The X-Ray Point-Source Population of NGC 1365: The Puzzle of Two Ultraluminous X-ray Sources

I. Strateva, S. Komossa

Max Planck Institute for Extraterrestrial Physics, Germany

Abstract

A series of *Chandra* exposures of the barred supergiant galaxy NGC 1365 revealed 26 point-sources within 200″ (≈ 20 kpc) of the center. The majority of these sources are high-mass X-ray binaries (HMXBs), containing a neutron star or a black hole accreting from a luminous companion at a sub-Eddington rate. Using seven *Chandra* and five *XMM-Newton* exposures, supplemented by optical and infrared data, we study in detail two highly-variable ultraluminous X-ray sources (ULXs): NGC 1365-X-1, one of the most luminous ULXs known since the *ROSAT* era, and NGC 1365-X-2, a newly discovered extremely luminous ULX. Their maximum X-ray luminosities (4–6$\times10^{40}$ erg s^{-1}) and multiwavelength properties suggest the presence of more exotic objects and accretion modes: accretion onto intermediate-mass black holes (IMBHs) and beamed/super-Eddington accretion onto stellar-mass compact remnants. We argue that these two sources bridge the gap between typical X-ray binaries and IMBHs: a M=40–60 $M_\odot$ black hole with a beamed/super-Eddington accretion mode in the case of X-1, and a M=80–500 $M_\odot$ Kerr black hole in the case of X-2 are consistent with all observations.

The Point-Source Population

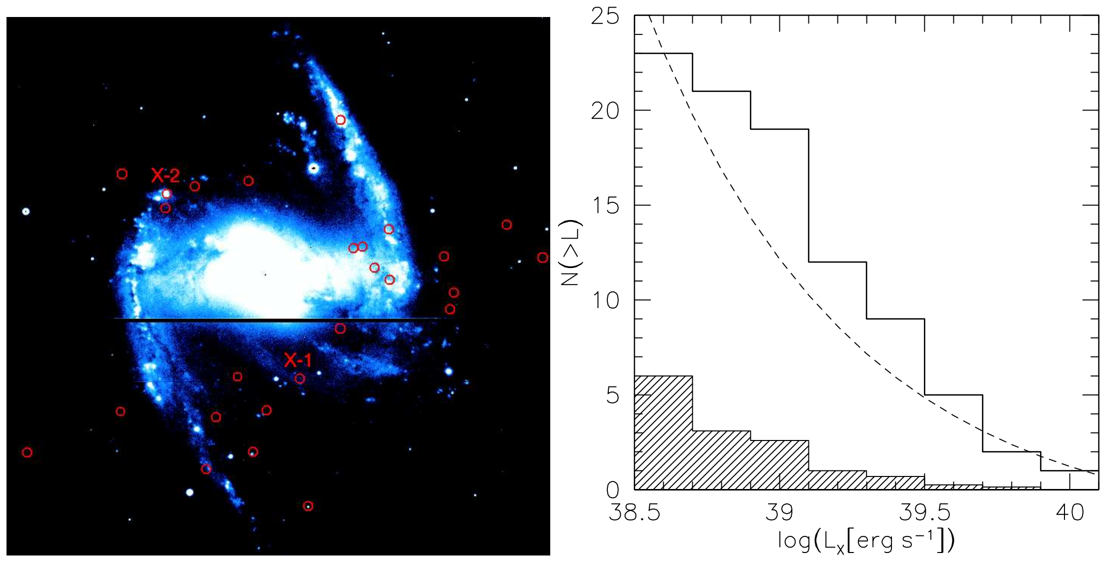

Figure 1: Left: VLT image of of the inner 6′ × 6′ of NGC 1365; the positions of the 26 X-ray point sources are indicated by 3″-radius circles. **Right:** The cumulative number of X-ray point sources detected during the 2003 *Chandra* observation (open histogram) and the expected number of background sources based on the $\log N - \log S$ results of Hasinger et al. (2001, hatched histogram). The dashed line shows the numbers of observable high-mass X-ray binaries in a spiral galaxy with a star-formation rate of 12 $M_\odot$ yr^{-1} (Grimm et al. 2006).

X-1 and X-2: Two ULXs at a Glance

- X-1 coincides with a minor spiral arm of NGC 1365, X-2 – with a giant (670 pc, $M_V = -12.4$) HII region
- For both X-1 and X-2, assuming a distance of 21 Mpc to NGC 1365, $L_{X max}$=4–6$\times10^{40}$ erg s^{-1} imply masses of at least 300–450 $M_\odot$ for sub-Eddington accretion rates ($\dot{m} \leq 1$).
- Their optical-to-X-ray ratios – $1.5 < \log$[X/O]<2.7 (X-1) and $-2 < \log$[X/O]< -1 (X-2) – are outside the range typical for active galaxies (AGNs): $-1 < \log$[X/O]< 1. The X-ray-to-infrared flux ratio of X-1 is $0.04 < \log$[X/K_s]< 0.6, while red, obscured AGNs from 2MASS typically have $\log$[X/K_s]< 0.05.
- X-1 is a persistent source, X-2 is a transient; both vary on timescales of days to years.

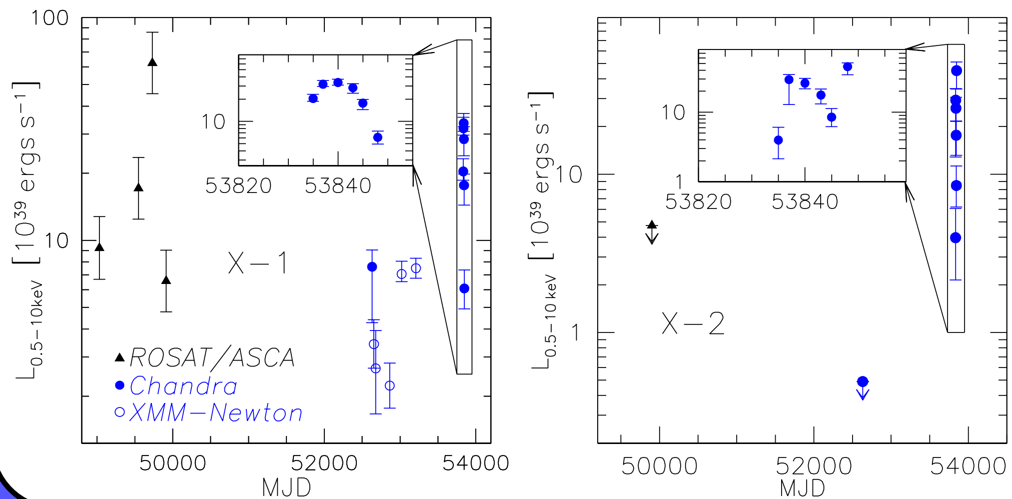

Figure 2: Time variability of the X-ray luminosities of X-1 (left) and X-2 (right). The inset zooms on the six April 2006 *Chandra* observations in both cases.

X-2: a Rapidly-Rotating IMBH?

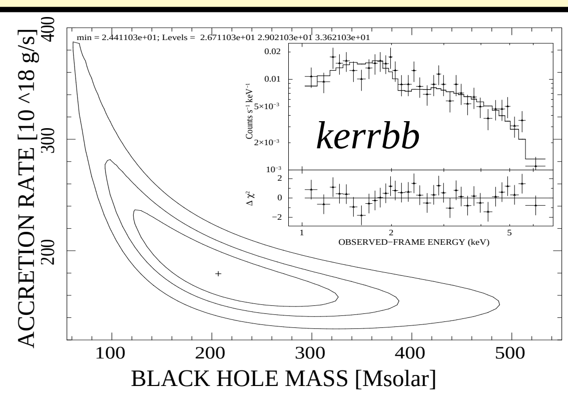

Figure 3: Confidence parameters of the Kerr black hole fit (inset) to the highest S/N *Chandra* spectrum.

- Multicolor-disk emission models result in disks that are too hot (1.8<T<4 keV, 95% confidence) for black-holes which are massive enough to explain the high observed luminosities, even for high beaming/super-Eddington emission models.
- Emission from a disk around a maximally spinning black hole ($a = 0.998$; Figure 3) can explain the *Chandra* spectra.

X-1: an IMBH with Super-Eddington Accretion?

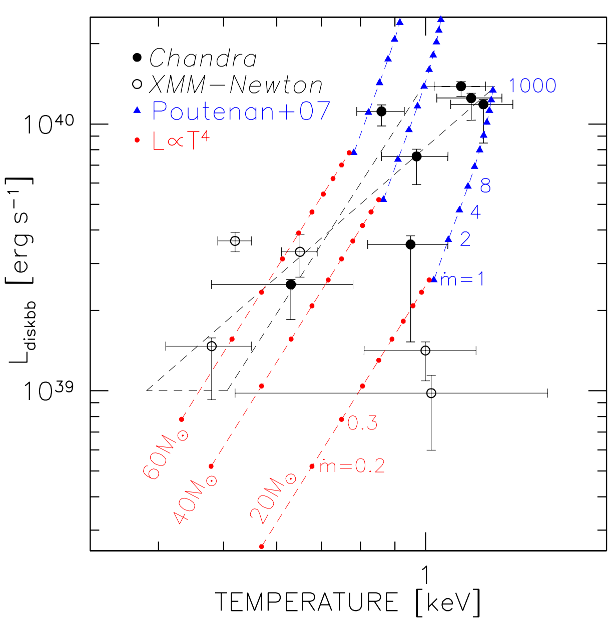

Figure 4: Temperature luminosity relation for X-1. Sub-Eddington (0.1<ṁ<1) accretion modes are shown in red, the supercritical (1<ṁ<1000) accretion models of Poutenan et al. 2007 in blue.

- Both absorbed power-laws and multicolor-disk (MCD) emission plus comptonized corona models provide equally good fits to the 7 *Chandra* and 5 *XMM-Newton* spectra.
- The estimated MCD temperatures and accretion-disk luminosities follow a $L \propto T^\alpha$ relation (shown with dashed lines in Figure 4), with $\alpha = 2.8^{+1.1}_{-0.6}$, consistent with the $L \propto T^4$ relation expected of sub-Eddington accreting black holes with masses between 40 $M_\odot$ and 60 $M_\odot$, if we allow for supercritical accretion (e.g., Poutenan et al. 2007) during the *Chandra* flare .
- See also the X-1 analysis of Soria et al. (2007).

Implications

- ULXs with luminosities exceeding 10^{40} erg s^{-1} could harbor IMBHs; beamed or super-Eddington modes are more appropriate for less luminous ULXs.
- The optical counterpart of X-2, a luminous HII region, is the most likely place to find an IMBH – both in terms of formation mechanisms, which require very dense environments, and in terms of the availability and capture of a suitable donor star to supply the accretion material. The lack of optical counterpart for X-1 makes the association with an IMBH more problematic, but not implausible; recent theoretical work suggests that most *primordial* IMBHs with masses <1000 $M_\odot$ would be ejected from the dense globular cluster where they formed (e.g., Holley-Bockelmann et al. 2007).

References

[1] Grimm, H.J., et al. 2006, Populations of High Energy Sources in Galaxies, 230, 353

[2] Hasinger, G., et al. 2001, A&A, 365, L45

[3] Holley-Bockelmann, K., et al. 2007, ArXiv e-prints, 707, arXiv:0707.1334

[4] Poutanen, J., et al. 2007, MNRAS, 377, 1187

[5] Soria, R., et al. 2007, MNRAS, 379, 1313