Geometrical constraints on

The origin of timing signals from black holes

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We present a systematic study of the effect of the orbital inclination on the fast time-variability properties of black-hole transients observed by RXTE. We find that the amplitude of low-frequency quasi periodic oscillations (QPOs) depends on the orbital inclination. Type-C QPOs are stronger for nearly edge-on systems, while type-B QPOs are stronger when the accretion disk is closer to face-on. Furthermore, we find that the broad band noise associated with both types of QPOs is consistent with being inclination-independent.

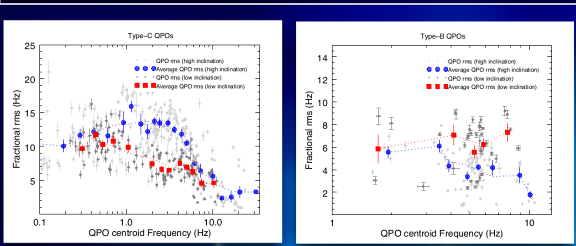


Fig.1 - QPO rms as a function of the QPO centroid frequency. The blue point correspond to QPO detected in high-inclination sources, red squares correspond to QPOs detected in low-inclination sources. These are 'average' points and have been obtained applying a logarithmic rebin to the grey points, corresponding to the values from the individual observations from many sources. Here we did not separate the sources, but we only distinguish between high- and low-inclination ones. Note that the axes are scaled differently for type-C and -B QPOs.

Sample selection

We assumed that the main difference among sources is the inclination of the orbital plane to the line of sight.
We selected only those sources and outbursts which have been densely monitored by RXTE. A dense monitoring is required in order to be sure that any high-inclination feature is be observed, if present. We divided the sources of our sample into high and low incli- nation sources (inclination angle i > 70 deg. and i > 70 de., respectively). All the high-inclination systems have either an accurate inclination measurement or have eventually shown high-inclination features, i.e. absorption dips or eclipses and presence of equatorial winds (see Ponti et al. 2012).

We classified all the remaining systems as low inclination objects, apart from XTE J1859+226 and MAXI J1543-564, that we classified as intermediate inclination systems (see Motta et al. 2014b).

Our final sample includes the following 13 sources: Swift J1753.5-01, 4u1543-47, XTE J1650-500, GX 339-4, XTE J1752- 223, XTE J1817-330, XTE J1859+226, MAXI J1543-564, 4u1630- 47, GRO J1655-40, H1743-322, MAXI J1659-15, XTE J1748-288 (see Table).

Data Analysis

We examined all the RXTE archival observations of the sources in our sample. For each observation we computed power spectra from RXTE/PCA data in the energy band 2-26 keV. We used a Nyquist frequency of 1024 Hz and a frequency resolution of 0.008 Hz. We averaged the PDS and subtracted the contribution due to Poissonian noise (see Zhang et al. 1995).

We selected for our analysis only observations where a somewhat narrow (Q > 2) low-frequency (< 50 Hz) feature was identifiable on top of flat-top or power-law shaped noise

System	Outburst	Inclination (degrees)
Swift J1753.5-01	2005-2010	
4u1543-47	2002	20.7 ± 1.5
XTE J1650-500	2001	> 47
GX 339-4	2002, 2004, 2007, 2010	$\geqslant 40$ - 45
XTE J1752-223	2009	$\leqslant 45$
XTE J1817-330	2006	
XTE J1859+226	1999	$\geqslant 60$
MAXI J1543-564	2011	
XTE J1550-564	1998, 2000	74.7 ± 3.8
4u1630-47	2002, 2003, 2004, 2005	
GRO J1655-40	1996, 2005	70.2 ± 1
H1743-322	2003, 2004, 2008 (Jan. and Oct.), 2009, 2010 (Jan. and Aug.)	75 ± 3
MAXI J1659-152	2010	
XTE J1748-288	1998	

components in the PDS. We fitted the noise components with a number of broad Lorentzian shapes.

LFQPOs are well-described by a variable number of narrow Lorentzians depending on the presence of harmonic peaks. When more than one peak was present, we identified the fundamental based on the QPO evolution along the outburst.
Based on the results of the fitting, we excluded from the analysis non-significantly detected features (significance < 3σ).

We classified the LFQPOs following the method outlined by Motta et al. 2012 (based on Casella et al. 2005), dividing them into type-A, type-B and type-C QPOs.

Due to the very low number of detections, we decided to exclude type-A QPOs from this work.

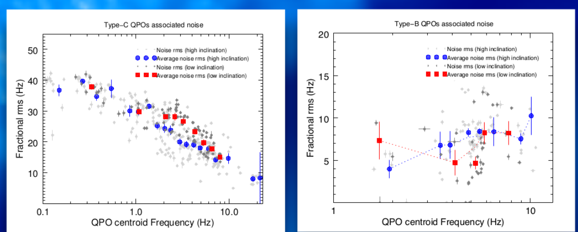
For each PDS we measured the fractional rms of each component of the spectrum (i.e. each Lorentzian used to fit the spectrum).

We measured the rms as the square root of the integral over all the available frequencies of each component in the fit to the PDS. This means that the rms values we reported are measured between 1/128 Hz and 1024 Hz. Whenever a QPO is formed by more than one harmonic peak, we measured the rms of the QPO adding in quadrature the rms of the harmonic peaks. The rms of the noise comes from all the remaining components. The total rms is measured adding in quadrature the rms of all the components of the PDS.

RESULTS

We plotted the rms of the QPO, the noise rms and the total rms as a function of the QPO centroid frequency, dividing the sources in high inclination and low inclination.
We find that the rms distributions of both type-C and type-B QPOs of high-inclination vs low-inclination sources are significantly different. Instead, the noise associated to both type of QPOs appears to be inclination independent.
The main results of our analysis are shown in Figure 1 and Figure 2.

Fig. 2 - Rms of the noise associated with the QPOs in Fig. 1 as a function of the QPO centroid frequency. Color code is the same for Figure 1. The average points have been produced as described in Figure 1.



Assuming that inclination constitutes the only difference between the sources of our sample, we find that:

- **Type-C QPOs** appear stronger in high inclination sources.
- **Type-B QPOs** show the opposite behavior, being stronger for low-inclination sources.
- **The noise** associated to both type-C and type-B QPOs is consistent with being inclination independent.

Our results confirm that:

- Type-C QPOs, type-B QPOs and the broad band noise associated with both QPOs are three geometrically/physically different phenomena.
- Type-C QPOs are consistent with having a geometrical origin and the relativistic precession is the only mechanism that satisfies all our observational constraints.
- The broad band noise might correspond to intrinsic brightness variability induced by fluctuations in the mass accretion rate, thus non sensitive to inclination effects.
- Fast transition between type-C and type-B QPOs could be the best trackers in the X-rays of the relativistic ejections typical of most BH transients.