Summary

Aims and Scope

Two-peak quasi-periodic oscillations (QPOs) are observed in X-ray power-density spectra of several accreting low-mass neutron star (NS) binaries. We explore and summarize mass-spin relations and limits on NS compactness implied by various QPO models. Finally we confront these relations with NS parameters given in Table 1.

Main Findings

- For each two-peak QPO model and source, the model consideration results in a specific relation between the NS mass $M$ and angular momentum $j$ rather than in their single preferred combination.
- The considered QPO models require the QPO excitation radii in 4U 1636-53 to be close to the inner-most stable circular orbit in the accretion disc (ISCO).
- The application of concrete EoS removes the degeneracy in the mass and angular momentum determined from the QPO models. Moreover, the applied NS EoS are compatible only with some of the considered QPO models.
- The inferred mass of NS in 4U 1636-53 is rather high, above $1.5M_{\odot}$.

Implications of kHz QPO models for Mass and Spin of Atoll Source 4U 1636-53

Observations of the peculiar Z-source Circinus X-1 display unusually low QPO frequencies. On the contrary, the atoll source 4U 1636 displays the twin-peak QPOs at kHz frequencies (see the left panel of Figure 1). The consideration of various kHz QPO models for the data of these various models in question makes the angular momentum $j$ unstable (the solution lies on a curve). The preferred combinations of $M$ and $j$ are indicated by the green line. The green line in Figure 1(a) indicates the best QPO model to the kHz QPO data of 4U 1636-53. The best fit model to the kHz QPO data of 4U 1636-53 is associated to the ISCO. The white lines indicate corresponding 1σ confidence levels. The dashed yellow line indicates a simplified estimate on the upper limit on $M$ and $j$ assuming that the highest observed upper kHz QPO frequency in 4U 1636-53 is associated to the ISCO.

Assumed two-peak QPO Models and Implications NS Parameters

In the poster we assume two low-frequency QPO models:

RP model: The relativistic precession model which explains the kHz QPOs as a direct manifestation of modes of relativistic epicyclic motion of blobs at various radii rather than just a manifestation of the spin (see, e.g., Török et al. 2010, ApJ 714, or their poster in Session 3.5); for a fixed EoS the model predictions are shown in Figure 2. The angular momentum $j$ is limited by the ISCO. The considered kHz QPO models require the QPO excitation radii in 4U 1636-53 to be close to the inner-most stable circular orbit in the accretion disc (ISCO).

TD model: The twin-peak QPO model, upper kHz QPOs are generated by a simple deformation of large-accretion sub-discs ( Damian-Scott et al. 2010, ApJ 714). The TD model predictions are shown in Figure 2. The TD model is limited by the ISCO. The considered kHz QPO models require the QPO excitation radii in 4U 1636-53 to be close to the inner-most stable circular orbit in the accretion disc (ISCO).

QPO Models vs. NS EoS (Global Approach)


Other Considered kHz QPO Models vs. NS EoS in 4U 1636-53

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RP model: the relativistic precession model which explains the kHz QPOs as a direct manifestation of modes of relativistic epicyclic motion of blobs at various radii rather than just a manifestation of the spin (see, e.g., Török et al. 2010, ApJ 714, or their poster in Session 3.5); for a fixed EoS the model predictions are shown in Figure 2. The angular momentum $j$ is limited by the ISCO. The considered kHz QPO models require the QPO excitation radii in 4U 1636-53 to be close to the inner-most stable circular orbit in the accretion disc (ISCO).

TD model: The twin-peak QPO model, upper kHz QPOs are generated by a simple deformation of large-accretion sub-discs ( Damian-Scott et al. 2010, ApJ 714). The TD model predictions are shown in Figure 2. The TD model is limited by the ISCO. The considered kHz QPO models require the QPO excitation radii in 4U 1636-53 to be close to the inner-most stable circular orbit in the accretion disc (ISCO).

Fits to Data and Excitation Radii Inferred from QPO Models

Figure 1. The $\chi^2$ maps of various QPO models for the NS EoS. The $\chi^2$ maps result from the fits of RP model to the kHz QPO data of 4U 1636-53. The NS EoS are assumed for the rotational frequency inferred from X-ray burst measurements. The green line indicates the best QPO model to the kHz QPO data of 4U 1636-53. The white lines indicate corresponding 1σ confidence levels. The dashed yellow line indicates a simplified estimate on the upper limit on $M$ and $j$ assuming that the highest observed upper kHz QPO frequency in 4U 1636-53 is associated to the ISCO.

Figure 2. The $\chi^2$ maps of various QPO models for the NS EoS. The $\chi^2$ maps result from the fits of RP model to the kHz QPO data of 4U 1636-53. The NS EoS are assumed for the rotational frequency inferred from X-ray burst measurements. The green line indicates the best QPO model to the kHz QPO data of 4U 1636-53. The white lines indicate corresponding 1σ confidence levels. The dashed yellow line indicates a simplified estimate on the upper limit on $M$ and $j$ assuming that the highest observed upper kHz QPO frequency in 4U 1636-53 is associated to the ISCO.

Figure 3. The example of best fits to data based on individual models for j = 0 and related excitation radii. The peculiar Z-source Circinus X-1. Left: Frequency relations. The pair of the highest twin-peak QPO frequencies observed in the source is marked by the yellow circle. Right: The QPO excitation radii inferred from the data and each of the fits shown in the left panel. The outer solid circles correspond to the highest observed upper kHz QPO frequencies. The TD model is not included because it does not match the data of Circinus X-1.

Figure 4. The example of best fits to data based on individual models for j = 0 and related excitation radii. The peculiar Z-source Circinus X-1. Left: Frequency relations. The pair of the highest twin-peak QPO frequencies observed in the source is marked by the yellow circle. Right: The QPO excitation radii inferred from the data and each of the fits shown in the left panel. The outer solid circles correspond to the highest observed upper kHz QPO frequencies.

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