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Energy dependent variability as a diagnostic of the ultraluminous state: key results

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Abstract. The nature of ultraluminous X-ray sources is still the subject of much debate. However, it seems increasingly likely that many are in a new super-Eddington accretion state, and there may be some spectral state progression with increasing Eddington ratio. Here, we present some key results from a sample of ULXs observed by *XMM-Newton*, composed of the highest count rate EPIC data. We use this to gain new physical insights, and break some of the degeneracies inherent in spectral studies, by systematically examining the short-term, energy dependent temporal properties of ULXs. We show that the faintest ULXs typically have disc-like X-ray spectra, whilst the spectra of many brighter sources appear dominated by optically thick coronae, or a soft component consistent with a wind, with variability properties implying this latter distinction may be an inclination dependent effect.

1. Introduction

Ultraluminous X-ray sources (ULXs) are non-nuclear X-ray point sources in external galaxies, with X-ray luminosities in excess of 10^{39} erg s^{-1}. The emerging consensus is that the majority of ULXs are probably powered by accretion at around and exceeding the Eddington limit, onto black hole primaries with masses $\lesssim 80M_{\odot}$, which may form in regions of low metallicity (Zampieri & Roberts 2009; Belczynski et al. 2010). Gladstone et al. (2009) identify three types of super-Eddington ULX spectra, which they speculate are in a sequence with increasing accretion rate: around the Eddington limit ULXs have a broadened disc-like spectrum; at higher accretion rates a two component spectrum emerges, which initially peaks in the hard component (ultraluminous state; UL); then, the balance of the two components shifts towards the softer component at the highest accretion rates (extreme ultraluminous state; ex. UL). At the highest accretion rates, the soft component may be associated with a wind (Poutanen et al. 2007), and the hard component with a Comptonised corona (Gladstone et al. 2009) or the inner hot disc (Middleton et al. 2011).

2. Key results from a new study

Here we briefly describe a few key results from our new *XMM-Newton* study of a sample of ULX; a thorough account of the study will be presented in Sutton et al. (in prep.).

Firstly, we used energy spectra as the basis of an empirical method to classify each observation as having a broadened disc, UL or ex. UL spectrum. Next, we extracted a

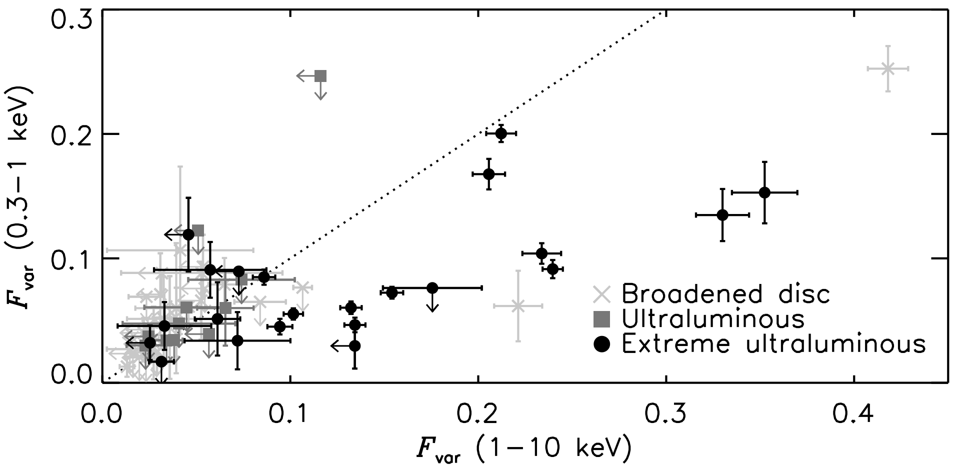

Fig. 1. Fractional variability from the 1–10 keV and 0.3–1 keV energy bands plotted against each other. Fractional variability was extracted from light curves with 200s temporal binning. Observations of each of the three spectral types of ULXs are clearly identified. The dotted line corresponds to the two variability components being equal.

few statistics to characterise each observation, namely: deabsorbed broad-band (0.3–10 keV) luminosity; spectral hardness (approximated as the ratio of the 0.3–1 and 1–10 keV deabsorbed fluxes); and fractional variability in three bands (0.3–10, 0.3–1 and 1–10 keV) from light curves with 200s temporal binning. Notably, we find that the ex. UL observations are spectrally softer than the UL observations, but occur over a similar range of X-ray luminosities. However, unlike the UL observations, many of the ex. UL observations are highly variable, with the variability being significantly stronger in the hard-band than the soft band (Fig. 1).

The spectral and timing properties that we see in the UL and ex. UL observations appear to be inconsistent with these two spectral types being degenerate in X-ray luminosity alone. Rather, they suggest that the inclination of the ULX system plays a significant role in determining spectral state at luminosities above $\sim 3 \times 10^{39}$ erg s^{-1}. One possible geometry is illustrated in the toy model of Middleton et al. (2011; their Fig. 8). Here, the hard X-rays originate from close to the centre of the disc, and the soft X-rays from the photosphere of a massive outflowing, funnel shaped wind. Then, the balance of the two components can depend on the angle at which the system is observed: face on we see geometrically beamed hard emission, so an UL spectrum; at higher inclinations the wind contributes a higher proportion of the flux, so we see a ex. UL spectrum. Also, if the edge of the wind is clumpy, at certain inclinations it can result in variable obscuration of the line-of-sight to the central regions, imprinting the hard variability we see in the ex. UL state.

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