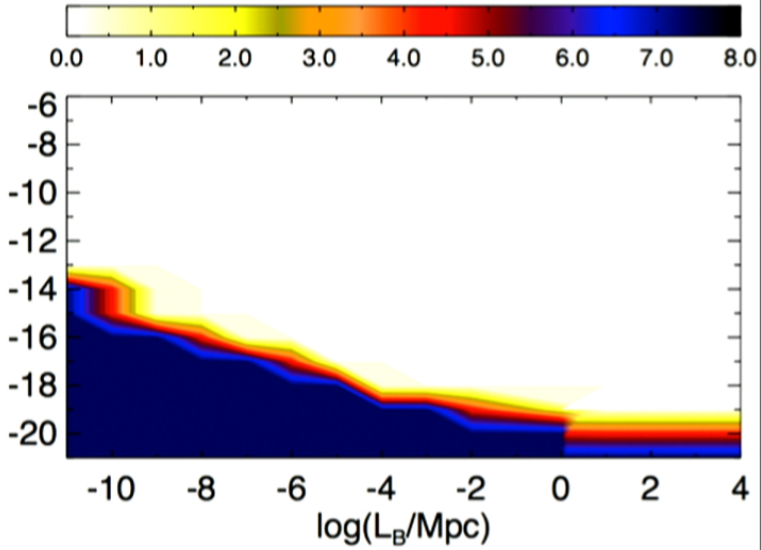
- IceCube reported the detection of astrophysical PeV neutrinos (Aartsen 2015, ApJ, 809,98)
- Star-forming galaxies are a primary candidate *PRL submitted*

2FHL limits the contribution of star-forming galaxies to the neutrino background →



IGMF/Cascade Constraints

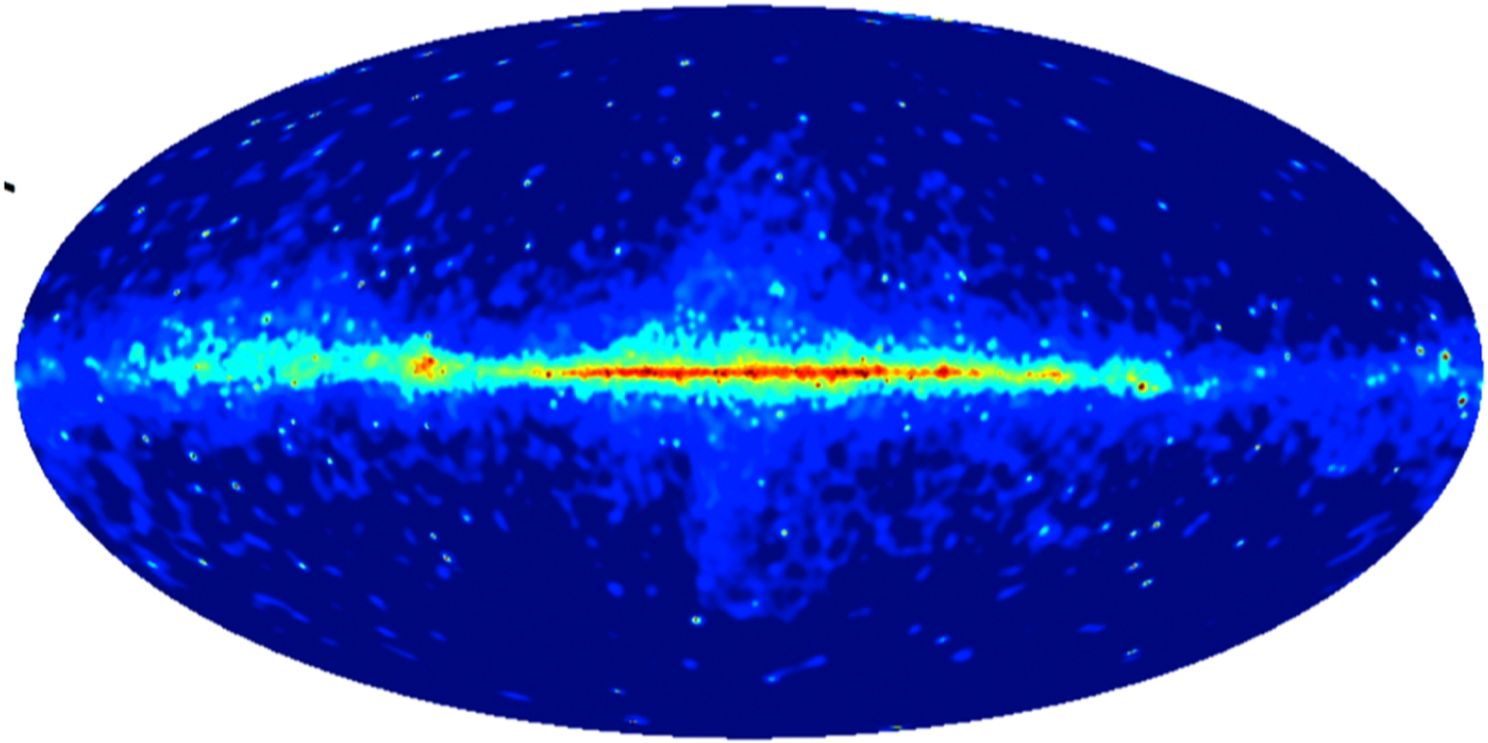




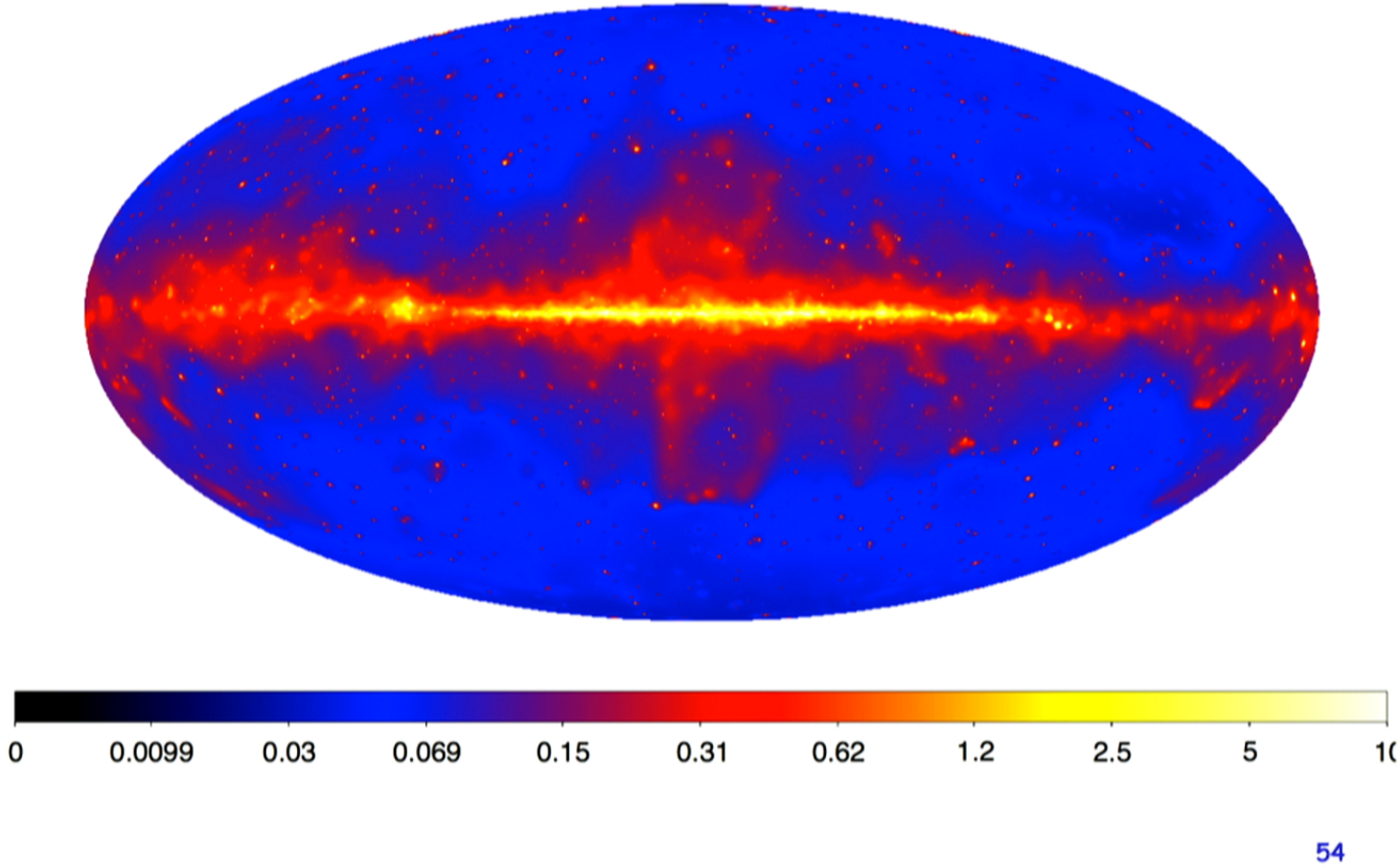
- Analysis of the GeV-TeV spectra of 5 BL Lacs yields robust lower limit on the IGMF strengths for any parameter choice (Finke+15, arxiv: 1510.02485v1)

- **Most importantly:**
  - **The cascade component in these rather hard blazars is <10%**

1FHL Catalog (>10 GeV, 3yrs)



3FHL Catalog (8yrs, >10 GeV)



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Conclusions

- Blazars produce 50% of the EGB and likely 100% of the anisotropies
- Within uncertainties (peak E, B strength etc), cascade component seems unimportant
  - And might not exist after all
- BL Lac evolution is slow if not negative
  - Negative evolution is 'interesting', if not unexpected
    - Make sense if BL Lacs are drawn from FRI
    - FRI are mostly found in clusters
  - Some tension might arise if the EGB if strong positive evolution is in there
- High redshift hard BL Lacs exist
  - Great for EBL, blazar heating etc.

Finally: don't forget selection effects