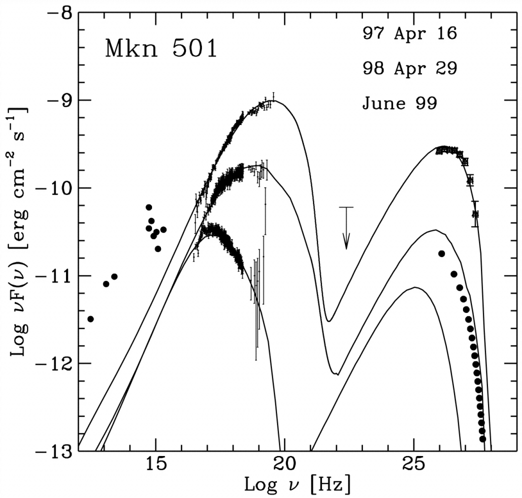
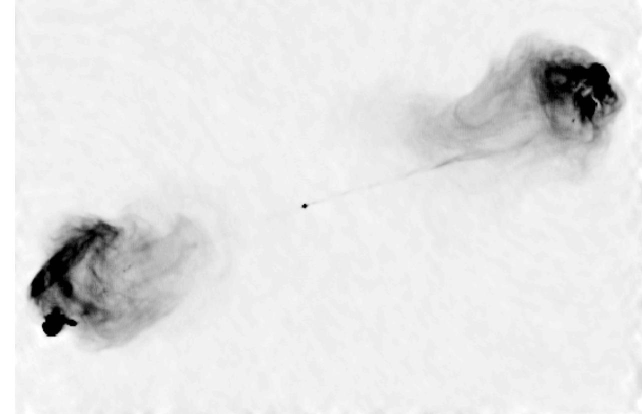




An observationally driven approach to blazars

On the importance of selection effects

Paolo Padovani, ESO, Germany

based on work mostly done with Paolo Giommi, Yu-Ling Chang, and Bruno Arsioli (ASI)

- The two blazar classes
- A new, simplified approach to blazars tested by numerical simulations
- Results and implications
- Testing the blazar sequence

The beginning

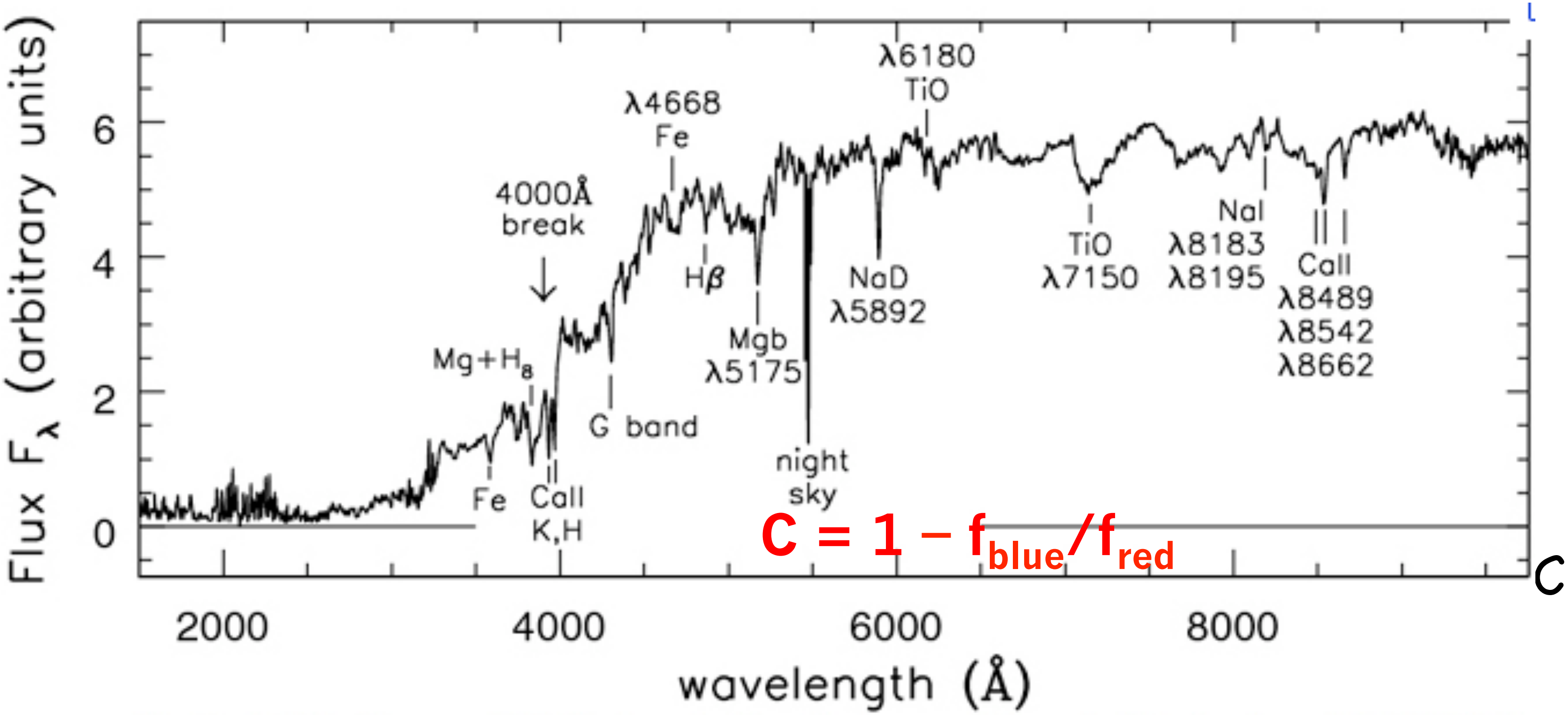
Blandford & Rees (1978):

We would therefore like to propose the hypothesis that Lacertids (and perhaps also optically violent variable quasars) are active galactic nuclei where the continuum emission is enhanced by being beamed toward us.

A few years later ...

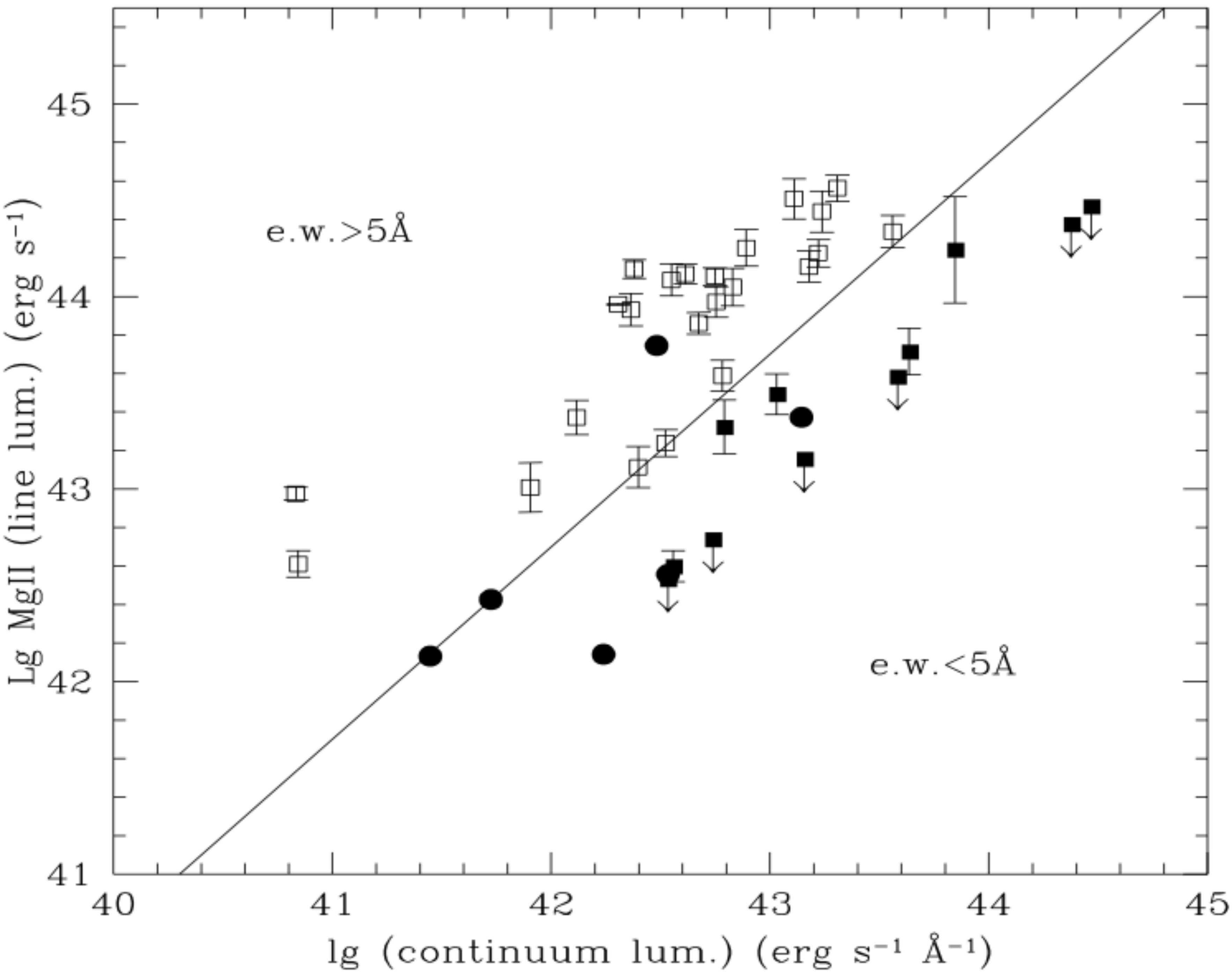
- BL Lac definitions:
  - ✓ Stickel, PP, Urry et al. (1991) [radio selected]: flat spectrum ($\alpha_r \leq 0.5$) and $EW_{rest} < 5$ Å
  - ✓ Stocke et al. (1991) [X-ray selected]: EW < 5 Å and Ca H&K break = C < 25% (C ~ 50% in ellipticals)
  - ✓ Scarpa & Falomo (1997): no evidence of bimodal EW distribution
  - ✓ Marchã et al. (1996) [radio selected]: region of EW – C space (C up to 40%)
  - ✓ Landt, PP, & Giommi (2002): confirmed C < 40%

A few years later ...



$$C = 1 - f_{blue}/f_{red}$$

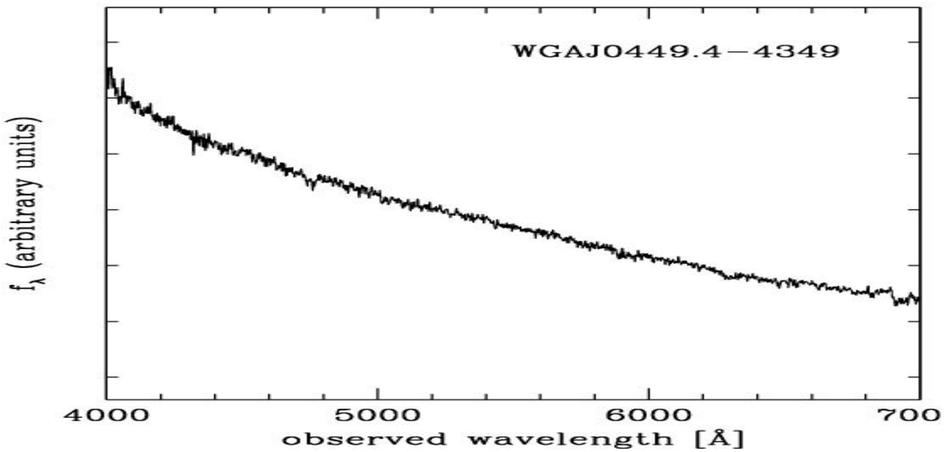
- ✓ Landt, PP, & Giommi (2002): confirmed C < 40%



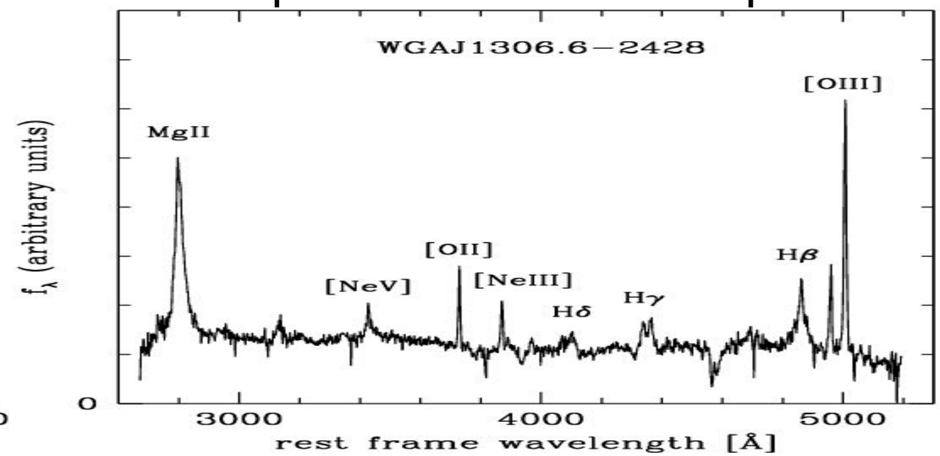
e.w.>5Å
e.w.<5Å
Lg MgII (line lum.) (erg s^{-1})
lg (continuum lum.) (erg s^{-1} Å^{-1})
41
42
43
44
45
40
41
42
43
44
45

The two blazar classes

BL Lacs



Flat spectrum radio quasars



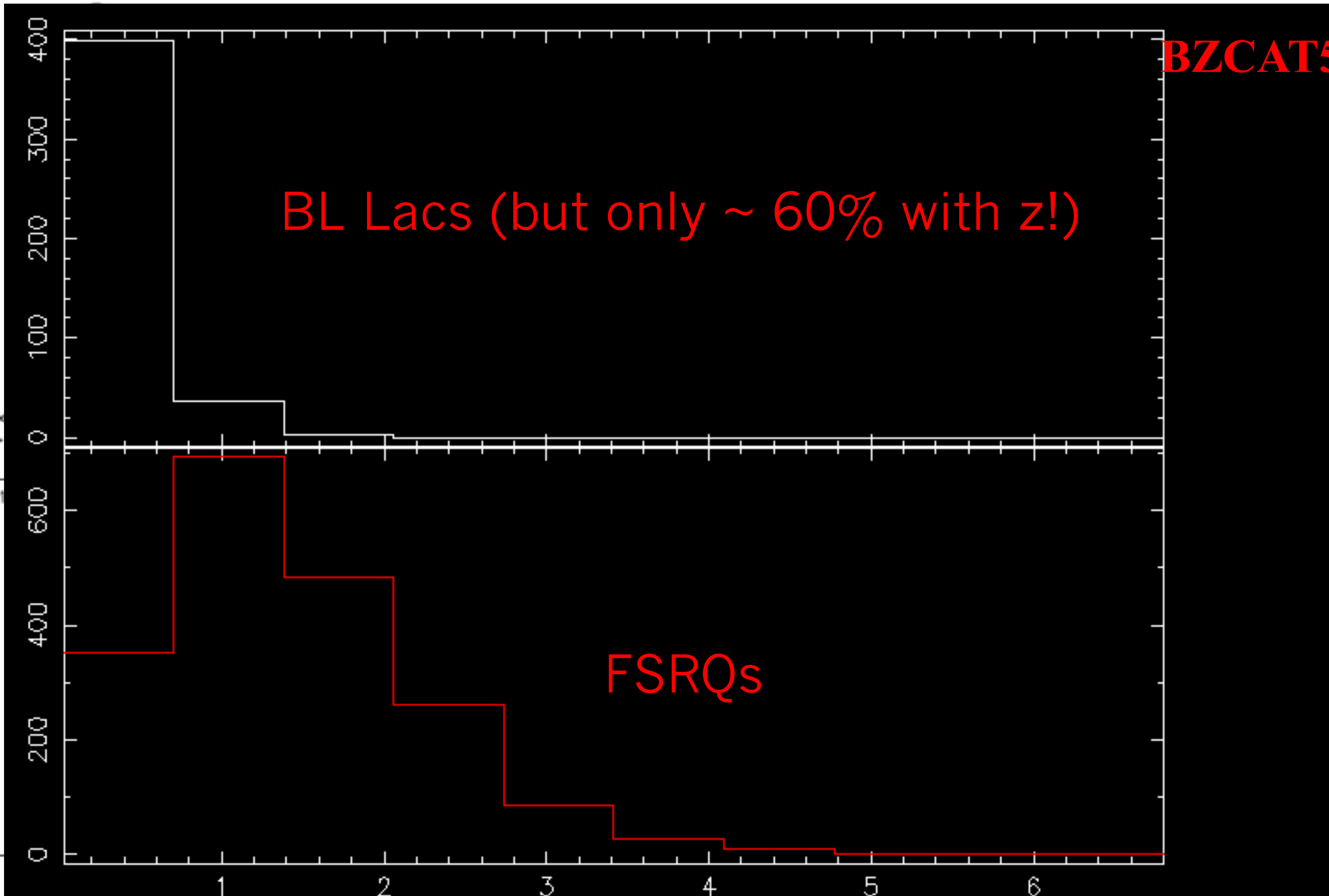
- What's the dividing line between BL Lacs and FSRQs?
- When does a radio galaxy become a BL Lac?

Some puzzling differences between BL Lacs and FSRQs

- Optical spectra (by definition); but a few transition objects: e.g., BL Lac, 3C 279
- Extended radio powers: generally FSRQs → FR II-like and BL Lacs → FR I-like; but *radio-selected* BL Lacs can reach FR II levels (e.g., Rector & Stocke 2001, Kharb et al. 2011)
- Redshift distributions; BL Lacs: <z> ~ 0.4 (*but ~ 41% no z*), FSRQs: <z> ~ 1.4
- Evolution (e.g., Stickel et al. 1991; Rector et al. 2000; Padovani et al. 2007; Giommi et al. 2009):
  - ✓ FSRQs and *radio-selected* BL Lacs → similar positive evolution
  - ✓ *X-ray selected* BL Lacs → no or even negative evolution

redshift

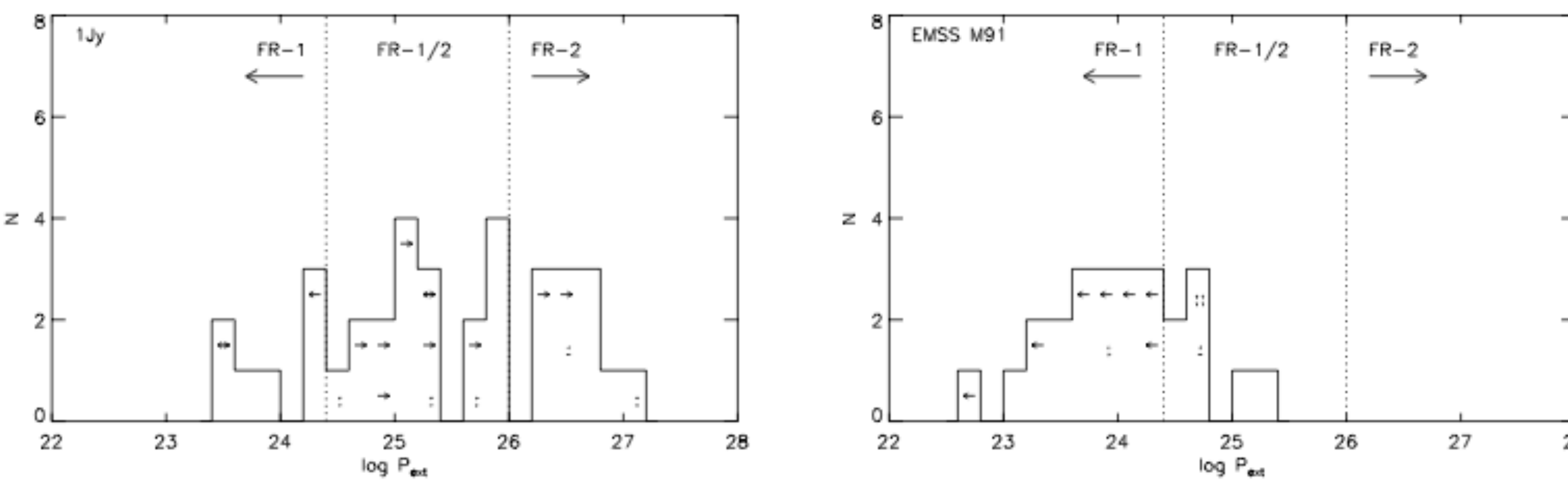
Some puzzling differences between



redshift

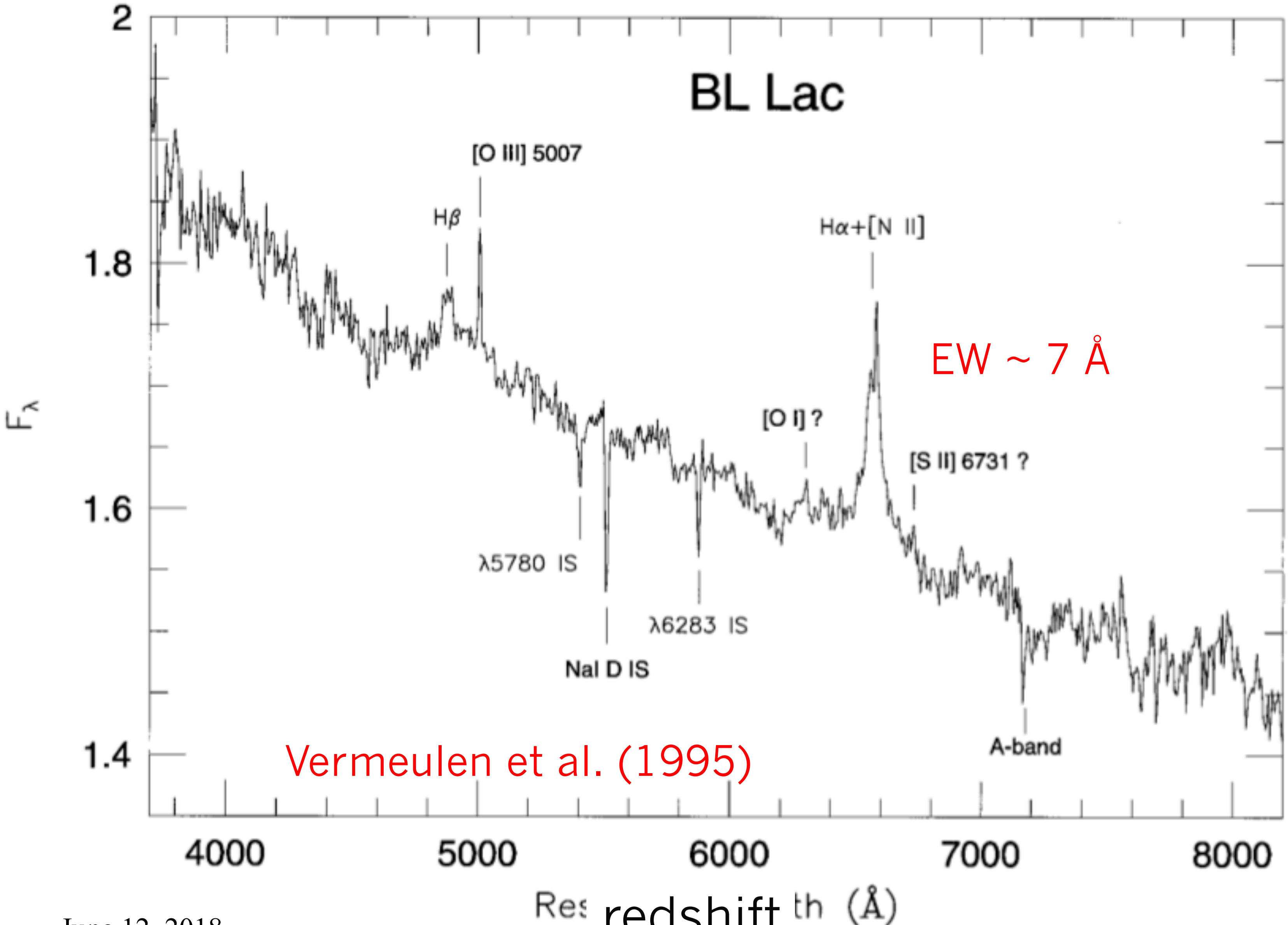
Some puzzling differences between BL Lacs and FSRQs

- Optical spectra (by definition); but a few transition objects: e.g., BL Lac, 3C 279
- Extended radio powers: generally FSRQs → FR II-like and BL Lacs → FR I-like; but *radio-selected* BL Lacs can reach FR II levels (e.g., Rector & Stocke 2001, Kharb et al. 2011)



redshift

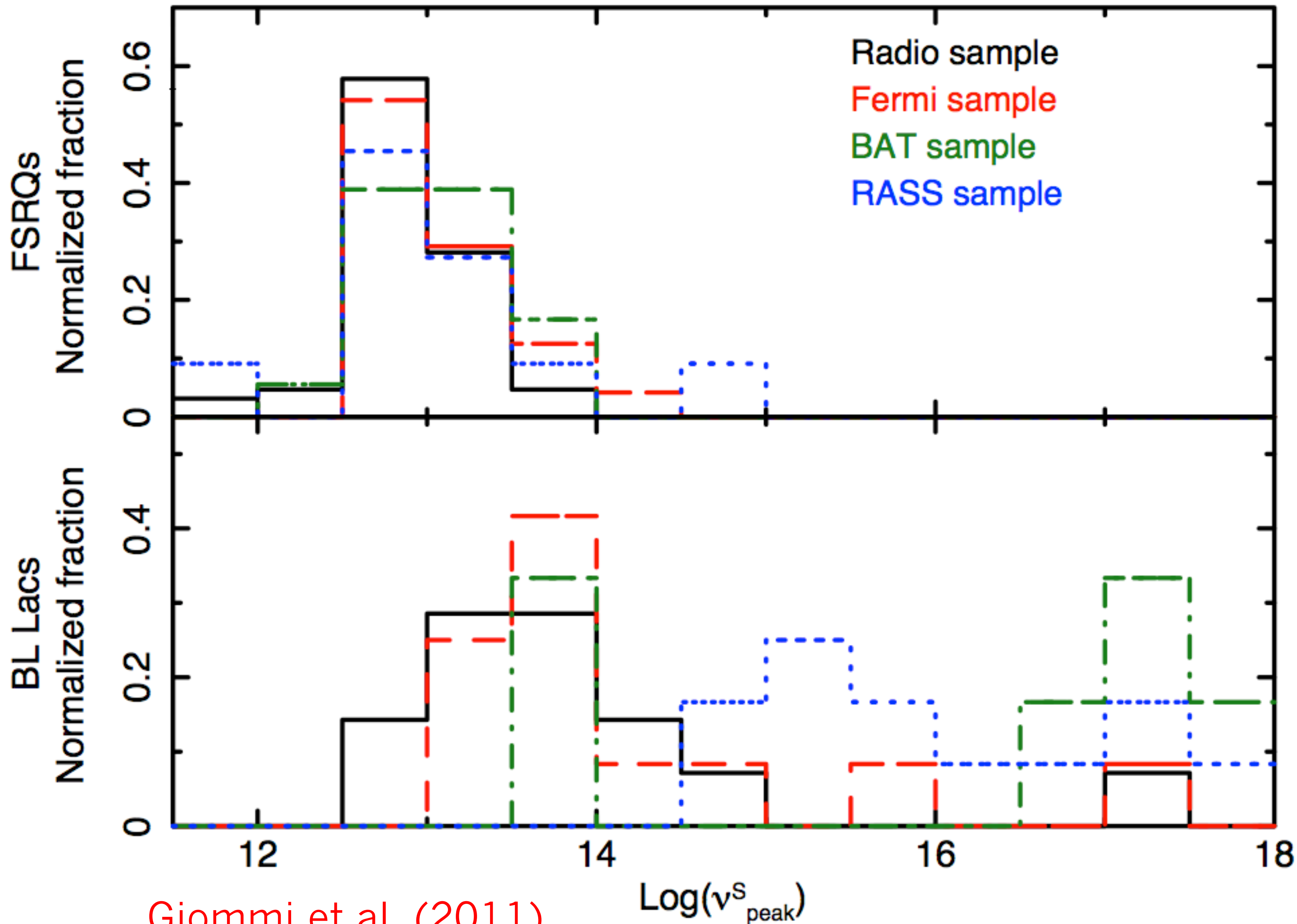
Some puzzling differences between



-
- and
ach
011)
z),
-
- tion

Some puzzling differences between BL Lacs and FSRQs (continued)

- Synchrotron peak frequencies
- Different mix in radio and X-ray selected samples; e.g. WMAP5: ~ 15 % BL Lacs; EMSS: ~ 70 % BL Lacs

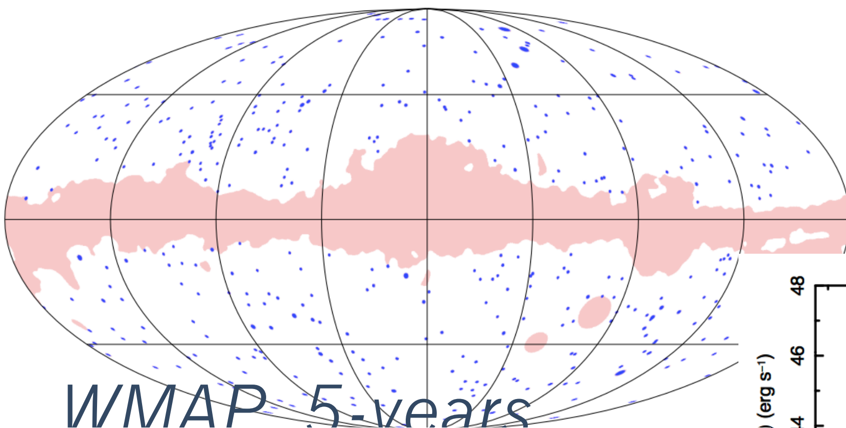


Giommi et al. (2011)

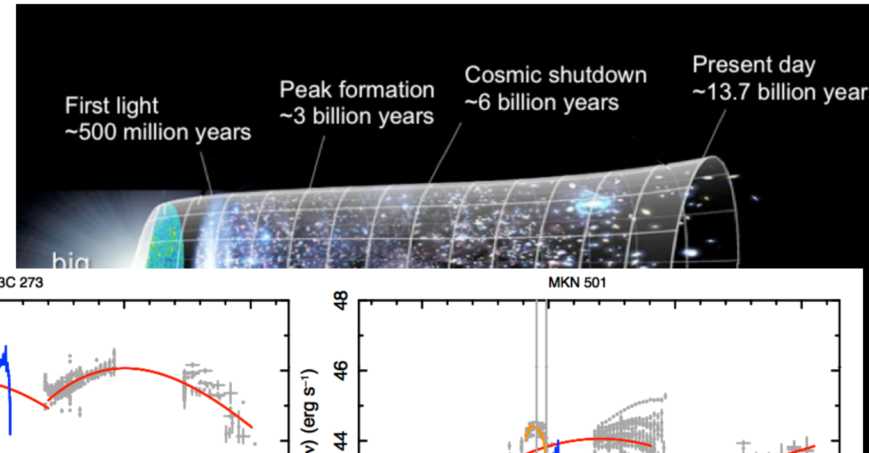
A new scenario: the Blazar Simplified View

- Some of these differences explained by unified schemes: BL Lacs ←→ FR Is/LERGs and FSRQs ←→ FR IIs/HERGs
- However, no explanation for (e.g.,):
  - ✓ transition objects
  - ✓ different evolution of radio- and X-ray-selected BL Lacs
  - ✓ widely different ν_{peak} distributions for FSRQs and BL Lacs (related to different class mixes)
- Our approach: start from unified schemes and add dilution and selection effects as new important components
- Observed optical spectrum is result of three components:
  - non-thermal, jet-related
  - thermal, accretion-disk related
  - host galaxy

The Blazar Simplified View (BSV)



+



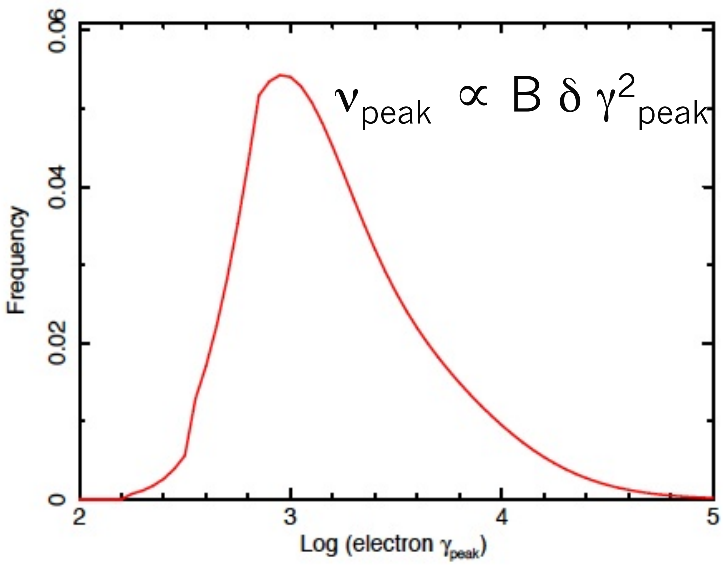
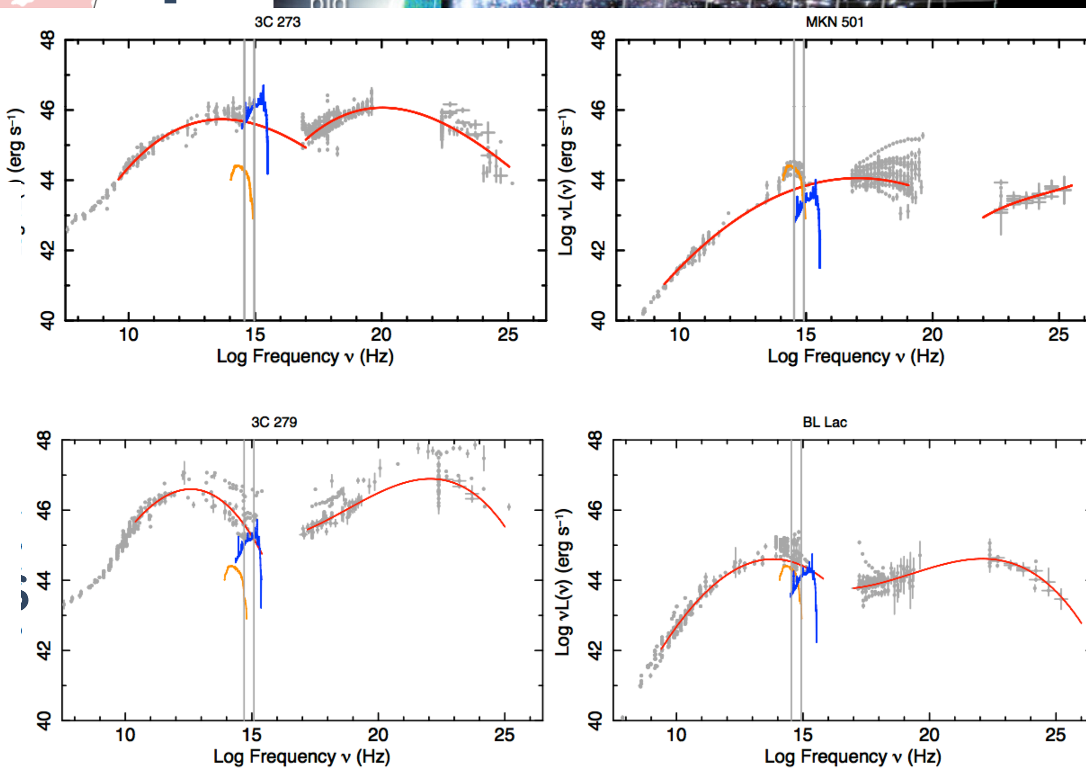


Figure 4. The distribution of the Lorentz factors of the electrons radiating at the peak of the synchrotron SED used for



Monte Carlo simulations

- Source classification:
  - ✓ FSRQ: EW_{rest} of *any* line in the observer's window (3,800 – 8,000 Å) > 5 Å
  - ✓ BL Lac: EW_{rest} of *all* lines in the observer's window < 5 Å; non-measurable z if EW_{rest} < 2 Å or $f_{jet} > 10 \times f_{galaxy}$
  - ✓ Radio Galaxy: Ca H&K break > 40%

Goal: to *keep assumptions down to a minimum and obtain robust results* (not to reproduce perfectly ALL observables)

Simulations have also predictive power!

Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

Mon. Not. R. Astron. Soc. **420**, 2899–2911 (2012) doi:10.1111/j.1365-2966.2011.20044.x

A simplified view of blazars: clearing the fog around long-standing selection effects

P. Giommi,[1★] P. Padovani,[2] G. Polenta,[1,3] S. Turriziani,[1] V. D'Elia[1,3] and S. Piranomonte[3]

[1] *ASI Science Data Center, c/o ESRIN, via G. Galilei, 00044 Frascati, Italy*
[2] *European Southern Observatory, Karl-Schwarzschild-Strasse 2, D-85748 Garching bei München, Germany*
[3] *INAF-Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*

Accepted 2011 October 20. Received 2011 October 4; in original form 2011 July 13

radio and X-ray bands

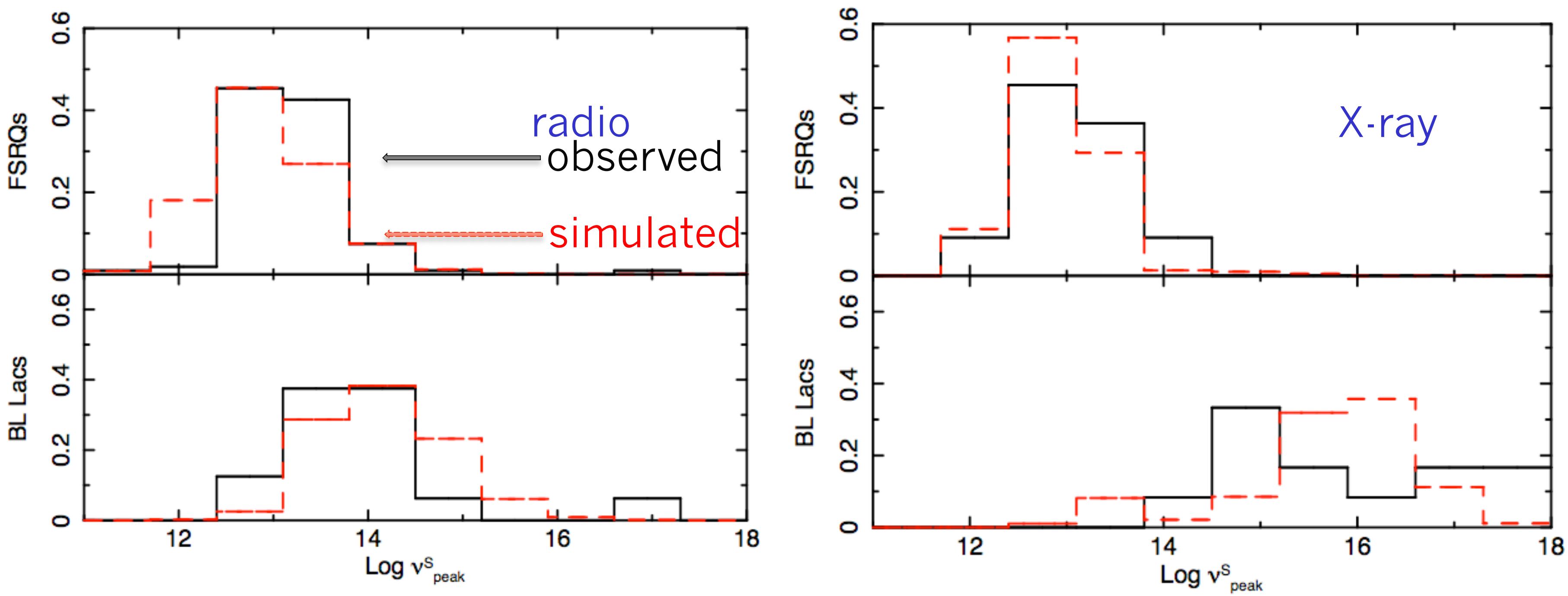
ABSTRACT

We propose a scenario where blazars are classified into flat-spectrum radio quasars (FSRQs), BL Lacertae (BL Lac) objects, low-synchrotron, or high-synchrotron peaked objects according to a varying mix of the Doppler-boosted radiation from the jet, the emission from the accretion disc, the broad-line region, and the light from the host galaxy. In this framework, the peak energy of the synchrotron power (ν^{S}_{peak}) in blazars is independent of source type and radio luminosity. We test this new approach, which builds upon unified schemes, using extensive Monte Carlo simulations, and show that it can provide simple answers to a number of long-standing issues, including, amongst others, the different cosmological evolution of BL Lac objects selected in the radio and X-ray bands, the larger ν^{S}_{peak} values observed in BL Lac objects, the fact that high-synchrotron peaked blazars are always of BL Lac type, and the existence of FSRQ–BL Lac transition objects. Objects so far classified as BL Lac objects on the basis of their *observed* weak, or undetectable, emission lines are of two physically different classes: intrinsically weak lined objects, more common in X-ray-selected samples, and heavily diluted broad-lined sources, more frequent in radio-selected samples, which explains some of the confusion in the literature. We also show that strong selection effects are the main cause of the diversity observed in radio and X-ray samples, and that the correlation between luminosity and ν^{S}_{peak}, which led to the proposal of the 'blazar sequence', is also a selection effect arising from the comparison between shallow radio and X-ray surveys, and to the fact that high-ν^{S}_{peak}–high-radio-power objects have never been considered because their redshift is not measurable.

Key words: radiation mechanisms: non-thermal – BL Lacertae objects: general – quasars: emission lines – radio continuum: galaxies – X-rays: galaxies.

Some results

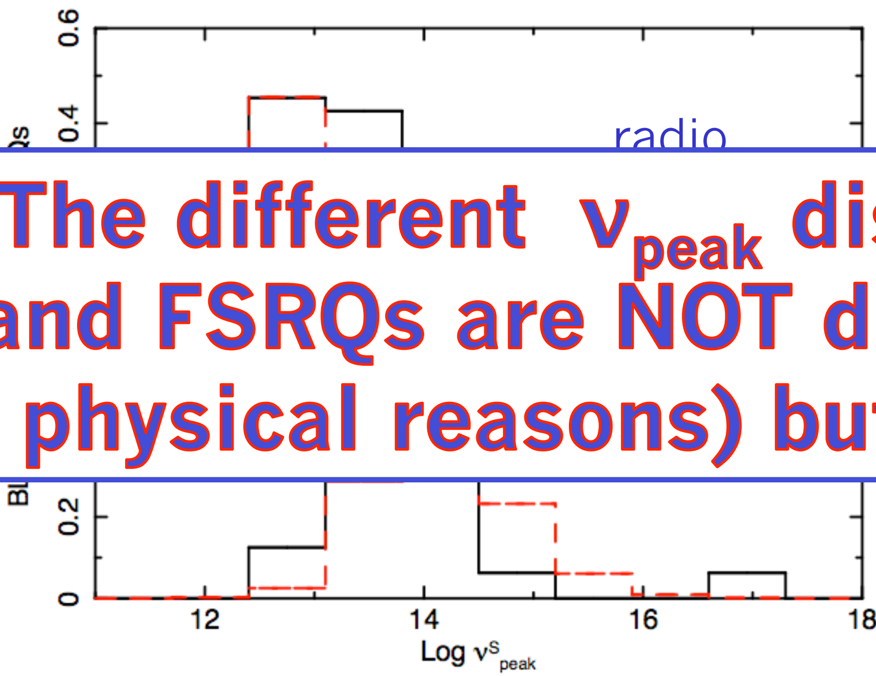
Table 1. Results from a simulation of a radio flux density limited survey (0.9 Jy)

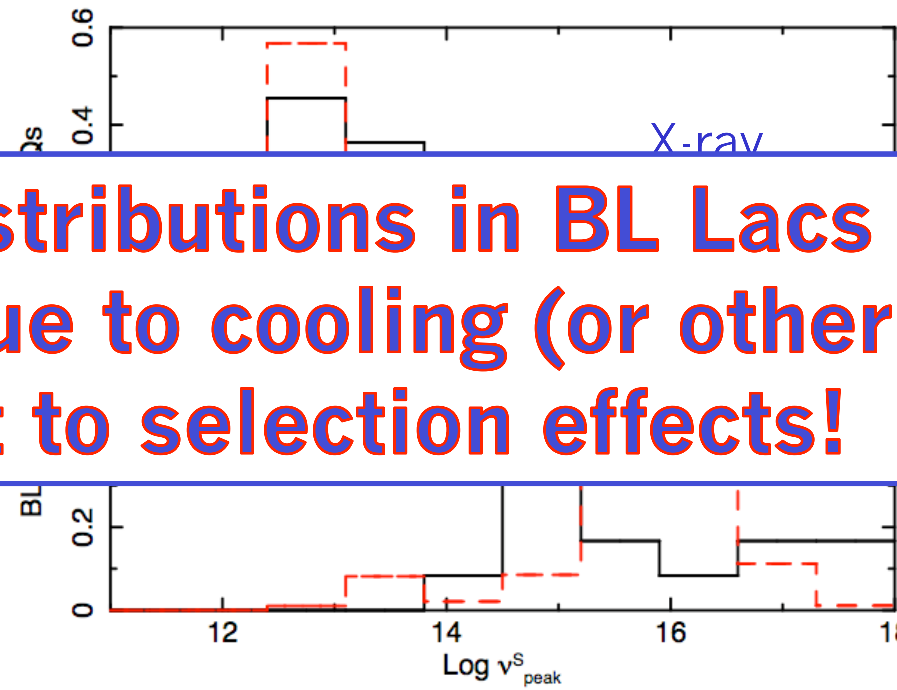


Source type	Number of		
BL Lacs (log $\nu^S_{\rm peak} > 17$)	185 (177)	0.34	0.34
Radio galaxies	1,542	0.04	0.48
Total	10,000	0.58	0.55

Some results

Table 1. Results from a simulation of a radio flux density limited survey (0.9 Jy)





The different ν_{peak} distributions in BL Lacs and FSRQs are NOT due to cooling (or other physical reasons) but to selection effects!

Source type	Number of		
BL Lacs (log $\nu^S_{\rm peak} > 17$)	185 (177)	0.34	0.34
Radio galaxies	1,542	0.04	0.48
Total	10,000	0.58	0.55

Some implications

- **BL Lacs belong to two physically different classes:**
  - ✓ intrinsically weak lined objects
  - ✓ beamed FSRQs with diluted emission lines: *"masquerading" BL Lacs*
- **BL Lacertae is not a BL Lac!**
- There are *only* two blazar types: non-evolving low-excitation and evolving high-excitation sources
- Ghisellini et al. (2011):
  - ✓ **FSRQS: L_{disc}/L_{Edd} > 0.01** → radiatively efficient
  - ✓ **BL Lacs:L_{disc}/L_{edd} < 0.01** → radiatively inefficient

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY

MNRAS **431,** 1914–1922 (2013)
Advance Access publication 2013 March 14

doi:10.1093/mnras/stt305

A simplified view of blazars: the γ-ray case

P. Giommi,[1,2★] P. Padovani[2,3] and G. Polenta[1,4]

[1] *ASI Science Data Center, c/o ESRIN, via G. Galilei, I-00044 Frascati, Italy*
[2] *Associated to INAF – Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*
[3] *European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[4] *INAF – Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*

Accepted 2013 February 18. Received 2013 February 15; in original form 2012 September 7

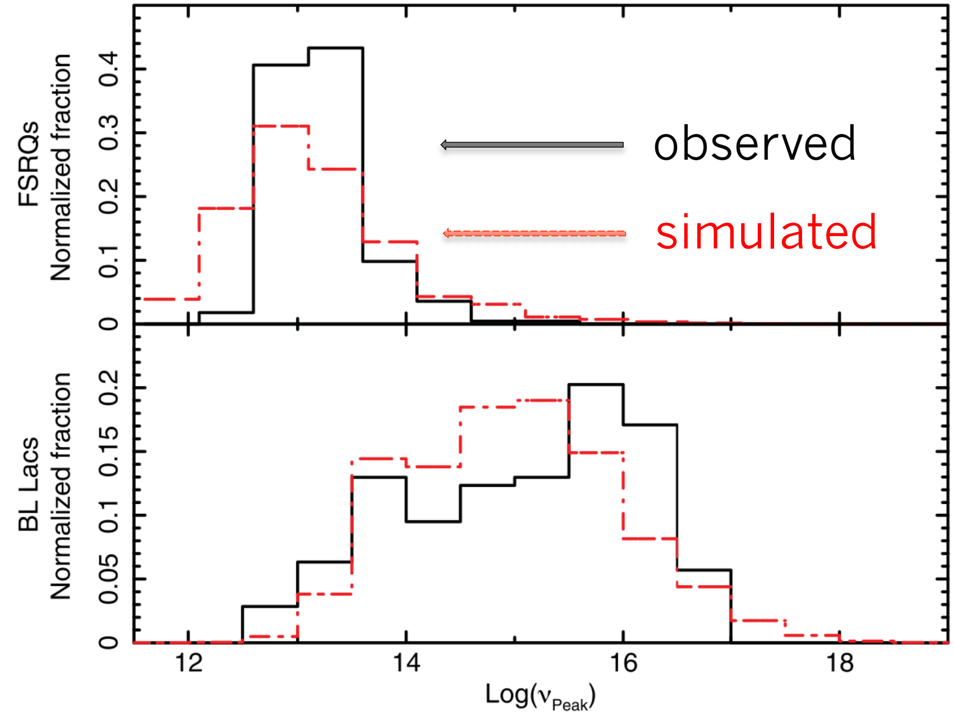
γ-ray (*Fermi*) band

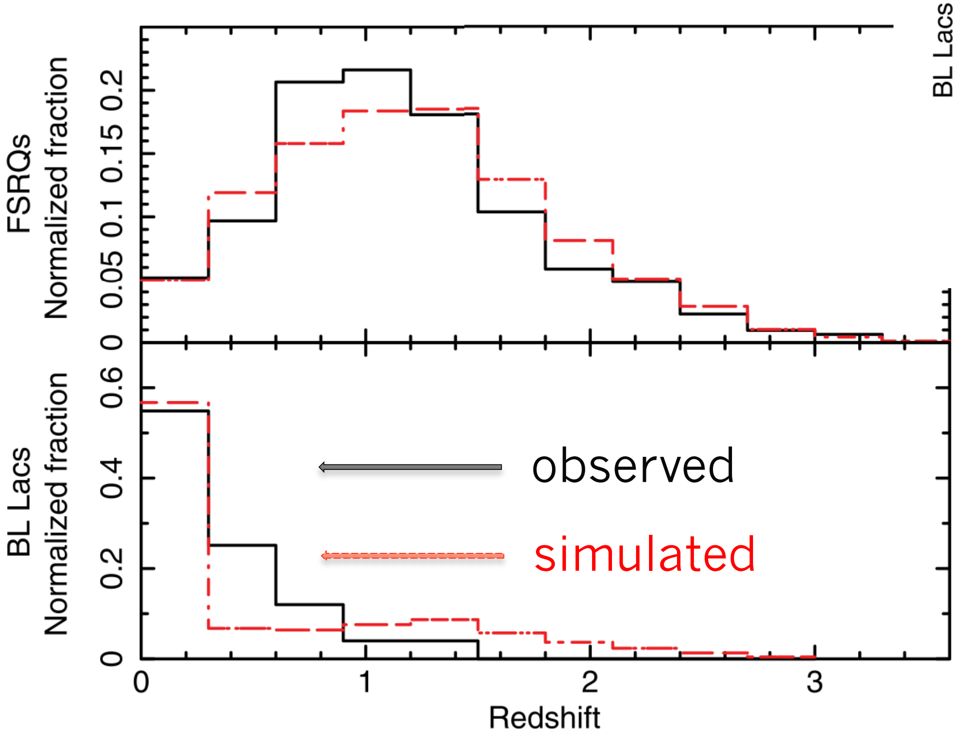
ABSTRACT

We have recently proposed a new simplified scenario where blazars are classified as flat spectrum radio quasars (FSRQs) or BL Lacs according to the prescriptions of unified schemes, and to a varying combination of Doppler-boosted radiation from the jet, emission from the accretion disc, the broad line region and light from the host galaxy. Here we extend our approach, previously applied to radio and X-ray surveys, to the γ-ray band and, through detailed Monte Carlo simulations, compare our predictions to *Fermi*-Large Area Telescope (LAT) survey data. Our simulations are in remarkable agreement with the overall observational results, including the percentages of BL Lacs and FSRQs, the fraction of redshift-less objects and the redshift, synchrotron peak and γ-ray spectral index distributions. The strength and large scatter of the oft-debated observed γ-ray–radio flux density correlation are also reproduced. In addition, we predict that almost 3/4 of *Fermi*-LAT BL Lacs, and basically all of those without redshift determination, are actually FSRQs with their emission lines swamped by the non-thermal continuum and as such should be considered. Finally, several of the currently unassociated high Galactic latitude *Fermi* sources are expected to be radio-faint blazars displaying a pure elliptical galaxy optical spectrum.

Key words: radiation mechanisms: non-thermal – BL Lacertae objects: general – quasars: emission lines – gamma-rays: galaxies – radio continuum: galaxies.

Some results: the 2LAC catalogue





Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **446,** L41–L45 (2015) doi:10.1093/mnrasl/slu164

A simplified view of blazars: the very high energy γ-ray vision

P. Padovani[1,2★] and P. Giommi[3,4,5]

[1] *European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[2] *Associated to INAF – Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*
[3] *ASI Science Data Center, via del Politecnico s.n.c., I-00133 Roma Italy*
[4] *Associated to INAF – Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy*
[5] *ICRANet-Rio, CBPF, Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro, Brazil*

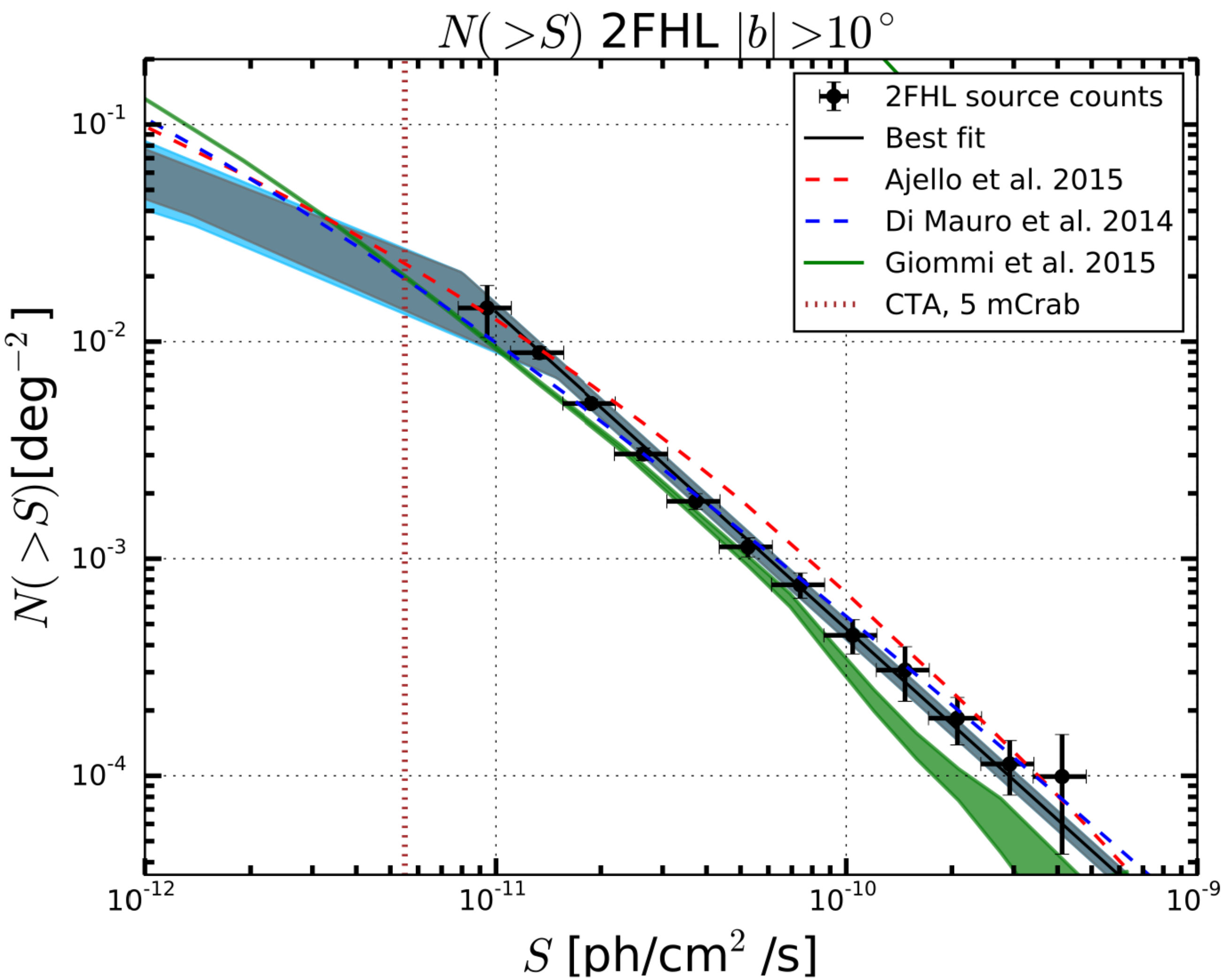
Accepted 2014 October 1. Received 2014 September 17; in original form 2014 August 6

ABSTRACT

We have recently proposed a simplified scenario for blazars in which these sources are classified as flat-spectrum radio quasars or BL Lacs according to the prescriptions of unified schemes, and to a varying combination of Doppler-boosted radiation from the jet, emission from the accretion disc, the broad-line region, and light from the host galaxy. This scenario has been thoroughly tested through detailed Monte Carlo simulations and reproduces all the main features of existing radio, X-ray, and γ-ray surveys. In this paper, we consider the case of very high energy emission ($E > 100$ GeV) extrapolating from the expectations for the GeV band, which are in full accordance with the *Fermi*-LAT survey results, and make detailed predictions for current and future Cherenkov facilities, including the Cherenkov Telescope Array. Our results imply that $\gtrsim$100 new blazars can be detected now at very high energy and up to $z \sim 1$, consistently with the very recent MAGIC detection of S4 0218+35 at $z = 0.944$.

Key words: radiation mechanisms: non-thermal – BL Lacertae objects: general – quasars: general – gamma-rays: galaxies – radio continuum: galaxies.

2FHL number counts (E > 50 GeV)



Ackermann et al. (2015)

Monthly Notices
of the
ROYAL ASTRONOMICAL SOCIETY
MNRAS **450,** 2404–2409 (2015) doi:10.1093/mnras/stv793

A simplified view of blazars: contribution to the X-ray and γ-ray extragalactic backgrounds

P. Giommi[1,2★] and P. Padovani[3,4★]

[1]*ASI Science Data Center, via del Politecnico s.n.c., I-00133 Rome, Italy*
[2]*Associated to INAF - Osservatorio Astronomico di Brera, via Brera 28, I-20121 Milano, Italy*
[3]*European Southern Observatory, Karl-Schwarzschild-Str. 2, D-85748 Garching bei München, Germany*
[4]*Associated to INAF - Osservatorio Astronomico di Roma, via Frascati 33, I-00040 Monteporzio Catone, Italy*

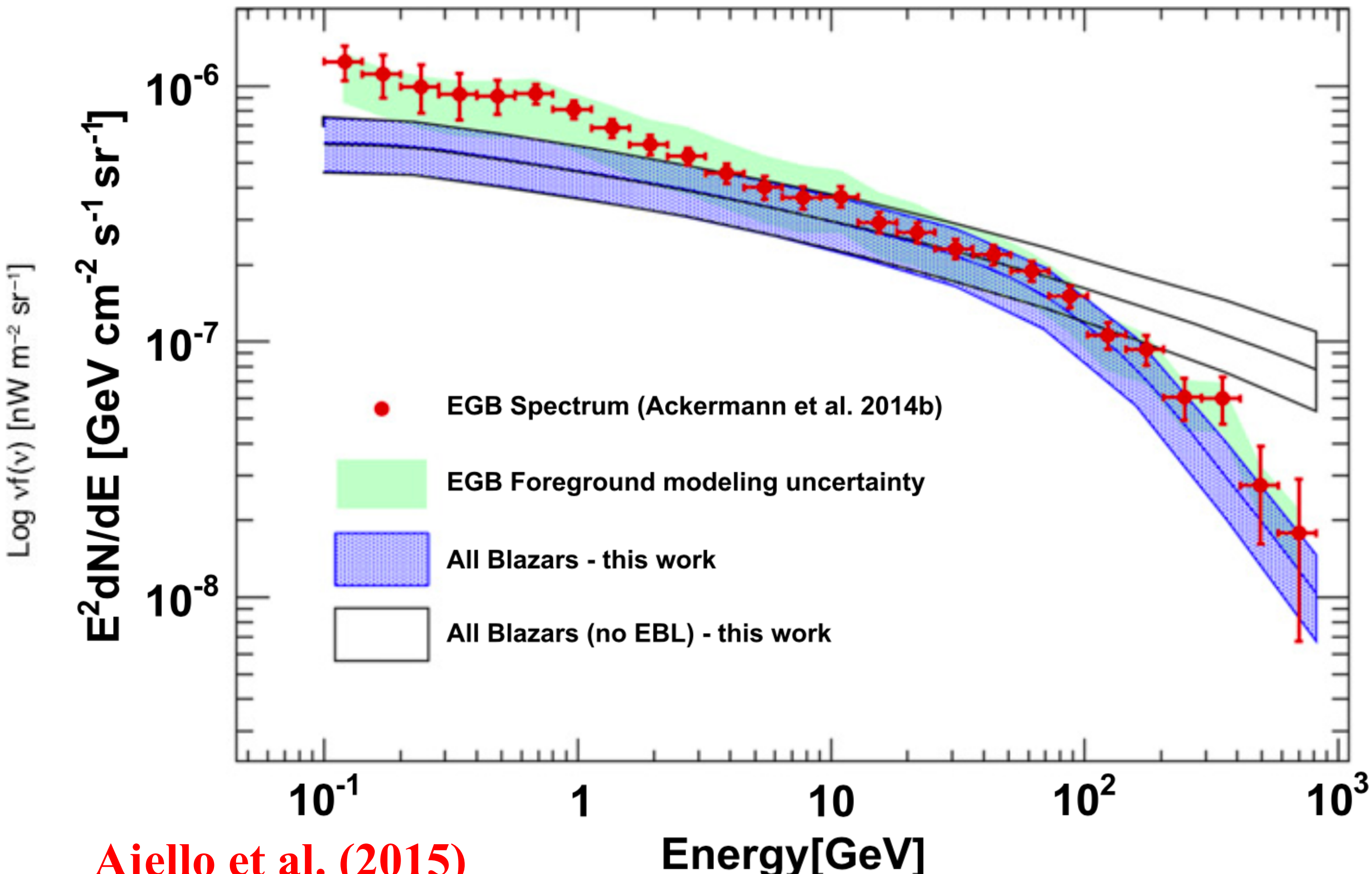
Accepted 2015 April 7. Received 2015 April 2; in original form 2015 February 19

ABSTRACT

The *blazar-simplified view* is a new paradigm that explains well the diverse statistical properties of blazars observed over the entire electromagnetic spectrum on the basis of minimal assumptions on blazars' physical and geometrical properties. In this paper, the fourth in a series, we extend the predictions of this paradigm below the sensitivity of existing surveys and estimate the contribution of blazars to the X-ray and γ-ray extragalactic backgrounds. We find that the integrated light from blazars can explain up to 100 per cent of the cosmic background at energies larger than ∼10 GeV, and contribute ≈40–70 per cent of the γ-ray diffuse radiation between 100 MeV and 10 GeV. The contribution of blazars to the X-ray background, between 1 and 50 keV, is approximately constant and of the order of 4–5 per cent. On the basis of an interpolation between the estimated flux at X-ray and γ-ray energies, we can expect that the contribution of blazars raises to ∼10 per cent at 100 keV, and continues to increase with energy until it becomes the dominant component at a few MeV. Finally, we show that a strong dependence of the synchrotron peak frequency on luminosity, as postulated by the *blazar sequence*, is ruled out by the observational data as it predicts a γ-ray background above a few GeV that is far in excess of the observed value.

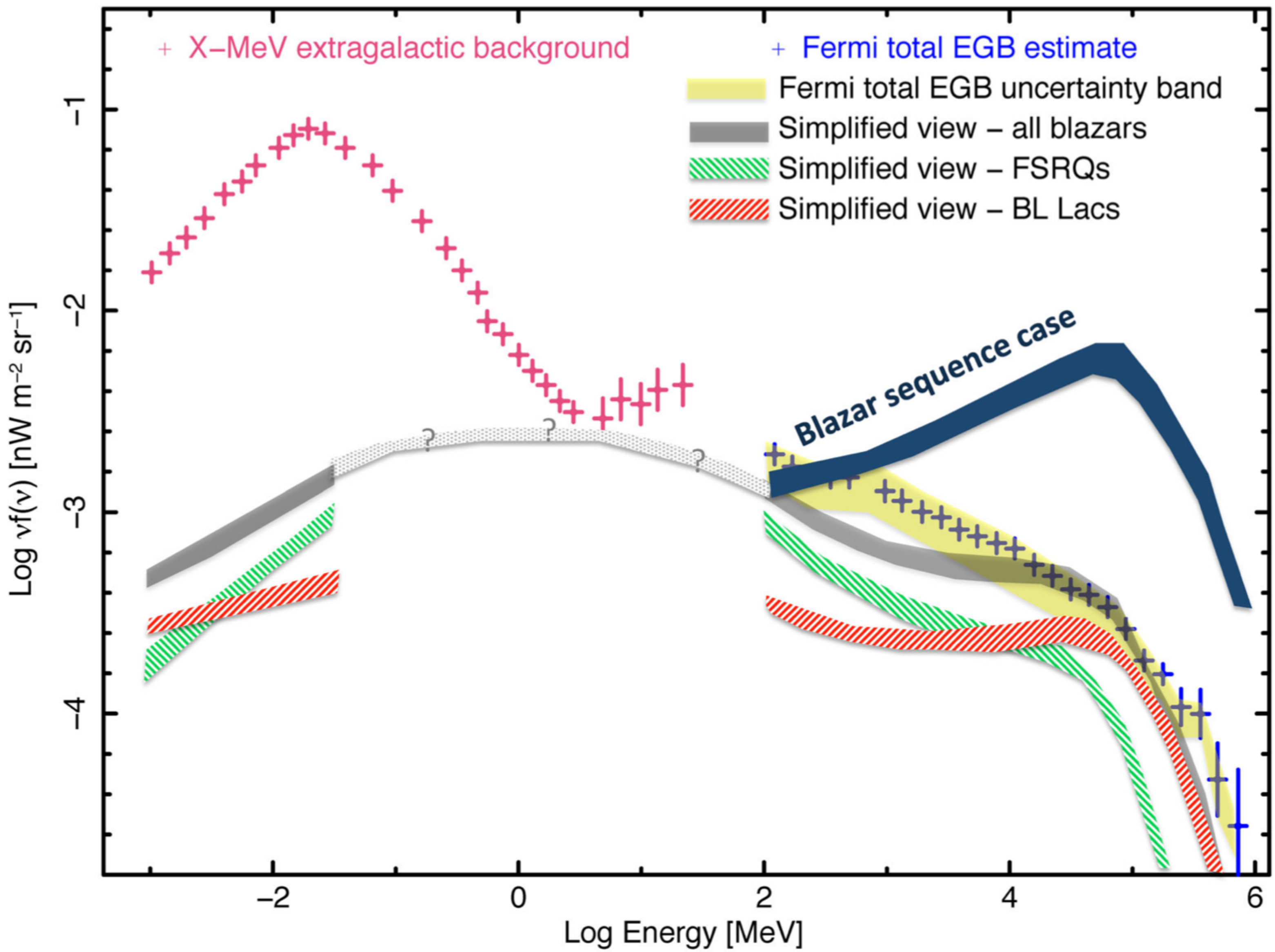
Key words: BL Lacertae objects: general – quasars: general – gamma-rays: diffuse background – gamma-rays: galaxies – radio continuum: galaxies – X-rays: diffuse background.

Main result

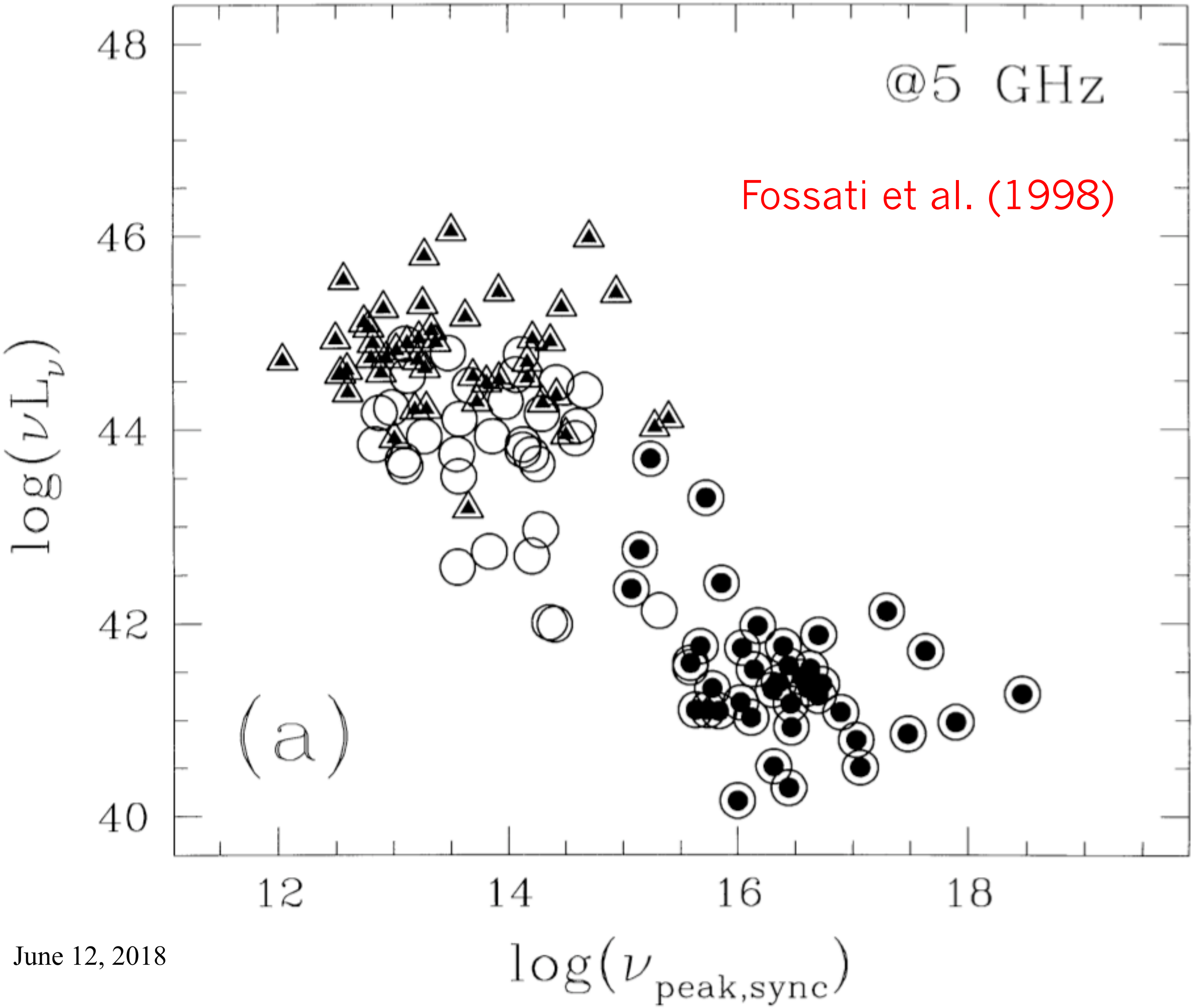


Ajello et al. (2015)

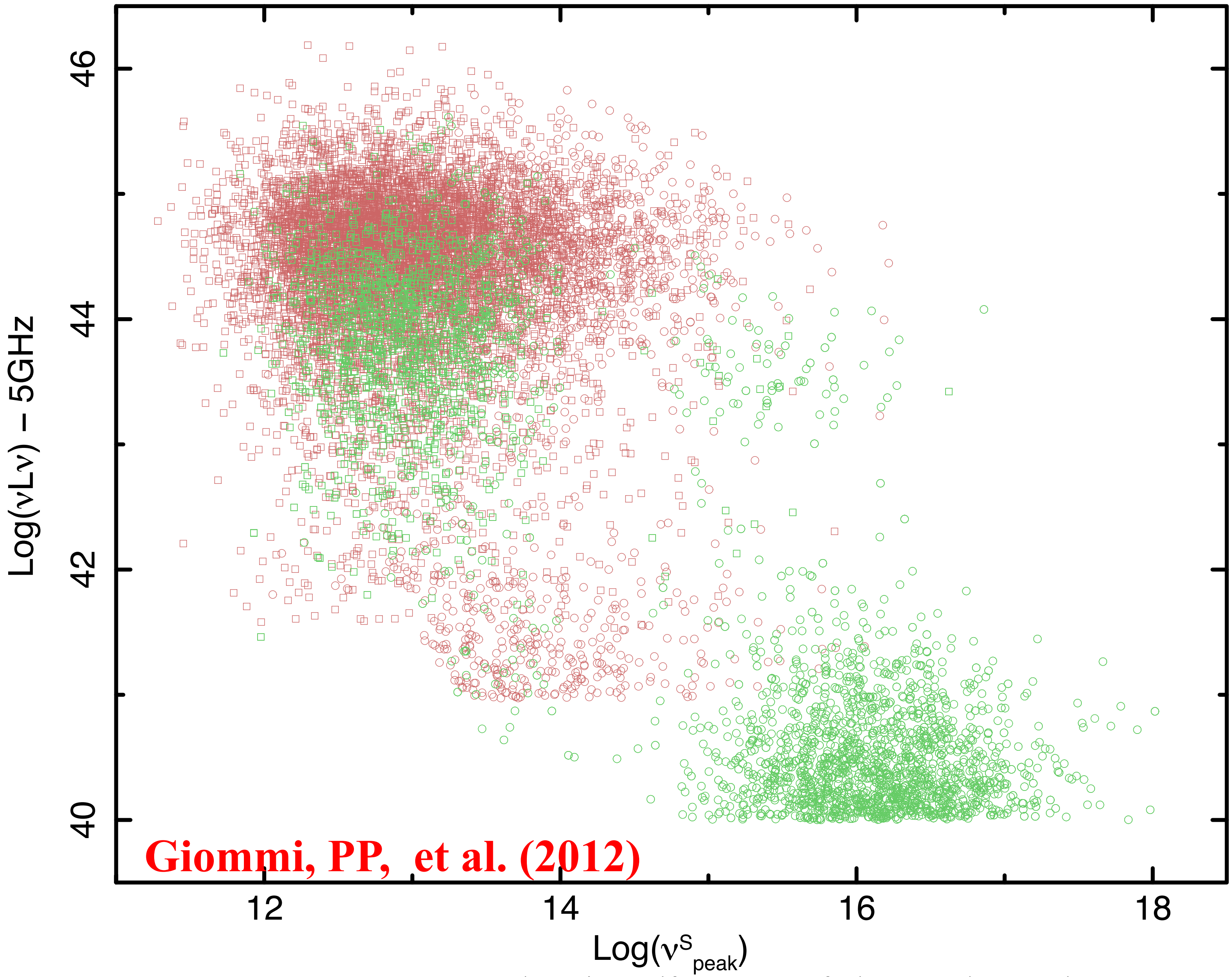
Main result

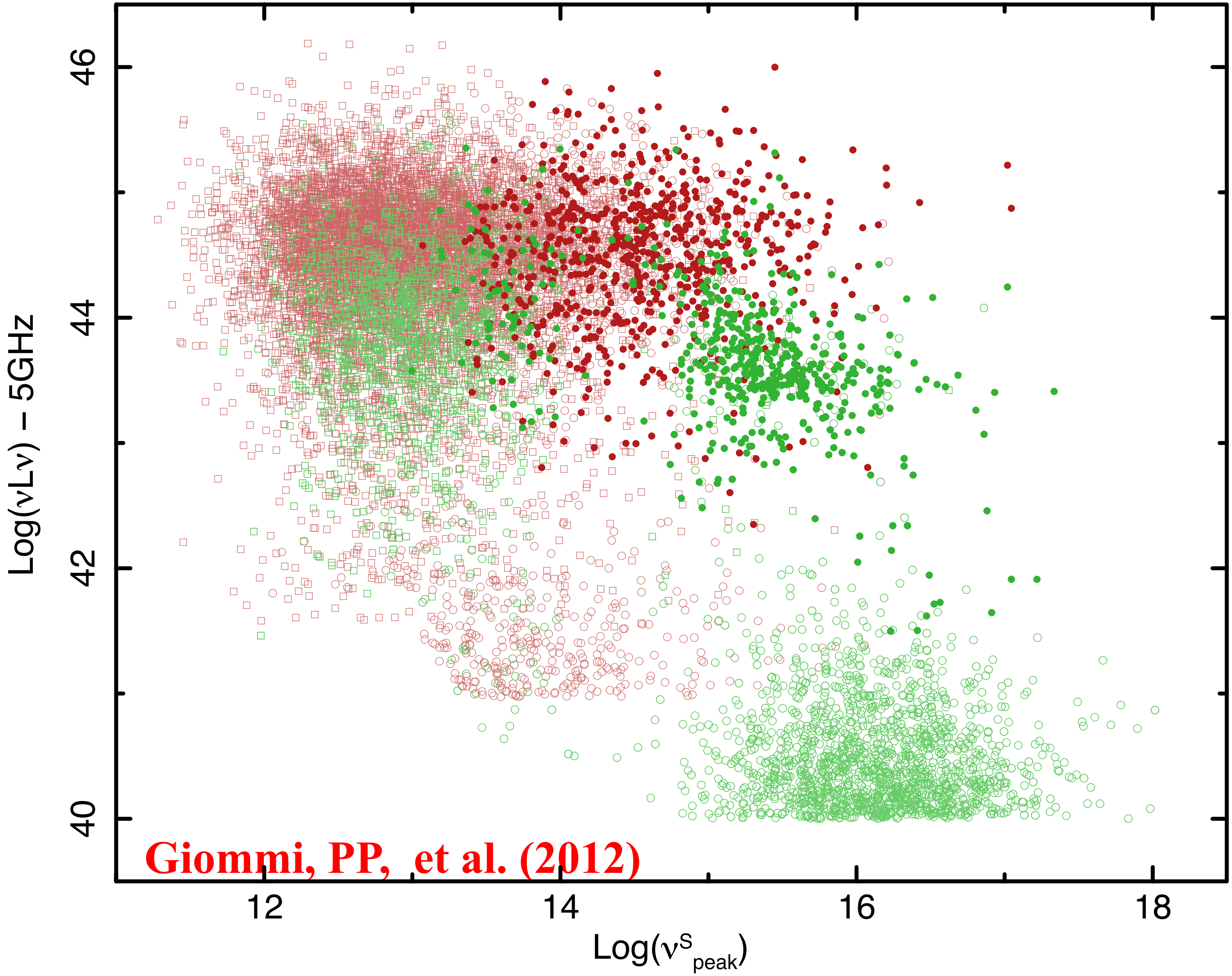


X–MeV extragalactic background
Fermi total EGB estimate
Fermi total EGB uncertainty band
Simplified view – all blazars
Simplified view – FSRQs
Simplified view – BL Lacs
Blazar sequence case
Log νf(ν) [nW m⁻² sr⁻¹]
Log Energy [MeV]
−1
−2
−3
−4
−2
0
2
4
6



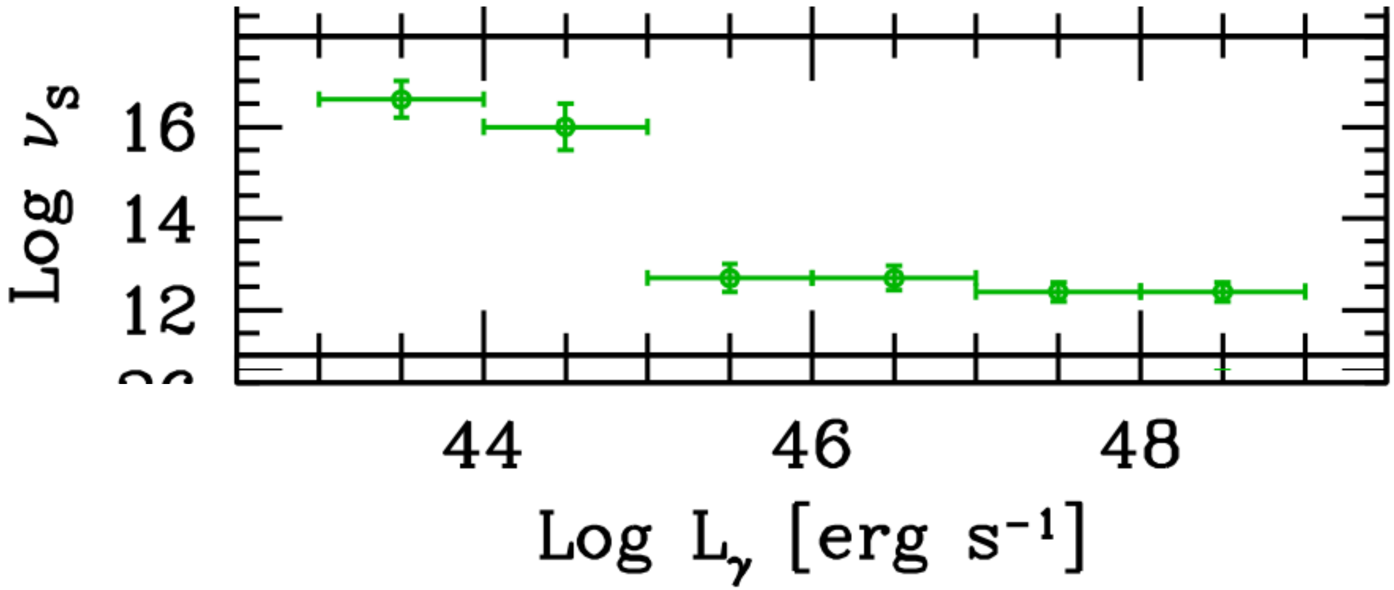
@5 GHz
Fossati et al. (1998)
(a)
48
46
44
42
40
12
14
16
18
log(νL_ν)
log(ν_peak,sync)


46
44
42
40
Log(νLν) – 5GHz
12
14
16
18
Log(ν^S_peak)
Giommi, PP, et al. (2012)



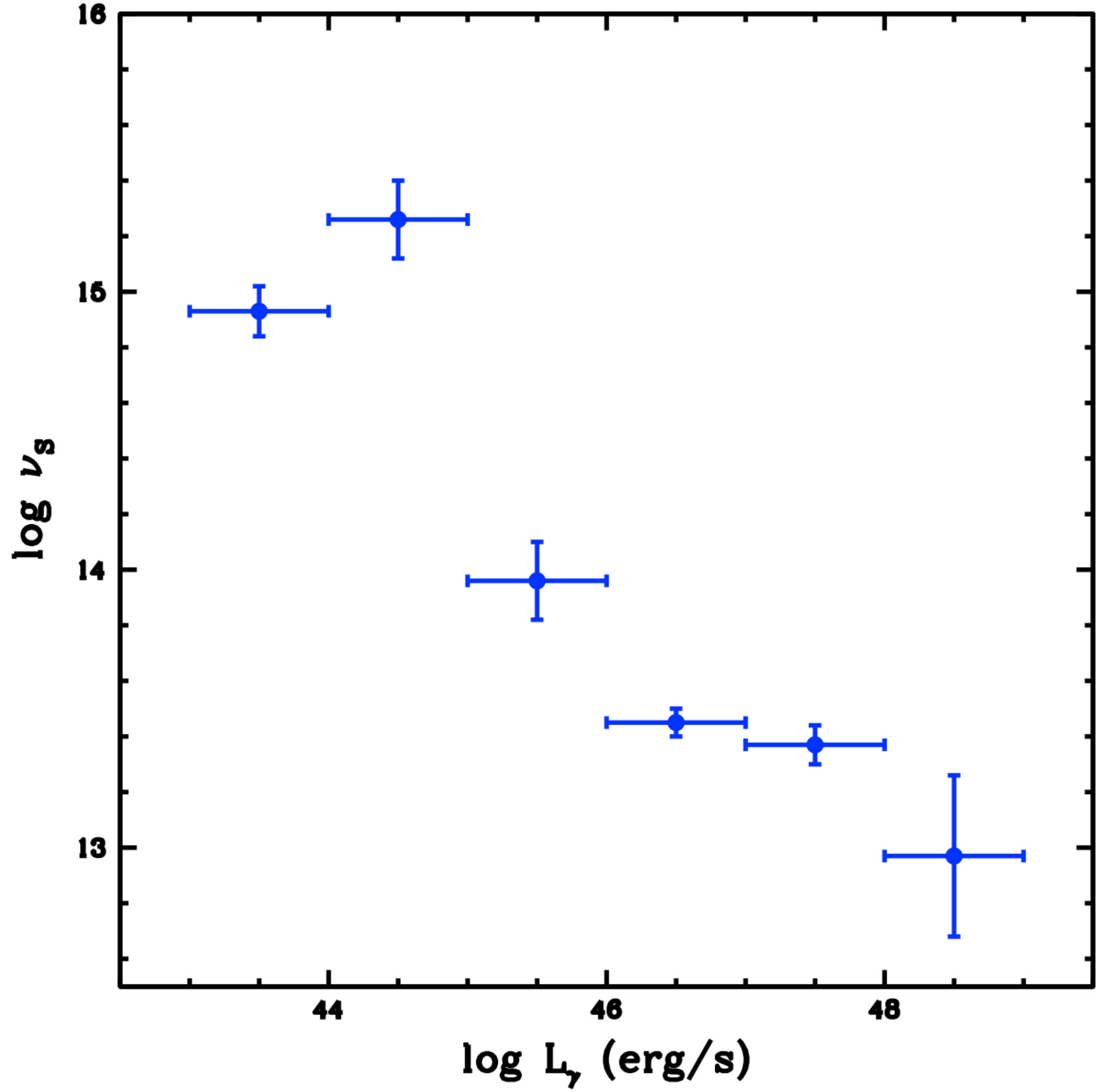
46
44
42
40
Log(νLν) – 5GHz
12
14
16
18
Log(ν^S_peak)
Giommi, PP, et al. (2012)

The "new" blazar sequence

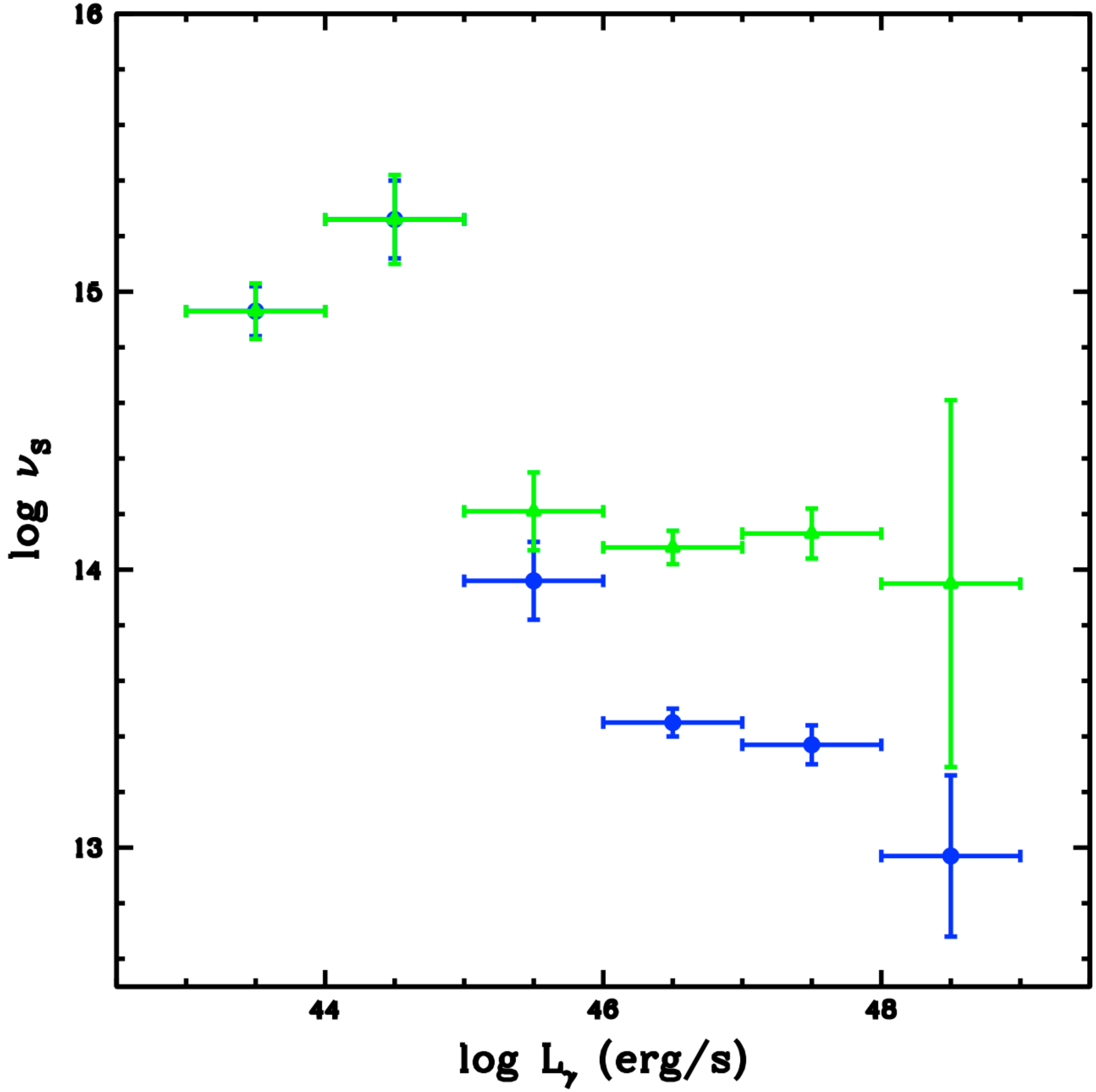


Ghisellini et al. (2017)

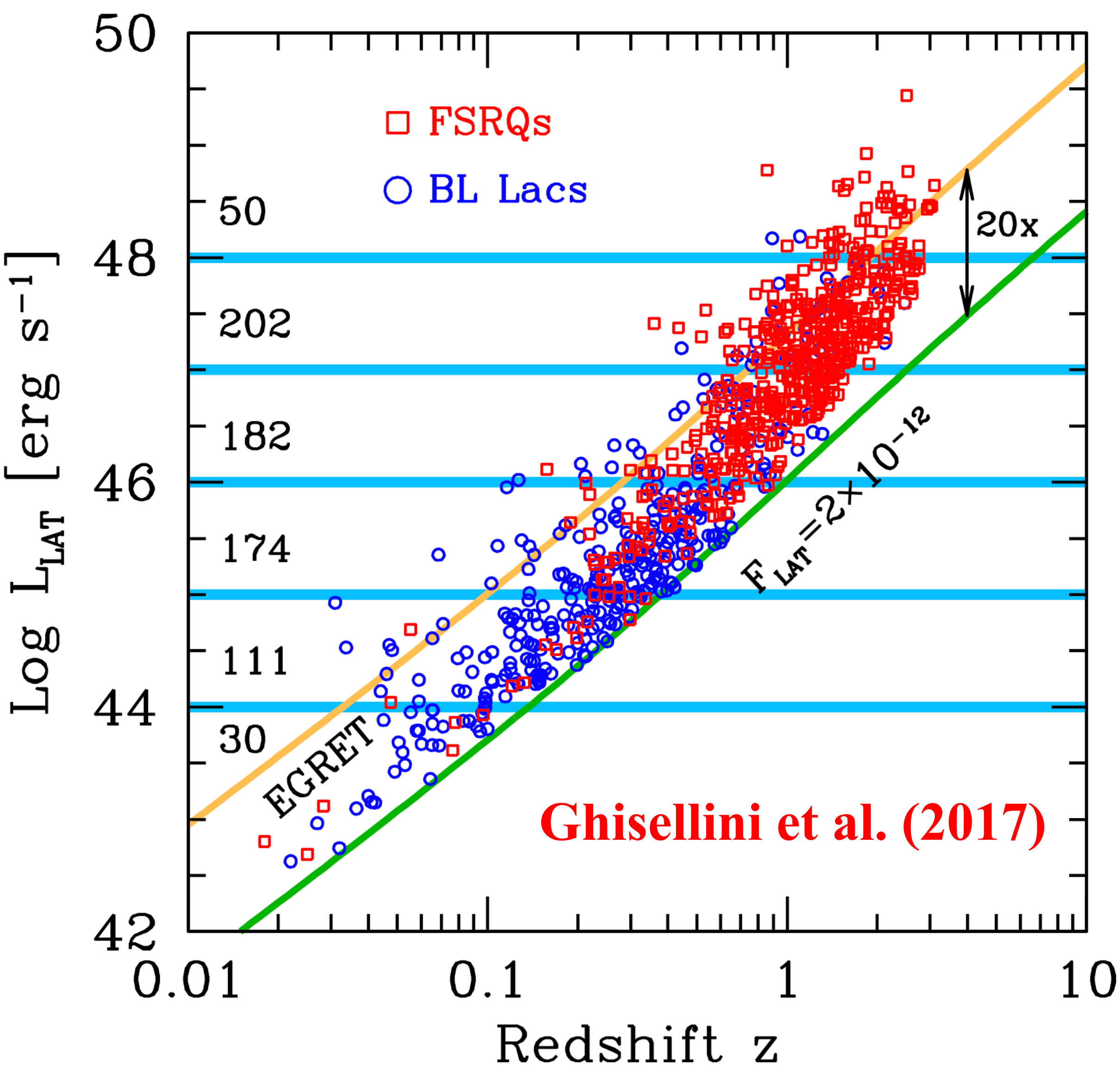
Testing the "new" blazar sequence



Testing the "new" blazar sequence

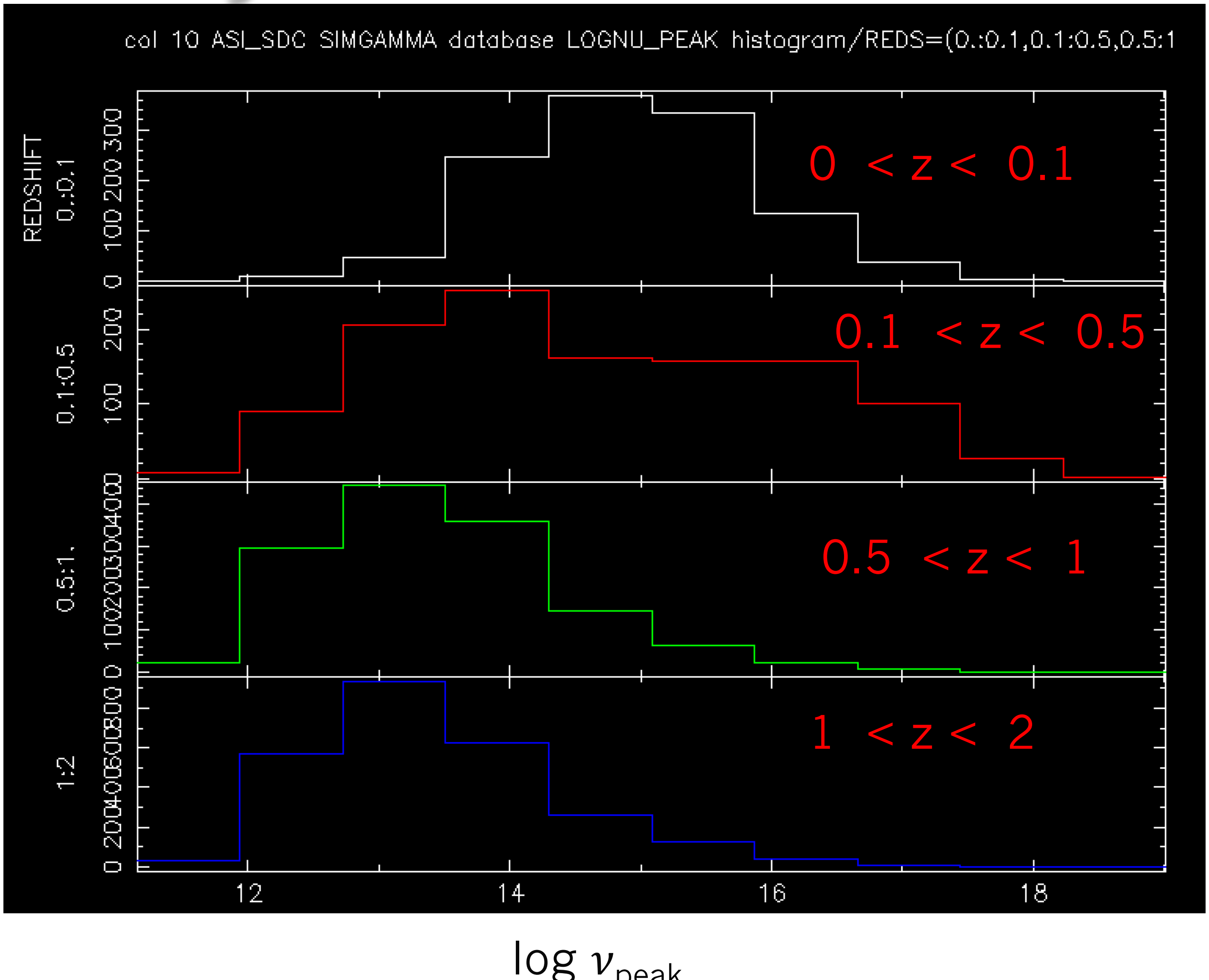


Why the anti-correlation?

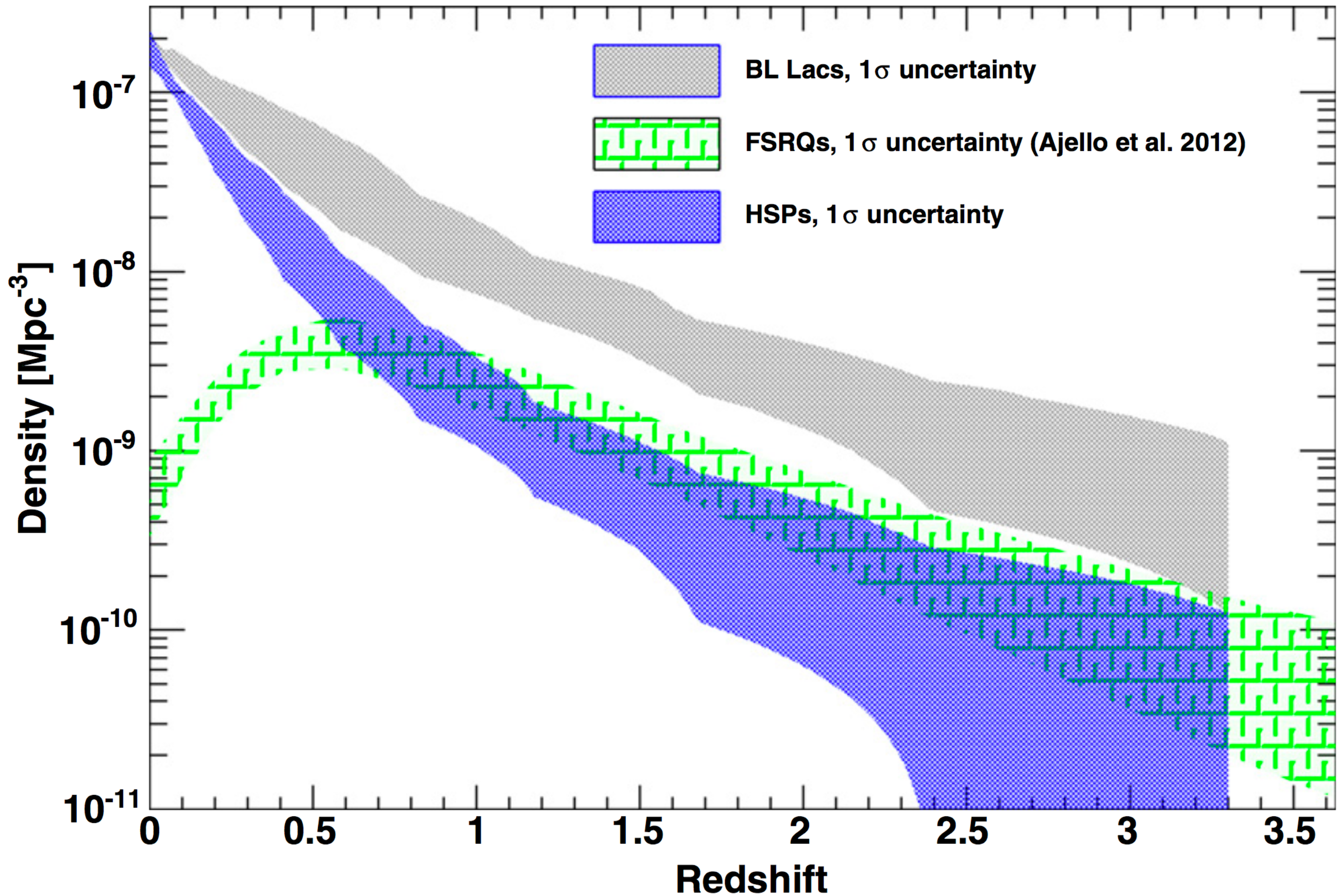


$10^{43} < L_\gamma < 10^{44}$ erg/s → $<z> \sim 0.07$

Why the anti-correlation?

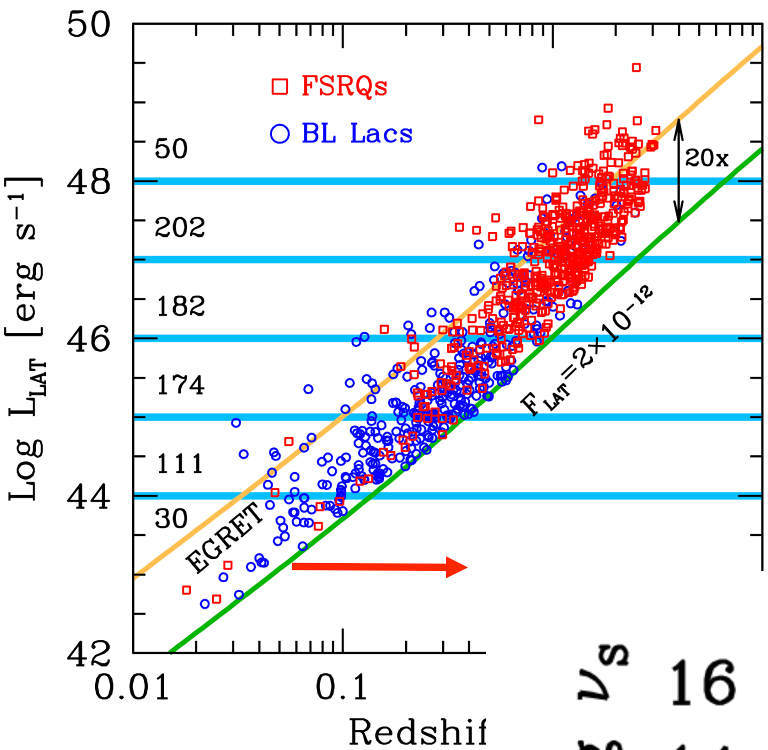


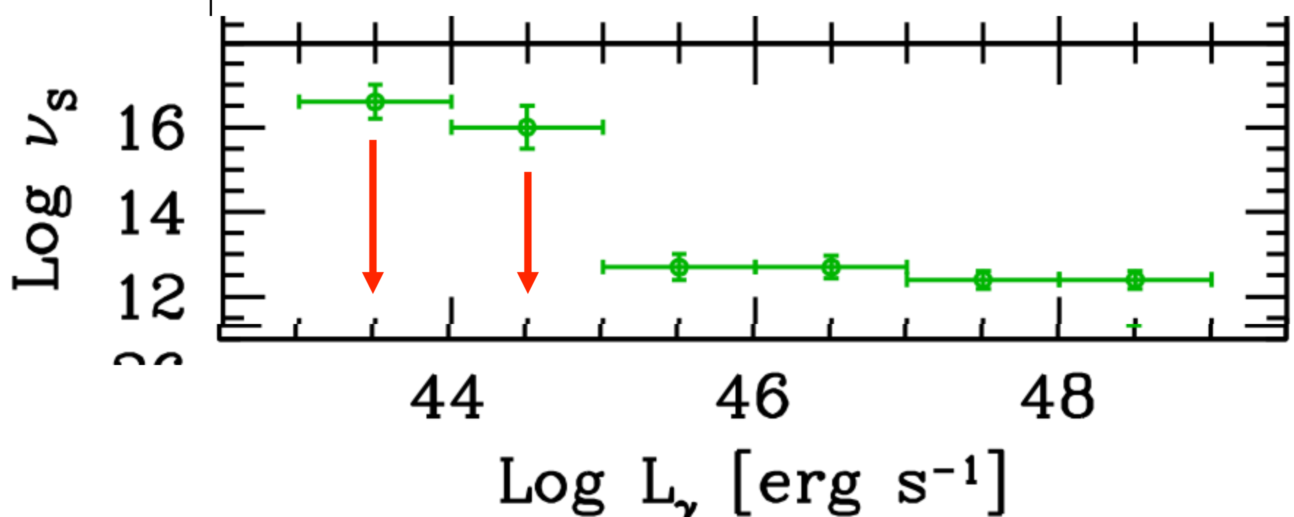
Why the anti-correlation?



Ajello et al. (2014)

Why the anti-correlation?



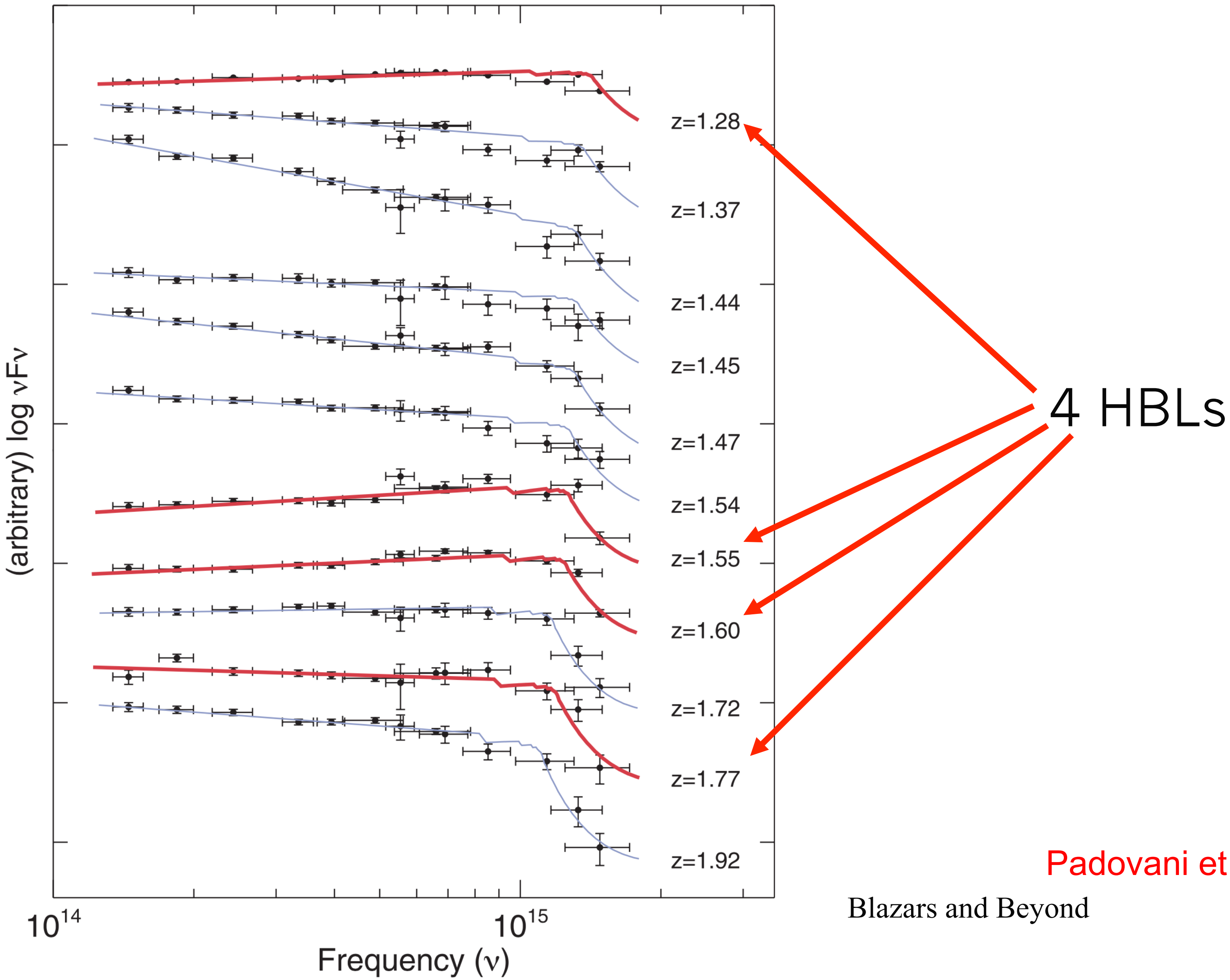


Testing the blazar sequence

1. Checking the power–$\nu_{\rm peak}$ anti-correlation;
2. Finding any "forbidden" objects, that is outliers from the correlation (high $\nu_{\rm peak}$–high power and/or low $\nu_{\rm peak}$–low power blazars);
3. Counting sources; that is, are HBL really more numerous than LBL? (and is this consistent with the X-ray background?).

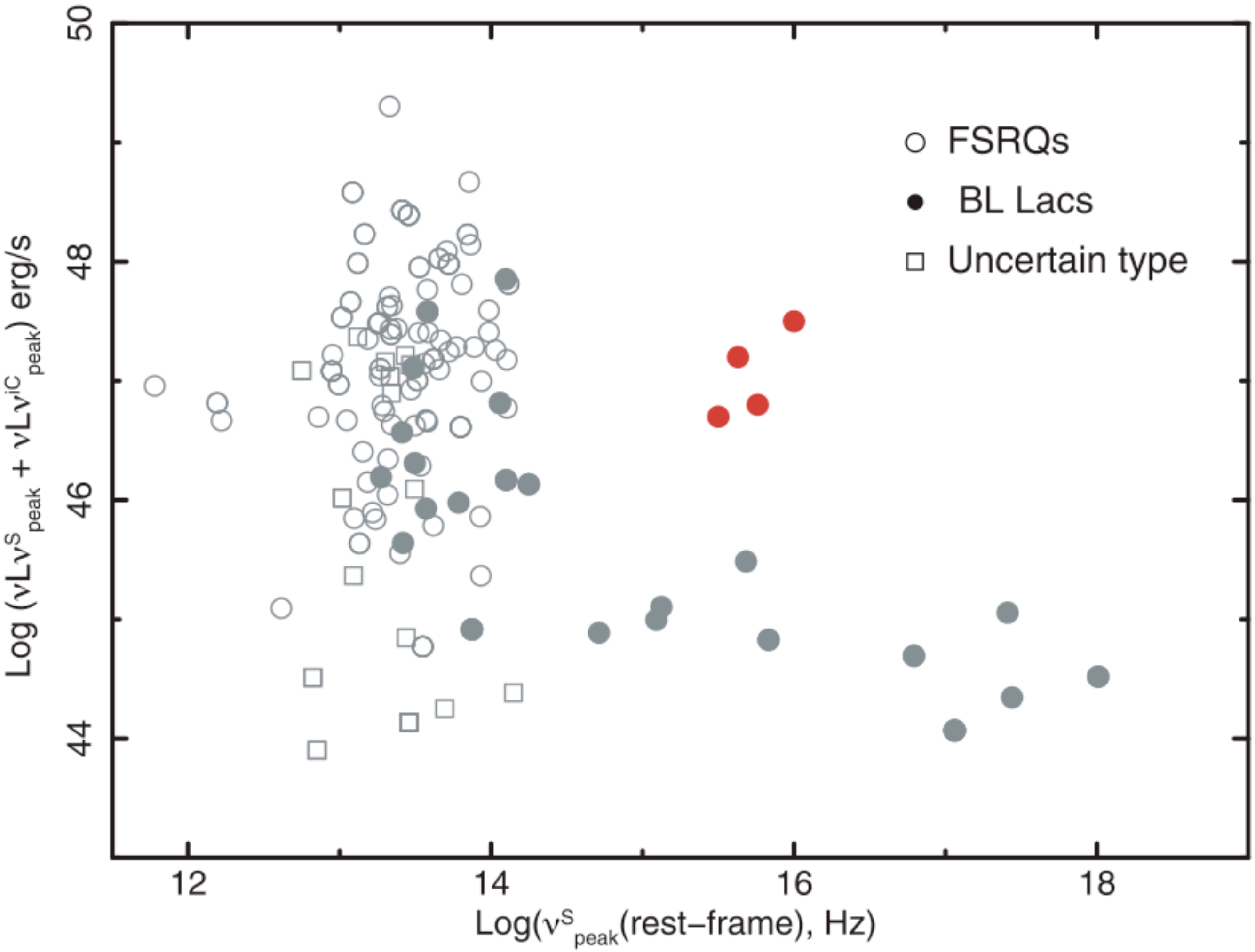
Padovani (2007)

Masquerading BL Lacs



Padovani et al. (2012)

Masquerading BL Lacs

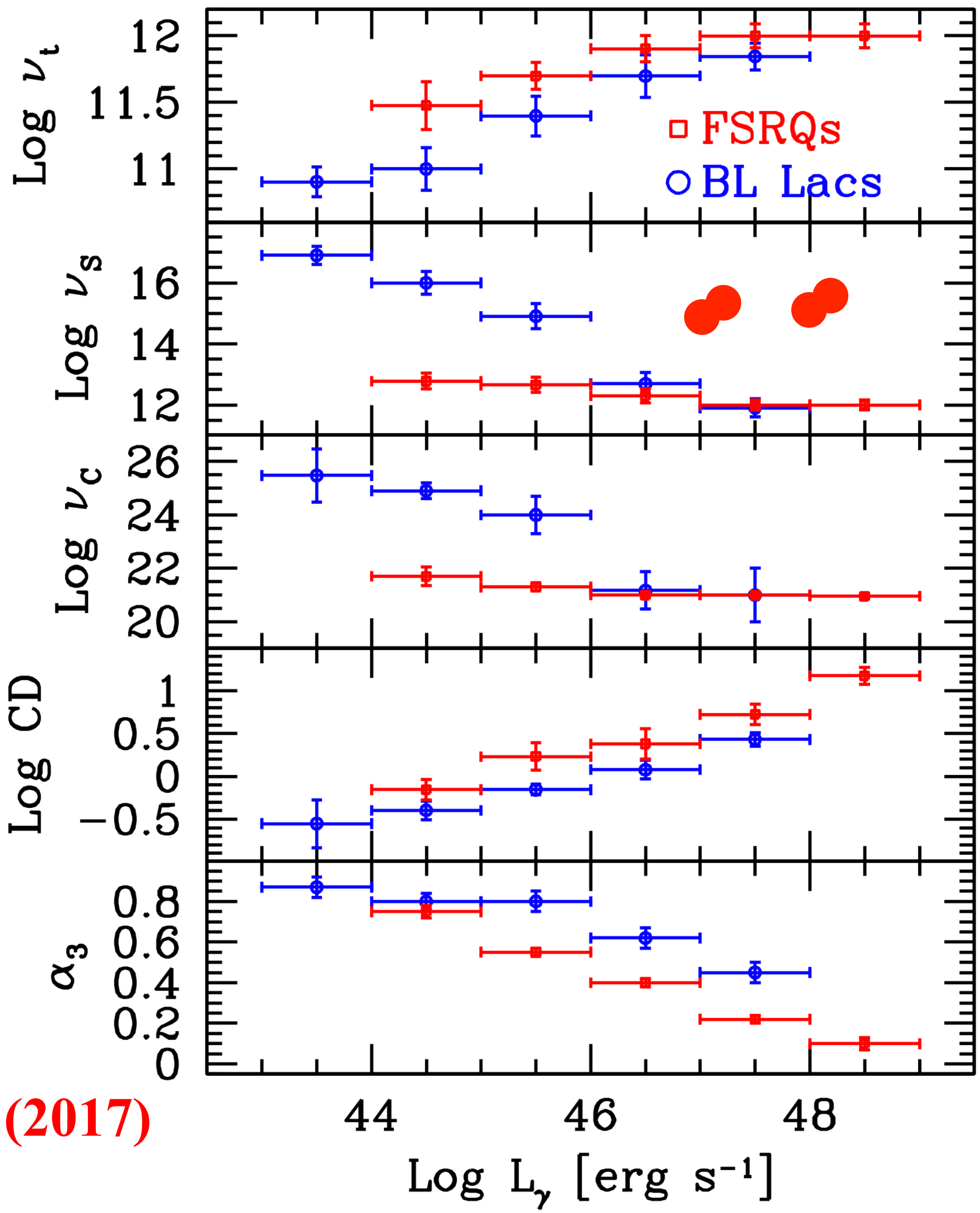


"Our conclusions agree with P12: the four blazars considered in our and their papers are probably FSRQs"

Ghiselllini et al. (2012)

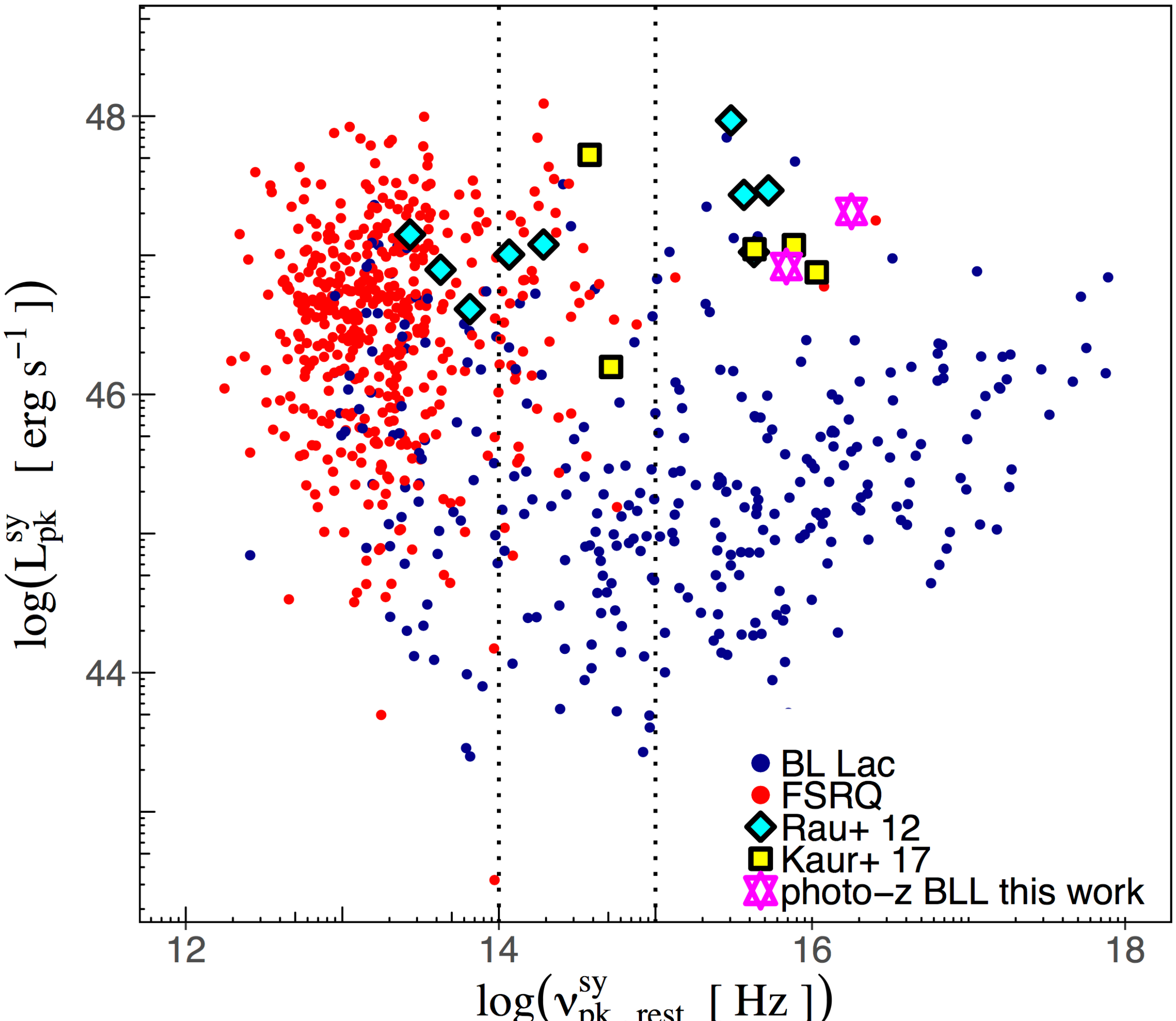
Padovani et al. (2012)

E... rs



Ghisellini et al. (2017)

Masquerading BL Lacs



Kaur et al. (2018)

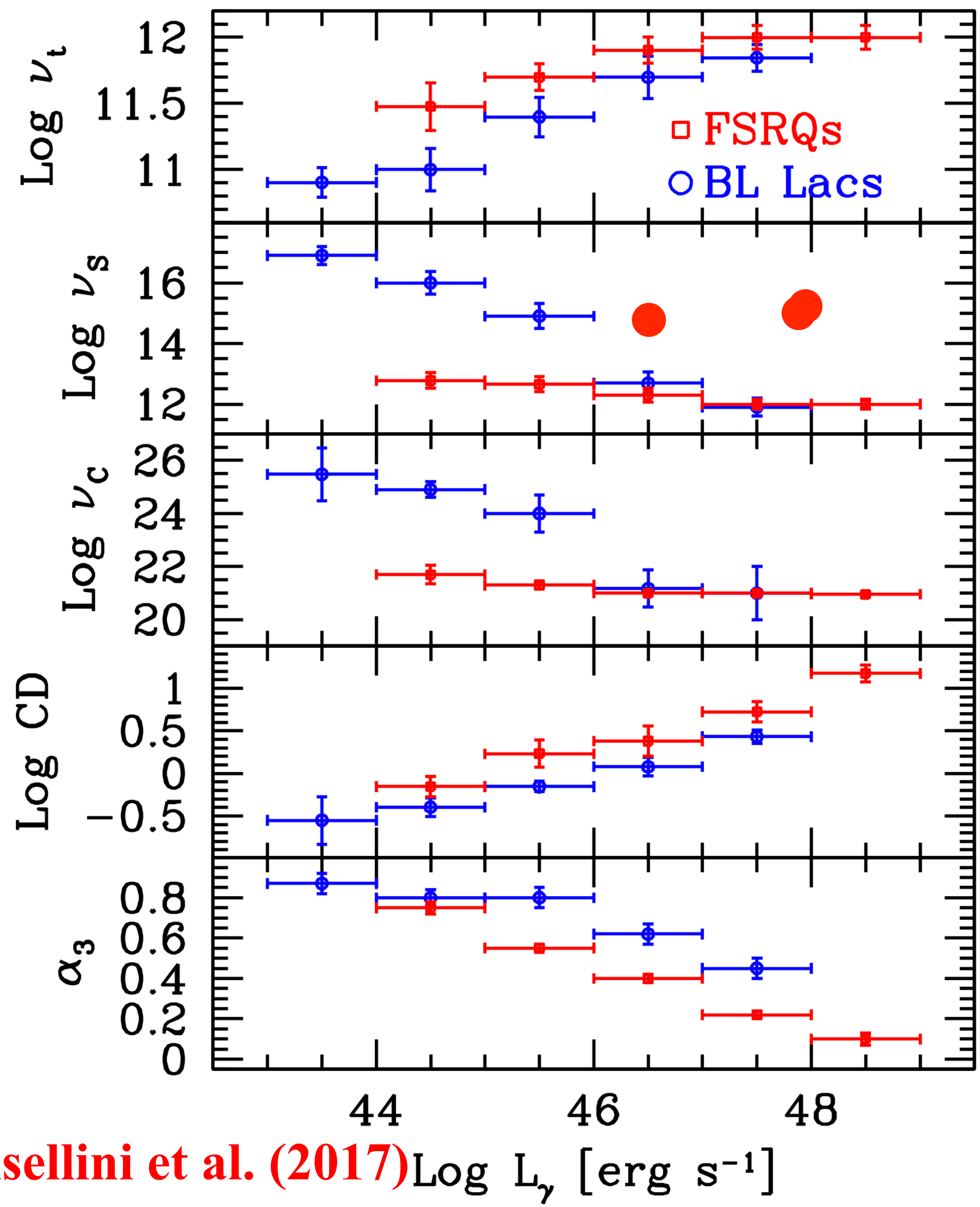
Blazar sequence outliers

Table 3
Properties of the Optical Spectra of 3FGL/LAC Sources

Object	α	S/N	EW_{min}	z
3FGL J0008.0+4713	+0.74*	10–50	0.50–3.10	>1.659[i]
3FGL J0049.7+0237	−0.01	27–95	0.30–1.20	>0.55[ll]
3FGL J0243.5+7119	−0.95	10–65	0.45–3.25	>0.45[ll]
3FGL J0505.5+0416	−0.62	40–150	0.15–0.65	0.423[g]
3FGL J0802.0+1005	−0.77	32–108	0.30–0.70	>0.58[ll]
3FGL J0814.5+2943	−0.95	54–161	0.20–0.55	0.703[g]
3FGL J1107.5+0222	−0.82	27–208	0.15–1.15	>1.0735[i]
3FGL J1109.4+2411	−0.50	22–71	0.35–1.15	>0.50[ll]
3FGL J1450.9+5200	−0.73	32–119	0.25–1.00	>2.470[i]
3FGL J2116.1+3339	−1.66	40–130	0.30–0.85	>0.25[ll]

Paiano et al. (2017)

utliers



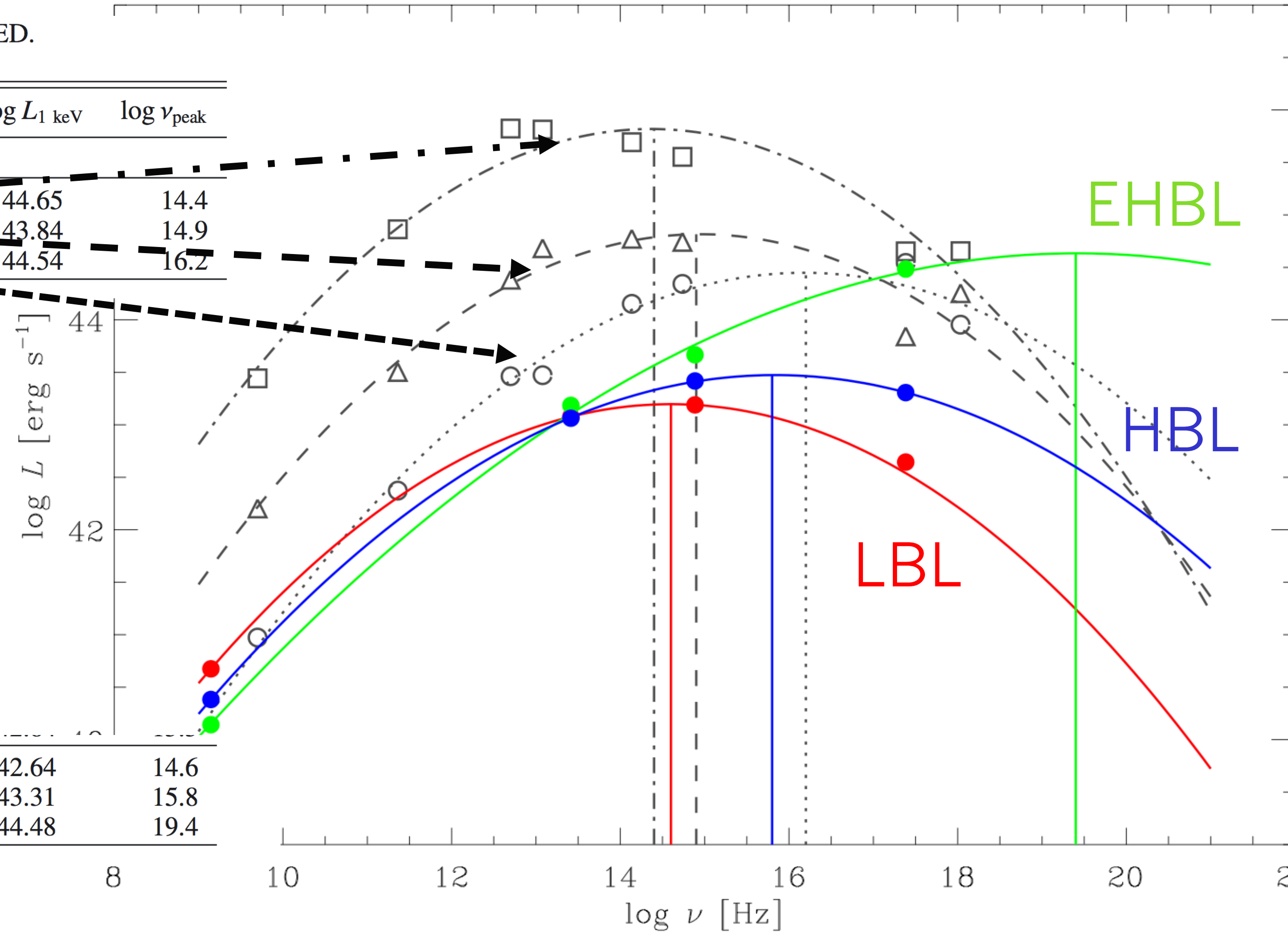
3FGL J0008.0+4713; z > 1.66
3FGL J1107.5+0222; z > 1.07
3FGL J1450.9+5200; z > 2.47

Ghisellini et al. (2017)

Low radio power blazars

ble 3. Properties of the median BL Lacs SED.

Selection	N	$\log L_{5\ \mathrm{GHz}}$	$\log L_{1\ \mathrm{keV}}$	$\log \nu_{\mathrm{peak}}$
Fossati et al. (1998)				
$\log L_r$ = 43–44	17	43.44	44.65	14.4
$\log L_r$ = 42–43	10	42.20	43.84	14.9
$\log L_r$ < 42	28	40.97	44.54	16.2
LBL	7	40.67	42.64	14.6
HBL	19	40.38	43.31	15.8
EHBL	4	40.14	44.48	19.4



Raiteri & Capetti (2016)

Low radio power blazars

Mon. Not. R. Astron. Soc. **356,** 225–231 (2005) doi:10.1111/j.1365-2966.2004.08441.x

The recognition of blazars and the blazar spectral sequence

S. Antón[1,2★] and I. W. A. Browne[1]
[1] *Jodrell Bank Observatory, University of Manchester, Macclesfield, Cheshire, SK11 9DL*
[2] *CAAUL, Observatório Astronómico de Lisboa, Tapada de Ajuda, 1349-018, Lisboa, Portugal*

Accepted 2004 September 23. Received 2004 September 16; in original form 2003 October 8

see also Padovani et al. (2003)

ABSTRACT

We analyse a group of radio sources, a subset of the 200-mJy sample, all of which have core–jet radio structures measured with very long baseline interferometry and have flat spectra stretching from the radio to the millimetre/submillimetre band. Thus the objects have most of the properties expected of blazars. However, they display varied optical properties ranging from 'Seyfert-like' objects, through BL Lac objects, to 'normal' elliptical galaxies. We investigate the distribution of synchrotron peak frequencies in their spectral energy distributions (SEDs) and find a broad distribution between 10^{12} and 10^{16} Hz. Our conclusion is that we should consider virtually all objects in the sample as blazars since much of the diversity in their classification based on traditional optical criteria arises from differences in the frequency at which the non-thermal emission begins to decline. Specifically, an object is only classified as BL Lac when its peak frequency falls in the near-infrared/optical range. We determine peak frequencies using the same method for objects from other blazar samples. An important result is that our objects do not follow the blazar spectral sequence proposed by Fossati et al. and Ghisellini et al. in which, on average, peak frequencies increase as the radio luminosity decreases. Most of our low radio luminosity sources have peaks in their SEDs at low frequencies, not at the expected high frequencies. We suggest that at least part of the systematic trend seen by Fossati et al. and Ghisellini et al. results from selection effects.

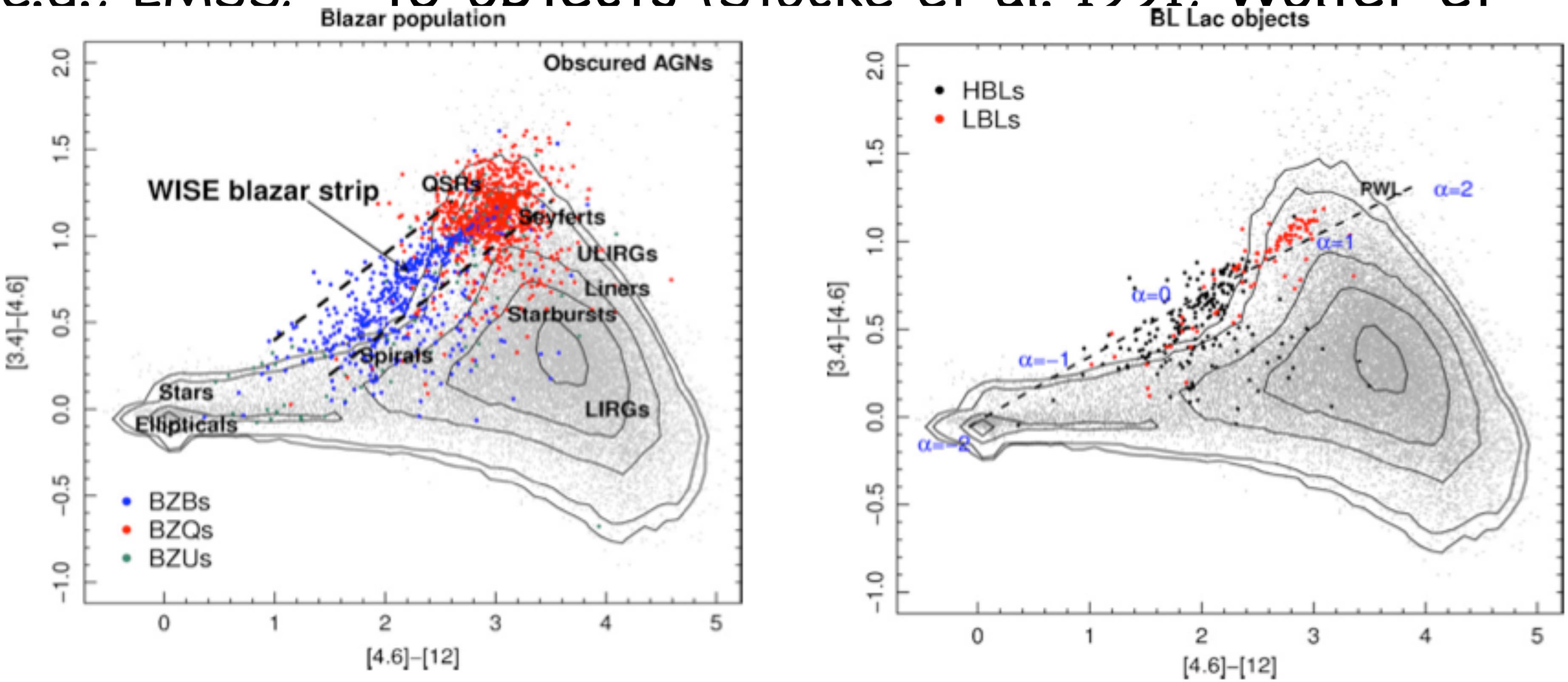
How does one find a large number of HBL?

- X-ray selected samples (peak of emission in UV/X-rays): e.g., EMSS, ~ 40 objects (Stocke et al. 1991, Wolter et al. 1991, Rector al. 2000)
- Use peculiar SED (high fx/fr values) to find HSPs in large radio/X-ray/optical catalogues: Sedentary survey, ~ 150 objects (Giommi, Menna, Padovani 1999)
- Massaro et al. and D'Abrusco et al. have shown (2011 – 2014) that blazars concentrate in a distinct region of the WISE IR colour- colour diagram (the WISE blazar strip [WBS])
- We have built the **largest** sample of HBLs starting from the latest version of the WISE catalogue (747M sources)

How does one find a large number of HBL?

- X-ray selected samples (peak of emission in UV/X-rays):

e.g., EMSS, ~ 40 objects (Stocke et al. 1991, Wolter et



the latest version of the WISE catalogue (747M sources)

Massaro et al. (2011)

A&A 598, A17 (2017)
DOI: 10.1051/0004-6361/201629487

Astronomy & Astrophysics

2WHSP: A multi-frequency selected catalogue of high energy and very high energy γ-ray blazars and blazar candidates*

Y.-L. Chang (張淯翎)[1,2,3], B. Arsioli[1,2,4], P. Giommi[2,4], and P. Padovani[5,6]

[1] Sapienza Università di Roma, ICRANet, Dipartimento di Fisica, Piazzale Aldo Moro 5, 00185 Roma, Italy
e-mail: stsun1223@hotmail.com
[2] Italian Space Agency, ASI, via del Politecnico snc, 00133 Roma, Italy
[3] ICRANet, P.zza della Repubblica 10, 65122 Pescara, Italy
[4] ICRANet-Rio, CBPF, Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro, Brazil
[5] European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
[6] Associated to INAF–Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monteporzio Catone, Italy
e-mail: yuling.chang@asdc.asi.it

Received 5 August 2016 / Accepted 18 September 2016

ABSTRACT

Aims. High synchrotron peaked blazars (HSPs) dominate the γ-ray sky at energies higher than a few GeV; however, only a few hundred blazars of this type have been cataloged so far. In this paper we present the 2WHSP sample, the largest and most complete list of HSP blazars available to date, which is an expansion of the 1WHSP catalogue of γ-ray source candidates off the Galactic plane.
Methods. We cross-matched a number of multi-wavelength surveys (in the radio, infrared and X-ray bands) and applied selection criteria based on the radio to IR and IR to X-ray spectral slopes. To ensure the selection of genuine HSPs, we examined the SED of each candidate and estimated the peak frequency of its synchrotron emission ($\nu_{\rm peak}$) using the ASDC SED tool, including only sources with $\nu_{\rm peak} > 10^{15}$ Hz (equivalent to $\nu_{\rm peak} > 4$ eV).
Results. We have assembled the largest and most complete catalogue of HSP blazars to date, which includes 1691 sources. A number of population properties, such as infrared colours, synchrotron peak, redshift distributions, and γ-ray spectral properties have been used to characterise the sample and maximize completeness. We also derived the radio log N–log S distribution. This catalogue has already been used to provide seeds to discover new very high energy objects within *Fermi*-LAT data and to look for the counterparts of neutrino and ultra high energy cosmic ray sources, showing its potential for the identification of promising high-energy γ-ray sources and multi-messenger targets.

Key words. galaxies: active – BL Lacertae objects: general – radiation mechanisms: non-thermal – gamma rays: galaxies

A&A 579, A34 (2015)
DOI: 10.1051/0004-6361/201424148

Astronomy & Astrophysics

1WHSP: An IR-based sample of ∼1000 VHE γ-ray blazar candidates★

B. Arsioli[1,2,4], B. Fraga[1,2,4], P. Giommi[3,4], P. Padovani[5,6], and P. M. Marrese[3]

[1] Sapienza Università di Roma, ICRA, Dipartimento di Fisica, Piazzale Aldo Moro 5, 00185 Roma, Italy
e-mail: [bruno.arsioli;paolo.giommi]@asdc.asi.it, bernardo.machado@icra.it
[2] Université de Nice-Sophia Antipolis, Nice, Cedex 2, Grand Château Parc Valrose, 06103 Nice Cedex 2, France
[3] ASI Science Data Center, ASDC, Agenzia Spaziale Italiana, via del Politecnico snc, 00133 Roma, Italy
[4] ICRANet-Rio, CBPF, Rua Dr. Xavier Sigaud 150, 22290-180 Rio de Janeiro, Brazil
[5] European Southern Observatory, Karl-Schwarzschild-Str. 2, 85748 Garching bei München, Germany
[6] Associated to INAF–Osservatorio Astronomico di Roma, via Frascati 33, 00040 Monteporzio Catone, Italy

Received 6 May 2014 / Accepted 1 April 2015

ABSTRACT

Context. Blazars are the dominant type of extragalactic sources at microwave and at γ-ray energies. In the most energetic part of the electromagnetic spectrum ($E \gtrsim 100$ GeV) a high fraction of high Galactic latitude sources are blazars of the high synchrotron peaked (HSP) type, that is BL Lac objects with synchrotron power peaking in the UV or in the X-ray band. Building new large samples of HSP blazars is key to understand the properties of jets under extreme conditions, and to study the demographics and the peculiar cosmological evolution of these sources.

Aims. High synchrotron peaked blazars are remarkably rare, with only a few hundreds of them expected to be above the sensitivity limits of currently available surveys, some of which include hundreds of millions of sources. To find these very uncommon objects, we have devised a method that combines ALLWISE survey data with multi-frequency selection criteria.

Methods. The sample was defined starting from a primary list of infrared colour–colour selected sources from the ALLWISE all sky survey database, and applying further restrictions on IR-radio and IR-X-ray flux ratios. Using a polynomial fit to the multi-frequency data (radio to X-ray), we estimated synchrotron peak frequencies and fluxes of each object.

Results. We assembled a sample including 992 sources, which is currently the largest existing list of confirmed and candidates HSP blazars. All objects are expected to radiate up to the highest γ-ray photon energies. In fact, 299 of these are confirmed emitters of GeV γ-ray photons (based on *Fermi*-LAT catalogues), and 36 have already been detected in the TeV band. The majority of sources in the sample are within reach of the upcoming Cherenkov Telescope Array (CTA), and many may be detectable even by the current generation of Cherenkov telescopes during flaring episodes. The sample includes 425 previously known blazars, 151 new identifications, and 416 HSP candidates (mostly faint sources) for which no optical spectra is available yet. The full 1WHSP catalogue is online at http://www.asdc.asi.it/1whsp/, providing a direct link to the SED building tool where multi-frequency data for

Looking for HBLs in WISE: how to find a needle in a haystack!

- Cross match ALLWISE (3.4, 4.6, 12 and 22 μm catalogue) with 3 radio surveys: NVSS, FIRST, and SUMSS [747 M → 2.1 M]
- Cross match results with a bunch of X-ray catalogues (e.g., RASS, 3XMM, WGACAT, etc.) [2.1 M → 28.4 k]
- Make a cut at $|b_{II}| > 10°$
- Then make following spectral slope cuts:
  - $0.05 < \alpha_{1.4GHz - 3.4\mu m} < 0.45$ [radio – IR HBL-like]
  - $0.4 < \alpha_{4.6\mu m - 1 keV} < 1.1$ [IR – X-ray HBL-like]

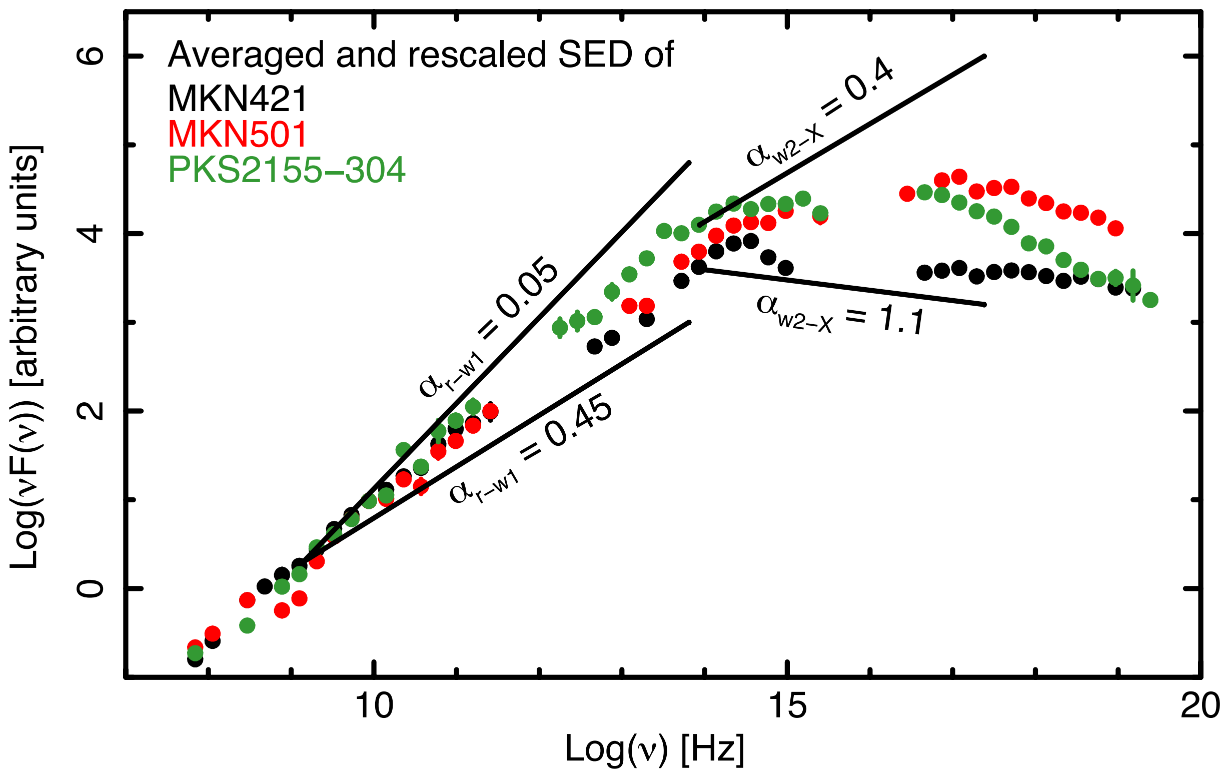
→ 5518

- Study all SEDs to single out the HBLs → 1691

Looking for HBLs in WISE: how to find a needle in a haystack!

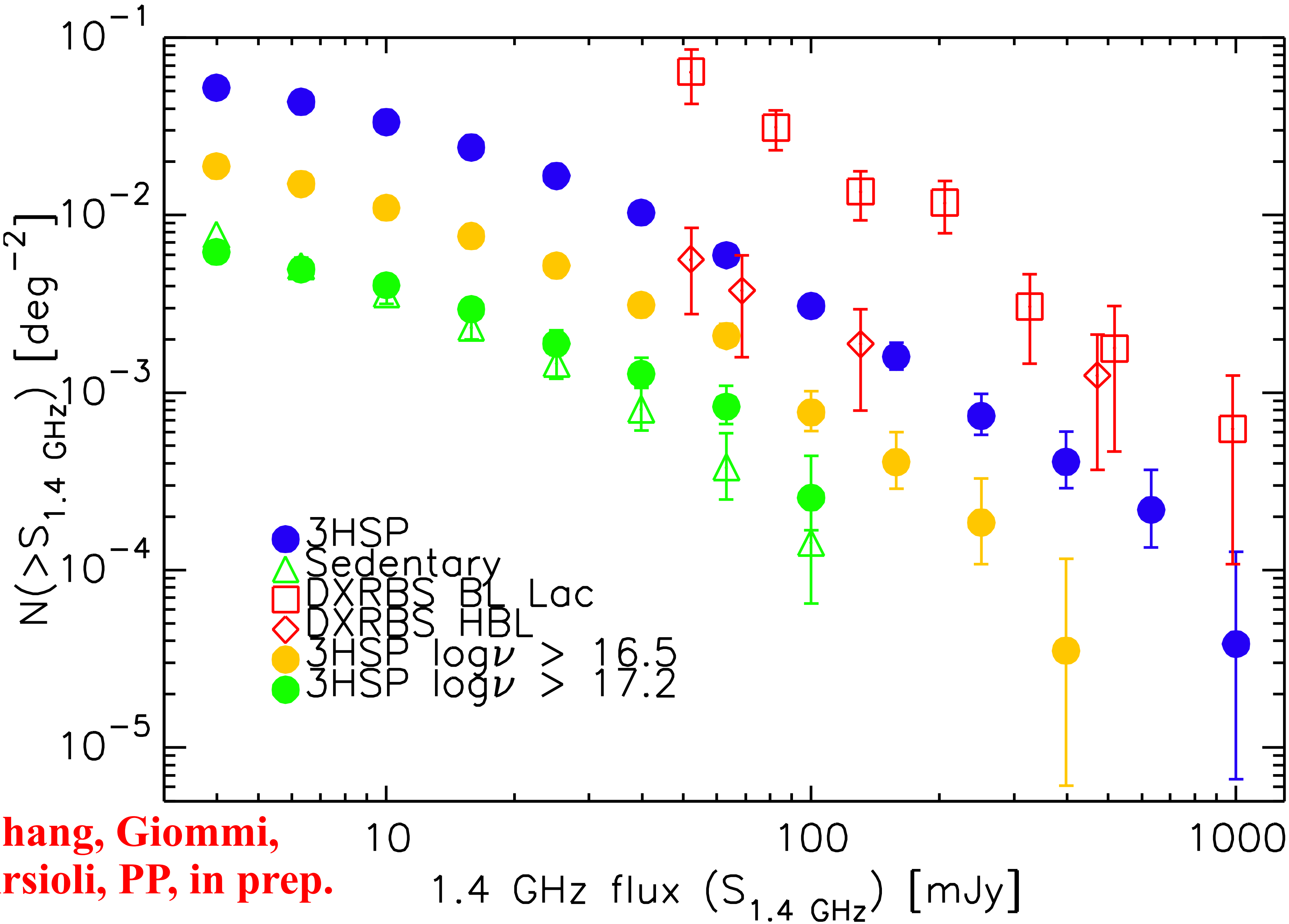
- Cross catalogu d SUMSS [747 M
- Cross alogues (e.g., RA k]
- Make
- Then r
  - L-like]
  - ke]

→ 5518



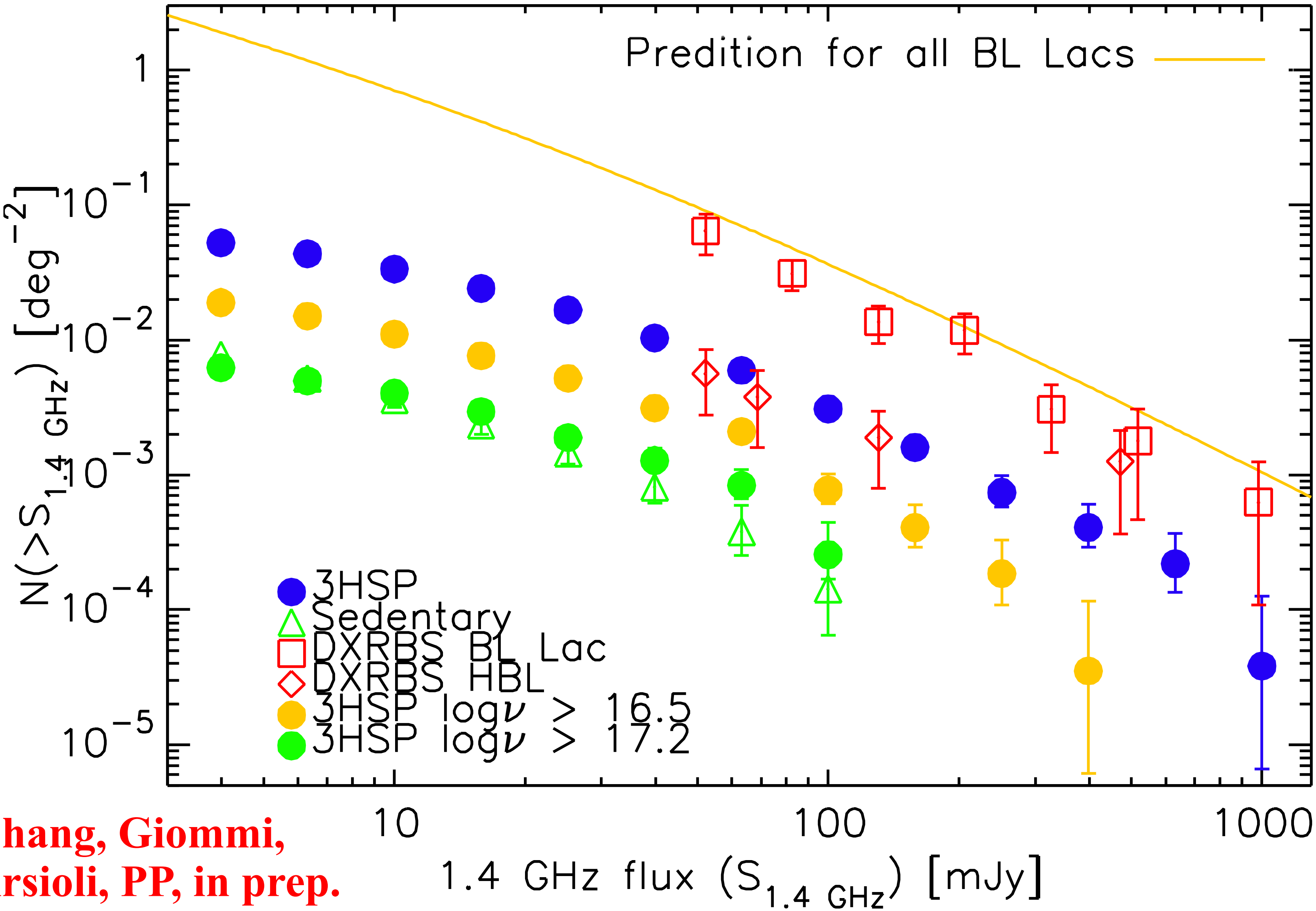
- Study all SEDs to single out the HBLs → 1691

HBL number counts



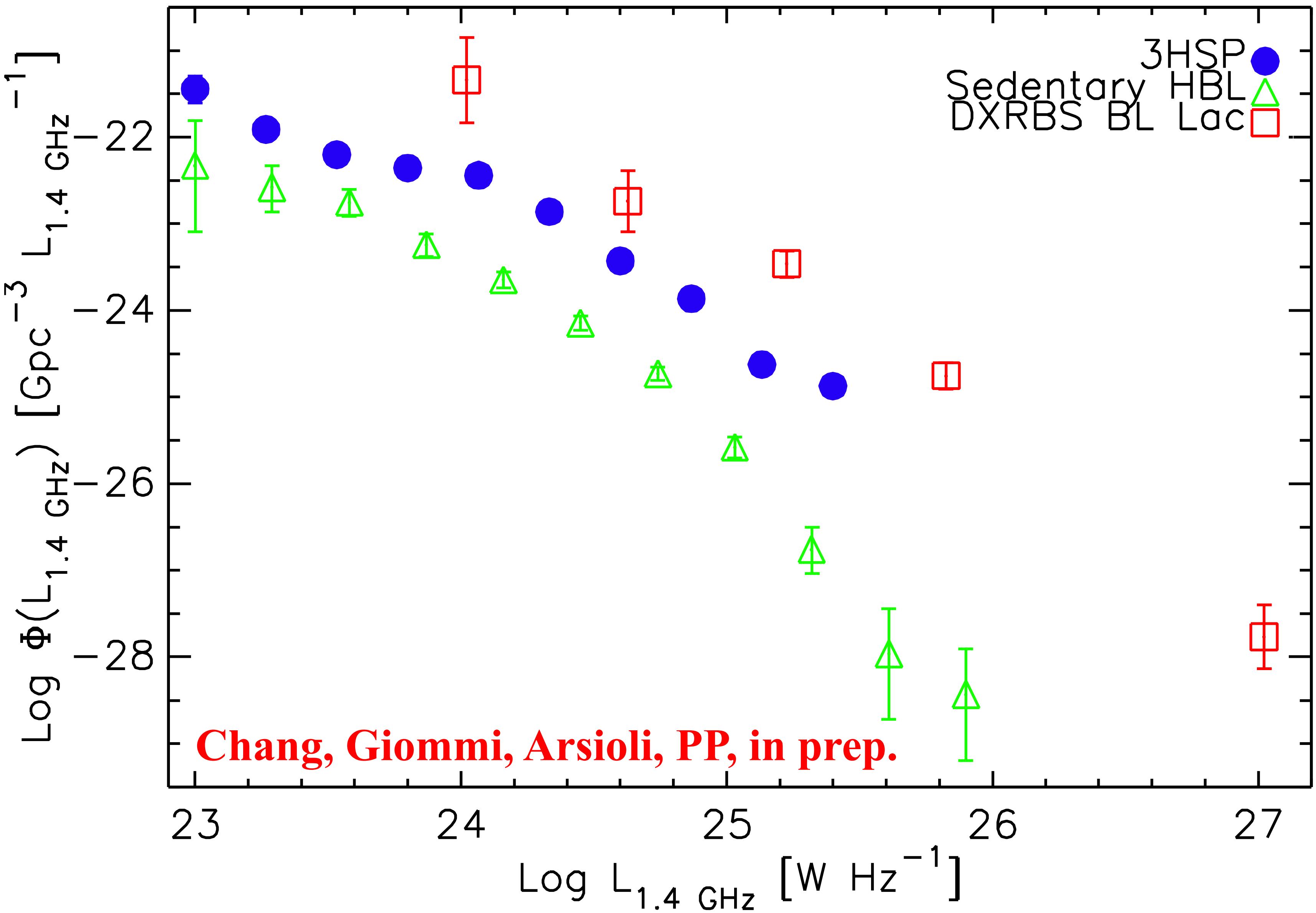
Chang, Giommi, Arsioli, PP, in prep.

HBL number counts



Chang, Giommi, Arsioli, PP, in prep.

HBL luminosity function



Summary

- We have put together many pieces of a puzzle which has been in the making for the past 20 years or so: the **Blazar Simplified View**
- Starting point: two populations
  - ✓ high-excitation (standard accretion disk), high P_r, evolving
  - ✓ low-excitation, low P_r, non-evolving
- Add non-thermal (jet), thermal (accretion), and host galaxy components + single $N(\gamma_e)$

Summary

- Main results:
  - ✓ blazar properties (incl. BL Lac/FSRQ differences) explained over the whole e.m. spectrum
  - ✓ BL Lacs are of two types:
    - ○ beamed FSRQs with swamped emission lines (HERGs) ["masquerading BL Lacs"]: → need to be grouped with FSRQs!
    - ○ weak-lined radio sources with jets (LERGs) ["real BL Lacs"]
  - ✓ blazar sequence due to selection effects
  - ✓ plenty of forbidden sources: high ν_{peak} – high power and low ν_{peak} – low power blazars
  - ✓ **HBL are a minority population**

The physics of the "blazar sequence"

- Ghisellini et al. (1998):

HBLs are sources characterized by the lowest intrinsic power and the weakest external radiation field (no or weak emission lines). Consequently the cooling is less dramatic and particles can be present with energies high enough to produce synchrotron emission extending to soft X-ray energies and TeV radiation through the SSC process.

FSRQs represent the most powerful blazars, where the contribution from the external radiation to the cooling is the greatest.

The physics of the "blazar sequence"

- Ghisellini et al. (2017):

We can conclude that in the comoving frame, $U'_{ext} \propto \Gamma^2$, therefore it is nearly constant if the Γ-factor is approximately the same in different sources. In this case the cooling rate is the same in FSRQs of different power.

For BL Lacs, instead, the main radiation mechanism for the high-energy hump is the synchrotron self-Compton process. It strongly depends upon the synchrotron radiation energy density in the comoving frame that is an increasing function of the observed luminosity. Therefore, the cooling is not constant, but it is more severe in more powerful BL Lacs.

The physics of the "blazar sequence"

- Ghisellini et al. (2017):

$U_{BLR} \sim 1/12\pi \sim 0.03$ erg/cm^3

$U_{Torus} \sim 0.07\ f\ U_{BLR} \sim 0.002\ f$ erg/cm^3
(f = torus covering fraction)

But Costamante et al. (2018): **(see also Isler's talk)**

… for the large majority of Fermi blazars (9 out of 10), there is NO evidence of strong interaction of the jet gamma rays with BLR photons. The emission seems to originate almost always outside the BLR, both on average and during high/flaring or low-flux states.

… differences like high/low-peaked SEDs and Compton dominance cannot be attributed to the cooling on BLR photons and their high energy density

The physics of the "blazar sequence"

- Ghisellini & Tavecchio (2008):

(ii) *Existence of 'blue' FSRQs* – the BLR radius $R_{\rm BLR} \propto L_{\rm disc}^{1/2} \propto \dot{M}_{\rm in}^{1/2}$, while the dissipation distance is $R_{\rm diss} \propto M$. Therefore, there is the possibility that relatively high-mass objects, with relatively faint disc (but with $L_{\rm disc} > L_{\rm c}$) have jets preferentially dissipating beyond the BLR (see also Georganopoulos, Kirk & Mastichiadis 2001; Pian et al. 2006). The emitting electrons would suffer less radiative cooling, implying a large $\gamma_{\rm peak}$ and a 'blue' SED. From equations (9) and (4) we have that $R_{\rm diss} > R_{\rm BLR}$ for

$$0.39 M_9 < L_{\rm disc,45} < 0.81 M_9^2 \left[\frac{a(\Gamma)}{300}\right]^2. \qquad (23)$$