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MMS Multi-Point Analysis of FTEs: Stress Balance, Plasma Energization, and Instabilities

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Flux Transfer Events (FTEs) are the product of magnetic reconnection at the dayside magnetopause. They may play significant roles in determining the global rate of reconnection and accelerating particles. This study investigates the magnetohydrodynamic forces inside and outside FTEs to infer the process through which these structures become force-free using Magnetospheric Multiscale (MMS) measurements. Akhavan-Tafti et al. [2017] demonstrated that FTE size at the subsolar magnetopause follows an exponential distribution. The observed non-linear distribution appears consistent with the plasmoid instability theory in which coalescence plays a significant role in generating large-scale flux ropes (e.g., Daughton et al., 2009; Fermo et al., 2010; Huang & Bhattacharjee, 2010; Loureiro et al., 2007; Shibata & Tanuma, 2001; Uzdensky et al., 2010). FTEs are also shown to contain regions of elevated plasma density which greatly contribute to thermal pressure gradient forces inside FTEs. It is shown that as FTEs evolve, the plasma is evacuated as the core magnetic field strengthens and the structure becomes more magnetically force-free.

The neighboring ion-scale FTEs formed at the subsolar magnetopause due to multiple X-line reconnection are forced to interact, and likely coalesce. Entropy is invoked to motivate the discussion on the essential role of coalescence in reconfiguring magnetic fields and current density distributions inside FTEs facilitating their observed exponential growth. Magnetic pressure gradient and ion thermal pressure gradient are shown to be the dominant forces inside FTEs. Local electron kinematics are studied and used to compare the contributions of parallel electric field, Fermi acceleration, and betatron acceleration mechanisms to particle energization (e.g., Dahlin et al., 2014; Drake et al., 2006) Parallel acceleration mechanisms are shown to be dominant inside and, more significantly, in the outer perimeters of FTEs (i.e. 10 ion-inertial lengths from the outer boundary) in the vicinity of the reconnection site. On the other hand, betatron acceleration controls perpendicular heating inside the FTE in the presence of magnetic pressure gradients.

Downstream of the reconnection site, the ‘freshly' reconnected field lines start to straighten due to the magnetic curvature force. Straightening field lines accelerate trapped electrons parallel to the local magnetic field as they shorten themselves (i.e. first-order Fermi acceleration). These acceleration mechanisms are shown to explain the observed anisotropic pitch angle distributions in the core and then at the edges of FTEs. Finally, the anisotropic plasma temperature and plasma instabilities are shown to be correlated. In particular, fire-hose instability is shown most pronounced inside FTEs, causing magnetic reconnection and associated particle acceleration to shut down, while the anisotropic plasma moments indicate the presence of the mirror-mode instability in the outer perimeters of quasi-force free FTEs [Drake et al., 2010].