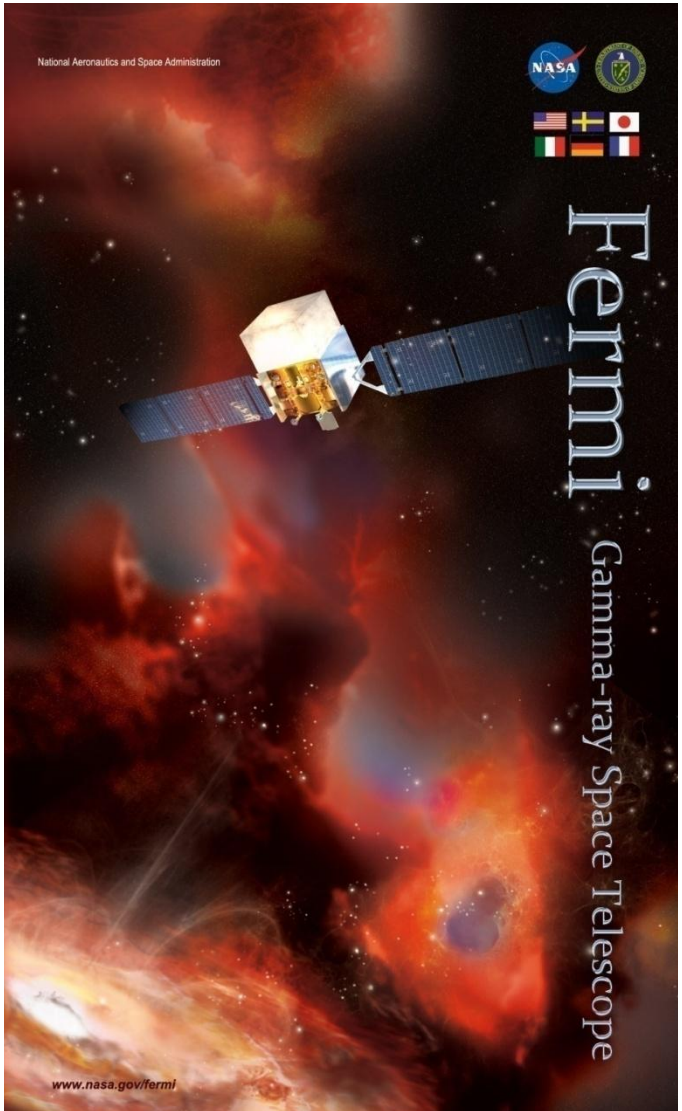
Fermi Gamma-ray Space Telescope

INAF Istituto di Radioastronomia

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA



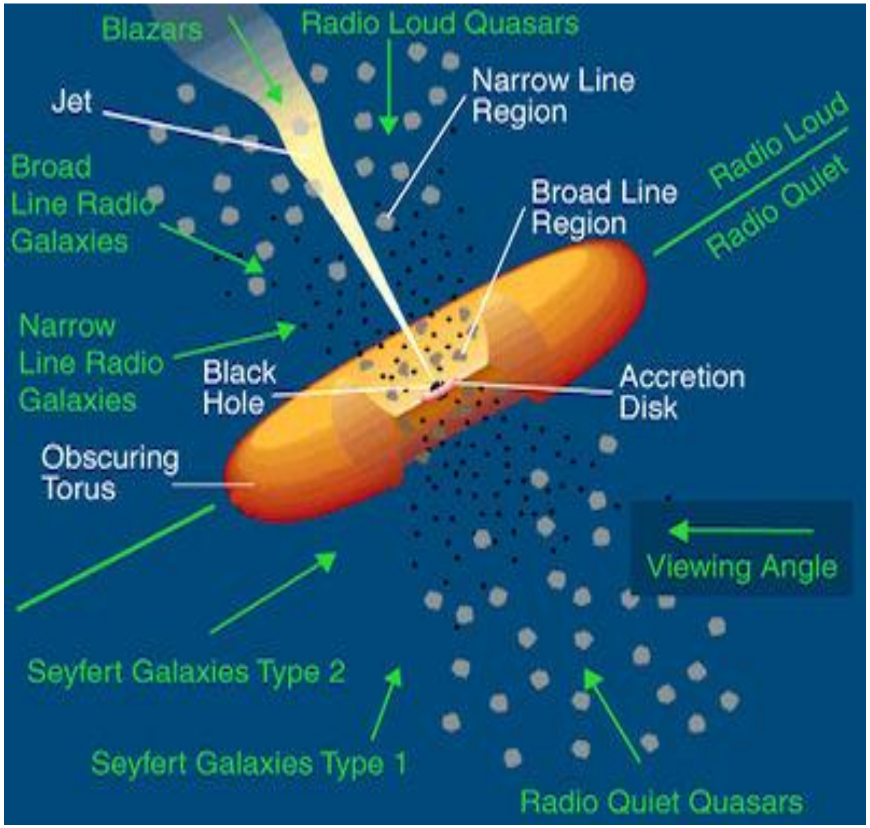
Multifrequency studies of narrow-line Seyfert 1 galaxies

Filippo D'Ammando

(DIFA and INAF-IRA Bologna)

+ M. Orienti, J. Finke, C. M. Raiteri, and many others…

Different classes of AGNs…

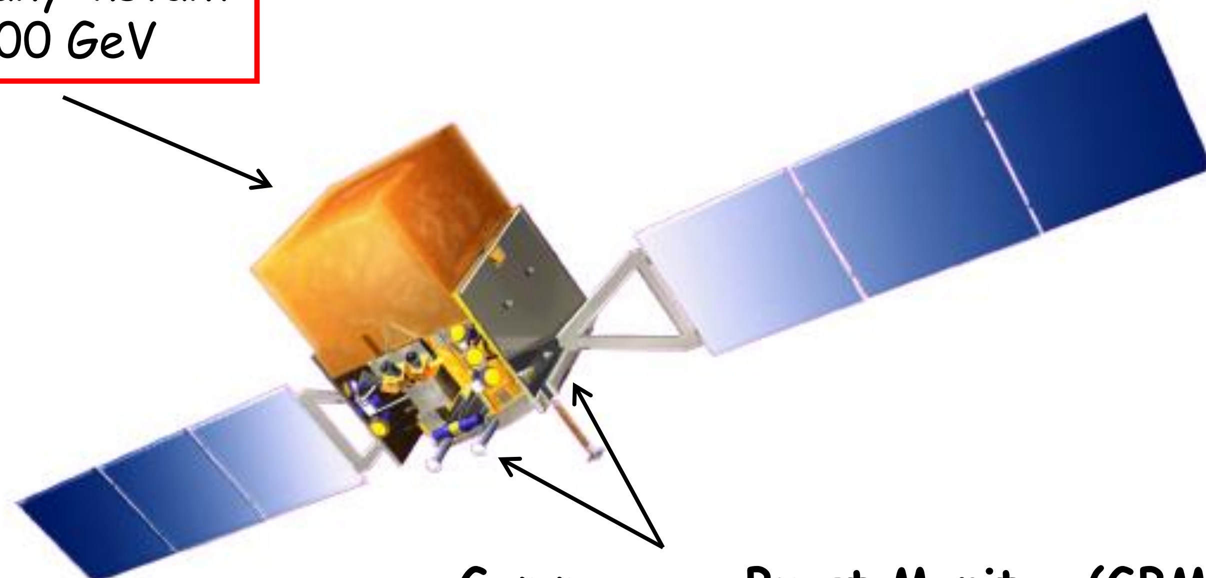


- **Quasars**
  Radio-quiet or radio-loud quasars
- **BL Lacertae Objects**
- **Radio Galaxies**
  Broad or narrow line radio galaxies (BLRGs, NLRGs)
  Fanaroff-Riley class I or II
- **Seyfert Galaxies**
  Seyferts type 1 - 2
  Narrow-Line Seyferts
- **Low-Luminosity AGN**
  Low-Ionization Nuclear Emission-line Region (LINER)
  "Regular" spiral like Sgr A*…

..only blazars and some (peculiar?) radio-galaxies do emit up to the gamma-ray domain?

The Fermi Gamma-ray Space Telescope

Large Area Telescope (LAT)
20% of the sky at any instant
from 20 MeV to >300 GeV



Gamma-ray Burst Monitor (GBM)
entire unocculted sky
transients from 8 keV to 40 MeV

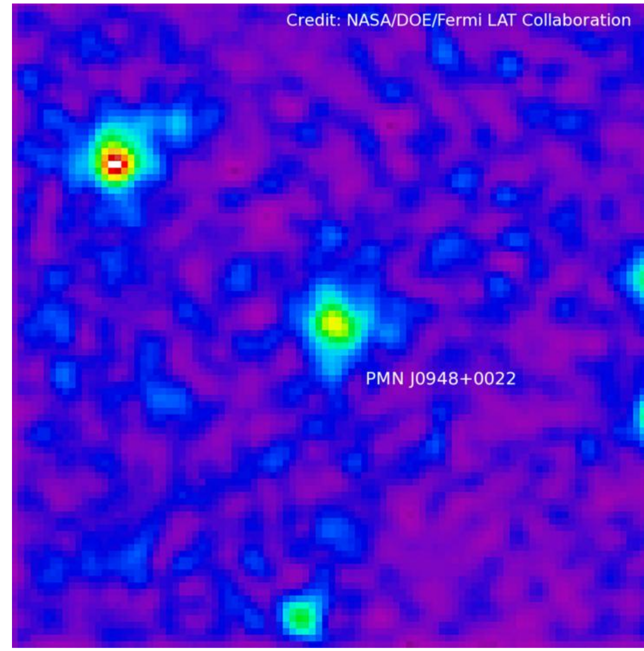
Launched from Cape Canaveral Air Station on 2008 June 11
nearly circular orbit at 565 km, 25.6°

Gamma-ray emitting NLSy1s

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

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

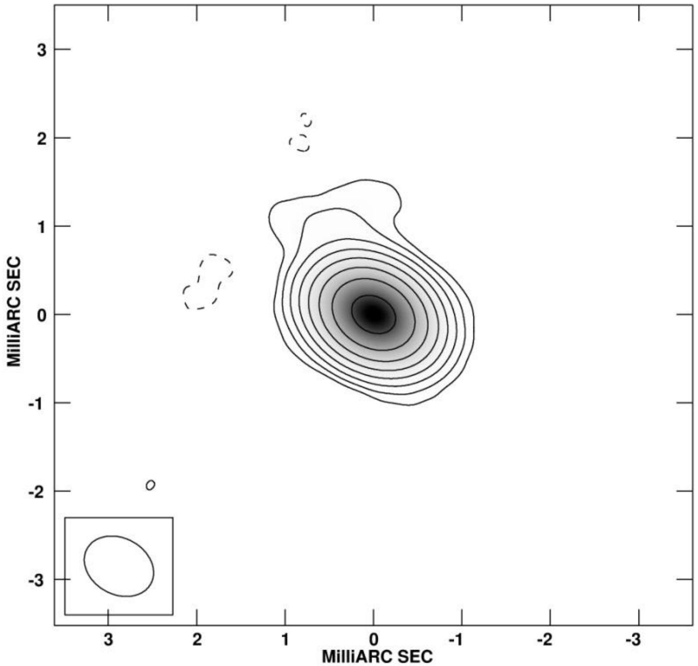
...the first detection of a γ-ray emitting narrow-line Seyfert 1 galaxy, PMN J0948+0022, during the first months of LAT observations was a great surprise!



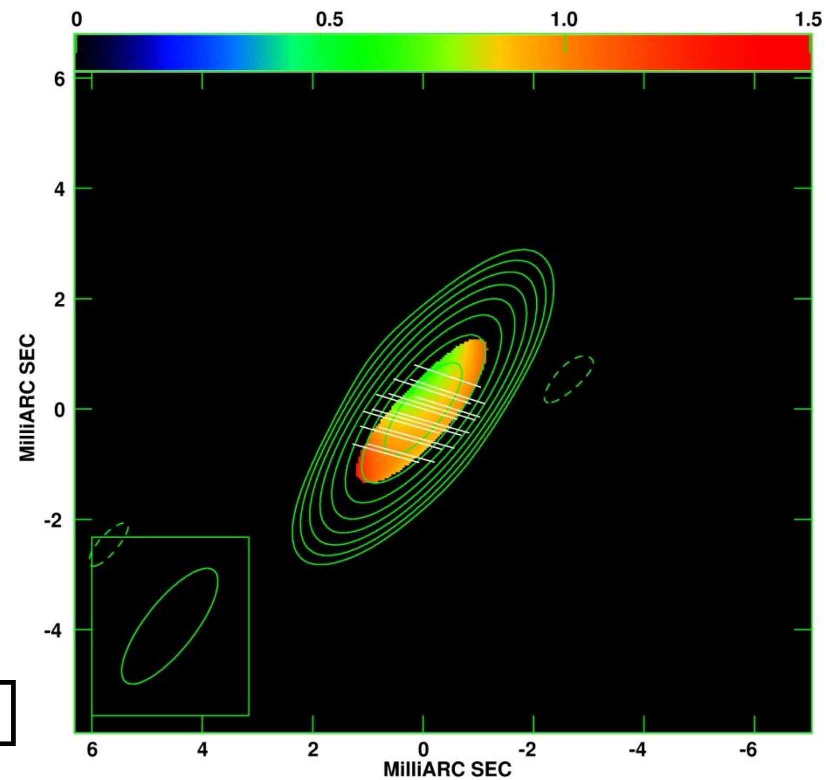
Confirmation of the presence of relativistic jets also in NLSy1

NLSy1s are thought to be 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)

Global e-VLBI observations of PMN J0948+0022



First e-VLBI science observations ever carried out with a global array including telescopes in Europe, East Asia, and Australia

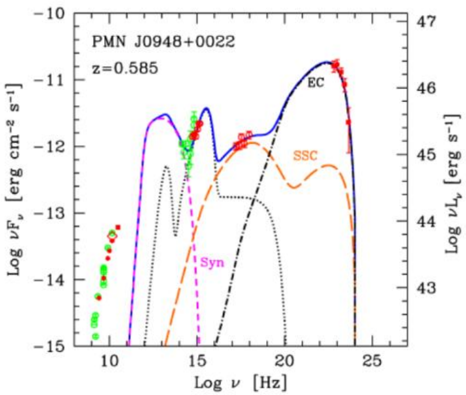


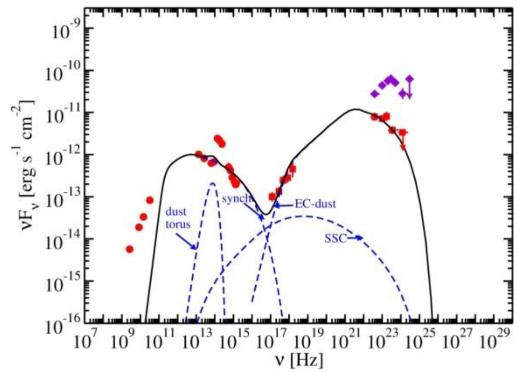
Observed brightness temperature of 3.4×10^{11} K. Polarization detected at a level of about 1%

Giroletti et al. 2009, A&A, 528, L11

Narrow-line Seyfert 1s and *Fermi*-LAT

5 narrow-line Seyfert 1s were detected with TS > 25





1H 0323+342

SBS 0846+513

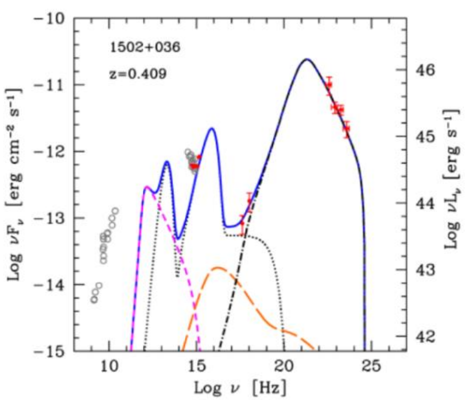
PMN J0948+0022

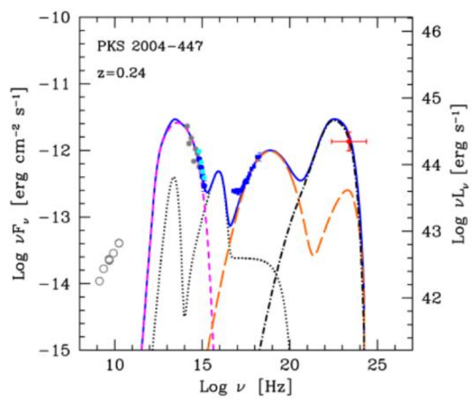
PKS 1502+036

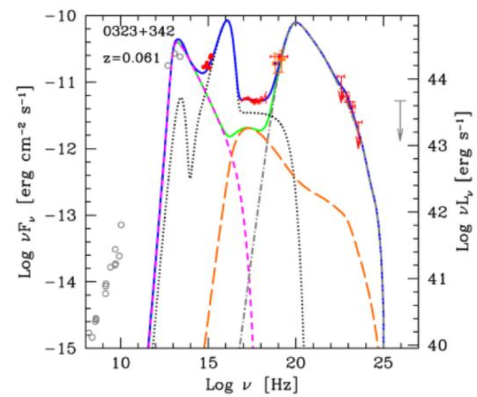
PKS 2004-447

See also Foschini et al. 2012, 2014

D'Ammando, Orienti, Finke et al. 2012

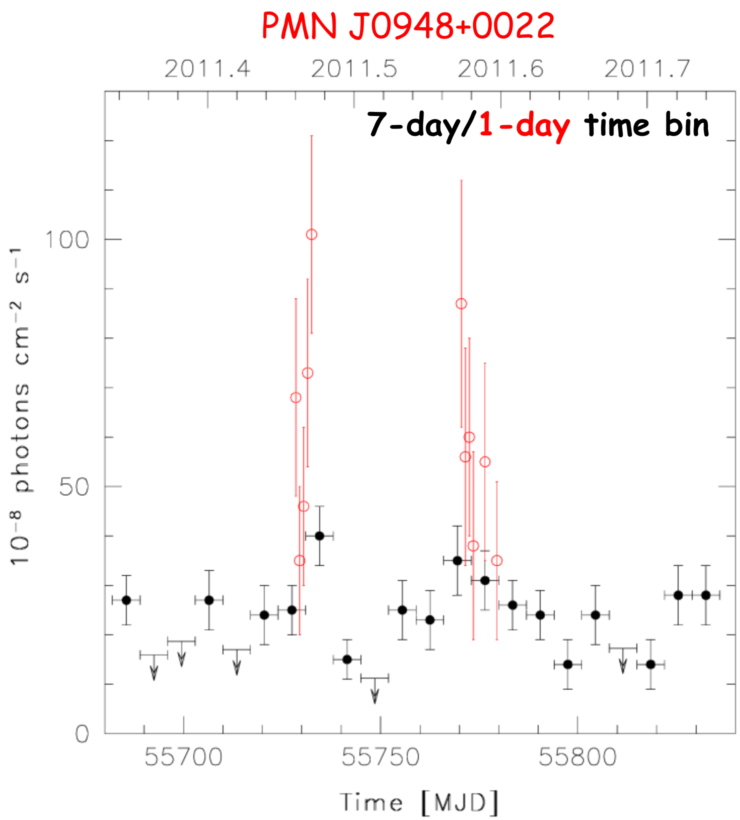


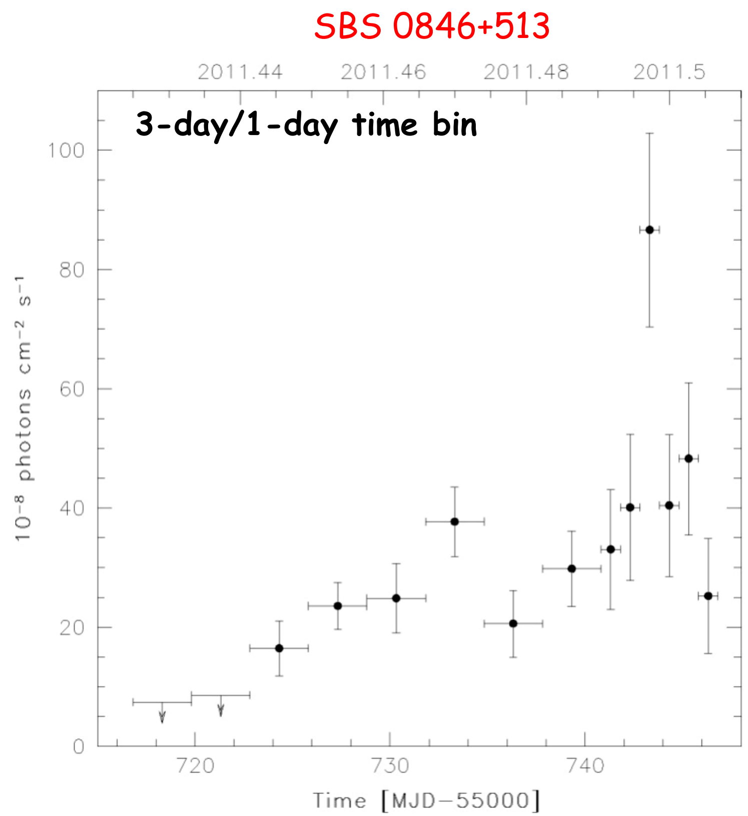




Abdo et al. 2009 (CA: L. Foschini)

NLSy1s are flaring gamma-ray sources!



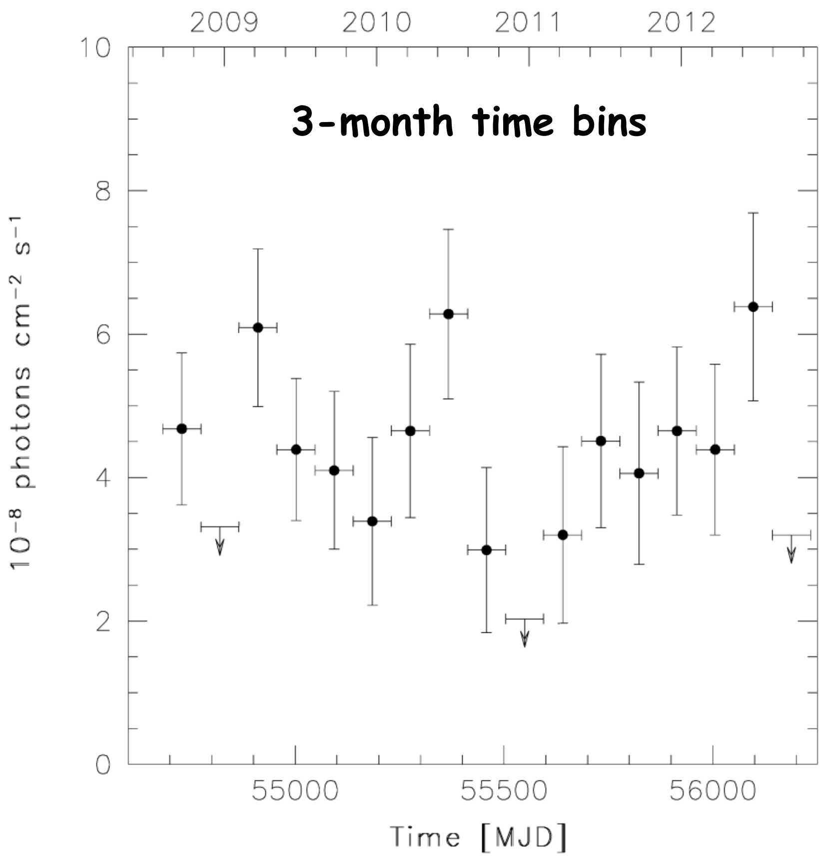


D'Ammando et al. 2014a, MNRAS, 438, 3521

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

PMN J0948+0022, SBS 0846+513, and recently 1H 0323+342 (ATel #5344) showed different flaring episodes with an apparent isotropic gamma-ray luminosity of ***~10^{48} erg s^{-1}*, *comparable to that of the bright FSRQs***

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 $\Gamma = 2.60\pm0.06$

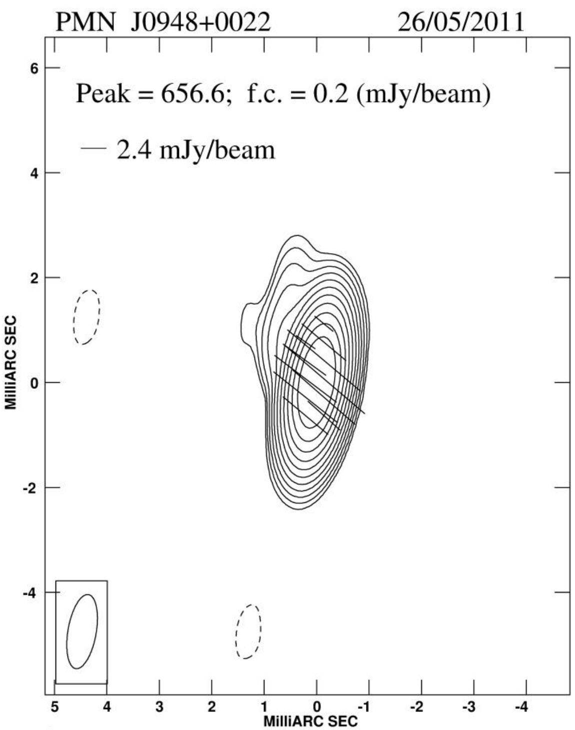
No significant flux variability was observed, with only a few detections on weekly time scales and a peak value of (18 ± 6)e-8 ph cm^{-2} s^{-1}

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

Core-jet structures in gamma-ray NLSy1s

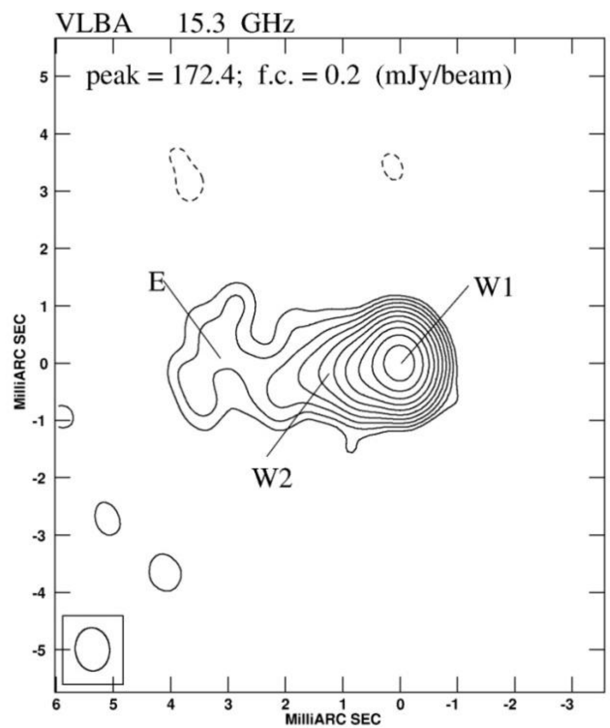
Core-jet structure on parsec scale resolved with the VLBA

PMN J0948+0022



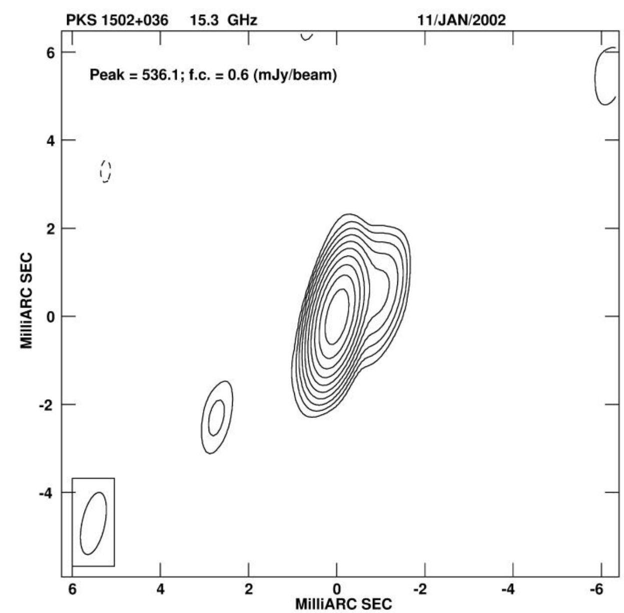
D'Ammando et al. 2014a

SBS 0846+513



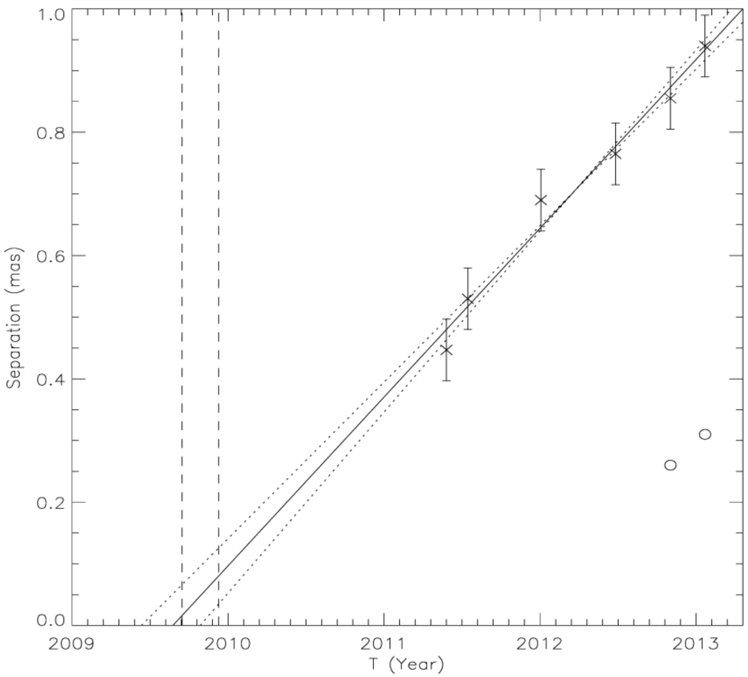
D'Ammando et al. 2012

PKS 1502+036



D'Ammando et al. 2013a

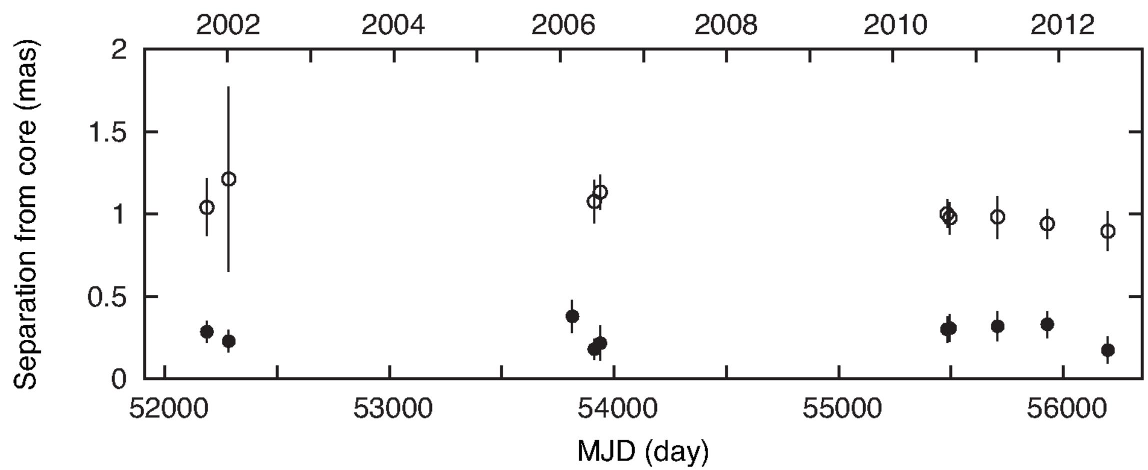
Proper motion of gamma-ray NLSy1s



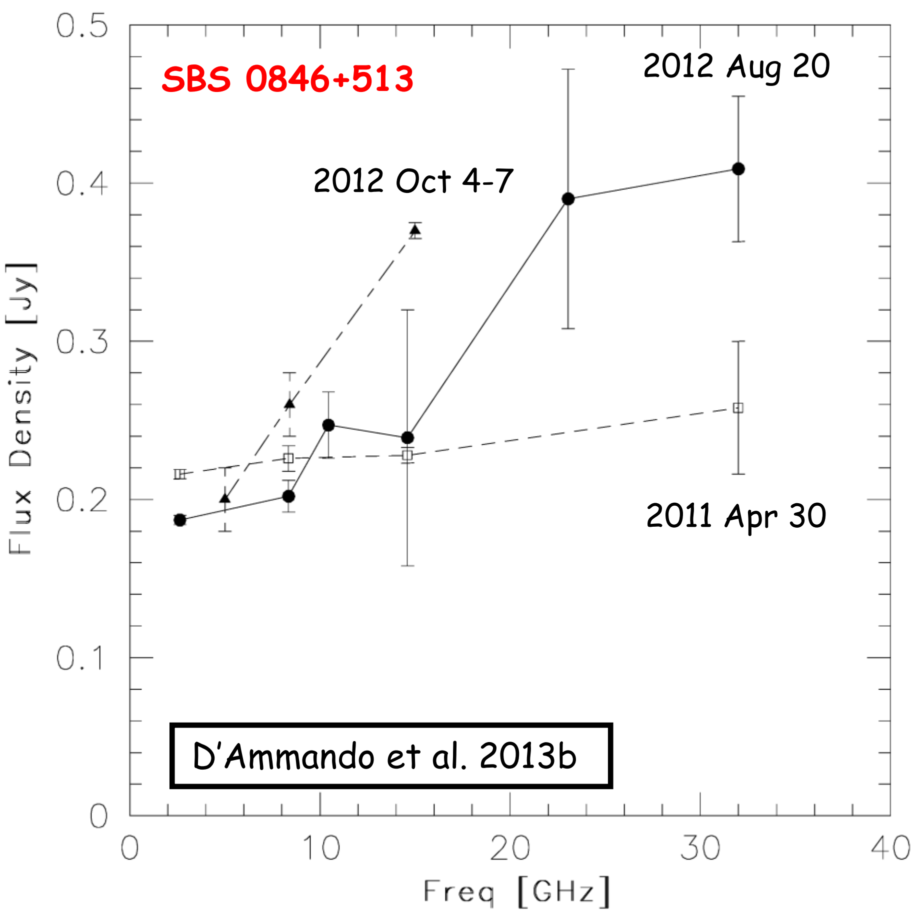
With 6-epoch MOJAVE data for SBS 0846+513 we obtained an apparent velocity of the jet knot **(9.3±0.6)c**, suggesting **the presence of boosting effect as well as in blazars**. The time of ejection is **T_0 = 24 August 2009**, likely connected with a radio flare. *No significant gamma-ray activity was detected in that period*

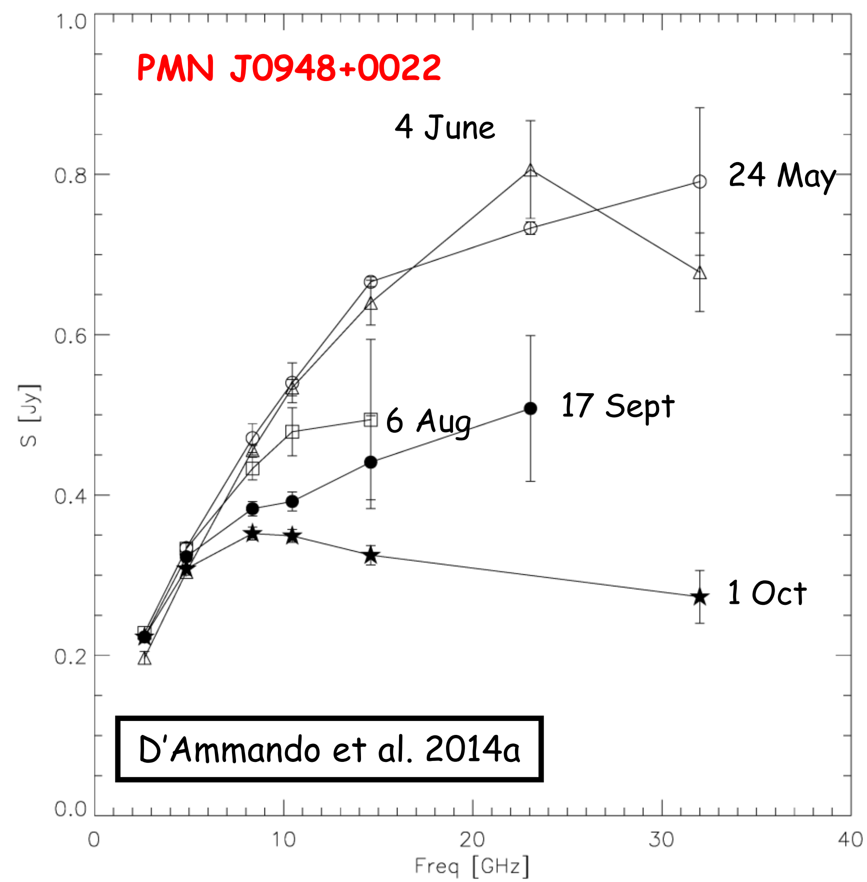
D'Ammando et al. 2013b, MNRAS, 436, 191

No significant proper motion was detected for the jet components of PKS 1502+036



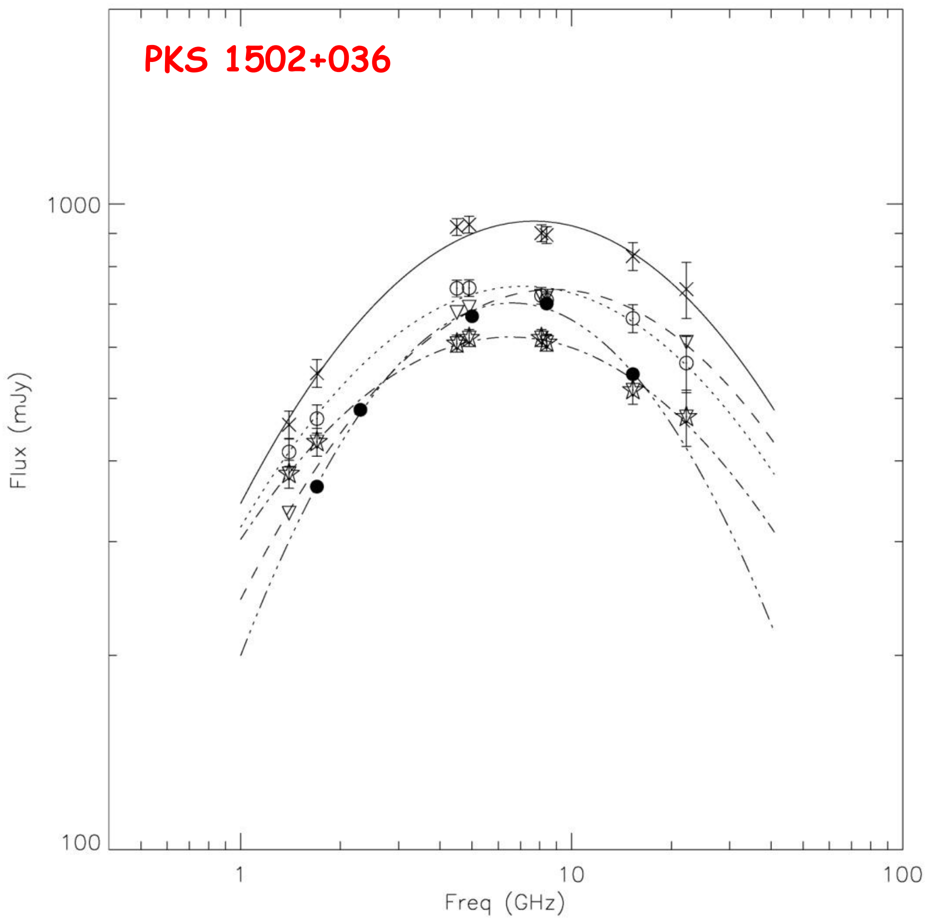
Radio spectra variability





Significant radio spectra variability was observed in NLSy1s, a typical blazar behaviour. For PMN J0948+0022 the higher flux was observed ***before*** the gamma-ray peak in 2011 June 20

Radio spectra variability

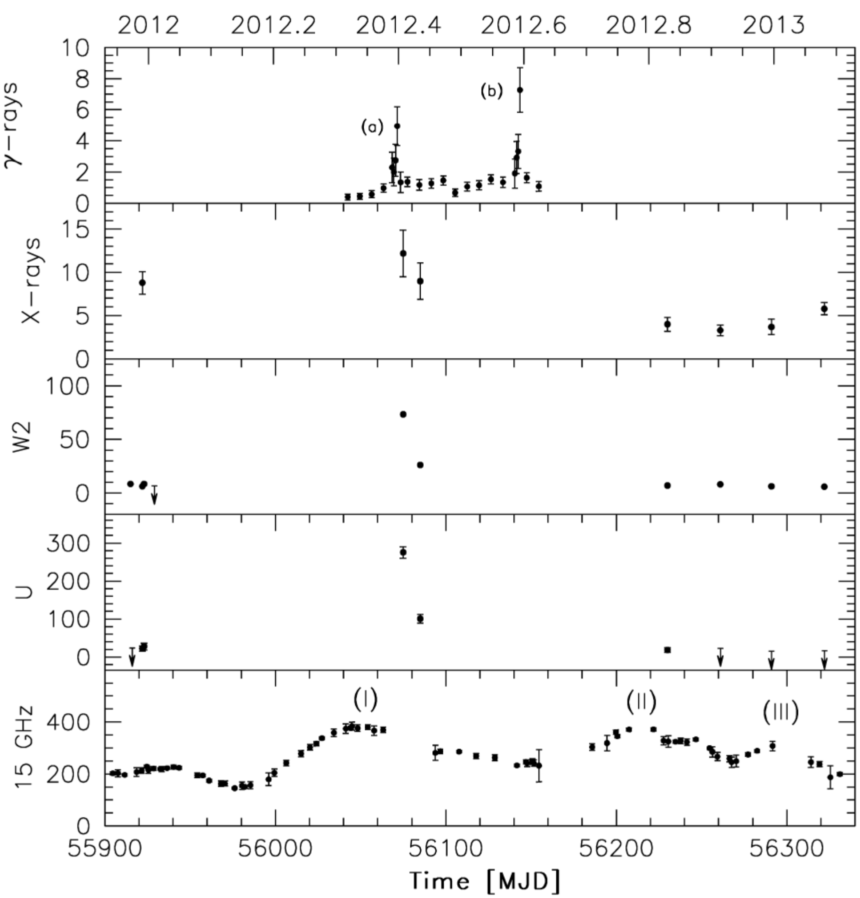


D'Ammando+2013a

Simultaneous multifrequency VLA observations carried out at different epochs showed substantial spectral and flux variability in PKS 1502+036

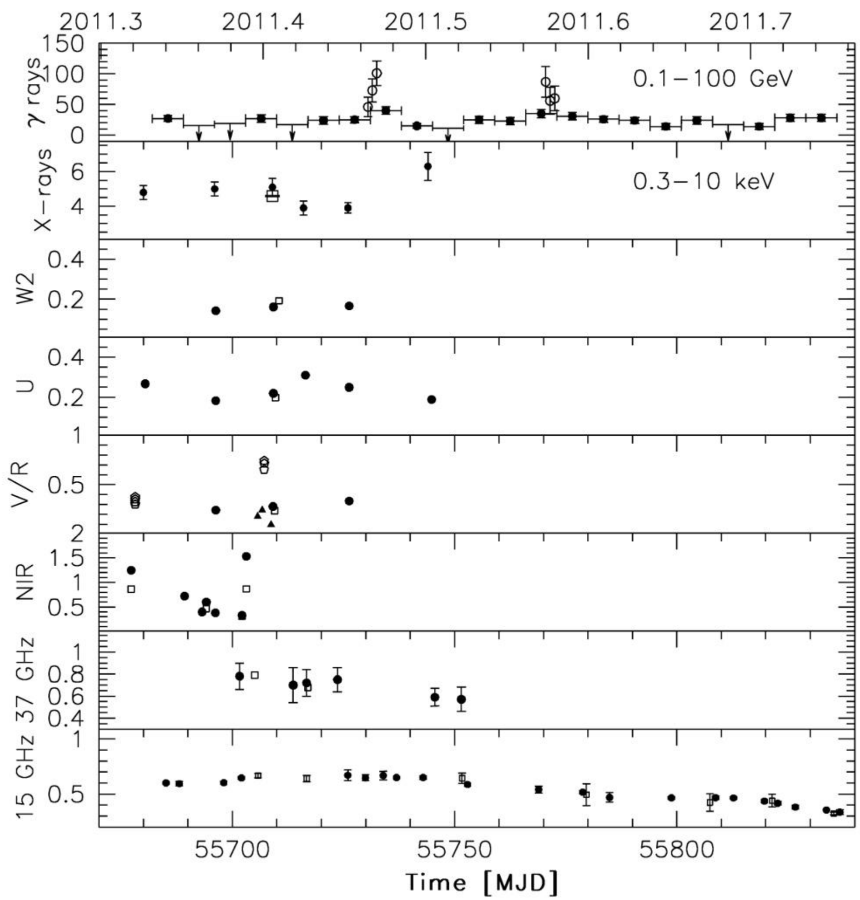
Complex correlated variability

SBS 0846+513



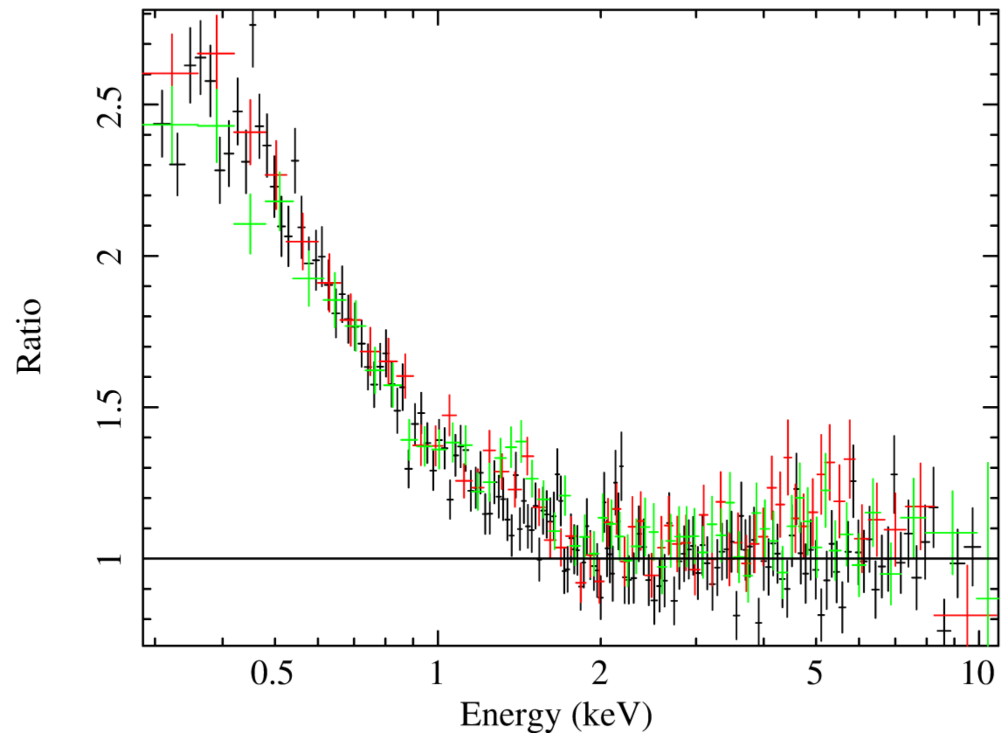
D'Ammando et al. 2013b

PMN J0948+0022



D'Ammando et al. 2014a

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 (1254)

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

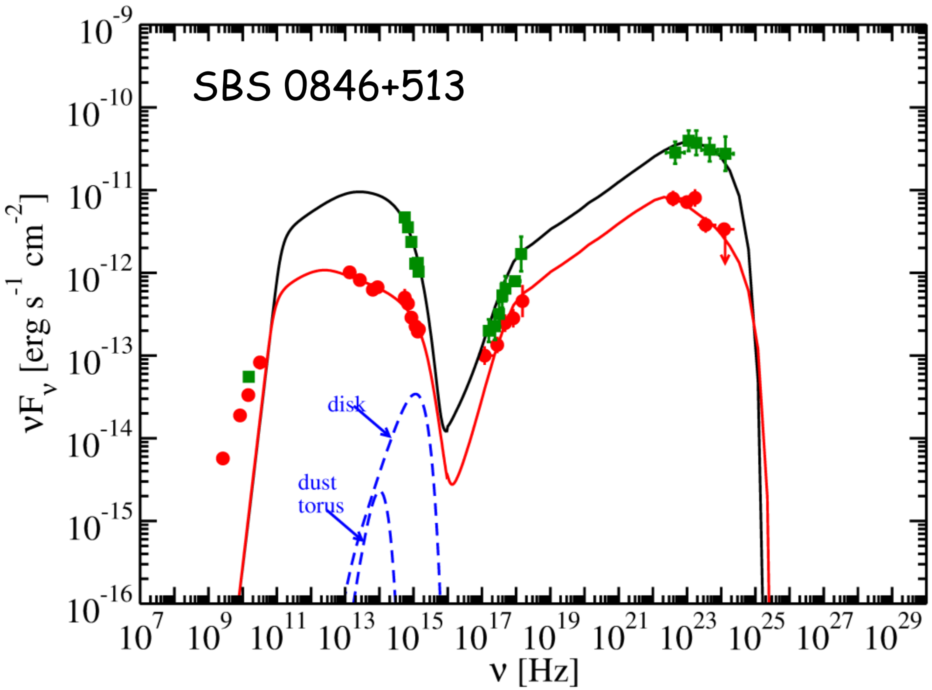
A clear soft excess was observed, notwithstanding the non-thermal jet emission!

D'Ammando et al. 2014a

A broken power-law provides an acceptable fit, χ^2_{red} = 1.10 (1252), with a break at energy E_{break} = 1.72$\pm$0.10 keV and photon indices Γ_1= 2.14$\pm$0.03 and Γ_2 = 1.48$\pm$0.04. The emission above 2 keV is dominated by the jet component, with no detection of an Iron line in the spectrum and a 90% upper limit on the EW of 19 eV

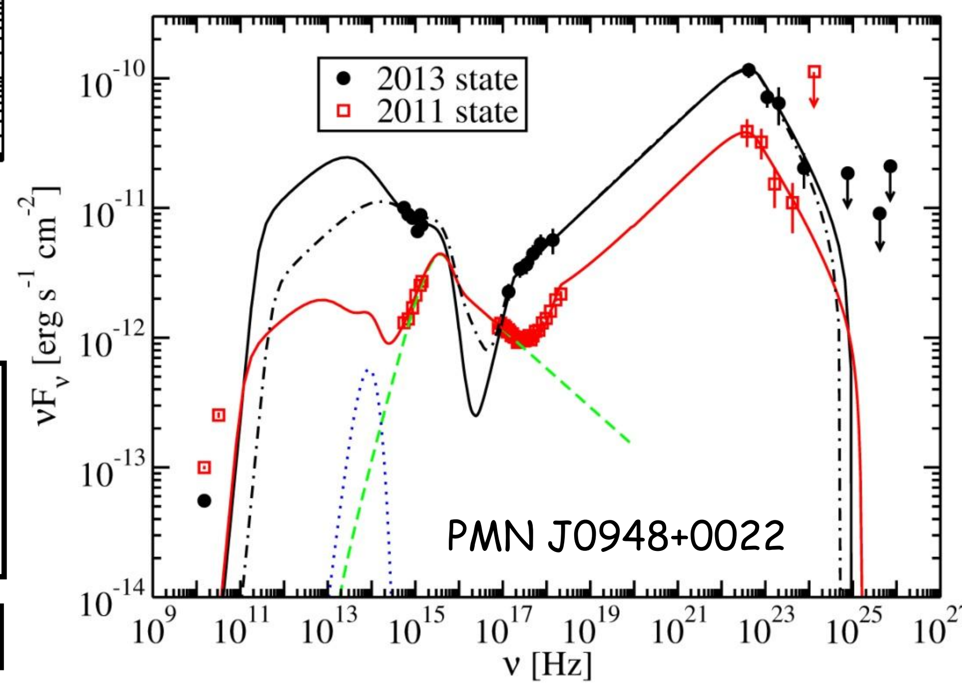
The soft component can be also fitted with a black body model with kT ~ 0.18 keV. Such a high temperature is inconsistent with the standard accretion disk theory

SED modeling of NLSy1s



The quiescent and flaring state, modelled by EC (dust), could be fitted by changing the electron distribution parameters as well as the magnetic field

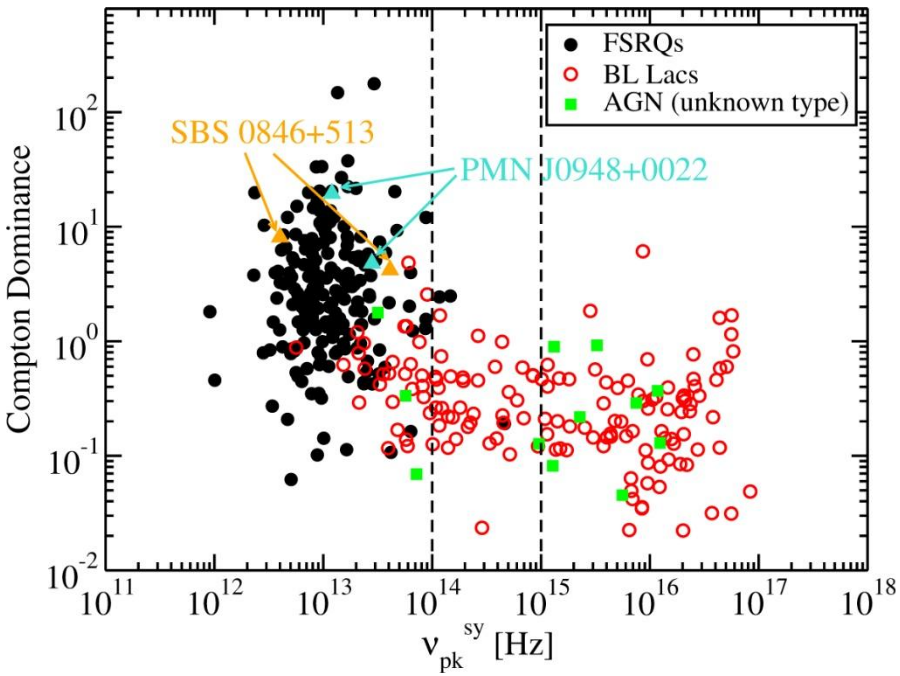
D'Ammando et al. 2013b



The 2013 flaring state may be modelled by EC (dust) or EC (BLR). In the latter, the source is far from the equipartition favouring the EC (dust) model.

D'Ammando et al. 2014b

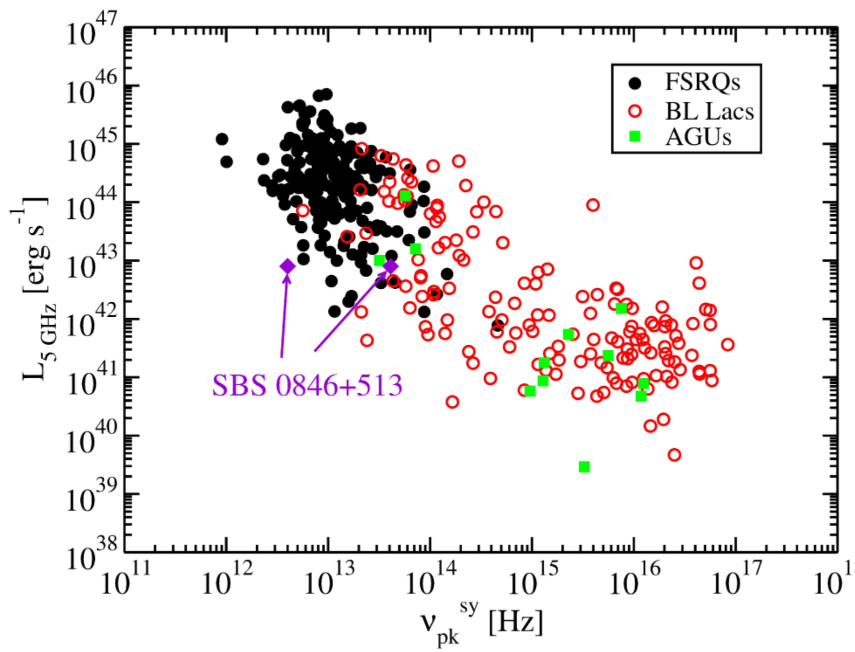
Comparison with γ-ray blazars



SBS 0846+513 and PMN J0948+0022 showed a Compton dominance typical of FSRQs during both the low and high activity state

D'Ammando et al. 2014b

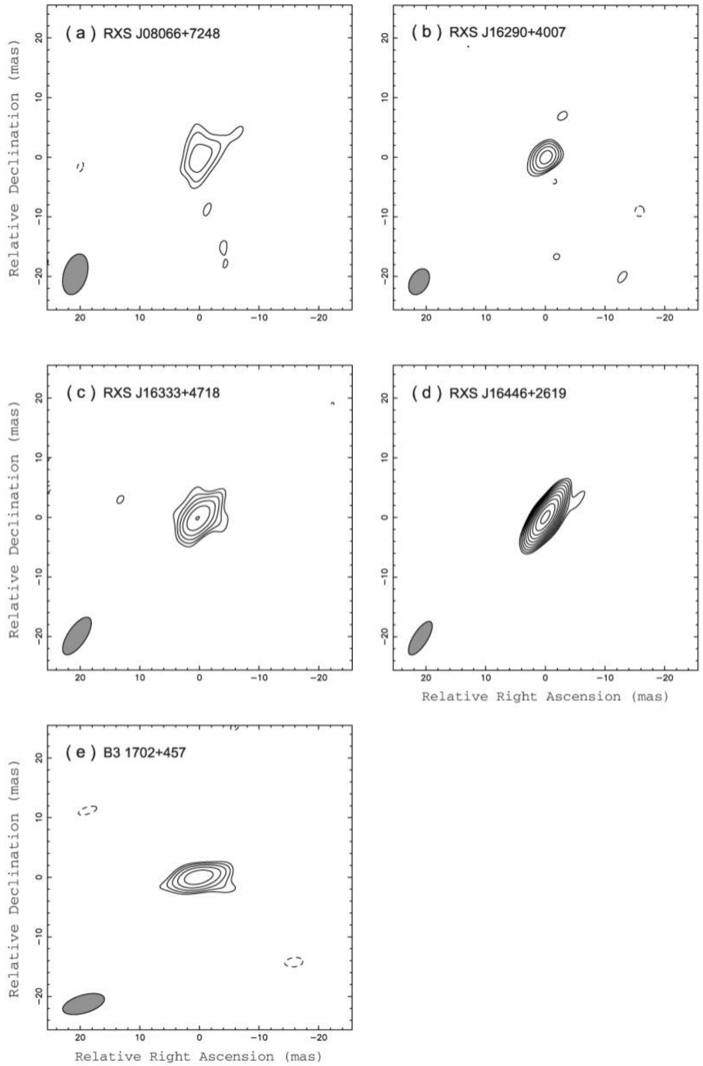
Figures adapted from Finke 2013



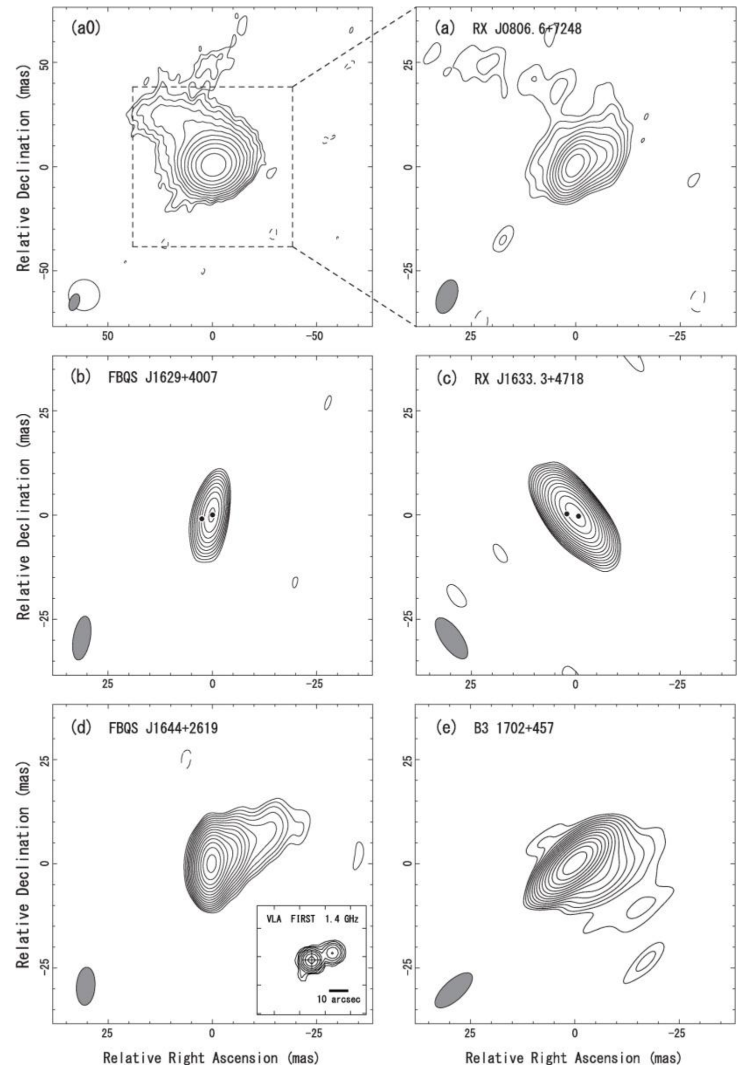
In the "classical" blazar sequence plot SBS 0846+513 seems to lie in the FSRQ region

D'Ammando et al. 2013b

Pc-scale radio structures in NLSy1s

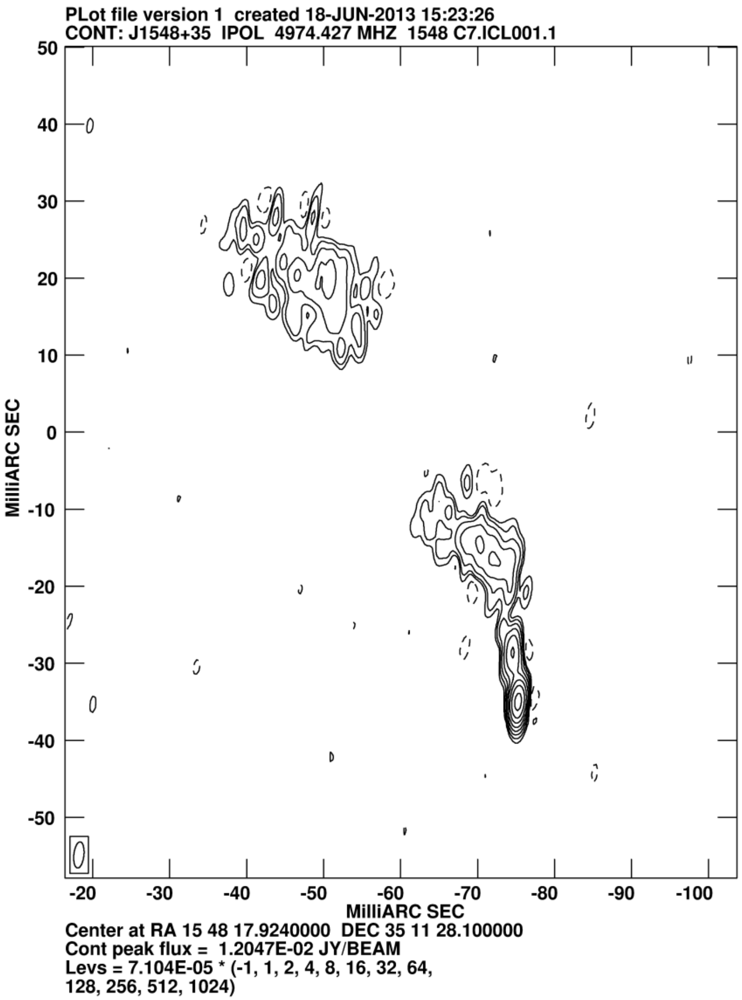


Doi+2007



Doi+2010

Searching for candidate γ-ray NLSy1s: J1548+3511

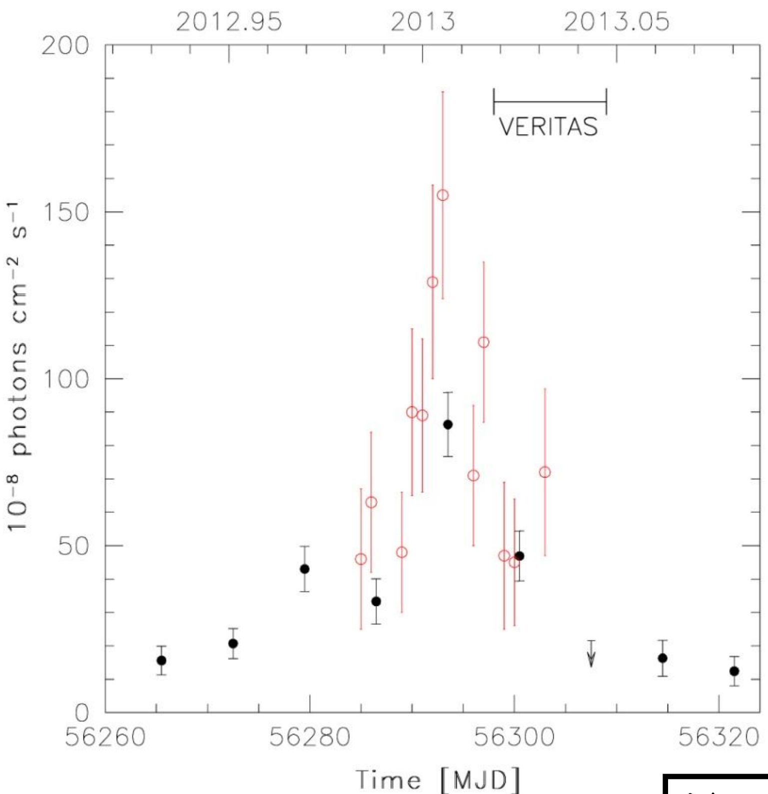


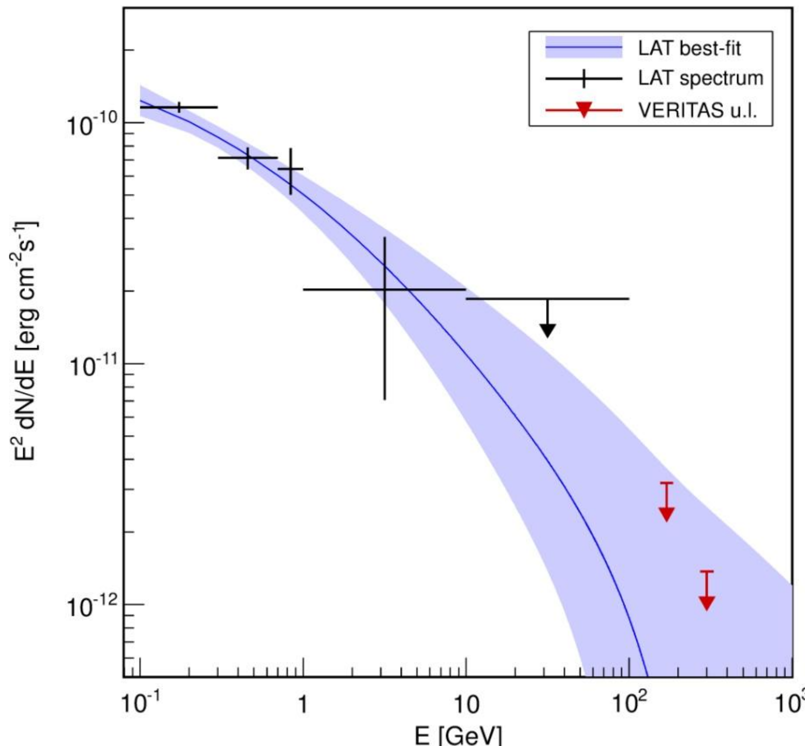
J1548+3511 showed a high brightness temperature, comparable to that observed in the NLSy1s already detected by *Fermi*-LAT (see Yuan et al. 2008), but no gamma-ray emission is detected from this source so far

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, D'Ammando, et al. in prep

NLSy1 as VHE emitting sources?





D'Ammando et al. 2014b

Following the most powerful flaring activity from PMN J0948+0022, the detection of VHE emission from this NLSy1 was attempted by VERITAS. Future observations with the Cherenkov Telescope Array (CTA) will constrain the level of gamma-ray emission at 100 GeV or below.

Summary and Open Questions

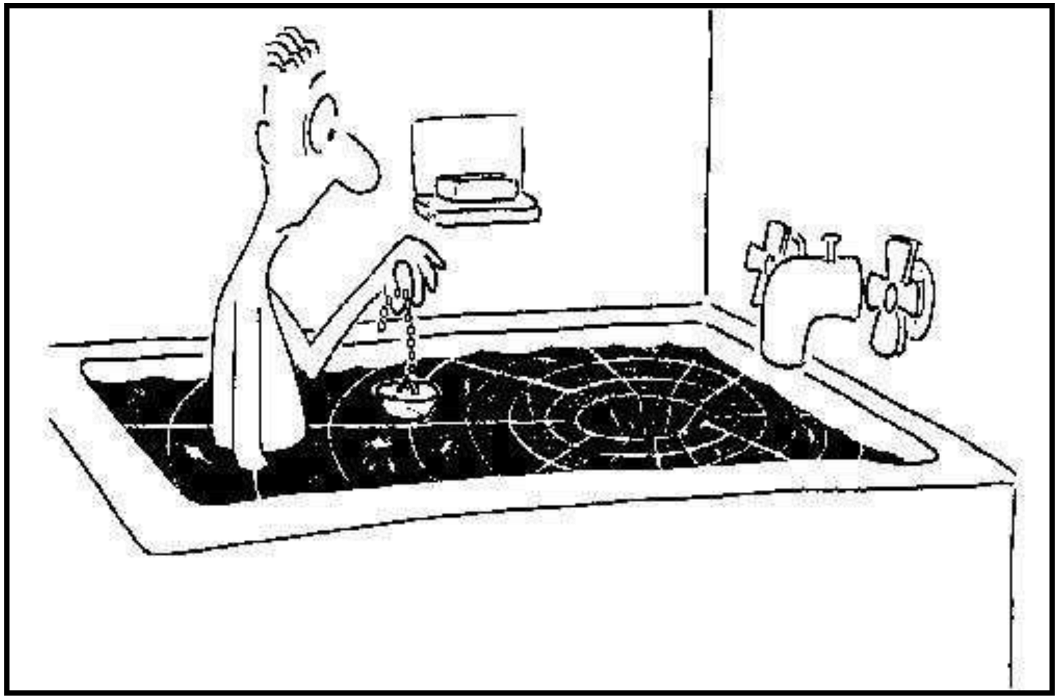
• At least three NLSy1s showed intense γ-ray flares, thus NLSy1 can host relativistic jets as powerful as blazars. Are these sources peculiar also among the NLSy1s?

• 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 . 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 both 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 thought to be 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 or actually the BH mass of these objects are 10^8-10^9 solar masses…but how is it possible to have such a large BH mass in a spiral galaxy? Are gamma-ray NLSy1s not in classical spiral galaxies?**



Thanks for your attention!

Back up slides

Host galaxy of gamma-ray NLSy1s

• Unfortunately only very sparse observations of the host galaxy of radio-loud NLSy1s are available so far

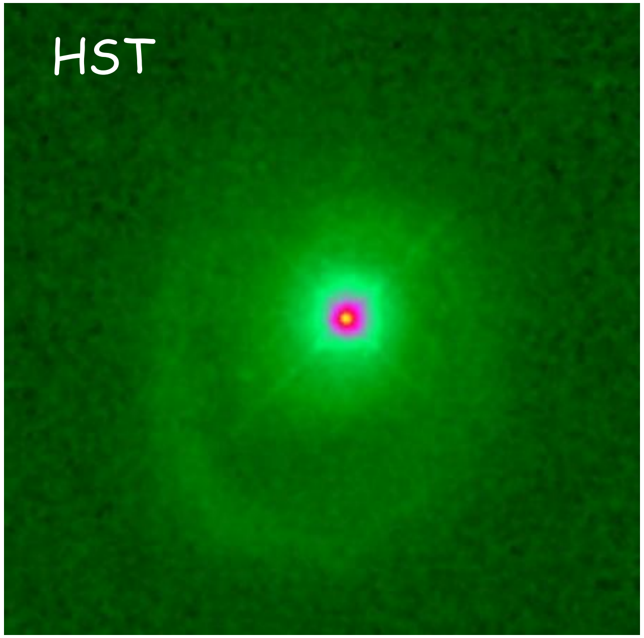
• The sample of objects studied by Deo et al. (2006) and Zhou et al. (2006) had $z < 0.03$ and $z < 0.1$, respectively, including both the radio-quiet and radio-loud objects. Four out five of the NLSy1s detected in gamma rays have $z > 0.2$

• Among the radio-loud NLSy1s detected by *Fermi*-LAT only for the closest one, 1H 0323+342, the host galaxy was clearly detected. A possible spiral arm seems to be observed by HST, but NOT observations suggests a possible ring structure and the presence of the residual of a galaxy merging

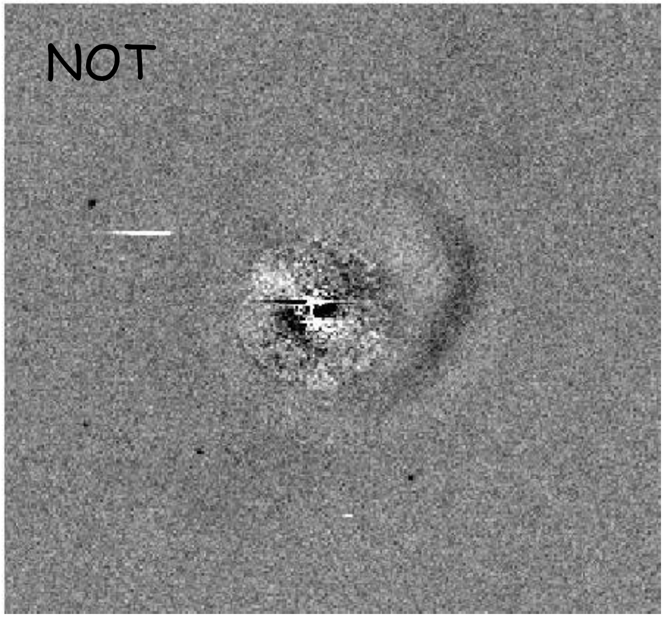
• No significant resolved structures have been observed by HST for SBS 0846+513 (Maoz et al. 1993), and no high resolution observations are available for the remaining gamma-ray NLSy1s

• **The possibility that the development of relativistic jets in these objects could be due to strong merger activity, unusual in disk/spiral galaxies, cannot be ruled out**

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

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

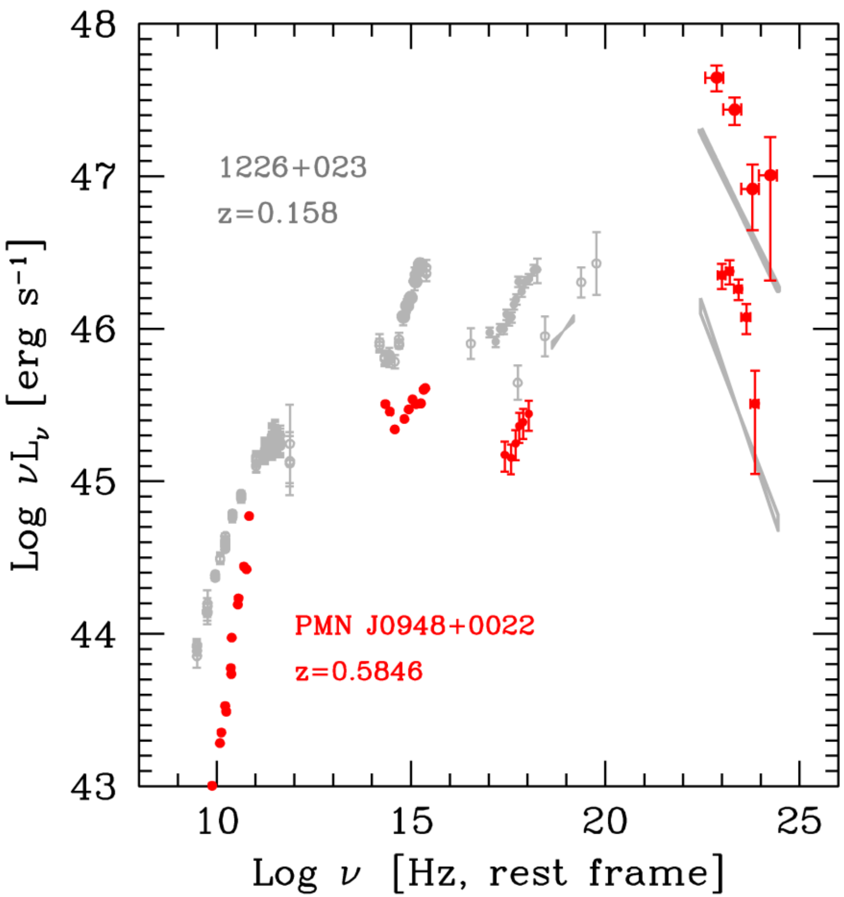
• One fundamental parameter could be the BH mass, with only large masses allowing relativistic jet formation

• 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**

FSRQs vs RL-NLS1s

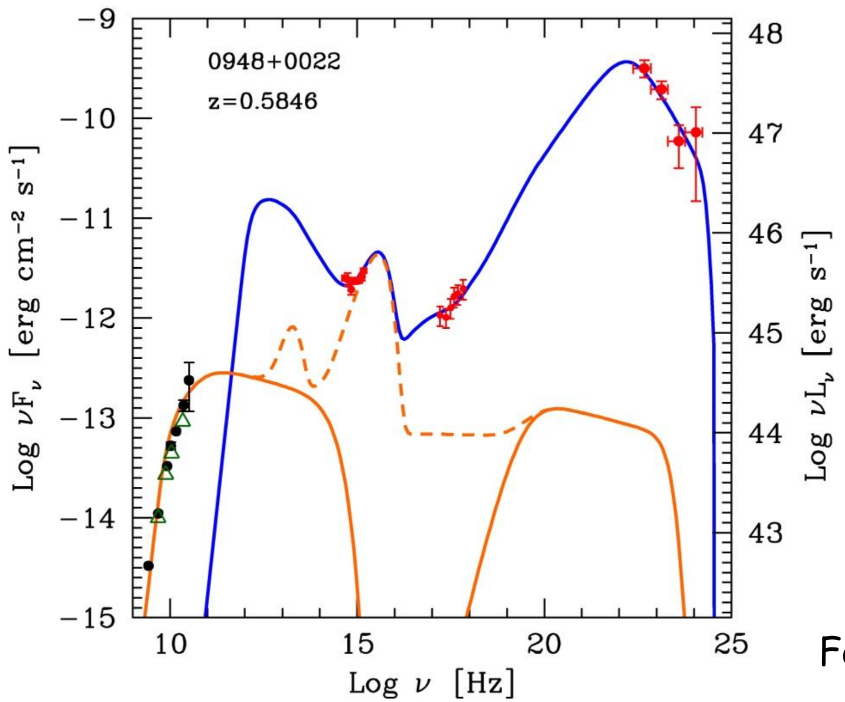


Foschini+2011

- 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

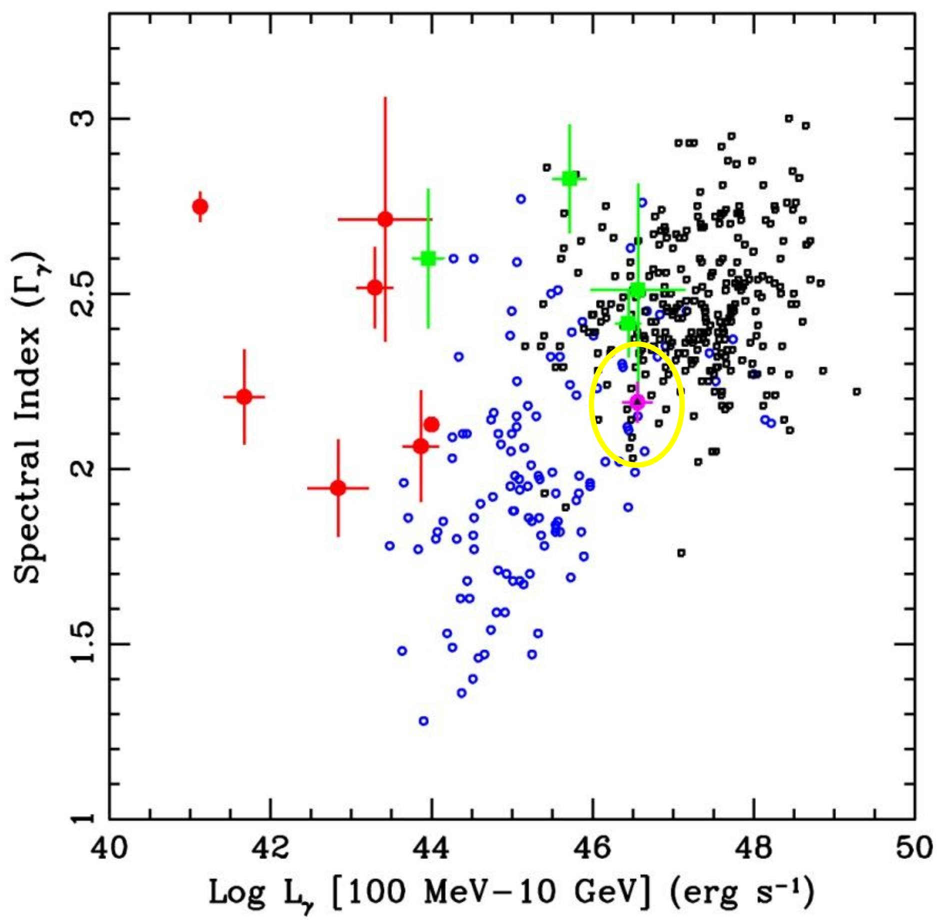
SED modeling of NLSy1s



Foschini et al. 2011

To account for the radio emission, an additional larger emitting region was considered for the 2010 flare from PMN J0948+0022. This region is 0.6 pc in size at 5.8 pc from the central BH. At this distance the EC (dust) is the dominant mechanism.

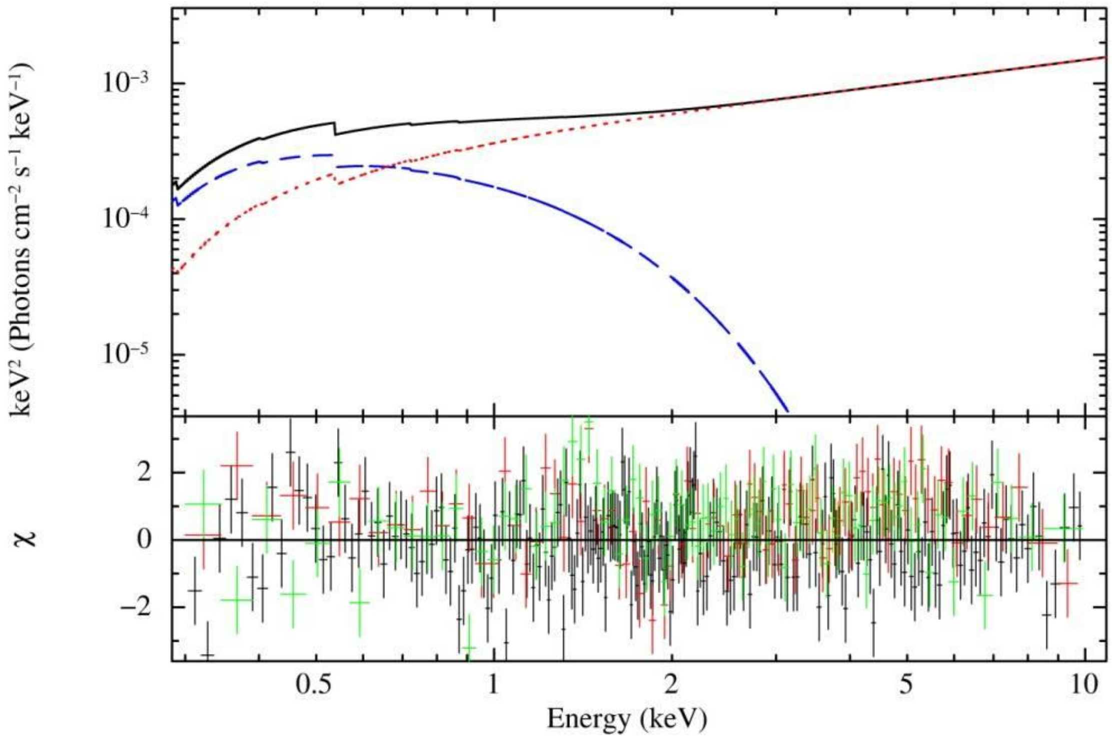
γ-ray luminosity and spectrum of SBS 0846+513



D'Ammando et al. 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

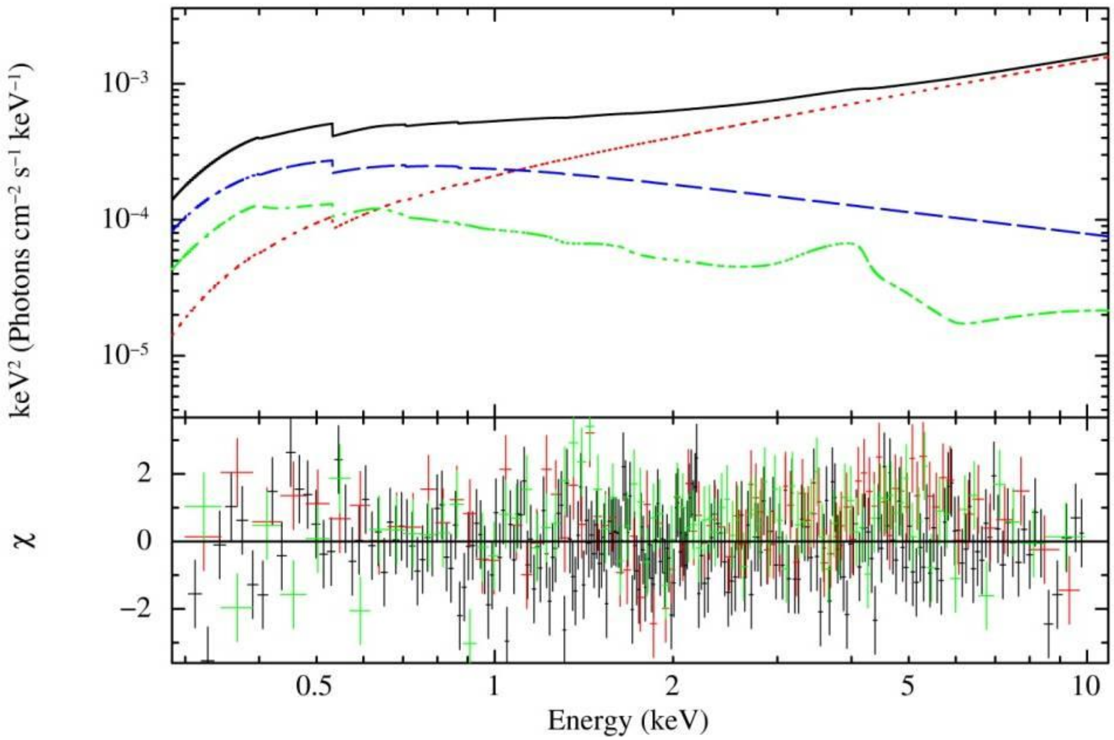
Comptonization model for PMN J0948+0022



Soft excess modeled as componization of the disc emission by a population of electrons with low temperature and large optical depth (in a transition region between the disc and the corona) provides a good fit, χ^2_{red} = 1.062 (1251)

T_0 = 11 eV (fixed), KTe = 0.50 (+0.16,-0.09) keV, τ = 10.2$\pm$0.2, Γ = 1.44 $\pm$0.03

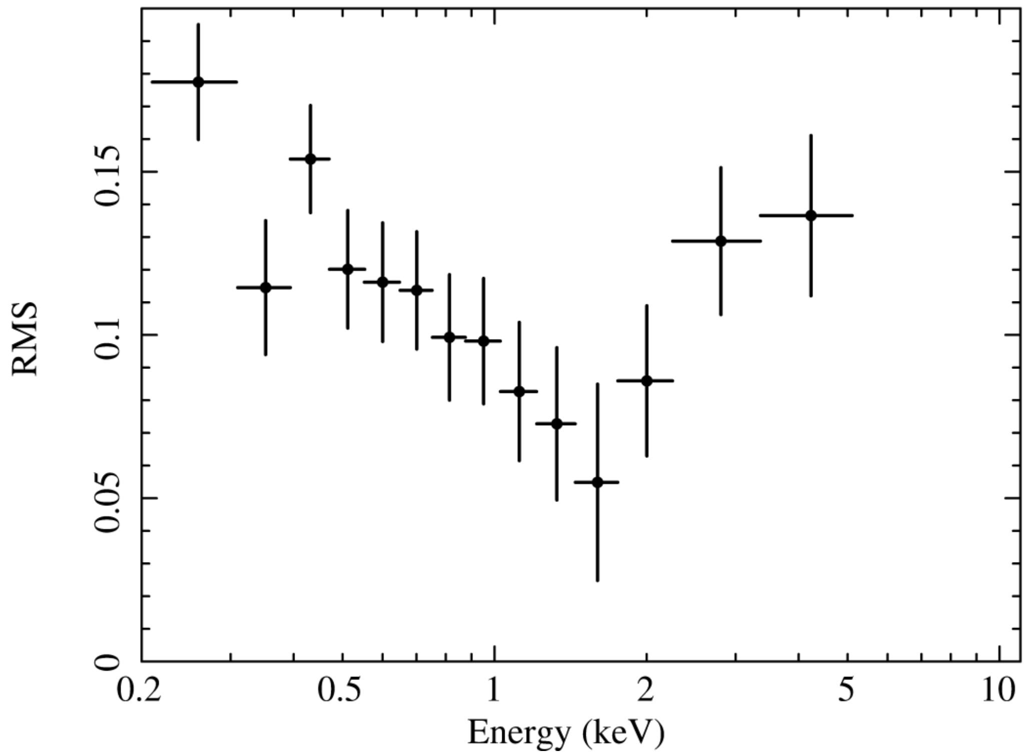
Reflection model for PMN J0948+0022



R_{min} = 6 rg
R_{max} = 400 rg
q = 3
i= 3°
Solar abundances

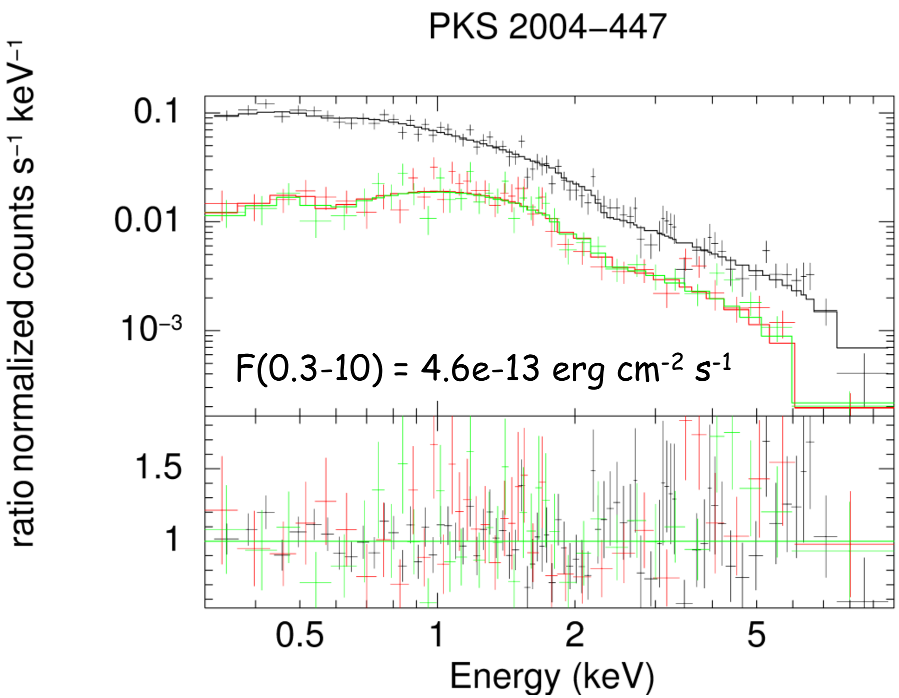
Soft excess modeled as relativistic blurred reflection from the accretion disk. The X-ray spectrum is composed by a steep spectrum (corona), a reflection component, and a hard power-law associated with the jet. The quality of the fit is similar to the Comptonization model, χ^2_{red} = 1.065 (1251)

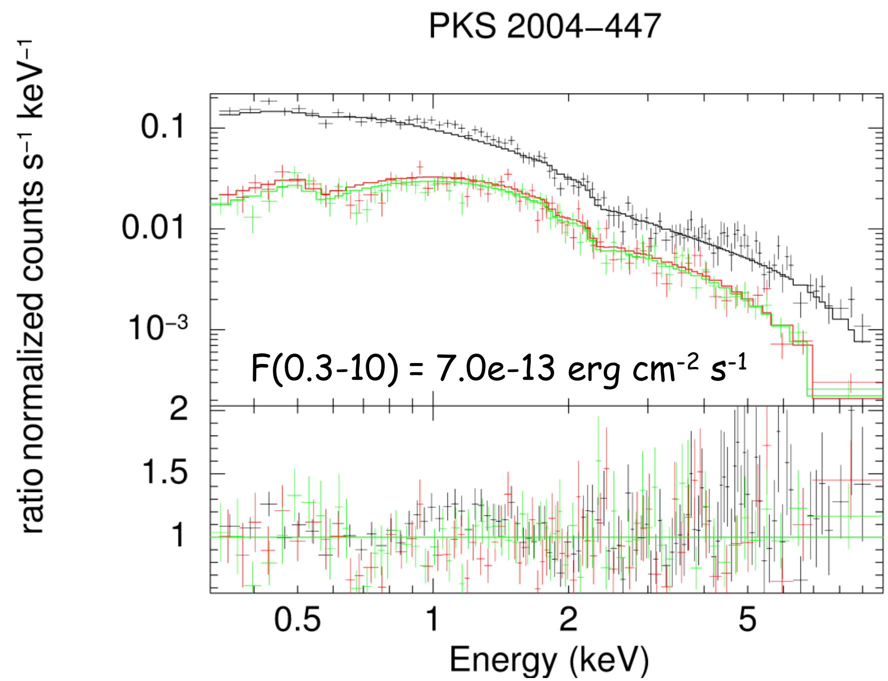
RMS variability spectrum



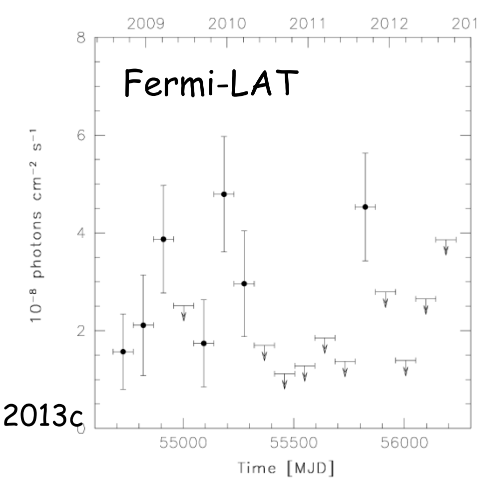
The RMS variability spectrum decreases with energy up to 1.7 keV, and then starts to increase again.

XMM observations of PKS 2004-447 in 2012





The photon index is Γ~1.7, consistent with a jet emission component but there is no evidence of the soft X-ray excess. Is it only a matter of statistics? Or is it connected with the low jet activity?



D'Ammando et al. 2013c