SSX Spheromak Merging Experiment
Michael Brown, Swarthmore, PI

Scientific Goals: We have three main goals at SSX. **First**, from a fusion energy science perspective, we have employed the magnetized plasma gun technique to form single spheromaks and merged pairs of spheromaks to study novel magnetic configurations. A single spheromak can be injected into a flux conserver and stabilized with a simple dipole field. Counter-helicity merging generates a novel configuration called the doublet CT. The doublet CT is an elongated FRC-like structure poloidally but maintains persistant toroidal fields at the ends. Most recently, we have been studying merging in an oblate flux conserver and we are planning to do experiments in more prolate geometries. **Second**, from a basic plasma physics perspective, we are interested in fundamental studies of magnetic reconnection. We have studied the 3D structure of reconnection using magnetic probe arrays (up to 600 individual measurements per shot). We have recently begun to study ion and electron heating due to reconnection using high resolution spectroscopy. During reconnection events, we have measured ion temperatures up to $T_i = 100\ eV$ and electron temperatures up to $T_e = 35\ eV$. Reconnection often generates bursts of flow with velocities up to $40\ km/s$. **Third**, SSX is an important introduction and training ground for undergraduate plasma research. The number of SSX-trained honors students has grown to 16, with each student pursuing active careers in plasma physics. SSX alumni Cameron Geddes, Amy Reighard, Slava Lukin, Tim Gray, and Tom Kornack have completed their plasma physics PhDs and are taking the next step in their plasma careers. An additional 16 students have worked in the SSX lab as assistants and are now pursuing careers in other disciplines.

Experimental Set-up: The SSX device at Swarthmore College features a $L = 1\ m$ long, high vacuum chamber in which we form $n \geq 10^{20}\ m^{-3}, T \geq 20\ eV, B = 0.1\ T$ spheromaks and FRCs. These objects are formed by the merger of either opposite helicity (counter) or equal helicity (co) spheromaks generated by coaxial plasma guns at either end of the machine. In all prior experiments in SSX, the merging has been performed in prolate flux conservers (eg $L = 0.6\ m, d = 0.4\ m$). Our new oblate flux conserver is slightly conical with $L = 0.4\ m, d = 0.5\ m$ and $6\ mm$ thick walls. We are planning experiments in extremely prolate flux conservers (eg $L = 1\ m, d = 0.2\ m$) in 2009.

We have studied the merging process and equilibrium of spheromaks and FRCs with a variety of magnetic probe arrays (our “bread-and-butter” diagnostic for over a decade now). We have found that quartz-jacketed probe arrays are less perturbative to these new, compact configurations. We have focused our diagnostic attention at the midplane but we have also done some experiments to study the axisymmetry of the spheromaks as they emerge from the guns. In addition, we continue to study the merged plasmas with our ion Doppler spectroscopy diagnostic, as well as a suite of electrostatic probes (Langmuir, Mach, and energetic ion).

Our ion Doppler spectrometer remains our most robust and unique diagnostic. No other 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. 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. Everything is in place for a productive sabbatical campaign (beginning summer 2009).

The SSX IDS instrument measures with 1 μs or better time resolution the width and doppler shift of the C_{III} impurity (H plasma) 229.7 nm line to determine the temperature and line-averaged flow velocity during spheromak merging events. Velocity resolution is about 5 km/s, corresponding to approximately $0.1 v_A$. The Czerny-Turner spectrometer has 1.33 m focal length, f/9.4, and uses a 316 $groove/mm$ Echelle grating blazed for a 63.5° angle. The C_{III} line is observed at 25th order where the spectrometer achieves a dispersion of 0.03 nm/mm. See Cothran, *RSI* **77**, 063504 (2006).

PSI Center contributions: There are several SSX related projects underway at the PSI-Center. **First**, George Marklin has generated a series of eigenmodes for the 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. These calculations will help us understand the complex structure of our magnetically relaxed structures. **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 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.