Dynamo Action in MRI-Driven Turbulence in a Cylindrical Annulus

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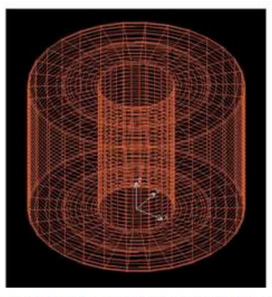
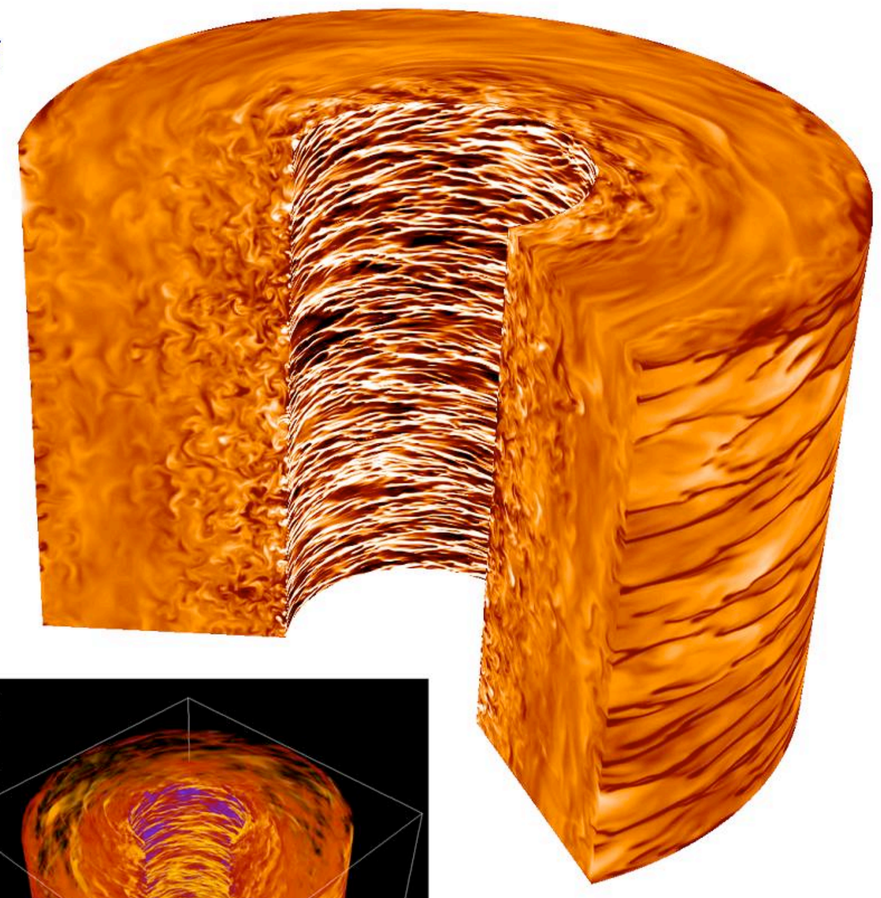
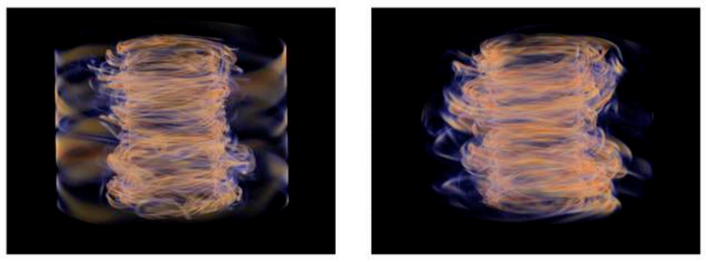
Axisymmetric and fully 3D global incompressible MHD numerical simulations of MRI-driven turbulence in cylindrical annulus with finite viscosity and resistivity:

- ✓ **upto Re=62000 and Rm=31000 (Pm=0.5)**
- ✓ **ANL spectral element code Nekton 5000 with upto 155000 elements and 10^3 collocation points per element [5, 6, 7]**
- ✓ **in the geometry inspired by Princeton MRI liquid sodium experiment (Schartman, Burin, Goodman & Ji 2006; Obabko, Cattaneo & Fischer 2008)**

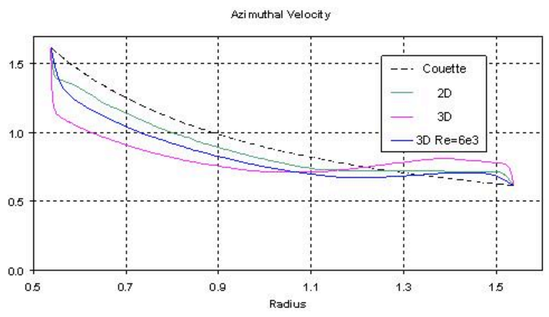


Nekton 5000 spectral element grid.

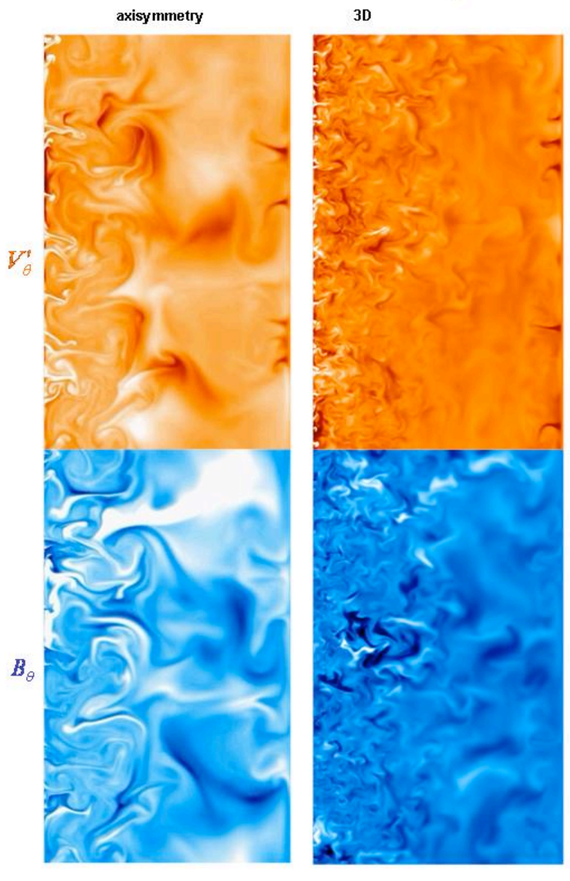




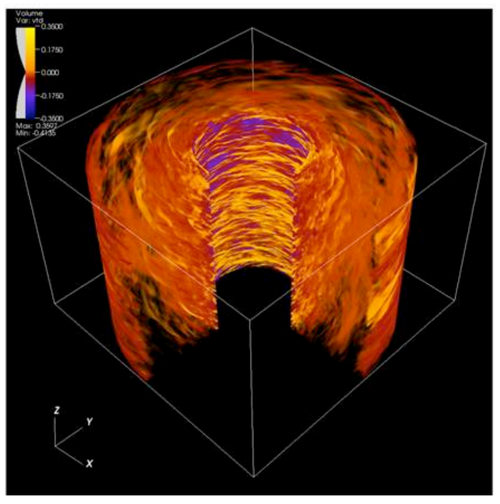
Viscous (left) and ohmic (right) dissipation[8] in the non-linear saturation of MRI at Re=6200. *The MRI saturation is achieved through comparable levels of viscous and ohmic dissipation.*



Averaged azimuthal velocity for axisymmetric case at Re=62000 (green) and 3D case at Re=6200 (blue) and Re=62000 (red). *The MRI saturation also involves modification of background velocity toward solid body rotation in 3D but flat rotational profile in axisymmetry.*



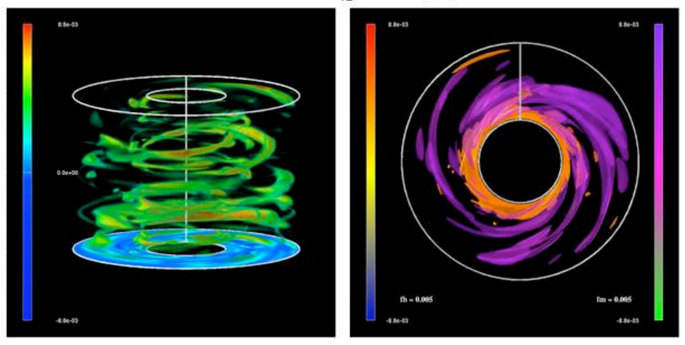
Poloidal cut of fluctuation of the azimuthal velocity (orange) and azimuthal magnetic field (blue) in axisymmetry (left) and in 3D (right) for Re=62000. *The transition from finer to coarser structures in velocity and magnetic field with radius increasing from the inner (left vertical boundary) to the outer cylinder (right vertical boundary) occurs sharply in axisymmetry being more diffused in 3D.*



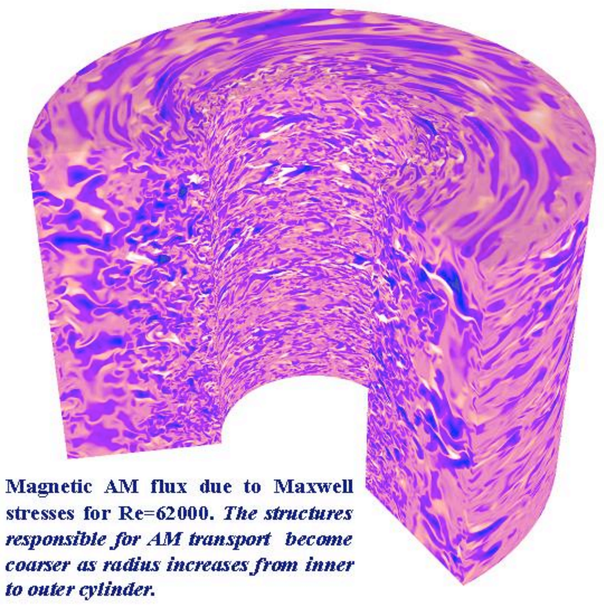
Pseudocolor plot (upper) and volume rendering (left[8]) of fluctuation of the azimuthal velocity field in 3D case with for Re=62000. *The fluctuations in azimuthal velocity have a structure of spiraling eddies and of high (light) and low (dark) speed streaks near cylinder boundaries.*

Angular Momentum Transport

AM Flux $F_{rz} = rV'_\theta V'_r - rB_\theta B_r$

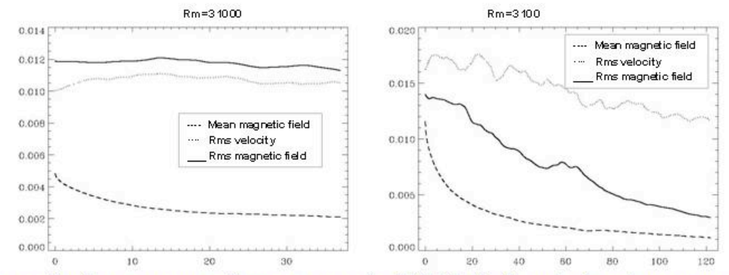


AM flux[8] for Re=6200 on the left and its contributions due to the velocity fluctuations (orange) and magnetic field (violet) on the right. *The Maxwell stresses dominate AM transport in the interior of the annulus while Reynolds stresses are important in cylinder boundary layers.*

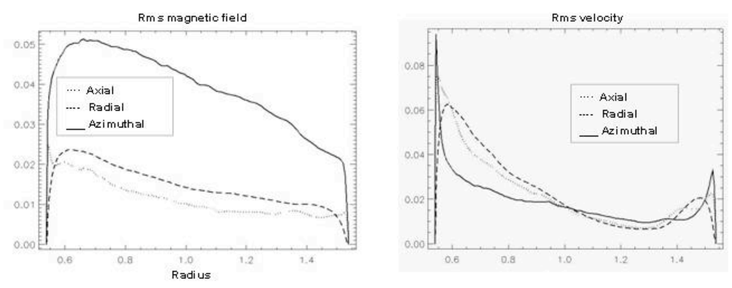


Magnetic AM flux due to Maxwell stresses for Re=62000. *The structures responsible for AM transport become coarser as radius increases from inner to outer cylinder.*

Small-Scale Dynamo at Pm=0.5



Time traces of volume-average of mean magnetic field (dashed) and of root-mean-square of magnetic field (solid) and velocity (dotted) for 3D case with Pm=0.5 and with Rm=31000 (left) and Rm=3100 (right) after switching off external magnetic field at the cylinder boundaries. *The fluctuations of magnetic field survive a decay of the mean magnetic field at high enough Rm.*



Cylinder-average of azimuthal (solid), radial (dashed) and axial (dotted) components of root-mean-square of magnetic field (left) and velocity (right) for 3D cases with Pm=0.5 and Rm=31000 (Re=62000). *The fluctuations of magnetic field are about 50 times smaller than characteristic shear velocity (~1) leading to the local Rm (based on rms velocity and correlation length) of the order 10^2 which is typical of small-scale dynamo systems.*

Conclusions :

- ✓ **Nonlinear saturation of MRI:**
  - **comparable viscous and ohmic dissipation**
  - **modification of the base flow toward solid body rotation in 3D and flat rotational profile in axisymmetry**
  - **angular momentum transport is dominated by Maxwell stresses**
- ✓ **Small-scale dynamo at Pm=0.5:**
  - **fluctuation of magnetic field survive a decay of the mean magnetic field at high enough magnetic Reynolds number Rm**
  - **dynamo at magnetic Prandtl number below one**
  - **typical small-scale dynamo system with the local Rm of the order of a few hundreds**

References:

Ji H, Schartman E, Burin M & Goodman J. 2006. Nature 444, 343

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