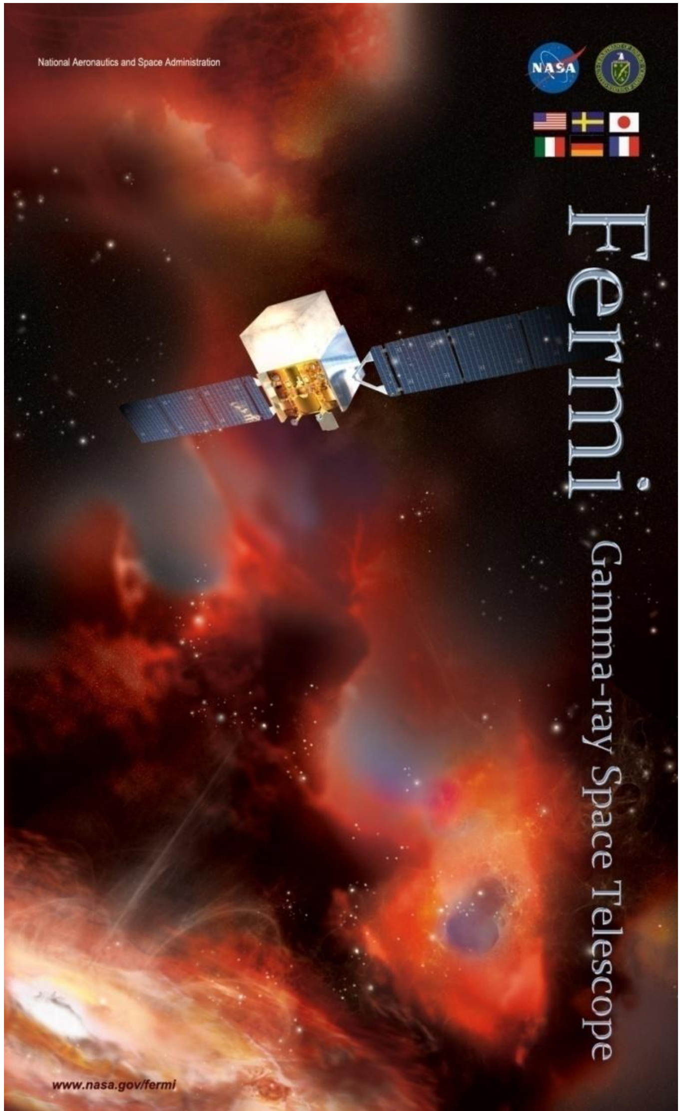
Fermi
Gamma-ray Space Telescope

INAF
Istituto di Radioastronomia



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

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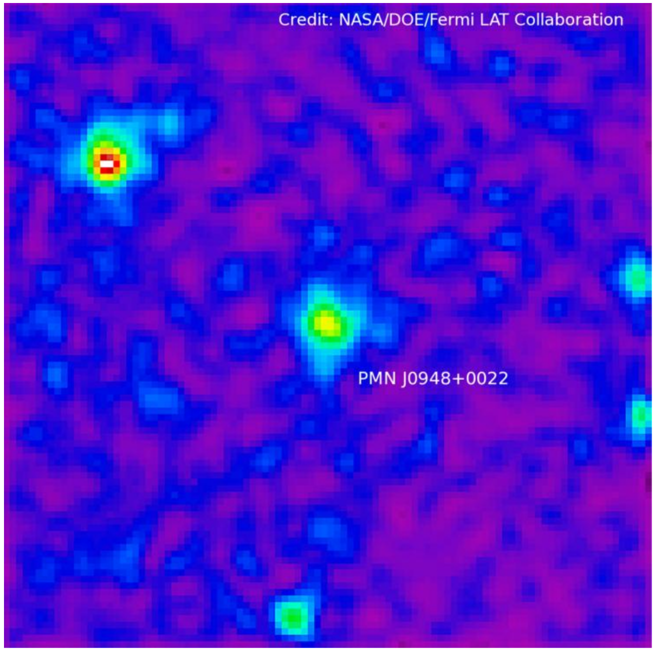
Gamma-ray emitting NLSy1s

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

- *Fermi*-LAT first 4 years of operation (1FGL, 2FGL, 3FGL) confirmed that the known extragalactic γ-ray sky is dominated by blazars but…

…the first detection of a γ-ray emitting Narrow-line Seyfert 1 galaxy, PMN J0948+0022, during the first months of LAT observations was a great surprise!

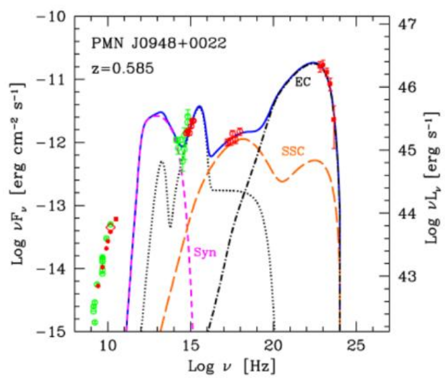


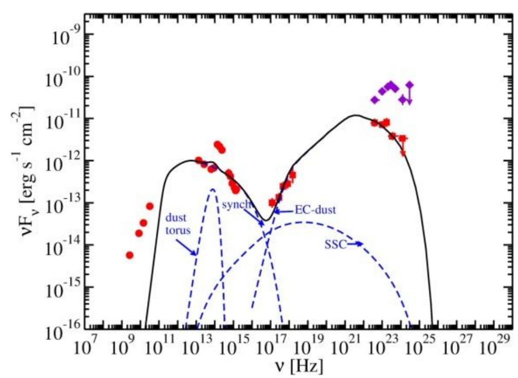
Confirmation of the presence of relativistic jets also in NLSy1s

NLSy1s are usually hosted in **spiral/disc galaxies**, the presence of a relativistic jet in some of 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 & 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

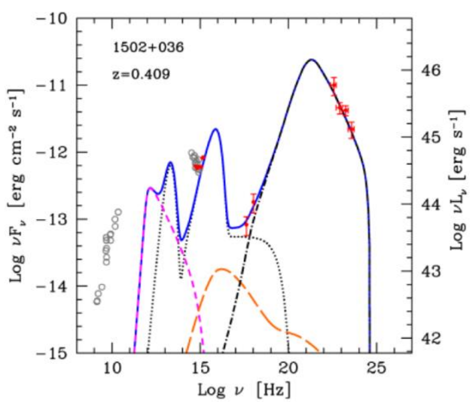
1H 0323+342

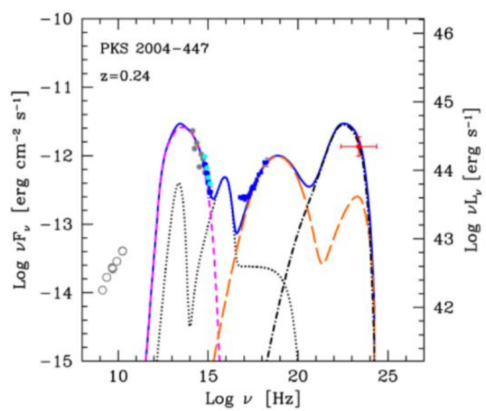
SBS 0846+513

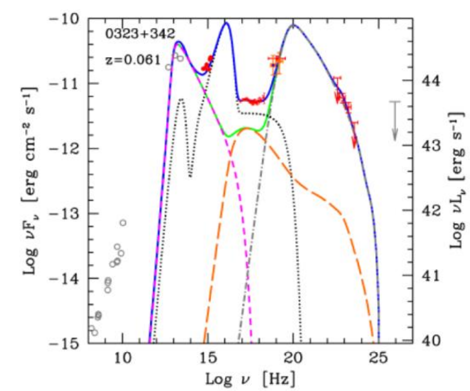
PMN J0948+0022

PKS 1502+036

PKS 2004-447

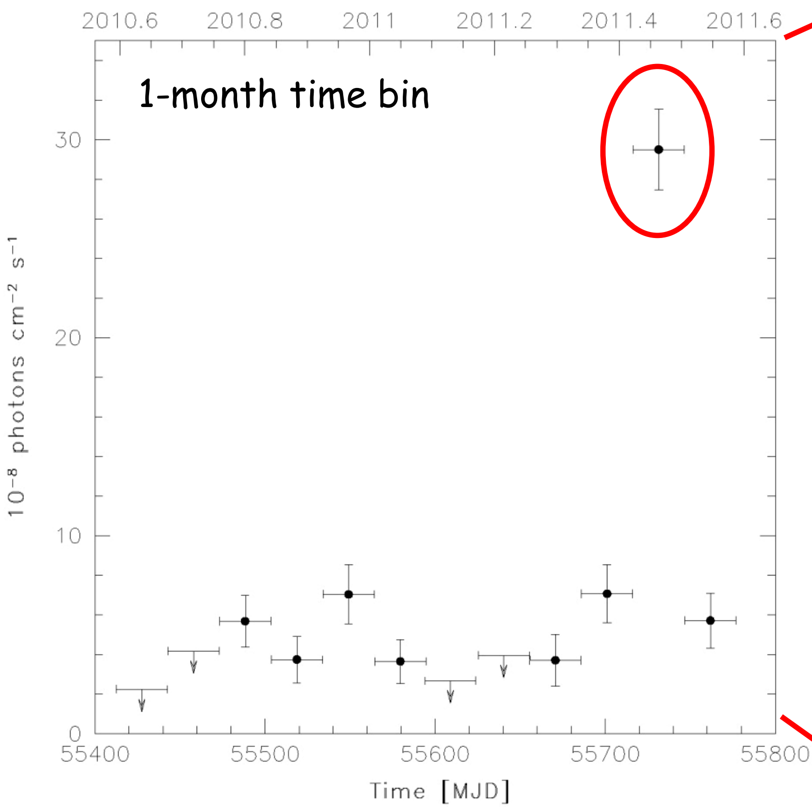


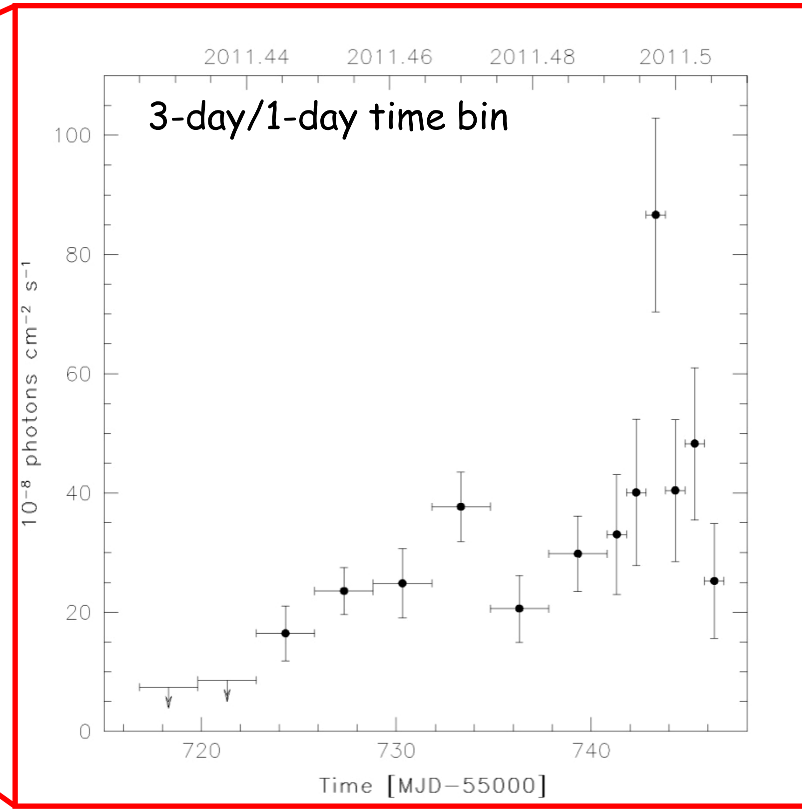




Abdo et al. 2009

SBS 0846+513: a flaring gamma-ray NLSy1



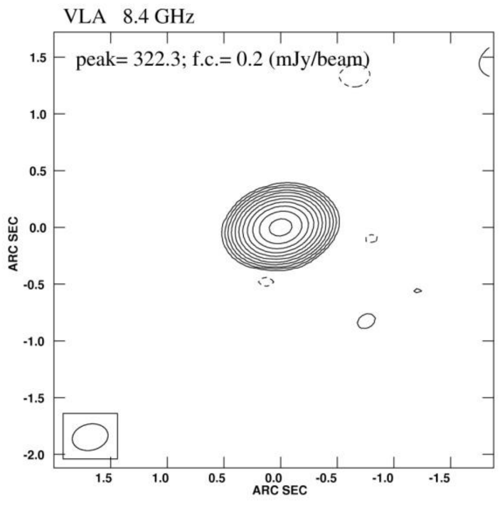


SBS 0846+513 was clearly detected in gamma rays **during the third year of *Fermi* operation**, with an average flux$_{E>0.1\ GeV}$ of (6.7±0.5)e-8 ph cm^{-2} s^{-1} and Γ = 2.23±0.05. An apparent isotropic luminosity of ***~10^{48} erg s^{-1}*, *comparable to that of the bright FSRQs*,** was observed at the daily peak on 2011 June 30

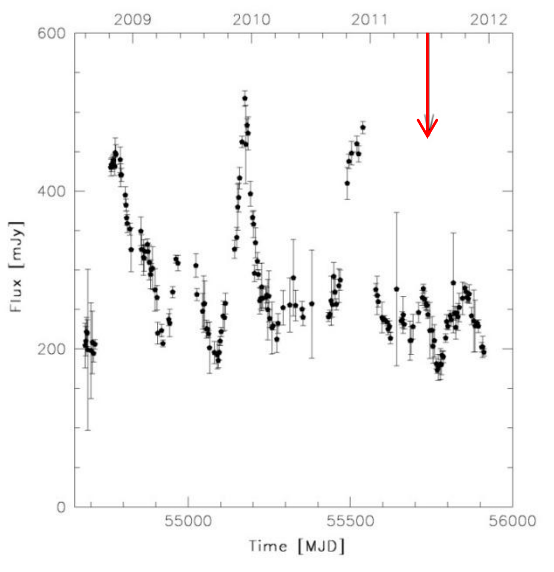
D'Ammando, Orienti, Finke, et al. 2012, MNRAS, 426, 317

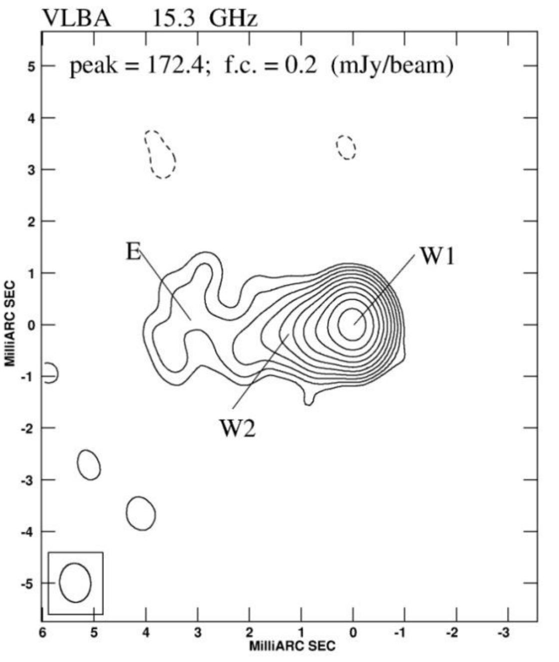
The radio view of SBS 0846+513

Core-jet structure on parsec scale resolved with the VLBA



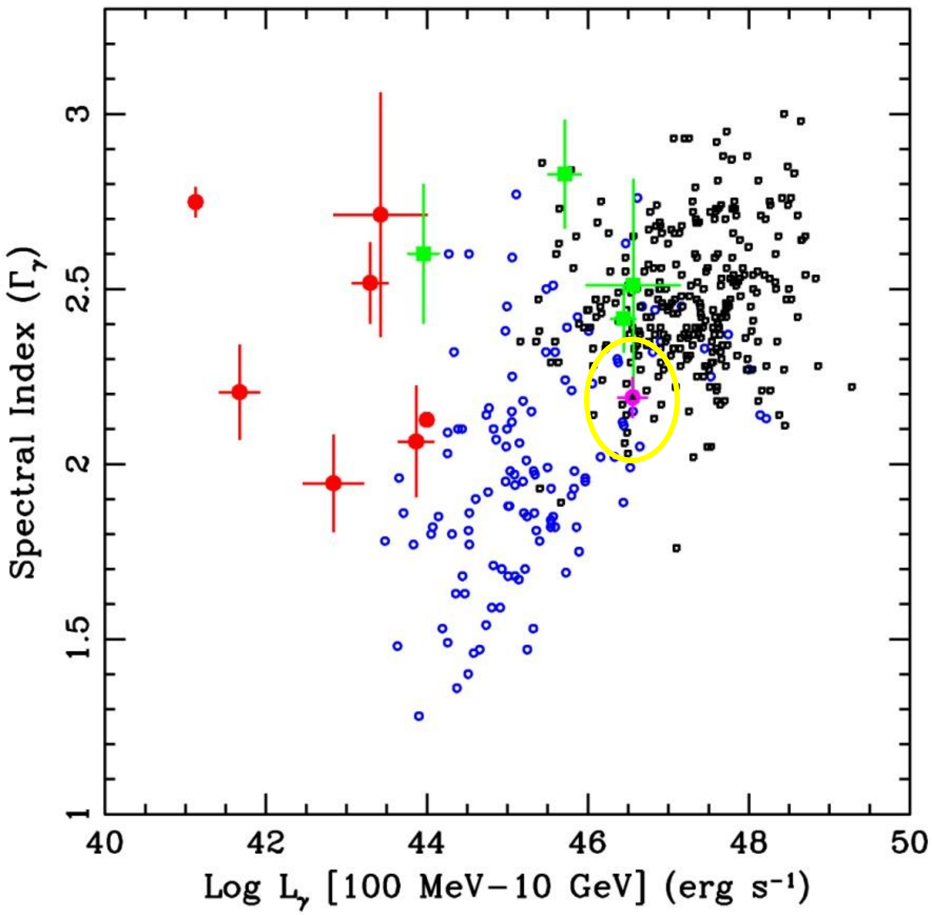
D'Ammando+2012





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

γ-ray luminosity and spectrum of SBS 0846+513

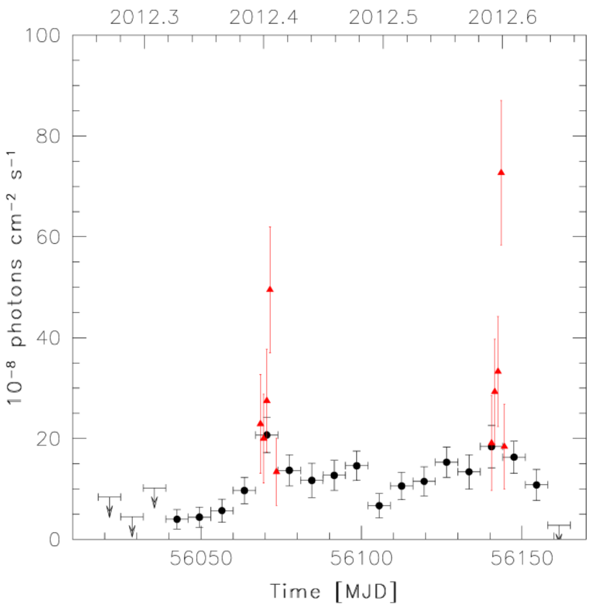


D'Ammando+2012

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

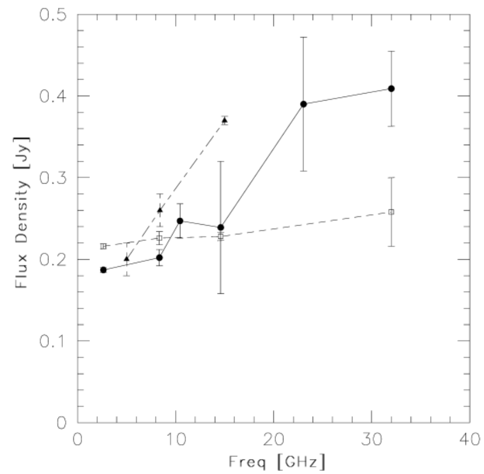
A new flaring activity from SBS 0846+513 in 2012

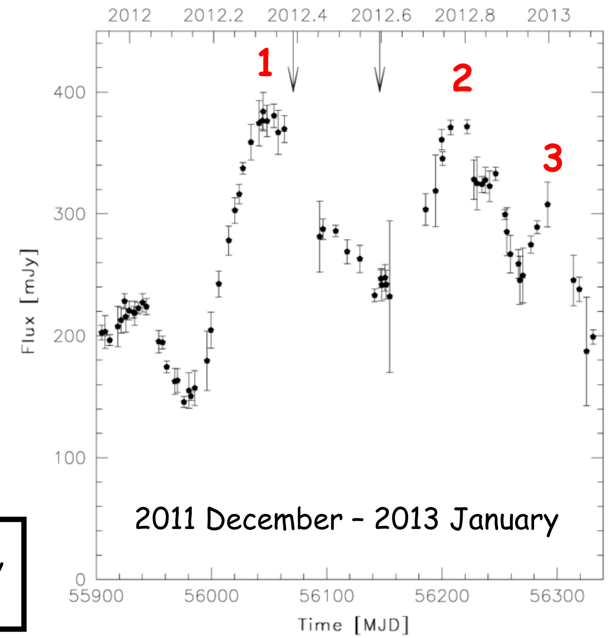
2012 April - August



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}

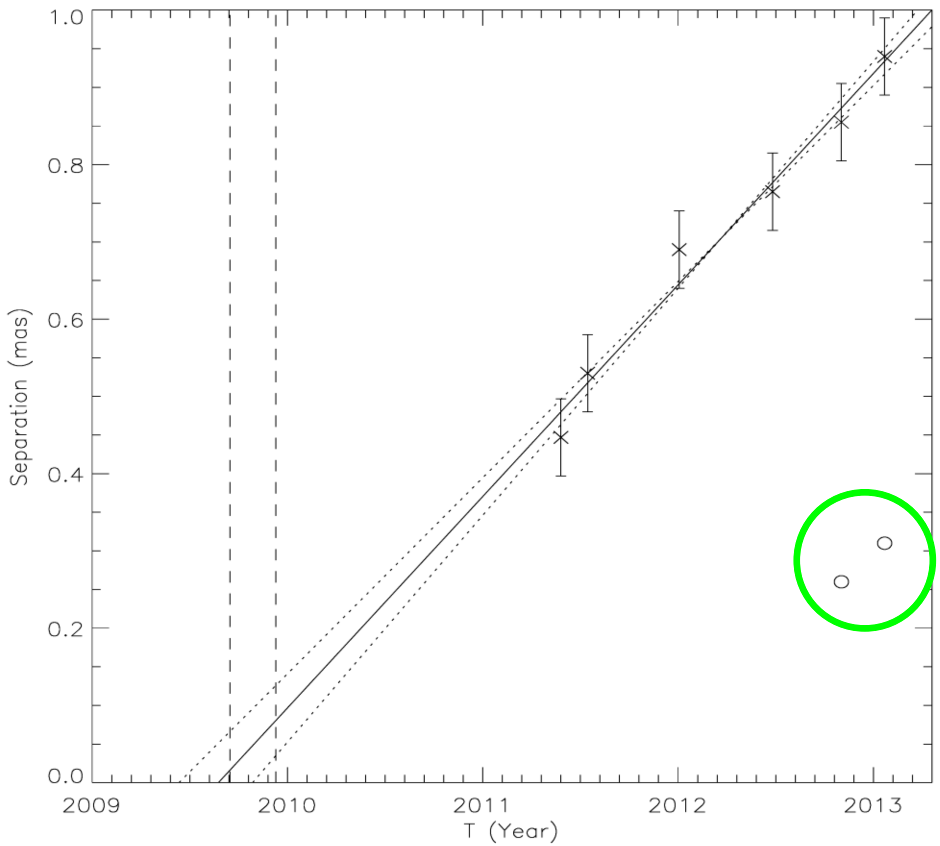




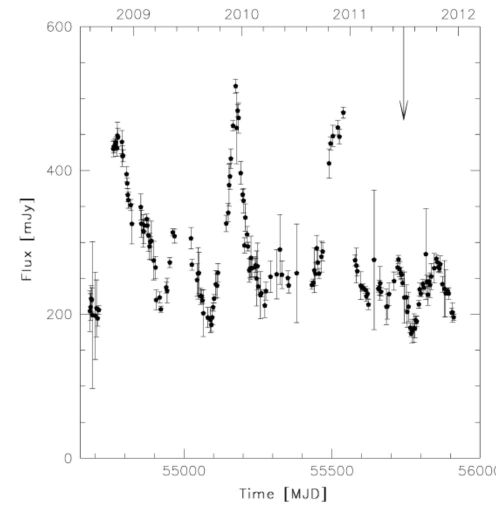
Variable at 15 GHz, with 3 outbursts in 2012 May, 2012 October, and 2012 December-2013. Significant radio spectra variability

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

Proper motion of SBS 0846+513



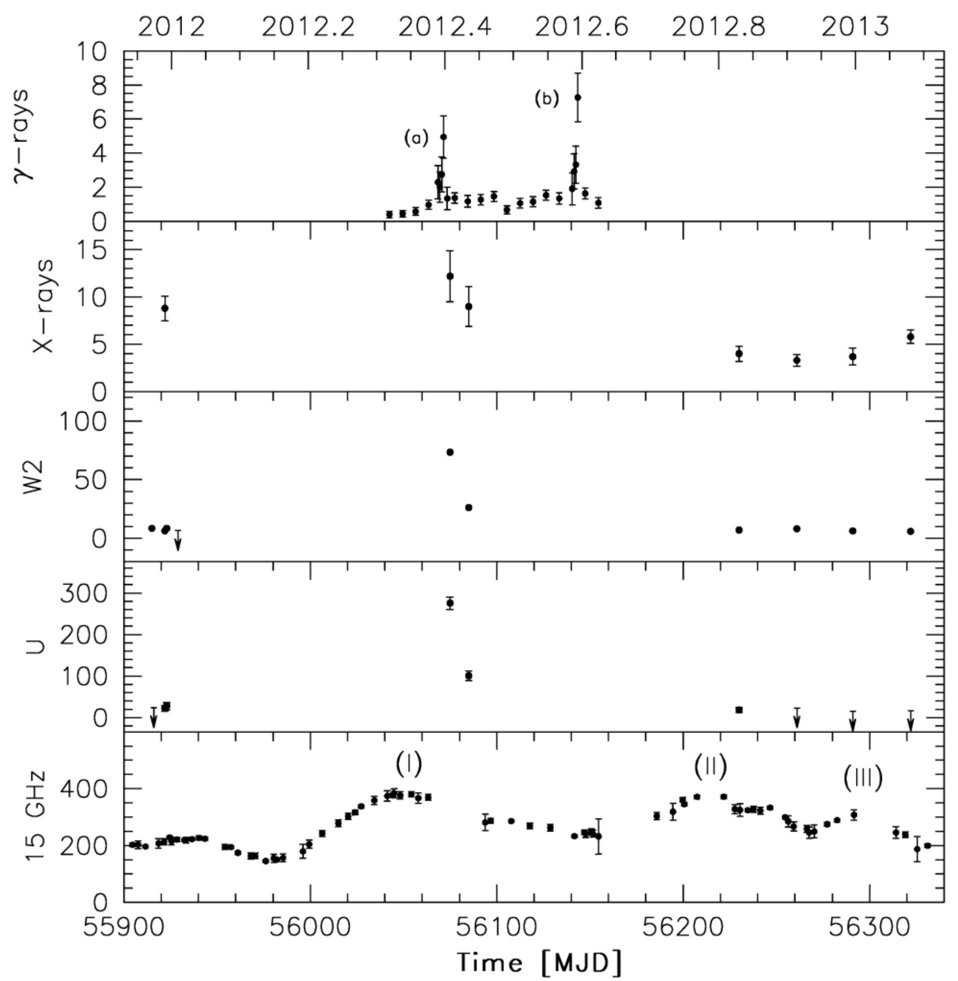
Tentative detection of a new feature



D'Ammando+2012

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



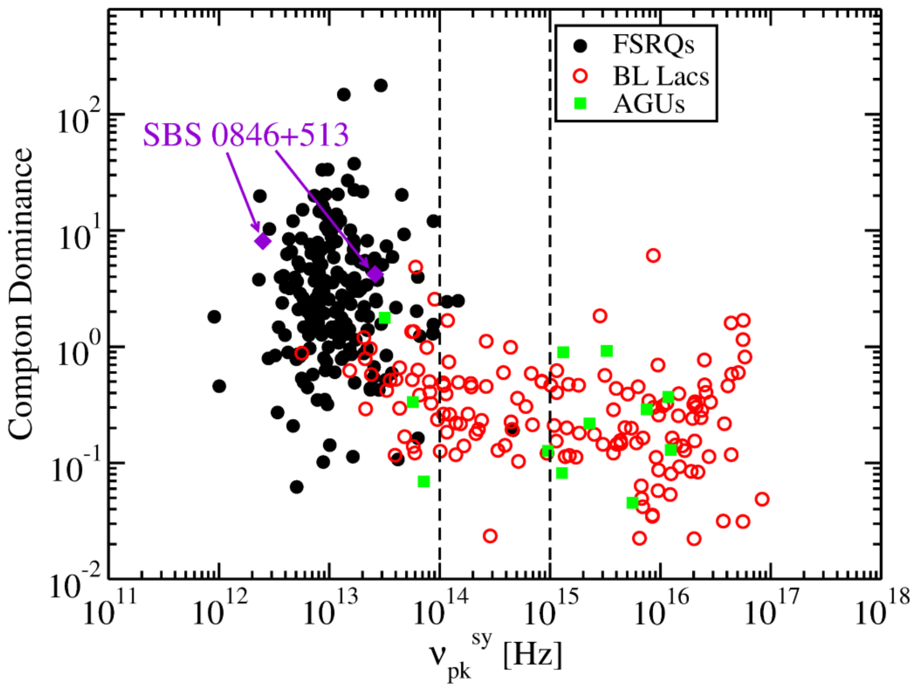
A significant increase of the activity was detected almost simultaneously in the optical, UV, X-ray and gamma-ray bands during 2012 May, enabling us to firmly identify the gamma-ray source with the NLSy1 SBS 0846+513

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

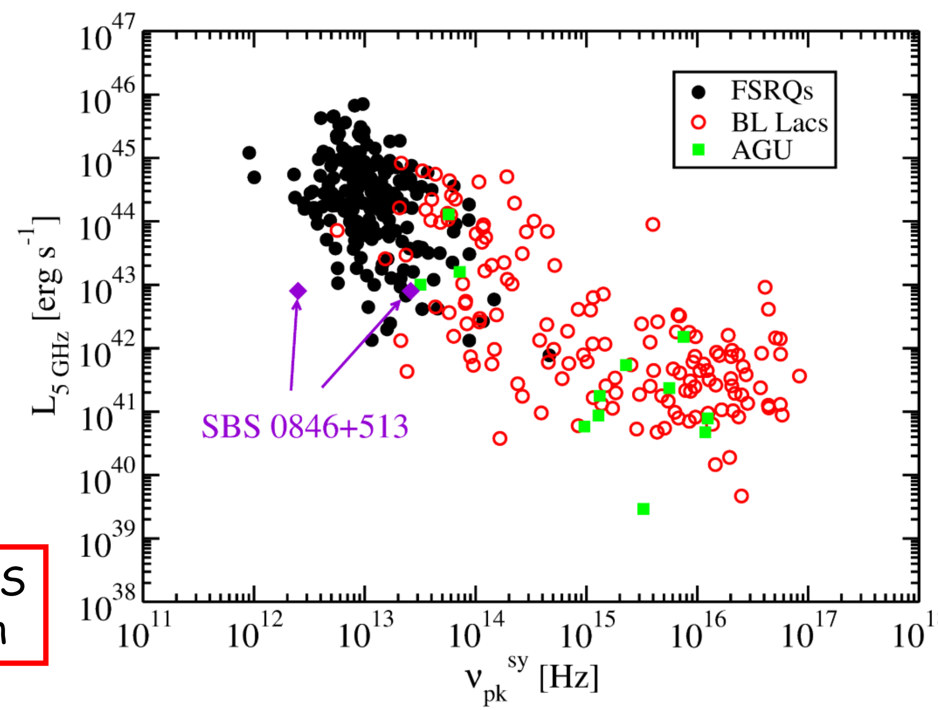
- the two γ-ray flaring episodes may be related to the radio activity in 2012 October and 2013 January

Comparison with γ-ray blazars



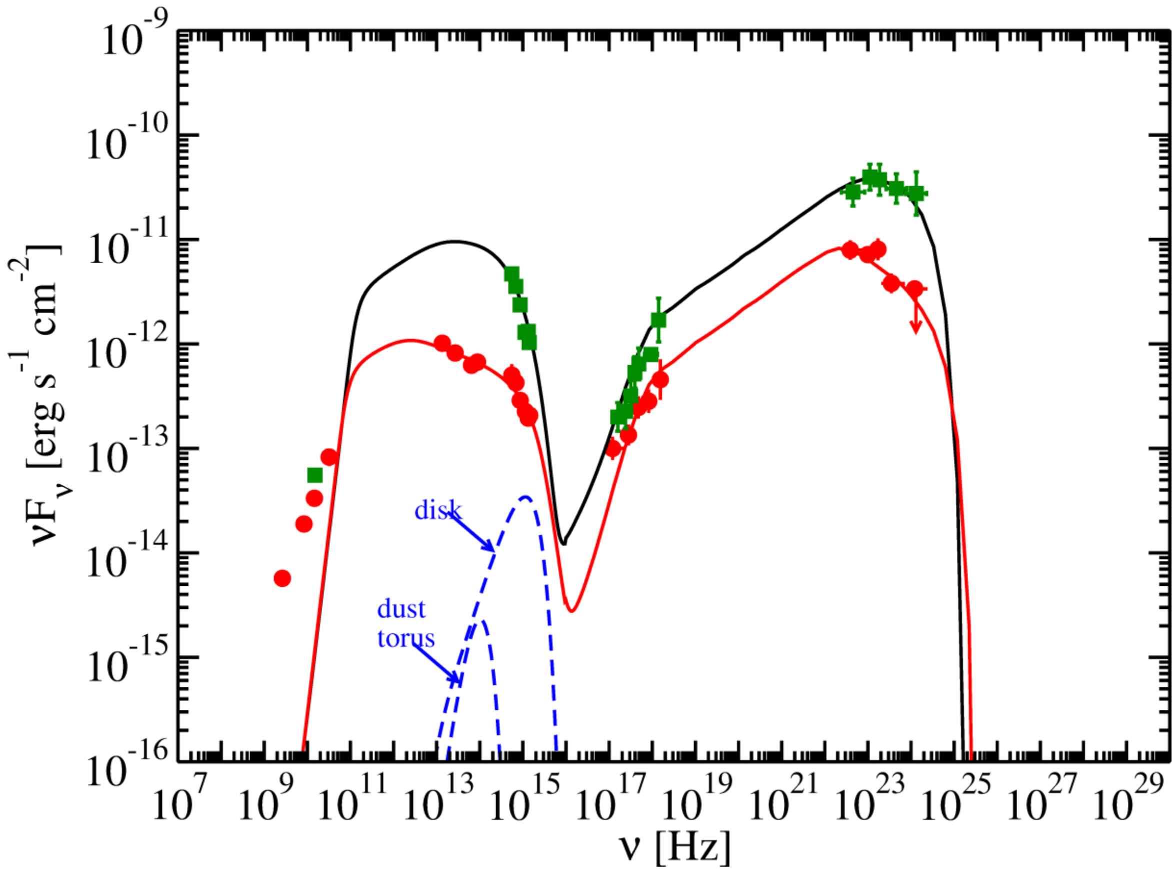
SBS 0846+513 showed a Compton dominance typical of FSRQs during both the low and high activity state

Figures adapted from Finke 2013



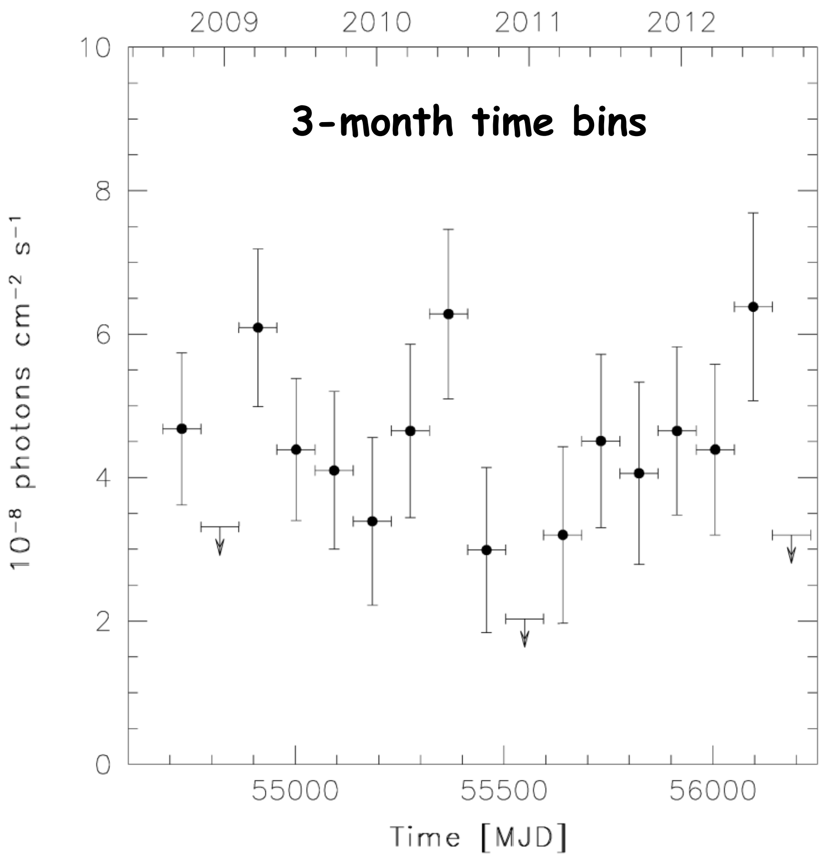
In the "classical" blazar sequence plot SBS 0846+513 seems to lie in the FSRQ region

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.

The ordinary life of PKS 1502+036

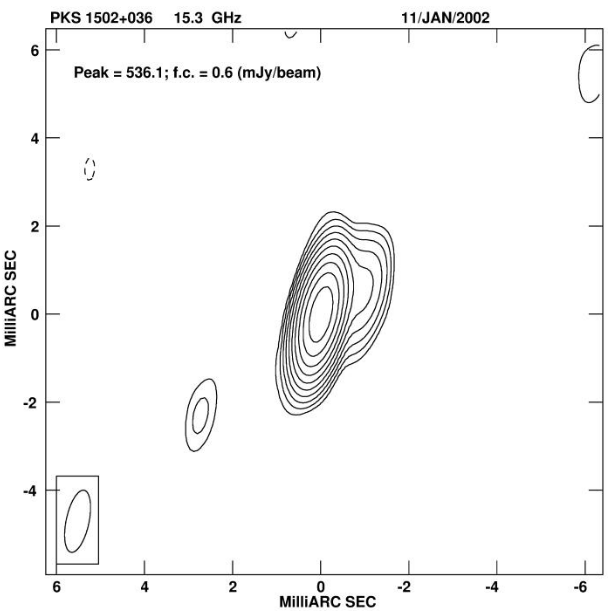


PKS 1502+036 was detected by LAT over 51 months (2008 August 4 - 2012 November 4) with TS = 314, an average flux (0.1-100 GeV) of (4.0 ± 0.4)e-8 ph cm^{-2} s^{-1} and a photon index $\Gamma = 2.60\pm0.06$

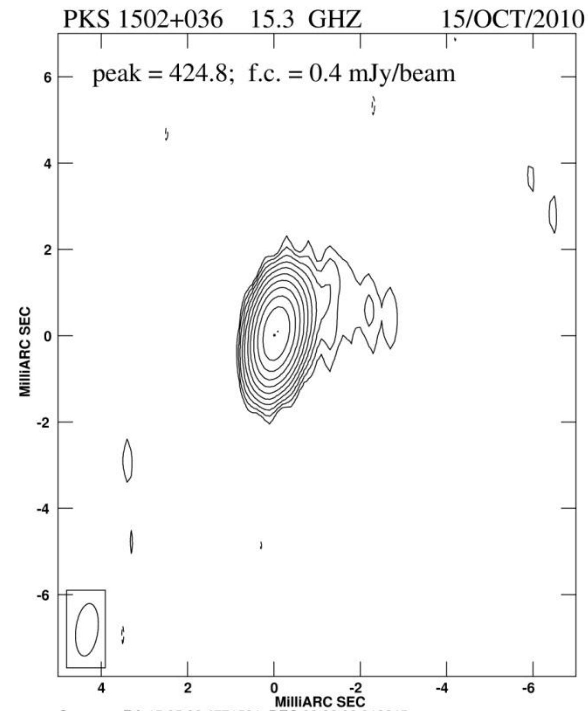
No significant flux variability, with only a few detections on weekly time scales and a peak value of (18 ± 6)e-8 ph cm^{-2} s^{-1}

D'Ammando, Orienti, Doi et al. 2013, MNRAS, 433, 952

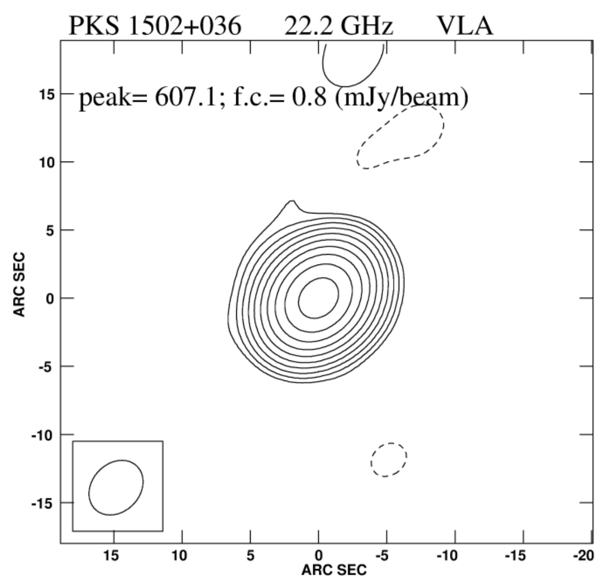
Radio structure of PKS 1502+036



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

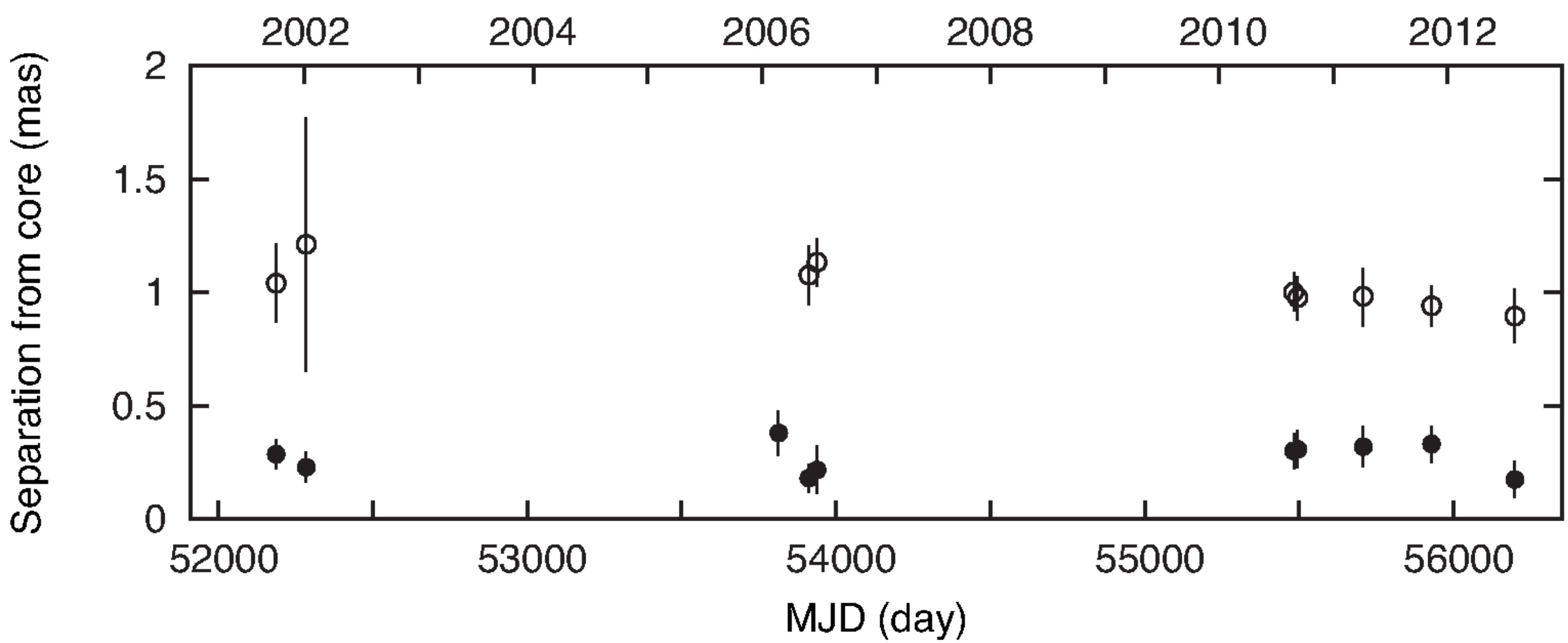


The radio emission is dominated by the core, while the jet-like feature accounts for about 4% of the total flux density



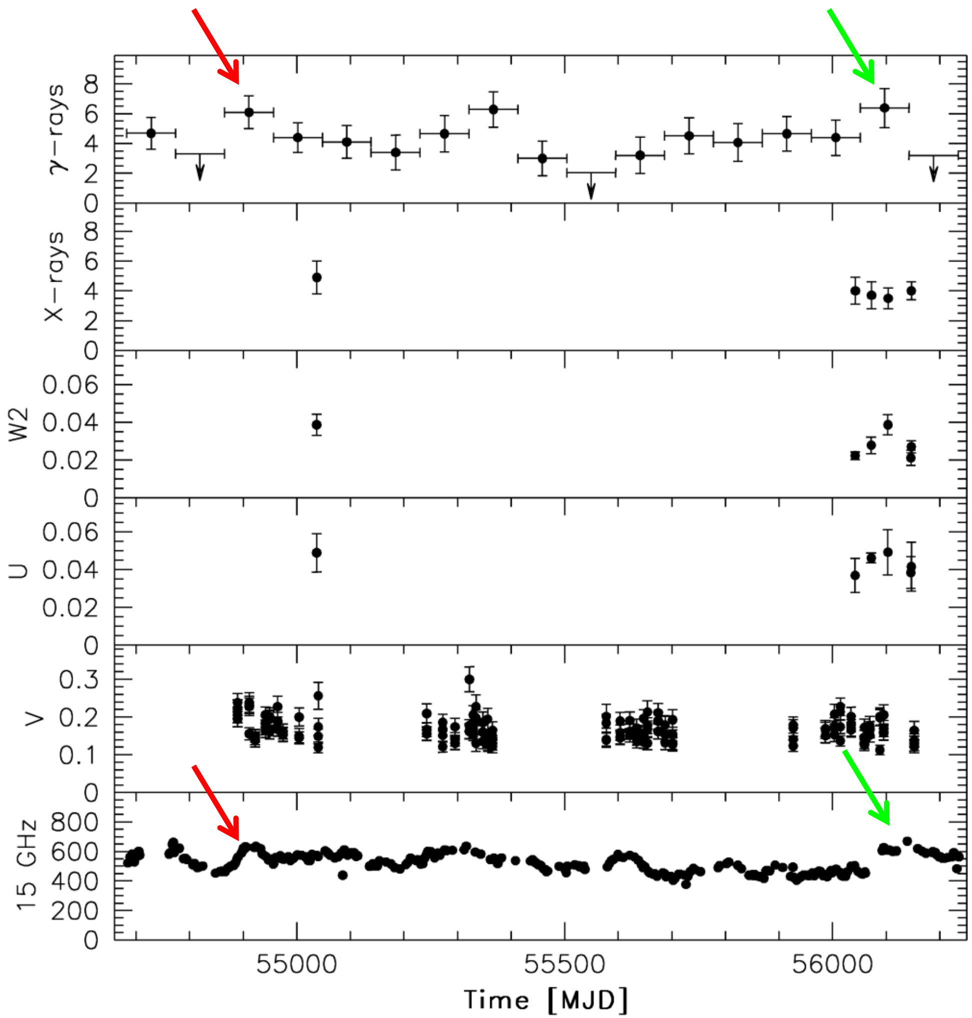
D'Ammando, Orienti, Doi, et al. 2013

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

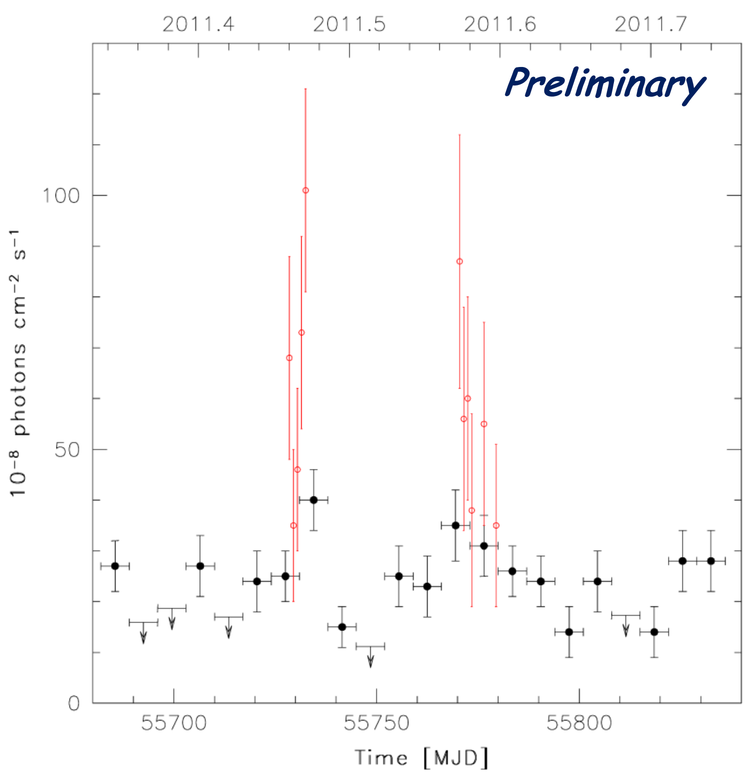


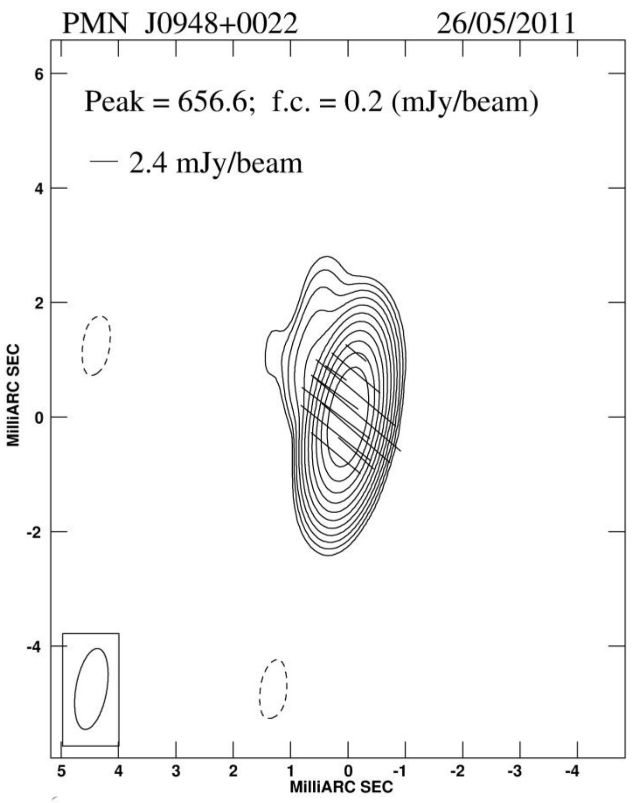
No flaring episodes have been detected in gamma-rays, but a flux density increase at 15 GHz has been observed during period of relatively high gamma-ray emission

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

7-day/1-day time bin

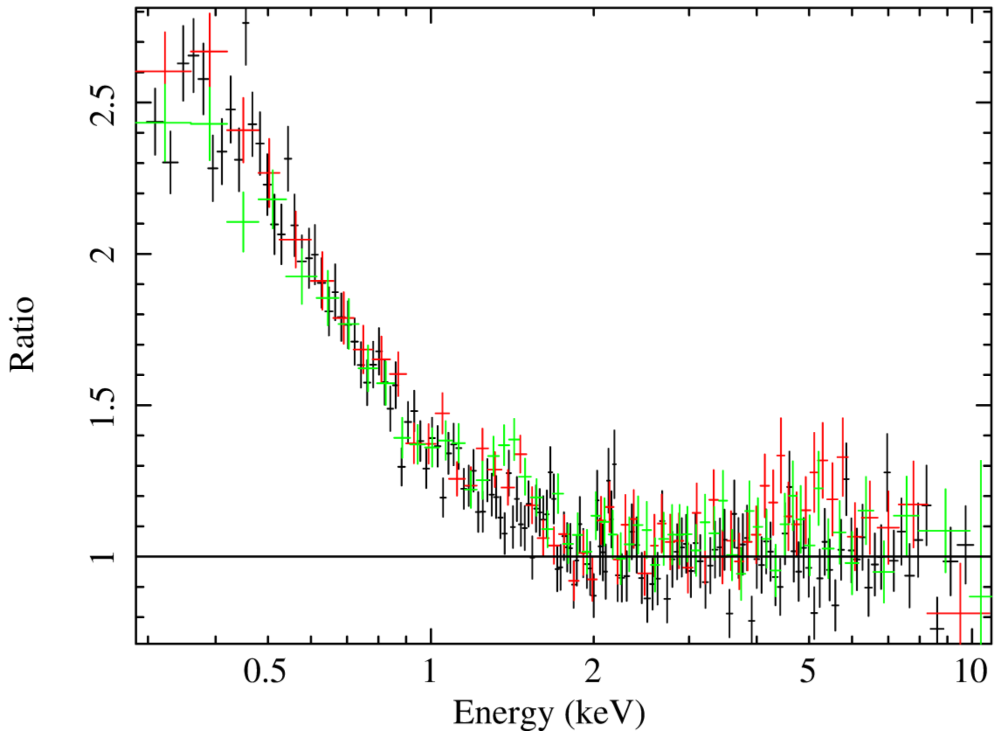




D'Ammando, Larsson, Orienti, et al. in prep

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

XMM observation of PMN J0948+0022



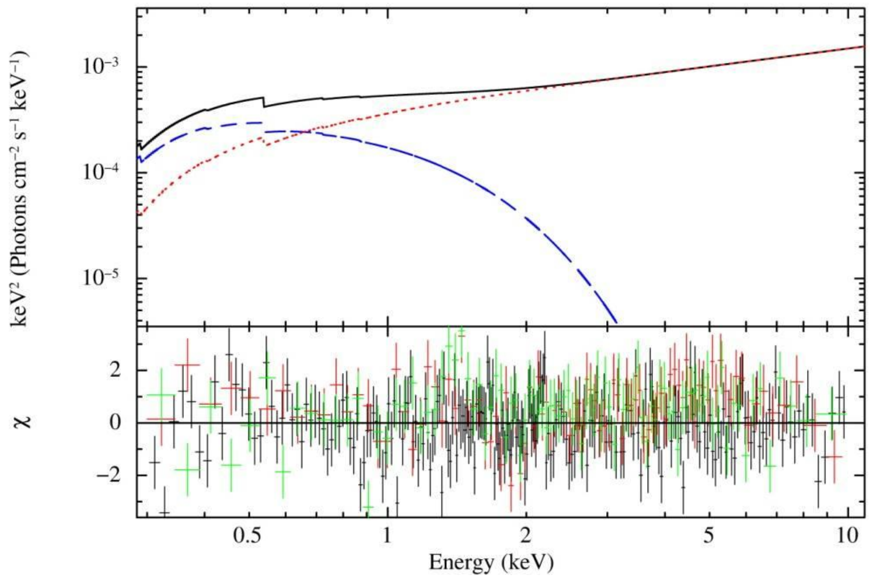
Γ = 1.88 ± 0.01 in the 0.3-10 keV energy range, χ^2_{red} = 1.87/1253

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

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

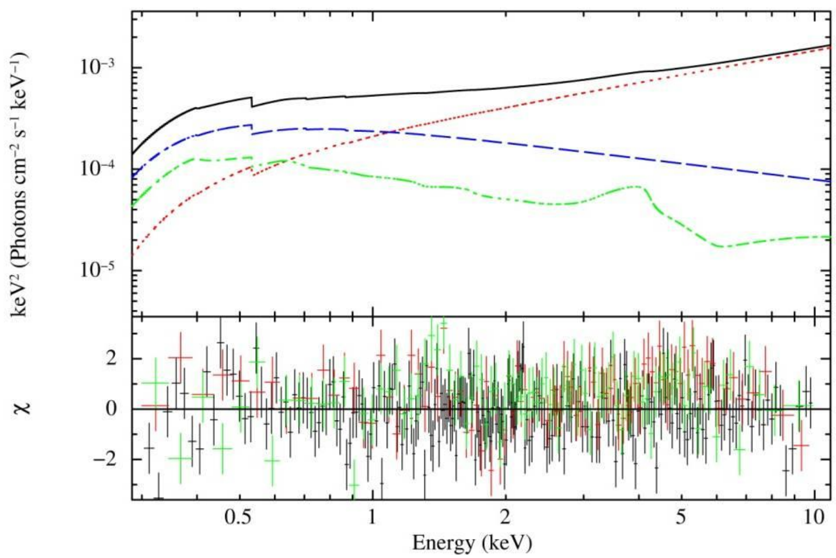
A power law + black body model gives a good fit (χ^2_{red} = 1.06/1251) with Γ = 1.44 ± 0.03, and kT = 0.18 keV. Such a high temperature is inconsistent with the standard accretion disk theory

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

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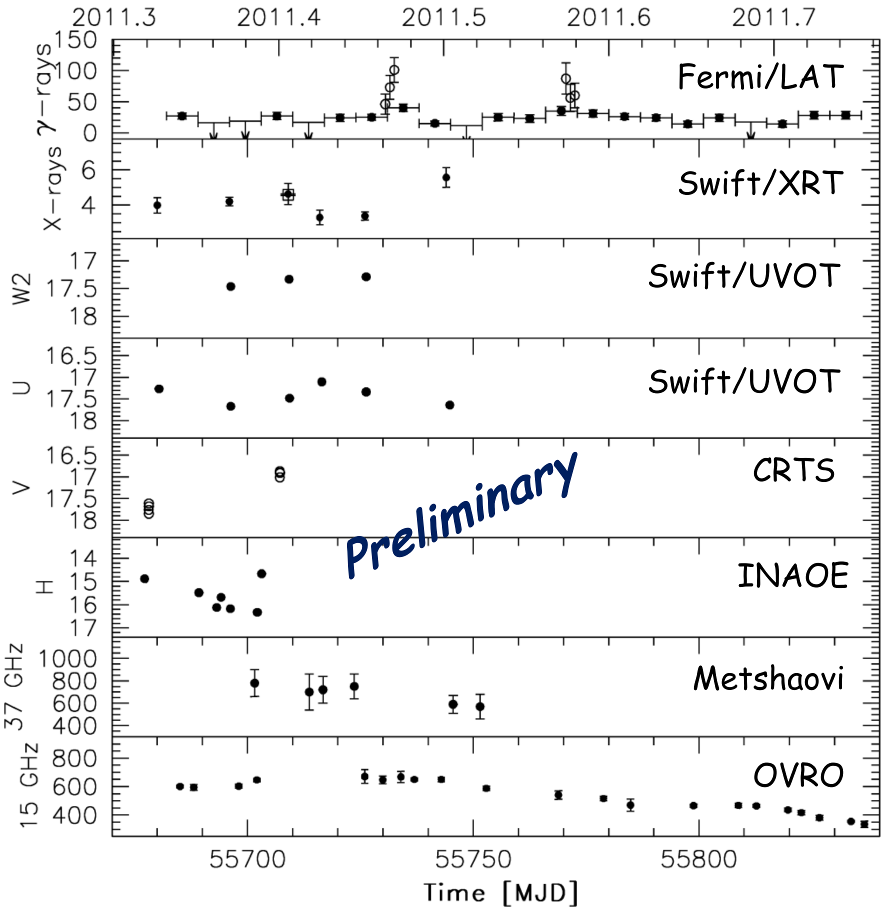
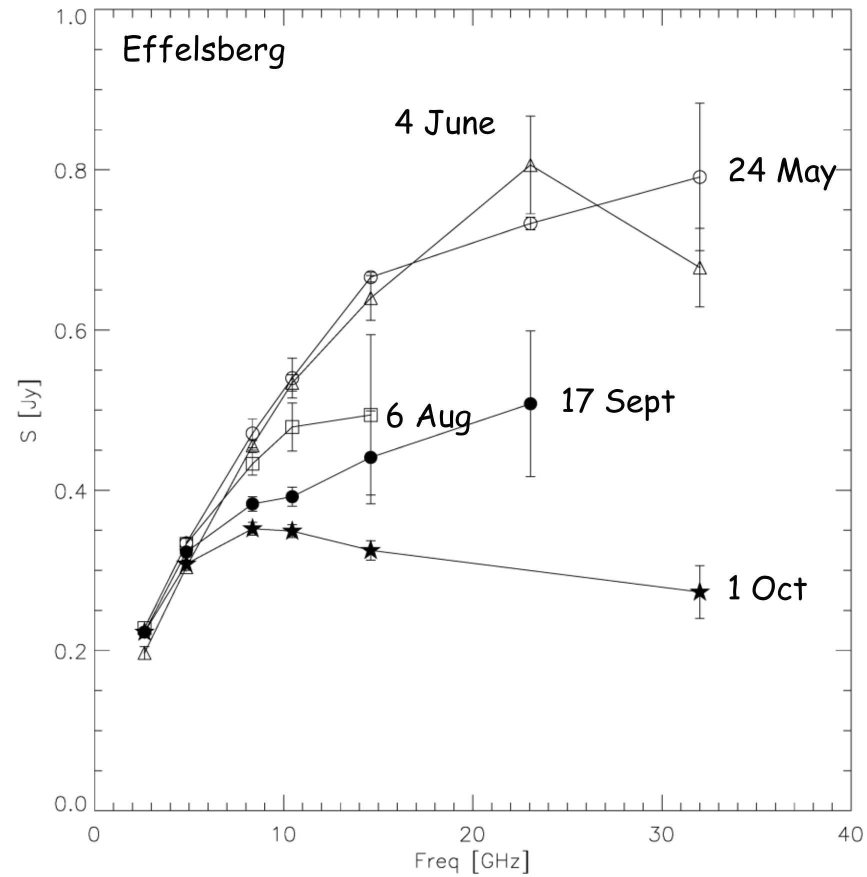
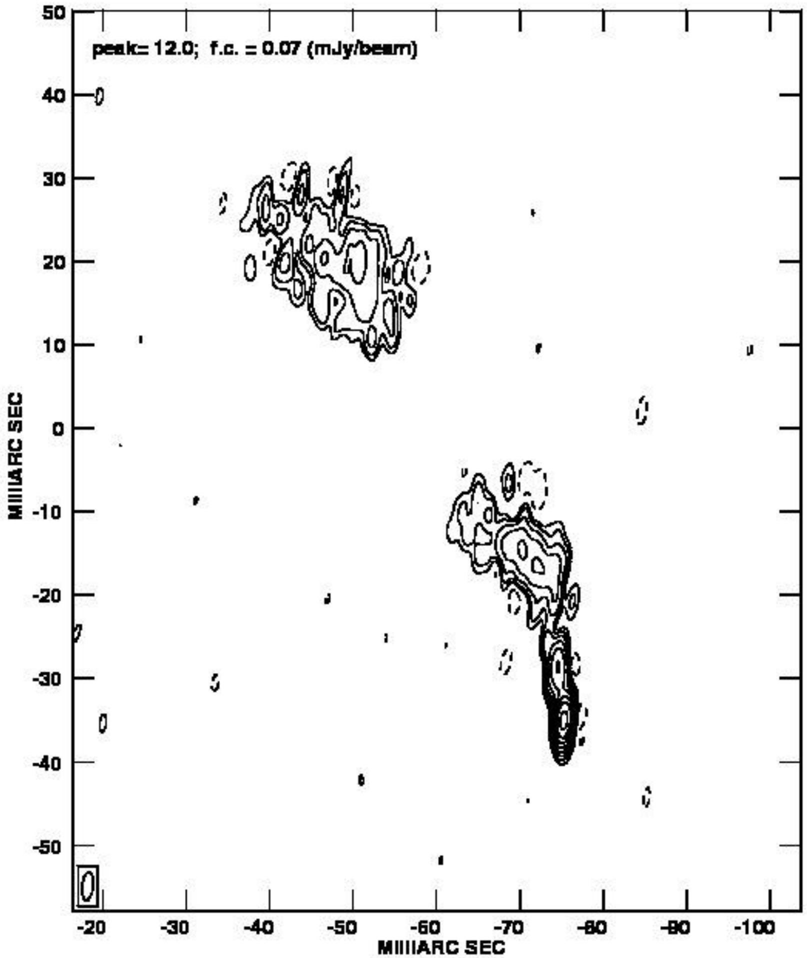




Radio spectra and fluxes show a high activity of the source still in 2011 May 24 ***before*** the peak of the gamma-ray activity

Searching for candidate γ-ray NLSy1s: J1548+3511



J1548+3511 showed a high brightness temperature, comparable to that observed in the NLSy1s already detected by LAT (see Yuan et al. 2008), but no gamma-ray emission was detected from this source so far

VLBA observations performed on 2013 January 2 at 5 GHz, 8.4 GHz and 15 GHz. **Core-jet structure with angular size ~70 mas.** The core has an inverted spectrum between 5 GHz and 15 GHz with spectral index ~ -0.3

Orienti, et al. in prep

Concluding Remarks

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

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

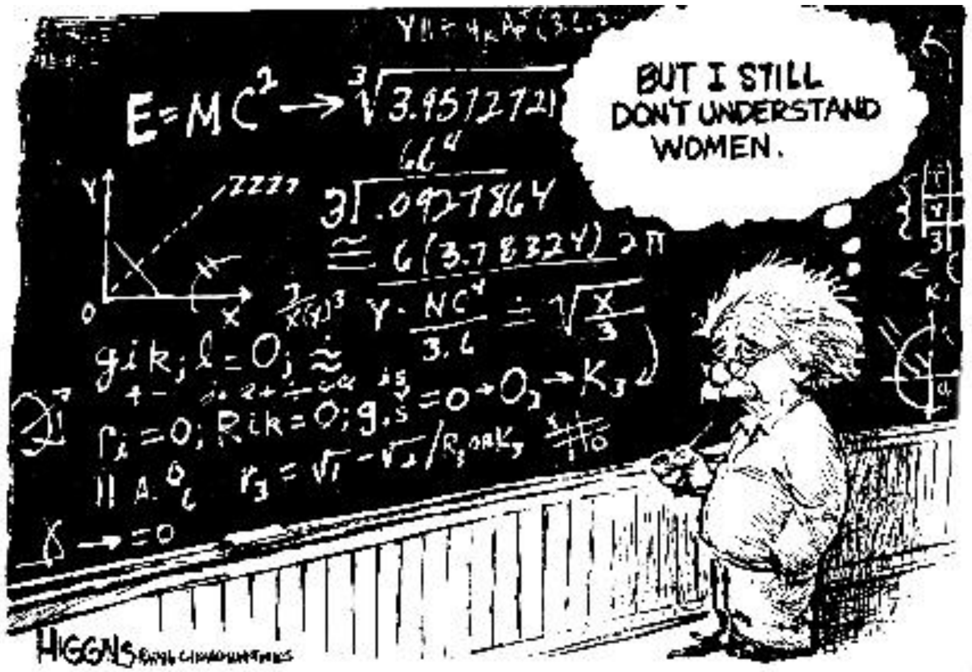
• A core-jet structure was detected in VLBA images of PKS 1502+036 and SBS 0846+513, but apparent superluminal velocity was observed only in SBS 0846+513

• *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 those of 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 γ-ray NLSy1s could be low mass version of the blazars in which the relativistic jet formation was triggered by a major merger (not in classical spiral galaxies?)**

Thanks for your attention!



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 Metsahovi Team, Luis Carrasco and the INAOE Team