EVN observations of weak blazars

F. Mantovani [1,2], M. Bondi [2], K.-H. Mack [2],

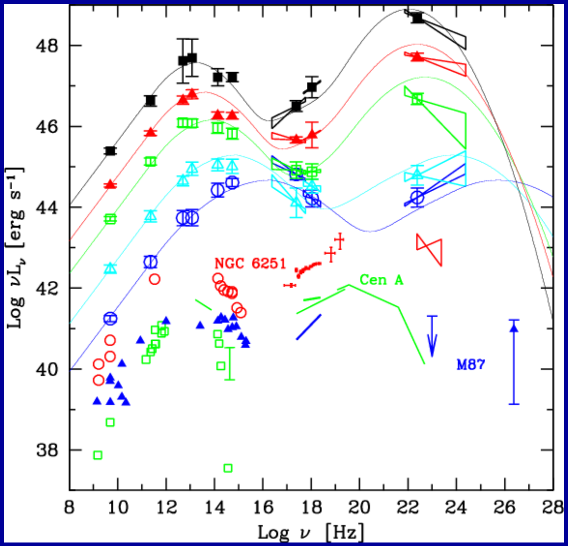
W. Alef [1], E. Ros [1], J.A. Zensus [1]

[1] Max-Planck-Institut für Radioastronomie, Bonn, Germany
[2] Istituto di Radioastronomia - INAF, Bologna, Italy

Blazars:	an extreme class of Active Galactic Nuclei
	FSRQs (high luminosity radio galaxies)
	BLLacs (low luminosity radio galaxies)
Characteristics:	high luminosity rapid variability high optical polarisation
Emission:	a broad continuum of non-thermal origin, extending from the radio wavelengths through gamma rays
Radio band:	flat radio spectra ($\alpha < 0.5$) core-dominated objects apparent superluminal speeds
Gamma band:	vast majority of sources in the *Fermi* 2FGL catalogue
Interpretation:	based on bright and luminous sources discovered in radio or X-ray surveys

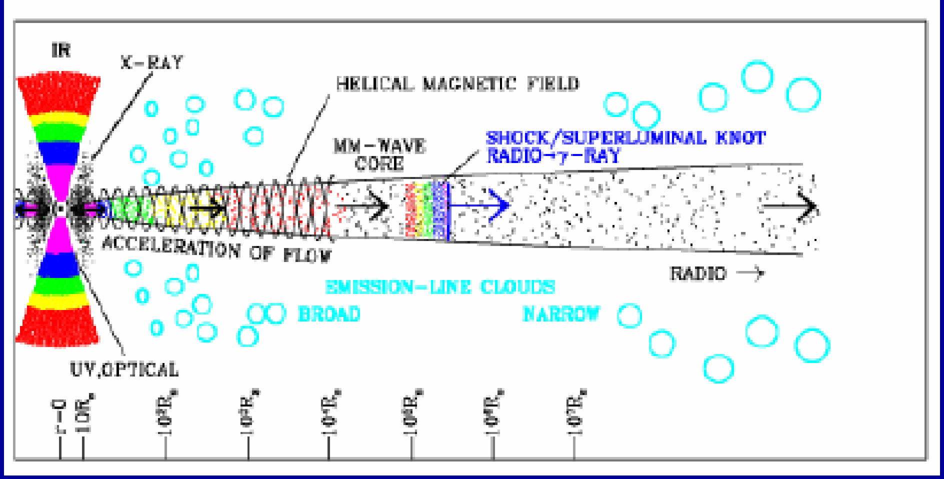
Any connection between radio and γ-ray emission ?

Radio emission:
synchrotron radiation
from relativistic electrons



γ-ray emission:
low energy photons plus
relativistic beaming →
up-scattering of the photons
(Inverse Compton)

Origin of gamma-ray
emission ?



Fermi - Large Area Telescope

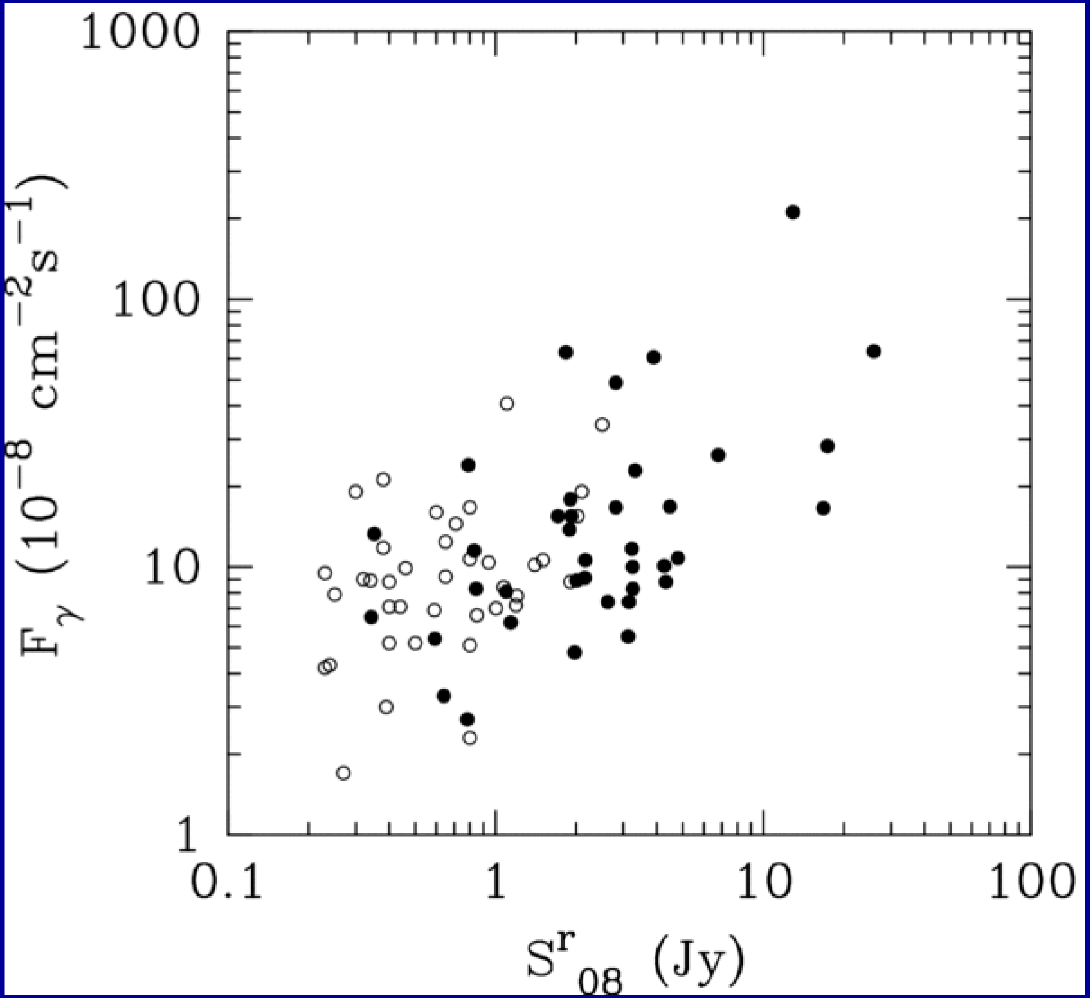
Single-Dish Monitoring Programmes

programme	freq. (GHz)	sampling	size	
OVRO	15	2-3 weeks	> 1000	
Effelsberg	2.6 – 43	monthly	≈ 60	*F-GAMMA*
IRAM	86 – 270	monthly	≈ 60	*F-GAMMA*
APEX	345	monthly	≈ 60	*F-GAMMA*
UMRAO	4.8, 8, 14.5	15 days	35	
Metsähovi	37	monthly	≈ 100	
RATAN-600	1 – 22	2-4 weeks	600	

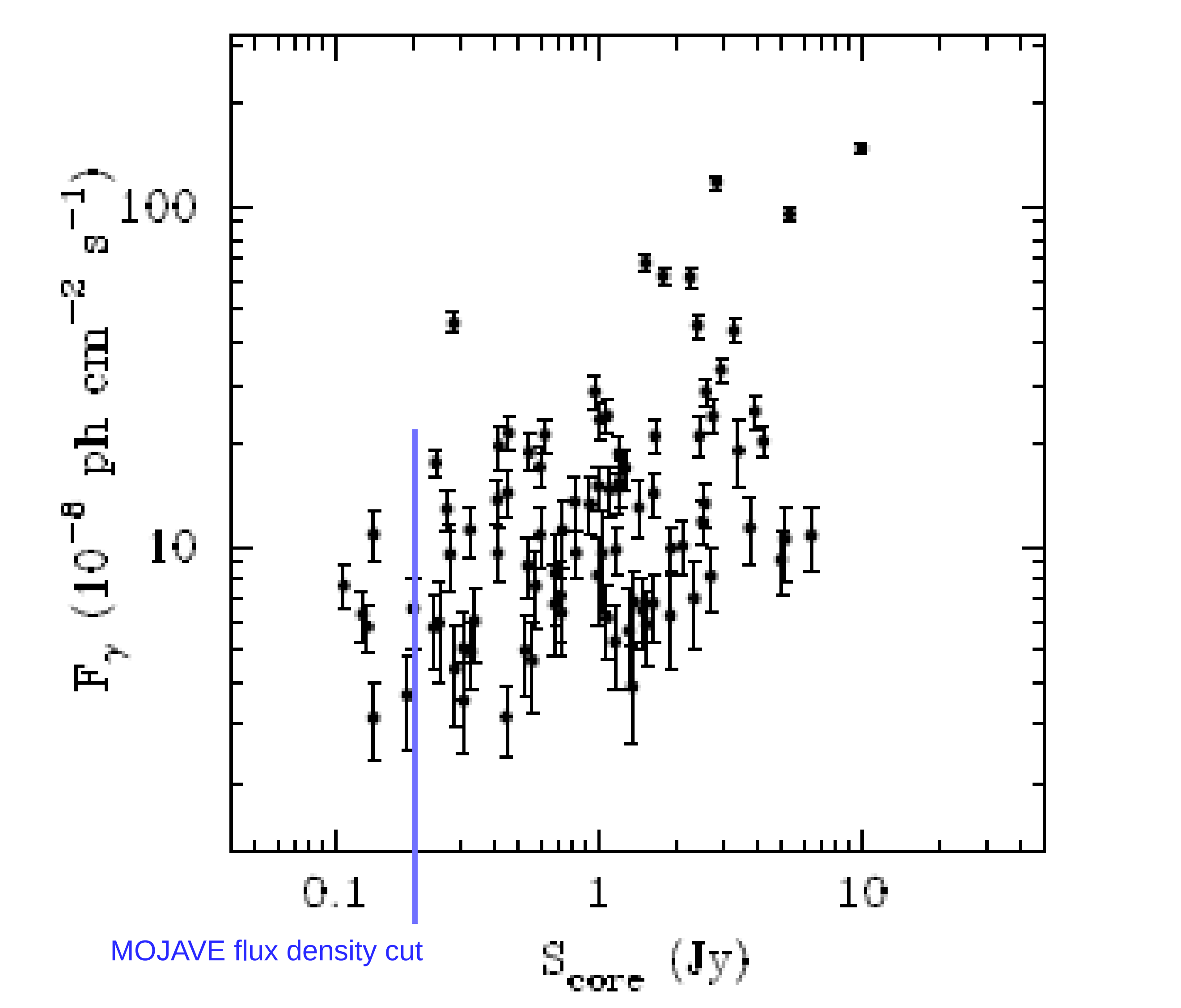
VLBI monitoring programmes

VLBA Monitoring at 43 GHz of EGRET blazars (Jorstad et al. 2001)
MOJAVE VLBA observations at 2 cm of 300 sources (Lister et al. 2009)
VISP VLBA Imaging and Polarimetry Survey at 5 GHz and 15 GHz survey of ~1100 AGN
TANAMI Tracking AGN with AU-SA array, 80 sources at 8.4GHz and 22GHz

Direct relation between
the γ-ray and parsec-scale synchrotron radiation



Average *Fermi* LAT 100 MeV-1 GeV photon flux (Abdo et al. 2009) vs. quasi-simultaneous 15 GHz flux density.
Filled circles: total VLBI flux density. Open circles single-dish flux density.
(Kovalev et al. 2009 ApJ 696,L17)



(Pushkarev et al. 2010 ApJ 722, L7)

Integrated 0.1–100 GeV *Fermi* photon flux vs. 15 GHz VLBA core flux density

(for data pairs in which the VLBA flux density measurement was taken 2.5 ± 0.2 months after the LAT flux measurements)

Deep X-ray Radio Blazars Survey

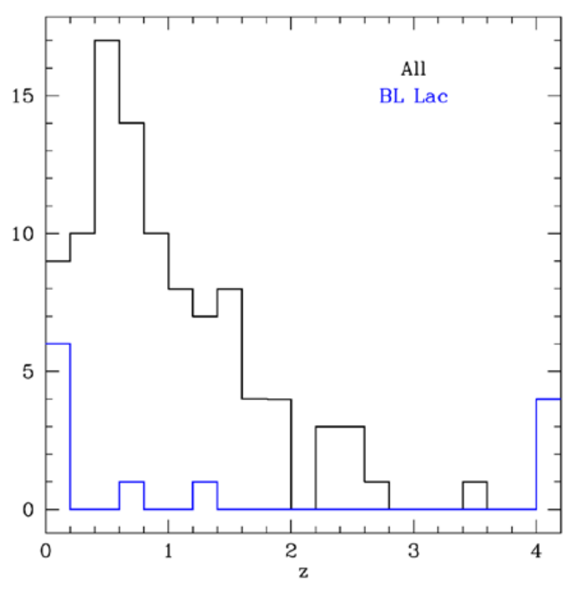
(Perlman et al. 1998; Landt et al. 2001)

Cross-correlation ROSAT sources — WGCAT – White, Giommi, Angelini 1995

and radio sources with flat radio spectra ($\alpha < 0.7$)

GB6 – Gregory et al. 1996
NORTH20CM – White and Becker 1992
PNM – Griffith and Wright, 1993

- flux density down to ~ 50 mJy at 5 GHz
- power down to ~ 10^{24} W Hz^{-1}
- nearly complete optical identification
- includes both FSRQs and BL Lac sources
  234 quasars, 181 FSRQs, 53 SSRQs
  36 BL Lacs
  28 NLRG



redshift distribution: < z > ≈ 1

“Weak blazars sample”

87 sources selected from the “Deep X-ray Radio Blazars Survey”

Selection criteria: Dec > – 10 deg

Investigation:

> Effelsberg multi-frequency observations

> European VLBI Network 5 GHz observations

Source coordinates derived from NVSS and FIRST images

Main aims

- verify the spectral index classification
- make the first mas resolution observations
- do the observations while *Fermi* is making its survey
- make a comparison with samples of bright blazars

  (MOJAVE, TANAMI, etc …)

Effelsberg observations

- 66 sources *bona fide* blazars
- 6 objects show an inverted spectra
- 27 sources show a steep spectum
- 9 sources show a GPS type spectral index
- 43 % show variability on a time scale of 20 years
- 36 sources are polarised at 5 GHz
- 7 of them have $|RM| > 200$ rad m^{-2}

Mantovani et al. 2011 A&A 533, 79

EVN observations

Frequency	5 GHz
Stations	12
Recording	512 Mbits, 2 bit sampling (~ 2.5 TBytes/station)
Strategy	5 scans, 6 minutes long each per source

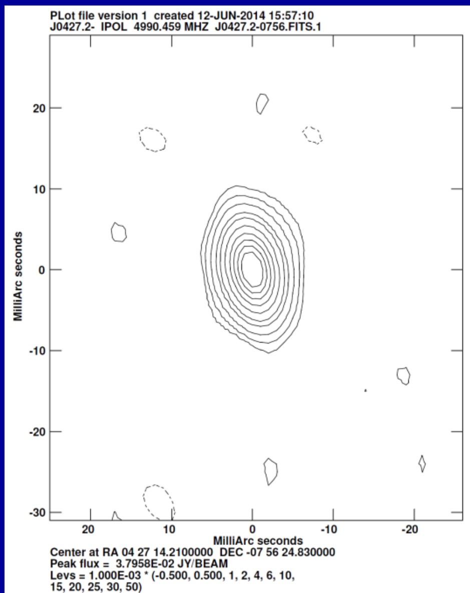
Observations	EM077A	22 Oct 2009	
	EM077B	30 May 2010	
	EM077C	31 May 2010	
	EM077D	23 Nov 2010	(e-VLBI correlation at JIVE)
	EM077E	15 Dec 2010	(e-VLBI correlation at JIVE)
	EM077F	31 May 2011	
	EM097A	24 Feb 2013	
	EM097B	27 May 2013	

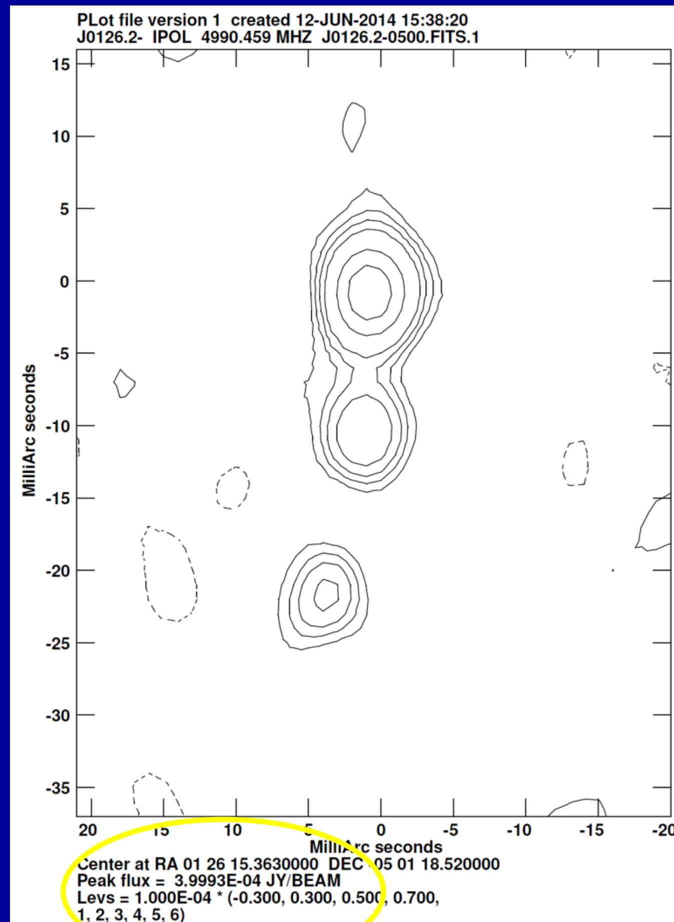
Correlation MPIfR DiFX software correlator
1 sec integration time → field of view ~ 11”

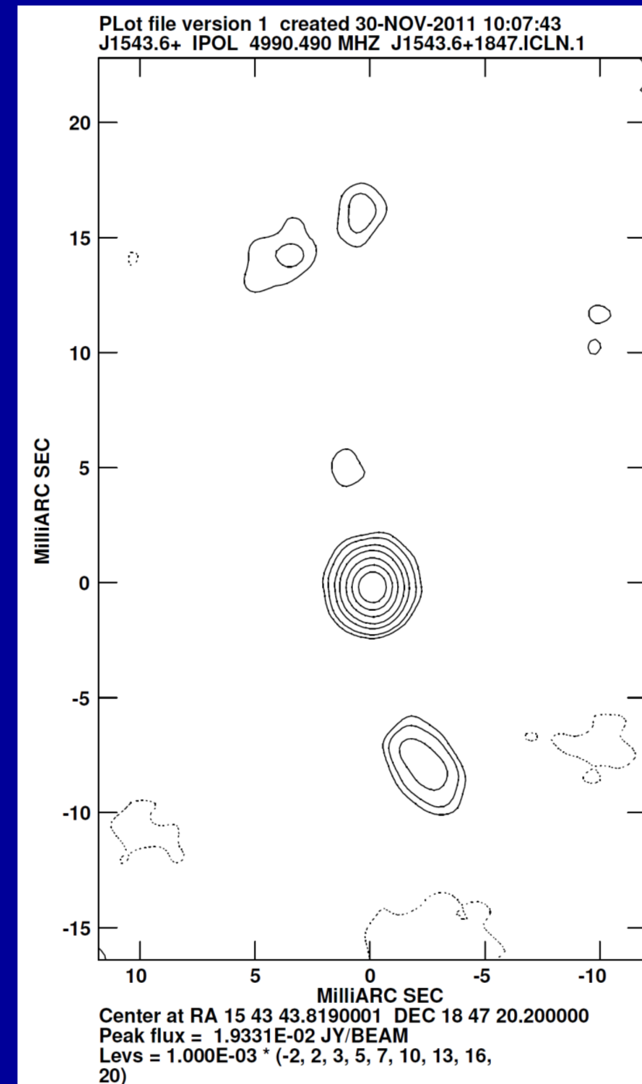
Thanks to both the EVN-PC and the EVN Scheduler for their support

Results from the EVN observations

- All the 87 sources were detected
- $(S_{EVN} / S_{EF})_{median} \approx 0.36 +/- 0.8$
- Structure: 45 core-jet
  39 point-like
  3 triples
- Tb in the range 10^{7} - 10^{12} K
  13 sources Tb > 10^{11} K







Peak flux = 0.4 mJy

rms noise = 0.03 mJ/beam

Classification according to spectral index

- Flat Spectra:
  56 FSRQs and BLLacs (blazars)
  2 NLRG

- Steep Spectra:
  10 SSRQs
  10 Compact Steep-spectrum Sources
  2 BLLacs (optical identification questionable)

- Convex Spectra:
  6 Giga-Peaked Sources
  1 BLLac (optical identification questionable)

CSSs and GPSs

X-ray ROSAT observations

$< L_X > \approx 5 \times 10^{44}$ ergs/sec

L_X similar for CSSs and GPSs quasars

Column density (1 – 15) x 10^{20} nH $cm^2 \approx$ Galactic nH

CSSs and GPSs quasars are not obscured by large column of cold gas surrounding their nuclei

15 DXRBS sources associated to *Fermi* γ-ray objects

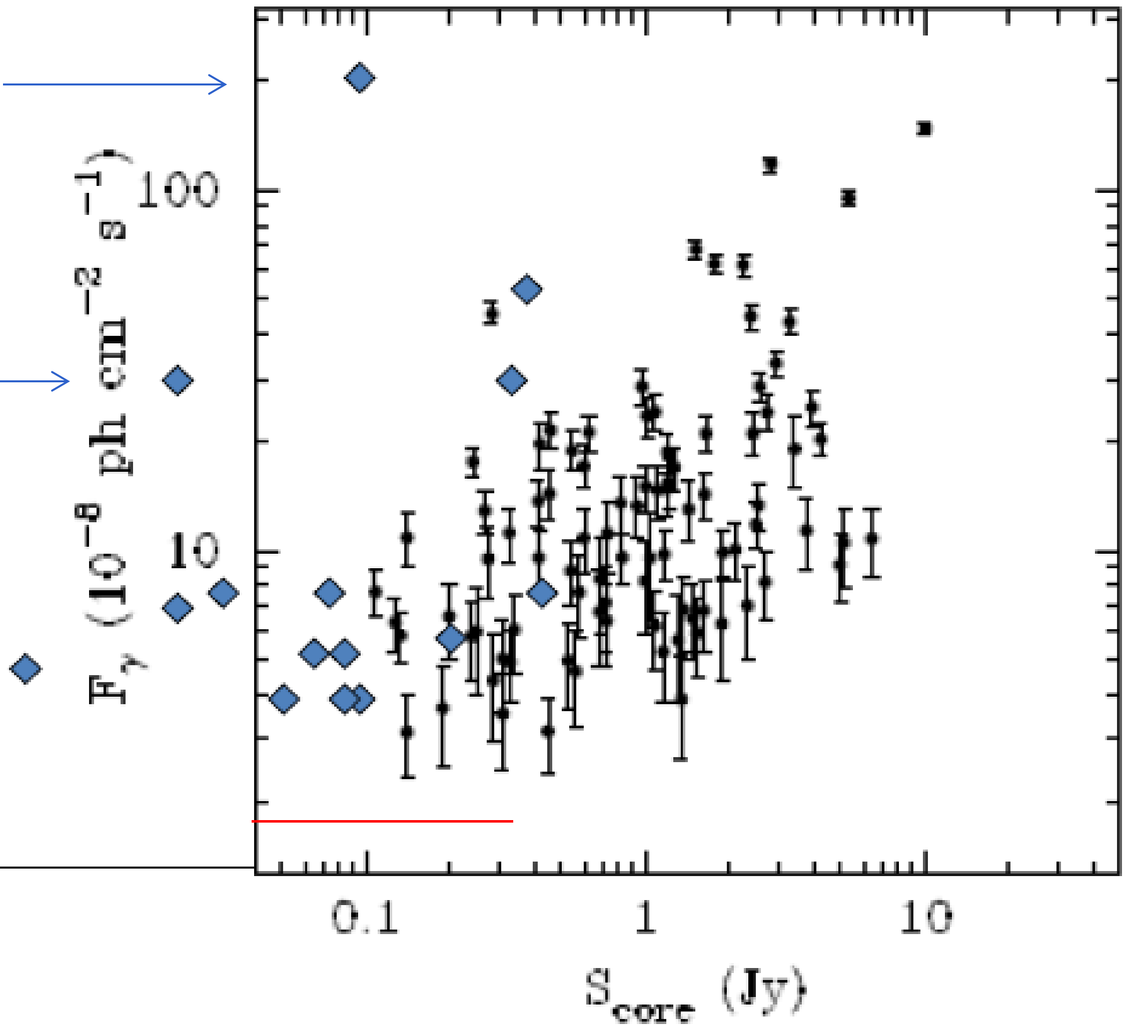
50% are BLLacs

Name NVSS	Name 2FGL	2FGL R.A.rms arcmin	2FGL Dec.rms arcmin	Radio-γ Sep. arcmin	Association	γ-Var.	Radio-Var.
J0204.8+1514	J0205.0+1514	8.1	6.5	2.7	4C15.05	T	yes
J0510.0+1800	J0509.9+1802	6.5	5.1	1.7	PKS 0507+17	T	no
J0847.2+1133	J0847.2+1134	5.3	4.6	0.8	RX J0847.1+1133		no
J0937.1+5008	J0937.6+5009	8.6	2.3	7.4	GB6 J0937+5008	T	yes
J1010.8−0201	J1010.8−0158	8.3	7.7	4.1	PKS 1008−01		yes
J1204.2−0710	J1204.3−0711	8.0	6.9	1.8	1RXS J120417.0−070959		no
J1231.7+2848	J1231.7+2848	2.3	2.2	0.4	B2 1229+29	T	no
J1332.7+4722	J1332.7+4725	13.6	13.1	10.4	B3 1330+476	T	yes
J1656.8+6012	J1656.5+6012	8.4	7.7	4.5	87GB 165604.4+601702		yes

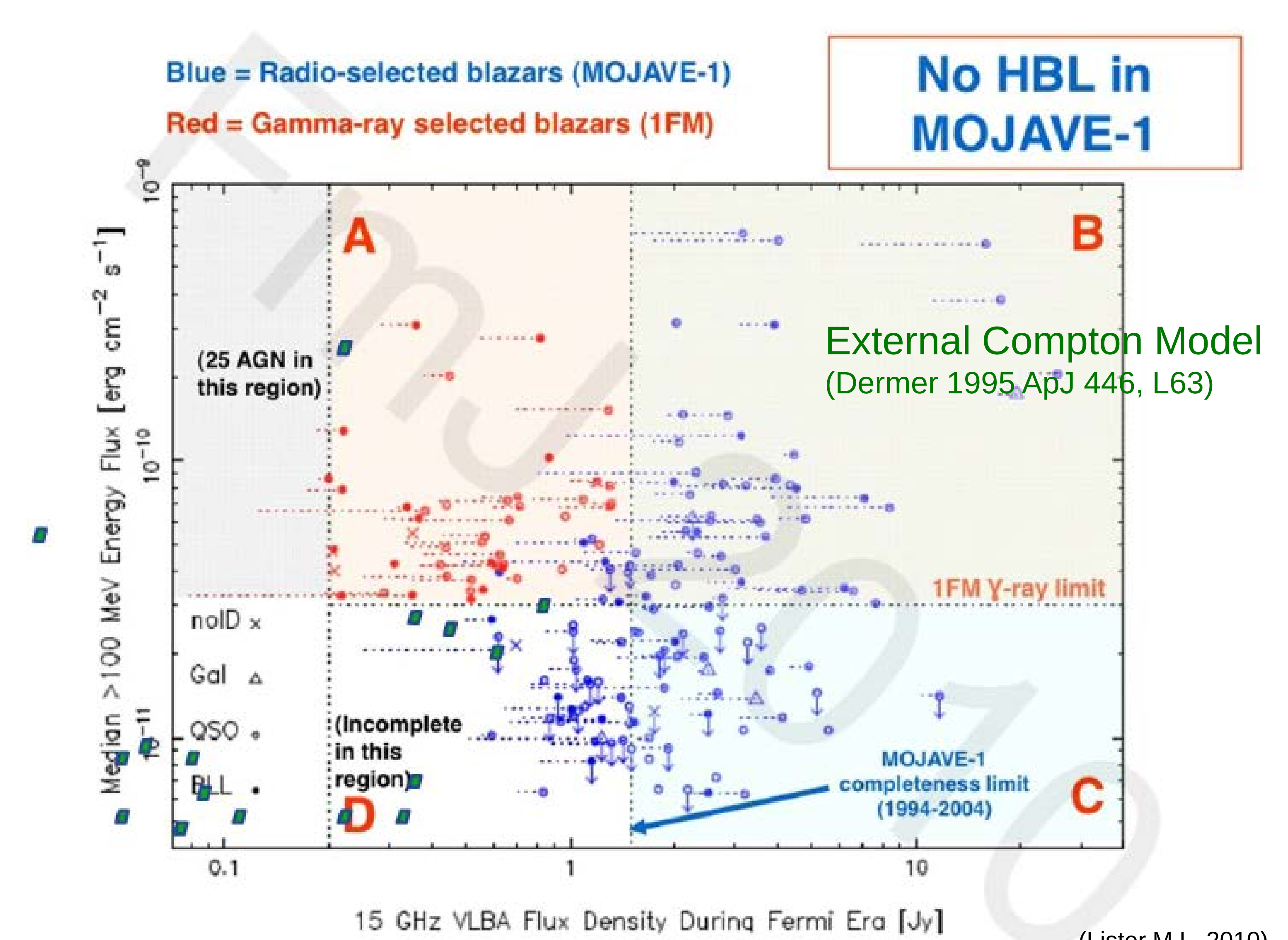
Name ATCA	Name 2FGL	2FGL R.A.rms arcmin	2FGL Dec.rms arcmin	Radio-γ Sep. arcmin	Association	γ-Var.	Radio-Var.
J0448.2−2110	J0448.6−2118	14.8	10.3	9.9	PKS 0446−212		
J0449.4−4349	J0449.4−4350	1.2	1.1	1.1		T	
J1610.3−3958	J1610.6−4002	18.5	11.5	6.1	PMN J1610−3958		
J1936.8−4719	J1936.8−4721	4.1	8.5	2.0	PMN J1936−4719		
J2258.3−5525	J2258.8−5524	10.2	9.0	9.1	PMN 2258−5526		
J2330.6−3724	J2330.6−3723	7.1	6.5	0.5	PKS 2327−376		

J0449.2-2110

J1231.7+2848



Pushkarev et al. 2010 + present paper



(Lister M.L. 2010)

Summary

- All 87 target sources detected
- 56 Blazars
- 2 NLRGs
- 29 CSSs plus GPSs
- Tb in the range $10^7 – 10^{12}$ K
- CSSs and GPSs quasars are not obscured by cold gas surrounding the nuclei
- 15 sources are associated to γ-ray objects
- 50% of the associated objects are BL Lacs
- S_{core} and γ-ray photon flux correlation confirmed
- External Compton model might be ruled out

Many thanks

for your attention

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- COST Action MP0905 Black Holes in a Violent Universe

External Compton model (Dermer 1995)

γ-ray emission boosted by a higher power of the Doppler factor than their radio emission ?

Synchrotron radiation beaming pattern $\alpha \quad \delta^{3+\alpha}$

External Compton-scattered photon $\alpha \quad \delta^{4+\alpha}$
(accretion disk photon field)

It implies lower radio / gamma for higher Doppler factor

Fermi and the "Faint blazars sample"

~ 13 % of the DXRBS objects has been possibly detected by *Fermi*

Are they too few or are they too many ?

EGRET → 130 blazars detected

Number counts are Euclidean: $N(>S)\ \alpha\ S^{-1.5}$

Fermi ~30 times more sensitive than EGRET → 20,000 expected detection

≤ 0.5 objects / deg^2 ≈ surface density in the Deep X-ray Radio Band Survey

List of SSRQs, CSSs and GPSs

Name	class	Max arcsec	min arcsec	P.A. deg		LS kpc	EVN struct	ROSAT erg/cm^2/sec	X-Lumin erg/sec	Col.Dens. nH cm^2	m 8.35	m 10.45	RM rad/m^2
J0015.5+3052	CSS?	<16.7	<16.3	–	N	<87.5	cj	2.82E−13	5.09E45	5.74E+20		< 1	14.4
J0126.2−0500	SSRQ	48.3	<17.1	43.3	N	156.9	cj	0.31E−12	1.90E44	4.08E+20		< 1	
J0204.8+1514	CSS?	<18.9	<16.8	–	N	<61.1	p	2.60E−13	1.54E44	5.53E+20		< 1	62.9
J0227.5−0847	GPS	1.38	1.02	136.8	F	5.4	p	0.22E−12	8.76E45	3.39E+20		< 1	
J0245.2+1047	BLLac	87.8	29.4	−36.0	N	79.6	p	7.80E−13	9.39E42	10.20E+20		< 1	
J0304.9+0002	SSRQ	8.12	4.14	162.1	F	32.9	cj	4.02E−13	5.27E44	6.51E+20		< 1	
J0421.5+1433	BLLac	67.9	18.5	66.6	N	265.7	p	3.51E−14	3.45E43	15.90E+20	10.8		−68.6
J0435.1−0811	GPS	21.2	<17.2	31.6	N	95.6	cj	1.26E−13	3.81E44	6.17E+20		< 1	
J0447.9−0322	CSS?	<18.2	<16.0	–	N	<81.2	cj	1.38E−12	3.96E45	3.80E+20		< 1	
J0518.2+0624	CSS?	<18.8	<17.5	–	N	<86.6	p	9.69E−14	3.94E44	12.00E+20	2.6		95.4
J0931.9+5533	GPS	23.8	18.9	64.4	F	65.8	cj	0.43E−12	9.56E43	2.22E+20		< 1	
J1006.1+3236	CSS	3.38	1.91	132.1	F	15.9	cj?	0.43E−12	2.45E45	1.47E+20		< 1	
J1101.8+6241	CSS	1.89	0.75	13.7	F	7.4	p	0.46E−12	9.00E44	0.90E+20		< 1	−8.1
J1116.1+0828	GPS	0.68	0.49	31.3	F	2.4	p	0.22E−12	2.02E44	2.85E+20		< 1	
J1213.2+1443	SSRQ	9.27	8.20	12.3	F	37.2	t	0.48E−12	1.14E45	2.82E+20	< 1		
J1224.5+2613	SSRQ	14.08	10.28	118.9	F	55.8	p	1.04E−13	2.22E44	1.77E+20	< 1		
J1225.5+0715	SSRQ	7.17	3.55	46.9	F	30.8	p	0.84E−13	6.05E44	1.72E+20		< 1	
J1404.2+3413	SSRQ	22.3	<18.7	5.8	N	94.3	cj	0.78E−13	3.60E44	1.23E+20		< 1	
J1406.9+3433	GPS	0.87	0.35	11.9	F	3.3	cj	0.11E−12	6.13E45	1.31E+20		< 1	
J1420.6+0650	CSS	0.85	0.0	179.4	F	2.0	cj	0.33E−12	5.58E43	2.18E+20			
J1427.9+3247	GPS	3.42	3.05	26.9	F	12.8	cj	0.38E−12	5.09E44	0.97E+20	4.5		0.5?
J1442.3+5236	CSS	4.80	1.21	119.1	F	20.0	cj	0.14E−12	3.29E45	1.46E+20		< 1	
J1507.9+6214	CSS	2.30	1.21	2.7	F	9.8	cj	0.12E−12	1.73E45	1.55E+20		< 1	
J1539.1−0658	BLLac	1.02	0.61	81.2	F	3.6	cj	0.70E−13	6.88E43	9.02E+20	< 1		
J1629.7+2117	CSS?	<17.1	<15.6	–	N	<71.0	cj	0.14E−12	4.82E44	4.11E+20	< 1		
J1722.3+3103	SSRQ	42.48	13.63	104.0	F	117.4	cj	0.16E−12	4.88E43	3.15E+20	< 1		
J1804.7+1755	SSRQ	40.30	<19.6	36.3	N	65.6	p	0.11E−12	7.74E43	8.27E+20	< 1		
J2322.0+2114	SSRQ	75.2	<17.5	57.3	N	300.4	p	1.49E−13	3.42E44	4.47E+20	< 1		
J2347.6+0852	SSRQ	42.7	21.5	−34.9	N	115.5	p	6.40E−13	1.76E44	5.75E+20	2.8		

Sources structure and radio spectral index

Structure	Steep $\alpha \leq -0.5$	Ultra Steep $\alpha < -0.7$	Steep-flat	Flat-Steep	Flat	GPS	Inverted	Not available
Point	4 (1)	6 (1)	9 (1)	1	13 (2)	2	5	1
Core-Jet	3	8	5 (1+1NLRG)	3 (1)	18 (3+1NLRG)	5 (1)	1	–
Triple	–	1	2	–	–	–	–	–