A Global View of X-ray time lags in Seyfert Galaxies

Erin Kara
ekara@ast.cam.ac.uk

Collaborators:
Will Alston, Andy Fabian, Ed Cackett, Phil Uttley, Abdu Zoghbi, Giorgio Matt, Andrea Marinucci, Dom Walton, Fiona Harrison, Michael Parker
Reverberation with XMM-Newton

The detectability of reverberation lags is based on three parameters: the flux of the source, the amount of variability, and the amount of data we have available. In Table 1, we highlight the exposure, 2–10 keV flux and 2–10 keV excess variance from 10 ks bins for the eight sources with Fe K lags. We compare these sources with other variable AGN to illustrate the detectability of reverberation lags. We compile a sample of variable AGN that are common between the González-Martín & Vaughan (2012) sample (which provides the 2–10 keV luminosity and the XMM-Newton exposure as of the data release), and the Ponti et al. (2012) sample (which provides the 2–10 keV flux).
Reverberation with NuSTAR

Swift J2127.4+5654

Spectrum

ratio data/model

Energy (keV)

Lag (s)

EK+15, see also Zoghbi+14
3.1.3 Further evidence for reverberation

Confirmation of the reverberation picture came from examining the differences in the lags at lower frequencies, where the 'hard lag' is observed (Zoghbi et al. 2011). As discussed above, the lag-energy spectrum at high frequencies shows a clear signature of reflection in the iron K lag, however, as we probe lower frequencies, the lag behaves in a very different way (See the low and high frequency lag-energy spectra of Ark 564 in Fig. 11). At low frequencies, instead of showing a downward trend, where the soft band is found to lag the continuum, we see the opposite. The lag increases with energy, with no clear spectral features. This is consistent with the hard lag found in black hole binaries, and confirms our picture that the high-frequencies show lags caused by reflection, while the hard lags are some separate process, unrelated to reflection. Furthermore, the hard lag has been found in NGC 6814, a source that is well described by just an absorbed power law, with very little neutral reflection (Walton et al. 2013). As expected, there is no soft lag in this source, but there is still a hard lag, suggesting that the hard lag is due to changes in the continuum, and not by reflection.

We are now delving into a regime where we can begin to disentangle the many contributions to the reverberation lag, i.e. we can isolate different light paths, and thus map the geometry of the source and inner flow. In IRAS13224-3809, we find that the reverberation lag is dependent on flux, which changes with the geometry of the corona (Kara et al. 2013b). At low-flux intervals, we are seeing the hard lag.
the dependence on the mass accretion rate according to the scaling relationship provided by McHardy et al. (2011, 2013). The fit is reproducible in the same interval. However, the low-frequency modes can still be produced in the simulated data by adding the proper level of Poisson noise variability power, which dominates this effect resulting in a drop to zero-value at high frequencies, where the intrinsic variability power of the source decreases. As previously mentioned, the zero-lag level of the coherence function is to produce a deviation of the coherence function from the statistical noise. As previously mentioned, the frequency spectrum above and below the zero-lag level is due to different variability processes. We accounted for it by adding Poisson noise contribution has been accounted for by adding a constant level of Poisson noise in the standard deviation of the mean count rate (the latter being estimated from the best fit). Fe K lag amplitudes), the lags have been scaled such that the lag between the Fe K lags). Since the initial discovery in NGC 4151, iron K lags have been found to scale with black hole mass, a result consistent with the kinematics of the inner accretion flow, as it encodes spectral and temporal properties of the X-ray emitting region. The dashed lines in the right panel represent different values of intrinsic coherence as measured from the data. The current sample of iron K lags plotted with the figure of merit, which has a value comparable to the Poisson noise component. Poisson noise variability is to produce a deviation of the coherence function from the statistical noise. As previously mentioned, the zero-lag level of the coherence function is to produce a deviation of the coherence function from the statistical noise. As previously mentioned, the frequency spectrum above and below the zero-lag level is due to different variability processes. We accounted for it by adding Poisson noise contribution has been accounted for by adding a constant level of Poisson noise in the standard deviation of the mean count rate (the latter being estimated from the best fit).
A Global View

The Sample

- All public XMM-Newton observations of Seyfert Galaxies
- Must be >40 ks exposure
- Must have some variability...
A scatter plot showing the relationship between 0.3-10 keV total counts on the x-axis and 0.3-10 keV F$_{\text{var}}$ on the y-axis.
13 confirmed iron K lags
13 confirmed iron K lags
Tentative iron K lags

**Best case**

**Worst case**
26 total iron K lags
Lag-mass relation

assuming disc inclination of 45 deg
Reverberation lag—mass relation

Black hole mass ($M/M_\odot$)

Iron K amplitude (s)

$9_\text{rg}$

$6_\text{rg}$

$1_\text{rg}$
26 total iron K lags
First broad iron line

evidence for light bending?

Tanaka+95, Fabian+03, Vaughan+03, Miniutti+04, Brenneman+06, Chiang+11, Miyakawa+12, Marinucci+14, …
MCG-6-30-15

[Figure 9.]

8 frequency range (b) from [1 of index 0 to describe the white noise). We see from the data to a simple power law model (with a power law similar between the two, but there are some differences in frequencies we are dominated by white noise. The slope is overall normalisation of the new observation is less at all frequencies in the bin. Qualitatively, we see that the combination of two frequency bins so that there were at least 10 frequency samples in the bin. The high-frequency lag-energy spectrum for frequency range (a) from [0–3] keV and 3–5 keV (same as in Fig. 6), now probing higher frequencies. The old observations are shown in red on the left, and the new are shown in blue.

[Figure 10.]

The lag-frequency spectrum between 0.3–1.6 keV and 1.6–5 keV (same as in Fig. 6), now probing higher frequencies. The old observations (with more high-frequency changes, denoted (a) and (b), through their lag-energy spectra. From this ratio plot, if we assume a twice broken powerlaw model for both the old and new observations, we fit a high-frequency break at 3 × 10^-4 Hz for the new observation. The low-frequency range (b) from [1.7-3] × 10^-3 Hz on the right. At such high frequencies we are close to the level of the noise, and so we cannot put strong constraints on the shape of the lag-energy spectrum, but the overall shape is similar to what we see in NLS1s. There is no clear Fe K lag, though there is an increase in both frequency bands above 3 keV, and possibly a second peak at around 7 × 10^-3 Hz, and a second peak at around 5–8 × 10^-3 Hz. The new observation shows a clear peak starting at around 2–4 × 10^-4 Hz, and possibly a second peak at around 7 × 10^-3 Hz, and a second peak at around 5–8 × 10^-3 Hz. The old observation shows a clear peak starting at around 2–4 × 10^-4 Hz, and possibly a second peak at around 7 × 10^-3 Hz, and a second peak at around 5–8 × 10^-3 Hz.
mean spectrum

covariance spectra:
spectrum contributing to lags

uncorrelated and/or
non-varying component
Mrk 766

Recent 100 ks NuSTAR observation
Parker, EK+ in prep

Frequency-resolved rms spectra
Arevalo+08
Conclusions

• Global study of time lags in Seyferts is ongoing

• Reverberation (confirmed+tentative) found in 26/45 sources

• Most non-detections clearly due to lack of statistics, but two sources—MCG-6-30-15 and Mrk 766—have “should” show reverberation

• Further evidence for light bending?