EPSC Abstracts
Vol. 6, EPSC-DPS2011-752, 2011
EPSC-DPS Joint Meeting 2011

Influences on planetary migration in 3D fully radiative discs

B. Bitsch and W. Kley
Institute for Astronomie and Astrophysik, University of Tübingen, Germany (bertram.bitsch@uni-tuebingen.de / Fax: +49-7071-295094)

Abstract

The inclusion of radiation transport in discs can change the direction of migration for low mass planets from inwards to outwards [1]. However, it remained unclear to what extend this outward migration is possible. Outward migration should stop at a certain distance to the central star. This region in the disc can therefore act as a feeding zone for planetary embryos. The magnitude of outward migration is also dependent on disc parameters (mass, viscosity, temperature profile, entropy gradient). A change in these parameters changes the disc structure and therefore the range of outward migration of embedded planets.

1. Introduction

Recent studies have shown that low mass planets can migrate outwards in fully radiative discs at a distance of about 5 AU from the star [2]. In order to sustain the outward migration of these planets, the disc has to meet certain criteria (temperature profile, entropy gradient, etc.). With increasing distance to the central star, the disc's temperature and density reduce. This reduction, however, has a dramatic effect on the torque acting on the planet (the torque determines the speed and direction of motion for planets on circular orbits). For larger distances to the star, the torque becomes negative and the planet would migrate inwards again. The planets therefore stop their outward migration at a point in the disc, while a planet moving inwards from further out stops its inward migration. This region in the disc can act as a feeding zone for planetary embryos.

The zero-torque radius for planets is dependent of the disc structure. The structure of our 3D fully radiative discs is determined by viscous heating and radiative transport/cooling to the surface. Therefore, the viscosity and the disc mass change the structure of the disc. A change in these parameters influences the zero-torque radius for low mass planets quite dramatically.

2. Simulation Setup

The protoplanetary disc is modeled as a three-dimensional (3D), non-self-gravitating gas whose motion is described by the Navier-Stokes equations. We treat the disc as a viscous medium, where the dissipative effects can then be described via the viscous stress-tensor approach. We also assume that the heating of the disc occurs solely through internal viscous dissipation and ignore the influence of additional energy sources (e.g. irradiation form the central star). This internally produced energy is then radiatively diffused through the disc and eventually emitted from its surface. For this process we use the flux-limited diffusion approximation, which allows us to treat the transition from optically thick to thin regions as an approximation. A more detailed description of the modeling and the numerical methodology is provided in [2].

3. Range of outward migration

In Fig. 1 the torque acting on planets at different distances to the central star in fully radiative discs is displayed. For all planet masses the largest positive torque (indicating outward migration) is around $r \approx 1.0 r_{Jup}$. At larger distances to the central star, the torque decreases continuously to negative torques, and this transition from positive to negative torques occurs at larger distances for smaller planet masses. For the lowest mass planet with $20 M_{Earth}$ the transition is at $r \approx 2.4 r_{Jup}$ (zero-torque distance to the central star). With even larger distances the torques remain negative but with diminishing strength, indicating inward migration. For larger planetary masses (25 and $30 M_{Earth}$) the zero-torque distance is decreasing (1.9 and $1.4 r_{Jup}$). For smaller distances to the central star, inside the maximum, the torque acting on the planet becomes smaller again, until it reaches about zero for $r_P = 0.5 r_{Jup}$ for all planetary masses.

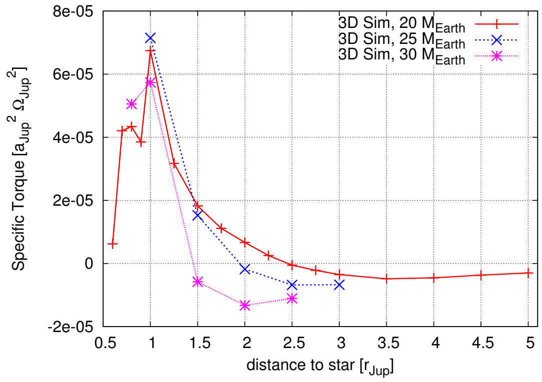

Figure 1: Torque acting on planets with three different masses embedded in fully radiative discs located at various distances from the star. Figure from [3]

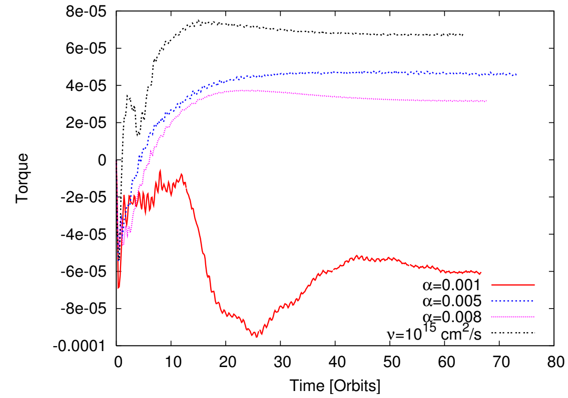

Figure 2: Torque acting on planets in fully radiative discs with different viscosities. The planets are located at $r_p = 1.0r_{Jup}$. Figure from [5]

4. Influences of viscosity on planetary migration

In fully radiative disc, the equilibrium state between viscous heating and radiative cooling/transport determines the structure of the disc. A change in viscosity therefore changes the structure of the disc (Temperature, density and aspect ratio H/r profile). In isothermal discs, a smaller aspect ratio resulted in a faster inward migration [4].

Lowering the viscosity in discs, results in a smaller aspect ratio of the disc, which influences the torque acting on an embedded low mass planet quite dramatically [5]. In Fig. 2 the torque acting on planets in fully radiative discs with different viscosity (α and constant) is displayed. A very low viscosity results in inward migration, while for increased viscosity, outward migration can be monitored.

The constant viscosity corresponds to $\nu = 10^{15}$ cm^2/s, a value that relates to an equivalent $\alpha = 0.004$ at r_0 for an isothermal disc aspect ratio of $H/r = 0.05$, where $\nu = \alpha H^2 \Omega_K$. Even as the disc structures are nearly identical in a no-planet scenario, the torque of an embedded planet is not equivalent.

5. Summary and Conclusions

Planets migrate outwards to a point in the disc, where outward migration is no longer supported. This so called zero-torque radius is dependent on the planetary mass. For more massive planets, the zero-torque radius is located further inwards. This region in the disc can act as a feeding zone for planetary embryos and is therefore important for the growth mechanism of large planets.

A change in the viscosity of the disc, changes the discs structure (e.g. the temperature gradient), which influences the speed of migration of an embedded low mass planet. A too low viscosity changes the direction from outwards to inwards. For high enough viscosities the planet migrates outwards. In a more massive disc, outward migration is possible to larger distances to the host star, as more material in the disc is able to sustain outward migration much longer.

References

[1] Paardekooper, S.-J., and Mellema, G.: Halting type I planet migration in non-isothermal disks, A&A, Vol. 459, L17-L20, 2006

[2] Kley, W., Bitsch, B., and Klahr, H.:Planet migration in three-dimensional radiative discs, A&A, Vol. 506, 971-987, 2009

[3] Bitsch, B., and Kley, W.: Range of outward migration and influence of the disc's mass on planetary migration, A&A, submitted.

[4] Tanaka, H., Takeuchi, T., and Ward, W.-R.: Three-Dimensional Interaction between a Planet and an Isothermal Gaseous Disk. I. Corotation and Lindblad Toruqes and Planet Migration, ApJ, Vol. 565, 1257-1274, 2002

[5] Bitsch, B., Boley, A., and Kley, W.: Influence of adiabatic index on planetary migration, in prep.