Numerical Modeling of the Galactic magnetic field structure

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To realize high accuracy components separations for CMB polarization data

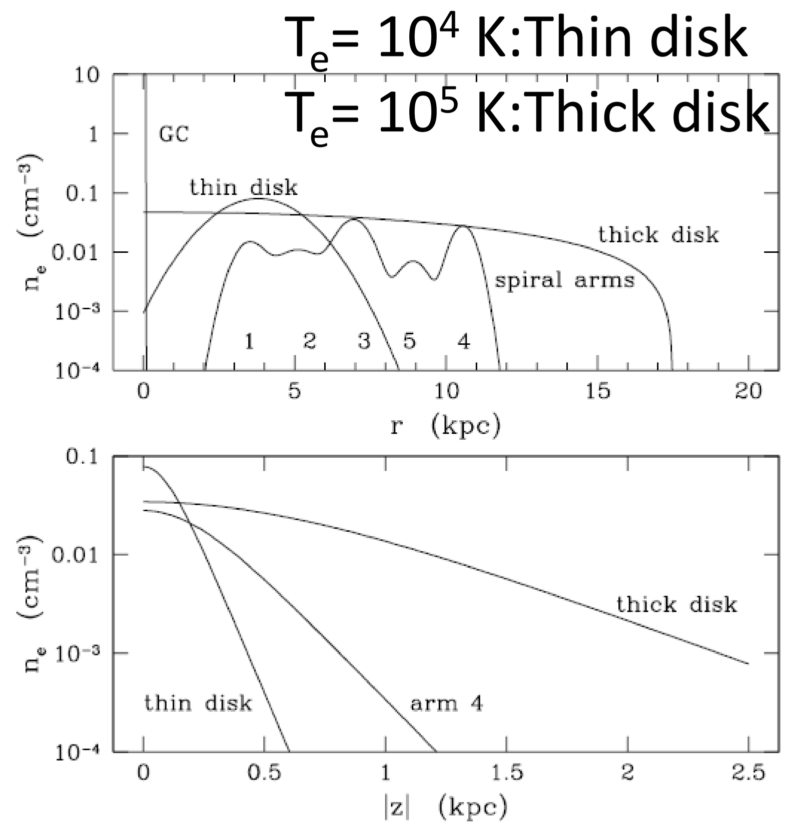
Current activities in Tohoku University

- Renewal of Galactic dust temperature and column density map using AKARI all sky survey data
- Construction of 3D global Galactic magnetic field model using MHD numerical simulation
- Plasma kinetic approach for modeling turbulent magnetic field
- Construction of component separation scheme based on hierarchical bayes

Modeling Galactic gaseous disk

$T_e = 10^4$ K:Thin disk

$T_e = 10^5$ K:Thick disk



Distribution of thermal electron density (Cordes & Lazio 2008:NE 2001)

Gravitational potentials: bulge, disk (Miyamoto, Satoh, Nagai 1980), Halo(NFW)

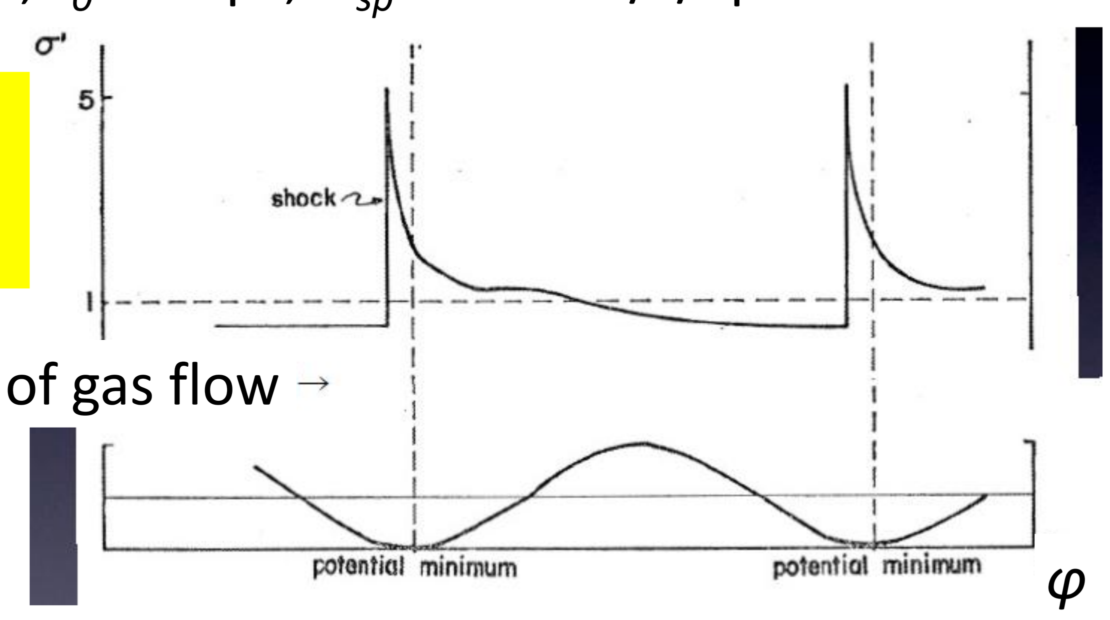
$$\Phi(r,z) = \Phi_{\rm bulge}(r,z) + \Phi_{\rm disk}(r,z) + \Phi_{\rm sp}(r,\varphi,z) + \Phi_{\rm halo}(r,z)$$

$$= \Phi_{\rm bulge}(r,z) + \Phi_{\rm disk}(r,z)\left[1 + \epsilon_{\rm sp}\frac{z_0}{\sqrt{z^2+z_0^2}}\cos\left\{m\left(-\varphi - \Omega_{\rm sp}t + \cot i_{\rm sp}\ln\frac{r}{r_0}\right)\right\}\right] + \Phi_{\rm halo}(r,z)$$

Spiral potential: $m=2$, $\varepsilon_{sp}=0, 0.02, 0.04$, $i_{sp}=14°$, $r_0=10$kpc, $\Omega_{sp}=12.2$ km/s/kpc

Expected phenomena: Spiral shock (Fujimoto 1966, Roberts 1969)

Mach number ≒ 3 Direction of gas flow →



Methods

Solve conservative form of mass, momentum, energy continuity equations by MacCorMack scheme which is second order accuracy both in time and space, and induction equation in Cylindrical polar coordinate. + von Neumann type Artificial viscosity. Ideal MHD is assumed.
$\Delta r=0.05$kpc in $0<r<10$kpc, $\Delta r[i+1]=1.05\Delta r[i]$ in 10kpc<r, $\Delta z=0.01$kpc in $0<z<2$kpc, $\Delta z[k+1]=1.05\Delta z[k]$ in 2kpc <z.
Number of girds $(r,\varphi,z)=(291, 66, 341)$ which cover $0<r<42$kpc and $0<z<13$kpc. Reflection boundary condition at z=0 surface.
Free and absorbing boundary conditions at outer boundaries. Absorbing boundary condition is set at $R=(r^2+z^2)^{0.5}=0.8$kpc inner sphere.

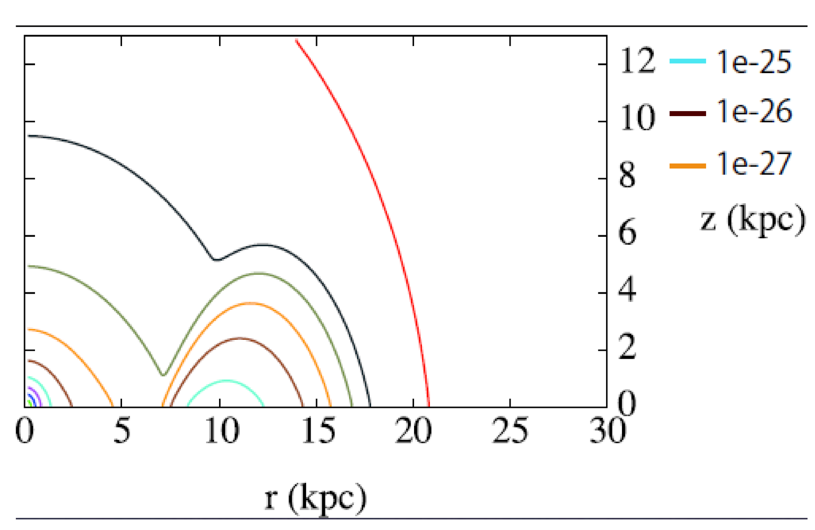
Initial conditions

Magnetohydrodynamical equilibrium rotation torus with tenuous halo

$$P_{\rm gas} = K\rho^{\Gamma} \quad \text{with } \Gamma=1.1$$

$$\rho_{\rm torus} = \left[\frac{\max\left(\Psi_b - \Phi - \frac{L_z^2}{2r^2},\ 0\right)}{\frac{\Gamma}{\Gamma-1}K\left\{1+\beta_b^{-1}(r/r_b)^{2(\Gamma-1)}\right\}}\right]^{\frac{1}{\Gamma-1}}$$

$$\Psi_b \equiv \Phi(r_b) + \frac{C_{sb}^2}{\Gamma-1} + \frac{\Gamma}{2(\Gamma-1)}v_{Ab}^2 + \frac{L_z^2}{2r_b^2}$$



where $\varepsilon_{sp}=0$

Angular momentum distribution : L_z=uniform

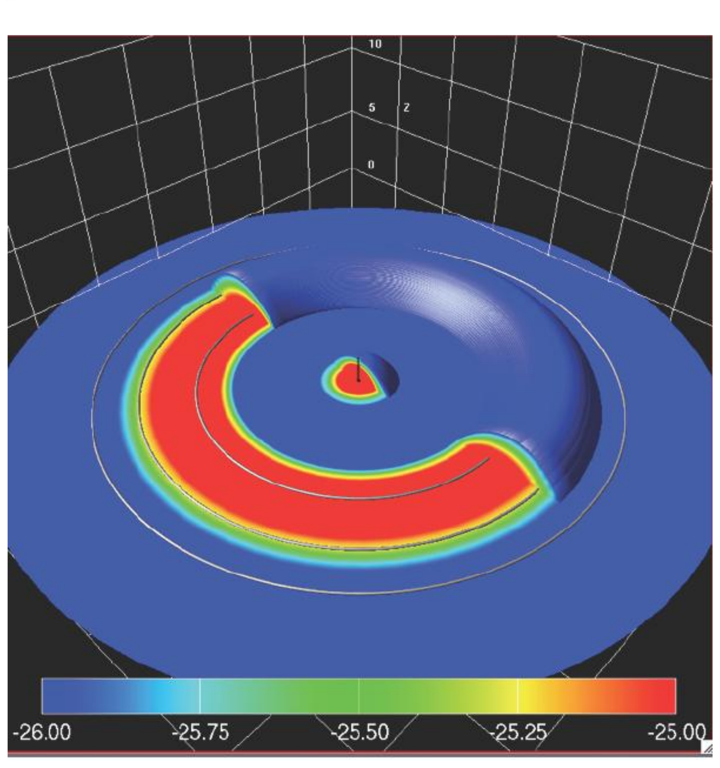
$\rho_b=3\times10^{-25}$g/cm^3, $T_b=1.5\times10^5$K @ $r_b=10$kpc

$\beta_b = P_{gas}/P_{mag} = 100$ within torus

$$\rho_{\rm halo} = \rho_{\rm halo0}\exp\left(-\frac{\mu m_p}{k_B T_{\rm halo}}(\Phi(r,z)-\Phi_b)\right)$$

where $T_{halo}=10^6$K and $\rho_{hlao0} = 10^{-4}\times\rho_b$

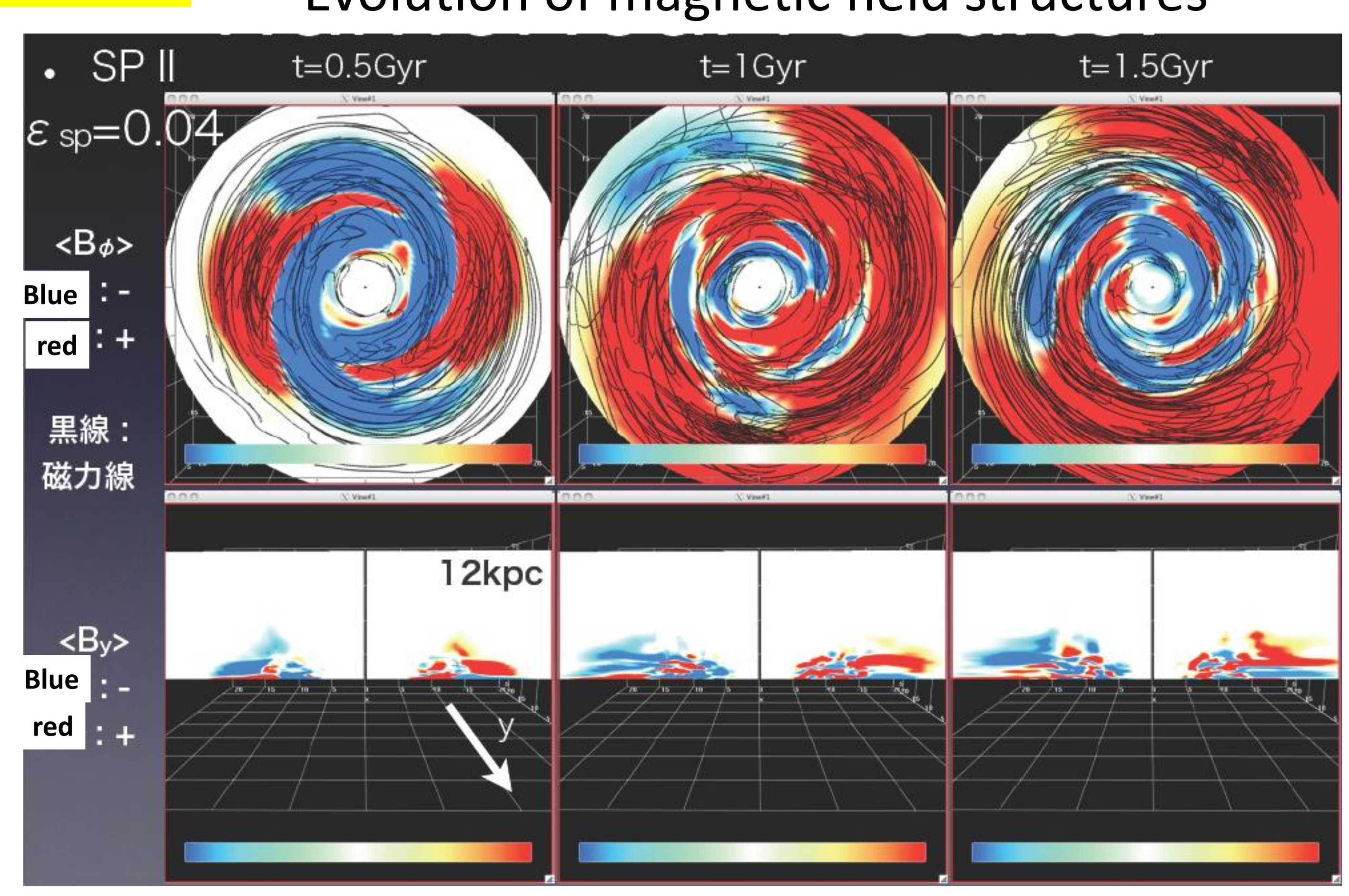
Start from equilibrium state to see physical process governing genesis and maintenance of the Galactic magnetic field clearly.

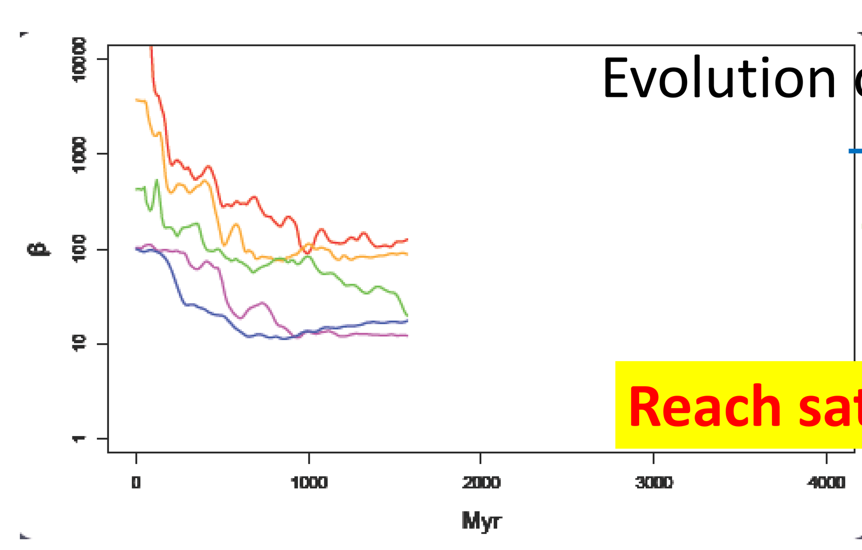


Initial toroidal magnetic field is assumed. Density distribution and magnetic field line in the initial state.

Results

Evolution of magnetic field structures

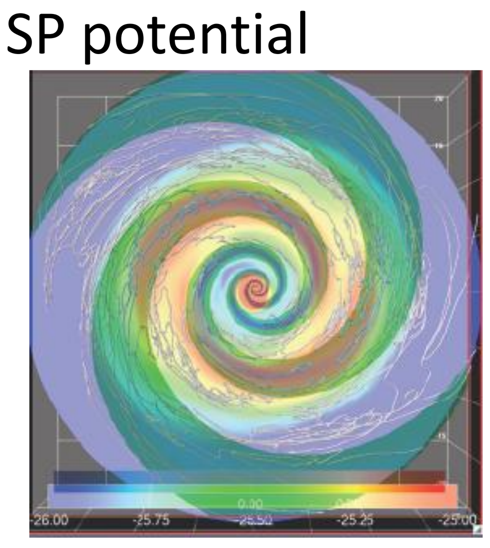




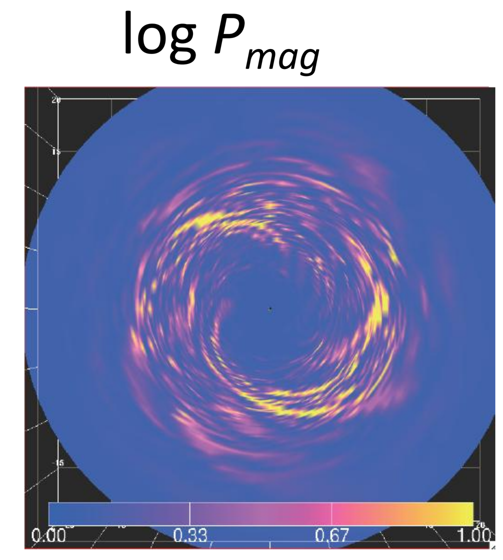
Evolution of plasma β in 8.5<r< 11.5kpc
—:0<z<2kpc, —: 2<z<4kpc
—: 4<z<6kpc, —: 6<z<8kpc
—: 8<z<10kpc

Reach saturation level of β=10

logρ+ B overlaid SP potential



log P_{mag}



@ t=1.5Gyr

We are going to examine more realistic cases; $T_b=10^4$K with radiative cooling and a finite magnetic resistivity in next step.