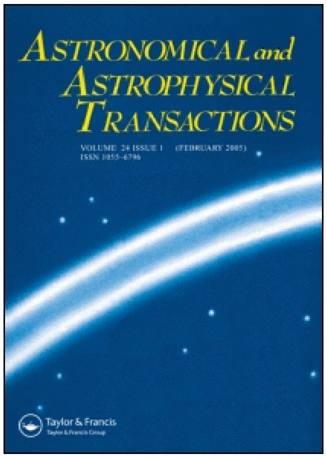

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NUMERICAL SIMULATION OF PROTOSTAR FORMATION IN MAGNETIZED MOLECULAR CLOUD CORES

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The two-dimensional numerical simulations of magnetized molecular cloud collapse has been done using integrated adaptive mesh in spherical coordinates. To take into account non-isothermality of late stages of collapse, we use a kind of "parametrical" approach to the radiative transfer through the cloud. Several numerical models are presented.

Keywords: MHD; Interstellar medium; Molecular cloud cores; Star formation; Numerical simulation, Collapse

1 INTRODUCTION

Many authors numerically investigated the problem of star formation in molecular cloud cores. Due to the large number of physical factors affecting the cloud contraction, the first results were obtained in 1D approximation (Larson, 1969; Winkler and Newman, 1980; Boss, 1984). The influence of rotation and large-scale magnetic fields leads to anisotrophy of the forces causing the cloud collapse. This anisotrophy induced researchers to develop multidimensional (2D and 3D) numerical studies of the problem. There were a great number of works made by different authors, that took into account either magnetic field or rotation during the cloud collapse, and there were only a few works that have considered both of these factors. However, the mutual influence of these factors results, for example, in such an important mechanism as magnetic braking.

In this paper we use the new 2D MHD numerical code "Enlil", which has been recently developed for modelling of axisymmetric self-gravitating MHD flows. It is based on the TVD scheme (Dudorov, Zhilkin, Kuznetsov, 1999) and uses adaptive mesh in spherical coordinates. This code allows the study of the process of star formation in molecular cloud cores in a more generalized and self-consistent statement of problem.

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2 EQUATION OF STATE

To solve the problem of protostellar cloud collapse, we use the axisymmetric self-gravitating MHD equations set (see Duddorov, Zhilkin, Kuznetsov, 1999) together with the following equation of state:

$$P = \frac{R}{\mu}\rho T, \tag{1}$$

where P – pressure, ρ – density, T – temperature and, μ – averaged molecular weight of gas. On the early isothermal stages of collapse $T = \text{const}$. This condition assumes that the cloud is transparent to it's own radiation and all the heating produced during its contraction transports by IR radiation outside the cloud.

In the late stages of contraction, the central dense region becomes opaque to IR radiation. In order to take into account radiative transfer through the cloud, we use a kind of "parametrical" approach. It assumes that heating acts on collapse only via gas pressure P, which appears in dynamical equations. The temperature in Eq. (1) is calculated from relation $T = A_\gamma \rho^{\gamma-1}$, where parameters $A_\gamma(T)$ and $\gamma(T)$ are selected to fit the temperature profile from Boss (1984). This profile was obtained from detailed 1D calculations of non-isothermal collapse (see also Winkler and Newman, 1980) and shows the evolution of the central temperature as a function of the central density.

In Eq. (1) we also take into account the processes of hydrogen dissociation and ionization: we calculate μ in Eq. (1) using hydrogen dissociation and ionization degrees derived in approximation of local thermodynamical equilibrium.

3 RESULTS

In this paper, we consider the clouds with initial mass $M = 1\,M_\odot$ and temperature $T = 10\,\text{K}$ having uniform density distribution (similarly to Boss, 1984). The initial cloud occupies the

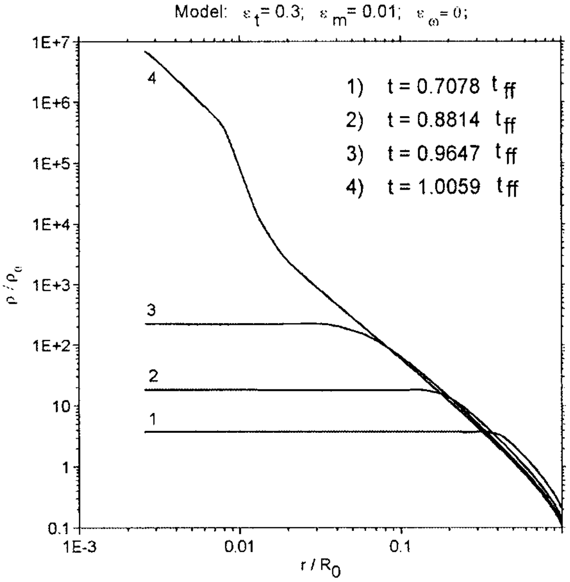

FIGURE 1 The density profiles in equatorial plane for model with $\varepsilon_t = 0.3$, $\varepsilon_\omega = 0$ and $\varepsilon_m = 0.01$.

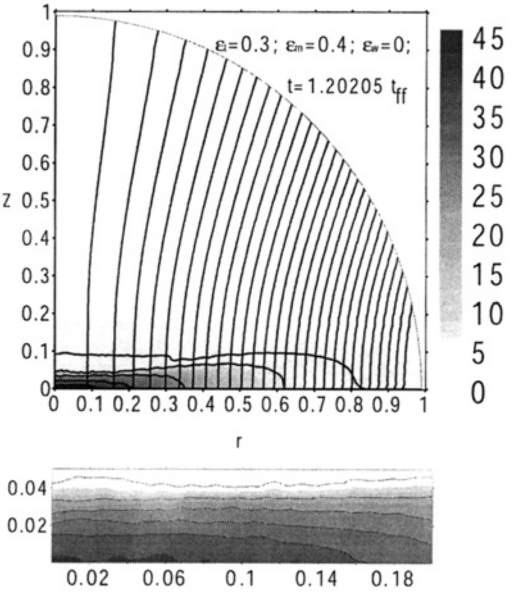

FIGURE 2 The collapse of the magnetized protostellar cloud with $\varepsilon_t = 0.3$, $\varepsilon_\omega = 0$ and $\varepsilon_m = 0.4$ for $t = 1.202\ t_{ff}$. Gray scale shows the density distribution. Vertical lines show the shape of magnetic field lines. The lower picture shows the structure of the disk inner region.

spherical region with radius R_0 and is penetrated by uniform magnetic field colinear to z-axis. The initially uniform rotation around z-axis is also allowed. There are three dimensionless parameters, characterizing the initial state of such cloud: ε_t, ε_m and ε_ω, which are the ratios of thermal, magnetic and rotational energies to the absolute value of gravitational energy, respectively. For $\varepsilon_t = 0.3$, we will have $R_0 = 6.7 \cdot 10^{16}$ cm and $\rho_0 = 1.6 \cdot 10^{-18}\ \mathrm{g \cdot cm^{-3}}$.

Figure 1 shows density profiles in the cloud midplane on different moments for model with $\varepsilon_t = 0.3$, $\varepsilon_\omega = 0$ and $\varepsilon_m = 0.01$ (the t_{ff} is the free-fall time of the cloud). For $t = 1.0059\ t_{ff}$, we have $\rho_{\mathrm{center}} \simeq 10^7 \rho_0$. This corresponds to temperature $T \simeq 100\,\mathrm{K}$, thus, the collapse of the central region is already non-isothermal.

Figure 2 shows the distribution of density (gray scale) and configuration of magnetic field lines on $t = 1.202\ t_{ff}$ for model $\varepsilon_t = 0.3$, $\varepsilon_\omega = 0$ and $\varepsilon_m = 0.4$. Due to the strong magnetic field, the cloud evolved into a flat disk with the ratio of semi-axes $\varepsilon \sim 10$. The lower picture shows the structure of the disk inner region.

During the cloud collapse, the central region of uniform magnetic field decreases. Out of this region, the geometry of the magnetic field becomes quasi-radial.

For clouds with strong magnetic fields ($\varepsilon_m \geq 0.5$), the collapse switches to quasi-statical contraction on the moment $t \simeq t_{fm} = t_{ff}/\sqrt{1 - \varepsilon_m}$. On this moment, the central density increases to about $10\rho_0$ and collapse almost stops. Such clouds evolve in diffusion time-scale.

4 CONCLUSION

In this paper, the recently developed numerical code "Enlil" was applied to the problem of protostar formation in magnetized rotating molecular cloud cores. This allowed us to improve our earlier results obtained using other numerical codes. Several numerical results are presented.

Acknowledgements

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References

[1] Dudorov, A. E., Zhilkin, A. G. and Kuznetsov, O. A. (1999). *Mat. Modelirovanie*, **11**, 101 (in Russian).
[2] Boss, A. P. (1984). *Ap. J.*, **277**, 768.
[3] Winkler, K. H. and Newman, M. J. (1980). *Ap. J.*, **238**, 311.