SF2A 2012
S. Boissier, P. de Laverny, N. Nardetto, R. Samadi, D. Valls-Gabaud and H. Wozniak (eds)

TOWARD A MODEL FOR HFQPOS IN MICROQUASARS

P. Varniere[1], M. Tagger[2], F. H. Vincent[1] and H. Meheut[3]

Abstract. There have been a long string of efforts to understand the source of the variability observed in microquasars but no model has yet gained wide acceptance, especially concerning the elusive High-Frequency Quasi-Periodic Oscillation (HFQPO). We first list the constraints arising from observations and how that translates for an HFQPO model. Then we present how a model based on having the Rossby Wave Instability (RWI) active in the disk could answer those constraints.

Keywords: Microquasars

1 What does a HFQPO model need to explain

Even if High-Frequency Quasi-Periodic Oscillations are much weaker than their Low-Frequency counterparts we now have data from several outbursts from eight different sources. Indeed, sources like XTE J1550-564, have exhibited HFQPOs with enough regularity to obtain a stringent list of constraints for any theoretical model wishing to provide an explanation for them (Remillard & McClintock 2006).

The first observational fact that one needs to explain is the **modulation of the flux** associated with the frequency. Indeed, even if HFQPO has a rms amplitude much lower than in the case of the LFQPO, the flux still modulates at a level of a few percent and it has been shown to be stronger at higher energies (see Remillard & McClintock 2006, for examples).

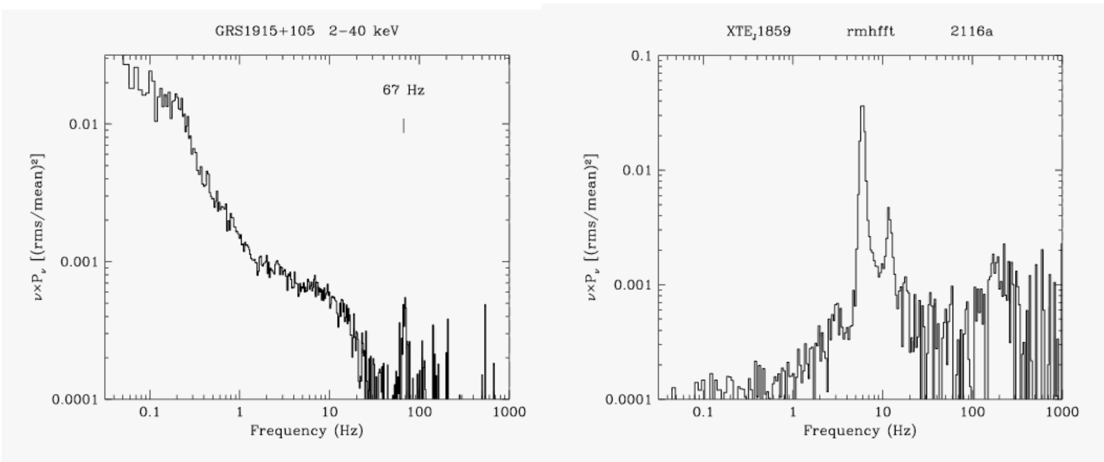

Fig. 1. Left: Power density spectrum (PDS) of GRS 1915+105 showing the 67 Hz. **Right:** PDS of XTE J1859+226 with LFQPO and HFQPO.

Since the observation of the 67 Hz HFQPO of GRS 1915+105 we know that HFQPOs can occur in the absence of LFQPOs. It is therefore required that the HFQPO model be independent of the LFQPO model.

[1] APC, Université Paris 7
[2] LPC2E, Orléans
[3] Physikalisches Institut, Universitat Bern

However, most HFQPO detections do occur in the presence of a LFQPO, as observed for example during the outbursts of XTE J1550-564 or XTE J1859+226. When they co-exist we have type A and B LFQPOs, not the standard type C.

All of this demonstrates that, even if **HFQPO and LFQPO models need to be independent, they also need to be coherent with each other as the two QPOs co-exist in the disk**. This is a more stringent requirement than it may at first seem, as one need not only find a model for the HFQPO's characteristics, but also a model that can coexist in a disk with an LFQPO.

Another exacting requirement coming from observation is the fact that the frequencies of HFQPOs, albeit more stable than in the case of the LFQPO, show a small but significant variation. In the case of XTE J1550-564 the Figure 2 represents the observed occurrences of the HFQPOs in 10 Hz bins during the outburst of 1998-99 and 2001.

Any model aiming to explain the HFQPOs must be able to reproduce the observed dispersion in the frequency.

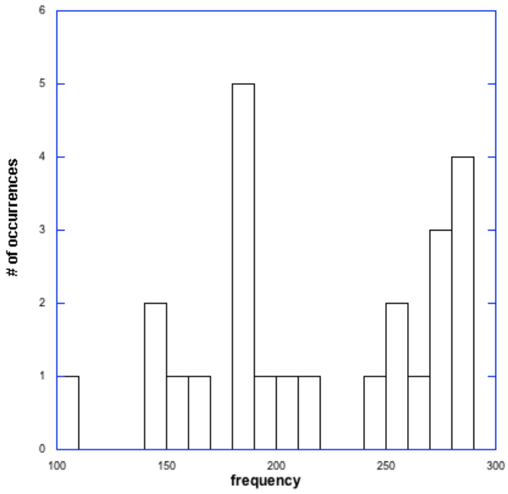

Fig. 2. Observed occurrences of the HFQPOs in 10 Hz bins during the outburst of 1998-99 and 2001.

Another characteristic of HFQPOs is that they can be observed either alone **or** in 'pairs' (with closely related frequencies, most of the time near a 2:3 ratio). **This points toward a mechanism that can select several linked frequencies depending on the disk conditions.**

Any model wishing to explain HFQPOs must be able to explain this small but stringent list of requirements. As we get more observations with future detectors we will be able to add to this list and further constrain the models.

2 The Rossby Wave Instability as a model for HFQPOs

The Rossby Wave Instability is an hydrodynamical instability that occurs in the presence of an extremum of the vortensity (defined by $\Sigma\Omega/(2\kappa^2) \cdot p/\sigma^\gamma$ where κ is the disk epicyclic frequency, Ω is the rotation frequency and σ is the surface density). Because of its characteristics, we proposed the RWI as a possible explanation for HFQPOs (Tagger & Varniere 2006).

In the case of a disk in which the inner edge approaches its last stable orbit an extremum of the vortensity becomes possible therefore leading to the RWI as shown in the hydrodynamic simulation shown on Fig.2. These graphs represent a slab ($z = 0$) of the density in a 3D disk in the Paczynsky & Wiita (1980) gravitational potential, which means a spin $a = 0$. We later used modified Newtonian potential (Artemova et al. 1996) to model the full range of spin and confirmed the results.

Because the inner edge of the disk must be close to its last stable orbit but not 'exactly' at it, there is a small radial range where the instability can develop (Tagger & Varniere 2006) leading to a change in observed frequency. As we do not know precisely the density profile in the disk, especially close to its last stable orbit, it is hard to put a hard boundary on the frequency changes but it could reach 30% without a dramatic change to the profiles.

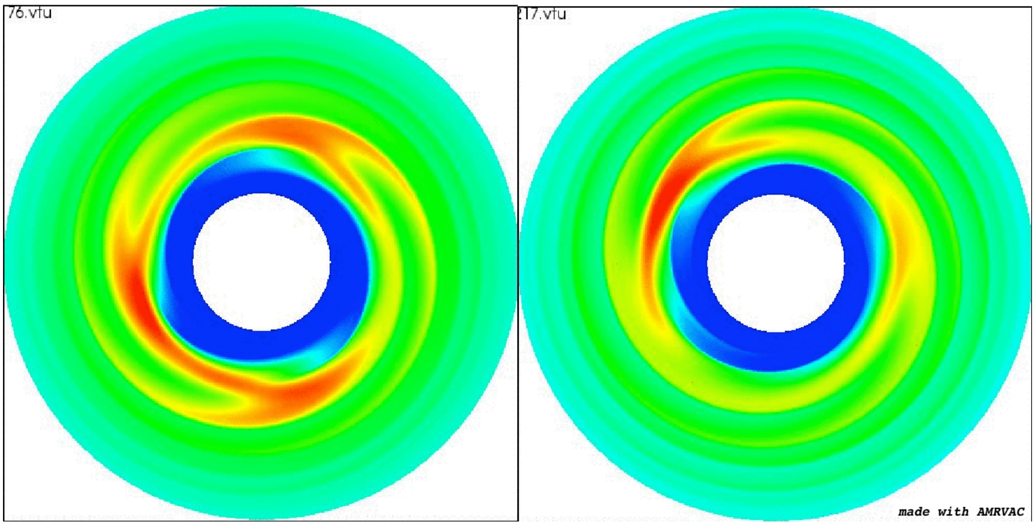

Fig. 3. Density slab of the disk from an hydrodynamic simulation of the RWI at two different times, using the code AMRVAC

Another interesting point is that the RWI does not require the disk to be in the condition for a LFQPO model to occur (Tagger & Varniere 2006). Nevertheless, the RWI was also demonstrated to be stronger in the presence of a vertical magnetic field[4] and we have recently shown the ability of the RWI and the AEI (a candidate to explain the LFQPO) to co-exist in a magnetized accretion disk (Varniere et al. 2001, 2012). Therefore, it could give rise to either HFQPOs alone or HFQPOs and LFQPOs depending on the disk condition, as is observed.

From numerical simulation, we also found that, depending on the disk conditions, the dominant mode can be $m = 3, m = 2$, (see Fig.2) more rarely $m = 1$, or a mix of these (Tagger & Varniere 2006) which fit well with the observed characteristics of HFQPOs.

We now perform 3D simulations of the RWI and confirm the previous 2D and analytical results and also produce the associated image(see Fig.4)/light curve using the code Gyoto (Vincent et al. 2011).

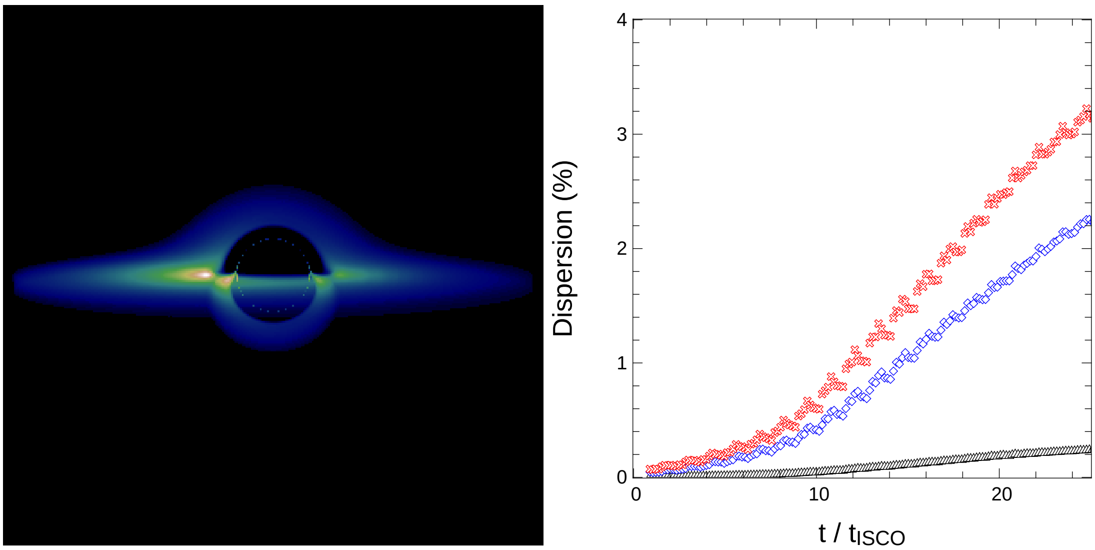

Fig. 4. Left: Ray tracing of a 3D simulations of the RWI at 85° inclination. Right: time evolution of the rms of the flux modulation at 85° , 45° and 5° inclination.

When the RWI is active in the disk the light curve is modulated up to a few % (Vincent et al. in prep.) and this modulation is energy dependent. The precise impact of the spin, especially the case of high spin, is still under study, but the RWI is present and modulate the flux.

3 Conclusions

The RWI is a promising model for HFQPOs as it gives rise to several observed features such as the possibility to have small variations in the frequencies as well as mode selection depending on the conditions in the disk. Moreover, this instability can co-exist with the Accretion-Ejection Instability (Varniere et al. 2001, 2012) proposed as a model for the ubiquitous LFQPO. Lastly, we have recently shown that this instability can effectively modulate the X-ray flux within the observed limit (Vincent et al. in prep.). In the future, we will explore the impact of the spin of the black hole, the link with ejection and the overall evolution of the system.

This work has been financially supported by the GdR PCHE in France and the ”campus spatial Paris Diderot”.

References

Artemova, I. V., Bjoernsson, G., & Novikov, I. D., 1996, ApJ, 461, 565

Paczynsky, B. & Wiita, P. J. 1980, A&A, 88, 23

Remillard, R. A. & McClintock, J. E., 2006, Ann. Rev. Astron. Astrophys. 44, 49

Tagger, M. & Varniere, P., 2006, ApJ, 652, 1457

Varniere, P., Tagger, M. & Rodriguez, J., 2011, A&A, 525, 87

Varniere, P., Tagger, M. & Rodriguez, J., accepted A&A

Vincent, F. H., Paumard, T., Gourgoulhon, E., & Perrin, G. 2011, Classical and Quantum Gravity, 28, 225011

Vincent, F. H., Meheut, H., Varniere, P., Paumard, T. in preparation