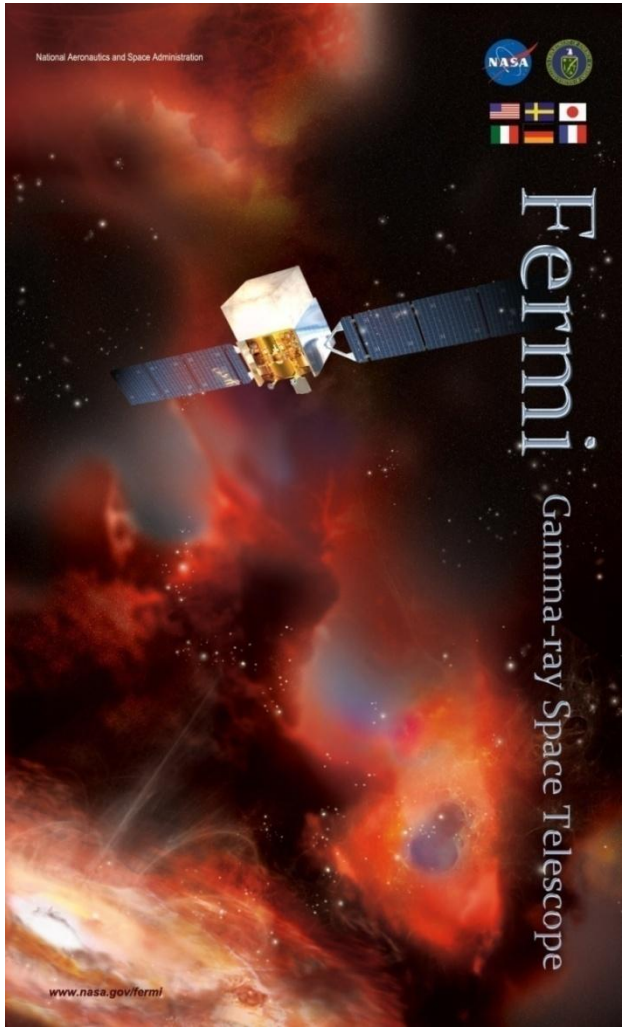


The X-ray view of the gamma-ray emitting narrow-line Seyfert 1 galaxies

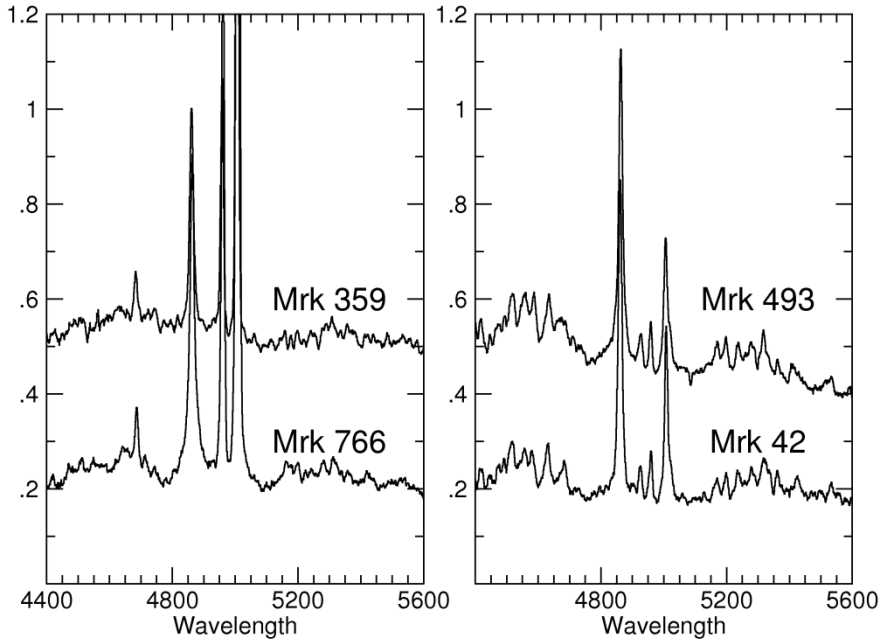
Filippo D'Ammando

(University of Bologna and INAF-IRA)

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

Narrow-Line Seyfert 1s

- Optical classification:
  - FWHM (Hβ) < 2000 km s^{-1} (NL)
  - [O III] λ5007/Hβ < 3 (Sy1)



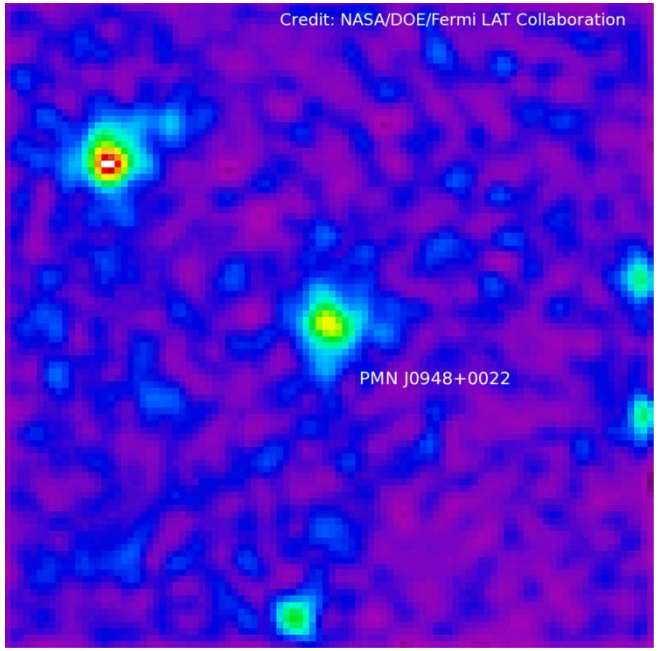
Osterbrock & Pogge 1985

- Other notable properties:
  - strong Fe II bump (Goodrich 1989)
  - relatively low BH masses (10^6-10^8 solar masses)
  - high accretion rates (up to Eddington limit)

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 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!

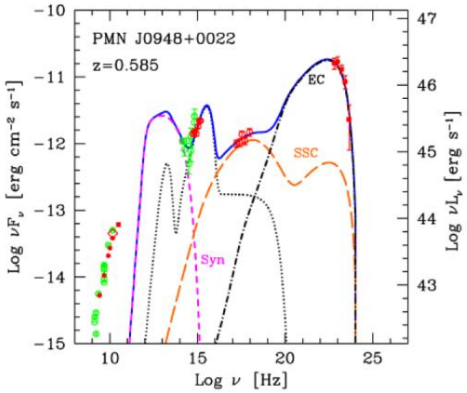


Confirmation of the presence of relativistic jets also in NLSy1

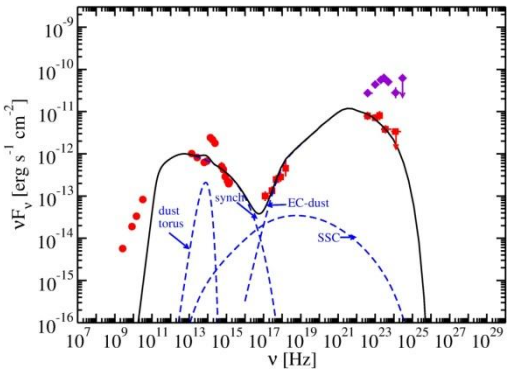
NLSy1s are thought to be hosted in **spiral/disc galaxies**, the presence of a relativistic jet in some of these objects seems to be in contrast to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies (e.g. Boettcher & Dermer 2002, Marscher 2010)

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

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



See also Foschini et al. 2012



D'Ammando, Orienti, Finke et al. 2012

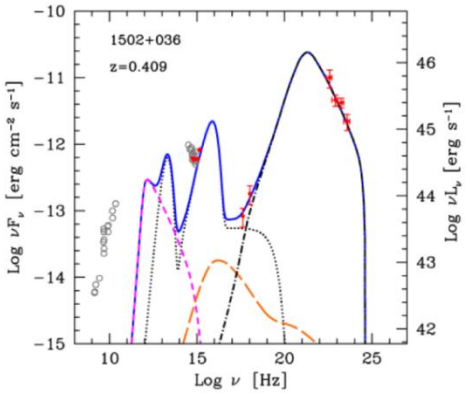
1H 0323+342

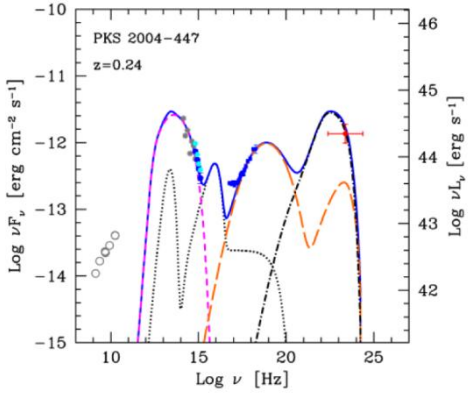
SBS 0846+513

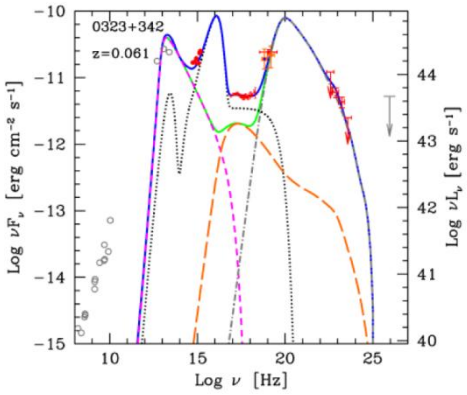
PMN J0948+0022

PKS 1502+036

PKS 2004-447



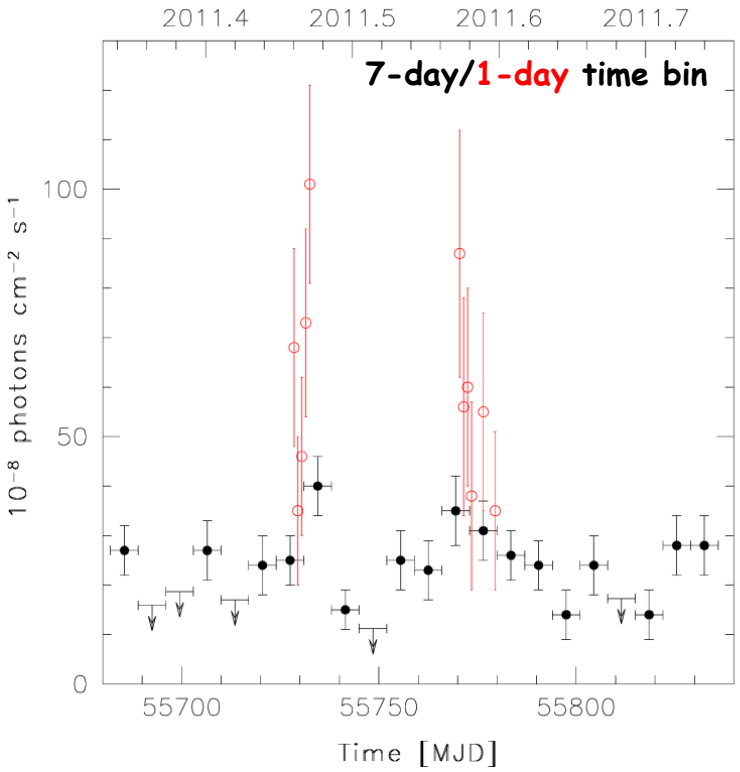




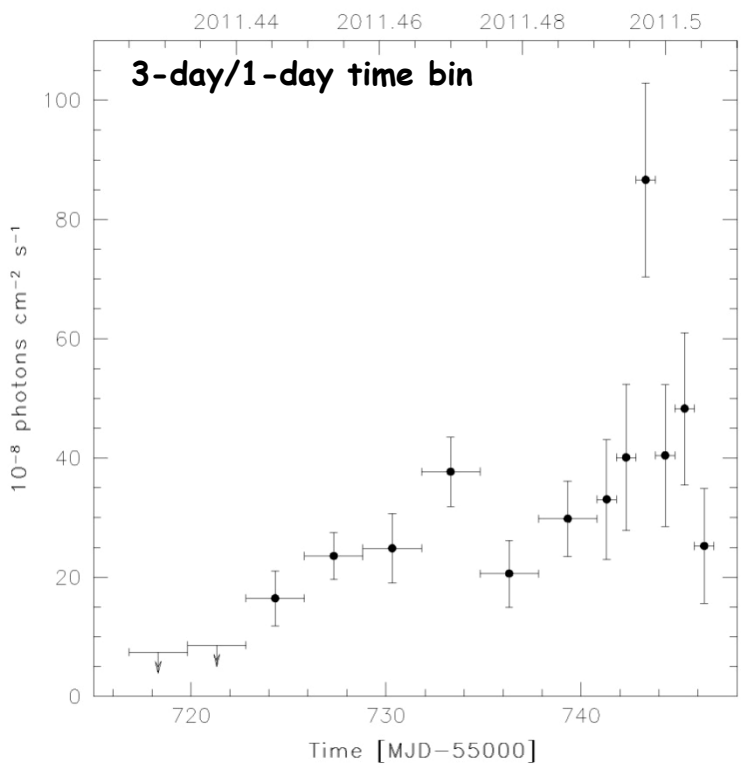
Abdo et al. 2009

NLSy1s are flaring gamma-ray sources!

PMN J0948+0022



SBS 0846+513

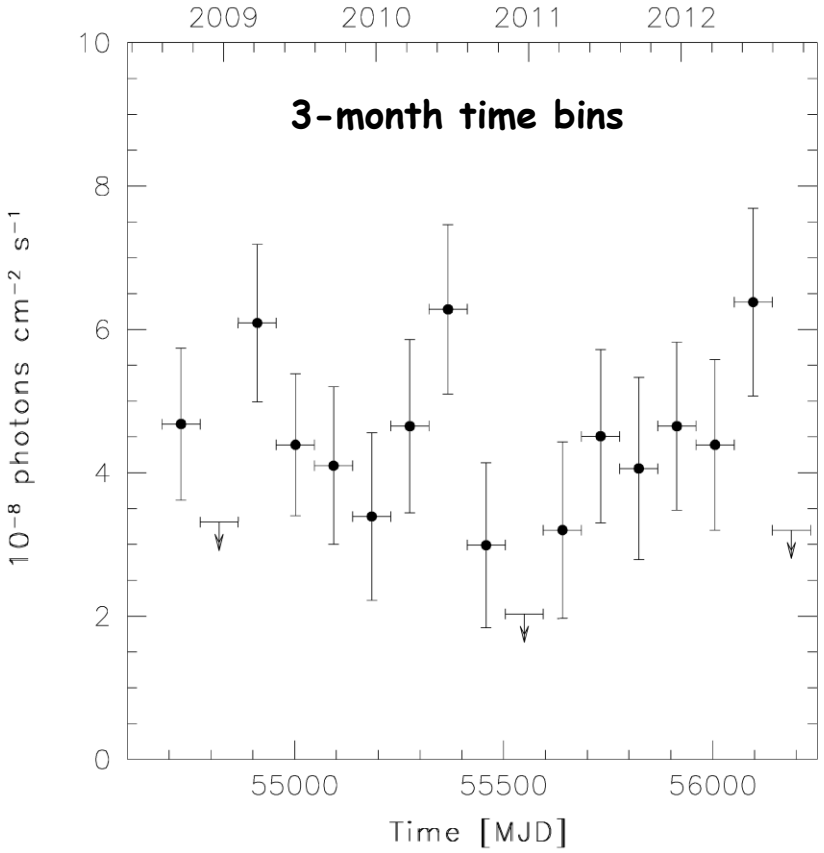


D'Ammando et al. 2014a, MNRAS, 438, 3521

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 Γ = 2.60±0.06

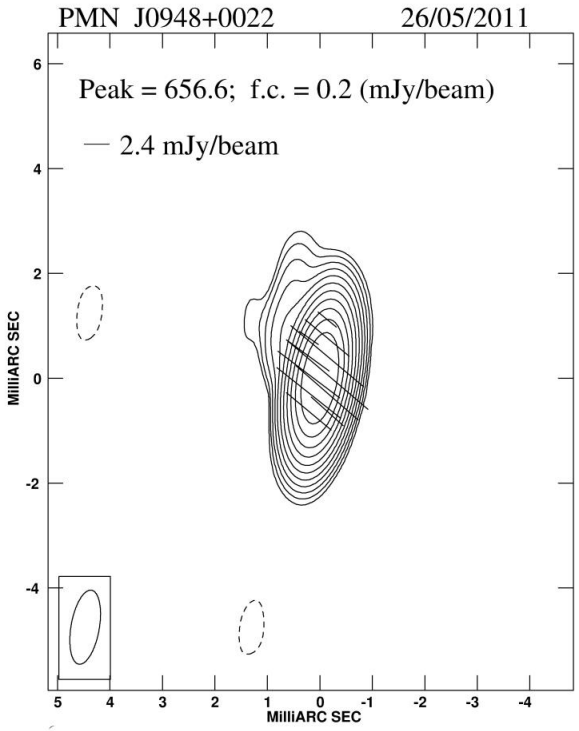
No significant flux variability was observed, with only a few detections on weekly time scales and a peak value of (18±6)e-8 ph cm^{-2} s^{-1}

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

Core-jet structures in NLSy1s

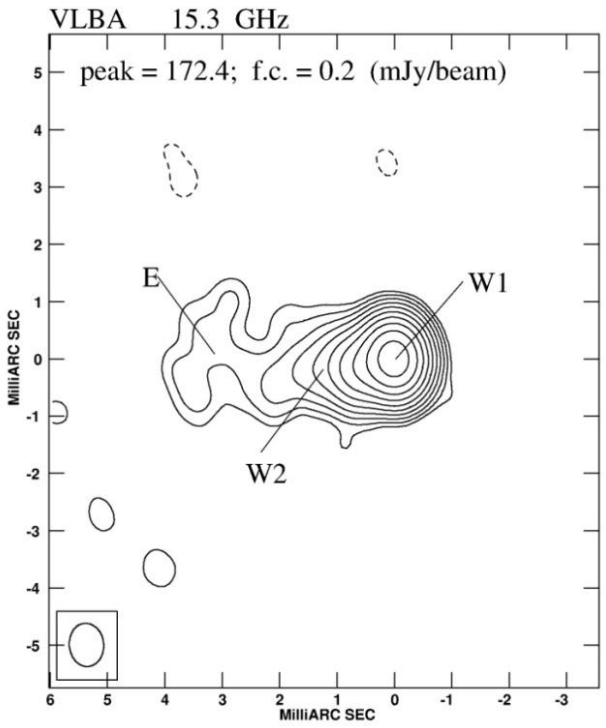
Core-jet structure on parsec scale resolved with the VLBA

PMN J0948+0022



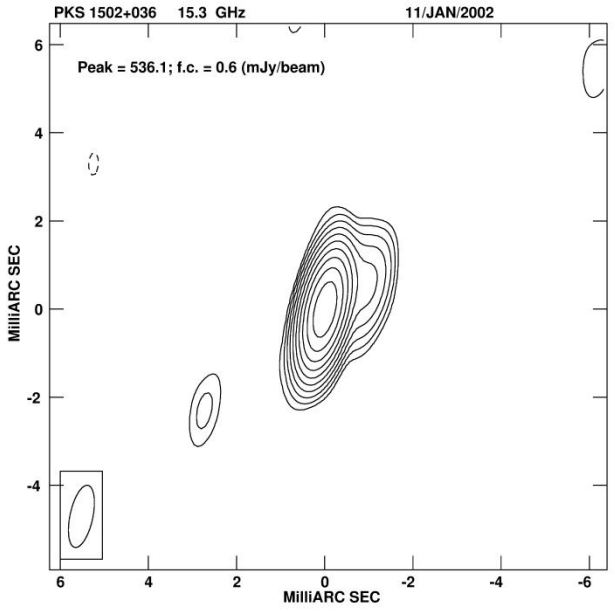
D'Ammando+2014a

SBS 0846+513



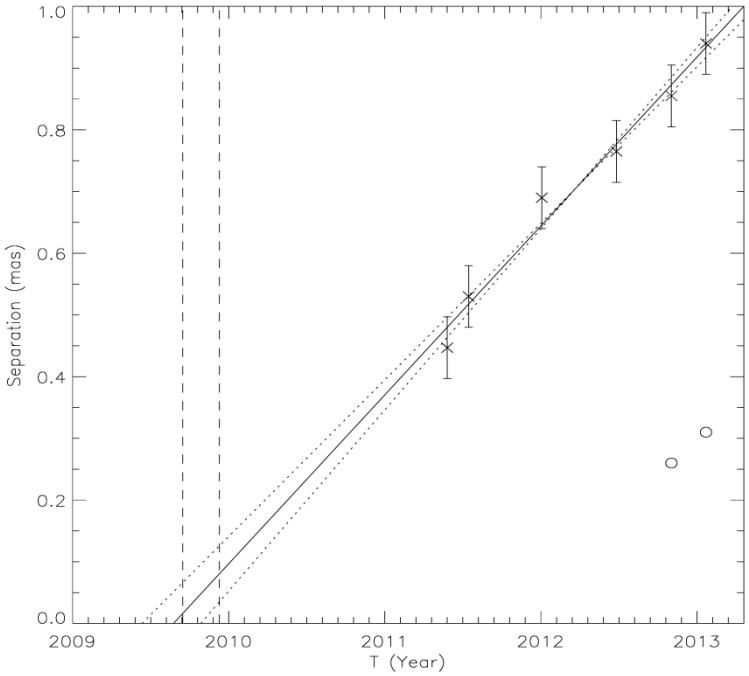
D'Ammando+2012

PKS 1502+036



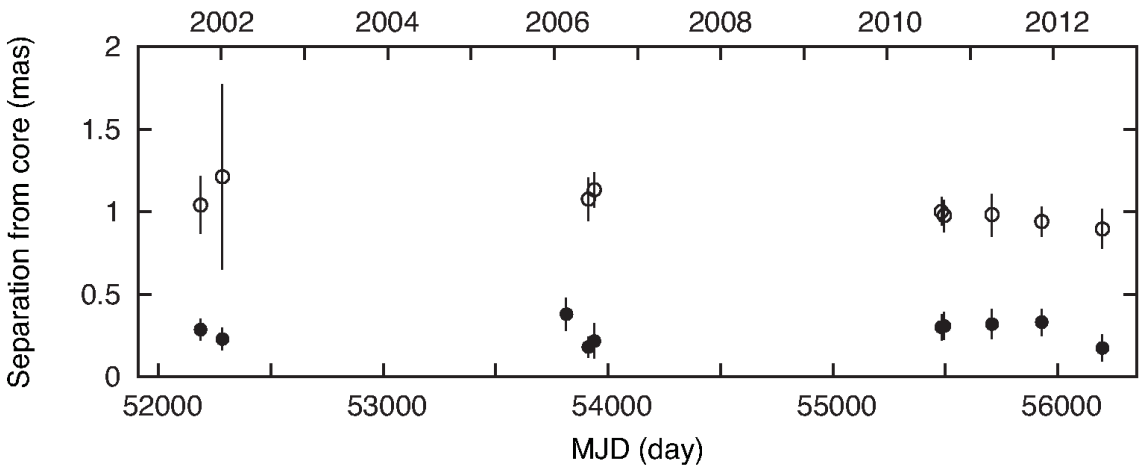
D'Ammando+2013a

Proper motion of gamma-ray NLSy1s



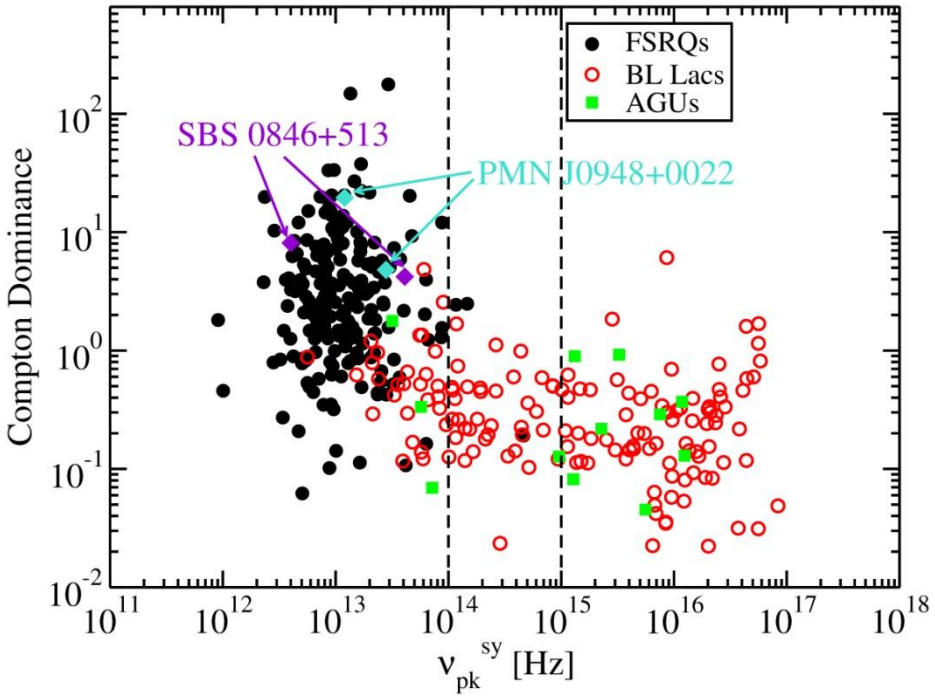
With 6-epoch MOJAVE data for SBS 0846+513 we obtained an apparent velocity of the jet knot **(9.3±0.6)c**, suggesting **the presence of boosting effect as well as in blazars**. The time of ejection is T_0 = **24 August 2009**, likely connected with a radio flare. *No significant gamma-ray activity was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

Comparison with γ-ray blazars

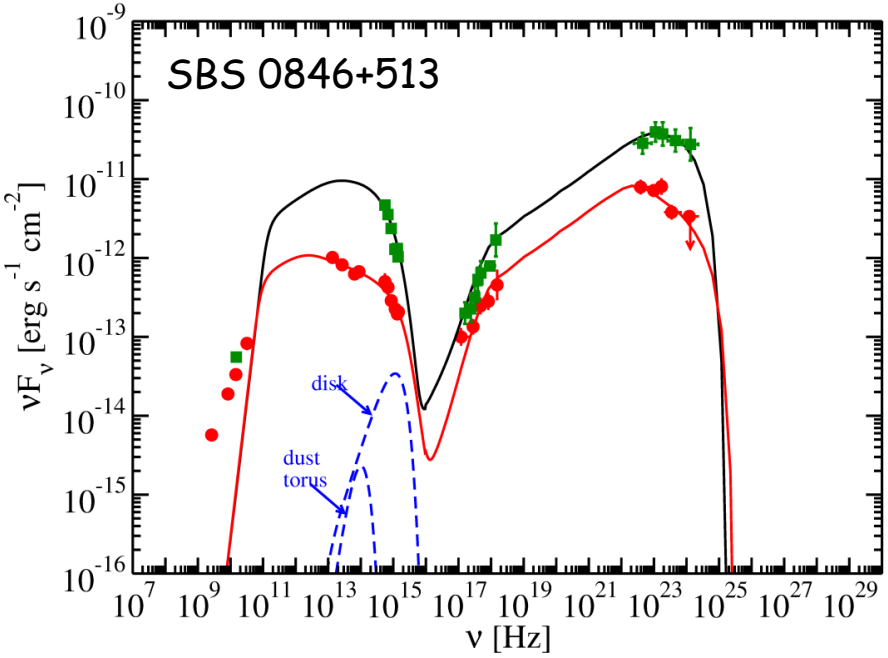


D'Ammando et al. 2013b

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

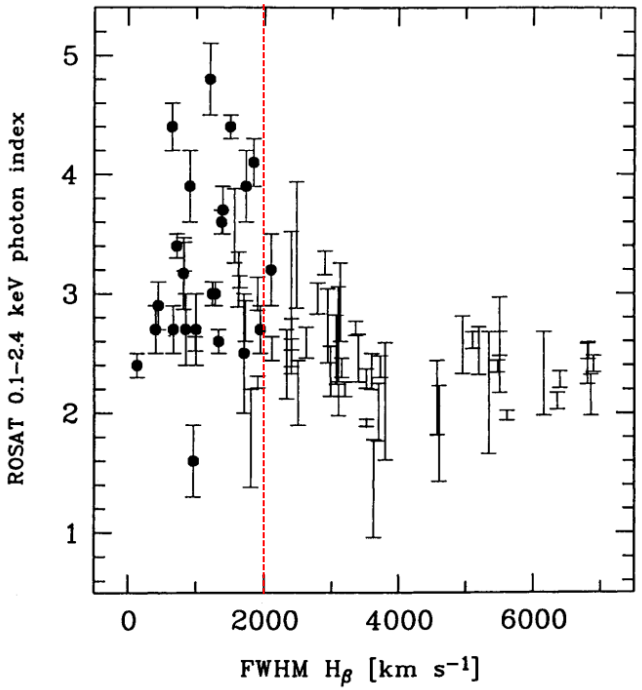
SBS 0846+513 and PMN J0948+0022 showed a Compton dominance typical of FSRQs during both the low and high activity state

D'Ammando et al. 2014b

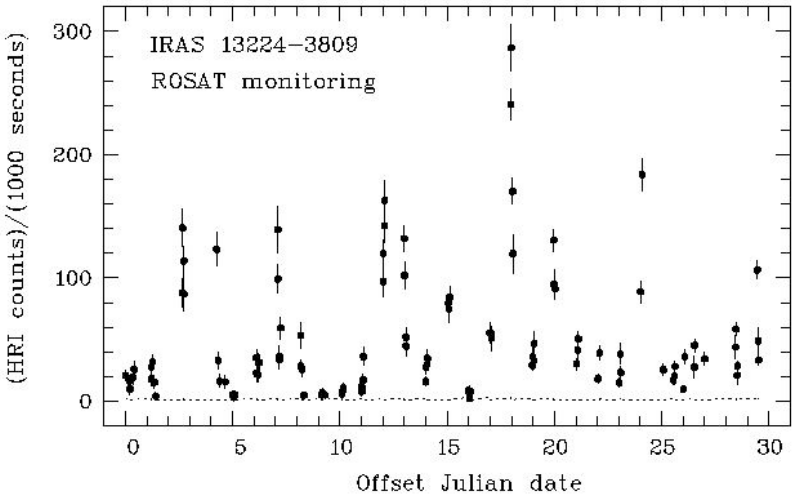


X-ray properties of NLSy1s

- soft X-ray excess
- extreme and rapid X-ray variability (supporting the low mass BH)
- steep power law in X-rays

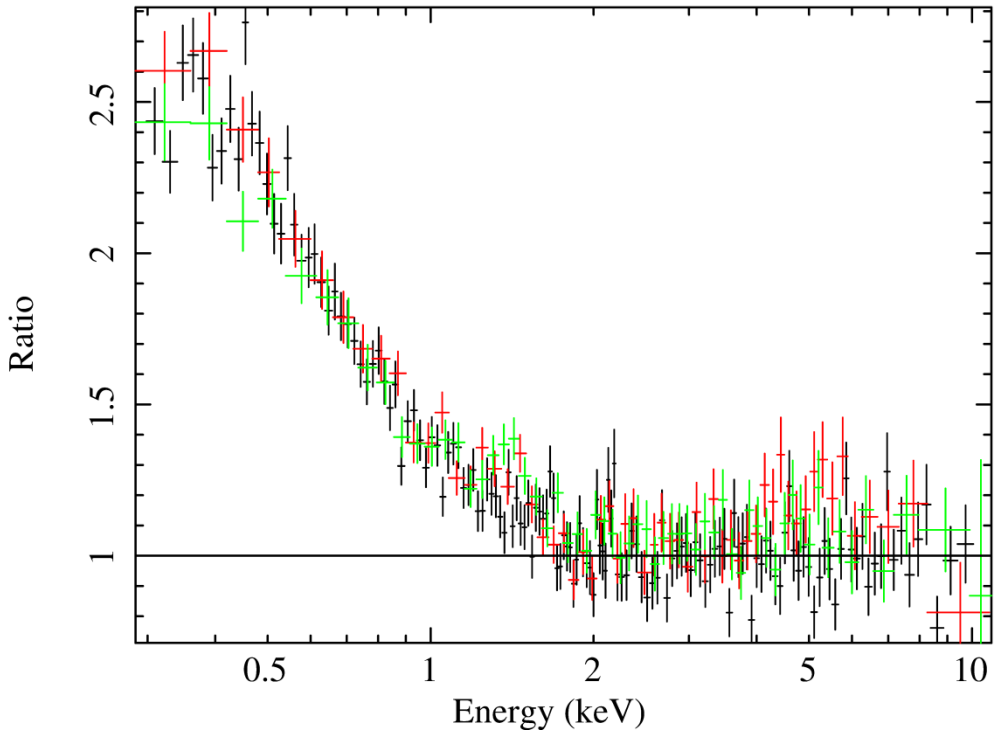


Boller et al. 96



Boller et al. 98

XMM observation of PMN J0948+0022



$\Gamma = 1.88 \pm 0.01$ in the 0.3-10 keV energy range, $\chi^2_{red} = 1.87$ (1254)

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

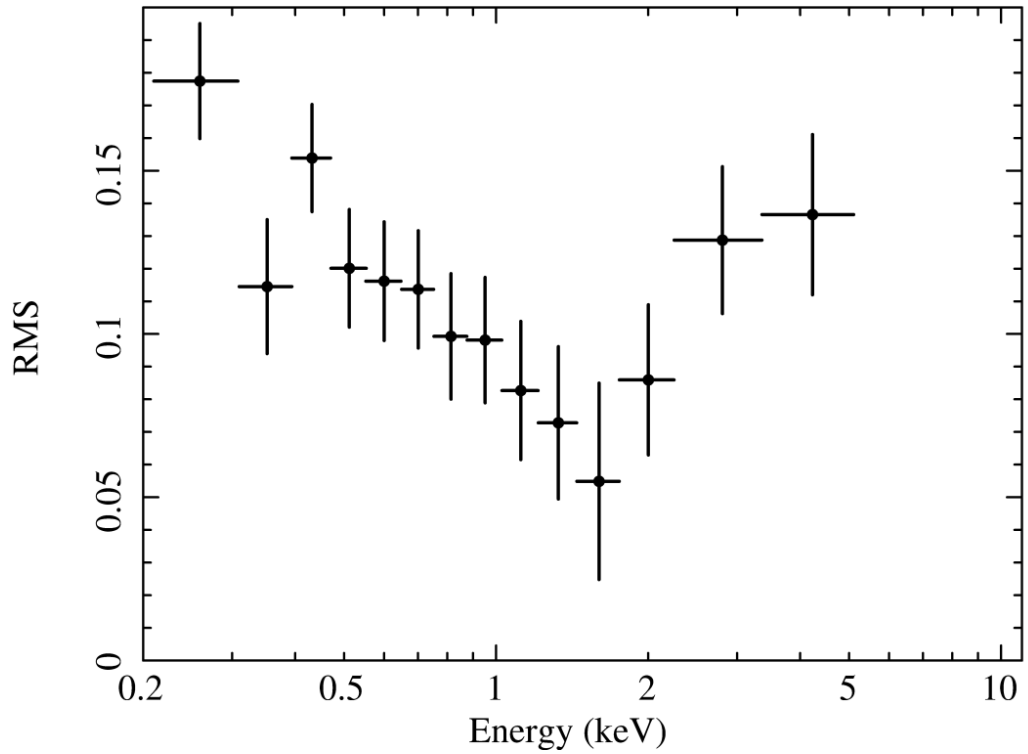
A clear soft excess was observed, notwithstanding the non-thermal jet emission!

D'Ammando et al. 2014a

A broken power-law provides an acceptable fit, $\chi^2_{red} = 1.10$ (1252), with a break at energy $E_{break} = 1.72 \pm 0.10$ keV and photon indices $\Gamma_1 = 2.14 \pm 0.03$ and $\Gamma_2 = 1.48 \pm 0.04$. 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

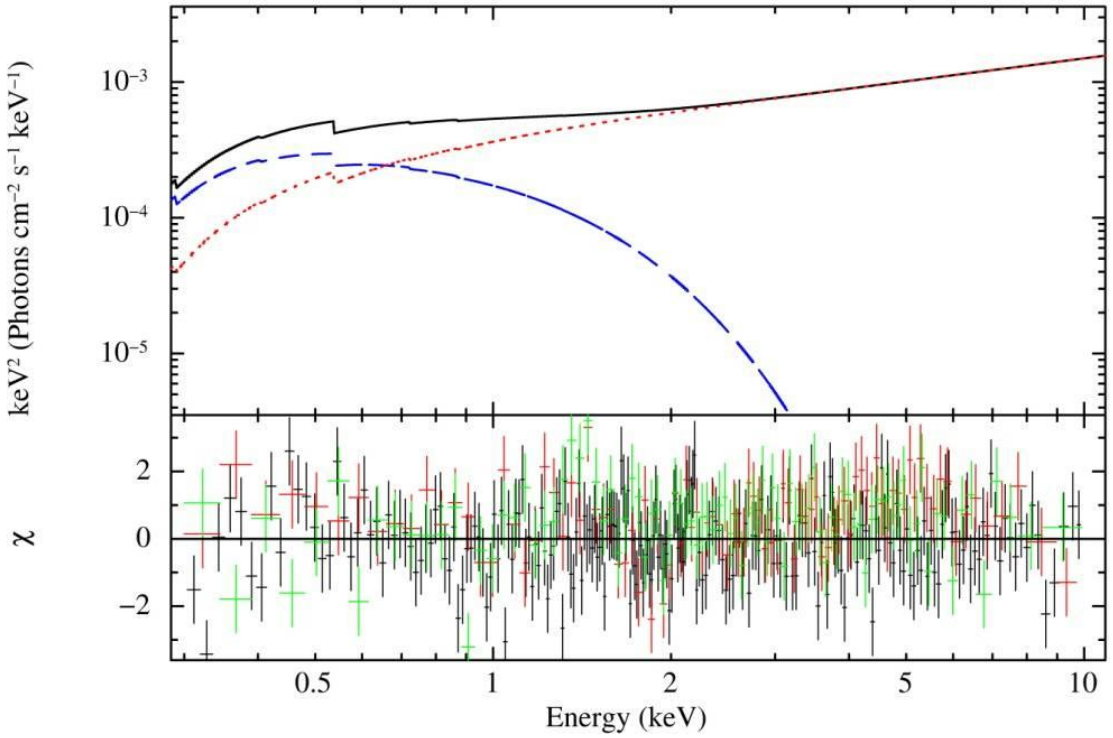
The soft component can be also fitted with a black body model with kT ~ 0.18 keV. Such a high temperature is inconsistent with the standard accretion disk theory

RMS variability spectrum



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

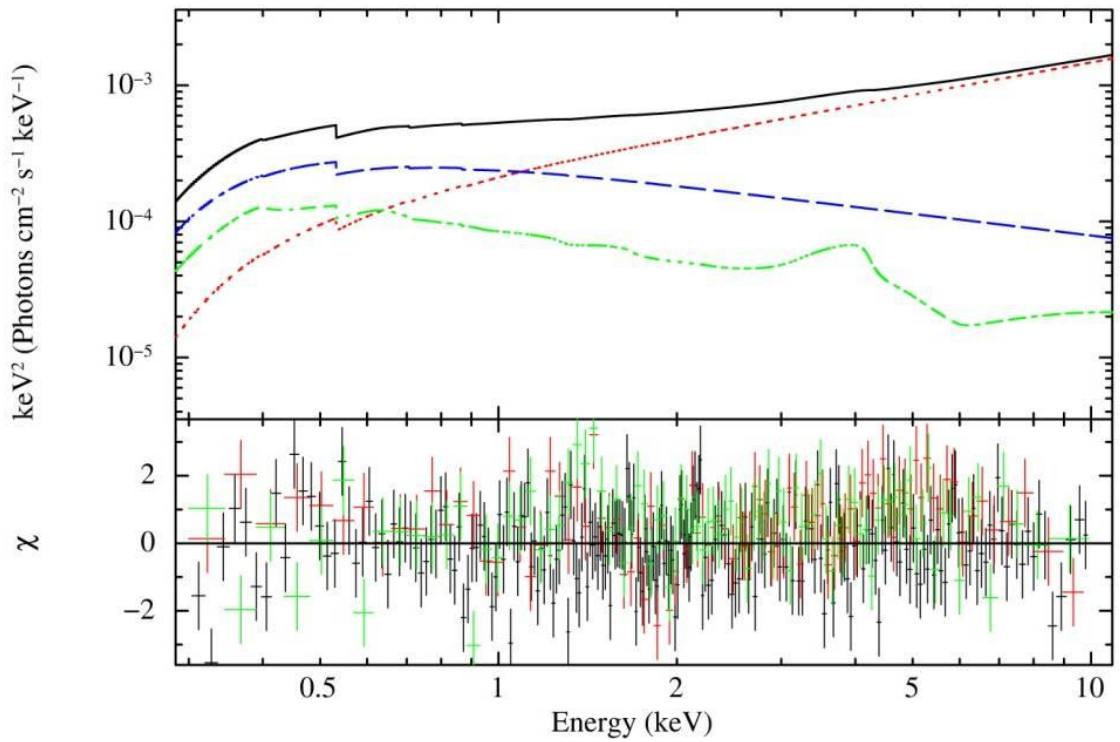
Comptonization model for PMN J0948+0022



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±0.2, Γ = 1.44 ±0.03

Reflection model for PMN J0948+0022

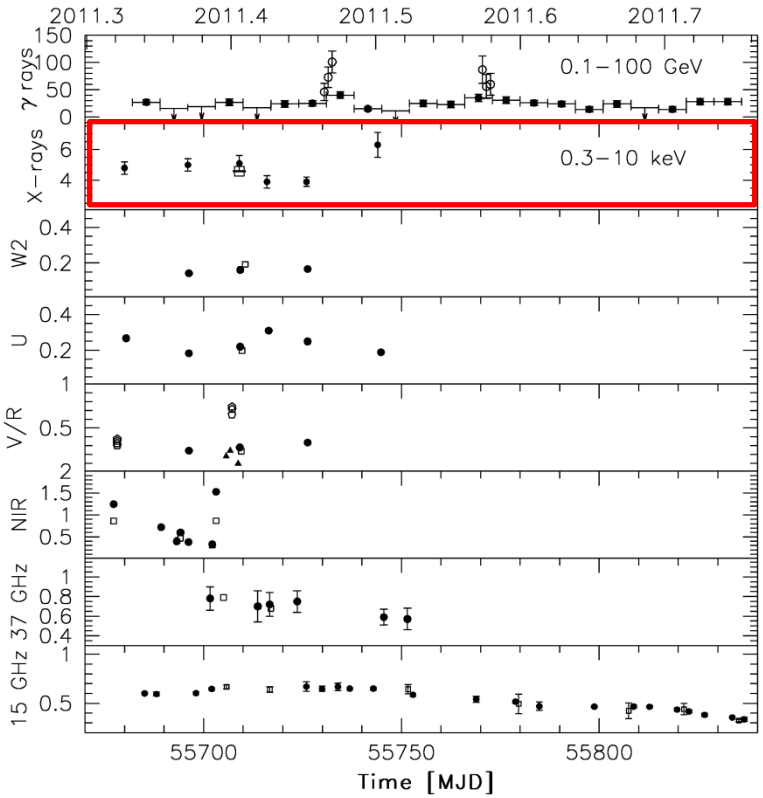


R_{min} = 6 rg
R_{max} = 400 rg
q = 3
i= 3°
Solar abundances

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)

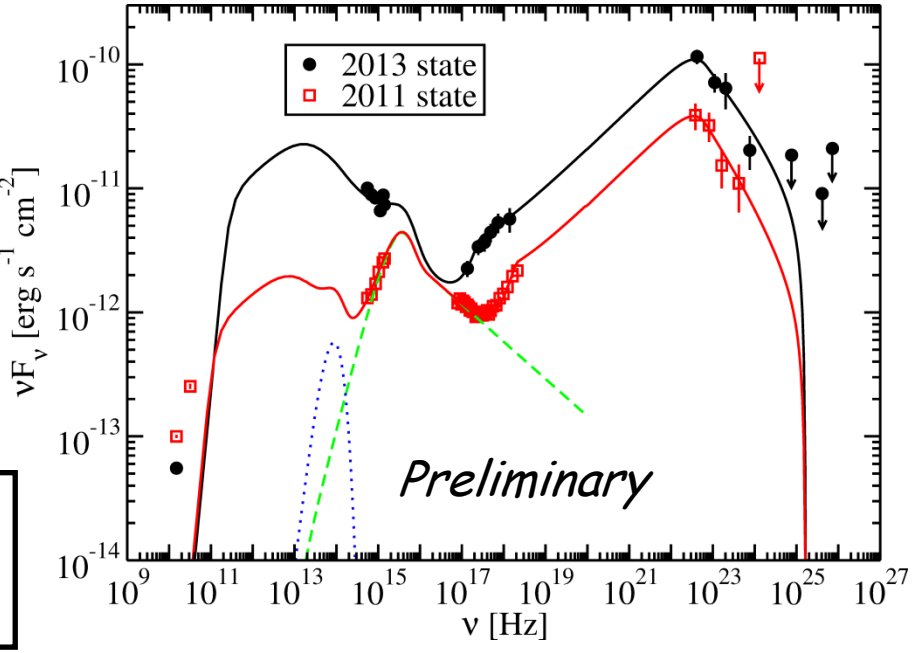
SED of PMN J0948+0022

D'Ammando et al. 2014a



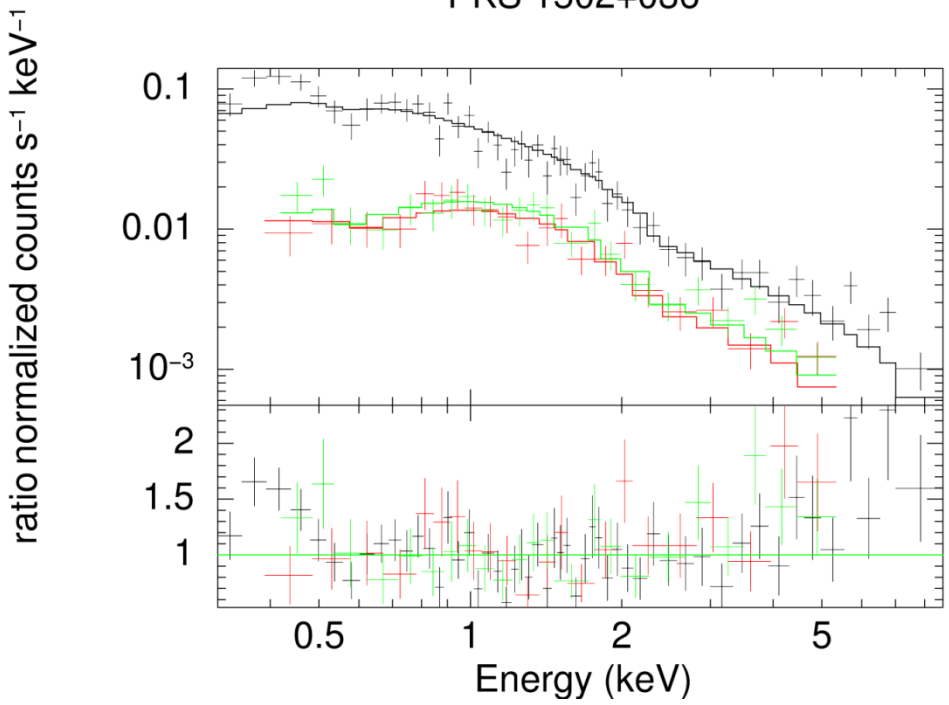
Γ = 1.4-1.8 in the *Swift*/XRT observations, suggesting a significant contribution of inverse Compton emission from a relativistic jet. Similar to what is observed for SBS 0846+513 (D'Ammando et al. 2013b) and PKS 1502+036 (D'Ammando et al. 2013a)

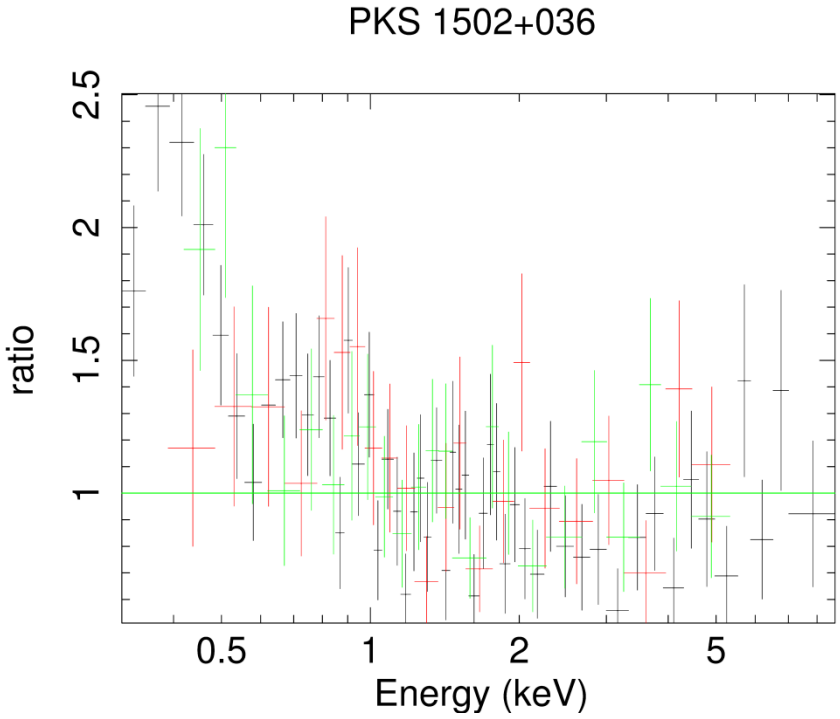
D'Ammando et al. 2014b



The soft excess in the SED of PMN J0948+0022 was modeled by disk emission that is Compton scattered by a corona

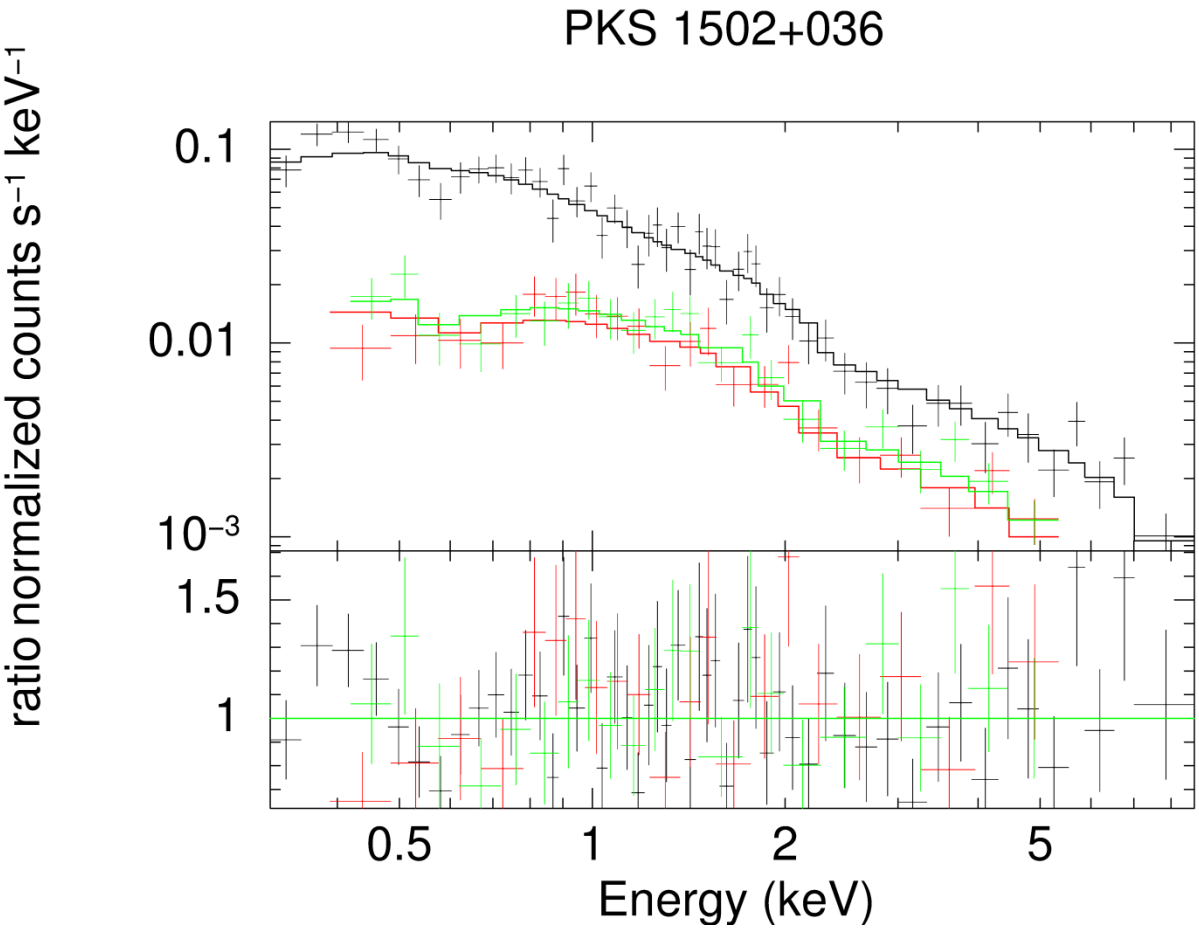
XMM observation of PKS 1502+036





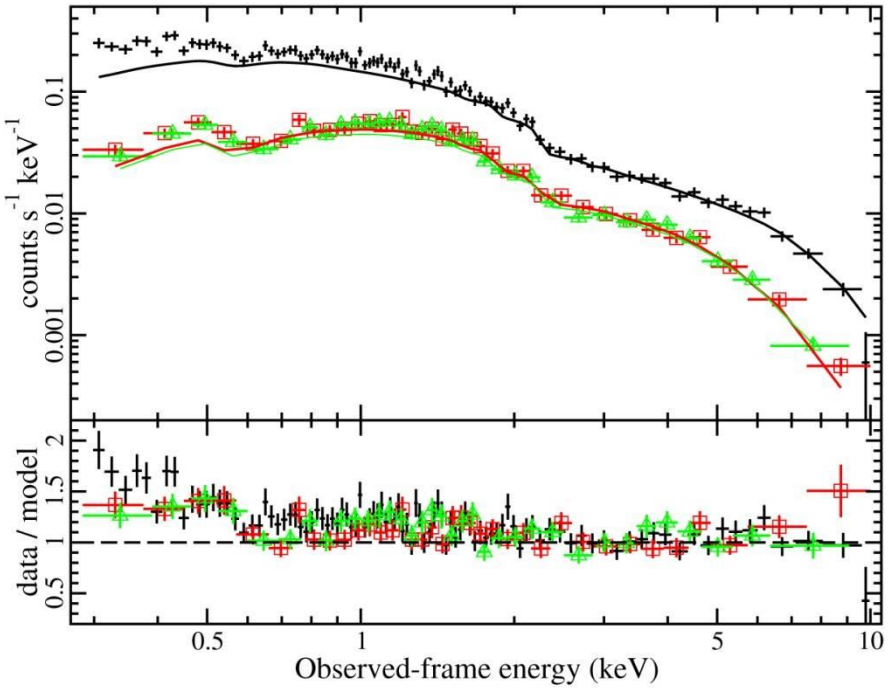
A single power law does not provide a good fit to the EPIC spectra, χ^2_{red} = 1.301 (95).
EPIC data shown as a ratio to a power law with Γ = 1.49 indicate a clear excess at lower (and higher) energies

XMM observation of PKS 1502+036



A broken power-law provides a better fit , χ^2_{red} = 0.944 (93), with Γ_1 = 2.27±0.18, Γ_2 = 1.49 (+0.12,-0.19), and E_{break} = 1.26 (+0.46, -0.19) keV. F(0.3-10) = (3.7±0.2)e-13 erg cm^{-2} s^{-1}

XMM observation of PKS 2004-447 in 2004



A single power law gives relatively good agreement for the observed 2-10 keV spectrum of each EPIC instrument, with $\Gamma = 1.44 \pm 0.06$.

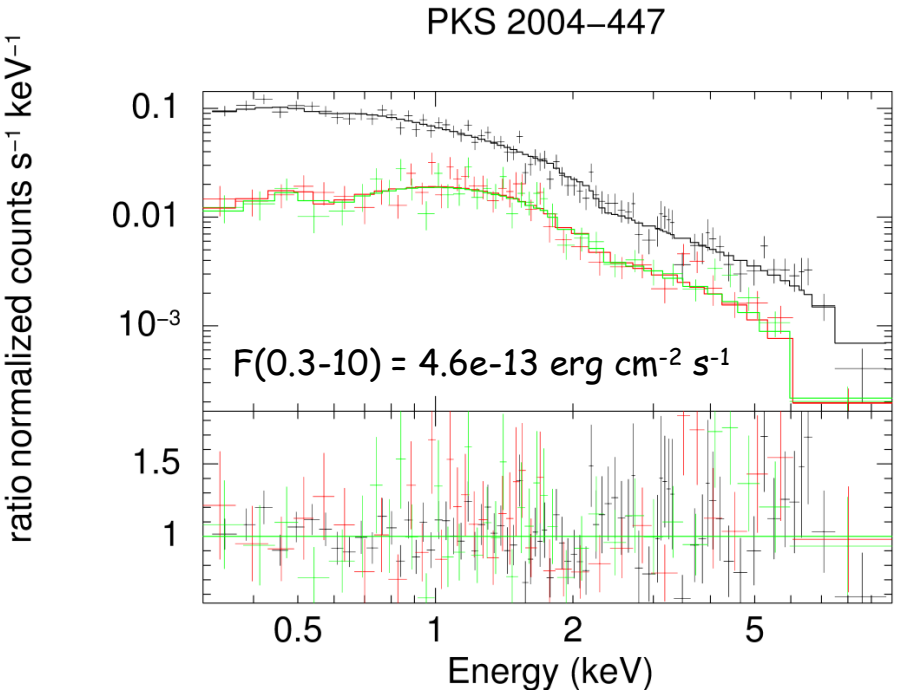
Extrapolating this power law to 0.3 keV revealed an excess at lower energies, with $\Gamma = 1.56 \pm 0.02$.

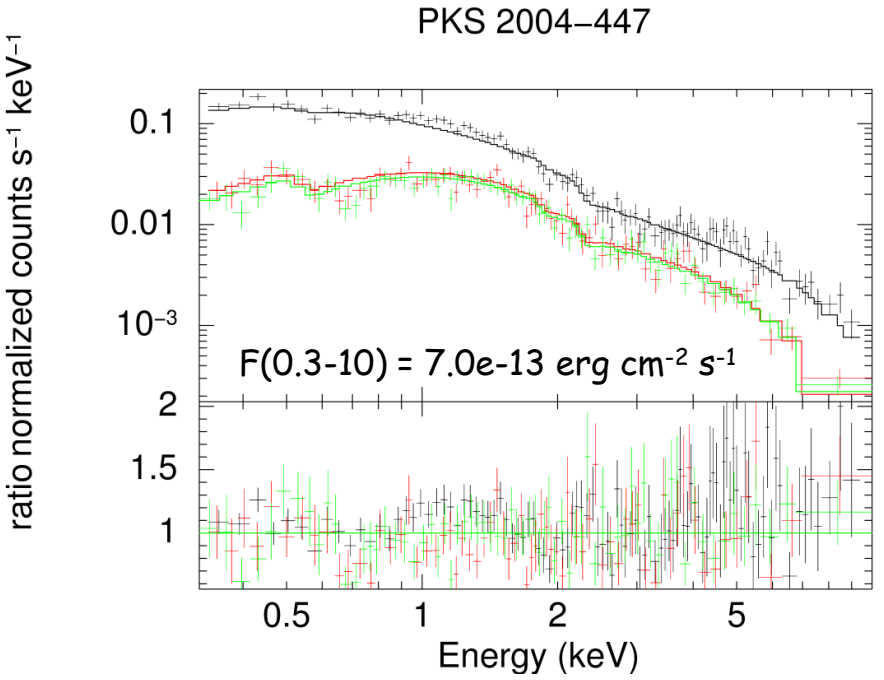
Gallo+06

A broken power-law provides a significant improvement, with $\Gamma_1 = 2.10$ (+0.23,-0.19), $\Gamma_2 = 1.52 \pm 0.02$ and $E_{break} = 613$ (+79, -59) eV. Flux(0.3-10) = 1.5e-12 erg cm^{-2} s^{-1}

The addition of an Iron line does not improve the fit, EW < 54 eV

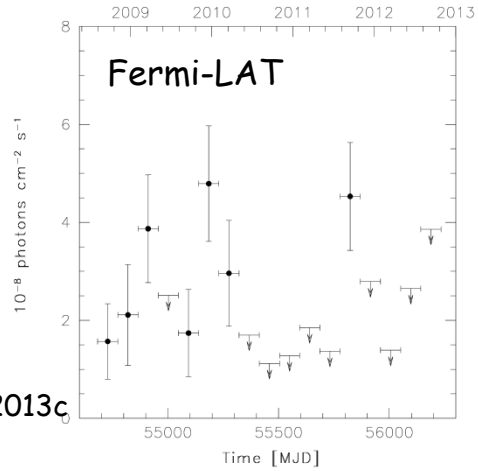
XMM observations of PKS 2004-447 in 2012





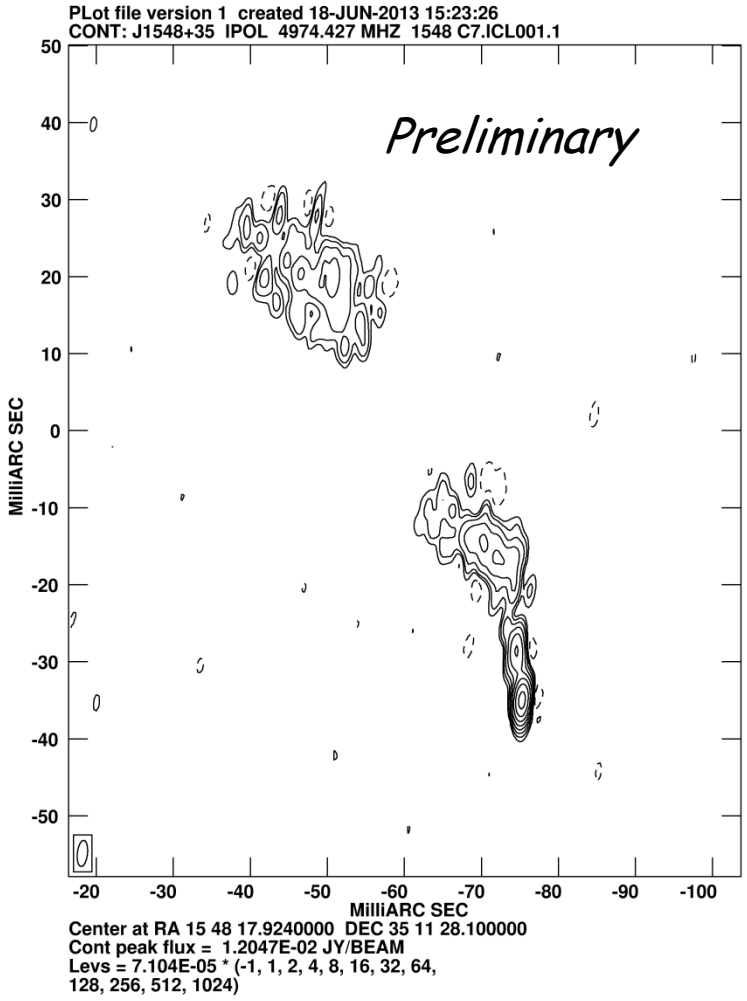
The photon index is Γ~1.7, consistent with a jet emission component but there is no evidence of the soft X-ray excess. Is it only a matter of statistics? Or is it connected with the low jet activity?

see also poster F16 by A. Kreikenbohm



D'Ammando et al. 2013c

Searching for candidate γ-ray NLSy1s: J1548+3511

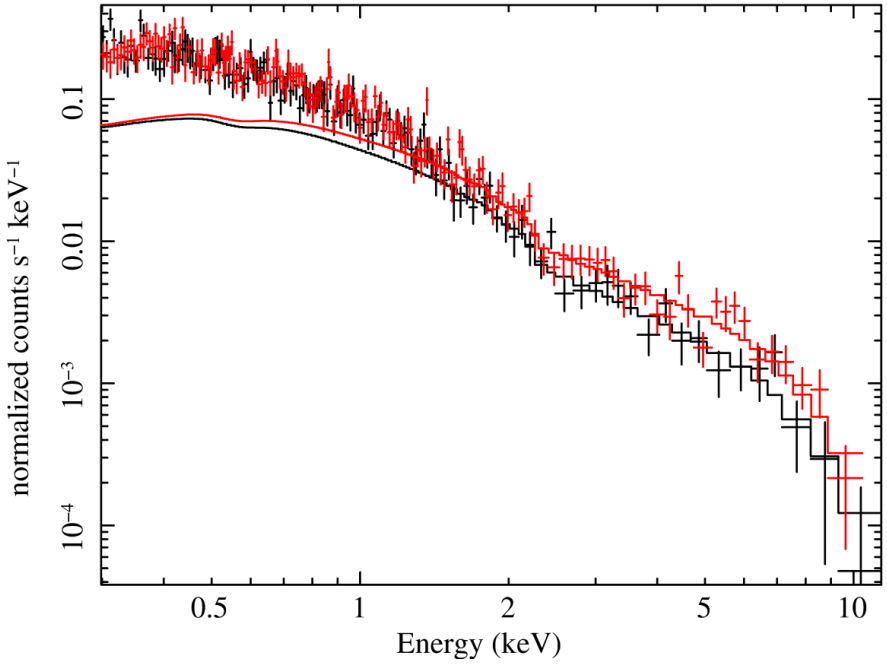


J1548+3511 showed a high brightness temperature, comparable to that observed in the NLSy1s already detected by *Fermi*-LAT (see Yuan et al. 2008), but no gamma-ray emission was detected from this source so far

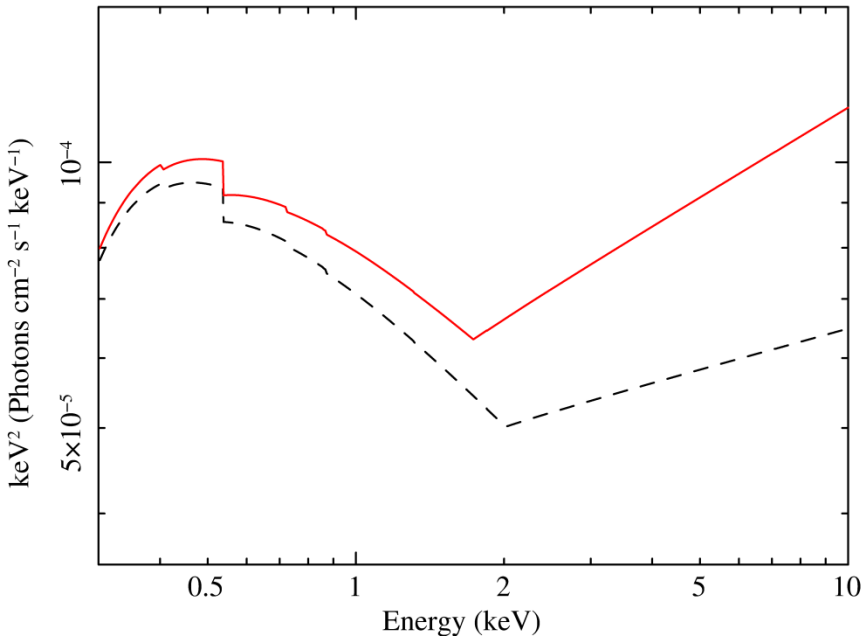
VLBA observations performed on 2013 January 2 at 5 GHz, 8.4 GHz and 15 GHz. **Core-jet structure with angular size ~70 mas.** The core has an inverted spectrum between 5 GHz and 15 GHz with spectral index ~ -0.3

Orienti, et al. in prep

XMM observations of J1548+3511



A clear excess was observed below 2 keV for the observations performed on 2011 August 8 and 20. The spectra are well fitted by a broken power-law model, with a soft slope below 2 keV and a harder slope above it



In the second observation (red) the source is somewhat brighter than in the first one (black), with a power-law index above the break harder and the E_{break} at slightly lower energy

Open Questions

• *The discovery of relativistic jets in a class of AGN thought to be hosted by spiral galaxies was a great surprise but…*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 NLSy1s could be low mass version of blazars in which the relativistic jet formation was triggered by a major merger or their BH masses 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?

• The X-ray spectra of the gamma-ray emitting NLSy1s are harder than those of the other NLSy1s, suggesting the relativistic jet being the dominant emission component. A clear soft X-ray excess was observed in PMN J0948+0022 below 2 keV, but we are observing the same Seyfert-like component of the radio-quiet NLSy1s?

• There are some evidence for two emission components in the X-ray spectra of PKS 1502+036, and PKS 2004-447 in 2004. The lack of such excess in the 2012 observations of PKS 2004-447 may be due to low statistics or to a period of low jet activity (implying a strong connection between the jet and the soft excess in the gamma-ray NLSy1s)

Thanks for your attention!