Timing studies of the soft emission in the low-hard state of black hole X-ray binaries with XMM-Newton

Holger Stiele

Albert K. H. Kong (NTHU)

National Tsing Hua University, Hsinchu

The X-ray Universe 2017, Roma
7. June 2017
Low mass black hole X-ray binary

Central object is a stellar mass (3–20 $M_\odot$) black hole.

Accretes matter from its low mass companion star ($M_s \approx 1 M_\odot$, type A,F,G,K,M) through a disc (Roche-lobe overflow).

X-ray emitting region close to event horizon $R_S$. 
State of the art
Timing properties of BH XRBs as seen with RXTE
(3 - 20 keV)

hardness - intensity diagram

power law noise

band limited noise and QPO

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Covariance ratios

Covariance spectrum: rms spectrum between a narrow energy band \((X)\) and a broad reference band \((Y; 1-4\text{ keV}; \text{Wilkinson \& Uttley 2009, MNRAS 397, 666})\)

\[
\sigma_{\text{cov}}^2 = \frac{1}{N-1} \sum_{i=1}^{N} (X_i - \bar{X})(Y_i - \bar{Y}) \quad \sigma_{\text{cov, norm}} = \frac{\sigma_{\text{cov}}^2}{\sqrt{\sigma_{\text{xs,y}}^2}}
\]

Error bars are smaller compared to normal rms spectrum

Covariance ratio: model independent way to compare variability on different time scales

Ratio of cov. spectra on long (segments of 270s with 2.7s time bins) and short time scales (segments of 4s with 0.1s time bins)

Increase of covariance ratio at lower energies has been interpreted as sign of additional disc variability on long time scales (Wilkinson \& Uttley 2009, MNRAS 397, 666)
**Some remain hard**

Some outbursts do not make it to the soft state

**H 1743-322** showed a so-called "failed" outburst in 2008 and 2014

**XMM-Newton** observed **H 1743-322** during these two "failed" outbursts

**GS 1354-64** showed a hard-state only outburst in 2015

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The analysis, we have considered only the data from the Proportional 2002 (206), 2004 (295) and 2007 (239) outbursts of GX 339.

In general the PDS show a BLN component. For observations taken during outburst rise a peaked noise component with a characteristic frequency of the QPO is in the range of 0.17 – 0.25 Hz, and the highest frequency is observed in the observation that is taken after the outburst reached its maximum (Fig. 2). The absolute rms displayed in the diagram (Fig. 1) is obtained by fractional rms was calculated following Belloni & Hasinger (1990). Comparing the count rate to the ones presented in Brocksopp et al. (2000). The hard photon index indicates that the photon index remains below \( \approx 1.6 \). rms variability > 10% \( \rightarrow \) GS 1354 remains hard. As it did in its 1997 outburst. Revnivtsev et al. 2000, ApJ, 530, 955; Brocksopp et al. 2001, MNRAS, 323, 517. Mulas-Darias et al. 2011, MNRAS 410, 679, H. Stiele.
Covariance ratio

**H1743**: flat covariance ratios are observed

**GS 1354**: decrease towards lower energies

In contrast to increase seen in e.g. GX 339-4, Swift J1753.5-0127, which has been interpreted as additional disc variability on long scales (Wilkinson & Uttley 2009, MNRAS 397, 666)

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Energy spectra

<table>
<thead>
<tr>
<th>param.</th>
<th>GX 339/04</th>
<th>GX 339/09</th>
<th>Sw1753/06</th>
<th>Sw1753/12/1</th>
<th>Sw1753/12/2</th>
<th>GS1354</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N_{dbb}$</td>
<td>$40922_{-13085}^{+15215}$</td>
<td>$10825_{-3448}^{+5996}$</td>
<td>$1526_{-771}^{+676}$</td>
<td>$3434_{-1102}^{+972}$</td>
<td>$5526_{-1630}^{+1511}$</td>
<td>$486_{-63}^{+104}$</td>
</tr>
<tr>
<td>$T_{in}$ [keV]</td>
<td>$0.202_{-0.009}^{+0.013}$</td>
<td>$0.223_{-0.012}^{+0.014}$</td>
<td>$0.213_{-0.040}^{+0.033}$</td>
<td>$0.270_{-0.006}^{+0.010}$</td>
<td>$0.257_{-0.009}^{+0.014}$</td>
<td>$0.50_{-0.02}^{+0.01}$</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>$1.65 \pm 0.01$</td>
<td>$1.53_{-0.05}^{+0.03}$</td>
<td>$1.73 \pm 0.03$</td>
<td>$1.57_{-0.07}^{+0.03}$</td>
<td>$1.60_{-0.06}^{+0.01}$</td>
<td>$1.51_{-0.03}^{+0.05}$</td>
</tr>
<tr>
<td>$E_{\text{cutoff}}$ [keV]</td>
<td>$7.6 \pm 0.2$</td>
<td>$7.4 \pm 0.2$</td>
<td>$&gt; 9.3$</td>
<td>$7.2 \pm 0.2$</td>
<td>$7.3_{-0.2}^{+0.1}$</td>
<td>$6.82 \pm 0.08$</td>
</tr>
<tr>
<td>$E_{\text{fold}}$ [keV]</td>
<td>$17.8_{-3.8}^{+6.5}$</td>
<td>$19.8_{-2.4}^{+5.6}$</td>
<td>$-$</td>
<td>$15.1_{-3.4}^{+3.9}$</td>
<td>$15.4 \pm 2.2$</td>
<td>$9.4 \pm 0.5$</td>
</tr>
</tbody>
</table>

- $\text{TBabs} \times (\text{diskbb} + \text{highecut} \times \text{nthcomp})$
- **GS 1354−64**: smaller inner disc radius; higher inner disc temperature
- ➔ Decrease in covariance ratio cannot be explained with faint disc component
- Intrinsic variability of disc?
- Driven by changes in the Comptonizing component?
- Indicate changes in the accretion geometry?

Covariance ratio

2 possible explanations:

- Higher inclination of H 1743–322 (around 80°; Homan et al. 2005; Miller et al. 2006) compared to other BH LMXRBs (< 70°; Motta et al. 2015) ➔ see H1743 more edge-on ➔ additional disc contribution on longer time scales does not show up

- Inclination of GS 1354–64 unknown

- Presence/absence of add. disc variability ➔ normal/“hard state only” outburst
Soft-to-Hard transition


GX 339-4

Swift/XRT monitoring of the 2014/15 outburst

XMM-Newton & NuSTAR observed source during soft-to-hard state transition
Averaged covariance ratio increases during outburst decay

- Long time scale variability contributes more to overall variability than short time scale one
- Increase towards lower energies steepens \(\rightarrow\) long time scale variability at soft energies becomes more and more important as source hardens

\(\rightarrow\) Accretion disc instabilities (invoked by damped mass accretion rate variations or oscillations in the disc truncation radius (Lyubarskii 1997; Meyer-Hofmeister & Meyer 2003)) get stronger when source hardens

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Summary

- Covariance ratio

GX 339-4, Swift J1753.5-0127 LHS outburst rise: ratio increases towards lower energies ➔ additional disc variability

H 1743-322, GS 1354–64: ratio remains flat or decreases

➔ Observed during “failed” outburst; disc variability

← type of outburst?

➔ Inclination?

Soft-to-hard transition: ratio increases; increase steepens

➔ Accretion disc instabilities get stronger when source hardens