Fermi Gamma-ray Space Telescope

INAF Istituto di Radioastronomia

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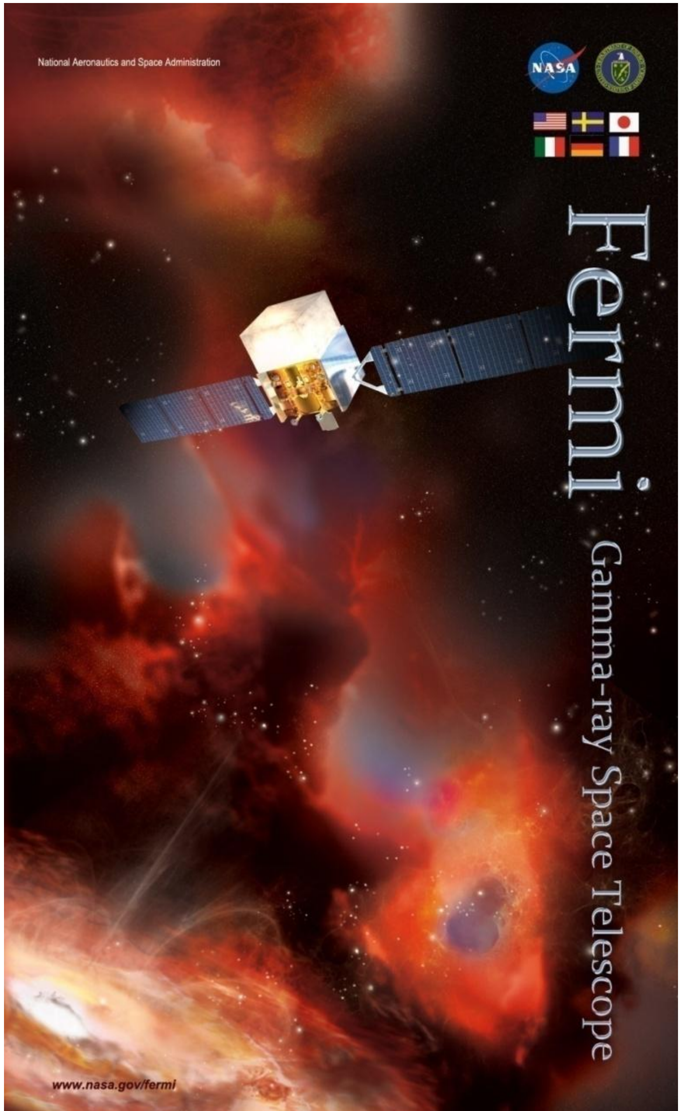

The XMM-Newton view of γ-ray emitting narrow-line Seyfert 1 galaxies

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on behalf of the Fermi-LAT Collaboration

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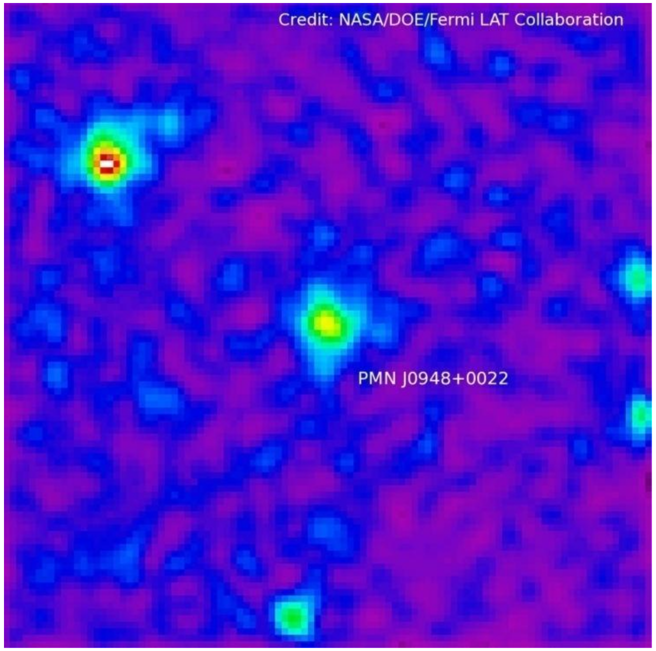
Gamma-ray emitting NLSy1

- Before the launch of the *Fermi* satellite, only blazars and a few radio galaxies were known to be γ-ray emitting AGN
- *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 γ-ray emitting narrow-line Seyfert 1 galaxies was a great surprise!

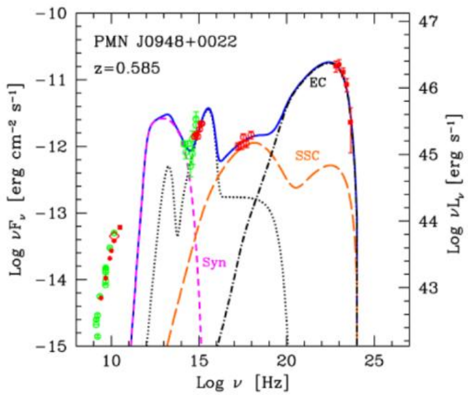


Confirmation of the presence of relativistic jets also in NLSy1

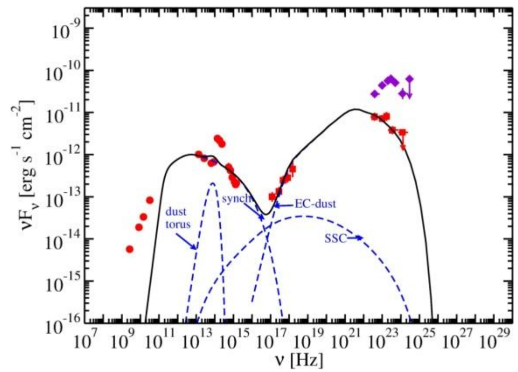
NLSy1 are thought to be hosted in **spiral/disc galaxies**, the presence of a relativistic jet in some of these objects seems to be in contrast to the paradigm that the formation of relativistic jets could happen only in elliptical galaxies (e.g. Boettcher & Dermer 2002, Marscher 2010)

Narrow-line Seyfert 1 in the 3FGL

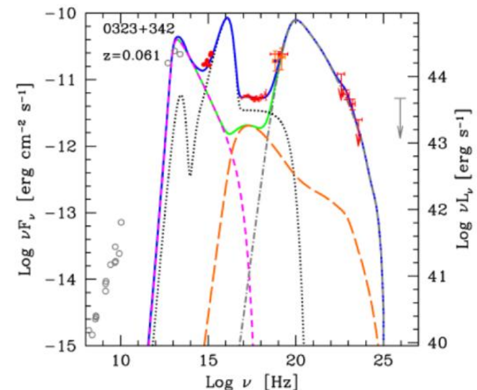
5 NLSy1 were reported in the Third Fermi-LAT Source catalogue (Acero et al. 2015)

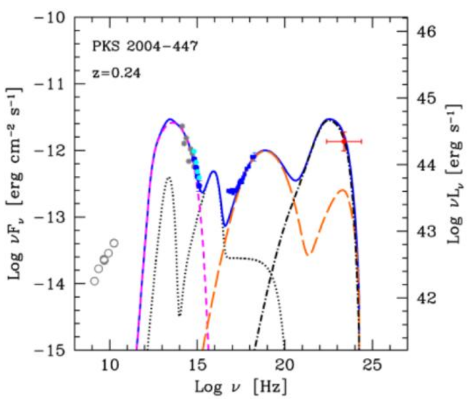


See Foschini et al. 2012, 2014

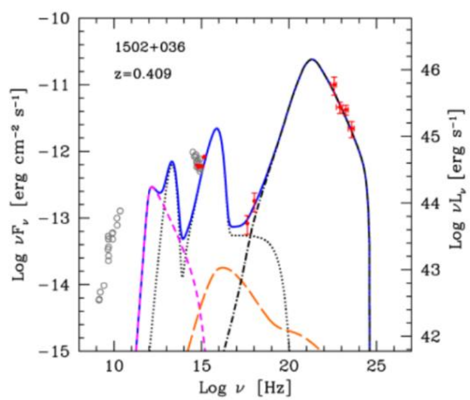


D'Ammando, Orienti, Finke et al. 2012





See Orienti, D'Ammando, et al. 2015



Abdo et al. 2009

1H 0323+342

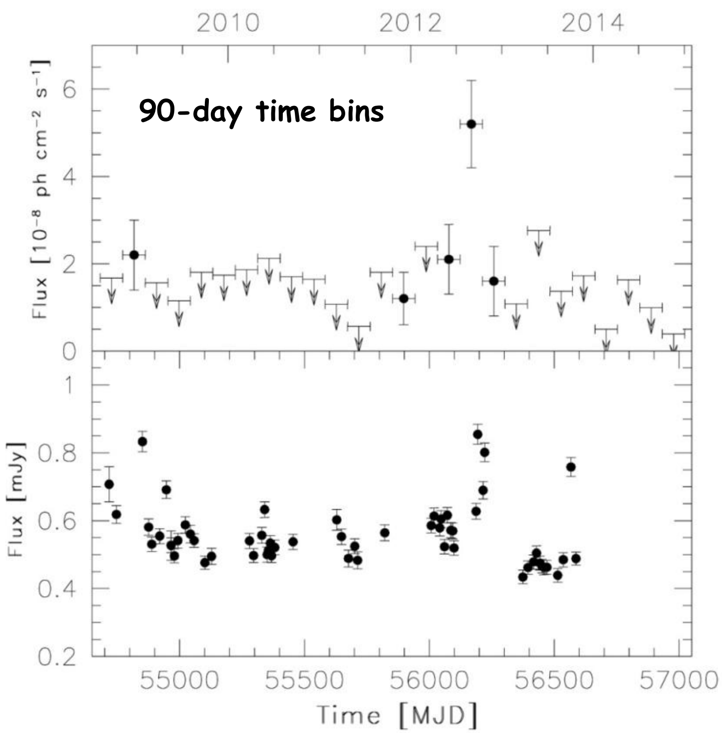
SBS 0846+513

PMN J0948+0022

PKS 1502+036

PKS 2004-447

New LAT detections with Pass 8 data

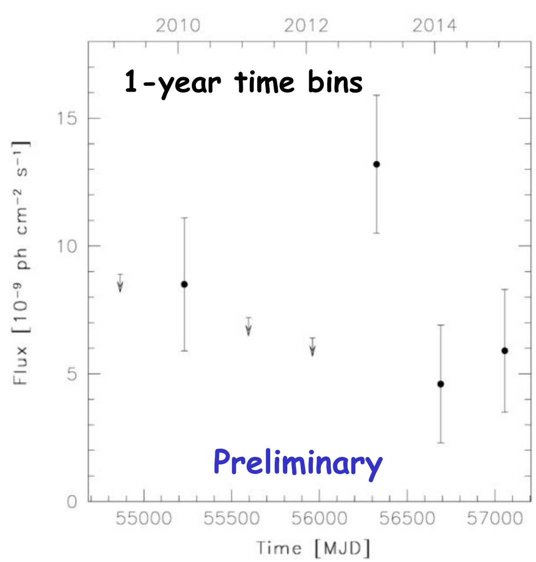


FBQS J1644+2619

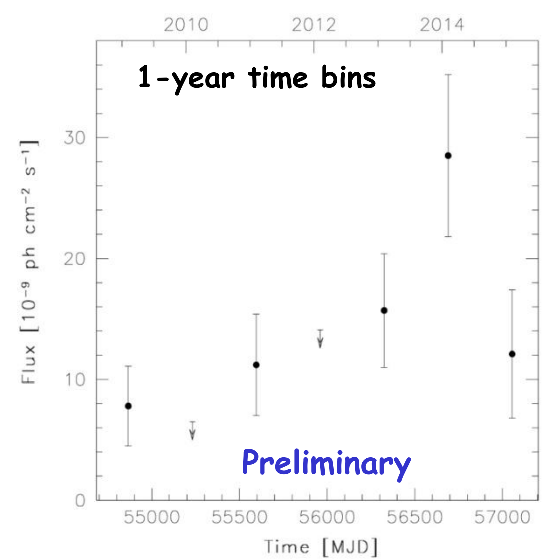
Both the LAT detection of FBQS J1644+2619 in 2008 November - 2009 January and in 2012 July-October correspond to periods of high optical activity, as observed in V-band by the Catalina Real-Time Transient survey.

D'Ammando et al. 2015, MNRAS, 452, 520

B3 1441+476

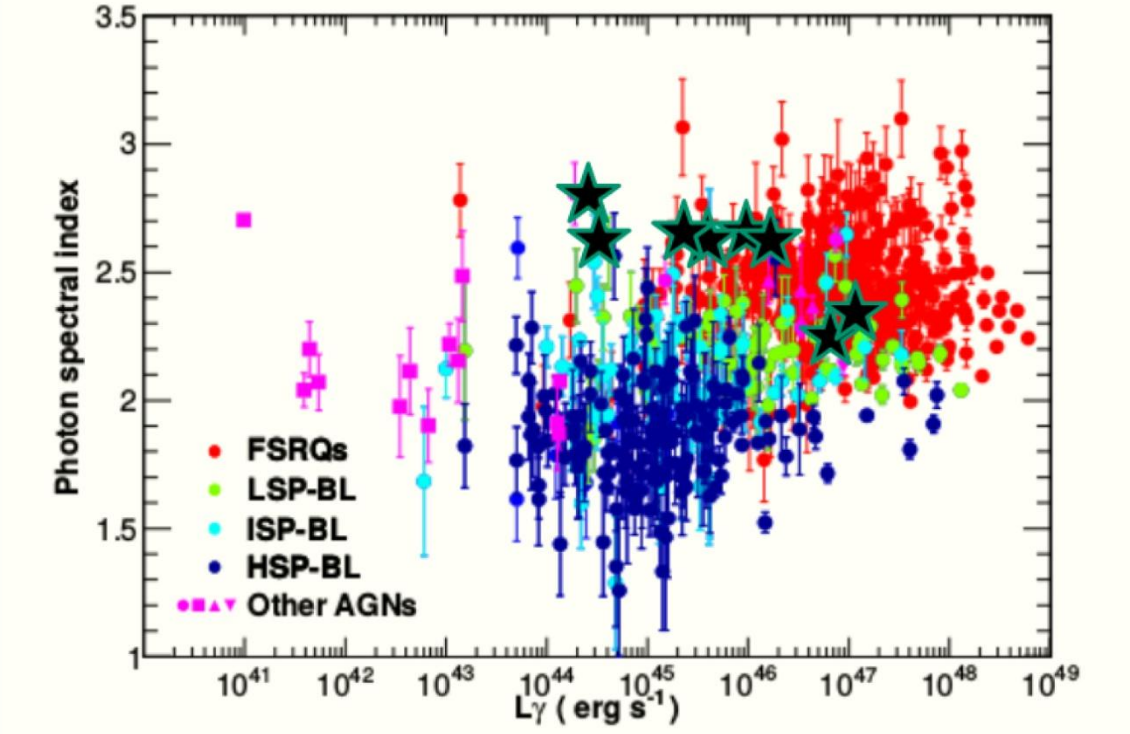


NVSS J124634+023808

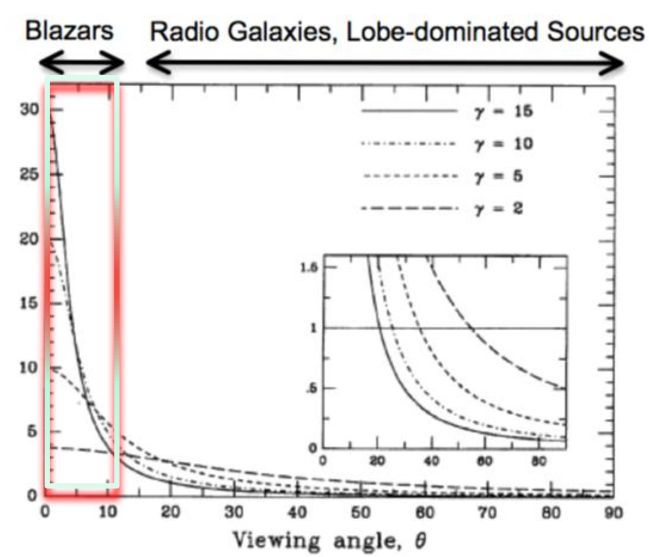


The *Fermi*-LAT view of NLSy1

Adapted from Ackermann et al. (2015)



D'Ammando et al. 2016, Galaxies, 4, 11



Urry & Padovani 1995

Blazar-like properties of γ-ray NLSy1

- On pc scale **a core-jet structure** was observed for SBS 0846+513, PKS 2004–447, 1H 0323+342, PKS 1502+036, and PMN J0948+0022

- **Apparent superluminal velocity of a jet component** was reported for SBS 0846+513, PMN J0948+0022 and 1H 0323+342*, but not in PKS 1502+036*

- An inferred **variability brightness temperature** of 2.5×10^{13}, 1.1×10^{14}, and 3.4×10^{11} K was obtained for PKS 1502+036, SBS 0846+513, and PMN J0948+0022, suggesting that the radio emission is Doppler boosted

- **Optical intraday variability** has been reported for PMN J0948+0022, SBS 0846+513, and 1H 0323+342

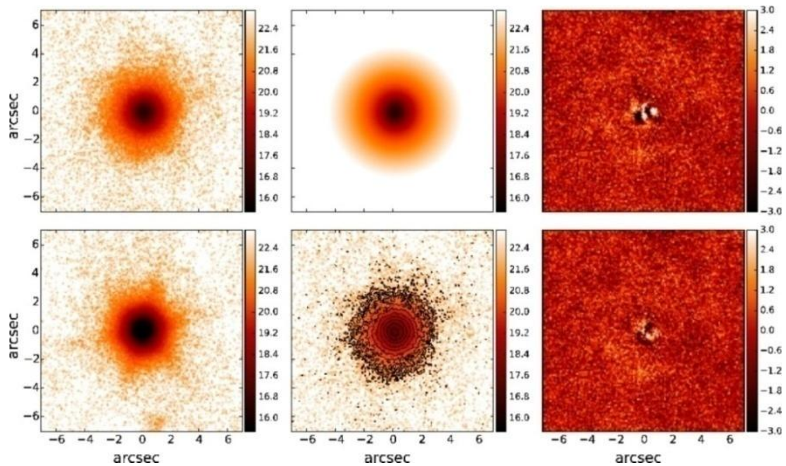
- The SED of γ-ray NLSy1 showed a double-humped shape typical of blazars, with the accretion disc emission visible in the low activity state of the SED of PMN J0948+0022, 1H 0323+342, and PKS 1502+036

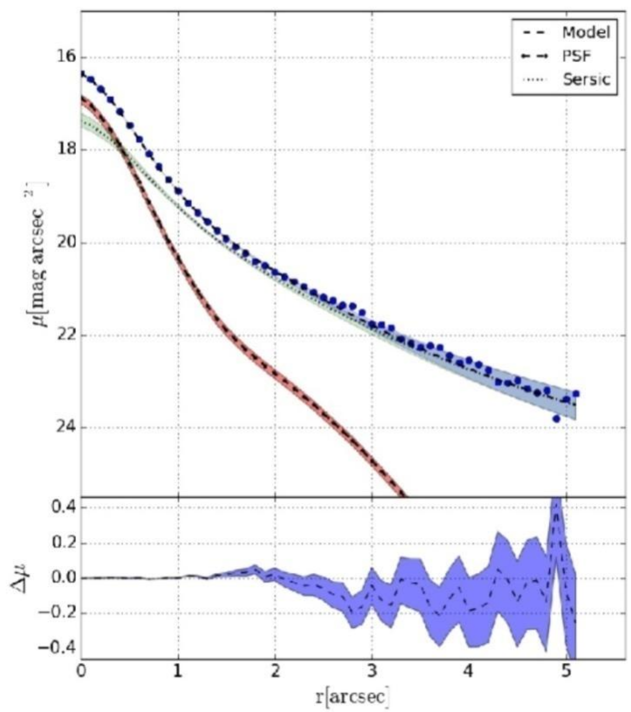
- The **BH mass of these sources seems to be underestimated** due to radiation pressure (Marconi et al. 2008) and/or projection effects (Baldi et al. 2016), with a real mass of 10^{8-9} $M_\odot$ (see also Calderone et al. 2013)

D'Ammando et al. (2016) and the reference therein

Host galaxy of FBQS J1644+2619

- 1H 0323+342: spiral-arm structure of the host galaxy (Zhou et al. 2007) or asymmetric ring, residual of a galaxy merger (Anton et al. 2008, Leon Tavares et al. 2014)
- PKS 2004-447: pseudo-bulge morphology of the host (Kotilainen et al. 2016)

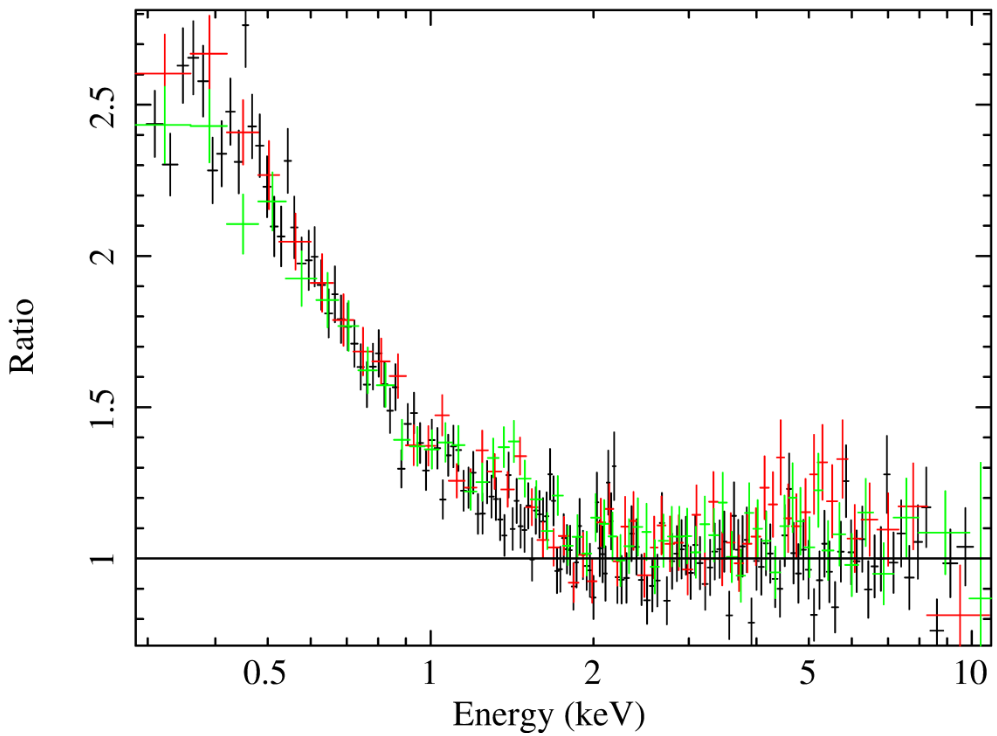




GTC observations of FBQS J1644+2619 in J band. The 2D surface brightness profile is modelled by a nuclear and a bulge component with $n = 3.7$. **Evidence of an E1 elliptical galaxy as host galaxy.**
The BH mass estimated by the IR bulge luminosity is **$(2.1\pm0.2)\times10^{8}$ $M_{\odot}$**, consistent with the values characterizing radio-loud AGN.

D'Ammando et al. 2017, MNRAS, 469, L11

XMM observation of PMN J0948+0022 in 2011



Γ = 1.88 ± 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±0.03

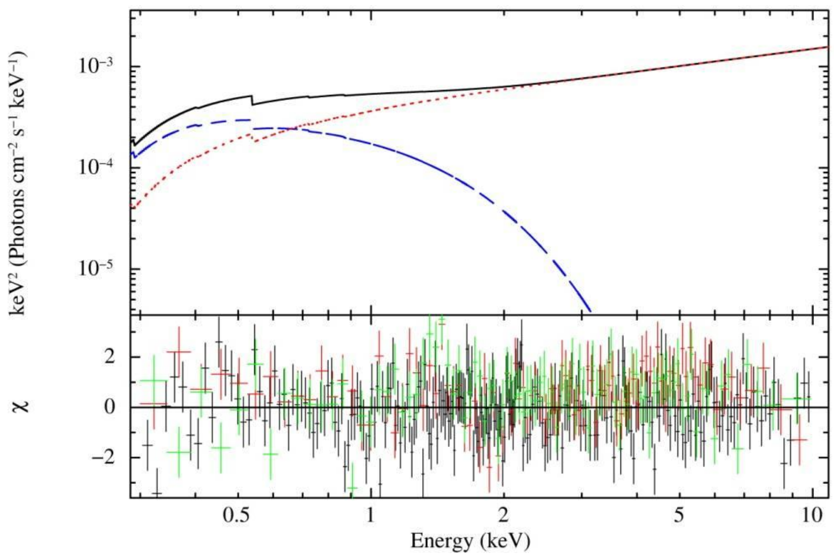
A clear soft excess was observed, notwithstanding the non-thermal jet emission!

D'Ammando et al. 2014, 438, 3521

A broken power-law provides an acceptable fit, χ^2_{red} = 1.10 (1252), with a break at energy E_{break} = 1.72±0.10 keV and photon indices Γ_1= 2.14±0.03 and Γ_2 = 1.48±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 fitted with a black body model with kT ~ 0.18 keV. *Such a high temperature is inconsistent with the standard accretion disk theory.*

Soft excess: comptonization vs reflection model

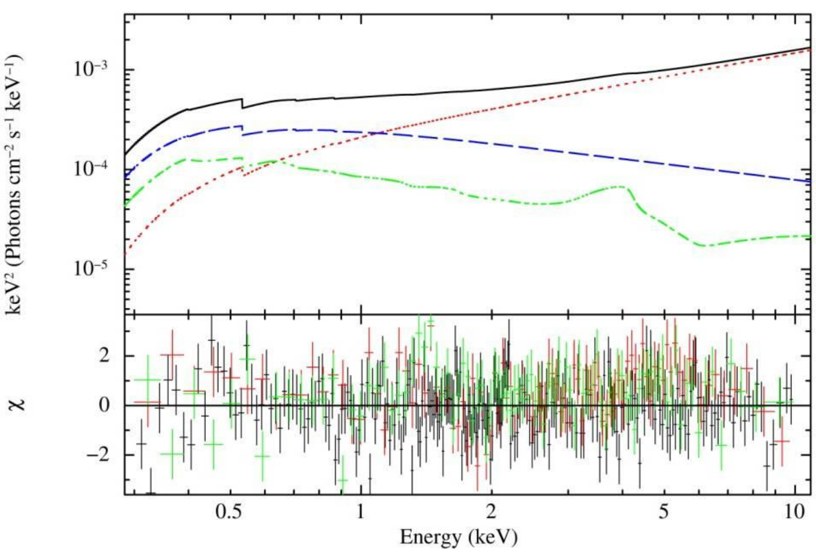


Componization of the disc emission by a population of electrons with low temperature and large optical depth (in a transition region between the disc and the corona) provides a good fit, χ^2_{red} = 1.062 (1251)

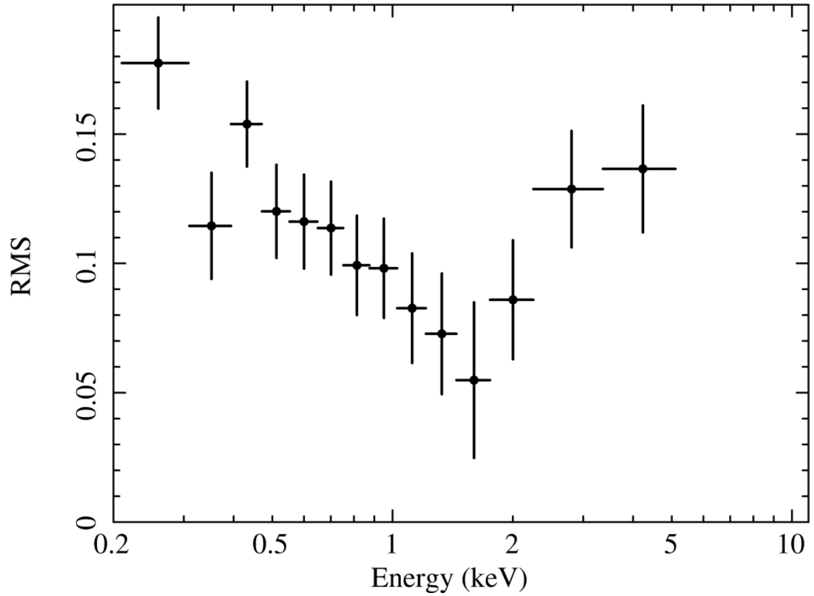
T_0 = 11 eV (fixed), KTe = 0.50 (+0.16,-0.09) keV, τ = 10.2$\pm$0.2, Γ = 1.44 $\pm$0.03

Applying a relativistic blurred reflection from the accretion disc the quality of the fit is similar to the Comptonization model, χ^2_{red} = 1.065 (1251)

XMM-Newton and NuSTAR observations in 2016 confirm the lack of a significant Iron line and of a reflection component (see Brenneman's talk)

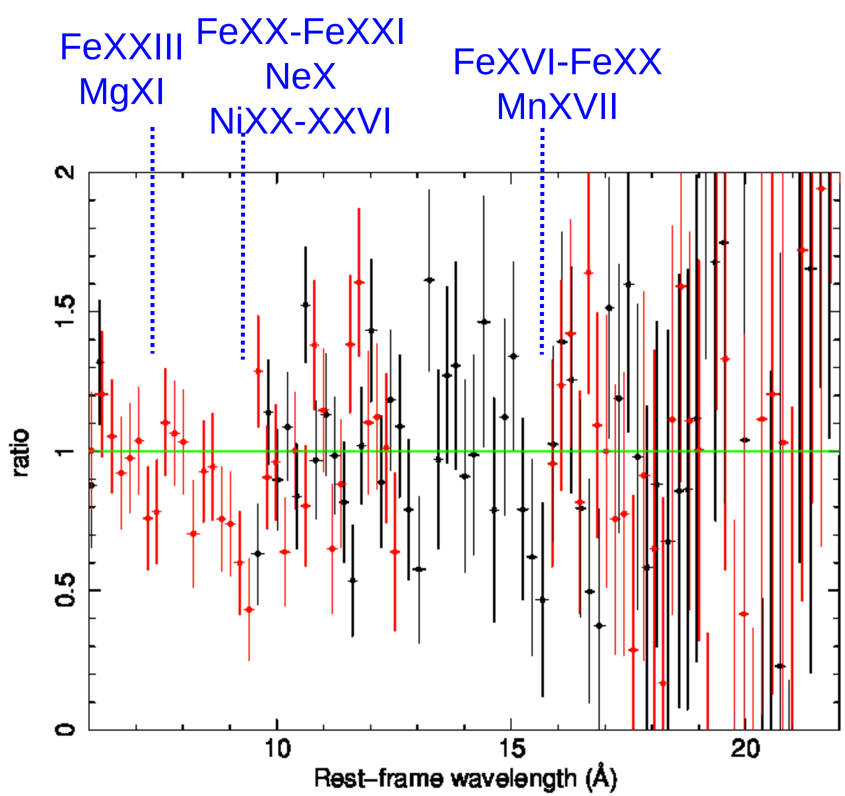


RMS variability spectrum and RGS



The RMS variability spectrum shows a break at 1.7 keV, above which the variability increases with the energy. This is usually observed in blazars (e.g. Gliozzi et al. 2006), supporting the interpretation that ***the X-ray emission above 2 keV is produced by a relativistic jet.***

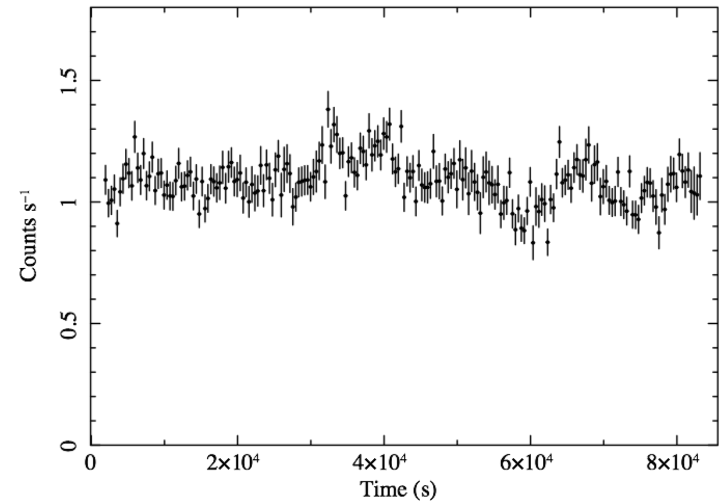
Possible absorption features in the RGS spectra, suggesting a jet not completely aligned to the line of sight

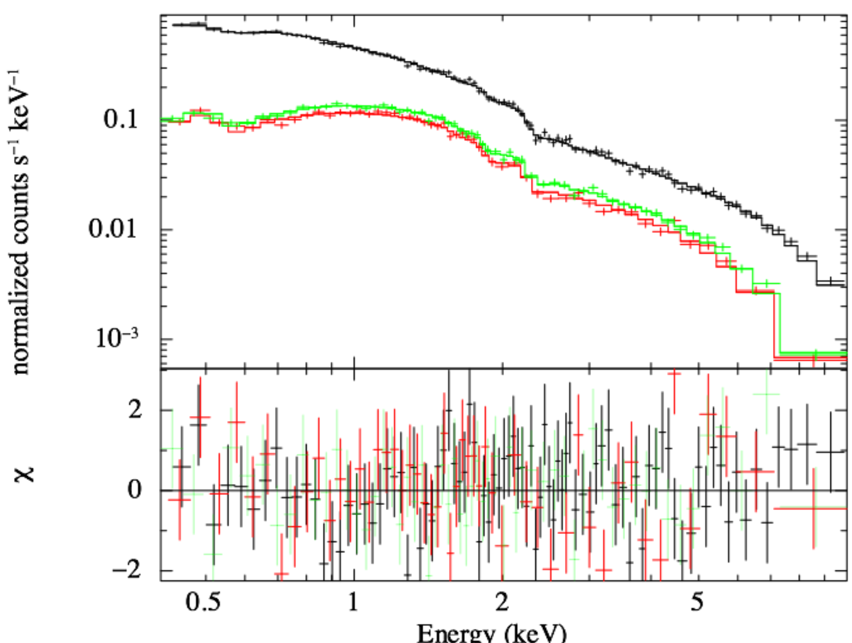


XMM observations of FBQS J1644+2619

90 ks observation on 2017-03-03
~ 40 ks affected by background flares

$F_{2\text{-}10\ keV} = (1.86 \pm 0.02) \times 10^{-12}$ erg cm^{-2} s^{-1}



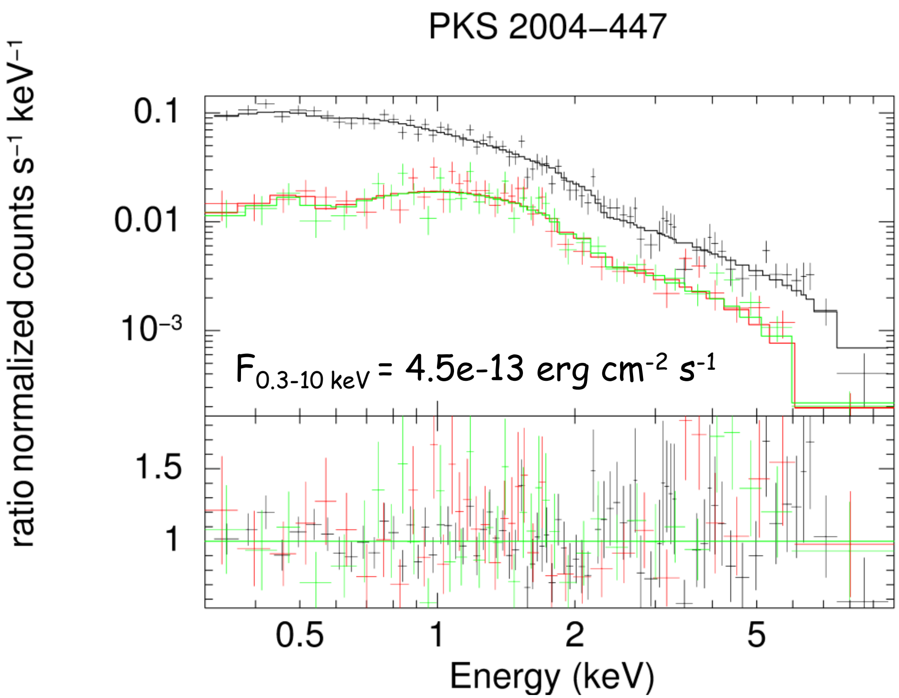


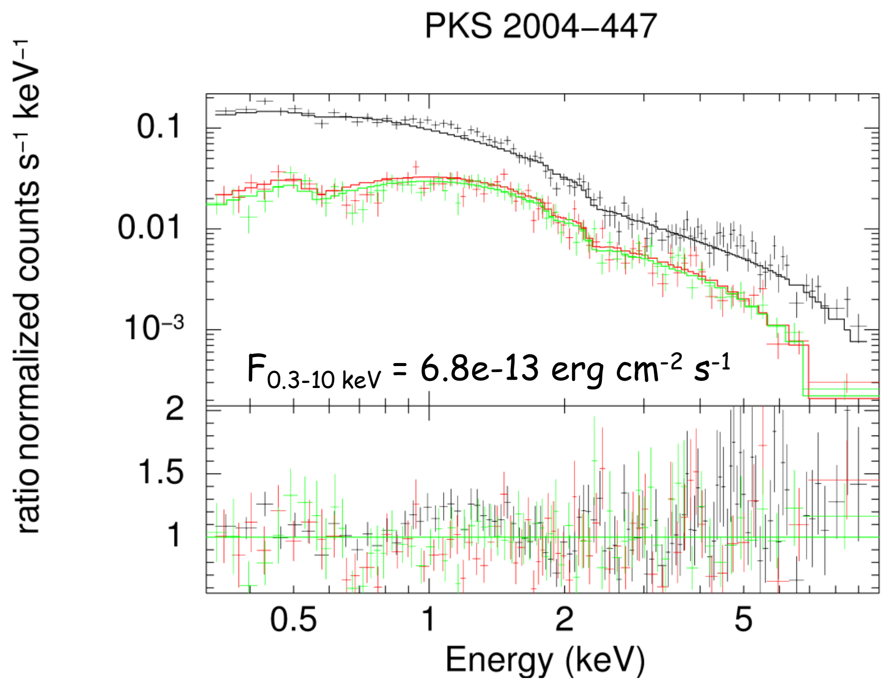
Time-averaged spectrum fitted by a broken power law model:
$\Gamma_1 = 1.91 \pm 0.02$, $\Gamma_2 = 1.66 \pm 0.03$, $E_{break} = 1.9 \pm 0.2$ keV

No Iron line and no evidence for intrinsic absorption

Larsson et al., in prep.

XMM observations of PKS 2004-447 in 2012

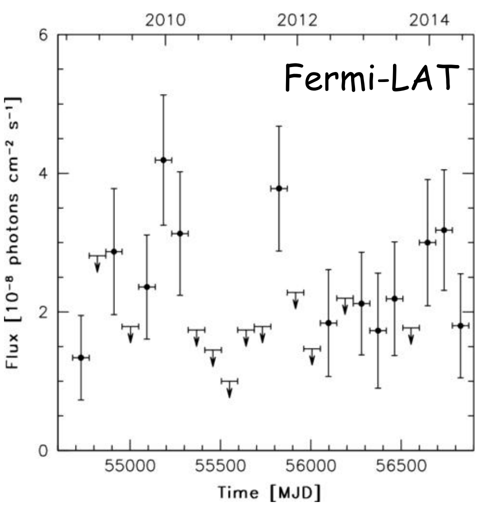




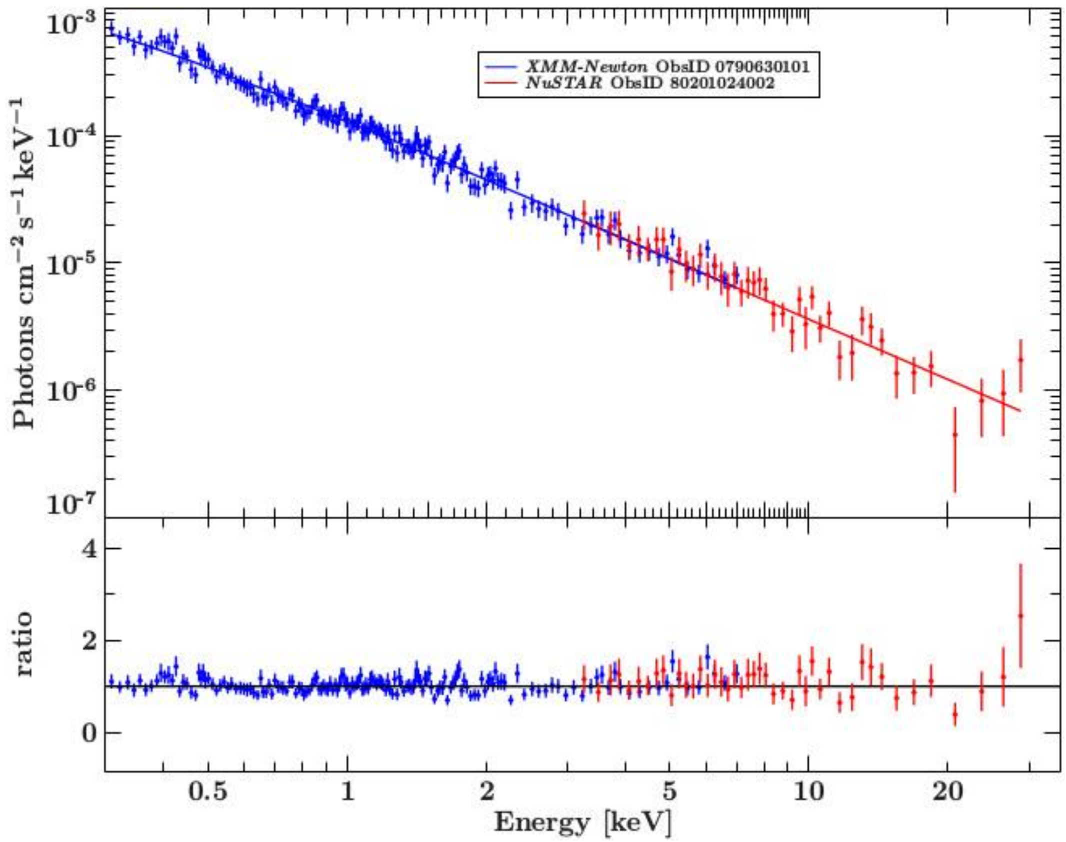
Orienti, D'Ammando et al. 2015, MNRAS, 453, 4037

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 Kreikenbohm et al. (2016, A&A, 585, 91)



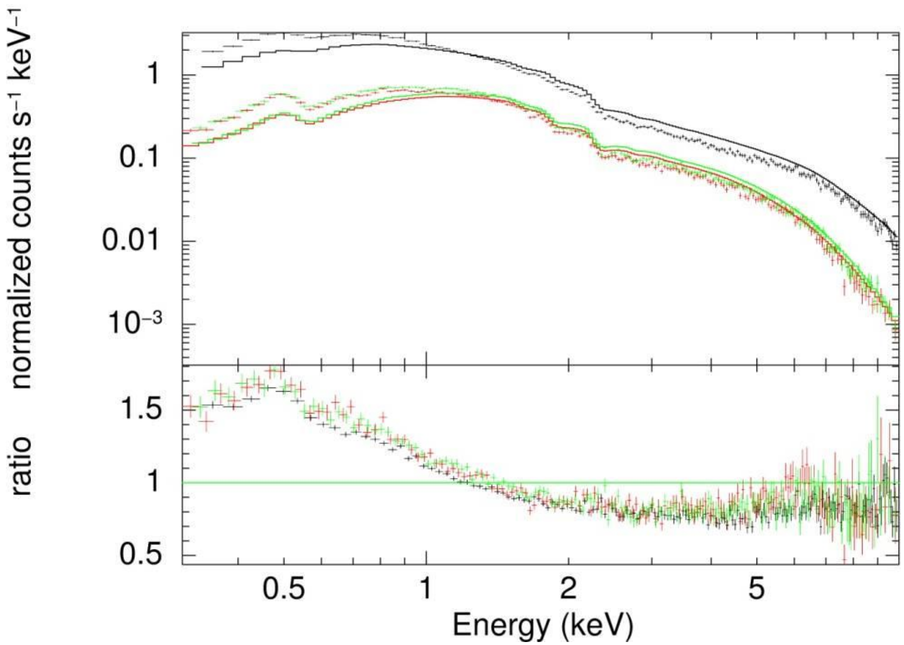
XMM+NuSTAR observations of PKS 2004-447

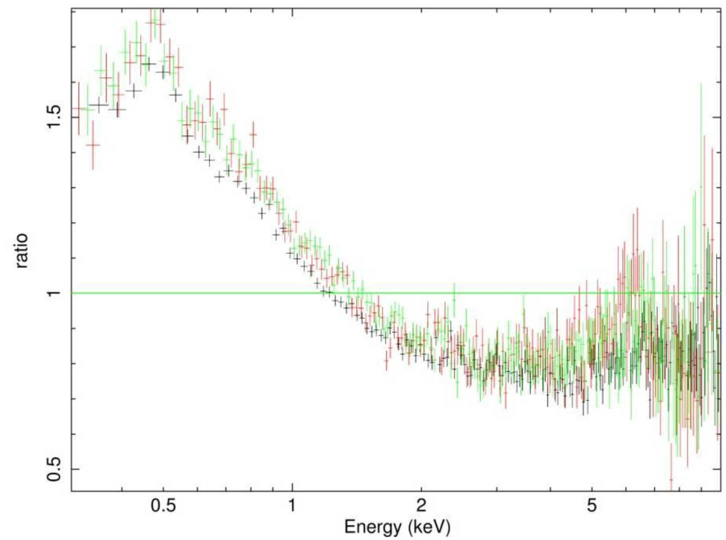


Kreikenbohm et al, in prep.

The 0.5-20 keV spectrum collected on 2016-05-05 by XMM-Newton and NuSTAR is well fitted by **a single power-law** with a photon index Γ = 1.58 ±0.02, $F_{0.3\text{-}10\ keV}$ = 9.8e-13 erg cm^{-2} s^{-1}

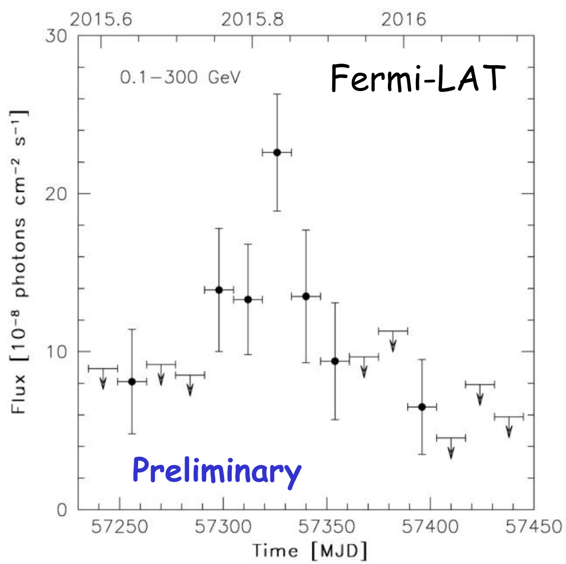
XMM observations of 1H 0323+342





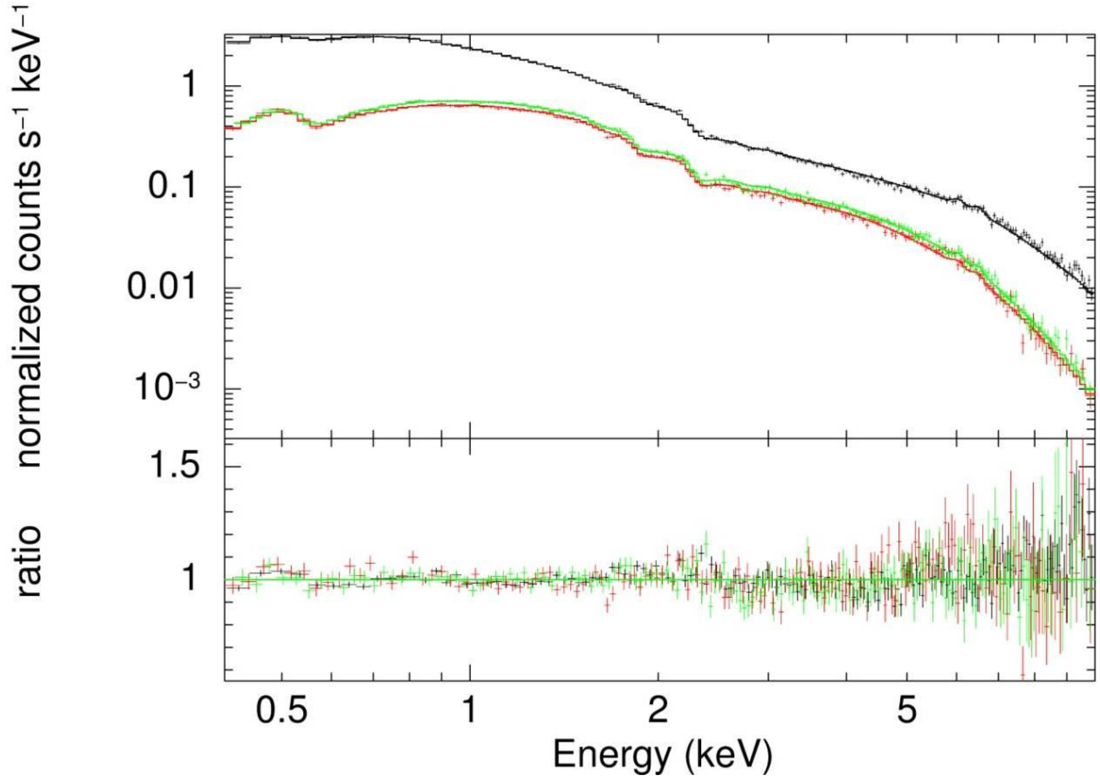
Γ = 2.04 ± 0.01 in the 0.3-10 keV energy range, $\chi^2_{red} = 7.97$

A simple power law in the 2-10 keV energy range does not provides a good fit ($\chi^2_{red} = 1.31$), Γ = 1.70±0.01



D'Ammando et al, in prep.

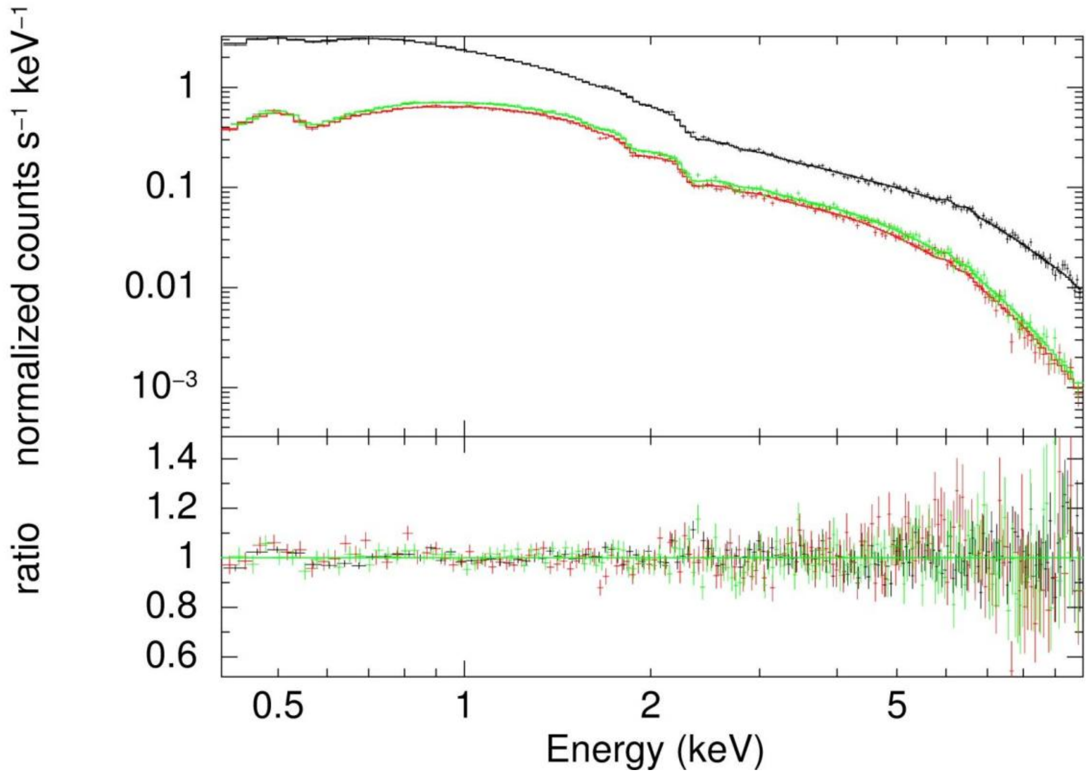
XMM observations of 1H 0323+342



Spectrum fitted by a broken power law model: $\Gamma_1 = 2.23 \pm 0.01$, $\Gamma_2 = 1.71 \pm 0.02$, $E_{break} = 1.94 \pm 0.06$ keV

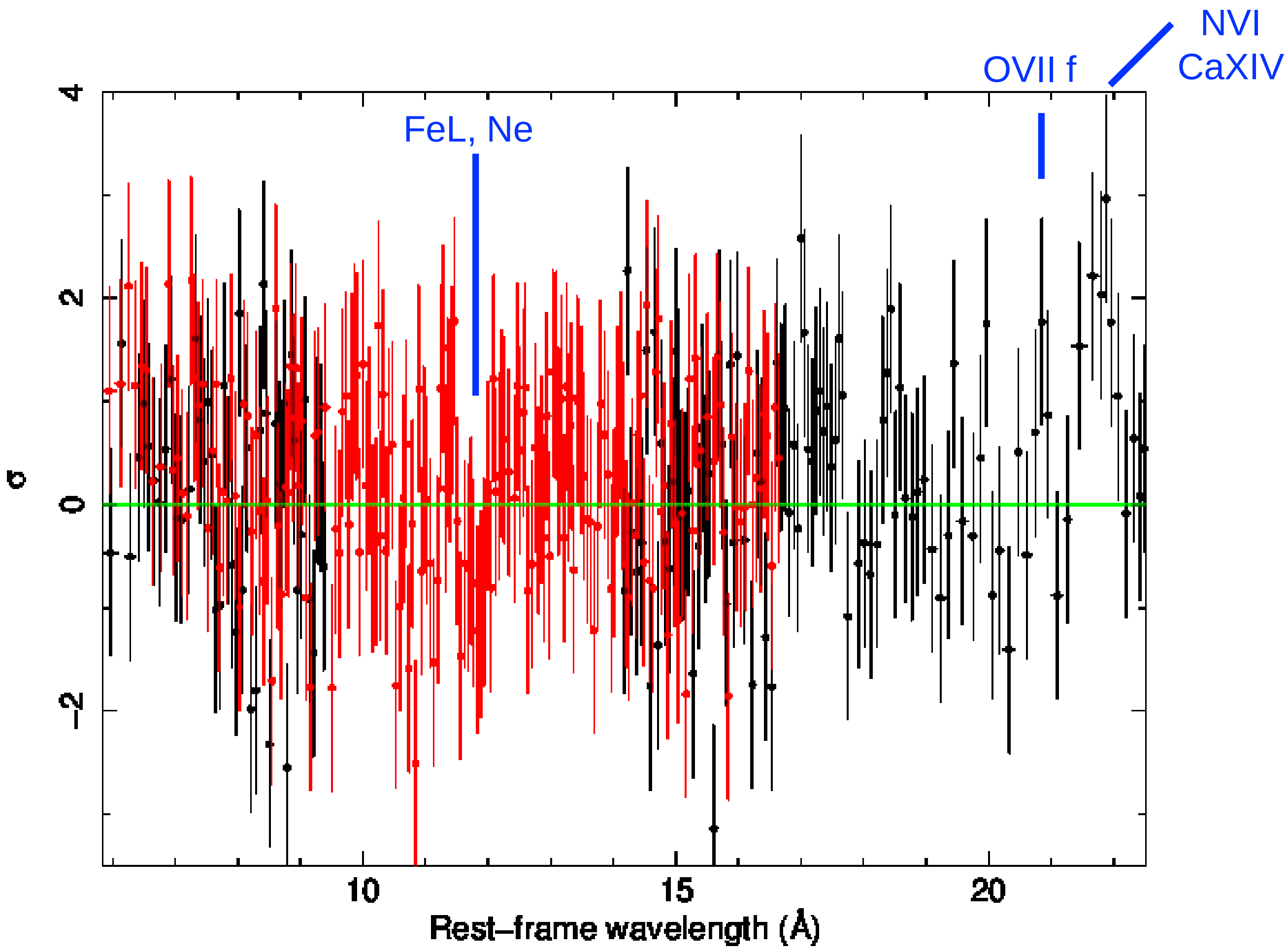
With the addition of a weak Iron Ka line at 6.42 $\pm$0.04 keV (EW ~ 50 eV) the fit improves by $\Delta\chi^2 = 40$ for 2 dof

XMM observations of 1H 0323+342



With the addition of a Componization model with T_0 = 60 eV, kTe = 0.57 keV, and τ = 10 to the broken power law plus weak Iron Kα line model the fit improves: χ^2_{red} = 1.17

RGS spectra of 1H 0323+342



Possible absorption and emission features in the RGS spectra, suggesting a jet not completely aligned to the line of sight

PKS 1502+036 and NVSS J1246+0238

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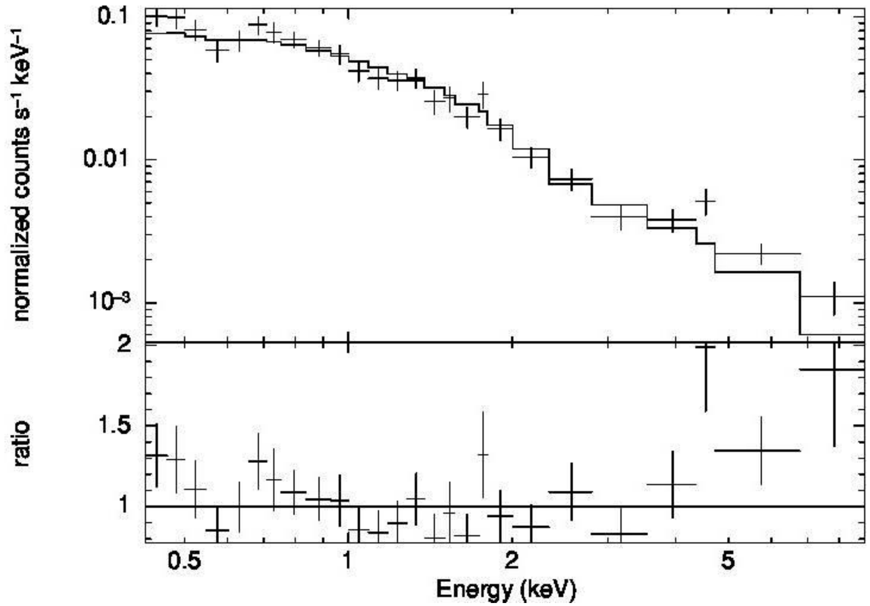
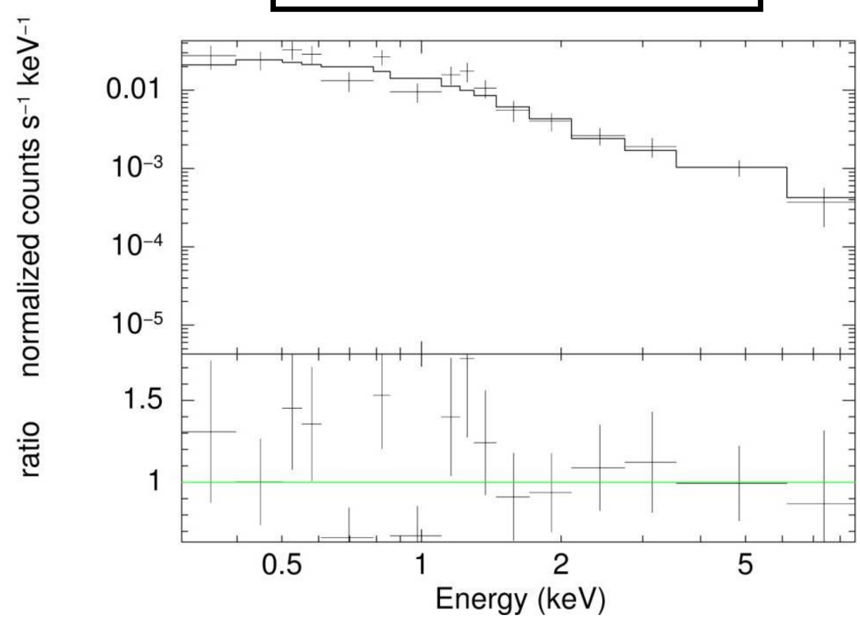


D'Ammando et al. 2016, MNRAS, 463, 4469

PKS 1502+036 was observed by XMM-Newton on 2012 August 7 for 17 ks. A simple power law is sufficient to describe the data, although some residuals are present at low and high energies. An improvement of the fit was obtained by using a broken power-law, but the uncertainties are large.

NVSS J124634+023808



A broken power law is the best fit model also for NVSS J1246+0238, but the statistics is poor.

Deeper observations are needed!

Summary and open questions

• *The discovery of relativistic jets in radio-loud narrow-line Seyfert 1 galaxies was a great surprise*. These sources behave as blazar-like objects at the low-end of the blazar BH mass distribution

• The BH mass and mechanism for the formation of a relativistic jet in the γ-ray emitting NLSy1 is under debate. At least one of the sources detected in γ-rays (i.e. FBQS J1644+2619) is hosted in an elliptical galaxy with a BH mass of $(2.1\pm0.2)\times10^8$ $M_\odot$

• The X-ray spectra of the γ-ray emitting NLSy1 are harder than those of the other NLSy1, suggesting the relativistic jet being the dominant emission component (at least above 2 keV)

• A clear soft X-ray excess below 2 keV was observed in PMN J0948+0022, FBQS J1644+2619 and 1H 0323+342 (not in PKS 2004-447, why?), are we observing the same Seyfert-like component of the radio-quiet NLSy1? Is there a strong connection between the jet activity and the soft excess in the γ-ray NLSy1?

• A weak reflection feature in the X-ray spectrum of these sources may be related to the fact that the accretion disc corona acts as the base of the jet?

• The detection of a weak Iron line in 1H 0323+342 and the possible detection of absorption and emission features in the RGS spectra suggests that these γ-ray emitting NLSy1 are observed at relatively small angle of view, but larger than blazars (i.e., $3 < \theta < 10$ deg)