New discovery on shape of reconnection layer by MRX

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An important discovery for understanding collisionless reconnection is made in a dedicated laboratory plasma experiment at PPPL. A neutral current sheet, or reconnection layer, often manifests the essential physics of magnetic reconnection, in key phenomena for self-organization of magnetized plasmas. In the magnetic reconnection region, the interplay between magnetic fields and plasma particles takes place and the key physics of their interaction can be studied. Fig.1 a,b present two typical current sheet theoretical model patterns in which magnetic fields of opposite polarity approach a region where they merge and reconnect. In both 2D models, newly reconnected field lines emerge from the reconnection region and move away. The traditional Sweet-Parker model assumes resistive MHD description, but gives very slow predictions for the reconnection rates due to the narrow neutral sheet shown in Fig.1(a). Alternatively, Petschek introduced shocks which open up the neutral sheet to a wedge shape as shown in Fig.1 (b), leading to a much faster rate of reconnection by eliminating the slow flow of the Sweet-Parker model. While the Petschek reconnection rate is more consistent with the observed fast reconnection rate observed in space and has become popularly cited, it has not yet been theoretically rigorously established because it is not compatible with resistive MHD characteristics. On the other hand, the MHD framework breaks down in the neutral sheet when its thickness is comparable to the ion skin depth (c/ω_{pi}). Then ions become demagnetized while electrons stay magnetized, leading to various two-fluid effects including the so-called Hall effect due to separation in ion and electron motions. One of the theoretical predictions of the Hall effect is the presence of a quadrupole out-of-plane magnetic field.

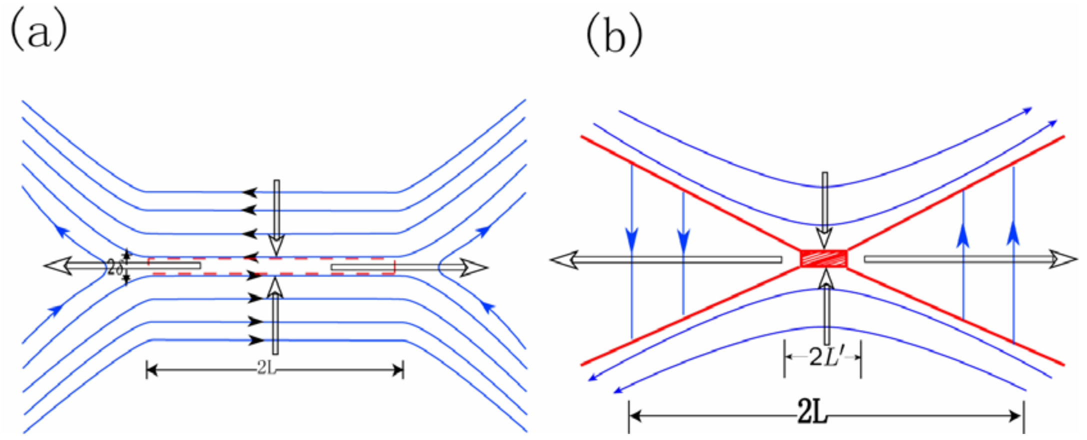

Fig.1 (a) Sweet-Parker Model; (b)Petschek Model

In Magnetic Reconnection Experiment (MRX), a well-controlled laboratory experiment at Princeton Plasma Physics Laboratory, these predicted two-fluid effects have been clearly observed during fast reconnection. Figure 2 shows how the profile of the MRX neutral sheet changes with respect to collisionality by comparing the neutral sheet configuration described by the measured magnetic field vectors and flux contours for high (collisional) and low density (nearly collsionless) cases. In the high plasma density case, shown in Fig. 2 (a), where the mean free path is much shorter than the sheet thickness, a rectangular shape neutral sheet profile of the Sweet-Parker model is seen, and the classical reconnection rate is measured. There is no recognizable out-of-plane Hall field in this case. In the case of low plasma density, shown in Fig. 2 (b), where the electron mean free path is longer than the sheet thickness, the Hall MHD effects become dominant as indicated by the out-of-plane field depicted by the color code. A double-wedge shape sheet profile of Petschek type, shown in Fig. 1 (b), appears deviating significantly from that of the Sweet-Parker model (Fig. 1(a)), and a fast reconnection rate is measured in this low collisionality regime. However, a slow shock, a signature of Petschek model, has not been identified even in this regime to date. **This important observation support a theoretical concept that the Hall effects originated from two-fluid dynamics contribute to the enhanced reconnection rate observed in the collisionless reconnection.**

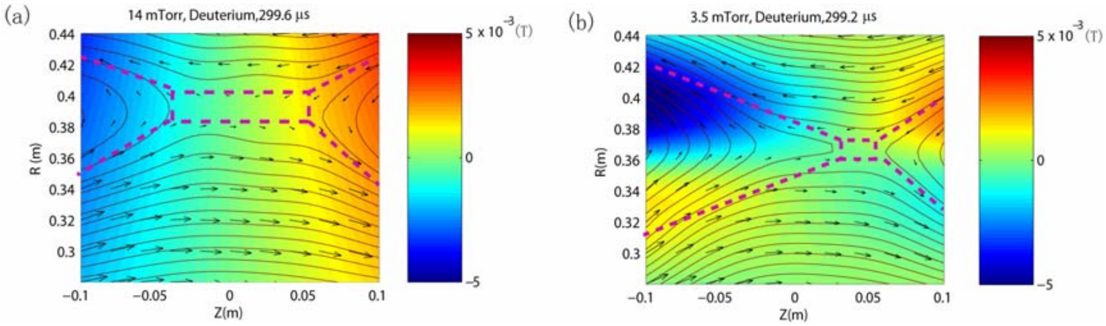

Fig.2*; Comparison of neutral sheet configuration described by measured magnetic field vectors and flux counters for high (collisional) and low density cases; (a) Collisional regime (*λ_{mfp} *~1mm <<* δ *)); (b) Nearly collisionless regime (*λ_{mfp} *~1cm ~*δ *). Out-of plane fields are depicted by the color codes ranged -50 G <Bt <50 G.*

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References:

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