Feeding Compact Objects: Accretion on All Scales
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The correlations between kHz and LF QPOs in the NSXBs

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Abstract. We study the correlations between low frequency (LF) and kHz quasi-periodic oscillations (QPOs) for 20 neutron star X-ray bianaries (NSXBs). We find that both upper and lower kHz QPOs correlate with the LF QPOs. However, the correlations show 5 parallel branches in the kHz QPO frequency vs. LF QPO frequency relation diagram. We notice that the source will jump from one parallel branch to another when different harmonic frequency of the LF QPO is used to plot the correlation between kHz and LF QPOs. We infer that the parallel branches maybe due to the multi-harmonic QPOs in the NSXBs.

Keywords. Accretion, stars: neutron, stars: oscillations, X-rays: binaries

1. Introduction

The kHz QPO is firstly found in Sco X-1 by RXTE (van der Klis *et al.* 1996). To date, about 35 NSXBs show kHz QPOs (Zhang *et al.* 2012). These kHz QPOs often show twin peaks, named as lower and upper kHz QPOs. The frequency separation between the twin kHz QPOs typically varies by tens of Hz as the lower/upper kHz QPO frequency changes by hundreds of Hz for a single source. The ratio between frequencies of the upper and lower kHz QPOs often close to the 3/2 value, but the other rational ratios occur in some sources as well (Zhang *et al.* 2006).

Various models are proposed to explain the kHz QPOs. Such as the sonic point and spin resonance model (Miller *et al.* 1998), orbital resonance model (Abramowicz *et al.* 2003), relativistic precession model (Stella and Vietri 1999), MHD Alfven-wave oscillation model (Zhang 2004) and so on. Although each model achieves success to a certain extent, the origin of kHz QPOs is still highly debated. In this work, we focus mainly on the correlations between kHz and LF QPOs and we hope this will help to distinguish or improve the QPO models.

2. Observations and Results

There are 35 X-ray sources reported to exhibit kHz QPOs, and only 20 sources whose kHz and LF QPOs frequencies are listed in the published papers. The characteristic frequency of QPOs in the literatures are turned into QPO frequency and the correlations between the frequencies of kHz and LF QPOs for the 20 sources are plotted in Fig. 1. The figure shows 5 parallel branches. (Except for Sco X-1, whose LF and kHz QPO frequencies are 13.64 Hz and 1129.70 Hz (van der Klis *et al.* 1996), which make it locating at the left top of the 5 branches.) The lowest and the upper half part of the 2nd lowest branches stand for the correlation between the frequencies of the lower kHz and the LF QPOs, while the remaining branches represent the correlation between the frequencies of the upper kHz and LF QPOs.

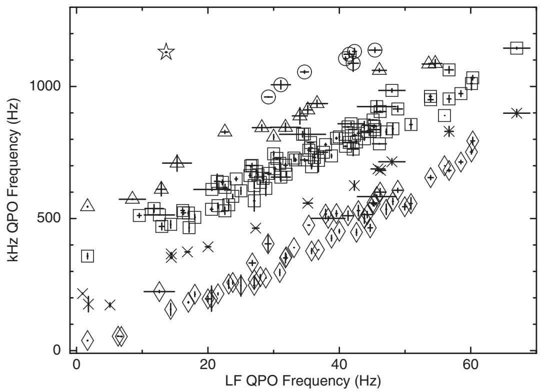

Figure 1. The correlations between the frequencies of kHz and LF QPOs. The lowest and the upper half part of the 2nd lowest branch stand for the correlation between the lower kHz and LF QPOs, while the remain represent the correlation between the upper kHz and LF QPOs.

3. Discussion

We have studied the correlations between the frequencies of kHz and LF QPOs of 20 NSXBs and found the lower kHz QPOs correlate with the LF QPOs. The result is consistent with that of Belloni *et al.* (2002). Moreover, the upper kHz QPOs also correlate with the LF QPOs in the manner of several parallel branches. A single source can simultaneously appear at more than one branch, suggesting that the different branches are not due to the source types.

The NSXBs' LF QPOs usually have a few harmonics and if the harmonic frequency is used to measure the correlation it will jump from one branch to another. For example, in one case of Cyg X-2, the LF QPO at 28.4 Hz has a sub-harmonic at 14.19 Hz and a first harmonic at 55.04 Hz, and its kHz QPO is at 652.30 Hz (Kuznetsov 2002). When the 14.19 Hz is used to measure the correlation, it locate at the 2nd topmost branch. However, the 28.4 Hz (or 55.04 Hz) QPO makes it locate at the middle (or lowest) branch. Moreover, for Sco X-1, if its LF QPO has a third harmonic at about 41 Hz and use the third harmonic to measure the correlation, it will locate at the uppermost branch. As a result, we infer that it is the multi-harmonics of the LF QPO causes the parallel branches in the correlations between the frequencies of the kHz and LF QPOs.

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