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Conditions for outward migration

Bertram Bitsch[1] **and Willy Kley**[1]

[1]Computational Physics, University of Tübingen,
72076 Tübingen, Germany
email: bertram.bitsch@uni-tuebingen.de, wilhelm.kley@uni-tuebingen.de

Abstract. The migration of protoplanets in discs not only depends on the thermodynamics of the ambient disc but also on the orbital parameters of the embedded planet. In the fully radiative regime, planets can migrate outward if their orbital parameters fit in a very small range. We simulate planets in fully radiative discs (and isothermal discs - for reference) and determine the influence of the orbital parameters (a, e and i) and the planetary mass on the migration time scale and direction.

Keywords. accretion disks, planetary systems: formation, radiative tranfer, hydrodynamics

1. Introduction

The migration of growing protoplanets depends on the thermodynamics of the ambient disc. Standard modelling, using locally isothermal discs, indicates an inward (type-I) migration in the low planet mass regime. Taking into account non-isothermal effects, recent studies have shown that the direction of the type-I migration can change from inwards to outwards. This change in the direction of migration crucially depends on the properties of the planet's orbit. Eccentricity and inclination influence the migration and can, under certain conditions, restrain the outward migration in non-isothermal discs. In the following we show results of our 3D Simulations of low mass planets, embedded in protoplanetary discs, on circular, eccentric and inclined orbits. All information here is presented in much more detail in the referenced papers.

2. Change of the planetary mass and of the orbital parameters

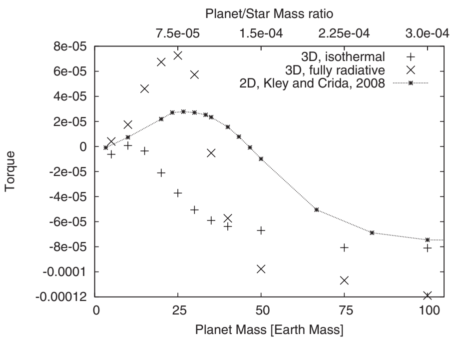

Fig. 1 Torque acting on planets with different masses for 2D and 3D isothermal and fully radiative simulations.

For circular orbits the torque is a direct measurement for the migration, a positive torque indicates outward migration, while a negative torque on the planet results in inward migration. Planets in the fully radiative scheme are prone to outward migration, but only if the planetary core does not exceed a certain threshold for it's mass. In our 3D simulations planetary cores up to $\approx 33 M_{Earth}$ can migrate outward. For 2D simulations the planet's mass can be a little higher (see Fig. 1). Above this limit gap opening diminishes the effect. For more details on this topic, please see Kley *et al.* 2009.

In Fig. 2 we present the theoretical change of the orbital elements of $20M_{Earth}$ planets on fixed orbits. For both thermodynamic cases, initial eccentricity e and initial inclination i will be damped in time, until the planet reaches a circular orbit in the midplane. Only for small eccentricities and inclinations outward migration is possible in the radiative case. The evolutions of a, e and i in time follows the theoretical predicted changes. As soon as the eccentricity is damped below $e \approx 0.02$ the planet can migrate outward.

The threshold for outward migration for inclined planets seems to be $i \approx 4.5°$; lower inclined planets migrate outwards. In the end, eccentricity and inclination have to be damped in order to support outward migration of low mass planets. For more informations on planets on eccentric and inclined orbits, please see Bitsch & Kley 2010 and Bitsch & Kley 2011, respectively.

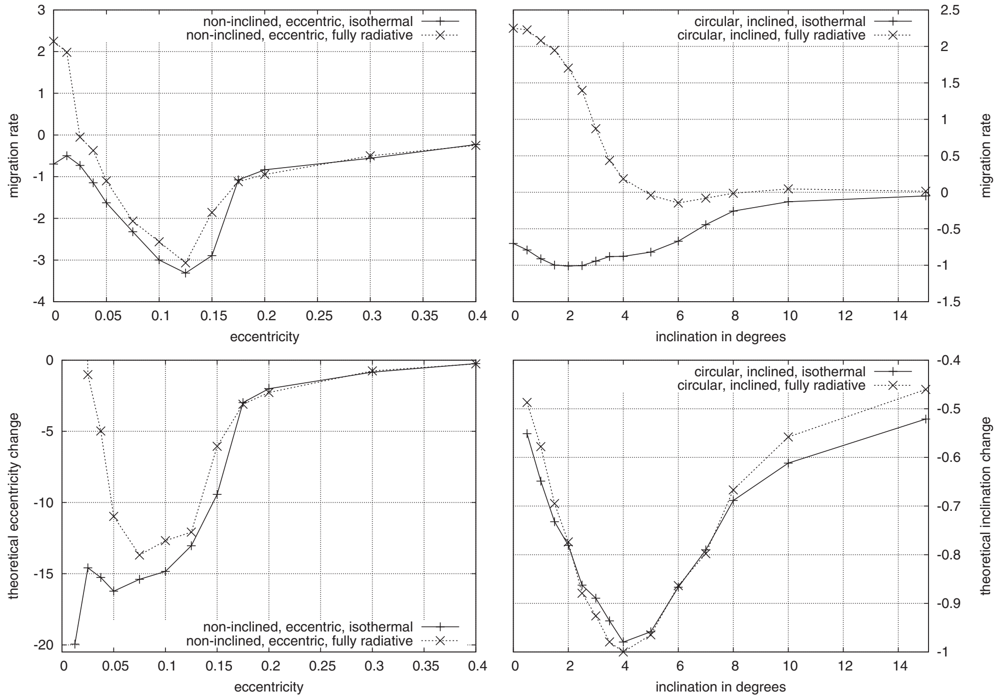

Fig. 2 Theoretical change of a, e and i for $20M_{Earth}$ planets on fixed orbits in isothermal (black '+') and fully radiative (grey-dotted 'x') discs.

3. Conclusions

The planetary mass, eccentricity and inclination are crucial parameters to determine whether the planet will migrate inwards or outwards. A planetary core embedded in a fully radiative disc, with $H/r = 0.037$ and $M_{Disc} = 0.01M_{\odot}$, is only prone to outward migration if the planetary mass is below $33M_{Earth}$, the eccentricity below $e \leqslant 0.02$ and the inclination is lower than $i \approx 4.5°$. Other disc parameters should result in other conditions for outward migration. The timescale for damping of e and i is much smaller than the migration timescale, leading to non-inclined, circular orbits, allowing outward migrating planets.

References

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