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IMPACT OF QPOS ON THE ENERGY SPECTRUM OF MICROQUASARS

P. Varniere[1] and R. Mignon-Risse[1]

Abstract. The presence of QPOs in the Power Density Spectra of x-ray binaries is quite ubiquitous and is often modeled as a hot structure orbiting in the disk. While we have been using timing and PDS to determine the presence and explore the possible origin of QPOs, they are, up to now, absent from the spectral analysis. Here we are using a simple analytical model to mimic the hot structure of several QPO models in order to determine their impact on the energy spectrum.

Keywords: microquasars, QPO, Xray

1 Introduction

When looking at the Power Density Spectrum of microquasars the most striking features are the presence of Quasi-Periodic Oscillations. Those Low-Frequency (< 30Hz) and High-Frequency (> 40Hz) QPOs cannot be neglected in the PDS, indeed, the LFQPO alone can have a rms of up to 30%. There are a lot of distinct models to describes them, but most of them imply a warm/hot structure orbiting the disk causing the X-ray modulation.

Nevertheless, when looking at the same data through the energy spectrum the disk is considered smooth with a monotonic temperature profile. If such a featureless disk can easily model states where there is no QPO or even if the QPO has a low impact (meaning low rms), it is incoherent to use it to describe states with prominent QPOs. Here we are checking if the structure at the origin of QPOs also has a measurable impact on the energy spectrum and its fits.

While it is hard to look at a direct impact on the energy spectrum because of its shape, we can look at a possible impact of the presence of QPOs on different correlations between the fit parameters. Then we will use our simplified model (Varniere & Vincent 2015, 2016) to compute energy emission from a disk having an increasingly strong QPO.

Using our model with the module `fakeit` from XSPEC we will be able create a synthetic spectrum of the system { disk with QPO and corona } which then can be fitted similarly to regular observations. The resulting parameters can then be plotted against the real correlation and see if the behavior found in presence of QPOs can be related to the difference in the temperature profile.

2 Link between the disk parameters and QPOs

It has been asserted early on that the properties of the LFQPOs, in particular their frequency, are related to parameters of the disk (Varniere *et al.* 2002) obtained through spectral fitting. As there is much less data for HFQPOs, no similar study has been led yet but HFQPOs seem to be linked with the presence of LFQPOs of type A or B (Remillard *et al.* 2002). Using data from XTE J1550-564 during the outburst of 98-99 and 2000, both known to harbor HFQPOs, we reduced the data and looked at the behavior of the different spectral parameters depending if there is or not a QPO observed.

Unsurprisingly it is for the disk parameters that we see a clear change in the behavior depending if there is or not a HFQPO detected. Indeed, on Fig. 1. we see that a departure from the correlation between r_{in} and T_{in}

[1] AstroParticule & Cosmologie (APC), UMR 7164, Universit Paris Diderot, 10 rue Alice Domon et Leonie Duquet, 75205 Paris Cedex 13, France.

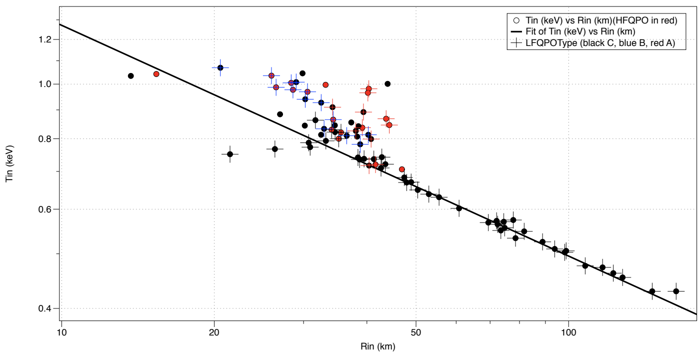

Fig. 1. Correlation between the inner edge position and inner edge temperature as given by the spectral fits for the outburst of 98-99 and 2000 of XTE J1550-564. Red dots represent observations with HFQPOs detected while there is none in the black dots. The crosses represent the type of LFQPO, black for the common type C, blue for type B and red for type A.

when HFQPOs or type A/B LFQPO are observed. As a side note we are looking to see if the few points that depart from the correlation without a published HFQPO frequency have or not some high frequency structure fine enough to be a HFQPO.

As all those data points come from the spectral fitting, it is possible that the departure from the correlation is rooted by the presence of a QPO/warm structure which cause the fit by a smooth disk to fail and gives unrealistic small values for the inner edge of the disk. To test that we need to be able to fit a disk with such structure in a controlled, hence simulated, manner.

3 Simple model for the temperature profile

QPO models often connect the signal modulations to the presence of structures embedded in the disk. Such structures include axisymmetric (see e.g. Bursa *et al.* 2004; Schnittman *et al.* 2006b; Vincent *et al.* 2014), or precessing tori (Schnittman *et al.* 2006c; Ingram *et al.* 2009) or hotspots (Karas *et al.* 1992; Schnittman & Bertschinger 2004; Tagger & Varniere 2006; Pechacek *et al.* 2013).

Our main concern here is not the origin of the structure, but the consequences on the emission. This means that, rather than taking full magnetohydrodynamic (MHD) simulations of the different models proposed to explain QPOs we are interested in, we decided to create a simple, analytical, model for the different structures in order to test more cleanly the different parameters. Indeed, in a full fluid simulation changing one parameter in the initial condition can have repercussions on several observable parameters and therefore it is harder to study the different effects separately.

We take a pertubative a pproach to the disk temperature profile by adding to the disk hydrostatic equilibrium temperature $T_0(r) \propto r^{-1}$ a component that depends on time, radius and azimuthal angle $T_1(t, r, \varphi) = T_0(r)d(r)\, s(r - r_s, \varphi)$. This allows us to minimize the number of parameters to characterize the structures in the disk while keeping a similar framework. $r_s = r_s(t, \varphi)$ represents the structure added to in the equilibrium disk in time-dependent polar coordinates, it can either be a torus or a hotspot. We choose to decompose T_1 as a height function d that depends only on r and a shape function s which is finite only near the disc structure we are studying. This allows us to keep the same structure to take into account a variety of shapes mimicking a variety of models. For simplicity we take the shape function to be gaussian and the height function to be a power-law of r only and related to the equilibrium temperature $T_0(r)$. This provides a simple but useful framework to model a disk with added perturbative structures. Within this framework the perturbed temperature reads

$$T(t, r, \varphi) \quad = \quad T_0(r) \times \left[1 + \gamma \left(\frac{r_c(t)}{r} \right)^{\beta} \exp\left(-\frac{1}{2} \left(\frac{r - r_s(t, \varphi)}{\delta} \right)^2 \right) \right] \qquad (3.1)$$

where $r_c(t)$ is the position of the temperature maximum in the disk (the center of the torus or hotspot). This quantity is allowed to be a function of time. The quantity β measures how fast the temperature decreases from the maximum at r_c, δ parametrizes the radial extent of the structure while γ is the maximum amplitude of the perturbation.

Using these simple models we are able to reproduce several observables such as, for example, the rms amplitude of QPOs as shown in Varniere & Vincent (2015, 2016), hence validating this simple model as representing a disk with a QPO.

Using those parametrized temperature profiles we have created XSPEC models of disks having such structure (`disktor` and `diskblob`, which will be made available once optimized). This allow two things: first we can fit observations with our non-monotonic disk profile and second, using the procedure `fakeit` in XSPEC we created synthetic spectra of a power-law plus the disk emission taking into account the presence of a warm/hot structure. It is this that we will use here to access if the change in the temperature profile does indeed impact the spectrum and hence the fitted parameters.

4 Impact on the energy spectrum fitting

In order to see if the presence of a HFQPO in the disk can reproduce the departure seen in Fig. 1. we computed severals sets of synthetic spectra with the physical parameters of XTE J1550-564. Each set consists of a regular, diskbb-like, disk with slowly increasing structure parameters aiming to reproduce the time evolution effect of a growing QPO and an 'origin point'(with a QPO amplitude of 0) on the (r_{in}, T_{in}) diagram. We then fitted the sets of synthetic spectra with XSPEC following the standard procedure.

The results of the fit from the synthetic spectra are represented as grey stars on Fig. 2. in the case of an 'origin point', at $(45, 0.7)$. They occupy the same space as the HFQPO/type B LFQPO data points from XTE J1550-564 hence strengthening the link between QPO, hot spot, and fit-difficulties. Other sets of parameters, not shown here, reach the type A LFQPOs.

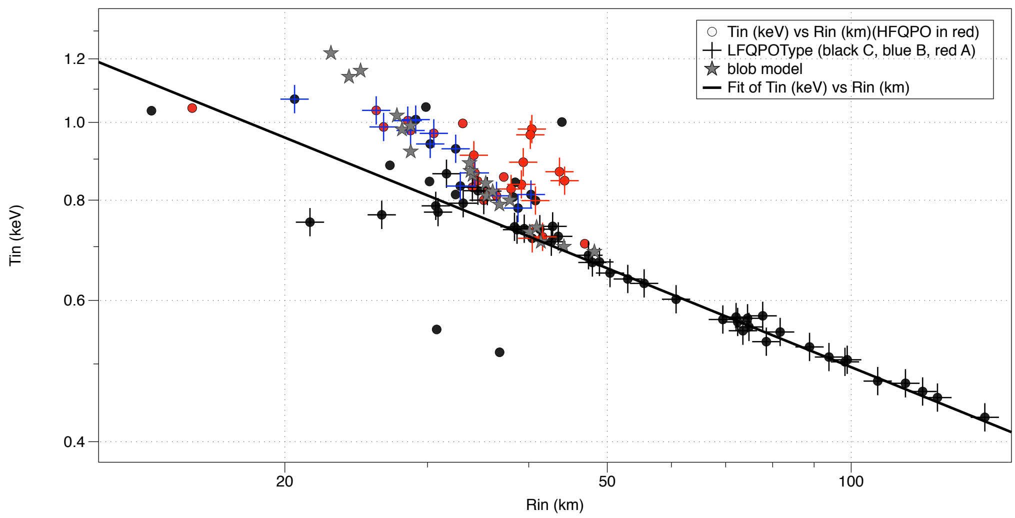

Fig. 2. Correlation between the inner edge position and inner edge temperature as given by the spectral fits for the outburst of 98-99 and 2000 of XTE J1550-564. Red dots represent observations with HFQPOs detected while there is none in the black dots. The crosses represent the type of LFQPO, black for the common type C, blue for type B and red for type A. The grey stars are the result of the synthetic spectra fit.

Following the evolution of the grey stars we see that as soon as the QPO has a non-zero amplitude there is an error on the disk parameters. The error is growing with the QPO amplitude but already with a 5% rms for the QPO we get an error of about 14% on T_{in} and 12% on r_{in}. This error is mostly going toward smaller r_{in} and higher T_{in}, indeed in our case of a 'real' inner edge at 45km we get some fit results up to about 20km for an rms of 20%. We see that, even with RXTE resolution and range, neglecting the QPO in the spectral analysis leads to large errors. As a side note, such departure from correlation could be used to detect, purely from spectral analysis, the possible presence of HFQPOs.

5 Conclusions

Using a simple model to mimic the emission from a disk with a non-monotonic temperature, as has been theorized to be the case in the presence of QPOs, we have created synthetic spectra with increasingly strong QPOs. This allowed us to study in a clean environment the impact of a QPO on the energy spectrum and determine if we can neglect them in the spectral fit.

First, our simulated observations are coherent with the departure from correlation seen in the T_{in}-r_{in} diagram of XTE J1550-564 in presence of HFQPO and LFQPOs B or A. In the case of very small amplitude QPOs there is a negligible impact on the energy spectrum and it can be ignored in the spectral fit. Nevertheless, in the case of an amplitude as small as 5% rms we cannot neglect the presence of the hot structure as it leads to significant errors in the fits. Especially those errors tend to give a smaller inner radius and higher inner temperature. Therefore there is a need to improve the disk fitting by taking into account the structures at the origin of the QPOs if we want to constraint the disk parameters in their presence.

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