Suzaku observations of ultraluminous X-ray sources in nearby galaxies

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Ultraluminous X-ray sources (ULXs) are extra-galactic X-ray sources for which the observed luminosity in the 0.3 − 10 keV band reaches or exceeds the Eddington limit for a ~10 $M_\odot$ black hole ($L_X > 10^{39}$ erg s^{-1}). Recent results indicate that the majority of ULXs are stellar remnant black holes accreting material at or above the Eddington rate, rather than sub-Eddington accretion onto intermediate mass black holes. However, precisely how these ULXs accrete material at a super-Eddington rate remains an open question. In this work, we present the results of an analysis of 16 high quality spectra (> 7000 counts) extracted from a sample of 10 ULXs detected in nearby galaxies (D < 4.2 Mpc), using Suzaku data. We confirm that these high quality datasets require two component models to provide an adequate description of the spectra. We examine a range of physical models to describe the data. Using a multicolour disc blackbody (MCD) plus Comptonised corona model allows the properties of the putative corona constituting the hard component to be investigated. Alternatively, fitting by a blackbody (BB) plus slim disc model allows a simple calculation of an outflowing wind radius, assuming a photosphere at the base of the wind provides the soft component. Finally, modelling the hard spectral component using a Kerr black hole model, we demonstrate that the mass of the black hole powering these ULXs can be estimated and is found to be relatively low (~ 10 $M_\odot$).

Spectral analysis

***Table 1.** The ULX sample and its properties.*

ULXs	L_X [a] (× 10^{39} erg s^{-1})	Spectral state[b]	M_{BH} [c] ($M_\odot$)
M33 X-8	1.5	Disc	4.5 ± 0.3
NGC 1313 X-1 Oct 2005	20.5	Disc	5.1 ± 0.3
NGC 1313 X-1 Dec 2008	5.7	HUL	
NGC 1313 X-2 Oct 2005	5.7	Disc	< 3.3
NGC 1313 X-2 Dec 2008	1.6	HUL	
IC 342 X-1 Aug 2010	5.5	Disc/HUL*	< 3.3
IC 342 X-1 Mar 2011	5.6	HUL*	
IC 342 X-2 Aug 2010	11.6	HUL*	17.9 ± 0.8
IC 342 X-2 Mar 2011	7.7	HUL*	
NGC 2403 X-1	2.9	Disc	15.7 ± 1.1
2XMM J073702.1+653935	0.79	Disc	< 3.6
M81 X-6 May 2006	4.2	Disc	22.3 ± 1.0
M81 X-6 Sep 2011	5.0	Disc	
Holmberg IX X-1 Apr 2012	12.5	HUL	10.7 ± 0.2
Holmberg IX X-1 Oct 2012	13.9	HUL	
Circinus XMM2	5.5	Disc	8.8 ± 1.9

[a]Source luminosity in the 0.3 – 10 keV band. [b]The ULX spectral state as defined by Sutton et al. (2013), i.e. broadened disc (Disc), hard ultraluminous (HUL) or soft ultraluminous (SUL). [c]The mass of black hole powering the ULX (see below). *Highly absorbed ULXs, the classification may be uncertain.

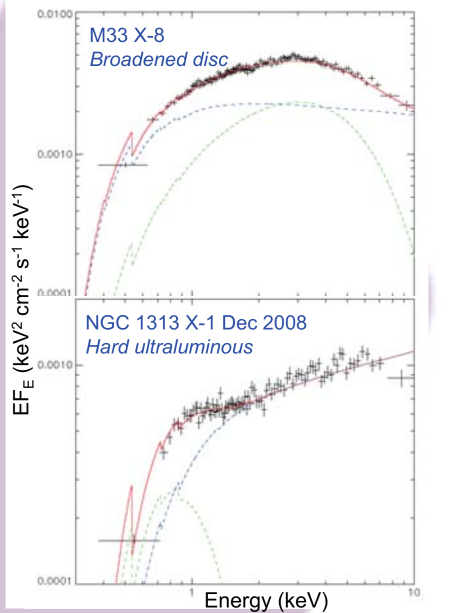

***Figure 1.** Examples of ULX spectra fitted by MCD plus power-law model.*

We begin the analysis by modelling the ULX spectra with a simple, double component model - MCD plus power-law. The model works effectively to describe the spectra. The fitting result is used to classify all ULX spectra into three categories following the method of Sutton et al. (2013): broadened disc (Disc), hard ultraluminous (HUL) and soft ultra luminous (SUL), as shown in column 3 of Table 1.

Mass of black hole powering ULXs

We start by assuming that the soft spectral component represents the emission from the photosphere at the base of an outflowing wind; and that the hard emission is from the innermost parts of the accretion disc. We model these two components using a BB model and a relativistic accretion disc model (KERRBB). This provides a good fit, and estimates the black hole masses as ~ 3 – 22 $M_\odot$ (column 4 of Table 1), implying that ULXs are powered by stellar mass black holes. We note that the black hole spin is unconstrained in this model fitting.

Disc plus comptonisation model

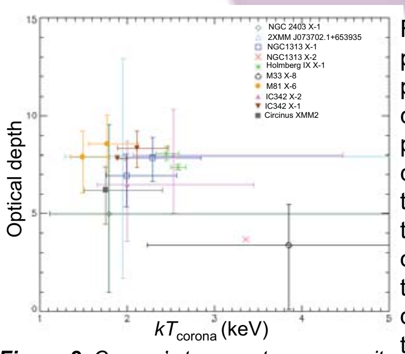

***Figure 2.** Corona's temperature versus its optical depth (the seed photon temperature is free from the disc temperature).*

Fitting the data by a MCD plus comptonisation model – presuming that the hard component is instead provided by a comptonising corona – a similar result to the former studies is found; the model infers a cool and optically thick corona whilst the soft component is a cool disc (kT_{disc} ~ 0.2 keV). A temperature – optical depth anti-correlation is present if we tie the corona's seed photon temperature to the disc temperature - similar to previous results (e.g. Vierdayanti et al. 2010, Pintore et al. 2012, 2014). However, the anti-correlation disappears when the seed photon temperature is untied (Fig. 2), suggesting an artificial relationship.

Outflowing wind?

Alternatively, we can model the spectra by a BB plus slim disc model. Assuming that slim accretion disc provides the hard component, we are able to estimate a provisional size for the outflowing wind by calculating a surface area of the (unabsorbed) BB component we use to model the soft emission. We convert the surface area into a wind radius by assuming spherical geometry for the wind with 80% covering fraction. The results are shown in Fig. 3. Discounting the data points associated with IC 342 X-2 (for which the absorption correction is both large and so very uncertain), there appears to no strong relationship between putative wind radius and luminosity. This does not support the L ~ $T^{-3.5}$ relation reported for some ULXs (e.g. Kajava & Poutanen 2009).

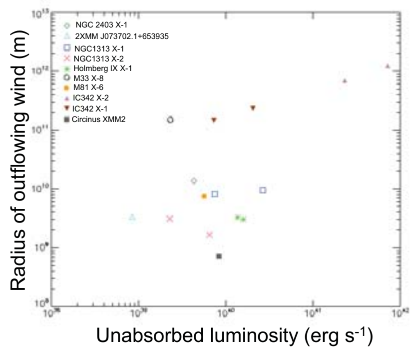

***Figure 3.** The radius of outflowing wind against ULX luminosity.*

References

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