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The Early Era: How do protostellar discs form?

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Abstract. Discs are a key element in star and planet formation; however, magnetic fields can efficiently transport angular momentum away from the central region of the collapsing core during the dense core collapse, preventing disc formation. We perform numerical simulations of magnetically supercritical collapsing cores with a misalignment between the rotation axis and the magnetic field (Joos *et al.* 2012) and in a turbulent environment (Joos *et al.* 2013). The early formation of massive discs can take place at moderate magnetic intensities if the rotation axis is tilted or in a turbulent environment, because of misalignment and turbulent diffusion.

Keywords. star formation, low mass stars, disc formation, magnetohydrodynamics, turbulence, numerical simulations

1. Introduction

Discs are a key element in star and planet formation: protostars probably grow by accreting material from protostellar accretion discs, which at later stages are the natural progenitors of planets. The formation of discs is a challenging theoretical question, and the conditions for their presence remain unclear.

Magnetic fields certainly play an important role, and they can efficiently transport angular momentum away from the central regions of the collapsing core, thereby preventing the early formation of massive discs. This occurs even for relatively low magnetic field intensities (Mellon & Li 2008; Price & Bate 2007; Hennebelle & Fromang 2008), at a level largely in accordance with the observational measurement of core magnetizations (Crutcher 1999; Falgarone *et al.* 2008). However, most previous simulations were performed in a particular configuration, where the magnetic field and the rotation axis are initially aligned and without turbulence.

We therefore perform three-dimensional, adaptive mesh, numerical simulations of magnetically supercritical collapsing dense cores in both non-turbulent and turbulent environments, using the magneto-hydrodynamic code Ramses (Teyssier 2002; Fromang *et al.* 2006).

2. Orientation matters

We perform a first set of simulations with an initial mass of 1 $M_\odot$ and an angle α between the rotation axis and the magnetic field varying from 0 to 90°.

We show that it affects the transport of angular momentum: specific angular momentum in the inner part of the collapsing core increases with the angle α. More momentum is therefore available to form discs.

Indeed, transport processes are less efficient when α increases. First, the strong magnetic braking acting in the aligned configuration is due to a strong lever arm, due to the peculiar geometry of the problem (with the typical hourglass shape of the magnetic field lines). In misaligned configurations (i.e. in other geometric configurations), the strengh of this lever arm decreases, and, therefore, so does the magnetic braking. Second, the outflows launched by the growth of a magnetic tower transport an significant amount of angular momentum. The suppression of the outflows with increasing α is responsible for a weaker transport of angular momentum.

More angular momentum is therefore available to build more massive discs. Even a small angle (of 20°) is sufficient, in the intermediate magnetisation case, to form disc 3 times larger than in the aligned configuration.

3. The role of turbulence

The interstellar medium is known to be turbulent, and turbulent energy is known to cascade down to small scales. Star formation is therefore occuring in a turbulent environment. To investigate the effects of turbulence, we perform simulations with an initial core mass of 5 $M_{\odot}$ since more massive clouds are expected to be more turbulent (Larson 1981).

Turbulence effects are twofold: first, the angular momentum included in the turbulent velocity field imposed as initial conditions induces a misalignment between the rotation axis and the magnetic field. We already show how this orientation matters and help to form more massive discs. Second, turbulence is responsible for an efficient diffusion of the magnetic flux; magnetic flux is diffused out of the inner part of the collapsing core, decreasing the strengh of the magnetic braking. It also favors the formation of more massive discs.

4. Conclusions

In contrast to earlier analyses, we show that the transport of angular momentum acts less efficiently in collapsing cores with non-aligned rotation and magnetic fields. We also show that the turbulence is responsible for a misalignment between the rotation axis and the magnetic field and can diffuse out of the magnetic field of the inner regions efficiently. The magnetic braking is therefore reduced, and massive discs can be built.

The early formation of massive discs can take place at moderate magnetic intensities if the rotation axis is tilted or in a turbulent environment, because of misalignment and turbulent diffusion.

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