Oscillatory migrating large scale magnetic field in Direct Numerical Simulations of MHD Equations

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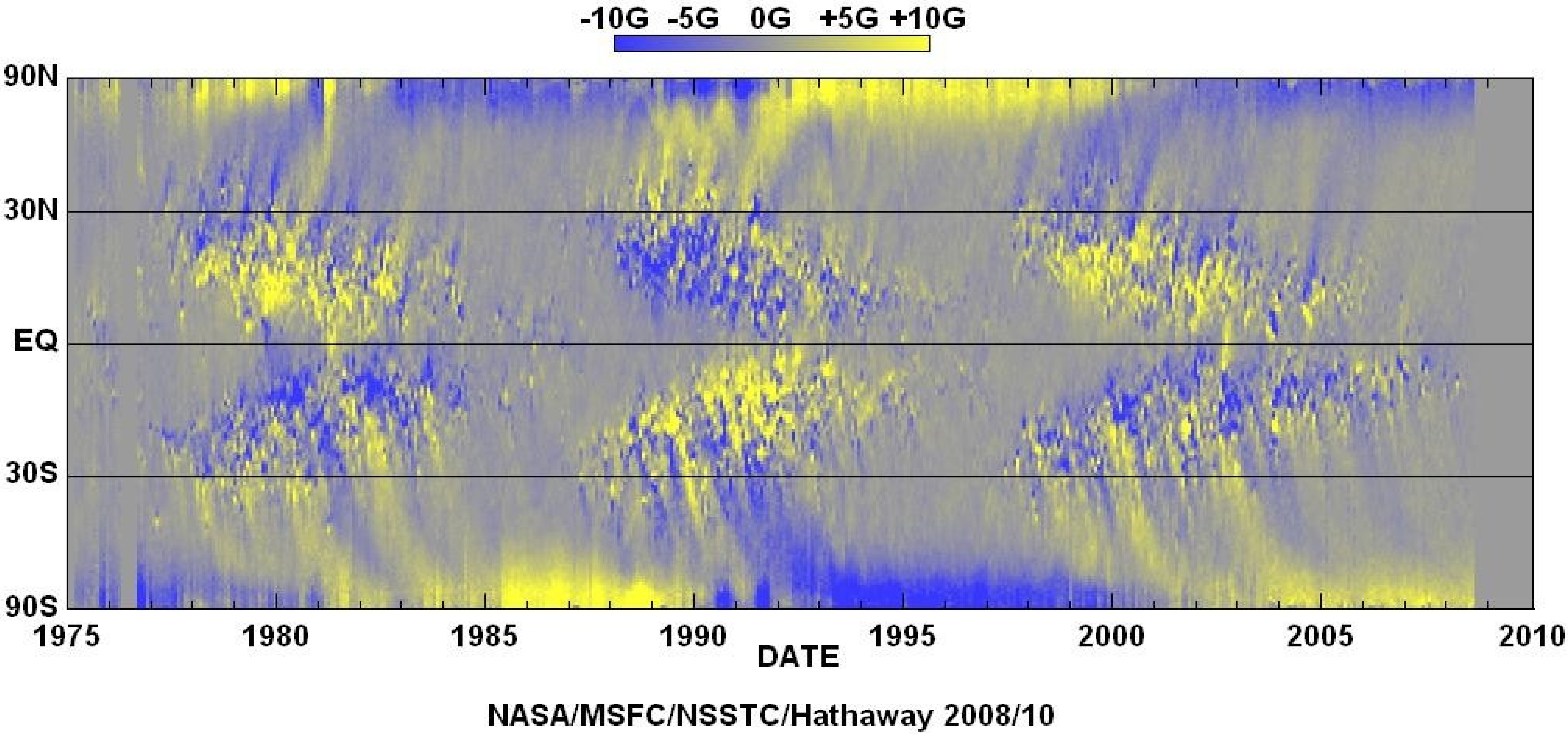
- David Moss, Manchester University.

Butterfly Diagram

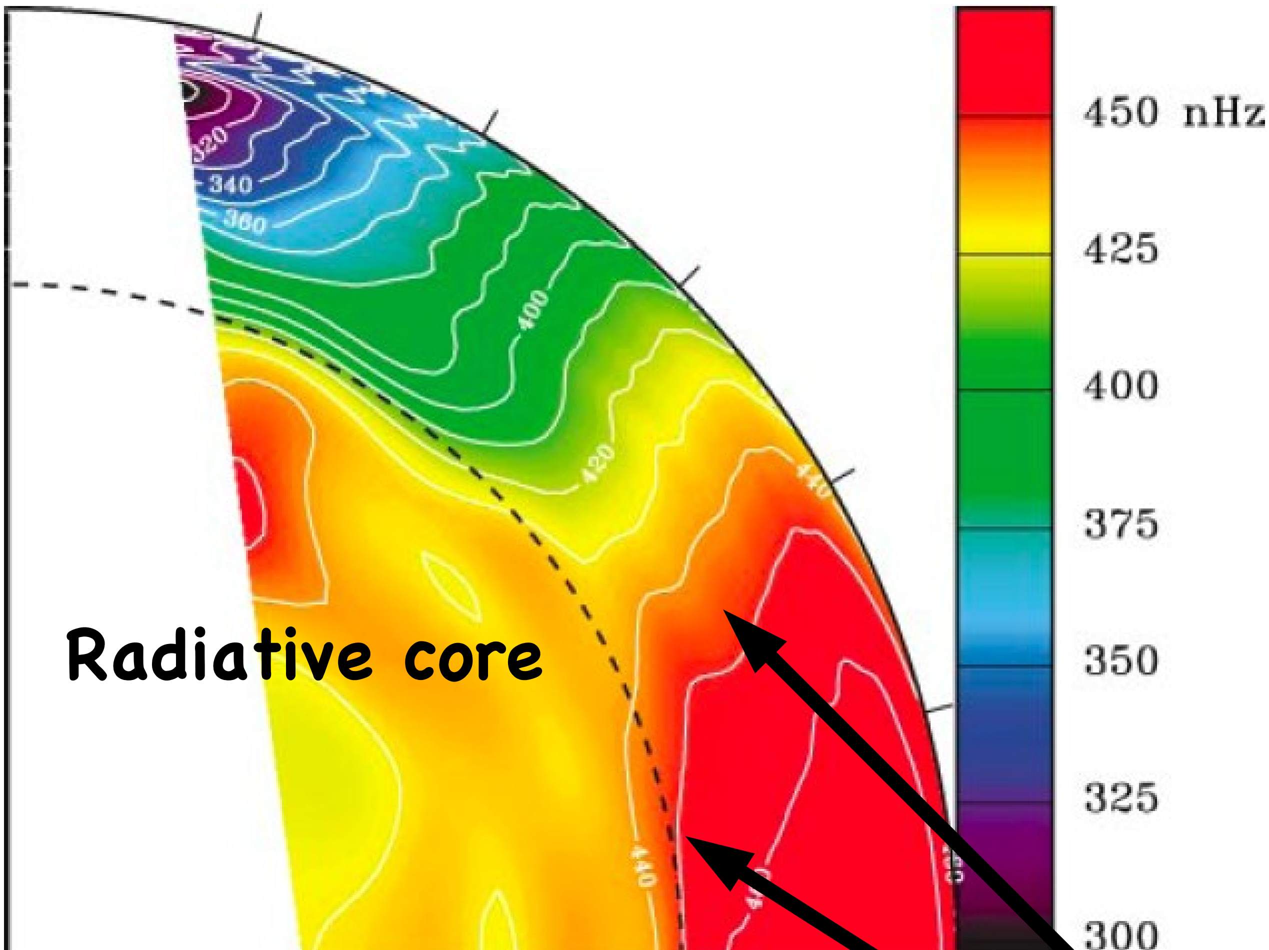


- Longitudinally averaged magnetic field

Solar dynamo: important features.

- Oscillations and polarity reversal, 22 year solar cycle.
- Equatorward migration of sunspots.
- Poleward migration of the diffusing field.
- At the solar surface the azimuthally averaged radial field is rather weak (about 1G) compared to the peak magnetic field in sunspots (about 2 kG).

Turbulence in the sun.



- Helioseismology
- Large scale shear or differential rotation.
- Convection and rotation.

- Observation from MDI (Schou et al 1998)

Compressible Magnetohydrodynamics (MHD)

$$\rho \frac{D\vec{U}}{Dt} = -\nabla p + \vec{J} \times \vec{B} + \vec{F}_{visc} + \vec{f}$$

$$\frac{\partial \rho}{\partial t} = -\nabla \cdot (\rho \vec{U})$$

$$\vec{J} = \nabla \times \vec{B}$$

$$\frac{\partial \vec{B}}{\partial t} = \nabla \times (\vec{U} \times \vec{B} - \eta \vec{J})$$

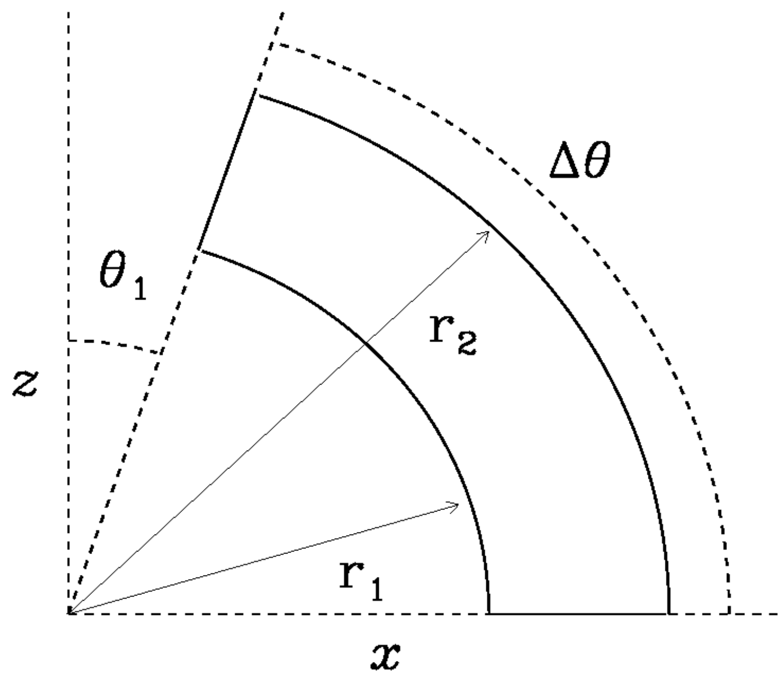
Advective derivative

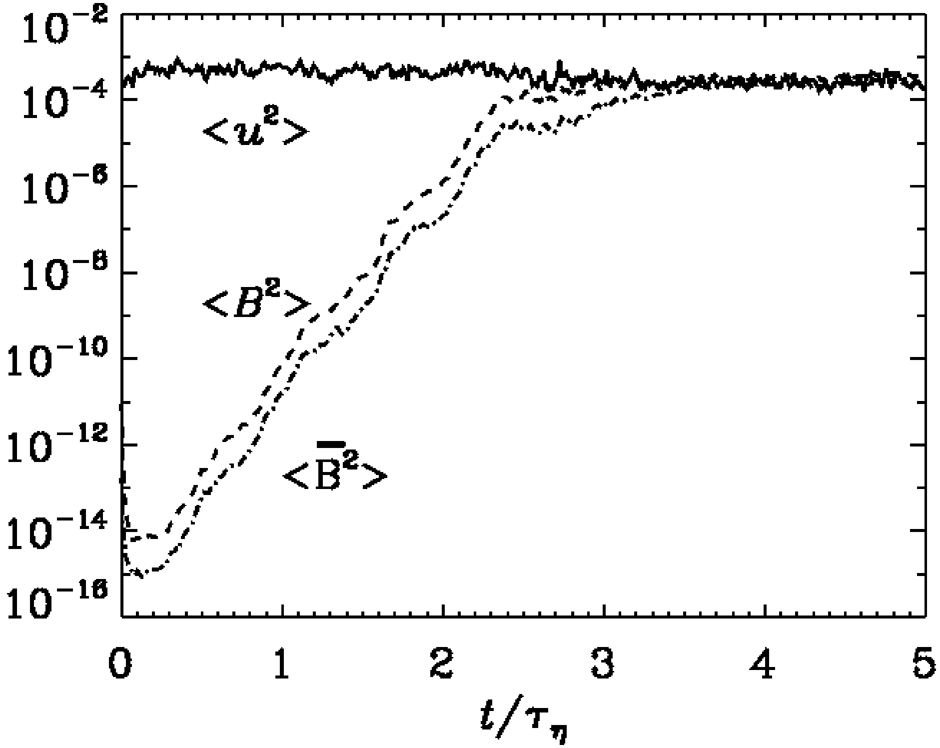
Lorentz force

viscous force

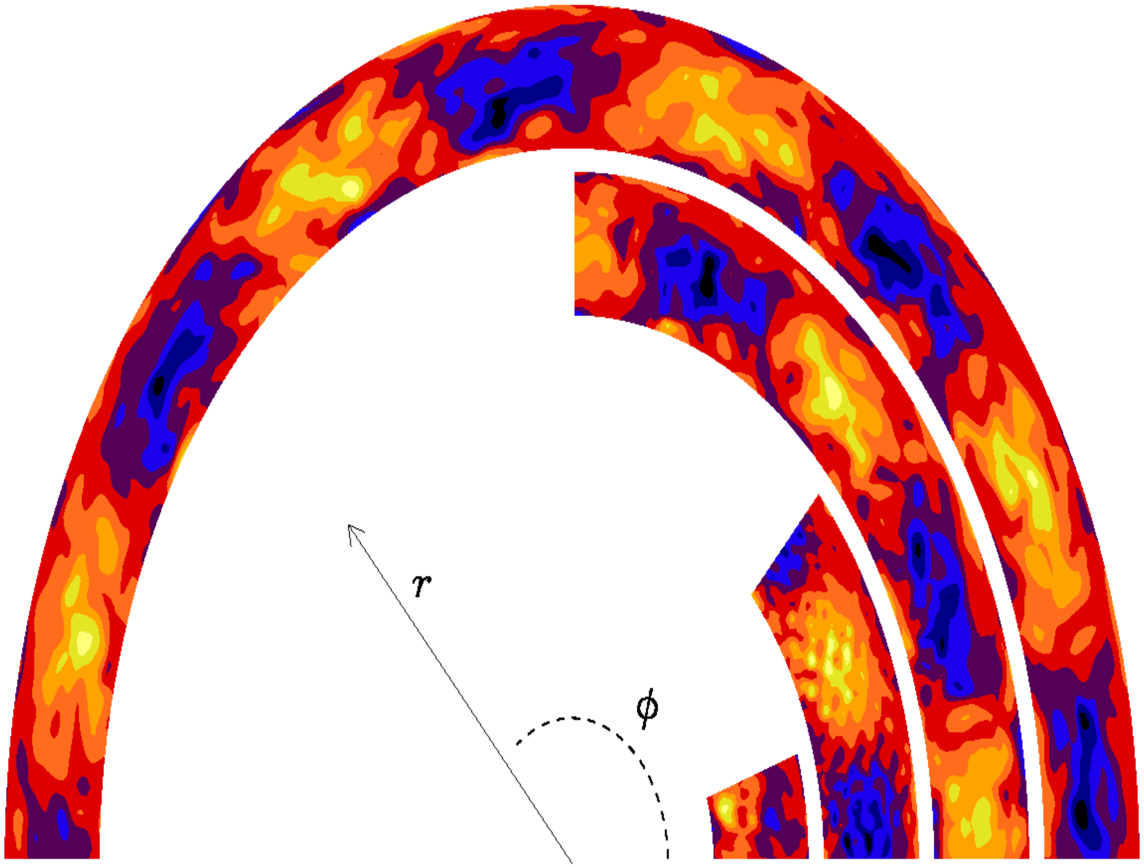
Magnetic diffusivity

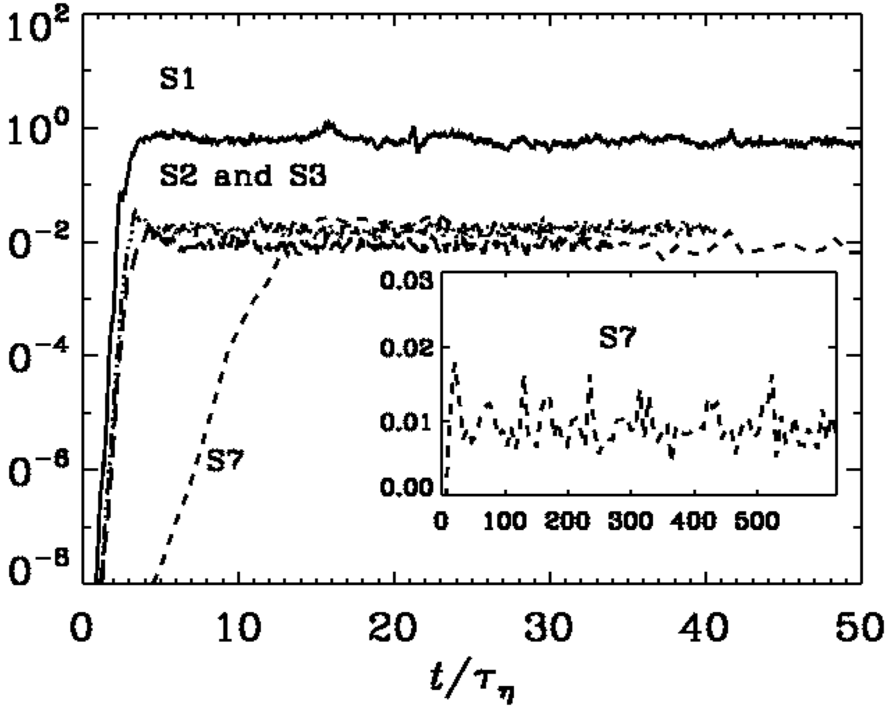
DNS of spherical wedges in one hemisphere



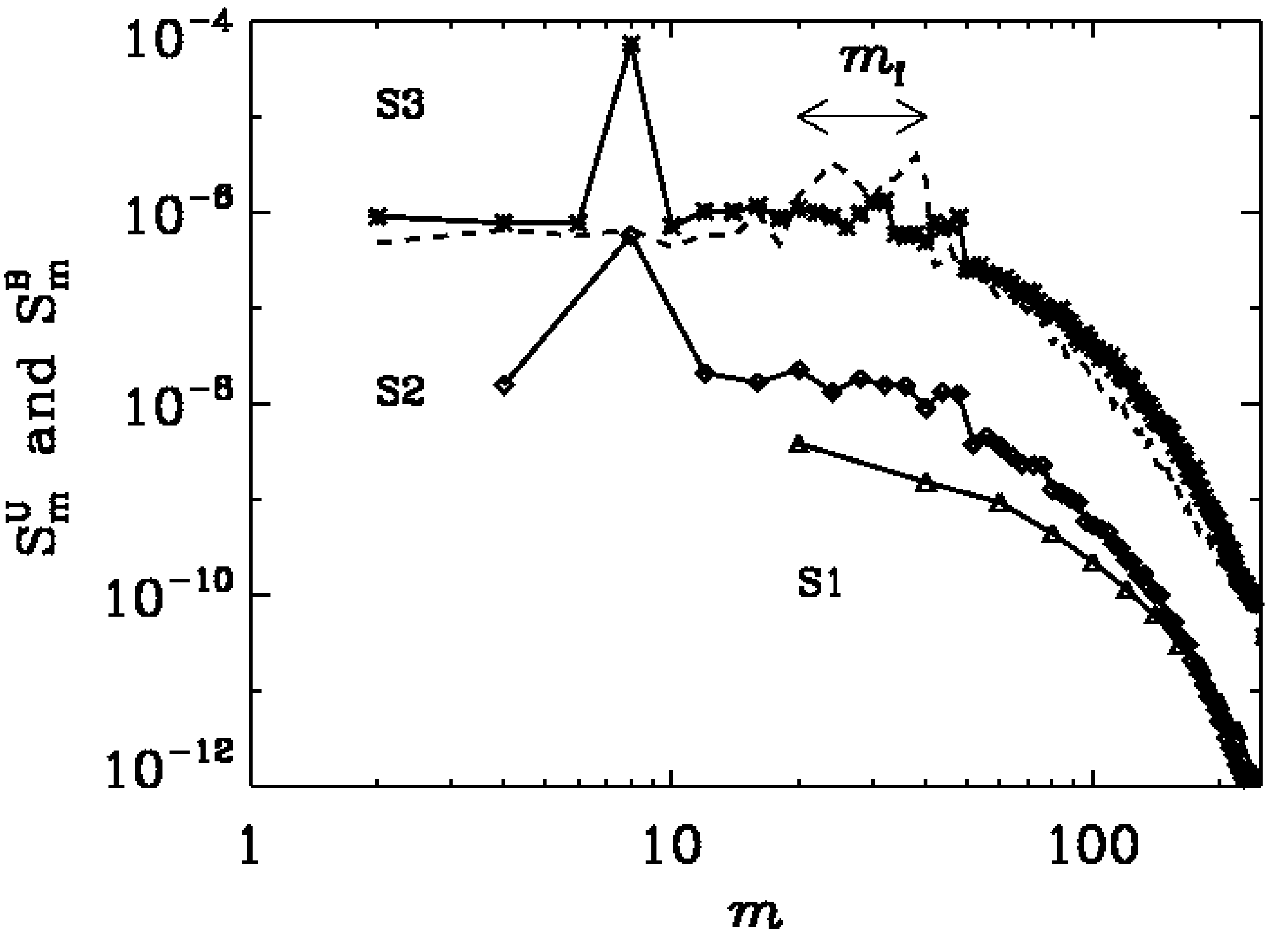


Increasing box in azimuthal direction





Length scales of magnetic field.



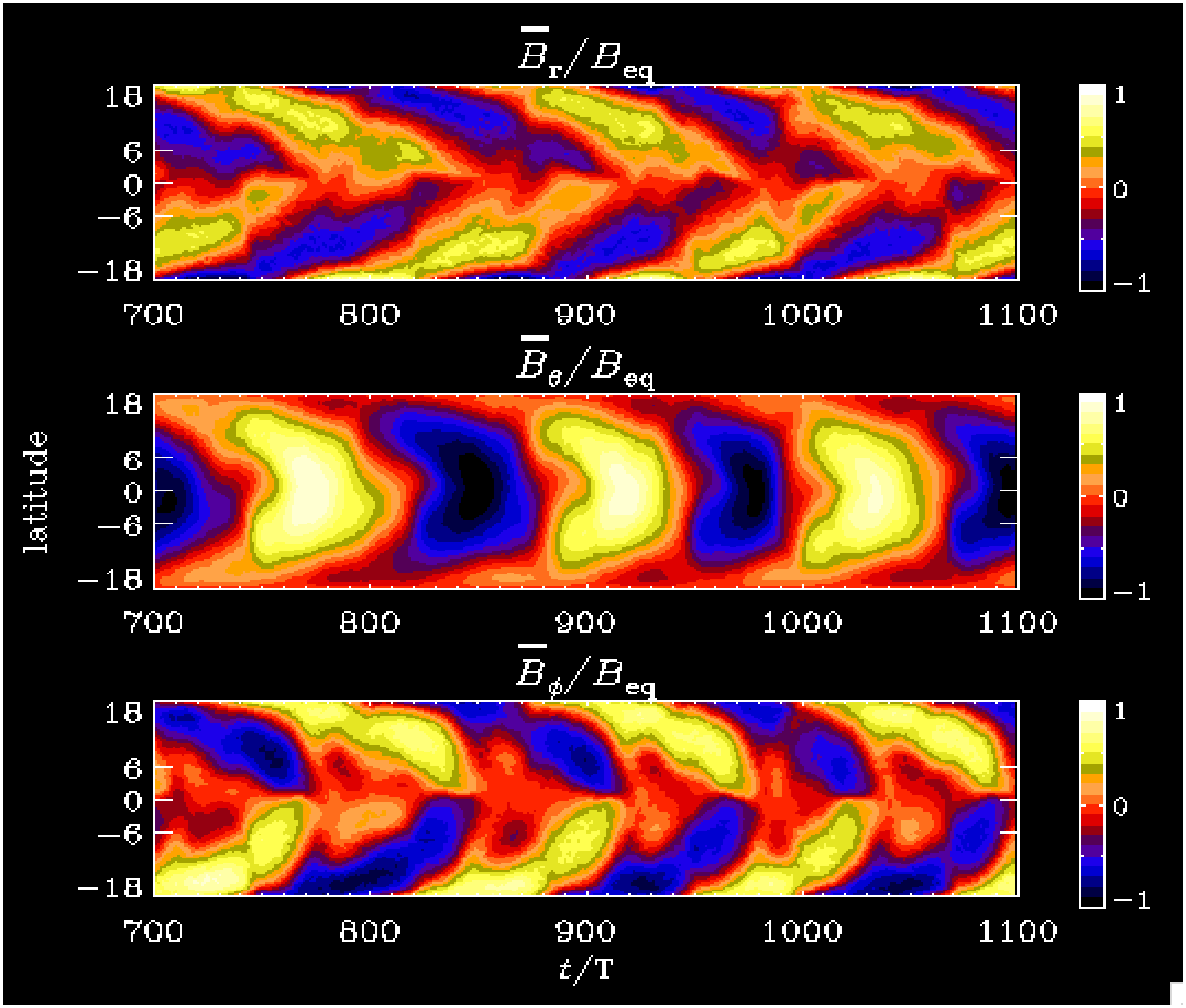
Summary

- The large scale magnetic field forms itself in cells along the azimuthal direction. Each cell has about unit aspect ratio.
- Cartesian simulations with similar aspect ratio shows similar behaviour.
- Extending the domain in azimuthal direction gives rise to the clusters repeating themselves.
- Extending the domain in the meridional direction gives no significant change.
- How to define large-scale magnetic field ?

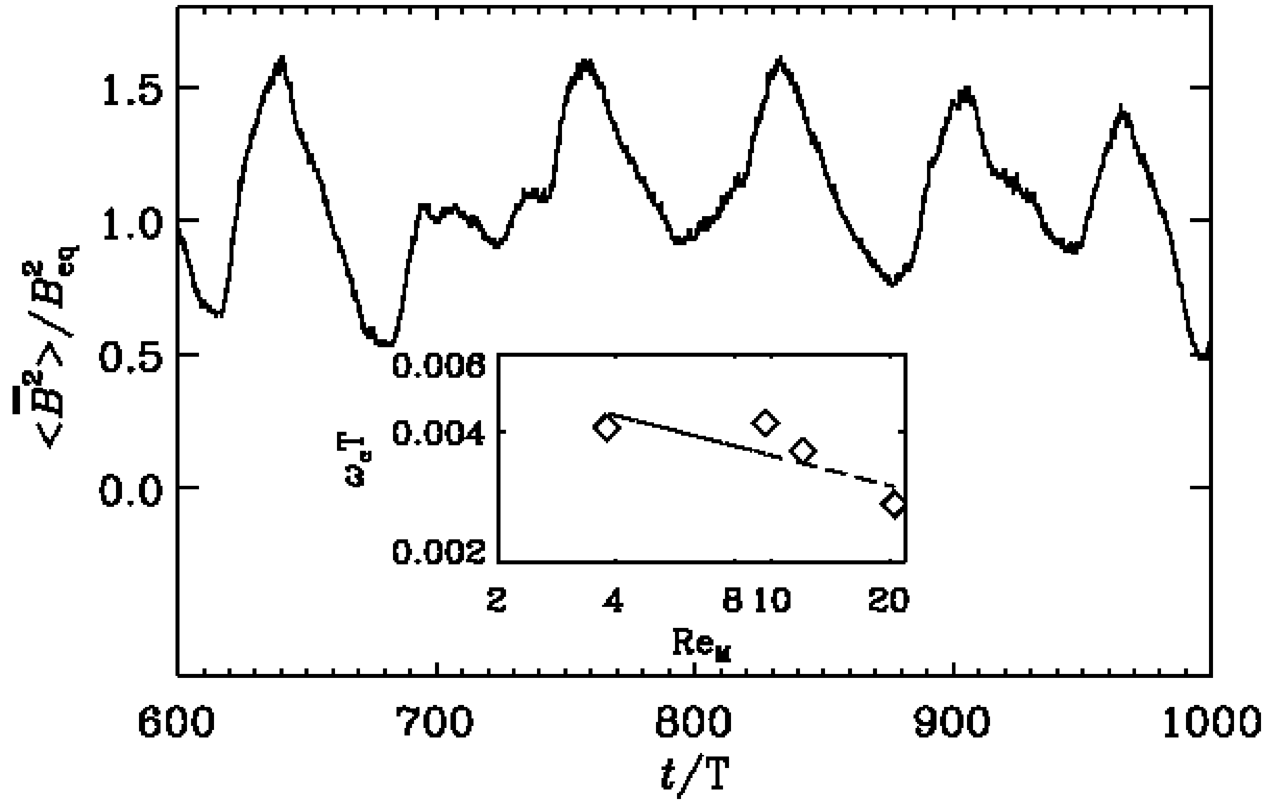
Simulations with two signs of kinetic helicity.

- Next consider simulations with two hemispheres with two different kinetic helicity.
- The Chandrasekhar-Kendall functions needs to be matched at the equator.
- We again observe large scale magnetic field, but the field does not form cells but extends over the whole azimuthal direction.
- The field shows very interesting dynamical behaviour.

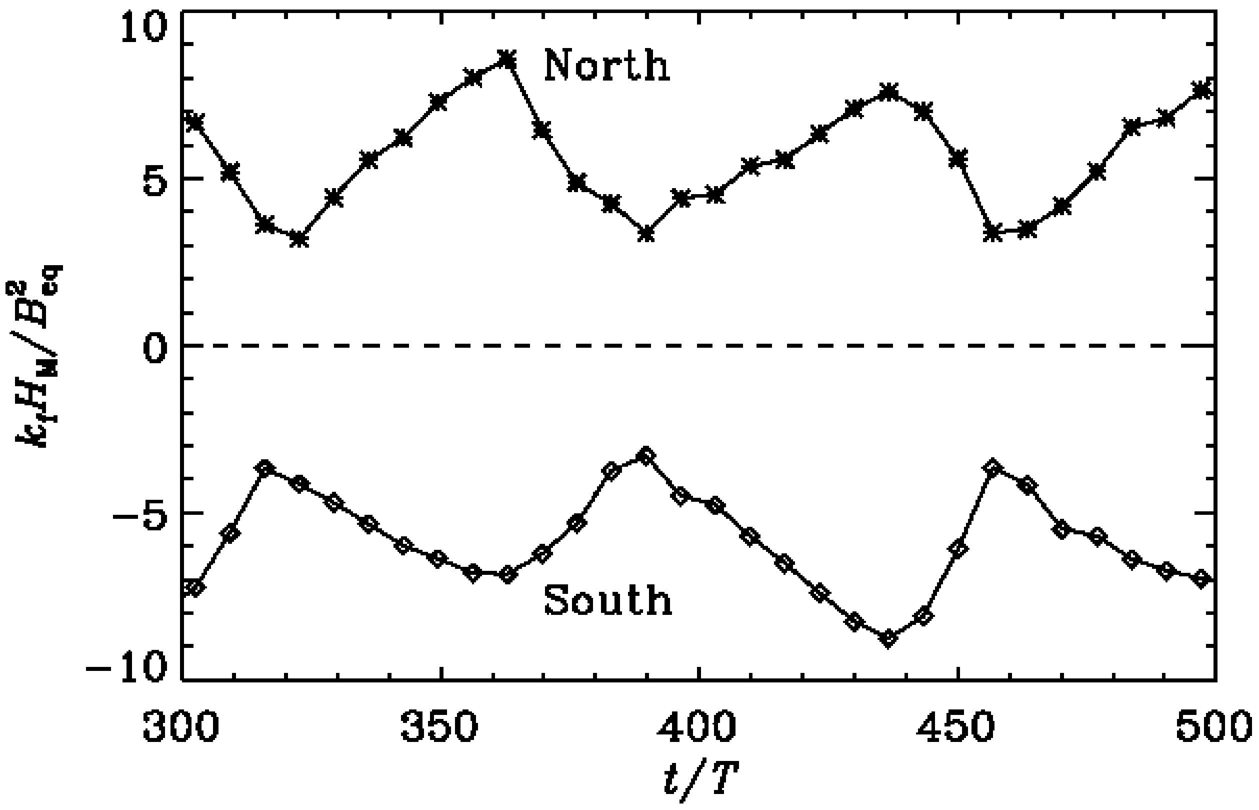
Butterfly diagram



Frequencies of oscillations



Magnetic helicity in open domains



Fine prints

- We have no convection, rotation, and differential rotation.
- Our Reynolds numbers are small.
- How does the frequency of oscillations change with magnetic Reynolds number ? (This question is best answered in mean field simulations)
- To generate similar kinetic helicity from convective simulations and rotation will require rapid rotation.
- We present a model with minimum number of added ingredients which shows interesting dynamical behaviour of large scale magnetic field, e.g., equatorward migration, oscillations and polarity reversal.