The third *Fermi* catalogues of gamma-ray sources and active galactic nuclei

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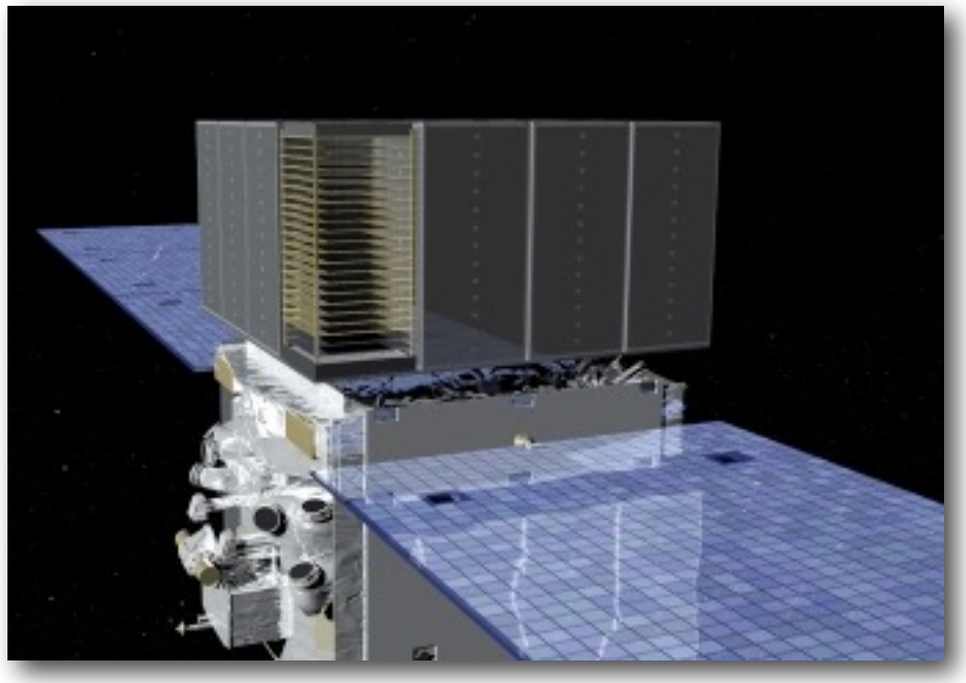
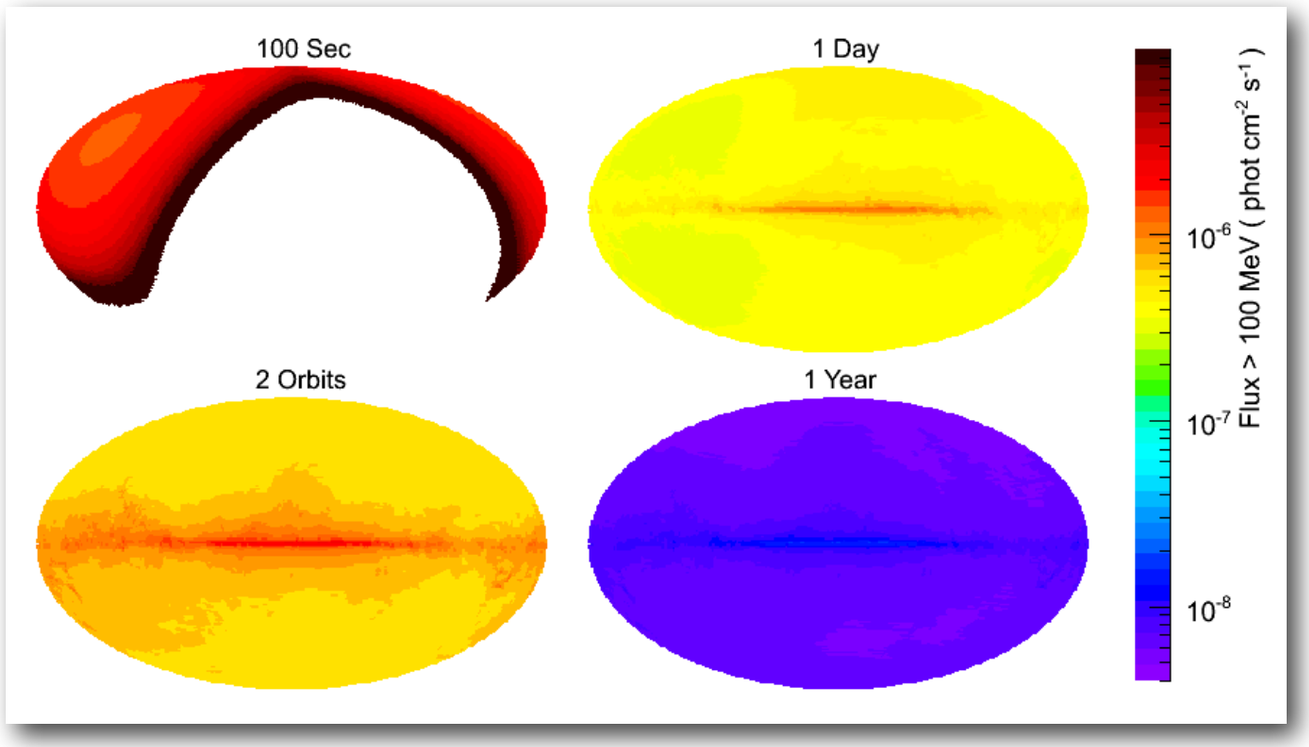
Outline

- **Introduction: *Fermi* and gamma-ray surveys**
- **The third catalogue of gamma-ray sources (3FGL)**
- **The third catalogue of gamma-ray AGNs (3LAC)**
- **Cross-matching high energy and low frequency data (3LAC-MWACS)**

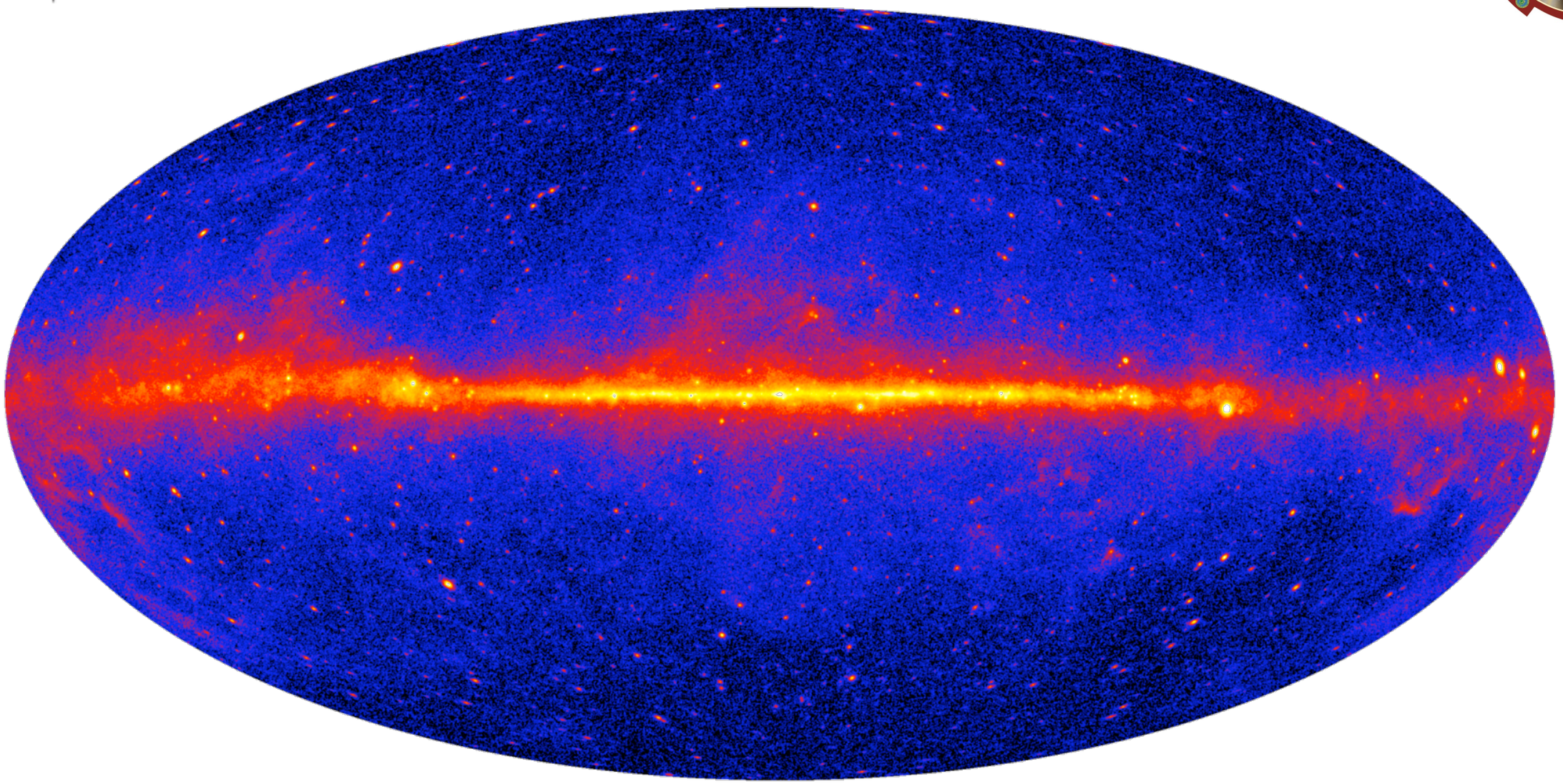
The Large Area Telescope (LAT) onboard *Fermi*

- **A gamma-ray telescope launched in June 2008**
  - **20 MeV - 300 GeV photon energies**
  - **2.4 steradian field of view**
  - **A_{eff}:~8000 cm^2 at 1 GeV**
  - **PSF: $\theta_{68\%}$~0.8° at 1 GeV**
  - **altitude: 565 km, inclination: 25.6°**
  - **91 min orbital period: views the entire sky every ~3 hours and provides uniform sensitivity over whole sky in ~day time scale. Great opportunities for**
    - **transients**
    - **MWL campaigns on single sources**
    - **all sky survey and population studies**
  - **public data, available within 12 h**
  - **operation guaranteed until 2018**





The Third *Fermi* gamma-ray source catalogue (3FGL, Acero et al. 2015 ApJS)



- 4 years of survey data
- Energy range 100 MeV - 300 GeV
- 3033 sources
  - 2192 at |b|>10°
  - 1100 un-associated
  - 25 spatially extended

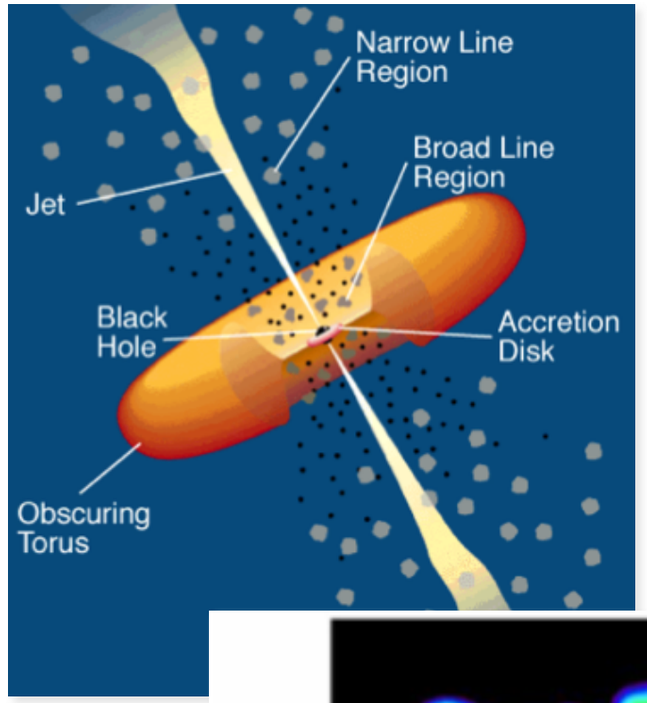
Evolution of *Fermi* catalogues

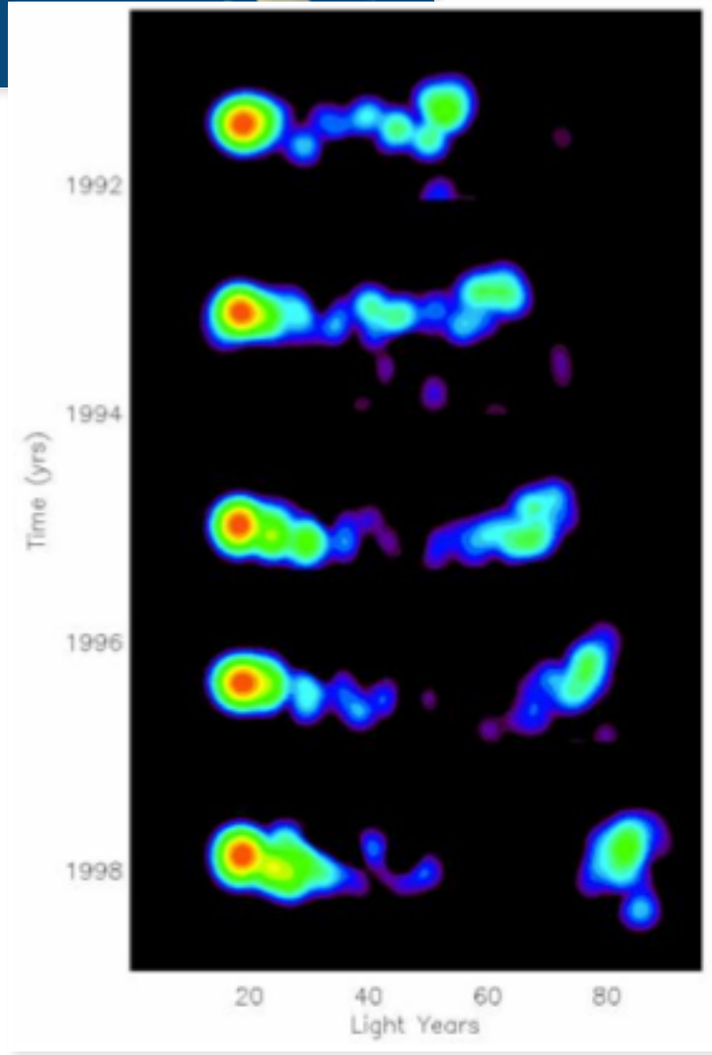
catalogue	integration	#sources	% of unassociated sources	reference
0FGL	3 months	205	18%	Abdo et al. (2009)
1FGL	11 months	1451	43%	Abdo et al. (2010)
2FGL	2 years	1873	31%	Nolan et al. (2012)
3FGL	4 years	3033	33%	Acero et al. (2015)

- Catalogues improve not only thanks to longer exposure but also to improved analysis method
  - instrument characterisation, diffuse model, counterpart catalogues, etc.
- Each catalogue is accompanied by an AGN catalogue
  - 0LAC, 1LAC, 2LAC, 3LAC (later slides)
- Other catalogues have been produced focused on specific classes or energy ranges
  - hard sources, pulsars, GRBs

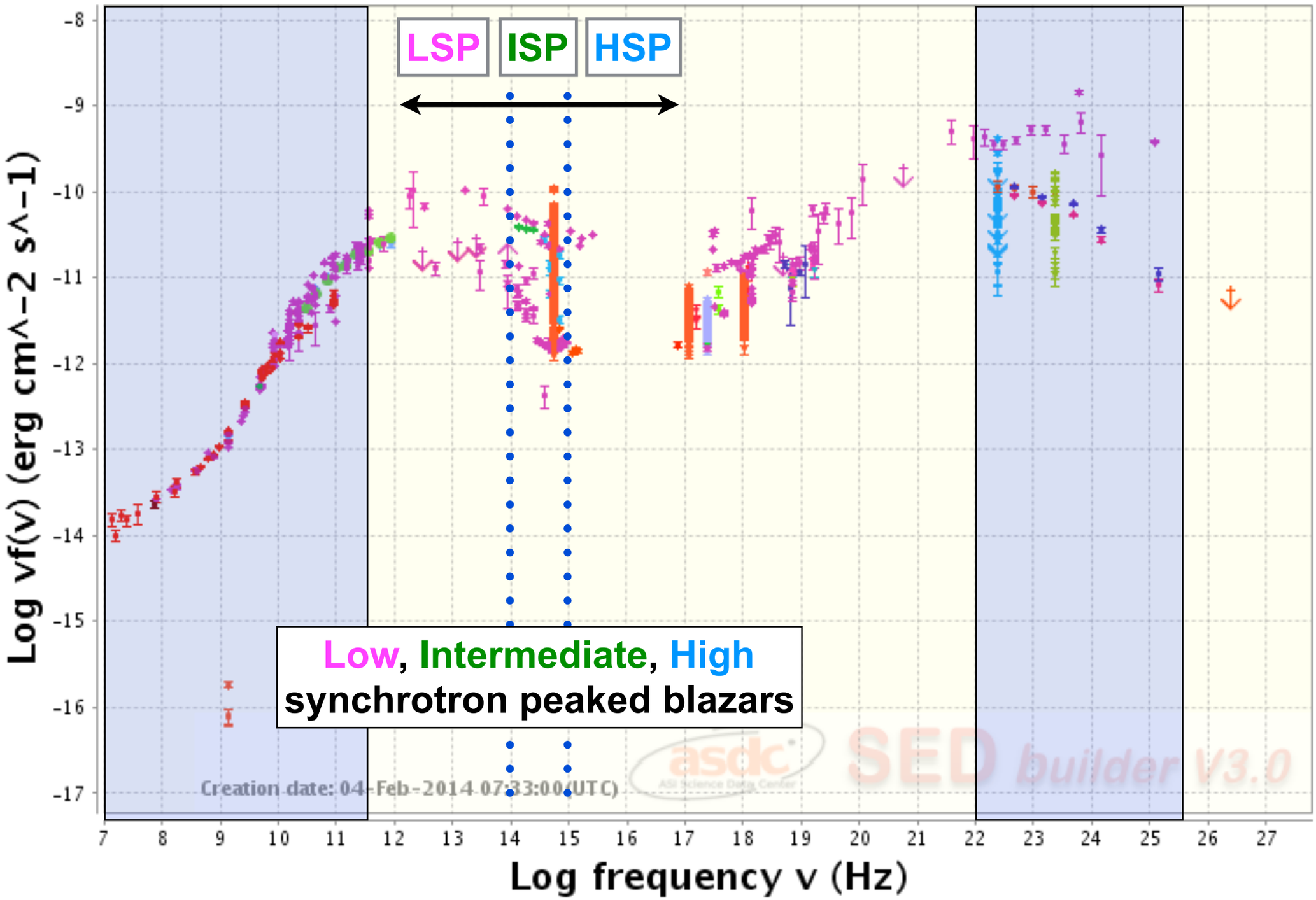
a quick blazar introduction

- **Blazars=flat spectrum radio quasars (FSRQ)+BL Lac type objects (BLL)**
- **beamed counterparts of radio galaxies, dominated by emission from relativistic jets powered by accretion on SMBH**
  - **FSRQ: strong lines in optical spectra, prominent accretion disk signature, high radio and bolometric luminosity (FR2 counterparts), “red” SEDs**
  - **BLL: weak or no lines, radiatively inefficient accretion disk, low luminosity (FR1 counterparts), “blue” SEDs**



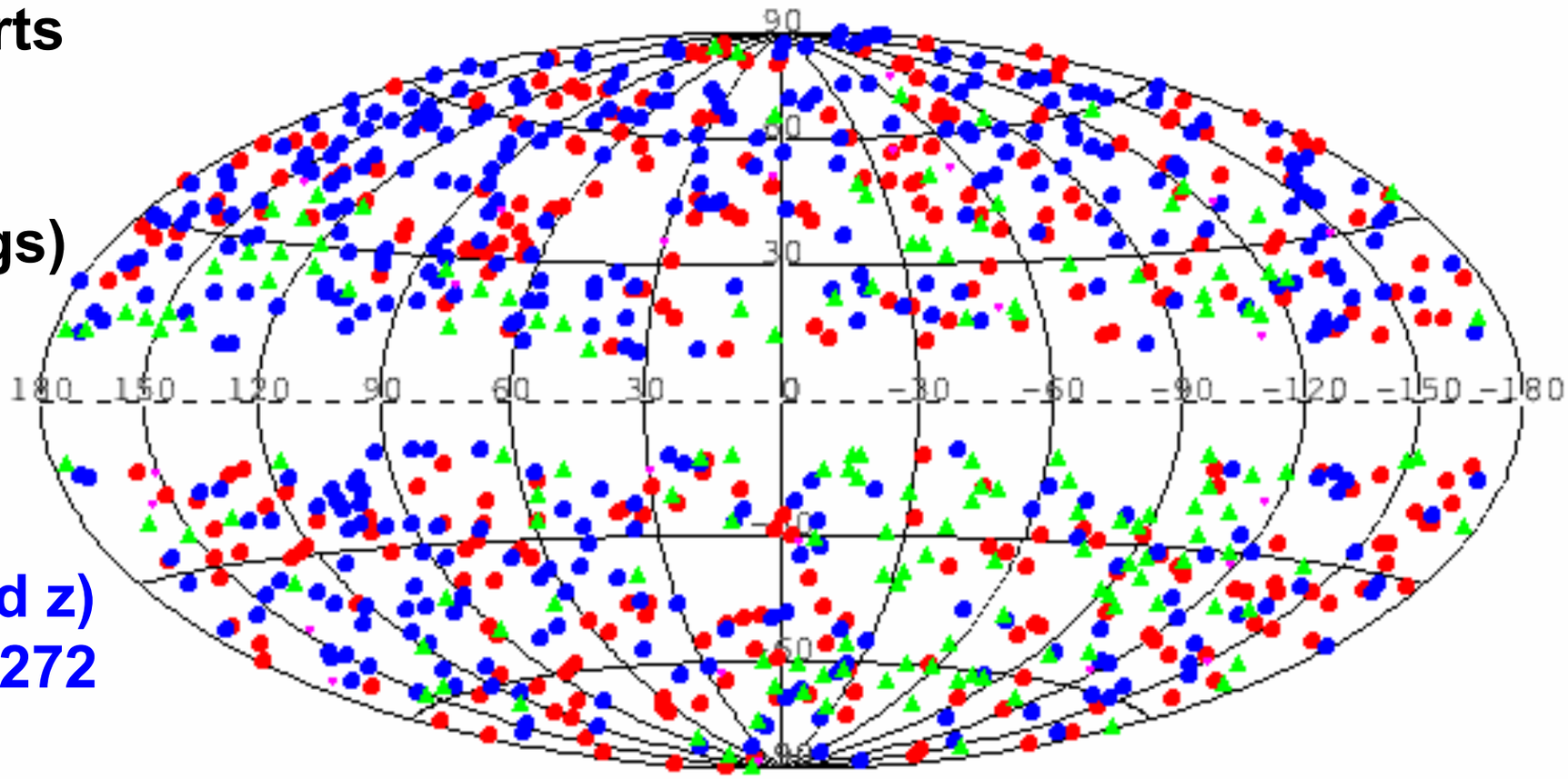


blazar spectral energy distribution (SED)



The Third LAT AGN catalogue (3LAC, Ackermann et al. 2015, ApJ 810, 14)

- 48 month data set
- 2192 TS>25, |b|>10° sources
- 3LAC: 1591 counterparts
  1563 sources
- 1444 AGNs in *Clean Sample* (no dup., no flags)

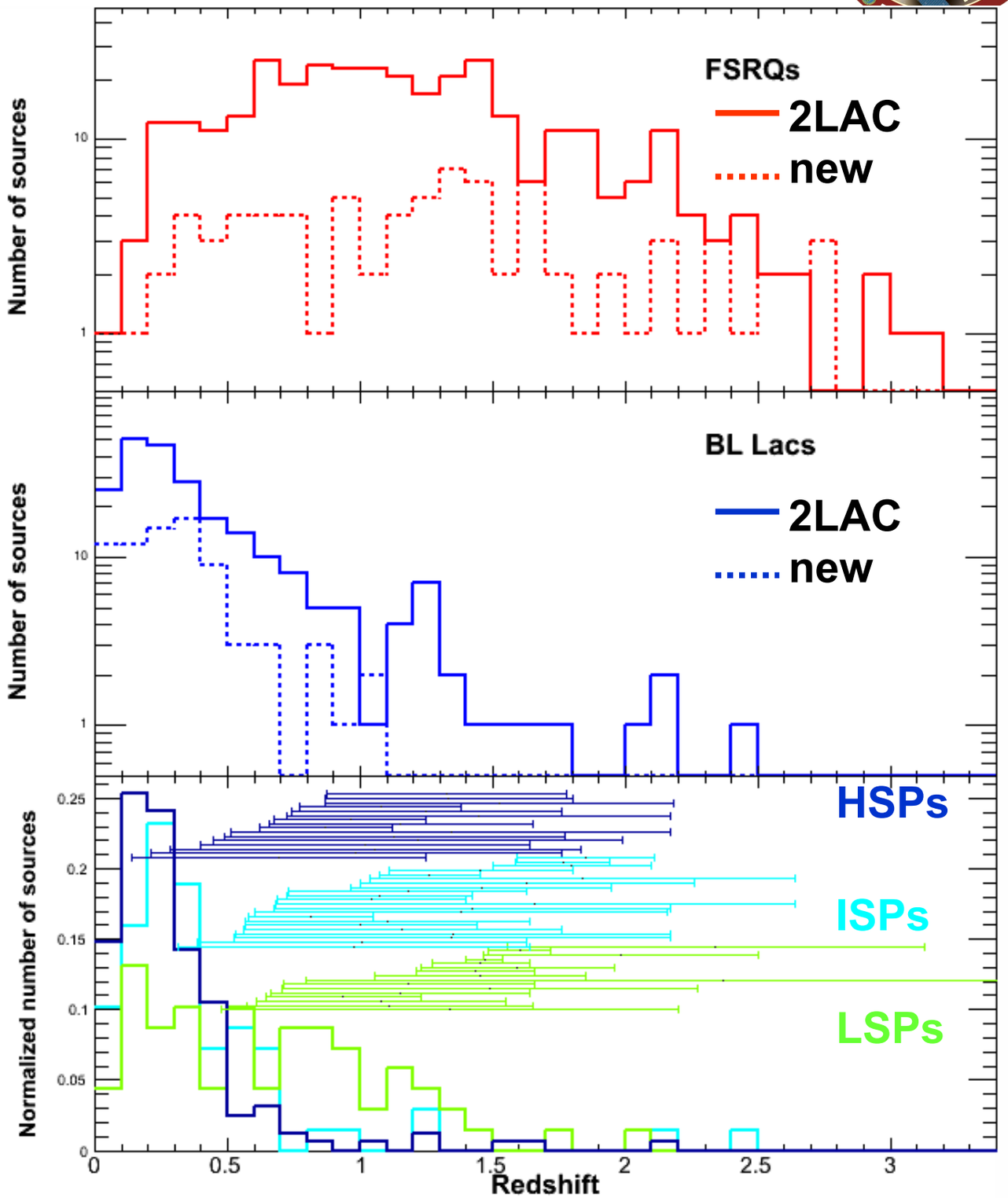


- Census :
  - 415 FSRQs
  - 602 BLLacs
    (~50% with measured z)
    162 LSPs, 178 ISPs, 272 HSPs, 20 no class.
  - 413 of unknown type (BCUs)
  - 23 other AGNs

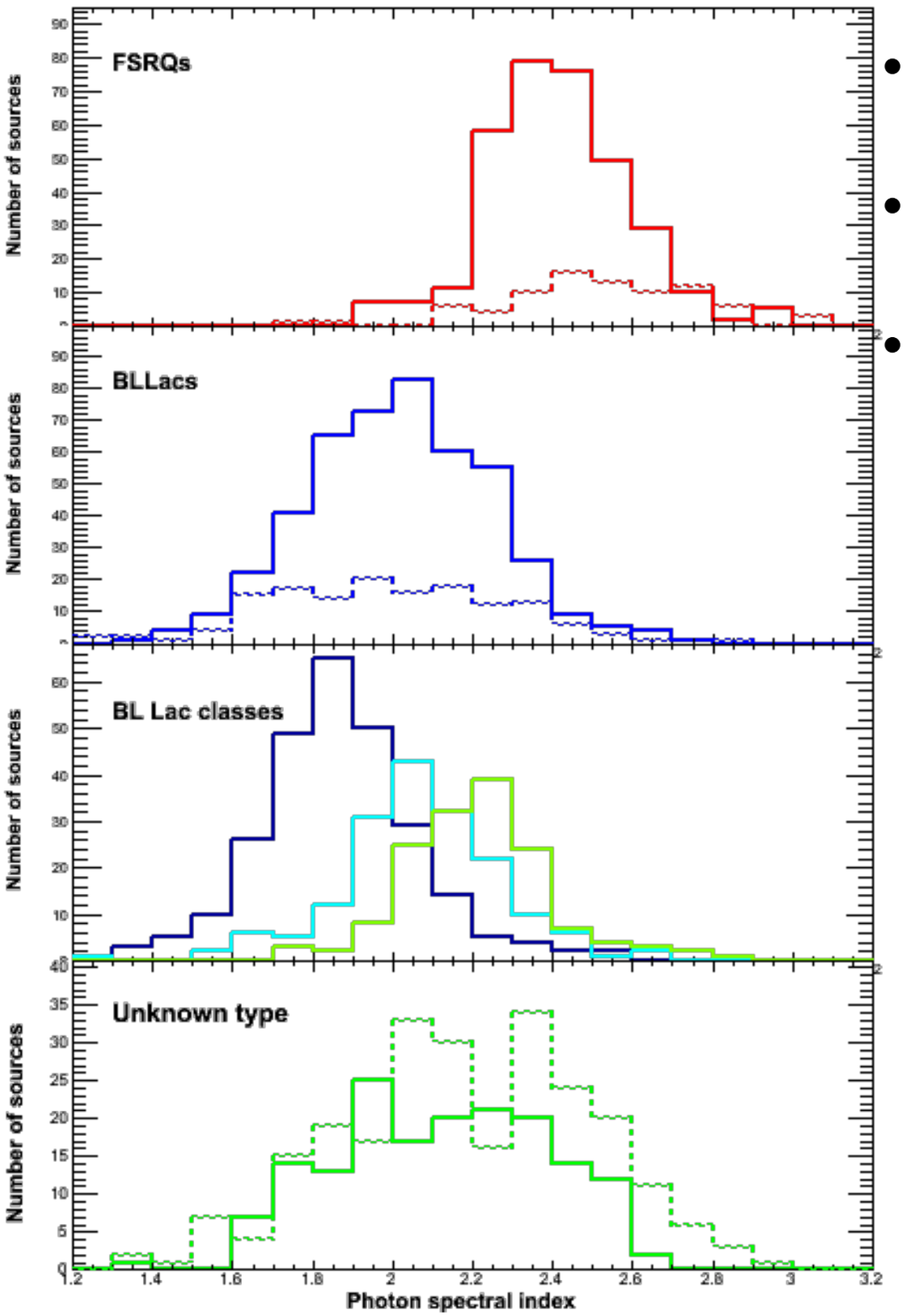
- Differences between Northern and Southern Hemispheres:
40% of BL Lacs in Southern Hemisphere

Redshifts

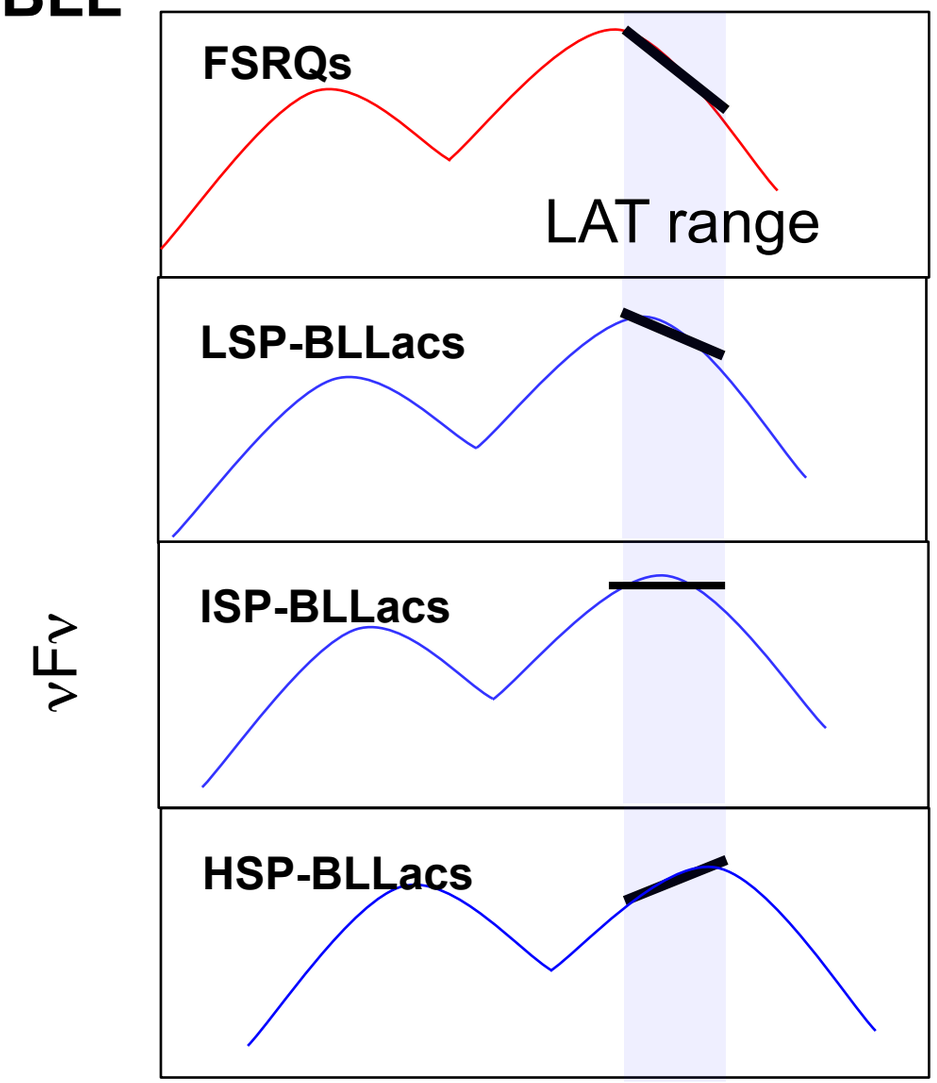
- slightly higher z for new FSRQs relative to 2LAC ones
  - <z>=1.33 vs. 1.17
  - maximum redshift still z=3.1
- 295/604 BL Lacs have no measured redshifts (55%, 61%, 40%) for (LSPs, ISPs and HSPs)
  - 134 constraints from Shaw et al. (2013)
  - Redshift limits for BL Lacs not compatible with measured redshifts
    - measured redshifts are biased low
    - Are many BL Lacs FSRQs with emission lines swamped by the non-thermal continuum?



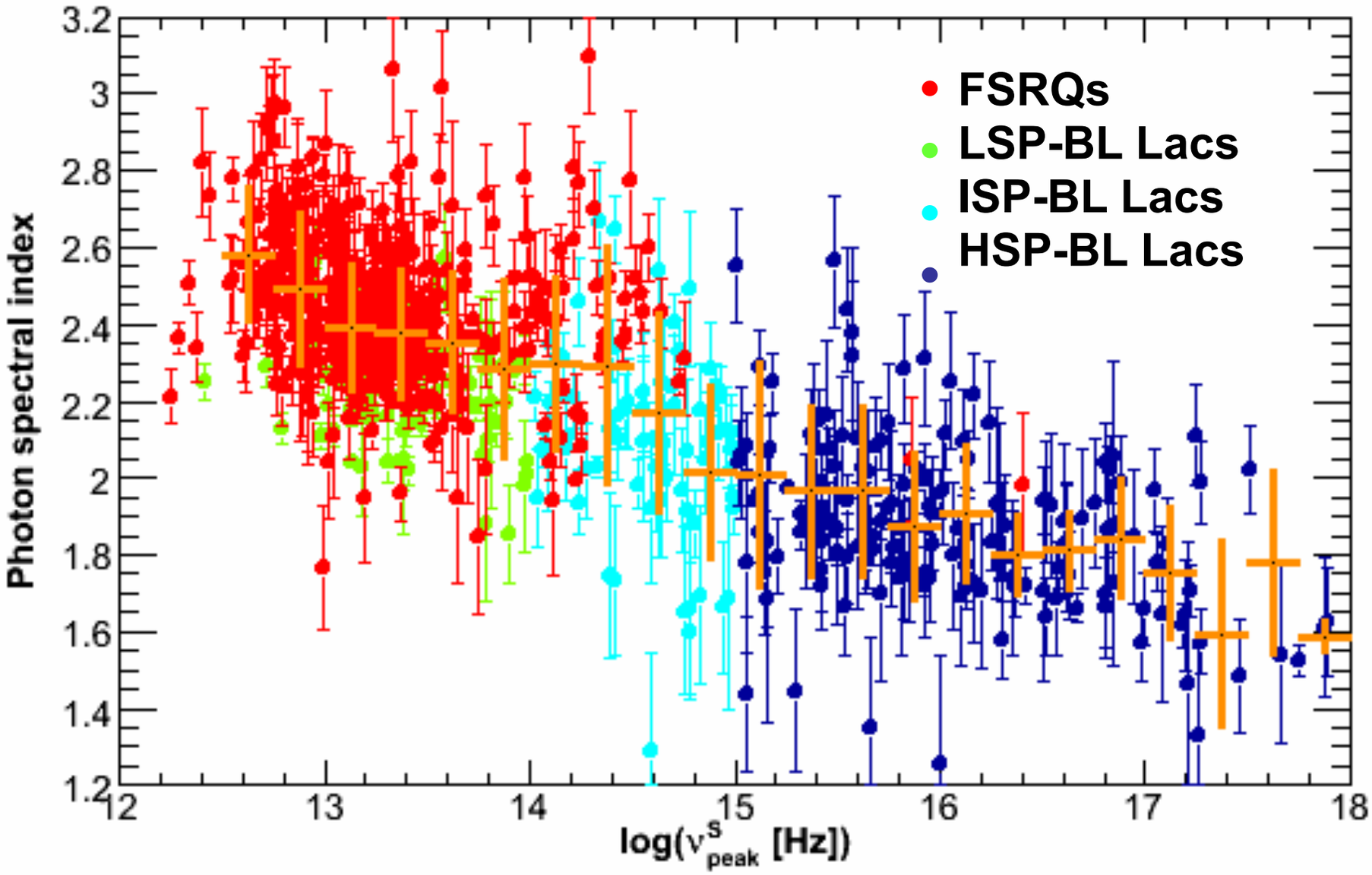
Photon index and spectral curvature



- Little overlap between FSRQ and BLL
- New FSRQ slightly softer than 2LAC ones: <Γ>=2.53 vs. 2.41
- BCU spectral index distribution straddling the two classes
- significant spectral curvature in 91 FSRQ and 32 BLL

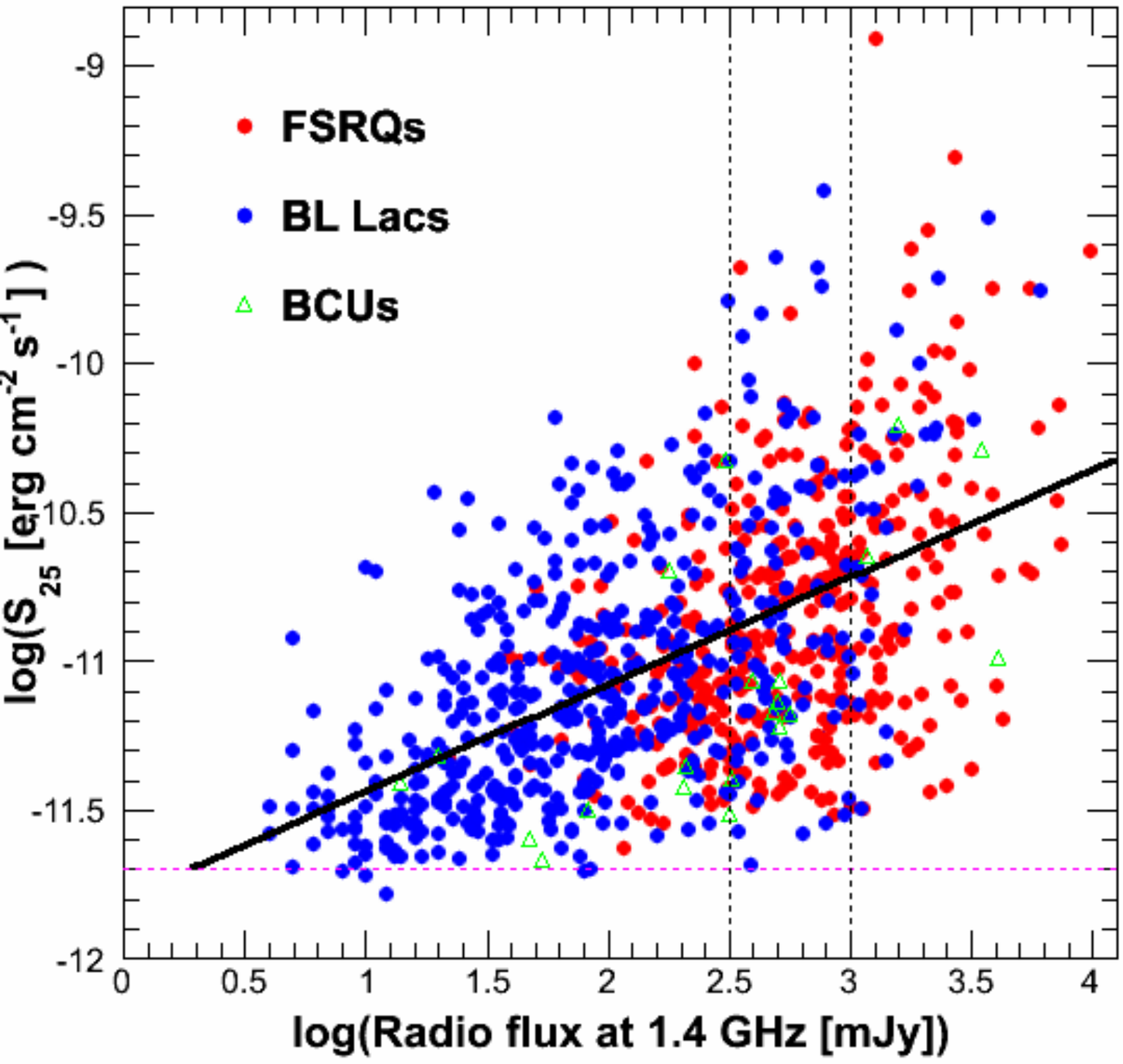


Spectral photon index vs ν_{peak}

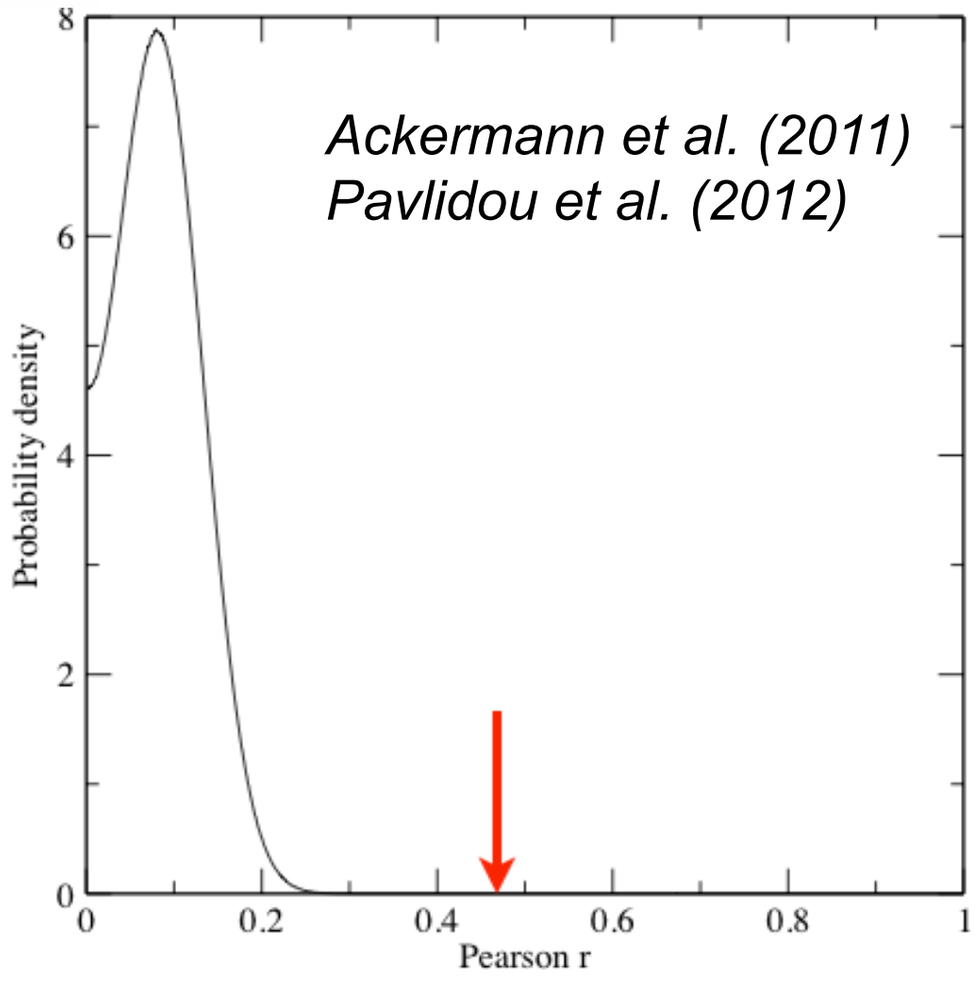


- Correlation between spectral hardness and vpeak confirmed
- Lowest index~1.5, as predicted by shock-acceleration models
- Same correlation applies to BCUs

Radio/gamma-ray connection



- **Pearson coefficient: 0.52**
  - **was 0.47 for 1LAC**
  - **which implied a chance correlation p<1e-7**
  - **also for FSRQ and BLLacs separately**



Improving association methods

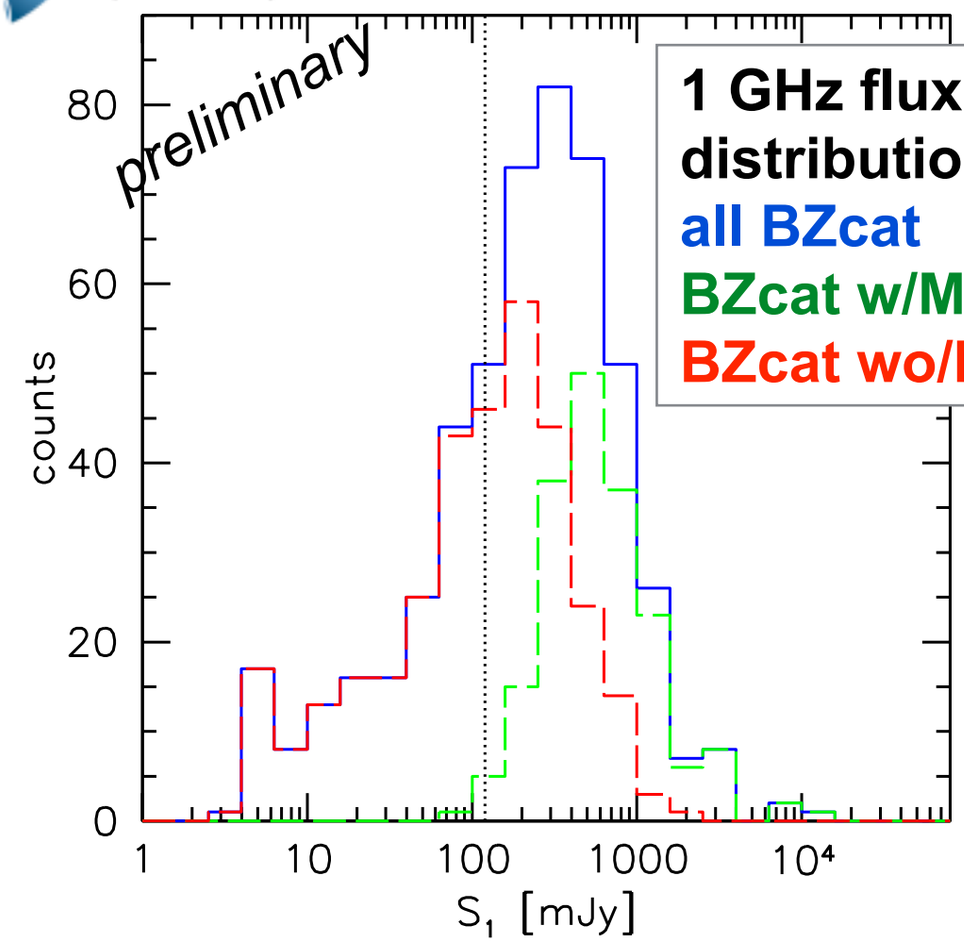
- In 3FGL, still a ~1/3 unassociated fraction (>1000 sources!)
- Association of high energy sources to low energy counterparts is generally based on chance of random spatial coincidence
  - works well for medium-bright gamma-ray sources
  - low gamma-ray fluxes ~ low radio flux densities ~ high space density
  - low gamma-ray fluxes ~ large positional uncertainties
    - so: way too many candidates if we only consider spatial coincidence
- Need to add some physics, e.g. VLBI detection, low frequency spectral index, IR colors
  - e.g. Massaro et al. (2013), Nori et al. (2014), Schinzel et al. (2013), Lico et al. (in prep.)

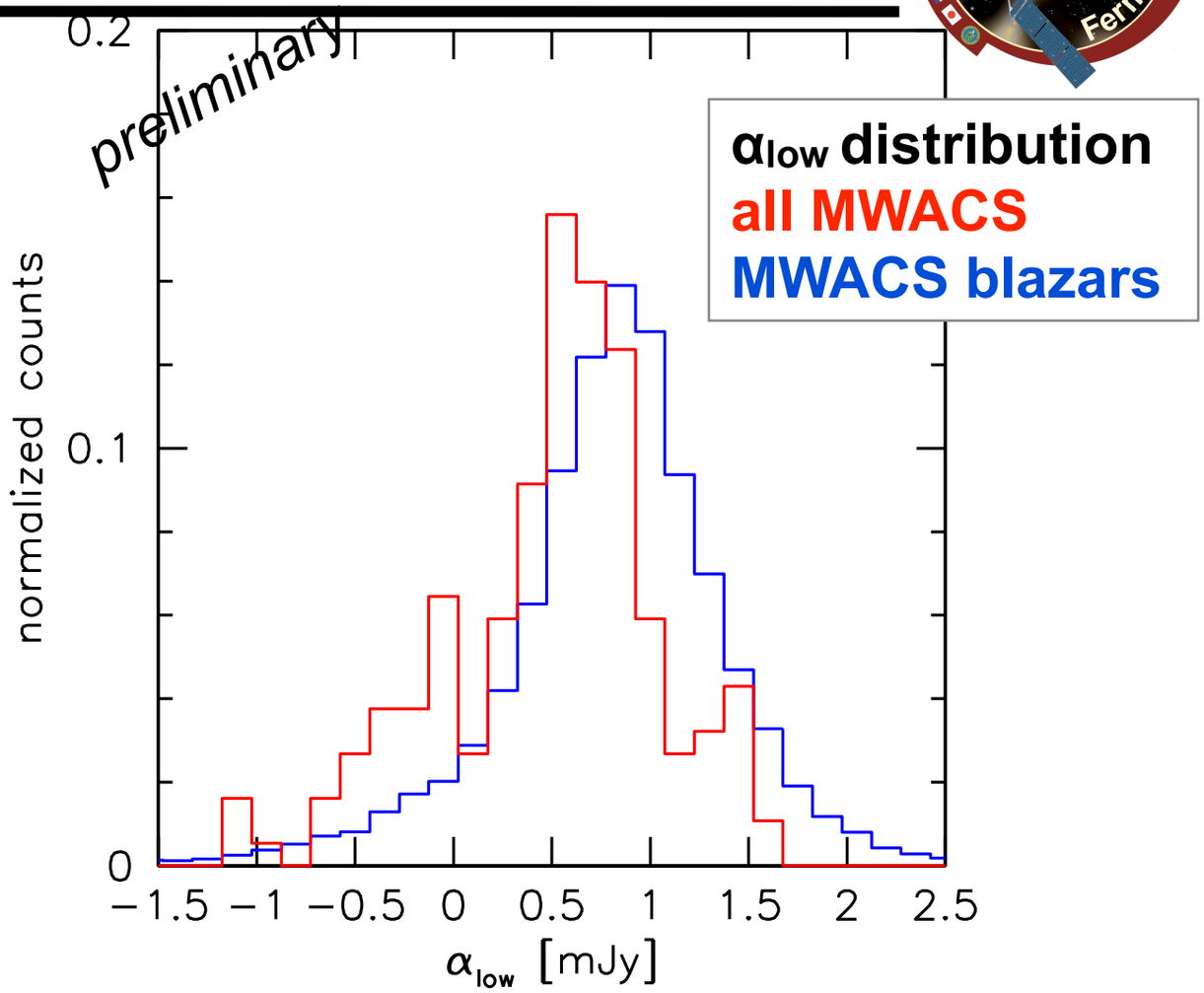
3FGL-MWACS cross-correlation

- **Waiting for SKA and other pathfinder/precursor surveys**
  - **MWA commissioning survey (MWACS, Hurley-Walker et al. 2015)**
  - **simultaneous 120, 150, 180 MHz data**
  - **6100 sq deg**
  - **120 mJy limiting sensitivity, 3' angular resolution**
  - **14110 sources… how many (gamma-ray) blazars?**
    - **186 from BZCat (over 517 sources in same sky area)**
    - **88 from 3LAC (over 249)**
    - **given relatively large flux density threshold, mostly are FSRQs**

	BZCat		3LAC	
Total	186/517	36%	88/247	35%
FSRQ	147/327	45%	52/71	73%
BLLacs	23/153	15%	19/87	22%
BCU	16/37	43%	8/16	50%
candidates	—	—	8/73	11%

Spectral properties





- From the BZCat, MWACS detects preferably the brightest blazars
- however, there are several undetected BZCat sources that have $S_{1\ GHz}$ larger than the MWACS threshold (dotted line)
  - these must be inverted-spectrum sources!

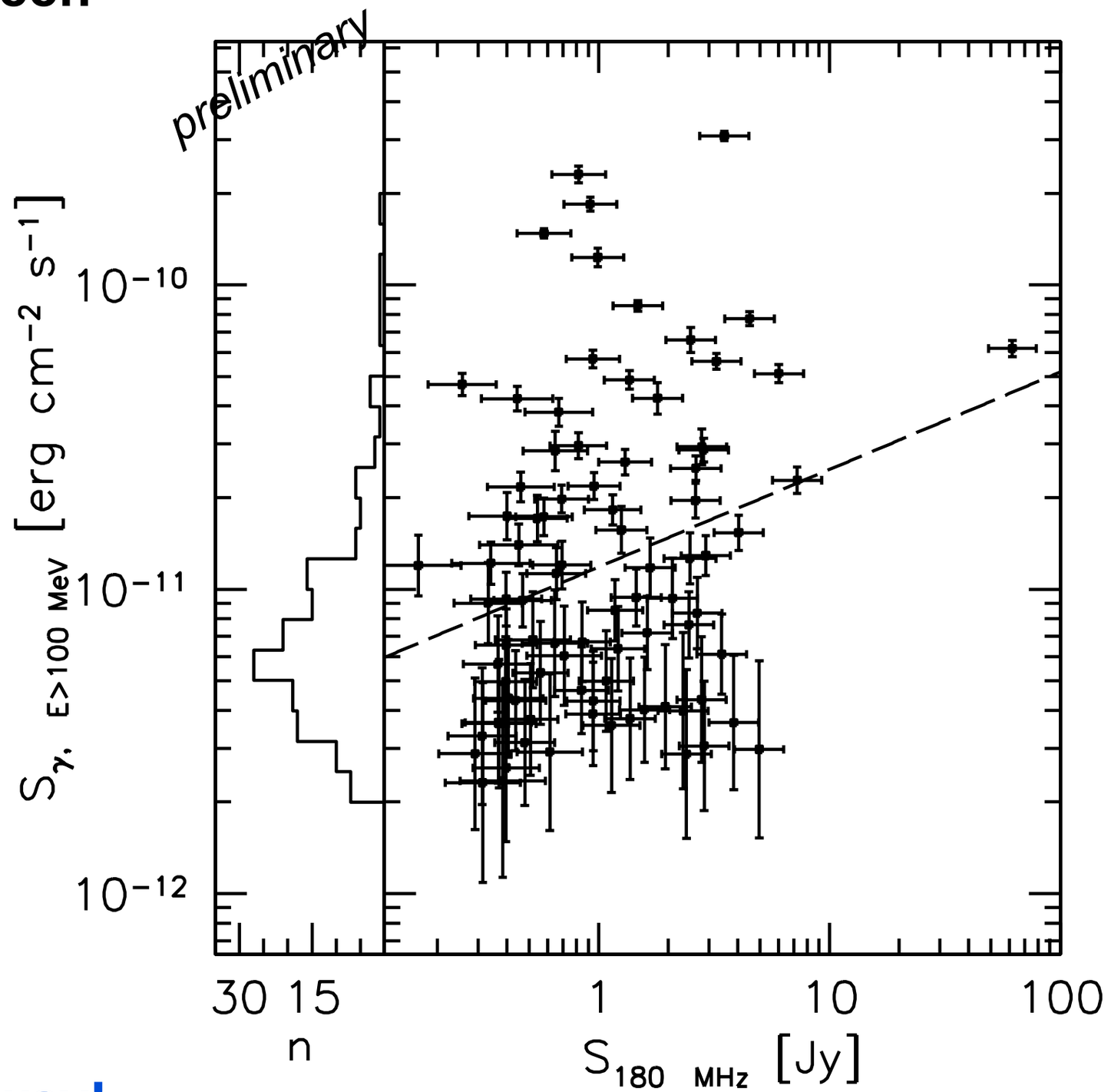
- entire MWACS
  - $\langle\alpha_{low}\rangle = 0.81 \pm 0.01$
- blazars
  - $\langle\alpha_{low}\rangle = 0.51 \pm 0.05$
- gamma-ray blazars
  - $\langle\alpha_{low}\rangle = 0.47 \pm 0.09$

MWACS-*Fermi* connection

- **no significant correlation between S_{MWACS} and 3FGL energy flux**
  - **82 sources**
  - **r=0.27**
  - **p=0.06**

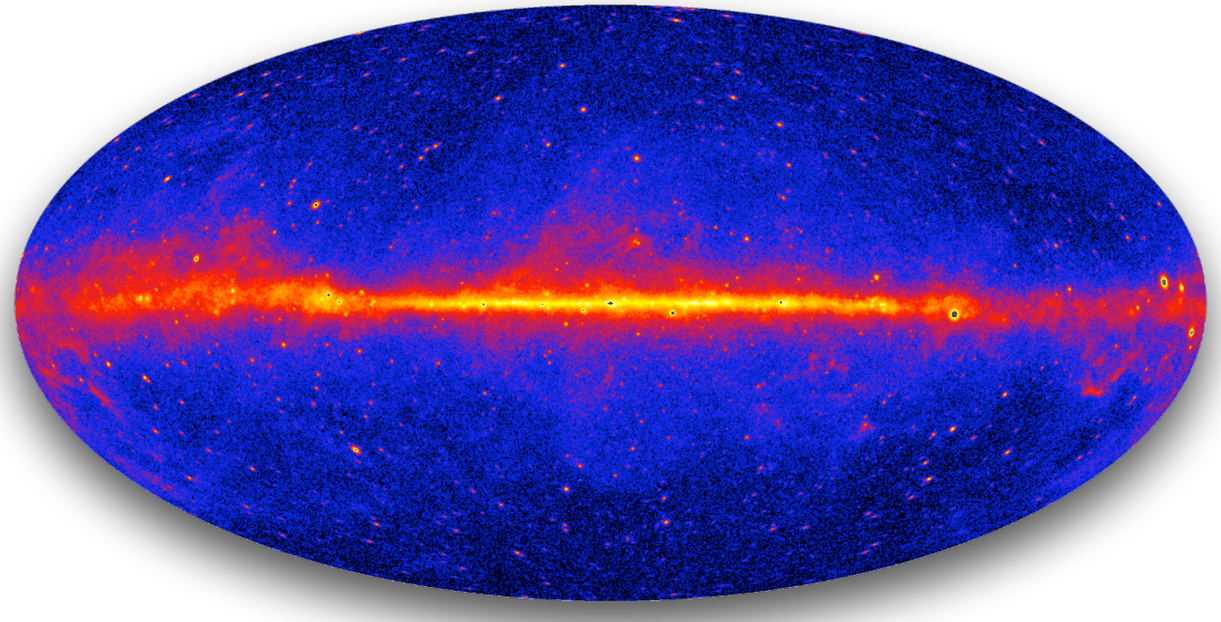
- **search for UGS counterparts**
  - **13 MWACS matches are found within r95 of all 3FGL un-associated sources**
  - **but on average 15 are found starting from a fake gamma-ray sky!**

- **there is potential, but better surveys are needed!**
  - **fortunately, they're on their way!**



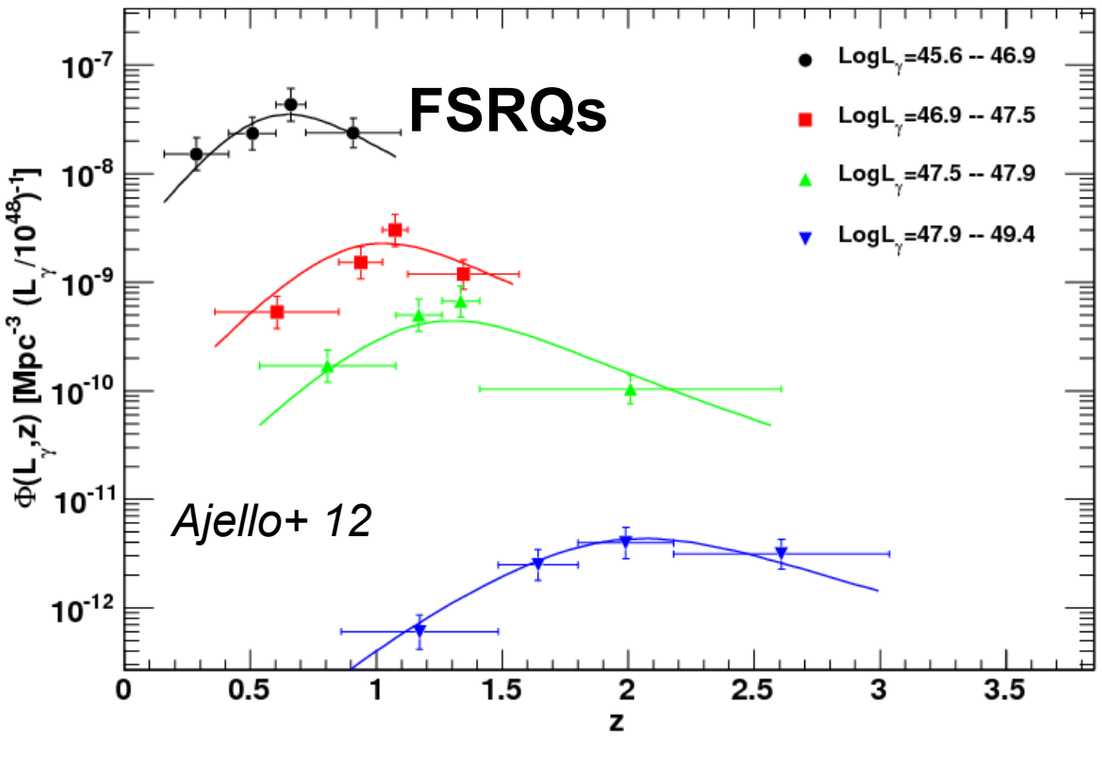
Conclusions

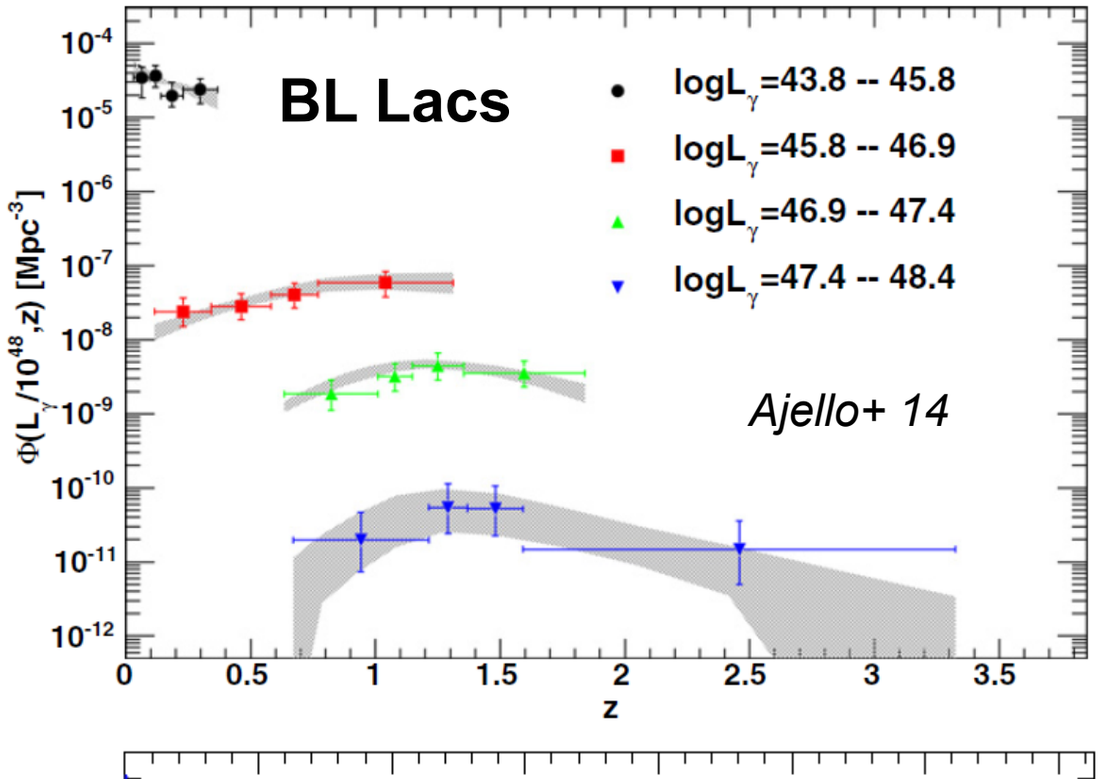
- **For blazars (and not only), gamma rays are the energy band in which most power is radiated**
- ***Fermi* has taken gamma-ray source counts at least even with radio surveys from the ‘70s!**
- **Great prospects for synergies between radio and gamma-ray surveys for study of the non-thermal universe**



EXTRA SLIDES

Blazar luminosity functions





- **Rise in HSP-BL Lac density corresponds to a drop-off in FSRQ density**
- **Evolution of FSRQS into HSPs due to starvation of accreting matter?**