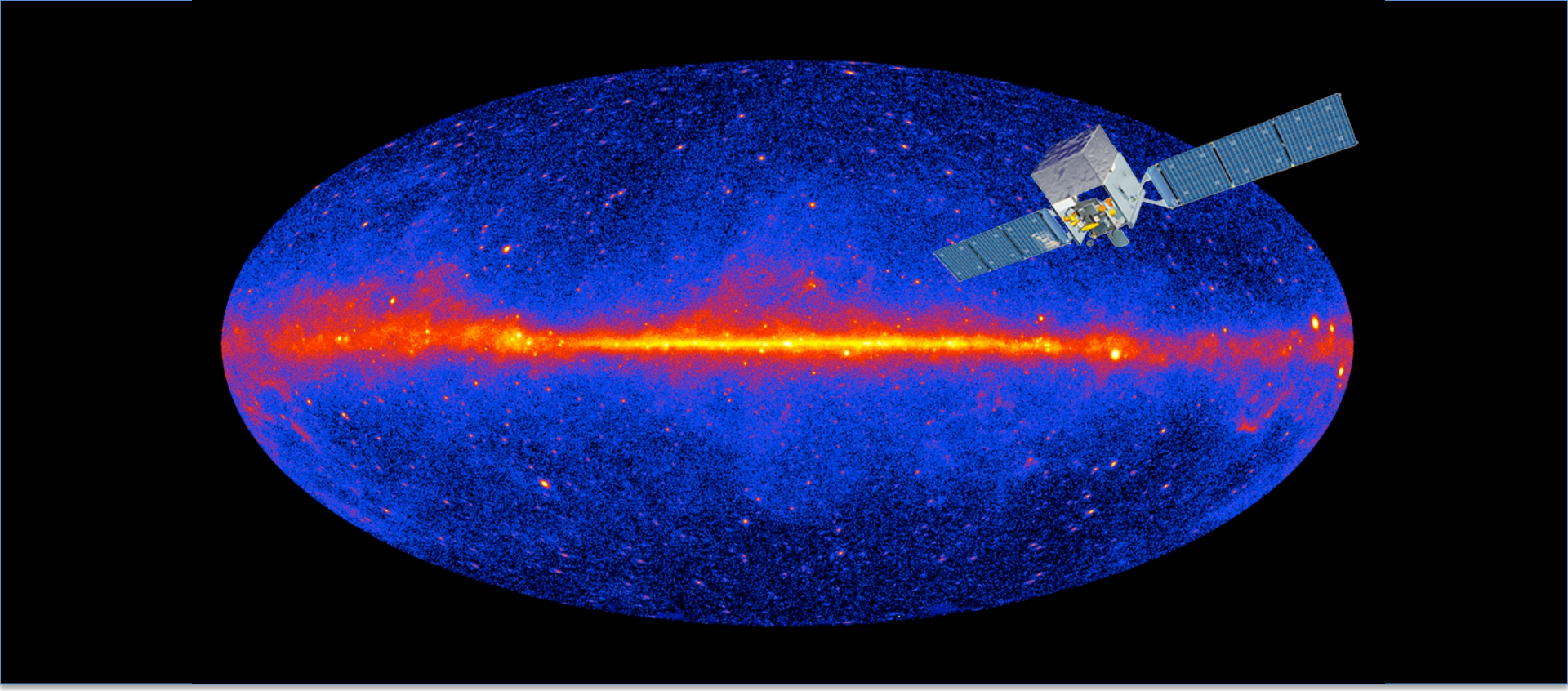
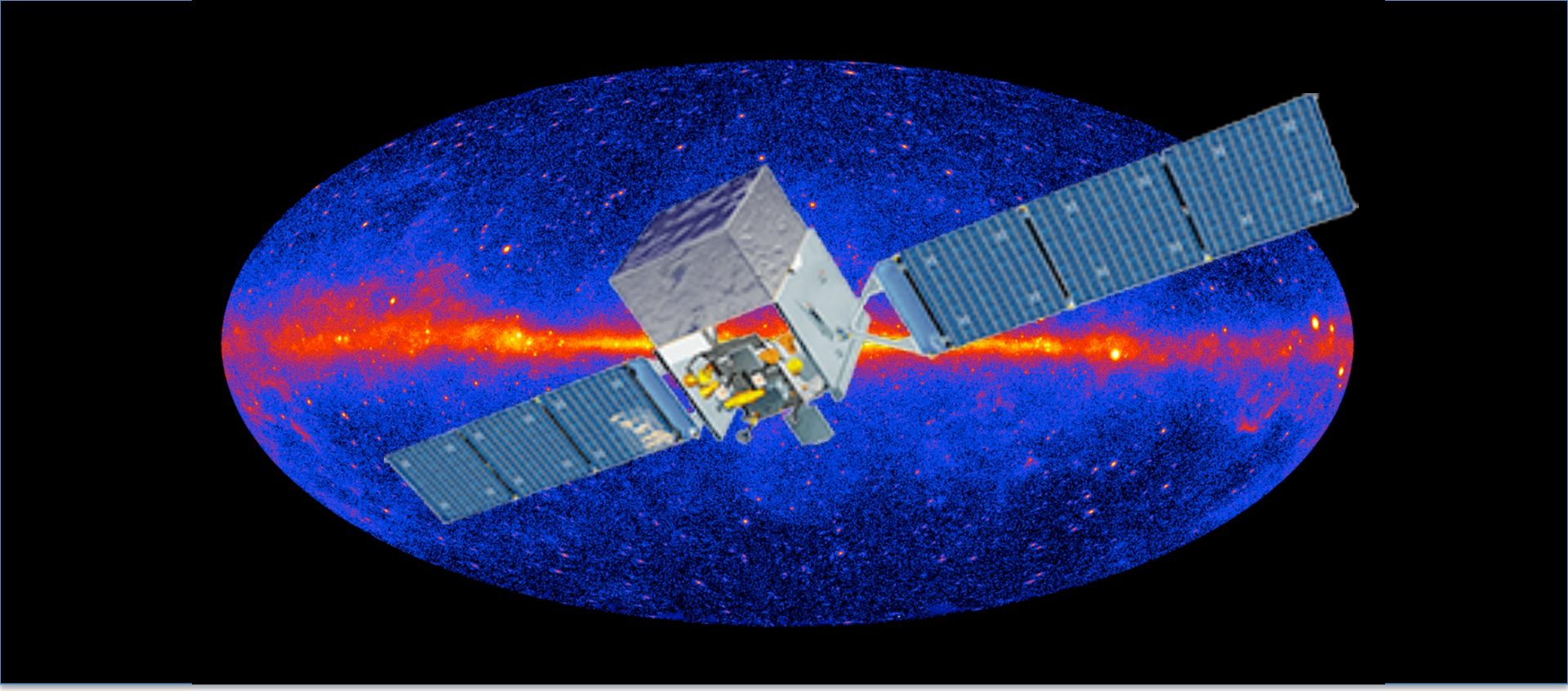


BLAZAR FLARING PATTERNS (B-FLAP)

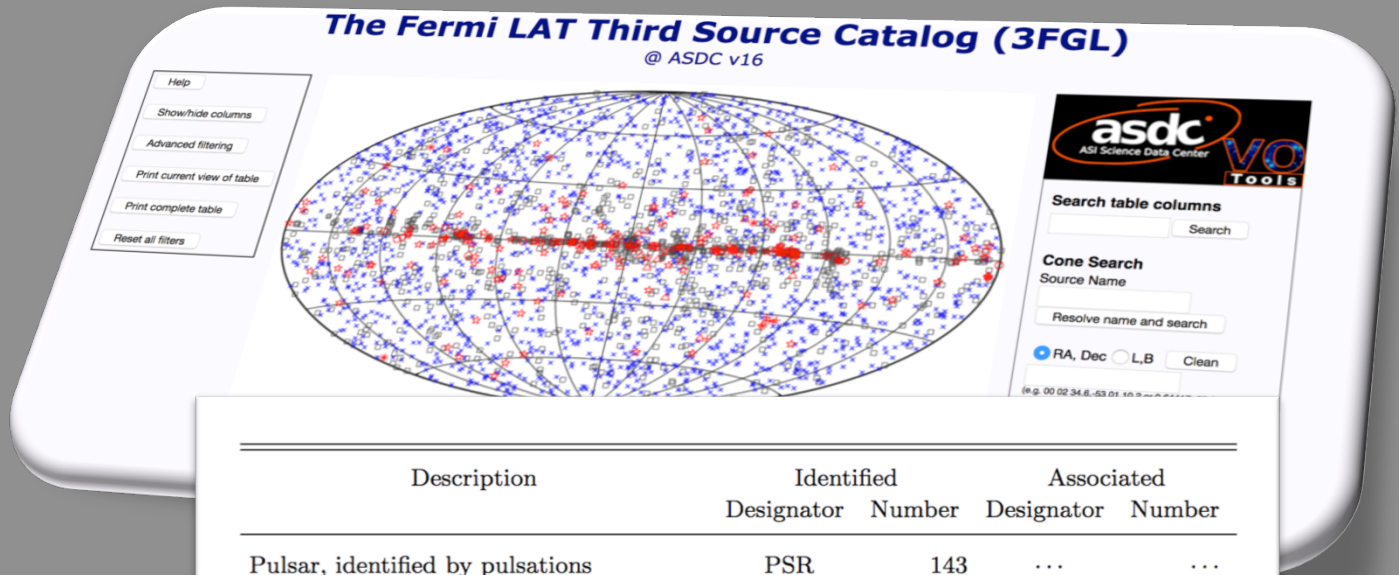
CLASSIFYING BLAZARS OF UNCERTAIN TYPE DETECTED BY FERMI GAMMA-RAY SPACE TELESCOPE

GRAZIANO CHIARO
ASTROSIESTA IASF /INAF 13 / 4/2017



The Large Area Telescope (LAT) is the principal scientific instrument on the Fermi Gamma Ray Space Telescope spacecraft launched into a near-earth orbit on 11 June 2008.

The LAT is an imaging high-energy gamma-ray telescope covering the energy range from about 20 MeV to more than 300 GeV.

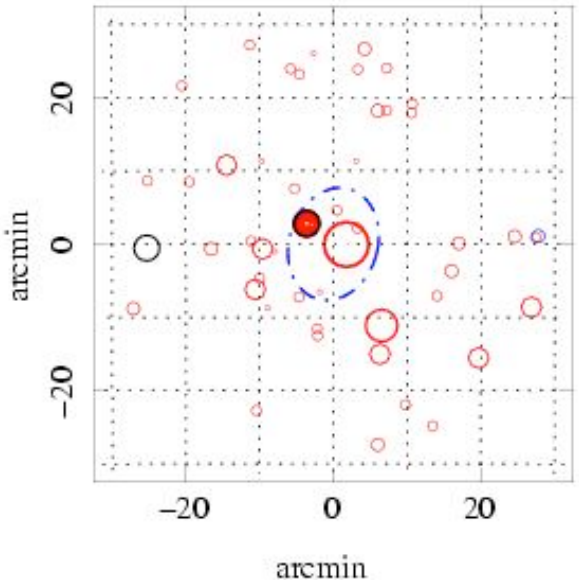


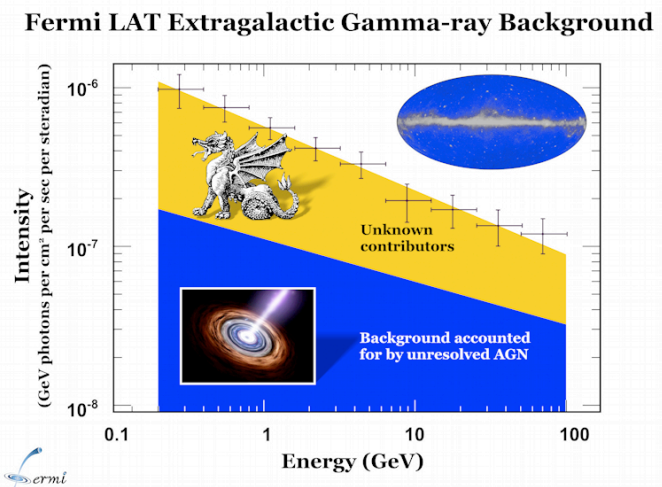
3FGL CATALOG

3033 detected sources

1583 unclassified

Description	Identified Designator	Identified Number	Associated Designator	Associated Number
Pulsar, identified by pulsations	PSR	143	...	...
Pulsar, no pulsations seen in LAT yet	...	...	psr	24
Pulsar wind nebula	PWN	9	pwn	2
Supernova remnant	SNR	12	snr	11
Supernova remnant / Pulsar wind nebula	...	...	spp	49
Globular cluster	GLC	0	glc	15
High-mass binary	HMB	3	hmb	0
Binary	BIN	1	bin	0
Nova	NOV	1	nov	0
Star-forming region	SFR	1	sfr	0
Compact Steep Spectrum Quasar	CSS	0	css	1
BL Lac type of blazar	BLL	18	bll	642
FSRQ type of blazar	FSRQ	38	fsrq	446
Non-blazar active galaxy	AGN	0	agn	3
Radio galaxy	RDG	3	rdg	12
Seyfert galaxy	SEY	0	sey	1
Blazar candidate of uncertain type	BCU	5	bcu	568
Normal galaxy (or part)	GAL	2	gal	1
Starburst galaxy	SBG	0	sbg	4
Narrow line Seyfert 1	NLSY1	2	nlsy1	3
Soft spectrum radio quasar	SSRQ	0	ssrq	3
Total	...	238	...	1785
Unassociated	...	...	...	1010





THE PROBLEM

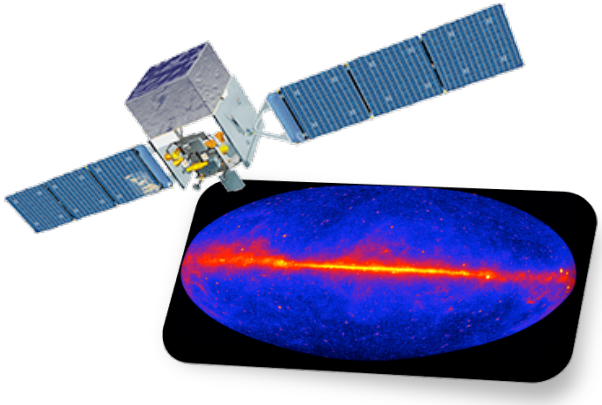
The difficulty of finding counterparts

of high-energy -ray sources

because

- positional errors in their measured locations,
- limited photon statistics / faint sources
- poor angular resolution of the gamma –ray telescopes
- bright diffuse gamma-ray emission from the Milky Way and extragalactic

GeV γ–ray sky = 20% Point sources + 80% Diffuse γ -ray



THE GOAL

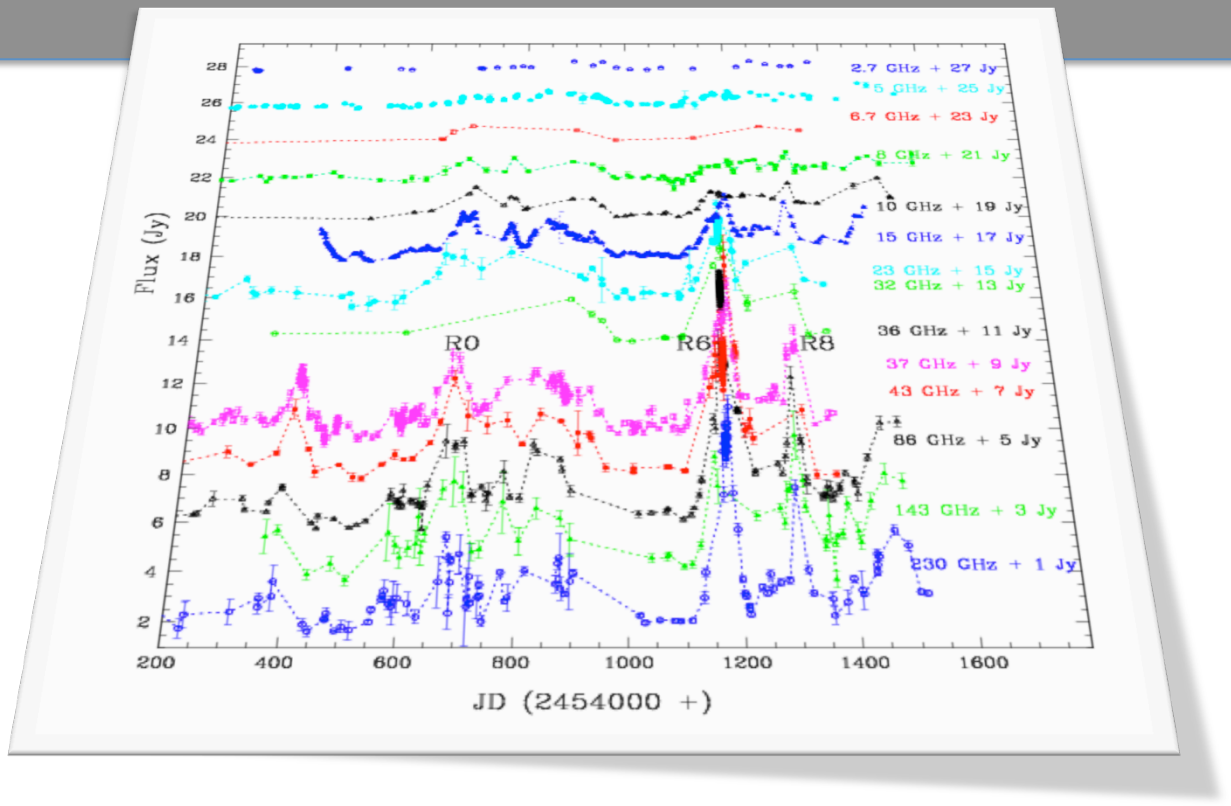
because
Blazars represent more than 50% of the AGN Sky (100 MeV – 300 GeV)

A fast and easy
screening method
for uncertain blazars classification.

In contrast to non-active galaxies which have a constant luminosity,

AGN emission is frequently observed to be variable.

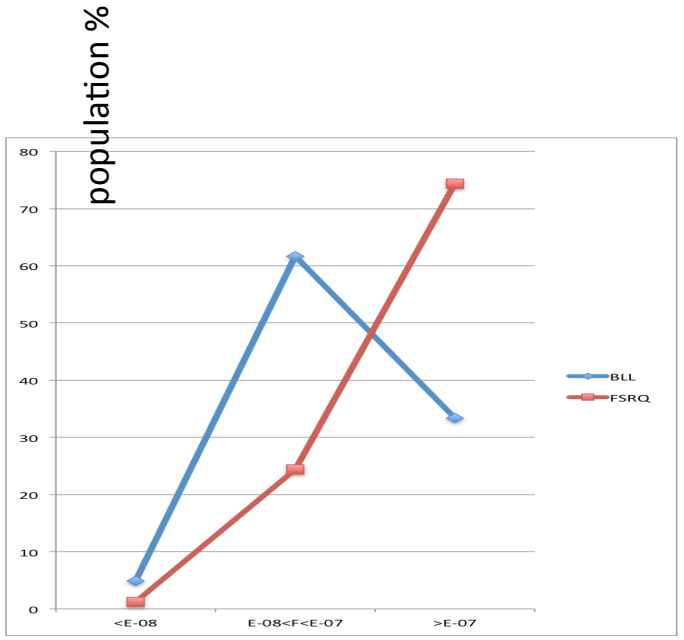
Variability could be used for the purposes of this study



First thoughts - The Parameter

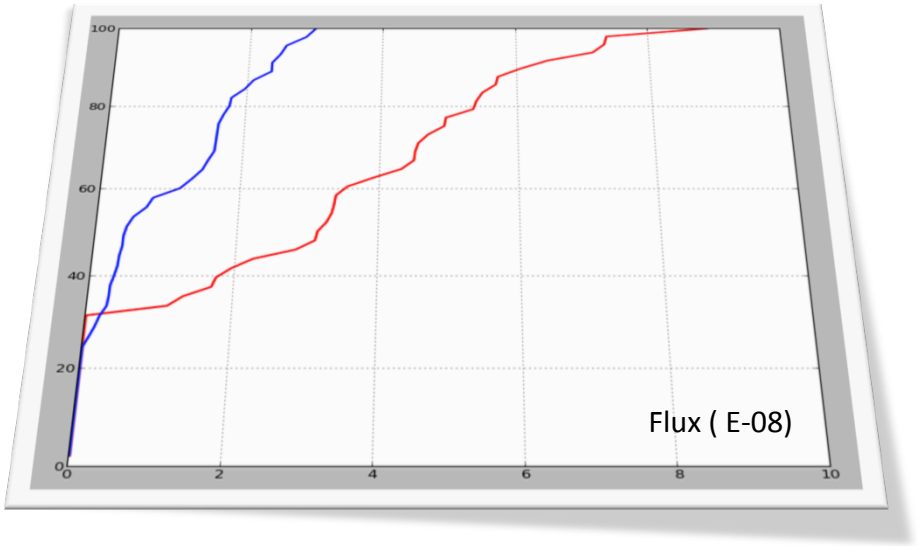
Flux (ph cm ^-2 s ^-1)	BL Lac	FSRQ
> E-07	33.36%	74.40%
E-08<F<E-07	61.71%	24.36%
<E-08	4.93%	1.24%

BL Lacs and FSRQs - population /flux percentage distribution in 3FGL



The parameter might be the γ flux (ph cm ^-2 s ^-1)

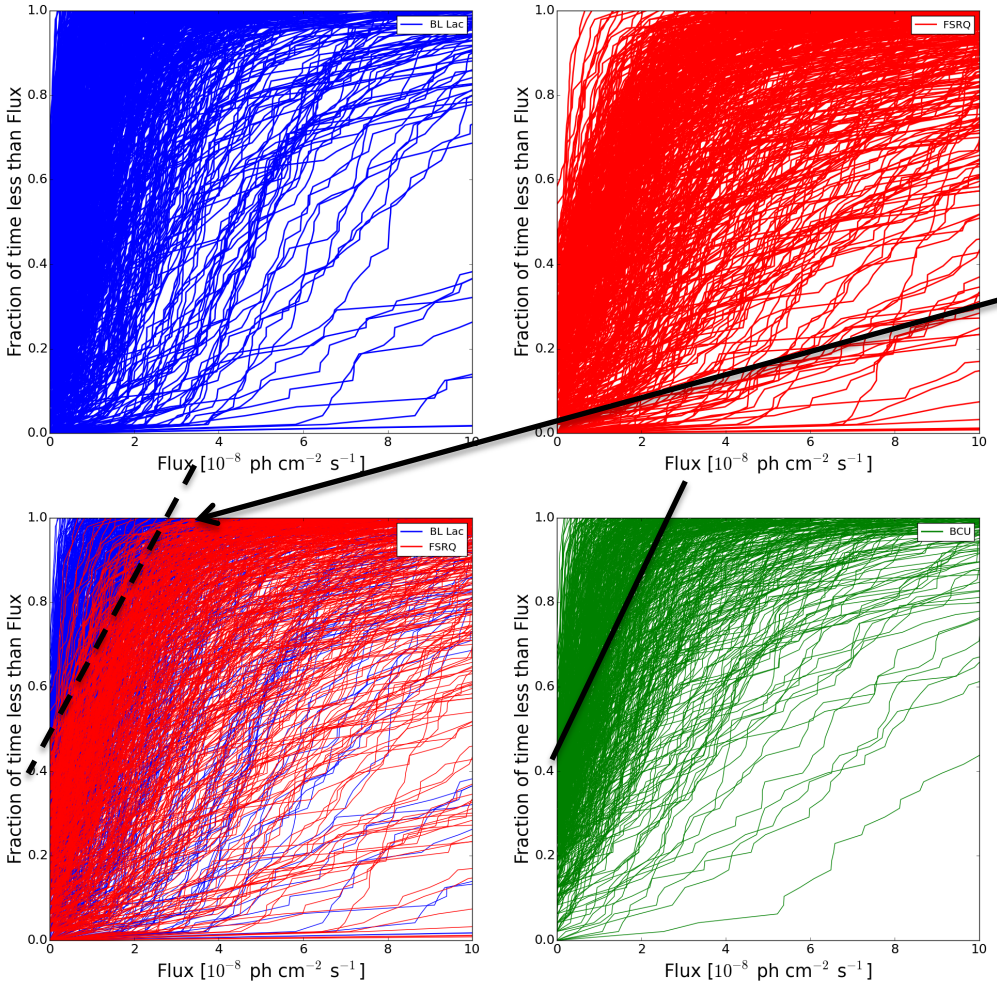
Empirical Cumulative Distribution Function (ECDF)



Because BL Lac are LESS VARIABLE than FSRQ.

BL Lac ECDFs are shifted to the left respect to FSRQ.

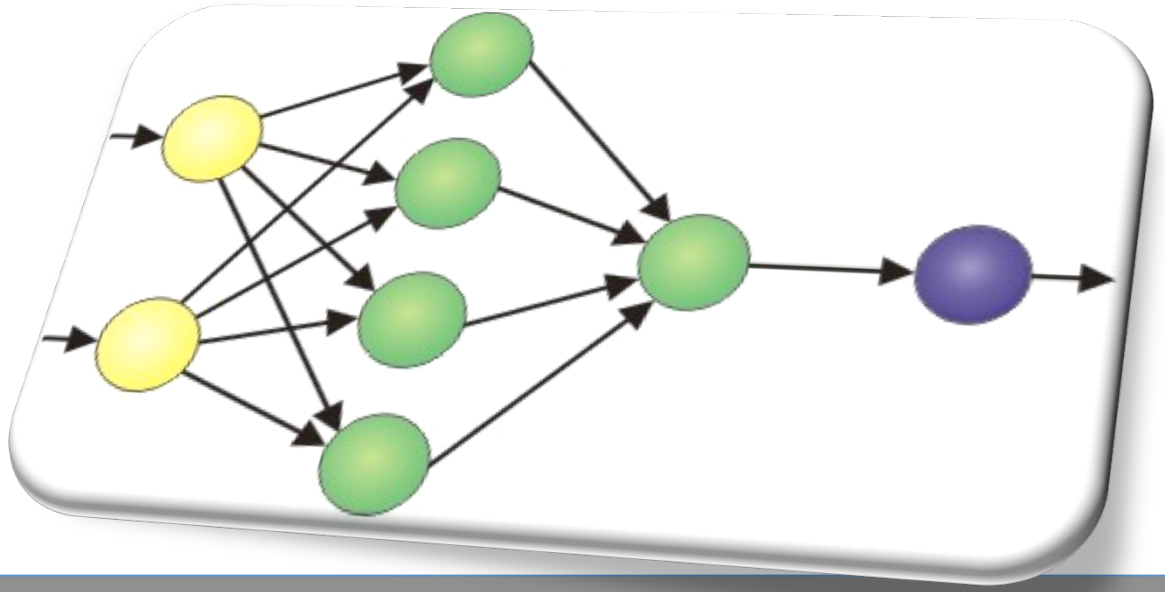
B-FlaP ECDF



It is possible to recognize a specific area where the BL Lac / FSRQ overlap is minimal.

This area, at values of the max flux less than 2.5 E-08 ph cm^-2 s^-1.

First QUALITATIVE recognition of BCUs as BL Lac objects



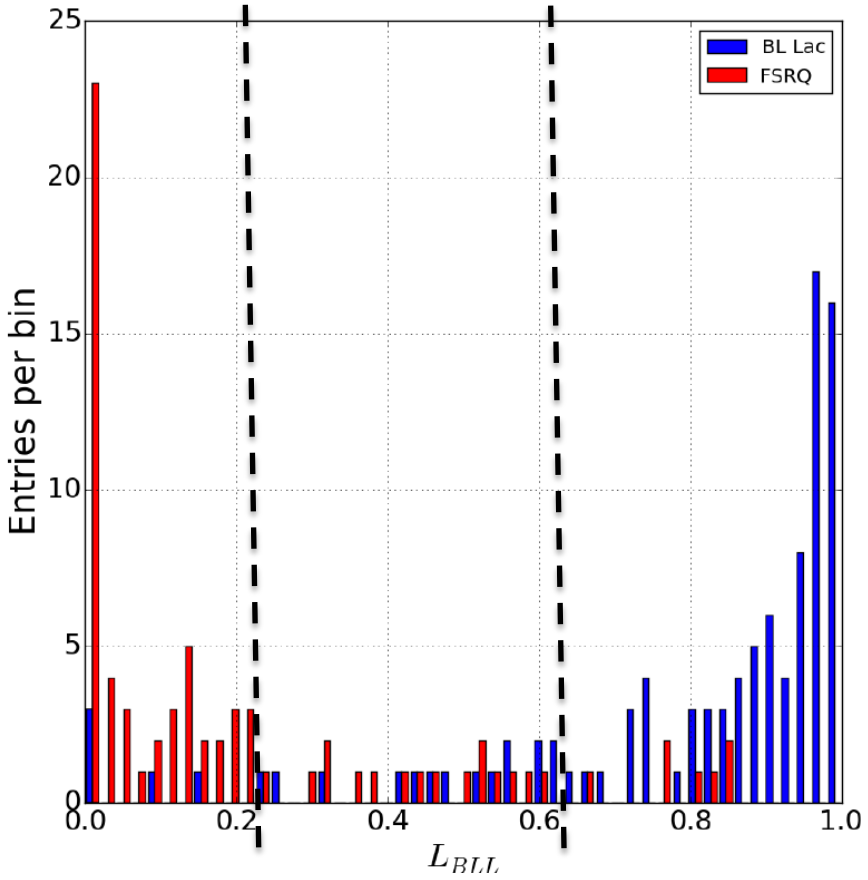
Machine Learning Artificial Neural Network

From “looking by eye” to Likelihood

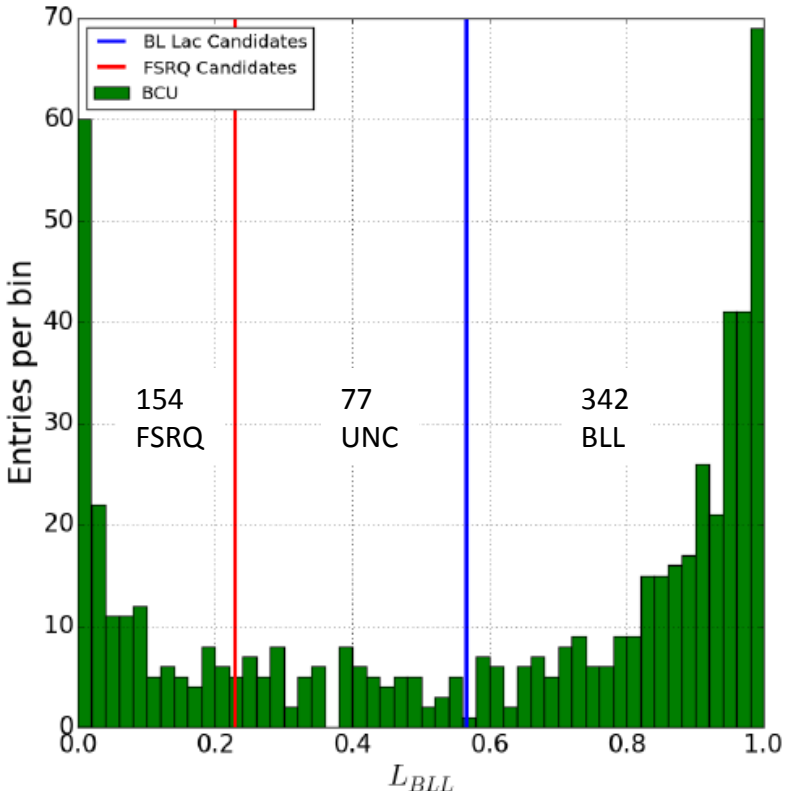
This is the two-class approach where we encoded the output of the associated blazars so that LBLL is 1 if the object is a BL Lac and LBLL is 0 if it is a FSRQ.

Precision ~ 90%

Sensitivity
~ 90% BLL
~ 70% FSRQ



First result

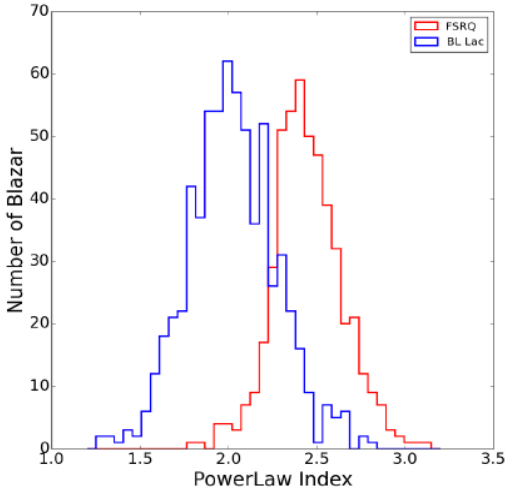


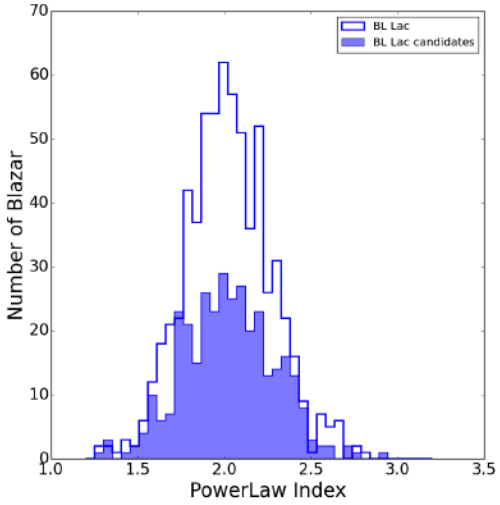
BLL_{3FGL}	$FSRQ_{3FGL}$	BCU_{3FGL}
660(38.4%)	484(28.2%)	573(33.4%)

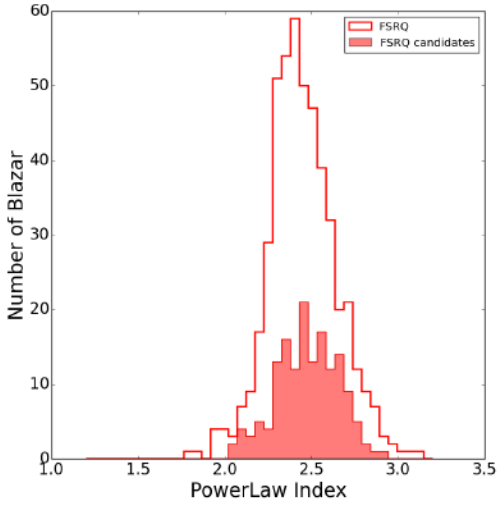
$BLL_{3FGL+ANN}$	$FSRQ_{3FGL+ANN}$	$BCU_{3FGL+ANN}$
1002(58.3%)	638(37.2%)	77(4.5%)

Validation

Spectral index of a source as a measure of the dependence of radiative flux density on wavelength



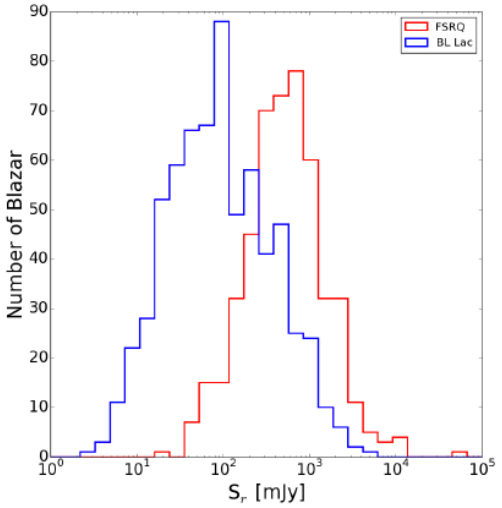


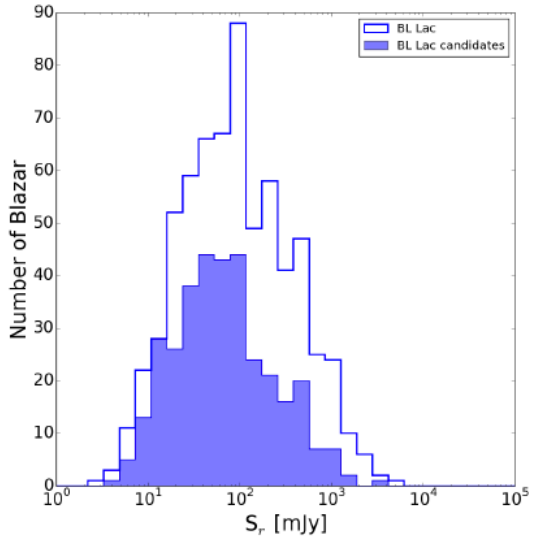


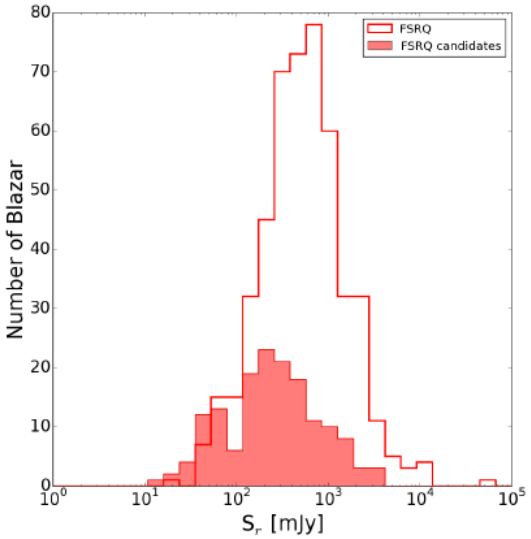
Marcello Giroletti
IRA Bologna

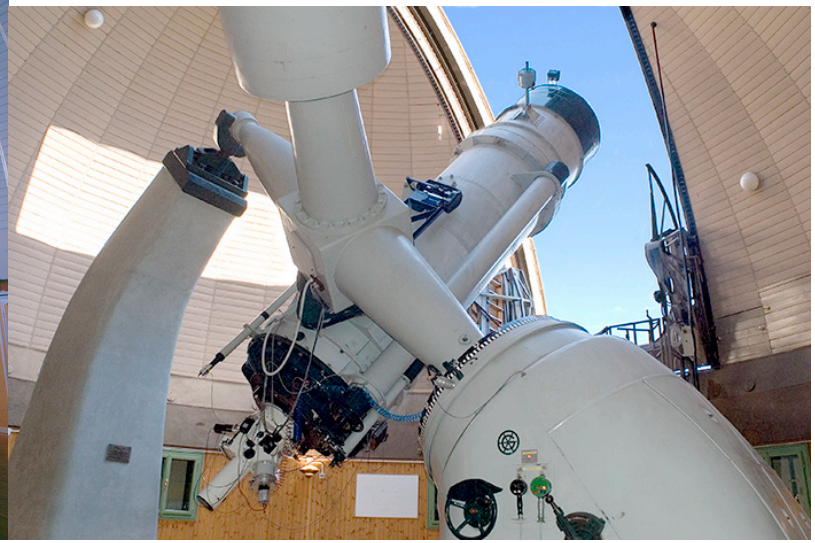
RADIO COUNTERPART

Validation


FSRQ
BL Lac
Number of Blazar
S_r [mJy]


BL Lac
BL Lac candidates
Number of Blazar
S_r [mJy]


FSRQ
FSRQ candidates
Number of Blazar
S_r [mJy]



Giovanni La Mura
OAPD UniPD

OPTICAL COUNTERPART

Validation

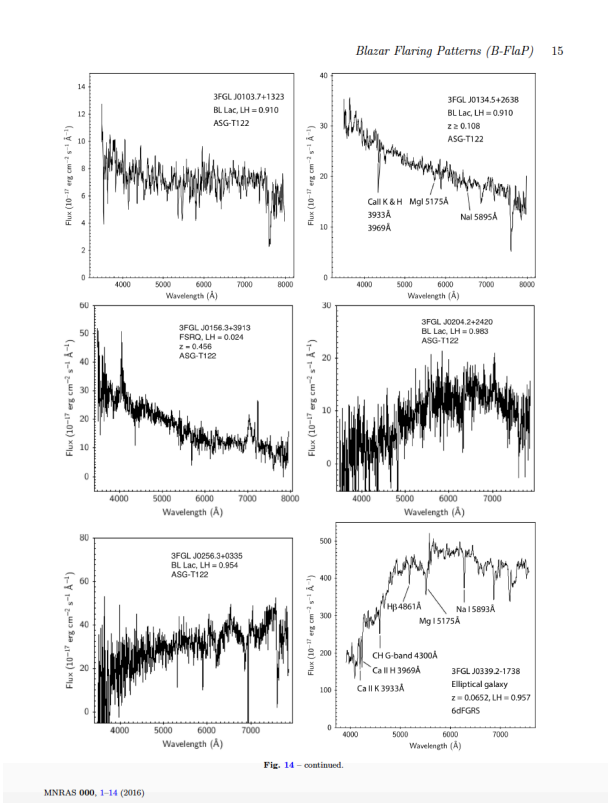


Fig. 14 – continued.

MNRAS 000, 1–14 (2016)

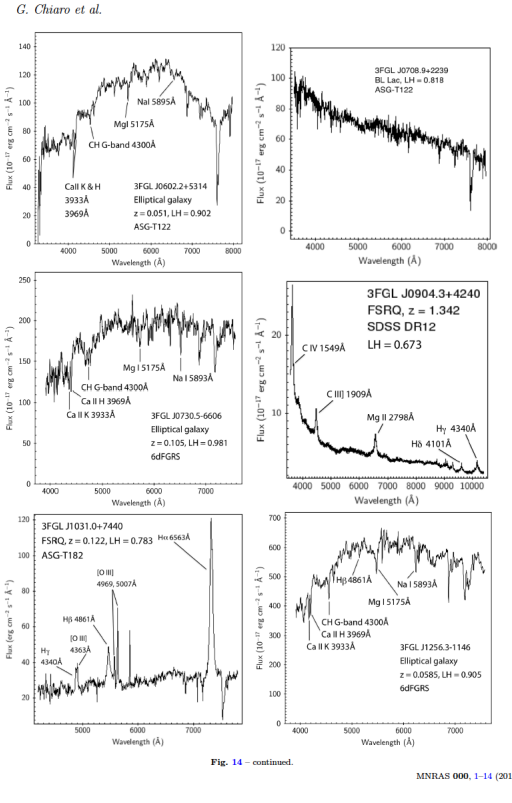


Fig. 14 – continued.

MNRAS 000, 1–14 (2016)

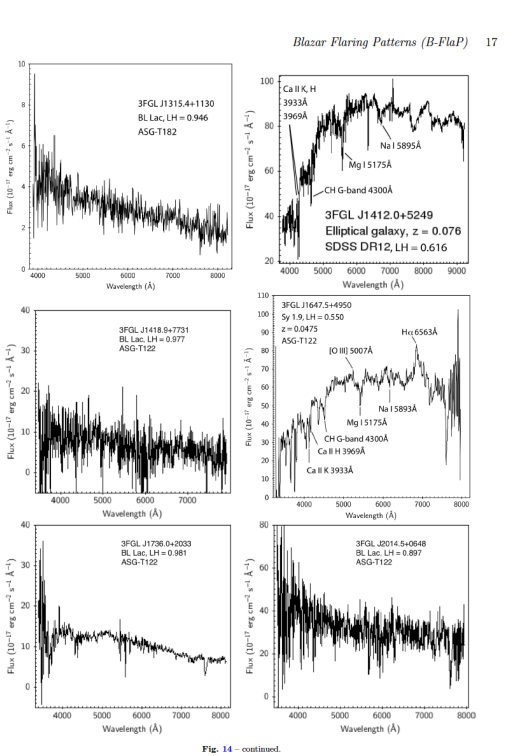
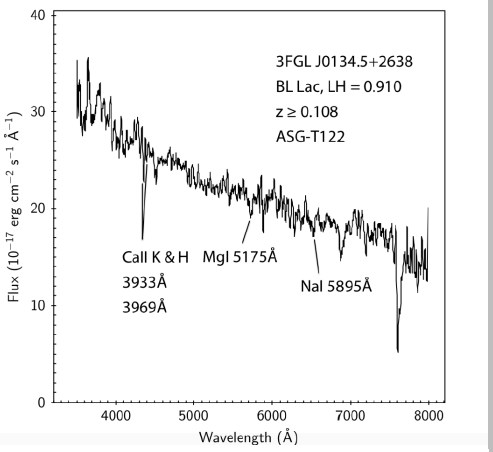


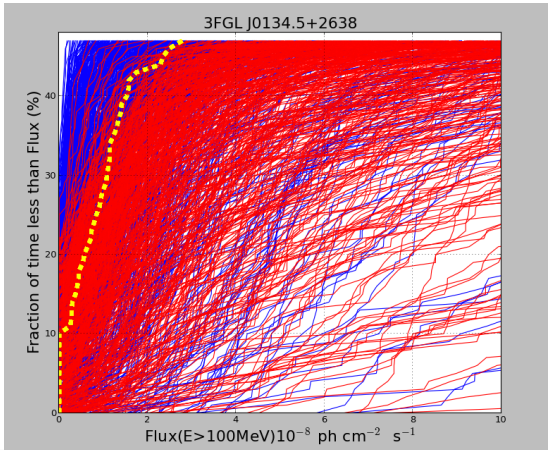
Fig. 14 – continued.

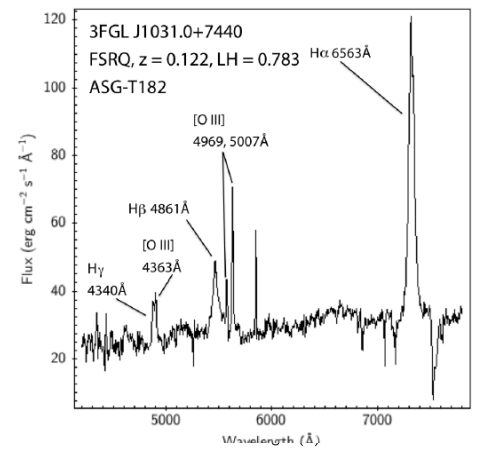
MNRAS 000, 1–14 (2016)

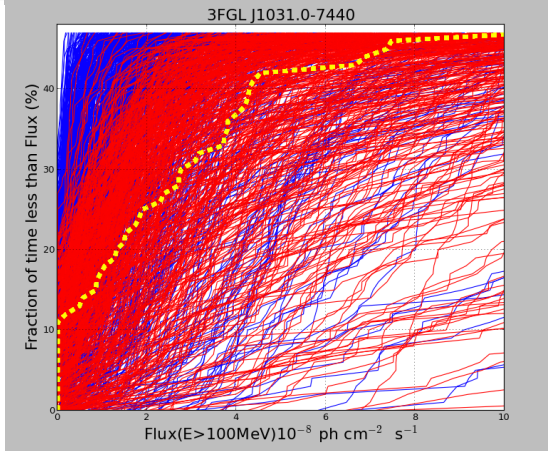
One of the most important optical campaign for 3FGL BCUs

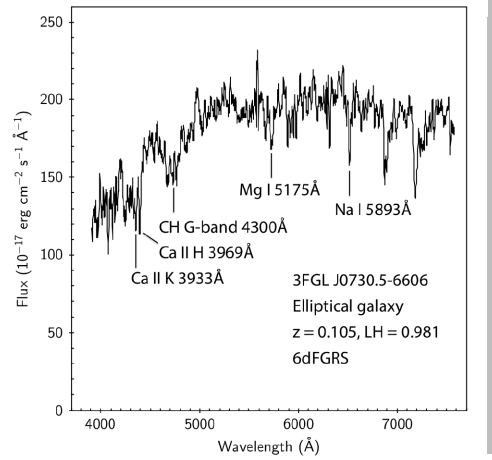
Validation

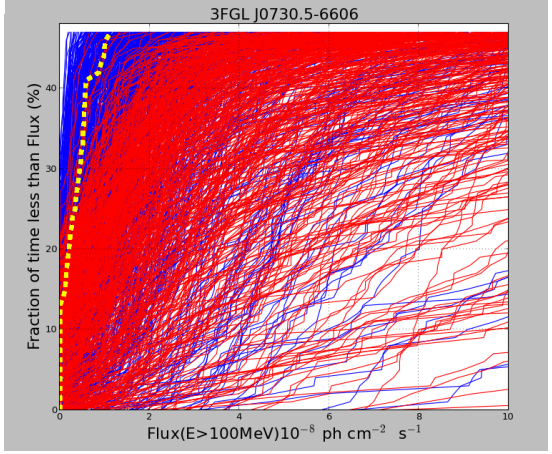

3FGL J0134.5+2638
BL Lac, LH = 0.910
z ≥ 0.108
ASG-T122
CaII K & H
3933Å
3969Å
MgI 5175Å
NaI 5895Å
Flux (10^{-17} erg cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)


3FGL J0134.5+2638
Fraction of time less than Flux (%)
Flux(E>100MeV)10^{-8} ph cm^{-2} s^{-1}


3FGL J1031.0+7440
FSRQ, z = 0.122, LH = 0.783
ASG-T182
Hα 6563Å
[O III]
4969, 5007Å
Hβ 4861Å
[O III]
4363Å
Hγ
4340Å
Flux (erg cm^{-2} s^{-1} Å^{-1})

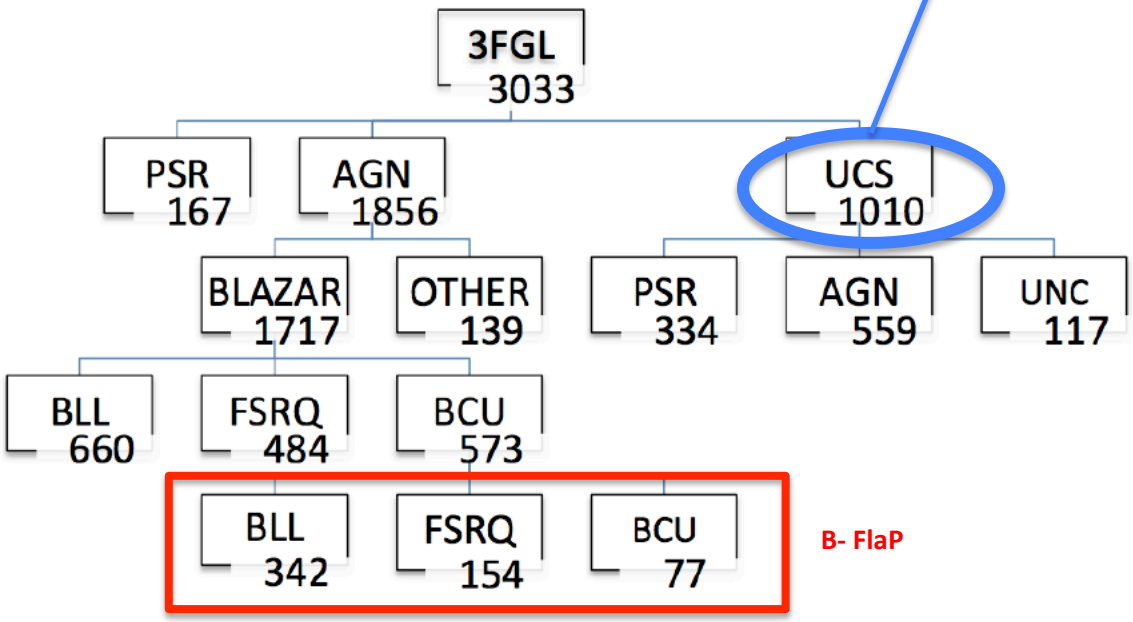

3FGL J1031.0-7440
Fraction of time less than Flux (%)
Flux(E>100MeV)10^{-8} ph cm^{-2} s^{-1}

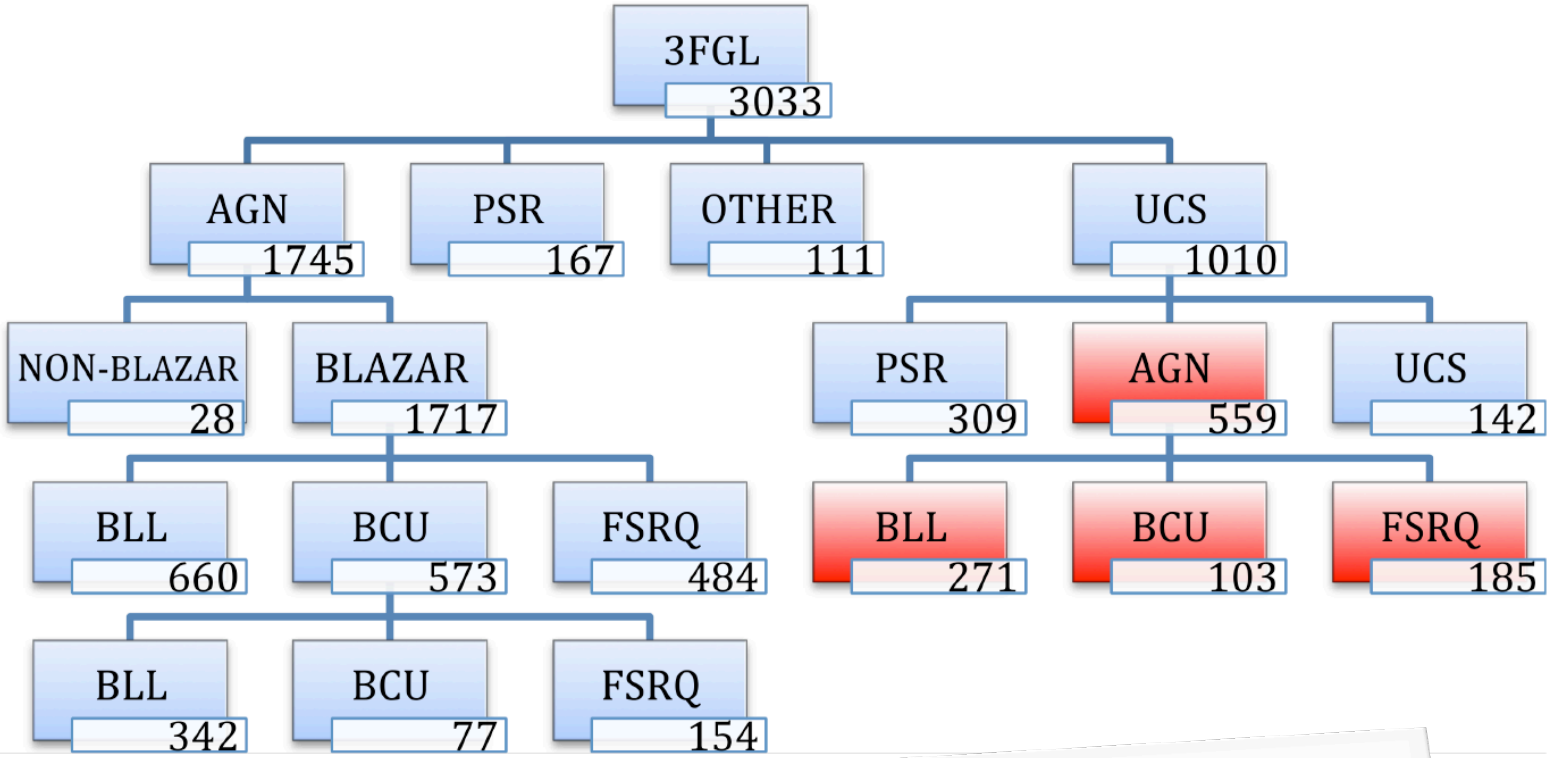

Mg I 5175Å
Na I 5893Å
CH G-band 4300Å
Ca II H 3969Å
Ca II K 3933Å
3FGL J0730.5-6606
Elliptical galaxy
z = 0.105, LH = 0.981
6dFGRS
Flux (10^{-17} erg cm^{-2} s^{-1} Å^{-1})
Wavelength (Å)

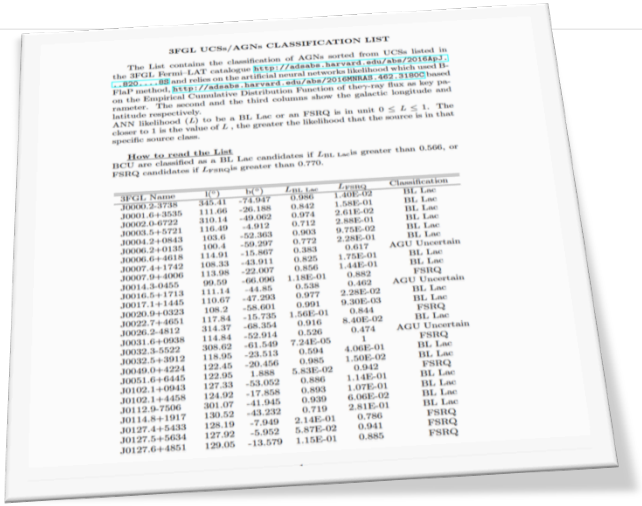

3FGL J0730.5-6606
Fraction of time less than Flux (%)
Flux(E>100MeV)10^{-8} ph cm^{-2} s^{-1}

3 FGL zoo

Parkinson Saz P. et al.,2016, ApJ, 820, 8







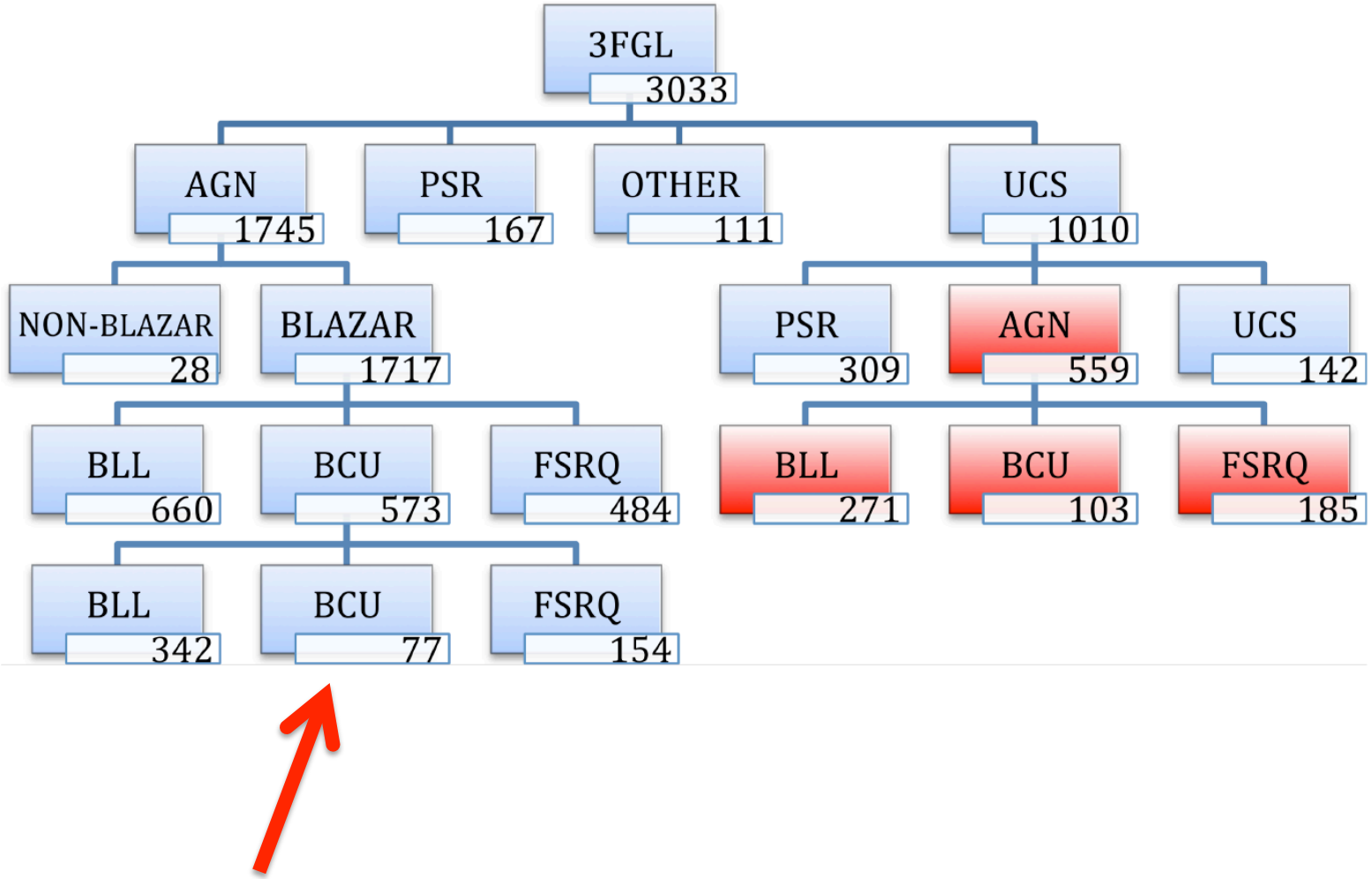
3FGL UCSs/AGNs CLASSIFICATION LIST

The List contains the classification of AGNs sorted from UCSs listed in the 3FGL Fermi-LAT catalogue http://adsabs.harvard.edu/abs/2015ApJ...810...14A and relies on the artificial neural networks likelihood which used B-FlaP method, http://adsabs.harvard.edu/abs/2016MNRAS.462.3180C based on the Empirical Cumulative Distribution Function of ther-ray flux as key parameter. The second and the third columns show the galactic longitude and latitude respectively.
ANN likelihood (L) to be a BL Lac or an FSRQ is in unit $0 \leq L \leq 1$. The closer to 1 is the value of L, the greater the likelihood that the source is in that specific source class.

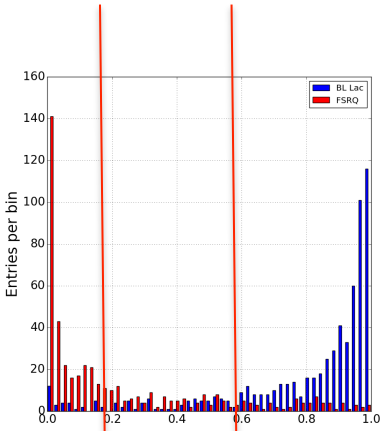
How to read the List
BCU are classified as a BL Lac candidates if $L_{\rm BL\ Lac}$is greater than 0.566, or FSRQ candidates if $L_{\rm FSRQ}$is greater than 0.770.

3FGL Name	l(°)	b(°)	$L_{\rm BL\ Lac}$	$L_{\rm FSRQ}$	Classification
J0000.2-3738	345.41	-74.947	0.906	1.40E-02	BL Lac
J0001.6+3535	111.66	-26.188	0.842	1.58E-01	BL Lac
J0002.0-6722	310.14	-49.062	0.974	2.61E-02	BL Lac
J0003.5+5721	116.49	-4.912	0.712	2.88E-01	BL Lac
J0004.2+0843	103.6	-52.363	0.903	9.75E-02	BL Lac
J0006.2+0135	100.4	-59.297	0.772	2.28E-01	AGU Uncertain
J0006.6+4618	114.91	-15.867	0.383	0.617	BL Lac
J0007.4+1742	108.33	-43.911	0.825	1.75E-01	BL Lac
J0007.9+4006	113.98	-22.007	0.856	1.44E-01	FSRQ
J0014.3-0455	99.59	-66.096	1.18E-01	0.882	AGU Uncertain
J0016.5+1713	111.14	-44.85	0.538	0.462	BL Lac
J0017.1+1445	110.67	-47.293	0.977	2.28E-02	BL Lac
J0020.9+0323	108.2	-58.601	0.991	9.30E-03	FSRQ
J0022.7+4651	117.84	-15.735	1.56E-01	0.844	BL Lac
J0026.2-4812	314.37	-68.354	0.916	8.40E-02	AGU Uncertain
J0031.6+0938	114.84	-52.914	0.526	0.474	FSRQ
J0032.3-5522	308.62	-61.549	7.24E-05	1	BL Lac
J0032.5+3912	118.95	-23.513	0.594	4.06E-01	BL Lac
J0049.0+4224	122.45	-20.456	0.985	1.50E-02	FSRQ
J0051.6+6445	122.95	1.888	5.83E-02	0.942	BL Lac
J0102.1+0943	127.33	-53.052	0.886	1.14E-01	BL Lac
J0102.1+4458	124.92	-17.858	0.893	1.07E-01	BL Lac
J0112.9-7506	301.07	-41.945	0.939	6.06E-02	BL Lac
J0114.8+1917	130.52	-43.232	0.719	2.81E-01	FSRQ
J0127.4+5433	128.19	-7.949	2.14E-01	0.786	FSRQ
J0127.5+5634	127.92	-5.952	5.87E-02	0.941	FSRQ
J0127.6+4851	129.05	-13.579	1.15E-01	0.885	FSRQ

	3FGL	B-FLAP
BL LAC	660	1272
FSRQ	484	823
PULSAR	167	520
OTHERS	139	139
BLAZAR UNCERTAIN	573	77
UNASSOCIATED	1010	117
BL LAC	58% of blazars	61%
FSRQ	42%	39%
BLAZAR UNCERTAIN		-87%
UNASSOCIATED		-88%

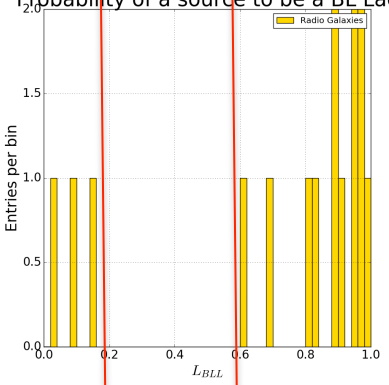


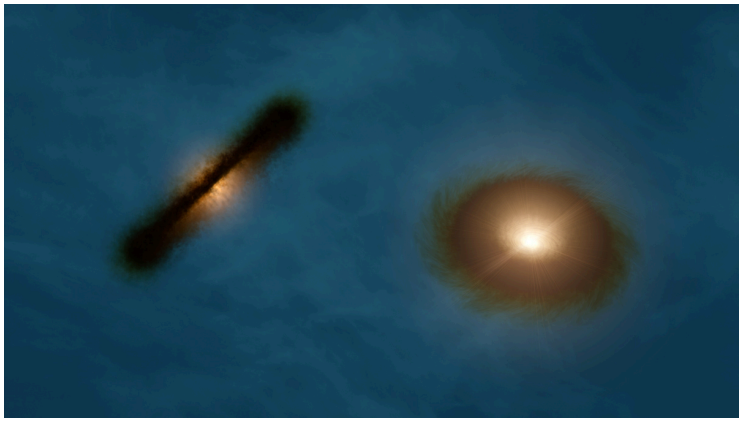
What's beyond blazars ?



Probability of a source to be a BL Lac

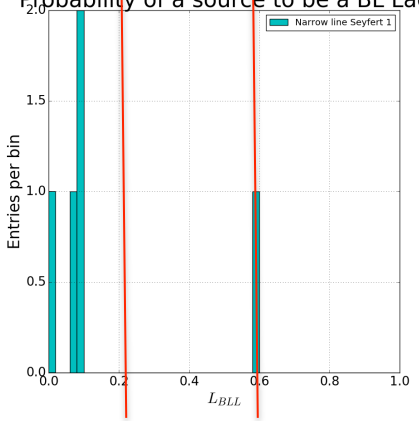
MAGN



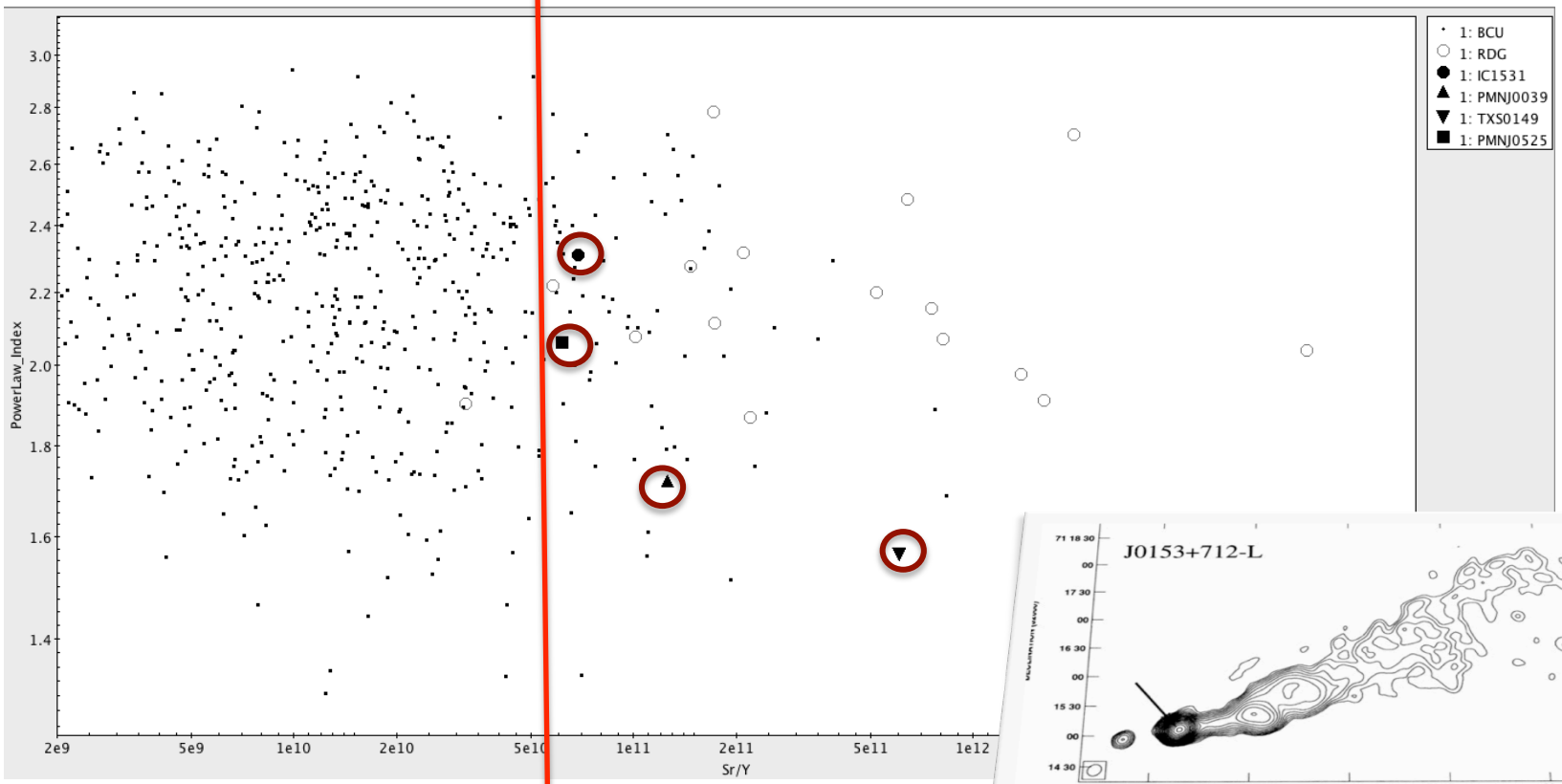


Probability of a source to be a BL Lac

NLS1



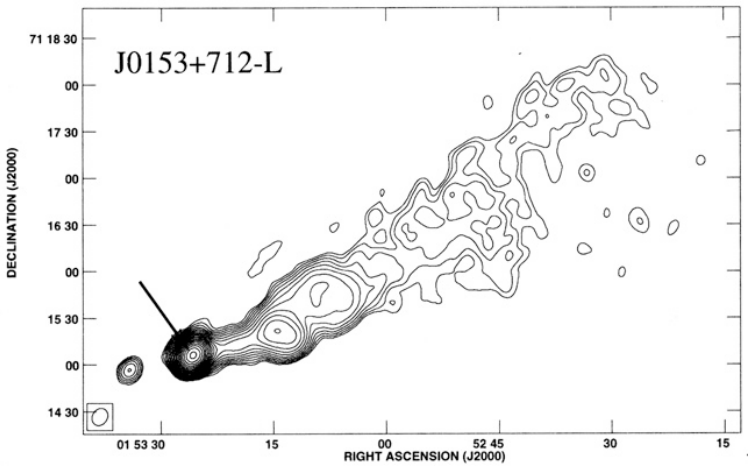
0.566 < L < 0.850
1.7 < PI < 2.7
Avg sign > 4.0

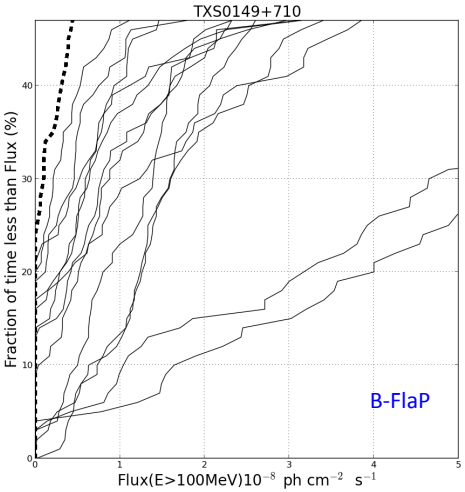


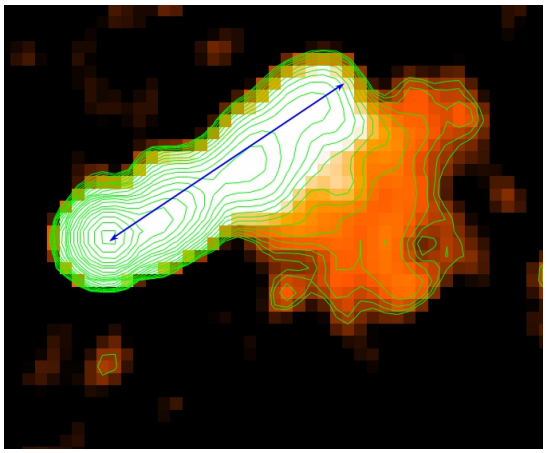
PI

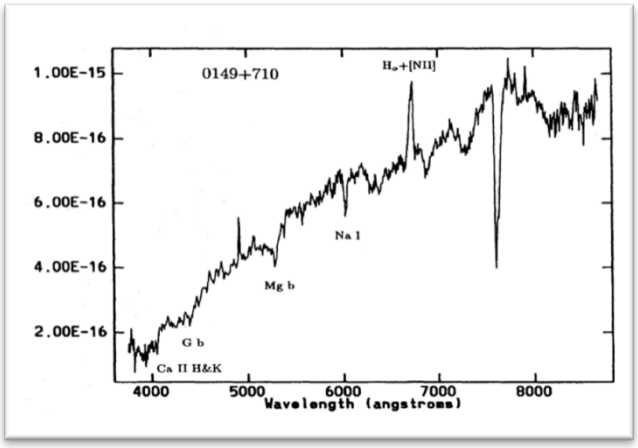
Sr/Y

3FGL J0153.4+7114 - TXS 0149+710

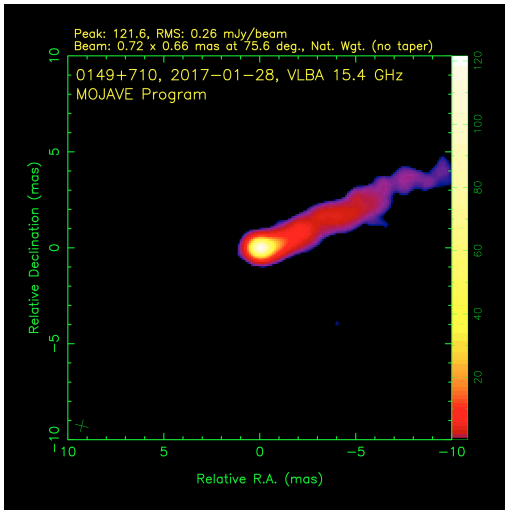


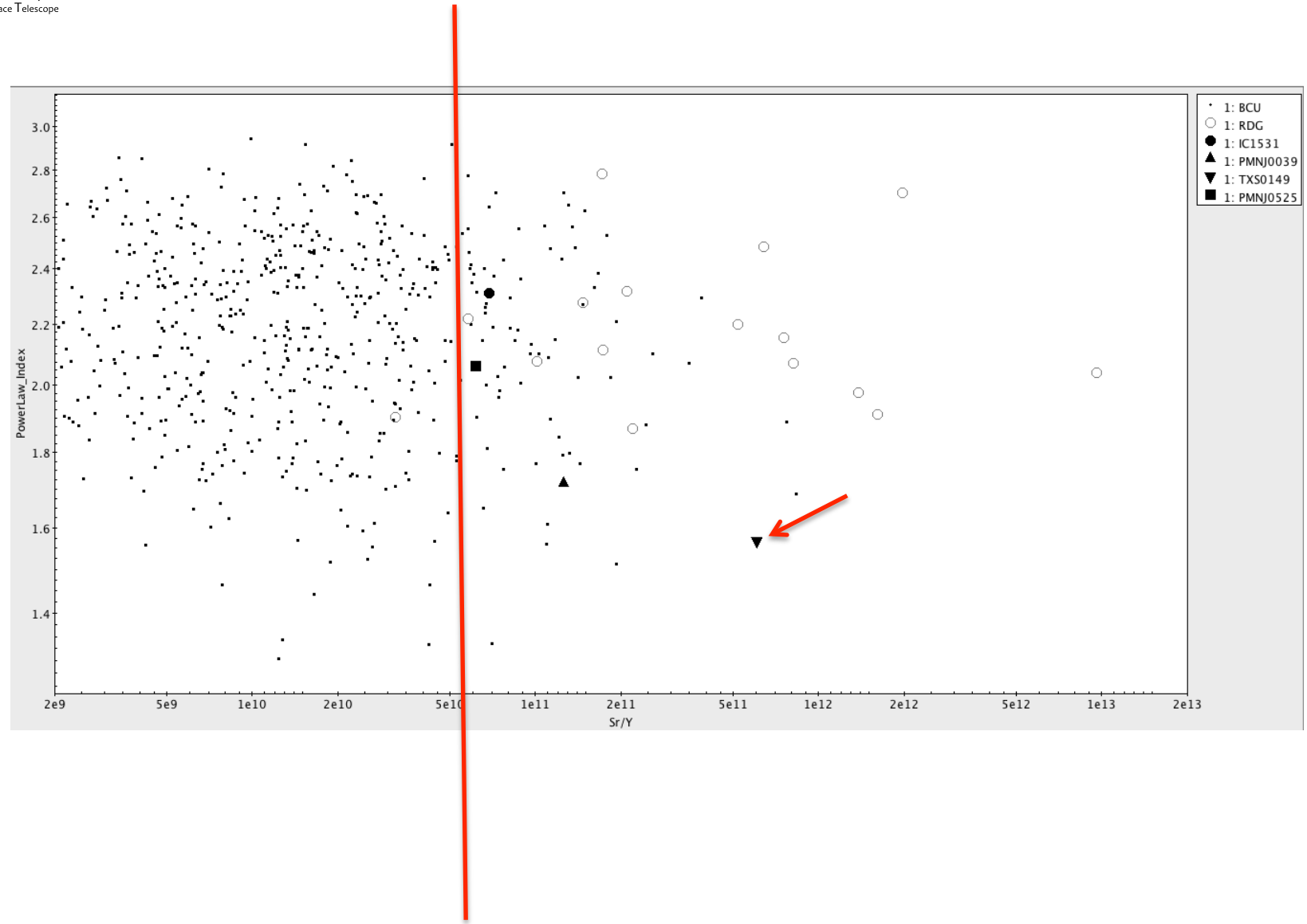




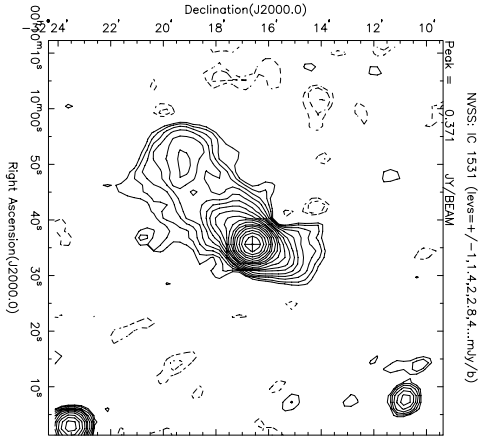


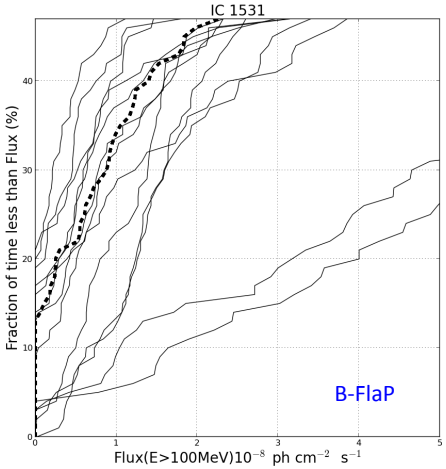
Elliptical galaxy
RA 28.357712 Dec
71.251795 z = 0.022
R= 593.4 Kpc
1.4 GHz = 578.2 milliJy
3FGL significance = 7.056

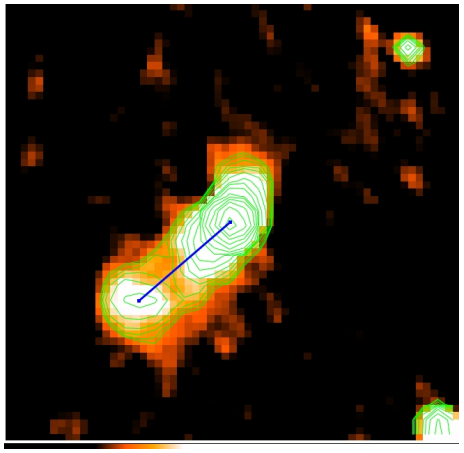


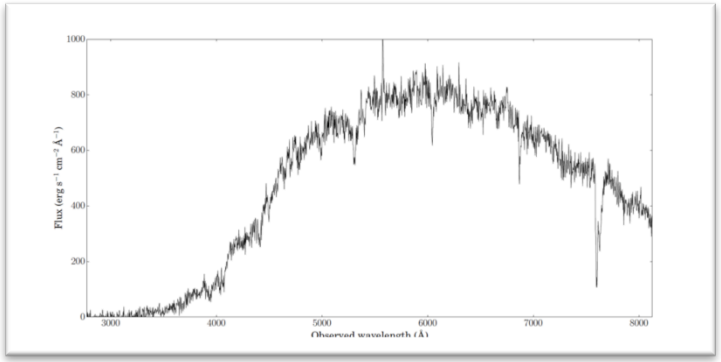

1: BCU
1: RDG
1: IC1531
1: PMNJ0039
1: TXS0149
1: PMNJ0525
PowerLaw_Index
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
2e9
5e9
1e10
2e10
5e10
1e11
2e11
5e11
1e12
2e12
5e12
1e13
2e13
Sr/Y

3FGL J0009.6-3211 - IC 1531



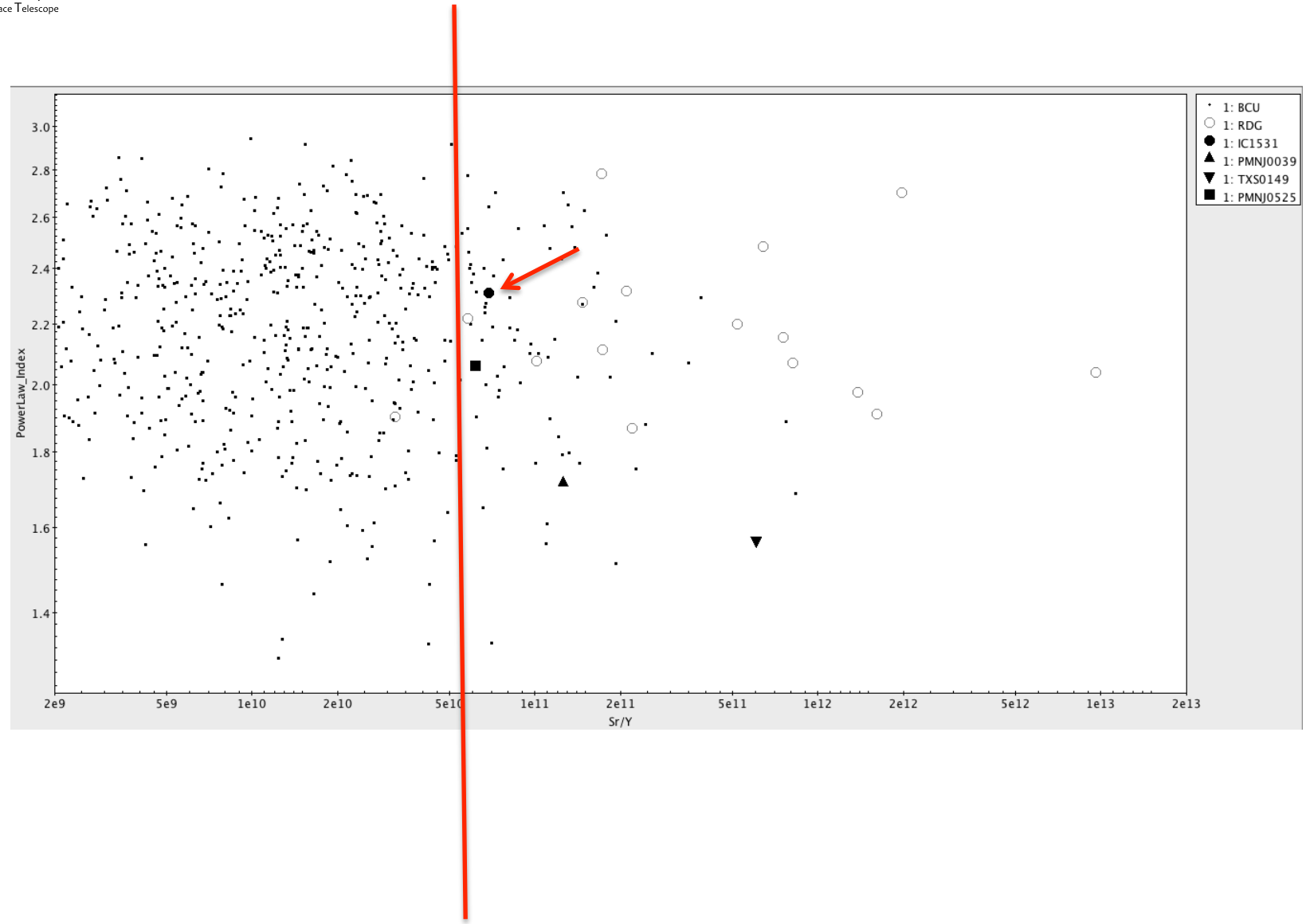




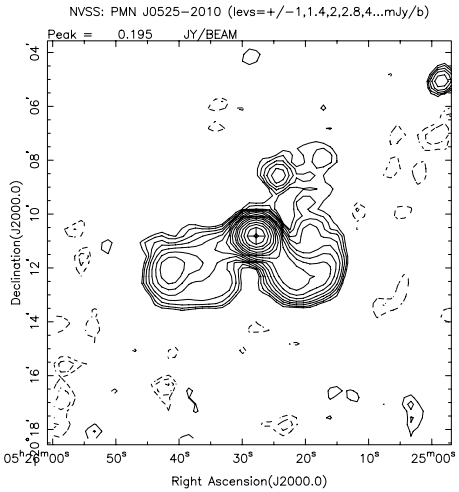


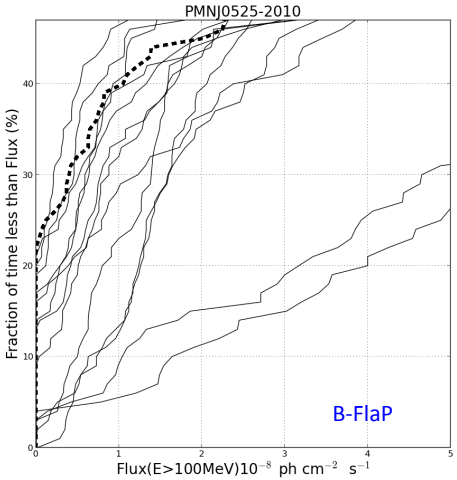
Elliptical galaxy
RA 2.398017 Dec -32.276817
z = 0.025641
R = 416.24 Kpc
1.4 GHz = 388.7 milliJy
3FGL significance = 5.536

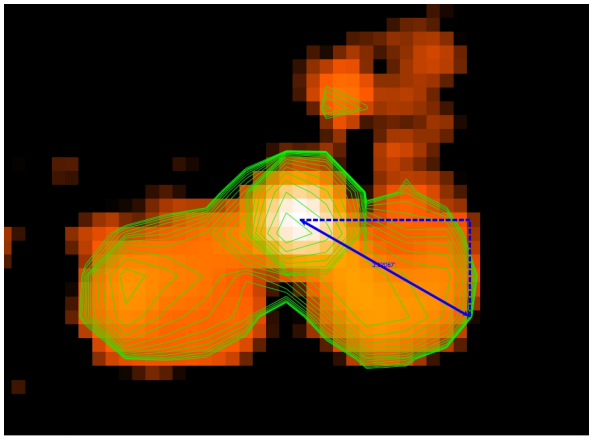
Bassi T. Dept Physic & Astron. Univ Bologna I -Master Thesis

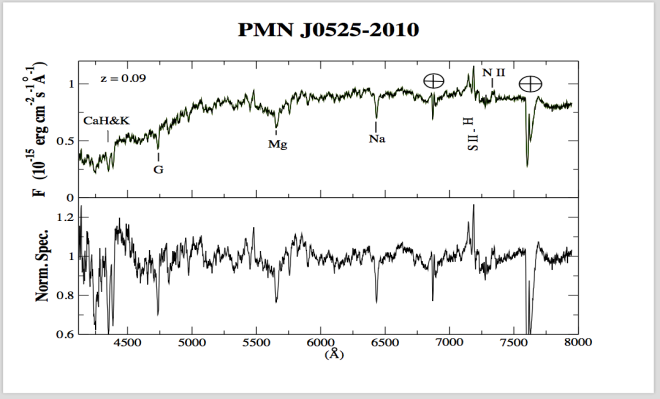

1: BCU
1: RDG
1: IC1531
1: PMNJ0039
1: TXS0149
1: PMNJ0525
PowerLaw_Index
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
2e9
5e9
1e10
2e10
5e10
1e11
2e11
5e11
1e12
2e12
5e12
1e13
2e13
Sr/Y

3FGL J0525.8-2014 - PMN J0525-2010



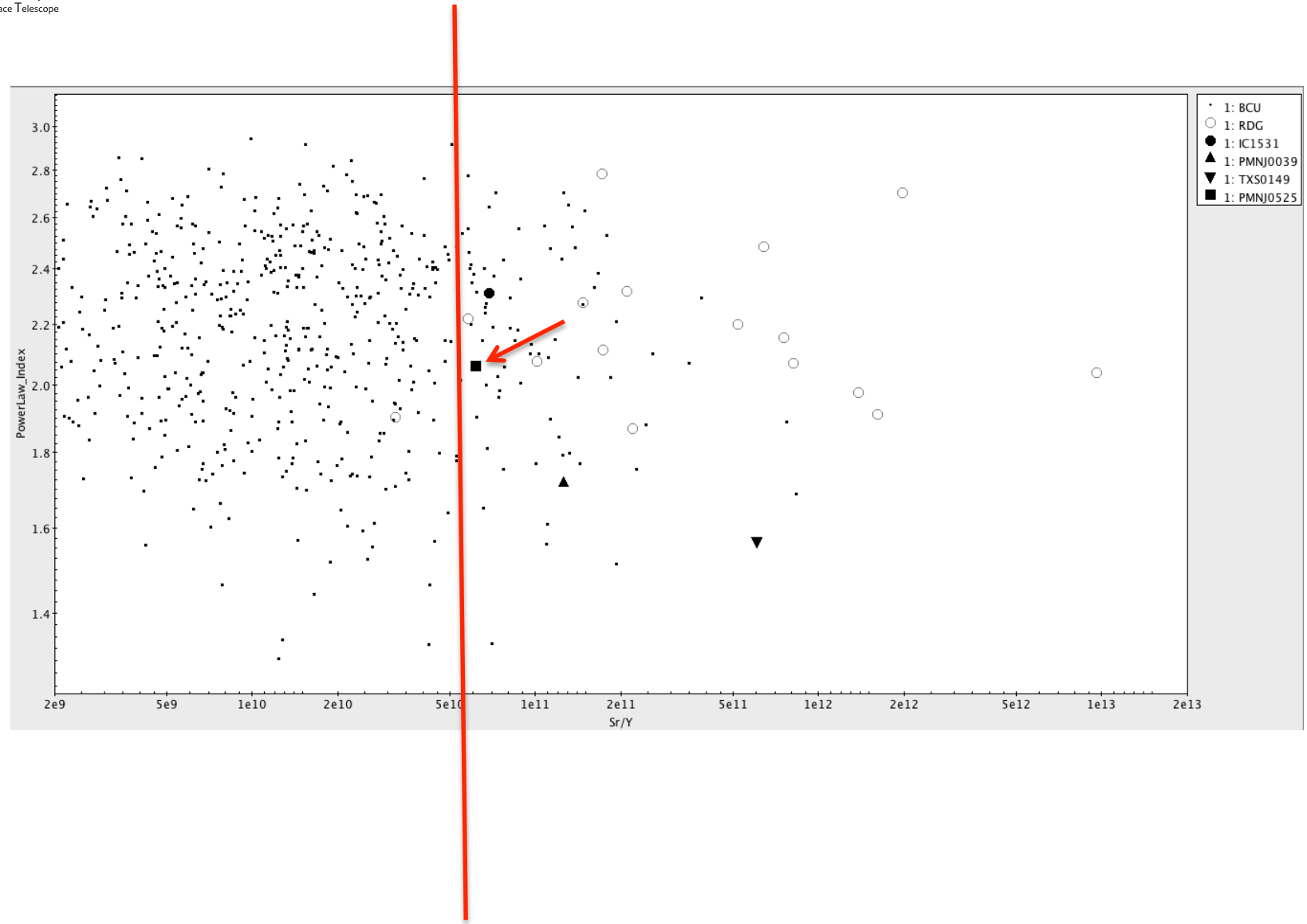




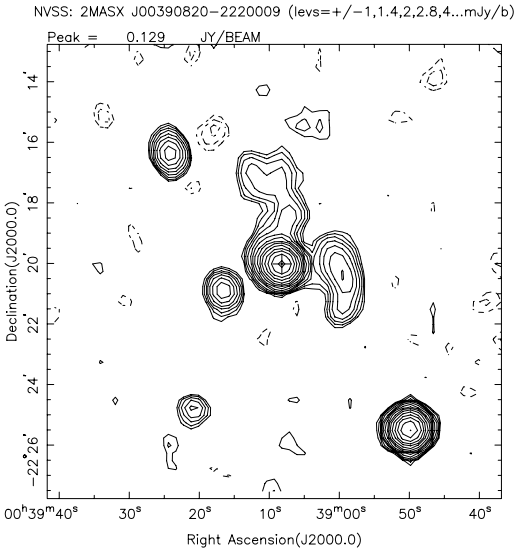


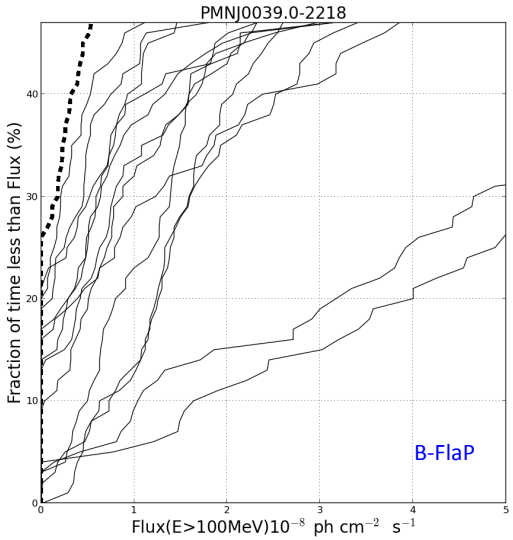
Nuria Alavarez Crespo, Univ Torino

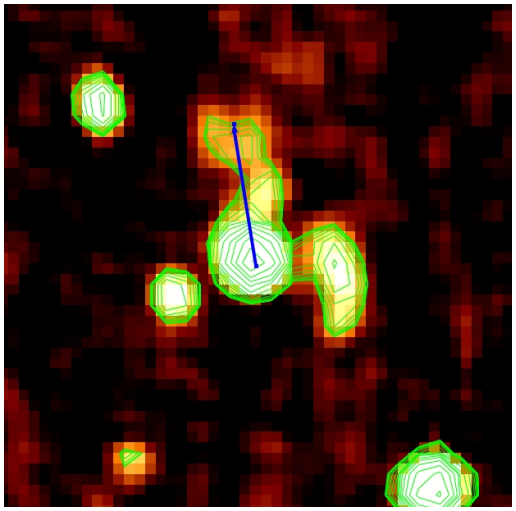
Elliptical galaxy
RA 81.366333 Dec -20.181750
z = 0.092
R = 435.16 Kpc
1.4 GHz = 230.4 milliJy
3FGL significance = 5.271

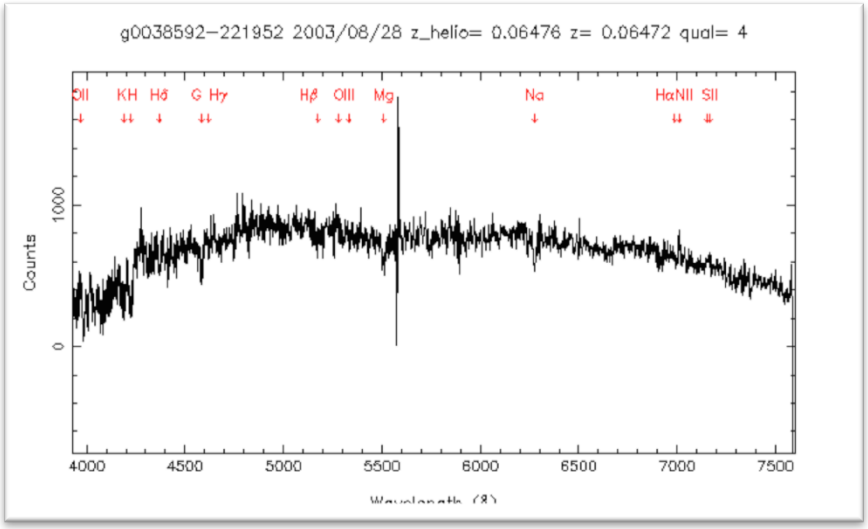

1: BCU
1: RDG
1: IC1531
1: PMNJ0039
1: TXS0149
1: PMNJ0525
PowerLaw_Index
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
2e9
5e9
1e10
2e10
5e10
1e11
2e11
5e11
1e12
2e12
5e12
1e13
2e13
Sr/Y

3FGL J0039.0-2218 - PMN J0039 -2218



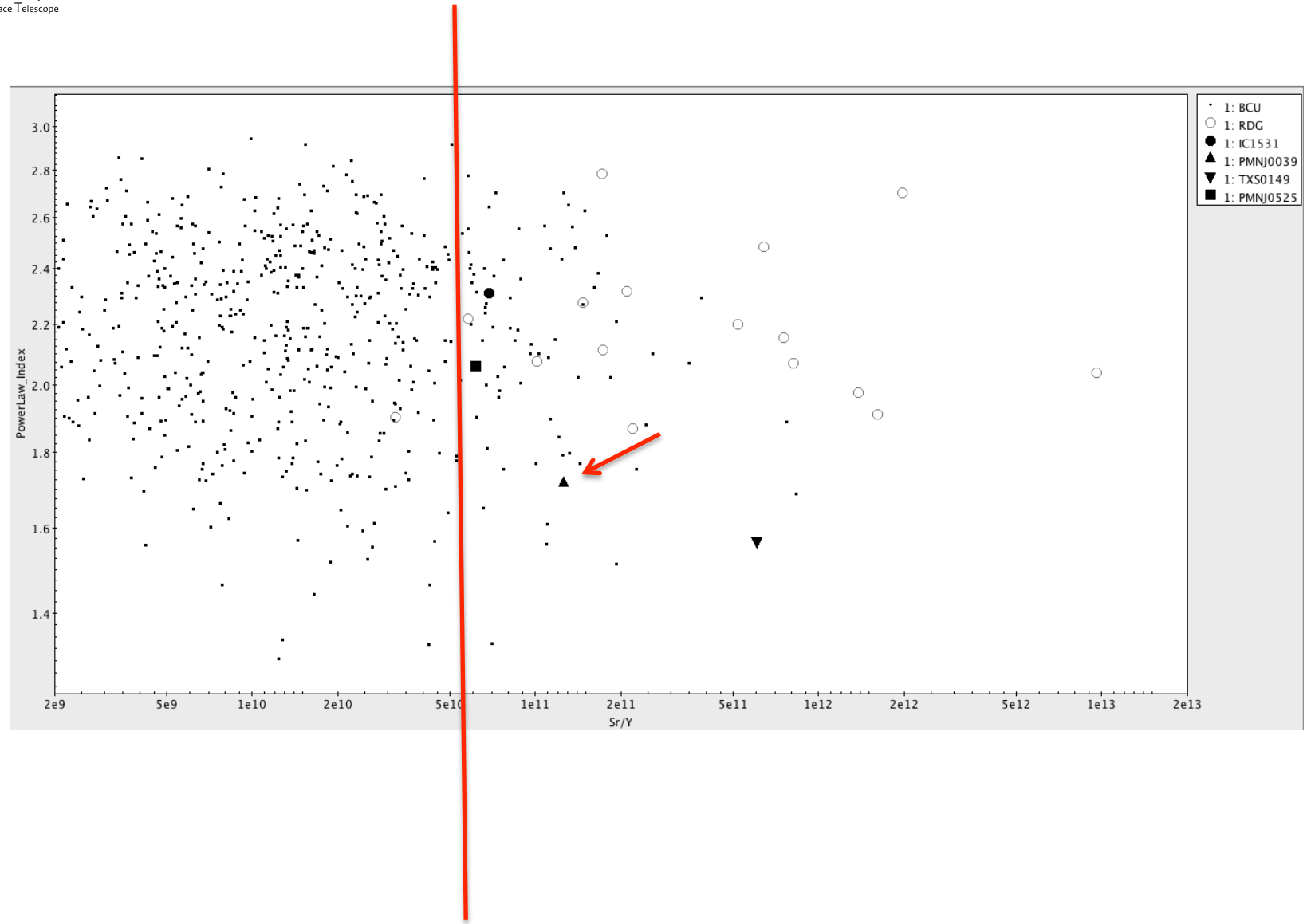


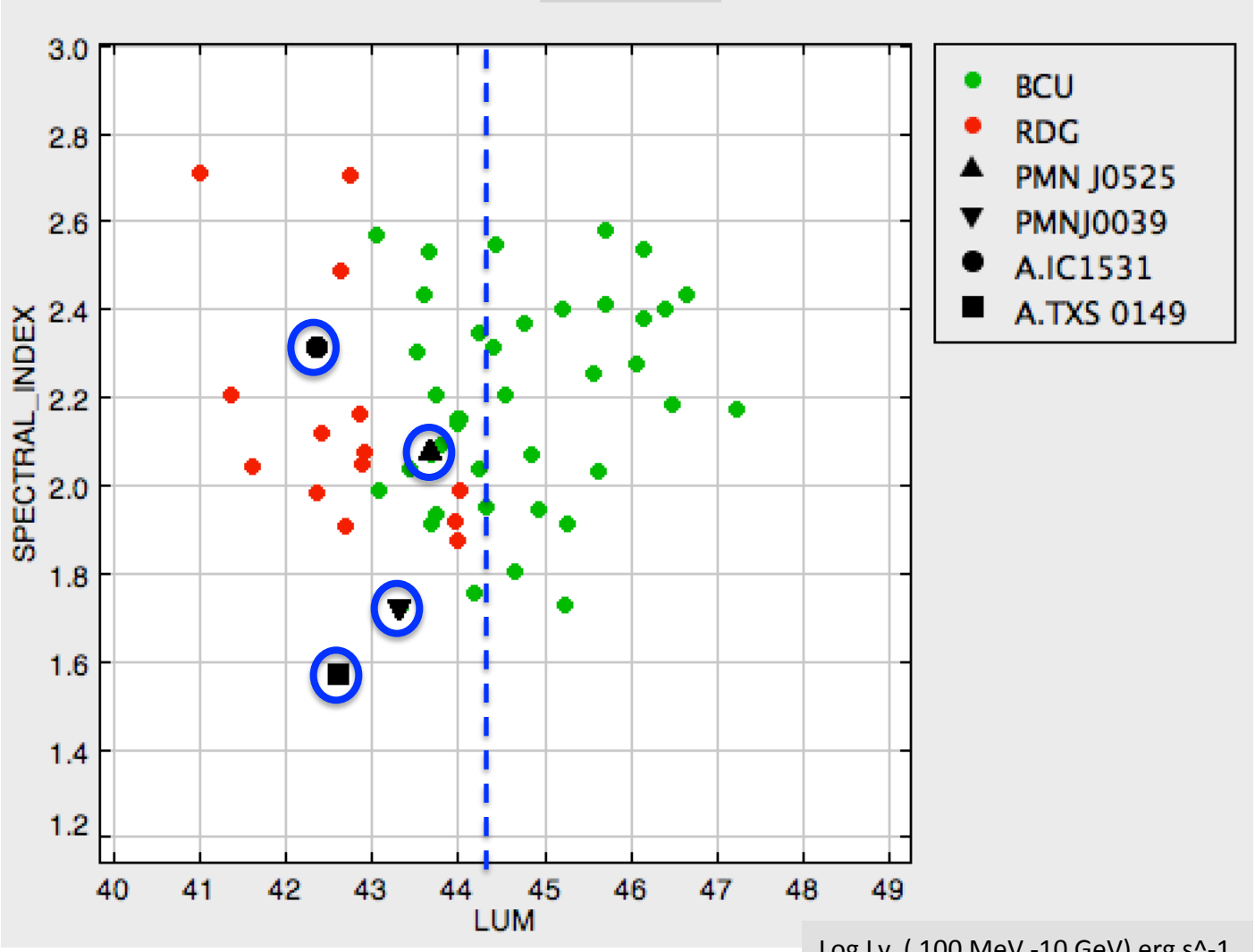




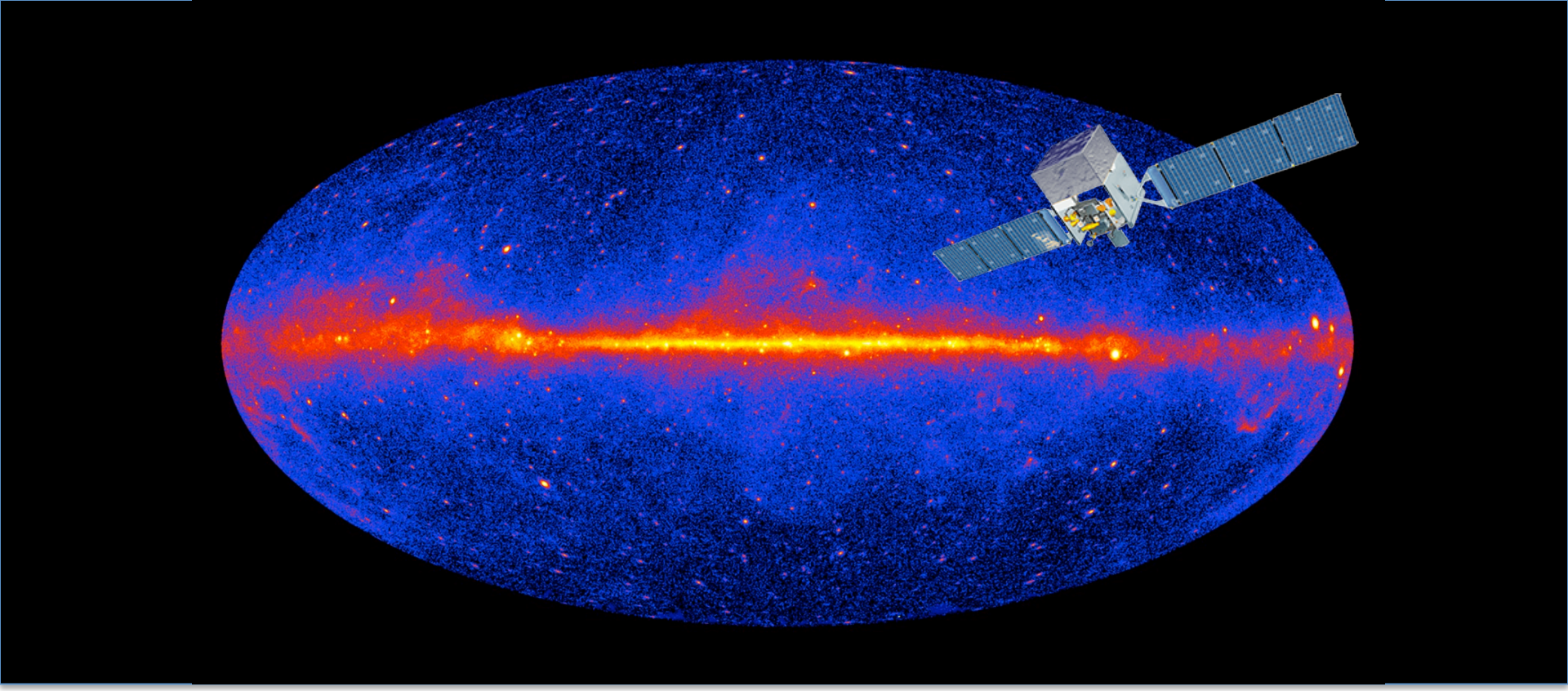
Elliptical galaxy
RA 9.784208 Dec -22.333722
z = 0.064380
R= 350 Kpc
1.4 GHz = 117.0 milliJy
3FGL significance = 5.411

6dFGRS – DR3


1: BCU
1: RDG
1: IC1531
1: PMNJ0039
1: TXS0149
1: PMNJ0525
PowerLaw_Index
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
2e9
5e9
1e10
2e10
5e10
1e11
2e11
5e11
1e12
2e12
5e12
1e13
2e13
Sr/Y

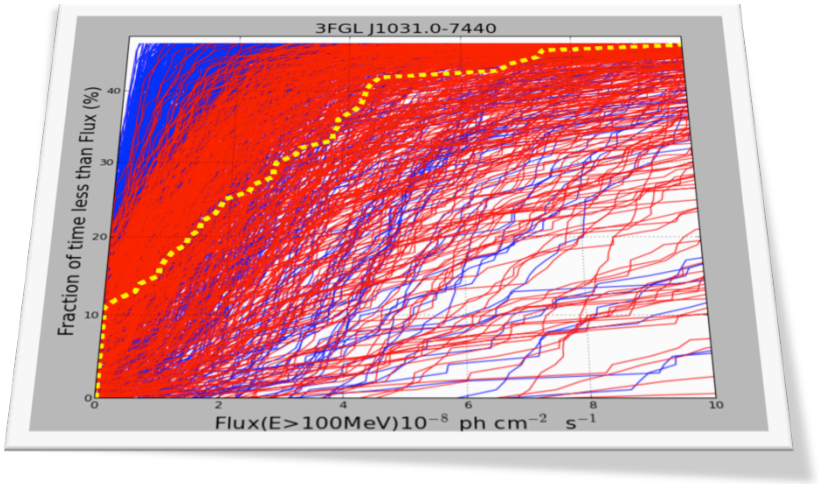


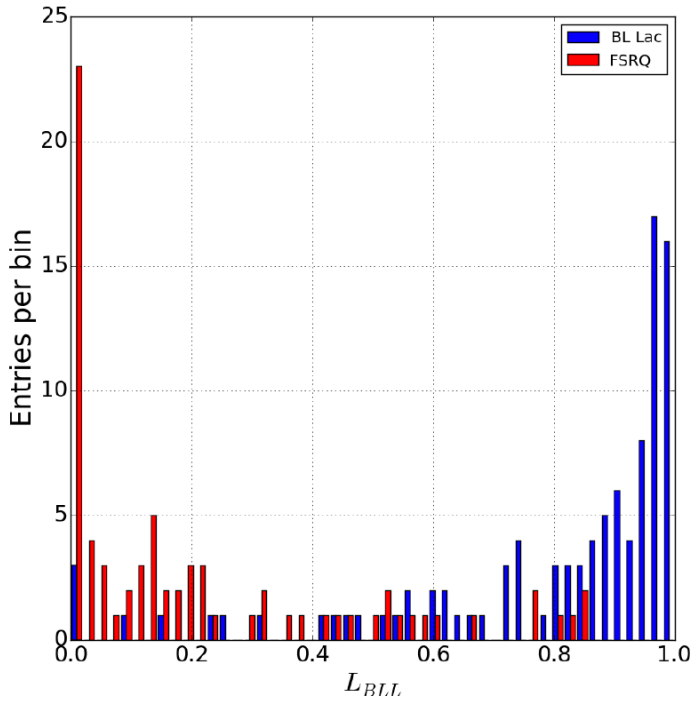
Abdo (2010) ApJ 720,912
Grandi P. (2015) MNRAS , 457, 2-8



BLAZAR FLARING PATTERNS (B-FLAP)

LESSON LEARNED





Although γ-ray flux by B-FlaP method cannot replace confirmed and rigorous techniques for blazar classication, it may be configured as

an additional powerful approach for the preliminary and reliable identication of uncertain γ- ray objects mainly blazars.

when detailed observational data are not yet available.

Blazar Flaring Patterns (B-FlaP)
Classifying Blazar Candidate of Uncertain type in the Third Fermi-LAT catalog .

G.Chiaro et al. (2016) MNRAS, Vol.462, Issue 3, p.3180-3195

Thanks for listening.

Graziano