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# ON TYPE I MIGRATION IN CIRCUMBINARY DISCS

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**Abstract.** Many planets have now been found in binary systems. Here, we study some aspects of planet formation in binary systems and focus on type I migration in circumbinary discs. In order to investigate the evolution of a low-mass planet embedded in a circumbinary disc, we have performed 2D hydrodynamical simulations. Our results suggest that the stability of a planet depends strongly on the planet mass and on the binary eccentricity. For example, a 50 $M_\oplus$ planet is stable as long as $e_{bin} \leq 0.2$ whereas we find that a 10 $M_\oplus$ planet is ejected if $e_{bin} \geq 0.1$.

For low binary eccentricities, it appears that the system can achieve a state of secular resonance where the apsidal lines of the planet and of the binary are aligned, preventing the planet from close encounters with the binary. For high binary eccentricities, secular resonance is not achieved and close encounters are possible, leading to the ejection from the system.

## 1 Introduction

About 60 % of solar-type stars reside in binary or multiple star systems. To date, 29 planets have been discovered in such systems, most of them orbiting one component of the system (Boss 2006). Observations indicate that the mass distribution and the orbital characteristics of these planets are different from the ones of planets orbiting single stars. In particular, the planets found in binary systems appear to be the most massive and to have a very low eccentricity when their period is shorter than about 40 days (Eggenberger et al. 2004). This suggests not only that planet migration can occur in such systems but also that this process differs probably from planet migration in single star systems.

In the following, we are interested in how planet migration proceeds in circumbinary discs, when the planet orbits around the two components of the binary system. We consider type I migration, which corresponds to planets with mass up to a few Earth masses. The case of type II migration (corresponding to Jupiter mass planets) has been studied by Nelson (2003).

## 2 Numerical Methods

To investigate this issue, we have performed 2D hydrodynamical simulations of low-mass planets embedded in a circumbinary disc. We follow the disc evolution using the hydrocode Genesis (de Val-Borro et al. 2006). Hydrodynamical equations are solved in polar coordinates and the number of grid cells used is $N_r = 512$ and $N_\phi = 512$. The orbital evolution of the planet resulting from its interaction with the disc is computed using a fifth-order Runge-Kutta scheme. In these calculations, the force of the disc on the binary is not included and the orbital elements of the binary remain fixed.

The unit of mass is taken to be the mass of the central binary $M_{bin} = 1$, the unit of time is the orbital period at $R = 1$ and the gravitational constant is set to $G = 1$. The binary semi-major axis is $a_{bin} = 0.4$ and the mass ratio between the two stars is set to $q_{bin} = 0.1$. We consider different values for the binary eccentricity, ranging from $e_{bin} = 0.05$ to $e_{bin} = 0.5$.

The parameters for the initial disc model are the following: the disc mass is $M_d = 0.02\ M_{bin}$ and its aspect ratio is $H/R = 0.05$. We use a standard Shakura-Sunyaev prescription for the viscosity (Shakura & Sunyaev 1973) with $\alpha = 5 \times 10^{-3}$. The inner and outer edges of the disc are located at $R_{in} = 0.8$ and $R_{out} = 6$ respectively.

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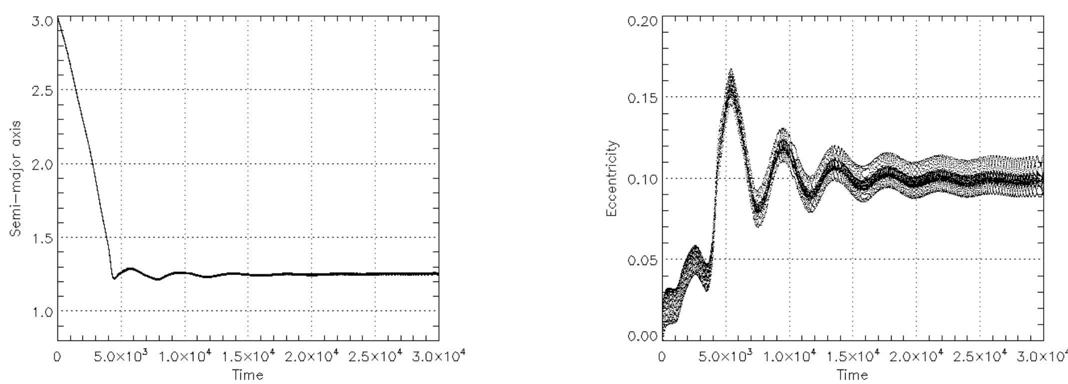
Our calculations are divided into two steps. Firstly, we consider only the disc+binary system and let the disc evolve until a quasi-stationary state is reached. As shown by previous numerical simulations (Artymowicz & Lubow 1994), a cavity is formed at the inner edge of the disc due to the gravitational torques created by the binary. Then, we put a planet in the disc and let it interact with both the binary and the disc.
The initial planet semi-major axis is $a_p = 3$ and we have used two values for the planet mass, namely $M_p = 50\ M_\oplus$ and $M_p = 10\ M_\oplus$.

## 3 Results

It appears that the evolution of the planet depends strongly on the binary eccentricity and on the planet mass. For $M_p = 50\ M_\oplus$, the planet remains on a stable orbit as long as $e_{bin} \leq 0.2$. Higher values of the binary eccentricity lead to ejection from the system. For $M_p = 10\ M_\oplus$, the orbit is stable only for $e_{bin} = 0.05$.
Below, we examine in more details these two regimes of evolution and focus on simulations in which the planet mass is $M_p = 50\ M_\oplus$.

### *3.1 Low binary eccentricities*

Figure 1 shows the orbital evolution of the planet in the case where $M_p = 50\ M_\oplus$ and $e_{bin} = 0.2$. After a period of inward migration due to the interaction with the disc, the migration stops and both $a_p$ and $e_p$ oscillate in phase before reaching a constant value. At this time, the planet is located just outside the inner edge of the disc and its eccentricity is similar to the disc eccentricity.



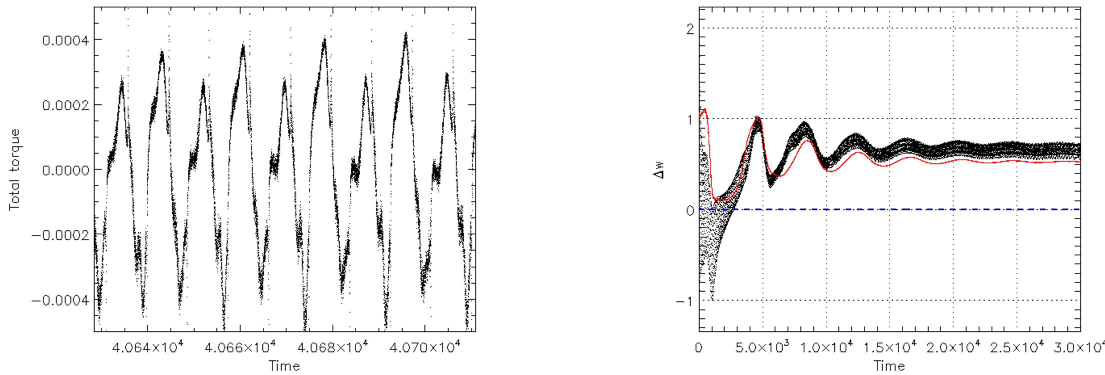

(a) (b)

**Fig. 1.** Evolution of the planet in the case where $M_p = 50\ M_\oplus$ and $e_{bin} = 0.2$.

Examination of the torques exerted on the planet at the end of the calculation reveals (see Fig. 2a) that migration stops because the average torque exerted by the disc on the planet over one orbital period is equal to zero. It appears that such a configuration can be obtained when the system has reached a state of secular resonance, where the relative longitude of pericentre between two bodies retains a constant value. Here, the apsidal lines of the planet $\omega_p$ and of the binary $\omega_b$ are aligned whereas the relative longitude of pericentre between the disc and the planet $\omega_d - \omega_p$ has a constant value but different from zero (Figure 2b). Because the orbits of the planet and of the binary are aligned, $e_p$ can not reach high values, preventing the planet from having close encounters with the binary.

### *3.2 High binary eccentricities*

For higher values of the binary eccentricity, we find that the planet does not remain on a stable orbit but is ejected from the system. Figure 4 shows an example of such an evolution. Here, the planet mass is $M_p = 50\ M_\oplus$ and the binary eccentricity is $e_{bin} = 0.3$. From this figure, it is clear that the ejection from the system is due




(a) (b)

**Fig. 2.** (a): Torques exerted by the disc on the planet as a function of time. Here, $M_p = 50\ M_\oplus$ and $e_{bin} = 0.2$. Torques are computed at the end of the computation when $a_p$ and $e_p$ have reached a constant value. (b) Relative longitude of pericentre between the planet and the disc (black line) and between the binary and the disc (red line).

to close encounters with the binary. Note also that in this case, the disc is very eccentric.

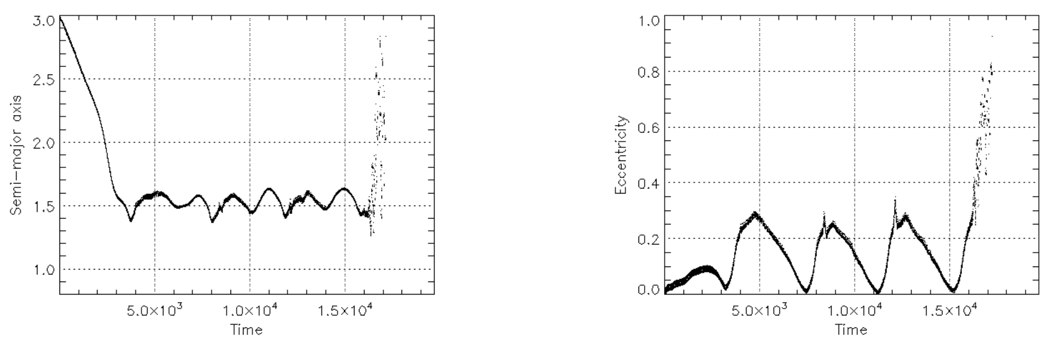



**Fig. 3.** Semi-major axis and eccentricity evolution of a 50 $M_\oplus$ planet. Here, the binary eccentricity is $e_{bin} = 0.3$.

In figure 3, we display $a_p$ and $e_p$ as a function of time. Both $a_p$ and $e_p$ oscillate with large amplitude but never converge to a constant value. The maximum value reached by $e_p$ is about 0.3, which is enough to lead to close encounters with the binary and subsequently to the ejection from the system.
Examination of the forces exerted on the planet by the disc and the binary show that $a_p$ is driven by both the disc and the binary whereas $e_p$ is mainly driven by the binary. The reason for this is that here, the system is not in a configuration of secular resonance and in particular, $\omega_p - \omega_b \neq 0$. Thus, secular interactions between the planet and the binary can lead to large amplitude oscillations of $e_p$.

## 4 Conclusion

We have investigated how type I migration behaves in circumbinary discs by performing hydrodynamical simulations of low-mass planets embedded in circumbinary discs. Our results show that a planet can reside on a stable orbit in binary systems with low eccentricities. For a $M_p = 50\ M_\oplus$, we find stability if $e_{bin} \leq 0.2$ whereas for a $M_p = 10\ M_\oplus$, ejection is possible if $e_{bin} \geq 0.1$.
For low binary eccentricities, orbital stability is possible because the system can achieve a state of secular resonance where the apsidal lines of the planet and of the binary are aligned, preventing the planet from close

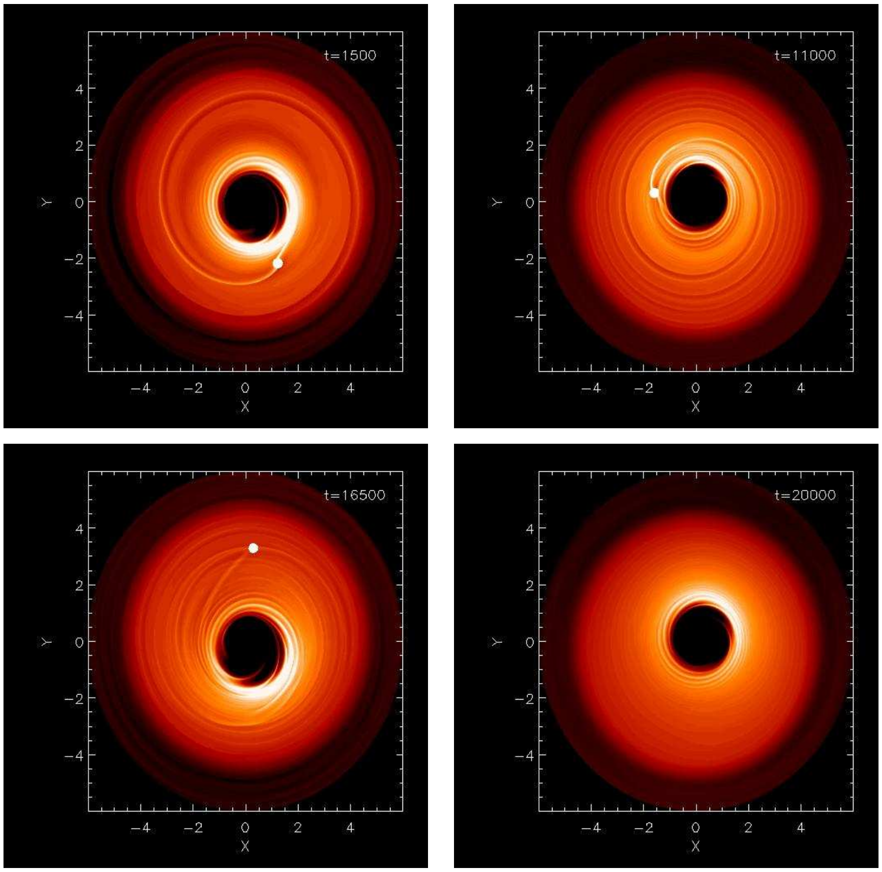



**Fig. 4.** Evolution of the planet in the case where $M_p = 50\ M_\oplus$ and $e_{bin} = 0.3$.

encounters with the binary. However, for high binary eccentricities, secular resonance is not achieved and close encounters are possible, leading to the ejection from the system.

In these simulations, the back-reaction of the disc on the binary is not included. However, taking into account this force could have important effects because the evolution of the system is mainly driven by secular interactions. New numerical simulations incorporating this effect are currently under way to investigate this.

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