MHD SIMULATIONS OF MASS OUTFLOWS FROM STAR FORMING REGIONS

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ABSTRACT: We have begun a project to produce self-consistent 2-D MHD simulations of the generation and collimation of mass outflows from star forming regions. We describe our code development work, and present preliminary results.

1. Introduction

Observational studies of star forming regions have demonstrated the ubiquity of energetic mass outflows from objects in the late stages of star formation (Lada, 1985). The most dramatic examples of these flows are molecular bipolar outflows and protostellar jets. How such flows are driven and collimated is an important unresolved problem. However, many models have been developed incorporating magnetic fields, e.g. protostellar winds collimated by a magnetized ambient medium (Königl, 1982), hydromagnetic winds driven from a molecular accretion disk (Pudritz and Norman, 1983), and magnetocentrifugal wind driven from a protostar rotating near breakup (Shu *et al*, 1988). We have begun a new project to numerically model mass outflows from star forming regions in hopes of identifying the most promising scenarios.

2. The ZEUS-2D Code

ZEUS-2D is a time-explicit, Eulerian ideal MHD code developed for this project by the authors. It uses the hydrodynamic algorithms described in Norman and Winkler (1986) and the CT scheme of Evans and Hawley (1988) for evolving the magnetic fields. A coordinate independent formulation permits computations in any orthogonal coordinate system. The code has been rigorously tested against a battery of problems including the 1-D magnetic Riemann problem of Brio and Wu (1988), a 1-D Weber-Davis (1967) wind solution, and the 2-D solar coronal transient solution of Low (1984). Currently, a 2-D radiation transport module (full transport solution) is being developed to allow the self-consistent evolution of an embedded radiation field concurrent with the hydrodynamics.

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3. Results

We have studied the collimation of a non-magnetic, isotropic wind by a magnetized external medium in cylindrical (RZ) geometry. The ambient magnetic field is taken to be of uniform strength B_o parallel to the Z axis, while the ambient gas is isothermal and plane stratified according to $\rho(Z) = \rho_o(1 + (Z/a)^2)^{-m/2}$, $0 \leq m \leq 2$, where a is the core radius. The stellar wind is modelled by continously adding mass into a small spherical source region at a rate and with an internal energy which gives the desired mechanical luminosity. Figure 1 shows the result from a typical calculation. Magnetic collimation of the expanding bubble produces a smooth surfaced bubble elongated in the direction of the magnetic field lines, with a dense cap of material accumulated near the bubble apex. The eccentricity of the bubble increases in time at a rate determined by the magnetic field strength and the luminosity of the source. The rate is consistent with the analytic predictions of Königl (1982, cf. Appendix)

$$Z_o(t) \propto t^{2/(2-m)} \qquad R_o(t) \propto t^{-m/(4-m)} \qquad 0 \leq m < 2 \tag{1}$$

We have found for $m > 0$ the bubble tip accelerates along the Z axis, but does not flare and "blow out" due to the strong lateral confinement from the uniform magnetic field.

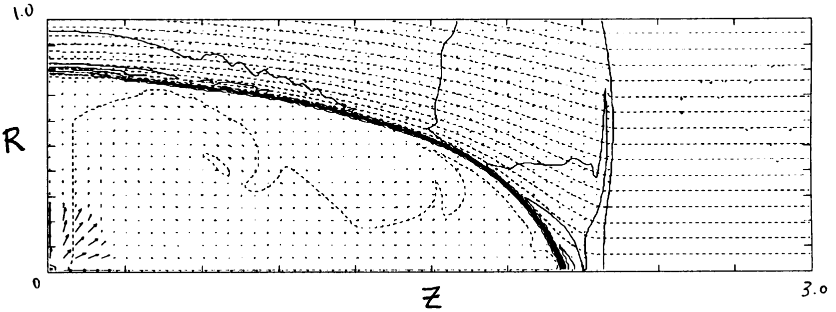

Figure 1. Magnetic Collimation of a protostellar wind creates an elongated bubble in the direction of the magnetic field. Density contours (solid lines) are superposed on the displaced magnetic field lines (dashed lines) and velocity vectors

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