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Following the Rossby Wave Instability into the Kerr Metric

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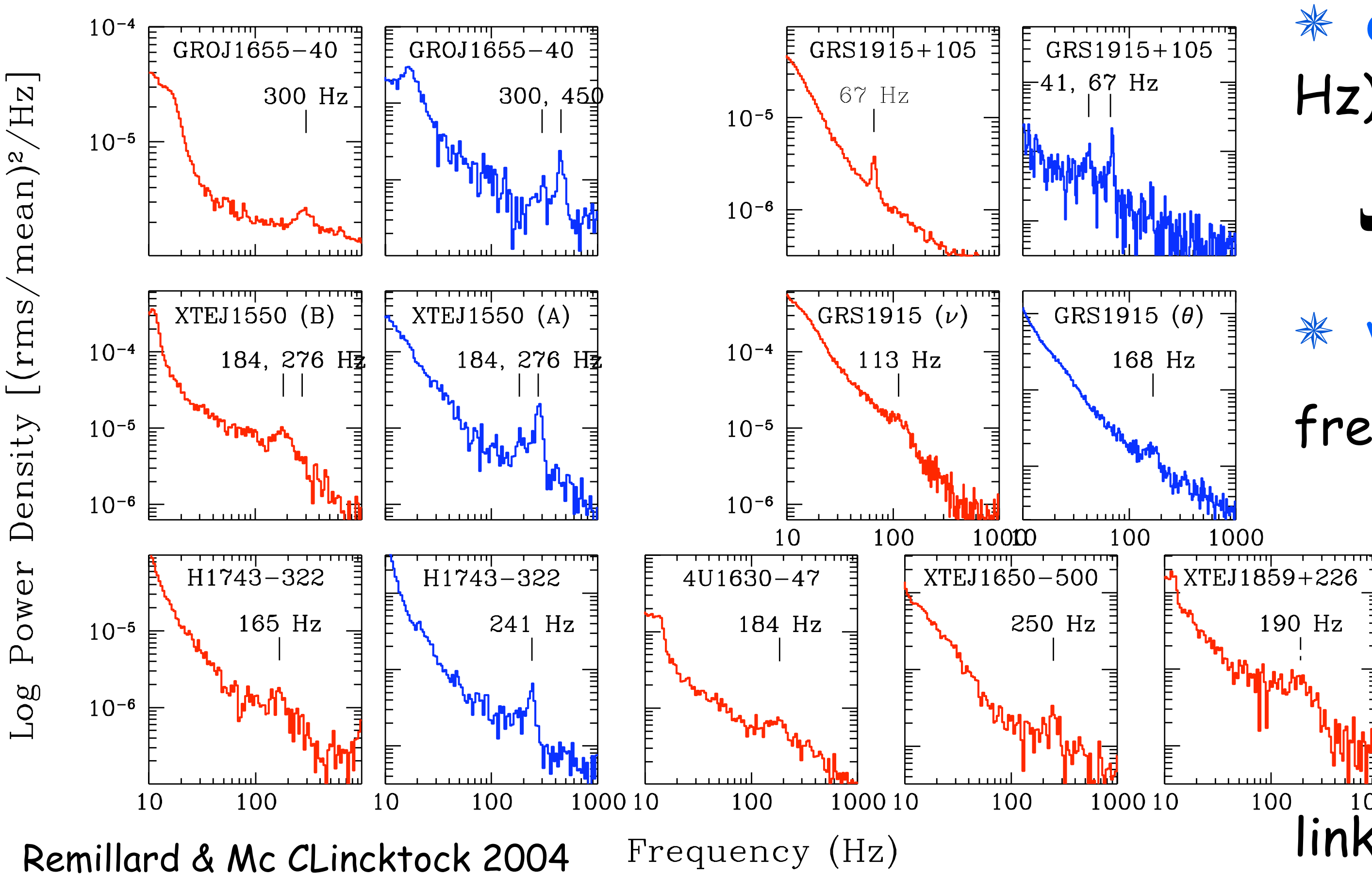
why the Rossby Wave Instability in full GR?

The Rossby Wave Instability (RWI) is one of the few models proposed to explain high frequency Quasi-Periodic Oscillations in black hole systems.



Remillard & Mc CLincktock 2004

✳ observed frequency range (up to a few hundreds Hz) link this phenomena with the last stable orbit

➥ **GR is needed to fully compute the phenomena**

✳ variations in the observed frequency (change in frequency of about +/- 15%)

✳ HFQPOs appear alone or in “pairs” (with related frequencies)

⇒ need one mechanism that can select several linked frequencies depending on the disk conditions

✳ HFQPOs can occur in the absence of LFQPOs

✳ when they co-exist we have “unusual” LFQPO (type A and B)

✳ HFQPOs rms amplitudes are much lower than LFQPO and seem anti-correlated with the LFQPO rms

⇒ the HFQPO model need to be **coherent with a LFQPO model** as they have to co-exist in the disk **while being independent**

⇒ the HFQPO model also need to be able to develop in a **wide range of disk conditions** as LFQPOs can reach high rms value hence changing the condition in which the HFQPO model exists

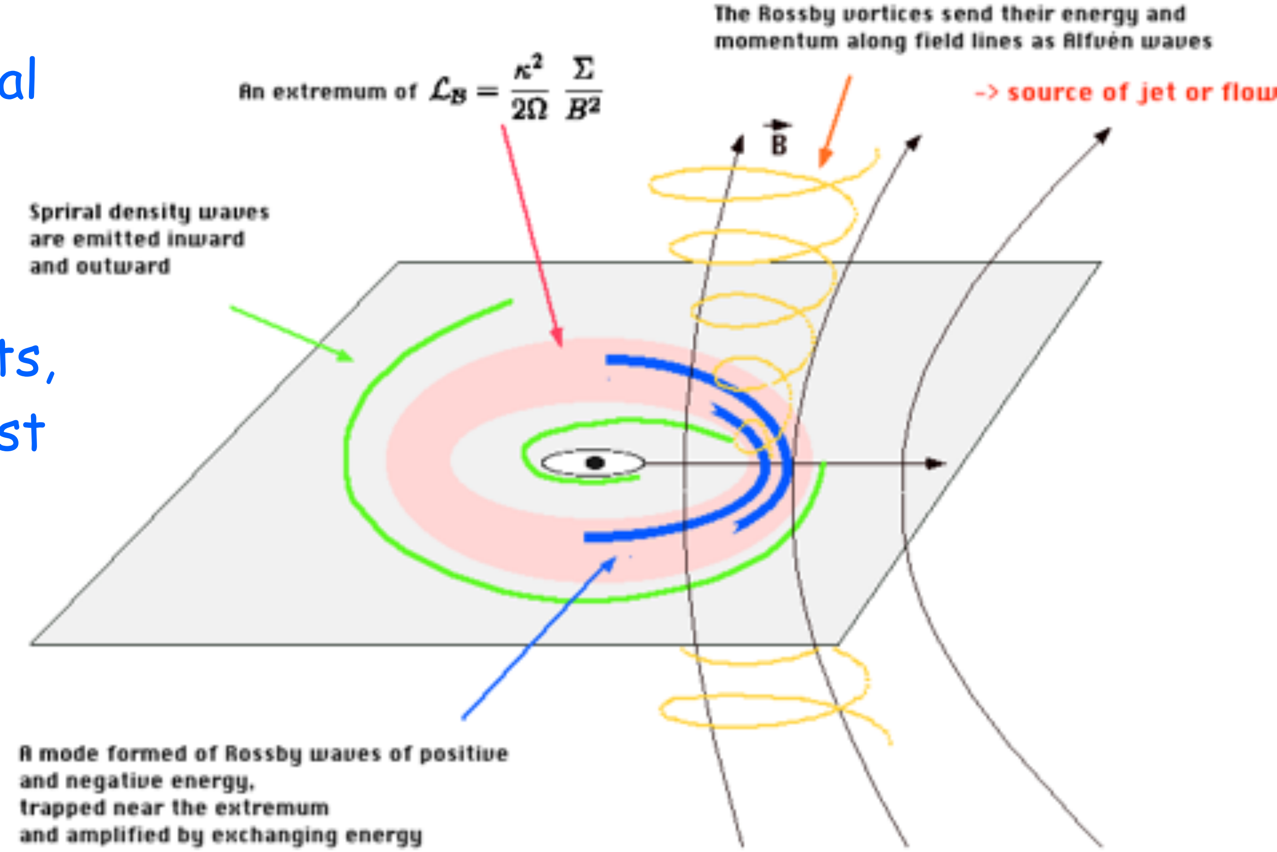
classical RWI

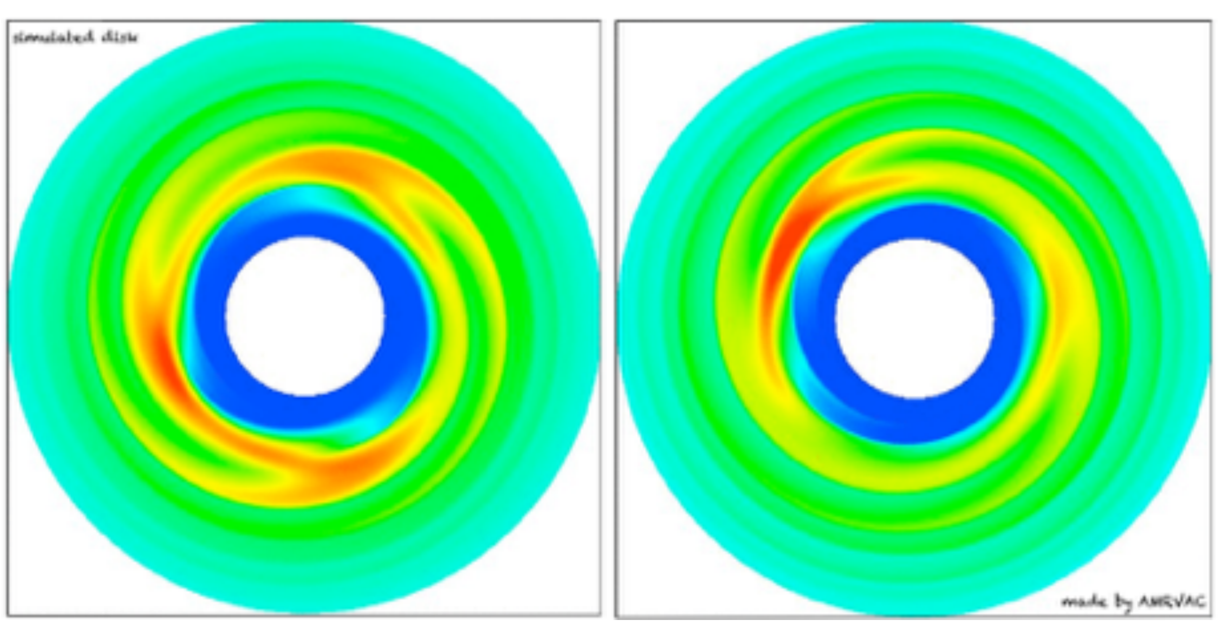
The Rossby Wave Instability (RWI) is is an hydrodynamical instability proposed to explain high frequency Quasi-Periodic Oscillations in black hole systems.

it requires having an extremum of vortensity which exists, for example, in disks with their inner edge **close** to the last stable orbit.

$$\mathcal{L} = \frac{(\nabla \times \mathbf{v})_{|z}}{\Sigma} \text{ or } \mathcal{L}_B = (\nabla \times \mathbf{v})_{|z} \cdot \frac{\Sigma}{B^2}$$

➥ the existence of the RWI is linked to the position of the vortensity extremum





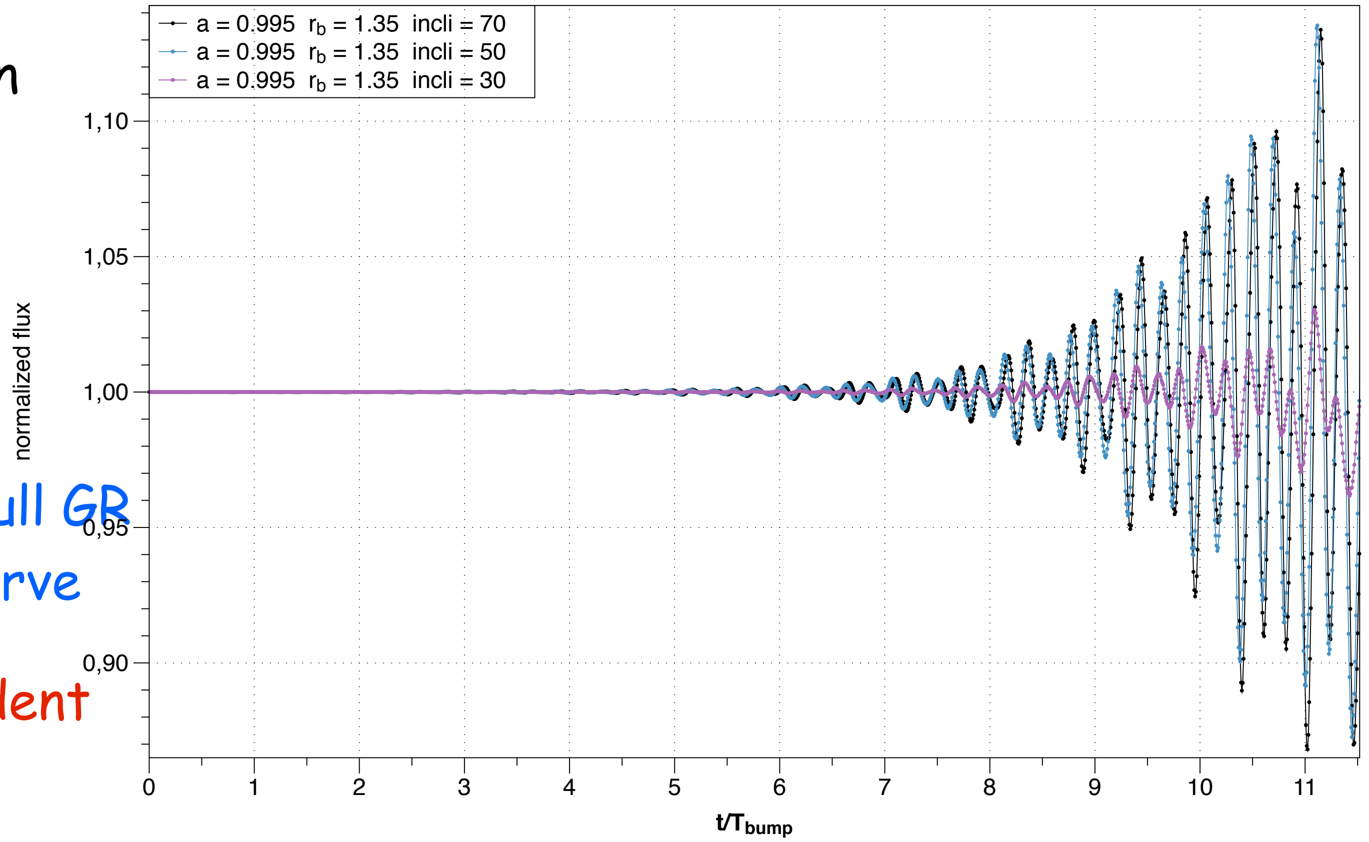
✳ One interesting characteristic of this instability is that, depending on physical condition in the disk, the m=1 mode is not dominant but it is rather a mix of the m=2, 3 and higher modes that dominates.

➥ here we have one mechanism that can select several linked frequencies depending on the disk conditions

RWI from PN to GR

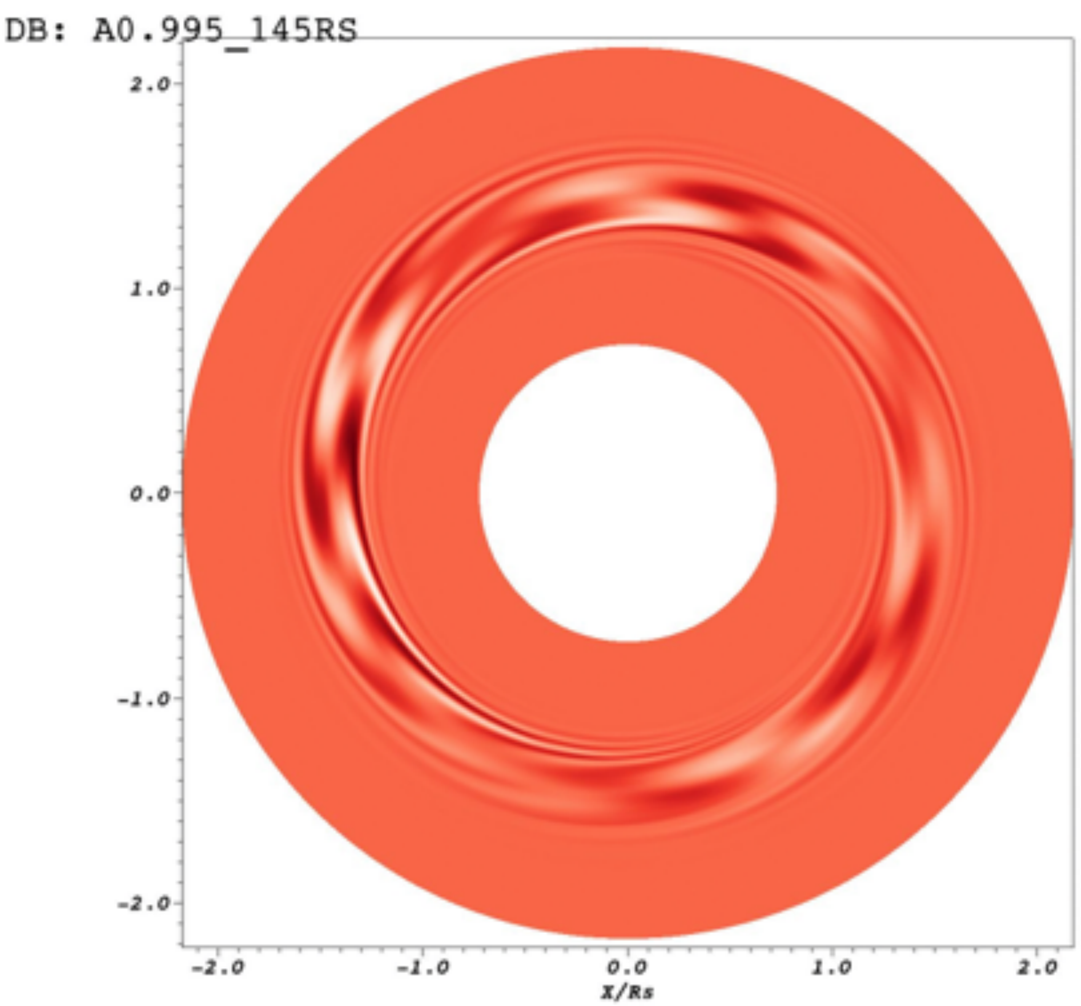
at first we studied the RWI in the Pseudo-Newtonian approach with $\mathcal{L} = \frac{\kappa^2}{2\Omega\Sigma}$

and were able to show that the RWI is triggered by the maximum of the epicyclic frequency



* using 3D simulation of this instability coupled with full GR ray-tracing we computed the associated image/light curve

⇒ a few % modulation is visible and is energy dependent

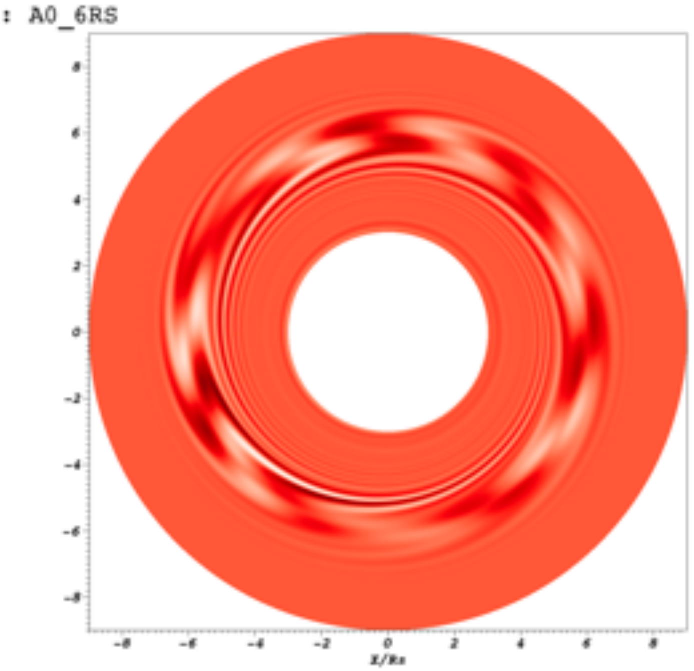


* using the newly developed GR-AMRVAC code we were able to follow the RWI from a purely Newtonian setup (at 150 rg) to a case with a=0.995 and the inner edge of the disk at its last stable orbits.

→ hence proving that the RWI exist and is unstable in a full GR calculation.

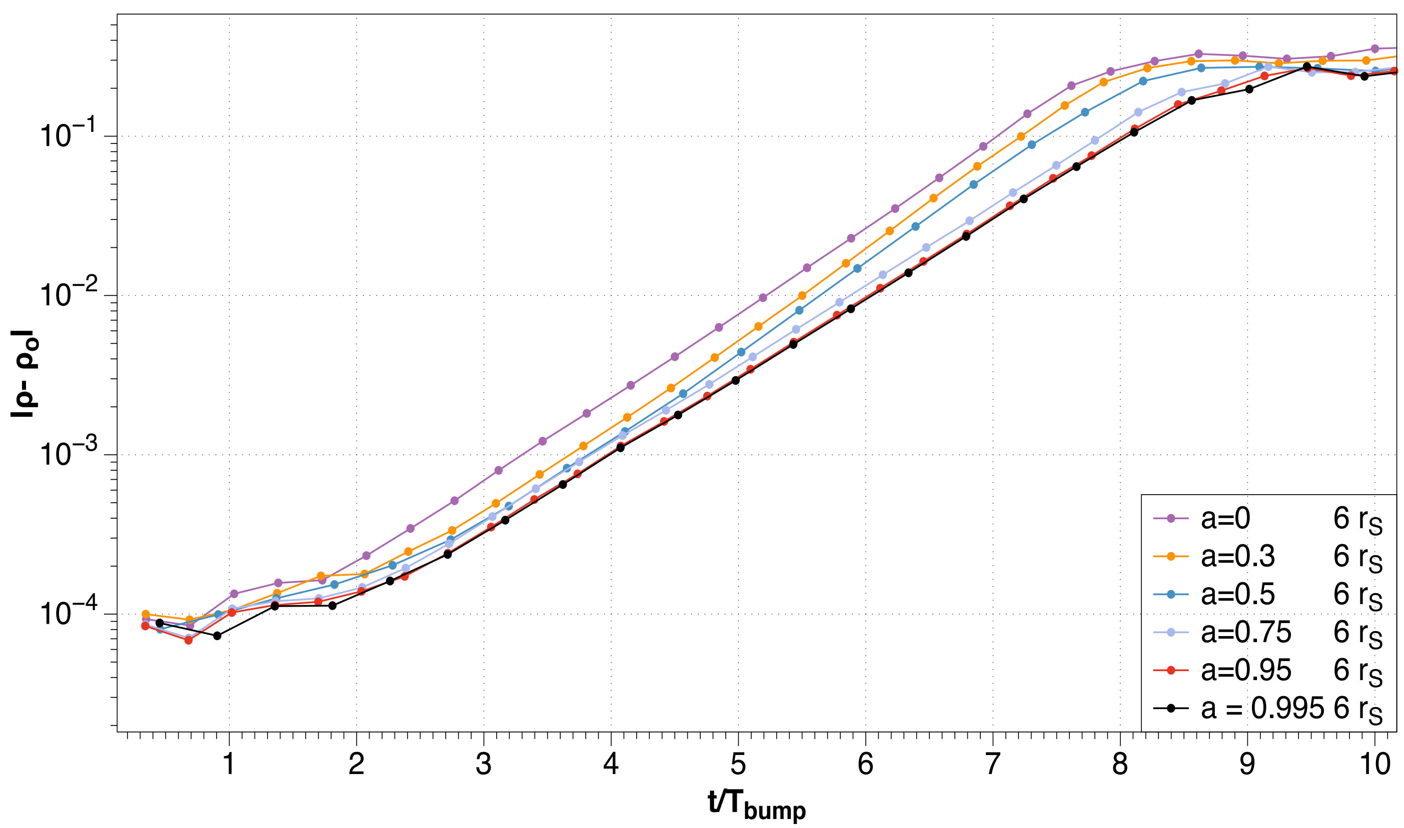
Increasing the spin

spin from 0 to 0.995



instability from 12 rg to 2.90 rg

increasing the spin and getting closer to the black hole the instability looks qualitatively the same



looking at the same location/frequency, for different spin we see a small difference in the growth time of about one orbits and a relatively similar saturation level

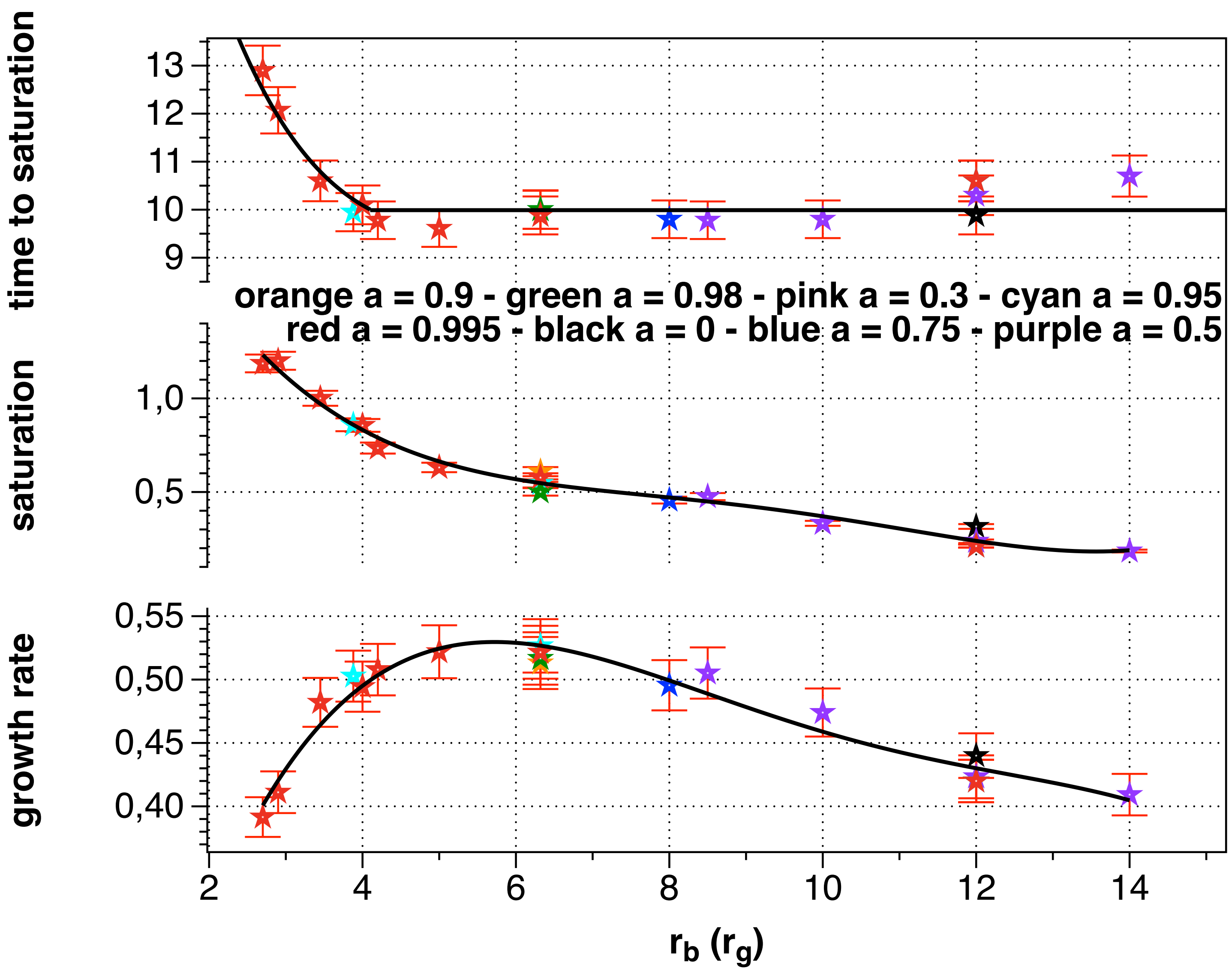
=> no direct impact of spin at a given frequency on the instability behavior

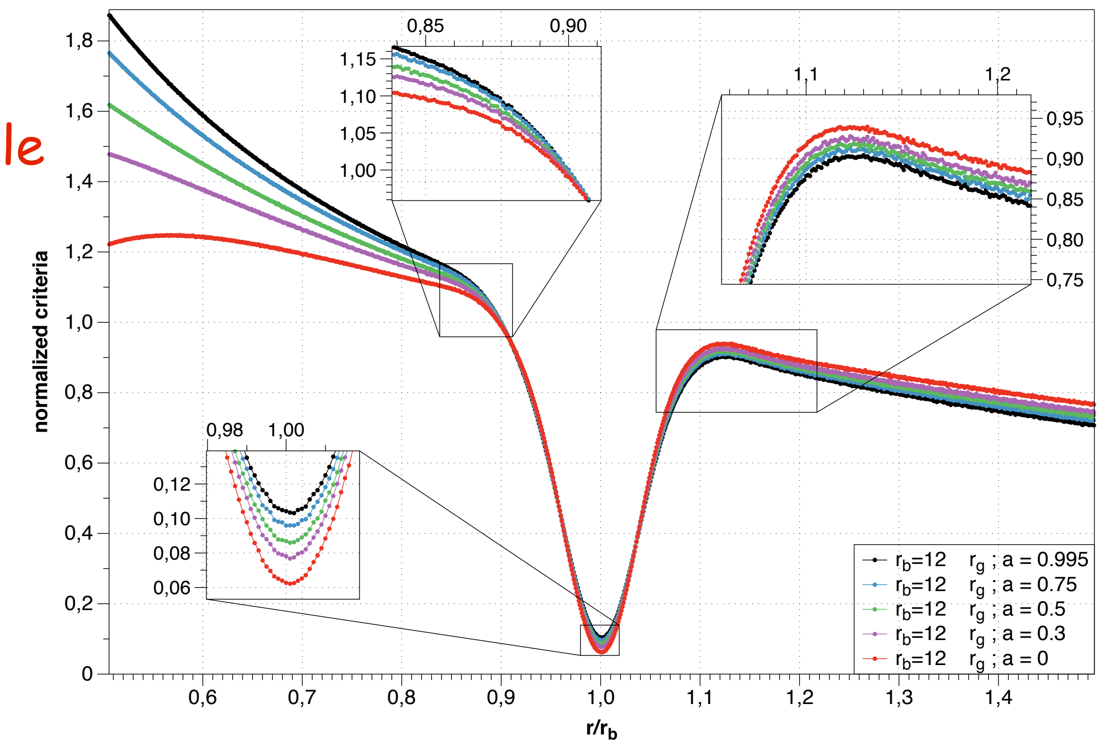
=> but the perception the observer has of the instability has to take into account GR

plunging into the Kerr Black Hole

✳ As the spin increases, we can reach closer to the black hole giving access to higher frequencies

➥ and the RWI will develop in a stronger gravity well





while no impact was detectable at a given frequency we see that as the spin increases:

- the growth rate seems to reach a maximum then decreases
- the RWI reach a higher saturation but on a slightly longer timescale

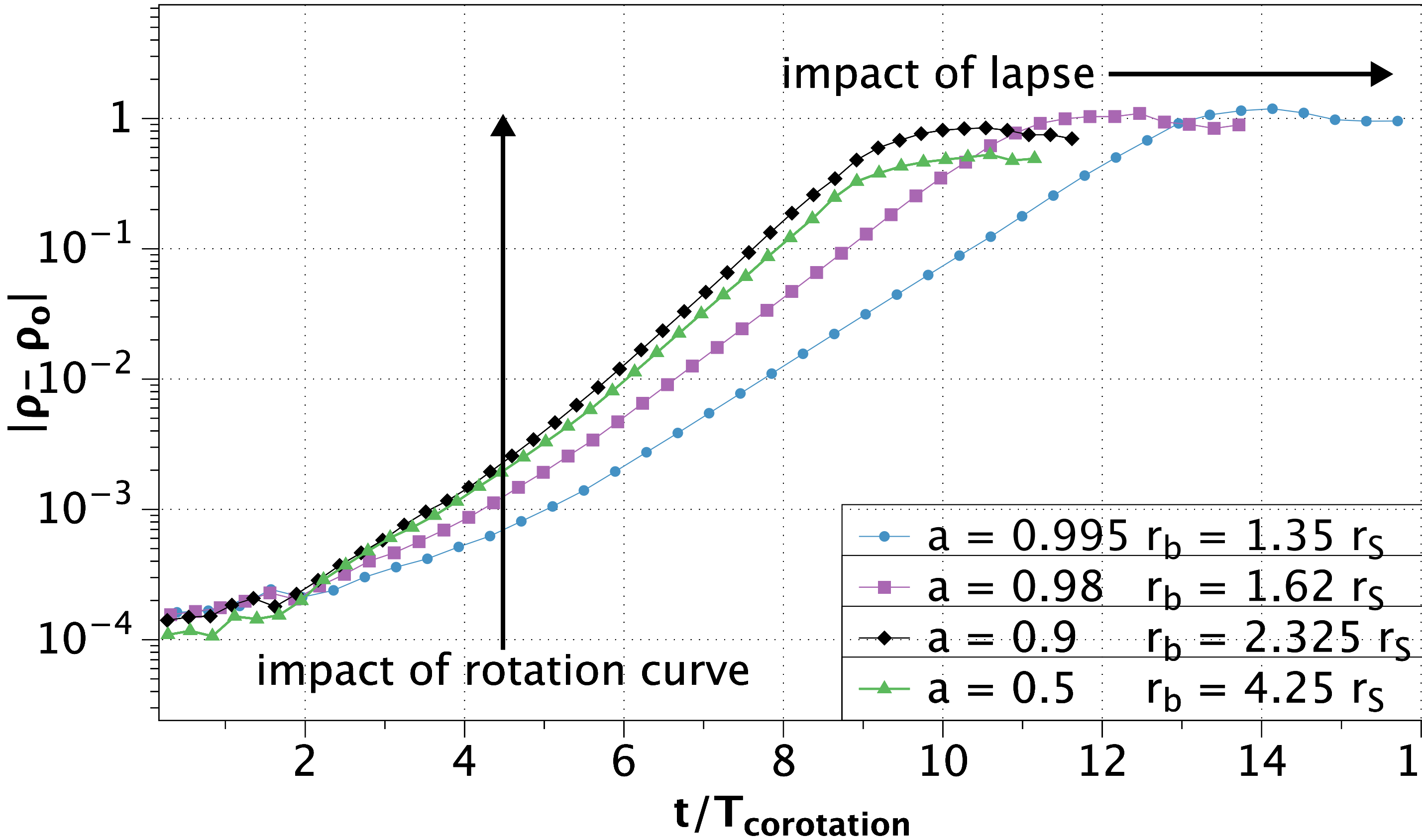
✳ the next step is to focus on observable as we did in the PN case by computing both energy and power density spectrum

⇒ We are also working on better understanding the constraints from observations.

link with observables

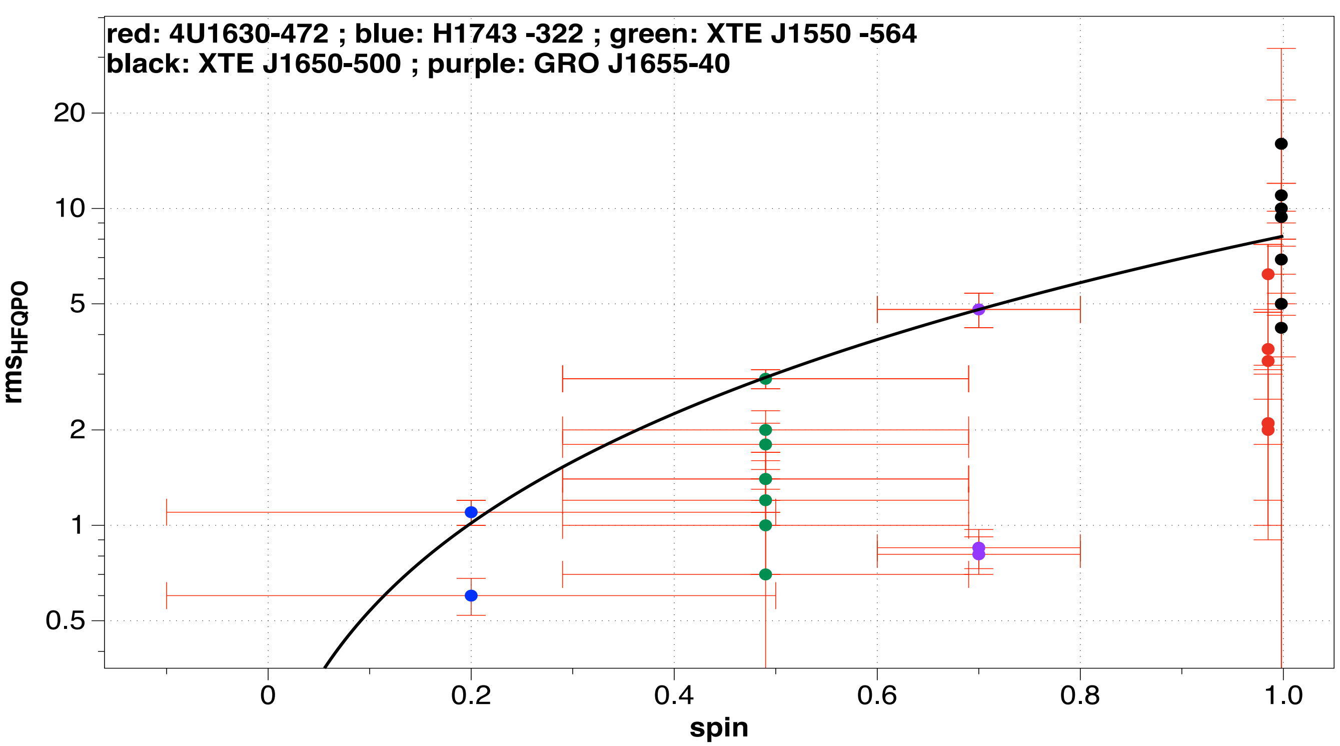
* in the HFQPO model the RWI will be triggered when the inner edge of the disk gets close to the last stable orbit of the black hole

➥ we can compare the behaviour of the RWI when for different LSO/spin couple



the main difference is that **higher spin implies a higher saturation level for the instability**

while this is not a direct observable, we can look at the maximum amplitude observed for each black hole with a know spin



* with only a few HFQPO sources with known spin, and taking into account the spin controversy, it is a weak observable

⇒ getting more spin measurement for the rest of the HFQPO sources would help

➜ we are also looking for other observables

Conclusion

- The RWI is an instability that can occur in the strong gravity of a Kerr black hole as it was theorized.

- The spin of the black hole does have an impact on the instability and through it to the detectability of HFQPO

  ➜ but it is indirect as it is related to how close to the black hole the accretion disk, and hence where the instability, can developed.

  ➜ nevertheless, it might lead to observational tests and we are looking for more spin/HFQPO couples.

- We are also working on creating synthetic observations related to our simulations, and also an XSPEC model to directly fit observation.

  $\Rightarrow$ directly comparing the impact on the energy spectra and PDS