## Happy New Year 2004 from SSX-FRC!

I guess the big news from 2003 is that our regular DOE grant (that supports postdoc Chris Cothran and the day-to-day operation of SSX) was renewed! Writing the renewal constituted a large effort for all of us (mb, Chris, Mike Schaffer, Elena Belova) until April 2003. The renewal means that Chris can stick around for a while and our collaboration with Mike S and Elena will continue. Chris just finished his first 3 year stint on SSX and now begins (we hope) another 3 year stint on SSX-FRC. We will also continue our theory collaboration with Bill Matthaeus of Bartol.

We were also funded as participants in a new NSF Center on Magnetic Self Organization in Laboratory and Astrophysical Plasmas (CMSO for short). Other CMSO participants include Wisconsin, Chicago, Princeton, and Livermore. This will provide some support for Chris and some students but more importantly, will give us more access and entree into the astrophysical and computational communities (eg the "Flash" computation center at Chicago). We might even do a collaborative experiment at say Wisconsin or Livermore down the road. Our participation in the Center was announced on the main Swarthmore website (still there as of 1/28/04... http://www.swarthmore.edu/). Here are the websites for the new NSF Center (not much content there yet) and for the SSX contribution:

http://www.cmso.info/

http://plasma.physics.swarthmore.edu/selforg/index.html

Our main effort in early 2003 was the push to run SSX-FRC through its paces and collect a lot of data. We did numerous scans through spring 2003 and these were organized over the summer of 2003 (thanks in large measure to Jerome Fung for working on a searchable database for the scans). Since shutting down SSX and packing up the lab in early June 2003, we've been studying that data and planning for the next phase of operation. The centerpiece in the next phase is a new ion doppler spectrometer that Chris designed and is being set up as we speak.

### Plans for 2004:

**Ion Doppler Spectroscopy (IDS):** We have just taken delivery of a McPherson model 209 Czerny-Turner 1.33 meter focal length ($f/9.4$ aperture) spectrometer for use in an ion doppler spectroscopy system on SSX. This purchase was made through our main DOE experiment grant. Our goal

is to make time resolved ($1\mu s$ or better) temperature and flow measurements. The McPherson spectrometer will be used with a 316 g/mm echelle grating blazed for at 5664 nm to achieve a dispersion of 0.032 nm/mm. Additional input optics, including a fiber optic bundle, will ensure the grating is maximally filled and permit the selection of a narrow cylindrical chord. Output optics will image the focal plane (with 3x magnification in the dispersive plane) onto the active area of a Hamamatsu model H7260 multi-anode photomultiplier tube. The output of each anode (up to 32 channels) will go through an amplifier stage then be digitized. The goal will be to measure the dynamics of the line as a function of time. All of this hardware is in house now or will be shortly.

We are presently learning how to use and calibrate the spectrometer. Chris has spent a lot of time the past few months reworking the design of the input/output optics and making purchases of new optical equipment. Steve Palmer will be assisting with some hardware and mounts while Jim Haldeman will be providing some electronics help (wiring amplifiers and the like down the road). The spectrometer is being set up in a temporary space just for winter 2004 (Catherine Crouch's lab). Chris (and perhaps Aaron Modic) will be doing calibration runs in the coming months (Jan-Apr 2003). The SSX lab is undergoing a renovation which will be completed this April/May 2004. The SSX device and new ion doppler spectrometer will be installed in a new laboratory in the Swarthmore College Science Center (upstairs on the north side of the building) and operated by mb, Chris, and Swarthmore undergraduates (Jerome and Aongus) this summer 2004. We will be rebuilding the screen room and Ambrose Rigging Company will be returning the SSX device/power supplies/racks, etc. We're currently working on a schedule for when all this will happen (and in what order). The goal is to be ready to take data on SSX by the end of June 2004.

**3D magnetic structure measurements:** We plan to continue our mapping of the 3D magnetic structure of the merging, reconnection, and self-organization processes in SSX. We are studying our existing magnetic data with an eye towards self-organization issues (reconnection, helicity, relaxation) as well as magnetic confinement issues (FRC stability). In addition, we will continue to monitor energetic ion flux as well as flow and heating with our IDS system described above.

**Simulations:** We feel that SSX is a unique experiment to study MHD physics on a "tabletop" setting. The machine is flexible enough that we can easily change boundary conditions (flux conserver size, bias field) or ini-

tial conditions (counter- or co-helicity, single or double spheromak, arbitrary delay between east and west). Coupling a flexible MHD experiment with a flexible 3D MHD simulation affords a unique opportunity to test models including non-MHD aspects (eg, two fluid effects and contributions from $\nabla \cdot \mathbf{P}$). Our immediate plan is work with colleagues Elena Belova at PPPL and Mike Schaffer at GA on Dr. Belova's 3D code called HYM (for HYbrid MHD). The code has options to switch between three different physics models: (1) resistive 3D MHD with the $\mathbf{J} \times \mathbf{B}$ (Hall) term in Ohm's law, (2) a hybrid option that treats the electrons as a fluid and the ions as particles, and (3) an option that merges the MHD code with an energetic kinetic ion component ($\beta_{beam} \cong \beta_{MHD}$).

**Papers and manuscripts (2003):** Several manuscripts that were begun in 2002 appeared in print in 2003. Chris is also working on several more that should be submitted early in 2004 (see below).

1. M. Landreman, C. D. Cothran, M. R. Brown, M. Kostora, and J. T. Slough, "Rapid Multiplexed Data Acquisition: Application to Three-dimensional Magnetic Field Measurements in a Turbulent Laboratory Plasma", *Review of Scientific Instruments* **74**, 2361 (2003).

2. C. D. Cothran, M. Landreman, W. H. Matthaeus, and M. R. Brown, "Three Dimensional Structure of Magnetic Reconnection in a Laboratory Plasma", *Geophysical Research Letters* **30**, 1213 doi 10.1029/2002GL016497 (2003).

3. C. D. Cothran, A. Falk, A. Fefferman, M. Landreman, M. R. Brown, and M. J. Schaffer, "Partial and complete spheromak merging at SSX: 3D studies of reconnection and FRC formation", *Physics of Plasmas* **10**, 1748 (2003).

4. P. Dmitruk, W. H. Matthaeus, N. Seenu, and M. R. Brown, "Test Particle Acceleration in Three-dimensional Magnetohydrodynamic Turbulence", *Astrophysical Journal Letters* **597**, L81 (2003).

5. H. Ji, M. R. Brown, S. Hsu, H. Li, and R. P. Drake, "Mini-conference and related sessions on laboratory plasma astrophysics", *Physics of Plasmas* (to appear) (May 2004)

**Manuscripts in progress (2004):** Chris has been working on at least four possible manuscripts that should be ready for submission soon.

1. **Doublet CT or hybrid CT discovery paper (PRL):** Here's where we announce that we observe this interesting new object with FRC fields at the mid-plane and spheromak fields at the ends. We'll discuss counter-helicity merging, requirement for radial current at the mid-plane, $J \times B$ forces generate flow and/or twisted structure. Elena Belova's modeling will be very useful here.

2. **Co-helicity state (PoP letter, PRL, PP&CF or N. Fusion):** This might also be a discovery paper along the lines of the RFP... ie we set the initial conditions then the dynamics find this new state (conserving helicity). We'd talk about co-helicity merging as a good example of Taylor relaxation. Elena's modeling would be nice here too.

3. **Single spheromak:** We observe that a one gun single spheromak tilts, but RCC current parallel to spheromak current "catches" the spheromak, preventing a tilt. This is sort of a hybrid of the flux conserver method and feedback coil method for stabilization... more analysis needed... check single spheromak with guns in RR mode vs RL mode, etc. Could be dipole alignment, could be line tying. Elena's modeling would be nice here too (if possible).

4. **Ohm's law (ApJ):** Stuff we might include: (1) analysis of $\nabla \times (v \times B)$, (2) scatter plot of $J_y$ vs $(J \times B)_y$, (3) look at $\hat{B}$ dotted into Ohm's law, (4) look at a plot of $(J \cdot B)/B^2$, (5) note that $v \times B$ should dominate E outside and $J \times B$ should dominate inside... $dJ/dt$ should dominate at the $c/\omega_{pe}$ scale (which we can't resolve).

**Students:** Because of the SSX-FRC shutdown, we dropped down to just one (excellent) student for summer 2003: Jerome Fung. Jerome is a sophomore physics major and we're looking forward to having him re-join the group this summer. Jerome is likely to be joined by other students as we re-establish the lab in the newly renovated Science Center. It looks like junior Aongus O Murchadha will be joining us this summer. Senior Aaron Modic will be doing some work this spring.

**Talks and presentations (2003):** We were in Albuquerque this past fall 2003 for the APS-DPP meeting. Chris presented a poster (with

Jerome as co-author). I was involved in organizing a "mini-conference" on laboratory astrophysics. We also went to the innovative confinement concepts meeting (ICC 2003) and compact torus workshop (CT 2003) in Seattle in May 2003. I went to the plasma experiments in lab and space meeting (IPELS 2003) in Montana in June 2003. Chris gave an invited talk at the US/Japan workshop on reconnection in Catalina in Nov 2003 (mb was one of the organizers). We have also made a few trips in association with the new NSF Center. I went to a preliminary organizational meeting in Madison in Feb 2003, Chris went to Chicago in Nov 2003, we both went to Princeton in September 2003).

**Review of 2003 operation:** We shut down SSX-FRC in June 2003 for a move and lab renovation. Since summer, we have been analyzing lots of data. Jerome was instrumental in organizing our data sets and some preliminary analysis. Our main goal is to discover a more stable operating regime for our doublet CT objects. We did scans in which we varied gun parameters like current and flux, their product is proportional to helicity, their ratio is the $\lambda$ parameter from $\nabla \times B = \lambda B$. These scans adjust magnetic energy and helicity. We also scanned gas valve timing (which adjusts density by a factor of two or so). Scanning the stuffing flux adjusts helicity and density. Of course, switching the sign of the stuffing flux generates co-helicity merging (both the same, L/L or R/R). We ran a lot with 12 probe stalks and at the end ran with 20. As mentioned above, we're pleased to be working with Dr. Elena Belova of Princeton on the modeling of some of these results. Elena studies the FRC $n = 1$ tilt mechanism with hybrid and two-fluid simulations. It looks like some of her results might be applicable to our experiment.

cheers and happy new year, mb