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Restrictions to Neutron Star Properties Based on Twin-Peak Quasi-Periodic Oscillations

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Abstract. We consider twin-peak quasi-periodic oscillations (QPOs) observed in the accreting low-mass neutron star (NS) binaries and explore restrictions to NS properties that are implied by various QPO models. For each model and each source, the consideration results in a specific relation between the NS mass M and the angular-momentum j rather than in their single preferred combination. Furthermore, the inferred restrictions on NS properties (or QPO models) are weaker for the low-frequency sources than for the high-frequency sources.

Keywords. X-rays: binaries; stars: neutron; stars: fundamental parameters; stars: rotation

1. Aims and Scope

Twin-peak QPOs appear in the variability of several X-ray low-mass NS binaries. The correlations between the upper and lower frequency of these QPOs have been extensively investigated and confronted with the individual models (e.g, Stella & Vietri, 1999, Zhang, 2004, Abramowicz *et al.*, 2005, Zhang *et al.*, 2006, Belloni *et al.*, 2007a, Lin *et al.*, 2011).

The peculiar Z-source Circinus X-1 displays very low QPO frequencies while the atoll source 4U 1636-53 displays very high QPO frequencies (e.g., Boutloukos *et al.*, 2006, Barret *et al.*, 2005, Belloni *et al.*, 2007b). In a serie of works - Török et al. (2010, 2012) and Urbanec *et al.* (2010) - we consider these sources and explore restrictions to NS properties implied by various QPO models.

2. Main Findings

For each considered model and source, the investigation results in a specific relation between the NS mass M and the angular-momentum j rather than in their single preferred combination. We also further explore a finding that the low-frequency sources data are matched by the models better than those of the high-frequency sources. Based on the relativistic precession (RP) model introduced by Stella & Vietri (1999), we demonstrate that this dichotomy is related to strong variability of the model predictive power across the frequency plane implied by the radial dependence of the frequencies of orbital motion. As a consequence, restrictions on the models resulting from observations of the low-frequency sources are weaker than those in the case of the high-frequency sources. These findings are illustrated in Figures 1 and 2.

Moreover, for a particular non-geodesic modification of the RP model that we consider in Török *et al.* (2012), the data of both classes of sources are well-matched (see Figure 2 for illustration). This result is valid not only for the RP model but also for some models assuming non-axisymmetric radial and vertical disc-oscillation modes.

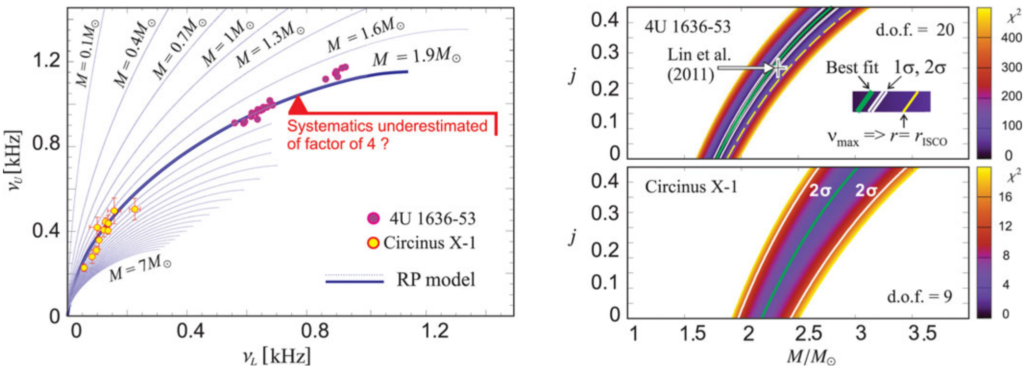

Figure 1. Left: Frequencies predicted by the RP model for $j = 0$ vs. the data. Right: The quality of the fits for $j \neq 0$. The best χ^2 for a fixed M and the corresponding 1σ and 2σ confidence levels are shown together with the value found for the RP model by Lin *et al.* (2011). The dashed-yellow line indicates the upper limits on M and j assuming that the highest observed QPO frequency corresponds to the innermost stable circular orbit (ISCO).

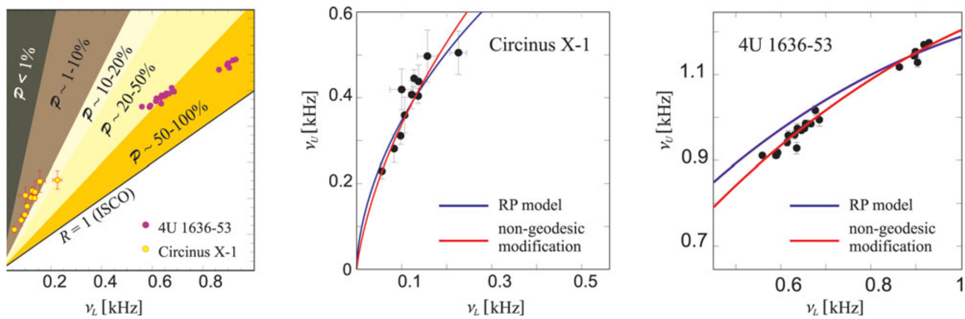

Figure 2. Left: The predictive power of the RP model associated to displayed quantity P depends on the ratio R between the QPO frequencies. Middle and Right: Geodesic vs. non-geodesic fits of the Circinus X-1 and 4U 1636-53 data. See Török *et al.* (2012) for details.

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