Cosmic Magnetic Fields: From Planets, to Stars and Galaxies
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Global simulations of galactic dynamo driven by cosmic-rays and exploding magnetized stars

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Abstract. We conduct global galactic–scale magnetohydrodynamical (MHD) simulations of the cosmic–ray driven dynamo. We assume that exploding stars deposit small–scale, randomly oriented, dipolar magnetic fields into the differentially rotating ISM, together with a portion of cosmic rays, accelerated in supernova shocks. Our simulations are performed with the aid of a new parallel MHD code PIERNIK. We demonstrate that dipolar magnetic fields supplied on small SN–remnant scales, can be amplified exponentially by the CR–driven dynamo to the present equipartition values, and transformed simultaneously to large galactic–scales by an inverse cascade promoted by resistive processes.

Keywords. Galaxies: ISM - magnetic fields - ISM: cosmic rays - magnetic fields - MHD

It has been suggested by Rees (1987) that galactic seed fields were created and amplified in stars during early stages of galactic evolution, and then spread into the interstellar medium (ISM) by stellar explosions, and subsequently amplified in plerionic (Crab–type) supernova remnants (SNRs). Rees (1987) estimates that a contribution of 10^6 randomly oriented plerionic SNRs may lead to 10^{-9}G mean magnetic fields on galactic scales. The initial setup of our galactic disk is based on the model by Ferriere (1998), with the gravitational potential by Allen & Santillán (1991). The global CR–driven dynamo model involves basic elements of local dynamo models presented by Hanasz et al. (2004): (1.) Cosmic rays supplied in randomly distributed SNRs, which are described as relativistic gas diffusing anisotropically along magnetic field lines, according to the diffusion–advection transport equation, supplemented to the standard set of resistive MHD equations. (2.) A finite resistivity of the ISM, responsible for dissipation of small–scale magnetic fields. Moreover, we assume that no magnetic field is present in the initial configuration, and that each SN supplies a weak, randomly oriented, dipolar magnetic field within the supernova remnant, together with the portion of CRs, while the thermal energy output from supernovae is neglected. Simulations have been performed with the aid of PIERNIK MHD code (see Hanasz et al 2009a,b and references therein), which is a grid–based MPI parallelized, resistive MHD code based on the Relaxing TVD (RTVD) scheme by Jin & Xin (1995) and Pen et al. (2003). The original scheme is extended to deal with the diffusive CR component (see Hanasz & Lesch (2003)). The simulation has been performed with the spatial resolution of 1000x1000x160 grid cells, in the domain spanning 25 kpc x 25 kpc x 8 kpc in x, y and z directions, respectively. We show that the CR driven dynamo, seeded by small–scale magnetic dipols and cosmic rays supplied in supernova remnants, amplifies magnetic fields exponentially by several orders of magnitude (Fig. 1), up to the saturation level, and develops large scale magnetic fields in the disk and the surrounding galactic halo (Fig. 2). The horizontal slice demonstrates the spiral structure of the amplified field. Formation of large lobes of unipolar magnetic

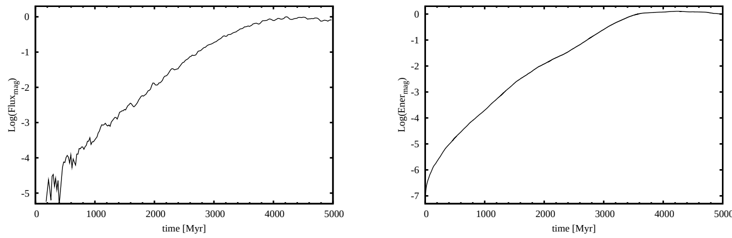

Figure 1. Temporal evolution of toroidal magnetic flux (left) and total magnetic energy (right). The final saturation level corresponds to the equipartition magnetic fields

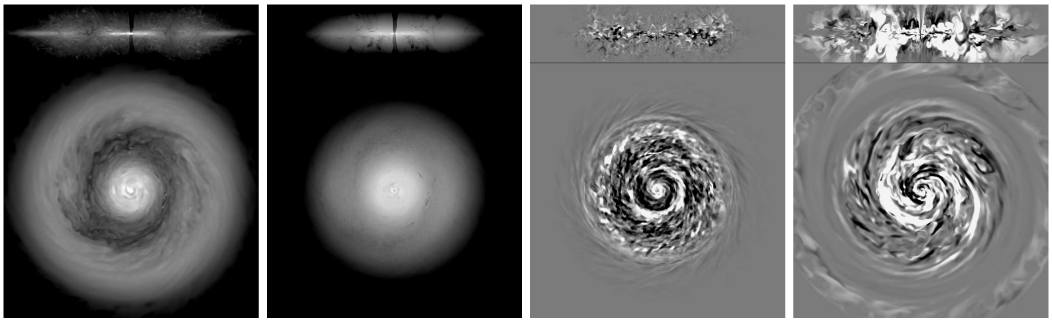

Figure 2. Logarithm of gas density (1st panel) and cosmic ray energy density (2nd panel) at $t = 4.2$Gyr . Distribution of toroidal magnetic field at $t = 0.5$ Gyr (3rd panel) and $t = 5$ Gyr (4th panel). Unmagnetized regions of the volume are marked with the gray colour, positive and negative toroidal magnetic fields are marked with white and black colours, respectively. Initially the toroidal magnetic field strength is a few 10^{-8}G and at the saturated state it is a few μG.

fields is apparent in vertical slices through the disk volume. The magnetic field large–scale structure forms the X–shaped configuration. The experiment supports strongly the idea by Rees (1987) that galactic dynamos may have been initiated by small–scale magnetic fields of stellar origin.

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