Active Galactic Nuclei with Fermi-LAT

Elisabetta Cavazzuti
ASI and GSFC
(with the help of past LAT speakers)
Fermi Summer School 2017, Lewes

What is an Active Galactic Nuclei

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  - Amount of **accretion** onto the SMBH: LUMINOSITY
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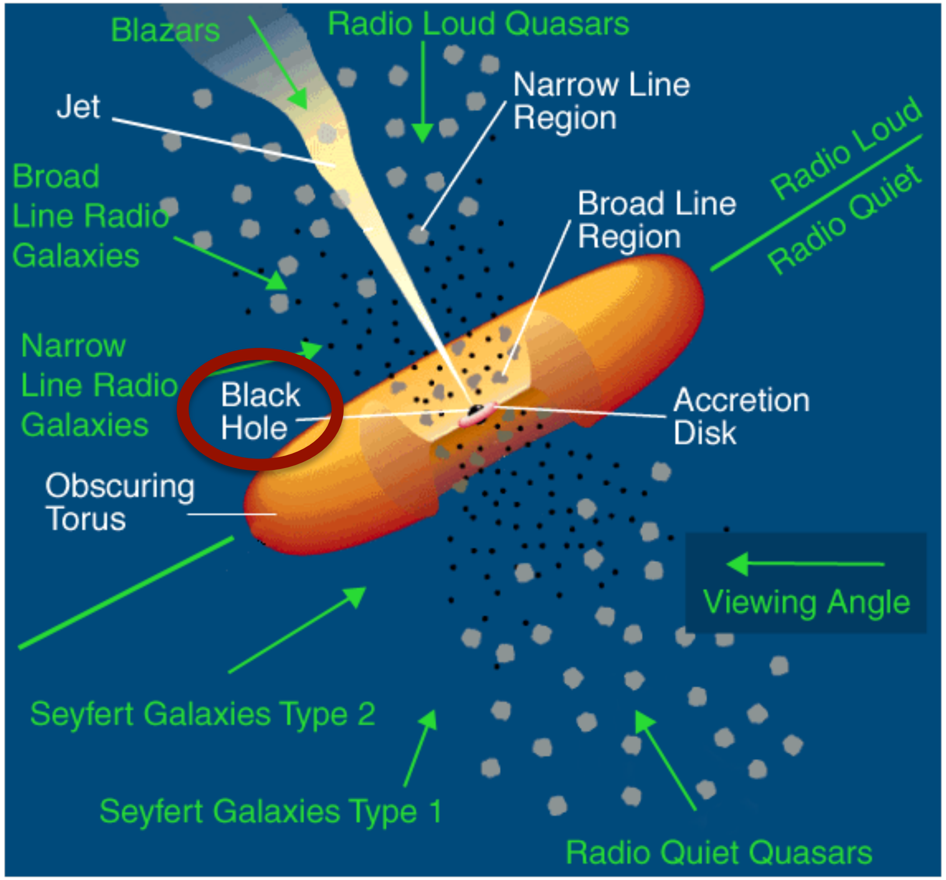
Up to many thousand times more luminous than the entire Milky Way but the energy is released within a region approximately the size of our solar system!

Active Galactic Nuclei

Urry&Padovani 1995



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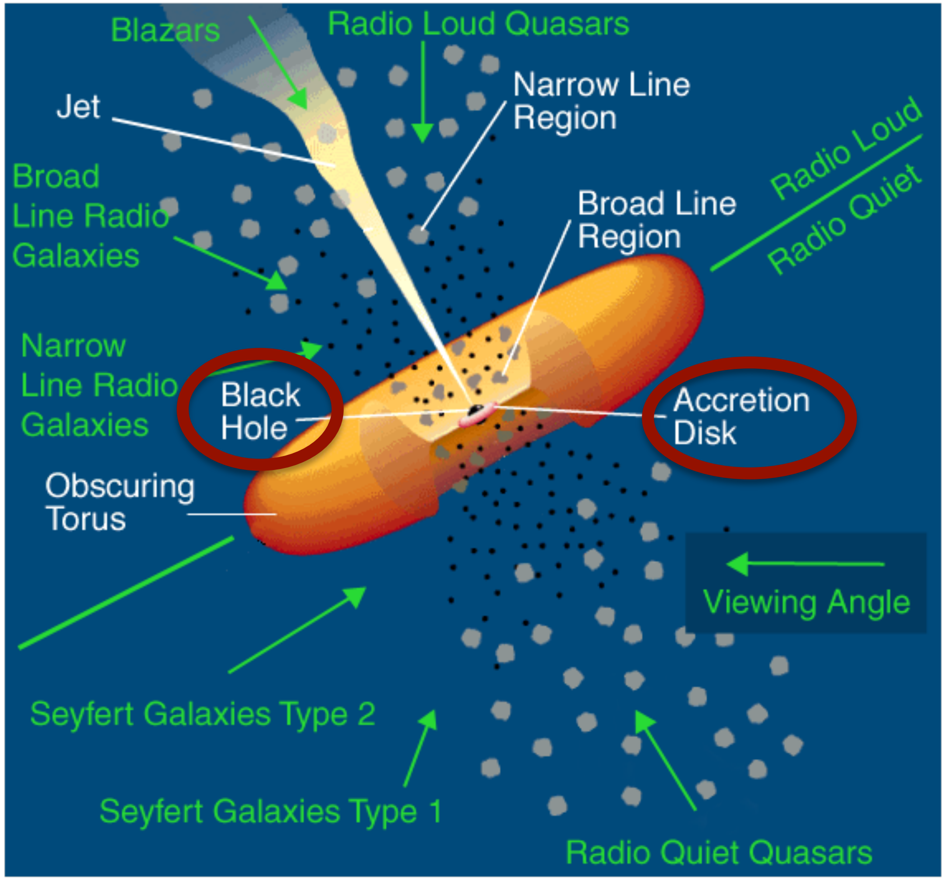

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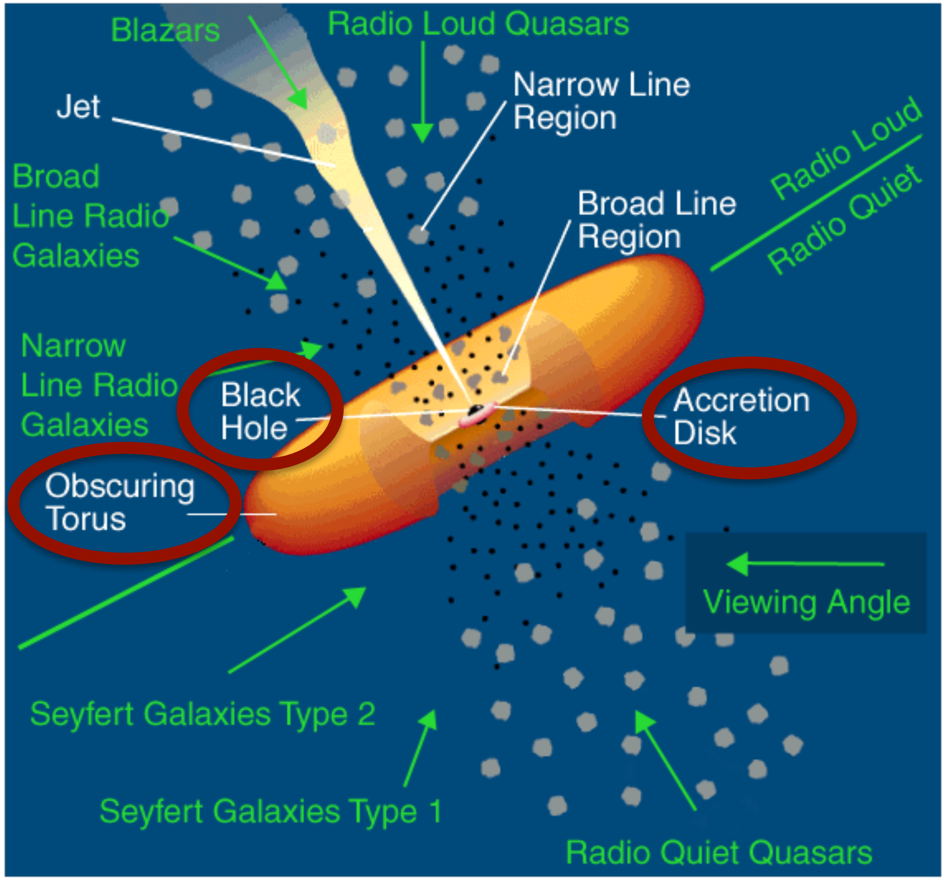

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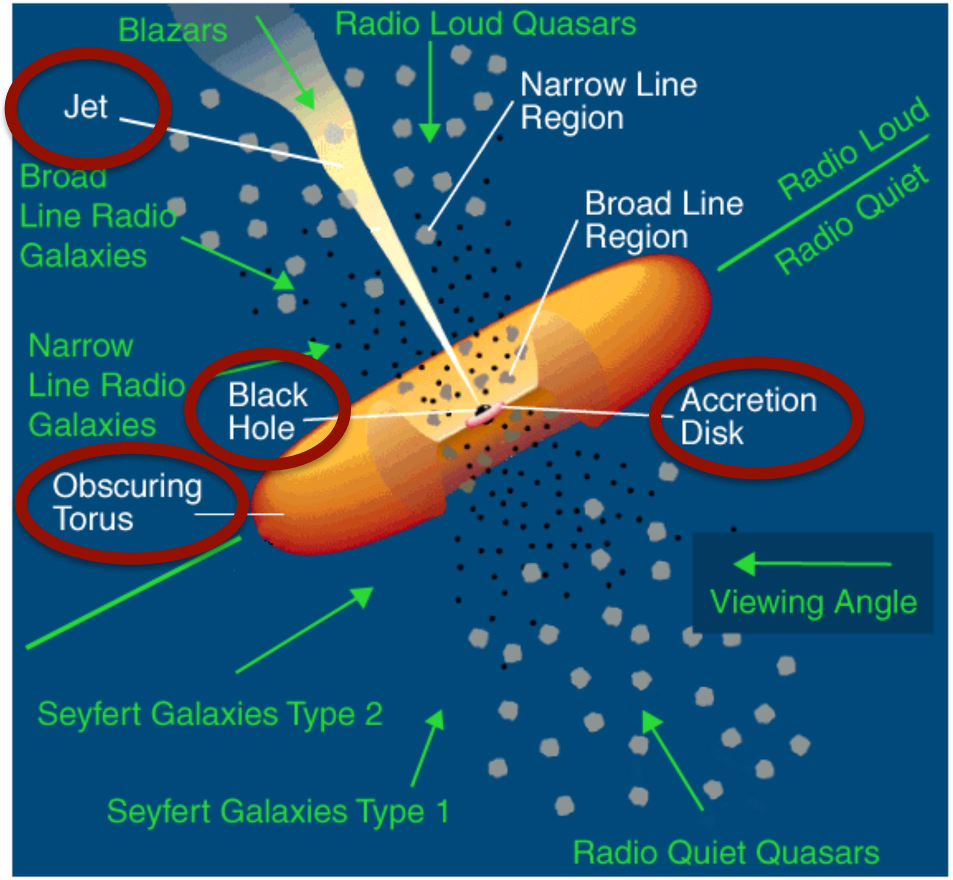

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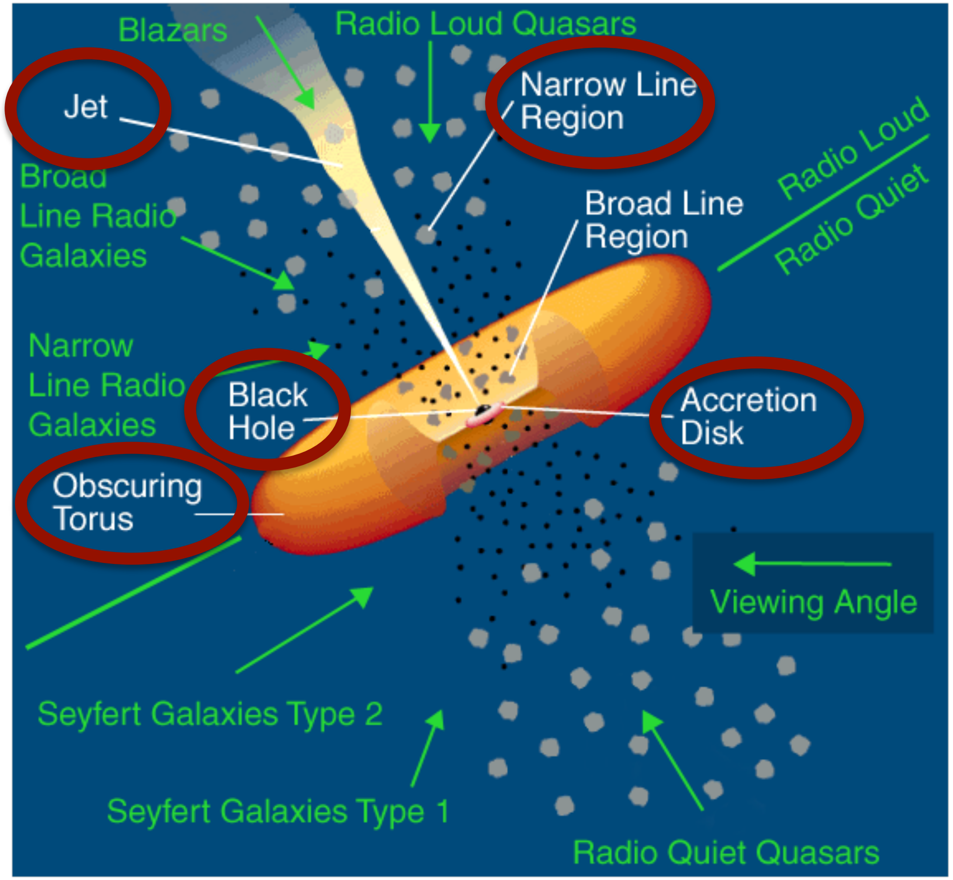

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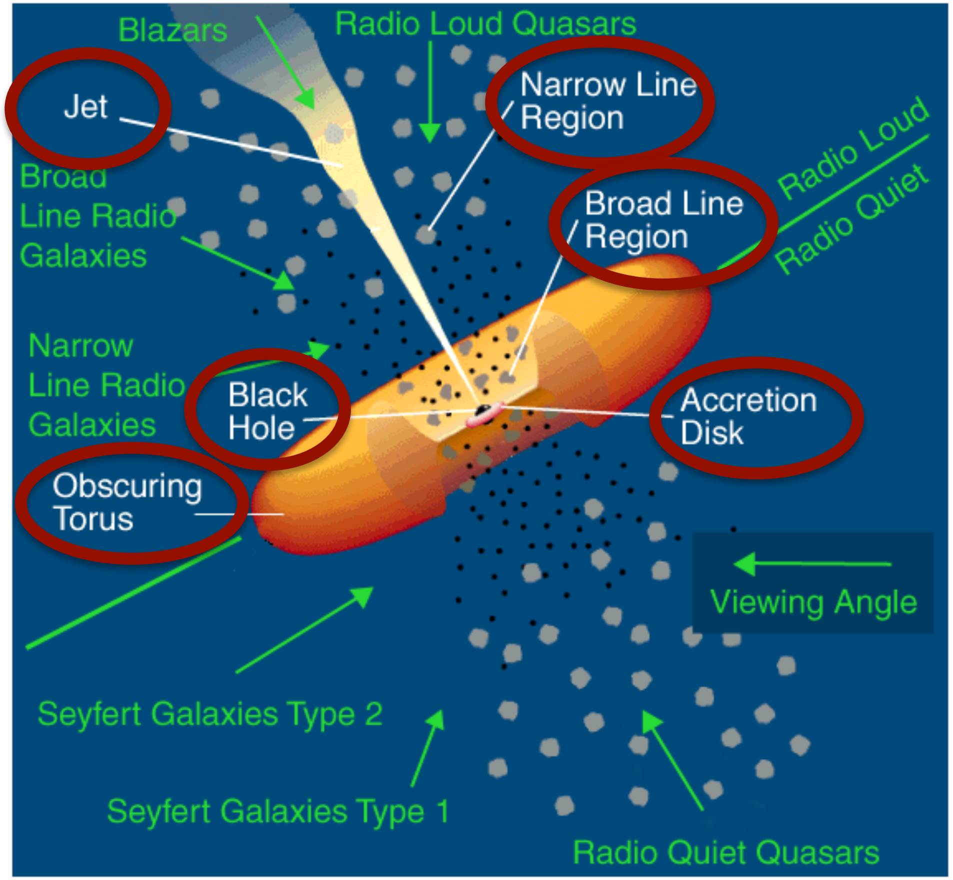

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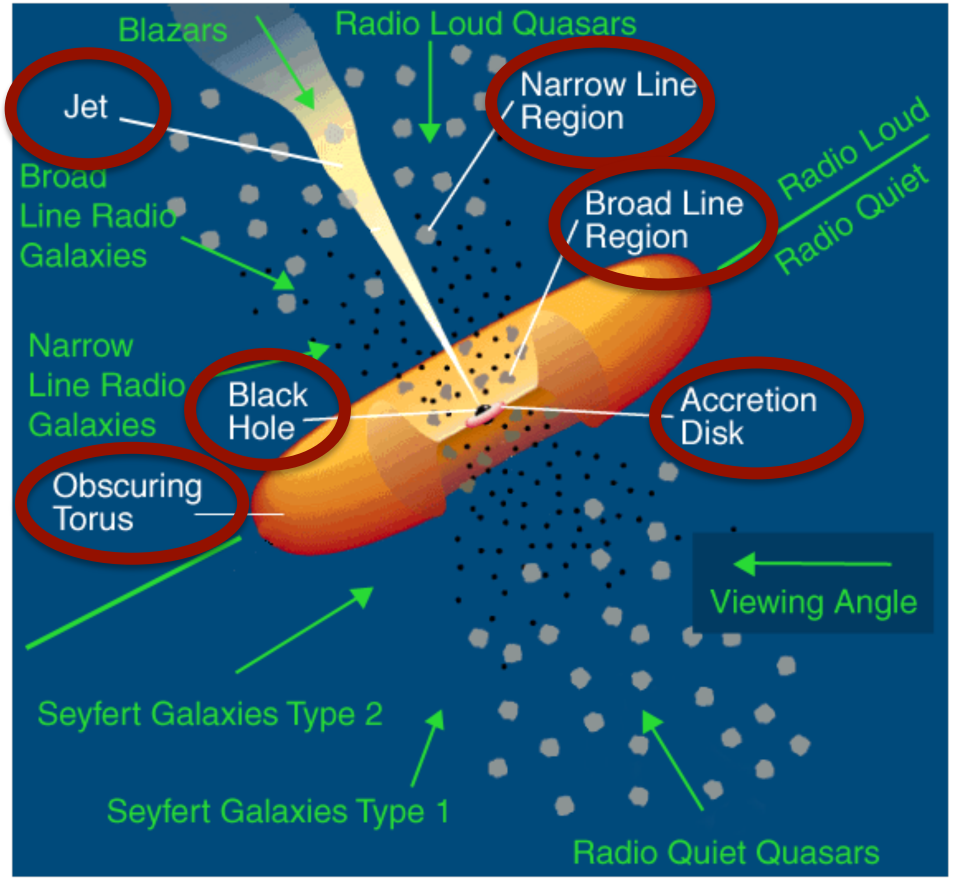

Radio loudness:

$$\frac{\text{Radio (5GHz) Flux}}{\text{Optical (B) Flux}} \geq 10$$

(Kellermann et al. 1989)

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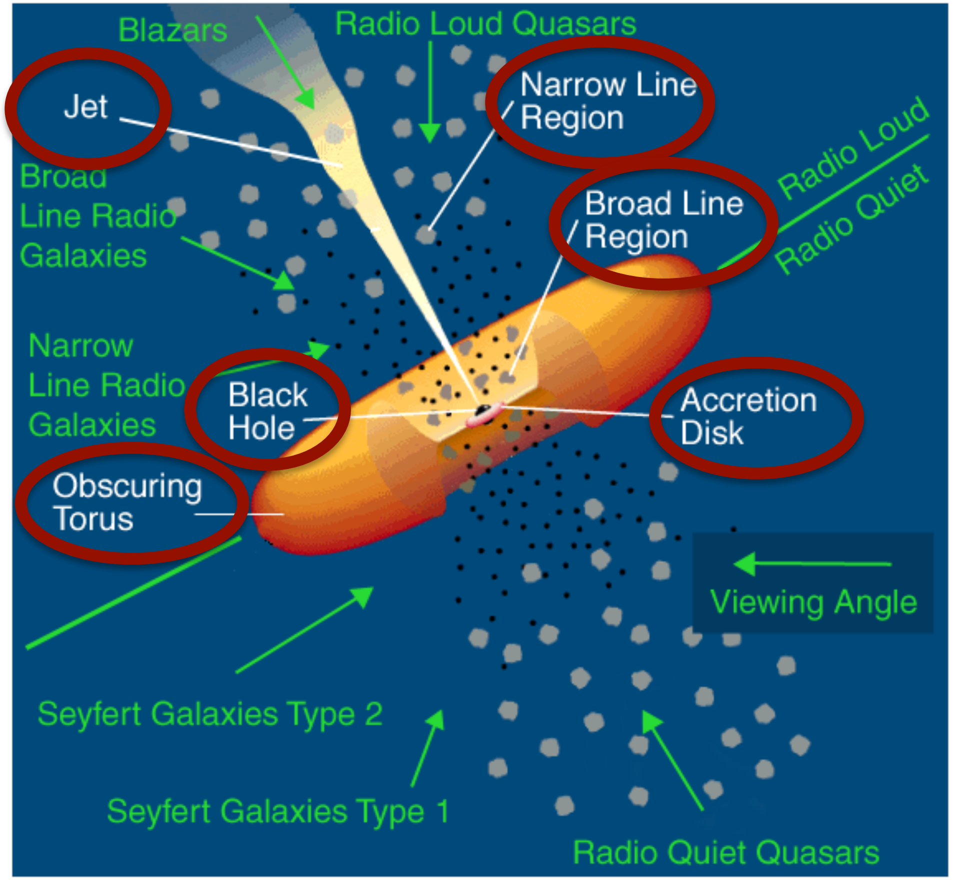

Radio-loud objects have emission contributions from both the jet(s) and the lobes that the jets inflate.
These emission contributions dominate the luminosity of the AGN at nearly all λ

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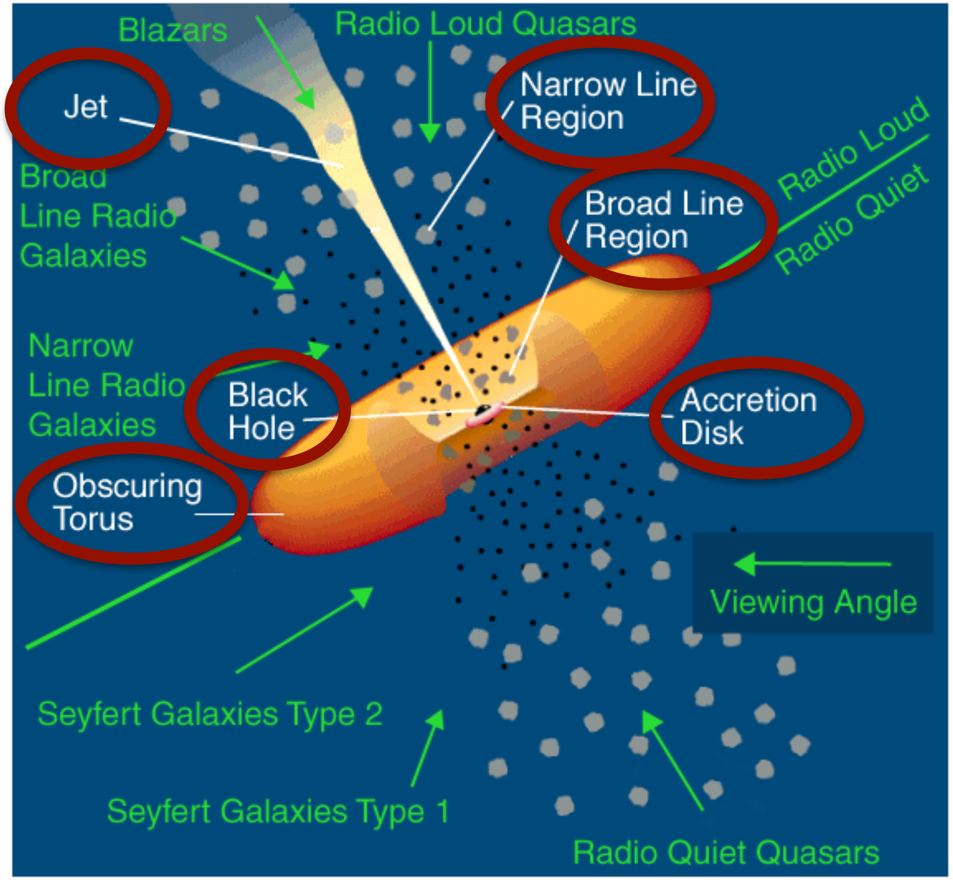

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AGN are a few % of all galaxies

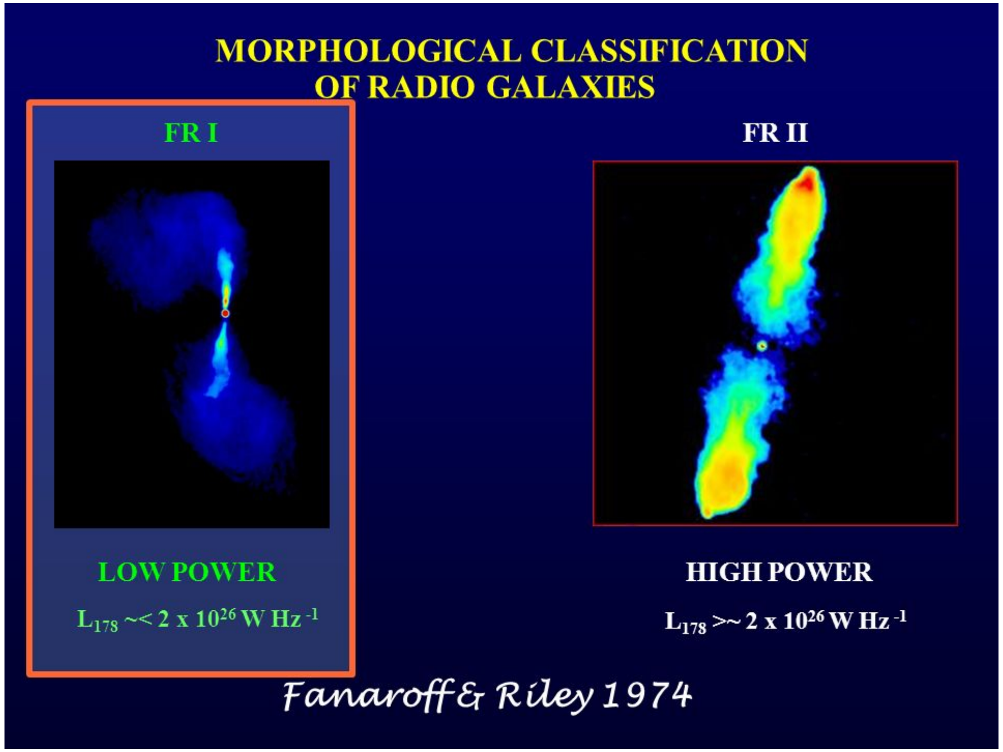
- Central nucleus outshines the rest of the galaxy
- High luminosity
- Emission across the entire e.m. spectrum, from radio to TeV
  -> non thermal
- Strong variability
- Radio-loud sources
  -> relativistic jets, superluminal motion

Radio Galaxies

5-15% of active galaxies

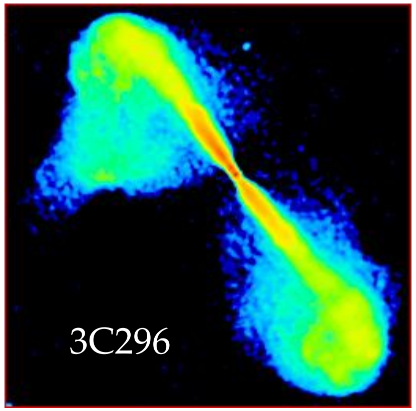
(others are mostly Seyferts)

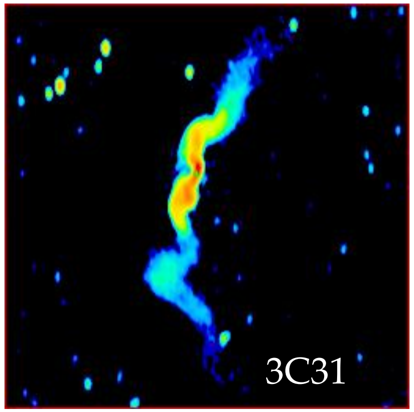
- ✓ Mostly of the elliptical type (Seyferts : spirals)
- ✓ Galaxies displaying extended radio lobes (up to 10 x larger than the galaxy)

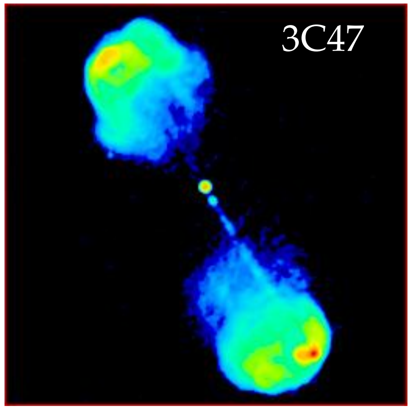


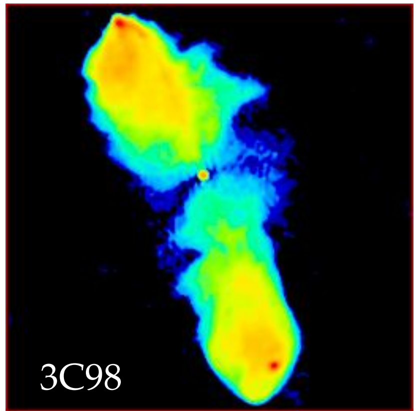
2 classes

- **Fanaroff-Riley 1:** large opening angle, brighter close to the core, low luminosity, close
- **Fanaroff-Riley 2:** highly collimated jet, lobe brightened with hot spots, luminous, distant

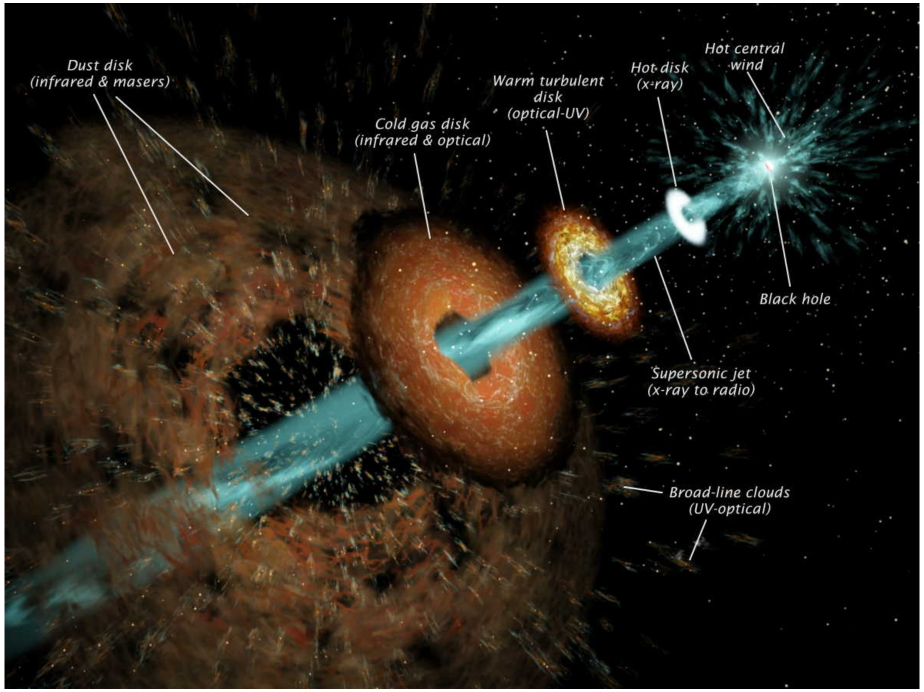








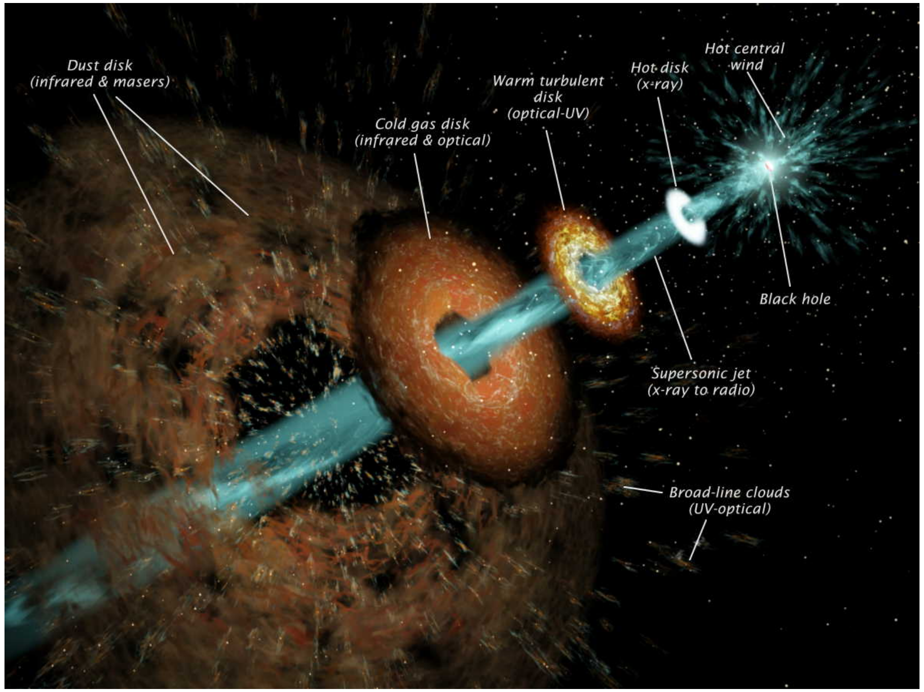
Blazars



< 5% of the whole AGN class

- ✓ beamed (jet at ≤ 20-30°) **(point at us!)**
- ✓ broad band SED,
  L up to 10^{49} erg s^{-1}
- ✓ compact morphology
  (core flux >> extended flux)
- ✓ flat radio spectrum ($\alpha_r \leq 0.5$)
- ✓ rapid and large variability (large $\Delta L / \Delta t$),
  superluminal motions
- ✓ high and variable optical polarization

Blazars



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<u>blazars dominate the extragalactic sky</u> in a number of *new* observational windows
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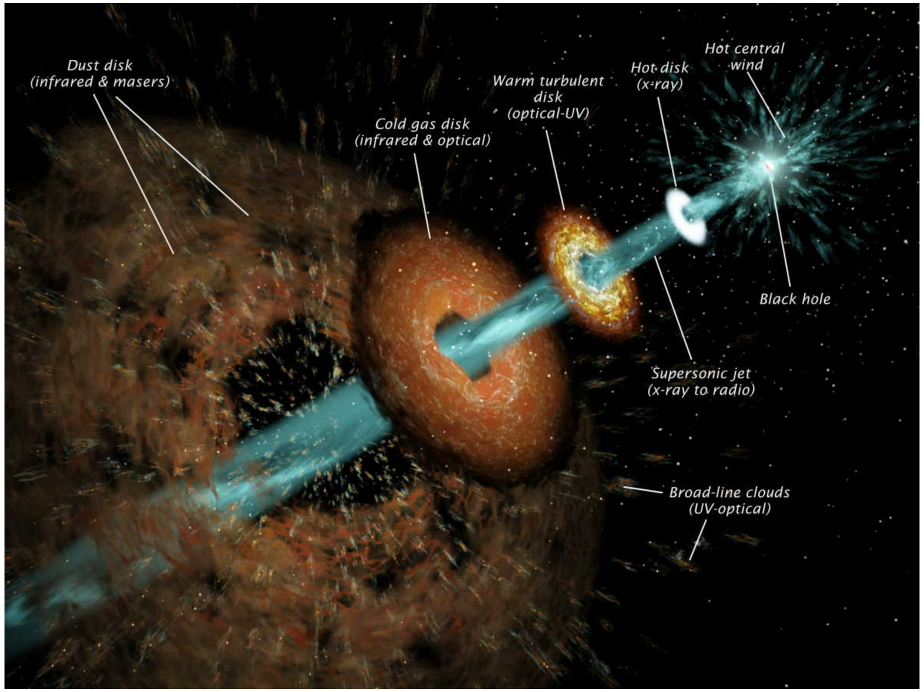

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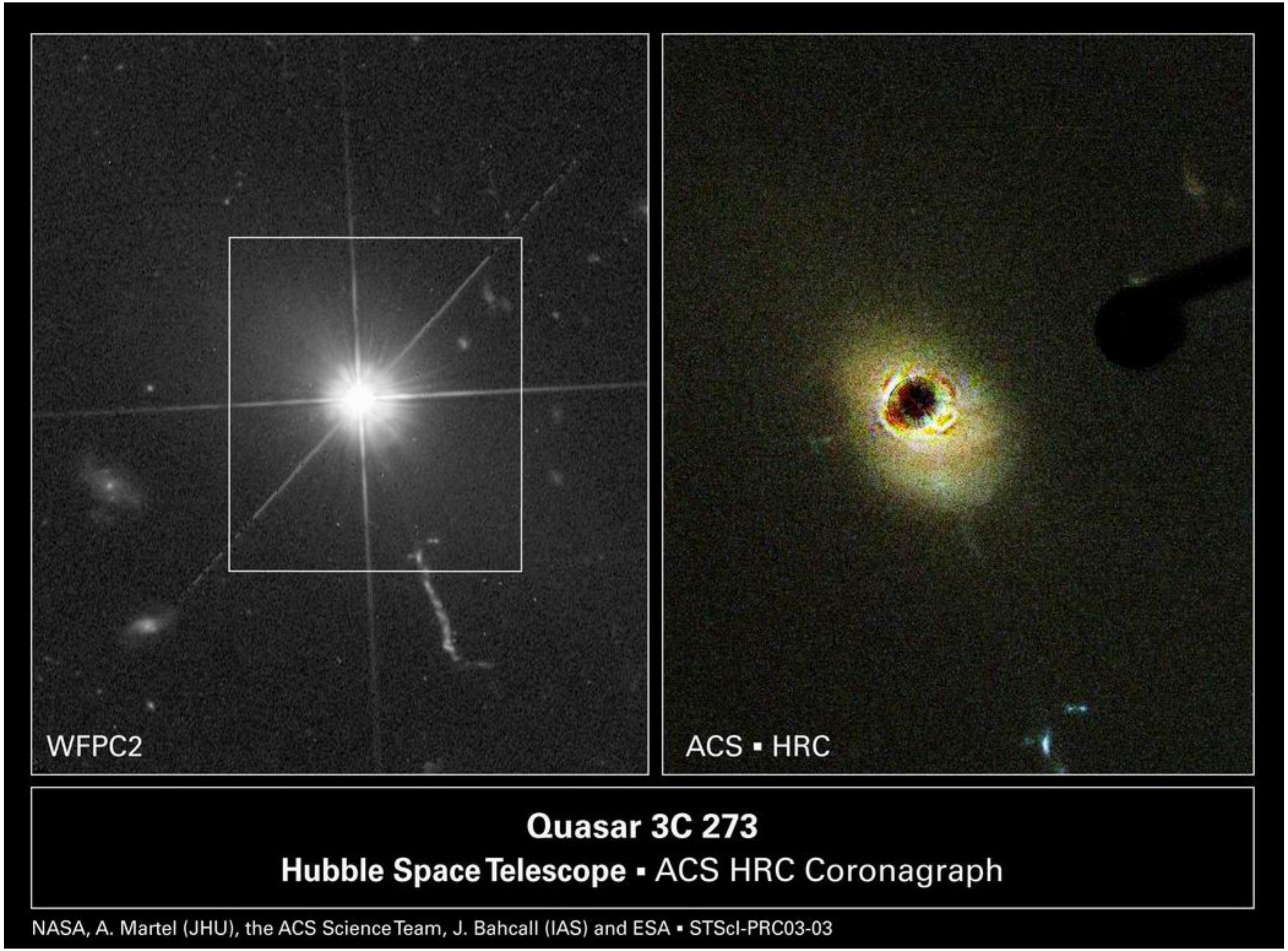
As of today, about **3.561 blazars (BZCAT 5th edition,** www.asdc.asi.it/bzcat**)** are known and before the operations of Fermi, Swift, Planck and other facilities, only small good statistical samples existed.

What do they look like?



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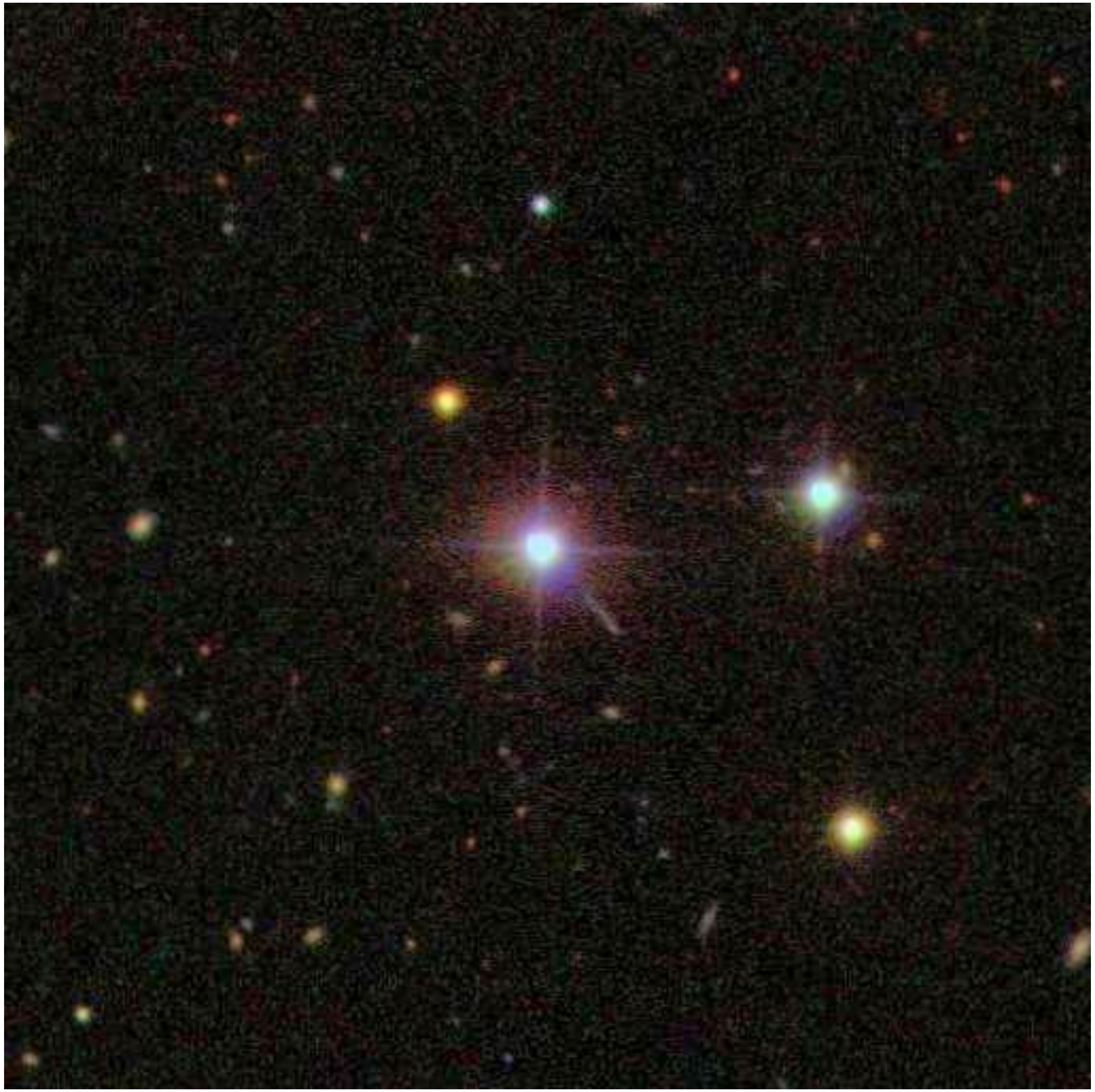

Credit: SDSS /
Size: 3´× 3´

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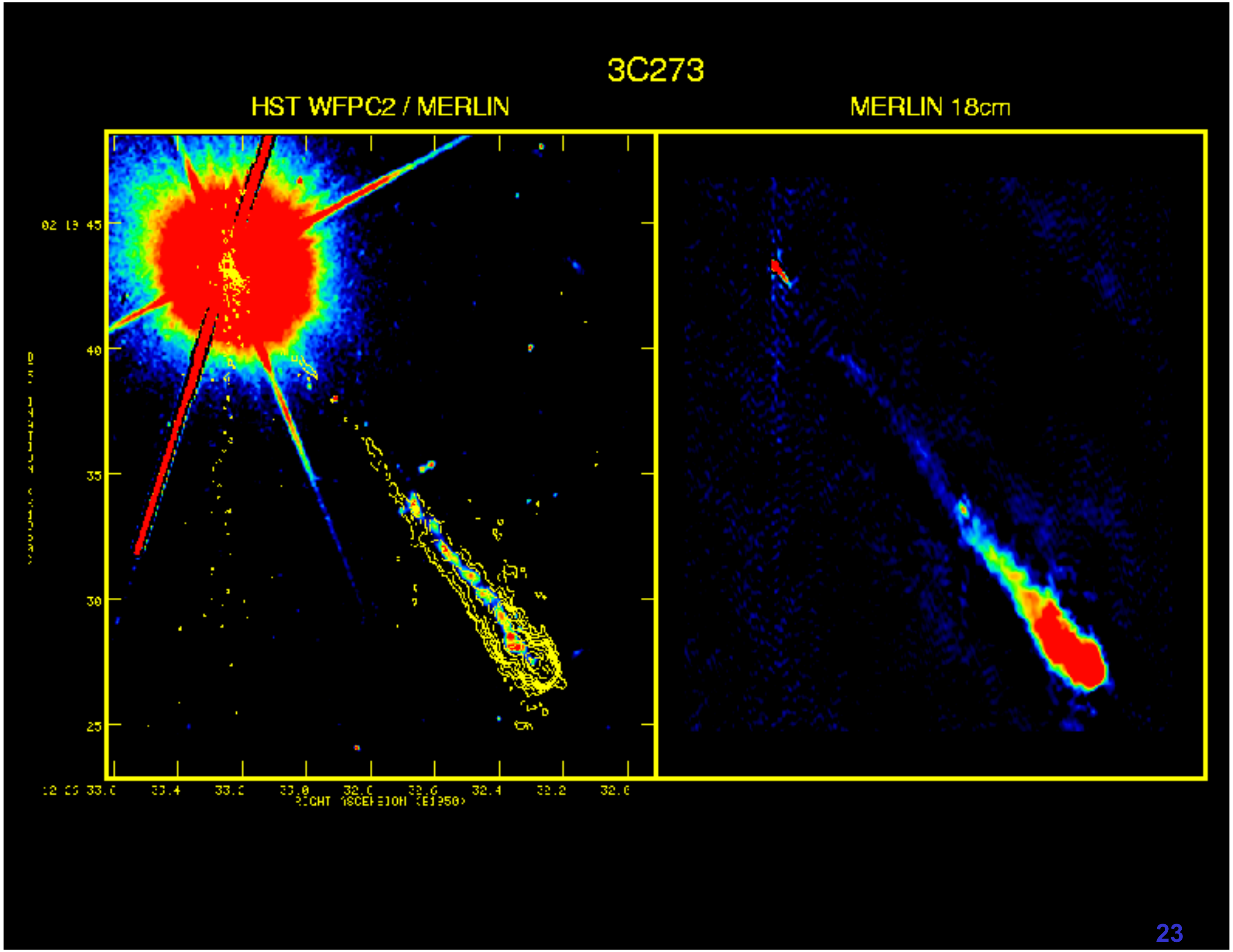

Credit: Hubble Space Telescope (WFPC2) / MERLIN

Blazar classes

FSRQ: Flat Spectrum Radio Quasar

BL Lac: named after prototype BL Lacertae

class	FSRQs	BLLacs
Optical property	Optical spectrum: strong broad emission lines	Optical spectrum: nearly featureless
Environment	intense radiation field (disk, clouds, torus)	low radiation field
Power	~10^{46-48} erg/s	~10^{45-46} erg/s
Parent population	Fanaroff-Riley 2	Fanaroff-Riley 1
Synchrotron hump in SED	Peak in IR	Peak in Opt/IR: LBL Peak in UV/X-rays: HBL
Redshift	0.1 – 4...	< 1 ??????

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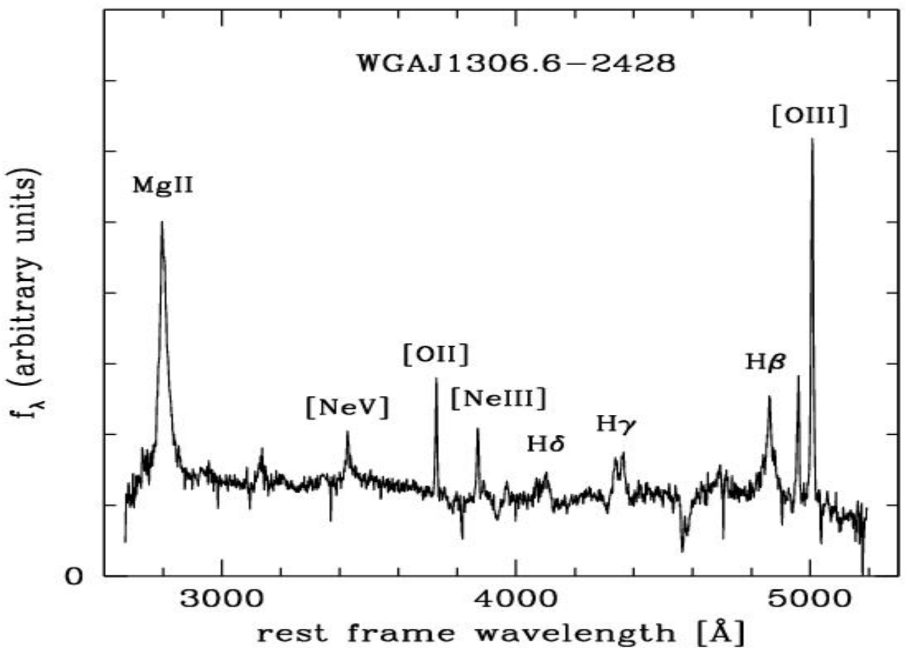

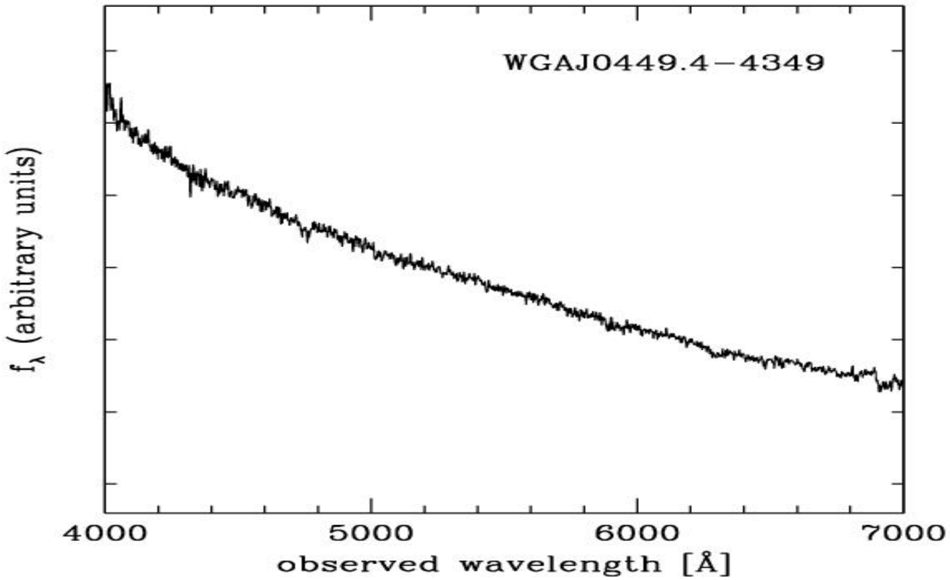

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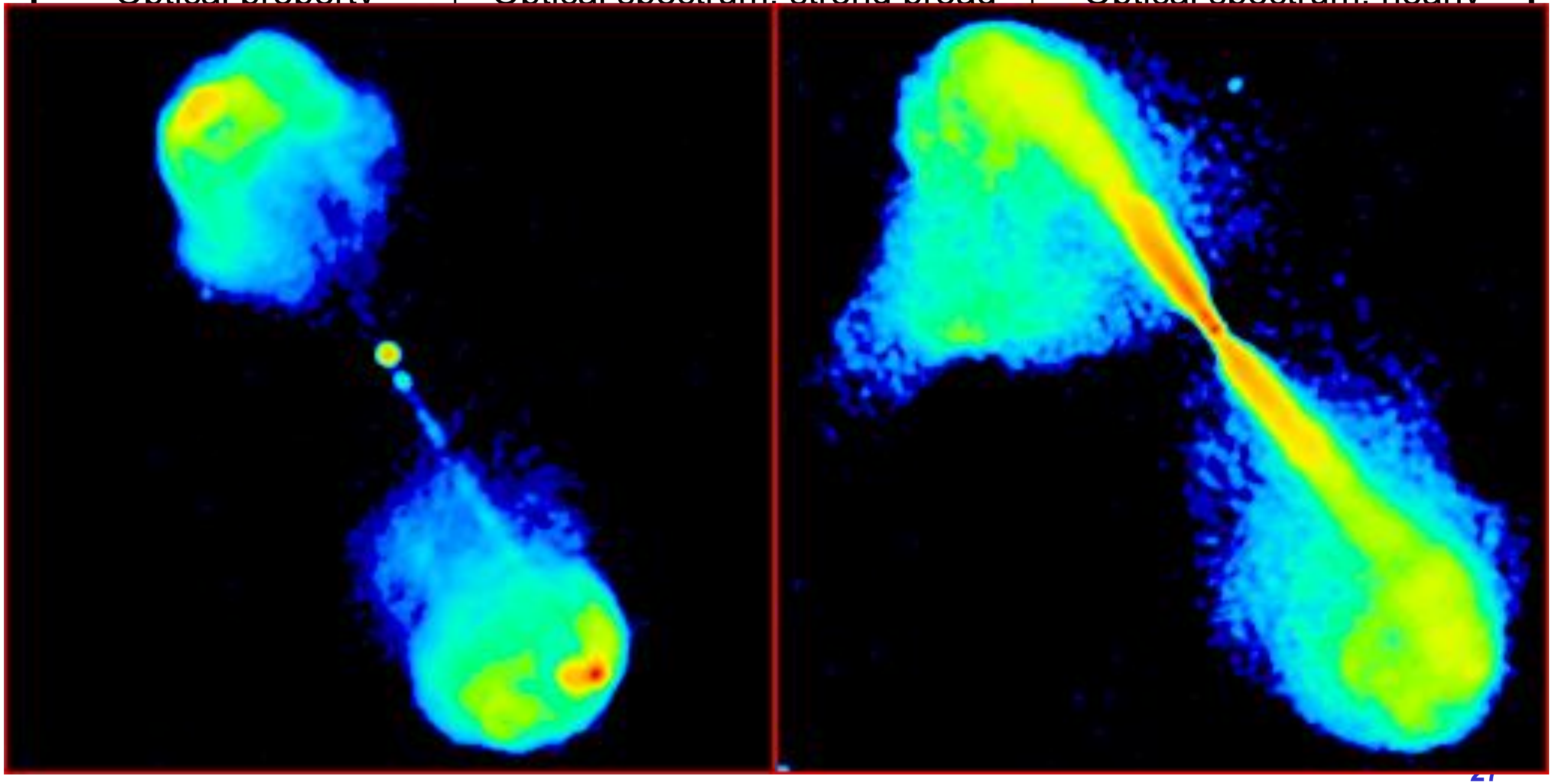

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BL Lacs redshifts are hard to measure, even at Kech Telescope!
Many redshifts are missing. Be careful when you draw conclusions!

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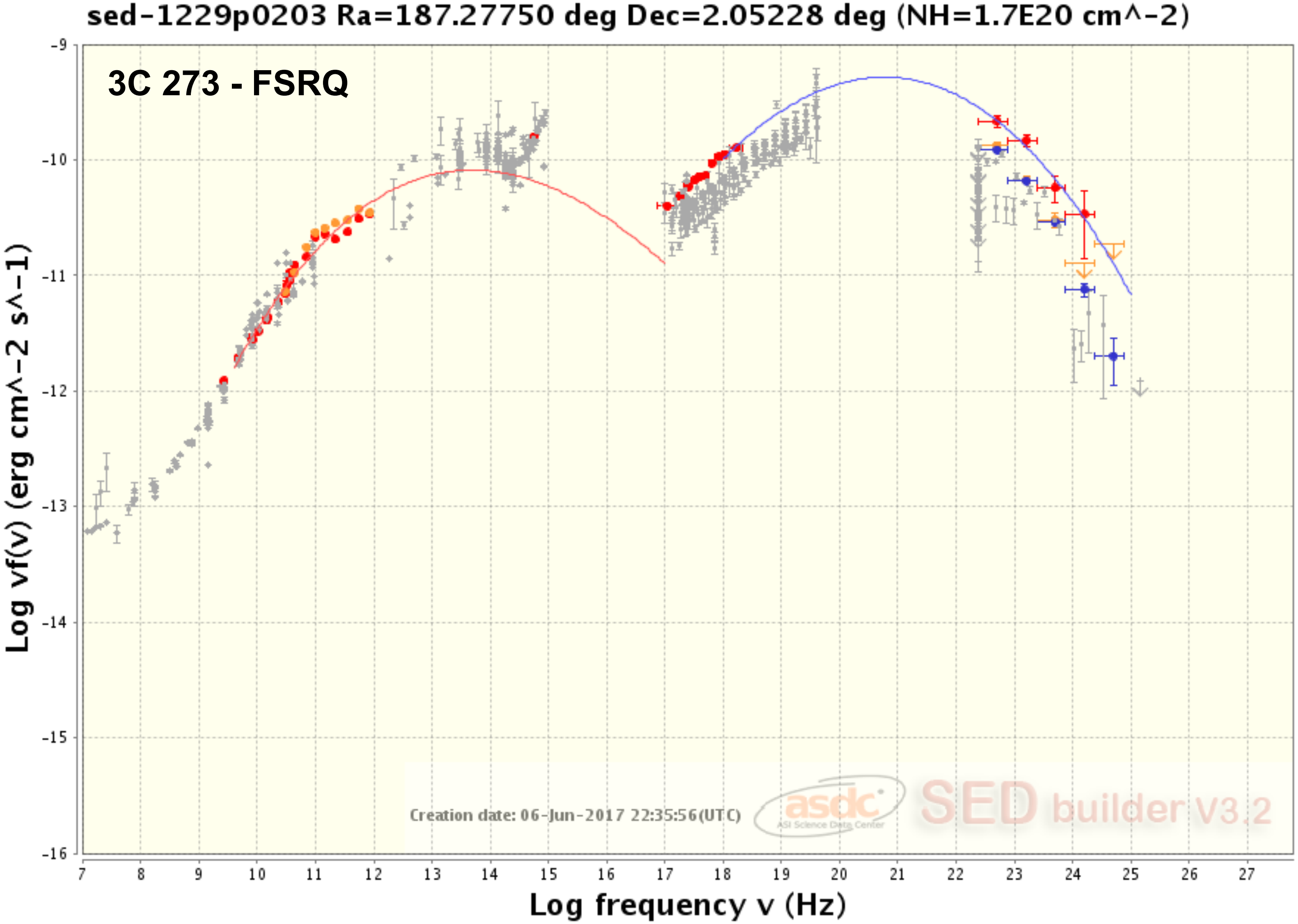

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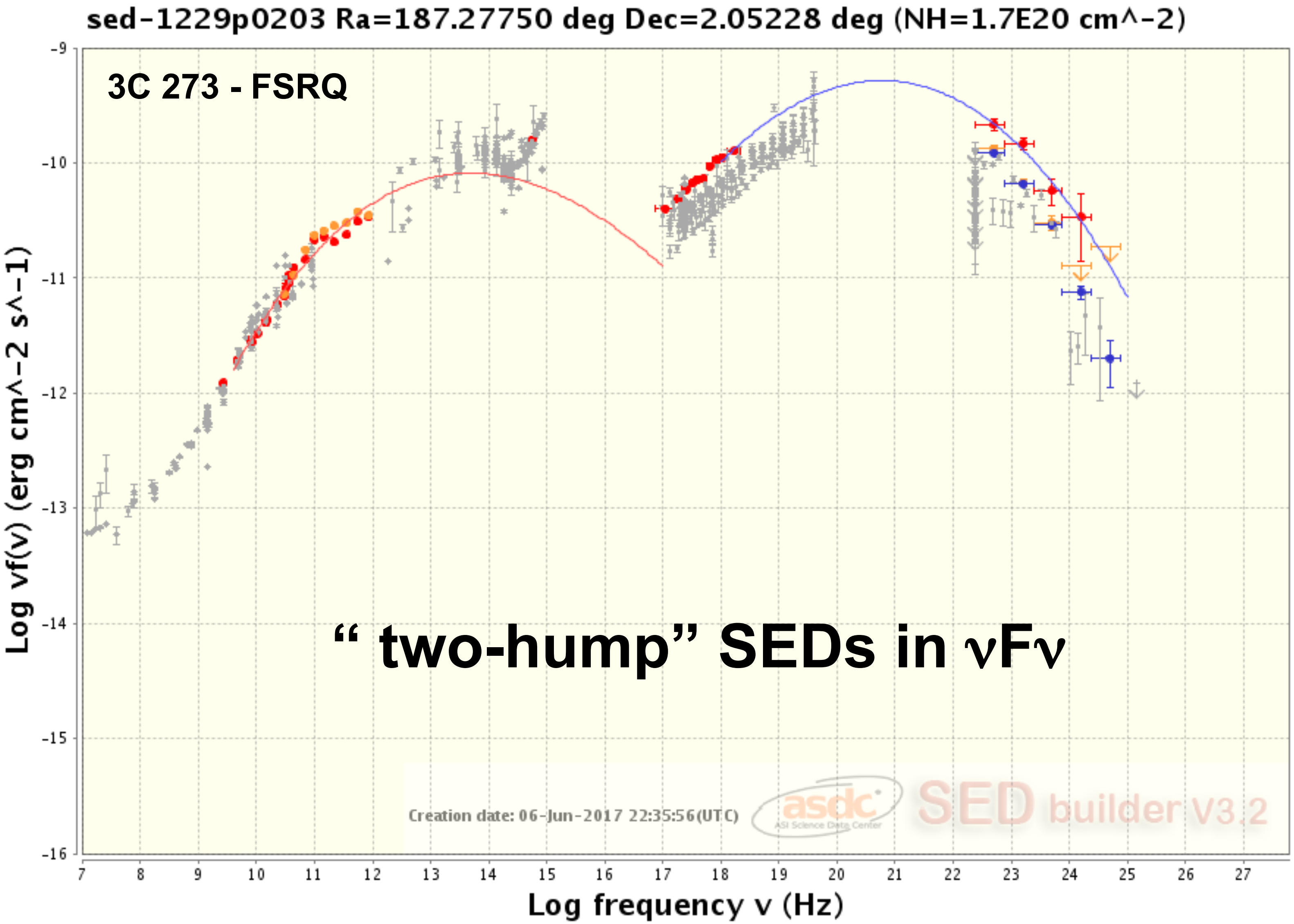
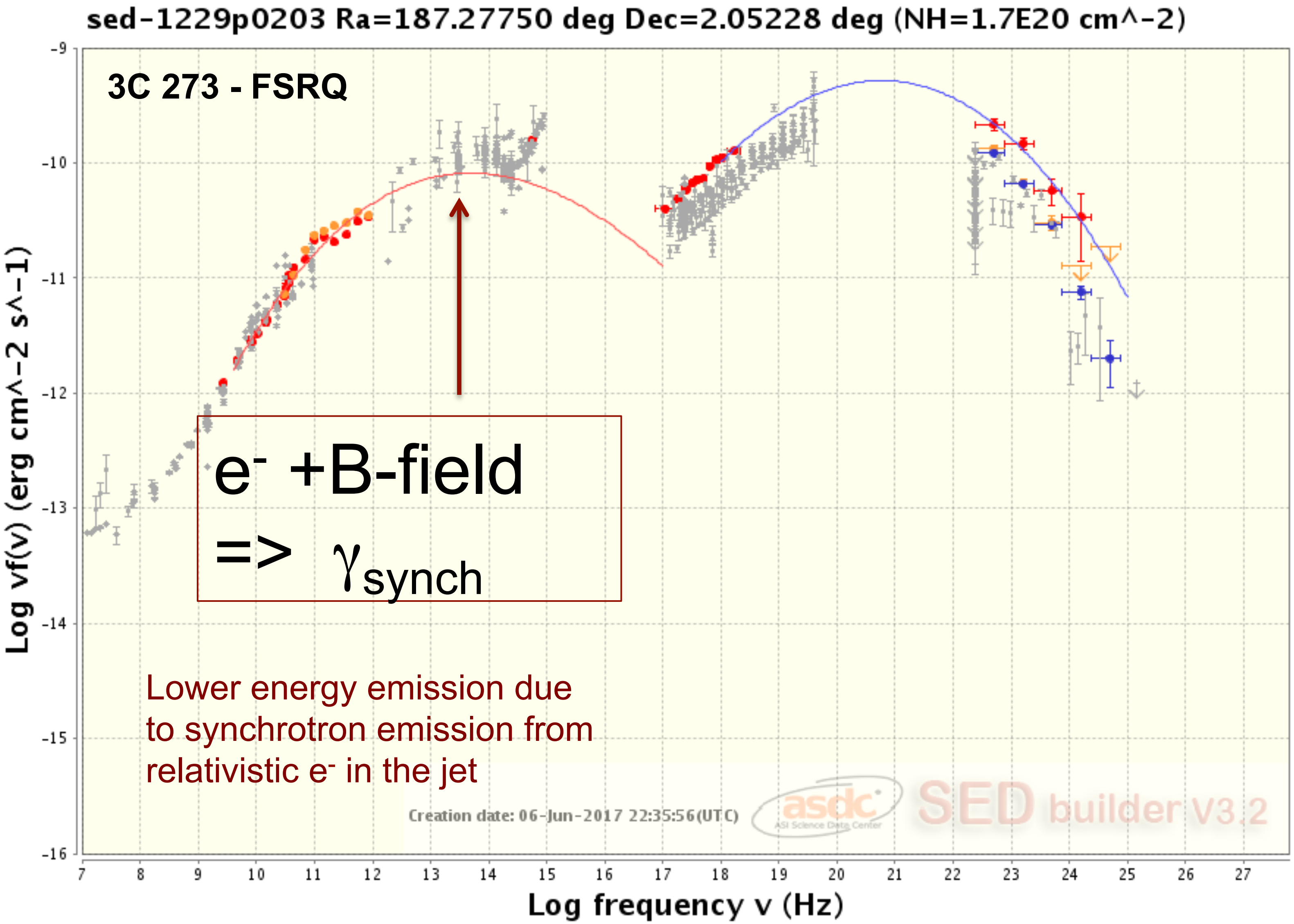


Blazars: SED properties

" two-hump" SEDs in νFν



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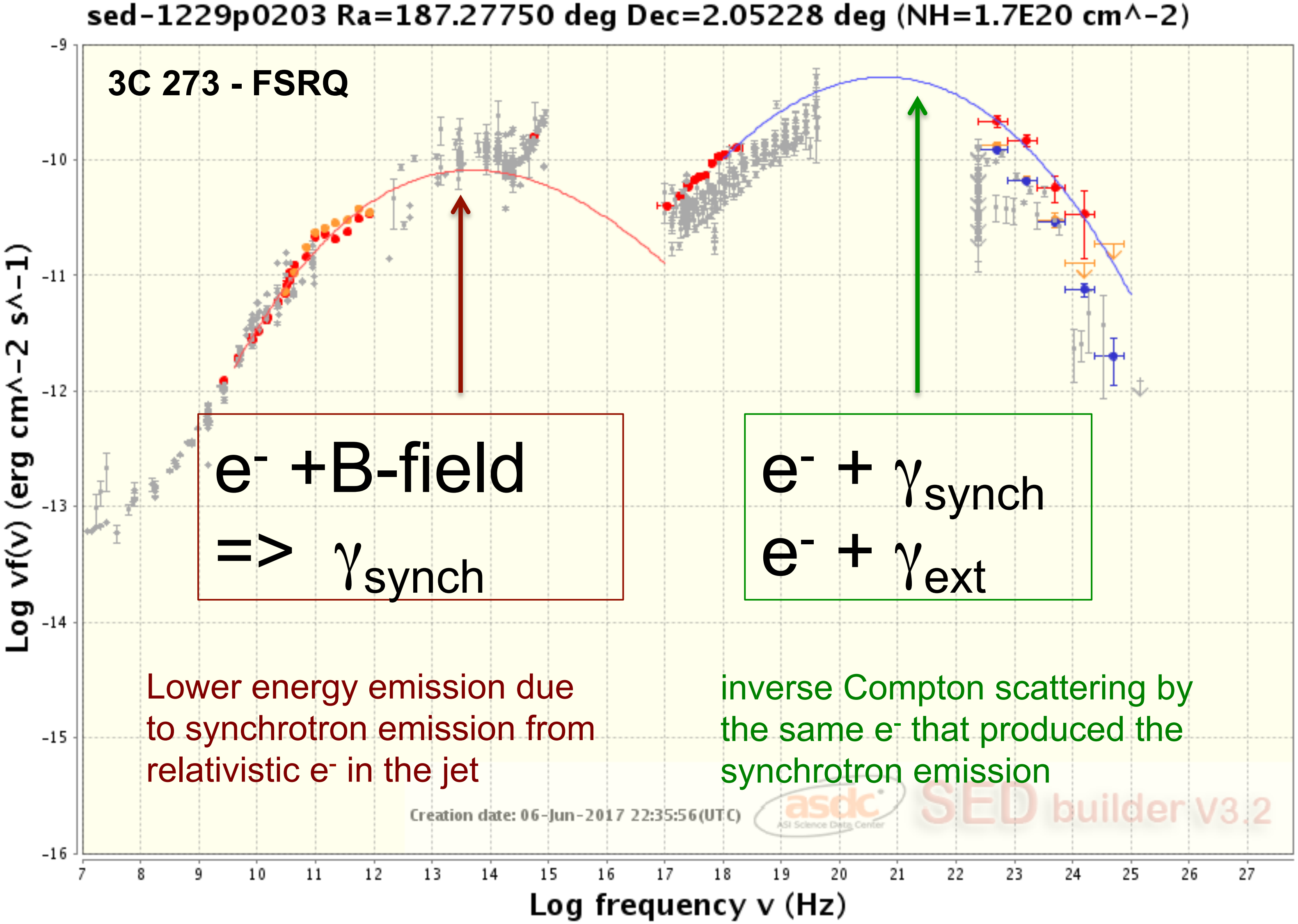
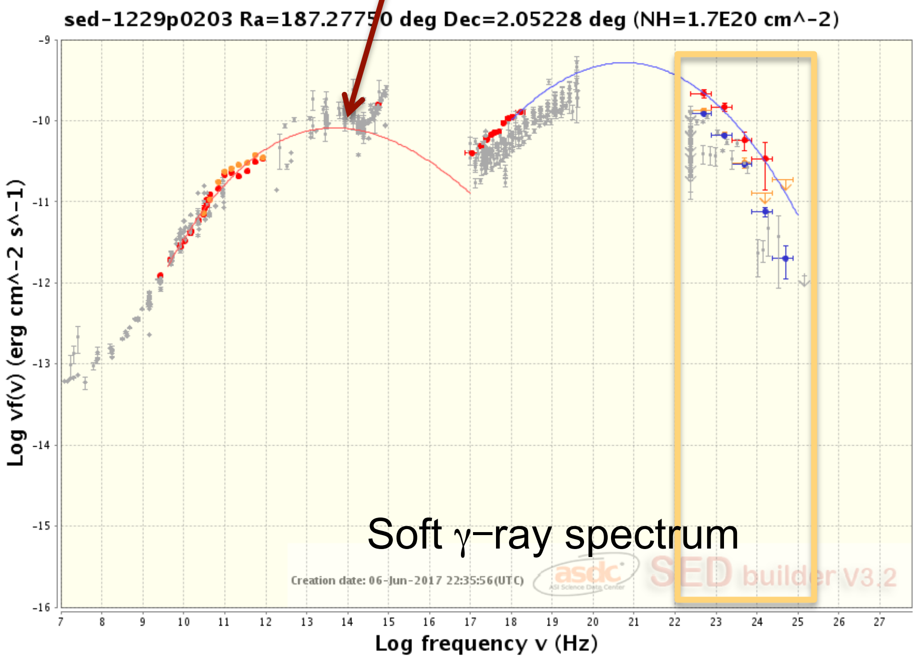


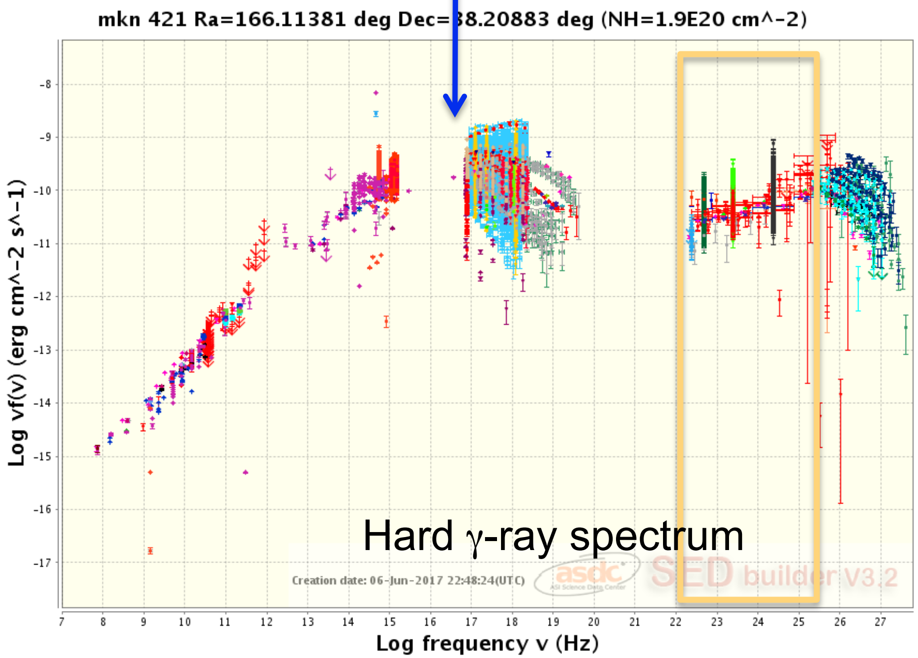
Blazars: SED properties

Low synchrotron peaked
LSP/LBL
IR-optical (ν_{syn}<10^{14}Hz)

High synchrotron peaked
HSP/HBL
X-rays (ν_{syn}>10^{15}Hz)

Intermediate synchrotron peaked
ISP/IBL
UV (10^{14}<ν_{syn}<10^{15}Hz)

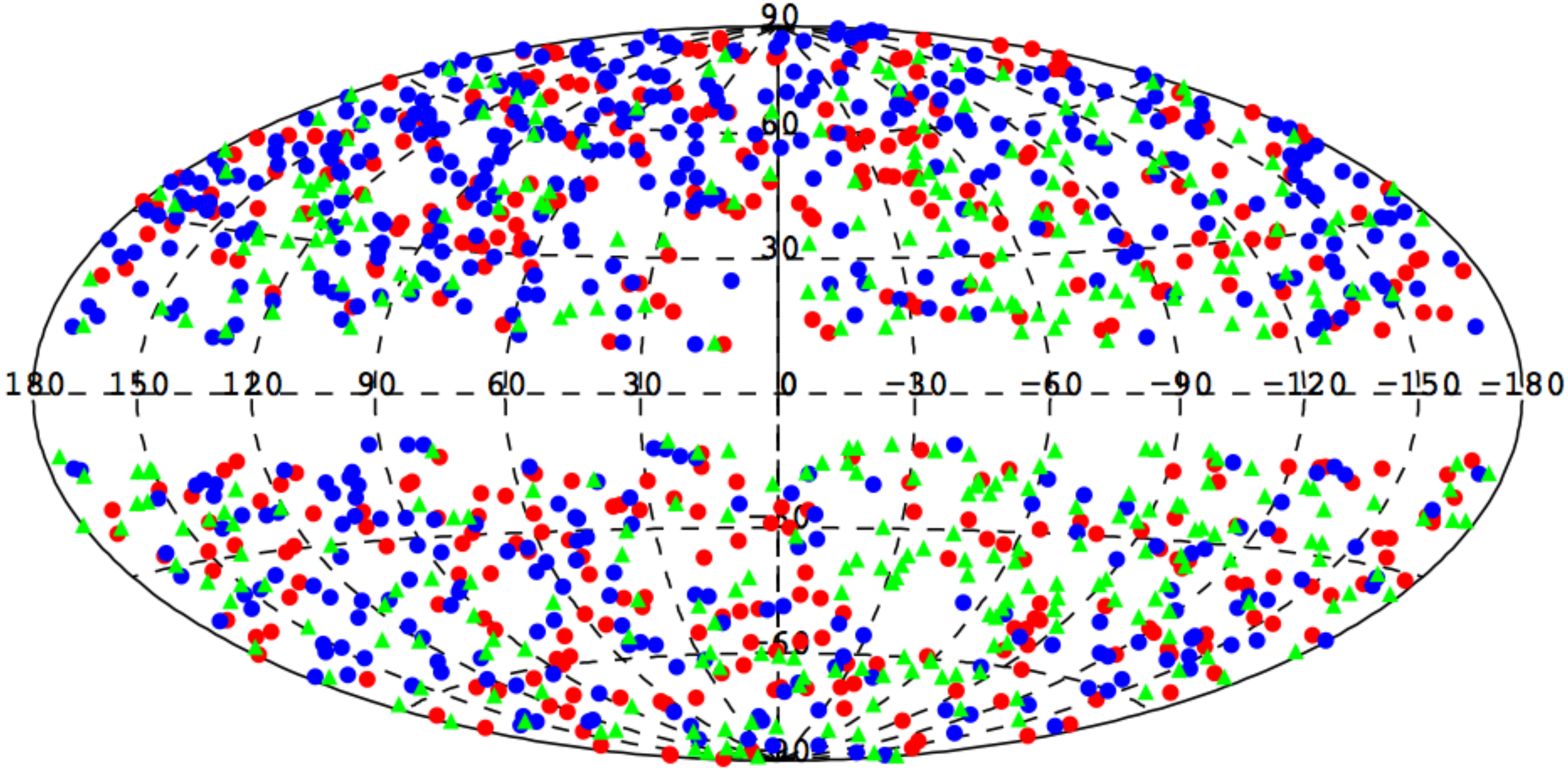




Fermi LAT AGN

Third catalog of AGN with LAT

FSRQ, BL Lac, BCU



The 3rd Catalog of AGN Detected by the Fermi LAT (3LAC)
Ackermann, M. et al. 2015, ApJ, 810, 14

AGN classification in LAC catalogs

Two classification schemes:

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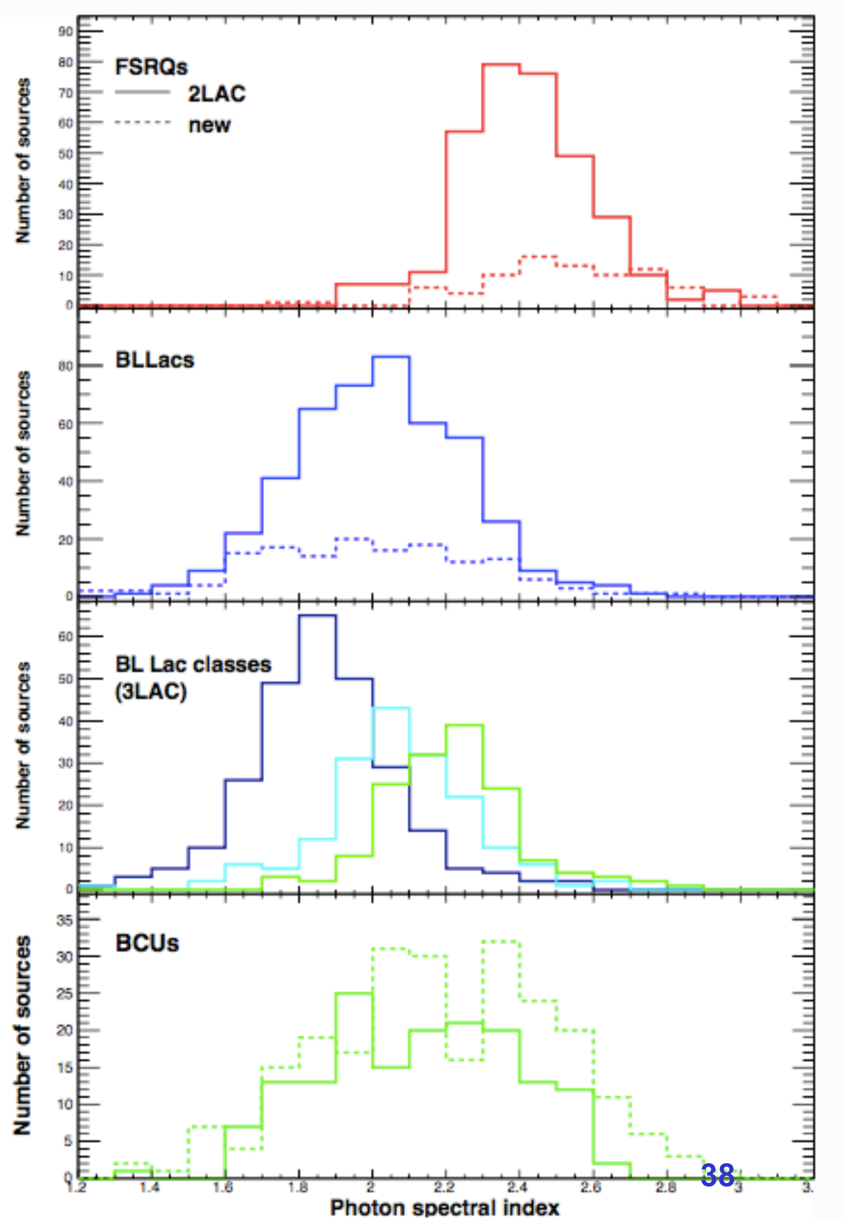
Optically-based (strength of broad lines): FSRQs, BL Lacs, BCUs (Blazar Candidate of Unknown type)

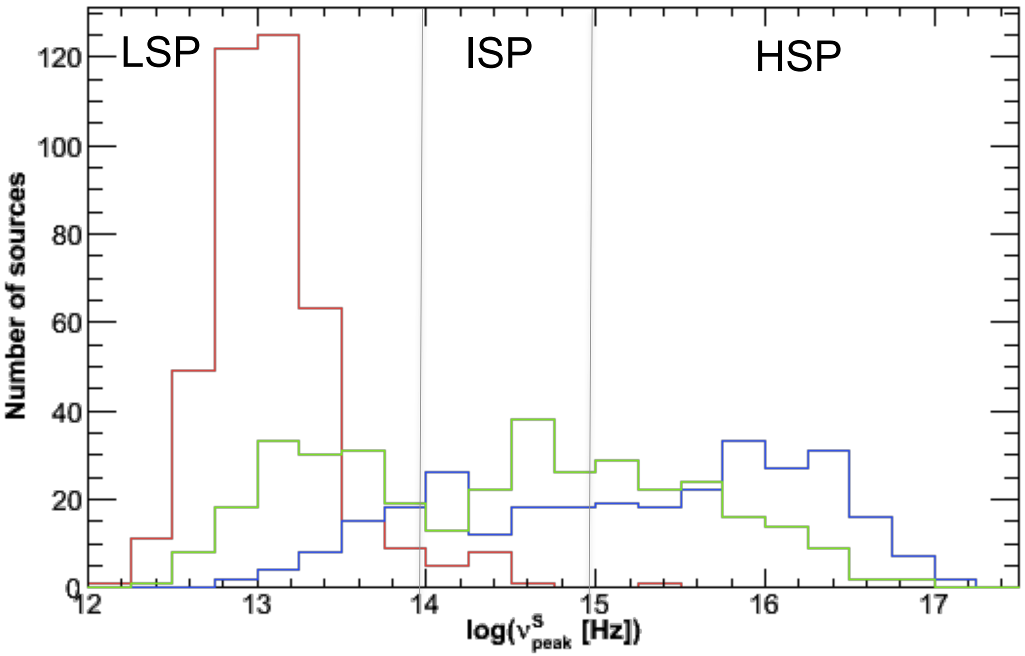


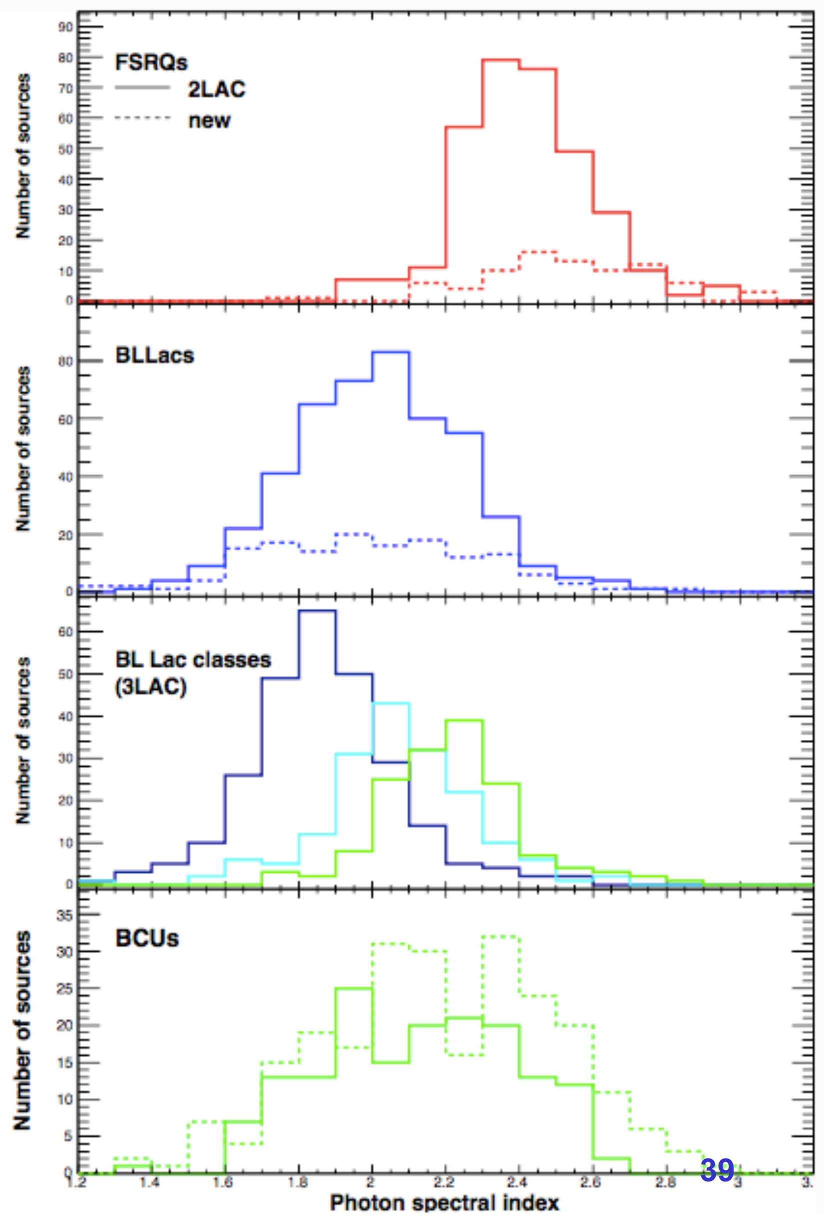
AGN classification in LAC catalogs

Two classification schemes:

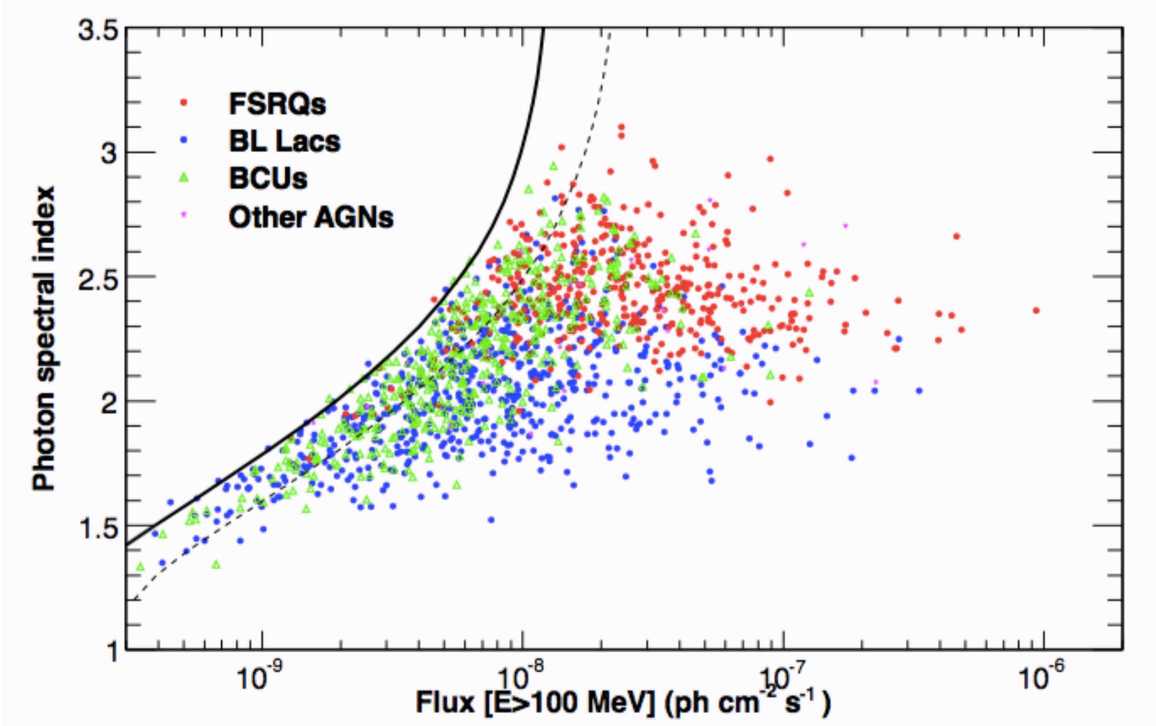
Optically-based (strength of broad lines): FSRQs, BL Lacs, BCUs (Blazar Candidate of Unknown type)

SED-based: Low-, Intermediate-, High-Synchrotron-Peaked sources (LSPs, ISPs, HSPs resp.)





Flux and energy flux



The solid (dashed) curve represents the approximate 3FGL (2FGL) detection limit based on a typical exposure.

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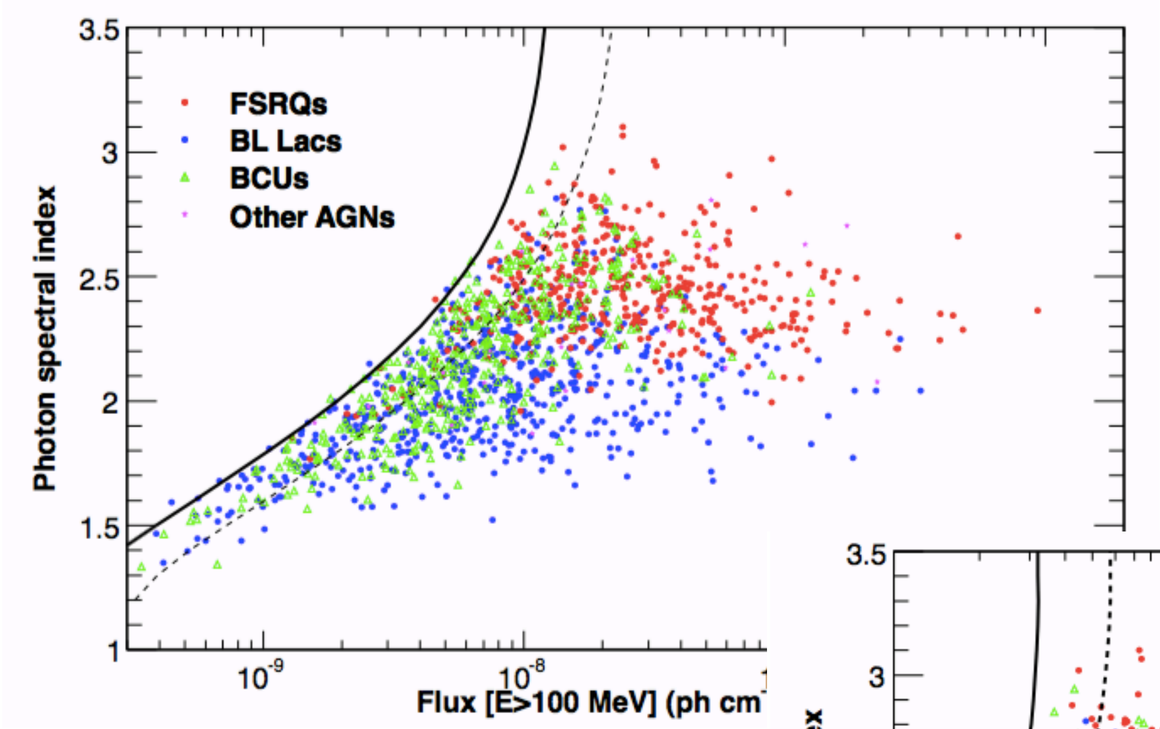

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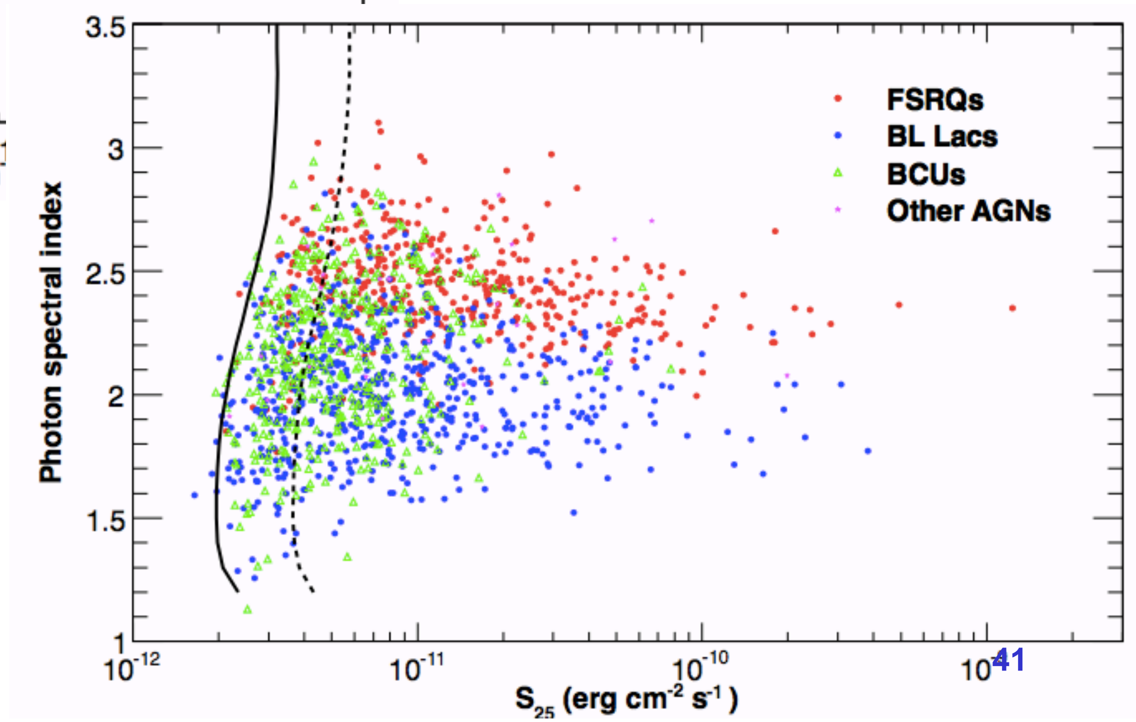
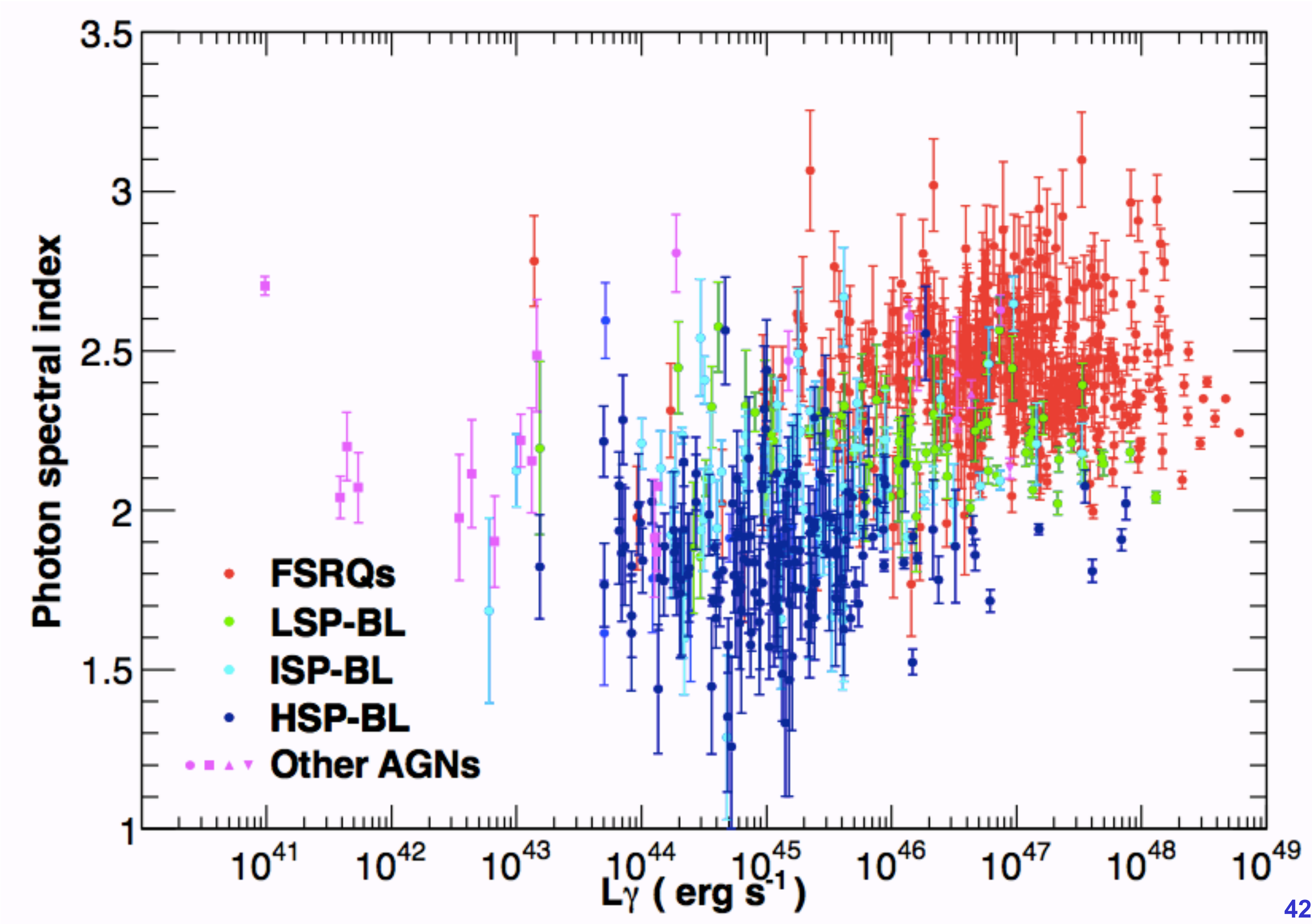
Strong bias in photon flux but not in energy flux and thus in luminosity neither

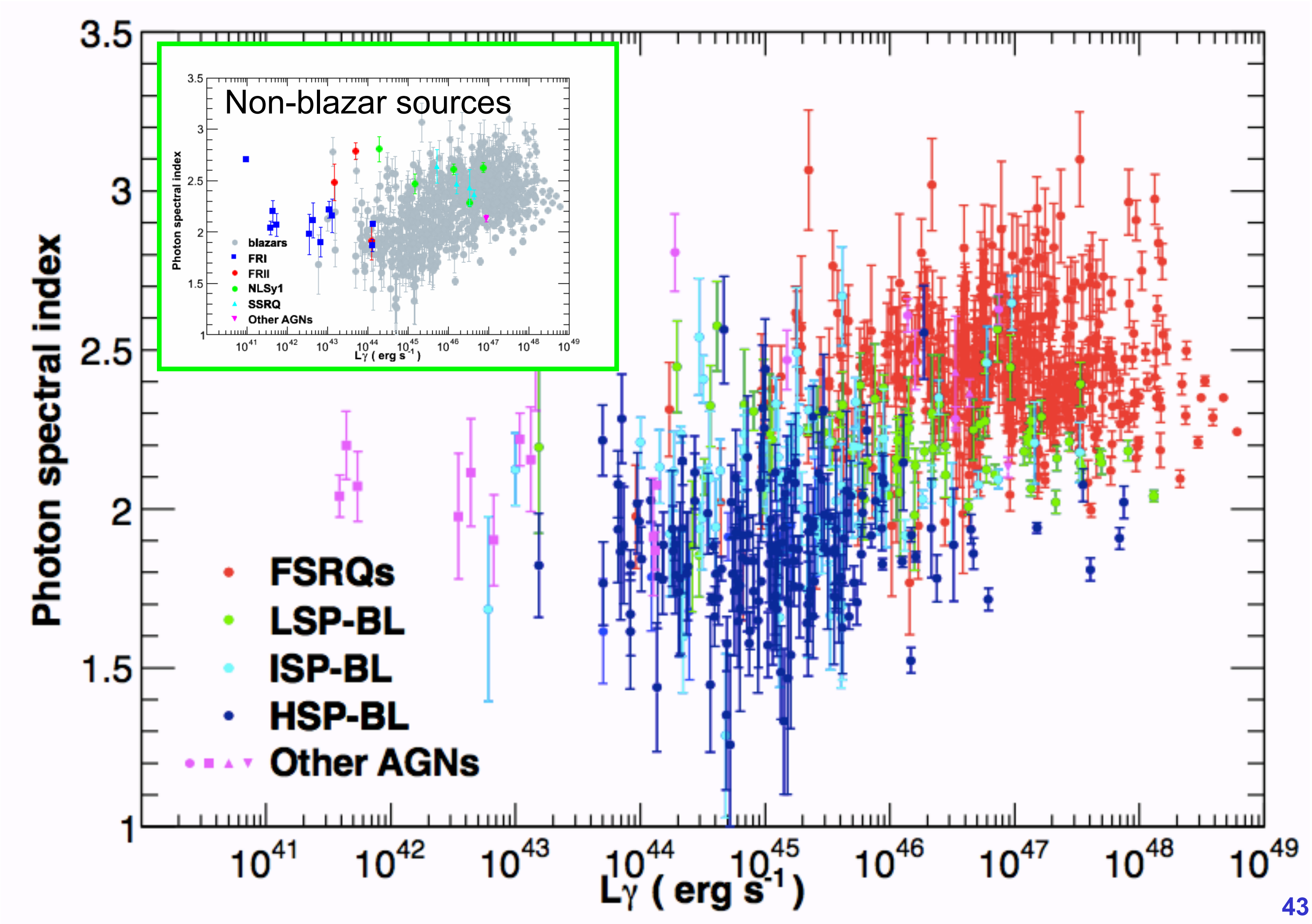


Luminosity



Photon spectral index
3.5
3
2.5
2
1.5
1
10^{41} 10^{42} 10^{43} 10^{44} 10^{45} 10^{46} 10^{47} 10^{48} 10^{49}
Lγ (erg s-1)
FSRQs
LSP-BL
ISP-BL
HSP-BL
Other AGNs

Luminosity



Photon spectral index
Lγ (erg s-1)
FSRQs
LSP-BL
ISP-BL
HSP-BL
Other AGNs
Non-blazar sources
blazars
FRI
FRII
NLSy1
SSRQ
Other AGNs

Blazar population

CAVEAT !!!

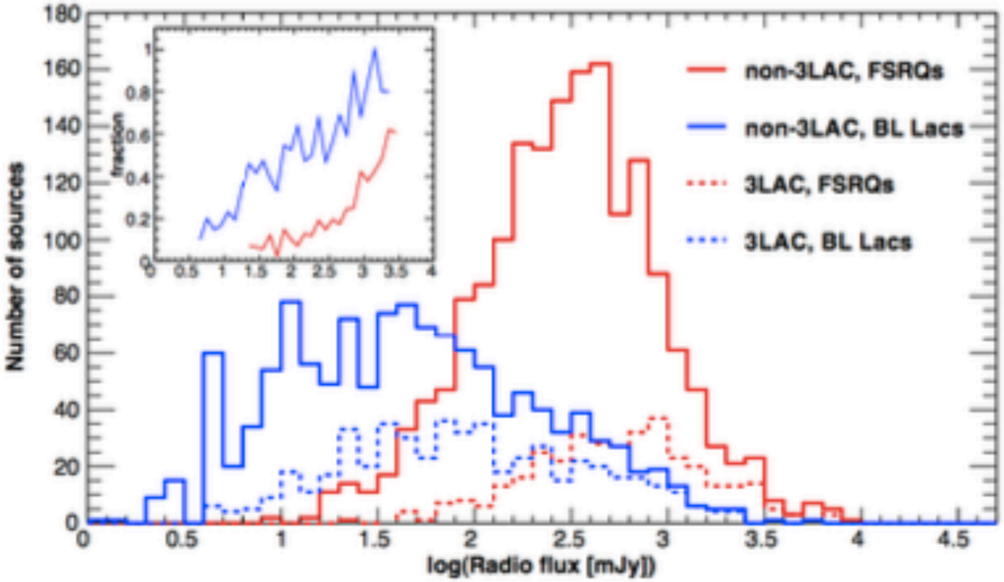
295/604 BL Lacs have no measured redshifts

(55%, 61%, 40%) for (LSPs, ISPs and HSPs)

Form your own opinion about it!

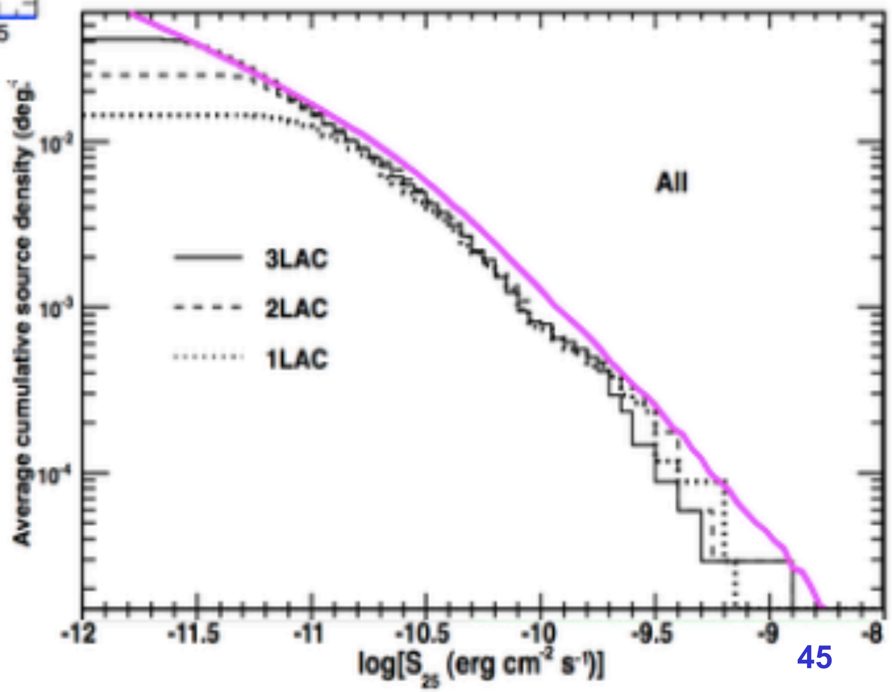
Blazar Sequence, Blazar Divide (Fossati, Ghisellini et al xxx)
Giommi&Padovani (xxx)

3LAC and the missing FSRQ

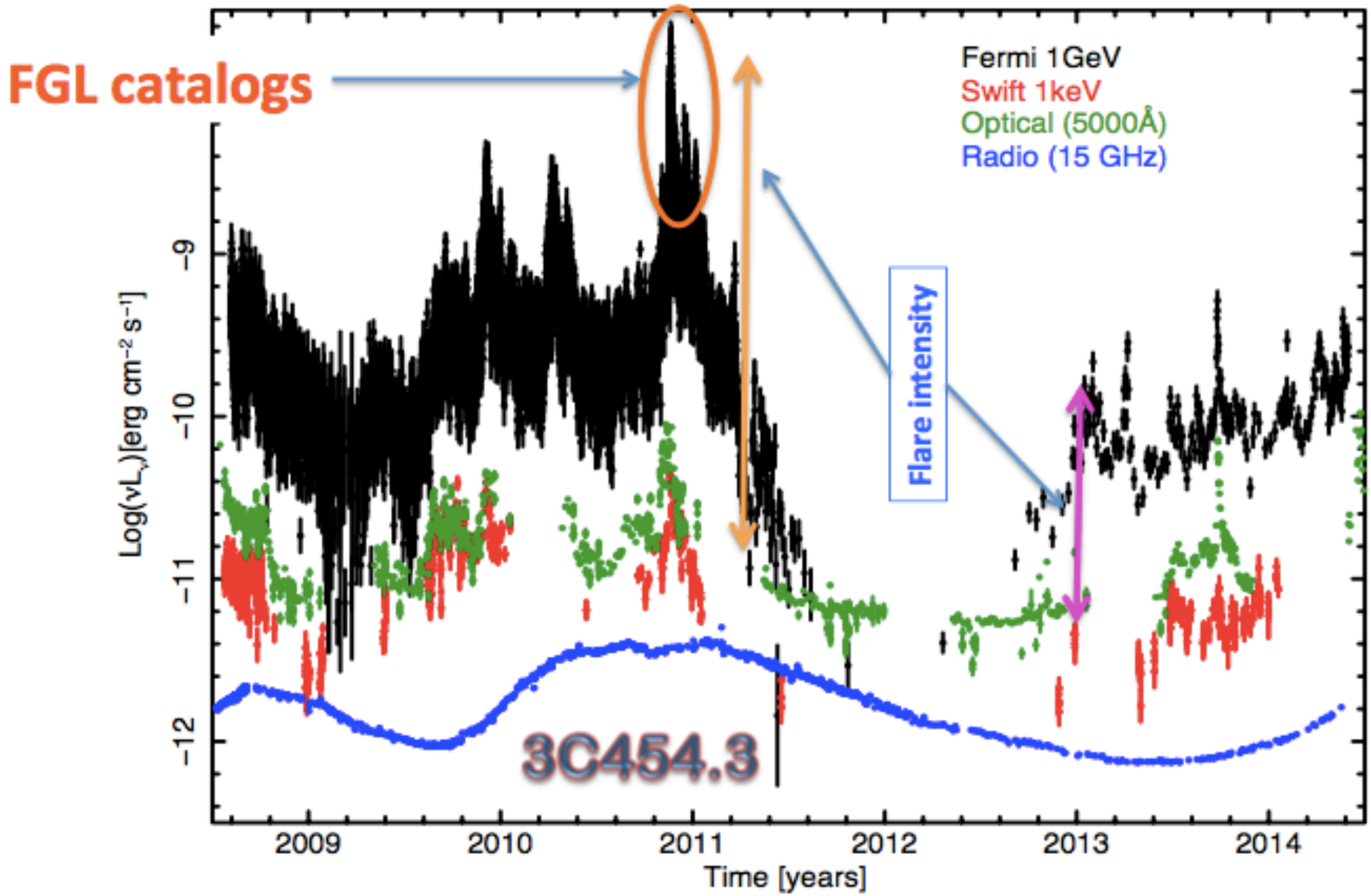


Missing sources

- FGL catalogs detect less LSP sources than HSP ones.
- Steep sources (such as FSRQ) show the brightest gamma-ray flares.
- Such big flares allow to detect the steeper sources, otherwise not enough bright (in gamma-ray).



Transient gamma-ray sources



Flat Spectrum – Low Synchrotron peaked radio source

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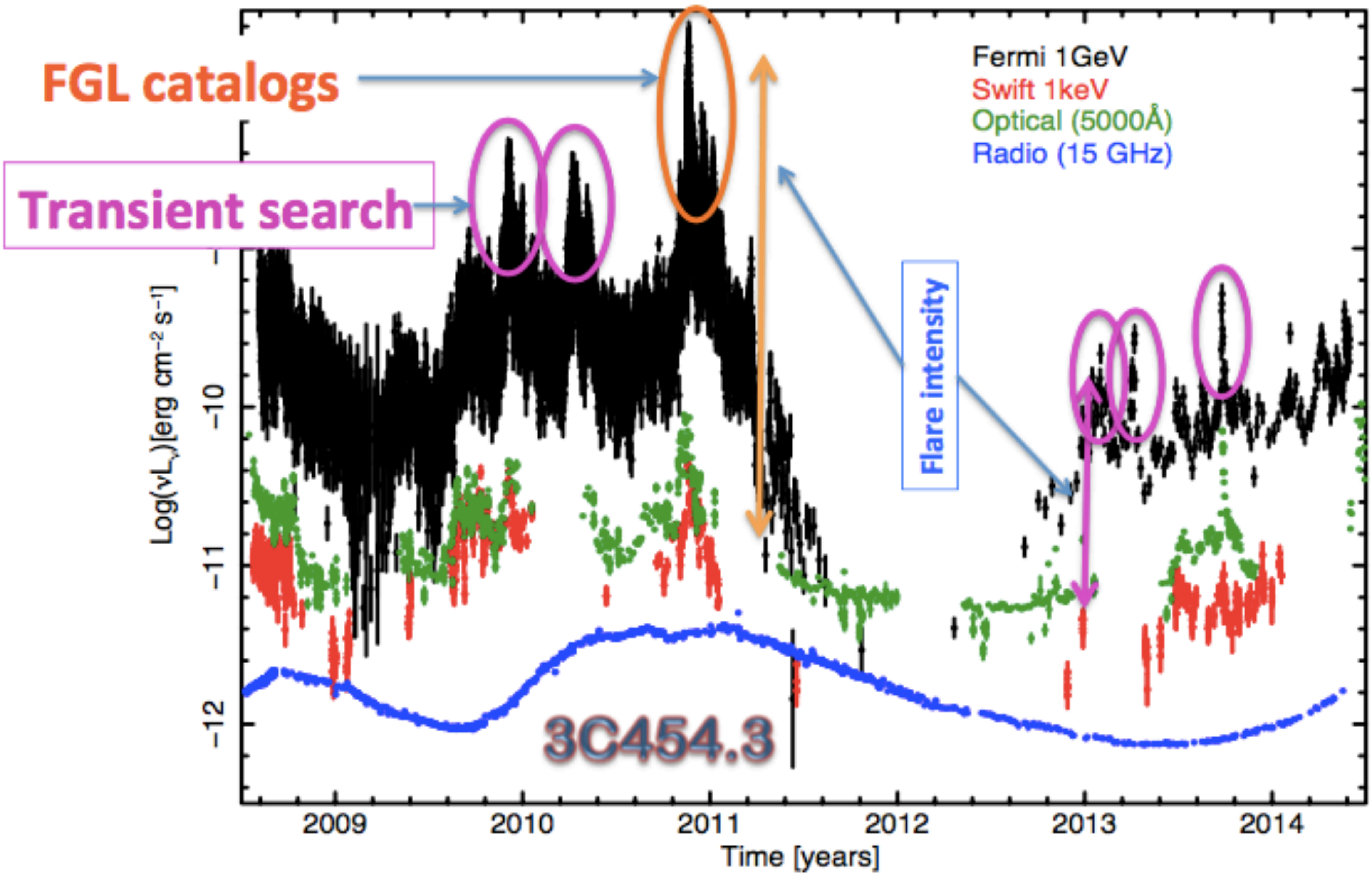
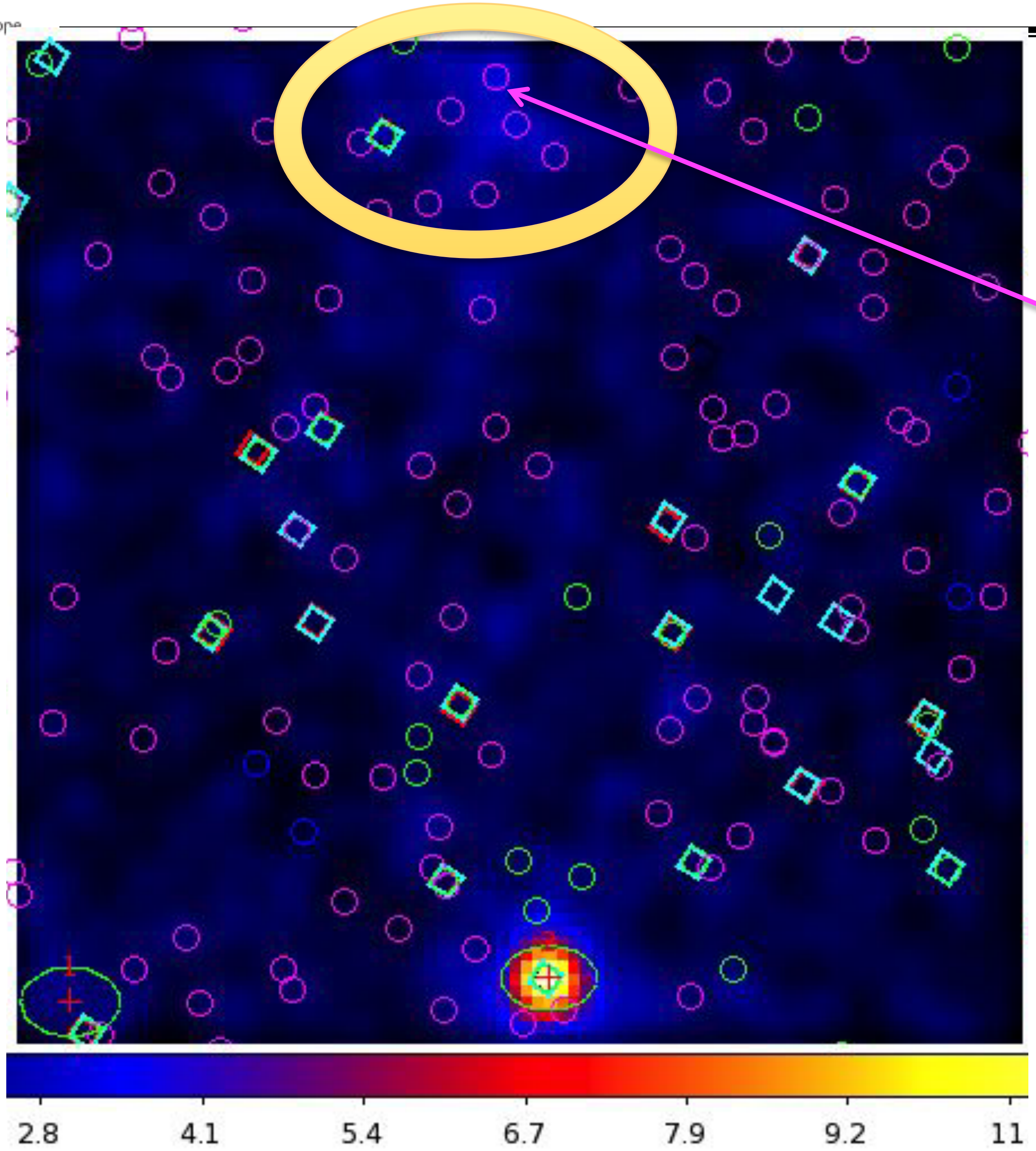


Flat Spectrum − Low Synchrotron peaked radio source

A variable sky



CRATES source:
Typical Flat Spectrum
Low Synchrotron
Peaked radio source

TS=91 in month 46

TS=106 in month 55

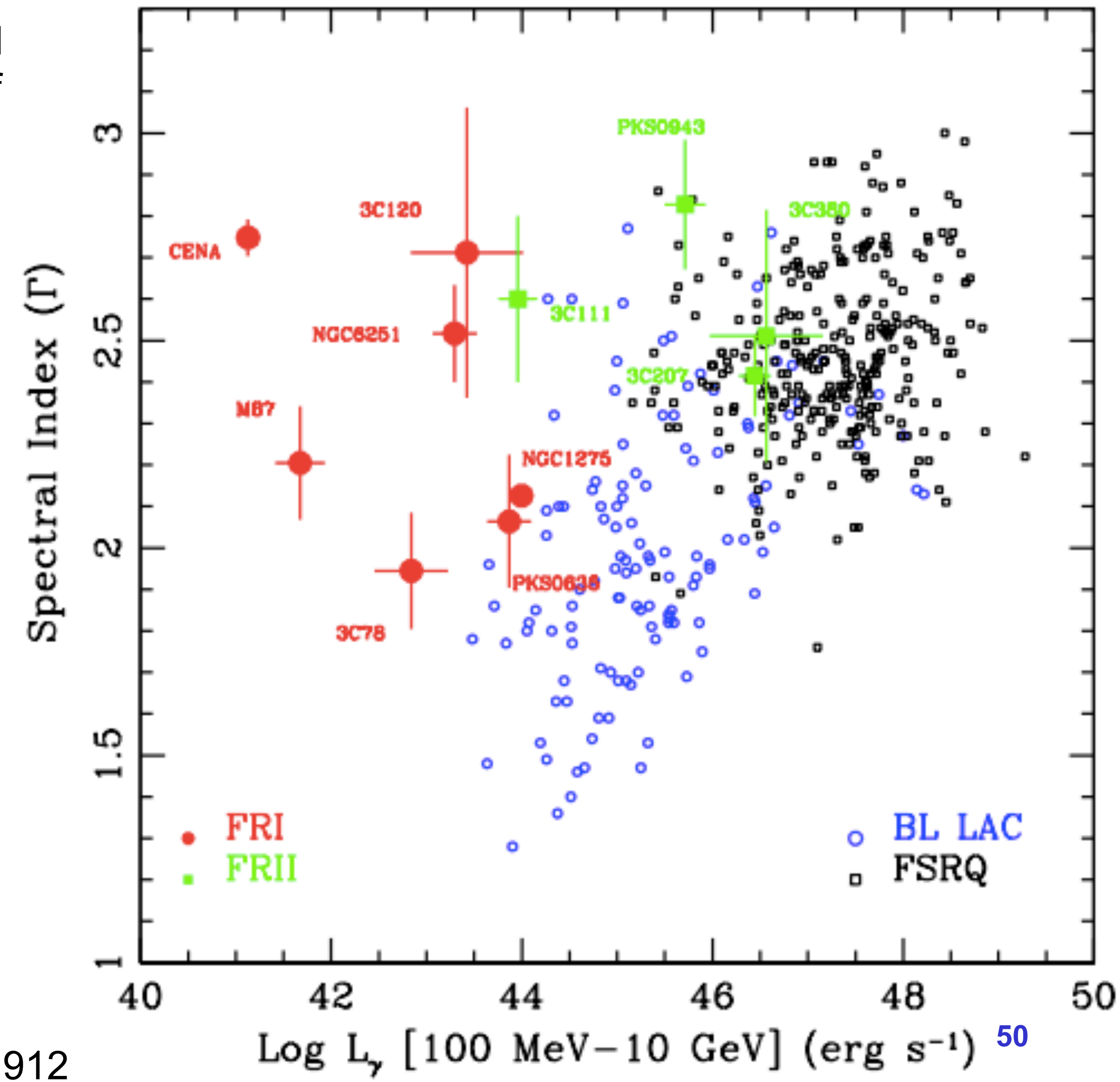
A certain Region of Interest, analysed over 77 months

Some (past and) recent major results

Radio galaxies

Local **radio galaxies** (z < 0.1) and blazars occupy different regions of the plot, with non-blazar AGN generally characterized by lower luminosity.

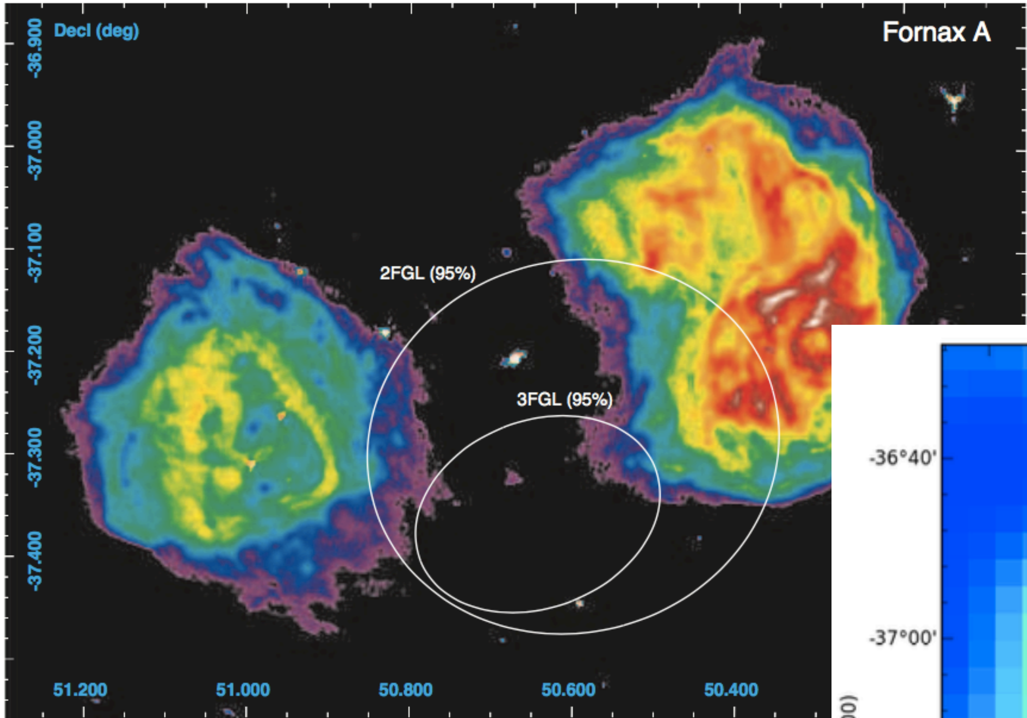
On the contrary, the two more distant **steep spectrum radio quasars** (z > 0.6) fall within the range of γ-ray luminosities of FSRQs.



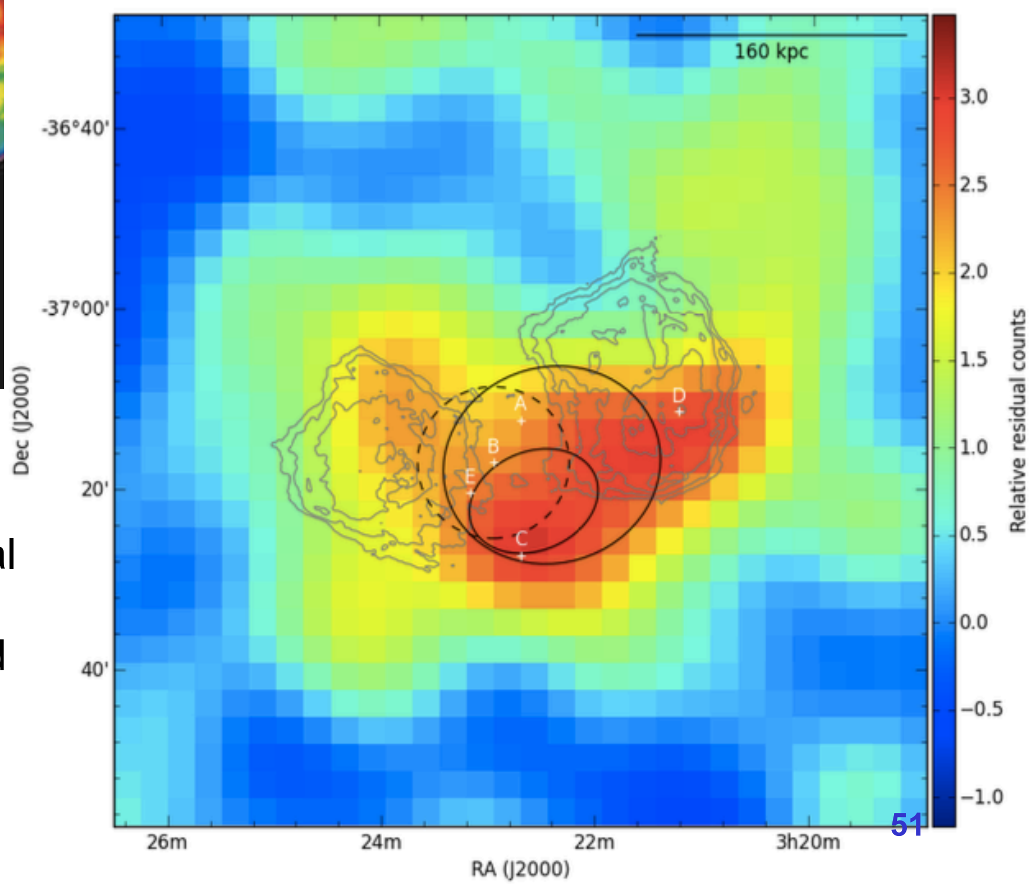
The non-blazar AGN detected by Fermi so far are characterized by **large core dominances** (ratio between IC and Synch peak fluxes)

Abdo, A. A. et al. 2010, ApJ, 720, 912

Fornax A lobes



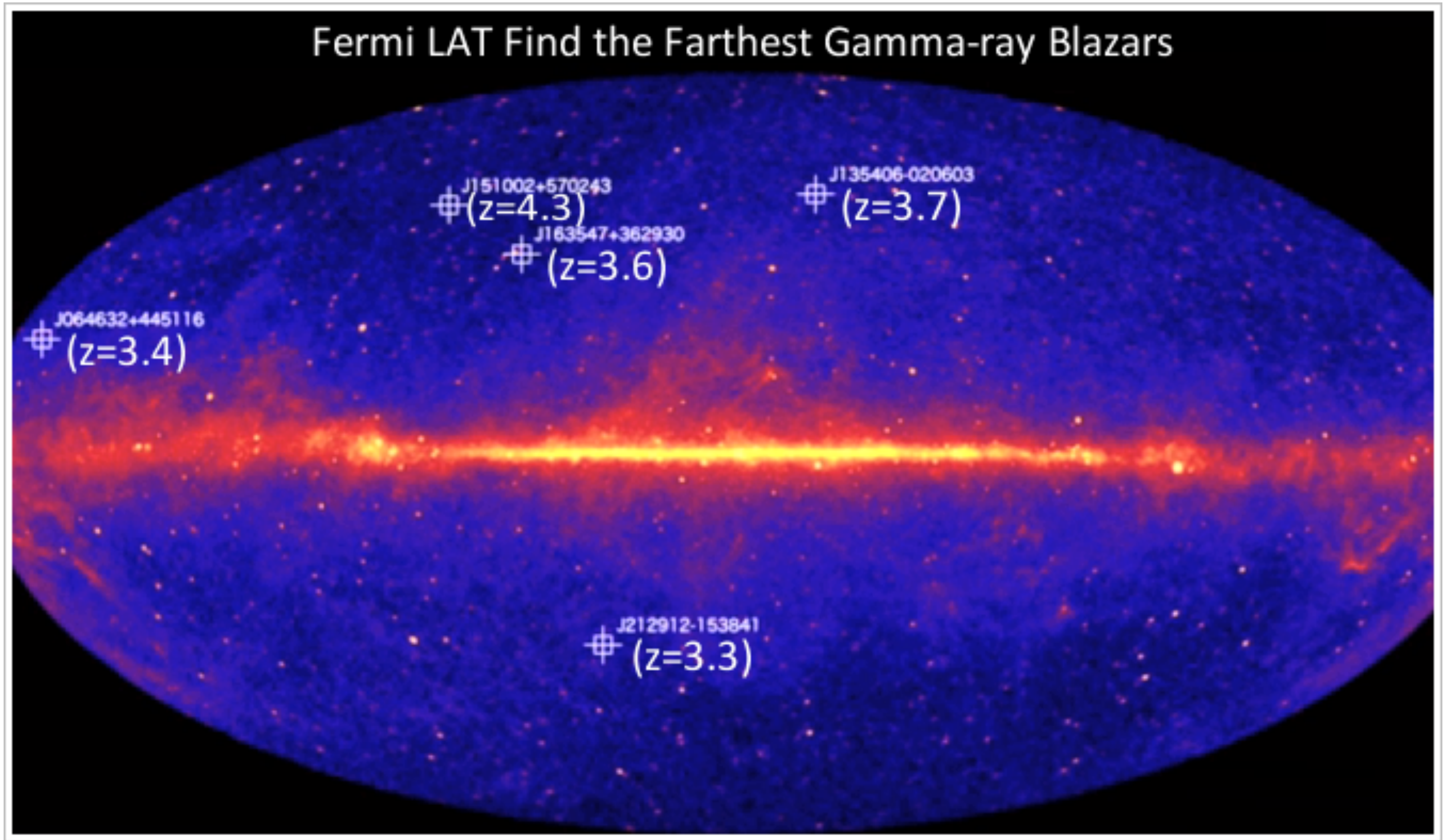
A leptonic emission that arises due to IC scattering of EBL photons off of relativistic electrons in the radio lobes underestimates the observed γ-ray emission for any current EBL estimate



A hadronic-only model (proton-proton interactions) requires implausibly large total cosmic-ray energy when compared to an estimate of the Fornax A outburst assumed to have created the lobes

Ackermann, M. et al. 2016, ApJ, 826, 1

The most distant γ-ray detected blazars



Ackermann, M. et al. 2017, ApJL, 837, L5

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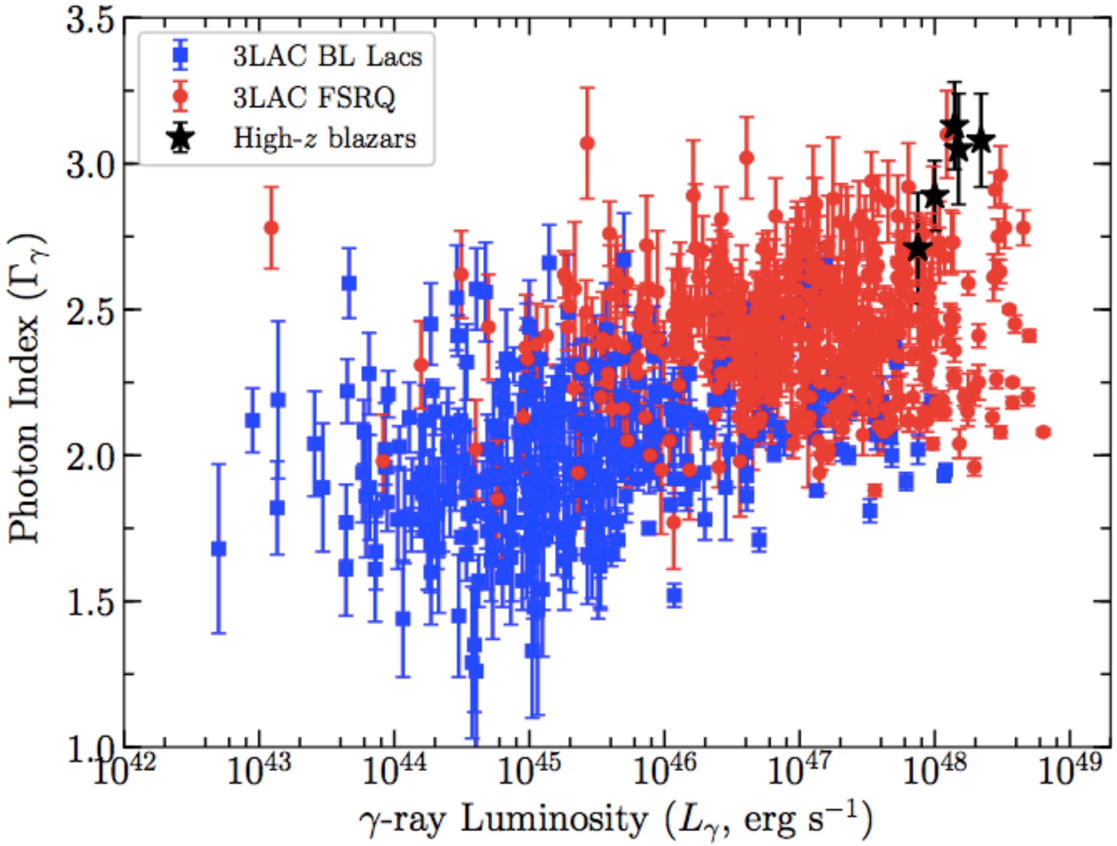


NVSS J151002+570243 (z = 4.31) is now the farthest known γ- ray emitting blazar

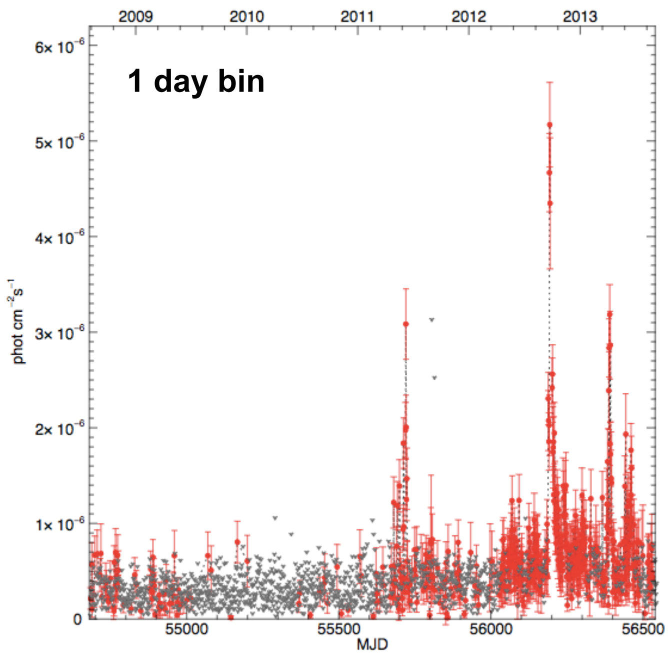
Ackermann, M. et al. 2017, ApJL, 837, L5

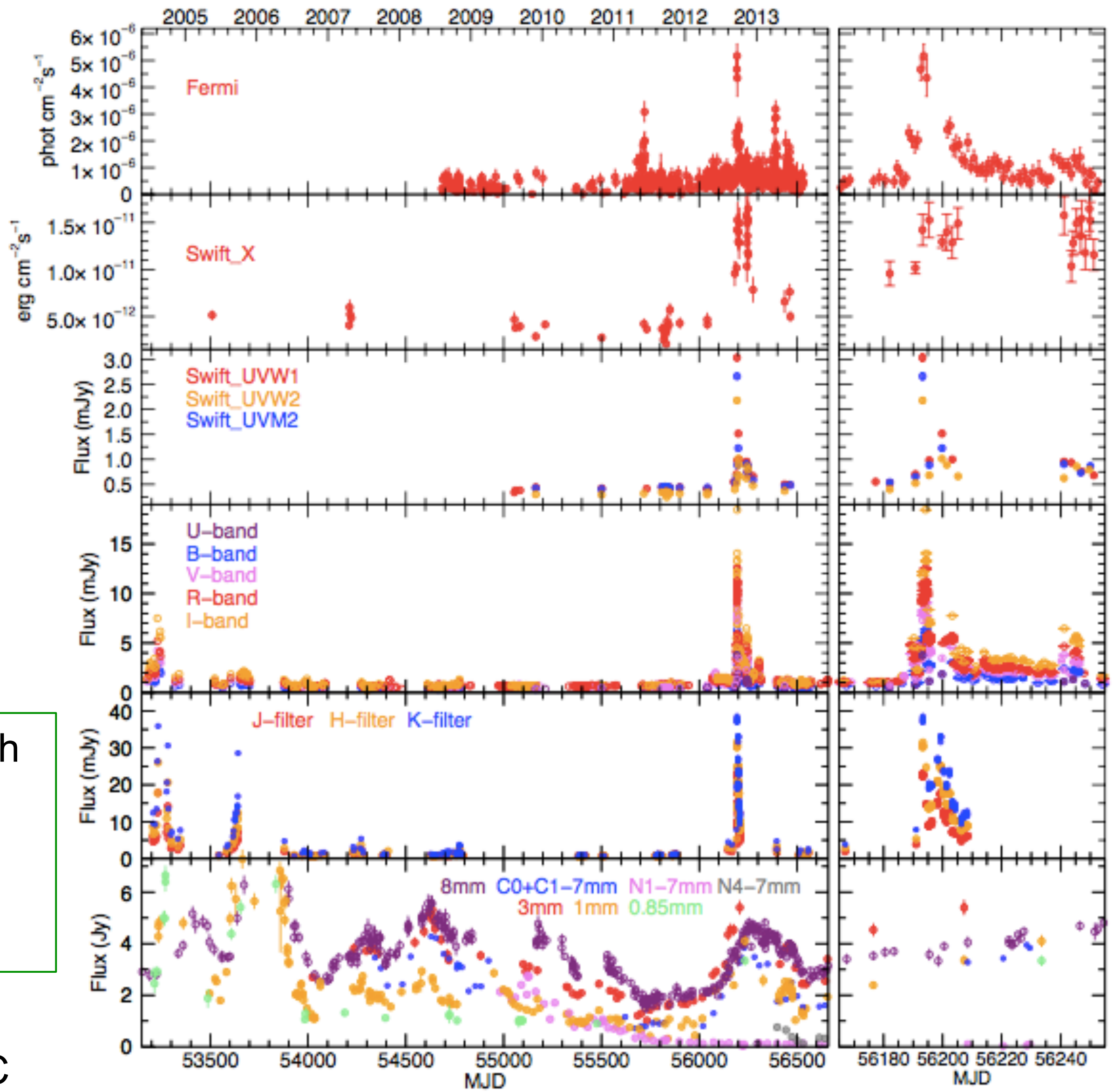
~1.4million quasars included in the Million Quasar Catalog (MQC; Flesch 2015)

- select all z > 3.1 sources and
- retain only radio-loud
- 92 months of LAT data
- (ROI) of 15◦ radius centered on each quasar and define a sky model that includes all γ-ray sources detected in the 3FGL

expand the energy range considered so it spans **60 MeV to 300 GeV to be more sensitive to spectrally soft γ-ray sources**, i.e., blazars whose high-energy peak is shifted to lower energies (~1−10 MeV) as typical for high-z blazars.

CTA 102 (FSRQ)

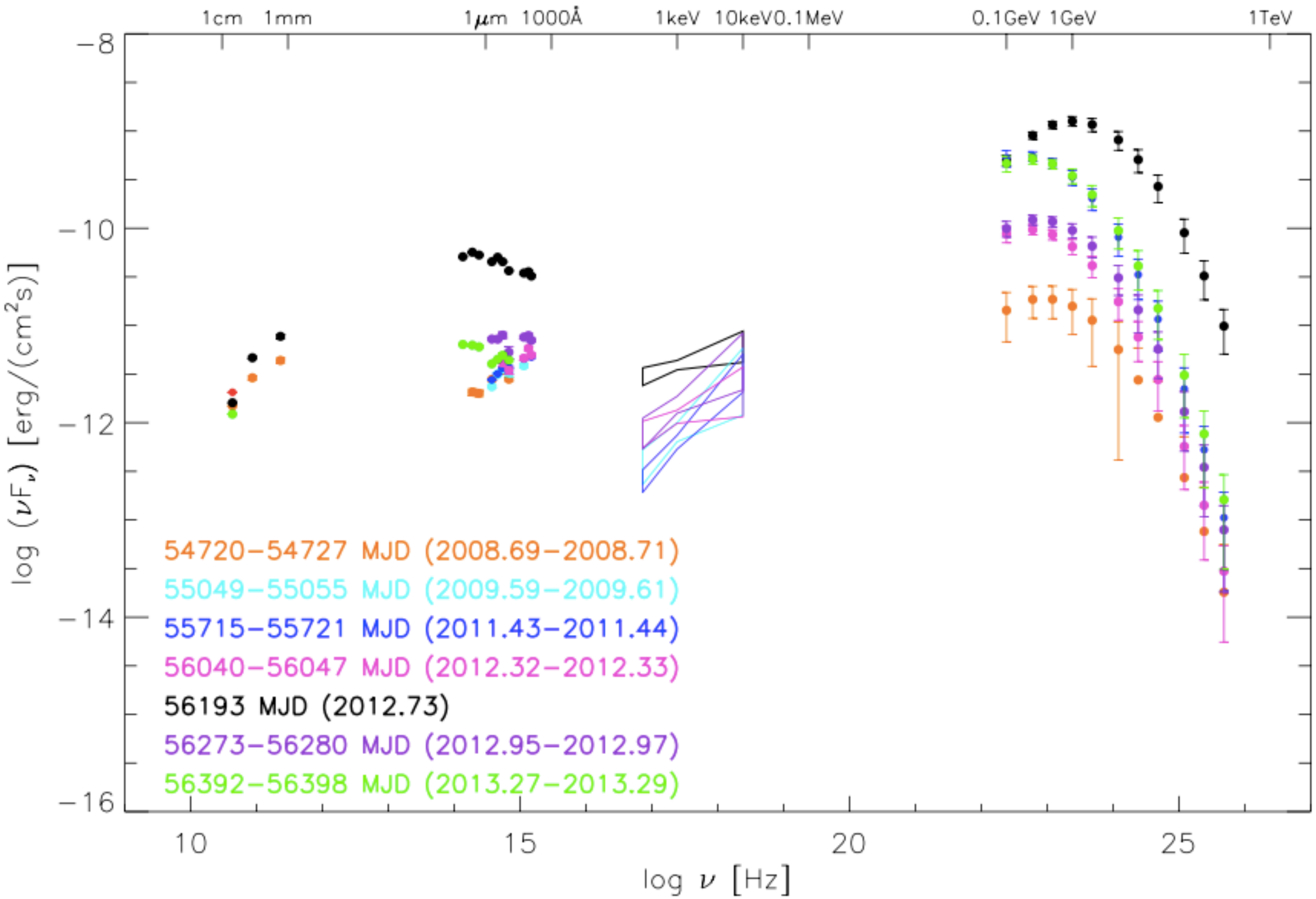




the γ-ray outburst is coincident with flares at all the other frequencies and is related to the passage of a new superluminal knot through the radio core.

Casadio et al, 2015ApJ, 813, 51C

CTA 102 (FSRQ)



Casadio et al, 2015ApJ, 813, 51C

erratic blazar nature, revealing **both strong connections across wave bands in one outburst and no obvious connections for other events.**

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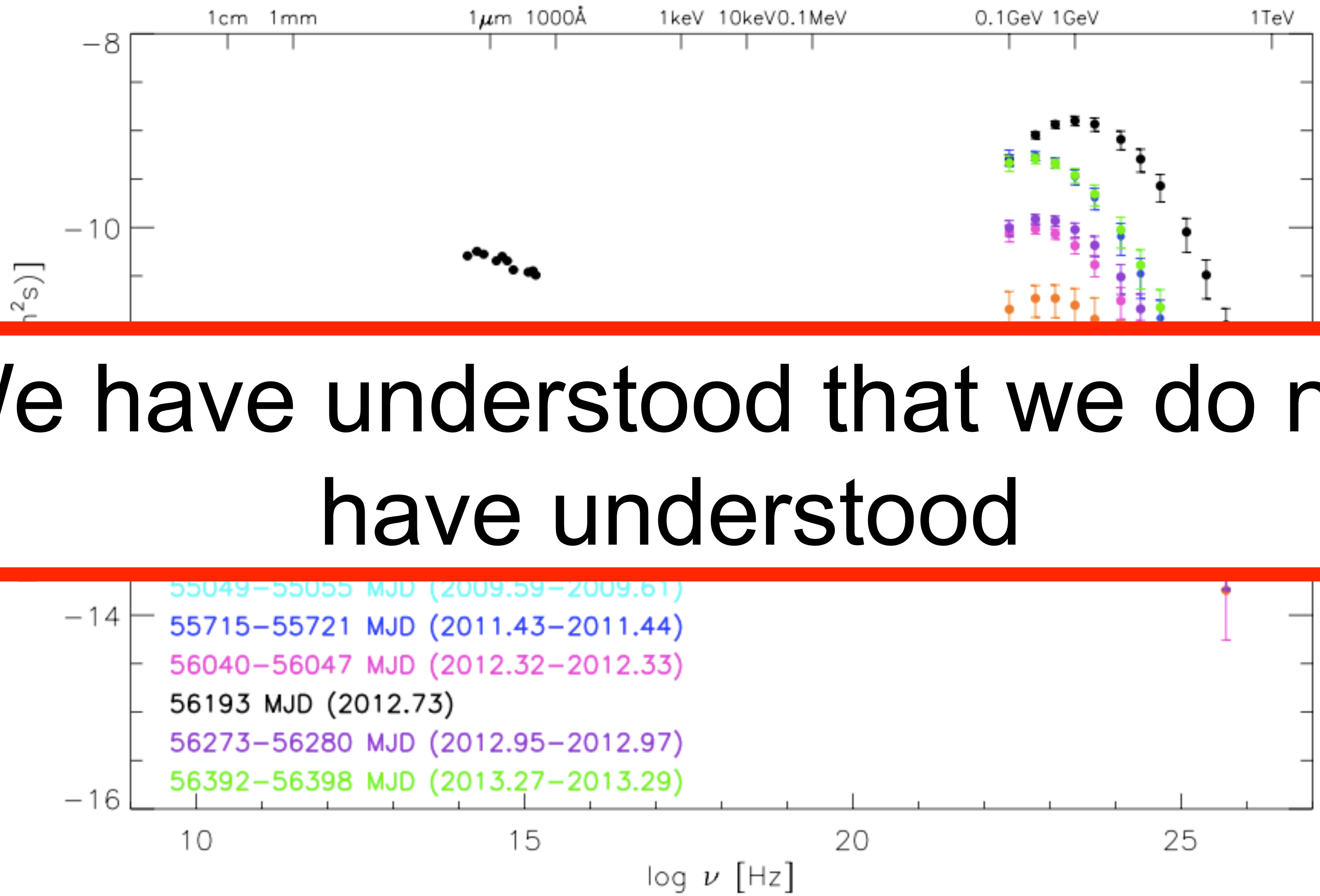
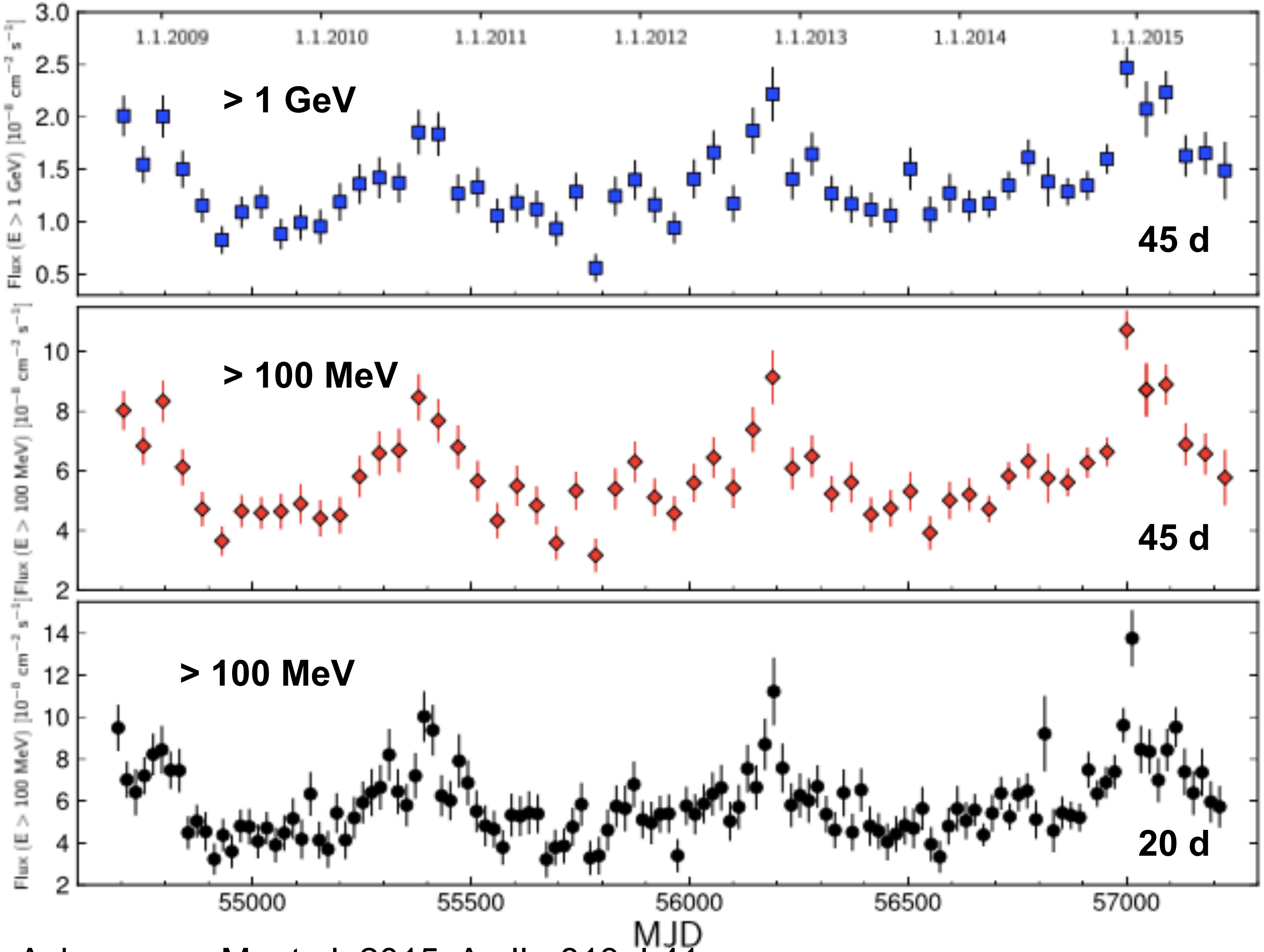


We have understood that we do not have understood

Casadio et al, 2015ApJ, 813, 51C

erratic blazar nature, revealing **both strong connections across wave bands in one outburst and no obvious connections for other events.**

Quasi-periodic Modulation in PG 1553+113

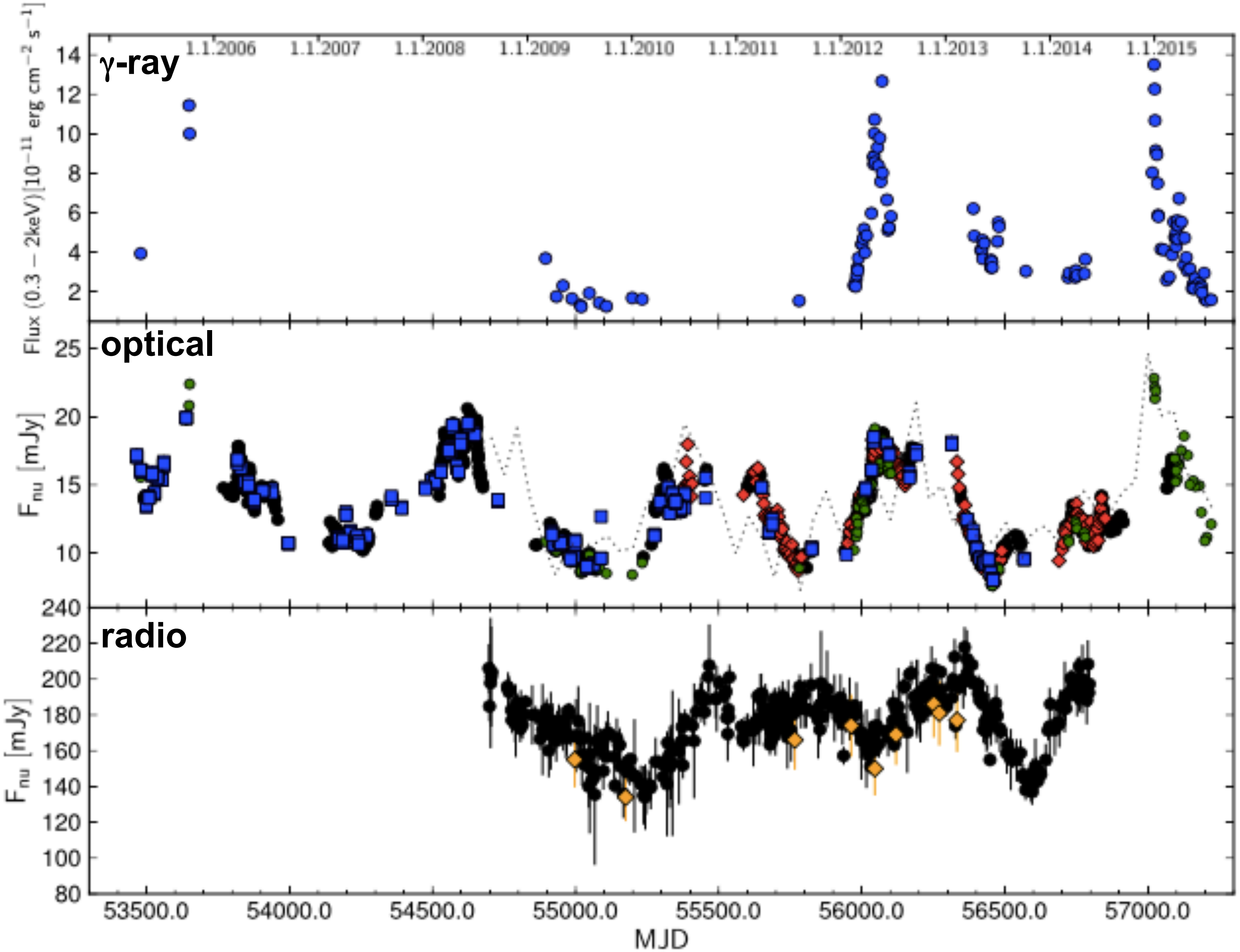


Ackermann, M. et al. 2015, ApJL, 813, L41

- BL Lac HSP 0.395 < z < 0.62
- **one of the brightest BL Lacs in the X-ray band**
- **TeV source (HESS, MAGIC)**
- **PeV ν ?**

~ 6.5 years Pass8 data

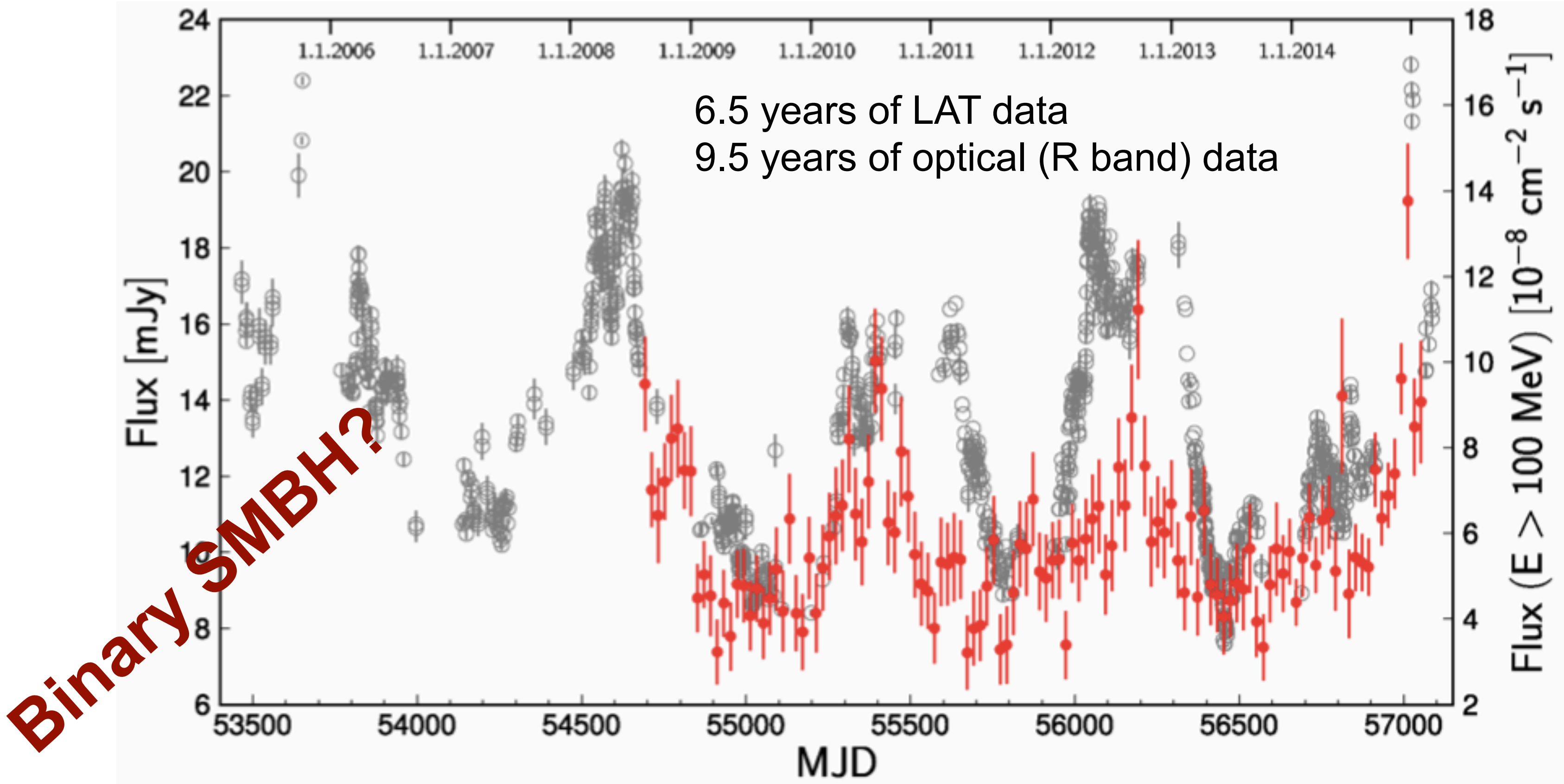
Quasi-periodic Modulation in PG 1553+113



Critical MW data

Ackermann, M. et al. 2015, ApJL, 813, L41

Quasi-periodic Modulation in PG 1553+113



The periodicity analysis methods applied to optical and radio light curves found compliant results with the gamma-ray light curves.

- Composite optical light curve period search: ~752+/-8 days (2.06+/-0.02years)
- Radio light curve period search: ~695+/-75 days (1.9+/-0.2 years)

Contribution to Extragalactic Gamma-Ray Background

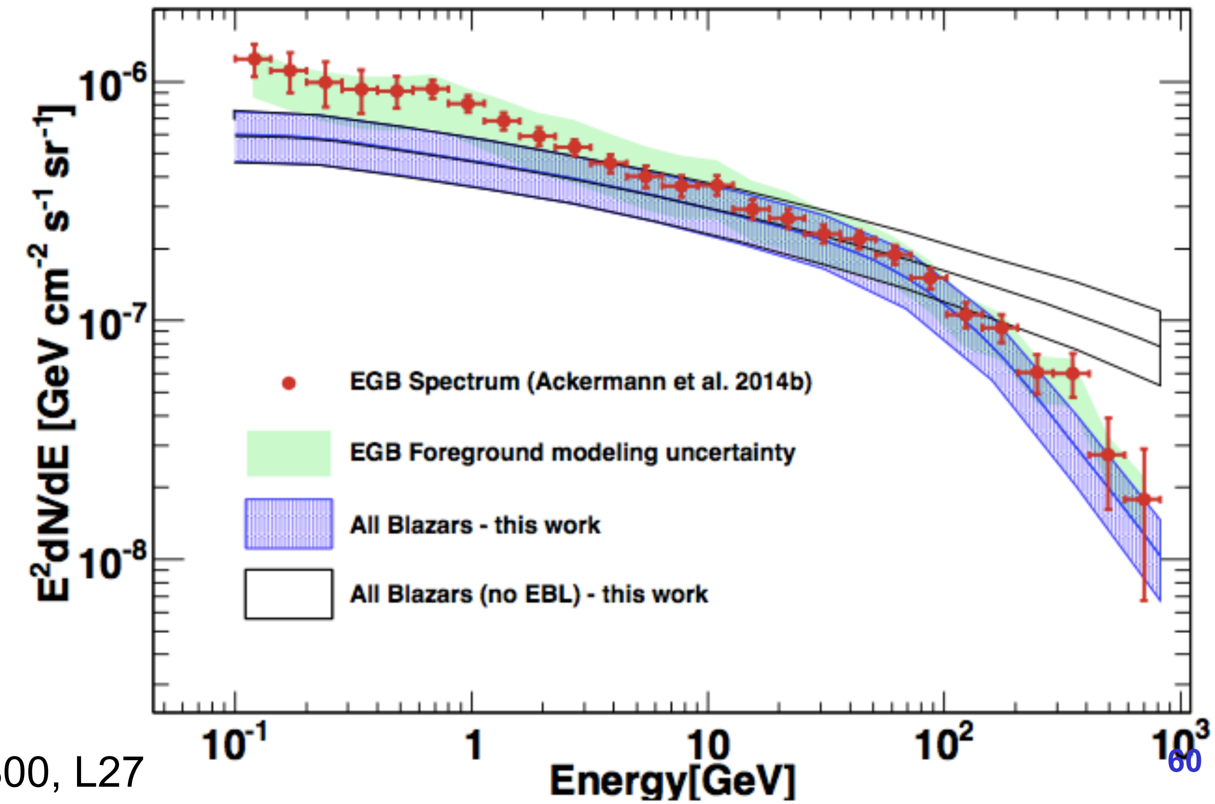
EGB total intensity of 1.1×10^{-5} ph cm^{-2} s^{-1} sr^{-1}

Blazars contribute a grand-total of (5-7)× 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

– Resolved sources : ~4× 10^{-6} ph cm^{-2} s^{-1} sr^{-1}

– Unresolved blazars: ~(2-3)×10^{-6} ph cm^{-2} s^{-1} sr^{-1} (in agreement with Abdo+10)

Blazars, star-forming galaxies and radio galaxies can explain the intensity and the spectrum of the EGB

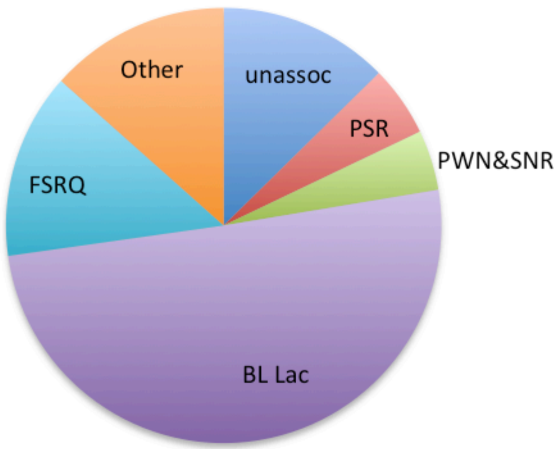


Ajello, M. et al. 2015, ApJL, 800, L27

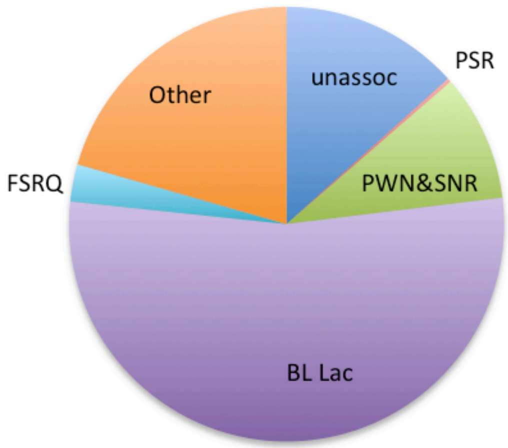
GeV – TeV connection

Fermi High energy source Lists (FHL)

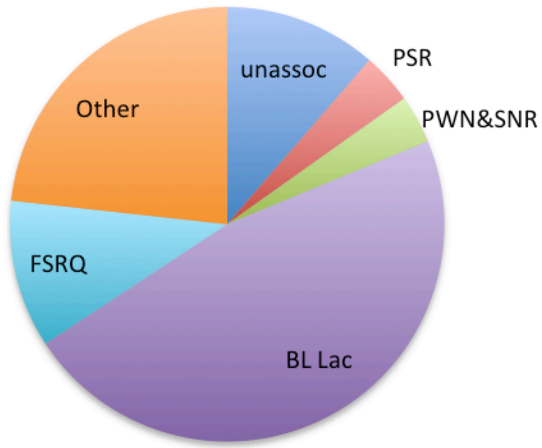
1FHL > 10 GeV, 36 months years



2FHL, > 50 GeV, 80 months

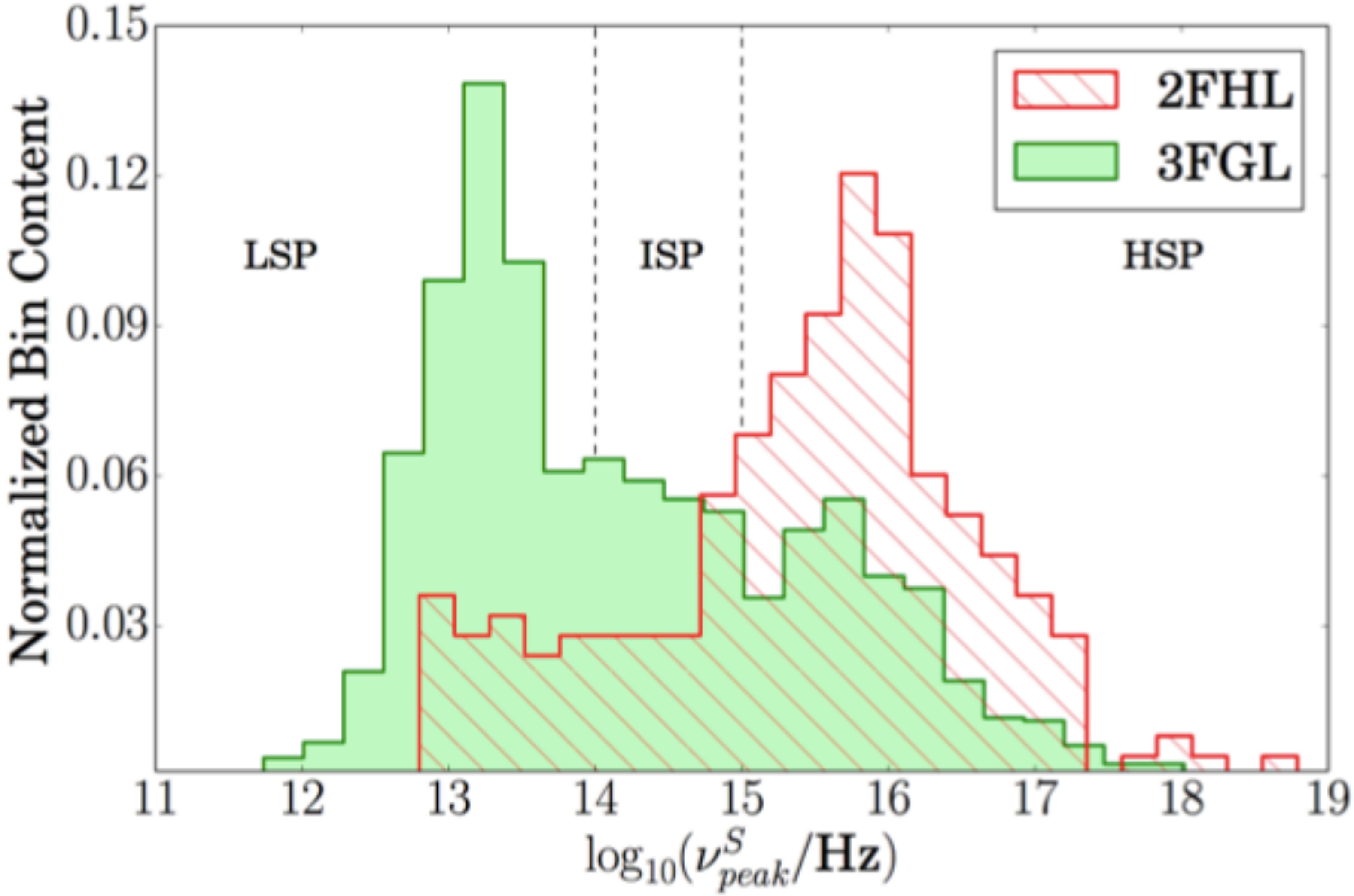


3FHL, > 10 GeV 84 months



AGN are still the vast majority of counterparts

Blazars synchrotron peak distributions



Different population than 3FGL

Blazars synchrotron peak distributions

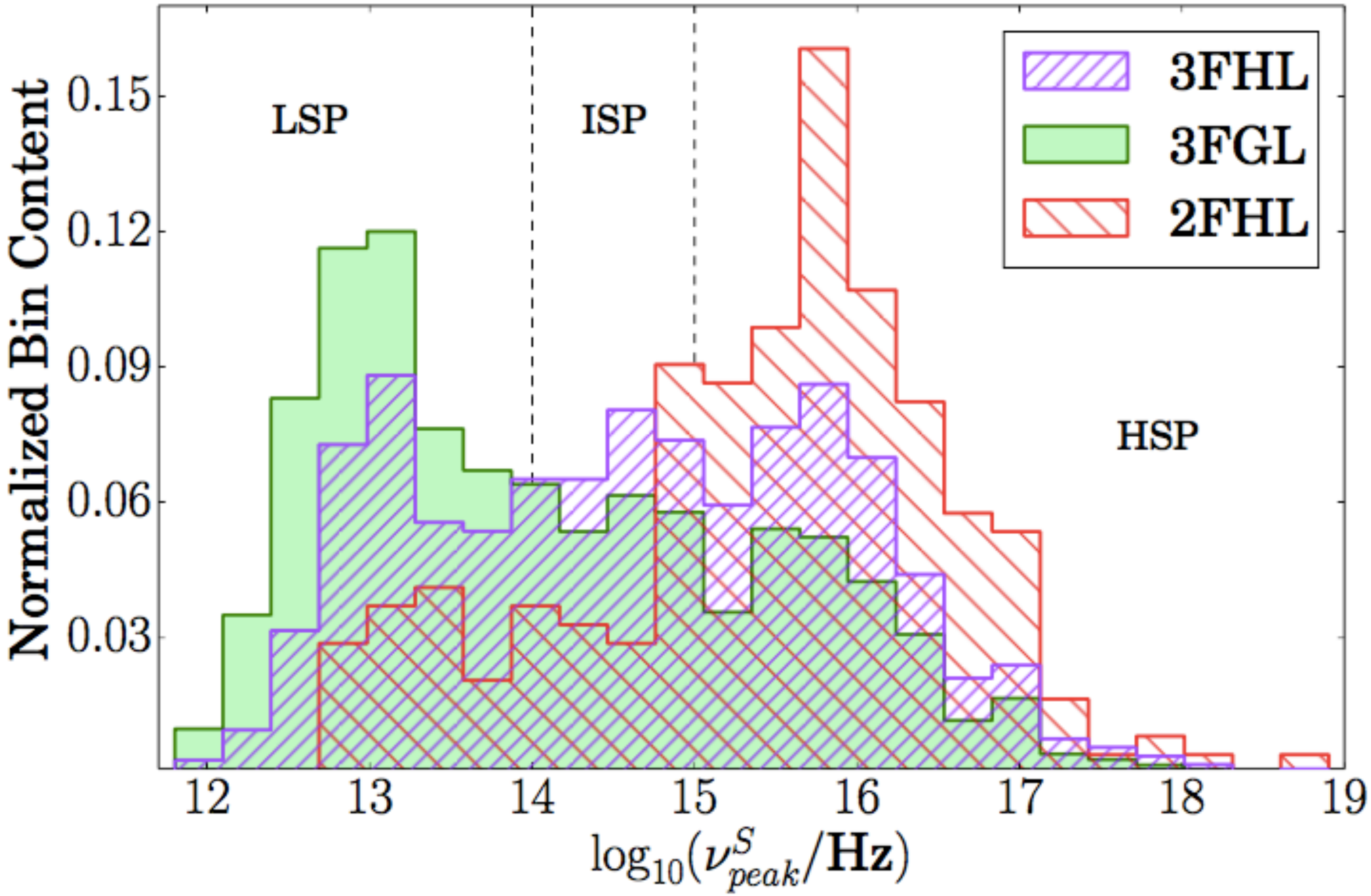


Fig. 14.— Normalized distributions of the frequency of the synchrotron peak for the blazars detected in the 3FGL (0.1–300 GeV), 2FHL (50 GeV–2 TeV), and 3FHL (10 GeV–2 TeV) catalogs.

BL Lac spectral index distributions

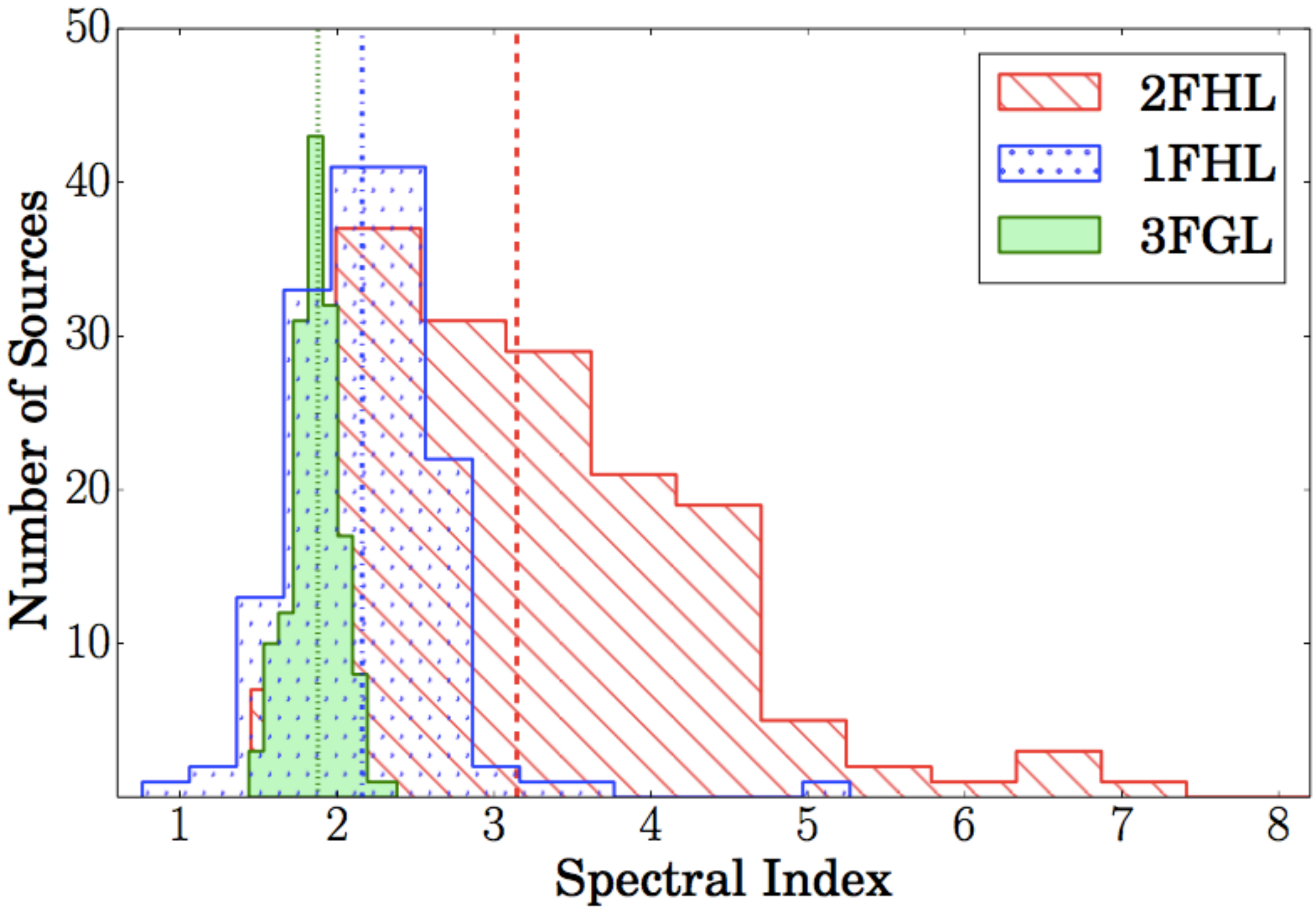
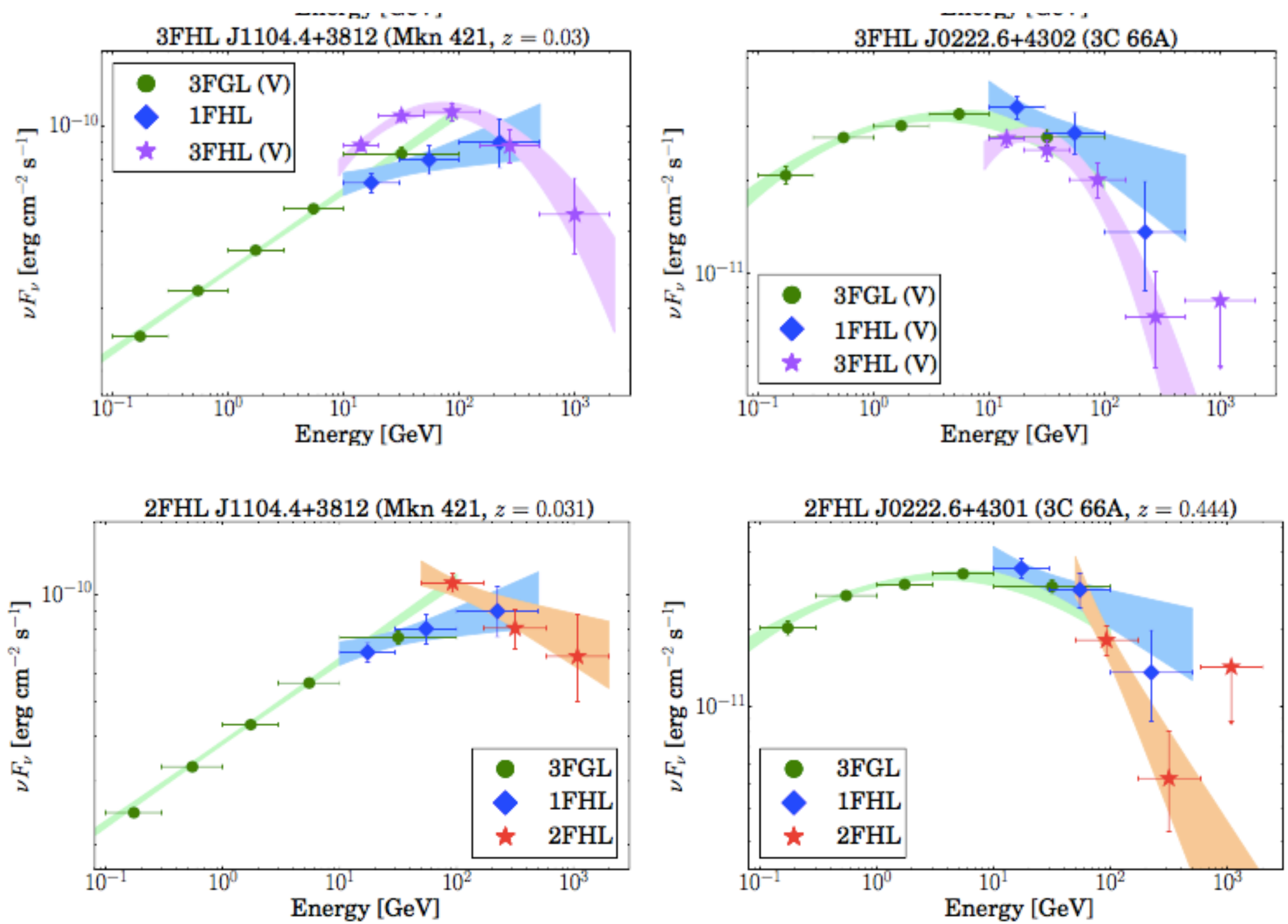
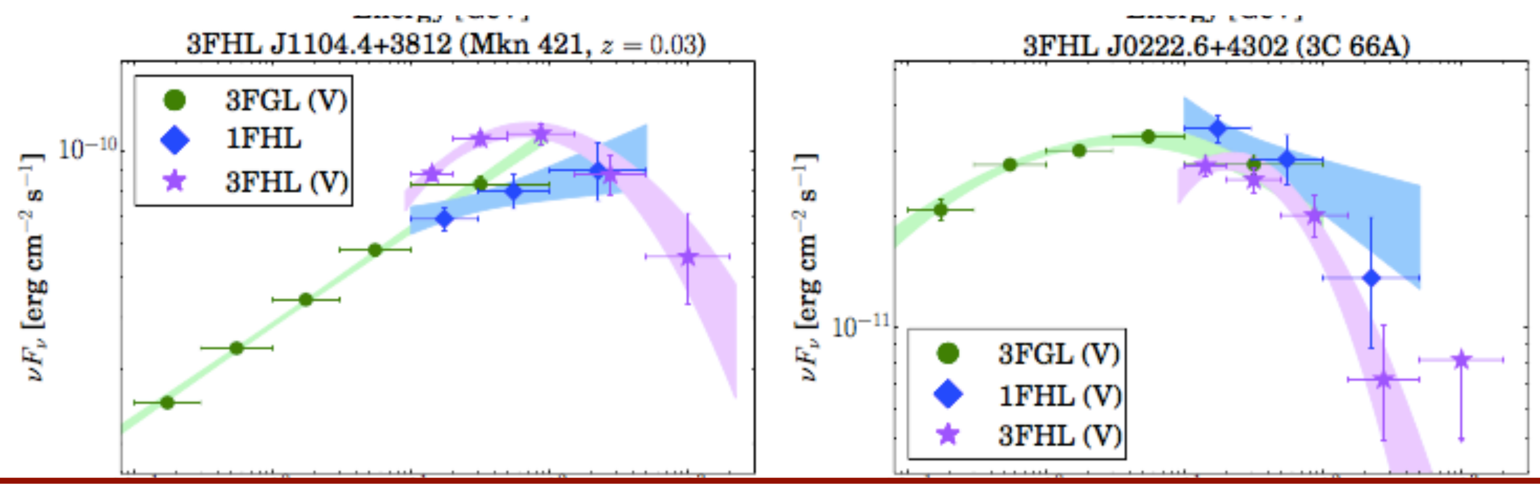


Fig. 10.— The distribution of spectral indices for a subsample of 158 BL Lacs that are in common among the 2FHL (backslash orange), 3FGL (slash green), and 1FHL (purple). The medians of the distributions are shown with vertical lines. The higher the energy band, the larger the index; therefore sources get softer with increasing energy. The scatter of the distribution is also larger with increasing energy, partly because of the lower statistics.

Multi wavelength high energy SED



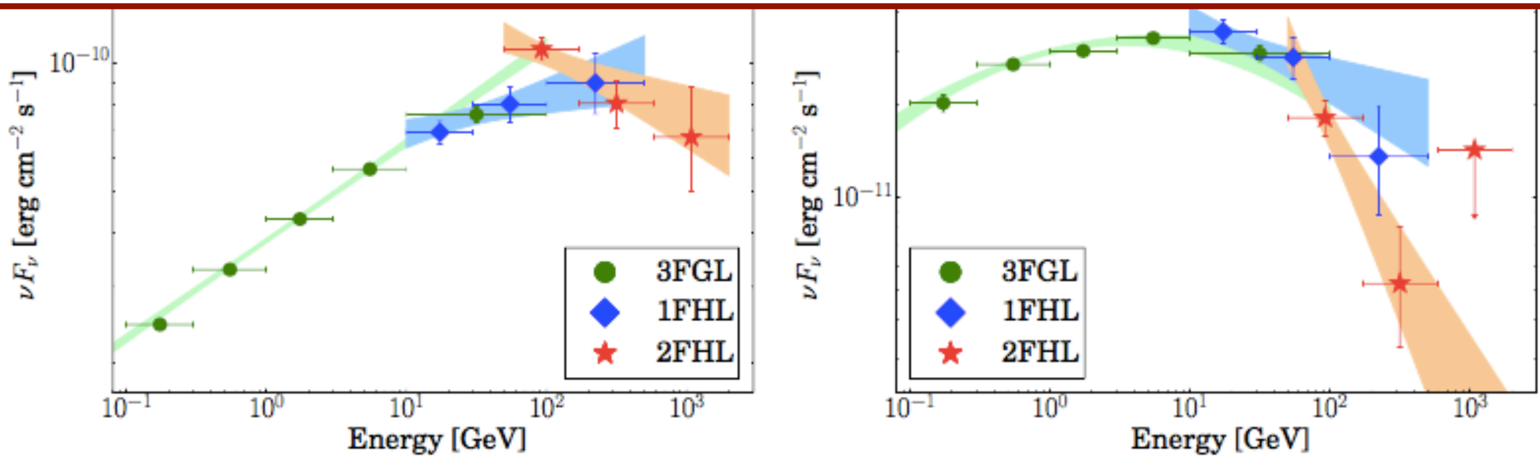
Multi wavelength high energy SED



Being sensitive over ~4 decades in energy, the LAT resolves the high-energy peak

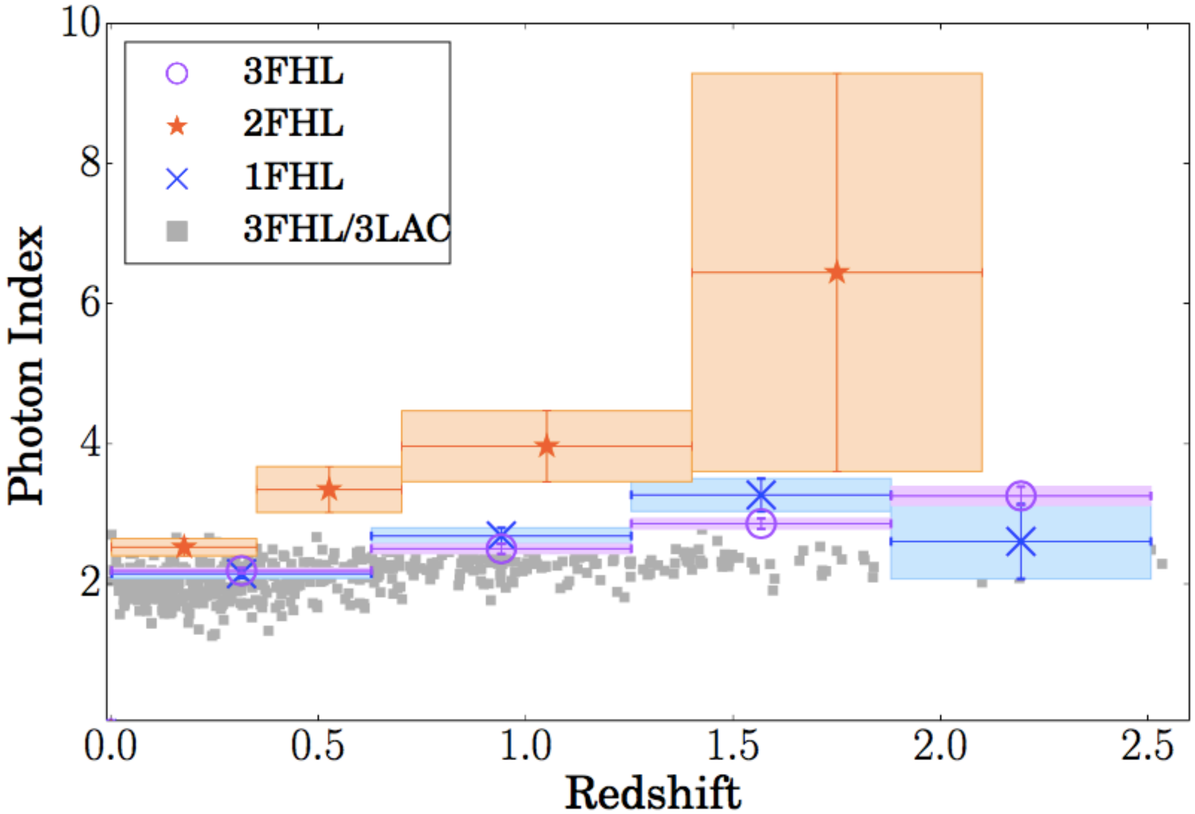
– Sources become **softer at higher energies**

– Sources becomes **softer at high redshift**



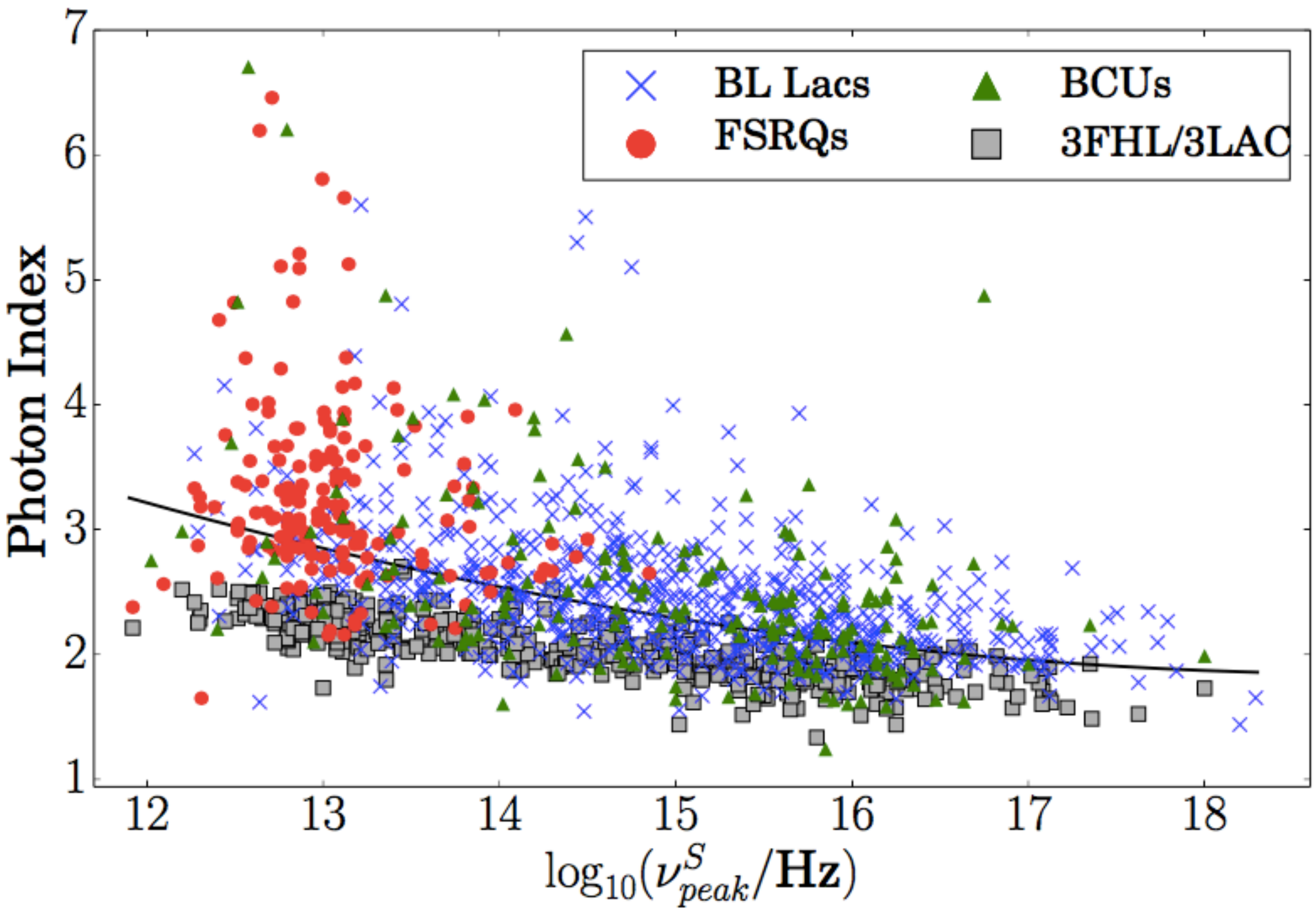
EBL attenuation

Photons with energies greater than about 30 GeV suffer from **attenuation** over cosmological distances as a consequence of the **pair production interactions with extragalactic background light (EBL) photons**



clear **softening of the spectral index above 10 GeV with increasing redshift**, which is likely due to EBL attenuation.

Photon spectral index



The trend of **a strong hardening of the energy spectra with increasing peak frequency** already seen above 100 MeV in the Fermi-LAT AGN catalogs (e.g., Ackermann et al. 2015) is even more pronounced above 10 GeV. This enhanced effect relative to 3LAC is due to the **larger EBL attenuation suffered by high-redshift sources (most of them being LSPs) in comparison with the lower-redshift ones (preferentially HSPs)**.

Thank you for listening!