

# ROSSBY-WAVE INSTABILITY AND PLANETESIMAL GROWTH IN PROTOPLANETARY DISKS

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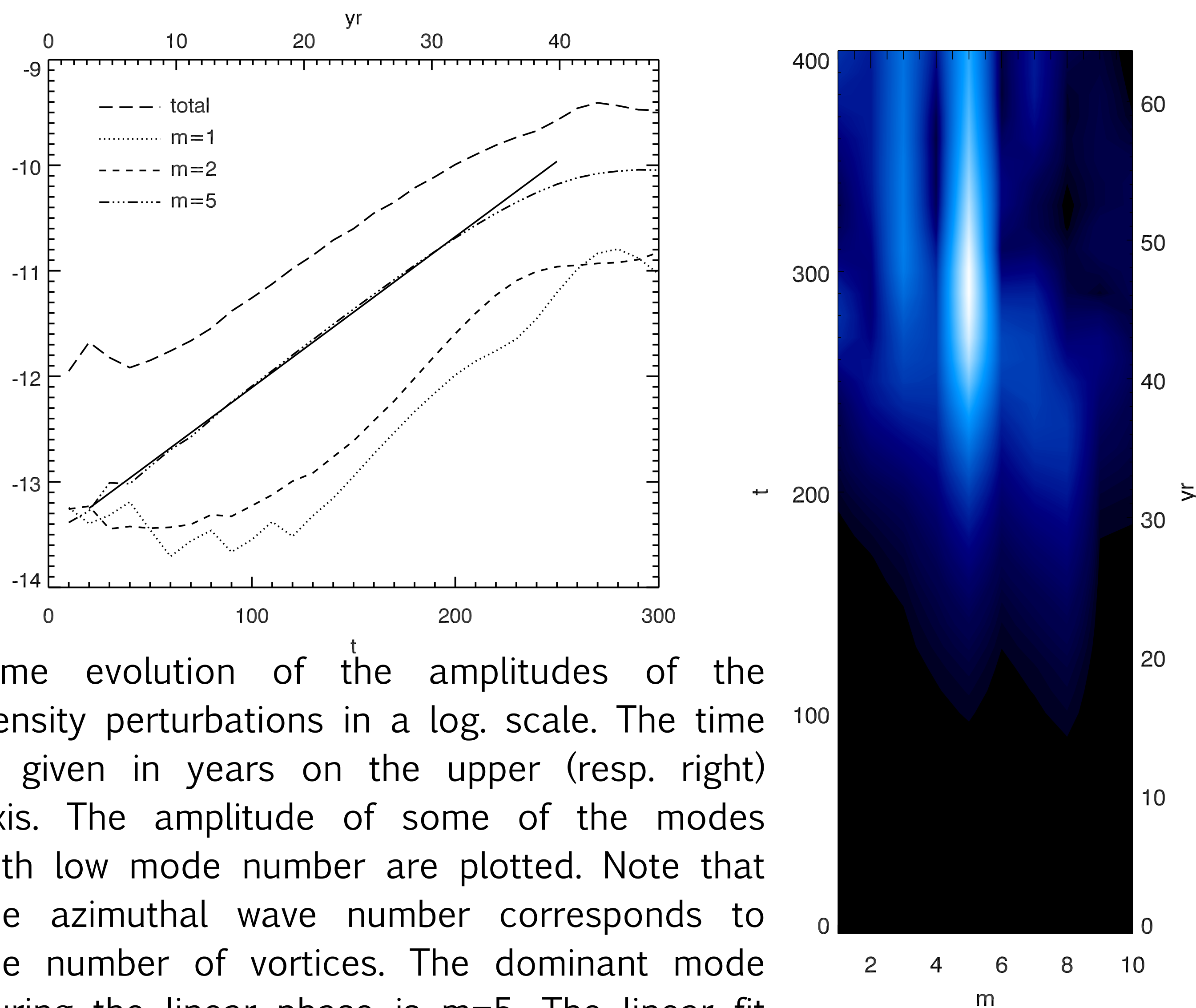
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## CONTEXT AND SETUP

In the current formation theory, planets are supposed to be built from colliding planetesimals of kilometre or larger size, but **the formation of these planetesimals is still an issue**. Multiple scenarios have been proposed to overcome this difficulty (e.g. Chiang & Youdin, 2010). Here we consider the presence of vortices formed by the Rossby wave instability (RWI, Lovelace et al. 1999). The RWI can develop, in particular, at the edges of the “dead zone” of the protoplanetary disk. In this scenario the ‘meter size barrier’ is outstripped by the presence of **vortices that can concentrate solids in their centre and accelerate the growth process**.

We perform global 3D simulations of a radially and vertically stratified disk. The first phase consists in the linear and non-linear growth of the RWI in a gas disk. We also **follow the concentration of solids in the 3D Rossby vortices** over a few rotation times. The dust is added, as a fluid without pressure, at the end of the linear phase when the RWI has reached saturation. Multiples grain sizes from *1mm* to *5cm* are used with a constant density distribution. Initially the solids density is axisymmetric with a dust-to-gas density ratio of  $10^{-2}$ .

## LINEAR GROWTH OF THE RWI

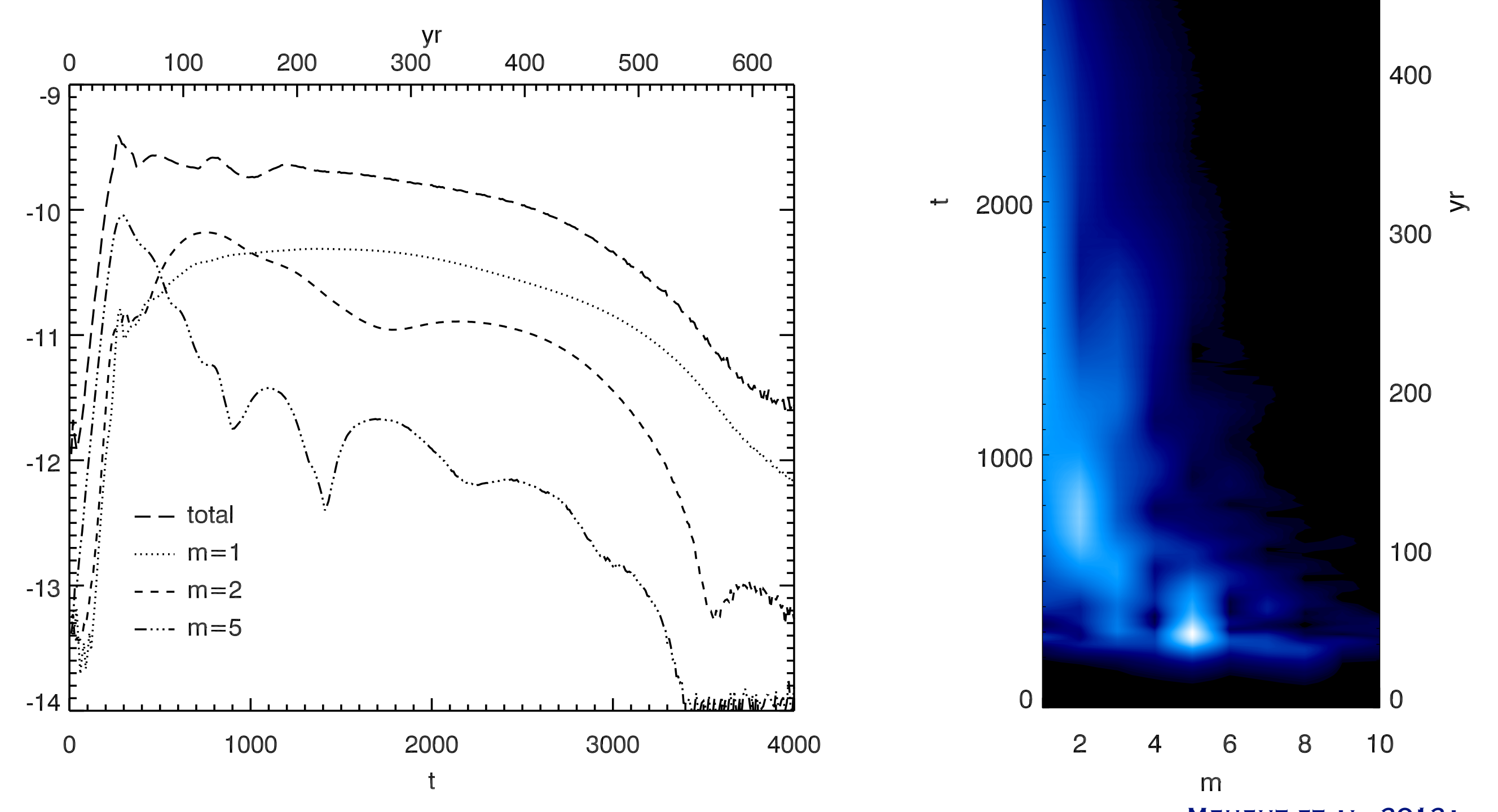


Time evolution of the amplitudes of the density perturbations in a log. scale. The time is given in years on the upper (resp. right) axis. The amplitude of some of the modes with low mode number are plotted. Note that the azimuthal wave number corresponds to the number of vortices. The dominant mode during the linear phase is  $m=5$ . The linear fit of the growth of the dominant mode, gives a growth rate of  $0.033\Omega_0$ .

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## NON-LINEAR EVOLUTION

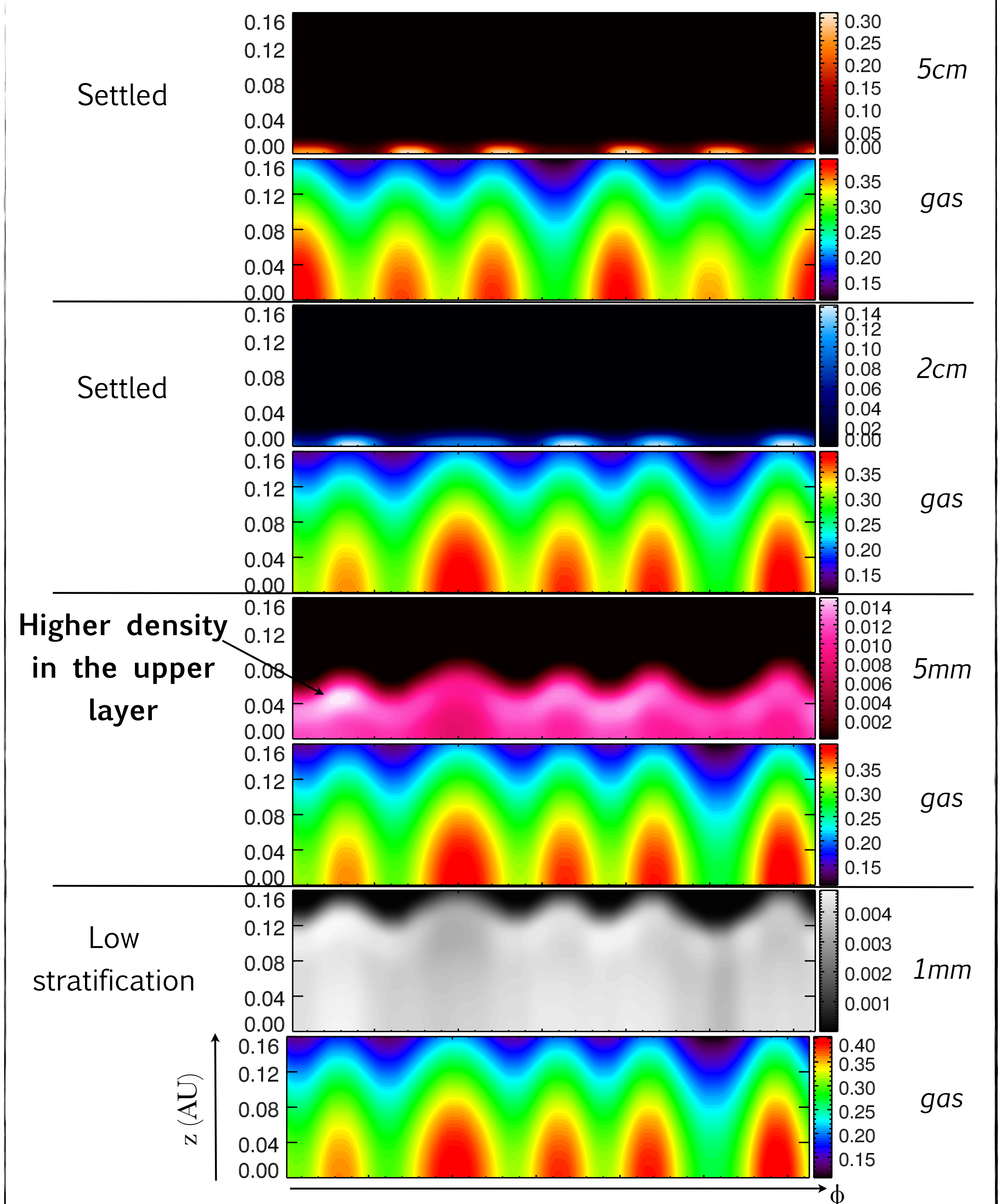
As can be seen on the long term evolution of the RWI, the 5 vortices tend to merge. The most unstable mode non-linearly gives way to dominant  $m=1$  and  $2$  modes.



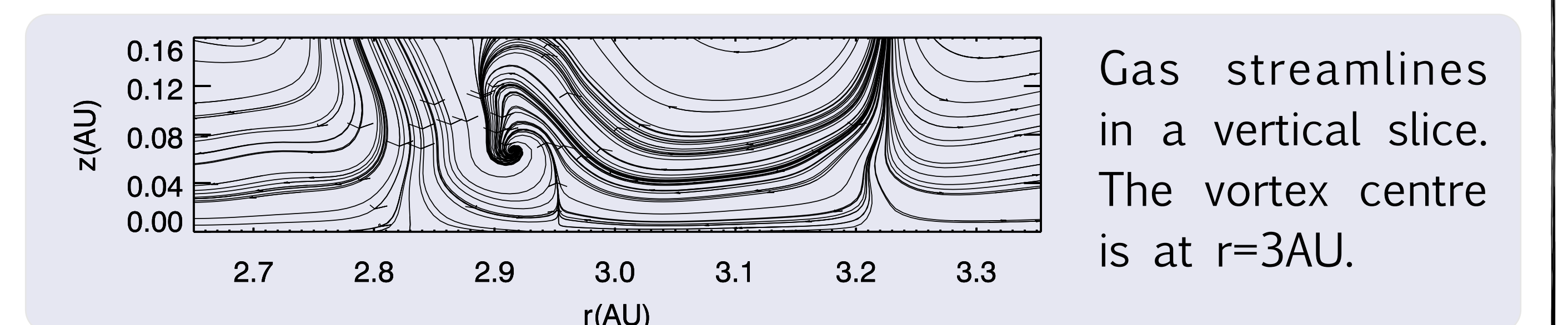
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Chiang, E. & Youdin, A. N. 2010, Annual Review of Earth and Planetary Sciences, 38, 493 -- Lovelace, R. V. E., Li, H., Colgate, S. A., & Nelson, A. F. 1999, ApJ, 513, 805 -- Meheut, H., Casse, F., Varniere, P., Tagger, M. 2010, A&A, 516, A31 -- Meheut, H., Keppens, R., Casse, F., & Benz, W. 2012a, A&A, 542, A9 -- Meheut, H., Meliani, Z., Varniere, P., Benz, W. 2012b, A&A, 45, A134 -- Meheut, H., Lovelace, R.V.E., Lai, D., MNRAS, 698, 2013

## CONCENTRATION OF SOLIDS



Densities of gas and solids ( $\times 10^{-9} g.cm^{-3}$ ) at the radius of the vortices formed by the RWI after 3 rotation periods and for 4 different solid sizes. The larger grains have settled and reach a **dust-to-gas density ratio of  $\sim 1$** . The intermediate size grains (*5mm*) are **lifted by the gas vertical velocity** inside the Rossby vortices and very low stratification is obtained for the smaller grains.

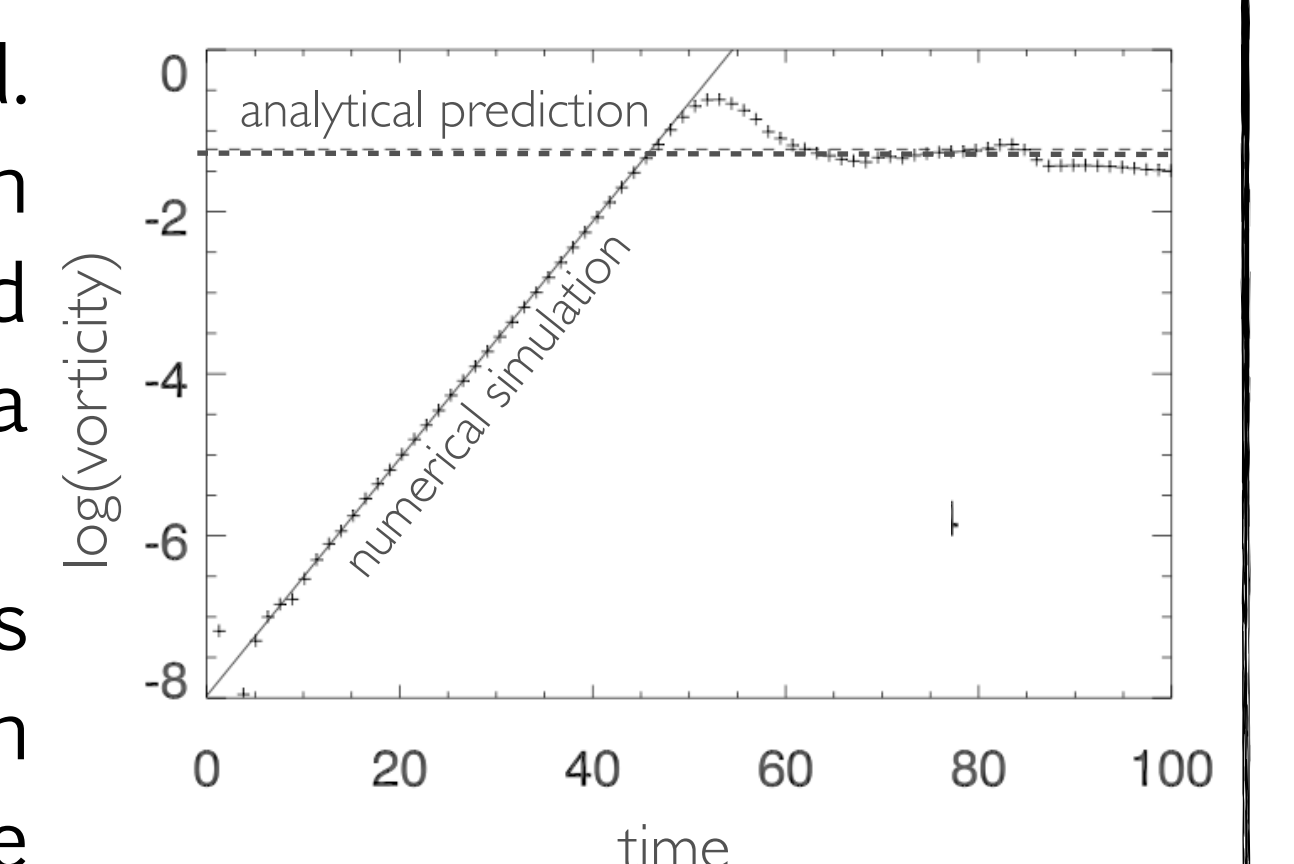


Gas streamlines in a vertical slice. The vortex centre is at  $r=3AU$ .

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## SATURATION

- The saturation phase of this instability remained poorly understood. We tested the non-linear saturation mechanism analogous to that derived for wave-particle interaction in plasma physics.
- The final amplitude of the vortices is correctly predicted. And we provide an empirical formula for the growth rate of the instability and its saturation amplitude.



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## SUMMARY

- The 3D linear growth rate of the RWI is similar to the 2D one. But the structure of the vortices largely differs due to the vertical stratification.
- Non-linearities give way to an evolution toward the larger scales.
- The 3D **Rossby vortices are highly efficient** for concentrating the solids when they are partially coupled to the gas ( $\sim 5cm$ ).
- Due to the vertical velocity of the gas in the vortex, **the sedimentation process can be reversed**. The *mm* size dust is lifted and higher concentrations are obtained in the upper layer of the disk than in its midplane.
- The Rossby wave instability is a promising mechanism for planetesimals formation.**

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