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A new paradigm for type II migration

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Abstract

Recent results question the classical view of type II migration, that is a giant planet following the disk viscous evolution and therefore migrating at the viscous drift rate. We have explored the parameter space, and propose a new understanding of this phenomenon, which agrees with the numerical results.

1. Introduction

Type II migration concerns giant planets in the protoplanetary disk. Above typically a hundred Earth masses, a planet is massive enough to repel the inner and the outer disk away from its orbit, and carve an annular gap[1]. It has long been thought that these planets, locked inside their gap, follow the viscous spreading of the disk[2] : the planet being repelled outwards by the inner disk and inwards by the outer disk can not move with respect to the gas and is thus carried by the accretion disk towards the star. This migration – which occurs on a viscous timescale, that is much slower than the type I migration which affects small mass planets – could explain the presence of hot Jupiters[3]. However, recent works suggest that this classical picture may well be too simplistic[4, 5, 6] : numerical simulations show that planets do not migrate at the drift speed of the gas. Here, we propose an other description of the type II migration, which may reconcile our understanding of this phenomenon with the numerical experiments.

2. Constraints

In our previous work[5], we have confirmed previous findings that the migration rate of giant planet depends on the surface density of the disk (while the gas drift speed does not). But we have also carefully checked with a thorough study that the migration speed is really proportional to the viscosity of the gas (like the gas drift speed).

Like other authors before [7, 4], we have observed some gas flow across the gap, which could potentially decouple the planet from the disk evolution. However, we have also shown that this only happens at large viscosity, when the gap is not very deep. Enabling the planet to accrete the gas cuts the flow. We found that this has almost no influence on the migration speed at low to moderate viscosities. At large viscosity, the migration rate was changed, but this was mostly due to a drastic change in the shape of the gap, caused by the planet removing a lot of gas from the system.

In summary, the migration speed is proportional to the viscosity, but not equal to the viscous drift speed of the gas. The gas flow across the gap is negligible. The migration speed is roughly proportional to the surface density of the disk, especially in small mass disks.

3. A new model

We build on the idea put forward by [4] that when the planet is at equilibrium inside its gap, the gas may not be at equilibrium with the planet, and reciprocally.

Consider a planet on a fixed orbit which opens a gap. The location of the planet defines the center of the gap. The fixed planet may well feel a non zero torque from the gas. This torque is obviously proportional to the surface density of the gas. Now, let the planet free while the gas is fixed ; it will move to a different orbital radius, where it feels zero torque. Then, the gas is not at equilibrium any more. Its distribution adjusts to the new position of the planet ; this evolution happens viscously, and brings us back to the initial situation.

We see that the two timescales naturally come to play together. The motor of the migration is the torque the planet feels at the center of the gap, which is proportional to the gas surface density. But the migration speed is regulated by the viscous evolution of the gas. In this presentation, we will explain how they combine in a single formula for the migration speed. This new formula is tested against numerical simulation spanning a vast area of the parameter space.

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