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A generalized two-fluid picture of non-driven collisionless reconnection and its relation to whistler waves[1]

YOUNG DAE YOON, Caltech

A generalized, intuitive two-fluid picture of 2D non-driven collisionless magnetic reconnection is described using results from a full-3D numerical simulation. The relevant two-fluid equations simplify to the condition that the flux associated with canonical circulation $\mathbf{Q} = \mathbf{m_e}\nabla \times \mathbf{u_e} + \mathbf{q_e}\mathbf{B}$ is perfectly frozen into the electron fluid. $\mathbf{Q}$ is the curl of $\mathbf{P} = \mathbf{m_e}\mathbf{u_e} + \mathbf{q_e}\mathbf{A}$, which is the electron canonical momenrum. Since $\nabla \cdot \mathbf{u_e} = \mathbf{0}$ by assumption, the $\mathbf{Q}$ flux tubes are incompressible and so have a fixed volume. Because they are perfectly frozen into the electron fluid, the $\mathbf{Q}$ flux tubes cannot reconnect. Following the behavior of these $\mathbf{Q}$ flux tubes provides an intuitive insight into 2D collisionless reconnection of $\mathbf{B}$.

In the reconnection geometry, a small perturbation to the central electron current sheet effectively brings a localized segment of a $\mathbf{Q}$ flux tube towards the X-point. This flux tube segment is convected in the out-of-plane direction with the central electron current, effectively stretching the flux tube, decreasing its cross-section to maintain a fixed volume and so increasing the magnitude of $\mathbf{Q}$. Also, because $\mathbf{Q}$ is the sum of the electron vorticity and the magnetic field, the two terms may change in such a way that one term becomes smaller while the other becomes larger while preserving constant $\mathbf{Q}$ flux. This allows magnetic reconnection, which is a conversion of magnetic field into particle velocity, to occur without any dissipation mechanism. The entire process has positive feedback with no restoring mechanism and therefore is an instability. The $\mathbf{Q}$ motion provides an interpretation for other phenomena as well, such as spiked central electron current filaments. The simulated reconnection rate was found to agree with a previous analytical calculation having the same geometry.

Energy analysis shows that the magnetic energy is converted and propagated mainly in the form of the Poynting flux, while helicity analysis shows that the canonical helicity $\int \mathbf{P} \cdot \mathbf{Q} \mathbf{dV}$ as a whole must be considered when analyzing reconnection. A mechanism for whistler wave generation and propagation is also described, with comparisons to recent spacecraft observations

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