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BUILDING THE MINIMUM MASS SOLAR NEBULA

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Abstract. Most planetary formation simulations rely on simple protoplanetary disk models evolved from the usual, though inaccurate, Minimum Mass Solar Nebula. Here, we suggest a new consistent way of building a protoplanetary disk from the collapse of the molecular cloud: both the central star and the disk are fed by the collapse and grow jointly. We then model the star physical characteristics based on pre-calculated stellar evolution models. After the collapse, when the cloud initial gas reservoir is empty, the further evolution of the disk and star is mainly driven by the disk viscous spreading, leading to radial structures in the disk: temperature plateaux at the sublimation lines of the dust species and shadowed regions that are not irradiated by the star. These irregularities in the disk surface mass density or midplane temperature may help trap planetary embryos at these locations, eventually selecting the composition of the planet cores. In addition, we redefine the disk timeline and describe the stages that lead to the MMSN model.

Keywords: Protoplanetary disks, Planets and satellites: formation, Planet-disk interactions, Accretion disks, Planets and satellites: dynamical evolution and stability, Hydrodynamics

1 Introduction

In order to understand the impact of the early evolution of protoplanetary disks over planet populations, we numerically model the formation and evolution of protoplanetary disks around young Classical T Tauri type stars. We consider the joint growth of the star and disk as they are fed in gas by the collapse of the initial molecular cloud.

2 Model

2.1 Cloud and star model

We interpolate the stellar physical properties from tables of pre-calculated stellar evolutions (Piau & Turck-Chièze 2002; Piau et al. 2011). The disk gains mass from the molecular cloud. The star gains mass from the molecular cloud and accretion by the disk viscous spreading.

2.2 Disk model

We model the disk as an α-disk (Shakura & Sunyaev 1973) for which the viscous spreading can be calculated from the equations of Lynden-Bell & Pringle (1974). We model than evolution using the 1D + 1D numerical hydrodynamical code PHYVE (Protoplanetary disk HYdrodynamical Viscous Evolution) detailed in Baillié & Charnoz (2014); Baillié et al. (2015, 2016); Baillié (2018).

This model relies on a strong coupling between the disk dynamics, thermodynamics (involving cloud and stellar irradiation heating, viscous heating and radiative cooling), geometry (including self-shadowing effects) and composition (through the opacity model of Semenov et al. (2003) to compute its structure and viscous evolution.

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3 Disk formation and evolution

Figure 1 shows the mass evolution of the forming star and protoplanetary disk. The disk grows during the collapse phase for 170 kyr before emptying on the star by viscous spreading

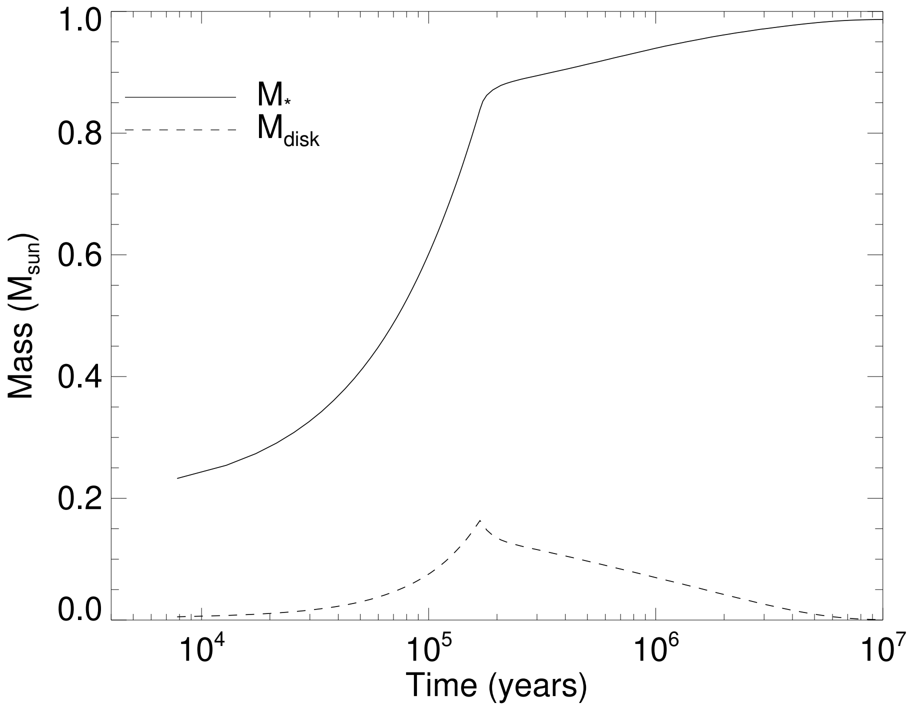

Fig. 1. Time evolution of the star and disk masses. The gravitational collapse that feeds the disk and the star ends after 170,000 years.

The disk gets hotter until the end of the collapse phase and then cools down. Sublimation lines migrate accordingly as the disk evolves.

Most of the inner disk is self-shadowed (up to the heat transition barrier). Sharp edge and positive temperature gradient can be found at the heat transition barrier. In addition, we find enlarged snow and sublimation zones at the temperature plateaux.

4 Impact of the disk evolution on planet migration

Torques are very sensitive to density and temperature gradients. Assuming that disks of similar ages have similar mass accretion rates, we can rescale the MMSN timeline to fit the timeline of the disk formation by collapse. The evolution from the disk formation to an MMSN-like stage seems to require about 1 Myr. Though the MMSN evolves faster, disks of similar mass accretion rates will present similar planet traps and deserts at the sublimation lines and heat transitions (Figure 2).

5 Conclusions and perspectives

The disk forms in 170 kyr and reaches an MMSN-like stage in 1 Myr. Planet traps follow the sublimation lines and induce a trapped migration . Modeling the disk formation by the cloud collapse allows to understand the trapping possibilities in the first million years of planet formation.

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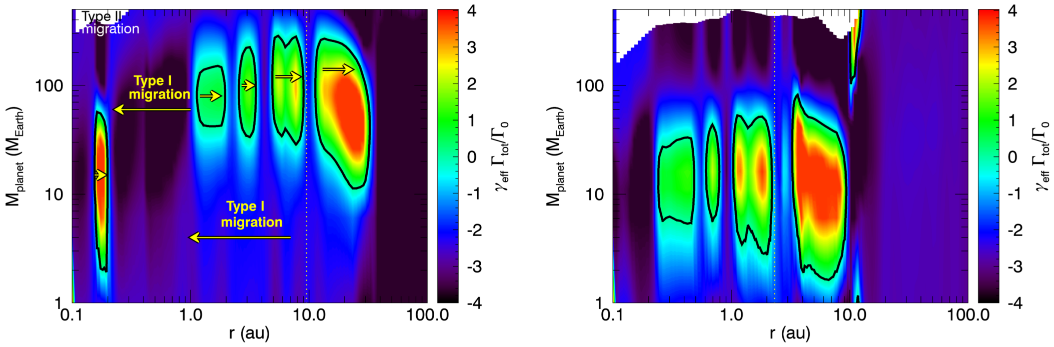

Fig. 2. Migration torque of a protoplanet with given radial distance to the central star r_P and mass M_P, in a protoplanetary disk after 200,000 years (upper panel) and after 2 million years (lower panel) of evolution. Black contours (0-torque contour) delimit the outward migration conditions while the rest of the migration map shows inward migration. Planetary traps are located at the outer edges of the black contours while planetary deserts are at their inner edges. The yellow dotted line marks the water ice line and the white area delimits the region where planets can open a gap.

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