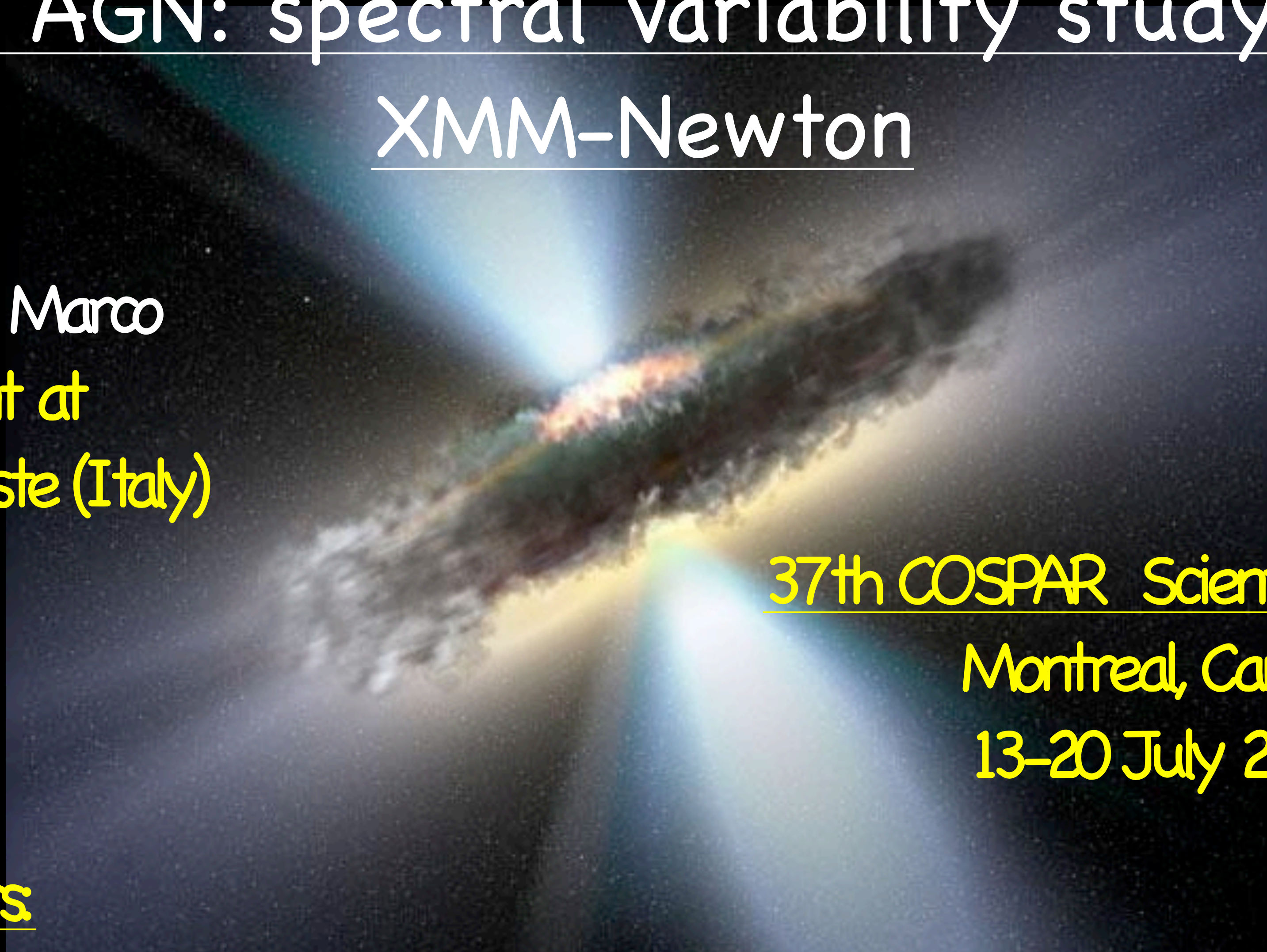
Transient Fe K line complex features in radio quiet AGN: spectral variability study with XMM-Newton



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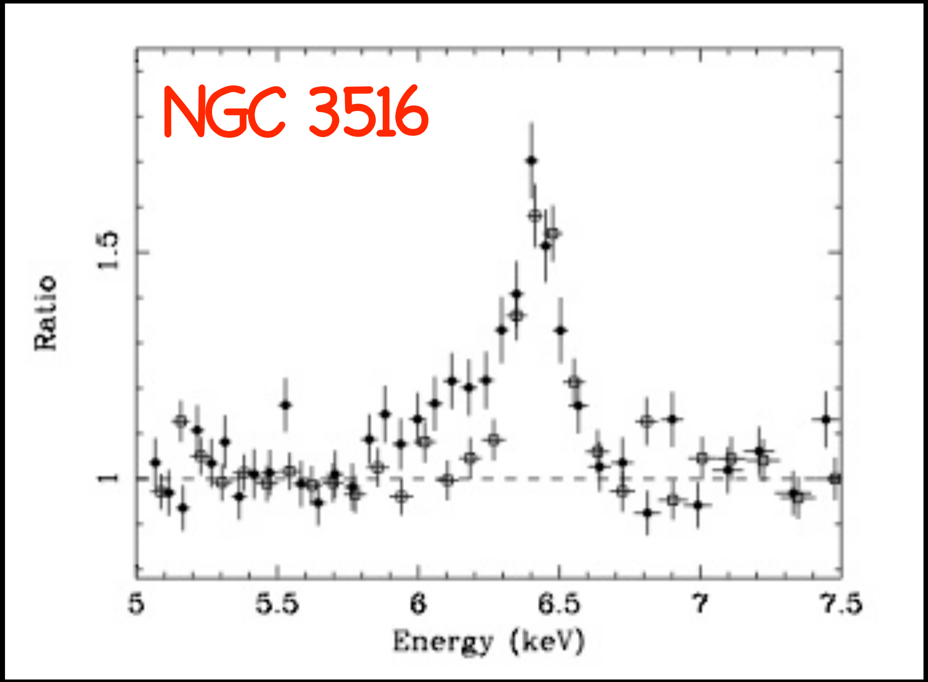
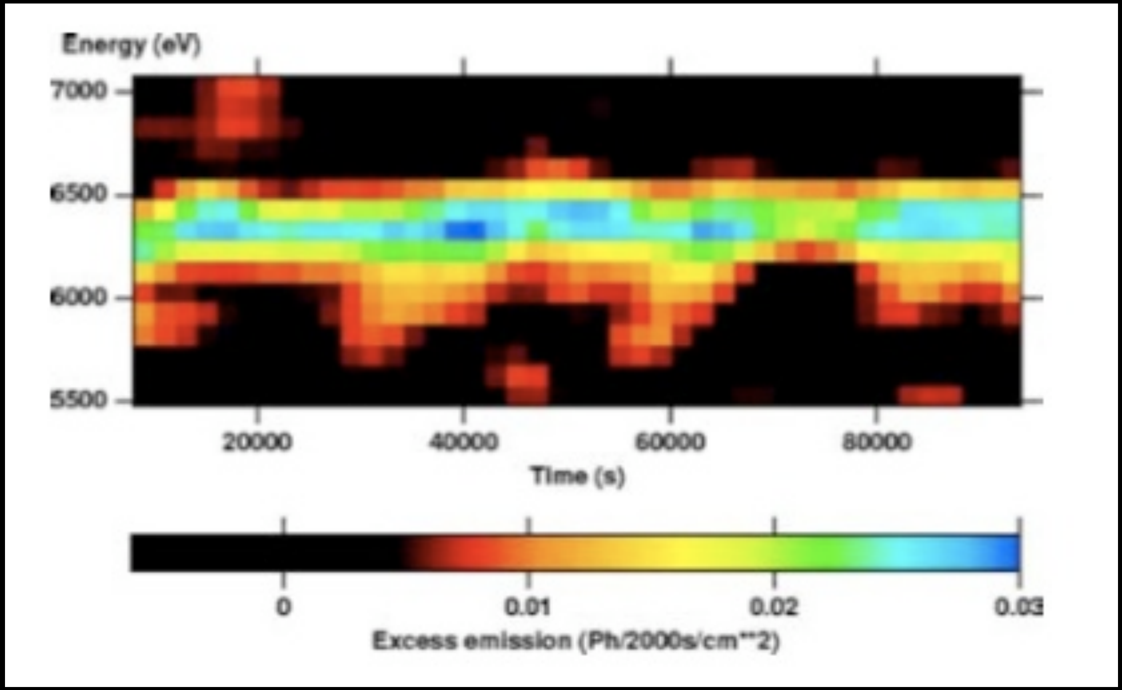
Introduction

Relativistic Fe K lines are well known to be powerful tools for the study of the inner accretion flow.

Variability is useful to understand the dynamics of the flow, the geometry and structure, etc.





Iwasawa et al. 2004

---> recent discovery of (possibly transient) redshifted narrow lines [see Longinotti et al. 2007 and references therein]

Introduction

NCG 3516 [Turner et al. 2002, Iwasawa et al. 2004]
MKN 766 [Turner et al. 2006]
NGC 3783 [Tombesi et al. 2007]
MKN 841 [Petrucci et al. 2007]
ESO 113-G010 [Porquet et al. 2007]

....

!!! No Systematic study on a complete sample does exist !!!

XMM-Newton sensitivity and effective area are high enough to provide early indications of orbital-time scale spectral variability [Miller 2007]

The Sample

Complete sample (see Guainazzi et al. 2006) including 31 sources (selected from the RXTE Slew Survey) for the study of relativistic Fe lines time-averaged properties.

- ✔ Flux limit: F(2-10 keV) $\geq 1.5 \times 10^{-11}$ erg/cm^2/s
- ✔ Cold absorption limit: $N_H < 1.5 \times 10^{22}$ cm^{-2}
- ✔ XMM-Newton observation duration: long enough to collect $\geq 10^5$ source counts between 2-10 keV

✔ Observations with public data prior to Jan 2008

✔ 7 sources excluded because already extensively studied in their Fe K line variability properties*

Final Sample: 11 sources (14 observations in total)

De Marco, Iwasawa, Cappi, Dadina, Miniutti, Celotti & Tombesi 2008 [submitted]

*MCG-6-30-15 [Vaughan & Fabian 04, Ponti et al. 04], NGC 3516 [Iwasawa et al. 04], NGC 3783 [Tombesi et al. 07], MKN 766 [Turner et al. 06], NGC 4051 [Ponti et al. 06], MKN 509 [Ponti et al. in prep.], ESO 198-G24 [Miniutti et al. in prep.]

Method: mapping of excess emission

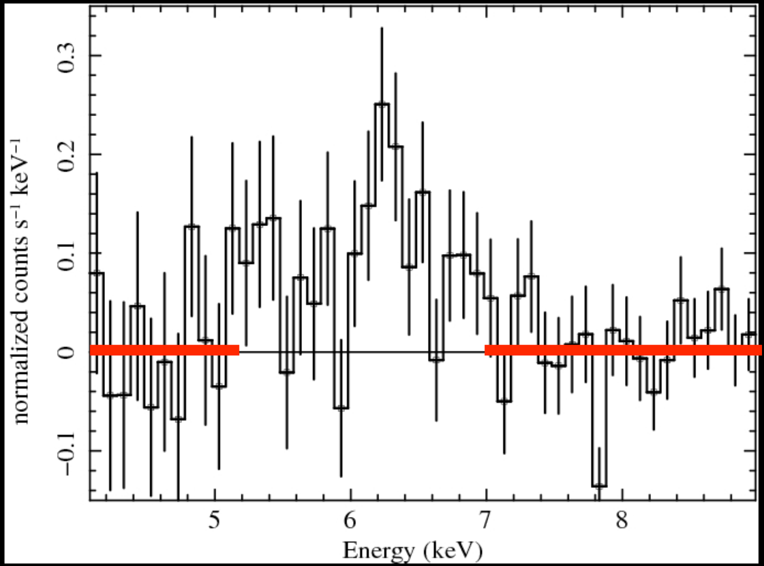
(Iwasawa, Miniutti & Fabian 2004)

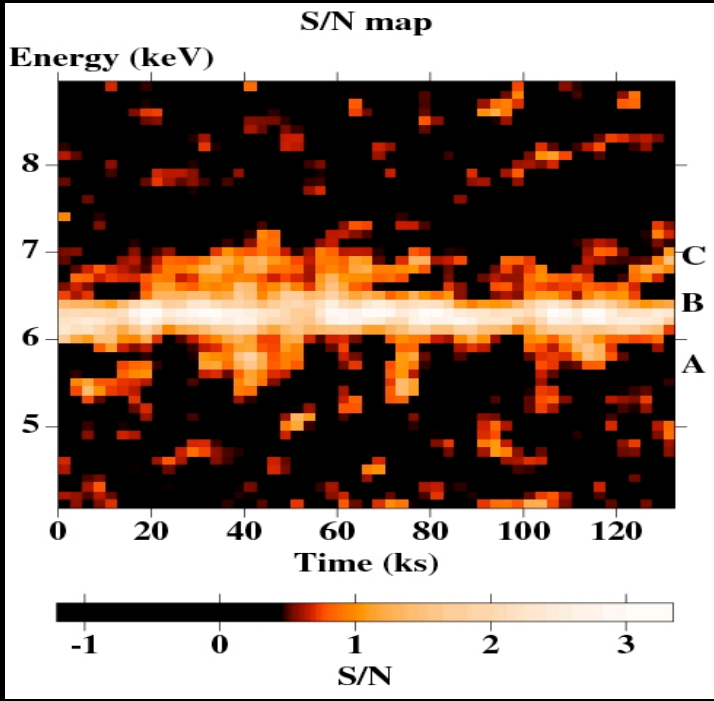
1) Time resolved spectra (4-9 keV, with time resolutions of 2.5-5 ks)

2) Continuum fit: power law + cold absorption excluding the Fe K line complex energy band (E=5.0-7.0 keV)

3) Residuals: data – model

4) Excess residuals maps (in time vs energy plane)





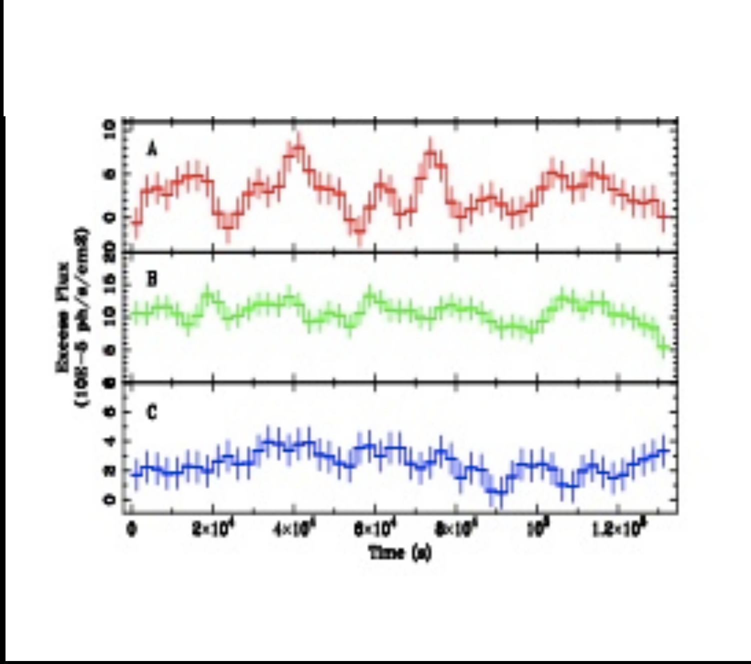
Method: mapping of excess emission

5) Residuals light curves : integration over 3 pre-defined energy bands and plot as a function of time

BAND A: 5.4–6.1 keV -redshifted Fe Kα

BAND B: 6.1–6.8 keV -neutral/mildly ionized Fe Kα

BAND C: 6.8–7.2 keV -highly ionized Fe Kα/Fe Kβ



6) Monte Carlo simulations of 1000 excess maps (assuming constant lines parameters and variable power law normalization) to estimate light curves errors and variability significance

Results

Table 2. Variability significances obtained from Monte Carlo simulations in the rest frame energy bands A (5.4–6.1 keV), B (6.1–6.8 keV) and C (6.8–7.2 keV).

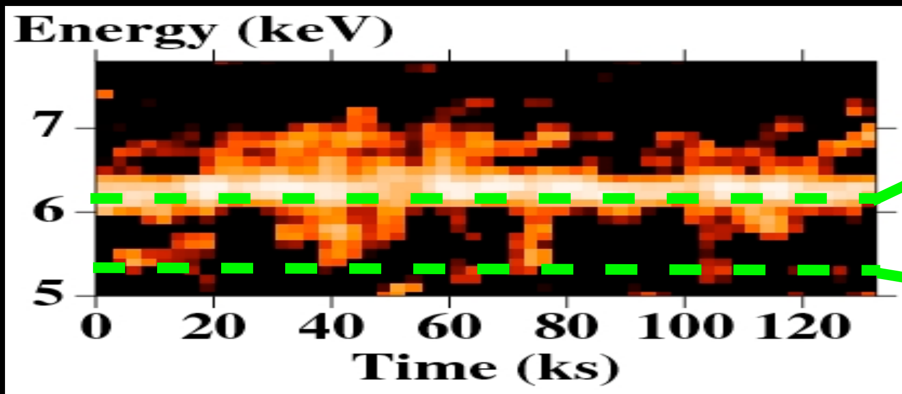
Sources	Band A	Band B	Band C	Δt (ks)
IC 4329a	98.9%	76.7%	12%	15
NGC 4593	9.1%	10.6%	55.1%	
NGC 7314	94.8%	41.8%	62.1%	10
NGC 5548 (obs. I)	28.9%	81.7%	83.5%	
NGC 5548 (obs. II)	88.5%	27.8%	10.7%	
AKN 120	64.0%	37.7%	46.6%	
NGC 3227	40.9%	53.4%	17.4%	
MKN 110	28.5%	6.8%	56.7%	
NGC 7469 (obs. I)	83.3%	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

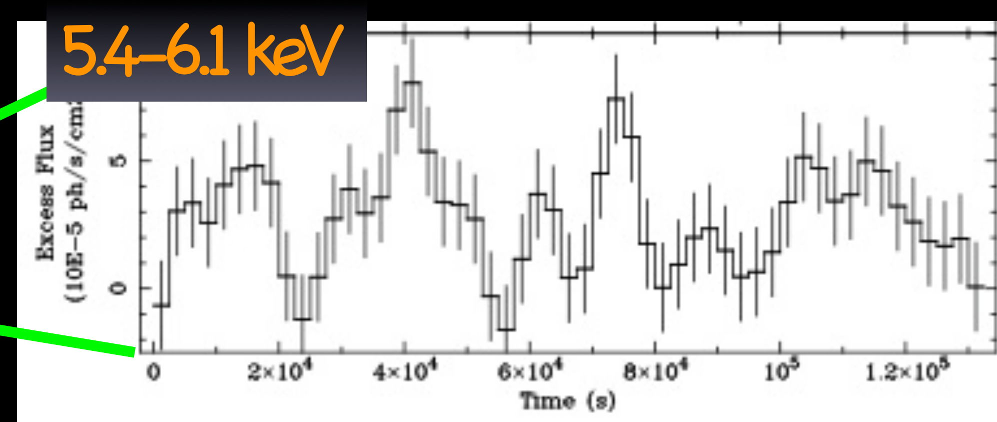
4 sources out of the 11 of our sample show Fe K line complex significant, at > 90%, variability

Plus sources already studied: 8 out of 17 have variable Fe lines !!

!!! NEW XMM-NEWTON DATA WILL ALLOW TO COMPLETE THE ANALYSIS ON ALL THE 31 SOURCES AND SURVEY A STATISTICALLY COMPLETE SAMPLE FOR TRANSIENT FEATURES!!!

A Case Study For IC 4329a

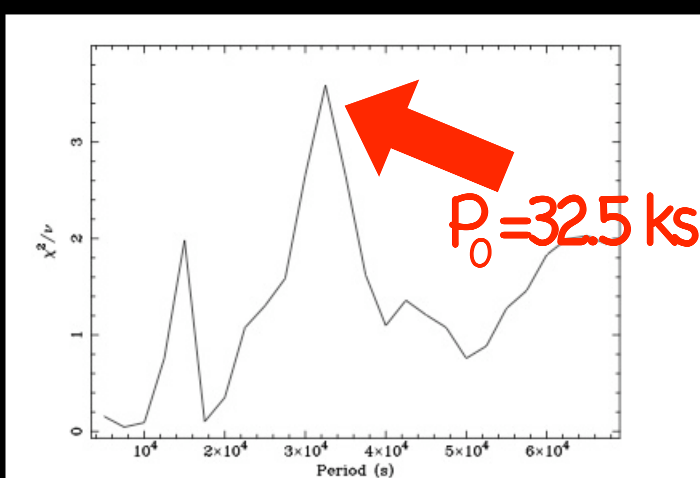




Variability significance: 98.9%

Intensity Modulation Time-Scale :

epoch folding over 26 trial periods (P = 5 – 67.5 ks, ΔP = 2.5 ks) [e.g. Leahy et al. 1983]



Test of global significance against white noise:

folding of 1000 simulated light curves;

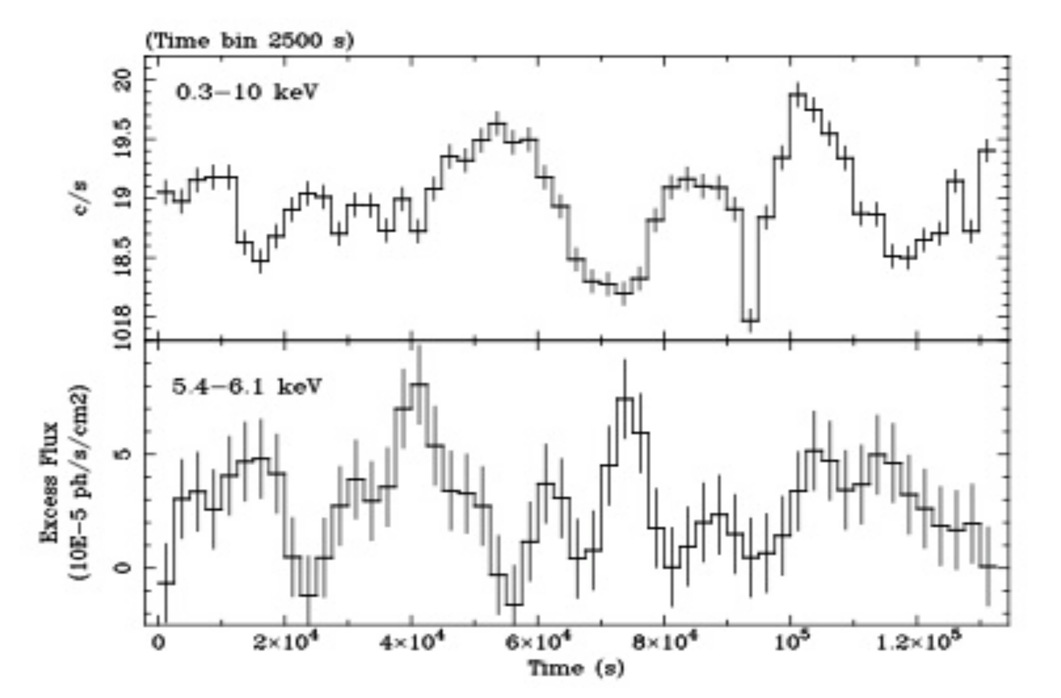
distribution of $\xi = \max\{X^2(P)/\langle X^2(P)\rangle\}$

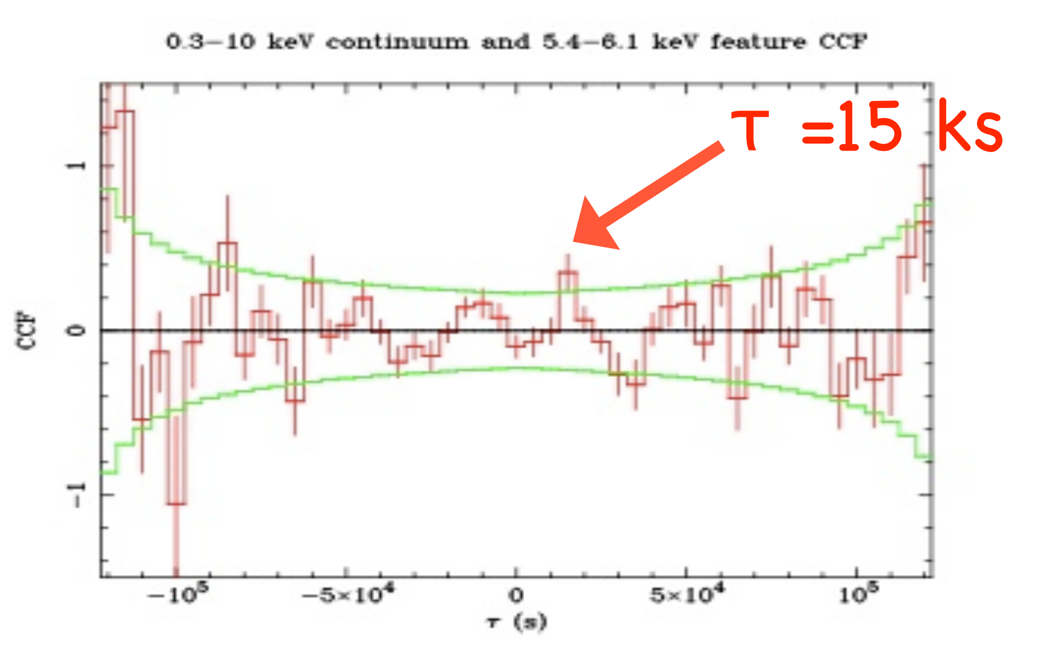
[Benlloch et al. 2001]

P_0 peak significance: 97.8%

A Case Study For IC 4329a

Detrended Continuum Light Curve (subtraction of low frequency variability components)





Discrete Cross Correlation Function [Edelson & Krolik 1988]

Significant at ~97% confidence level against white noise

—— 2.3σ (causally unrelated time series)

A Case Study For IC 4329a

- The Fe line power spectrum (PSD) is unknown!!!
- ASSUMPTION: the Fe K line has the same red noise PSD as the continuum
- Typical power law index values: β~1.0-2.0 (Uttley & McHardy 2004)

0.3-10 keV continuum light curve PSD (with fractional rms squared normalization): integration over a small interval of frequencies around $1/P_0$ gives a 3% fractional rms << feature light curve relative error (~63%)

CONCLUSION: negligible contribution from the red noise component to the observed variability !!!

- 2nd ASSUMPTION: variability amplitude of the red noise component is of the same order of the feature one (rms~60%)

A Case Study For IC 4329a

- simulation of 1000 light curves with RED + WHITE noise PSD (Timmer & König 1995)
- adopted PSD template: $N(\nu^{-\beta}+\sigma^{-2})$, with β=1.3

- Global significance test for intensity modulation:

P_0 Peak significance: 95.7%

β=1.0-2.0 ---> Peak significance:~95%-96%

(almost independent on the choice of β)

- Time lag significance test (simulated and continuum light curves CCF):

Time lag significance: 96.6%

A Model for IC 4329a

- Intensity modulation time-scale ($P_0 \sim 32.5$ ks):
- estimate of the Keplerian orbital radius of the emitting material

$T = 310\ [a + (r/r_g^{3/2})\ ]\ M_7\ \mathrm{sec}$

- $r \sim 22\ r_g$ (for M_{BH}=9.9x10^6 $M_\odot$, Peterson et al. 2004)

- Time lag ($\tau \sim 15$ ks):
- estimate of the distance between the production sites of continuum and line emission: $\tau = 2d\ (\cos i)/c$ sec
- $d \sim 150\text{–}300\ r_g$ (for a disk $i = 0^\circ\text{–}60^\circ$ and M_{BH}=9.9x10^6 $M_\odot$)

A Model for IC 4329a

- Intensity modulation --> consistent with the "orbiting spot" scenario (e.g. Dovčiak et al. 2004, Goosmann et al. 2006, see also Murphy talk)

BUT

- Flare models assume a X-ray source located at few r_g from the disk (Nayakshin & Kazanas 2001) --> at odd with the distance derived from CCF time lag
- In orbiting spot scenarios energy modulations are also expected --> not detected (as for NGC 3783, Tombesi et al. 2007)

HENCE

- IC 4329a variability pattern not consistent with standard interpretations
- Support to models which locate the X-ray source at more elevated heights (like lamp-post models, e.g. Reynolds et al. 1999)

Thank you!

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