Variability patterns of the Fe K line complex in radio quiet AGN

B. De Marco[1], K. Iwasawa[2], M. Cappi[3], M. Dadina[3], G. Miniutti[4], A. Celotti[1], F. Tombesi[3]

(1)SISSA/ISAS, Trieste, Italy; (2) INAF-Osservatorio Astronomico di Bologna, Italy; (3) INAF-IASF Bologna, Italy; (4) Laboratoire APC, Paris, France

Abstract:

We present a model independent spectral variability study of a sample of 11 radio quiet AGN in the 4-9 keV energy band, with the aim of tracing variability of Fe K line complex features. Using XMM-Newton data we mapped the emission in excess of the continuum in the time-energy plane. For IC 4329a, the brightest source of the sample, we present a more detailed analysis of the intensity modulation characterizing the detected feature in the E=5.4-6.1 keV energy range. A total of 4 out of 11 sources show significant variability signatures between 5.4-7.2 keV. In the case of IC 4329a, the detected variable feature is characterized by intensity modulations on a time scale of 32.5 ks, significant at about 96% confidence level, revealing a complex variability pattern. The line modulations apparently lag behind the short-time scale continuum (E=0.3-10 keV) variations by about 15 ks.

Introduction:

The reflection X-ray spectrum of bright radio quiet AGN can be used as a probe of the disk innermost regions. In particular, relativistic Fe K lines are well known to be powerful tools for this kind of studies. The debate on their production mechanism has been reinforced by the recent discovery of narrow (apparently transient) emission features in the 4-6 keV energy range (e.g. Turner et al. 2002, Iwasawa et al. 2004, Longinotti et al. 2007 and references therein). These features are most probably produced into discrete regions of the disk, but their origin is yet unknown. Several models, as the so-called orbiting spot model (Nayakshin & Kazanas 2001, Dovciak et al. 2004), attempt to explain their occurrence. However variability studies are key tools in providing insights onto their real nature.

We present a systematic spectral variability study in the Fe K line complex energy band on a sample of bright, poorly absorbed, radio quiet AGN. The aim of this work is to look for variable Fe K features and to map their variability patterns using the excess map technique (Iwasawa et al. 2004).

The sample:

The original complete sample includes 31 sources selected by Guainazzi et al. 2006 for the study of the time averaged properties of relativistic Fe lines.

The sources are characterized by:

1) $F_{2\text{-}10\ keV} \geq 1.5\times10^{-11}$ erg/s/cm^2

2) $N_H < 1.5\times10^{22}$ cm^{-2}

3) XMM-Newton observation long enough to collect at least 10^5 source counts between 2-10 keV.

Here we focus on sources with public data prior to Jan 2008 and exclude those already extensively studied in their Fe K line variability properties.

Table 1. Sources list: (1) name; (2) redshift; (3) estimated SMBH mass; (4) estimated Keplerian orbital period at r=10 r_g; (5) observation identifier; (6) flux in the 2–10 keV energy band; (7) duration of the observation; (8) chosen time resolution for the excess map analysis; (9) chosen energy resolution for the excess map analysis.

Source (1)	z (2)	M_{BH} ($10^7 M_\odot$) (3)	$T_{orb}(10r_g)$ (ks) (4)	Obs Identifier (5)	$F_{2-10keV}$ (10^{-11} erg cm^{-2} s^{-1}) (6)	Obs Duration (ks) (7)	Δt (ks) (8)	ΔE (keV) (9)
IC 4329a	0.0161	$0.99^{+1.79}_{-1.19}$ [a]	10	0147440101	9.6	133	2.5	0.1
NGC 4593	0.0047	$0.54^{+0.94}_{-0.30}$ [a]	5.3	0059830101	4.0	76	2.5	0.1
NGC 7314	0.0048	0.47[b]	4.6	0111790101	3.9	43	2.5	0.1
NGC 5548	0.0170	6.71±0.26[a]	69	0089960301[e]	3.9	93	2.5	0.1
				0089960401[f]	5.2	37	2.5	0.1
AKN 120	0.0323	15.0±1.9[a]	147	0147190101	3.8	112	2.5	0.1
NGC 3227	0.0039	4.22±2.14[a]	41	0400270101	3.7	106	2.5	0.1
MKN 110	0.0353	2.51±0.61[a]	25	0201130501	2.8	47	2.5	0.1
NGC 7469	0.0164	1.22±0.14[a]	12	0207090101[e]	2.8	85	2.5	0.1
				0207090201[f]	2.9	79	2.5	0.1
MKN 279	0.0305	3.49±0.92[a]	34	0302480401[e]	2.7	59	5.0	0.1
				0302480501[f]	2.5	59	5.0	0.1
MR 2251-178	0.0640	$25.1^{+25.5}_{-11.7}$ [c]	246	0012940101	2.0	64	6.0	0.1
AKN 564	0.0247	0.26±0.03[d]	2.5	0206400101	1.6	99	5.0	0.2

References: [a] Peterson et al. 2004; [b] Padovani & Rafanelli 1988; [c] Brunner et al. 1997; [d] Botte et al. 2004.
Notes: [e] observation I; [f] observation II.

Excess map analysis:

The method is widely described in Iwasawa et al. 2004 and briefly summarized in the following:

i) time resolved spectra (at the time resolution chosen for the map) were extracted in the 4-9 keV energy band;

ii) the continuum was determined fitting a power law plus cold absorption model to the 4.0-5.1 keV and 7.0-9.0 keV energy range (i.e. excluding the Fe K line complex band);

iii) spectra were rebinned at the chosen energy resolution for the map and residuals to the best fit continuum model were computed;

iv) residuals were visualized in the time vs energy plane (Fig. 1);

v) residuals light curves were extracted in the following 3 energy bands:

- A) 5.4-6.1 keV: redshifted Fe Kα line band;
- B) 6.1-6.8 keV: neutral and/or mildly ionized Fe Kα line band;
- C) 6.8-7.2 keV: Fe Kβ and/or highly ionized Fe Kα line band .

vi) residuals light curves errors and variability singificances were determined via Monte Carlo simulations.

Results:

We present preliminary results obtained from the analysis of 11 sources of the complete sample (for a total of 14 observations, Table 1).

High variability significance (>90%) is found in the Fe K line complex residuals of **4 out 11 sources (IC 4329a, NGC 7314, MKN 279** and **AKN 564**, see Table 2).

Estimated variability time scales range from ~10 to ~25 ks.

Table 2: Variability significances obtained from Monte Carlo simulations in bands A, B and C.

Sources	Band A	Band B	Band C	Δt (ks)
IC 4329a	**98.9%**	76.7%	12%	15
NGC 4593	9.1%	10.6%	55.1%	
NGC 7314	**94.8%**	41.8%	62.1%	10
NGC 5548 (obs. I)	28.9%	81.7%	83.5%	
NGC 5548 (obs. II)	88.5%	27.8%	10.7%	
AKN 120	64.0%	37.7%	46.6%	
NGC 3227	40.9%	53.4%	17.4%	
MKN 110	28.5%	6.8%	56.7%	
NGC 7469 (obs. I)	83.3%	87.2%	87.7%	
NGC 7469 (obs. II)	62.0%	46.9%	4.0%	
MKN 279 (obs. I)	54.6%	26.9%	80.2%	
MKN 279 (obs. II)	1.5%	**94.4%**	66.9%	15
MR 2251-178	67.5%	4.1%	50.9%	
AKN 564	14.1%	**93.9%**	**95.7%**	20–25

IC 4329a:

This is the source with the highest flux and the longest exposure of the analyzed sample. A deepest study of the variability pattern characterizing the variable feature (E~5.4-6.1 keV, at 98.9% confidence level) of IC 4329a has been carried out.

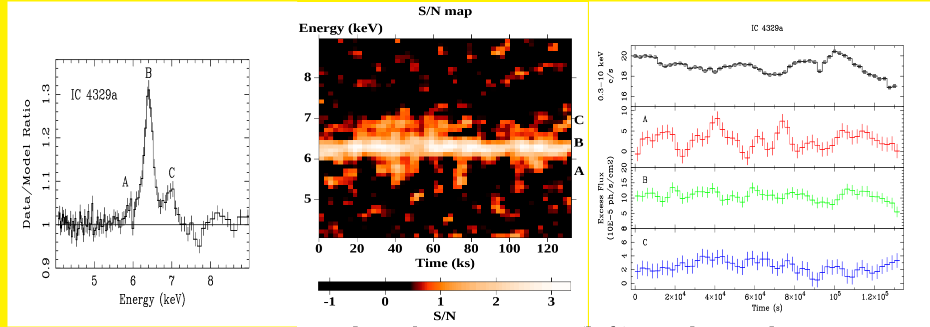

Fig. 1: IC 4329a time averaged 4-9 keV spectrum (left), 2.5 ks resolution excess map (middle) and 0.3-10 keV continuum and residuals light curves (right).

Intensity modulation time-scale:

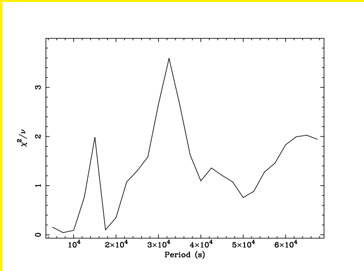

Fig. 2: Reduced χ^2 vs period plot from epoch folding of 5.4-6.1 keV feature in IC 4329a.

We applied the epoch-folding technique (e.g. Leahy et al. 1983, Benlloch et al. 2001) to IC 4329a band A residuals light curve to search for a significant intensity modulation time scale between 5.0 ks and 67.5 ks. A maximum peak was found at P_0=32.5 ks (Fig. 2). The significance of the peak has been assessed against random fluctuations due to red plus white noise.

The 32.5 ks time scale results significant at the 95.7% confidence level.

Correlation with the 0.3-10 keV continuum:

The feature light curve has been cross correlated with the 0.3-10 keV continuum light curve, subtracted of a 4-th order polynomial trend (to remove low-frequency variability components, Fig. 3 upper panel). The computed Discrete Correlation Function (Edelson & Krolik 1988) is shown in Fig. 4 and reveals a possible ~15 ks time lag of the reprocessed emission with respect to the continuum one.

Tests against red plus white random fluctuations yield a significance of 96.6% for the observed time lag.

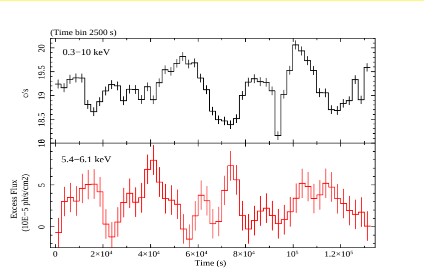

Fig. 3: 0.3-10 keV detrended continuum light curve (upper panel) and 5.4-6.1 keV residuals light curve (lower panel) rebinned at the time resolution of 2.5 ks.

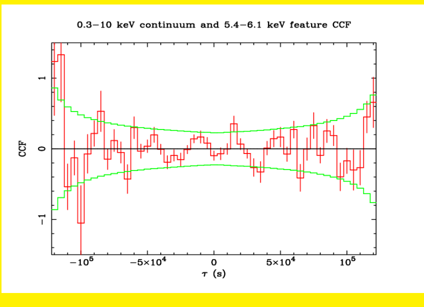

Fig. 4: Discrete Correlation Function between the 0.3-10 keV detrended continuum and the 5.4-6.1 keV residuals light curve (at the time resolution of 5 ks). Positive lags correspond to time delays of the reprocessed with respect to the primary one.The green curves represent the 2.3σ correlation level produced by white noise processes.

Conclusion:

We found significant (>90%) variability in 4 out of 11 analyzed sources, between 5.4-7.2 keV.

The detected variable feature (E=5.4-6.1 keV) in the brightest source of the analyzed sample, IC 4329a, consistent with Fe Kα red-shifted emission, is characterized by intensity modulation on a time-scale of 32.5 ks, which, for M_{BH}= 9.9x10^6 $M_\odot$ (Peterson et al. 2004), yields an estimate for the Keplerian radius of the emitting region of ~22 r_g. However, the observed time lag (~15 ks) implies a distance between the primary and reprocessed emission regions of 150-300 r_g.

This is not simply consistent with an orbiting spot scenario, where the active regions illuminating the disk should be located at few r_g above the disk (Nayakshin & Kazanas 2001). Such result gives more support to lamp-post models, which assume a higher X-ray source. This explanation would also account for the lack of any observed energy modulation.