# Living on the edge: the RWI in Kerr metric

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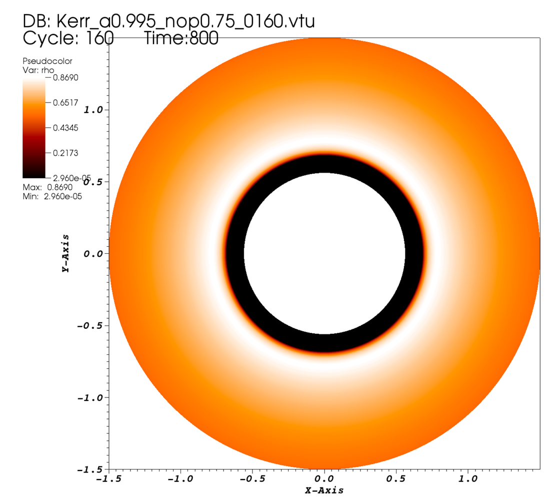
## Abstract:

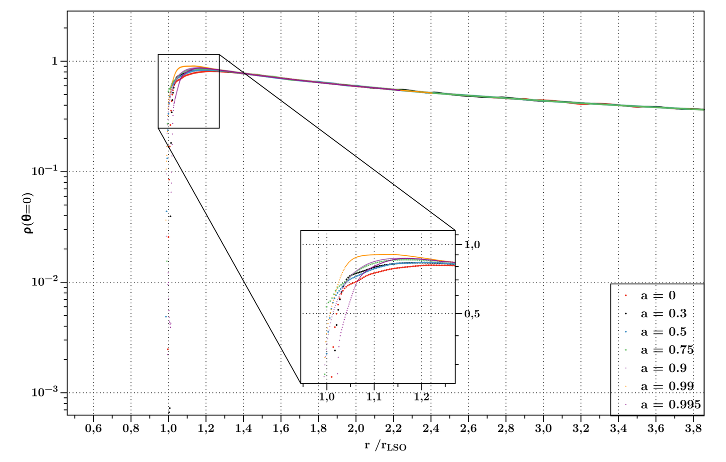
The Rossby-Wave Instability (RWI) has been proposed to be at the origin of the high-frequency QPOs observed in black-hole systems. Here we are presenting the first full GR simulations of the instability around a Kerr black-hole which allows us to explore the impact of the spin on the instability. Those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

## Introduction: Forming the Inner edge of the disk

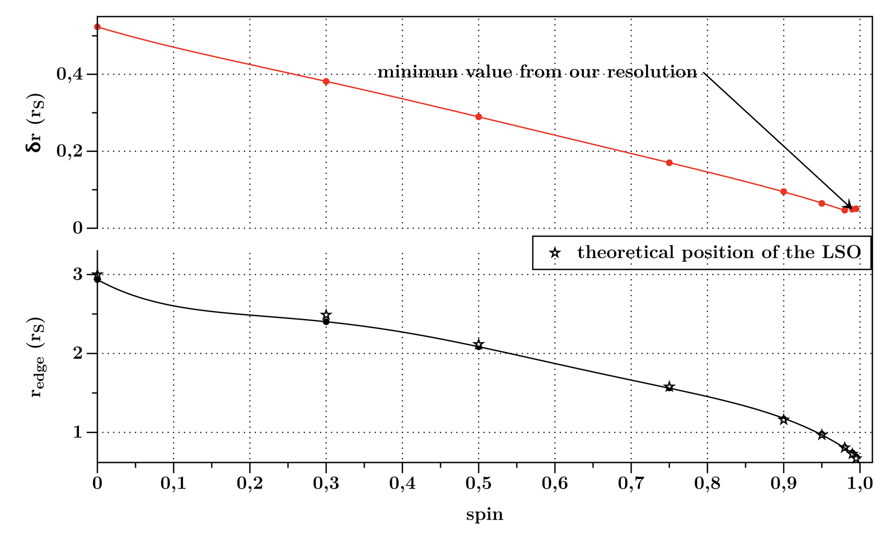
- In order for the Rossby-Wave Instability to develope it needs an extremum of the vortensity. While this is difficult to obtain, a natural place for this to occur is near the last stable orbit of the black-hole where we get an extremum of the epicyclic frequency.

The first step was to form self consistently the inner edge of the disk in a Kerr metric to see if we would get the extremum of the vortensity needed for the RWI to exist.



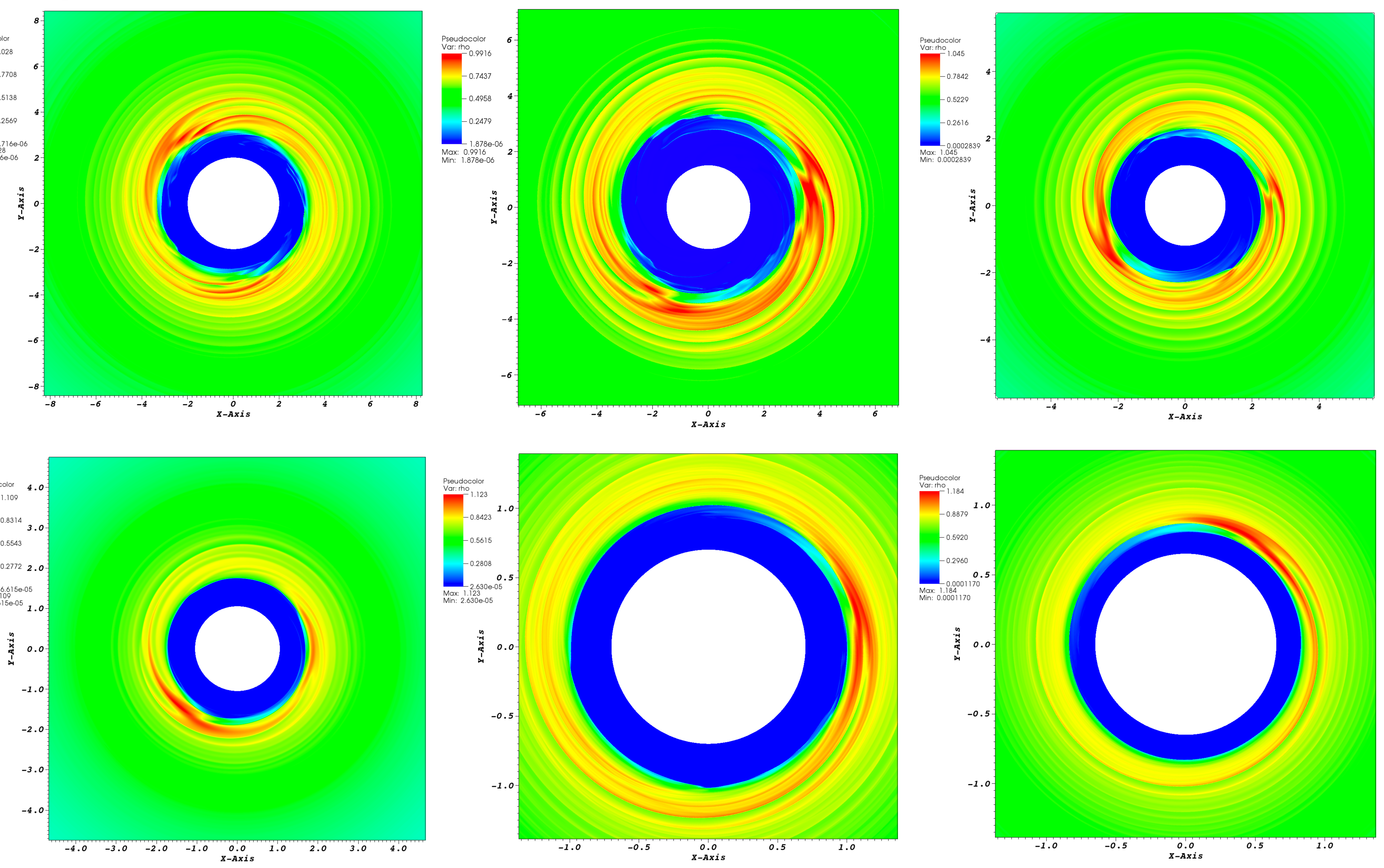
First, we see that the inner edge forms very close to the last stable orbit and that, as the spin increase, the inner edge of the disk gets sharper and thinner




⇒ Not only do we get the needed extremum of vortensity as the spin increases, but this extremum is also better defined as the spin increases

## Following the RWI forming at the edge of the disk

In order to follow the RWI we ran simulations with an increasing spin in $\{0, 0.3, 0.5, 0.75, 0.95, 0.98\}$ while zooming on where the last stable orbit, hence the RWI, is expected.

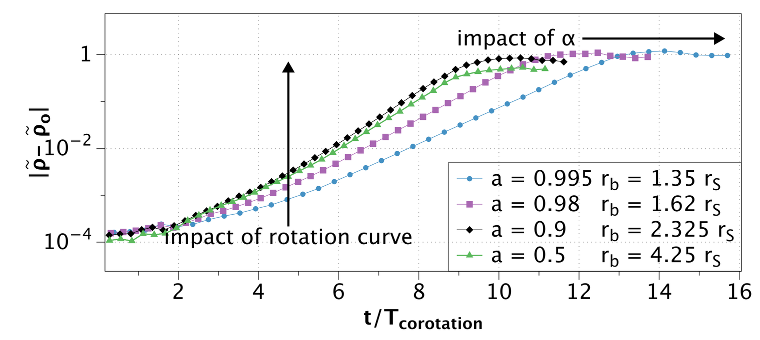


In every case the RWI develops close to the last stable orbit, the exact position depending on the density profile at the inner edge of the disk. One noticeable thing is that, as the spin increases, the RWI features become narrower and for a spin above 0.99 we cannot resolve it.

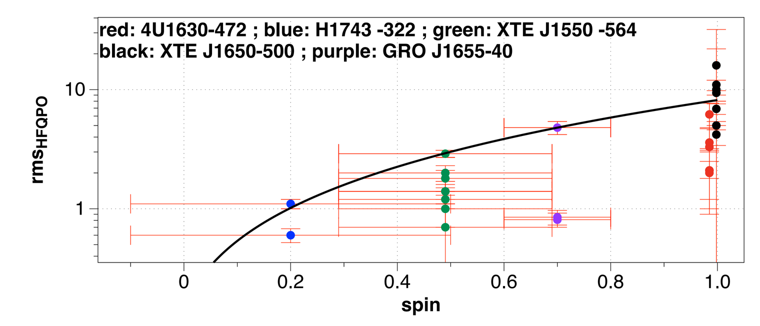
## Comparison with HFQPOs

While a direct comparison of the numerical simulation with observations is impossible, using the **NOVAs** framework we can create lightcurves and spectrums that we can then compare with observables.

- Looking at the growth rate of the RWI in the case of different black-hole spins we get higher saturation levels, hence detectabilities, as the spin increases.



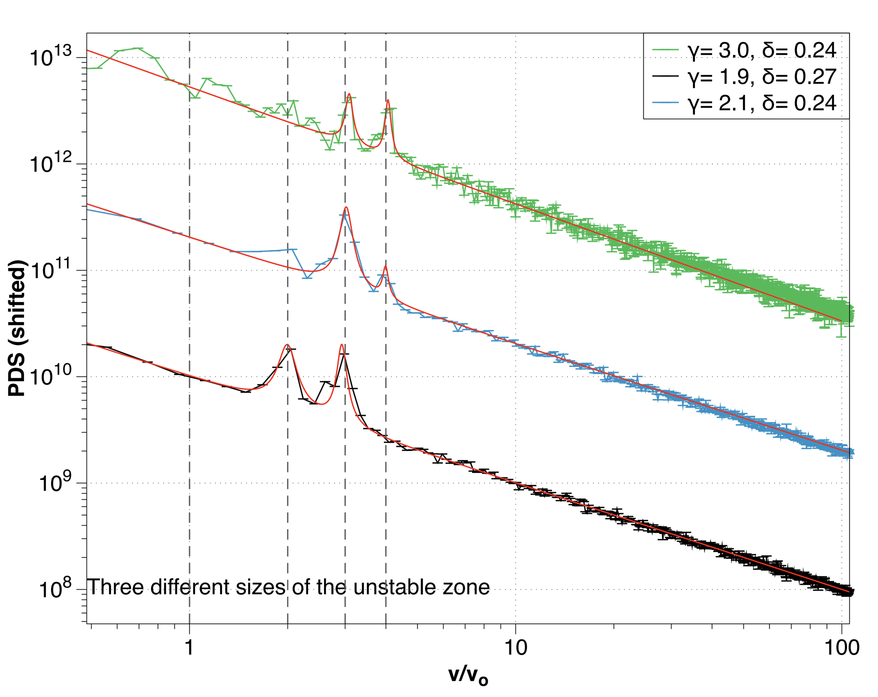

- This is not a direct observable; in observations we can look at the rms distribution of HFQPOs as function of spins to see if we do indeed get higher rms for higher spins.




⇒ We need more black-holes with known spins to confirm this.

## Timing study

- From those simulations we can see which modes of the RWI are dominant in Fourrier space which is where HFQPOs are detected.




⇒ Depending on the local disk conditions we get a wide variety of peak distributions.

## Conclusions:

⋆ 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 dependant on the local disk conditions. All of the observed HFQPOs' 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.

References:

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

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