Suzaku Observation of Two Ultraluminous X-Ray Sources in NGC1313

December 7, 2006 @ Suzaku 2006 Conference

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Ultraluminous X-ray sources (ULXs)

- X-ray sources with $L_x \geq 3 \times 10^{39}$ erg/s: $L_{\text{edd}} > 20 M_{\odot}$
- Often associated with regions of star formation.
- Show variability by a factor of ~5.
- Two spectral states: PL and MCD (La Paroal et al. 2001, Kubota et al. 2001)

- Promising candidate for intermediate-mass black holes (IMBHs).
- Key to understand the black hole radiation in high accretion rate. Study of spectral change is important
ULXs are important to verify the unified picture of BH radiation.
Suzaku observation of NGC1313

- Nearby face-on Sb galaxy at d=3.7Mpc
- Hosts three X-ray luminous sources
- X-1 and X-2 have been extensively studied in X-rays (twice by ASCA, more than 15 times by XMM and 8 times by Chandra.
- Ideal target for ULXs study
- Observed on 2005 October 15 for 90 ks (net exposure ~30 ks)
**X-2: Light Curve/Spectra**

Unfolded Spectra

**XMM archival data**
- 2003/12/21, 12/23, 2005/2/7, 2006/6/5
- 2003/12/25
- 2000/10/17, 2004/1/8, 1/16 and 1/23

(Miller et al. 2003; Feng & Kaaret 2006)

**HF**

**LF**

MCD-type with $T_{in}=1.2-1.6$ keV

PL-type ($\Gamma \sim 2.2$)
**Time-averaged Spectra of X-1/X-2**

**XIS0 (0.3-10 keV)**

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**X-1**

- **Crab Ratio (arbitrary)**
- **Lx = 2.5 \times 10^{40} \text{ erg/s}**
- **PL-like with HE cutoff**

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**X-2**

- **Lx = 6 \times 10^{39} \text{ erg/s}**
- **MCD-like convex spectrum**
Spectral Variability of X-2

- Intensity change by ~50%
- Spectral change: hardens as the source gets brighter

**HF phase:**
- p-free
  - \(T_{\text{in}}=1.86 \text{ keV}, \; p=0.63, \; \chi^2/\nu=151/143\)
- MCD
  - \(T_{\text{in}}=1.50 \text{ keV}, \; 1R_{\text{in}}=80 \text{ km}, \; \chi^2/\nu=172/144\)

**LF phase:**
- MCD
  - \(T_{\text{in}}=1.24 \text{ keV}, \; R_{\text{in}}=100 \text{ km}, \; \chi^2/\nu=72/76\)

**Suzaku BI spectra**

Employ a p-free disk model to examine a disk temperature profile

\[
T(r) = T_{\text{in}} \left(\frac{r}{r_{\text{in}}}\right)^{-p}
\]

- Standard disk (MCD): \(p=0.75\)
- Slim disk: \(p=0.75 \rightarrow 0.5\)
  (Watarai et al. 2001)

X2 is in Slim Disk State
X-1: Light Curve/Spectra

Highest Luminosity ever observed (2.5 x 10^{40} \text{ erg/s})

XMM archival data
- 2004/6/5
- 2003/12/21, 2004/1/8 and 1/17
- 2000/10/17 and 2005/2/7 Oct 17
- 2003/8/23

(S Miller et al. 2003; Feng & Kaaret 2006)

Suzaku data:
- PL-type with HE cutoff

most of XMM data:
- PL-type with $\Gamma=1.7-2.4$
Spectral Variability of X-1

- Spectrum changes above 1 keV
- Opposite to X-2: softens as the source gets brighter

\[
\begin{align*}
\text{p-free fit:} & \\
\text{HF phase: } & T_{in}=2.1 \text{ keV, } p=0.60, \frac{\chi^2}{\nu}=243/219 \\
\text{LF phase: } & T_{in}=2.7 \text{ keV, } p=0.51, \frac{\chi^2}{\nu}=84/95 \\
\text{MCD+cutoffPL fit:} & \\
\text{HF phase: } & \Gamma=0.9, E_c=3.4 \text{ keV, } \frac{\chi^2}{\nu}=240/218 \\
\text{LF phase: } & \Gamma=1.6, E_c=6.0 \text{ keV, } \frac{\chi^2}{\nu}=83/94
\end{align*}
\]

Contradict to Slim disk prediction

- Variable cutoff PL: dominate the spectrum comptonization
- Stable cool disk (R_{in}=4000 \text{ km}, T_{in}=0.2 \text{ keV}): disk truncated (or cooled) due to comptonization

Likely to be in the Very High State
Note on BH mass

• X-2 is interpreted to be in Slim Disk State
  ➢ $L_x$ is close to $L_{edd}$
  ➢ $M_{edd} \approx 50M_{sun}$

• X-1 is likely to be in the Very High State
  ➢ $L_x \leq L_{edd}$
  ➢ $M \geq 200M_{sun}$
  ➢ Even if a super-Eddington condition by a factor of 3 is allowed, $M \geq 70M_{sun}$ is required.

ULXs in NGC1313 are IMBH
Summary

• ULXs are promising candidates of IMBH.
• Spectral change is a key to understand ULXs/BH radiation

• Suzaku found intensity-correlated spectral changes from two ULXs in NGC1313 and strengthened the analogy to BHBs
• X-1 and X-2 are interpreted to be in the Very High State dominated by Comptonization and the Slim Disk State shining close to the Eddington limit, respectively.
• $M \geq 50 M_{\text{sun}} \rightarrow$ IMBH
BackUp Slides
HR-diagram of BHB/ULXs

- Stellar mass BHs
- Advection Dominated Disk (Slim Disk)
- Standard Disk

$L \propto T^2$

$10^{38}$

$10^{39}$

$10^{40}$

$L$ (erg/s)

ULXs

NGC1313 X-2
Spectral Variability of X-2

• Intensity change by ~50%
• Spectral change: hardens as the source gets brighter

• Employ a p-free disk model to examine a disk temperature profile

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- Standard disk (MCD): \( p=0.75 \)
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Suzaku BI spectra

- HF phase: p-free
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- HF phase: MCD
  \( T_{\text{in}}=1.50 \text{ keV}, \ 1R_{\text{in}}=80 \text{ km}, \ \chi^2/\nu=172/144 \)
- LF phase: MCD (p=0.75)
  \( T_{\text{in}}=1.24 \text{ keV}, \ R_{\text{in}}=100 \text{ km}, \ \chi^2/\nu=72/76 \)

X2 is in Slim Disk State