X-ray timing and spectral studies from Ultra-Luminous X-ray sources

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A unified characterization of the spectral evolution of black hole binaries has been done in the last 30 yrs. The notion of source states characterizing the X-ray emission from black-hole binaries revealed to be a very useful tool to disentangle the complex spectral and aperiodic phenomenology displayed by those classes of accreting objects. Ultra-Luminous X-ray sources are accreting black holes that might represent strong evidence of the Intermediate Mass Black Holes (IMBH), proposed to exist by theoretical studies but with no firm detection (as a class) so far. It is then worth it to ask whether a definition of spectral states is possible for these systems, too. I present the first study that has been done in this direction.

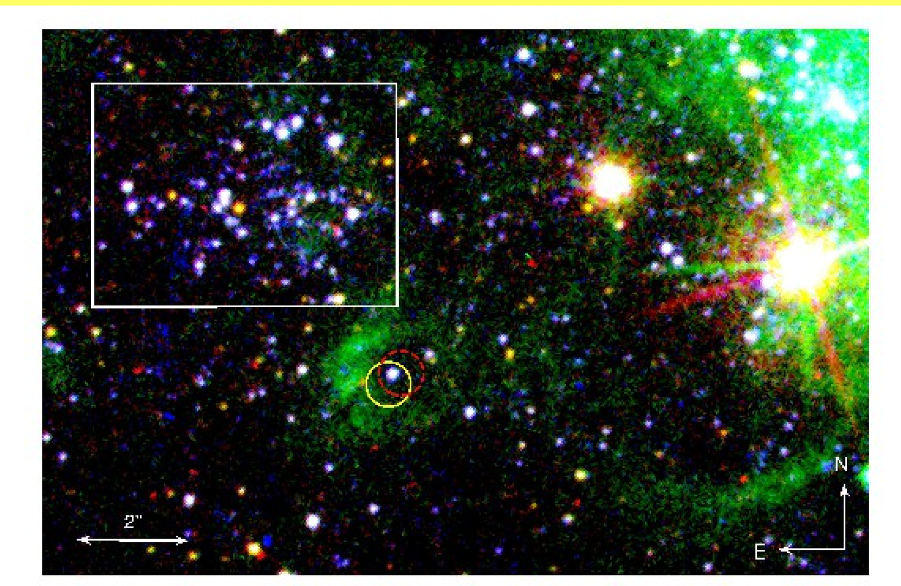
The ULX paradigm: IMBHs or stellar-mass BHs?

- Ultra-Luminous X-ray sources (ULXs) are point like, off nuclear, extra-galactic sources, with observed X-ray luminosities (L_X>10^{39} erg s^{-1}) higher than the Eddington luminosity for a stellar-mass black-hole (L_X≈10^{38} erg s^{-1}).
- Assuming an isotropic emission, in order to avoid the violation of the Eddington limit, ULXs might be powered by accretion onto Intermediate Mass Black Holes (i.e. IMBHs) with masses in the range 100−$10^5 M_{\odot}$. But some studies suggest that at least some ULXs, but not the most luminous ones, are consistent with stellas-mass BHs accreting at moderate rate with masses of ≈ 50−100$M_{\odot}$ (Soria et al. 2007, Mapelli et al. 2009).

What can X-ray timing tell us?

- Variability in accreting stellar-mass BHs is usually studied by means of the Fourier Analysis, which allows to produce Power Density Spectra (PDS) where several different components are usually observed. BHBs PDS are usually composed by <u>broad components (usually noise components, associated to red noise or band-limited noise)</u> and narrow components (called Quasi Periodic Oscillations, QPOs). Although we still know little about the physical origin of these temporal features, their phenomenology has proved useful in defining and identifying accretion states (Belloni 2011).
- A study of the fast time variability from several ULXs have found that for some sources the fast variability is suppressed for a reason which is currently unknown (Heil & Vaugan, 2010). They also found that a group of ULXs (including NGC 5408 X–1) have similar variability and PDS as luminous BHBs and Active Galactic Nuclei (AGN) in the observed frequency band-pass (10^{-3} − 1Hz).

The ULX in NGC5408

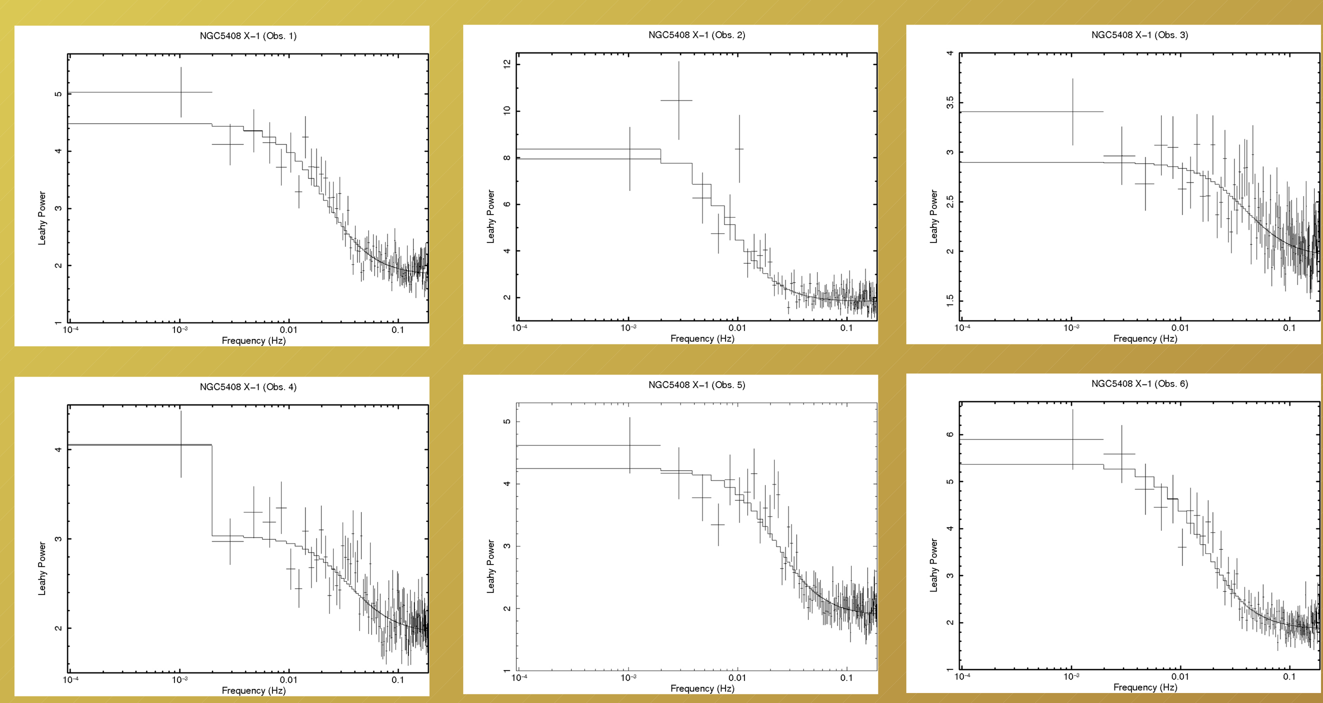


HST image (blue - F225W, green – F502N, red - F845M) of ULX NGC 5408 X-1 (circled), the surrounding field and a nearby stellar association (box) (from Grise et al. 2012)

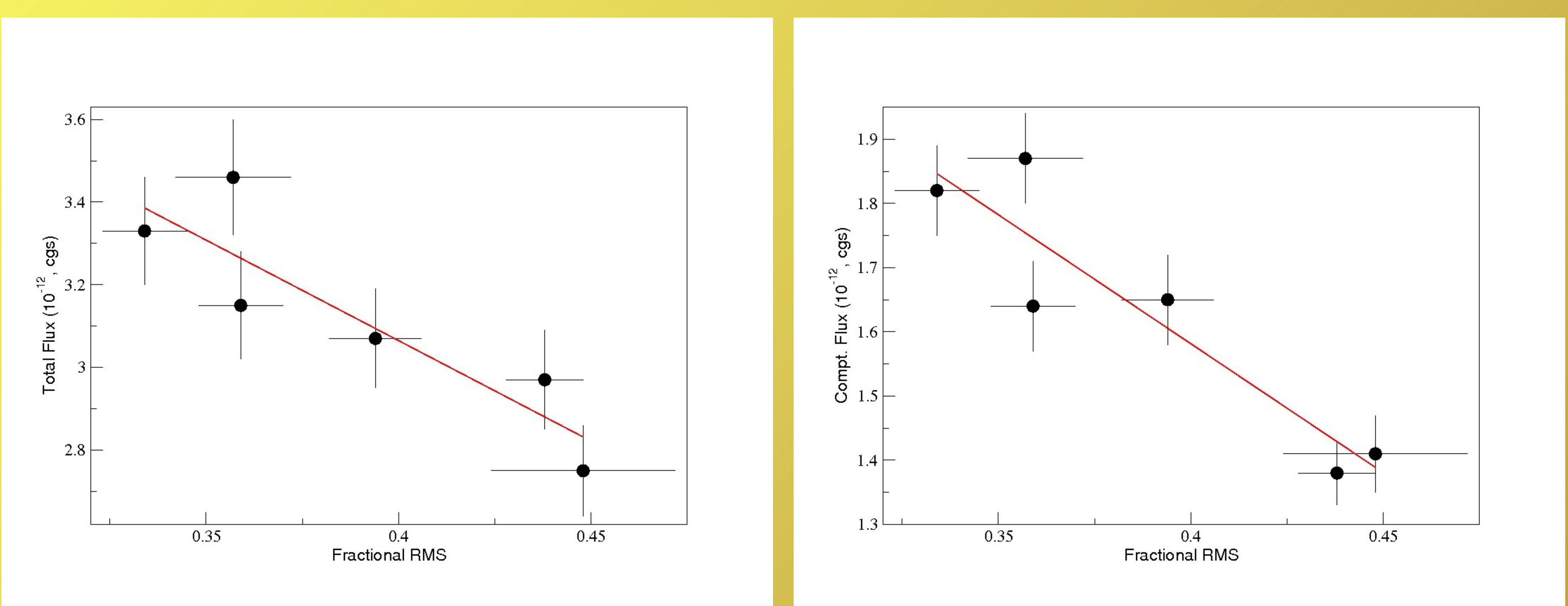
- Discovered with the Einstein observatory (Stewart et al., 1983). It is located in a close-by (D =4.8 Mpc) small (size of 2.2x1.1 kpc) starburst galaxy.
- This ULX peaks in X-ray luminosity above L_X = 1x10^{40} erg s^{-1}. Its proximity and brightness make it an <u>excellent target for performing X-ray timing and spectral studies</u>.
- Spherically symmetric nebulae around NGC 5408 X–1 have been detected in radio and optical bands (Pakull & Mirioni 2003; Soria et al. 2006; Lang et al. 2007; Cseh et al. 2012), likely ruling out beaming effects.
- Strohmayer & Mushotzky (2009) found a QPO in its PDS centred at 0.01Hz and inferred a mass for the black hole in the range of 10^3−10^4 $M_{\odot}$. Later studies, based on the kT_{in} vs. L_X relationship, infer lower masses (≈10-100 $M_{\odot}$; Kajava & Poutanen, 2009; Gladstone et al. 2009), therefore possibly accreting at super-Eddington rates.

The accretion state of the ULX in NGC5408

- We performed a timing-spectral analysis of the longest (≈100 ks) available XMM-Newton observations of NGC5408 X-1.
- We studied the fast-time X-ray variability from NGC5408 X-1 in the 0.3-10keV and 10^{-4}-0.19 Hz energy and frequency ranges, respectively. The PDSs are well described by a zero centred Lorentzian for the flat-topped noise plus a constant describing the Poissonian noise.
- We have found that the fractional rms of the variability in the 1-10 keV energy range is variable and in the range 30-50%.
- Additionally there is an anti-correlation between the total (and/or high-energy) unabsorbed flux versus the fractional rms of the source.
- These properties closely resemble the ones by for GX339-4 in the bright phase of the low/hard state (Munoz-Darias et al. 2011). <u>We suggest that NGC5408 X-1 is accreting in an unusual bright hard state.</u>



Power density spectra of the XMM-Newton EPIC/pn+MOS data in the energy and the frequency range (1-10 keV) and 10^{-4}-0.19 Hz, respectively during observations 1-6 (top-left to bottom right).



Total source (left) and high-energy component (right) unabsorbed fluxes versus the fractional variability in the 1-10 keV and 10^{-4}-0.19 Hz energy and frequency ranges, respectively.

Related publications:

- ***Caballero-Garcia et al., 2013, "The aperiodic variability of the Ultraluminous X-ray source in NGC 5408", IAU Symposium proceedings.***
- ***Caballero-Garcia, Belloni & Wolter, 2013, "Broad band variability and energy spectra from NGC5408 X-1 with XMM-Newton" (submitted to MNRAS).***