Energy dependence of variability in low mass X-ray binaries

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The observed power spectral shape depends on the energy band, and hence spectral component, we are looking at.
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\(_s\) \\lessgtr 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
requires its own classification scheme → shows 12 variability classes


XMM–Newton observations (2003 & 2004) during

χ variability class ≈ conventional “hard” state


band limited noise and quasi-periodic oscillation (+ upper harmonics)

overall shape agrees between XMM and RXTE

source highly absorbed below 1.5 keV  


4.5 – 8 keV

(4.9 – 14.8 keV)

PDS of GRS 1915+105

Distinct soft and hard band PDS in GRS 1915

Walton D. J., Reis R. C., Cackett E. M., Fabian A. C., Miller J.


R. C.,


Wijnands R., Yang


Zhang W., Jahoda K., Swank J. H., Morgan E. H., Giles A. B.,

Martocchia et al.

Kirsch et al. (2006). Background spectra have been extracte

components are given as dashed lines.

Power density spectra of all five

(see Figure 9).


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PDS: Zoom in Low Energies

1.5 – 2.5 keV
decent fit with power law


1.5 – 2.5 keV
1.5 – 8 keV

using a ZC-Lorentzian break frequency at \( \sim 0.45 \) Hz, while at \( \sim 3.35 \) Hz in the 1.5 – 8 keV band

same observations;
same state

similar result found for MAXI J 1659-152 based on Swift and RXTE data


fits into the picture of a relation between State C and the hard intermediate state
The observed power spectral shape depends on the energy band, and hence spectral component, we are looking at.

Stiele & Yu 2014, MNRAS 441, 1177
PDS in low hard state

- sample of eight observations of 5 different BH XRBs
- two energy bands 1–2 keV and 4–8 keV
determine characteristic frequency in a soft (1–2 keV) and hard (4–8 keV) band, where \( \nu_{\text{max}} = \sqrt{\nu^2 + \Delta^2} \) is the centroid frequency and \( \Delta \) is the half width at half maximum (Belloni et al. 2002, ApJ, 572, 392), for each component present in the power density spectra.

For most observations we find that at least for the component with the highest characteristic frequency

\[
\nu_{\text{max}, 1-2\text{ keV}} < \nu_{\text{max}, 4-8\text{ keV}}
\]
Covariance ratios


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

- Error bars are smaller compared to normal rms spectrum
- Model independent way to compare variability on different time scales
- Ratio of rms spectra on short (segments of 4s with 0.1s time bins) and long time scales (segments of 270s with 2.7s time bins)
- Increase of covariance ratio at lower energies has been interpreted as sign of additional disc variability (Wilkinson & Uttley 2009, MNRAS 397, 666)
Covariance ratio of H 1743

XMM observed H 1743 in 2008 and 2014 during a so-called “failed” outburst. Flat cov. ratio are observed 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)

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

- presence/absence of add. disc variability ➔ normal/“hard state only” outburst

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Power spectral state depends on which spectral component we are looking at!

- From energy spectra: ratio of disc blackbody flux to flux of the Comptonized component > 10% in observations where
  \[ \nu_{\text{max}, 1-2\,\text{keV}} < \nu_{\text{max}, 4-8\,\text{keV}} \]

- Energy dependence of \( \nu_{\text{max}} \rightarrow \) seed photon input for Comptonized photons varies between different energy bands (Gierlinski & Zdziarski 2005; MNRAS 363, 1349)

- Energy dependence of \( \nu_{\text{max}} \) mainly observed at \( \nu > 1\,\text{Hz} \rightarrow \) inner disc radius moves inward during outburst evolution (Ingram & Done 2011, MNRAS 415, 2323)
Summary

- energy dependence of power density spectra

  in low hard state:

  - break frequency of band-limited noise evolves with energy (Stiele & Yu 2015, MNRAS 452, 3666)

  in (hard) intermediate state:

  - two different PDS states coexist simultaneously in the hard and soft band (Stiele & Yu 2014, MNRAS 441, 1177)

- observed PDS state depends on which spectral component we are looking at
On the energy dependence of the persistent and bursting emission in GX 17+2

GX 17+2 is a bursting, radio loud Z source
- Distance: 8 kpc (Kuulkers et al. 2002)

**XMM-Newton observations of GX 17+2**

![Graph showing XMM-Newton observations of GX 17+2](image.png)
Light curves – energy dependence

- bin width: 9.997s
- different burst duration in different energy bands:
  - 2 – 4 keV: light curve peaks about 20 – 30 s after peak in other energy bands
  - 1 – 2 keV: burst not (really) visible
  - persistent soft emission

Evolution of spectral parameters during burst

- decrease of $A_{bb}$
- $T_{bb}$ constant within error bars

The background spectrum is modelled using an absorbed blackbody plus non-thermal Comptonisation model with the parameters given in the table:

<table>
<thead>
<tr>
<th>parameter</th>
<th>type-I</th>
</tr>
</thead>
<tbody>
<tr>
<td>absorption [10$^{22}$ cm$^2$]</td>
<td>1.33 ± 0.03</td>
</tr>
<tr>
<td>$T_{bb}$ [keV]</td>
<td>1.079 ± 0.003</td>
</tr>
<tr>
<td>$A_{bb}$ [km$^2$]</td>
<td>269 ± 4</td>
</tr>
<tr>
<td>nthcomp norm</td>
<td>0.113 ± 0.002</td>
</tr>
<tr>
<td>$\Gamma$</td>
<td>1.57 ± 0.05</td>
</tr>
</tbody>
</table>

$A_{bb}$: background > burst

$T_{bb}$: background < burst
Results

- light curves show that the persistent emission contains a soft component (below 2 – 3 keV) that is also present during the burst and that remains unchanged during the (type-I) burst.

- spectral analysis of the persistent and of the bursting emission shows that the soft component of the persistent emission is emitted in a larger area and at lower temperature than the bursting emission.

→ the soft persistent emission origins in the boundary layer, while the bursting emission origins in unstable nuclear burning on the neutron star surface.