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LIVIN' ON THE EDGE: THE RWI IN THE KERR METRIC

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Abstract. The Rossby-Wave Instability (RWI) has been proposed to be at the origin of the high-frequency QPOs observed in black-hole systems. Here we are presenting the first full GR simulations of the instability around a Kerr black-hole which allows us to explore the impact of the spin on the instability. Those simulations, coupled with a full GR ray-tracing, allow us to directly compare our simulation with the observables we get in X-ray.

1 Introduction: Forming the Inner edge of the disk

In order for the Rossby-Wave Instability to develop it needs an extremum of the vortensity (defined by $\mathcal{L} = (\nabla \times V)_\perp/\rho$). While this is often difficult to obtain, a natural place for this to occur is near the last stable orbit of the black-hole where we get an extremum of the epicyclic frequency. Using `NOVAs`(Casse et al. 2017; Casse & Varniere 2018) we ran simulations to form, self consistently, the inner edge of the disk in a Kerr metric in order to check if we would get the extremum of the vortensity needed for the RWI to exist.

As expected the inner edge of the disk formed close to the theoretical position of the last stable orbit and we note that, as the spin increases, the inner edge of the disk gets sharper and thinner therefore creating the condition for the RWI to develop.

2 Application to the fast variability of black-hole binaries

The RWI has been proposed to explain the high-frequency QPOs, partially because of its ability to have multiple modes present at the same time. Here we will explore new way to compare the RWI with observations.

2.1 *What is at the origin of the different HFQPO pairs*

While different pairs of HFQPOs have been sometimes observed, we are not any closer to understanding what triggers those compared to only one. Using `NOVAs` we explored several slightly different setups and then produced

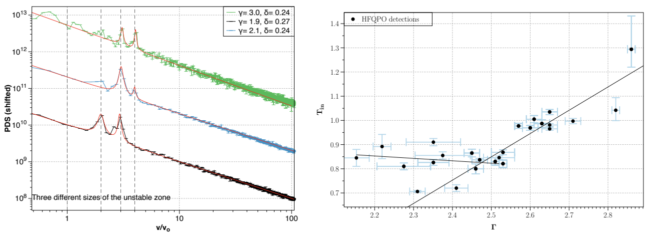

Fig. 1. Left: three PDSs obtained for a=0.9 but different local conditions. **Right:** scatter plot of the power-law slope, Γ, versus the temperature at the inner edge of the disk, T_{in}, for all the HFQPO observations in XTE J1550-564.

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the associated PDS to see when we get a certain type of HFQPO pair. Depending on the setup we get different modes of the RWI and in turn those create different patterns in the PDS depending on which modes dominate and this translates to different peak distributions in the PDS as seen on the left of Fig.1.

While those simulations did not yield to a clear criteria for the different peak distributions, we were able to reproduce all the observed peak distributions (Varniere & Rodriguez 2018) with a variation of the inner part of the system by about 30%. Such variation is compatible with the observations of XTE J1550-564 (see Fig.1.).

2.2 Evolution of HFQPOs with spin

While a direct comparison of the numerical simulation with observations is impossible, using the NOVAs framework we can produce lightcurves and spectrums that we can then compare with observables. One of the first things we looked at is the growth of the RWI in the case of different black-hole spins (Varniere et al. 2018). As you can see on the left of Fig.2. we get higher saturation levels, hence detectabilities, as the spin increases. While this is not a direct observable, we can still look at how the maximum rms amplitude of the observed HFQPOs behaves as function of spin. The right graph of Fig.2. compiled all the HFQPOs' rms published

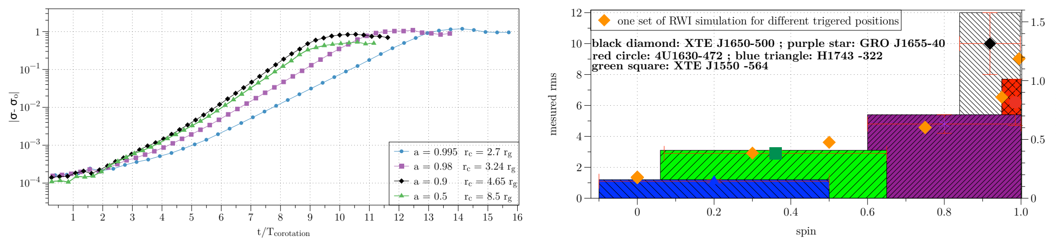

Fig. 2. Left: growth of the RWI as function of the time for different spins. **Right:** distribution of the rms amplitude of HFQPOs as function of spin for all the known couples.

for black-holes with known spins. Even if this is a limited sample, we see a similar trend as the one we have in our simulations, namely that high spin systems have higher rmses. We will be continuing to look for new HFQPO/spin couples to add to that plot as soon as new data become available.

3 Conclusion

Using our new `NOVAs` framework we are able to show that the RWI does indeed develop at the inner edge of a disk at its last stable orbit when full GR is taken into account.

The number and relation between the dominant peaks in Fourier space is dependent on the local disk conditions. All of the observed HFQPO distributions as of today require changes in the local disk compatible with the observed values.

When computing the RWI for the full range of spins we saw that, under similar conditions, the higher spins will have a higher saturation level. While we do not have observations of different systems under the same conditions, we looked at the maximum rms observed as function of spin and showed that higher spin systems tend to get HFQPOs with higher rms.

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