Soft X-Ray Time Lag Behaviour of Mrk 1040

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Abstract

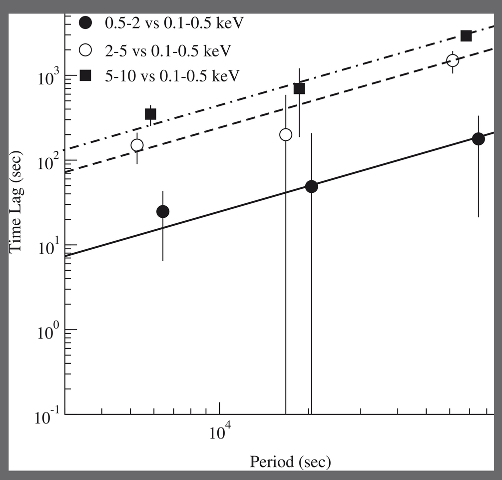
Temporal studies of X-ray binaries and Active Galactic Nuclei have shown that hard flux react to variation of soft flux with a time lag. The reverse case, or soft lag, has only been seen in a few rare Quasi-periodic Oscillations in X-ray binaries and recently for the AGN, 1H 0707-495, on short timescales of ~ 10^3 s.

We present XMM-Newton analysis of Mrk 1040 which seems to exhibit soft time lags on the dominant variability timescale of ~10^4 s. If the lags are frequency independent, it could be due to reverberation effects of a relativistically blurred reflection component responding to a varying continuum. Or alternatively, it could be due to Comptonization delays in the case when high energy photons impinge back on the soft photon source. Both models can be tested and their parameters tightly constrained, because they will need to predict the photon spectrum, the r.m.s variability and time lag as a function of energy.

Introduction

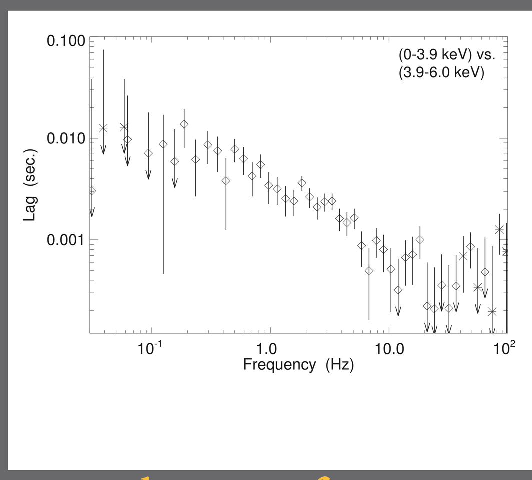
- Active Galactic Nuclei (AGN) show large amplitude variability in X-rays.
- Study of time lag is vital to understand the nature of variability, geometry of system and physical process.
- Typically, AGN and Galactic black hole systems exhibit hard time lags, e.g.

NGC 4051



Time lag versus Fourier period for the cross-spectrum of the soft energy band (0.1-0.5 keV) versus the 0.5-2, 2-5, & 5-10 keV bands (filled, open circles and filled squares, respectively) (McHardy, 2004)

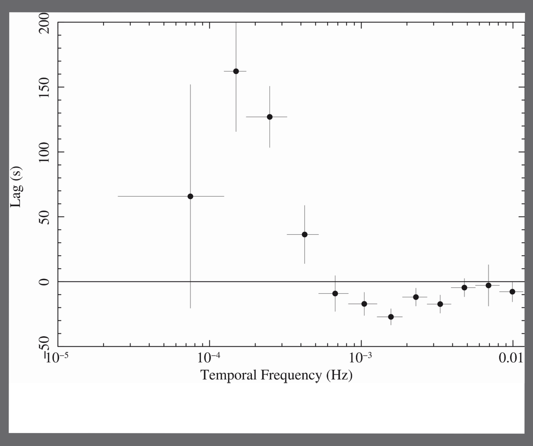
Cyg X-1



Time lag as a function of Fourier frequency for 3.9-6.0 keV vs. the lowest energy band 0-3.9 keV. Diamonds represent hard lagging the soft, whereas asterisks represent soft lagging the hard. (Nowak et al. 1999)

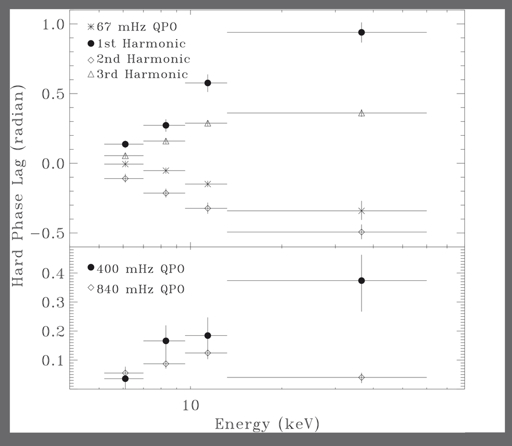
The opposite trend or SOFT LAG is seen in very few cases:

1H 0707-495



Soft lag in AGN 1H 0707-495 between 0.3-1.0 & 1.0-4.0 keV based on short timescales of ~1000 s, (Fabian et al. 2009)

GRS 1915-105



Low frequency QPO in the black hole system GRS 1915-105, (Cui 1999)

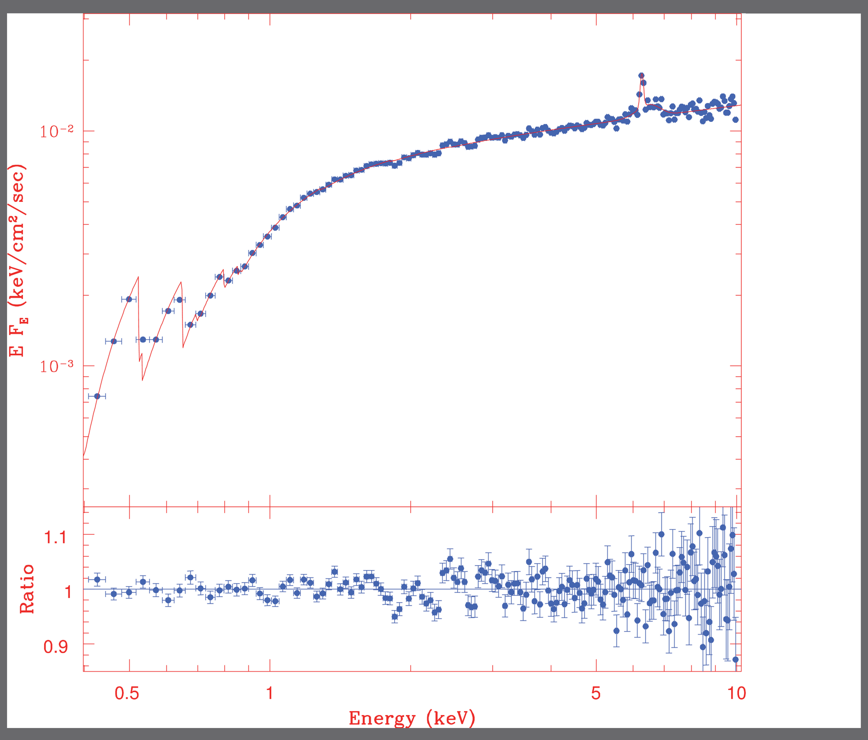
Mrk 1040: Surprising Case!

- Seems to exhibit soft lags in the dominant variability timescale of 10^4 s.
- This is revealed in the XMM-Newton observation of this source.

XMM-Newton Analysis of Mrk 1040

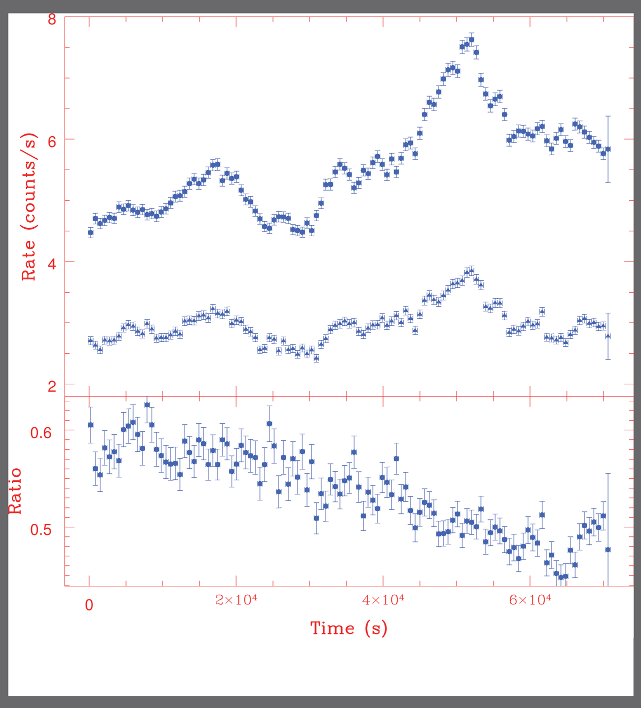
- XMM-Newton observed Mrk 1040 on 13 February, 2009 for the duration of 90.9 ks.
- We processed and filtered the EPIC-pn data in a standard way using the Science Analysis Software (SAS) version 10.0 and using the recent calibration files.
- Flaring particle background were identified above 10 keV in the full field lightcurve and excluded.
- A continuous exposure of 70.4 ks used for both spectral and temporal analysis.
- We extracted source and background spectra from a source-centered circular region of radius 36" and an off-source region, respectively, and using single and double events with FLAG=0.

Unfolded Spectrum



- Fitted by an empirical model consisting of absorbed dual-Comptonisation components and some prominent lines and edges.
- There is intrinsic neutral absorption, a soft excess feature, multiple Iron line emissions, plus edges and absorption features, probably due to a warm absorber.
- The complex Iron line features indicate the possibility of a complex blurred reflection component.
- With a high energy spectral index of ~1.7, moderate intrinsic absorption and soft excess, the spectrum of Mrk 1040 is typical of AGNs of its class.

Hardness Ratio

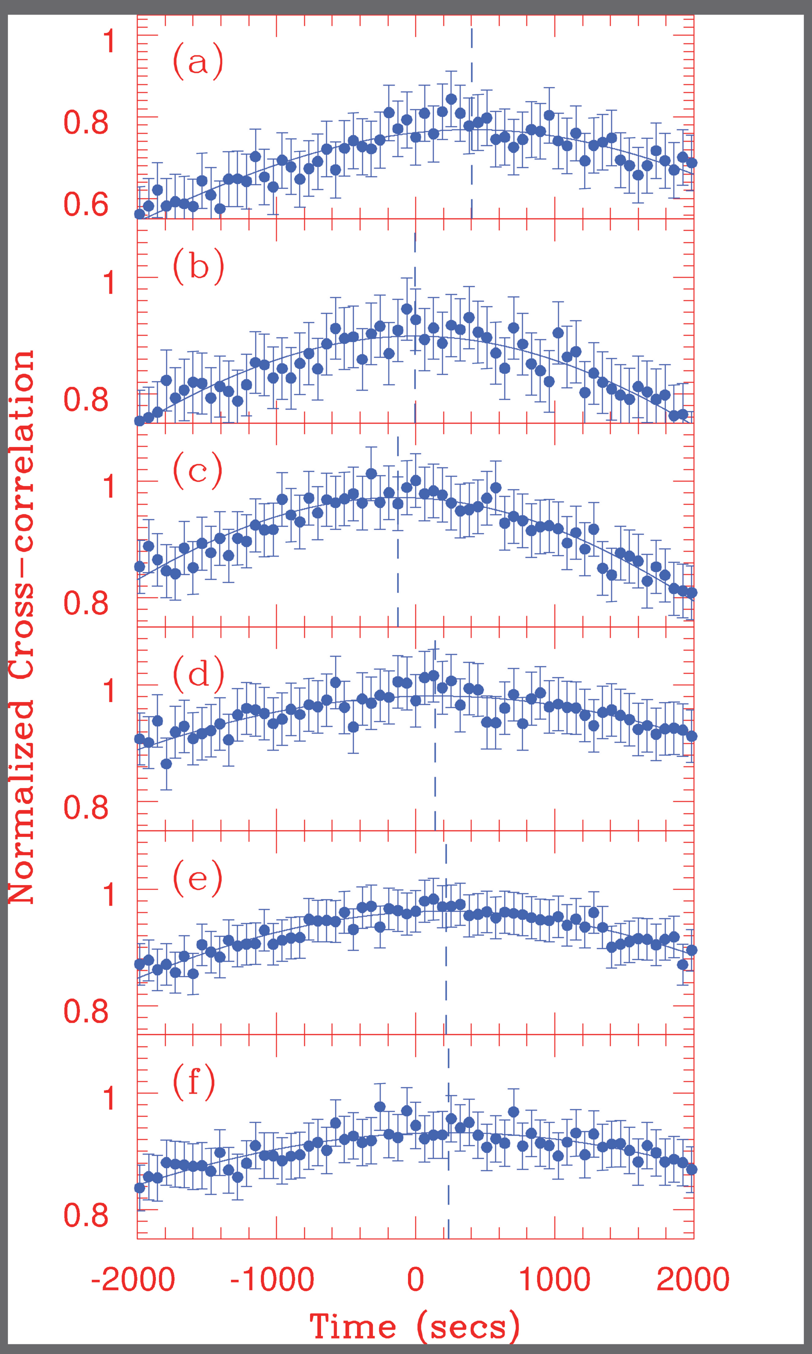


The top panel shows the background subtracted X-ray 640 s binned lightcurves of Mrk 1040 in soft, 0.2-2.0 keV (circles) and hard, 2.0-10.0 keV (triangles) energy bands.

- Bottom panel shows that the hardness ratio significantly decreases from ~ 0.6 to ~ 0.45 indicating spectral evolution of the source on long (~10^5 s) timescales.
- Variation in the hardness ratio is clearly uncorrelated with the variability of the lightcurves.
- Hence its origin cannot be due to changes in the absorption medium which would effect primarily the soft band.

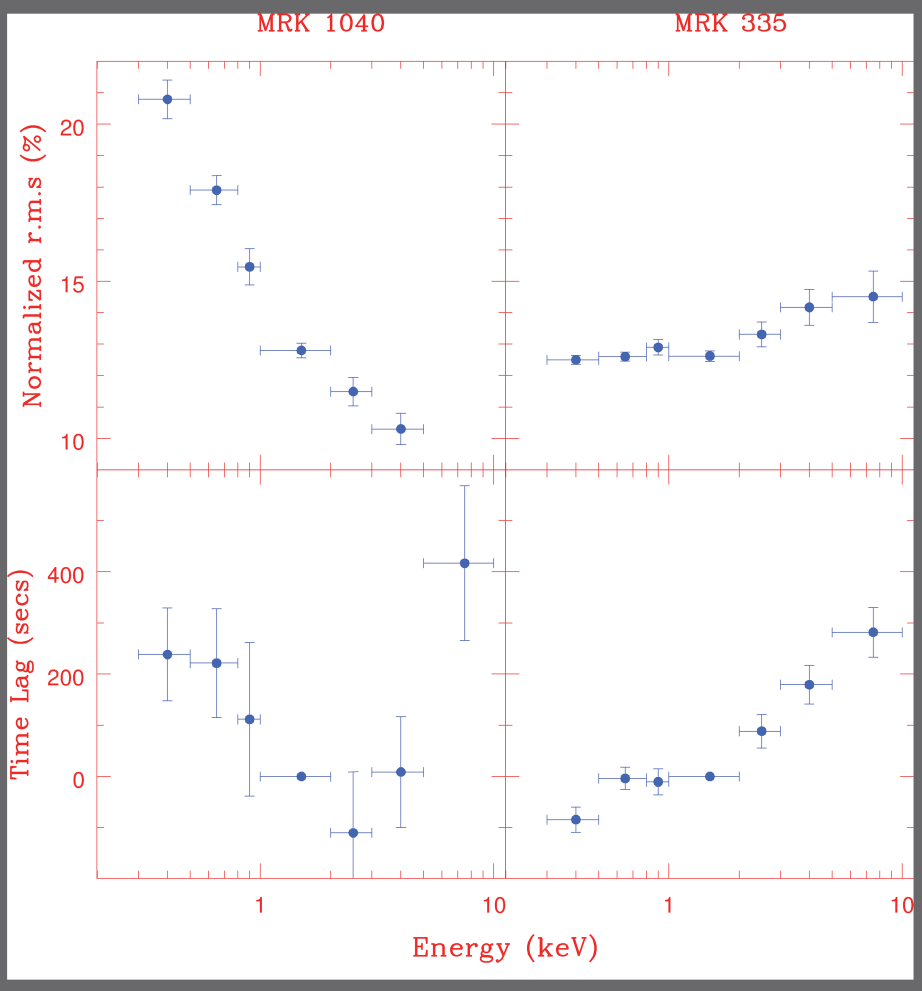
Cross-Correlation Analysis

- XRONOS task "crosscorr", norm=2, "slow" mode.
- 64 s binned lightcurves.
- Well correlated with cross-correlation function peaking at values > 0.8.
- We fit functions with a Gaussian and obtain the best-fit centroid.



The cross-correlation function for different energy bands. The reference energy band is 1.0-2.0 keV. From top to bottom: (a) 5.0-10.0 (b) 3.0-5.0 (c) 2.0-3.0 (d) 0.8-1.0 (e) 0.5-0.8 (f) 0.3-0.5. The solid line is the best fit Gaussian curve and the dashed vertical lines mark the centroid.

RMS & Time lag vs Energy



R.M.S variability and the time lag as a function of energy for Mrk 1040 (left) and Mrk 335 (right)

- Below 2 keV, the time lag decreases with energy which means that there is a soft lag.
- For energies > 2 keV, the time-lag increases with energy as in the regular case of hard lags.
- We compare with the other source Mrk 335, rms and time lag computed using an identical analysis of its similar length XMM-Newton observation.
- Although the rms varies differently with energy, the time lag for Mrk 335 increases with energy (i.e. hard lags).

Discussion

- Soft lags could be possible as a result of Comptonisation, where hard X-rays may impinge back on the input photon producing region and hence affect the soft photons.
- Alternatively, it could be due to reverberation of a complex gravitationally blurred reflection component to variations of the continuum.
- Both models can be tested and their parameters tightly constrained to self-consistently explain the lag and r.m.s versus energy as well as the photon spectrum.
- Note however, that for both scenarios, the time lag should not be frequency dependent.

References

a. Tripathi et al. 2011, ApJL, 736, L37
b. Fabian et al. 2009, Nature, 459, 540
c. McHardy et al. 2004, MNRAS, 348, 783
d. Nowak et al. 1999, ApJ, 510, 874
e. Cui, W. 1999, ApJ, 524, L59