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Development of Electron Holes and Anomalous Resistivity in 3-D Magnetic Reconnection

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Magnetic reconnection with a guide field is explored with full particle simulations and theory to understand the development of turbulence and anomalous resistivity and its impact on the rate of reconnection and particle heating (1). Electrons around the magnetic x-line and separatrices are accelerated to high velocity by the reconnection electric field. The resulting magnetic-field-aligned electron beams are unstable to Buneman as well as current driven lower-hybrid waves. The Buneman instability evolves into distinct nonlinear structures consisting of localized regions of bipolar parallel electric field with net positive charge, "electron holes". The electron holes are localized both parallel and transverse to the magnetic field with scale lengths of 10's of Debye lengths. The holes couple strongly to a current driven lower-hybrid wave. The complex nonlinear interaction bewteen the electron holes and lower hybrid wave controls both the lifetime and the spatial distribution of electron holes parallel to the magnetic field. The interaction of the electron beam with the turbulence produces extended tails on the electron velocity distributions. The turbulence induced anomalous resistivity is spatially patchy and highly time dependent. Comparisons are made with recent observations of electron holes at the Earth's magnetopause. An important parallel between the problem of anomalous resistivity during magnetic reconnection and lower hybrid current drive is established. Implications for magnetic reconnection and particle energization in laboratory and astrophysical plasmas are discussed.

1. J. F. Drake, M. Swisdak, M. A. Shay, C. Cattell, B. Rogers and A. Zeiler, Science **299**, 873, 2003.