Magnetic reconnection is a fundamental process in magnetized plasmas. Field lines of opposite polarity diffuse over a localized region, known as the diffusion region, where they break and reconnect. Magnetic reconnection thus changes global topology of the magnetic field. Reconnection is observed to occur naturally in laboratory plasmas and astrophysics. For example, sawtooth oscillations are a relaxation mechanism driven by magnetic reconnection in tokomak fusion reactors. Additionally, reconnection is believed to play a key role in solar flares, coronal mass ejections (CMEs) and in interactions between solar wind and Earth's magnetosphere. In all of these events, a defining characteristic of the reconnection event is the conversion of stored magnetic energy to particle energy. Indeed, it is observed that reconnection is nature's most efficient mechanism for the relaxation of magnetic energy. The Sweet-Parker model of reconnection predicts that half of the magnetic energy released during reconnection is converted to kinetic energy of the bulk, while the other half is deposited in particle thermal energy. The connection between energetic particles, particle heating and magnetic, reconnection has been well established[1] however the mechanisms responsible for this conversion are poorly understood, or understood only in certain simplified regimes.

For the relatively low Lundquist numbers achieved on MRX and other reconnection experiments, only collisionless and collisional single X-line regimes can be reached. These regimes offer insight into some reconnection dynamics and correlations, however they fail to fundamentally capture the geometry and dynamics of reconnection in realistic fusion or astrophysical plasmas. Research on the Magnetic Reconnection eXperiment[2] (MRX) at the Princeton Plasma Physics Laboratory has demonstrated the applicability of the Sweet-Parker model, with small modifications, in describing single X-line collisional reconnection. This model was insufficient for single X-line collisionless reconnection however. Yoo[2] (2013) explored the importance of two fluid effects on reconnection in this collisionless regime and found that on scales below the ion skin depth, electrons and ions have fundamentally different motion, which gives rise to an in-plane electric field. This in-plane "Hall" electric field ballistically accelerates ions to a fraction of the Alfvén speed and significant ion heating is observed in the downstream region of the reconnection layer. The heating of particles cannot be explained by classical heating mechanisms such as fluid viscosity and electron-ion collisions. As such, a re-magnetization effect is proposed to explain the downstream heating of ions that is observed. As ions move into regions of larger magnetic field strength they process in tighter gyro-orbits that lead to an increased effective viscosity that helps explain the anomalous heating.

While this research has been instrumental in the understanding of ion energization mechanisms in these limited regimes, there is much work to be done in understanding ion heating and acceleration in multiple X-line regimes. MRX and other reconnection experiments around the globe diagnose reconnection events that fundamentally differ from the reconnection events observed in fusion and astrophysical plasmas. To that end, the Facility for Laboratory Reconnection Experiments (FLARE) has been constructed to explore magnetic reconnection in the regimes in which magnetic reconnection occurs in fusion reactors and throughout the universe. FLARE is hoping to reach Lundquist numbers on the order of 10^5 , exceeding the theoretical threshold[3] for the plasma instability. In these realistic regimes, the geometry of reconnecting diffusion layers is fundamentally different from the geometry of diffusion layers studied on present day reconnection experiments.

At high Lundquist number and system size, reconnection is characterized by the presence of multiple null points, or "X-lines". This regime of reconnection necessarily leads to the formation of magnetic islands known as plasmoids. These plasmoids contribute to the energization of ions in a way that has yet to be explored in dedicated laboratory experiments. It is likely that particles trapped within these plasmoids will experience first order Fermi acceleration. Additionally, particles trapped between plasmoids may undergo a form of stochastic heating, or the plasmoids may provide a form of effective downstream viscosity as they are expelled from the diffusion layer. This research aims to characterize and explain the acceleration and heating of ions in these new, hyper-realistic multiple X-line geometries.

Experiments on MRX utilized a local Ion Dynamics Spectroscopy Probe (IDSP) to make local ion temperature measurements. Thousands of discharges, known as "shots", were used to reproduce a global ion temperature profile. On FLARE, this approach is unfeasible to the high operating costs. Additionally, the reproducibility of shots on FLARE is yet unknown and thus global ion temperature measurements are necessary to properly characterize ion heating and acceleration during multiple X-line reconnection. I propose the construction of a tomographic ion Doppler spectroscopy system to take global ion temperature measurements in FLARE. Assuming toroidal symmetry, line of sight measurements of the spectral radiance of the He II line (4.686E-7m) will be inverted to obtain the plasma emissivity. The full width at half maximum of the spectrum then provides the ion temperature. On FLARE, it will be necessary to remove the effects of radial flows, which may be of the same order as thermal broadening effects. Additionally, at the low electron temperatures expected on FLARE (<20eV) the plasma emissivity may vary by more than order of magnitude between lines of sight. These complexities significantly constrict the operation of this diagnostic. As such, phantom profiles have been developed to help determine the number of viewing chords necessary and the effectiveness of proposed data analysis. The spectroscopic system will consist of collection optics, a Holospec Spectromer, an ICCD camera and data analysis software that will be developed in the coming year.

Once this diagnostic is functional it will be used in tandem with induction coils, Langmuir probes, Mach probes, and the IDSP to characterize ion heating in multiple X-line geometry. The diagnosis of plasmoids and multiple X-line geometries are crucial to this experiment and will be verified by polodial flux contours obtained with the induction coils installed on FLARE. It will first be necessary to prove the existence of the desired multiple X-line regimes on FLARE. Once this has occurred, the proposed spectroscopic system will be calibrated using a neon discharge with similar spectral lines to the He II line of interest. It will then be used to collect global ion temperature measurements on each shot, using the IDSP to confirm the inversion process and to assist in the removal of radial flows in regions where the ideal MHD treatment fails. An extensive parameter scan in (S,λ) will be performed. Additionally dependence of ion heating on guide field strength will be explored.

References:

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