Nuclear Spectroscopic Telescope Array

Probing the nature of Ultraluminous X-ray Sources using broad-band X-ray data

**Ultraluminous X-ray Sources:**

Ultraluminous X-ray sources (ULXs) are point sources in nearby galaxies with X-ray luminosities \( L_X > 10^{39} \) erg/s, in excess of the Eddington luminosity for the typical Galactic stellar-mass black holes (StMBHs). Understanding the origin of these extreme luminosities remains one of the biggest mysteries in high-energy astrophysics. Possible explanations include the existence of (poorly understood) regime of super-Eddington accretion onto StMBHs, or the presence of massive (\( \sim 100 \, M_\odot \)) black holes.

With the launch of the first ever focusing hard X-ray optics aboard NuSTAR, it has finally become possible to observe ULXs at hard X-rays. We have undertaken a substantial program observing extreme (\( L_X > 10^{40} \) erg/s), coordinated with soft X-ray coverage from XMM-Newton and/or Suzaku, in order to probe the broadband X-ray spectra of these enigmatic sources for the first time.

**Broadband X-ray Spectra**

Over its first two years of operation, NuSTAR has undertaken targeted observations of \( \sim 10 \) well known ULXs, providing the first systematic high energy view of these sources. In all cases to date, we find that the hard X-ray continuum is very steep, robustly confirming the spectral curvature tentatively hinted at by observations with soft X-ray detectors alone.

**Spectral Variability:**

Holmberg IX X-1

Circinus ULX5

The NuSTAR strategy has been to perform two observations of each target, separated by \( \sim \) a week. While many sources display consistent spectra (e.g., above), a number show strong, yet unusual spectral variability between epochs (left). Although Circinus ULX5 was observed as a Target of Opportunity, the variability is marked when compared with archival data. We are now actively seeking to probe spectral variability in a larger sample of ULXs for comparison.

**A Vanishing Act: NGC 5907 ULX1**

One of the NuSTAR targets was NGC 5907 ULX1, known to reach \( L_{\text{peak}} \sim 5 \times 10^{40} \) erg/s. In the first observation this source was unexpectedly faint, barely detected by XMM. However, it was clearly present in the second, only \( \sim 4 \) days later, implying a brightening of \( \sim 2 \) orders of magnitude. This detection displayed a broadband spectrum similar to the other ULX targets.

**NuSTAR Targets:**

Key NuSTAR targets include:

- IC 342 X-1, X-2 (NuSTAR, XMM; below)
- Holmberg IX X-1 (NuSTAR, XMM, Suzaku)
- NGC 1313 X-1, X-2 (NuSTAR, XMM)
- Circinus ULX5 (ToO; NuSTAR, XMM)
- Holmberg II X-1 (NuSTAR, XMM, Suzaku)

**Key Results:**

- NuSTAR has performed the first ever high energy observations of ULXs, helping provide high quality broadband (-0.3-30 keV) spectra.
- All sources observed to date show curved high-energy continua, inconsistent with standard powerlaw-like Comptonisation emission, as would have been expected if these sources host massive (\( \sim 100-1000 \, M_\odot \)) black holes accreting at substantially sub-Eddington rates.
- A number of ULXs also show strong spectral variability between observed epochs, with distinct differences to the sub-Eddington state transitions observed from Galactic BH binaries.
- We caught an astonishing rise of \( \sim 2 \) orders of magnitude in only 4 days from NGC 5907 ULX1.
- It seems that we are witnessing an unusual, likely high-Eddington accretion regime. This is supported by the spectacular precedent set by the extreme ULX M82 X-2, \( L_{\text{peak}} \sim 2 \times 10^{41} \) erg/s, discovered by NuSTAR to be a highly super-Eddington accreting pulsar (Bachetti et al. 2014, Nature; see talk by Prof. Harrison).

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