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# Migration of accreting giant planets

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## Abstract

Giant planets forming in protoplanetary disks migrate relative to their host star. By repelling the gas in their vicinity, they form gaps in the disk's structure. If they are effectively locked in their gap, it follows that their migration rate is governed by the accretion of the disk itself onto the star, in a so-called type II fashion. Recent results [3] showed however that a locking mechanism was still lacking, and was required to understand how giant planets may survive their disk. We propose that planetary accretion may play this part, and help reach this slow migration regime.

## 1. Introduction

Planets form in protoplanetary disks and interact gravitationally with them. In general, asymmetric distributions of material yield gravitational torques acting upon a planet and hence, promote angular momentum exchanges between the planet and the gas.

While several regimes have been identified (see [1] for a review), depending on the masses of both objects relative to their star, the general outcome of those interactions is a fast migration of planets towards their star as they lose angular momentum to the disk.

In this work, we focus on the type II migration, which concerns giant planets in a gap. In this regime, theoretically, the planets do not drift *with respect to* the gas, but rather *follow* the gas, as it spreads and accretes onto the star. However, it was shown [3] that giant planets migrate generally faster as they are not locked in their gap because they are able to transfer material from the inner disk to the outer disk. Here we investigate the influence of planetary accretion on this matter.

## 2. Type II with accretion

We ran simulations using `FARGO 2D` code [5]. A Jupiter mass $m_J = \frac{m_\odot}{1000}$ planet was used in a disk that extends radially from $0.2$ to $3\ a_J$, where $a_J$ is Jupiter's semi-major axis, and we assume a solar mass star $m_S = m_\odot$ to calibrate the star accretion rate. We consider an $\alpha$-viscosity [6] driven accretion $\dot{M} = 3\pi\nu\Sigma$.

Planetary accretion is handled using an enhanced version of the recipe developed by [4] that was presented in [2]. During each time-step $\delta t$, a fraction $f \times \delta t$ of the material inside the Hill radius of the planet $R_H = a_P(m_P/3m_S)^{1/3}$, and $m_S$ the mass of the host star, is removed from the simulation. We used a smooth transition function

$$\begin{array}{llll} \texttt{if} & d/R_H < 0.3, & f(d) & = 1 \\ \texttt{elif} & d/R_H < 0.8, & f(d) & = \cos^2(\pi\frac{d}{R_H} - 0.3) \\ \texttt{else} & & f(d) & = 0 \end{array} \quad (1)$$

where $d$ is the distance to the planet. We performed four simulations with different accretion rates, controlled by the parameter $K$ as described later. Time evolution of the semi-major axis $a$ is shown in Fig. 1.

### 2.1. Obtention of initial conditions

The initial density profile $\Sigma(r)$ was set to a power law that ensures an accretion rate $\dot{M} = 5 \times 10^{-8} m_\odot \mathrm{yr}^{-1}$, with $\alpha = 3 \times 10^{-3}$. In order to keep control on the theoretical migration rate, we impose the inflow to stay constant at the outer boundary of the grid. It follows that, a stationary state is characterized by uniformity of $\dot{M}(r)$, which is what we aim for before releasing the planet.

To obtain our initial conditions for comparative migration, we prepared the simulations in two stages during which the planet's orbital parameters were not allowed to evolve. First we slowly introduced the planet's mass over 1000 jovian orbital periods $T_J$, with a smooth function of time $m_P(t) = m_J \sin^2(2\pi t/1000)$. In order to evacuate faster the gas originated in the orbital vicinity of the planet, we use planetary accretion while the mass is being introduced. Finally, we ran 150 additional orbits using each simulation's respective value for $K$.

### 2.2. Results

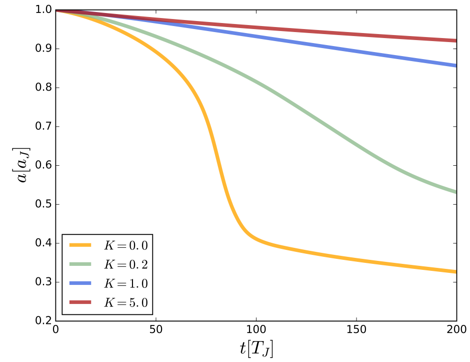


Figure 1: Semi-major axis $a$ with respect to time $t$. The accretion rate $\tau_{acc}(d)$ is $Kf(d)$, where $f$ is described by Eq. 1. Accretion slows down migration as it prevents gas to be transferred from the inner to the outer part of the disk. In this example, the accreted mass is not added to that of the planet.

When the planet migrates without accreting (orange curve on Fig. 1), it undergoes an episode of runaway migration and loses $60\%$ of its semi-major axis in $\sim 100$ orbits. Any one of the accretion rates we tested here allows us to avoid this behavior. Moreover, it is evident that the migration rate $\dot{a}$ dramatically decreases with the accretion rate. Our inter-

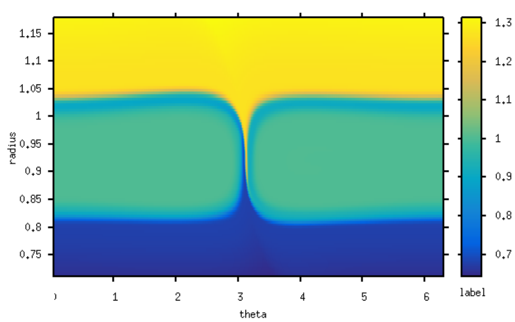


Figure 2: Colormap of the disk material's initial radius, taken $200T_J$ after releasing the planet. The planet is at $(r, \theta) = (0.93, \pi)$, accreting with $K = 5$.

pretation is that accreted material from the inner disk contributes about twice as less to the angular momentum transferred to the planet as it only survives half of the collisional encounter. Additionally, as this material can not pile up "behind" the planet, the latter can not be pushed faster than the outer disk accretes. As shown on Fig. 2, material from the inner disk can get temporarily trapped in the so-called horseshoe region around the planet's orbit but is not transferred to the outer disk, while the latter is essentially blocked by the planet. If we add the accreted mass to the planet, the migration gets even slower still because the planet gains inertia as it migrates, while the torque provided by the disk does not scale with $M_P$. This allows to reduce the minimal value of the accretion rate required to restore type II.

## 3. Summary and Conclusions

We demonstrate that the accretion rate onto a giant planet has a dramatic influence on its migration rate. In particular, we have shown that planetary accretion prevents gas exchanges across the gap between the inner and the outer disk. This locks the planet inside its gap and restores the standard picture of type II migration. Additionally, if material from the outer disk disappears into the planet, the outer disk becomes less efficient at pushing the planet, whose migration can then be slower than type II.


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