Happy New Year 2007 from SSX!

Here's a quick review of 2006 (including the second half of my sabbatical which was Spring 2006) as well as plans for 2007.

We made several trips this past year to present SSX results. I gave a talk at American Geophysical Union meeting in SF called, "High velocity plasma jets and 3D magnetic structure in the Swarthmore reconnection experiment", in Dec. 2006. A big event in 2006 was the US/Japan Workshop on Physics of Compact Toroid Plasmas here at Swarthmore College, Nov. 2006. I attended an interesting Gordon Conference on Physics Research and Education: Electromagnetism, "Undergraduate Plasma Physics Research at the Swarthmore Spheromak Experiment", at Mount Holyoke College, MA, June 2006. I was also at the American Physical Society April Meeting, Dallas, TX, Apr. 2006, "High velocity plasma jets and 3D magnetic structure in the Swarthmore reconnection experiment". The year started with an invited talk at Innovative Confinement Concepts, "Novel Spheromak Configurations", in Austin, TX, Feb. 2006 (Chris and I were delayed here due to a blizzard if I recall). I also visited TCNJ (2/06), Trinity (3/06), Iowa State (3/06), Wake Forest (4/06), and Auburn (4/06) for APS talks. We have ICC 2007 coming up in Maryland in February and a reconnection workshop in March.

Our main results in 2006 are presented in the theses of Vernon Chaplin and Jason Horwitz (see below). They measured more details during that important $30 - 40$ μs reconnection timeframe during merging experiments (increase in both T_e and ion flow). Both Vernon and Jason presented their work at APS-DPP here in Philadelphia and I really think it will form the basis of some nice papers in 2007 containing both optical and probe measurements of lab plasmas (connected to astrophysical and space plasmas).

In September 2006, Chris Cothran moved on to teach at nearby Haverford College (a two-year stint). We're still in touch... in fact, he just told me that Shannon just had their baby on Jan 6 (Thomas Jefferson Cothran, 7 lbs 7 oz)!

Summary of 2006:

Mach probes: Local spheromak flow was studied in summer 2006 by Jason with two Mach probes ($r_1 \leq \rho_i, r_2 \geq \rho_i$) absolutely calibrated by time-of-flight with a fast set of magnetic probes at the edge of SSX. MB helped with the new edge array of mag probes. The calibration constant Jason

measures is consistent with theories but is different for the two probes. Both Mach probes feature six ion collectors housed in a boron nitride sheath. The larger Mach probe (Mach II) will ultimately be used in the MST reversed field pinch (in fact, we built it using MST flanges, see photo). Jason measured axial flow speeds as high as 70 km/s during spheromak injection. During counter-helicity merging at $30 - 40$ μs, he observed the expected average azimuthal flow at a radius outside the reconnection region (about 10 km/s... recall that IDS measurements have shown radial/azimuthal outflow jets up to 40 km/s). He wasn't able to see a clear indication of flow at the inner radius. I've attached a photo of Mach II.

Vacuum ultraviolet and soft x-ray spectroscopy: Vernon has been using our 0.2 m vacuum ultra-violet (VUV) spectrometer on the midplane of SSX. It has it's own pumping port, bellows, and valve system so we can isolate it from the main experimental volume if necessary. We've recently been able to monitor the time signatures for L_α 122 nm, C_{IV} 155 nm, C_{III} 97.7 nm, and of course our favorite line C_{III} at 229.7 nm. Vernon has demonstrated that our laboratory plasmas lie in the non-trivial thermodynamic regime between coronal and local thermal equilibrium. This means that he has had to run exhaustive checks with the full-blown PrismSpect atomic physics code (without approximations). He also verified via time-dependent modeling that complex ionization/excitation equilibrium in the plasma is achieved in the plasma quickly (within 10 to 20 μs). This result implies that we can often use time-independent simulations to model the plasma if we wait long enough for the plasmas to evolve. In particular, Vernon has identified the ratio of two bright carbon ion lines (C_{IV} 155 nm/C_{III} 97.7 nm) as being an especially good temperature diagnostic for our laboratory plasmas. In addition, the carbon line C_{III} at 229.7 nm seems to be brighter in SSX than can be explained with atomic physics modeling. Vernon has measured electron heating up to $T_e = 35$ eV during reconnection (about 40 μs). By setting upper limits on impurity radiation from other ions (N, O), Vernon has set tight upper limits on impurity fractions in SSX ($n_O/n_C = 1/1000$).

Vernon has also analyzed data from a soft x-ray array using PrismSpect. The array is essentially a crude x-ray spectrometer featuring fast matched PIN photodiodes with thin (100 nm) metal filters (Al, Sn, Ti, Zr) in front of each one (50 nm for Ti I think). Using model spectra, Vernon has been able to interpret both the VUV line emission data and the SXR flux data to give a dynamical measurement of the plasma temperature on every pulse of the machine. That diagnostic also gives $T_e \cong 35$ eV. I've attached a photo of

the new SXR array.

Simulations: Elena Belova of PPPL and Nick Murphy of Wisconsin (CMSO) are continuing to provide computational support with HYM and NIMROD respectively. We have been analyzing the output of Elena's 3D code with an eye towards representing data the same way we measure it (for example line-averaged and density-weighted flow measurements from IDS).

Lab updates: Leon Maurer (Dartmouth physics student and son of a math colleague) worked this fall in the lab. He was very successful at getting a new high-power heat blanket installed on SSX (we can now bake the SSX vacuum walls to even higher temperatures). Leon also worked on a new gas delivery system (H_2, He, N_2) which will feature all stainless steel tubing and a new pump-out feature on the double o-ring on the main SSX flanges. SSX is **very** clean these days. Leon also revised the SSX website which we'll launch soon. As noted above, Leon also worked on analyzing Elena's data with an eye towards presenting her results (on **v** and **B** for example) the same way we measure it.

Other diagnostics: During summer 2006, Jason made more progress on prototype magnetic probes with spacings of 3 mm inserted in tiny quartz tees. We are continuing development on fast amplifiers and integrators for use with our probes. Tobin Munsat at U Colorado (and his student) will be helping us with this. We're also planning transimpedance amplifiers for the 16-32 IDS channels (10 MHz).

We installed 4 new "fast edge probes" (48 channels altogether) and tested them with the prototype integrator/line driver circuit (10 MHz, deadbug). The signals look beautiful (clean, high frequency 150 mV signals into 50 ohms)! We see more high frequency structure with the line driver attached than with the plain integrator. Both are better than passive integrators we tested side-by-side.

Papers and manuscripts (2006): We had three manuscripts appear in print in 2006. We're also working on several more that should be submitted soon (see below).

1. **M. R. Brown**, C. D. Cothran, J. Fung, M. Chang, J. Horwitz, M. J. Schaffer, J. Leuer, E. V. Belova, "Dipole Trapped Spheromak in a Prolate Flux Conserver", *Physics of Plasmas* **13**, 102503 (2006).

2. C. D. Cothran, J. Fung, **M. R. Brown**, and M. J. Schaffer, "Fast, High

Resolution Echelle Spectroscopy of a Laboratory Plasma", *Review of Scientific Instruments* **77**, 063504 (2006).

3. **M. R. Brown**, C. D. Cothran, and J. Fung, "Two Fluid Effects on 3D Reconnection in the SSX Experiment with Comparisons to Space Data", *Physics of Plasmas* **13**, 056503 (2006).

Manuscripts in progress (2007): We have been working on at least three possible manuscripts that should be ready for submission soon.

1. **Properties of the Doublet Compact Torus Configuration:** Here's where we report the observation and characterization of a novel doublet compact toroidal (CT) configuration formed in SSX. It is studied in the prolate (tilt unstable) 0.4 m diameter, $L = 0.6$ m length, 3 mm wall copper flux conserver in SSX formed by counter helicity merging of spheromaks. The doublet CT is characterized by fully reconnected poloidal flux but persistance of oppositely directed toroidal fields. Three dimensional MHD simulations of this configuration are also discussed.

2. **Dynamics of a Tilted $m = 1$ Spheromak in a Prolate Flux Conserver:** Here's where we discuss a fully tilted, $m = 1$ spheromak, formed by co-helicity merging of two spheromaks (either right-right or left-left handed) and studied in the prolate (tilt unstable) 0.4 m diameter, $L = 0.6$ m length, 3 mm wall copper flux conserver in SSX. Chris presented some of this at APS 2006.

3. **Simultaneous Bi-directional Plasma Jets from a Laboratory Magnetic Reconnection Volume (PRL?):** We report the first direct laboratory measurement of simultaneous bi-directional outflows from a reconnection event. The ratio of inflow speed to outflow speed is the normalized reconnection rate. A rapid reconnection rate is corroborated with a separate measurement of reconnecting magnetic flux.

Students: Vernon and Jason both have nice complete drafts of their theses. Final versions will be done Spring 2007. We haven't lined up anyone for summer 2007 but we have some possibilities (stay tuned). Jerome has started at Harvard. Aongus continues at Wisconsin. I saw several SSX alums at the APS-DPP 2006 meeting here in Philadelphia (Dave S, Tim Gray, Amy

R gave an invited talk, Dave A, Slava, and Cameron). Some SSX alums are just finishing their PhDs... Cameron won the APS-DPP prize for best PhD plasma thesis in 2006 (recall that he won the APS-DPP undergraduate thesis prize for SSX work back in 1999). Tom K finished his PhD at Princeton recently.

Plans for 2007: Other than writing up results and completing the Vernon/Jason senior theses, we have some longer range plans. We were successfully renewed by DOE OFES to continue this work. Specifically, we are planning a new oblate flux conserver (actually a trapezoid of revolution) for summer 2007. We have some preliminary drawings (due to Leon) and Mike S has done a preliminary equilibrium calculation. Nick M has even done a 2D merging calculation to demonstrate that this idea is plausible. Tobin Munsat and his student Jeremy Nuger are gearing up to help us with tiny mag probe arrays and high bandwidth amplifiers. In the coming year, we hope to build up a suite of amplifiers so we can look at dim lines with the IDS and SXR. As we make SSX cleaner with new polished stainless steel gas lines, new valves, beefier bakeout, etc, we may find less and less impurity radiation signal. We are searching now for a new SSX postdoc (ad is in Physics Today now). In the meantime, David Cohen is going on leave in Fall 2007, so he is planning to help us continue the work Vernon has started. In particular, David will modify the PrismSpect analysis of SSX spectra. We hope to calculate the effect of non-Maxwellian electron distributions on model spectra. Perhaps we can resolve the anomalous intensity of the carbon line C_{III} at 229.7 nm.

cheers and happy new year, mb