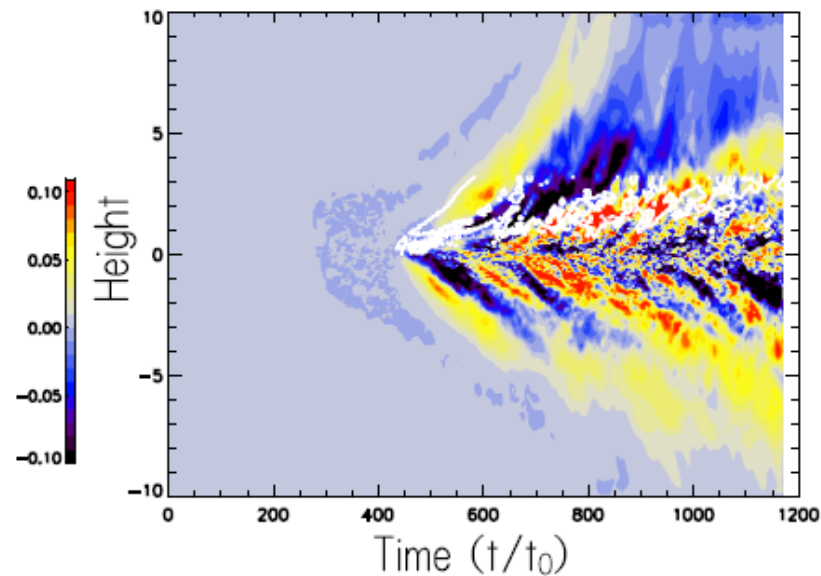
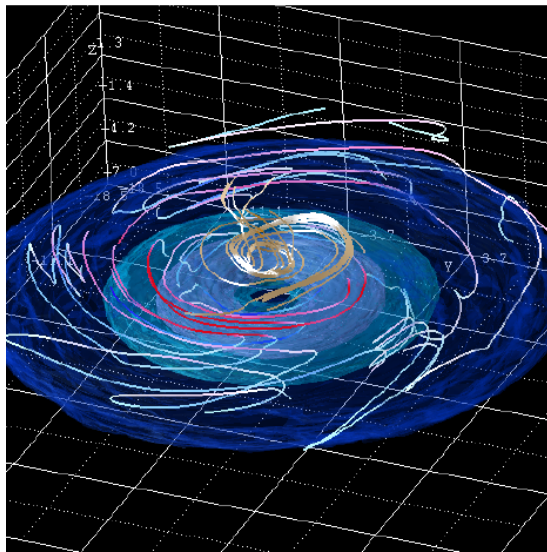
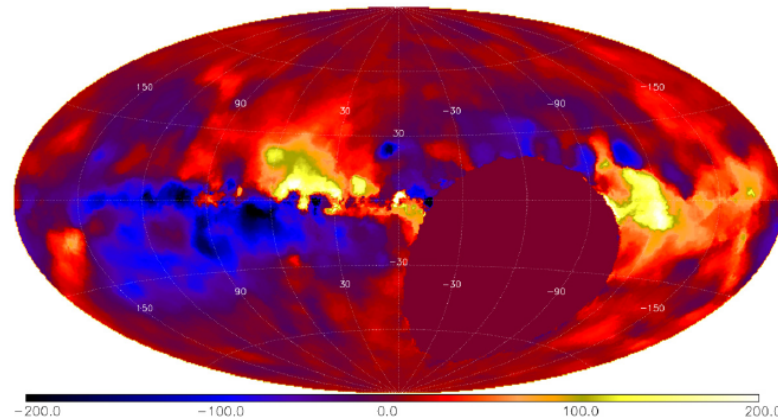
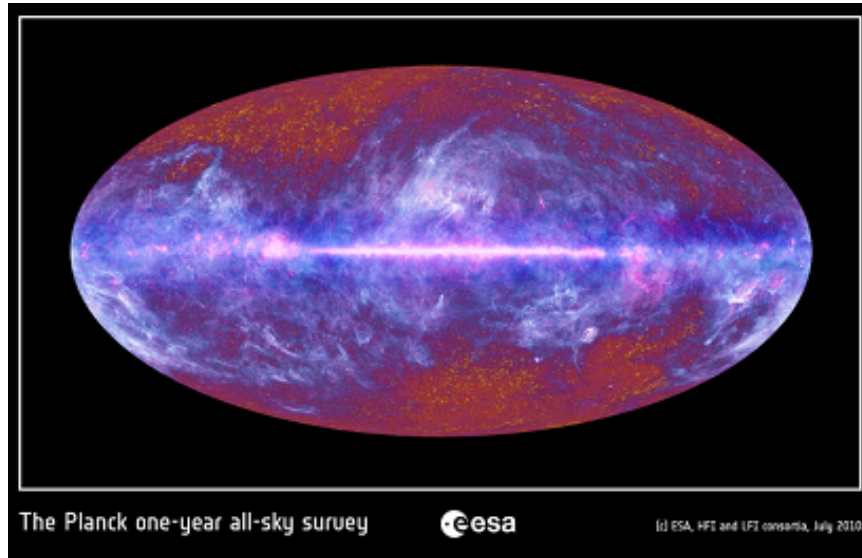


Global Three-dimensional Magnetohydrodynamic Simulations of Disk Dynamos

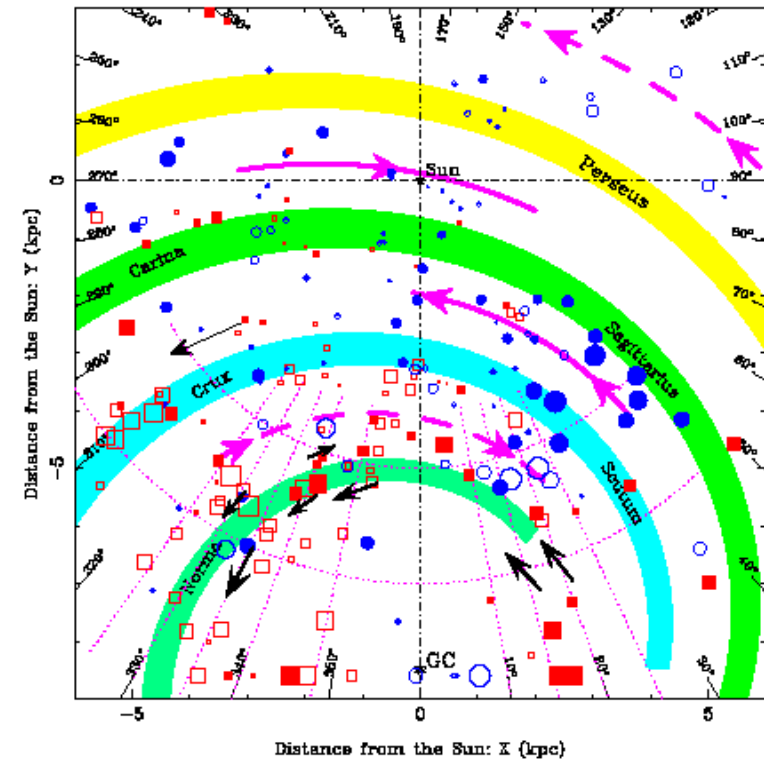


Ryoji Matsumoto ,Takayuki Ogawa , Takafumi Ono
(Chiba Univ.), and Mami Machida (Kyushu Univ.)

Magnetic Fields in Our Galaxy

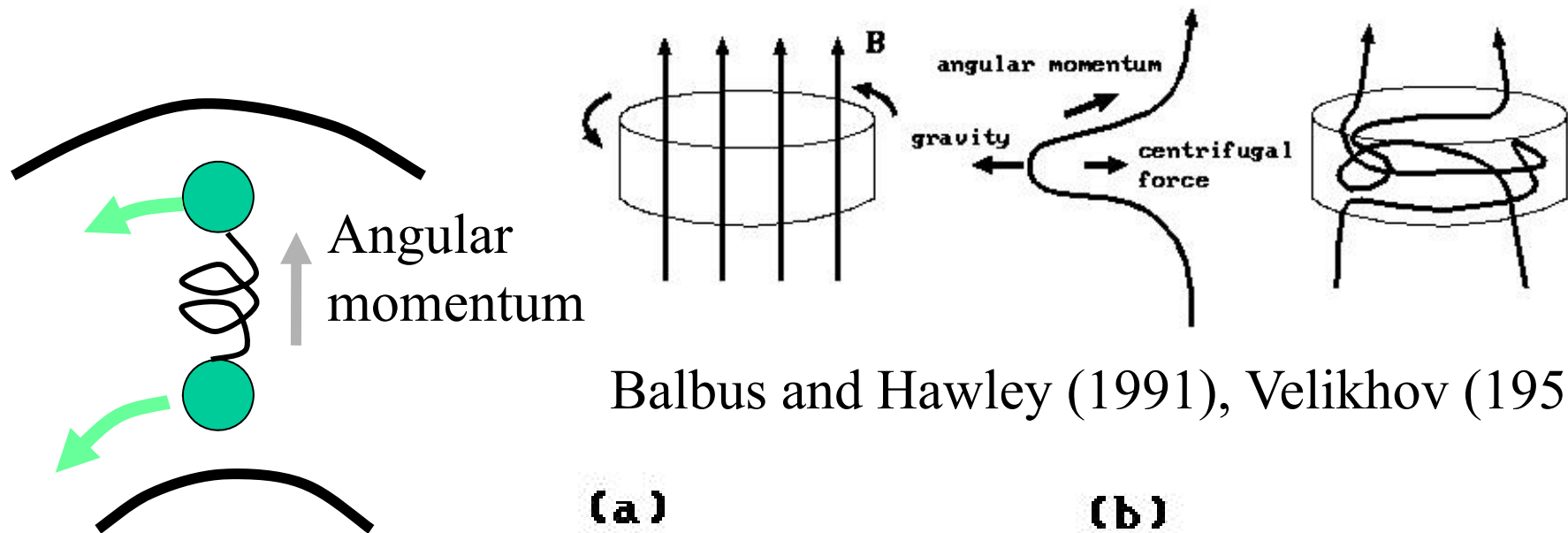


Rotation Measure (Taylor et al. 2009)

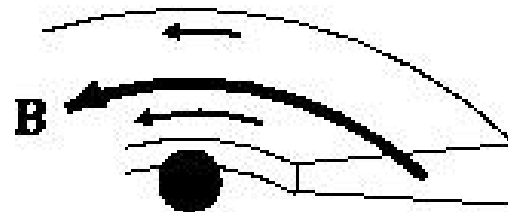


Galactic magnetic field
measured by Faraday
Rotation (Han et al. 2002)

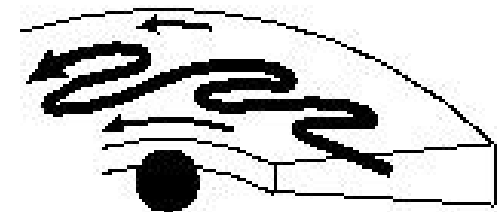
Amplification of Magnetic Fields by Magneto-rotational Instability (MRI)



(a)

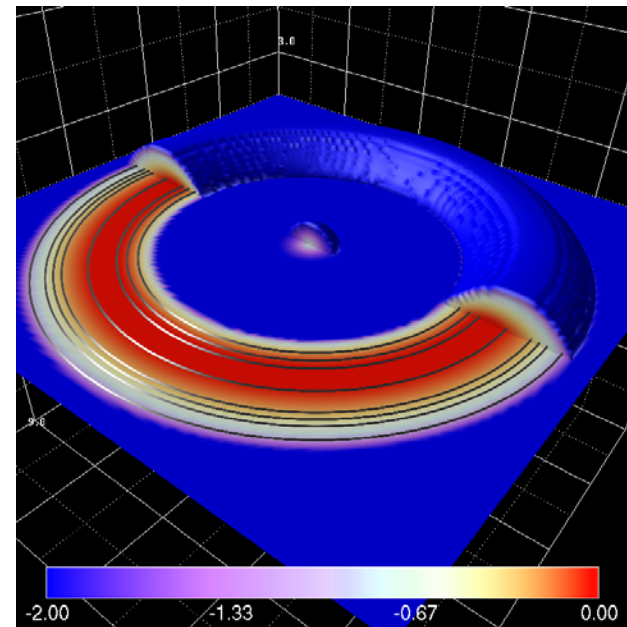


(b)



Global 3D MHD Simulation of Galactic Gas Disks

- Gravitational Potential
 - Axisymmetric potential by Miyamoto (1980)
- Initial Condition
 - Constant angular momentum torus
 - Weak Azimuthal field
- Symmetric boundary condition at equatorial plane
- Absorbing boundary condition at $r=0.8\text{kpc}$

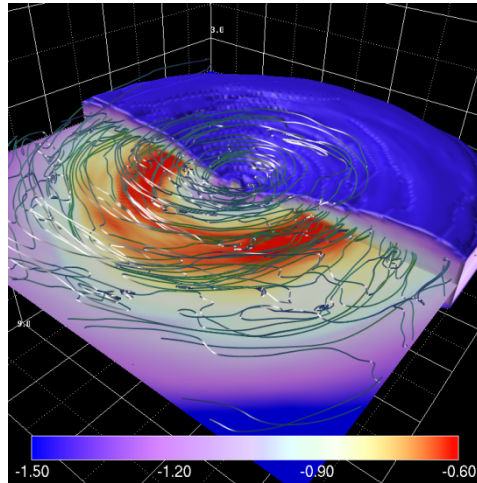


250*64*320mesh

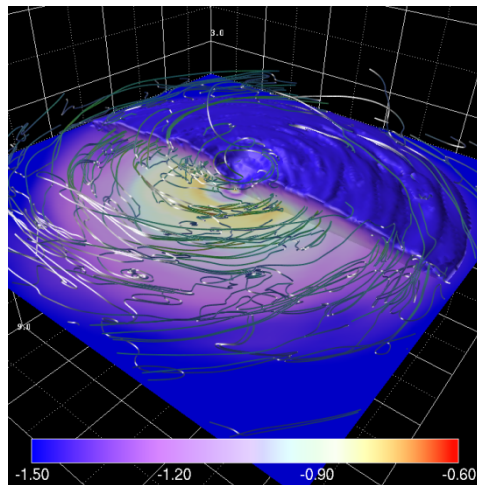
Nishikori et al. 2006

Result of Simulation

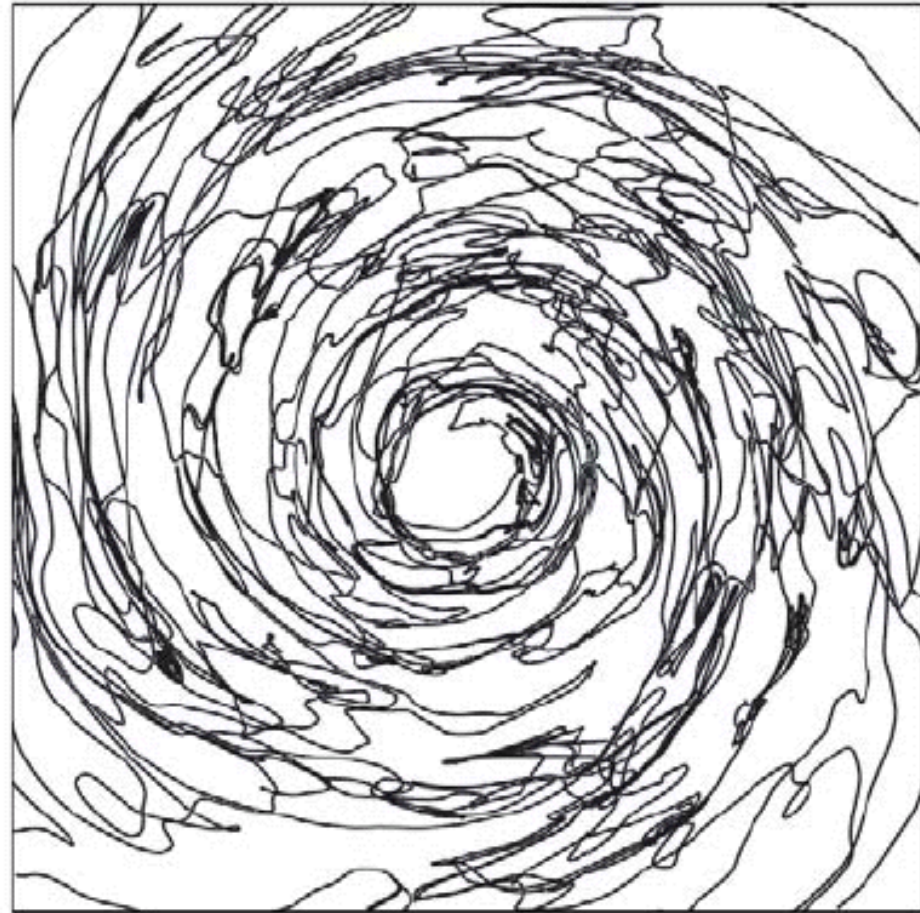
2Gyr



3.5Gyr

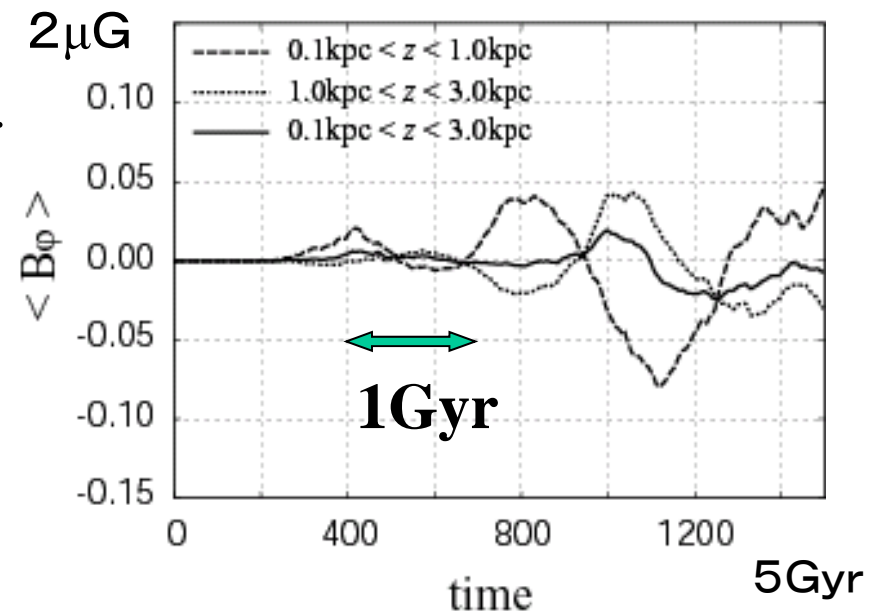
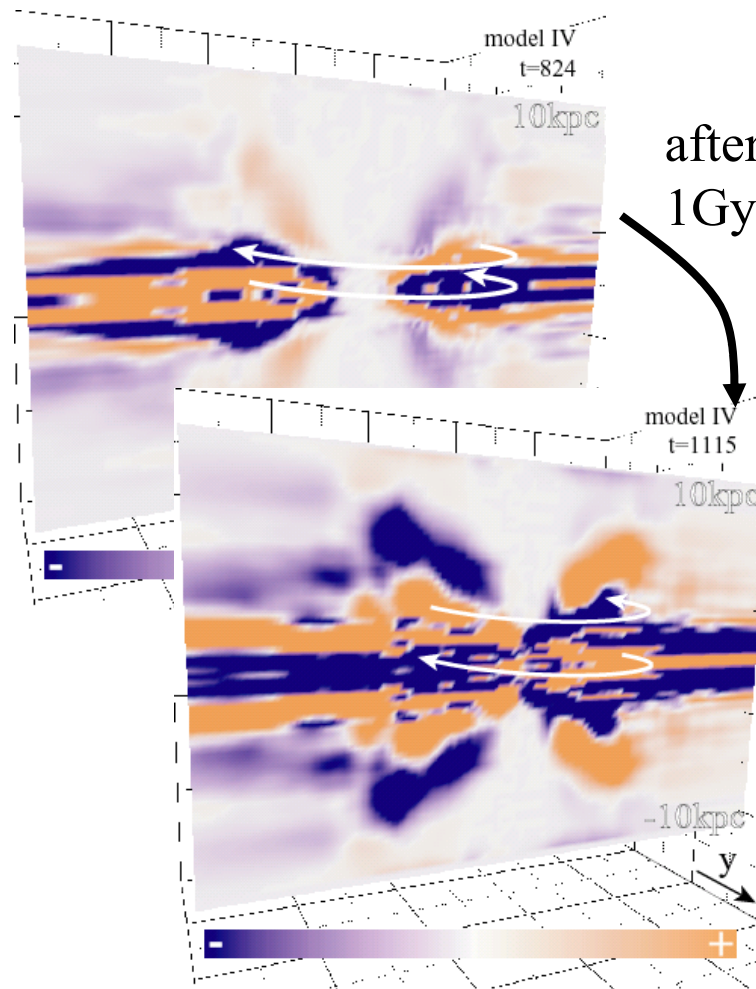


$\rho + B$



$t = 3.8$ Gyr

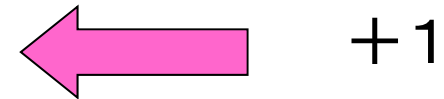
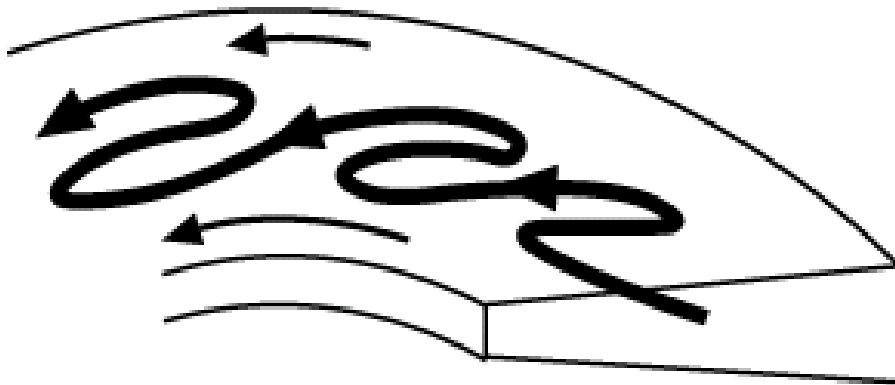
Reversal of Mean Azimuthal Magnetic Fields



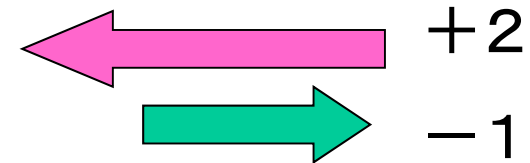
Time variation of mean azimuthal magnetic field at $5\text{kpc} < r < 6\text{kpc}$

How are Azimuthal Magnetic Fields Reversed ?

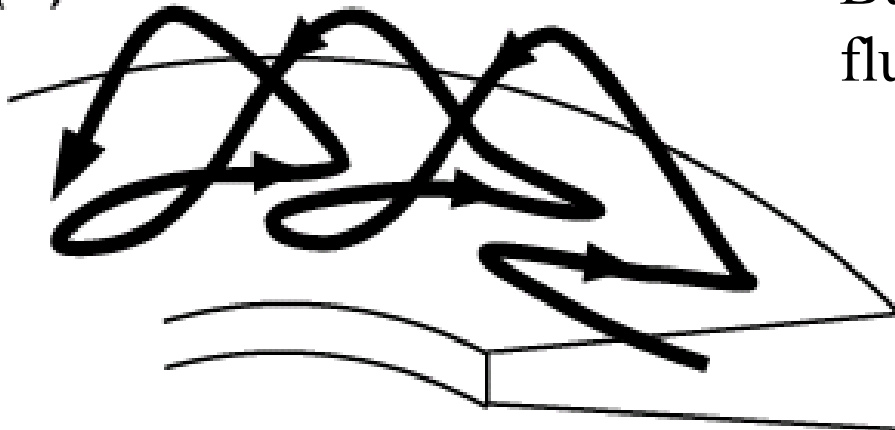
(a)



Growth of MRI



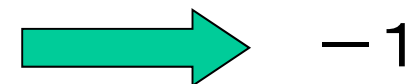
(b)



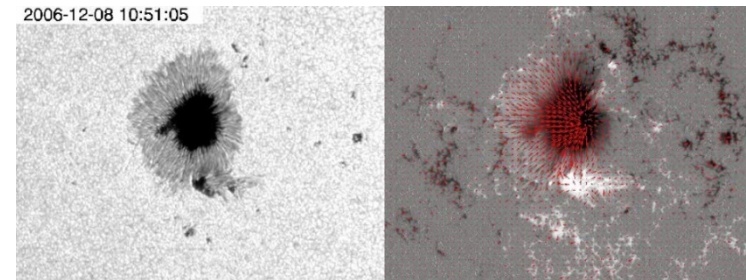
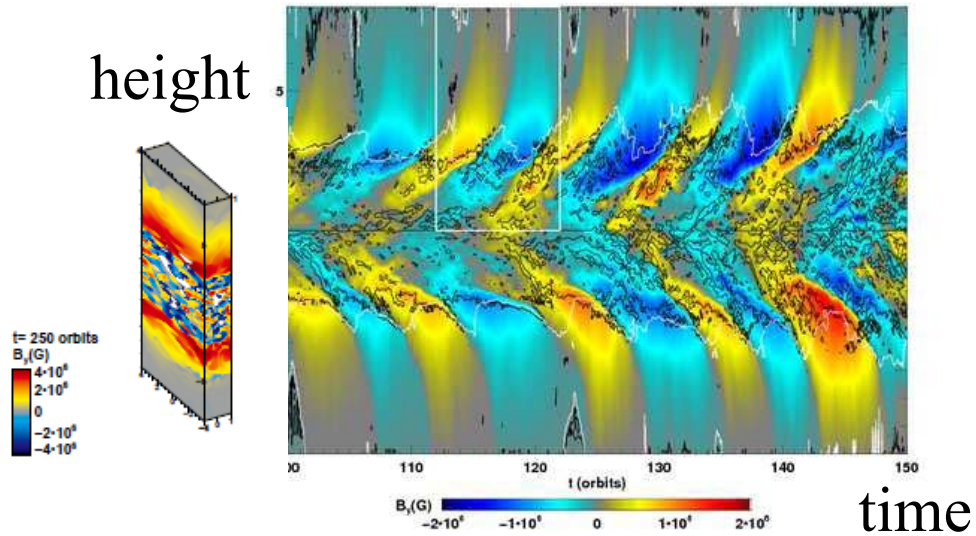
Buoyant escape of magnet flux by Parker Instability



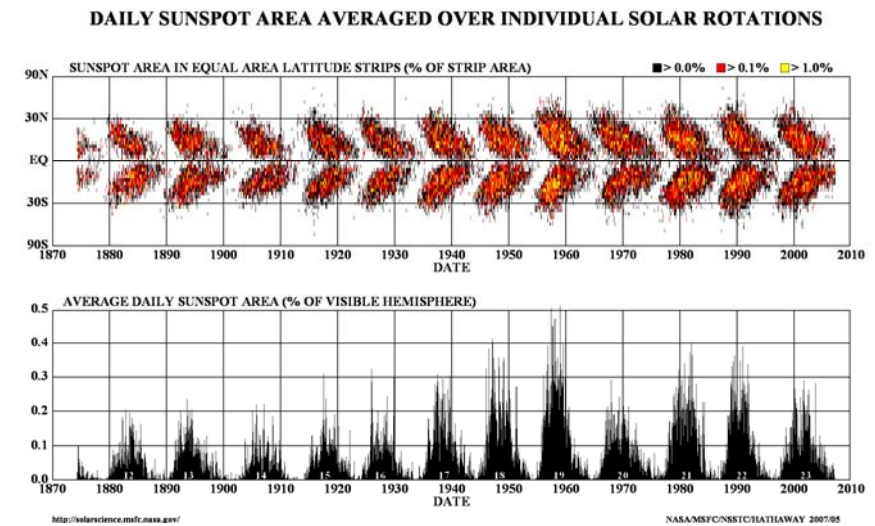
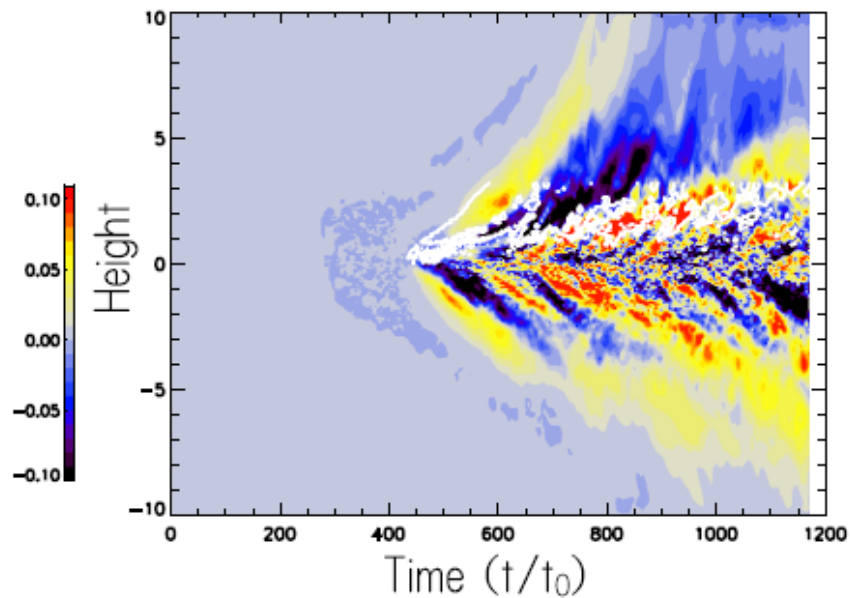
↑ buoyancy



Butterfly Diagram

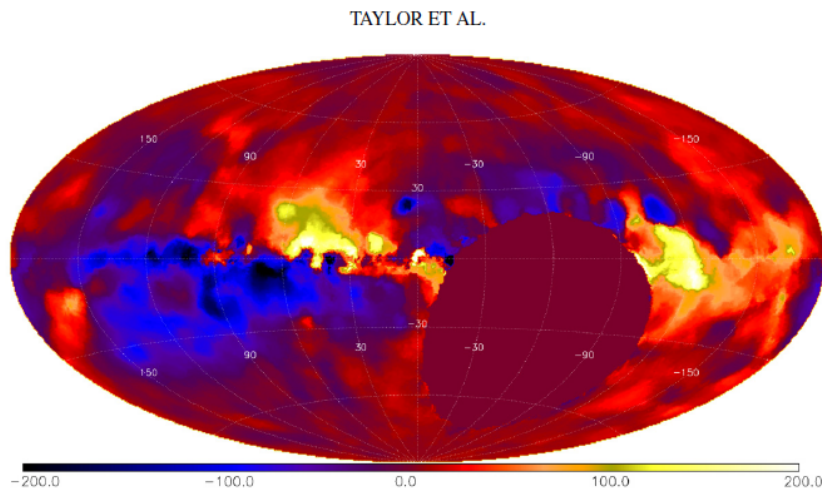


Optical image of sunspots

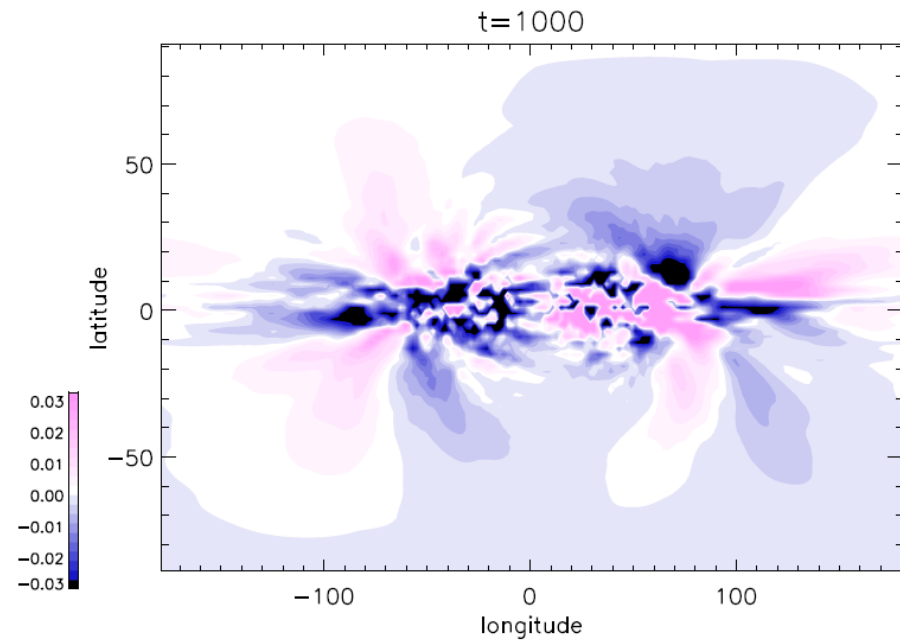


Butterfly Diagram of Sunspots (NASA)

Comparison with Observation



All Sky map of Rotation
Measure in Galactic
Coordinates
(Taylor et al. 2009)

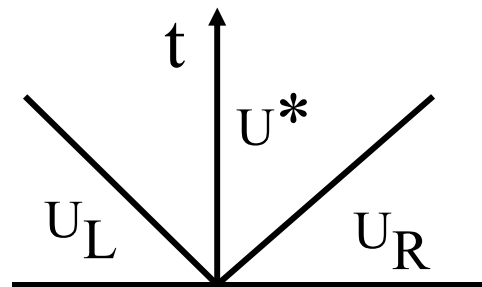


Rotation Measure at 8kpc from
the galactic center obtained
from our simulation
(Machida et al. 2012)

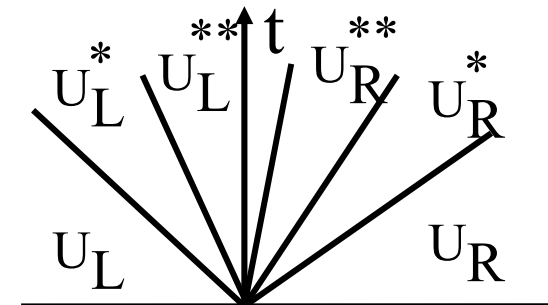
Implementation of New Simulation Engine

- HLLD Scheme (Miyoshi and Kusano 2005)

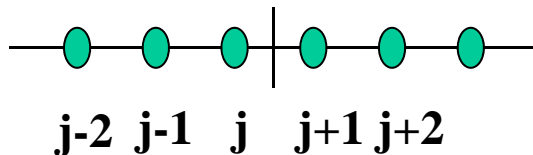
HLL
Scheme



HLLD
Scheme

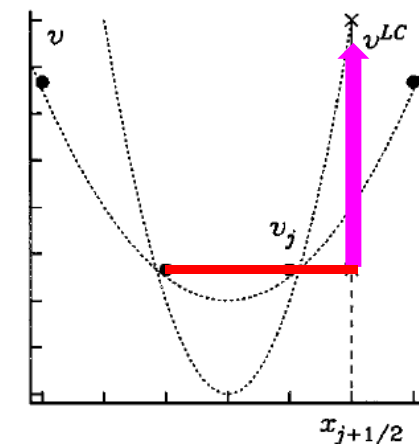
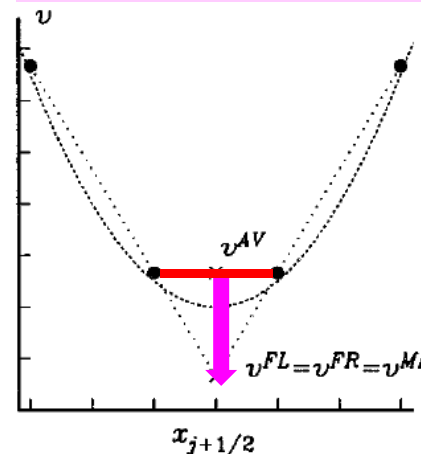


- MP5 Scheme (Suresh and Huynh 1997)

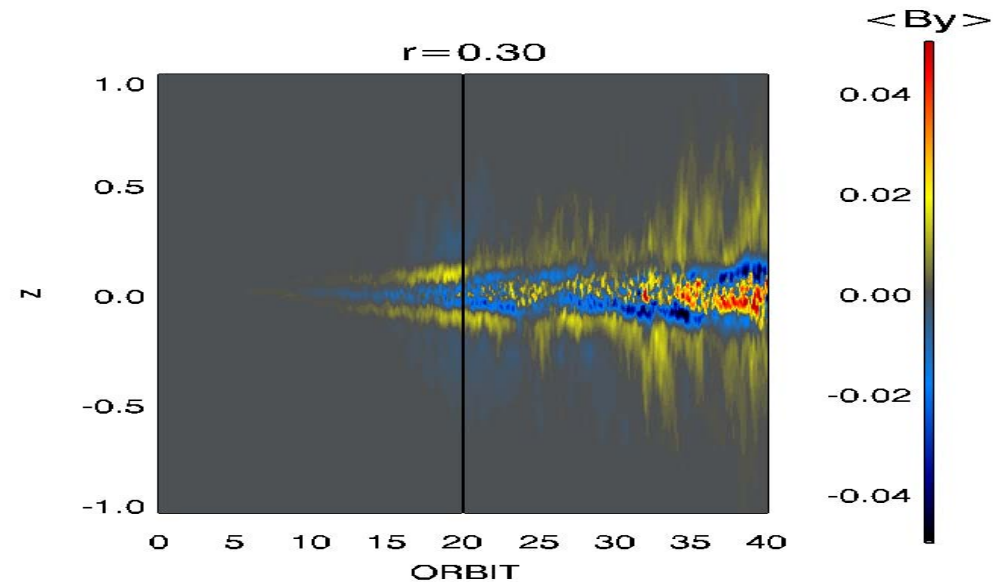
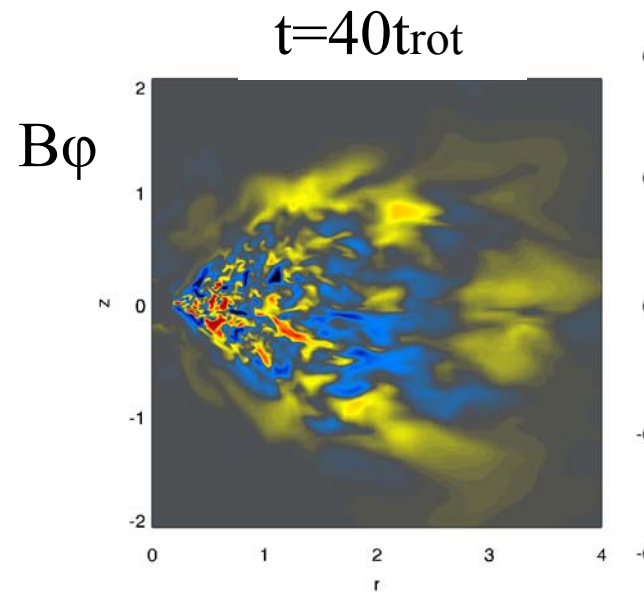
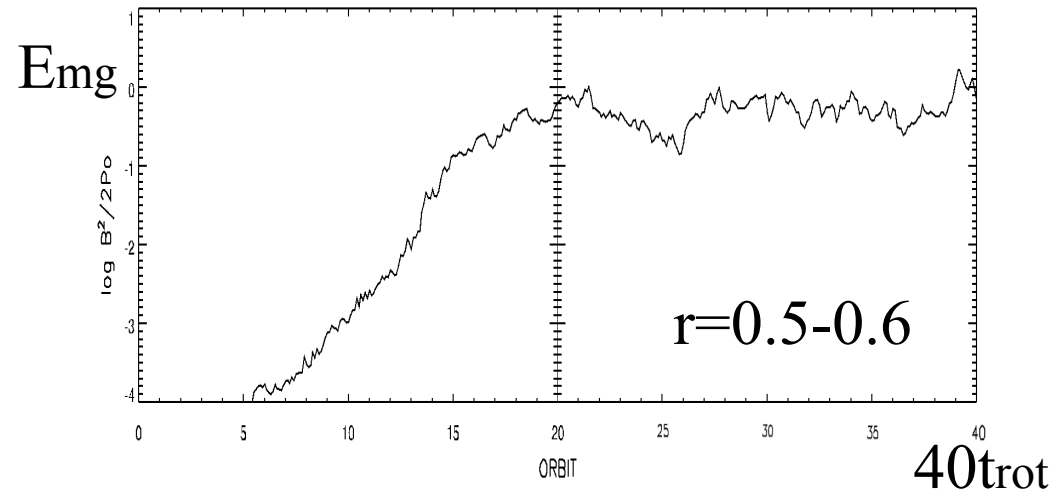
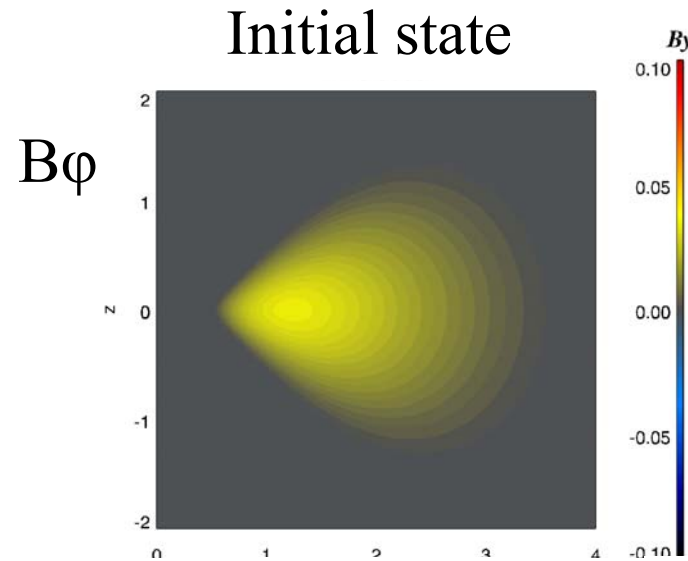


By determining 4th order polynomial using values at 5 points, compute the value at cell interface at $j+1/2$

Preserve peaks and gradients by enlarging monotonicity intervals



Time Variation of Magnetic Fields



Summary and Discussion

- We carried out global 3D MHD simulation of differentially rotating disks without assuming equatorial symmetry.
- Disk magnetic fields are amplified by MRI and saturate when $\beta \sim 10$. Azimuthal magnetic flux in regions where $\beta < 5$ buoyantly escape from the disk by nonlinear Parker instability.
- Mean azimuthal magnetic fields change their direction quasi-periodically with time scale of about 10 rotation period.
- New 3D MHD code based on HLLD scheme has been implemented and applied to accretion disks

END