Can the ULX spectral properties unveil the nature of their compact objects?

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Introduction

Ultraluminous X-ray sources (ULXs) are a class of extragalactic, point-like sources with luminosity from $\sim 10^{39}$ erg s^{-1} up to 10^{42} erg s^{-1} and previously thought to be powered by black holes (BHs) only. However, the recent discovery of three pulsating neutron stars (NSs) in the ULX M82 X-2 [1], NGC 7793 P13 and NGC 5907 X-1 [4,5] proved that ULXs can be powered by objects different from BHs. The ULXs spectra are generally described with a cold (kT $\sim 0.1 - 0.6$ keV) soft thermal component coupled to a high-energy component with a cut-off below 10 keV (e.g [8,2,7,6]). However, the quality of ULX spectra is generally low and the interpretation of their spectral properties is still debated.

Aim of the work

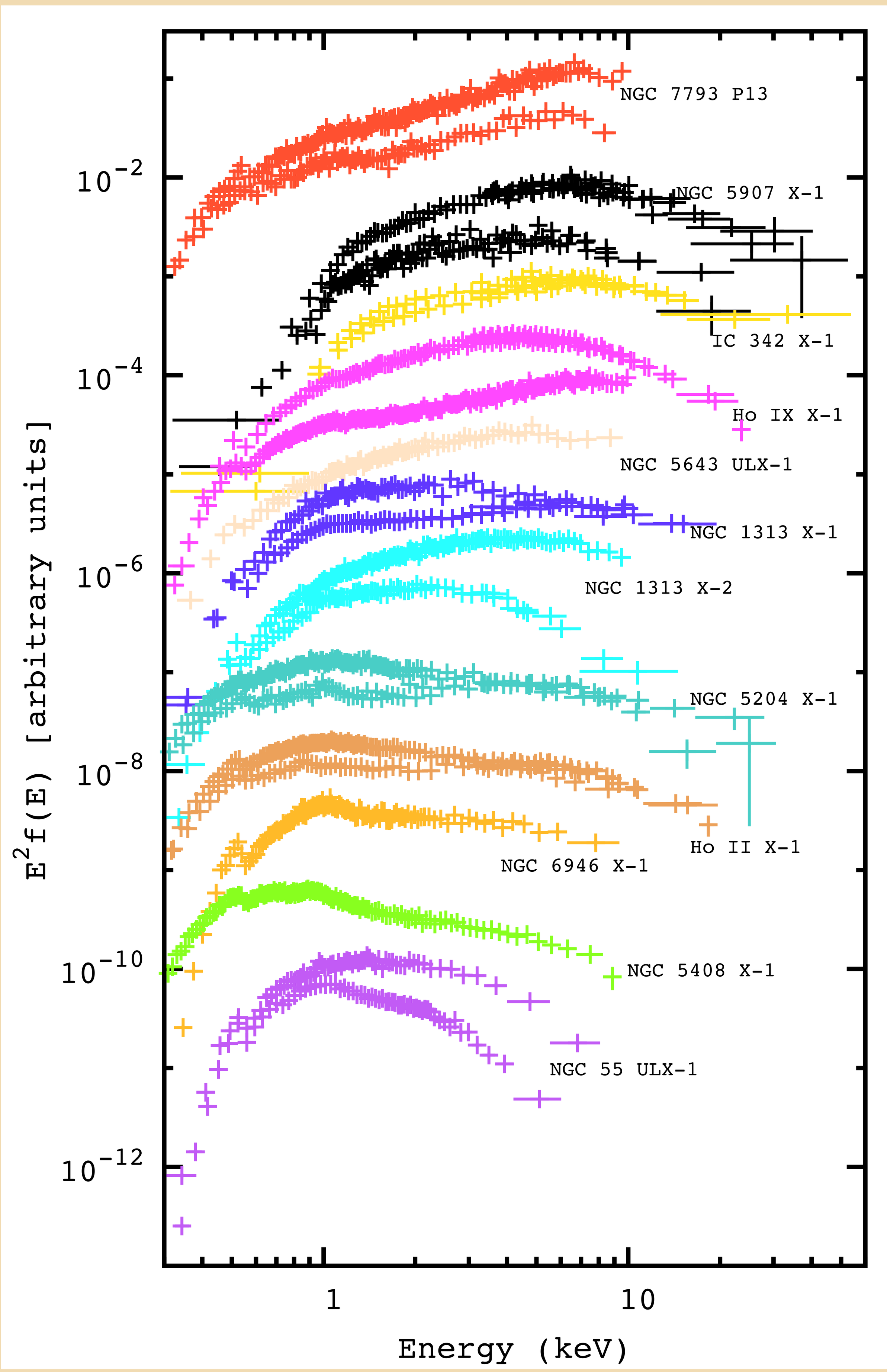
- Motivated by the discovery of X-ray pulsations from M82 X-2, NGC 7793 P13 and NGC 5907 X-1, we adopted a simple spectral model extensively used to fit the X-ray continuum of accreting magnetic NSs, especially X-ray pulsators in Galactic high mass X-ray binaries (see [9,10,3]).
- **The "Pulsator-like" model**: absorbed power-law with exponential cut-off characterized by two parameters, the cut-off energy E_c and the folding energy E_f: $\mathbf{F(E) = k \cdot E^{-\Gamma} e^{-(E-E_c)/E_f}}$, plus an additional soft blackbody component (when necessary).

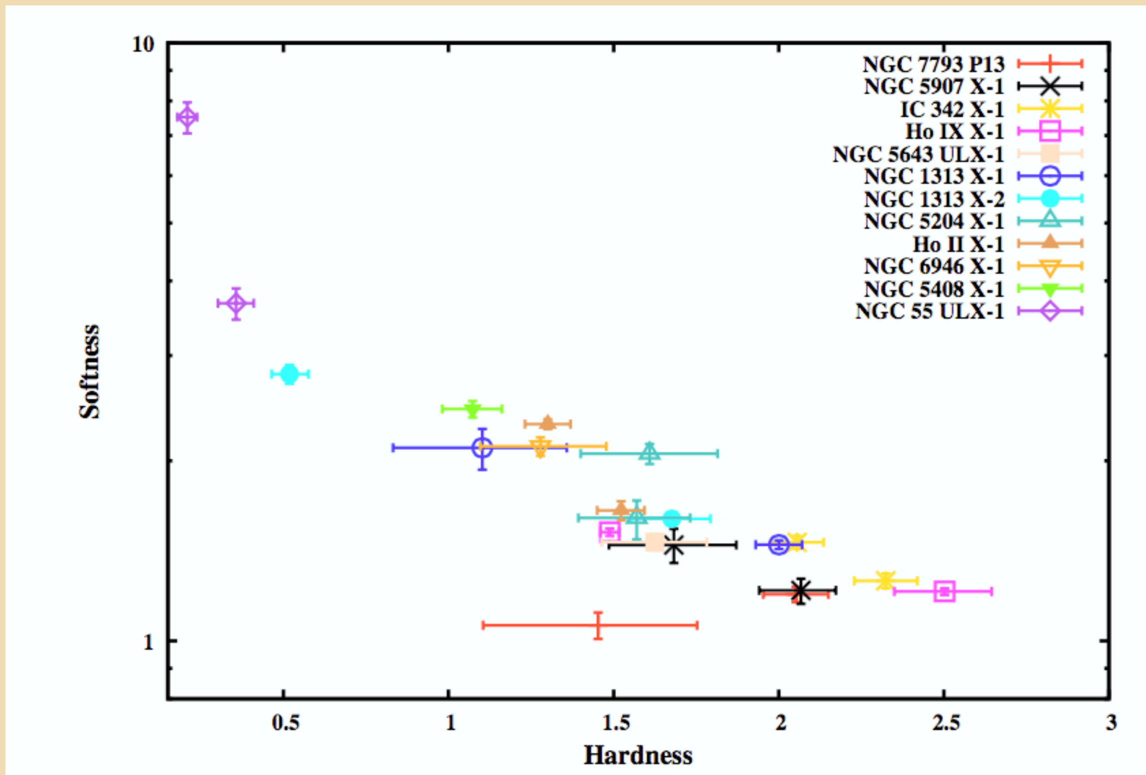
Selection of the sample

- 12 ULXs (Figure 1), including two ULX pulsars (PULXs), located at distances smaller than 15 Mpc.
- The sample spans a broad luminosity range from $\sim 10^{39}$ erg s^{-1} to $\sim 10^{41}$ erg s^{-1}.
- Good quality *XMM-Newton* and, in some cases, (nearly) simultaneous *NuSTAR* observations.
- For sources with significant spectral variability, we considered only the two observations with the most differing source spectral parameters.

Broadband spectral fits

- The "pulsator-like" model can describe well the spectra of virtually all the ULXs of our sample (Figure 1-left).
- Blackbody temperatures between ~0.15–0.3 keV are required in most of the cases. A variety of power-law spectral slopes and cut-off parameters is found.
- We characterize the harder spectral component, where the absorption and the additional soft component are negligible, through 1) a color-color diagram using the fluxes in the 2–4 keV, 4–6 keV and 6–30 keV energy bands derived from the "Pulsator-like" model best-fits (Figure 1, top-right), 2) by fitting the spectra above 2 keV with a simple cut-off powerlaw model and creating the contour plots for the cut-off energy and the corresponding photon index (Figure 1, bottom-right).
- This allows us to gather information on the innermost regions of the accretion flow close to the compact object.
- We highlight that the two known PULXs in the sample lie in the regions of the color-color diagram and contour plot that correspond to the hardest spectra.
- IC 342 X-1 and Ho IX X-1, because of their hard spectra, may be candidate NS. For the two XMM observations of IC 342 X-1, we found upper limits on pulsations (not corrected for possible orbital motions) of $13 \pm 1\%$ and $11.7 \pm 0.5\%$; instead, for Ho IX X-1, we found $4.6 \pm 0.5\%$ and $3.1 \pm 0.5\%$.





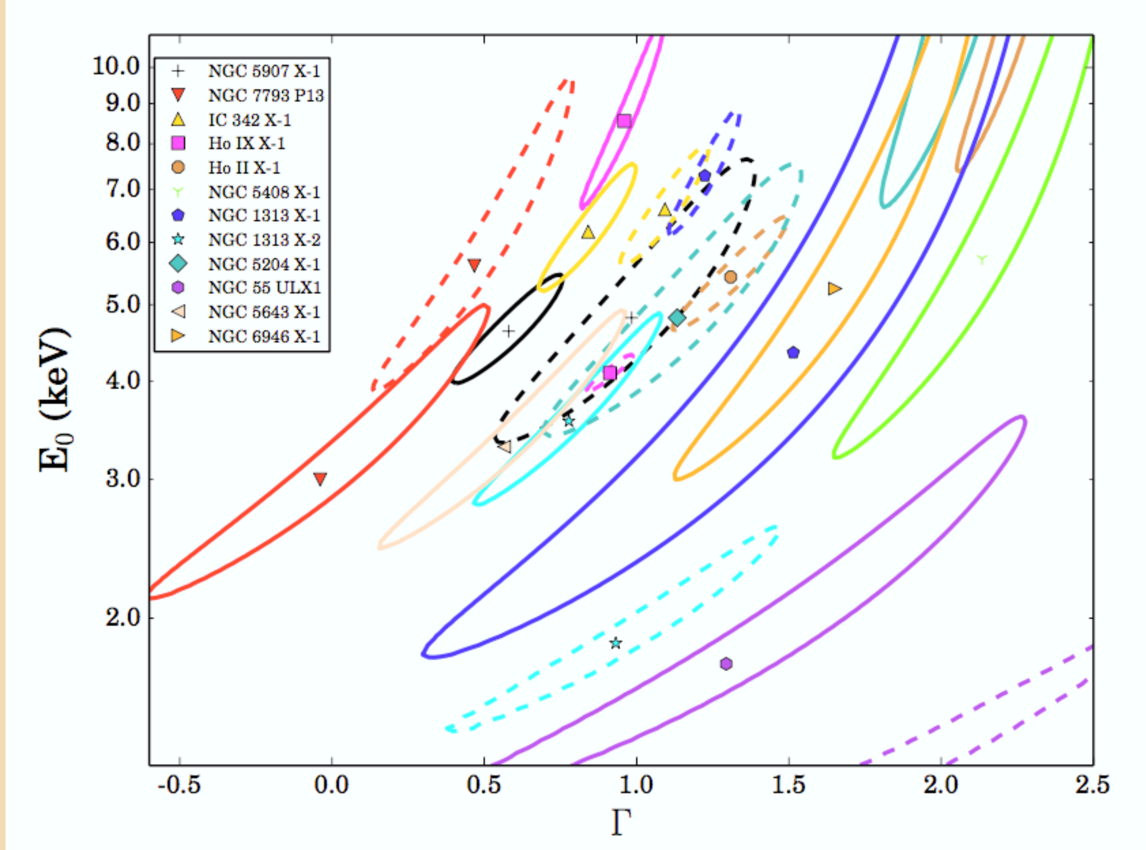


Figure 1. Left: unfolded ($E^2F(E)$) spectra of all the ULXs of our sample. For each source, we show the two most different spectral states obtained by fitting them with the "pulsator-like" model. For display purposes, the spectra have been rebinned and the flux is arbitrarily shifted on the y axis. Right-top: color-color diagram where the hardness and the softness are defined as the (6–30 keV)/(4–6 keV) flux ratio and (2–4 keV)/(4–6 keV) flux ratio, respectively. Right-bottom: $E_0 - \Gamma$ contour plot from the cut-off powerlaw fit. In both plots, the PULXs, IC 342 X-1 and Ho IX X-1 occupy the region with the most extreme values indicating that they are the hardest sources.

Conclusions

- We adopted a commonly used spectral model for accreting X-ray pulsating NS in the Galaxy to describe the spectra of a sample of bright ULXs.
- This model well describes the spectra of most ULXs, suggesting that spectral models based on accreting BHs may not have the interpretative power that has been ascribed to them up to now.
- The PULXs are amongst the hardest sources of our sample.
- IC 342 X-1 and Ho IX X-1 have comparably hard spectra and, based on this only, we suggest they are likely candidate NS ULXs.

References

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