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ON THE USE OF THE INDIRECT TERM IN PROTO-PLANETARY DISCS SIMULATIONS

A. Crida[1], P. Griveaud[1], E. Lega[1], F. Masset[1], A. Morbidelli[1], D. Kloster[1], L. Marques[1,2] and K. Minker[1,2]

Abstract. The indirect term, which accounts for the acceleration of the centre of the frame (that is: the star) with respect to an inertial frame, is generally included by default in numerical simulations. However, when the whole system is not self-gravitating (e.g. disk self-gravity neglected), the relevance of taking it into account is not so clear. Besides, including the indirect term may have dramatic consequences on the behaviour of the proto-planetary disk.

Keywords: Numerical simulations, accretion disks, planetary migration

1 Introduction: what is the Indirect term?

In a numerical simulation centred on the star instead of the centre of mass of the system, the frame is not inertial. Hence, an acceleration must be applied to all the elements of the system : the opposite of that felt by the star. This is basic mechanics. This acceleration is often called *the indirect term*.

2 Why is it an issue, then?

Often, simulations are run without computing the self-gravity of the gas, which is negligible and computationally expensive. But as soon as one element does not feel the direct gravity force of an other one, the consistency is broken. Through the indirect term, all objects feel a gravitational influence from the other ones, but this influence becomes incorrectly computed, as illustrated by the case of tides shown in Fig. 1.

Fig. 1. Tidal acceleration in the star-centred frame. Red arrows to the left: direct force from the planet (red dot). Green arrows to the right: indirect term.

Take a ringlet around a star, perturbed by a distant planet (or gas blob). The direct acceleration from the planet pulls the ring (and the star) towards the planet (that is: to the left in Fig. 1). The indirect term, opposite to the stellar acceleration, pulls the ring away from the planet (to the right, green arrows). The two almost balance, but while the latter is uniform, the former depends on the distance to the planet. Hence, they

[1] Universit Cte d'Azur, Observatoire de la Cte d'Azur, CNRS, laboratoire Lagrange, Nice, France
[2] MAUCA Master track in Astrophysics, Universit Cte d'Azur & Observatoire de la Cte d'Azur, Parc Valrose, 06100 Nice, France

can not cancel perfectly everywhere on the ringlet, and the result is the small tidal force, which is directed away from the star along the star-planet axis (Fig. 1).

We see that having only the direct or only the indirect term is worse than having none : it leads to a drift of the ring, while it should be stretched on the spot. Suppress the direct effect from the planet while keeping the indirect term, and you are just as wrong as when you forget the indirect term !

3 Should we care?

When the gas self-gravity is not computed, if the indirect term includes the acceleration felt by the star from the gas disk (as it should for the migrating planet), then every gas particle feels an indirect term which has no direct counterpart. We are in a situation like that of Fig. 1 where the red dot is a gas blob (e.g. a vortex), and the red arrows are not computed. As seen above, this is probably not good...

In some cases, it has no significant consequences. However, we found in numerical simulations that the indirect term from the gas disk applied to the gas may cause troubles. Among these issues are :

- Artificial enhancement and migration of vortices Zhu & Baruteau (2016).
- Different torque felt by a gap-opening planet with and without indirect term.
- Exponential rise of the eccentricity of the disk, possibly leading to its sudden destabilisation after a quiescent phase, as shown in Fig. 2. *

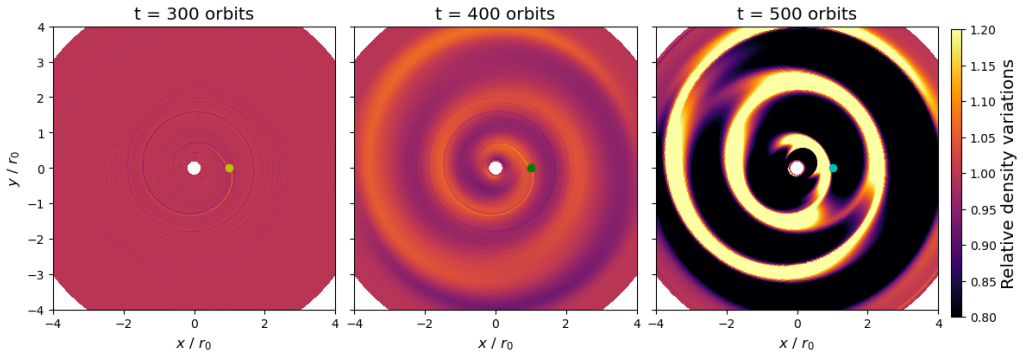

Fig. 2. Gas density in a simulation with an $M_p = 10^{-5}\,M_*$ planet on a circular orbit of radius r_0 in a disk with surface density $\Sigma_0 = 10^{-2} M_*/r_0^2$. With a smaller Σ_0 the instability occurs later. Without the indirect term from the gas, it does not happen, whatever Σ_0.

4 Conclusion

As soon as the system is not fully self-gravitating, there is no "*the indirect term*" anymore. We open the possibility that every element could have its own indirect term, opposite to the acceleration felt by the star from all the other objects which gravitationally affect this element, and only these objects.

We have already modified our FARGOCA code† in this way. We encourage others to be very careful with the indirect term, and explicit clearly in their papers what they use as indirect term(s).

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*Note: with the indirect term and adding the gas self-gravity, the instability still takes place. These new results are under investigation, and a paper is in preparation.

†`https://gitlab.oca.eu/DISC/fargOCA`

References

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