**INFLUENCE OF THE MAGNETIC FIELD ON THE COLLAPSE OF A PROTOSTELLAR CORE.**

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## 0.1 Introduction

Studying the collapse and the fragmentation of a protostellar molecular dense core is of great relevance for the star formation process. If the rôle of the magnetic field has early been suspected (e.g. Shu et al. 1987), it is still a disputable issue. Recent progress have nevertheless been done and various 2D (Allen et al. 2003) as well as 3D numerical calculations have been performed (Machida et al. 2005, Banerjee & Pudritz 2006, Hosking & Whitworth 2003, Ziegler 2005, Fromang et al. 2006, Price & Bate 2007).

Here, we present further 3D numerical calculations of a collapsing magnetized dense core. Our main goals are to investigate the influence of the magnetic field strength on the disk, the outflows and the fragmentation.

## 0.2 Numerics and initial conditions

We perform 3D numerical simulations using the AMR MHD code, RAMSES (Fromang et al. 2006). RAMSES is based on shock capturing schemes and can handdle ideal MHD, self-gravity and cooling. The AMR facilities offers access to the high resolution needed to treat the problem.

Here we consider simple initial conditions, namely an initially uniform sphere in solid body rotation. The magnetic field is initially uniform and parallel to the rotation axis. Initially, the ratio of the thermal over gravitational energy, $\alpha$, is about 0.4 whereas the ratio of rotational over gravitational energy, $\beta$, is equal to 0.045. An $m = 2$ perturbation of amplitude 0.1 has been added.

The strength of the magnetic field is expressed in terms of mass-to-flux over critical mass-to-flux ratio, $\mu$. The case $\mu = 1$ corresponds to a cloud just magnetically supported, i.e. magnetic forces balance gravitational forces. We consider three cases, $\mu = \infty$ (hydro case), $\mu = 20$ (very supercritical cloud) and $\mu = 2$ (highly magnetized super critical cloud).

In order to avoid the formation of a singularity and to mimic the fact that at very high density, the dust becomes opaque and therefore the gas becomes nearly adiabatic, we use a barotropic equation of state: $C_s = C_s^0 \times (1 + (\rho/\rho_0)^{2/3})^{1/2}$, where $\rho_0 = 10^{-13}$ g cm$^{-3}$.

The calculations start with initially $64^3$ grid cells. As the collapse proceeds, new cells are introduced in order to ensure that the Jeans length is described everywhere with at least 10 cells. Nine levels of AMR are used for a total of about $10^6$ of grid cells.

## 0.3 Disk and fragmentation

Figure 1 shows the equatorial density and velocity field for the case $\mu = \infty$ (hydrodynamical case). As expected, because of angular momentum conservation during collapse, a centrifugal disk-like structure forms. As it has been found in many hydrodynamical calculations, this massive disk is very unstable and quickly fragments into few objects.

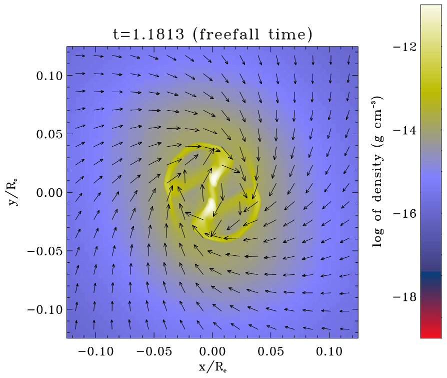


Figure 1: Hydrodynamical case. Density and velocity fields in the equatorial plane.

Figure 2 shows results for $\mu = 20$ (i.e. very supercritical case). As can be seen, the size of the disk is nearly identical to the size of the disk formed in the hydrodynamical case. This is due to the fact, that the magnetic field strength is too low to provide a substancial magnetic braking. However, the field is nevertheless strongly twisted by the rotation which generates a strong toroidal component. This toroidal magnetic field stabilizes the disk against fragmentation by adding an extra support and by removing some material from the disk (see next section).

Figure 3 shows results for $\mu = 2$ (i.e. strongly magnetized super critical cloud). As revealed by the velocity field, no centrifugal disk has been formed at this stage. Detailed analysis (not presented here) shows that since the magnetic field has a strong influence, the gas collapses first along the magnetic field lines. Therefore the gas which forms the denser part of the cloud comes mainly from an area located along the polar direction which has initially a low angular momentum. Also magnetic braking extracted some angular momentum though it has a more stronger influence at latter time when significant displacements in the equatorial plane have occured.

## 0.4 Outflows

Figure 4 shows the density and velocity fields in the xz plane for $\mu = 20$. As can be seen a bubble-like structure forms instead of a thin disk. The bubble is actually slowly (with respect to the infall speed) expanding from the centrifugally supported disk. It is due to the growth of the toroidal magnetic field which generates an outward gradient of magnetic pressure which

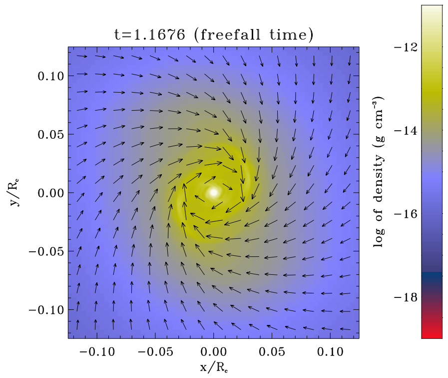


Figure 2: Same as Fig. 1 for $\mu = 20$.

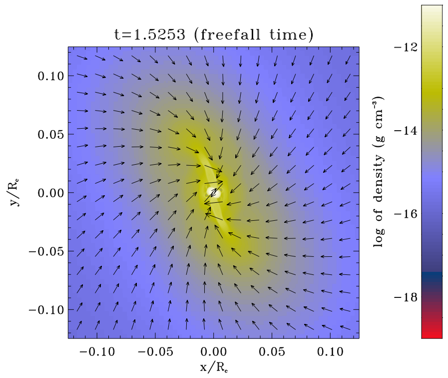


Figure 3: Same as Fig. 1 for $\mu = 2$.

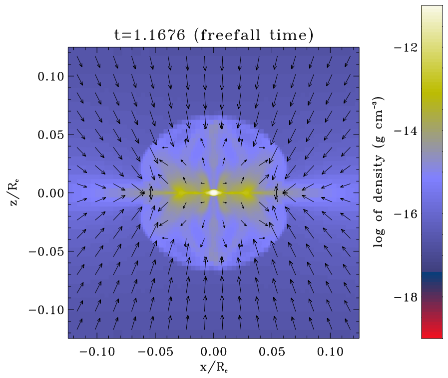


Figure 4: Density and velocity in the xz plane for $\mu = 20$.

pushes the gas in the outer direction. At $z = 0$, the velocity near the polar axis, is nearly perpendicular to the equatorial plane.

Figure 5 shows results for the case $\mu = 2$. An outflow stronger than in the case $\mu = 20$ is launched. The topology of the flow is also very different. The velocity field near $z = 0$ is not perpendicular to the equatorial plane and makes an angle of about $30 - 40^\circ$ with it. The flow is quickly recollimated by the toroidal component of the magnetic field and becomes parallel to the z-axis. Alltogether this is similar to the prediction of the Blandford & Payne (1981) model.

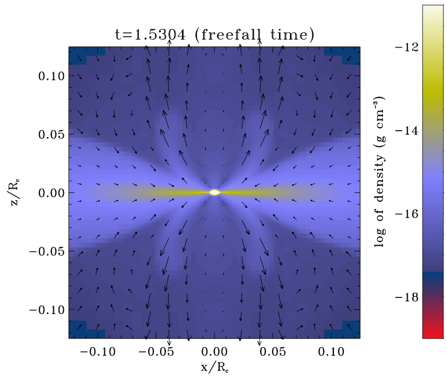


Figure 5: Same as Fig. 4 for $\mu = 2$.

## 0.5 Conclusion

Performing 3D AMR numerical simulations for various magnetic field strengths, we find that even modest value of the magnetic field, have a strong impact on the collapse of a protostellar dense core. In particular, magnetic field tends to stabilize the massive circumstellar disk against fragmentation, reducing the number of objects which forms. Magnetic field also leads to the lauching of outflow-like structures. It should however be noted that the velocity of these outflows ($\simeq 3$ km/s) is much lower than the observed velocities. As a matter of fact, calculations of the second collapse phase which results from the dissociation of the dihydrogen, show that stronger outflows can be launched.

## 0.6 References

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