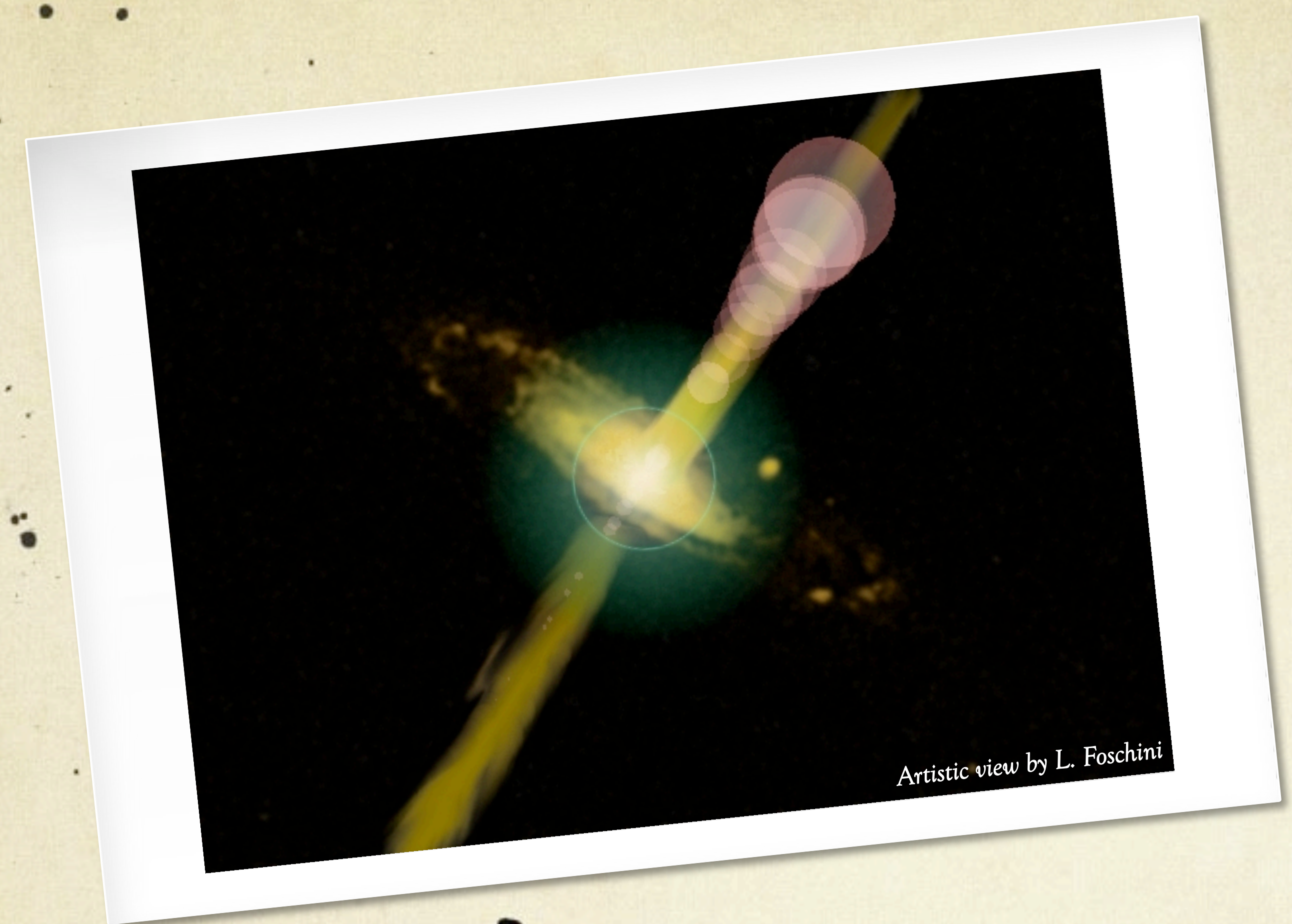


Evidence of powerful relativistic jets in NLS1 galaxies

Luigi Foschini
INAF Osservatorio Astronomico di Brera – Merate (LC), Italy

Narrow-Line Seyfert 1 Galaxies (Osterbrock & Pogge 1985, ☞ *talk Pogge*):

- Relatively low masses (*vexata quaestio* ☞ *see talks of tomorrow, the "mass day"*) and high accretion rates (Boroson & Green 1992) ☞ *talk Boroson*

- Generally radio-quiet, but a small part is **radio-loud** (~ 7%, Komossa et al. 2006)

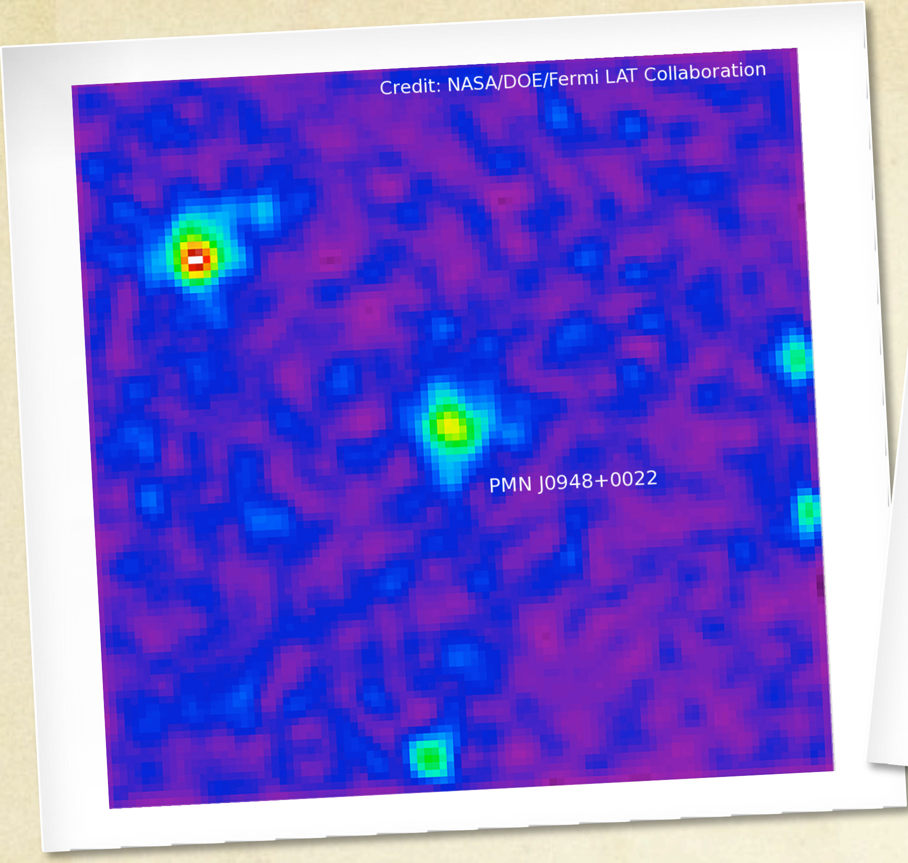
- First radio-loud NLS1 discovered in 1986 (PKS 0558-504, Remillard et al. 1986) ☞ *talk Gliozzi*

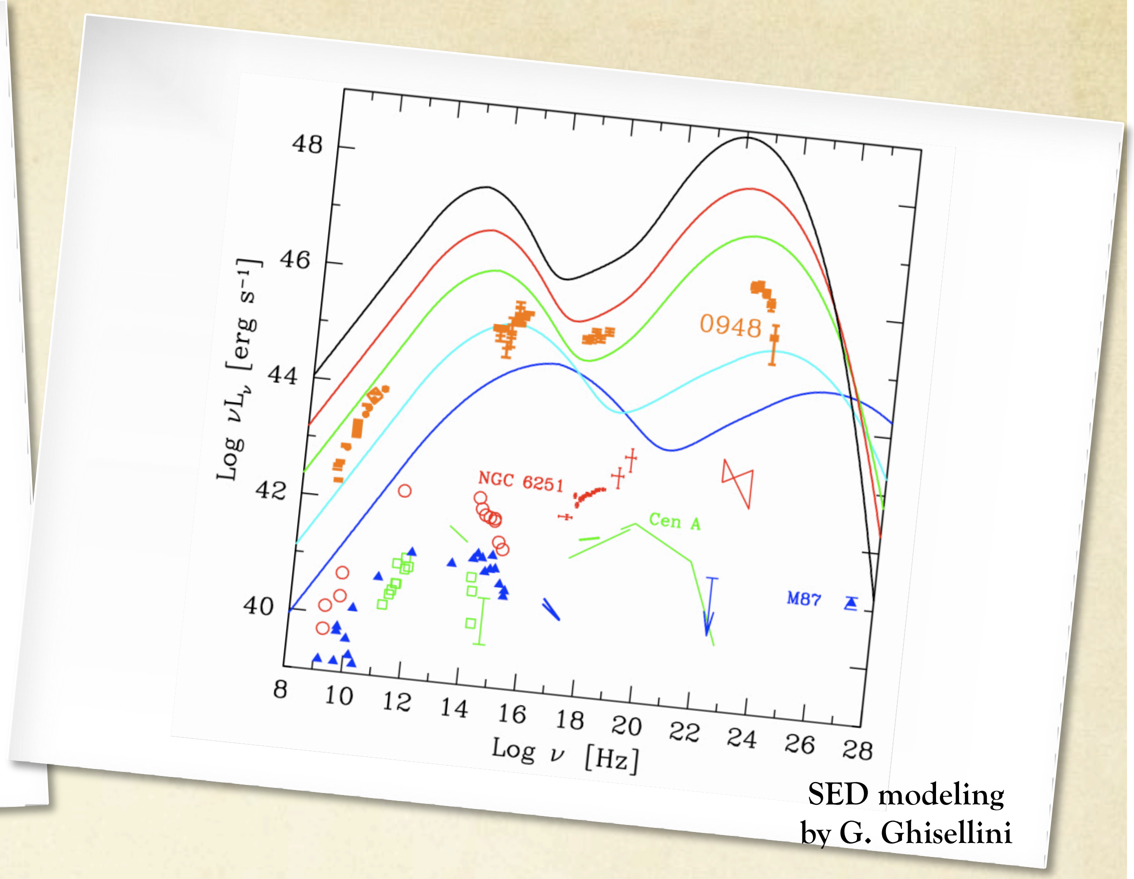
- In early 2000s, a few more radio-loud NLS1 were found (Grupe et al. 2000, Oshlack et al. 2001, Zhou et al. 2003, Komossa et al. 2006)

- First (negative) attempts to detect NLS1 at very high-energy γ-rays ($E > 400$ GeV) with *Whipple* (Falcone et al. 2004)

- More radio-loud NLS1 in surveys: Whalen et al. 2006 (*First Bright Quasar Survey*, radio-quiet + radio-loud), Yuan et al. 2008 (*Sloan Digital Sky Survey*, only radio-loud)

- 2008 June 11: launch of the *Fermi Gamma-ray Space Telescope*... **discovery of GeV γ rays from NLS1!**





SED modeling
by G. Ghisellini

PMN J0948+0022 (0.585) a.k.a. SDSS J094857.31+002225.4

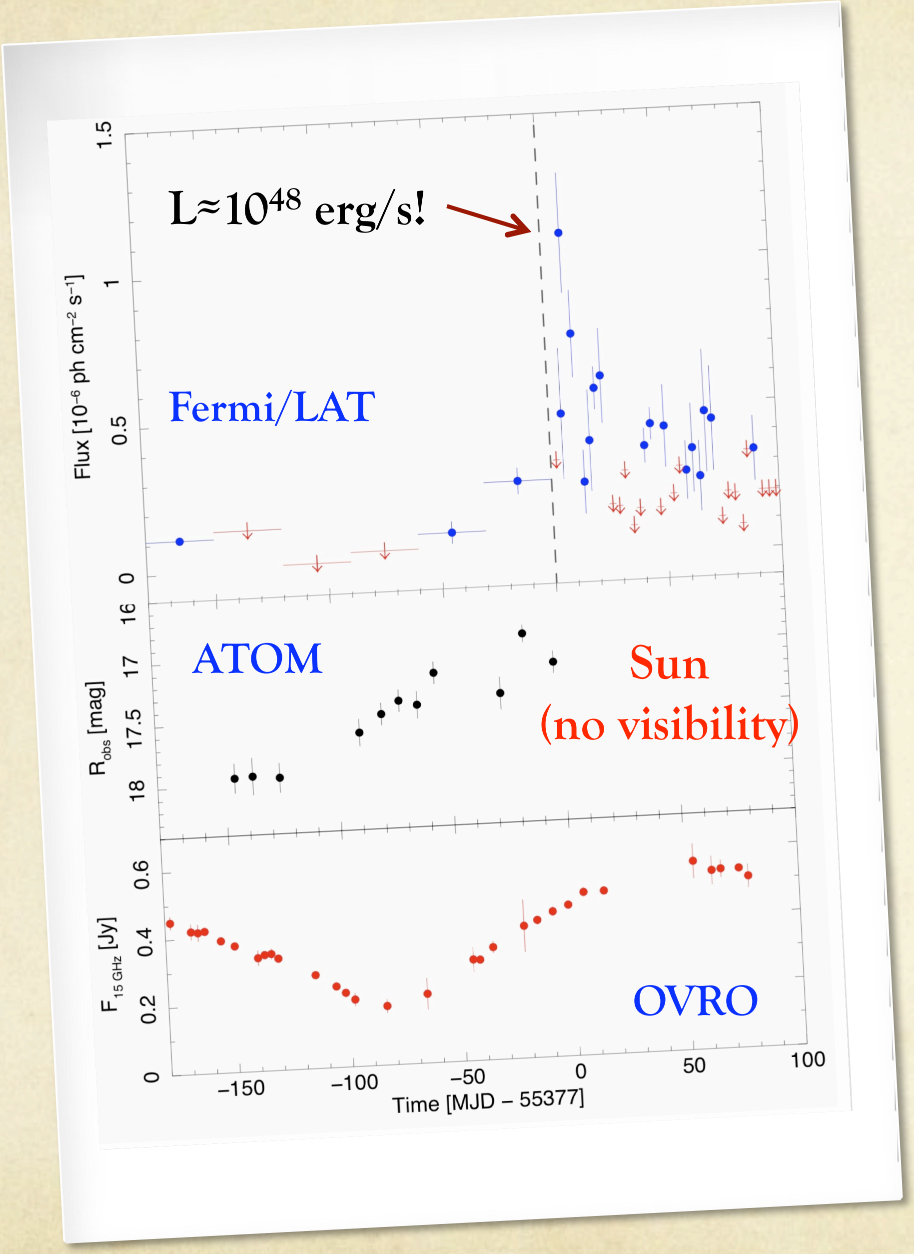
The first NLS1 detected at high-energy γ−rays (E > 100 MeV).

Found after the first three months of Fermi operations (17σ)

Abdo et al. (corresponding author L. Foschini), 2009, ApJ, 699, 976

Foschini et al., 2010, in: "Accretion and Ejection in AGN: A Global View", Como (Italy), 22-26 June 2009, ASP Conf. Proc. 427, p. 243

Found to be radio-loud by Zhou et al. (2003)



2010 MW Campaign

Two MW Campaigns on PMN J0948+0022:

2009 March-July:

- Triggered to better understand the nature of the source;
- γ-ray activity in early April 2009 (peak ≈ 4×10^{-7} ph cm^{-2} s^{-1}), followed by an increase of radio emission after ≈ 2 months;
- Confirmation of the association of the γ-ray source with the NLS1 J0948+0022.

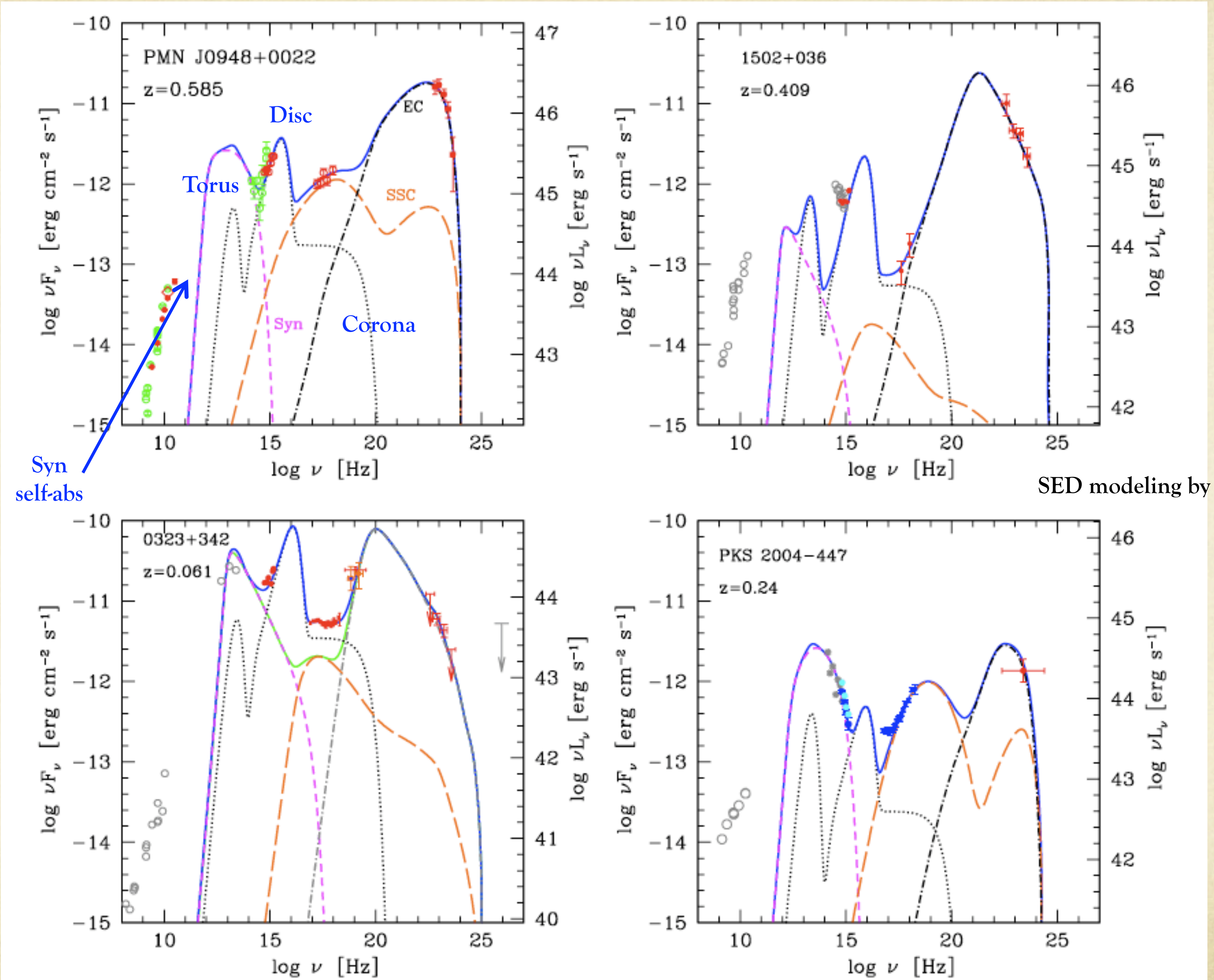
Abdo et al. (contact author: L. Foschini), 2009, ApJ, 707, 727.

2010 July-September:

- Triggered by the first γ-ray outburst (peak ≈ 10^{-6} ph cm^{-2} s^{-1} ➤ L ≈ 10^{48} erg/s!);
- Extreme power, when compared to the emission at other wavelengths.

Foschini et al., 2011, MNRAS, in press (arXiv: 1010.4434)

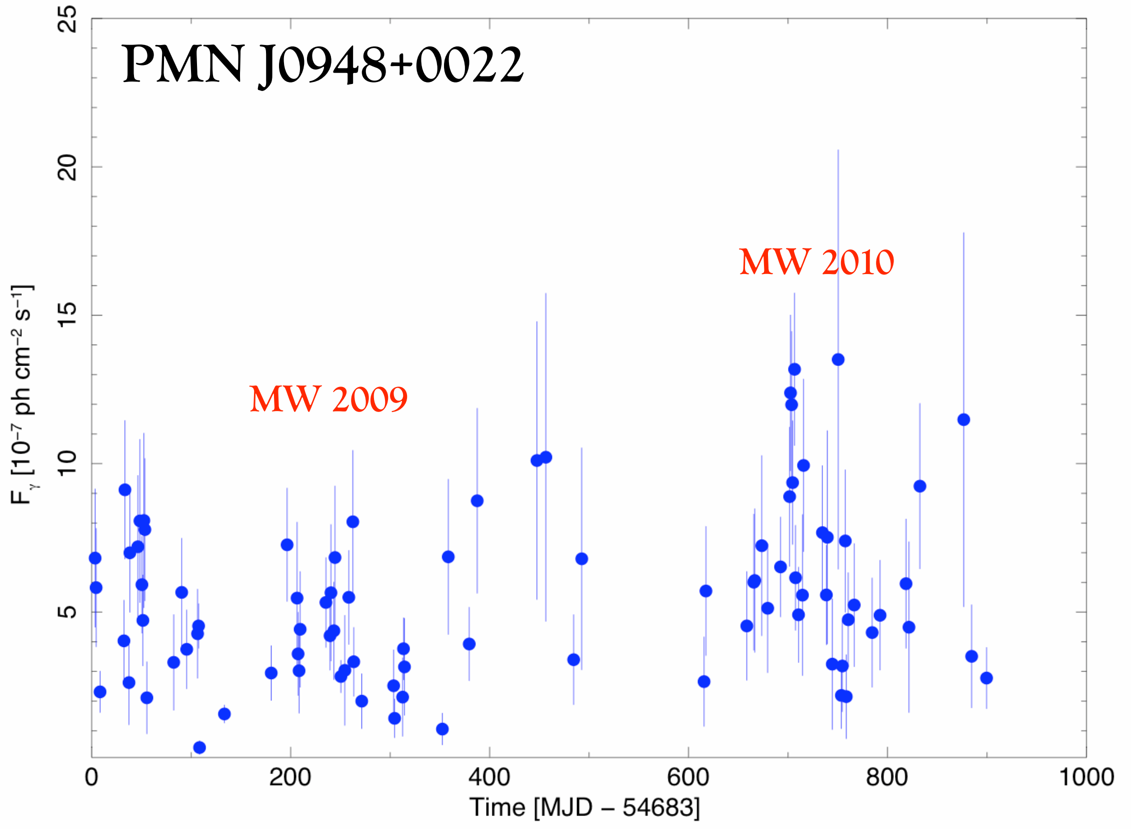
4 γ−NLS1 were detected in 12 months of Fermi/LAT data

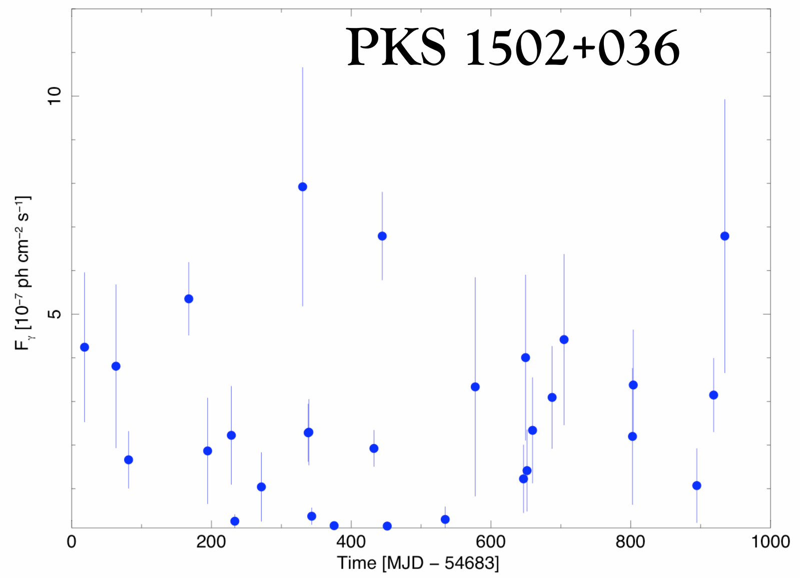


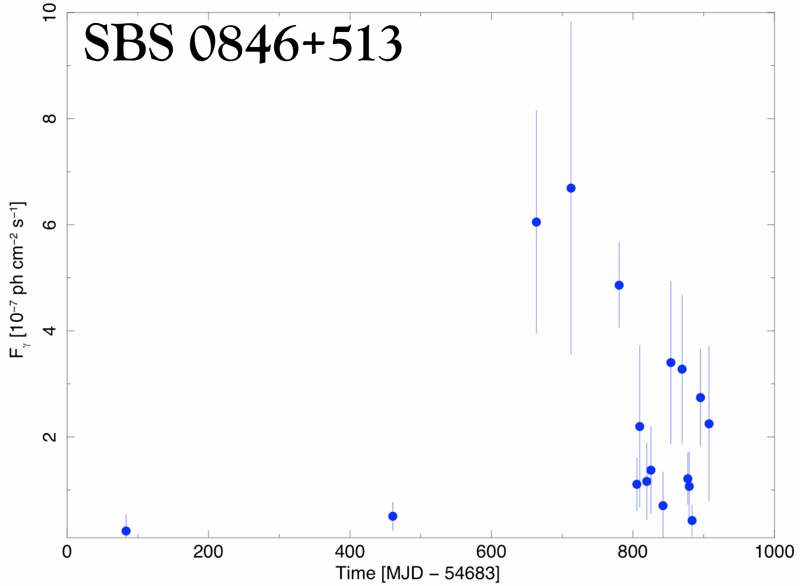
SED modeling by G. Ghisellini

Abdo et al. (contact author: L. Foschini), 2009, ApJ, 707, L142

Variability at γ rays



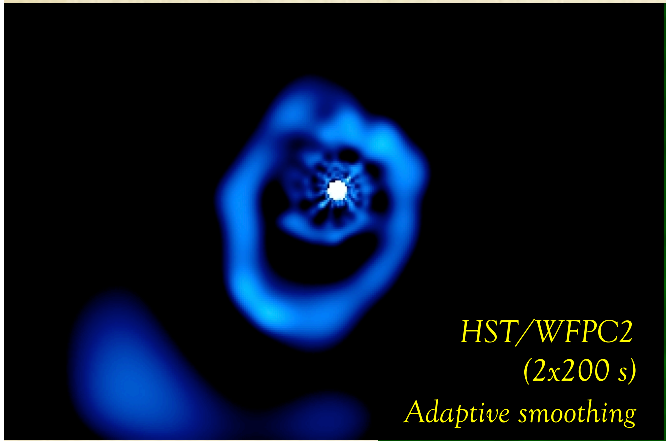


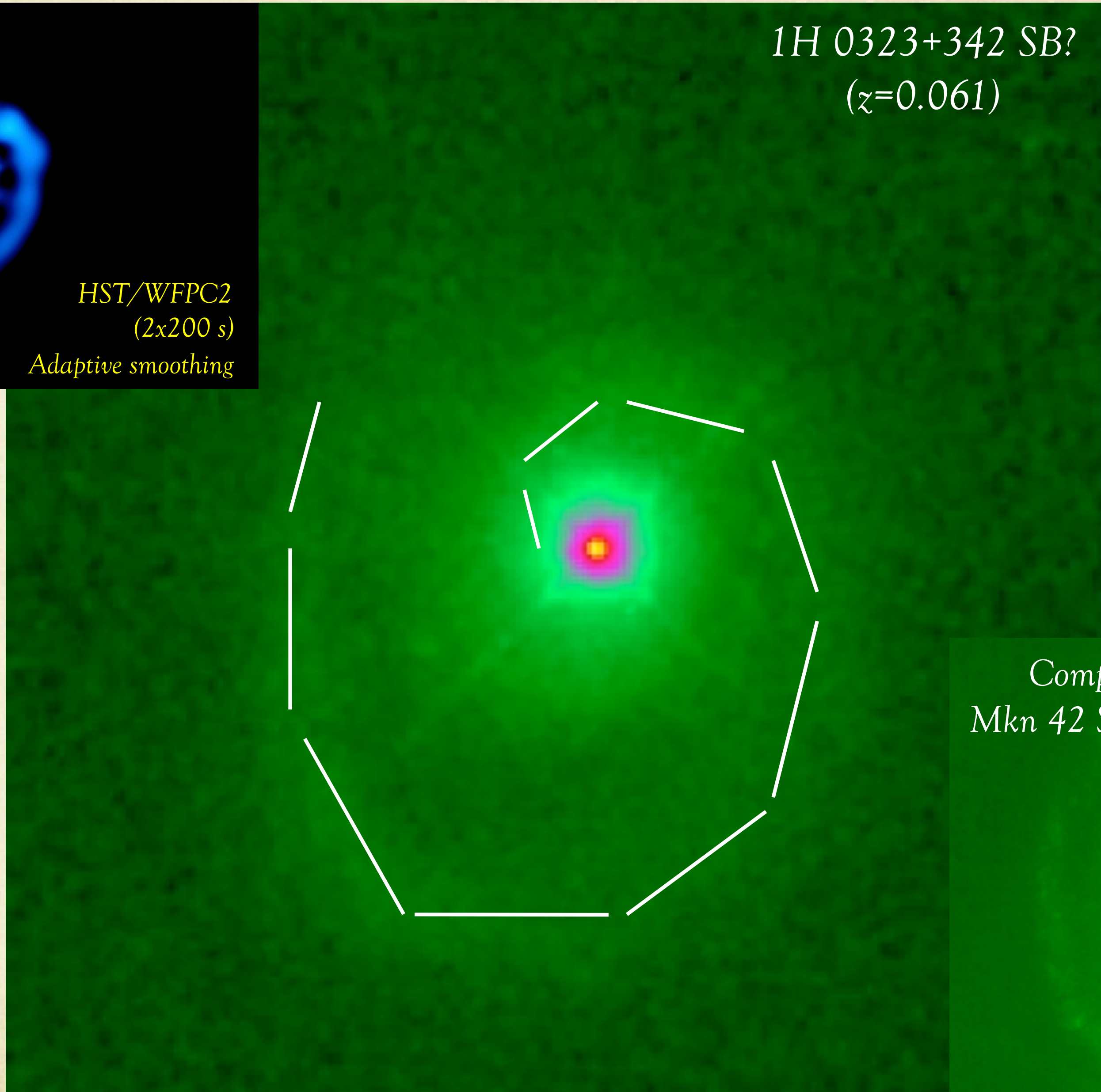


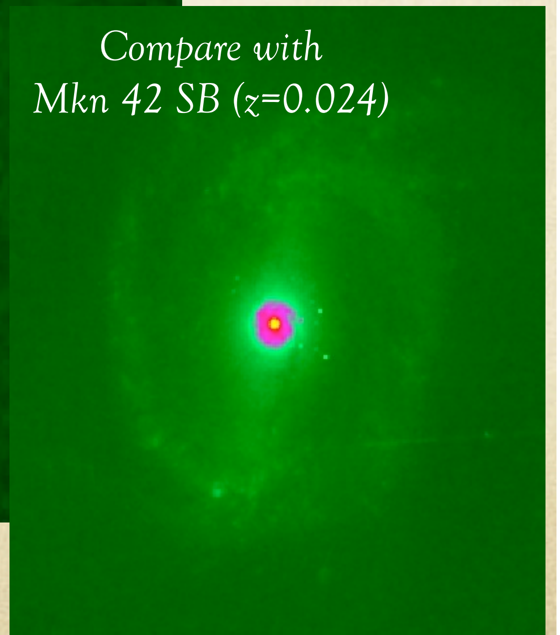
Minimum detected time scale (1-3 day bin light curves):

1H 0323+342:	< 2.7 d	
SBS 0846+513:	12±8 d	NEW!
PMN J0948+0022:	< 0.8 d	
FBQS J1102+2239:	25±12 d	NEW!
SDSS J124634.65+023809.0:	21±4 d	NEW!
PKS 1502+036:	1.3±0.5 d	
PKS 2004-447:	6.2±1.7 d	

Host Galaxies



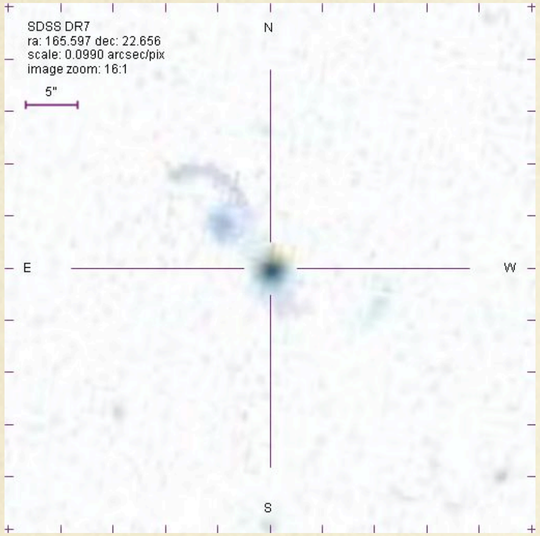




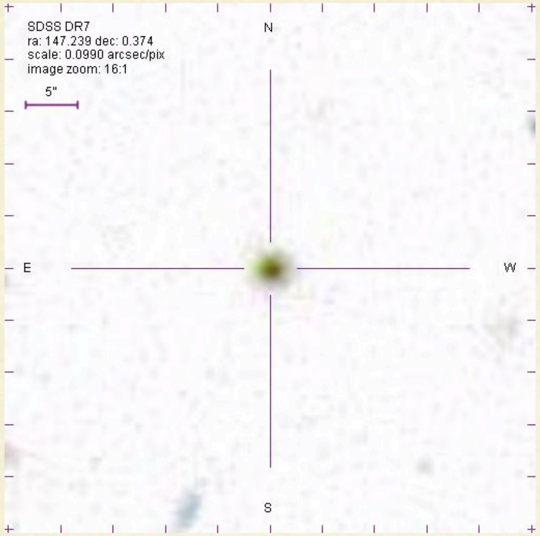
Zhou et al. (2007): spiral morphology

Anton et al. (2008): ring due to a recent merger

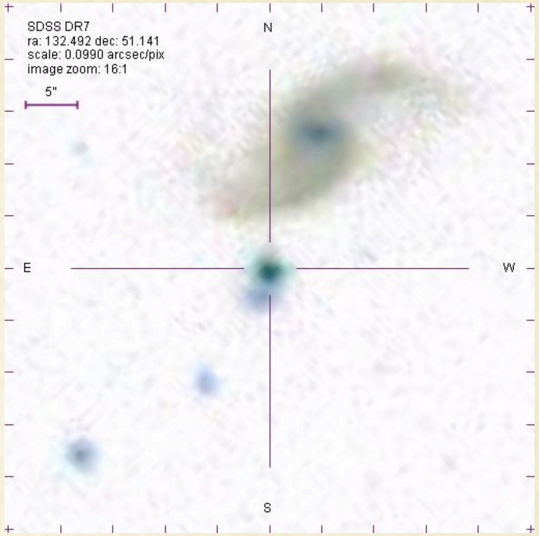
Host Galaxies (from SDSS DR7)



FBQS J1102+2239 (z=0.455)



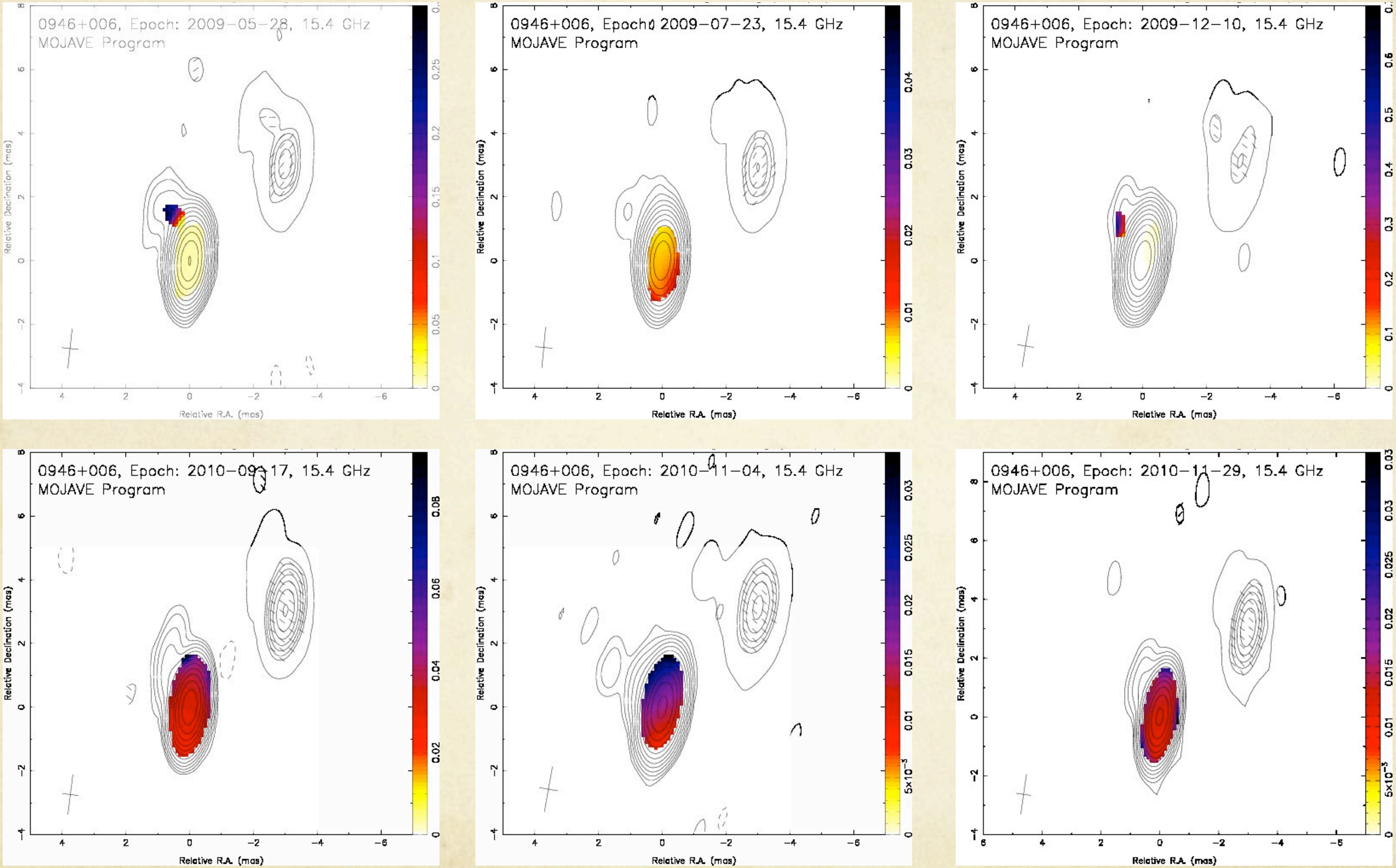
PMN J0948+0022 (z=0.585)



SBS 0846+513 (z=0.584)

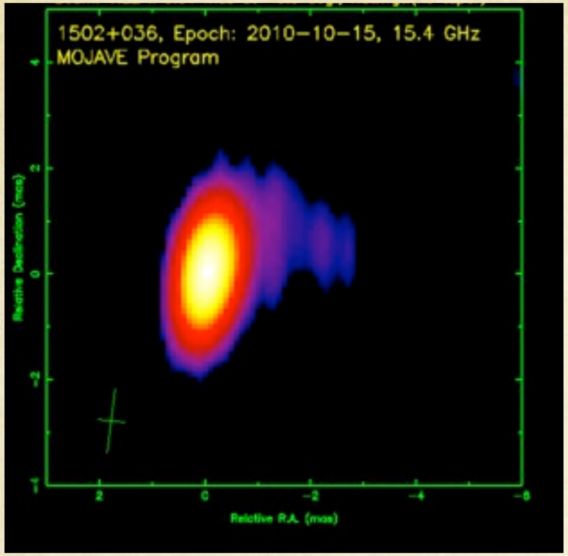
Radio morphology: PMN J0948+0022 ☞ *talk Giroletti*

(6.6 *pc/mas*)

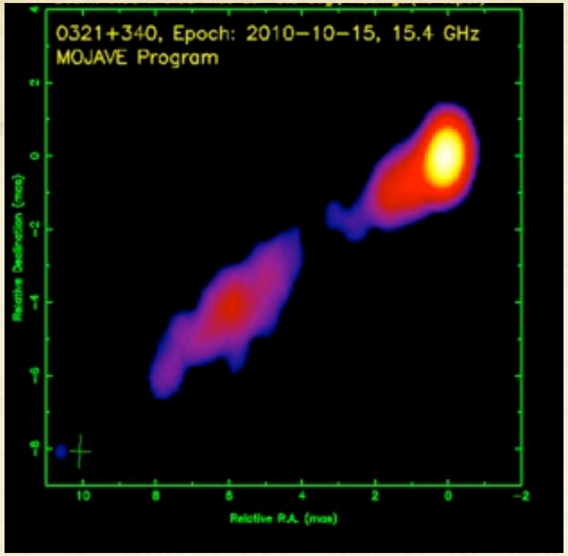


VLBA (2cm/15 GHz) – MOJAVE Project (☞ http://www.physics.purdue.edu/MOJAVE/)

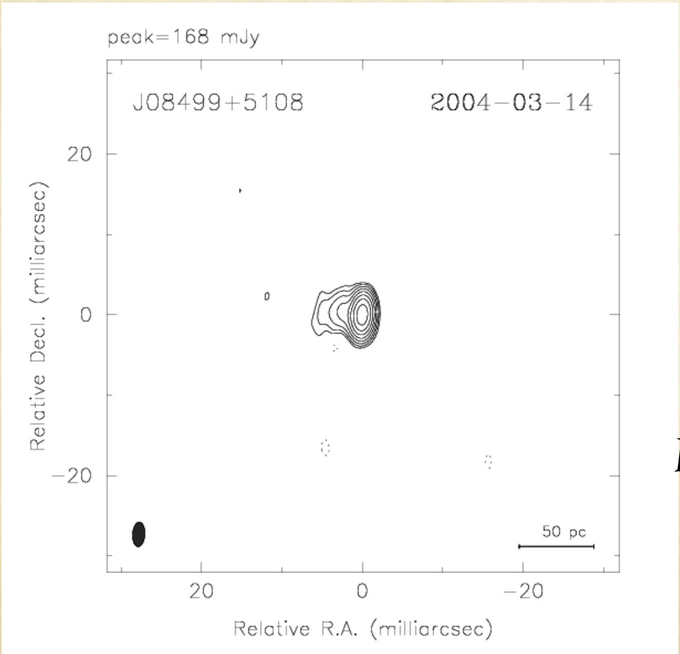
Radio morphology



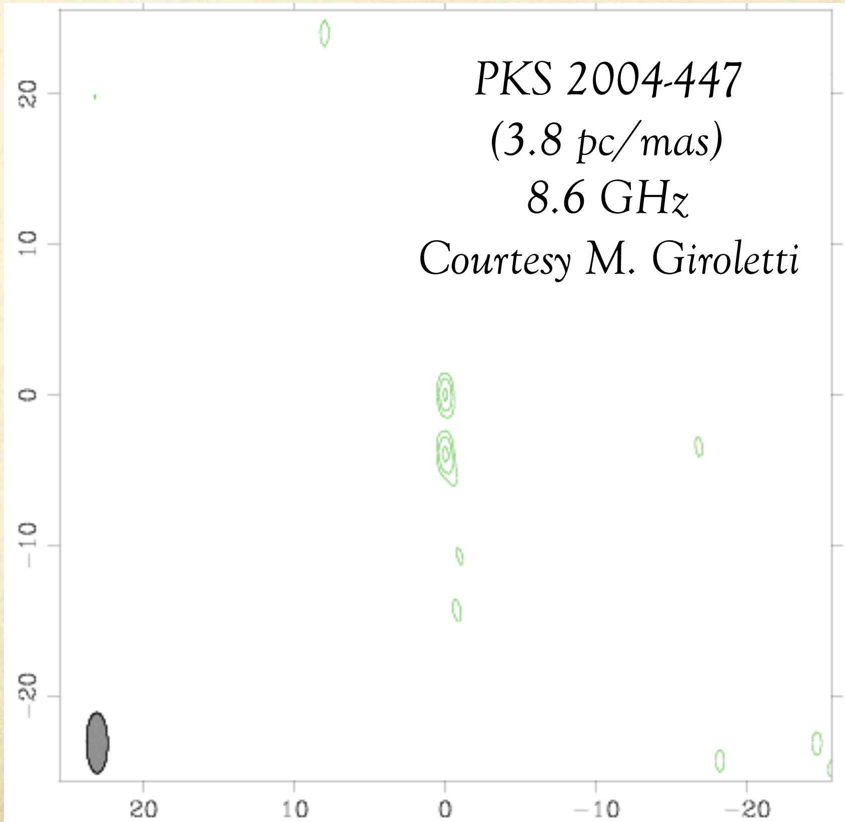
PKS 1502+036
(5.4 pc/mas)



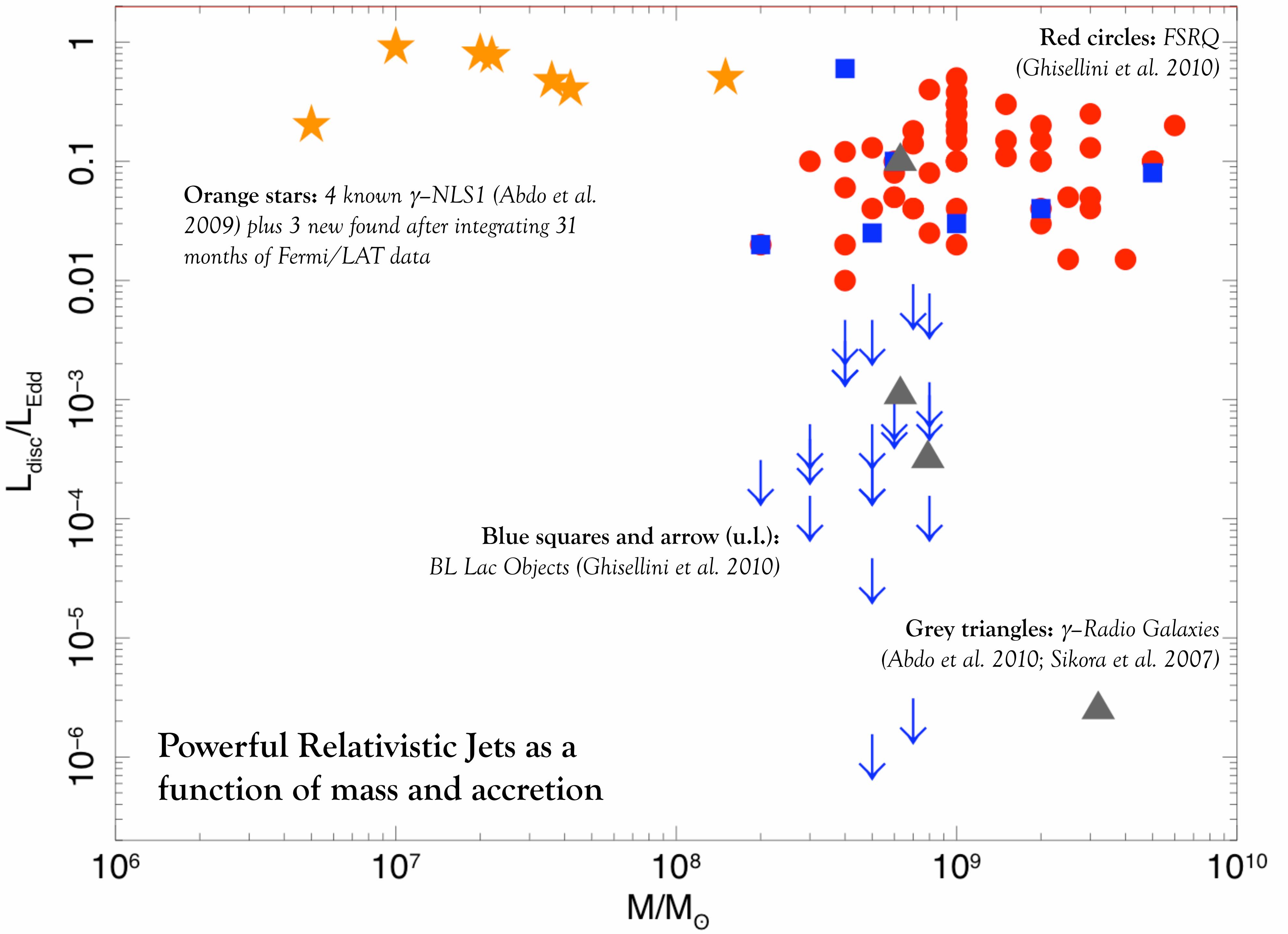
1H 0323+342
(1.2 pc/mas)



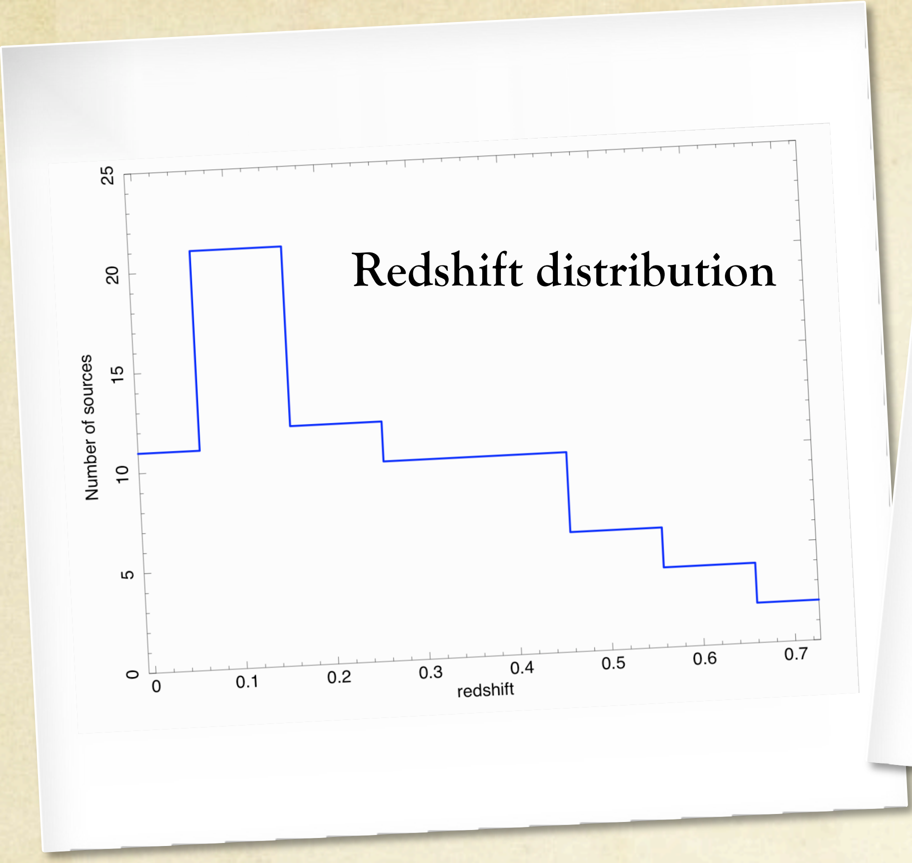
SBS 0846+513
(6.6 pc/mas)
VLBI 5 GHz
Helmboldt et al. (2007)

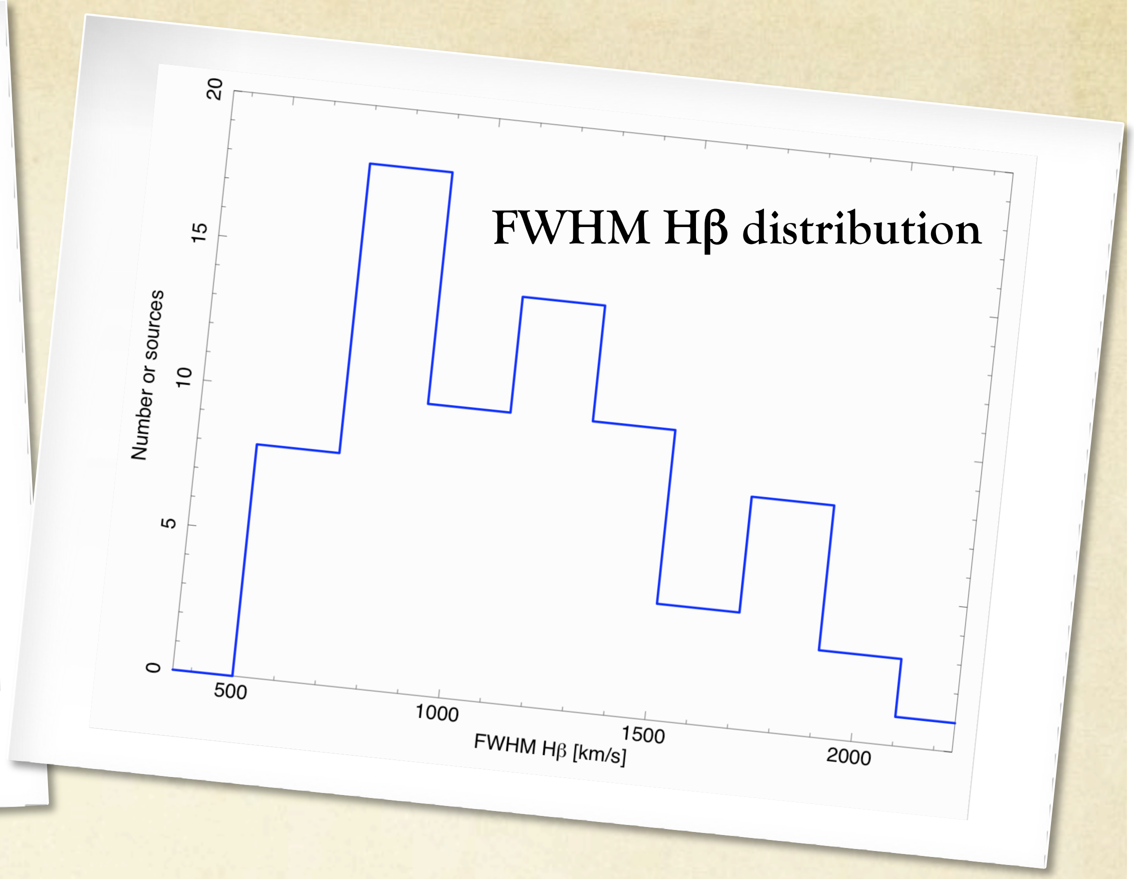


PKS 2004-447
(3.8 pc/mas)
8.6 GHz
Courtesy M. Giroletti



Red circles: FSRQ
(Ghisellini et al. 2010)
Orange stars: 4 known γ–NLS1 (Abdo et al. 2009) plus 3 new found after integrating 31 months of Fermi/LAT data
Blue squares and arrow (u.l.):
BL Lac Objects (Ghisellini et al. 2010)
Grey triangles: γ–Radio Galaxies
(Abdo et al. 2010; Sikora et al. 2007)
Powerful Relativistic Jets as a function of mass and accretion
L_{disc}/L_{Edd}
$M/M_{\odot}$
1
0.1
0.01
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}





Sample: 76 NLS1

- 45 from FBQS (Whalen et al. 2006)
- 23 from SDSS (Yuan et al. 2008)
- 8 from various sources (Zhou & Wang 2002, Komossa et al. 2006, Oshlack et al. 2001, Gallo et al. 2006)

Radio-quiet ($R = f_r/f_o < 10$): 30
Intermediate ($10 < R < 20$): 7
Radio-loud ($R > 20$): 39

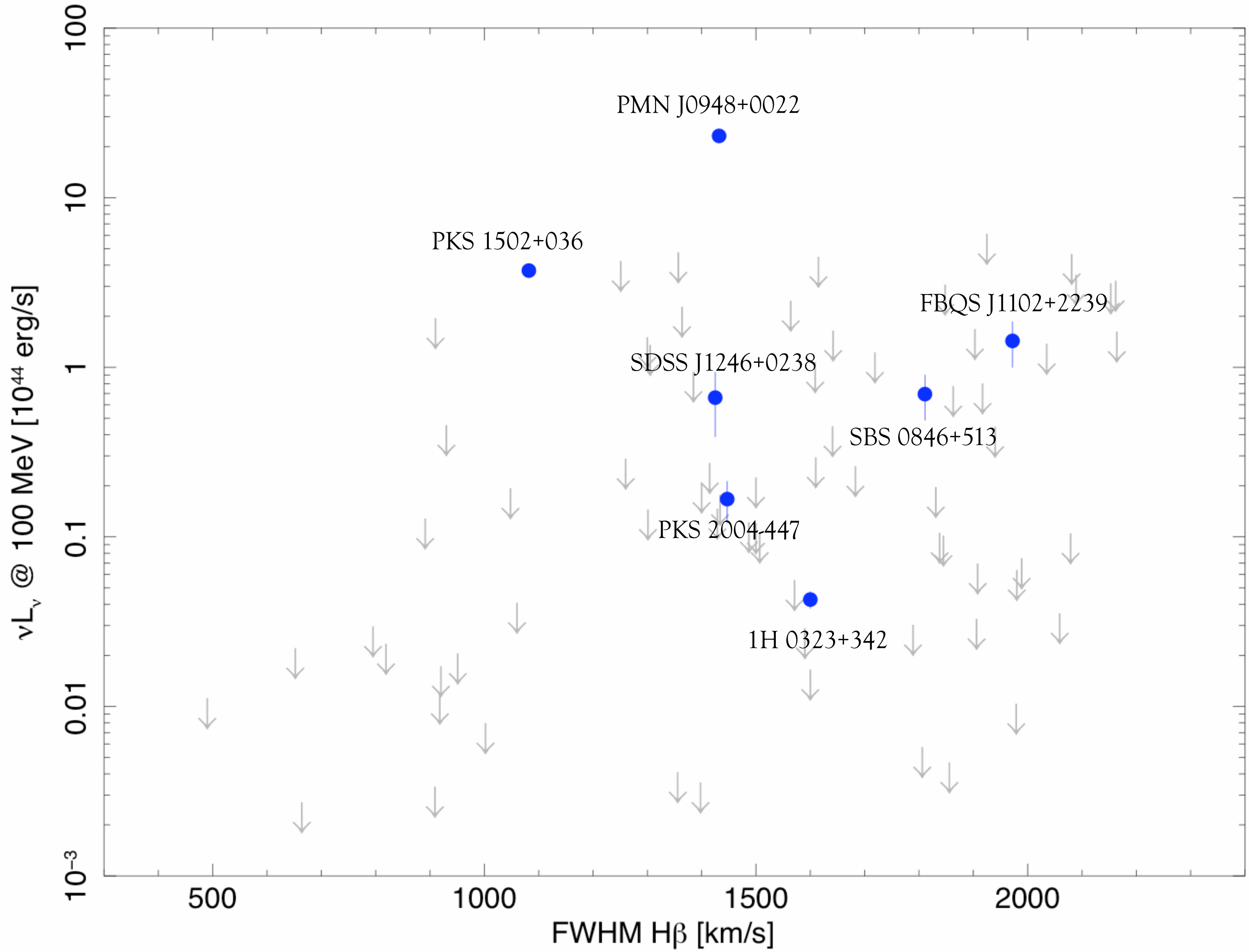
Radio: 1.4 GHz, *FIRST*
Optical: 440 nm, *SDSS* (a few from *USNO*)
X-ray: 1 keV, *ROSAT*
γ−ray: 100 MeV, *Fermi*

Dereddened for Galactic absorption (Kalberla et al. 2005)

K-corrected
$\alpha_r=0$ $\alpha_o=-0.5$ $\alpha_X=1$ $\alpha_\gamma=1.7$

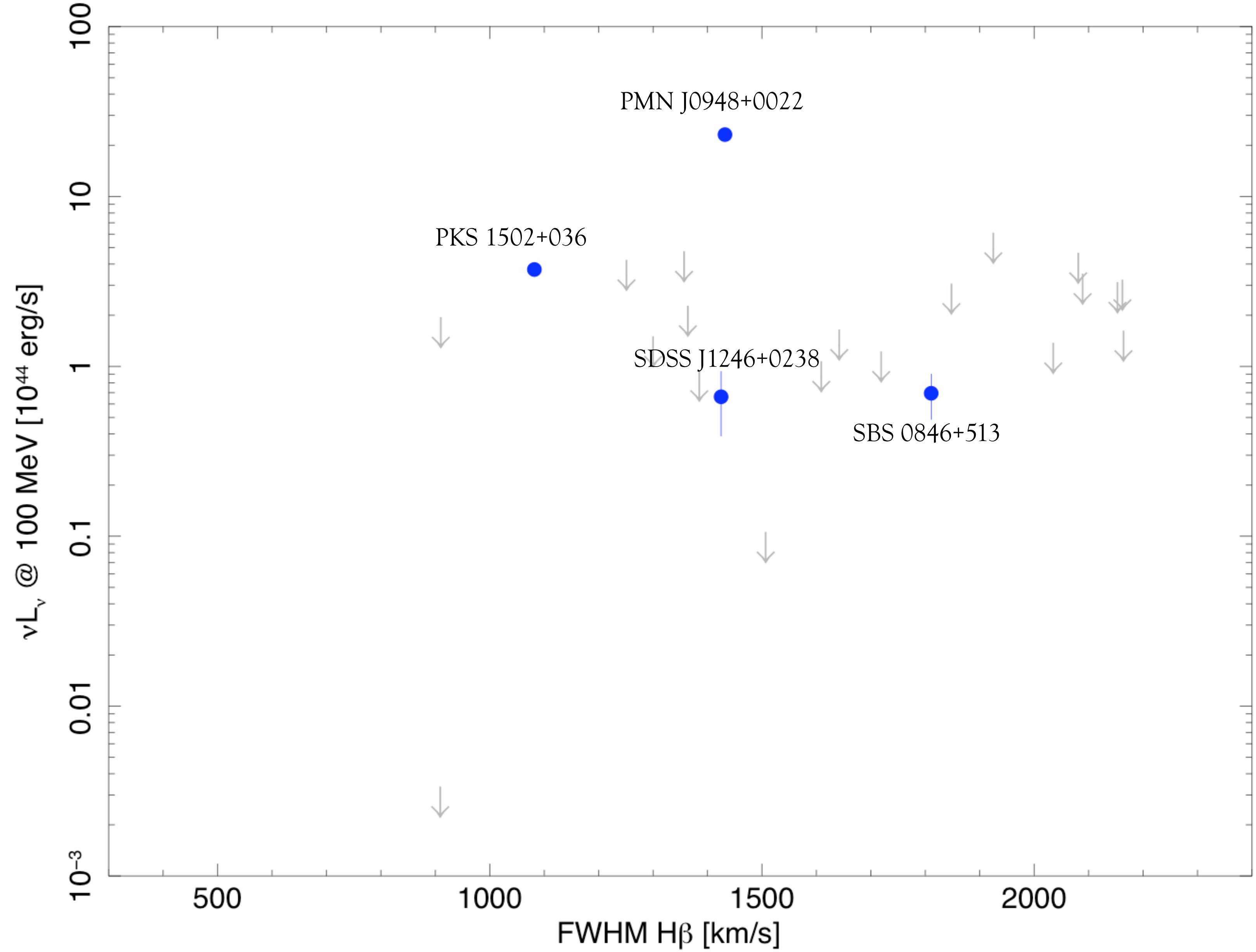
Multiple observations were available for PMN J0948+0022 (MW campaigns, mostly from 2009)

γ vs FWHM Hβ

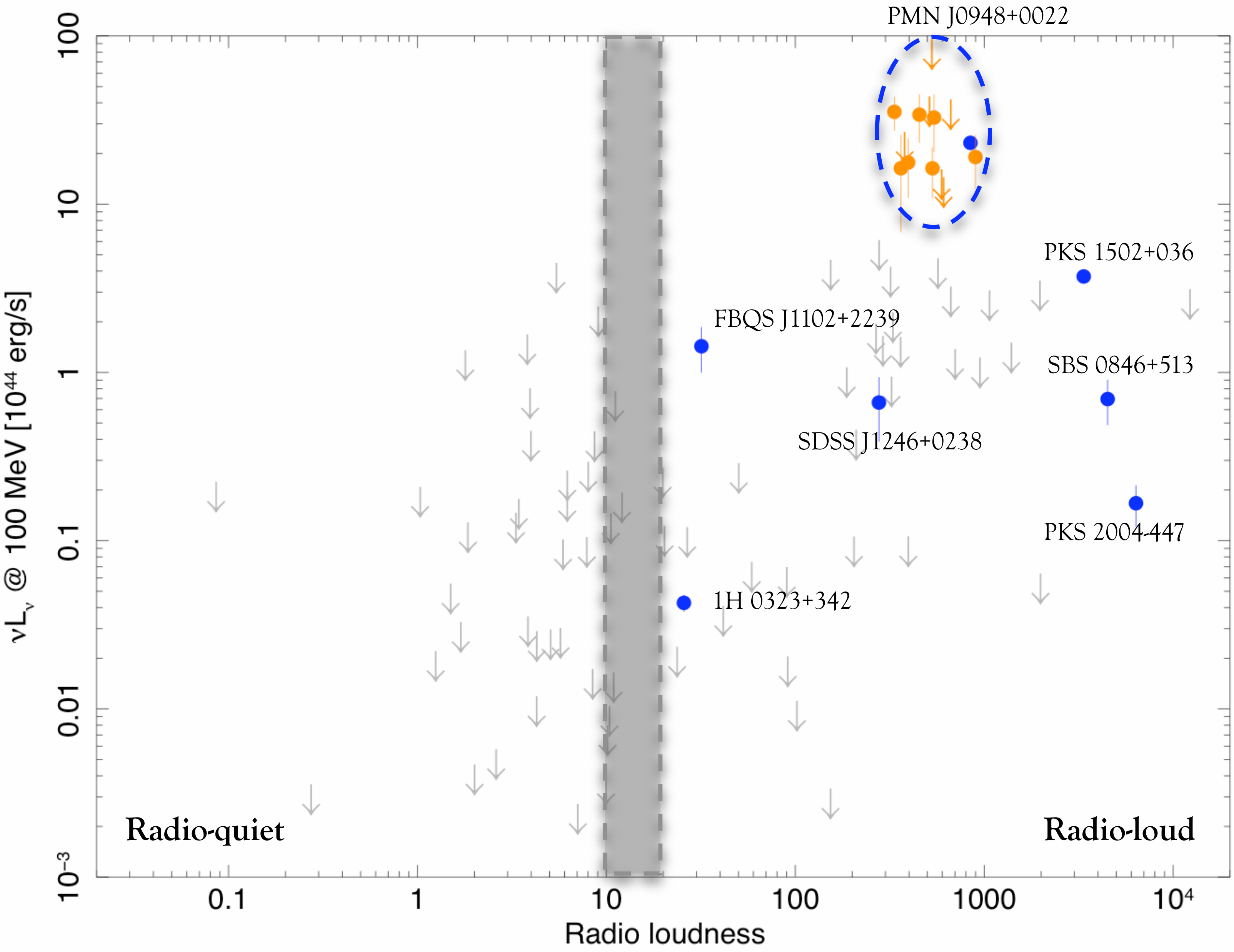


PMN J0948+0022
PKS 1502+036
FBQS J1102+2239
SDSS J1246+0238
SBS 0846+513
PKS 2004-447
1H 0323+342
νLν @ 100 MeV [10^44 erg/s]
100
10
1
0.1
0.01
10^-3
500
1000
1500
2000
FWHM Hβ [km/s]

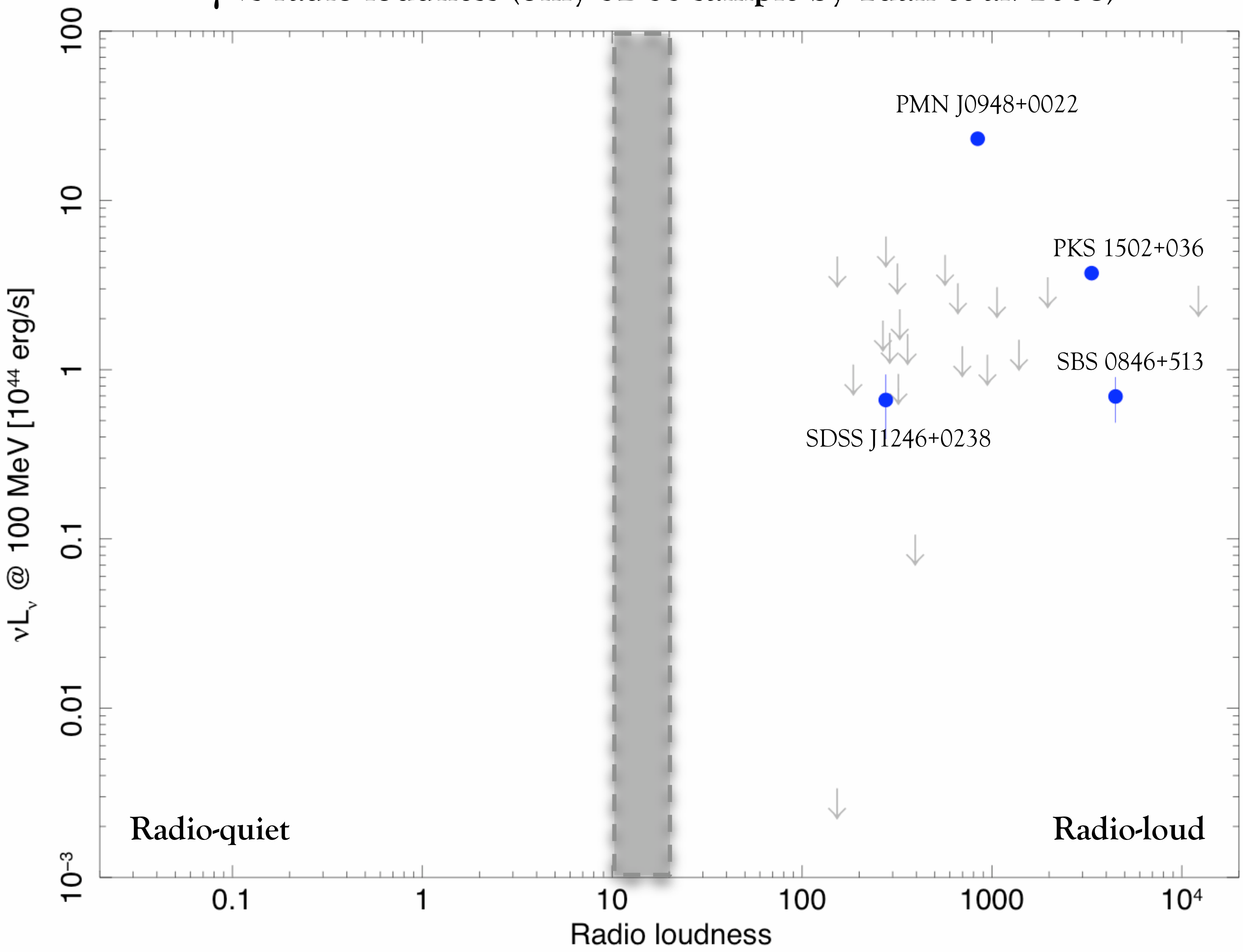
γ vs FWHM Hβ (only SDSS sample of Yuan et al. 2008)



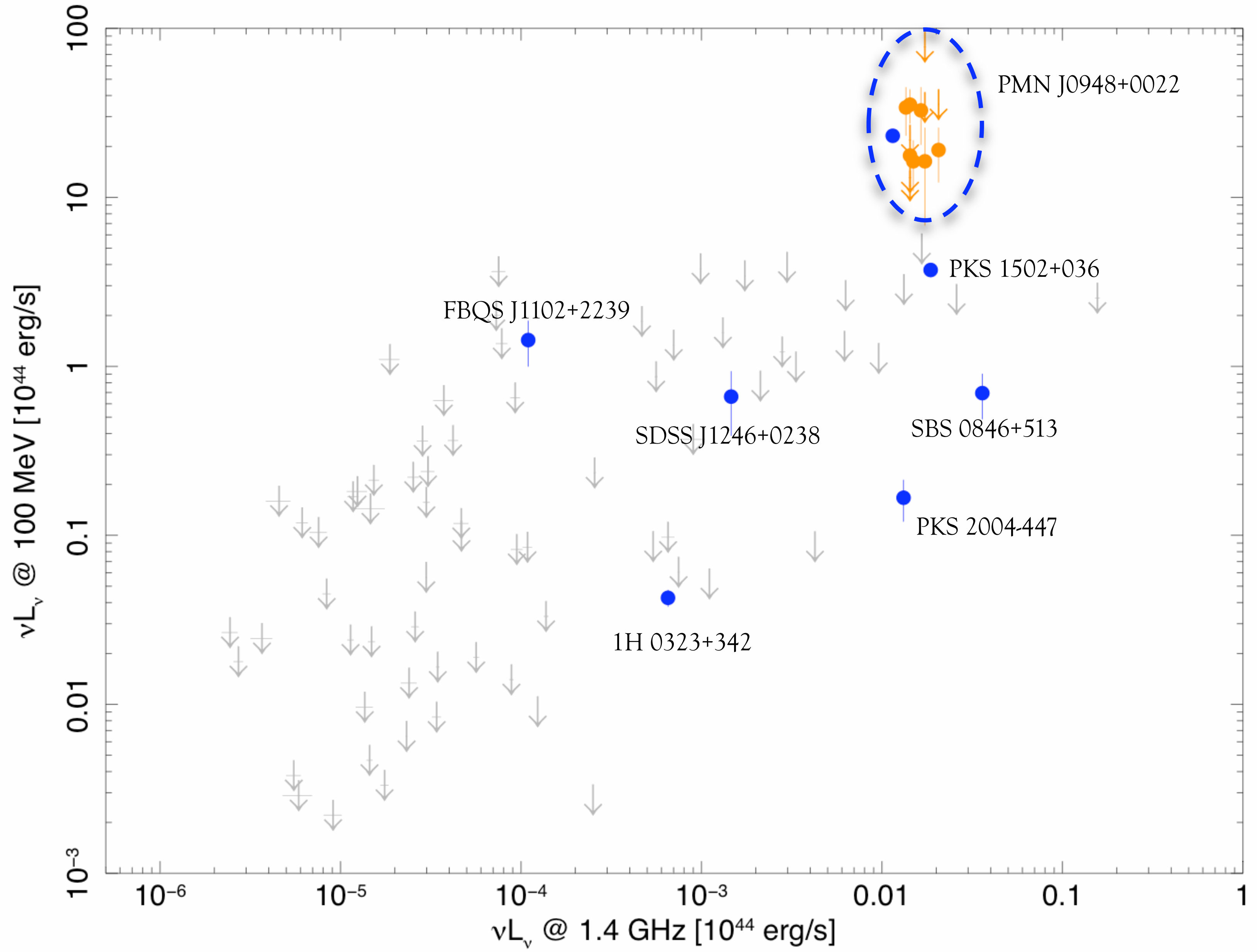
γ vs radio loudness



γ vs radio loudness (only SDSS sample by Yuan et al. 2008)

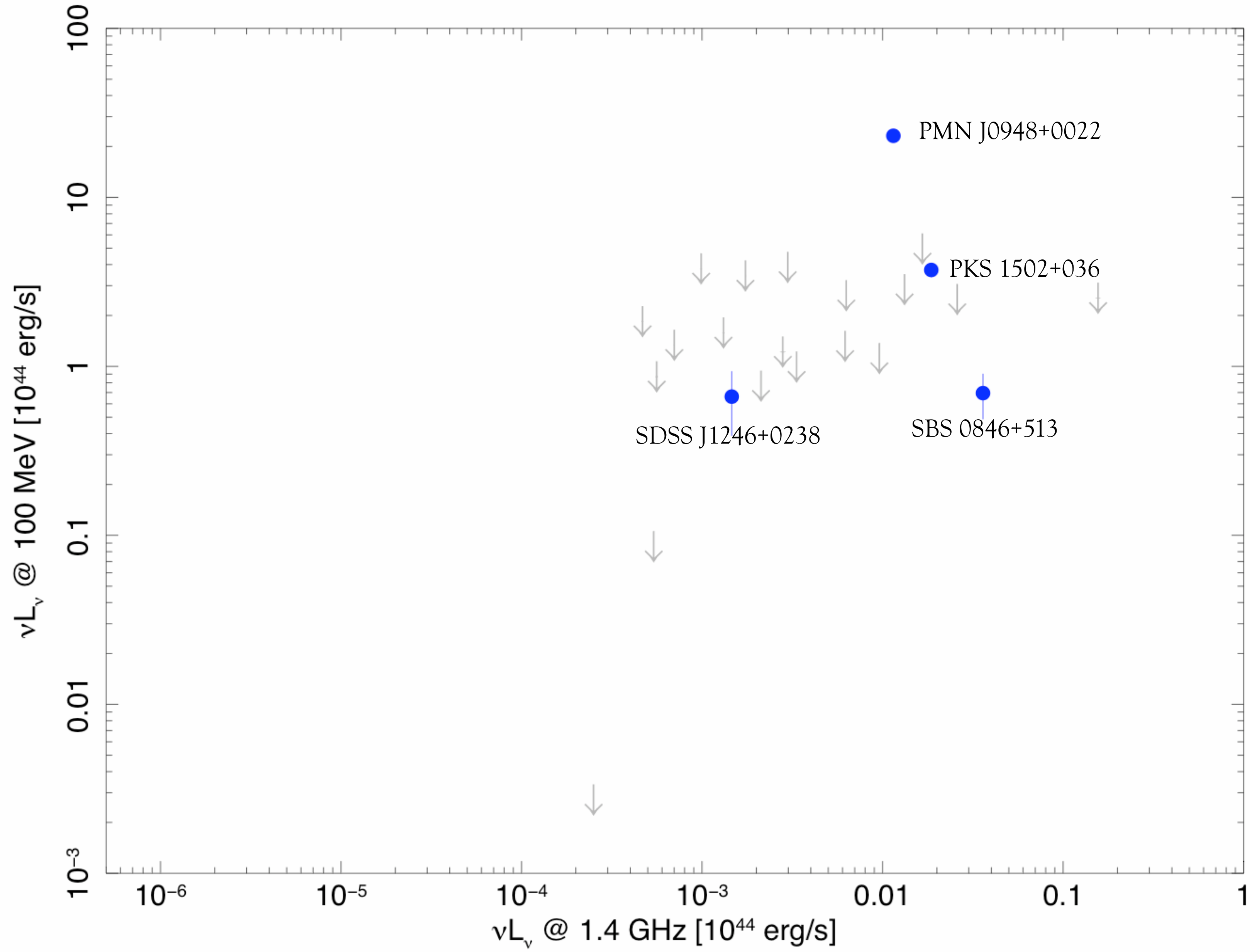


γ vs radio

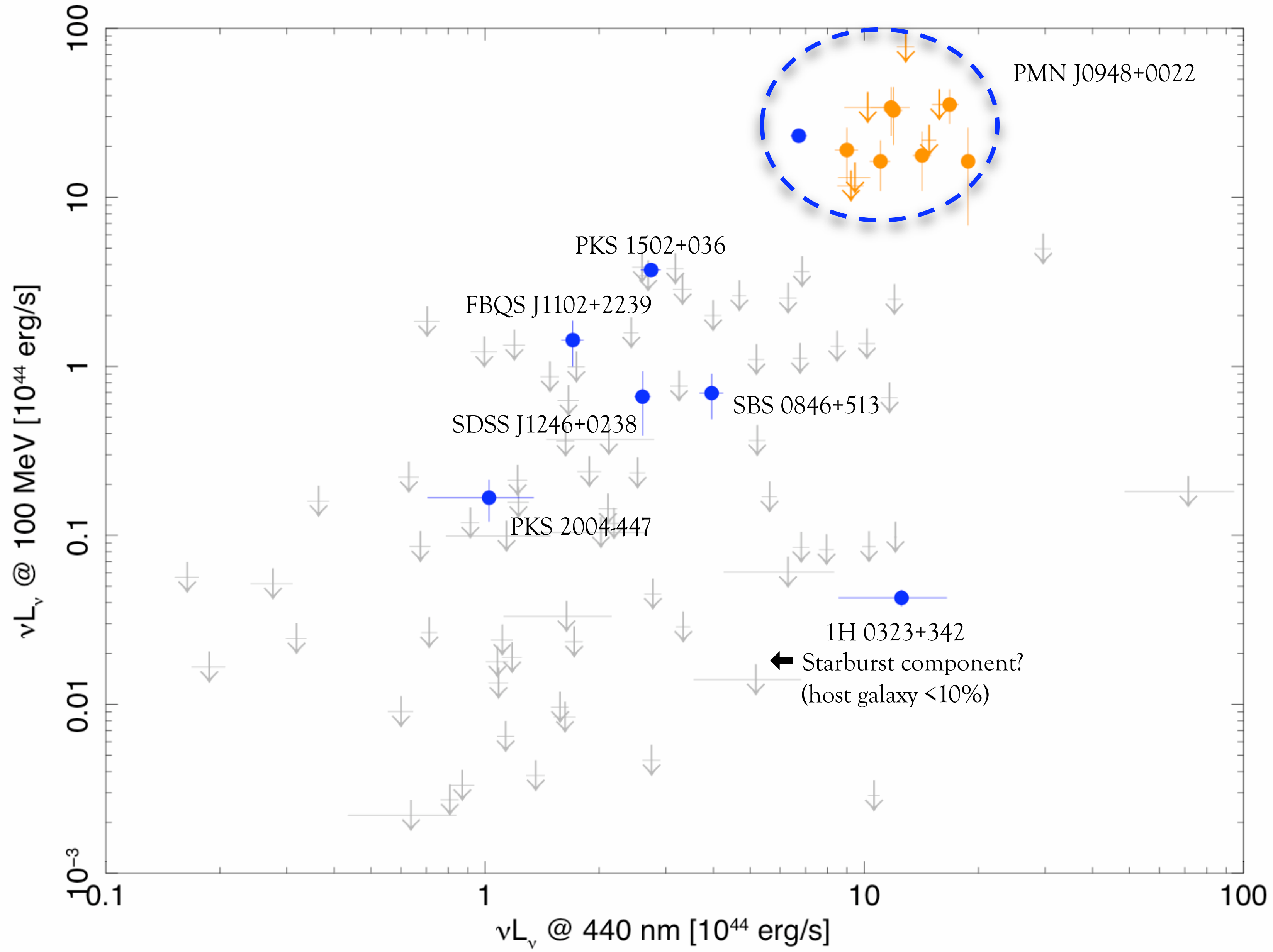


PMN J0948+0022
PKS 1502+036
FBQS J1102+2239
SDSS J1246+0238
SBS 0846+513
PKS 2004-447
1H 0323+342
νL_ν @ 100 MeV [10^{44} erg/s]
νL_ν @ 1.4 GHz [10^{44} erg/s]
100
10
1
0.1
0.01
10^{-3}
10^{-6}
10^{-5}
10^{-4}
10^{-3}
0.01
0.1
1

γ vs radio (only SDSS sample by Yuan et al. 2008)

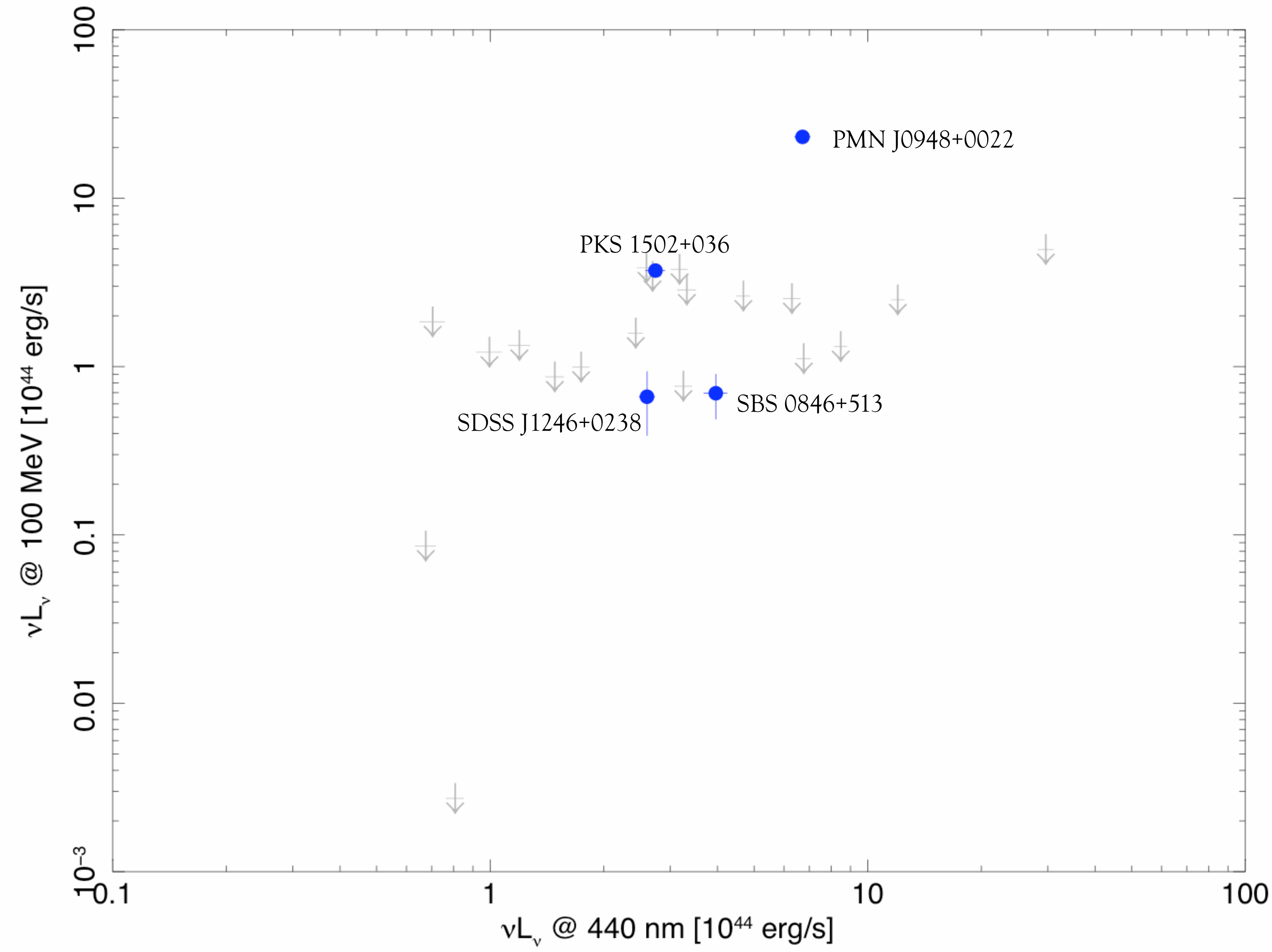


γ vs optical

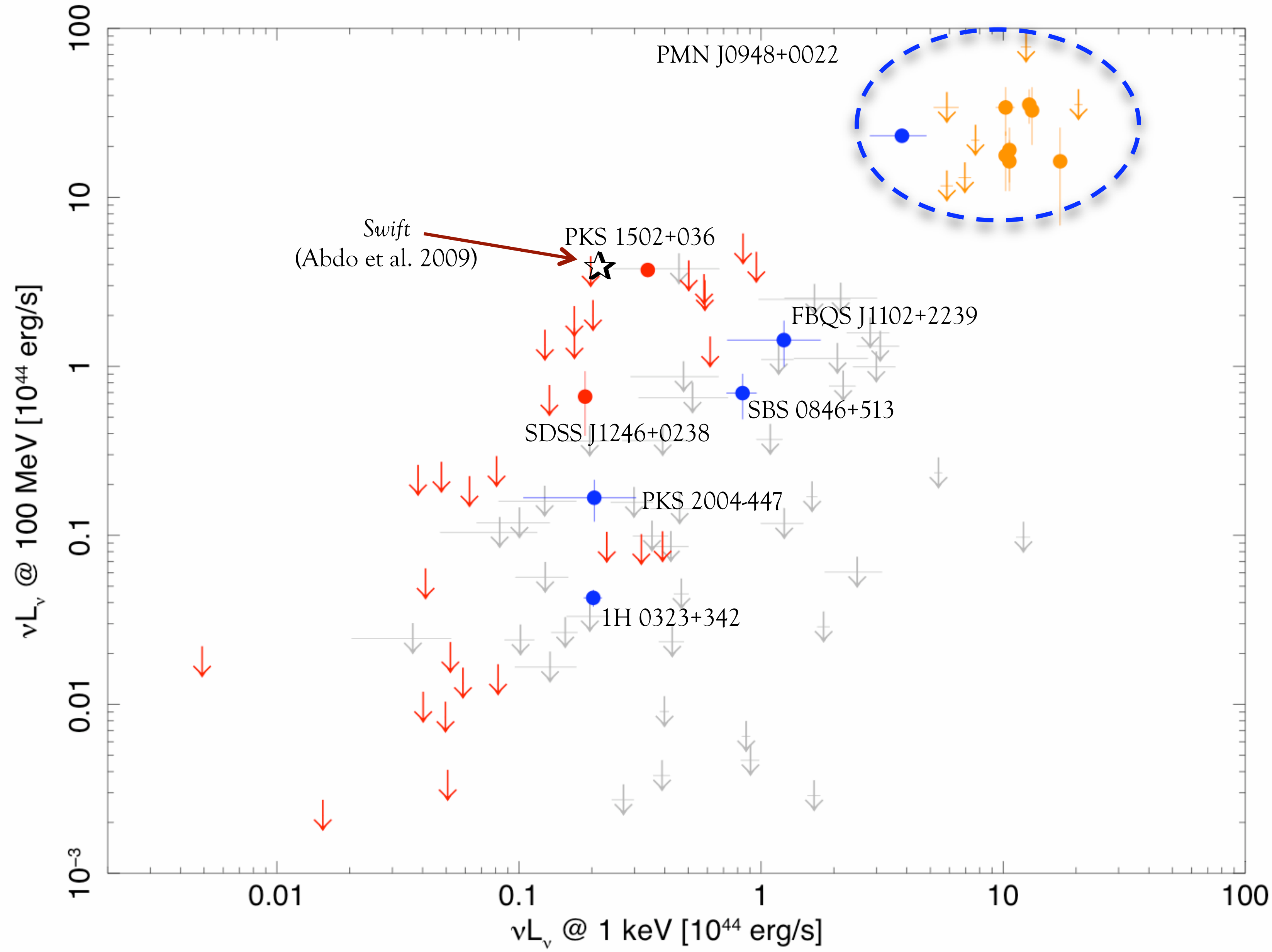


PMN J0948+0022
PKS 1502+036
FBQS J1102+2239
SBS 0846+513
SDSS J1246+0238
PKS 2004-447
1H 0323+342
Starburst component?
(host galaxy <10%)
νLν @ 100 MeV [10^44 erg/s]
νLν @ 440 nm [10^44 erg/s]
100
10
1
0.1
0.01
10^-3
0.1
1
10
100

γ vs optical (only SDSS sample by Yuan et al. 2008)

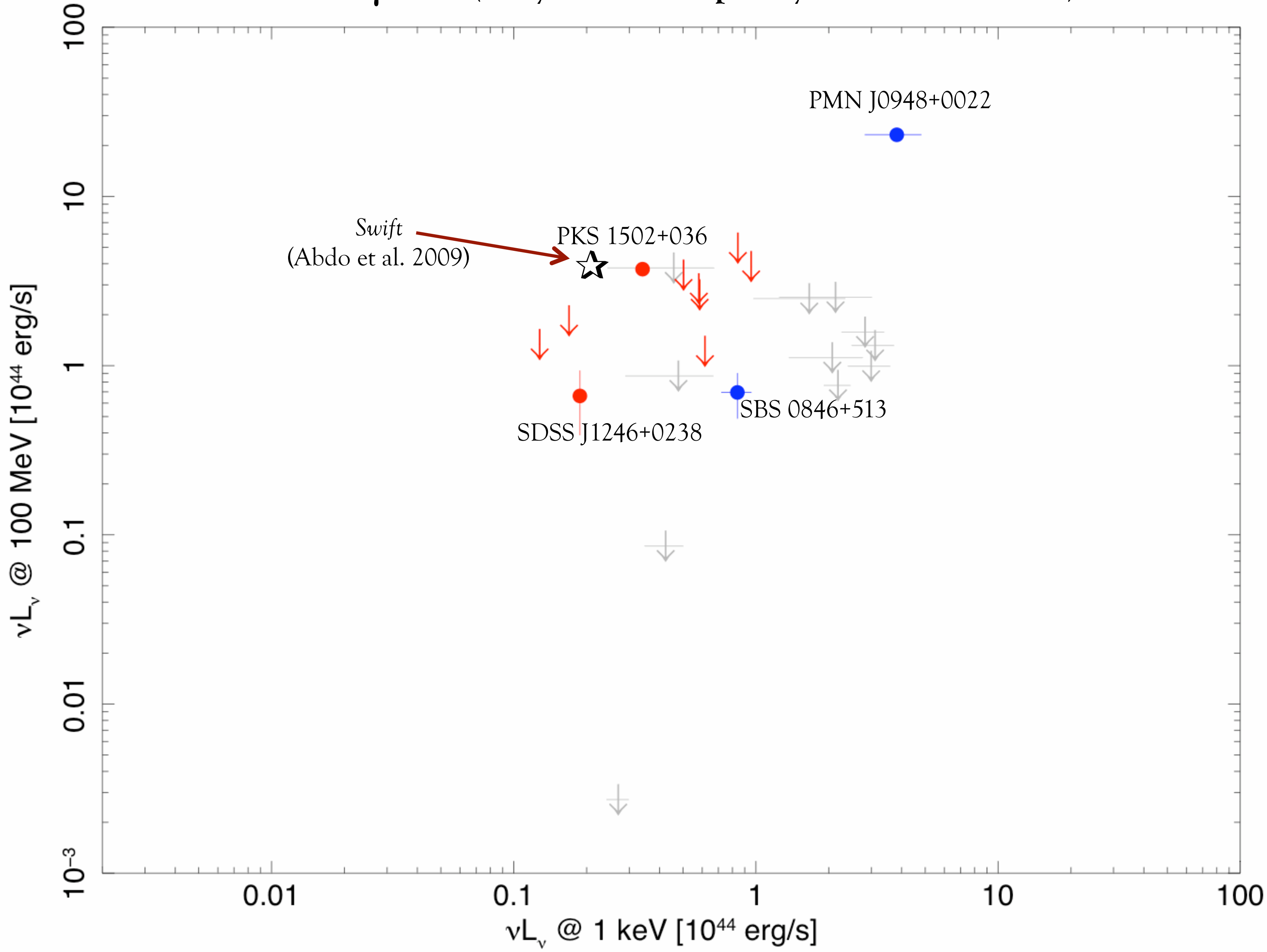


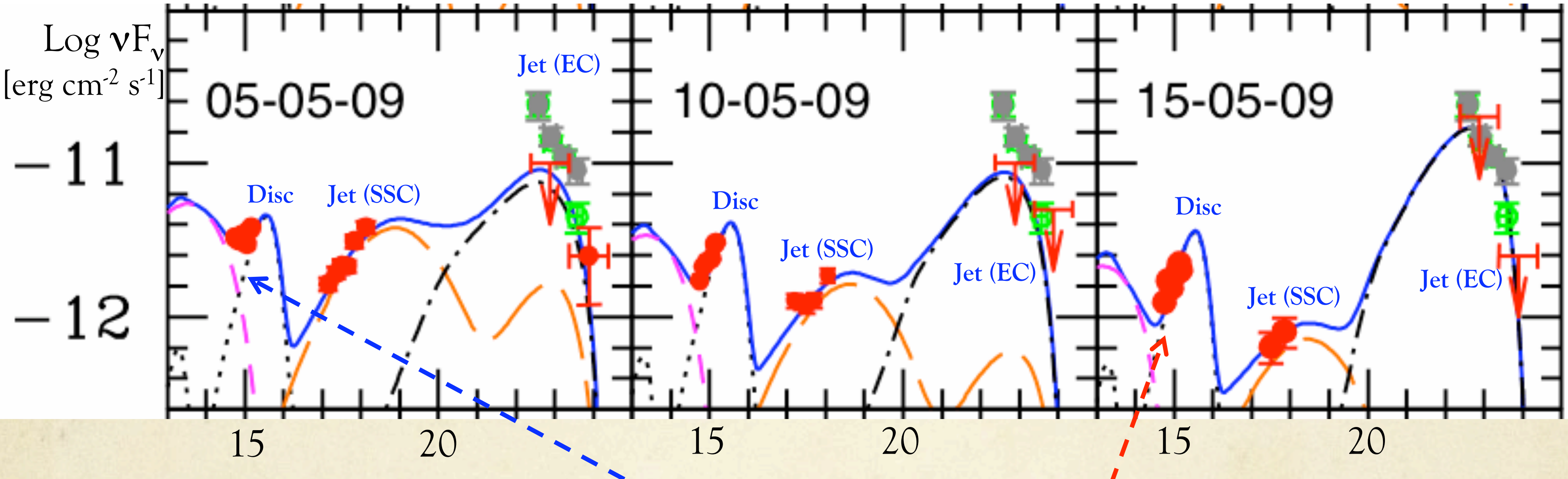
γ vs X



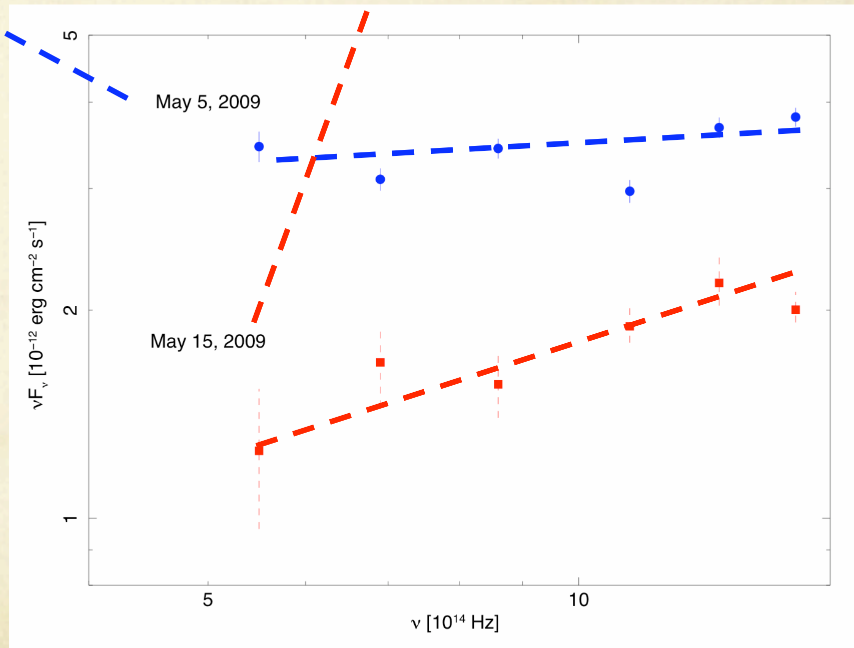
PMN J0948+0022
Swift
(Abdo et al. 2009)
PKS 1502+036
FBQS J1102+2239
SBS 0846+513
SDSS J1246+0238
PKS 2004-447
1H 0323+342
νL_ν @ 100 MeV [10^{44} erg/s]
νL_ν @ 1 keV [10^{44} erg/s]
100
10
1
0.1
0.01
10^{-3}
0.01
0.1
1
10
100

γ vs X (only SDSS sample by Yuan et al. 2008)





SED modeling by G. Ghisellini



2009 MW Campaign on J0948+0022

☟

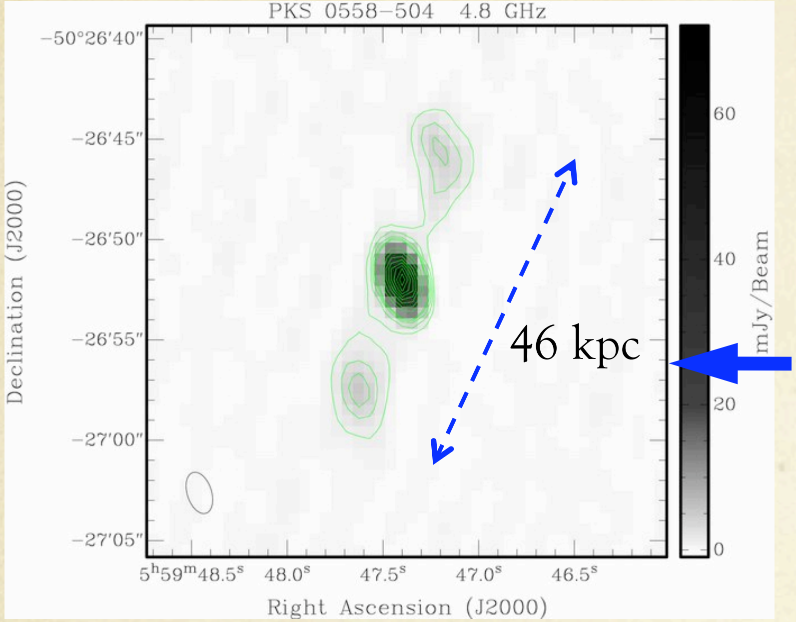
correlation between optical, X- and γ rays

☟

jet emission

Abdo et al. (contact author: L. Foschini), 2009, ApJ, 707, 727.

Search for the parent population: **radio galaxies in spirals**



For any number of beamed sources, with bulk Lorentz factor **Γ**, there should be a number $\propto \Gamma^2$ of un-beamed sources (parent population).

7 γ−NLS1 with **Γ**≈10 ⇒ ≈ 700 NLS1 RG

One found by Gliozzi et al. (2010) ☞ *talk*, which is PKS 0558-504, but where are the others??

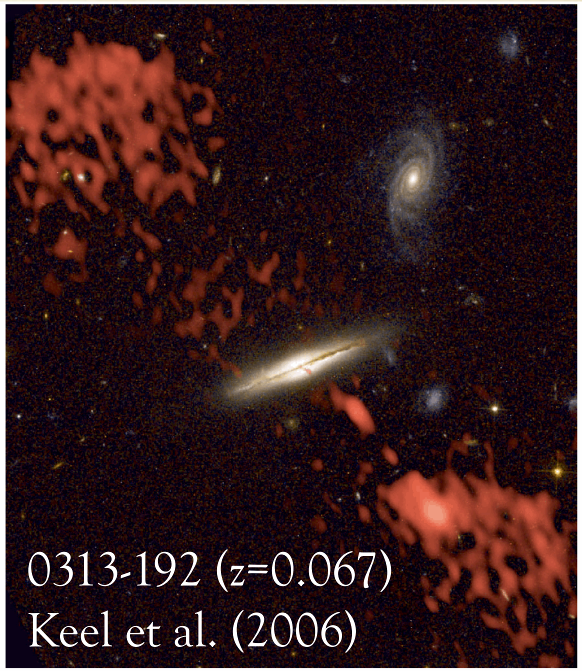
Should we search among NLS1 or among RG in spirals?

Some cases of RG in spirals are already available in literature, but they were not "seen". Possible misclassification of E with S0, but also the opposite (bright S0 are classified as E).

Some examples found (14), but checking for more sources...

2 γ-ray detections with *Fermi*: PKS 0336-177 (1LAC) and possibly PKS 1413+135 (under study); searching for more as data accumulate.

Inskip et al. (2010, MNRAS, 407, 1739) in a sample of 42 radio sources (2Jy sample) found that **12%** are hosted in "disk" galaxies.



0313-192 (*z*=0.067)
Keel et al. (2006)

CONCLUSIONS 1

Observational Facts

- *First detections at high-energy γ rays of NLS1 by using Fermi/LAT*
- *7 NLS1 detected to date;*
- *Relatively low masses (10^6-10^8 $M_\odot$)*
- *High accretion rate (>20% Eddington)*
- *Typical jet behavior: observed correlated multiwavelength activity*
- *One (1H 0323+342) surely hosted in a spiral galaxy; likely also the others (z < 1)*
- *Very compact radio morphology (< few tens of pc); no evidence of large scale structures, except for one (PKS 0558-504)*
- *No evident correlation in study of samples of γ rays with other wavelengths; this suggests that the present γ-ray detections are linked to the activity of the source: first NLS1 detected is PMN J0948+0022, which has been very active during the last 2 years (2 MW Campaigns); one of the latest detections is SBS 0846+513, which become active during the latest months; future detections regulated by sources activity.*

CONCLUSIONS 2

Implications and Open Questions

- *NLS1 is the third class of γ-ray* AGN, *after blazars (BL Lac+FSRQ) and radio galaxies.*

- *Collapse of the jet/elliptical paradigm: it is more and more evident that it was an observational bias. Worth reminding the words by* R. *Blandford in* 1978: *"As the continuum emission is proposed to originate in the central 10 pc, I don't think the nature of the surrounding object is particularly relevant to the model.". Now, it seems he was right!*

- *What is the mechanism triggering powerful relativistic jets?*

- *Are NLS1 very young sources, as suggested by several facts: redshift distribution (z<1), recent mergers residuals (and sometimes starburst activity), very compact radio structure*

- *What is the parent population?*