

QPOs in Microquasars: the Spin Problem

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Abstract.

In Galactic microquasars with double-peak kHz quasi-periodic oscillations (QPOs), the ratio of the two frequencies is 3:2. This supports the suggestion that double-peak kHz QPOs are due to a non-linear resonance between two modes of accretion disk oscillations. For the microquasars with known mass, we briefly compare the black hole spin estimates based on the orbital resonance model with the recently reported spin predictions obtained by fitting the spectral continua. Results of these two approaches are not in good agreement. We stress that if the spectral fit estimates are accurate and can be taken as referential (which is still questionable), the disagreement between the predicted and referential values would represent a rather generic problem for any relativistic QPO model, as no spin influence would appear in the observed $1/M$ scaling of the QPO frequencies. The epicyclic frequencies relevant in these models are often considered to be equal to those of a test particle motion. However modifications of the frequencies due to disc pressure or other non-geodesic effects may play an important role, and the inaccuracy introduced in the spin estimates by the test particle approximation could be crucial.

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1. Estimating the black hole spin from the resonance models

The resonance model (Kluźniak & Abramowicz 2000) explains the twin peak QPOs as being caused by a 3:2 non-linear resonance between two global modes of oscillations in accretion flow in strong gravity. The modes in resonance are often assumed to be the epicyclic modes. The *orbital resonance model* (see Kluźniak & Abramowicz 2003) demonstrates that *fluid accretion flows* admit two linear quasi-incompressible modes of oscillations, radial and vertical, with corresponding eigenfrequencies equal to the radial and vertical epicyclic frequencies for free particles (Aliev & Galtsov 1981; Nowak & Lehr 1998). According to the resonance hypothesis, the two modes in resonance have eigenfrequencies ν_r (radial epicyclic frequency) and ν_v (vertical epicyclic frequency ν_θ or Keplerian frequency ν_K). Several resonances of this kind are possible and have been discussed (see, e.g., Abramowicz & Kluźniak 2004).

Formulae for the Keplerian ν_K and the epicyclic frequencies ν_r and ν_θ in the field of a Kerr black hole with mass M and spin a are well known, and have the general form

$$\nu = \left(\frac{GM_0}{r_G^3} \right)^{1/2} f_i(x, a) \doteq 32.3 \left(\frac{M_0}{M_\odot} \right) f_i(x, a) \text{ kHz}, \quad i \in \text{K, r, } \theta \quad (1.1)$$

where $f_i(x, a)$ are functions of a dimensionless black hole spin a and a dimensionless radial

Table 1. Spin estimates from the resonance models for microquasars (for details and other considered resonances see, e.g., Török *et al.* 2005; Török 2005). Spin intervals correspond to the 1σ uncertainty in mass, the small error resulting from uncertainty of the frequency measurement is for XTE 1550-564 (GRO 1655-40, GRS 1915+105) up to 0.03 (0.01, 0.05).

Model for	Interval of possible spin a relevant for							
	1550-564		1655-40		1655-40*		1915+105	
3:2 [ν_θ, ν_r]	+0.89	— +0.99	+0.96	— +0.99	+0.88	— +0.93	+0.69	— +0.99
2:1 [ν_θ, ν_r]	+0.12	— +0.42	+0.31	— +0.42	+0.10	— +0.25	-0.41	— +0.44
3:1 [ν_θ, ν_r]	+0.32	— +0.59	+0.50	— +0.59	+0.31	— +0.44	-0.15	— +0.61

* The two columns for GRO 1655-40 indicate numbers following from the two different mass analysis - Beer & Podsiadlowski (2002) vs. Greene *et al.* (2001). Note that while the spin estimates from the 3:2 parametric resonance is for both the cases similar ($a \approx 0.9$), for the other models, the given mass range implies a large range of spins.

coordinate $x = r/M$. For a $n : m$ orbital resonance, the dimensionless resonance radius $x_{n:m}$ is determined as a function of spin a by an equation $n\nu_r = m\nu_\nu$ ($\nu_\nu = \nu_\theta$ or ν_K) †. Thus, from the observed frequencies and from the estimated mass, one can determine the relevant spin (Abramowicz & Kluźniak 2001; Török *et al.* 2005). We summarize the spin estimates for the three microquasars in Table 1.

2. Comparison with the fits of spectral continua

Except for one case, all the resonances considered in Török *et al.* (2005) are consistent with reasonable values of the black hole spin covering the range $a \in (0, 1)$. In particular, the 3:2 epicyclic parametric (internal) resonance model, supposed to be the most natural one in Einstein gravity (Horák 2005), implies the spin $a \sim 0.9$.

The most recent results of the spectral fits correspond for GRO 1655-40 to the spin $a \in (0.65, 0.75)$, and for GRS 1915+105 to $a > 0.98$ (McClintock *et al.* 2006). Obviously, the value for GRS 1915+105 is in agreement with the prediction of the 3:2 parametric epicyclic resonance model, but the same prediction for GRO 1655-40 does not match the spectral fitting. No particular resonance model considered so far can cover the spectral limits to the spin for both microquasars. It could be interesting that the recently proposed 3:2 periastron precession resonance (Bursa 2005b) implies the spin of GRO 1655-40 to be $a \sim 0.7$. Nevertheless, eventually periastron precession resonance requires the spin of GRS 1915+105 $a < 0.8$ which is in strong disagreement with the spectral fitting limit, $a > 0.98$.

3. Troubles with the spin: $1/M$ scaling

In principle one cannot exclude the possibility of different mechanisms exciting the high frequency QPOs in different sources, but there are many indices that the mechanism is the same or similar (e.g., van der Klis 2005; Török *et al.* 2006). McClintock & Remillard (2003) found that the upper QPO frequency in microquasars scales well as $\nu = 2.793(M_0/M_\odot)^{-1}$ kHz which is in good agreement with the $1/M$ scaling of the first term in equation (1.1).

On the other hand the exact $1/M$ scaling holds only for the fixed value of the spin a as functions f_i in equation (1.1) are sensitive to the spin. The spectral limits to the spin for the two microquasars are *very different*: $a \sim 0.7$ vs. $a > 0.98$, and, in addition,

† Because of the properties of Kerr black hole spacetimes, *any* relativistic model of black hole QPOs should be rather sensitive to the spin a , however this sensitivity can be negligible on large scales of mass (Abramowicz *et al.* 2004).

functions $f_i(a, x)$ are more sensitive to the value of the spin when it is close to $a = 1$ (e.g., Török & Stuchlík 2005). Hence, if the spin values obtained from the spectral fits are correct, the observed high frequency QPOs do not show sensitivity to the spin a under the assumption of a unified QPO model. This is a serious problem for any relativistic QPO model handling with the orbital and epicyclic frequencies (1.1).

4. Requirement of a more realistic description

It was found recently that the pressure effects may have a strong influence on the oscillation frequencies. Šrámková (2005) and Blaes *et al.* (2006) studied properties of the radial and vertical epicyclic modes of slightly non-slender tori within Newtonian theory using the Paczyński-Wiita potential, and found the epicyclic frequencies to decrease with increasing thickness of the torus. The same behaviour was found for the resonant radius where the frequencies are in a 3:2 ratio, which on the contrary implies *increase* of the resonant frequencies. Considering the appropriate corrections to frequencies in the Kerr metric, one can reestimate the values of the spin using the resonance model. If the results in the Kerr metric were following the same trend as those in the Paczyński-Wiita case, the spin for some configurations can be *lower* than previously estimated. †

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† In case of the 3:2 parametric resonance, the maximal realistic increase of the resonant frequency due to the pressure effects is about 15 percent (Blaes *et al.* 2006), which for GRO 1655-40 and the mass estimate by Beer & Podsiadlowski lowers the spin down to $a \sim 0.8$.