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

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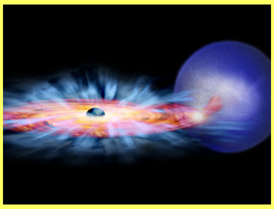
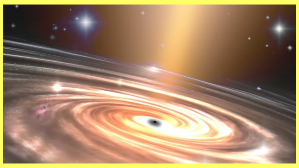
A unified characterization of the spectral evolution of black hole binaries has been done in the last 30 yrs. The study of the spectral and aperiodic variability characterizing the X-ray emission from stellar-mass black-hole binaries has revealed to be a very useful tool to understand the mass of the black hole and the physics of accretion on these sources. Ultra-Luminous X-ray sources (ULXs) 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. Their X-ray properties have been seen to be different from the case of stellar-mass black hole binaries. I will present the results that we have obtained from two outstanding ULXs (NGC5408 X-1 and the ULXs in M82) and discuss on the properties that can be derived from the study of their X-ray emission.

The Ultra-Luminous X-ray source paradigm



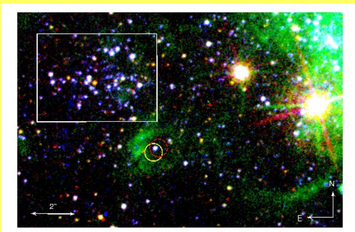
Stellar-mass Black Hole (BHB)



Supermassive Black Hole (AGN)

- Ultra-Luminous X-ray (ULX) sources are point-like, off-nuclear sources observed in other galaxies, with ***total observed*** luminosities greater than the Eddington luminosity **for a stellar mass black hole** ($L_x \sim 10^{38}$ erg/s).
- Therefore either the emission *is not isotropic* or the black hole has a higher mass ($M_{BH} \geq 20\ M_\odot$).
- This opens a real possibility to the *existence of the InterMediate-Mass Black Holes* (IMBHs; $M_{BH} \geq 10^2$-$10^4\ M_\odot$; Colbert & Mushotzky, 1999).
- The existence of these ULXs-IMBHs is controversial but only one case recently confirmed (ESO 243-49 HLX1; Farrell et al. 2011).

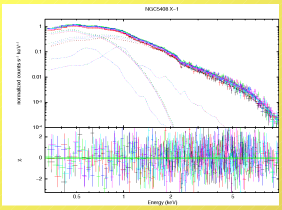
The Ultra-Luminous X-ray sources NGC 5408 X-1, M82 X-1, M82 X-2

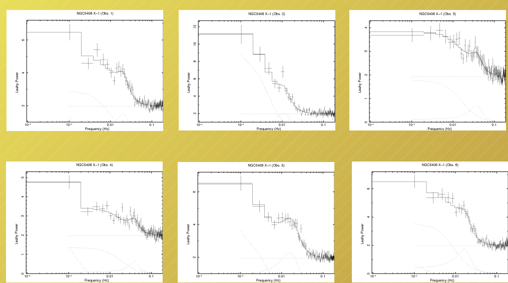


HST image (blue - F225W, green - F502N, red - F845M) of ULX NGC 5408 X-1 (circled), the surrounding field and a nearby stellar association (box) (from Grise et al. 2012)

- NGC 5408 is a nearby (D=4.8 Mpc) ULX with a peak (*RXTE*, 0.3-10 keV, 2008-2009) X-ray luminosity of $L_x = 2\times10^{40}$ erg/s (Strohmayer, 2009).
- We studied the 6-Long 100 ks observations with XMM-Newton performed in 6 years (2006-2011).
- M82 is a *starburst* galaxy located at a distance of D=3.9Mpc
- M82 contains two ULXs (separated by 5” in the sky). M82 X-1 is the brightest, reaches a luminosity of $L_x \geq 10^{40}$ erg/s and is of persistent nature. The second is of transient nature (M82 X-2).

Fast variability from NGC5408 X-1





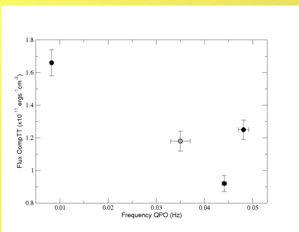
(Upper-left) EPIC-pn XMM-Newton spectra from NGC5408 X-1 during observations 1-6 fitted with the spectral model.

(Upper-right) XMM-Newton EPIC/pn+MOS PDSs in the energy and frequency range 1-10 keV and 0.0001-0.19Hz of NGC5408 X-1 (from Caballero-Garcia et al., 2013a)

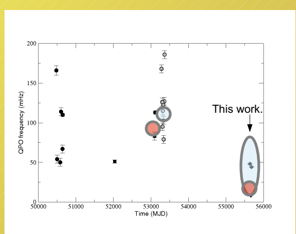
- Little spectral evolution (slight spectral hardening), in spite of the observations spread in 6 yr
- Fit with several phenomenological models (*diskbb* or *diskpn* for the soft X-rays and *powerlaw* or *compTT* for the high-energies; 2 *apecs* for the diffuse emission from a **starburst**).
- $\Gamma \approx 2$ and cold (and constant) inner disc temperature ($kT_{in} \approx 0.17$ keV).
- **The high level of fast variability (frac.rms 30-40%) indicate a *hard state*.**

<u>NGC5408 X-1 might be a relatively massive ($10^3\ M_\odot$) accreting in a “HIMS”-like state</u>.

Fast variability from M82 ULX-1 and ULX-2



(Upper-left) Unabsorbed (1-10 keV) flux from the high-energy component versus the frequency of the QPOs from our work.



(Upper-right) Time history of the centroid frequencies of the QPOs from M82 from the sample of Mucciarelli+06; Strohmayer & Mushotzky (2003) and Kaaret+ (2006).

Comparing the QPO from X-1 at $\nu \approx 50$ mHz with previous findings (Mucciarelli+06; Strohmayer & Mushotzky, 2003, Kaaret+06) we see that all the detections are distributed in the 1:2:3 ratio. *<u>If really distributed harmonically, the QPOs found from M82 X-1 could be interpreted as the first indication of HFQPOs in ULXs. The QPO from X-2 might be an analog to the LFQPOs observed in BHBs.</u>*

Related publications:

“X-ray variability and energy spectra from NGC 5408 X-1 with XMM-Newton”,Caballero-Garcia, M. D., Belloni, T. M. and Wolter, A., 2013, MNRAS, 435, 2665

“Quasi-periodic oscillations and energy spectra from the two brightest Ultra-Luminous X-ray sources in M82”, Caballero-Garcia, M. D., Belloni, T. and Zampieri, L., 2013, MNRAS, 436, 3262