The Value of Swift for Low Luminosity Low Mass X-ray Binaries

..from the perspective of X-ray burst observations

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Outline

- **Introduction**
  - X-ray bursts
  - History of low-L LMXBs
  - Potential of Swift
- **An extreme example: J1718**
  - Swift monitoring
  - Bursting behavior
- **Possible spin-off**
  - X-ray burst absorption spectra
- **X-ray burst observations with BAT and XRT**
  - BAT statistics
  - Automatic slews to 4 X-ray bursts
  - Adjusting the automatic slew strategy
“Low Mass” X-ray Binaries

- Neutron star (or BH)
- Companion star with mass \(< 1 \, M_\odot\)
- Mass transfer occurs when the companion overflows its Roche lobe
- Accreted material lands on NS surface
- Companion can be a star or a degenerate dwarf (H rich or He rich)
- Binary evolution leads orbital period to shorten
  - days > hours > \(~10\) minutes
Structure of an Accreting Neutron Star

- Local accretion rate in low-B NSs: 10 to $10^5$ gm s\(^{-1}\) cm\(^{-2}\)
- After hours to days, accumulate columns of $y=10^8$ gm cm\(^{-2}\) (cf, $10^3$ for earth atmosphere)
- Pressure ($y$*g) builds up to ignition condition for runaway triple-alpha and rp-capture processes
- Can result in thermonuclear shell flash (unstable nuclear burning)
- Layer heats up to $10^9$ K and then cools radiatively

→ X-ray burst !!
X-ray Bursts

- Thermonuclear burning on neutron star surface
  - 5-100 sec typical duration
  - recurrent
  - 2-3 keV black body spectrum
- Peak burst flux sets the Eddington luminosity scale for the neutron star in the system
  - ratio of persistent to peak luminosity provides a good normalized measure of the accretion rate
    - >10% = high rate – possible continuous nuclear burning
    - <10% = low rate – unstable burning = bursts
    - <1% very low luminosity – possible ultracompact
- Variations based on
  - donor composition
  - mass transfer rate
- Probes of nuclear physics / thermonuclear burning
The ‘first’ X-ray burst is actually a good example!

- Still the brightest X-ray burst ever: $1.2 \times 10^{-6}$ erg s$^{-1}$ cm$^{-2}$ (57 x Crab!). Bright enough to disturb earth’s ionosphere.
- New analysis (Kuulkers et al 2009)
- Persistent flux = 0.1 Crab over 2-day time scale
  - $\rightarrow$ accretion rate < 0.1% of Eddington
- Underlying LMXB is a transient, going into a bright outburst (25 Crabs) 2 days later.
30 years later: BeppoSAX-WFC discovers many ‘burst-only’ sources

- BeppoSAX WFC: Two wide-field cameras (2-30 keV; 40 x 40 sq deg); detected 2300 X-ray bursts during 1996-2002
- High probability for detecting rare kinds of bursts (e.g., superbursts), including burst-only sources
- Compilation of ~15 sources by Cornelisse et al. (2004) and Degenaar & Wijnands (2009). Most seem transient, ~20% are persistent
- Definition: $L_{\text{non-burst}} < 0.01L_{\text{burst}}$
- In reality though, ‘burst-only’ is an instrument-dependent definition

<table>
<thead>
<tr>
<th>Object</th>
<th>$\delta^1$</th>
<th>$\delta^2$</th>
<th>Distance (kpc)</th>
<th>$L_{\text{peak}}$ ($10^{32}$ erg s$^{-1}$)</th>
<th>Follow up instr.</th>
<th>$\tau$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAX J1753.5-2349</td>
<td>3'08.6</td>
<td>-0'6</td>
<td>&lt;6.2</td>
<td>&lt;4</td>
<td>Chandra (4.1)</td>
<td>6.0</td>
</tr>
<tr>
<td>1RXS J1700.4-321857</td>
<td>35'28</td>
<td>+0'7</td>
<td>13</td>
<td>15 000</td>
<td>Chandra (3.4)</td>
<td>3.0</td>
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<tr>
<td>1RXS J1718.2-402934</td>
<td>34'73</td>
<td>-17'7</td>
<td>8</td>
<td>700</td>
<td>Chandra (7.8)</td>
<td>47.5</td>
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<tr>
<td>SAX J1752.4-3138</td>
<td>35'84</td>
<td>-2'6</td>
<td>9.2</td>
<td>&lt;3</td>
<td>Chandra (2.0)</td>
<td>21.9</td>
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<tr>
<td>SAX J1753.5-2349</td>
<td>5'3</td>
<td>+1'1</td>
<td>&lt;8</td>
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<td>Chandra (5.1)</td>
<td>8.9</td>
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<tr>
<td>SAX J1818.7+1424</td>
<td>42'3</td>
<td>+13'7</td>
<td>&lt;9.4</td>
<td>&lt;4</td>
<td>Chandra (3.9)</td>
<td>4.5</td>
</tr>
<tr>
<td>SAX J224.9+5421</td>
<td>10'26</td>
<td>-2'6</td>
<td>&lt;7.1</td>
<td>&lt;12</td>
<td>BeppoSAX (0.001)</td>
<td>2.6</td>
</tr>
</tbody>
</table>

Plus GRS J1741.9-2853, SAX J1828.5-1037, SLX 1737-282 (r), CXOGC J174553.5-290124, CXOGC J174540.0-290005, Swift J174553.7-290347, Swift J174622.1-290634 and XMM J174457-2850 (see Degenaar & Wijnands 2009)
Low luminosity accretors, probably ultracompact systems ($P_{\text{orb}} < 1 \text{ hr}$) with low mass transfer rates
What can Swift do

- Monitor the faint fluxes with the XRT through a versatile scheduling capability
  - Example: RX J1718.4-4029 – faintest measured NS accretor
- Watch for X-ray bursts through the very wide-field BAT telescope
- Slew to X-ray bursts and measure spectrum of very energetic bursts
RX J1718.4-4029 (Kaptein et al. 2000, in ‘t Zand et al. 2005, in ‘t Zand et al. 2009)

- X-ray burst detection with WFCs in 1996
- Originally unknown: is this a transient or persistent source?
- $L_{\text{non-burst}} < 0.3\% \times L_{\text{burst}}$
- ROSAT-survey detection in 1990 & 1994 at 0.03% $\times L_{\text{burst}}$
- Chandra measurement in 2004 at 0.03% $\times L_{\text{burst}}$
- Swift monitoring provides decisive clues
Swift XRT Monitoring of J1718

Red: Chandra-ACIS+HRC

Black: Swift-XRT

~0.01% of X-ray burst peak

0.5–10 keV flux [$10^{-11}$ erg s$^{-1}$cm$^{-2}$]

Time since April 1, 2008, 0:00 UT [d]

(in 't Zand, Bassa, Jonker et al. 2009)
Second X-ray burst ever with RXTE-ASM

- Two bursts in 19 years of persistent accretion
- $L_{\text{non-burst}} < 0.002 L_{\text{burst}}$
- Burst recurrence time is longest ever measured at $125 \pm 88$ day, taking into account exposure by BeppoSAX, RXTE-ASM, INTEGRAL and HETE-2.
Summary for RX J1718.4-4029

- Swift XRT monitoring
  - Confirms the persistent nature of the source, in a way that RXTE or Chandra could not do
  - J1718 is slowest persistently accreting neutron star known
- X-ray bursts recurrence time also substantiates the low mass accretion rate
- Optical photometry w/ Magellan are somewhat inconsistent with ultracompact binary classification, and need spectroscopic re-observation
Potential spin-off: measurement of $z$ on NS surface

- Lower mass accretion rate
  - Slower pycnonuclear reactions and e-capture reactions
  - Less heating = colder neutron stars
- Likely that ultracompact systems have H-poor companions
  - No hot CNO burning cycle
  - Again, colder neutron stars
- To reach ignition, thicker piles of fuel required
  $\rightarrow$ longer and more energetic X-ray bursts (in ‘t Zand et al. 2005, Cumming et al. 2006)
- Convection may bring up heavy ashes of nuclear burning into photosphere
  - Energetic X-ray bursts may have convection zone up to the photosphere (Weinberg, Bildsten & Schatz 2006)
- ‘Lots’ of heavy ashes imprint absorption features in burst spectrum
- Possible to measure gravitational redshift on neutron star surface
  $\rightarrow$ Go after these bursts with Swift slews! (i.e. BAT detection, XRT spectroscopy)
Example: 4U 0614+091

RXTE PCA spectrum during burst

Apparent absorption feature
• 4U 0614+091 is a low-luminosity accretor, X-ray bursts are very rare!
• Inefficient use of narrow-field instrument time to sit and wait for an X-ray burst to occur
• Previous claim of redshift measurement at neutron star surface (Cottam et al; EXO 0748-676) has not been confirmed
• Better to have Swift trigger a prompt follow-up observation when the burst is detected!
  • Burst durations are typically longer (100-200 sec), so it may be possible to detect redshift signatures in the burst tail
• BAT has already enabled X-ray burst science: detection of 4U 0614+091 spin period with BAT event data (Strohmayer et al 2008)
BAT statistics

*BAT designed for GRBs, not for XRBs (sensitive above >12 keV)*
However:

- For $kT_{\text{peak}}=2$ keV, 2% of photons are above 15 keV
- For $kT_{\text{peak}}=3$ keV, 10% are
- BAT exposure varies between 5 and 13 Msec per burster
- $\sim$1000 X-ray burst detections (more than # GRBs!)
- $\sim$32 X-ray bursters (more than half of the active ones)
- Good capability to detect and recognize radius-expansion (only then peak temperature becomes 3 keV)
- Capability to detect oscillations (4U 0614+091; Strohmayer et al. 2008)
Examples of BAT burst detections

- **4U 0614+09**

- **HETE J1900.1-2455**

  "Radius expansion" cooling dip
Swift automatic slews to X-ray bursts

- 8 slews so far
- 3 successful ones, in the sense that the tail of the burst was caught
- From SAX J1810.8-2609 (132 s delay), XTE J1701-407 (→) and A1246-588 (→→)

Falanga et al. (2009)

Delay 133 s

In ’t Zand et al. (2008)

Delay 201 s
Conclusions

- Swift provides the possibility to confirm the persistent nature of low-L source through monitoring
- Swift has the potential to see X-ray bursts from low-L sources
- A good number of X-ray bursts have been detected with BAT, but only 8 have resulted in slews. In roughly half of these the burst was detected with XRT
- Automatic slews are enabled since summer 2009 for M15 X-2, 1RXS J170854.4-31, 1RXS J1718-4029, 4U 1722-30, SLX 1737-282 and SAX J1752.3-3138, which will hopefully result in a higher X-ray burst slew rate