

# Momentum Transport Plan

2-10-2004

## Overall Goals:

The Center activities will be concentrated on the following physics topics:

1. Momentum transport by stochastic magnetic fields  
*Magnetic fields in both laboratory and space often have well ordered components on large scales and random or stochastic components on smaller scales. This is the case in all Center experiments, is observed in MHD computation of accretion disks with MRI, and is likely the case in astrophysical jets and in the sun. As particles and/or waves travel along the real field lines, they can wander in space and lead to transport of particles, energy, and momentum.*
2. Momentum transport by Maxwell Stress from current-driven instabilities  
*Magnetic fluctuations can directly affect plasma flow by producing Maxwell Stresses. In experiment, strong tearing mode activity is presumed to be responsible for rapid changes in plasma momentum and coupled modes can produce a nonlocal transport of momentum from one region of the plasma to another. Astrophysical jets have a magnetic geometry that is similar to the Center experiments and may be susceptible to similar tearing or kink type instabilities.*
3. Momentum transport by Maxwell Stress from magnetorotational instability  
*The leading candidate for momentum transport in accretion disks is the Maxwell Stress caused by the magnetorotational instability (MRI). Here a weak magnetic field couples with strong differential rotation giving rise to instability. A possibly important effect which has not yet been fully explored is that of a magnetized corona above and below the disk which couples to the disk plasma by magnetic field lines and may significantly alter the momentum transport by MRI. The MRI has never been observed in the laboratory but is being pursued in both plasma and liquid metal experiments.*
4. Generation and relaxation of momentum as part of a 2-fluid form of magnetic relaxation  
*In single fluid MHD, it has been shown that some systems will relax to a state of minimum magnetic energy subject to the constraint of total magnetic helicity. This idea has been a guiding principle in Center experiments, many of which undergo this type of relaxation to at least some degree. In two-fluid systems, a similar relaxation may occur with consequences for both the arrangement of the magnetic fields (or currents) and the plasma momentum. Although theory predicts that this should occur in some systems, the principle has never been confirmed in experiment and never been applied in astrophysics.*
5. Momentum transport in the sun  
*Recent observations of differential rotation in the solar interior pose new challenges to models for solar dynamics. A striking feature is the region of intense flow shear at the tachocline – the interface between the radiative and convective zones. Momentum transport in part determines the flow profile in the sun which in turn gives rise to dynamo action and produces the large scale magnetic fields we observe throughout the solar system.*

## Tasks and Plans:

- Below are the tasks and plans which Center members have indicated they will be pursuing.
- Note: Some tasks appear under more than one heading because they are relevant to more than one physics topic. Some tasks do not directly fall under one of the 5 overall goals and are included in a final heading, "Other momentum transport tasks".

### 1. Momentum transport by stochastic magnetic fields

- Measure  $\langle \tilde{p}_{\parallel} \tilde{B}_r \rangle$  in MST, a direct measure of this effect
  - *Edge probes, 1 yr to start, 0.5 yr to assess, 1.5 yr to physics, Fiksel + MRX + RA*
  - *Core,  $p_i$  from CHERS, 2 yr to physics, Craig + Ennis + RA*
  - *Core, B from FIR, 1 yr to physics, Ding*
  - *Core, B from MSE, 0.5 yr to start, 2.5 yrs to physics, Den Hartog + Craig + RA*
- Drive flows in MST, vary fluctuations, and measure momentum transport
  - *Biased probes, 1 yr to start, 0.5 yr to physics, Craig + Almagri*
  - *Neutral beam, 0.5 yr to feasibility, Fiksel, Ahn, Hudson*
- Measure mean flow profile and its evolution in MST, single point measurements
  - *CHERS for flow profile, 2yr to physics, Craig + Ennis + RA*
- Measure mean flow profile in MST, multi-point measurements
  - *CHERS, 1 yr if DOE funded, Craig + Den Hartog + technician*
- Drive flows in MRX and measure momentum transport
  - *Biased probes, Princeton, mid to long term*
  - *Neutral beam, Princeton + UW, mid to long term*
- Measure flows in SSX
  - *Operation of new IDS, Brown + Cothran + students*
- Include momentum transport in self-consistent theory
  - *1 yr to physics, Terry + postdoc*
- Assess relevance of self-consistent theory to astrophysics
  - *1 yr, Zweibel + Terry + postdoc*

### 2. Momentum transport by Maxwell Stress from tearing modes

- Measure  $\langle \tilde{j} \times \tilde{B} \rangle$  in MST, a direct measure of this effect
  - *Edge probes, 1.5 yrs, Fiksel + Almagri + RA*
  - *Core with FIR, 1 yr, Ding*
  - *Core with MSE, 0.5 yr to start, 2.5 yrs to physics, Den Hartog + Craig + RA*
- Drive flows in MST, vary fluctuations, and measure momentum transport
  - *Biased probes, 1 yr to start, 0.5 yr to physics, Craig + Almagri*
  - *Neutral beam, 0.5 yr to feasibility, Fiksel, Ahn, Hudson*
- Measure mean flow profile and its evolution in MST, single point measurements
  - *CHERS for flow profile, 2yr to physics, Craig + Ennis + RA*
- Measure mean flow profile in MST, multi-point measurements
  - *CHERS, 1 yr if DOE funded, Craig + Den Hartog + technician*
- Measure flows in SSX
  - *Operation of new IDS, Brown + Cothran + students*
- 3D MHD computation in SSX geometry with hybrid code

- *Begin now, Brown + Cothran + Belova + Schaffer + students*
  - g. Calculate tearing mode Maxwell Stress in RFP with DEBS/NIMROD
    - *1 yr, Ebrahimi*
  - h. General assessment of astrophysical jet problem
    - *1 yr, UW theory*
- 3. Momentum transport by Maxwell Stress from magnetorotational instability
  - a. Linear stability calculation for MRI in lab (apply to MST)
    - *1 yr, Mirnov*
  - b. Gallium experiment
    - *Operate experiment, short-mid term, Princeton*
    - *Nonlinear MHD theory, short-mid term, Princeton*
    - *Incompressible MHD computation, short-mid term, Princeton + UC + SAIC*
  - c. Evaluate the role of active disk coronae in angular momentum transport in accretion disks
    - *mid-long term, Goodman + Mikic + Schnack*
- 4. Generation and relaxation of momentum as part of a 2-fluid form of magnetic relaxation
  - a. Measure mean flow profile and its evolution in MST
    - *CHERS for flow profile, 2yr to physics, Craig + Ennis + RA*
  - b. Measure mean flow profile in MST, multi-point measurements
    - *CHERS, 1 yr if DOE funded, Craig + Den Hartog + technician*
  - c. Global merging in MRX
    - *Mid term, Princeton*
  - d. Drive flows in MRX
    - *Bias plasmas, mid-long term, Princeton*
    - *Neutral beam, mid-long term, Princeton + UW*
  - e. Evaluate 2-fluid relaxation theory
    - *Short-mid term, Princeton + Mahajan + Berger*
  - f. Measure flows in SSX
    - *Operation of new IDS, Brown + Cothran + students*
  - g. 3D MHD computation in SSX geometry with hybrid code
    - *Begin now, Brown + Cothran + Belova + Schaffer + students*
  - h. Observe relaxation with 2 fluid, 3D MHD computation
    - *NIMROD and/or modified DEBS, 1 yr, Ebrahimi + Schnack*
  - i. Assess relevance of 2-fluid relaxation to astrophysical jets
    - *Medium priority – on hold, Hegna*
  - j. Evaluate changes in magnetic and kinetic helicities through sawtooth in MST
    - *Magnetic helicity, 1 yr, Craig + Ding + Anderson*
    - *CHERS for flow profile, 2 yr to physics, Craig + Ennis + RA*
- 5. Momentum transport in the sun (same workplan as solar part of Dynamo topical area)
  - a. Development of incompressible/anelastic MHD spectral element code
    - *2 yrs, Cattaneo + Linde + Rosner*
  - b. Develop sub-grid-scale models and compare to direct numerical simulation

- *2 yrs, Cattaneo + Linde + Rosner*
    - c. Incorporate sub-grid-scale models into spectral element code
      - *3 yrs, Cattaneo + Linde + Rosner*
    - d. Investigate physics of integrated solar dynamo model
      - *4 yrs, Cattaneo + Linde + Rosner*
- 6. Other momentum transport tasks
  - a. Measure fluid Reynolds Stress  $v \cdot \nabla v$  in MST
    - *Edge probes, 2 yrs to start, 1.5 yrs to physics, Fiksel + RA*
    - *Core with CHERS, 2 yrs to start, 0.5 yrs to assess, Craig + Den Hartog*
  - b. Measure/calculate transport by charge exchange with neutral atoms in MST
    - *Begin spring 2004, 1 yr to physics, 0.3 MST postdoc*
  - c. Measure radial electric field (ExB flow) in MST versus time
    - *Heavy ion beam probe group from RPI, 2.5 yrs if funded by DOE*
  - d. Assess wind-driven B star disk problem
    - *Cassinelli to give seminar early 2004*