The twisted accretion disc in OJ 287 — a problem for the standard model and possible ways of its solution

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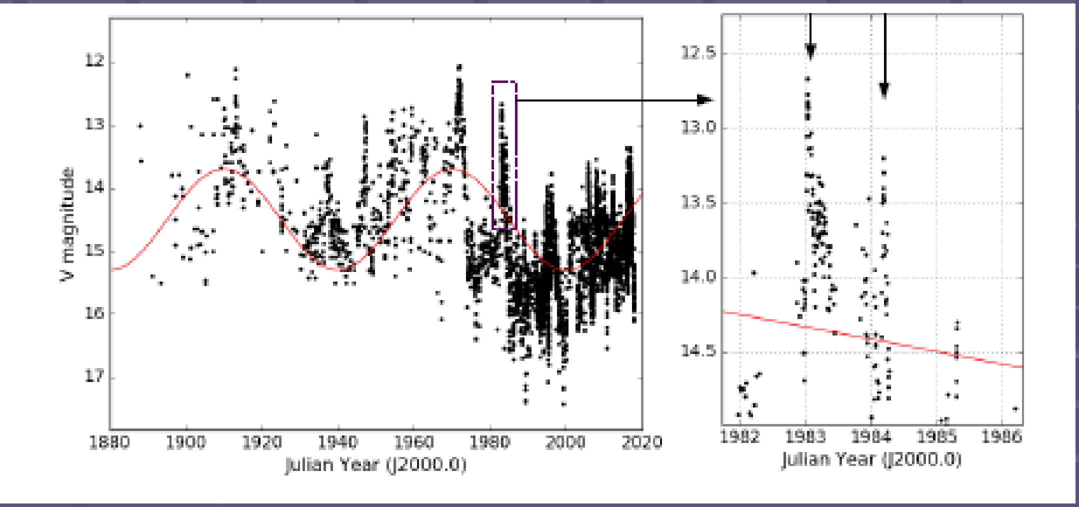
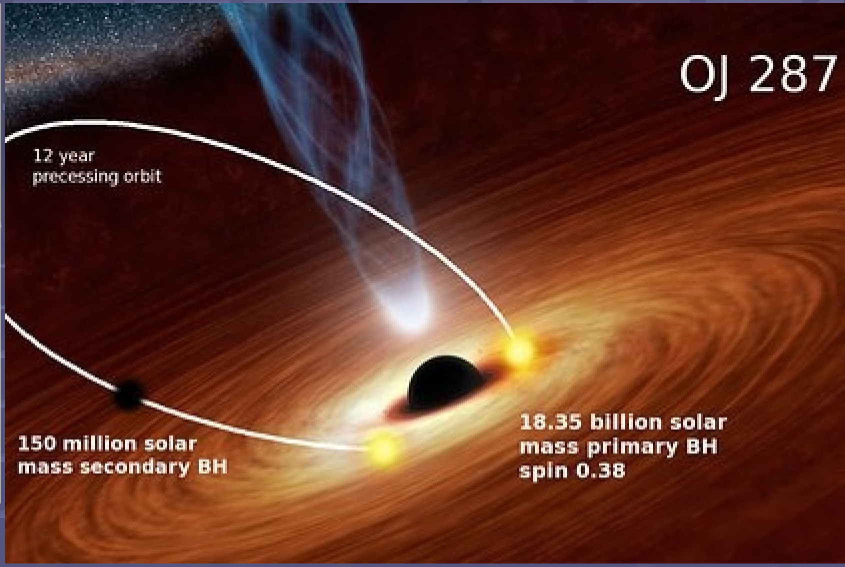
Precessing massive model of OJ 287



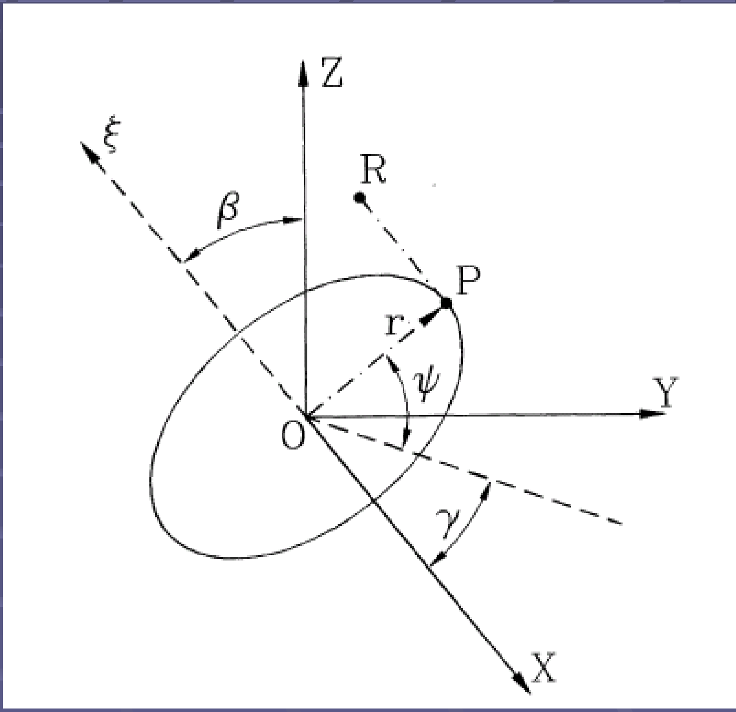


Main parameters of OJ 287 deduced from PM model: the orbital period P_{orb} in the observer's frame ~ 12yr (9yr in the rest frame), the primary mass M ~ 20 billions solar masses, the secondary mass m ~ 150 millions solar masses, semi-major axis ~ $60r_g$, $r_g=GM/c^2$, eccentricity e ~ 0.6-0.7. There are also some indications that the disc α should be large, α ~ 0.1. One can also assume that a typical ratio of the disk halthickness to radius δ is very small as in the standard Sunyaev-Shakura model, which gives δ ~10^{-3}. These parameters have been fixed in our preliminary modelling of the disc. It turned out, however, that in this case the basic property of the model that the secondary crosses the disk only twice per orbital period is absent!

Basic description of the theory of twisted disc appropriate for our case

The disc’s tilt and twist are characterized by two Euler angles β and γ. It is very convenient to introduce the complex quantity

$$\mathbf{W} = \beta e^{i\gamma}$$



Equations desribing disc's tilt and twist depend on terms determined by nodal and apsidal precession of the disc rings. The corresponding precessional frequencies determined by the presence of the primary are standard, the ones due to the presence of the binary are derived by double averaging of the appropriate terms In the perturbing potential over the binary period and period of a disc's ring. The corresponding term has the form

$$\dot{\mathbf{W}} \equiv \dot{\mathbf{W}}_b = i(\Omega_1(\mathbf{W}_b - \mathbf{W}) + \Omega_2 e^{2i\Psi_b}(e^{2i\gamma_b}\mathbf{W}^* - \mathbf{W}_b))$$

A simple approach to the disc's dynamics

Let's simply neglect hydrodynamical interactions in the disc and Consider the evolution of disc's rings accounting only the terms descrbing nodal precessions due to the primary and the binary

$$\dot{\mathbf{W}} = i(\bar{\Omega}_1 \dot{\mathbf{W}}_b + (\Omega_{LT} - \Omega_1)\mathbf{W})$$

$$\bar{\Omega}_{1,2} = \frac{1}{2\pi}\int_0^{2\pi} d\Psi_{eff}\Omega_{1,2}$$

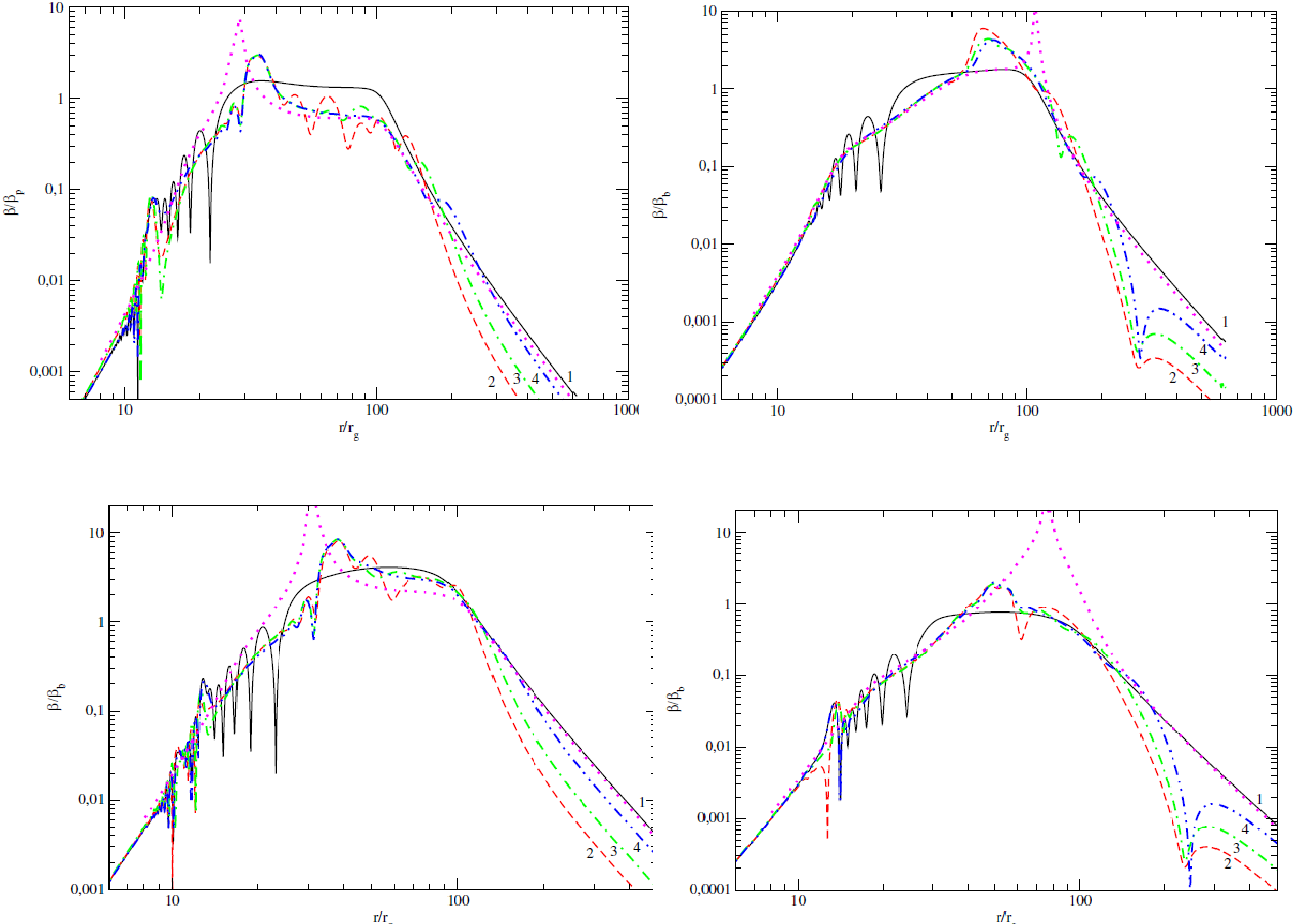
$$\mathbf{W}_b = \beta_b e^{i\gamma_b}$$

$$\mathbf{W} = \frac{\bar{\Omega}_1 \beta_b}{\Delta\Omega} e^{i\Omega^b_{LT} t}(1 - e^{i(\Omega_{LT} - \Omega_1 - \Omega^b_{LT})t}),$$

$$\Delta\Omega = \Omega^b_{LT} - \Omega_{LT} + \bar{\Omega}_1$$

The last term in the brackets has very sharp variations away from the resonance radius r_r defined by the condition $\Delta\Omega(r_r)=0$. It is reasonable to assume that it is averaged out by hydrodynamical interactions. Accordingly, we have $\beta = \frac{\bar{\Omega}_1 \beta_b}{\Delta\Omega}$

It turns out that the condition $\Delta\Omega(r_r)=0$ is satisfied within the orbit. This determines the strong disc response and leads to the problem.



β/βp
r/rg
β/βb
r/rg
β/βb
r/rg
β/βb
r/rg
1
2
3
4

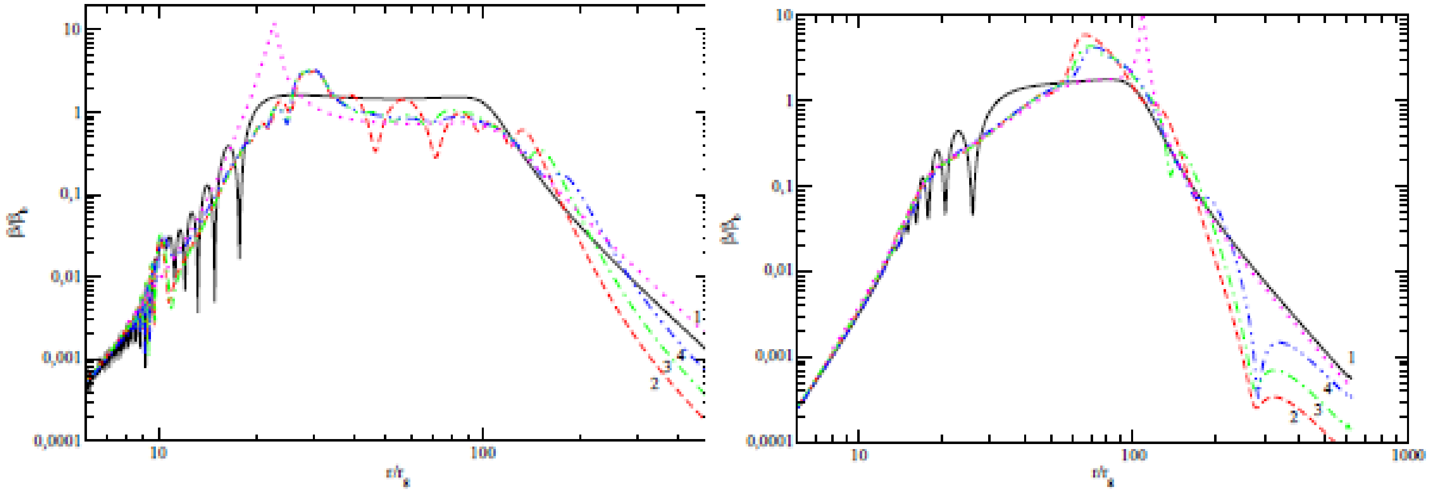
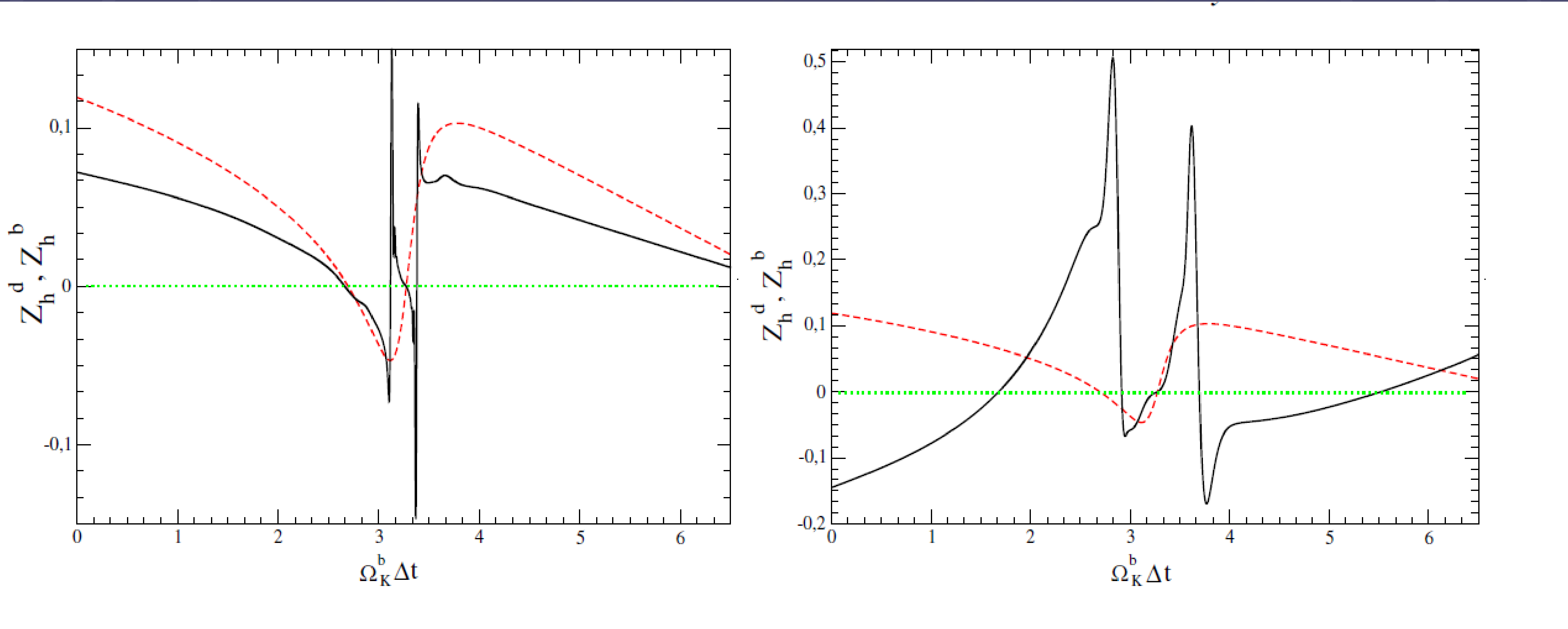
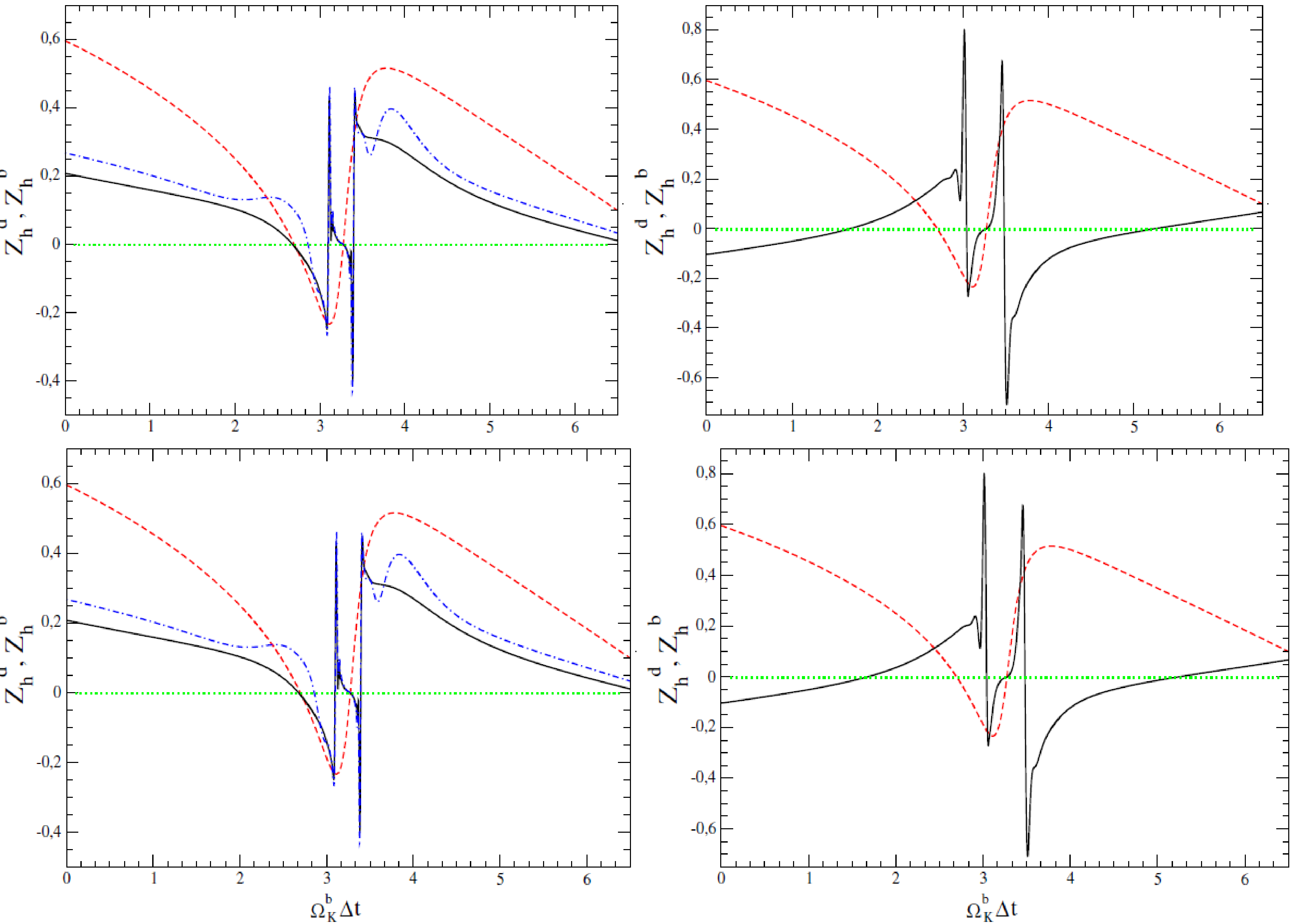


Figure 6. The same as Fig. 3, but for smaller $|\chi| = 0.25$. Also note that the dot dot dashed curves correspond to a slightly smaller $t = 8620\Omega_K^{b\ -1}$ in comparison to the analogous curves in Fig. 3.

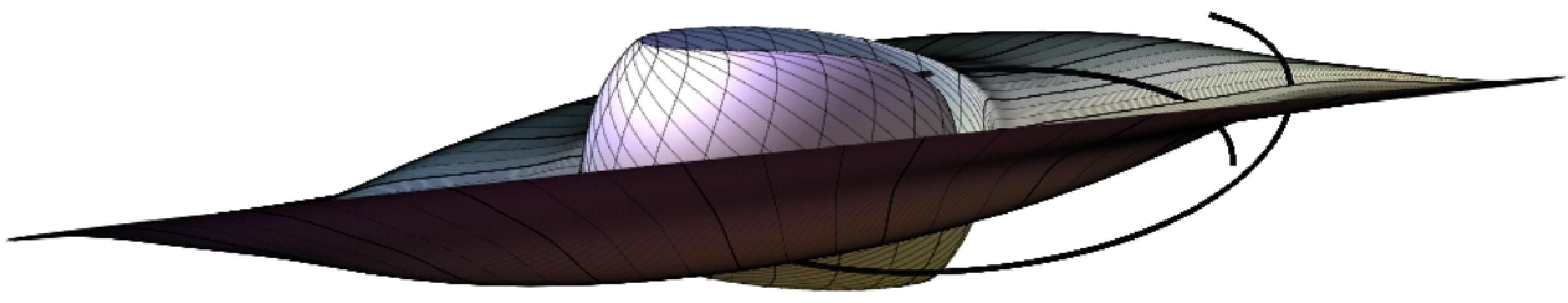
Number of disc crossings in our model per one orbital period

Let $Z_h^{\,b}$ and $Z_h^{\,d}$ be heights of the secondary and the disc above (or, below, if negative) taken along the orbit at the same moment of time. The secondary crosses the disc if and only if $Z_h^{\,b}=Z_h^{\,d}$.





0,6
0,4
0,2
0
-0,2
-0,4
0,8
-0,6
0 1 2 3 4 5 6
Z_h^d , Z_h^b
$\Omega_K^b \Delta t$



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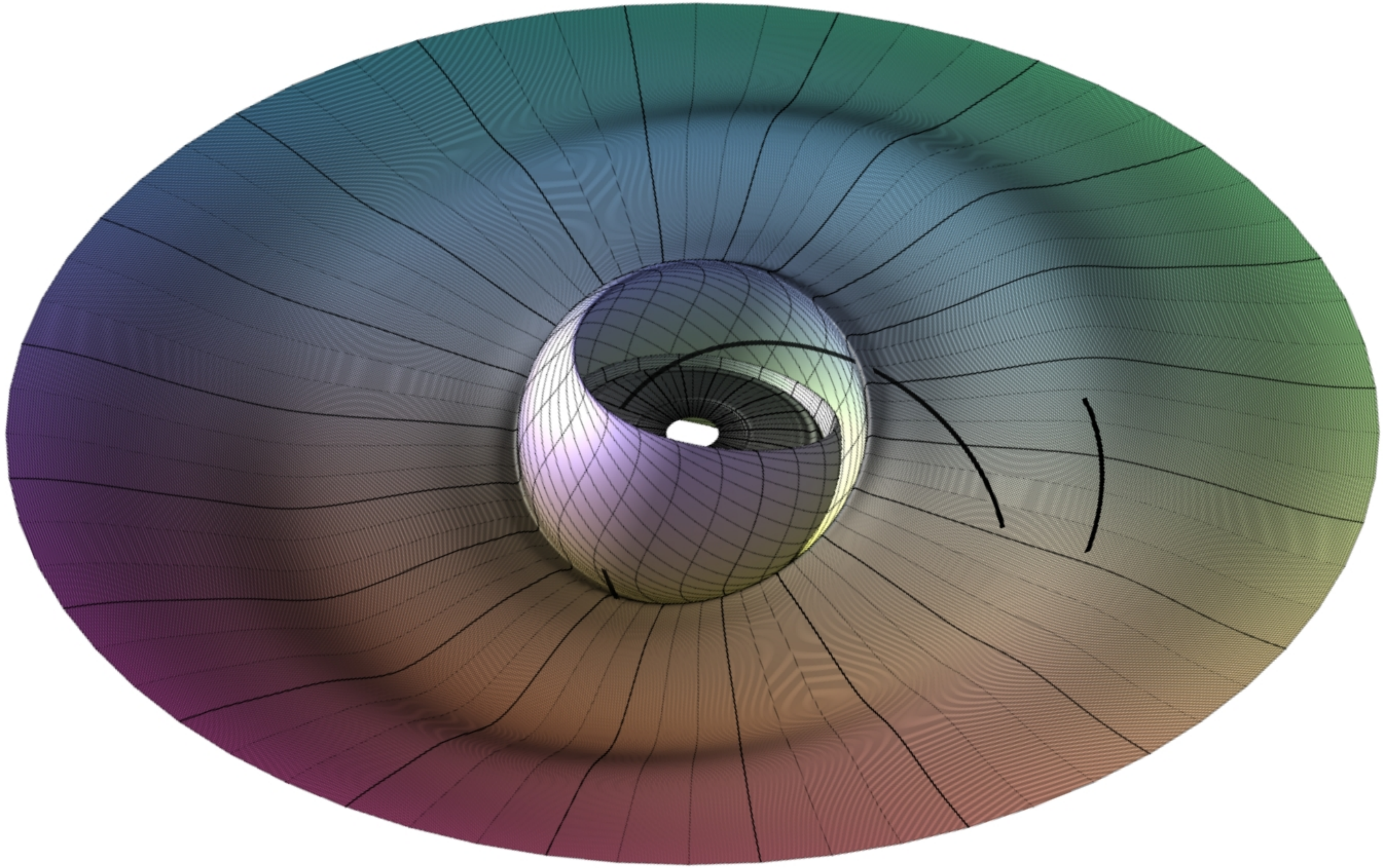

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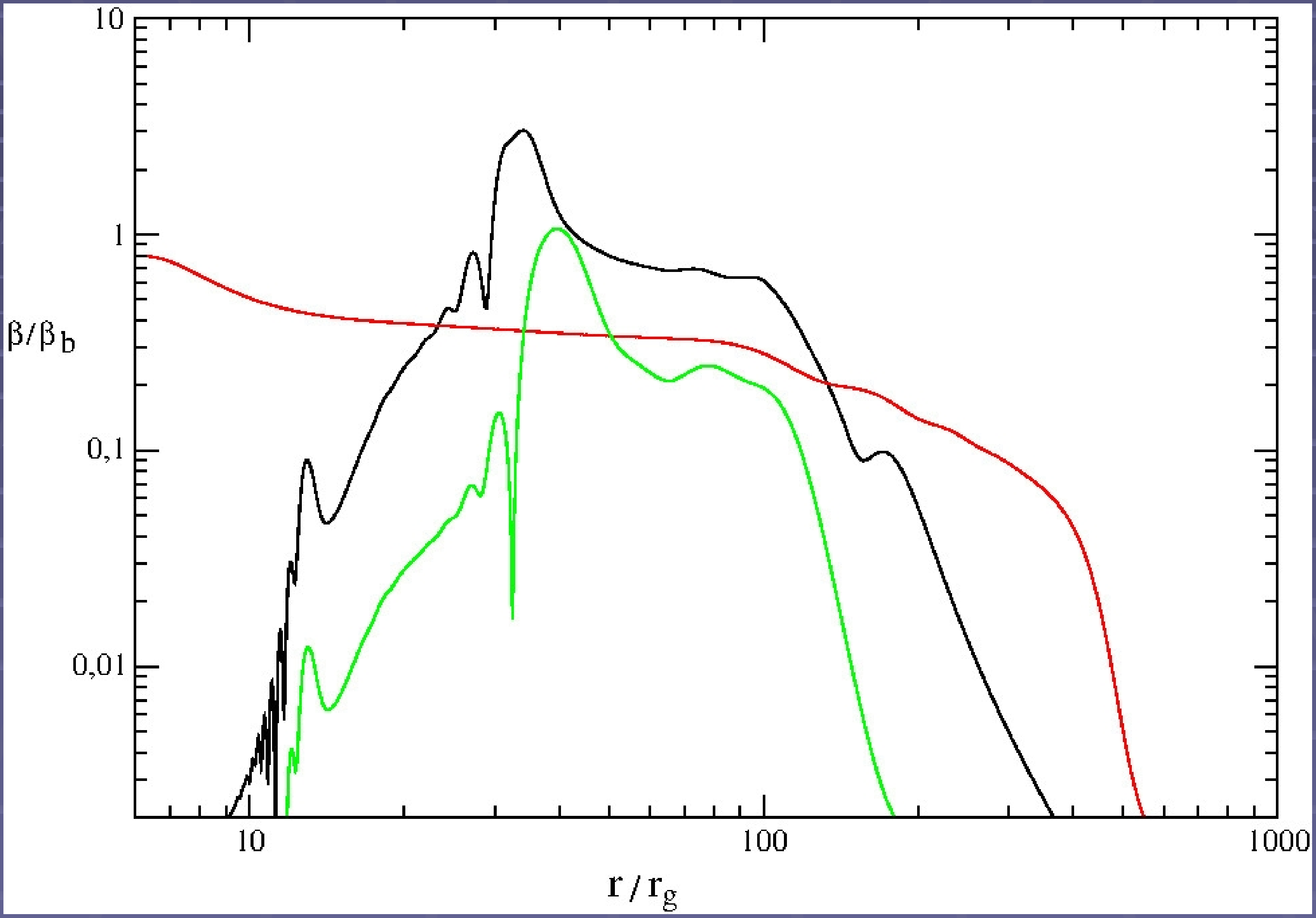
What to do in order to avoid the multiple disc's crossings? Clearly, we need to modify the standard model by changing either the properties of the binary or the properties of the disc.

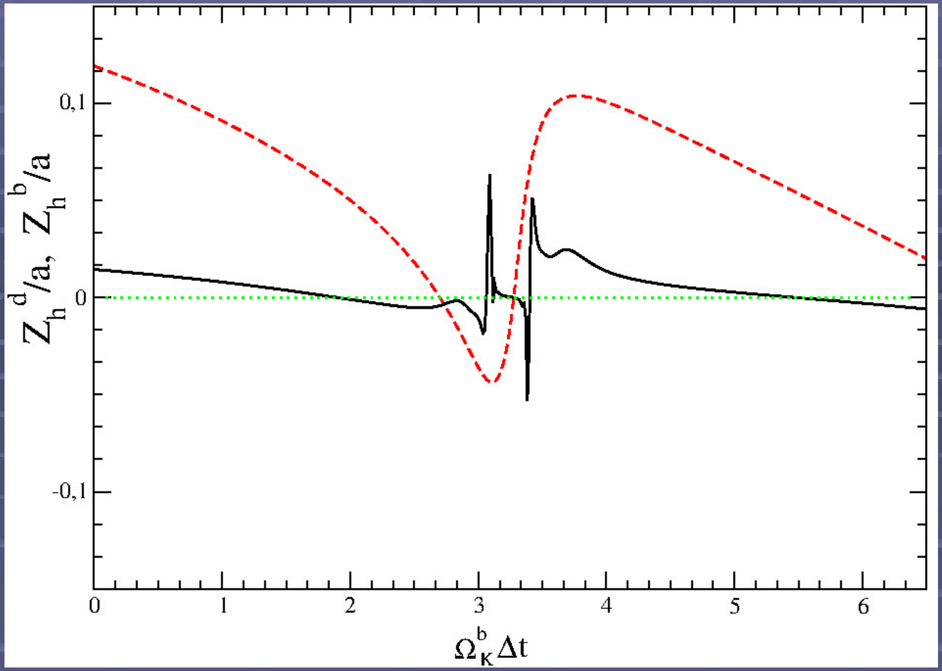
We'd like to do that in the least painful way. Namely, we'd like to keep the orbital parameters fixed and see, which parameters could lead to the situation when only two crossings of the disc occur.

There are three possibilities to try to do so.
1) One can try to make α smaller. However, we have checked that overall disc's shape remains similar in this case. The main difference with the case of the large α is that in the latter case there are some small scale variations of the disc inclination. Their properties can be understood in the framework of the standard theory of waves launching at the resonance (e.g. Goldreich & Tremain 1980).
2) One can make the mass ratio q smaller. This can make the disc response weaker. We use $q=10^{-3}$ in our test calculations.
3) One can consider a non-standard disc with a larger δ. We use $\delta=0.1$ in our test calculations.

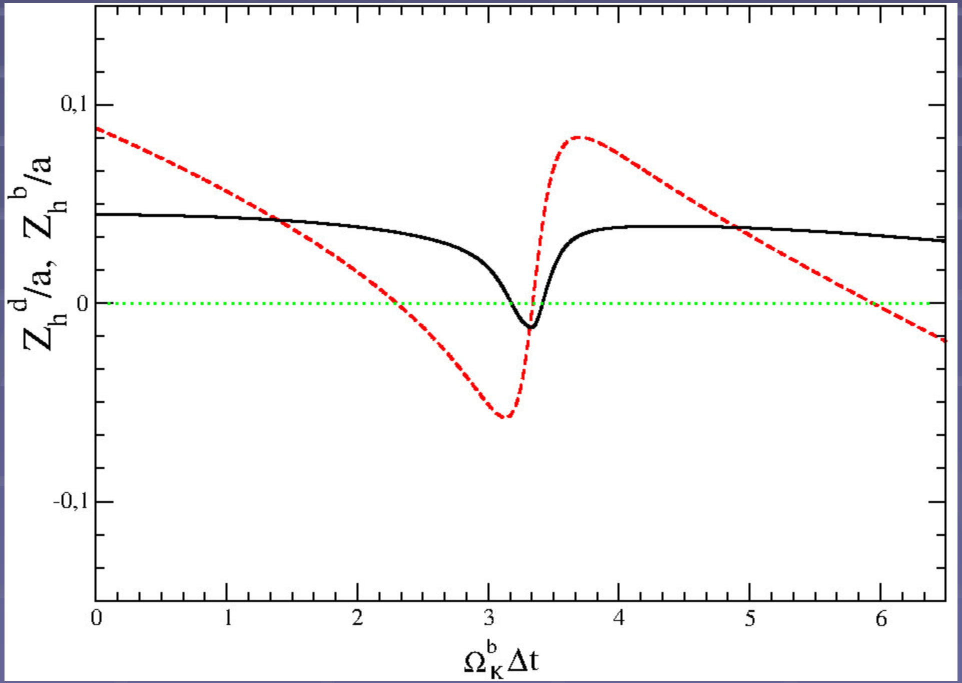
Note that we are going to fit parameters to obtain some 'realistic' sequence of the disc's crossings. Rather, we going to find out whether or not we can have two crossings per one orbital period.

Results





0,1
0
-0,1
$Z_h^d/a,\ Z_h^b/a$
0
1
2
3
4
5
6
$\Omega_\kappa^b \Delta t$



0,1
0
-0,1
$Z_h^d/a,\ Z_h^b/a$
0
1
2
3
4
5
6
$\Omega_\kappa^b \Delta t$

Conclusions

1) For the system with tentative parameters accepted in case of OJ 287 and standard model of the disc there are several (up to 6) crossings of the disc by the secondary. This fact can have dramatic implication for modelling of the light curves. It can either change significantly parameters of the system or refute PM model altogether.

2) When the mass ratio q gets smaller or the relative disc halfthickness δ gets larger the number of disc crossings per one orbital period decreases. This could help to alleviate the problem of multiple disc crossings observed in the standard case. However, a smaller q results in smaller energy release during the disc crossings. This may be problematic for the model. A larger δ cannot be desribed by the standard disc model. However, it is well known that there is descrepancy between theory and observations, which typically require a larger δ to explain modelling of accretion discs spectra.