PROBING THE SECULAR EVOLUTION OF EMBEDDED PROTOPLANETARY DISCS

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Abstract. We perform a large timescale core collapse simulation to explore the secular evolution of embedded protoplanetary discs. The secular evolution properties point towards evolved discs. The disc experiments three accretion phases where the magnetic braking is the main accretion driver in the pseudo-disc while self-gravity is the main accretion driver in the disc via Toomre instability.

Keywords: Stars: formation – Protoplanetary discs – Magnetohydrodynamics – Methods: numerical

1 Introduction

During the early class 0/I stages of their evolution, protoplanetary discs are embedded in an infalling envelope. They are small, massive and strongly magnetized. In class II discs however, the envelope is depleted. The disc is large and weakly magnetized, its mass being dominated by the protostar. This gap is reflected in numerical models, with core collapse models tracking the physics up to early class I while class II disc models assume hydrostatic equilibrium and power-law physics. We bridge this gap by performing core collapse simulations up to the end of class I (~ 100 kyr after first core formation) while resolving the disc vertical structure (~ 10 cells/H).

2 Model parameters

The setup is inspired from Masson et al. (2016). We start from an initial uniformly rotating supercritical ($\mu = 2$) 1 $M_\odot$ core of radius $R_0 = 2500$ au at $T_0 = 10$ K. The thermal behavior is handled using a barotropic equation of state following Marchand et al. (2016). The non-ideal effects of the magnetohydrodynamics are accounted using a chemical network adapted from Kunz & Mouschovias (2009).

3 Secular evolution properties

Left panel of figure 1 shows midplane radial profiles of surface density, rotation rate and poloidal magnetic field through the long-term evolution. Surface density has first a sharp transition between a high Σ disc and a low Σ pseudo-disc, then flattens to a power-law. Gas is first Keplerian over ≈ 10 au then circularizes up to a few 100 au. The poloidal magnetic field is a plateau in the disc and decreases from 100 mG down to roughly 1 mG.

4 Accretion history

Right panel of figure 1 shows spacetime diagrams of the surface density, poloidal magnetic flux and Toomre parameter, along with the disc radius. When Toomre parameter is near one, it predicts gravitational instability. The pseudo-disc region is always associated to high magnetic flux: there, accretion is driven by magnetic braking. There are three accretion phases in the disc: first, a small disc accretes via gravitational instability. Second, it is growing and stable. Third, it stagnates, the outer part is unstable and accretes.

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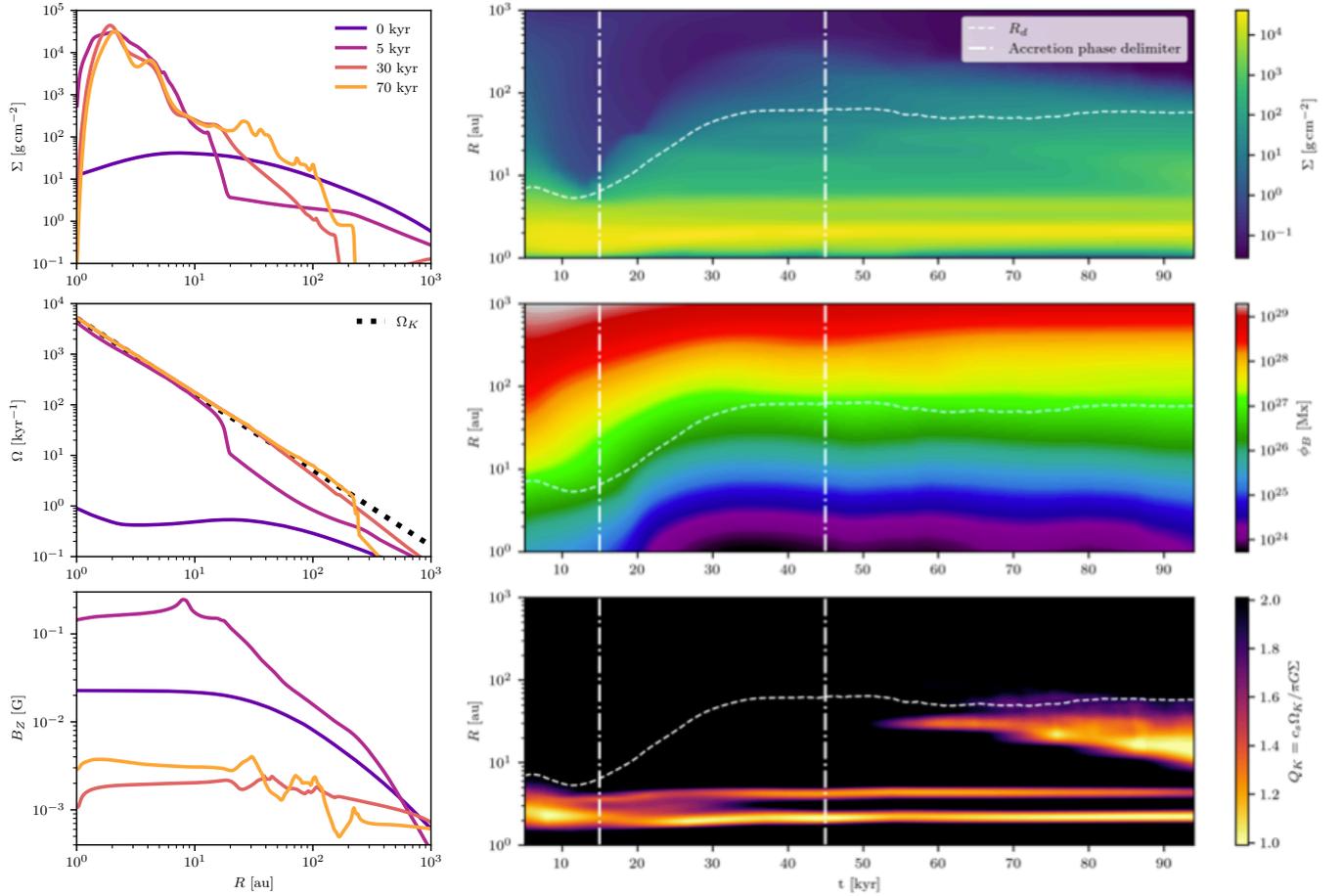
Fig. 1. Left: Radial profiles of the surface density (top), rotation rate (middle), and poloidal magnetic field (bottom) in the midplane, spanning over the whole secular evolution (the lighter, the later). In the middle panel, the black dashed line is the theoretical Keplerian rotation rate. **Right:** Spacetime diagrams of the surface density (top), poloidal magnetic flux (middle) and Toomre parameter (bottom). The dashed white line corresponds to the disc radius, and dash-dotted white lines delimit the three accretion phases.

5   Conclusions

The model is integrated for 100 kyr after disc formation and resolves the vertical structure ($dZ \sim 10^{-2}$ au). The secular evolution properties point towards evolved discs : realization of a surface density power law, magnetic field diffusion from 100 down to 1 mG and gas circularization from 10 up to a few 100 au. There are three phases in the disc accretion history : first a small, spiral-driven accreting disc. Second, an expanding smooth disc. Third an outer, spiral-driven accreting disc. Once a disc has settled, magnetic braking is mainly important in the pseudo-disc where it drives accretion while self-gravity controls the disc accretion through spiral-density waves triggered by Toomre instability.

References

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