SF2A 2025
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MODELING CIRCUMPLANETARY DISKS LIKE PROTOPLANETARY DISKS: A MISTAKE?

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Abstract. The numerical code PHYVE is a hydrodynamical code that allows to follow the formation and evolution of protoplanetary disks from the collapse of the molecular cloud to the photoevaporation phase. This code is able to model the surface mass density distribution consistently with the disk radial profile (including the disk composition and geometry). We aim at using this code for modeling circumplanetary disks by considering the protoplanetary disk as the source of infalling material, replacing the molecular cloud that was an initial parameter in the protoplanetary disk simulations. We will simulate the circumplanetary disk radial thermal profile and investigate the question of the crucial parameters differing from protoplanetary disks.

Keywords: Circumplanetary disks, Protoplanetary disks, Planets and satellites: formation, Accretion disks, Planets and satellites: dynamical evolution and stability, Hydrodynamics

1 Introduction

Most in-situ satellite formation simulations rely on simple circumplanetary disk models evolved from the usual, though inaccurate, Minimum Mass Sub Nebula. Here, we suggest a new consistent way of building a circumplanetary disk, directly inherited from the protoplanetary disk. After the collapse of the molecular cloud that forms the protoplanetary disk, the central star and the planets, when the cloud initial gas reservoir is empty, the further evolution of the circumplanetary disk 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 satellite embryos at these locations, eventually selecting the composition of the planet cores.

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; Marques et al. 2013). 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 that evolution using the 1D + 1D numerical hydrodynamical code PHYVE (Protoplanetary disk HYdrodynamical Viscous Evolution) detailed in Baillié & Charnoz (2014); Baillié et al. (2015, 2016, 2019).

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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2.3 Circumplanetary disk model

We consider a growing Circumpplanetary disk and planet around a Zero-Age Main Sequence star.

The CPD heating includes:

- PPD external heating (infalling material)
- CPD viscous heating
- Stellar irradiation

Tha angular momentum of the infalling material is the angular momentum of the PPD annulus of infalling gas and dust, taken from Baillié et al. (2019) simulations.

2.4 Initial conditions

We chose to consider a snapshot at 4 Myr (i.e. 1 Myr after the MMSN stage) from the simulations of Baillié et al. (2019), and locate our CPD at the snowline (1.7 AU). The infalling material is at 160K.

The CPD turbulent viscosity is taken equal to the PPD turbulent viscosity: $\alpha_{visc_C PD} = \alpha_{visc_P PD} = 10^{-2}$.

The stellar parameters, and the density profile are inherited from the PPD simulation.

- $M_* = 0.95 M_{Sun}$
- $R_* = 1.4 R_{Sun}$
- $L_* = 0.7 L_{Sun}$
- $T_* = 4280 K$
- $\Sigma \propto r^{-0.5}$

3 Disk formation and evolution

Additional physical effects include the disk self-shadowing, the adiabatic heating and the disk photoevaporation.

The protoplanetary disk forms in 170 kyr and reaches an MMSN-like stage in 2-3 Myr. Planet traps follow the sublimation lines, leading to a "trapped migration" of planetary embryos. Modeling the disk formation by the cloud collapse allows to understand the multiple trapping possibilities in the first million years of planet formation.

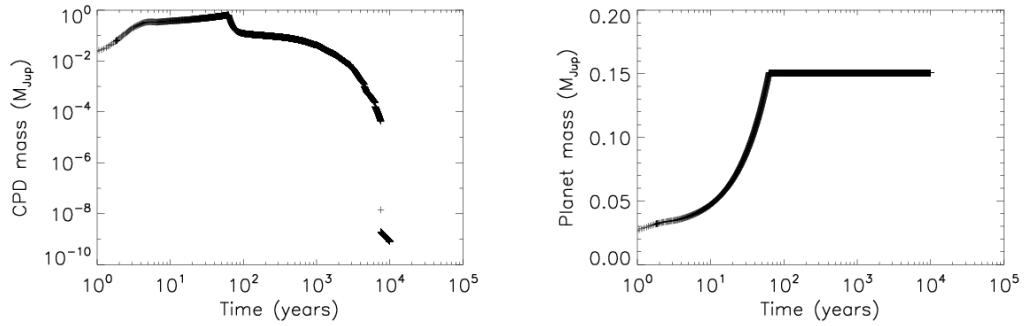

Fig. 1. CPD total mass evolution with time (left panel) and planet mass evolution with time (right panel).

Figure 1 shows that the CPD almost reaches 1 Jupiter mass in less than 100 years while the planet grows up to 0.15 Jupiter mass in the same time.

4 Perspectives

Before investigating the possibilities of trapping protosatellites at the icelines and the possible composition of the formed satellites, it is crucial to have a better estimate of the α parameter that drives the viscous evolution of the disk. It is unlikely that this parameter could be due to turbulence as it is the cas for protoplanetary disks. Therefore, both the value of this parameter and its origin are questionable and should be addressed in order to generate more realistic simulations for large satellites in-situ formation.

I would like to express my most complete gratitude to all those who helped organizing this 2025 SF2A meeting in Toulouse.

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