High resolution ion doppler spectroscopy at SSX

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Abstract

The Swarthmore Spheromak Experiment (SSX) studies magnetic reconnection by co- and counter-helicity spheromak merging. We recently installed a new high-resolution ion doppler spectroscopy (IDS) system to enhance our ability to diagnose flows and ion temperatures. Our IDS system features a 1.33 m Czerny-Turner monochromator with a 316 grooves/mm echelle grating, and a 32 channel photomultiplier tube array. On any given shot, we can observe any of 10 chords through the plasma with submicrosecond time resolution and an instrument temperature ∼6 eV. We observed the dynamics of the C III 229.7 nm line at 25th order with dispersion 0.008 mm/nm during counter-helicity, co-helicity, and single spheromak shots. We have begun to perform Abel inversions to determine radial velocity and ion temperature profiles. During counter-helicity shots, we have observed near-Alfvènic bi-directional flows due to reconnection.

Summary

Plasmas are ionized, electrically conducting gases, which unlike neutral gases support magnetic and electric fields, making their behavior much more fascinating but difficult to understand. One basic process in plasmas that is not yet completely understood is magnetic reconnection. Magnetic reconnection occurs when two elements of plasma carrying oppositely directed magnetic fields merge. During magnetic reconnection, the magnetic fieldlines change their topology, the field is consumed, and the energy density of the field is converted to thermal energy and flow. Magnetic reconnection has been suggested as a mechanism in numerous astrophysical phenomena, including the heating of the solar corona and the aurora borealis. The Swarthmore Spheromak Experiment (SSX) permits the study of the reconnection process under controlled laboratory conditions. At SSX, we study reconnection by merging co- and counter-helicity spheromaks, which are toroidal plasma configurations with both toroidal and poloidal magnetic fields. Typical plasma parameters include electron density $n_e \sim 10^{15}$ cm^{-3}, temperature $T_i + T_e \sim 30$ eV, and magnetic fields $|B| \sim 0.1$ T.

One outstanding question about the reconnection process is where the energy stored in the magnetic field goes. Increased plasma temperatures and plasma flows are two of the release consequences. We constructed an ion doppler spectroscopy (IDS) system in order to better study these consequences of reconnection. The IDS system observes light emitted by impurity atoms in the plasma. The spectral lines of atoms in plasma moving towards or away from the line of sight are Doppler shifted, and nonzero ion temperatures result in Doppler broadening of the spectral line. The IDS system thus provides a measurement of these plasma properties integrated along the line of sight of the system.

In our IDS system, light from the plasma is collected through an aperture stop and a spherical lens. We can thus collect light from any of 10 well-defined chords through the plasma. The light then passes through an optical fiber to the spectrometer itself, which is a 1.33 m Czerny-Turner monochromator with a 316 grooves/mm echelle grating. After leaving the spectrometer, the light passes through two lenses which magnify the image approximately 4 times before reaching the detector, a 32-channel photomultiplier tube (PMT) array whose channels are 1 mm across. The PMT array has the important advantage of fast (submicrosecond) time resolution, but its coarse pixels require the use of high spectral order and magnifying exit optics. We primarily observed the C III 229.7 nm line at 25$^{\mathrm{th}}$ order, for which our dispersion after magnification was 0.008 nm/mm.

Our most significant result is the observation of transient, Alfvènic, bi-directional flows during counter-helicity merging. Other experiments that have studied reconnection using IDS have observed broadened spectral lines which were interpreted as high ion temperatures. These experiments, however, lacked our rapid time resolution and thus may have been unable to resolve the swiftly evolving double-peaked structure that we observed. We are also performing Abel inversions to determine radial flow and velocity profiles, particularly for single-spheromak shots.

At present, data analysis for the Abel inversion is ongoing. Future directions with the IDS include the observation of other spectral lines and the installation of magnetic probes to permit simultaneous measurements of flow and magnetic field structure. Furthermore, a glow discharge cleaning system, designed and under construction, will allow us to decrease the plasma density and study plasmas that are in an increasingly kinetic, collisionless regime.