Long-term X-ray variability of ultraluminous X-ray sources

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See a recent review by Feng & Soria 2011
Ultraluminous X-ray Sources (ULXs)

- X-ray luminosity > Eddington limit for a 20 M\(\odot\) black hole (3x10\(^{39}\) erg/s)
- Not at galaxy nucleus
- Unresolved with Chandra
- They can be good candidates of IMBHs or stellar-mass BH with special accretion modes
- Lx\(\sim\)10\(^{40}\) erg/s can be explained without involving IMBHs
Connection between ULXs and Galactic X-ray binaries

- ULXs are a heterogeneous class of X-ray sources
- Some are similar to Galactic X-ray binaries but many of them are not
- A direct comparison seems to be difficult
- It is better to begin from scratch
- X-ray variability provides some of the important clues
- Let us start with some ULXs with extreme luminosities
M82 X-1: the best IMBH candidate within 5 Mpc

Kong+ 2007
M82 X-1: the best IMBH candidate within 5 Mpc

- Very luminous: $10^{41}$ erg/s
- Clearly offset from the galactic center
- Locate *near* a cluster (Kong+ 2007; Voss+ 2011)
- 62-d periodicity: orbital period?

![Graph showing flux vs. time](image)
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Kong+ 2007

![Image of M82 X-1 and nearby objects]
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Kaaret & Feng 2007
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- The QPOs disappeared

Feng & Karret 2010
Transient ULXs in M82 with Chandra

Chiang & Kong 2011
Spectral variables in M82

Chiang & Kong 2011
The nature of ULX transients in M82

- X-ray colors suggest that ULXs in M82 are more consistent with BH HMXBs (Colbert+ 2004)
- The X-ray luminosity function of M82 is consistent with HMXBs (Chiang & Kong 2011)
- Be HMXBs are transients. If M82 is HMXB dominant, ULX transients in M82 are most likely Be BH HMXBs. Lower luminosity systems may be NS systems.
Comparison with other galaxies

Chiang & Kong 2011
Monitoring observations of ULXs

• In the last 10 years, the most successful observations of ULXs are from Chandra and XMM

• They are usually pointed observations of nearby galaxies

• Apart from a few of nearby galaxies (e.g. M82), many galaxies were only observed less than 5 times in the past 10 years

• Frequent monitoring observations with Chandra and XMM are expensive
Monitoring observations of ULXs

- M82 X-1 is a special case that we can monitor with RXTE/PCA. Contamination is still an issue.
- Swift XRT provides an alternative to perform X-ray monitor of ULXs in nearby galaxies.
- Galaxies including Holmberg IX, NGC5408, and NGC4395 have been regularly monitored with Swift (Strohmayer 2009; Kaaret & Feng 2009; Kong 2011)
The 115-d periodicity of NGC5408 X-1

- $L_x \approx 2 \times 10^{40}$ erg/s
- 115-d orbital period (Strohmayer 2009)?
- Super-orbital period due to a precessing jet (Foster + 2010)?
- 2008 Apr-2009 Aug
- Maybe both are wrong?!
The 115-d periodicity of NGC5408 X-1

2008 Apr - 2011 Aug
It’s gone!
Another LMC X-3? (see Kotze & Charles 2011)
The recurrent outbursts of ESO 243-49 HLX-1: the most promising IMBH candidate

- Lx$\sim 10^{42}$ erg/s (Farrell+ 2009)
- 95Mpc
- Optical counterpart (Soria+ 2010)
- Spectral change (Servillat+ 2011)
- Recurrent outbursts $\sim 370$ days
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![Power vs Period](image)
Swift monitoring of ULXs

Holmberg IX X-1

M81 X-6

Kong 2011
Fast Timing Properties

Graph showing power and frequency relationship with markers for different masses and states:
- $10^6 M_\odot$ NGC 4051 RXTE+XMM
- $10^7 M_\odot$ NGC 3516
- $10^8 M_\odot$ Cyg X–1 low state
- $4 \times 10^7 M_\odot$ NGC 3516
- $10^8 M_\odot$ Cyg X–1 high state

McHardy+ 2004
Fast Timing Properties

From Feng & Soria 2011
Supersoft ULX transients

M101
kT~40-150eV

Kong+ 2004,2005
Supersoft ULX transients

Kong & Di Stefano 2003
NGC300
kT~60eV
Supersoft ULX transients

Kong & Di Stefano 2003

NGC300
kT~60eV
Supersoft ULX transients

- $L_x > 10^{39}$ erg/s
- $kT$ could be larger ($\sim 100$ eV) than classical SSSs.
- Nuclear burning on accreting WD with beaming or special accretion geometry
- NS (only seen in 1 case; Hughes 1994)
- BH and probably IMBH (Di Stefano and Kong 2003,2004)
ULXs in the Milky Way?

- 4U 1543-37: $4.2 \times 10^{39}$ erg/s
- GRS 1915+105: $2.4 \times 10^{39}$ erg/s
- V4641 Sgr: $6.2 \times 10^{39}$ erg/s
ULXs in the MC and M31?

- A0538-668: a pulsating NS in the LMC with $L_x \approx 1.2 \times 10^{39}$ erg/s (Skinner+ 1982)

- M31 ULX-1: $5 \times 10^{39}$ erg/s; “standard” LMXB (Middleton+ 2011)
A supersoft ULX transient in the SMC?

- Discovered by MAXI as XRF111111A/MAXI 0158-744 (GCN1254)
- $6.4 \times 10^{38}$ erg/s (2-4 keV; 400 mCrab); also detected with SSC at 1 Crab (0.7-7 keV); X-ray color => kT=0.4 keV
- Detected with Swift XRT/UVOT (ATel 3758, 3759, 3765).
- The X-ray spectra are supersoft (kT=60-100 eV)
- Peak X-ray luminosity: $7 \times 10^{39}$ erg/s (sensitive to absorption and kT)
A supersoft ULX transient in the SMC?
A supersoft ULX transient in the SMC?

MAXI J0158-744

Li+ in prep
A supersoft ULX transient in the SMC?

P.H.T. Tam on behalf of the ATOM collaboration
A supersoft ULX transient in the SMC?

- Optical counterpart is bright ($V \sim 15$)
- IR excess ($J=14.8$, $H=14.8$, $K=14.4$)
- Herbig Ae/Be candidate in the Magellanic Bridge (Nishiyama+ 2007); could also be a Be star
- UVOT grism observation
  - looks consistent with an early-type star
- A 1.5m SMARTS spectrum is coming
- Be/WD system (see Sturm+ 2011)? Be/BH system?
Future X-ray monitoring of ULXs

- Chandra and XMM are still very expensive, but TOO and DDT triggered by other facilities will provide detailed spectral and temporal information.

- More Swift XRT monitoring observations will be extremely useful.

- NuSTAR: 6-80 keV imaging telescope (2012 Feb)
  - will help to study any spectral change.

- eROSITA: the first imaging all-sky 0.5-10 keV survey (2013?)

- LOFT is useful for M82 X-1 and HLX-1, and to discover ULX transients in the MC and M31 (after 2020?)