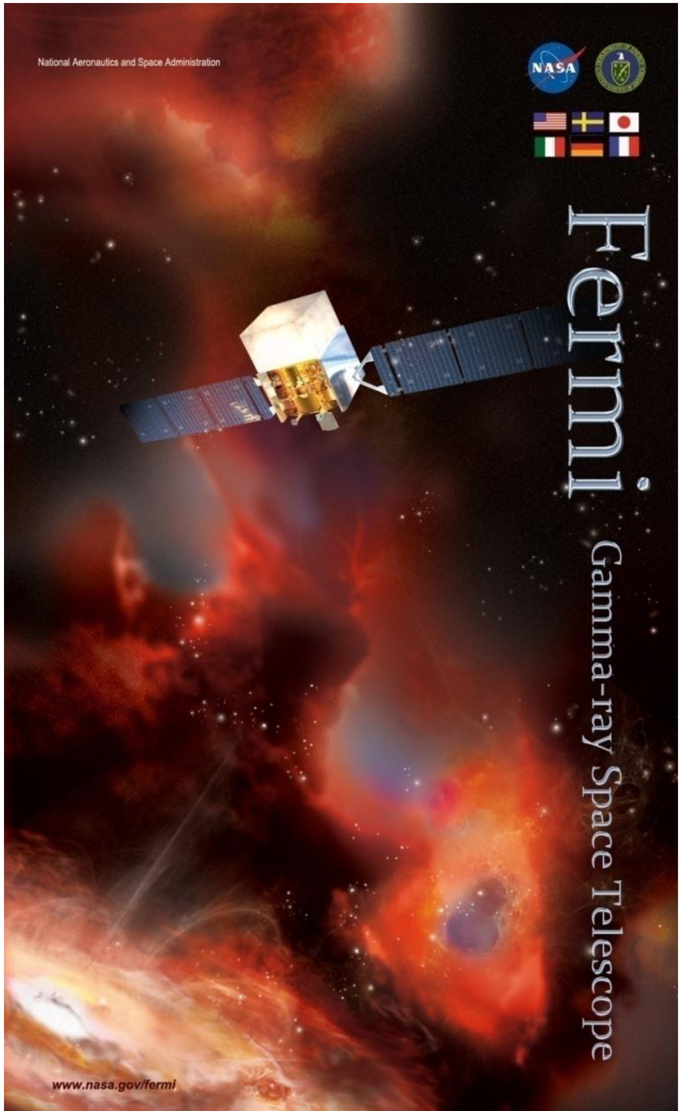
Fermi Gamma-ray Space Telescope

INAF Istituto di Radioastronomia



Relativistic jets in Narrow-Line Seyfert 1 galaxies. New discoveries and open questions.

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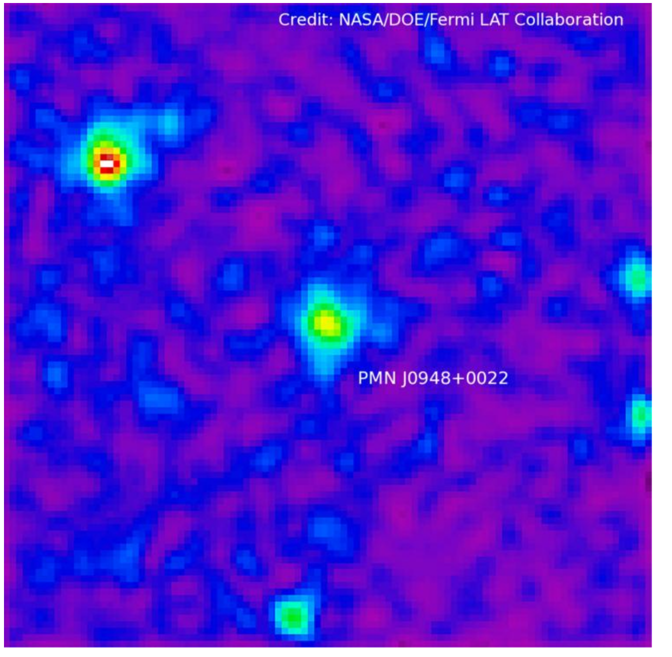
on behalf of the Fermi LAT Collaboration

Gamma-ray emitting NLSy1s

- Before the launch of the *Fermi* satellite, γ-ray emitting AGNs were only blazars and radio galaxies

- *Fermi*-LAT first 2 years of operation (1FGL and 2FGL) confirmed that the known extragalactic γ-ray sky is dominated by those two classes but...

...first detection of a γ-ray emitting Narrow-line Seyfert 1 in 2008: PMN J0948+0022 and after that other 4 NLSy1s were detected in gamma rays

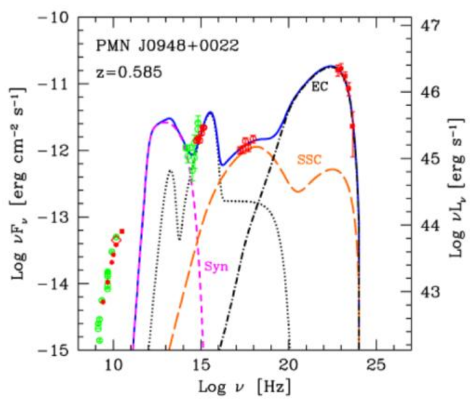


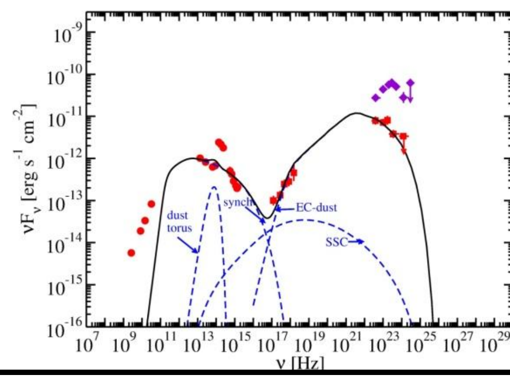
Confirmation of the presence of relativistic jets also in NLSy1s

NLSy1s are usually hosted in **spiral galaxies**, the presence of a relativistic jet in these objects seems to be in contrast to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies (e.g. Boettcher and Dermer 2002, Marscher 2010).

Narrow-Line Seyfert 1s and Fermi-LAT

5 Narrow-Line Seyfert 1s were detected at high significance





D'Ammando, Orienti, Finke et al. 2012

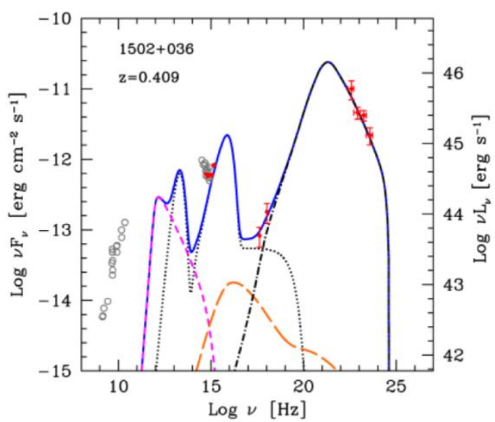
1H 0323+342

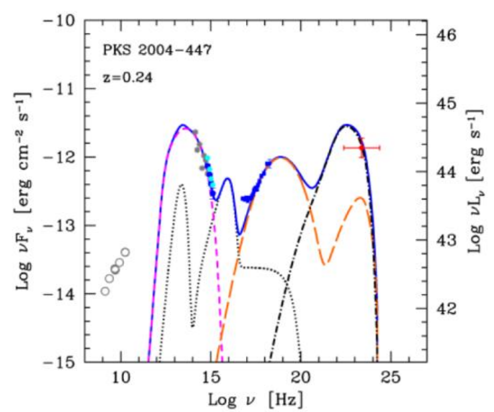
SBS 0846+513

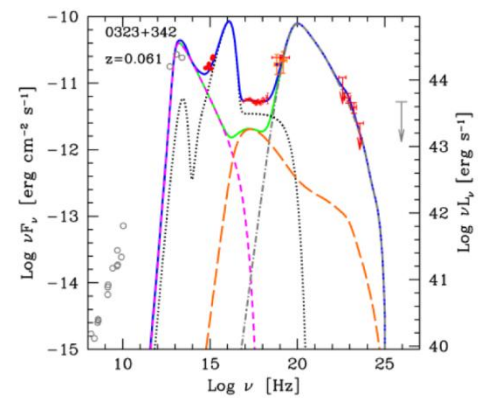
PMN J0948+0022

PKS 1502+036

PKS 2004-447

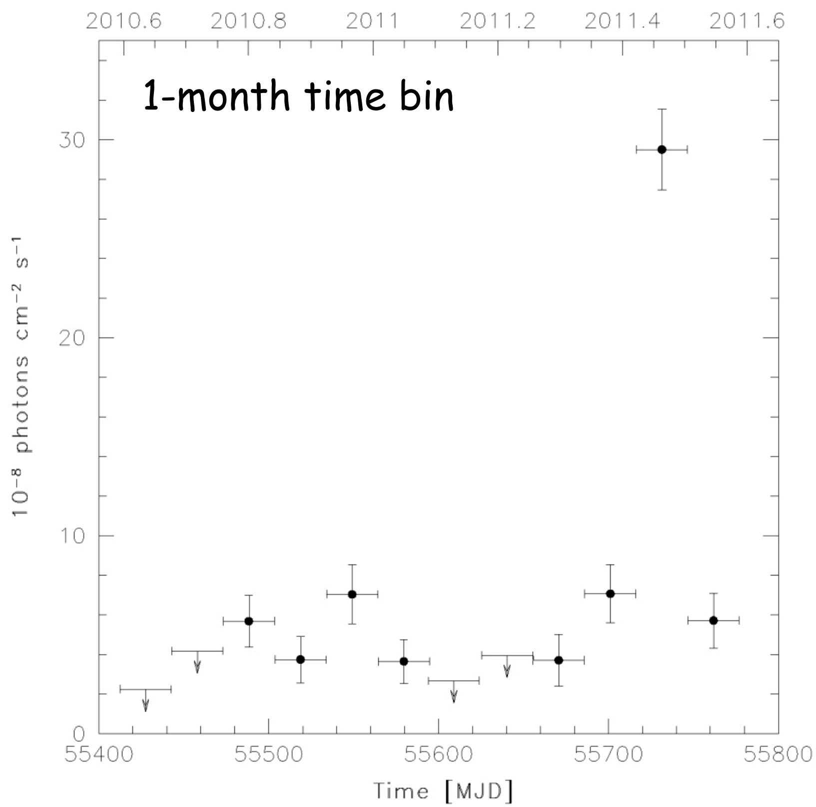






Abdo et al. 2009

SBS 0846+513: a new gamma-ray NLSy1

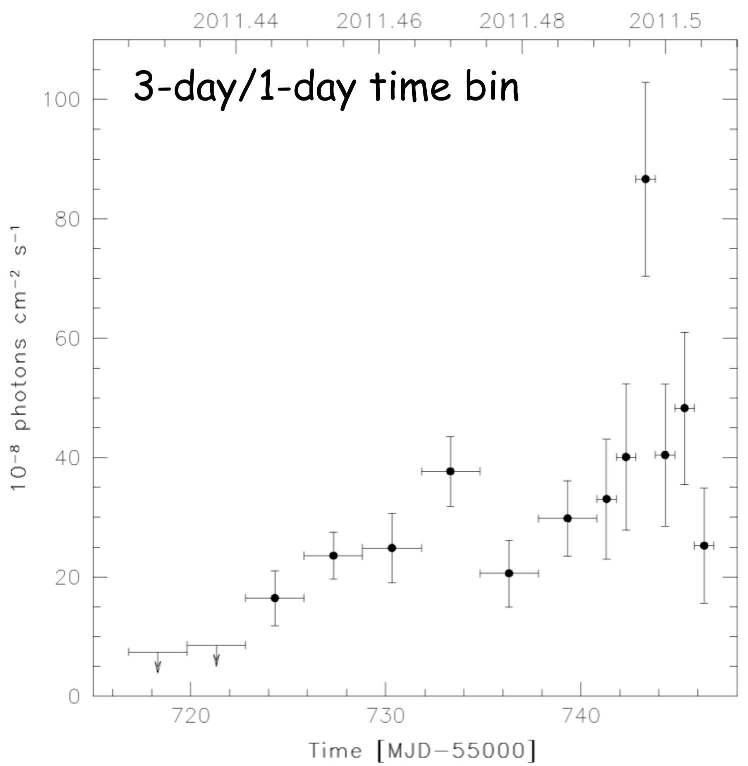


SBS 0846+513 was not detected in gamma rays with TS > 25 during the first 2 years of *Fermi* operation. UL ~8.5e-9 ph cm^{-2} s^{-1}

SBS 0846+513 was clearly detected in gamma rays with TS = 653 (~25σ) **during the third year of *Fermi* operation.** Flux $_{E>100\ MeV}$ = (6.7±0.5)e-8 ph cm^{-2} s^{-1} and Γ = 2.23±0.05

D'Ammando, Orienti, Finke, et al. 2012, MNRAS, 426, 317

A gamma-ray flare from SBS 0846+513



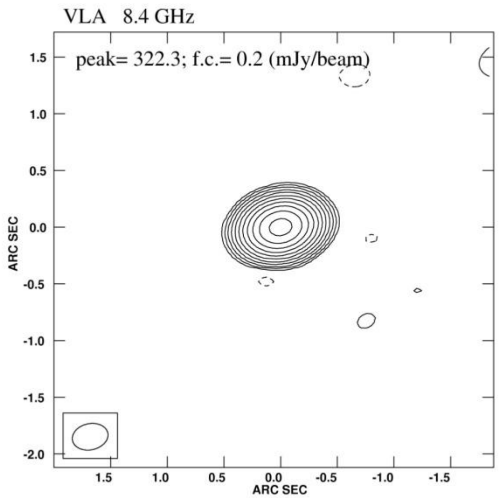
During the month of high activity there was spectral evolution in gamma rays, as already observed in other FSRQs

The gamma-ray peak with daily timescale on 30 June 2011 is (87±16)e-8 ph cm^{-2} s^{-1}, corresponding to an apparent isotropic luminosity of ***~10^{48} erg s^{-1}, comparable to that of the bright FSRQs***.

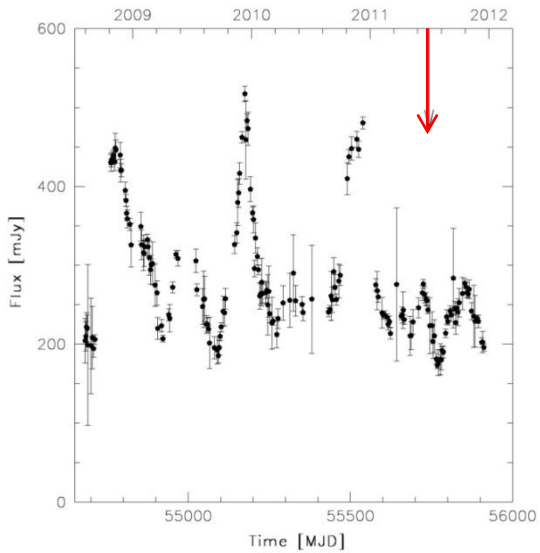
D'Ammando, Orienti, Finke , et al. 2012

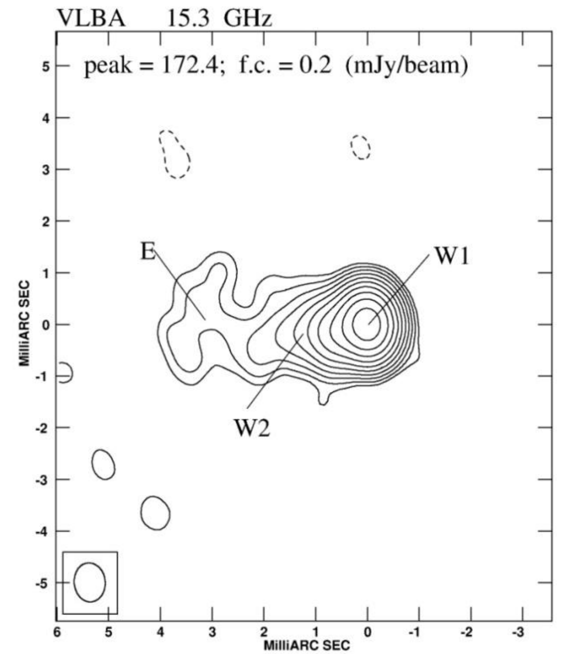
The radio view of SBS 0846+513

Core-jet structure on parsec scale. Unresolved with the VLA.



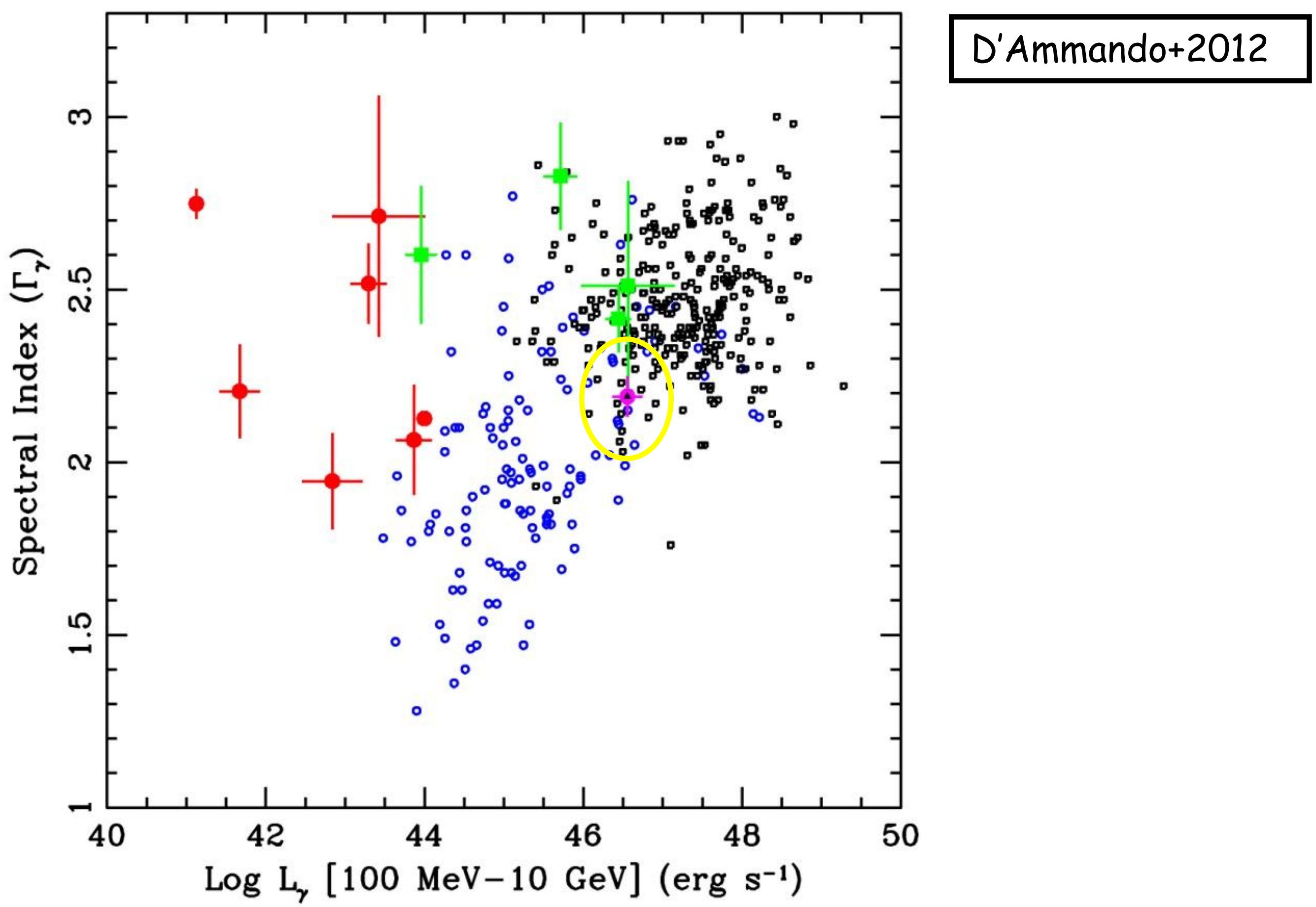
D'Ammando+2012





The OVRO light curve showed strong variability at 15 GHz, but not so high during the peak of the gamma-ray activity

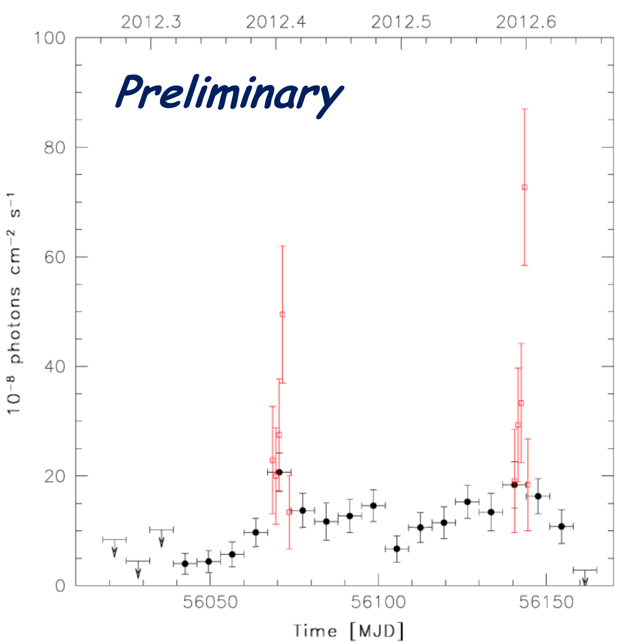
Gamma-ray luminosity and spectrum



The average apparent isotropic gamma-ray luminosity (0.1-10 GeV) is 3.6×10^{46} erg s^{-1} with Γ = 2.19. In the L_γ-Γ plane SBS 0846+513 lies in the blazar region

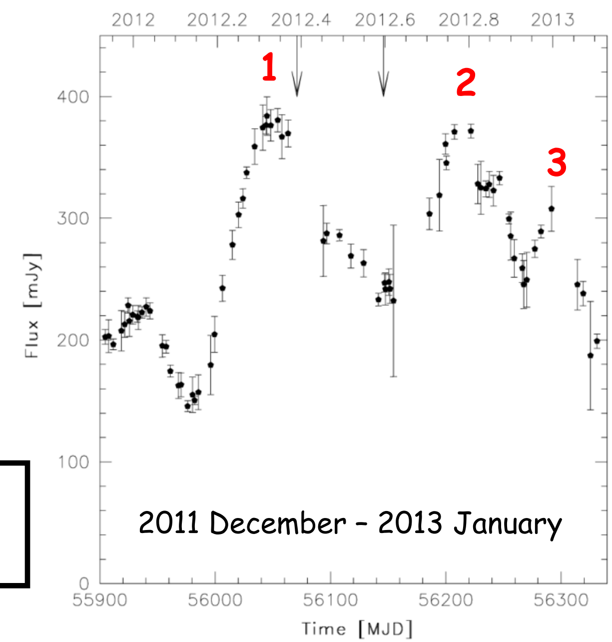
A new flaring activity from SBS 0846+513

2012 April - August



7-day time bins/1-day time bins

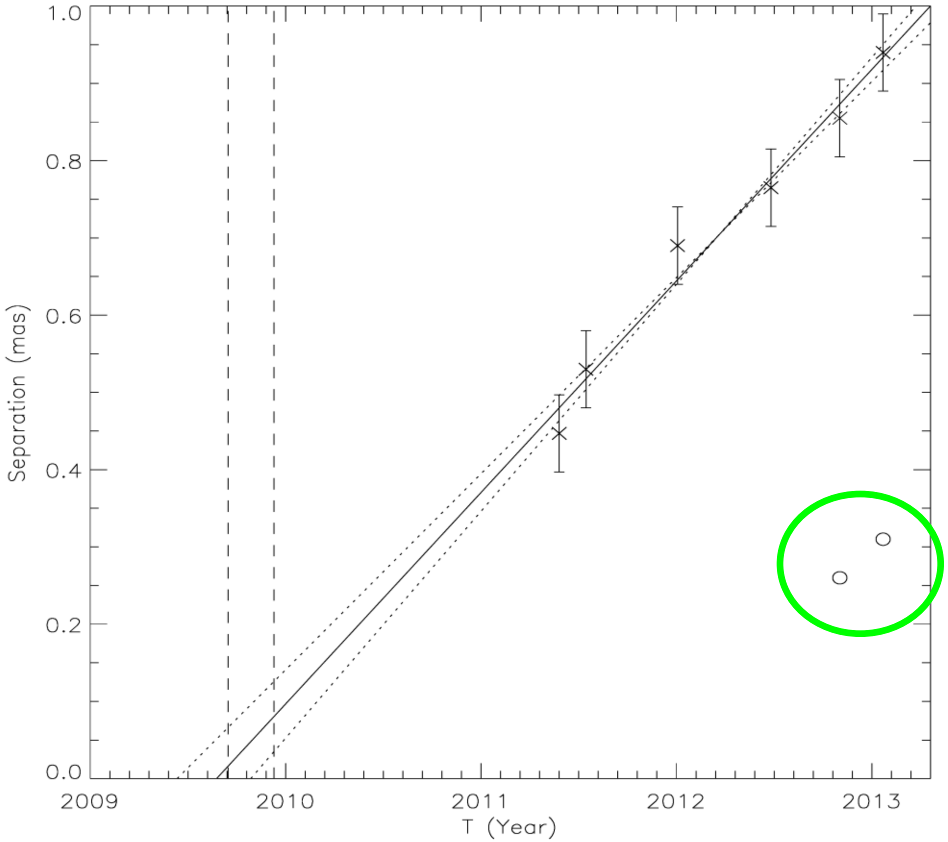
After some months of quiescent activity, two gamma-ray flaring episodes from SBS 0846+513 were observed in 2012 May and August, reaching a daily peak flux of (50±12)e-8 and (73±14)e-8 ph cm^{-2} s^{-1}

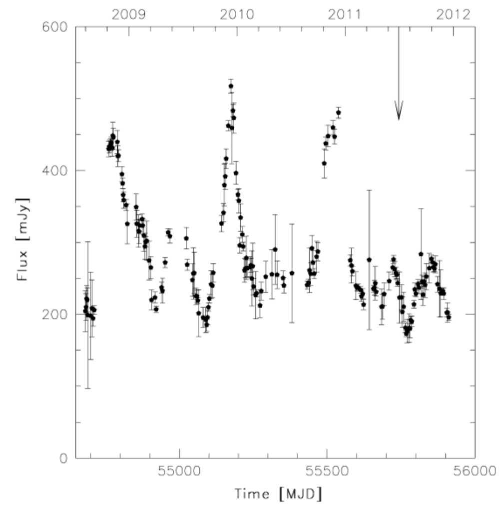


Variable at 15 GHz, with 3 outbursts detected in 2012 May, 2012 October, and 2012 December-2013 January

D'Ammando, Orienti, Finke, et al. 2013, MNRAS submitted

Proper motion of SBS 0846+513



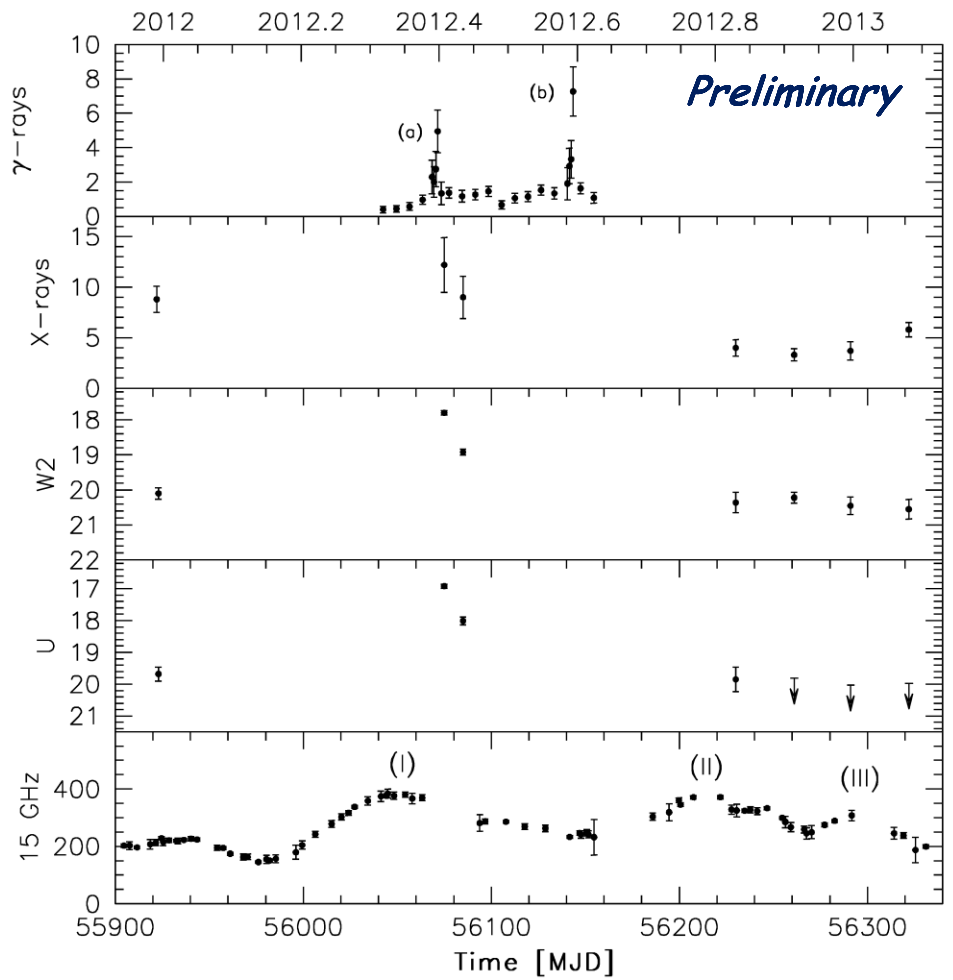


D'Ammando+2012

Tentative detection of a new feature

With 6-epoch MOJAVE data we obtained an apparent velocity of the jet knot **(9.3±0.6)c**, suggesting **the presence of boosting effect as well as in blazars**. The time of ejection is **T_0 = 24 August 2009**, likely connected with a radio flare. No significant gamma-ray activity was detected in that period.

Multifrequency light curves of SBS 0846+513



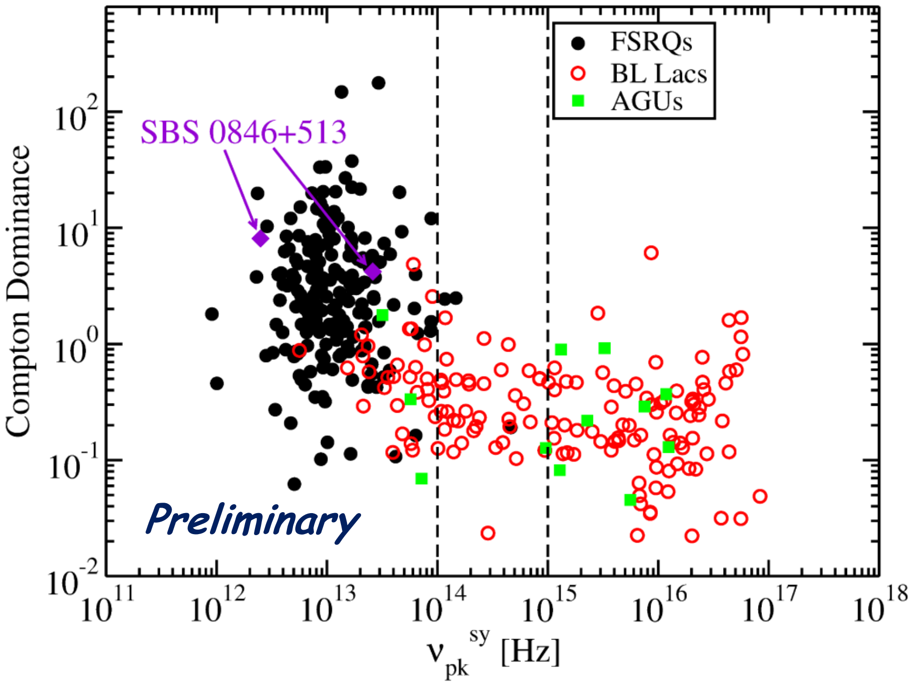
A significant increase of the activity was detected almost simultaneously in the optical, UV, X-ray and gamma-ray bands during 2012 May, enabling us to firmly identify the gamma-ray source with the NLSy1 SBS 0846+513

The relation between the radio and gamma-ray activity seems to be complex. Two possible scenarios are proposed :

- the radio and γ-ray emission in 2012 May could be originated in the same region at large distance from the BH

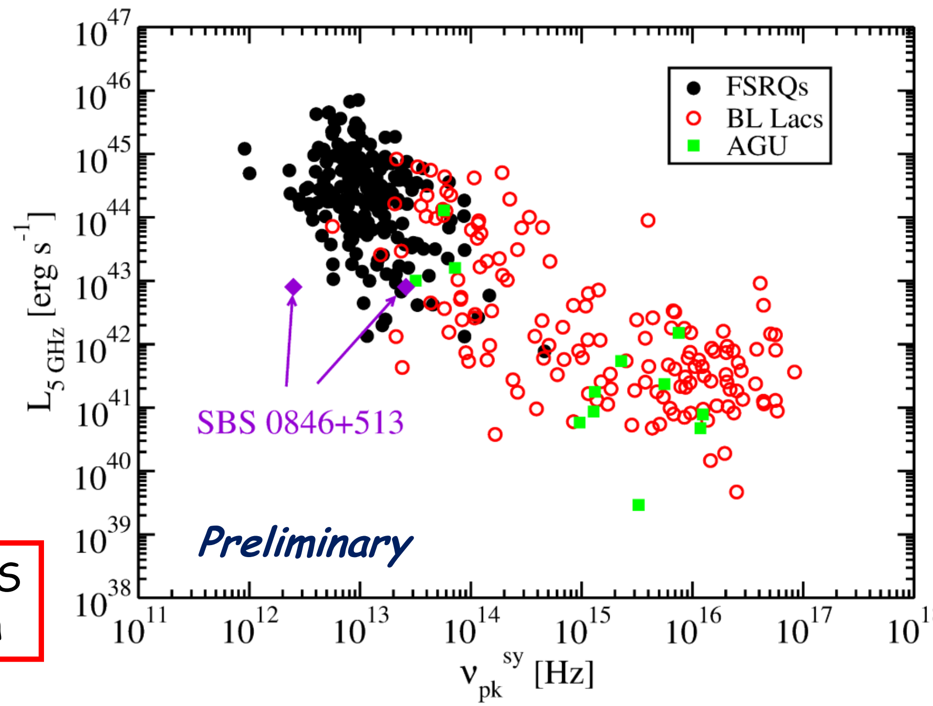
- the two γ-ray flaring episodes may be related to the radio activity in 2012 October and 2013 January

Comparison with blazars



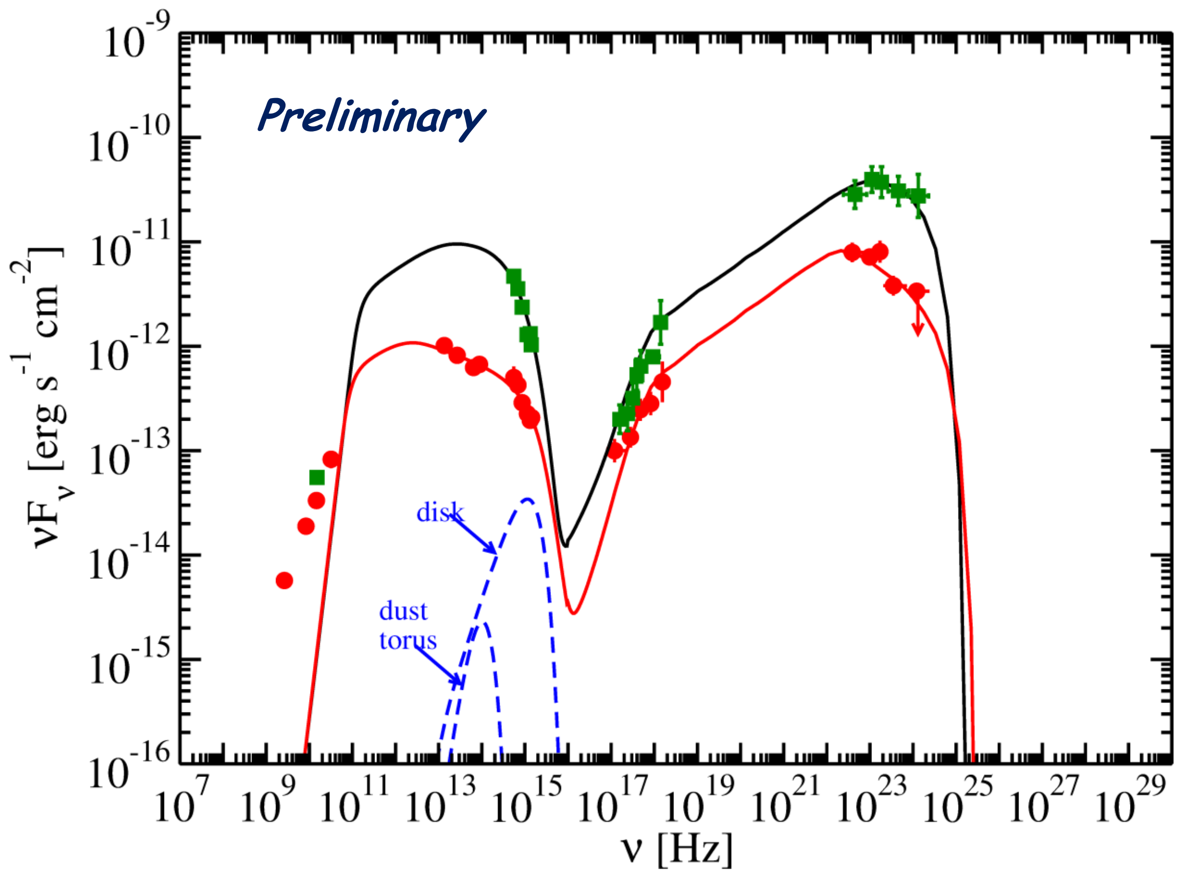
SBS 0846+513 showed a Compton dominance typical of FSRQs during both the low and high activity state

Figures adapted from Finke 2013



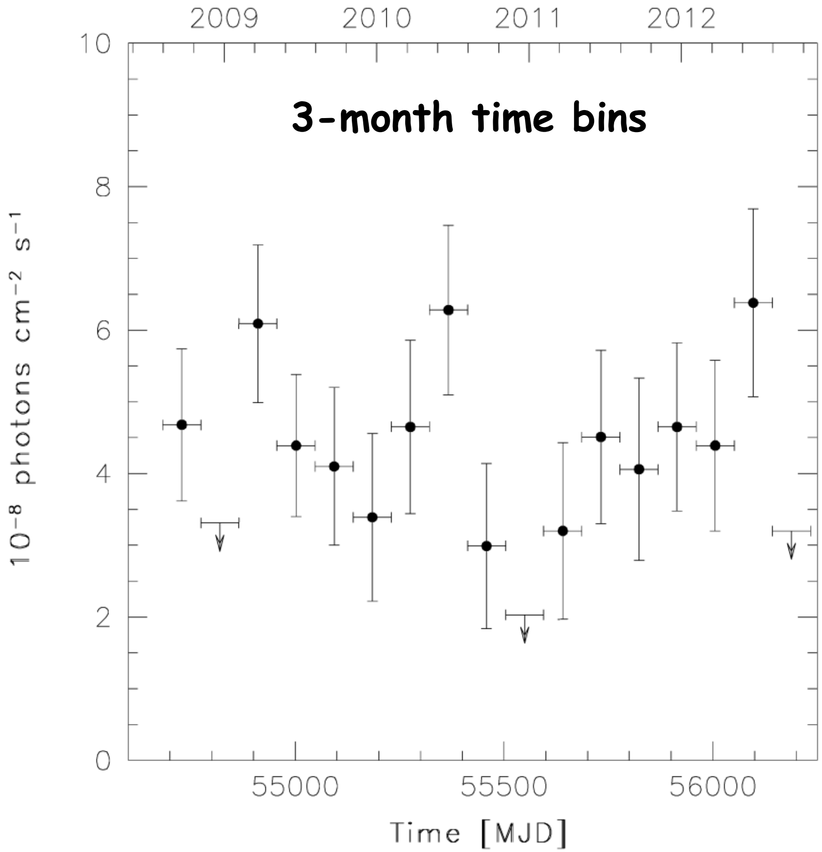
In the "classical" blazar sequence plot SBS 0846+513 seems to lie in the FSRQ region

SED modeling of SBS 0846+513



The quiescent and flaring state, modelled by EC (dust), could be fitted by changing the electron distribution parameters as well as the magnetic field.
During the flaring state a radiative power of 3×10^{44} erg s^{-1} was released by SBS 0846+513, ~5% of its Eddington luminosity (assuming a BH of 5×10^{7} solar masses)

The ordinary life of PKS 1502+036

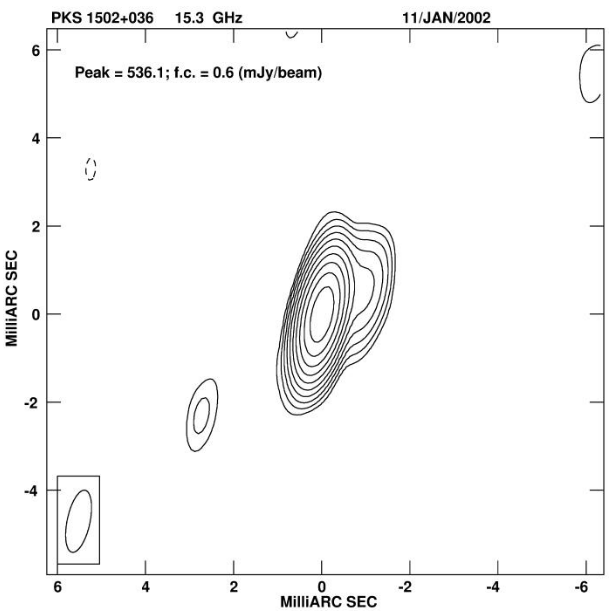


PKS 1502+036 was detected by LAT over 51 months (2008 August 4 – 2012 November 4) with TS = 314, an average flux (0.1-100 GeV) of (4.0 ± 0.4)e-8 ph cm^{-2} s^{-1} and a photon index $\Gamma = 2.60\pm0.06$

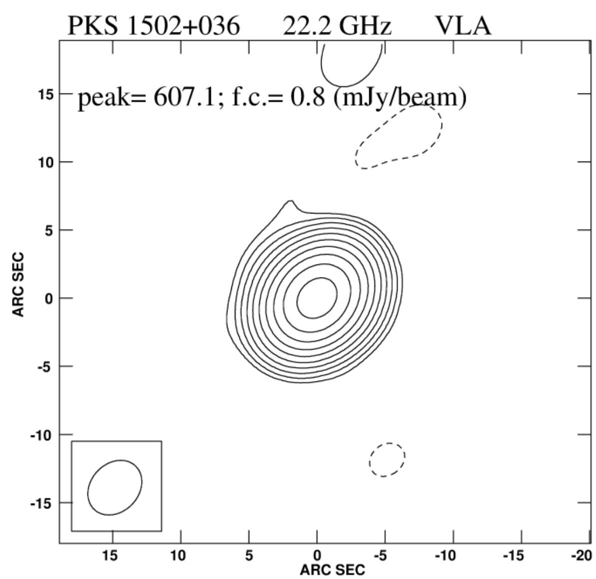
No significant flux variability, with only a few detections on weekly time scale and a peak value of (18 ± 6)e-8 ph cm^{-2} s^{-1}

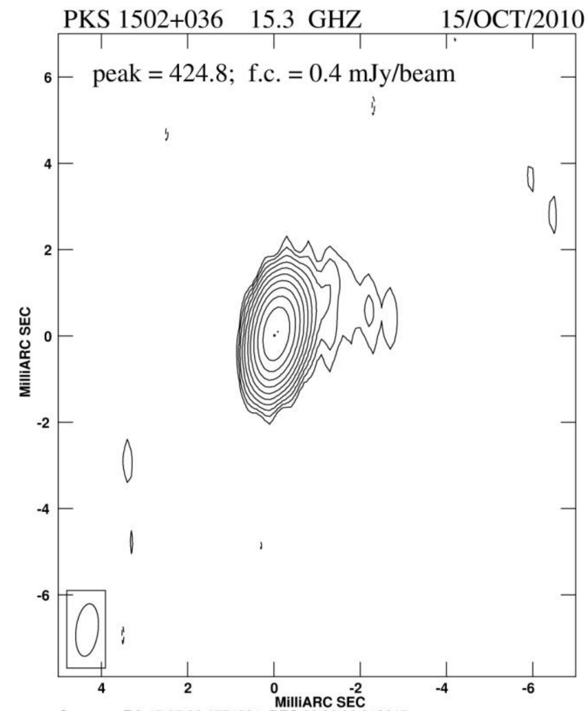
D'Ammando, Orienti, Doi et al. 2013, MNRAS in press

Radio structure of PKS 1502+036



The source is unresolved on the VLA arcsec scale. ***A core-jet morphology*** is quite evident in the 15 GHz VLBA images

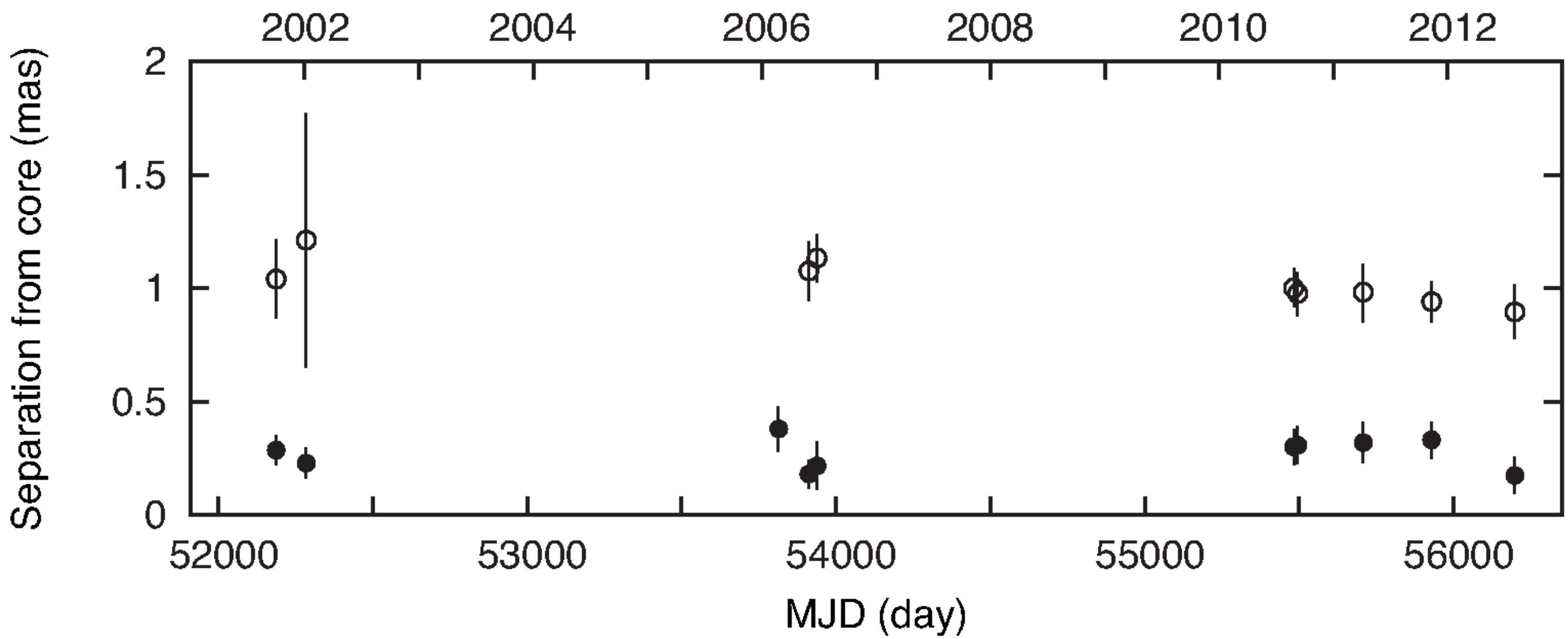




The radio emission is dominated by the core, while the jet-like feature accounts for about 4% of the total flux density

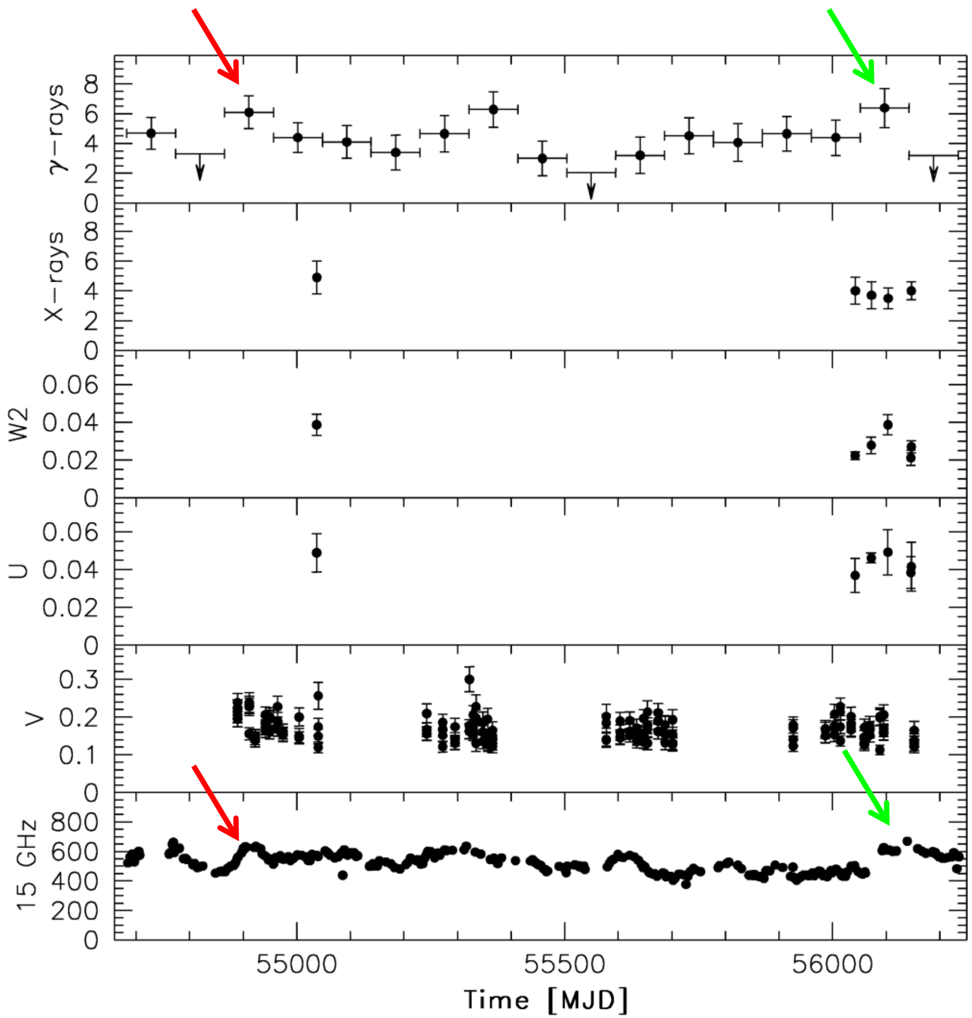
D'Ammando, Orienti, Doi, et al. 2013

Proper motion of PKS 1502+036



On the contrary of what is found in SBS 0846+513, no significant proper motion ws detected for the jet components of PKS 1502+036

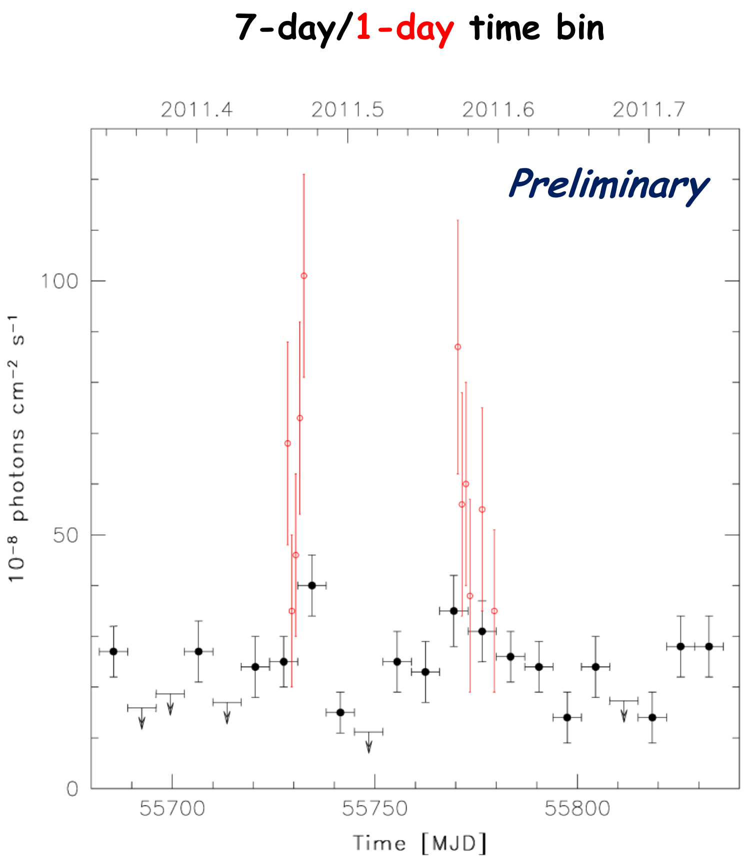
Multifrequency light curves of PKS 1502+036

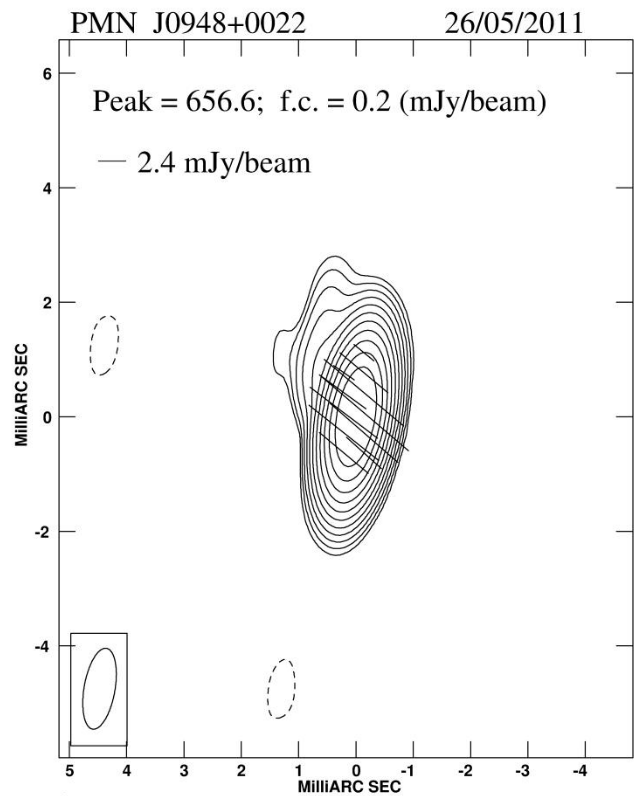


No flaring episodes have been detected in gamma-rays but a flux density increase at 15 GHz has been observed during period of relatively high gamma-ray emission

A slight increase from radio to UV has been observed at the end of 2012 June during a period of relatively high gamma-ray emission

A second gamma-ray flare of PMN J0948+0022

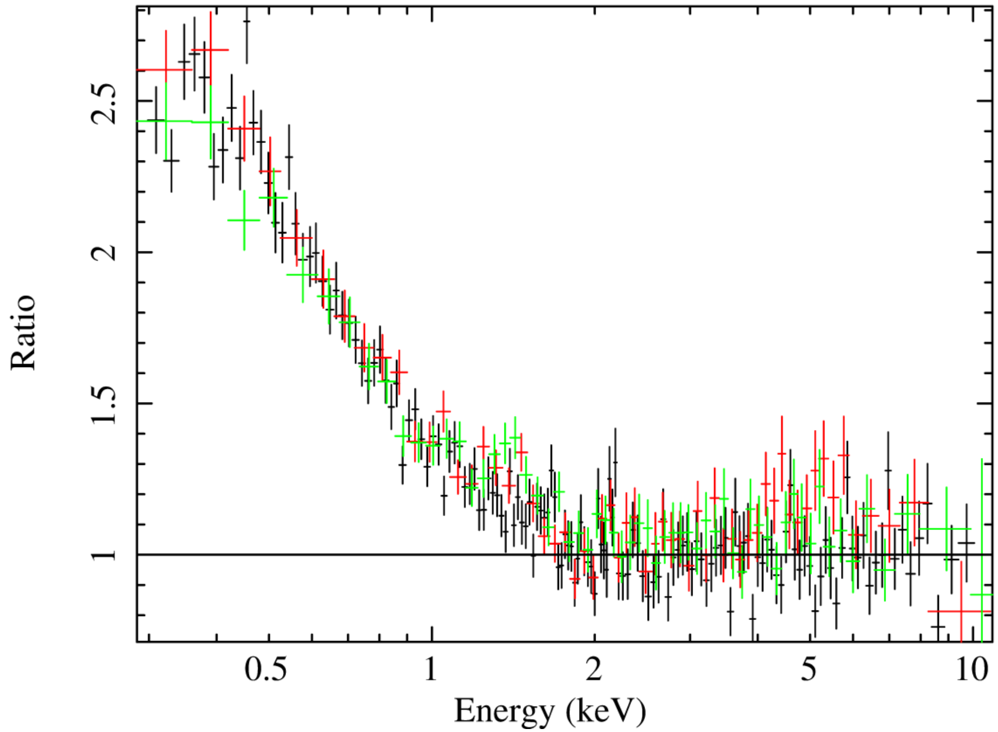




D'Ammando, Larsson, Orienti, et al. in prep

$L_\gamma \sim 10^{48}$ erg s^{-1} at peak on 20 June 2011, comparable to the July 2010 flare.
A possible core-jet structure was observed on parsec scale.

XMM observation of PMN J0948+0022



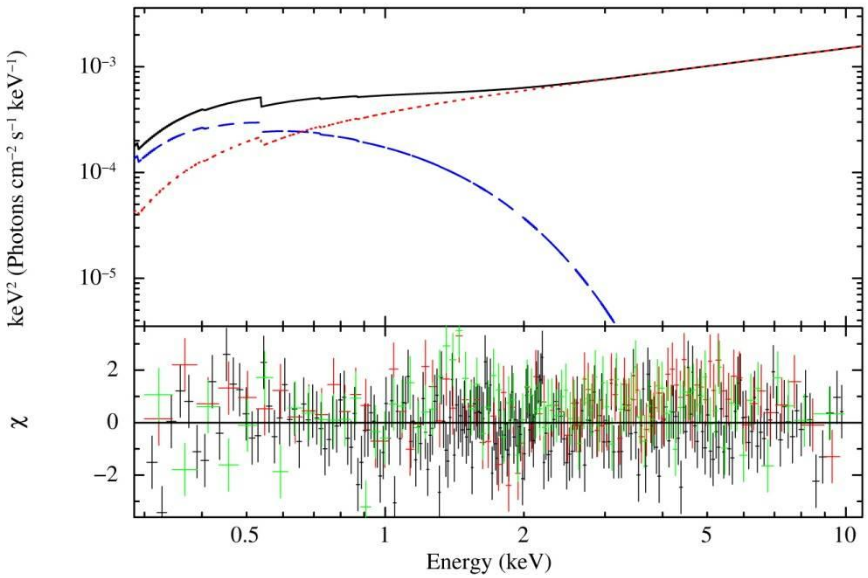
Γ = 1.88 $\pm$ 0.01 in the 0.3-10 keV energy range, χ^2_{red} = 1.87/1253

A simple power law in 2-10 keV is a good fit Γ = 1.48$\pm$0.03

A clear *soft excess* observed, notwithstanding the non-thermal jet emission!

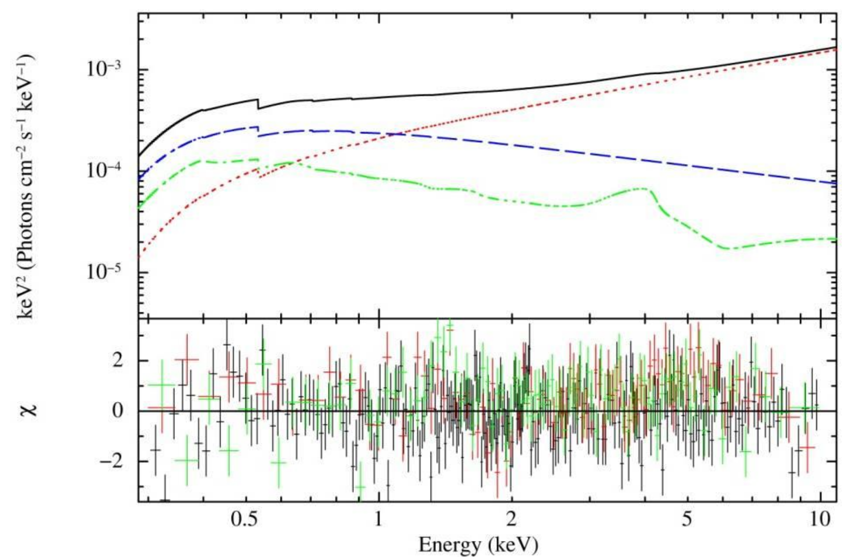
A power law + black body give a good fit (χ^2_{red} = 1.06/1251) Γ = 1.44 $\pm$ 0.03, kT = 0.18 keV. Such a high temperature is inconsistent with the standard accretion disk theory

XMM observation of PMN J0948+0022 (II)

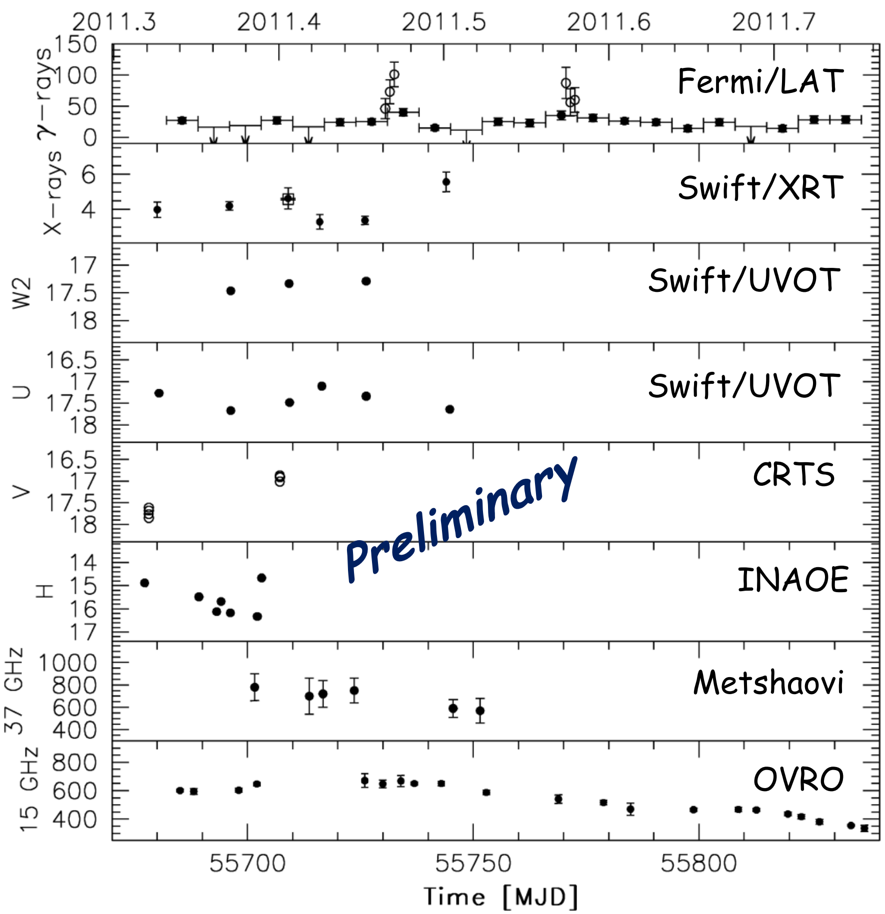


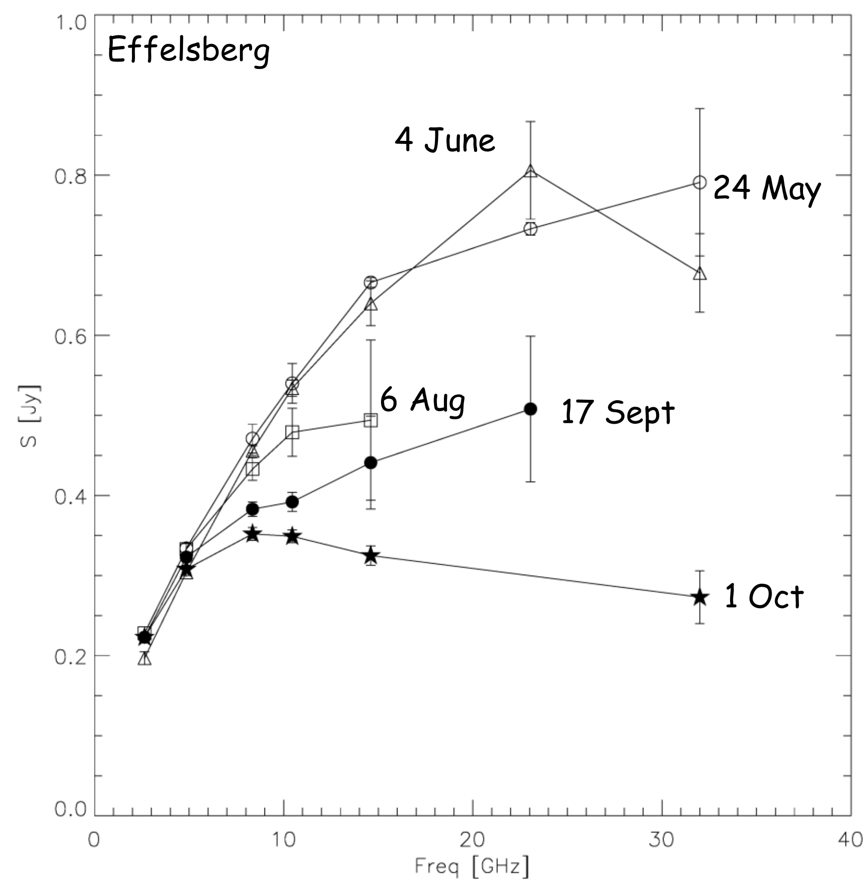
Soft excess modeled as componization of the disc emission by a population of electrons with low temperature and large optical depth (in a transition between the disc and the corona) gives a good fit (χ^2_{red} = 1.06/1251)

Soft excess modeled as relativistic blurred reflection from the accretion disk. The X-ray spectrum is composed by a steep spectrum (corona), a reflection component and a hard power-law associated with the jet



MWL data of PMN J0948+0022





Radio spectra and fluxes show a high activity of the source still in 2011 May 2 ***before*** the peak of the gamma-ray activity

Concluding Remarks

• At least two gamma-ray Narrow-Line Seyfert 1s showed intense gamma-ray flares, thus NLSy1 can host relativistic jets as powerful as blazars. Are these two sources peculiar also among the NLSy1s?

• Radio and gamma-ray data collected for SBS 0846+513 and PMN J0948+0022 suggest spectral and variability properties similar to blazars, but a complex radio and gamma-ray connection was observed for SBS 0846+513 during 2009-2013. The modelling of the SED of the gamma-ray emitting NLSy1s gives similar results to those of blazars

• A core-jet structure was detected in VLBA images of PKS 1502+036 and SBS 0846+513, but apparent superluminal velocity was observed only in SBS 0846+513

• *The discovery of relativistic jets in a class of AGN usually hosted by spiral galaxies was a great surprise but…*

BH masses of radio-loud NLSy1s on average are larger than the entire sample of NLSy1s. This could be related to prolonged accretion episodes that can spin-up the BH leading to the relativistic jet formation. Only for a small fraction of NLSy1s the high accretion lasts sufficiently long to significantly spin-up the BH

• **These gamma-ray NLSy1s could be low mass (and possibly younger) version of the blazars in which the relativistic jet formation was triggered by a merger**

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Thanks for your attention!

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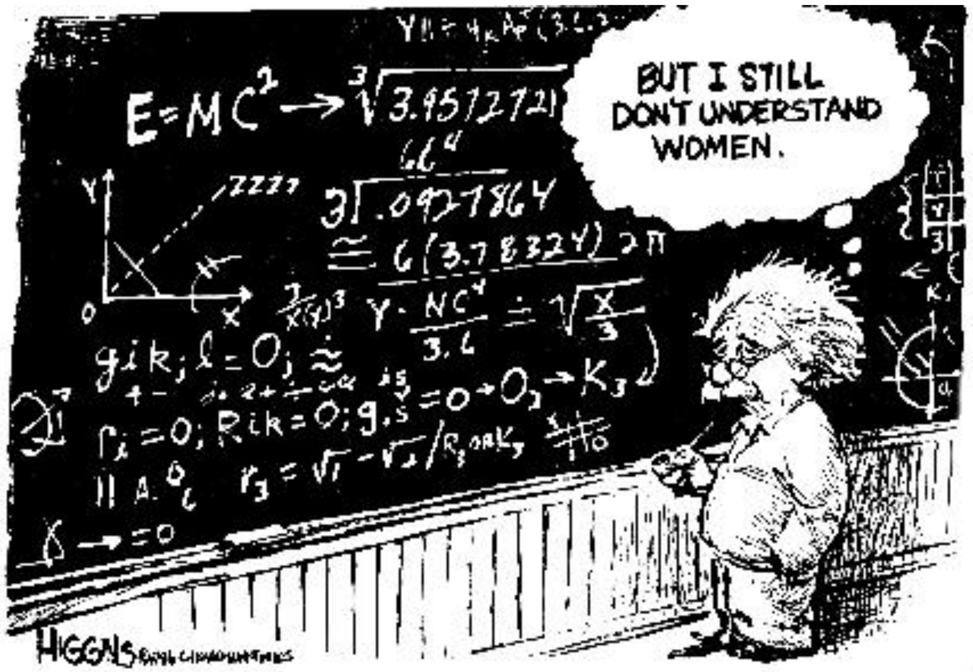


Thanks to Monica Orienti, Justin Finke, Josefin Larsson, Marcello Giroletti and the Fermi LAT Collaboration, Claudia Raiteri, Akihiro Doi, Lukasz Stawarz, Daniele Dallacasa, Talvikki Hovatta and the OVRO Team, Manolis Angelakis, Lars Fuhrmann and the F-GAMMA Team, M. Lister and the MOJAVE Team, Andrew Drake and the CRTS Team, Anne Lahteenmaki, Elina Lindfors and the Metshaovi Team, Luis Carrasco and the INAOE Team

Extra Slides

Radio-loudness and jet formation

• The mechanism at work for producing a relativistic jet is not clear, and the physical parameters the drive the jet formation is still under debate

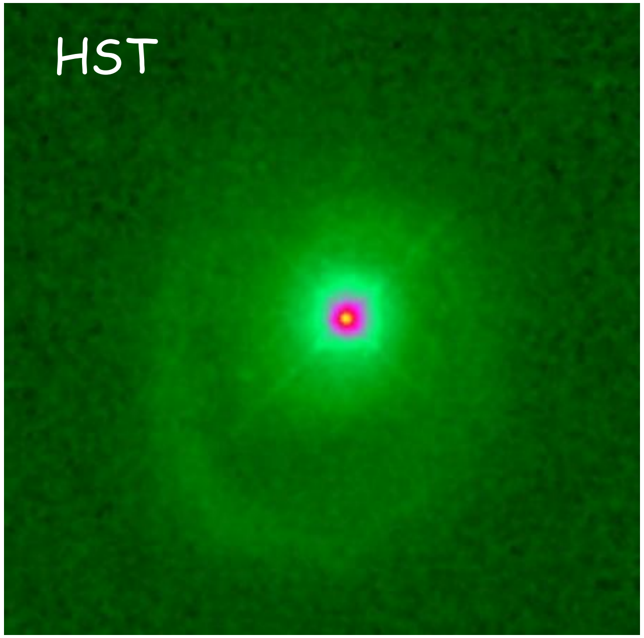
• One fundamental parameter could be the BH mass, with only large masses allowing relativistic jet formation

• Sikora et al. (2007) suggested that AGN with M_BH > 10^8 solar masses have radio laoudness 3 order of magnitudes greater than the AGN with M_BH < 3×10^7 solar masses

• Another fundamental parameters should be the BH spin, with SMBHs in elliptical galaxies having much larger spins than SMBHs in spiral galaxies

• **The spiral galaxies are characterized by multiple accretion events with random orientation of angular momentum vectors and small increments of mass, while elliptical underwent at least one major merger with large matter accretion triggering an efficient spin up of the SMBH**

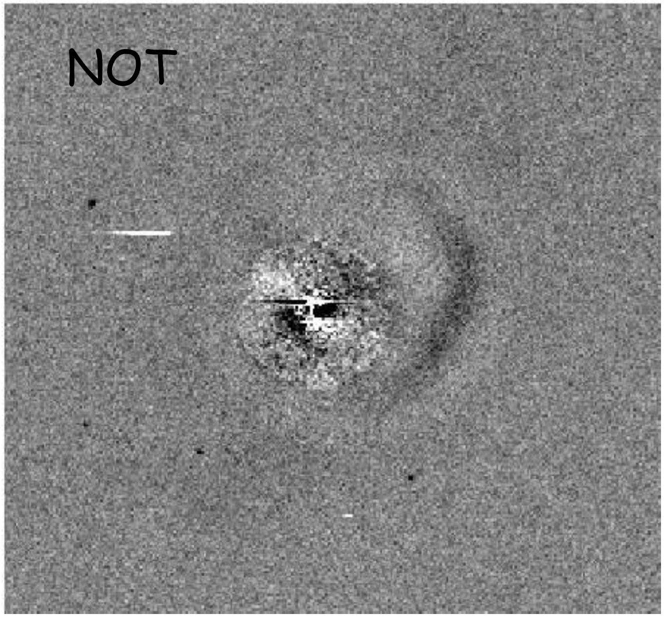
Host galaxy of 1H 0323+342



z = 0.061

Zhou et al. 2007: likely spiral morphology

Anton et al. 2008: circumnuclear region, residual of a merging galaxy?



No other HST observations of gamma-ray NLSy1 galaxies!

The development of relativistic jets in this object could be due to strong merger activity is not ruled out.

Host galaxy of gamma-ray NLSy1s

- Unfortunately only very sparse observations of the host galaxy of the radio-loud NLSy1s are available at this time

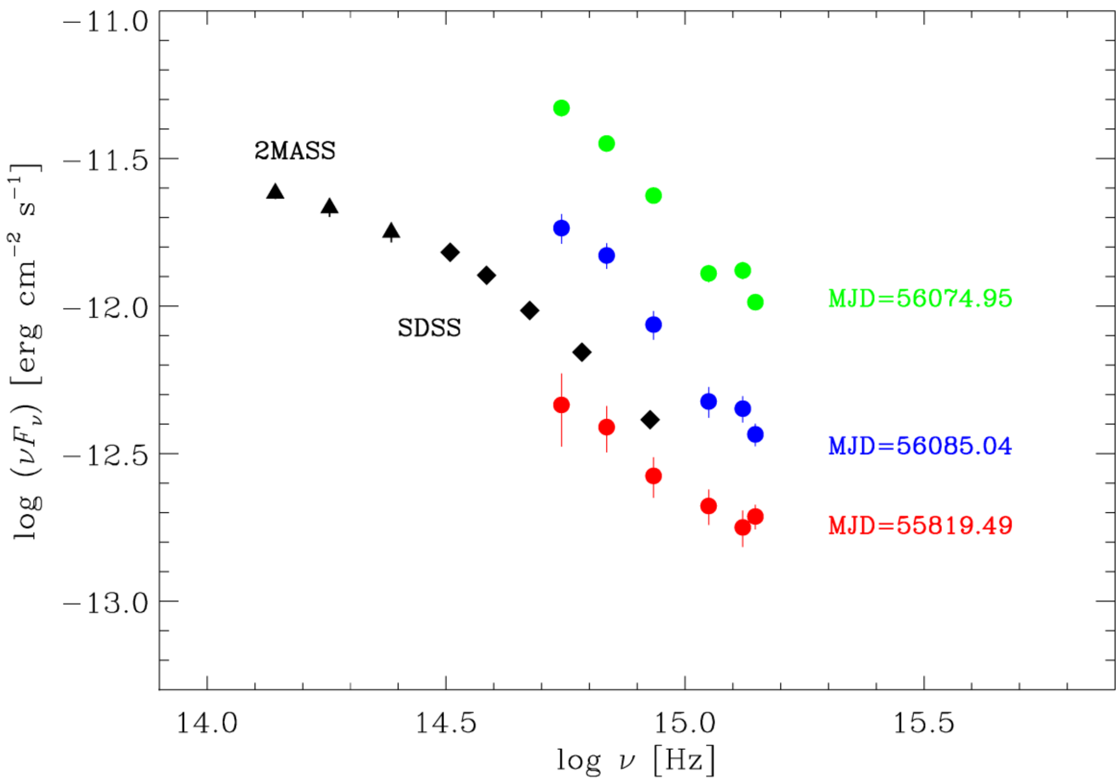
- The sample of objects studied by Deo et al. (2006) and Zhou et al. (2006) had $z < 0.03$ and $z < 0.1$, respectively, including both the radio-quiet and radio-loud objects

- The BH masses of radio-loud NLSy1s are generally larger with respect to the entire sample of NLSy1s: $(2\text{-}10)\times10^7$ solar masses (Komossa et al. 2006), even if still small when compared to radio-loud quasars

- The larger BH masses of radio-loud NLSy1s could be related to the prolonged accretion episode that can spin-up the BHs

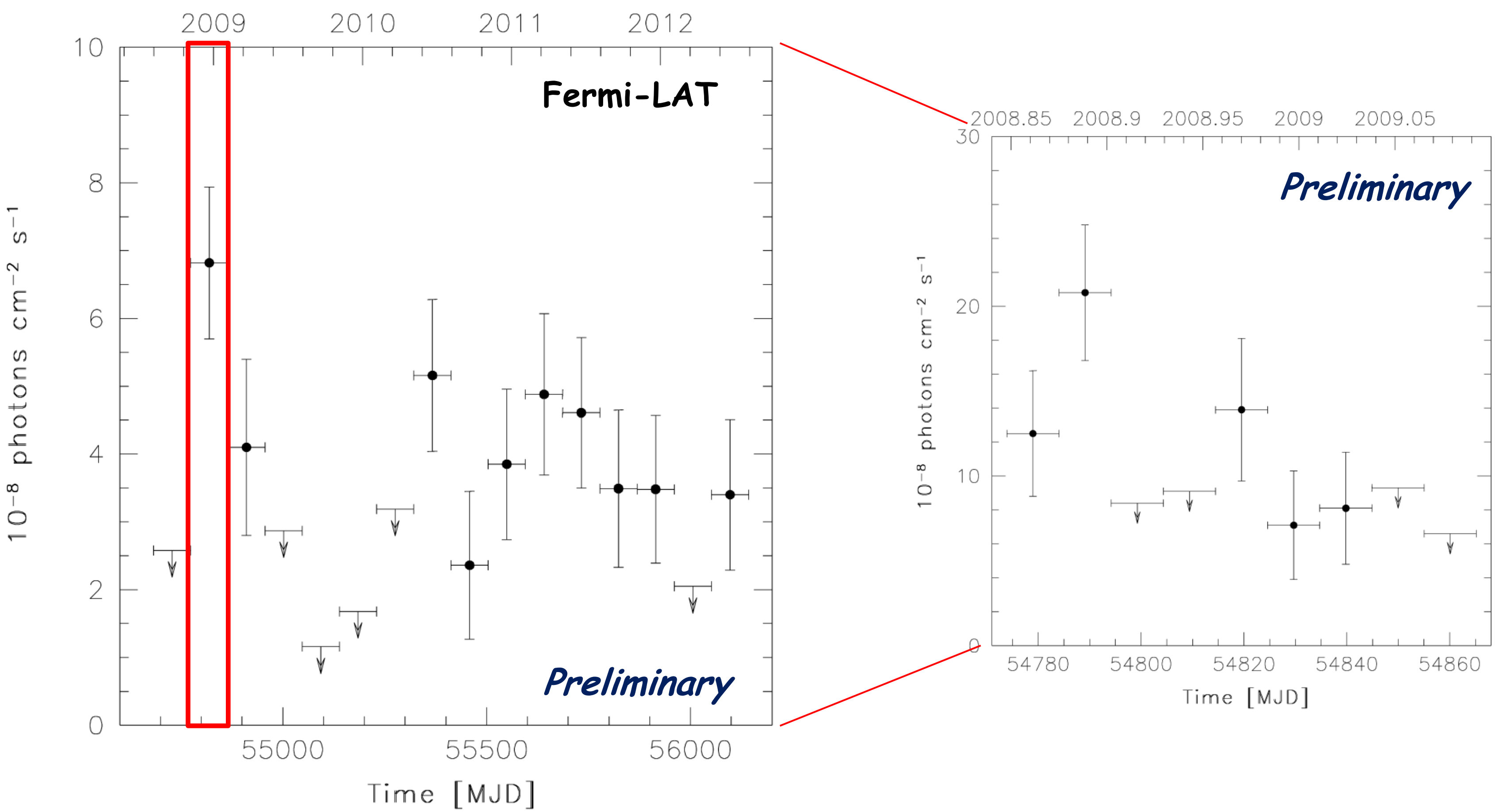
- **The small fraction of radio-loud NLSy1s with respect to radio-quasars could be an indication that in the former the high accretion usually does not last sufficiently long to significantly spin-up the BHs (Sikora 2009)**

optical/UV SED of SBS 0846+513



The comparison of the SEDs collected in optical/UV during different activity states suggested a significant increase of the synchrotron emission in 2012 May 27. It is unlikely that the small UV bump *observed only during the flaring state* is due to thermal emission from the accretion disk

1H 0323+342 – 4 years LAT observations



D'Ammando et al. in prep.

PKS 2004-447: a 'genuine' NLS1 or a CSO?

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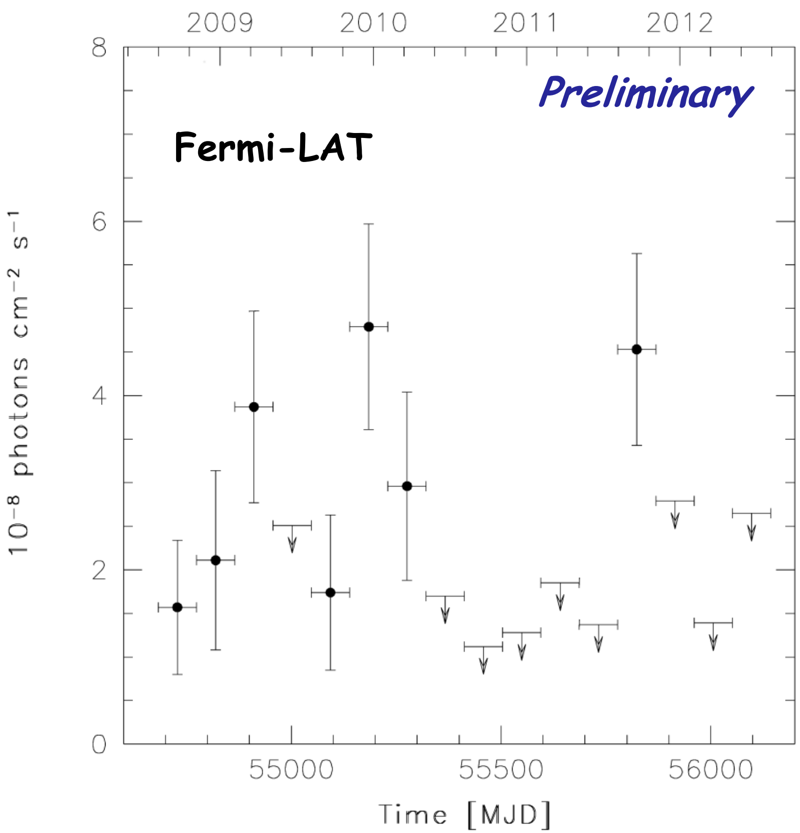
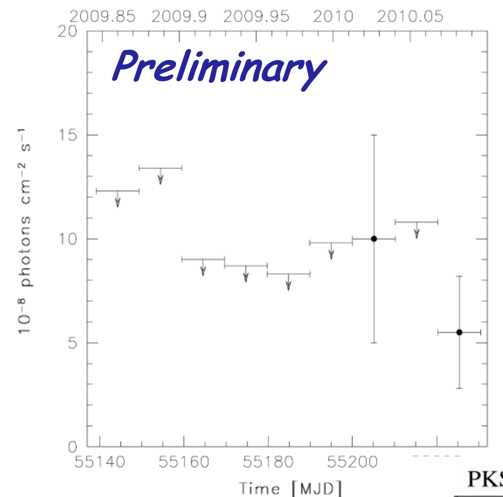
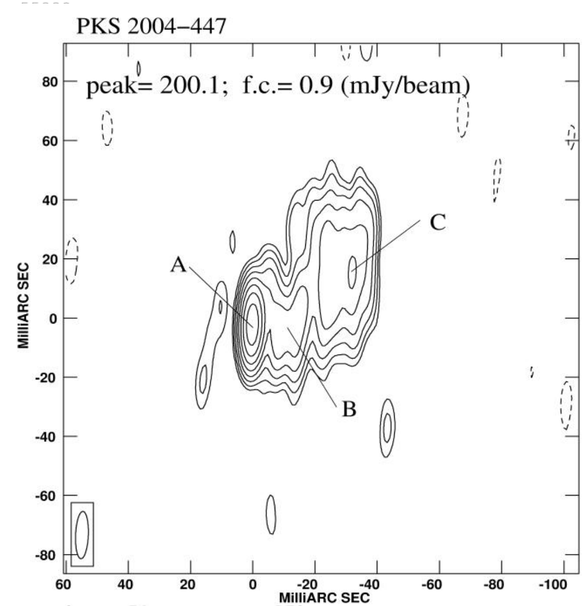




No significant activity in gamma rays

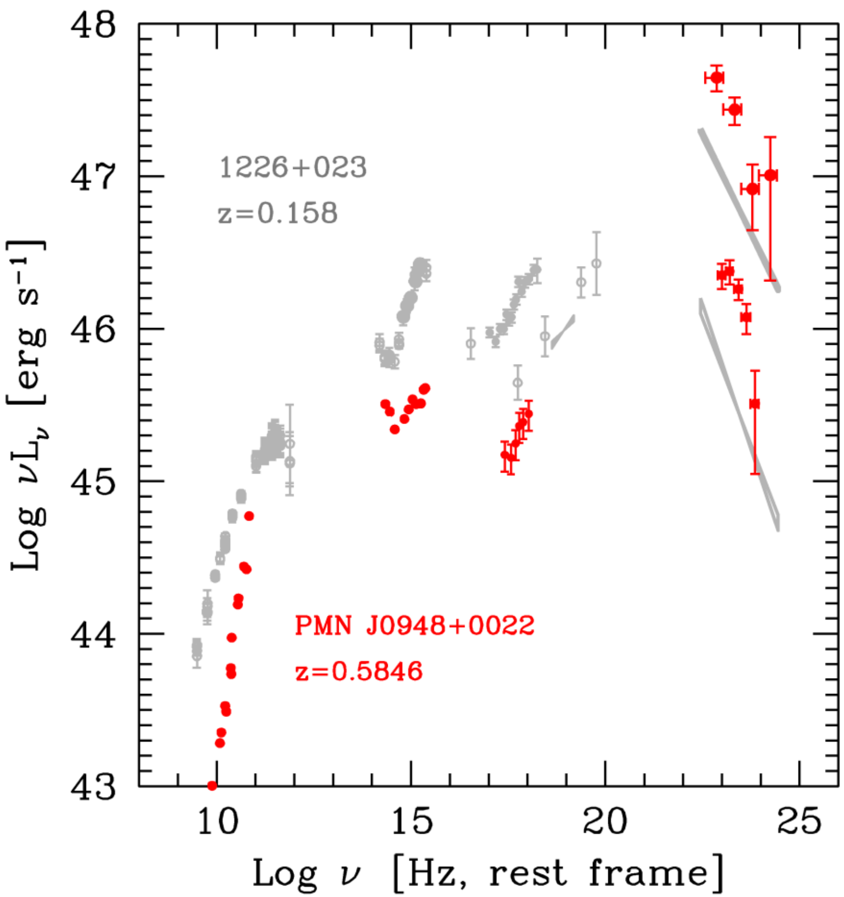
D'Ammando et al. in prep



Orienti, D'Ammando, Giroletti 2012

The bright and compact component A may be either the core or a very compact hot-spot like those found in a few young radio sources

FSRQs vs RL-NLS1s



Foschini+2011

- The comparison of the SED of PMN J0948+0022 in July 2010 with the SED of a typical blazar with a strong accretion disk (3C 273) shows that the Compton dominance is more extreme in the NLS1s

- The disagreement of the two SEDs can be accounted by the differences in mass of the central BH and Doppler factor of the two jets