VORTEX STRETCHING IN SELF-GRAVITATING DISCS

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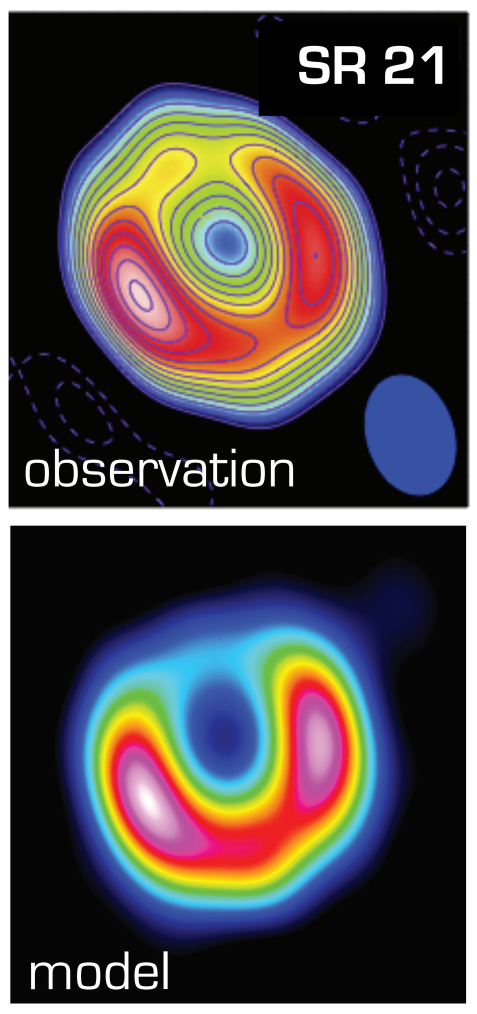
ABSTRACT

Horseshoe-shaped brightness asymmetries of several transitional discs are thought to be caused by large-scale vortices, (see Figures on the right, Regály et al. 2012). Here we present an investigation on the long-term evolution of the large-scale vortices formed at the viscosity transition of the discs' dead zone outer edge by means of two-dimensional hydrodynamic simulations taking disc self-gravity into account. The effect of disc self-gravity is found to be essential even for relatively low-mass discs. The vortex stretching can be explained by a combined action of a non-vanishing gravitational torque caused by the vortex, and the Keplerian shear of the disc.



INTRODUCTION

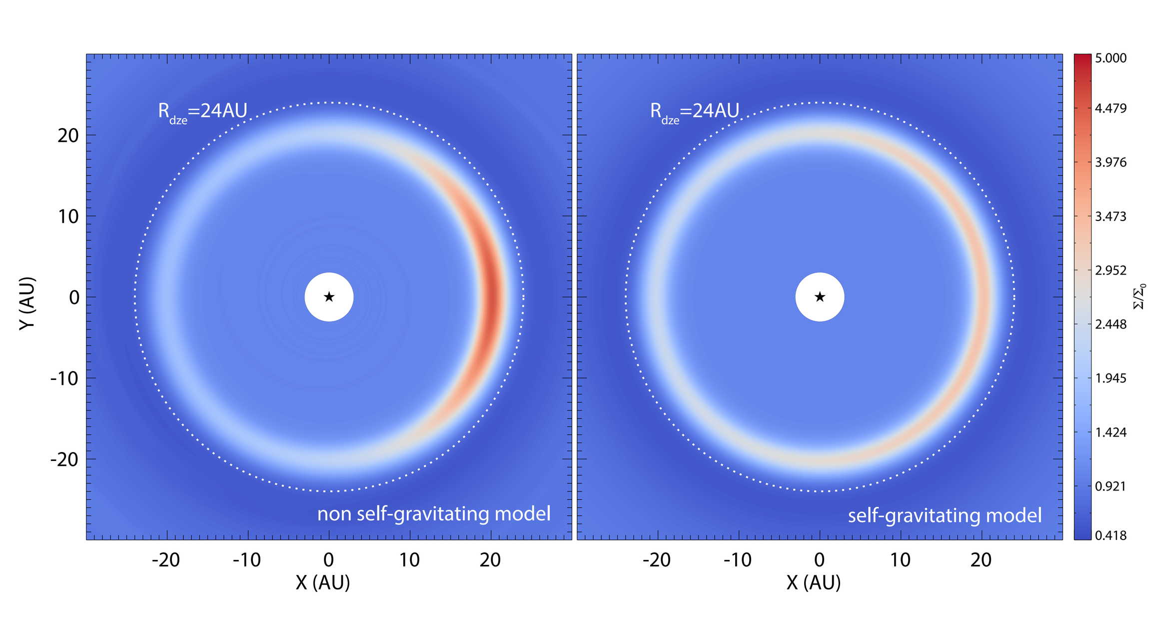
Dozens of transitional discs show remarkable brightness asymmetries. The horseshoe-shaped asymmetries seen in the mm-wavelength images are thought to be caused by large-scale anticyclonic vortices, although other phenomena can also lead to the development of such features.

Vortex formation can be triggered by the baroclinic instability or by the Rossby wave instability (RWI, first described by Rossby et al. 1939) via the coagulation of smaller scale vortices. The RWI is excited at the vortensity minimum, which can develop at the pressure bumps in protoplanetary discs, e.g., at the edges of a gap opened by a giant planet, at the edges of the accretionally inactive zone of discs, or in the outer regions of protostellar discs accreting from natal clouds.

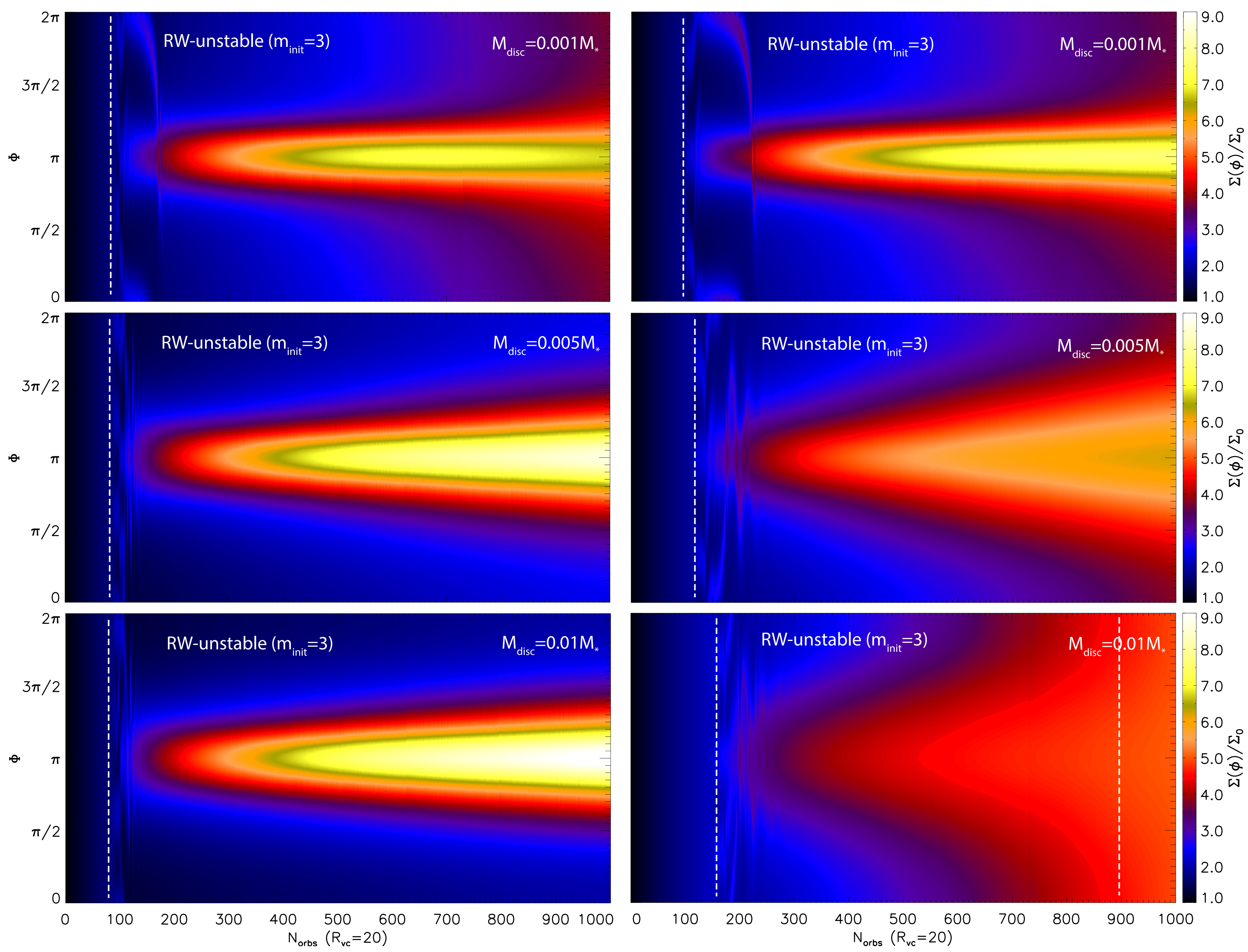
Here we present an investigation on the effect of disc self-gravity on both the formation and long-term evolution of vortices developed at the disc dead zone outer edge by means of 2D (thin-disc) hydrodynamic simulations assuming gravitationally stable discs with $0.001 \lesssim M_{disc}/M_{\star} \lesssim 0.01$.

VORTEX STRETCHING

We observed a delayed vortex formation and a weaker vortex at a sharp viscosity transition, if disc self-gravity is taken into account similarly to what was found for the gap-edge vortices by Lin & Papaloizou (2011) and Lin 2012.



VORTEX EVOLUTION IN NON SELF-GRAVITATING (LEFT) AND SELF-GRAVITATING (RIGHT) DISCS



Concerning the vortex morphology, we found that the full-fledged vortex becomes azimuthally elongated in self-gravitating discs. The aspect ratio of this vortex, χ, is proportional to the disc mass in self-gravitating discs and its value at the strongest stage of the vortex lies in the $10 \lesssim \chi \lesssim 40$ limits. In contrast, $\chi \simeq 10$ is independent of the disc mass in non-self-gravitating discs.

The azimuthal density contrast, $\delta\Sigma$, across the vortex is also sensitive to the disc mass and about 50 percent lower if self-gravity is included. In particular, $\delta\Sigma \lesssim 3(2)$ and $\delta\Sigma \lesssim 5(3)$ for $\alpha=10^{-4}$ ($\alpha=10^{-5}$) in the non-self-gravitating and self-gravitating models, respectively.

VORTEX EVOLUTION

The full-fledged vortex is subject to decay due to disc viscosity. Moreover, vortex decay is accelerated by disc self-gravity compared to the non-self-gravitating case. The rate of the vortex decay is proportional to the disc mass and becomes significant for $M_{disc}/M_{\star} \gtrsim 0.005$, where $Q_{init} \lesssim 50$ at the vortex radial distance initially.

The accelerated vortex decay can be explained by azimuthal stretching of the vortex caused by the vortex's non-vanishing gravitational torque and the Keplerian shear of the disc. Since the magnitude of the vortex gravitational torque is proportional to the disc mass, the vortex lifetime decreases with increasing disc mass. If disc self-gravity is neglected, an opposite correlation is observed between the vortex lifetime and the disc mass, which can be explained by the displacement of the barycentre of the star-disc system caused by the vortex itself (Mittal & Chiang 2015; Zhu & Baruteau 2016; Regály & Vorobyov 2017).

We also found that vortices developed at sharp viscosity transitions of self-gravitating discs can be well described by the GNG model (Goodman et al. 1987) as long as the disc viscosity is low, i.e for $\alpha_{dz} \lesssim 10^{-5}$.

Conclusion

Based on our results, we conclude that the formation of long-lasting vortices (e.g., more than a thousand orbital periods) requires a relatively small disc-to-star mass ratios being less than 0.5 percent and low disc viscosity in the dead zone, $\alpha \lesssim 10^{-4}$. Previous investigations proposed that large-scale vortices formed in gravitationally stable discs can collapse to massive planets, however as we showed that this can not be a plausible pathway to planet formation. This is because of the vortex stretching caused by disc self-gravity, which tends to decrease the density enhancement at the vortex centre.

REFERENCES

Goodman J., Narayan R., Goldreich P., 1987, MNRAS, 225, 695; Lin M.-K., Papaloizou J. C. B., 2011, MNRAS, 415, 1426; Lin M.-K., 2012, MNRAS, 426, 3211 Mittal T., Chiang E., 2015, ApJ, 798, L25; **Regály** Zs., Juhász A., Sándor Zs., Dullemond C. P., 2012, MNRAS, 419, 1701; **Regály**, Zs.& **Vorobyov**, E.2017, A&A, 601, A24; **Regály**, Zs.& **Vorobyov**, E.2017, MNRAS 471; Rossby, C.-G. et al., 1939, J. Marine Res., 2, 38; Zhu Z., Baruteau C., 2016, MNRAS, 458, 3918