FAST X-RAY OSCILLATIONS AND GENERAL RELATIVITY
EFFECTS IN NEUTRON STAR SYSTEMS

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Kilohertz quasi-periodic oscillations (kHz QPOs) are probably caused by matter in Keplerian orbit at some preferred radius in the accretion disc around a compact star. In a given source, QPO frequencies can drift by a few hundred Hz following changes of the inner disc radius, but the disc cannot move closer to the star than the radius of the innermost stable circular orbit (ISCO) predicted by general relativity, hence the kHz QPO frequencies must be limited by some maximum frequency.

Long before kHz QPOs were discovered, it had been already proposed that evidence of the ISCO around neutron stars could be observed in flux variability studies of X-ray binaries: For some equations of state, the neutron star lies within the radius of the ISCO. Clumps of matter crossing that radius will no longer be rotationally supported and will fall extremely rapidly onto the neutron star surface; effectively, the accretion disc is terminated at that radius. There is a maximum Keplerian frequency around such a neutron star, corresponding to the minimum possible radius of the inner edge of the disc; variability of the X-ray flux produced in the disc at frequencies larger than $\nu_K(r_{\text{ISCO}})$ should be strongly suppressed.

kHz QPOs models suggest that the radius of the inner disc edge decreases as mass accretion rate, $\dot{M}$, increases. Hence, when plotted against a quantity that measures $\dot{M}$, QPO frequency should increase, but only until the inner disc edge reaches the ISCO; at that point QPO frequency should remain constant even if the $\dot{M}$-related quantity keeps increasing.

This behavior may have been observed with the Rossi X-ray Timing Explorer (RXTE). Figure 1a shows, for the X-ray binary 4U 1820-30, the frequencies of both kHz QPOs vs. X-ray intensity, which is commonly assumed to be a good measure of $\dot{M}$. Frequencies increase more or less linearly with intensity up to $\sim 2500 \text{ counts s}^{-1}$, and from then on they remain constant, even as intensity increases by $\sim 30\%$. It is intriguing that such behavior is not observed in other sources with kHz QPOs.

For instance, Figure 1b shows a similar plot for one of the kHz QPOs in 4U 1608–52. Interesting in this plot is the coexistence of a good frequency-intensity correlation on timescales shorter than $\sim 1 \text{ day}$ (individual segments), with a lack of correlation on longer timescales. These long-term (uncorrelated) changes of frequency and intensity seen in 4U 1608–52 and other sources could in principle produce a diagram similar to that shown in Figure 1a. Figure 1c shows QPO frequency vs. X-ray intensity for the lower-frequency kHz QPO in 4U 1820–30, including new RXTE measurements: It is apparent that, as in 4U 1608–52, there are long-term uncorrelated variations of frequency and intensity in 4U 1820–30.

Source intensity may not be a good $\dot{M}$ tracer, or QPO frequency may depend upon $\dot{M}$ through the disc, with disc accretion not being a fixed fraction of total $\dot{M}$. Because in several sources a one-to-one relation between QPO frequency and spectral properties has been observed, possible evidence for a QPO frequency
saturation vs. spectral related quantities in 4U 1820–30 seemed to argue in favor of the ISCO interpretation for the maximum QPO frequency observed in this source. However, a careful analysis of the same observations shows that the evidence of the saturation is not so compelling, specially when some instrumental corrections, originally not applied, are taken into account.

To fully resolve this issue an X-ray timing mission with ∼10 times the area of RXTE may be needed.

Acknowledgments

This work was supported by the Netherlands Organization for Scientific Research, grant PGS 78-277, the Netherlands Foundation for research in astronomy, grant 781-76-017, the Netherlands Research School for Astronomy, and LKBF. The author is grateful to Max-Planck-Institut für Astrophysik for their hospitality.

References

1. M. van der Klis et al., IAUC 6319, 1 (1996)
2. T. Strohmayer et al., IAUC 6320, 1 (1996)
3. W. Kluźniak & R. Wagoner, ApJ 297, 548 (1985)
4. B. Paczyński, Nat 327, 303 (1987)
5. C. O. Lousto, Rev. Mex. A&A 13, 3 (1986)
6. W. Kluźniak et al., ApJ 358, 538 (1990)
7. M. C. Miller, ApJ 508, 791 (1998)
8. P. Kaaret et al., ApJ 480, L27 (1997)
9. W. Zhang et al., ApJ 500, L171 (1998)
10. M. Méndez et al. ApJ 511, L49 (1999)
11. M. Méndez et al. in prep. (2002)
12. M. Méndez in 19th Texas Symp., eds. J. Paul, et al., 15/16 (2000)
13. P. Kaaret et al. 1998, ApJ 497, L93 (1998)
14. P. Kaaret et al. 1998, ApJ 520, L37 (1999)
15. P. Bloser et al. 2001, ApJ 542, 1000 (2000)
16. D. Barret et al. 2001, in 3rd Microquasar Workshop, in press (2001)