Abstract

We carried out global three-dimensional ideal magnetohydrodynamic simulations for galactic gaseous disks in the gravitational potential of bulge, disk, halo and spiral arms. We considered radiative cooling energy loss of interstellar medium (ISM). Synchrotron intensity & polarization observations show magnetic fields in spiral galaxies are along with spiral arms. Our numerical results indicate that isothermal shocks generate in spiral arms and magnetic fields are amplified due to these shocks. We expect this results consist with observations.

Introduction & Motivation

In spiral arms, gravitational potential is deeper than disk average about 2-10%. ISM go through these potentials, isothermal shocks generate. Synchrotron radiation intensity & polarization observations suggest that magnetic fields are amplified and concentrate on shock front. We examined effect of spiral gravitational potential on the nonlinear evolution of galactic magnetic fields, we choose magnetohydrodynamic equilibrium state in axisymmetric potential for initial model in order to investigate physical process of state transition.

Simulation Model

Density distribution
Disk : magnetohydrodynamic equilibrium torus
Halo : isothermal hydrostatic equilibrium (T=10K)
Gravity : Miyamoto-Nagai’s axisymmetric potential including DM + spiral arm potential $\Phi_{sp}$ (Wada et al. 2011)
$\Phi_{sp}(r,\phi, z) = \Phi_{disk}(r, \phi) + \frac{v_0^2}{2} \sqrt{\frac{r_0^2}{r^2} + \frac{z^2}{z_0^2}} \cos \left( n \left( \phi - \Omega_{sp} t + \cot \theta_{sp} \ln \frac{r}{r_0} \right) \right)$
$r_0=0.02$, $z_0=0.3$ kpc, $n=2$, $\Omega_{sp}=12.2$ km/s/kpc, $L=15$, $r=1$ kpc are spiral potential strength, scale height, the number of arm, pattern angular velocity, pitch angle, scale radius.
Numerical Scheme : MacCormack(time, space 2nd order accuracy) + artificial viscosity
Simulation Region : $0.05$ kpc - $56$ kpc, $0<\phi <2\pi$, $0<kpc$ (cylindrical coord., z = 0 symmetric boundary)
ISM cooling : Raymond, Cox & Smith 1976 ($10^5 K < T < 10^10K$)
0 (otherwise)
applied disk region (white dashed line box)

Numerical Result

We found that isothermal shocks generate along spiral arms and magnetic field lines concentrate these shock fronts. We also found magnetic energy is amplified in disk. Plasma $\beta$ decreases and stays around $<5$. Toroidal magnetic fields reverse in z=0 equatorial plane due to magneto-rotational instability (MRI). Han et al. (2002) pointed out Milky Way galaxy magnetic fields reverse in equatorial plane with rotation measure (RM) observation. After the amplification of magnetic energy saturates, magnetic flux is rise from disk to halo by Parker instability. Nishikori et al. (2006), Machida et al. (2013) carried out global 3D MHD simulation and showed same results.

Summary & Discussion

We carried out 3D simulations of the time evolution of galactic gaseous disk in non-axisymmetric potential. We maintained galactic shocks over 3Gyr taking into account spiral potential and ISM cooling. Magnetic fields are amplified due to these shocks and $\beta$ stays around 5. Our results are consistent with other numerical simulations.

References