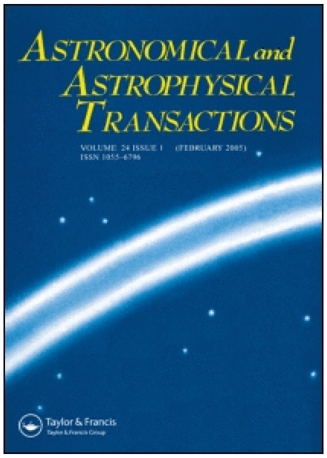

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TWO-DIMENSIONAL ADAPTIVE CODE FOR SIMULATION OF ASTROPHYSICAL MAGNETOHYDRODYNAMIC FLOWS

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TWO-DIMENSIONAL ADAPTIVE CODE FOR SIMULATION OF ASTROPHYSICAL MAGNETOHYDRODYNAMIC FLOWS

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Integrated adaptive mesh for simulations of two-dimensional (2D) self-gravitating, axially symmetric magnetohydrodynamic (MHD) flows in spherical coordinates is constructed and a new adaptive numerical 2D MHD code is developed. This code allows us to simulate efficiently the gravitational collapse of magnetized rotating protostellar clouds. Illustrative test computations are presented.

Keywords: Magnetohydrodynamics; Interstellar medium; Star formation; Numerical methods; Collapse

1 INTRODUCTION

All methods for adaptive mesh construction are based on the principle of optimal distribution of mesh nodes in the computational domain. This distribution of mesh nodes takes into account the reciprocal locations and velocities of individual subdomains having some solution peculiarities (large gradients, strong discontinuities, interphase boundaries, etc.). Two methods are applied at present for the construction of dynamically adaptive meshes.

Adaptive mesh refinement technology uses the tree structure of cell collection (Berger and Colella, 1989). Each hierarchy level of this structure gives the corresponding spatial and temporal resolutions. The algorithm allows us to insert dynamically the new cells and to delete the old cells when the complexity of the flow changes in a given region of the computational domain.

The other powerful method for the adaptation of computational algorithms consist of the construction of integrated, dynamically adaptive meshes. The theory of such meshes is based on the technique of the canonical transformations of the conservative hyperbolic equations (Rozhdestvensky and Yanenko, 1968).

In the present work the integrated, dynamically adaptive mesh for the simulation of the collapse of magnetized rotating clouds is briefly described.

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2 NUMERICAL TECHNIQUE

Recently we developed a simple quasimonotonic (TVD) finite-difference scheme with a high resolution in regions of smooth flow, for numerical solution of the magnetohydrodynamic (MHD) equations (Dudorov *et al.*, 1999). On the basis of this scheme we elaborated the numerical code Enlil for simulations of axially symmetric self-gravitating MHD flows in spherical coordinates. The integrated, dynamically adaptive grid is used in the code. The Poisson equation for the gravitational potential is solved in this code with the help of expansion by Legendre polynomials.

The integrated dynamically adaptive mesh is based on the following canonical transformation of independent variables:

$$\mathrm{d}r = \omega \mathrm{d}\tau + Q \mathrm{d}\xi, \quad \mathrm{d}t = \mathrm{d}\tau, \tag{1}$$

where ω is the radial velocity of grid motion and Q is the metric coefficient. The basic MHD equations in the new variables have the same conservative hyperbolic form. Therefore the same finite-difference scheme can be used for numerical solution of these equations. In our code the transformation (1) is chosen using a special procedure. The ξ nodes are distributed uniformly, while the r nodes are concentrated during the collapse to the cloud center.

3 RESULTS

As an example of the adaptive mesh capabilities we present here the results of numerical computation of the collapse of a magnetized rotating protostellar cloud. The initial cloud of mass $M = 1M_{\odot}$ and temperature $T = 10\,\mathrm{K}$ has a uniform density profile with $\rho = 1.6 \times 10^{-18}\,\mathrm{g\,cm^{-3}}$ and occupies a spherical region of radius $R = 6.7 \times 10^{16}\,\mathrm{cm}$. This model is characterized by the following dimensionless parameters: $\varepsilon_{\mathrm{t}} = 0.3$, $\varepsilon_{\omega} = 0.05$ and $\varepsilon_{\mathrm{m}} = 0.4$, where ε_{t}, ε_{ω} and ε_{m} are the initial ratios of the thermal, rotational and magnetic energies respectively to the absolute value of the gravitational energy.

Figure 1 shows the numerical distributions of the density (grey-scale field) and poloidal velocity (arrows) in the collapsing cloud at the time $t = 1.05t_{\mathrm{ff}}$, where t_{ff} is the free-fall time of the cloud. For better visualization of the dynamically adaptive mesh the central region of the cloud is shown with a different resolution. With the adaptive mesh the internal structure of the cloud can be computed with a high resolution. This example, at time $t = 1.05t_{\mathrm{ff}}$ the flattened (disc-like) cloud structure with a dense core and an accretion rarefied envelope is formed.

4 CONCLUSION

In this paper the integrated dynamically adaptive mesh for simulations of two-dimensional (2D), axially symmetric self-gravitating MHD flows in spherical coordinates is briefly described. On the basis of this adaptive mesh and TVD scheme for MHD equations a 2D numerical adaptive code Enlil is constructed. This code allows high-resolution simulations of gravitational collapse of magnetized rotating protostellar clouds, even for relatively small number of mesh nodes. Illustrative test computations demonstrate the good quality of the developed adaptive mesh.

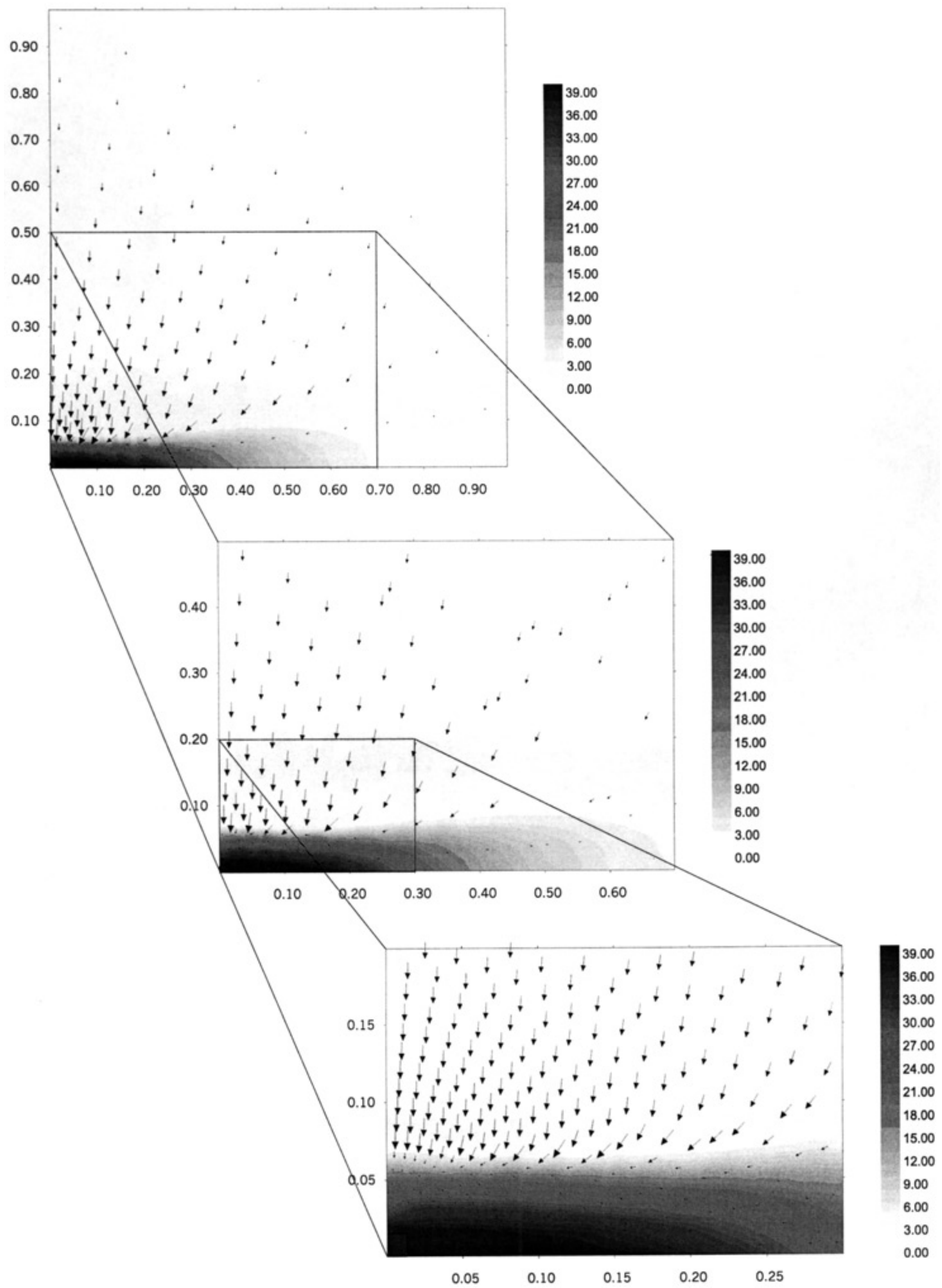

FIGURE 1 Gravitational collapse of a magnetized rotating protostellar cloud. Density distribution (grey scale) and poloidal velocity (arrows) distributions are shown for $t = 1.06t_{ff}$ with different resolutions of the central region.

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