Cosmic Magnetic Fields: From Planets, to Stars and Galaxies
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Cosmic-ray driven dynamo in the medium of irregular galaxy

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Abstract. We investigate the cosmic ray driven dynamo in the interstellar medium of irregular galaxy. The observations (Chyży et al. 2000, 2003) show that the magnetic field in irregular galaxies is present and its value reaches the same level as in spiral galaxies. However the conditions in the medium of irregular galaxy are very unfavorable for amplification the magnetic field due to slow rotation and low shearing rate.

In this work we present numerical model of the interstellar medium in irregular galaxies. The model includes magnetohydrodynamical dynamo driven by cosmic rays in the interstellar medium provided by random supernova explosions. We describe models characterized by different shear and rotation. We find that even slow galactic rotation with low shearing rate gives amplification of the magnetic field. Simulations have shown that high amount of the magnetic energy flow out off the simulation region becoming an efficient source of intergalactic magnetic fields.

Keywords. MHD, methods: numerical, galaxies: magnetic fields, galaxies: irregular

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1. Model and input parameters

The CR-driven dynamo model consists of the following elements (based on Hanasz et al. 2004, 2006): (1) the cosmic ray component is an relativistic gas described by diffusion-advection transport equation; (2) anisotropic diffusion of CR along magnetic field lines; (3) localized sources of CR: random explosions of supernova remnants in the disk volume, which supply the CR energy density; (4) uniform resistivity of ISM; (5) shearing boundary conditions and tidal forces are implemented to reproduce the differentially rotating disk in the local approximation (Hawley et al. 1995); (6) realistic vertical disk gravity following the model of Milky Way (Ferriére 1998) with scaled contribution of disk and halo to irregular galaxies. We used resistive MHD equations in 3D Cartesian domain of $25 \times 50 \times 400$ grid points. The initial conditions of system assumes the magnetohydrostatic equilibrium with horizontal, purely azimuthal magnetic filed corresponding to $p_{mag}/p_{gas} = 10^{-4}$.

2. Results

We perform a two series of numerical experiments for different values of angular velocity Ω and shearing parameter q (see caption of Fig. 1). In experiments A1–A5 we found that the efficiency of magnetic field amplification depends strongly on the angular velocity (Fig. 1 left), but for $\Omega \geqslant 0.03$ Myr^{-1} the amplification rate stabilizes and becomes

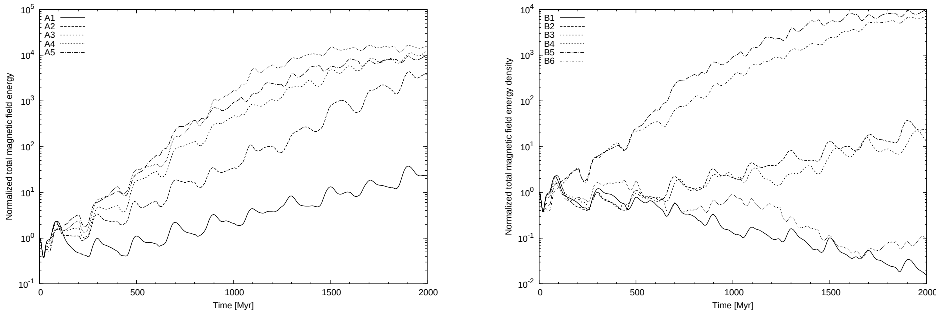

Figure 1. Plots of total magnetic field energy evolution during 2 Myr. The left panel shows the evolution for models (A1–A5) with different Ω (respectively 0.01–0.05 Myr^{-1}) and the right with different q: B1–B3 for $q = 0, 1, 1.5$ with $\Omega = 0.01$ Myr^{-1} and B4–B6 with $\Omega = 0.05$ Myr^{-1}.

roughly independent on Ω. In the second set of experiments we change the shearing rate (Fig. 1 right), for a constant angular velocity. We find no amplification for experiments with $q = 0$ (B1,B4). The other simulations show that the dynamo process does not depend on shearing rate, as long as q is finite. We find a similar evolution of the total magnetic field energy for $q = 1$ and 1.5 (B2,B3 and B5,B6, respectively).

To estimate the total production rate of magnetic field energy during simulation time, we calculate the outflowing magnetic energy density through the xy top and bottom domain boundaries. Our results show that large amounts of magnetic energy are lost through the open boundaries of the computational box, suggesting that irregular galaxies due to their weaker gravitation can be efficient sources of intergalactic magnetic fields.

3. Conclusions

In our work we found: a) the amplification of the total magnetic field energy in irregular galaxies is possible even with slow rotation and a weak shear; b) for dynamo action the shearing is needed, but the amplification rate on the shear is weak; c) the larger angular velocity the higher efficiency of the dynamo process; d) due to the weaker gravitation in irregular galaxies the outflow of magnetic field off the simulation domain is large, suggesting that they may effectively magnetize the intergalactic medium (Kronberg et al. 1999).

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