MAGNETOHYDRODYNAMIC SIMULATION OF THE EVOLUTION OF LARGE-SCALE MAGNETIC FIELDS IN DISK GALAXIES

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ABSTRACT. The amplification of a seed magnetic field by the hydrodynamic behavior of a disk galaxy is an important and challenging problem. We present our initial work on a numerical simulation of the amplification of such a field to large scales and its subsequent evolution. The computations will be carried out using a 3-D magnetohydrodynamic code.

I. Introduction

Recent VLA observations have shown that a large extra galactic Faraday rotation of more than 30 rad/m^2 in excess of the galactic background exists toward radio-loud quasars (Welter, Perry and Kronberg 1984). This excess rotation measure (RM) is strongly correlated with the presence of optical absorption lines believed to be the result of intervening gas clouds in the foreground of the quasar. Studies of the optical absorption line system together with those of the RM associated with them allow a determination of the line of sight magnetic field strength $B_{\parallel}$ (μG) in the absorbing gas clouds. The best fitting model yields an intervening absorbing cloud with $R \simeq 50$kpc, $n_e \simeq 10^{-3}$cm^{-3}, $B_{\parallel} \simeq 2\mu$G. There is even some indication of cosmological evolution of the RM going as $(1+z)^{0.9\pm0.6}$ out to a background quasar redshift of 2.

At least one of these absorption line clouds is known to be a member of a class known as damped Lyman-alpha clouds which are large enough to be protogalactic gaseous disks (Wolfe 1988). As such, the RM, which implies that field strengths of the order of μG existed inside protogalaxies over such large scales as early as redshifts greater than 2, provides an exciting challenge to and constraint on the theoretical modeling of the evolution of large-scale galactic magnetic fields. At redshifts of order 3, the age of the universe was only about 1/8 its present age, thus limiting to 10 the maximum number of rotation periods during which amplification of seed fields by differential rotation in a gaseous disk could have taken place.

This challenging problem motivates us to study the evolution of the large-scale magnetic field in protogalactic gaseous clouds and galactic disks computationally. Numerical simulations are an efficient way to study the evolution of these large-scale magnetic fields and to make predictions of their observable effects. A 3-D, nonlinear magnetohydrodynamics (MHD) code (Barnes, *et al.*, in preparation) has been adapted to apply to the galactic magnetic field problem. This code models the one- or two-fluid 3-D compressible MHD equations of Braginskii (1965) with finite conductivity in a cylindrical geometry.

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2. The Numerical Method and Applications

A detailed simulation of the large-scale magnetic field of a galaxy requires a supercomputing environment due to the memory and speed requirements. For a typical galaxy 10kpc in radius and 2kpc thick, a computational mesh of 250 radial by 50 axial by 8 toroidal points is adequate to study fluid effects. Such a computation must simulate the evolution of galactic magnetic fields out to 10^{17}secs (on the order of the age of the universe). Consequently, a way must be found to avoid unreasonable constraints on the time step of the computational algorithm. Standard numerical algorithms for MHD codes would constrain the time step to be no larger than 2×10^{12}secs. This represents a severe constraint requiring runs of one million time steps or more. However, the semi-implicit algorithm applied to MHD equations enables the simulation to run with time steps on the order of the Alfven time scale (10^{16}secs assuming a uniform plasma density of $1cm^{-3}$ and temperature of 1eV) or larger requiring only a few hundred time steps.

The semi-implicit method was first introduced in meteorological computations (Robert, 1969). Harned and Kerner (1985) formulated the first precise description of the approach for MHD simulations. The technique has been well tested and proven to be efficient and robust (Schnack, *et al.*, 1987; Barnes, *et.al*, in preparation).

The basic concept behind the semi-implicit method is the addition of similar terms to both sides of the partial differential equation to be solved. The terms are chosen to approximate the wave producing terms contained in the equation in question. Because of the freedom available in constructing these additional terms, it is straightforward to choose them such that the resulting algorithm is guaranteed to be unconditionally numerically stable.

There are several applications of our code in addition to modeling the evolution and structure of large-scale magnetic fields in disk galaxies and protogalactic clouds. The existence of magnetic fields in gaseous galactic halos could be examined and the MHD behavior of the disk plus halo system simulated. In addition numerically following the large-scale magnetic field of protogalactic gaseous clouds from the cosmological collapse phase through the formation of a disk provides an exciting opportunity for simulation and for making new predictions for observations.

Furthermore the flexibility of our code allows us to study the effects of the time-dependent conversion of gas mass into stars on the evolution and structure of the large-scale field. We also have the capability to implement realistic boundary conditions such as a tenuous plasma surrounding the disk in the simulation.

The results from our numerical simulations will be compared with the results of dynamo theory and with observations.

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