Magnetohydrodynamic Particle Acceleration Processes: SSX Experiments, Theory, and Astrophysical Applications

Michael R. Brown, PI (doc@swarthmore.edu)

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SCIENTIFIC/TECHNICAL REPORT

The purpose of the project was to provide theoretical and modeling support to the Swarthmore Spheromak Experiment (SSX). Accordingly, the theoretical effort was tightly integrated into the SSX experimental effort. During the grant period, Michael Brown and his experimental collaborators at Swarthmore, with assistance from W. Matthaeus as appropriate, made substantial progress in understanding the physics SSX plasmas. Highlights include:

1. Demonstration that the magnetic field configuration near the spheromak interaction zone forms dynamic X-points, with O-points (closed magnetic structures) sometimes in the center. This was further investigated using TRIM simulations of SSX.

2. Demonstration that flows at approximately the Alfv´en speed are generated in the plane orthogonal to the X-line.

3. Experimental determination that more energetic particle fluxes are seen in detectors along the X-line, and that these particles appear about an Alfv´en time after commencement of the thermal (Alfv´enic) flows.

4. Experimental study of the three dimensional structure of the reconnection zone, using a multiplexed array of tri-axial magnetic field probes.

5. An experimental study of the relative magnitude of several of the important terms in the generalized Ohm's law that describes various contributions to the electric field in the low collisionality SSX plasma.

6. Detection of a quadrupolar out-of-plane magnetic field relative to the quasi-planar magnetic Xpoint configuration that dynamically emerges in the reconnection zone between the interacting spheromaks. This is likely associated with the Hall term in the generalized Ohm's law, which is large, and even dominant, within an ion inertial scale of the X-line. Along with the near-simultaneous results from Princeton MRX, these are the first reported results of this type in a laboratory plasma.

Publications associated with the grant

Characterization of Magnetohydrodynamic Activity in the Swarthmore Spheromak Experiment, V. S. Lukin, G. Qin, W. H. Matthaeus, M. R. Brown, Phys. Plasmas 8, 1600 (2001).

Energetic particles and magnetohydrodynamic activity in the Swarthmore Spheromak Experiment, G. Qin, V. Lukin, M. R. Brown and W. H. Matthaeus, Phys. Plasmas, 8, 4816
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Observation of energetic ions accelerated by three dimensional reconnection, M. R. Brown, C. D. Cothran, M. Landreman, D. Schlossberg and W. H. Matthaeus, Astrophys. J. Letters 577, L63 (2002b)

Three dimensional structure of magnetic reconnection in a laboratory plasma, C. D. Cothran, M. Landreman, W. H. Matthaeus and M. R. Brown, Geophys. Res. Lett., 30 1213 (2003) doi:10.1029/2002GL016497,2003

Test particle acceleration in three-dimensional magnetohydrodynamic turbulence, P. Dmitruk, W H Matthaeus, N. Seenu and M R Brown, Astrophys. J. Lett 597, L81 (2003)

Generalized Ohm's law in a 3D reconnection experiment C. D. Cothran, M. Landreman, M. R. Brown and W. H. Matthaeus, Geophys. Res. Lett. 32 GL021245 (2005)

Fluid and Kinetic Structure of Magnetic Merging in the Swarthmore Spheromak Experiment, W. H. Mathaeus, C. D. Cothran, M. Landreman, M. R. Brown , Geophys. Res. Lett. 32 L23104 (2005)