First observation of a transition between “parallel tracks” in the kHz QPO frequency vs. intensity diagram

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Abstract. Contrary to theoretical expectations, observations with the Rossi X-ray Timing Explorer (RXTE) show that in X-ray binaries timing properties are not uniquely correlated with X-ray luminosity. For instance, although the frequencies of the kilohertz quasi-periodic oscillations (kHz QPOs) correlate with X-ray flux on short (∼few hours) time scales, on time scales longer than a day the QPO appears at more or less the same frequency, whereas the luminosity may be a factor of a few different. The result is a set of almost parallel tracks in a QPO frequency vs. X-ray flux plot. Despite the “parallel tracks” are a common phenomenon among kHz QPO sources, until now, after five years of observations with RXTE, not a single transition between two of these tracks had been seen. Here I present the first detection of such a transition, in 4U 1636–53.

1. Introduction

Observations with the Rossi X-ray Timing Explorer (RXTE) have revealed kilohertz quasi-periodic oscillations (kHz QPOs) in some 20 X-ray binaries. It is generally thought that these kHz QPOs reflect the motion of matter in orbit at some preferred radius in the accretion disk around the neutron star (see van der Klis 2000 for a review of the phenomenology of these QPOs, and for a description of the models so far proposed to explain them).

Calculations by Miller, Lamb, & Psaltis (1998) show that the inner radius of the disk is set by angular momentum losses to the radiation field: When mass flow through the disk increases, the inner radius of the disk decreases, and therefore the QPO frequency (the Keplerian frequency at this radius) increases. But because in accretion-powered systems luminosity is proportional to the mass accreted onto the compact object, from the above it follows that there should be a one-to-one relation between QPO frequency and bolometric flux.

To the extent that X-ray flux is a good measure of the bolometric flux (see, e.g., Ford et al. 2000), observations with RXTE seem to contradict the above expectations. Figure 1a shows a plot of QPO frequency vs. X-ray intensity for the transient source 4U 1608–52 (Méndez et al. 1999). Each segment there represents an uninterrupted observation lasting ∼1 hour, whereas different tracks denote observations separated by intervals longer than a day. From this Figure it is apparent that frequency and X-ray count rates are positively correlated during relatively short periods, but they are uncorrelated over longer time intervals.
2. Results and Discussion

Despite 5 years of observations with RXTE, so far no single transition between two tracks in a QPO frequency vs. X-ray intensity diagram had been observed. Here I report the first direct observation of one such transition, in an RXTE observation of 4U 1636–53 made in 1998 (see Figure 1b). The observation starts with the source at the upper end of “Track 1” (“BEGIN”), and ends at the upper end of “Track 2” (“END”). In between, 4U 1636–53 goes three times from one track to the other, as indicated by the arrows with numbers 1, 2, and 3. The transitions are very fast (\( \lesssim 300 \text{ s} \)), consistent with upper limits inferred from the time intervals between two consecutive tracks in this and other sources, in diagrams similar to the one shown in Figure 1a (e.g., Méndez 2000).

During the transitions in 4U 1636–53, X-ray intensity changes by \( \lesssim 3\% \). From Figure 1a we see that in 4U 1608–52 X-ray intensity differs by factors of a few between tracks (in 4U 1636–53 jumps of \( \sim 30\% \) are observed over longer time intervals than shown in Figure 1b), it is therefore not clear whether this larger differences in X-ray intensity are the cumulative effect of several small jumps, or if they have a completely different origin.

I will present these results in more detail elsewhere (Méndez & van der Klis, 2002, in preparation), and there I will discuss more extensively their implications upon models of the accretion flow in X-ray binaries.

References

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