PI: Fatima Ebrahimi, University of New Hampshire, **"Global Simulations of Dynamo and Magneto-rotational Instability in Madison Plasma Experiments and Astrophysical Disks " (March 1 2013- Feb 28 2014)**

Objectives: Large-scale magnetic fields have been observed in widely different types of astrophysical objects. These magnetic fields are believed to be caused by the so-called dynamo effect. Could a large-scale magnetic field grow out of turbulence (i.e. the alpha dynamo effect)? How could the topological properties and the complexity of magnetic field as a global quantity, the so called magnetic helicity, be important in the dynamo effect? In addition to understanding the dynamo mechanism in astrophysical accretion disks, anomalous angular momentum transport has also been a longstanding problem in accretion disks and laboratory plasmas. To investigate both dynamo and momentum transport, we have performed both numerical modeling of laboratory experiments that are intended to simulate nature and modeling of configurations with direct relevance to astrophysical disks. Our simulations use fluid approximations (Magnetohydrodynamics - MHD model), where plasma is treated as a single fluid, or two fluids, in the presence of electromagnetic forces. Our major physics objective is to study the possibility of magnetic field generation (so called MRI small-scale and large-scale dynamos) and its role in Magneto-rotational Instability (MRI) saturation through nonlinear simulations in both MHD and Hall regimes.

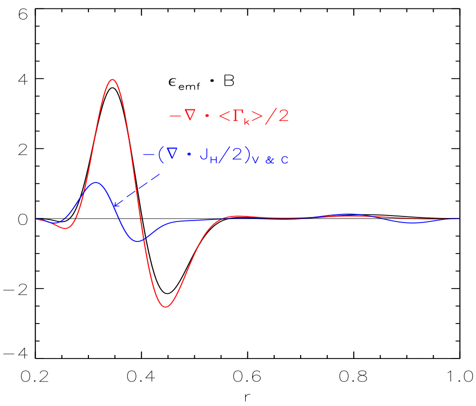


Figure 1: Dynamo term $\varepsilon_{emf} \cdot \overline{\boldsymbol{B}}$, total divergence form of fluctuation-induced helicity flux $-\nabla\cdot < \Gamma_k > /2$, and the divergence form of helicity flux given by Vishniac & Cho, during m=1 MRI mode nonlinear saturation.

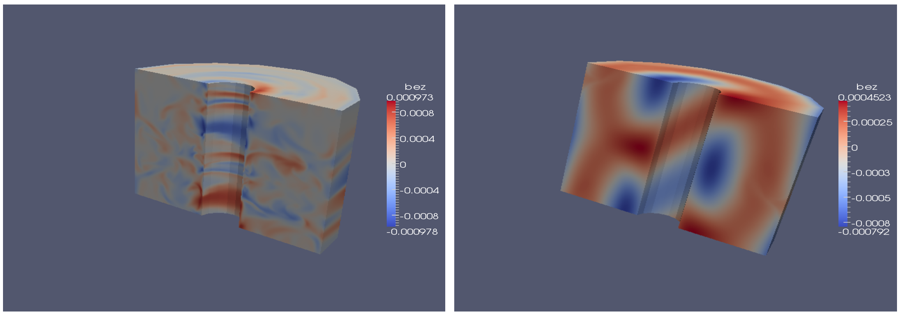
Accomplishments:[1] **(a) The role of magnetic helicity flux on the alpha dynamo effect** Self-organized plasmas are common throughout the universe. Examples include self-organized plasmas of flow-dominated astrophysical disks and magnetically-dominated star surfaces. We treat the dynamo problem in both laboratory (magnetically dominated) and astrophysical (flow dominated) plasmas from a common perspective. It is believed that the correlated flow and magnetic field fluctuations, the alpha effect, may play a critical role in generation of large-scale magnetic fields in a turbulent plasma. The constraint imposed by magnetic helicity conservation on the alpha effect is considered for the two important, and very different, examples of tearing instability in laboratory plasmas and magneto-rotational instability in flow driven astrophysical disks. The role of magnetic-helicity fluxes on the alpha effect and the final sustainment of large-scale magnetic field is examined. For the two examples of an unstratified Keplerian cylinder and a reversed-field pinch, a dominant contribution to the alpha effect, in the functional form of a total divergence of an averaged helicity flux, called the helicity-flux-driven alpha effect is demonstrated. [2] Figure 1 shows that dynamo effect and the large-scale magnetic field are sustained by the helicity-flux from a non-axisymmetric flow-driven MRI instability.

Accomplishments:[3] **(b) 3-D Hall dynamo generated by MRI in Madison Plasma Couette Flow eXperiment (PCX)** In some astrophysical disks, where plasma is weakly ionized, the ions can be demagnetized by collisions with neutrals and drift relative to the electrons. In this regime, the two-fluid Hall term, which arises from the difference between the electron and ion velocities, can become important. In plasma experiments in Madison, ions are demagnetized and

[1]Was partially supported by this grant
[2]Ebrahimi, Bhattacharjee PRL, 112, (125003), 2014
[3]Is fully supported by this grant

the two-fluid Hall term is also expected to be important. We have therefore performed both single fluid and two- fluid Hall simulations in the global domain of the experiment. These simulations will provide guidance, and have been necessary to obtain quantitatively reliable predictions for PCX. In our earlier work, we found that (a) the Hall effect is predicted to play a critical role for the onset of MRI in PCX, (b) two-fluid physics also significantly changes the nonlinear evolution and saturation of the axisymmetric MRI.[4] Here, we perform nonlinear full 3-D Hall-MHD simulations of plasma Couette experiment. To our knowledge, this may be the first global two-fluid simulations in cylindrical geometry of MRI turbulence. Very different dynamics for MRI simulations are obtained when two-fluid Hall physics is included. Simulations have been performed using the extended MHD code NIMROD in a Couette geometry with a radius of 0.5m and a height of 1m (similar to PCX geometry). Global 3-D Hall-MHD simulations are computationally challenging and require high resolutions. We have used 60x60 fourth order finite elements for the poloidal resolution and 84 modes in the toroidal direction. Figure 2 shows turbulent MHD dominated MRI-driven plasma vs laminar Hall dominated MRI-driven plasmas. It will be reported that a large-scale magnetic field structure (zonal fields) is generated in the Hall-MHD regime.[5] It will also be shown that angular momentum is transported through only a dominant m=1 mode in Hall, but through both axisymmetric and nonaxisymmetric modes in the MHD case.

Global MHD **Global Hall**



Published articles in refereed journals (Partially supported by this grant):

[1] F. Ebrahimi and A. Bhattacharjee. Helicity-flux-driven effect in laboratory and astrophysical plasmas. Phys. Rev. Lett., 112:125003, Mar **2014**. doi: 10.1103/PhysRevLett.112.125003. URL http://link.aps.org/doi/10.1103/PhysRevLett.112.125003.

Presentations at the conferences/workshops supported by this grant:

1- Invited talk - F. Ebrahimi "The role of magnetic helicity flux on the alpha dynamo effect", APS - DPP Mini-Conference: The magnetic universe in the honor of Stirling Colgate, New Orleans, October 27, 2014

2- Invited talk F. Ebrahimi "Helicity-Flux-Driven Alpha Effect in Laboratory and Astrophysical Plasmas", Magneto-Fluid Dynamics Seminar - Courant Institute, NYU March 2014

3- F. Ebrahimi "Magnetic Helicity –Application to Fusion and Astrophysical Plasmas", Physics Colloquium at Auburn University, February 2014

[4] F. Ebrahimi el al. Physics of Plasmas, **18**,(062904), 2011
[5] F. Ebrahimi el al. Manuscript under preparation

4- Invited talk F. Ebrahimi “Helicity-Driven Alpha Effect in Laboratory and Astrophysical Plasmas”, Max Planck/Princeton Center for Plasma Physics workshop, Princeton University Oct 30 -Nov 1, 2013

5- Invited talk F. Ebrahimi “Momentum transport and dynamo in flowing plasmas”, Plasma Physics Colloquium – Columbia University, May 2013

6- Invited talk F. Ebrahimi “Momentum transport in flowing plasma”, Princeton Center for Theoretical Science (PCTS) Workshop on Plasmas, Princeton University April 8-12, 2013

7- F. Ebrahimi, A. Bhattacharjee, “Global simulations of dynamo and turbulent magnetic helicity transport in flowing plasmas”, Bulletin of the American Physical Society, 58 Nov. 2013.