A detailed X-ray characterisation of ULXs

Andrew D. Sutton[1]*, Matthew J. Middleton[1], Timothy P. Roberts[1]

[1]Department of Physics, Durham University, South Road, Durham, DH1 3LE

Durham University

We present the initial highlights of work aimed at providing a holistic view of the X-ray properties of ultraluminous X-ray sources (ULXs), based on *XMM-Newton* data. This combines the diagnostic power of three analyses for each set of data, namely energy spectra, power spectral densities (PSDs) and RMS spectra, to provide the clearest view of the behaviour of these extraordinary objects. Here we show some initial highlights of this work, and discuss how these results limit physical models for the X-ray emission of ULXs, and the nature of their compact accretor.

NGC 4395 X-1 (D[1] = 4.61 Mpc N_H[2]= 1.35×10^{22} cm^{-2})					
Obs Id	Date	Off axis angle	Good time[3]	Number of counts	0.3-10keV flux
	(yyyy/mm/dd)	(arcmin)	(ks)		(ergcm^{-2} s^{-1})
0112521901	2002/05/31	4.13	5.8	1550 ± 40	3.7×10^{-13}
0112522701	2003/01/03	2.26	5.9	1730 ± 40	3.7×10^{-13}
0142830101	2003/11/30	1.88	61.3	10800 ± 100	3.7×10^{-13}

Table 1 Details of *XMM-Newton* EPIC observations of NGC 4395 X-1. [1]Karachentsev et al. (2003), [2]Dickey & Lockman (1990), [3]the good time after subtraction of flaring for the PN detector.

NGC 5204 X-1 (D[1] = 4.65 Mpc N_H[2] = 1.38×10^{22} cm^{-2})					
Obs Id	Date	Off axis angle	Good time[3]	Number of counts	0.3-10keV flux
	(yyyy/mm/dd)	(arcmin)	(ks)		(ergcm^{-2} s^{-1})
0142770101	2003/01/06	1.11	10.9	12400 ± 100	1.7×10^{-12}
0405690101	2006/11/15	1.19	8.4	18700 ± 100	2.6×10^{-12}
0405690201	2006/11/19	1.08	19.3	32800 ± 200	2.4×10^{-12}
0405690501	2006/11/25	1.13	16.0	19600± 100	2.0×10^{-12}

Table 2 Details of *XMM-Newton* EPIC observations of NGC 5204 X-1. [1]Karachentsev et al. (2003), [2]Dickey & Lockman (1990), [3]the good time after subtraction of flaring for the PN

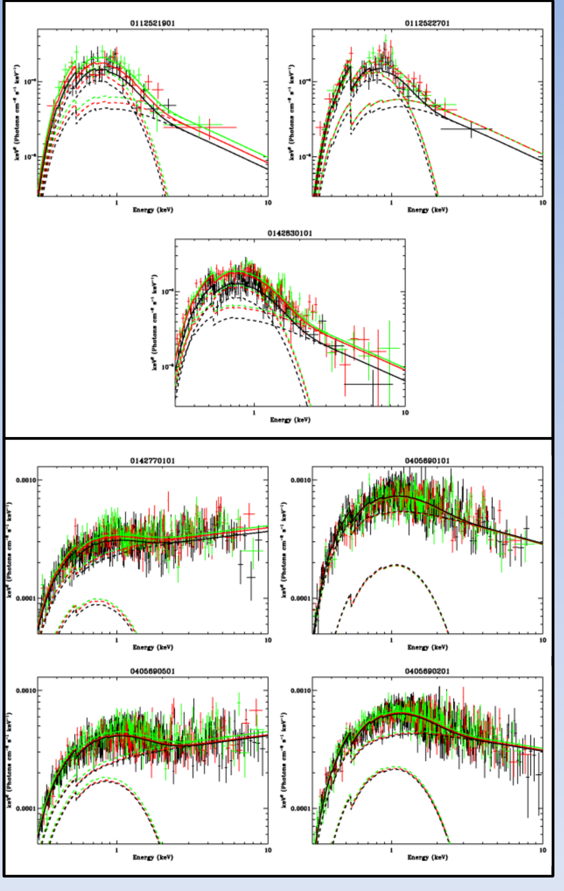

Fig. 1 *XMM-Newton* EPIC spectra of NGC 4395 X-1 (*top panel*) and NGC 5204 X-1 (*bottom panel*). The spectra are arranged clockwise from top left in the order shown in Tables 1 and 2. Spectra are fitted with an absorbed multi-colour-disc plus power-law model (diskbb + powerlaw in XSPEC).

As part of a larger *XMM-Newton* archival study, detections of two known ULXs - NGC 4395 X-1 and NGC 5204 X-1 - with in excess of 1000 counts were examined using three complementary diagnostic tools: energy spectra, RMS spectra and Power Spectral Density (PSD). The observations utilised are detailed in Tables 1 and 2. Data were reprocessed using epproc and emproc in SASv10, and X-ray spectra were extracted using xmmselect, then analysed using XSPEC 12.6.0. Multiple lightcurves were also extracted on timescales ~100 s with various energy binning, in order to test for constrained RMS. Broad band 0.3-10 keV lightcurves were extracted for each observation with temporal binning of 10 s, then split into at least 5 equal length periods of continuous good time per observation, from which a mean PSD was obtained.

Energy spectra were fitted with a doubly absorbed multi-colour-disc plus power-law model (Fig. 1), with one absorption component fixed to the galactic value (Dickey & Lockman 1990), and the other free to vary, to model any intrinsic contribution. The two component model is formally acceptable (i.e. not rejected at the 2σ level) in observations 0112521901 and 0112522701 of NGC 4395 X-1, plus 0142770101, 0405690201 and 0405690501 of NGC 5204 X-1, and is marginally acceptable (better than 3σ significance) in observation 0405690101 of NGC 5204 X-1. However, the two component model was rejected at greater than 3σ significance in observation 0142830101, although we note that Stobbart et al. (2006) showed that an additional MEKAL component significantly improved spectral fits to this particular observation, due to a spectral feature at ~1 keV. The recovered disc temperatures are typically cool for both sources, they vary in the range of 0.18 – 0.22 keV between observations of NGC 4395 X-1, and 0.26 – 0.36 keV for NGC 5204 X-1. Intrinsic absorption columns are ~1×10^{22} cm^{-2} in both of the sources.

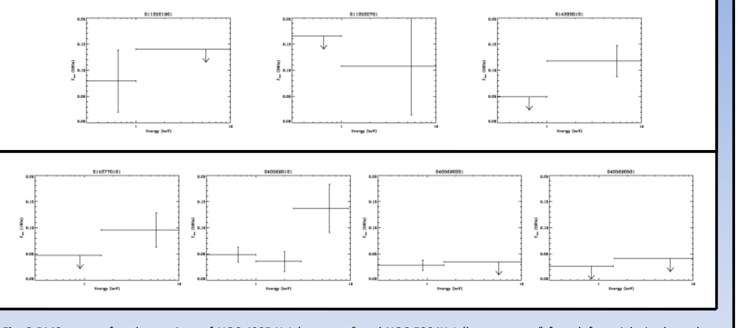

Fig. 2 RMS spectra for observations of NGC 4395 X-1 (top *panel*) and NGC 5204X-1 (bottom *panel*) from left to right in the order shown in Tables 1 and 2. Variability is calculated over timescales 100 - 500 s depending on the total good time available and the count rate of the source. Upper limits and errors shown correspond 1σ significance. Significant variability (≥ 2.9 σ) is detected in the high energy emission in observation 0142830101 (1-10 keV) of NGC 4395 X-1 and observations 0142770101 (1.5-10 keV) and 0405690101 (3-10 keV) of NGC 5204 X-1. Significant variability is also detected at low energy in observations 0405690101 (0.3-1 keV) and 0405690201 (0.3-1.5 keV) of NGC 5204 X-1.

Fractional variability is constrained at high energies in one observation of NGC 4395 X-1, and at both high and low energies in NGC 5204 X-1 (Fig. 2). Despite the constrained RMS, there is no significant red noise component in the broad band PSD of either source (Fig.3). The PSDs are dominated by low variability, low energy photons, and are restricted by low signal-to-noise, making this particular diagnostic tool of limited use in these particular sources.

NGC 4395 X-1 has a spectrum similar to BHBs in the sub-Eddington high state, which would necessitate an intermediate mass black hole (IMBH). The variable high energy component in this source is consistent with such a scenario. NGC 5204 X-1 seems to be spectrally similar to the very sub-Eddington low/hard state, which given its luminosity would again imply an IMBH, although its disc would be anomalously hot for this scenario.

Although a sub-Eddington solution appears plausible, NGC 4395 X-1 could instead be in a photosphere dominated super-Eddington state (cf. Middleton et al. 2011), where the hard variability is actually extrinsic, as a result of variable obscuration. Although the energy spectrum of NGC 5204 X-1 appears low/hard-state-like, when the 2-10 keV spectrum of observation 0142770101 is fitted with a broken power-law it results in $\Delta\chi^2$ = 23.5 for 2 degrees of freedom over a single power-law, and has an F-test probability of 2×10^{-5}. The presence of such a spectral break is not expected in the low/hard state, rather its presence indicates possible super-Eddington accretion (cf. Gladstone et al. 2009). The variation in spectral state is consistent with this scenario, and possibly indicative of changes between corona and photosphere-dominated states with flux.

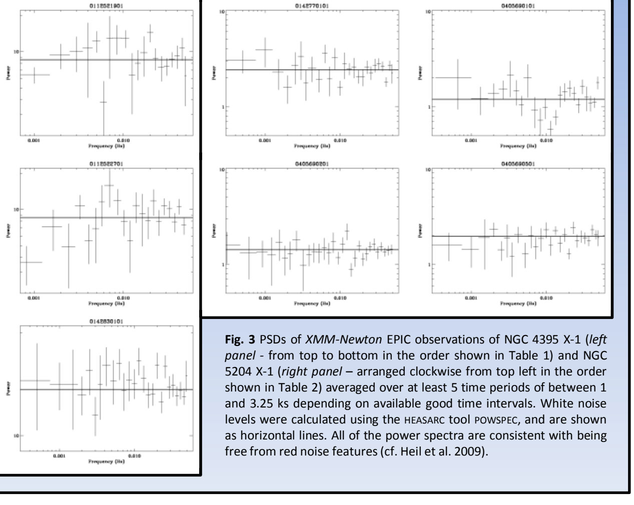

Fig. 3 PSDs of *XMM-Newton* EPIC observations of NGC 4395 X-1 (*left panel* - from top to bottom in the order shown in Table 1) and NGC 5204 X-1 (*right panel* – arranged clockwise from top left in the order shown in Table 2) averaged over at least 5 time periods of between 1 and 3.25 ks depending on available good time intervals. White noise levels were calculated using the HEASARC tool POWSPEC, and are shown as horizontal lines. All of the power spectra are consistent with being free from red noise features (cf. Heil et al. 2009).

*andrew.sutton@durham.ac.uk

Dickey J. M., Lockman F. J., 1990, Annu. Rev. Astron. Astrophys., 28, 215
Gladstone J. C., Roberts T. P., Done C., 2009, MNRAS, 397, 1836
Heil L. M., Vaughan S., Roberts T. P., 2009, MNRAS, 397, 1061
Karachentsev I. D., et al. 2003, A&A, 398, 467
Middleton M. J., Roberts T. P., Done C., Jackson F. E., 2011, MNRAS, 411, 644
Stobbart A. M., Roberts T. P., Wilms J., 2006, MNRAS, 368, 397