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The X-ray timing properties of the NLS1s IRAS 13224-3809 and I Zw 1

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Abstract. We discuss the timing properties of two Narrow-Line Seyfert 1 galaxies, IRAS 13224–3809 and I Zw 1, as observed with *XMM-Newton*. In IRAS 13224–3809 we find the rapid and persistent variability we have come to expect from this object; but no giant flaring events. Examining the light curves in various energy bands we are able to resolve a lag between the 3–10 keV and 0.3–0.8 keV bands. In addition, we are also able to determine a lag between the hardness ratio and light curve implying flux-induced spectral variability. I Zw 1 displays a strong hard (3–12 keV) flare during its observation. The flare appears to induce spectral variability, showing spectral hardening to be occuring as the flare intensifies. A detailed examination suggests that the spectral variability is most likely due to an increase in the 3–12 keV flux relative to the soft flux during the flare. The timing results are consistent with the flare originating in the accretion disc corona.

Key words. galaxies: active – galaxies: individual: I Zw 1, IRAS 13224–3809 – X-rays: galaxies

1. Introduction

As part of the Guaranteed Time Programme to study Narrow-Line Seyfert 1 galaxies (NLS1) with *XMM-Newton*, seven objects have been observed. In this presentation, we would like to discuss the timing properties of two important class members: IRAS 13224–3809 and I Zw 1.

During the *ROSAT* and *ASCA* era, IRAS 13224–3809 displayed some of the strongest X-ray variability ever observed in a radio-quiet AGN. Variability was persistent and rapid, and quite frequently (every few days) giant-amplitude flaring events, in which the count rate increased by a factor as high as 60, were observed (e.g. Boller et al. 1997). The 0.3–10 keV spectrum can be modelled by a strong, thermal soft-excess superimposed on a steep power-law continuum. In addition, there is a sharp, sudden flux drop at ~ 8 keV, but no significant emission line. The sharp deep edge and the absence of an emission line led Boller et al. (2003) to a partial-covering interpretation (Holt et al. 1980).

In contrast, the 0.3–10 keV spectrum of the prototype NLS1, I Zw 1, is steep and power-law in nature. The soft excess is weak and the low-energy spectrum, in general, is complicated, showing a number of emission and absorption features. Strong Fe Kα emission is also prevalent (Gallo et al. 2004).

In this presentation we will discuss the X-ray timing properties of IRAS 13224–3809 (Gallo et al. 2003) and I Zw 1 as observed

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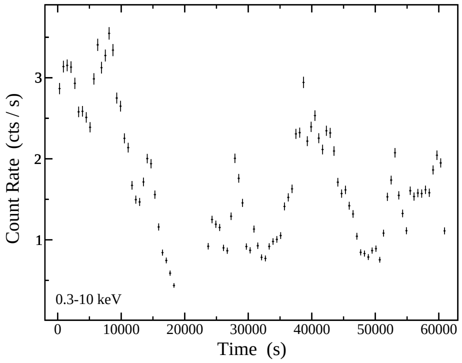

Fig. 1. The 0.3–10 keV light curve of IRAS 13224–3809 in 600 s bins.

with *XMM-Newton*. IRAS 13224–3809 was observed January 2002 for ~60 ks, and I Zw 1 was observed June 2002 for ~20 ks. We will discuss only the EPIC-pn data here; however, the MOS data were analysed and found to be entirely consistent.

2. IRAS 13224–3809

As with previous X-ray observations, IRAS 13224–3809 displayed the rapid and persistent variability that we have come to expect from it. The flux varied by a factor of eight over the course of the observation; however, unlike previous observations, no giant amplitude flaring events were detected (Fig. 1).

Light curves were created in seven energy bands between 0.3–10 keV, and each was examined for variability. All of the light curves were determined to be significantly variable ($> 3\sigma$) and correlated with each other. As such, it was natural to search for lags between the various energy bands by calculating cross-correlation functions (CCFs). Most of the CCFs were symmetric and consistent with no time delay; however, when the 0.3–0.8 keV band was cross-correlated with higher energy bands the CCF profiles became broad and somewhat flat-topped with a noticeable asymmetry toward longer lags. The most significant lag measured was between the 3–10 keV band and 0.3–0.8 keV band, with the hard band following the soft band by 460 ± 175 s (Fig. 2 left panel).

However, careful inspection of the light curves indicate that the hard X-rays do not always lag the soft; in some cases it appears that the reverse is true. To investigate further, we cut the soft and hard light curves into 12 segments, each 4500 s in duration with 50% overlap between them (so only every other segment is independent). We then computed the CCF in each of these shorter light curves. The results confirmed our visual suspicion — in some cases the hard X-rays lead the soft while at other times it lags (Fig. 2 right panel). The lags span approximately −1100 s to +1400 s and appear to be mildly correlated with the light curve in the sense that when the count rate is high, the hard lags the soft, and when the flux is low, the soft follows. The lag is positive more often than negative in our light curves, explaining why the full CCFs show a slight positive lag.

From the existing light curves seven hardness ratios were calculated. All were found to be variable at $> 2.6\sigma$. In addition, the overall trends in the hardness ratio variability curves were similar to the variability in the light curves. We examined the apparent correlation between the hardness ratio and the light curve by calculating the CCF between the 0.3–1.5 keV light curve and the 0.8–1.5 keV to 0.3–0.8 keV hardness ratio variability curve. The cross correlation is presented in Fig. 3, and shows that the hardness ratio curve lags behind the light curve by 2000^{+1500}_{-2000} s.

3. I Zw 1

The most obvious feature in the I Zw 1 light curve is a flaring event after ~10 ks, in which the count rate increased by 40% in less than ~2500 s. Indeed, except for this flaring event, the remainder of the light curve is surprisingly serene (for a NLS1) with fluctuations of only ~10%.

Examining the light curve in various energy bands we determined that the flare is concentrated in the hard 3–12 keV band. While the count rate in the 0.3–0.8 keV band increases

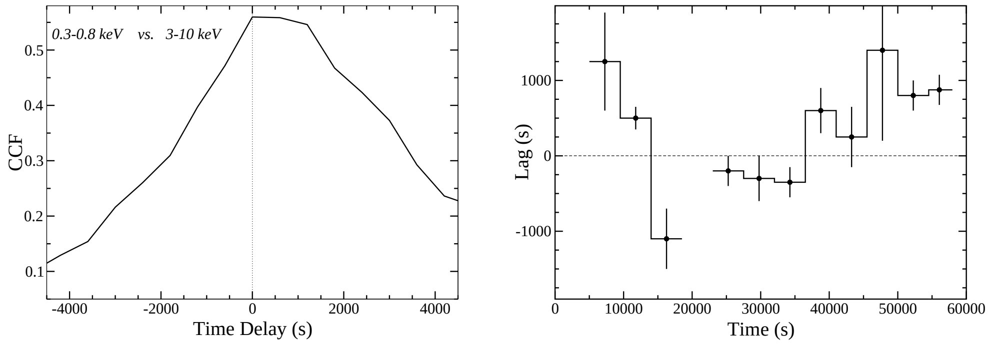

Fig. 2. Left panel: The CCF between the 3–10 keV and 0.3–0.8 keV light curves. The hard X-rays follow the soft by 460 ± 175 s. Right panel: The lag measured between the 3–10 keV and 0.3–0.8 keV light curves, in 4500 s intervals, over the duration of the observation. The lag alternates in such a way that at times the soft band leads the hard (positive lag), and at other times, the hard leads the soft (negative lag).

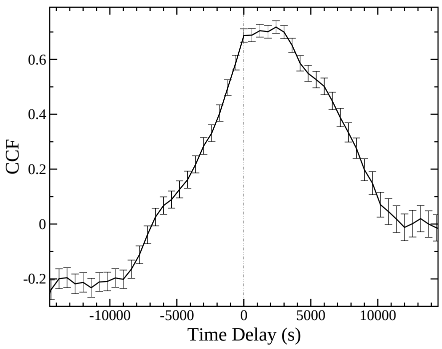

Fig. 3. The cross correlation of the H=0.8–1.5 keV and S=0.3–0.8 keV hardness ratio variability curve and the light curve. The CCF indicates a delay between the two curves, such that, the hardness ratio curve lags behind the light curve.

by only ~20% during the flare, the 3–12 keV count rate doubles (Fig. 4 left panel).

No leads or lags are detected between the various energy bands indicating that the light travel time between various emission regions is very small (> 100 s).

A hardness ratio variability curve indicates that spectral hardening is occuring, but only during the flaring event (Fig. 4 right panel). In fact, during the non-flare periods, the hardness ratio variability curve is consistent with a constant. Deeper investigation into the nature of the spectral variability suggests that the spectral hardening is due to an increase in the hard flux relative to the soft emission, rather than to a change in the intrinsic shape of the continuum (e.g. a pivoting of the power-law).

4. Discussion

4.1. IRAS 13224-3809

Perhaps the most interesting features found in the IRAS 13224-3809 observation were the lags between light curves in different energy bands and between light curves and hardness ratios. It is interesting to compare this result to those of Galactic black hole candidates (GBHC). Most GBHC do show a lag between the hard and soft X-rays, where the hard follow the soft by a few ms. Körding & Falcke (2003) suggest that the time lags can arise from a pivoting of the power-law. In order to create the hard lags the flux changes slightly before the power-law index is changed. Along with the lags presented in Figures 2 and 3 we are in fact also seeing changes in the photon index. However, with the current observation, it is not clear whether the spectral hardening is

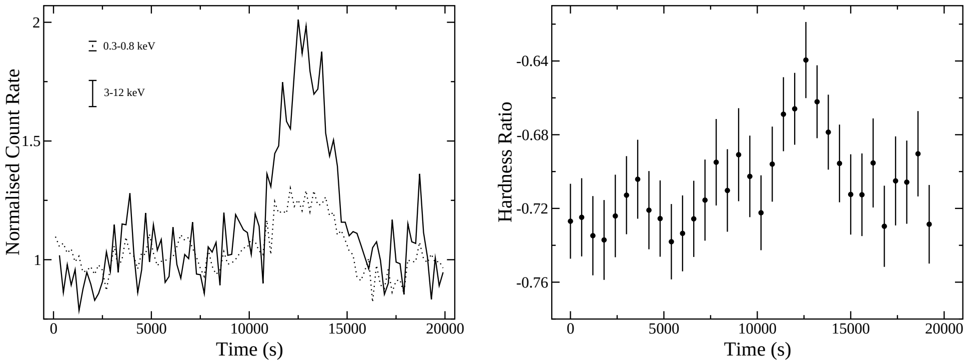

Fig. 4. Left panel: The 0.3–0.8 keV (dotted curve) and 3–12 keV (solid curve) normalised light curves. The vertical lines in the top left of the graph indicate the size of the average error bars. Right panel: Hardness ratio variability curve for H=2–12 keV and S=0.3–2 keV. Spectral hardening is observed precisely when the hard X-ray flare is occurring.

occuring as a result of the partial-covering phenomenon or if it is due to a pivoting power-law.

4.2. *I Zw 1*

The detection of a hard X-ray flare and spectral hardening during the flare are entirely consistent with theories of an accretion-disc corona which is being heated by magnetic reconnection. The apparent instantaneous response of the lower-energy emission mechanisms to the hard X-ray flare suggests that the light travel-time between the emission regions is < 100 s. The weakness of the flare at low X-ray energies may be indicating that the seed photons for the Comptonisation component are not coming from the 0.3–1 keV band, but probably from lower UV energies. This observation could perhaps be useful in constraining Comptonisation models.

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