Happy New Year 2009 from SSX!

Here's a quick review of 2008 as well as plans for 2009... I'll post this one on the SSX website. Check out ones from prior years if you like.

Big news for 2008 was the arrival of Tim Gray '01. His one year full time anniversary is coming up (he actually began coming to the lab part time in late 2007). Our main work this year was with the oblate flux conserver (details below). We had a busy summer but again, no senior research students. The large crew featured Lake Bookman '08 (now in New Zealand), Bevan Gerber-Siff '10, Ed Dewey '10 (in Hungary fall 2008), and Kevin Labe '11.

We continued with collaborations with Mike Schaffer of GA and Elena Belova of PPPL. New collaborations are developing with computational folks at the PSI-Center at the University of Washington (Giovanni Cone, George Marklin, Richard Milroy, even Slava Lukin '00), also Yu Lin at Auburn, and Tobin Munsat at Colorado.

Tim and I attended the 50th annual APS-DPP meeting in Dallas November 2008. We talked with lots of SSX alums there (Chris, Slava, Cameron, Tom K, Matt L, Amy, Dave A). Tim gave an invited talk at the Innovative Confinement Concepts Workshop in Reno, NV in June 2008 entitled, "Stable high-flux oblate FRCs in SSX". MB also gave an invited talk at the American Physical Society, April Meeting, St. Louis, MO, Apr. 2008 entitled "Bidirectional outflow jets in the SSX reconnection experiment", Prize to a faculty member for research in an undergraduate institution talk. MB also gave an invited talk at Magnetic Reconnection 2008, entitled "Outflow jets in the SSX reconnection experiment", Okinawa, Japan, Mar. 2008. MB was also pleased to present an invited talk at the American Association of Physics Teachers called "Flow and heating dynamics of merging spheromaks in SSX" at a session called Award Winning Research at Undergraduate Institutions, Baltimore, January 2008. MB also made a presentation to CMSO, "Spheromak Merging and Reconnection in an Oblate Geometry", Princeton, NJ, July 2008. Finally, there was a talk at the New England Space Science Consortium (NESSC), "Outflow jets, ion heating, and 3D structure in the SSX reconnection experiment", University of New Hampshire, September 2008.

Other stuff coming up in 2009 of interest... We will write a re-renewal proposal for our main DOE grant due in April (I think). Luckily, the CMSO was re-funded in 2008 so we have a little cushion for the next 5 years (unless NSF goes under). Tim and I are planning to go to the APS April meeting in Denver (in May actually) and the IPELS 2009 meeting in Stockholm in June. There's also a CMSO general meeting in April in Santa Fe, NM. I'm participating in some DOE committees (goes with getting older I guess)... something called Research Needs Workshop (ReNeW) to plan for ICC re-

search in the ITER era. I'll also continue with the NRC Plasma Science Committee as well as the University Fusion Association.

Summary of 2008:

Oblate flux conservers: Our main focus in the lab this past year was studying magnetic structures in the new oblate flux conserver. The oblate flux conserver consists of two identical copper cones (0.5 m in diameter, each half 0.2 m long) with cylindrical outer electrodes welded (check out some drawings on the website... photos are coming). Good news is that we can form spheromaks nicely in the chamber either with a single gun or co-helicity merging (topic of an upcoming paper by Tim). Bad news is that counter-helicity merging always (except for a few atypical shots) forms a jumbled mess.

We tried a lot of fixes including (1) switching to all quartz probes, (2) extended inner electrodes, (3) conical inserts (aluminum, suggested by Tobin) to make the conserver even more oblate, (4) doubling the capacitance of the banks to 1 mF each to slow the formation down, and (5) copper bridges to electrically connect the east and west sides. We verified that the spheromaks emerge from the guns in a pretty axisymmetric state. Something happens as they enter the large oblate flux conserver such that they never find their way to FRC axisymmetry. We hope that simulations can provide some guidance (Giovanni Cone and George Marklin at the UW PSI Center are working on that, see below). Our plan in 2009 is to revert to the right cylinders again (see below). George will be providing us with expected mode structures for a simple $L = 0.4\ m, D = 0.4\ m$ aspect ratio 1 cylinder and a super-prolate $L = 0.8\ m, D = 0.18\ m$ aspect ratio 5 cylinder.

Ion heating: Our main result from summer 2008 was a comparison of ion heating with carbon and helium ions during (unstable/turbulent) counter-helicity merging events. An ensemble average of 50 shots shows essentially no difference in the T_i trace for the two ions but in about a third of the shots, the carbon ion temperature trace shows a little heating event (up to 40 eV or so at 50 μs). Helium doesn't show this bump (stays around 20 eV). The sources of trace carbon and helium are different (carbon, we think, is liberated from the gun elecrodes... helium was a 1% back fill with both turbo and cryo pumps running). This is interesting since ion temperature increasing with mass has been observed in the solar wind ($T_i/T_p \geq M_i/m_p$) and in other lab experiments (eg MST in Wisconsin, $T_i/T_p = \sqrt{M_i/m_p}$, which is more like what we see). There will be a little session on ion heating at the APS 2009 April meeting in Denver that I helped organize. Next step (early 2009) will be to put helium, methane, etc directly in the hydrogen feed gas (and even switch to deuterium).

Doping experiments: Our ion Doppler spectrometer remains our most

robust and unique diagnostic. No other plasma experiment can boast our combination of high temporal resolution ($\leq 1\ \mu s$) and high spectral resolution ($\leq 5\ km/s$). Up to now, we have relied on nascent impurities such as carbon to provide our ion Doppler signal. We have recently designed and procured a new all stainless steel gas delivery and mixing system. We're set to hook it up in early 2009 (the stainless steel is all laid up, we need to make some modifications to the Kornack valves... we have some photos). To analyze our doping mixture and impurity line strengths, we have recently procured a compact residual gas analyzer (RGA100) from SRS and a compact, broad band spectrometer (HR2000) from Ocean Optics. IDS data now also has its own data acquisition system (from D-TACQ). Tim Gray has set up the system so that it runs in the background on every shot. The lineshape is recorded by the IDS system and saved to a hard disk for later analysis.

Electrostatic probes (Kevin/Bevin): Kevin and Bevin spent the summer of 2008 designing and building three moveable electrostatic probes. First, they built a copy of the the Mach probe Jason Horwitz built which is now at the University of Wisconsin. We tested it and it seemed to work fine but analysis was tough with our unstable discharges. Second, they built two very nice new moveable retarding grid energy analyzers... one with a purely radial view, the other with a side view to look for energetic ions along the axis or azimuthally. The RGEAs seemed to work but the signal was small (some modifications are in order) and again, data is difficult to interpret if the local magnetic field is flopping around. We have lots of photos of these. I'll post them on the website eventually but I can send a copy to anyone interested.

PSI Center contributions: There are several SSX related projects underway at the PSI-Center at the University of Wisconsin. First, George Marklin has generated a series of eigenmodes for the old prolate $L = 0.6\ m, d = 0.4\ m$ SSX flux conserver using his eigenvalue PSI-TET code. He is working on an eigenmode analysis for our present oblate and future prolate flux conservers. George visited the lab in December. His calculations will help us understand the complex structure of our magnetically relaxed structures. His first set of structures is posted on my website under "papers". Second, graduate student Giovanni Cone under the supervision of Richard Milroy is studying interchange instability properties for an oblate wall supported FRC with the 3D MHD code NIMROD. He plans to do 3D merging studies later in 2009. Finally, Slava Lukin '00 is using the 3D implicit high order finite (spectral) element code HiFi to perform SSX simulations in both viscous single-fluid and Hall MHD regimes. These dynamical simulations will help us understand the evolution from merging to final state in SSX. Hand-drawn boundaries are posted on my website.

Colorado collaboration: Tobin Munsat and his student Jeremy Nuger

sent us a beautiful high resolution magnetic probe array and associated electronics. It turns out that the Colorado FRC is very similar to SSX (spheromak merging in a prolate FC, bigger than SSX). Their probe arrays have about 5 mm resolution (16 locations in x, y, z... 48 channels total wound on a Macor stalk) in a 10×10 mm rectangular quartz enclosure (100 mm long). The amplifiers use LMH6703 op amps with a 10 MHz bandwidth and a gain of 5 with all SMA connectors. We hope to do some collaborative studies with Tobin in 2009.

Simulations: Yu Lin and Xueyi Wang from Auburn, and Tim and I had dinner in Dallas to talk about more hybrid simulations perhaps with an Auburn student. Tim (as well as Ed, Mike S, and Chris) have been analyzing the output of Elena's 2D code with an eye towards representing data the same way we measure it (for example line-averaged and density-weighted flow measurements from IDS). Tim has been rendering data using a software package called VisIt. Check out George Marklin's eigenstates on my website for an example. The idea is that SSX data and simulation output could be rendered in the same visualization package. For now, the PSI-Center tools (NIMROD and PSI-TET) are VisIt compatible. By the way, hand-drawn boundaries are posted on my website if anyone wants to run a simulation in an SSX-relevant geometry.

Papers and manuscripts (2008): Vernon's electron heating paper was submitted in 2008 (working on referee replies now). Yu Lin's hybrid modeling paper appeared (Y. Lin, X. Y. Wang, M. R. Brown, M. J. Schaffer, and C. D. Cothran, "Modeling Swarthmore Spheromak Reconnection Experiment using a Hybrid Code", *Plasma Physics and Controlled Fusion*) and a JFE paper appeared (ICC conference proceedings) but our main effort is to continue to push on several long-standing projects. A lot has been happening just at the end of 2008. Discussions with PSI-Center folks, Elena (and Princeton student Clayton), and Yu Lin. I would say that we made headway on all of them (some are 3-5 years old). Hopefully we can submit them in 2009.

1. "Properties of the Doublet CT configuration", MB is taking the lead here (we did more work on this over winter break). We have a new simulation from Elena and some new analysis from Chris (Abel inversions of IDS data). We hope to have some nice renderings of Elena's data using VisIt for the paper.

2. "Self Organization from Co-helicity Merging in SSX" or "Non-axisymmetric relaxed state in a prolate flux conserver", (this one got jump started with George Marklin's nice eigenmode analysis of our co-helicity states). Elena is also re-doing a co-helicity simulation for us with the cusp at

the midplane (right-right merging with "south" poles meeting at the midplane). The goal here would be to use VisIt to render George's eigenmodes (done already), Elena's simulation, and our experimental data. Could be a pretty eye-popping paper!

3. "Simultaneous Bi-directional Plasma Jets from a Laboratory Magnetic Reconnection Volume", this is Chris' jets paper.

4. "Stable Spheromak Formation with Merging in an Oblate Flux Conserver", this is Tim's co-helicity paper.

Students: We were pleased with the contributions from our largest summer student cohort ever. Bevan Gerber-Siff '10 and Kevin Labe '11 worked as a team to construct two new moveable retarding grid energy analyzers (one radial and one azimuthal). These will be used to internally probe the reconnection region for energetic ions. Preliminary results indicate a small population of super-thermal ions but more work is needed (signal is very small). Bevan and Kevin also built a third generation of Mach probe also on a sliding fitting. Ed Dewey '10 worked with collaborators Elena Belova and Yu Lin to correlate simulation results with experimental data. Lake Bookman '08 worked on a searchable database that will include all of SSX data, presentations, papers, theses, etc from the past decade.

Plans for 2009: MB will be on leave beginning May 2009 (until Sept 2010!). This should be a productive time for me and Tim (like my last sabbatical worked out for me and Chris). We need to write our renewal in the spring of 2009 but the current plan is to re-visit the right circular cylinders as soon as we're done with the oblate geometry. For starters, we'll modify our old prolate flux conserver to make a simple $L = 0.4\ m, D = 0.4\ m$ aspect ratio 1 cylinder and later make a super-prolate $L = 0.8\ m, D = 0.18\ m$ aspect ratio 5 cylinder. On the basic science side, we'll be in a position to mix a cocktail of different gases and study the effects on flow and heating with the IDS instrument. It looks like a lot of simulation collaborations will be coming together in 2009 (Elena/Clayton, PSI-Center with Giovanni, George, Slava, also Yu Lin and the Auburn group). Finally, a possibility is to convert one of the SSX power supplies to positive center electrode so that we can drive current along the open flux down the center of SSX. This could be interesting in an oblate geometry to kind of tickle an axisymmetric spheromak or to drive a kinked up, non-axisymmetric helical Taylor state in a super-prolate geometry.

cheers and happy new year, mb