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Breaking field lines during magnetic reconnection: it's turbulent electron viscosity and not anomalous resistivity

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The dissipation mechanism that breaks magnetic field lines during reconnection has remained a mystery since the first models of reconnection were proposed in the 1950s. Classical resistivity is too small to explain reconnection observations in tokamak sawteeth, the solar corona and heliosphere. 3-D particle-in-cell simulations of magnetic reconnection reveal that strong currents and associated high electron-ion streaming velocities that develop near the x-line can drive instabilities. The electron scattering caused by this turbulence produces an enhanced drag, "anomalous resistivity," that has been widely invoked as the dissipation mechanism. We have demonstrated with simulations and analytic modeling that during low-β reconnection with a guide field that electron current layers become strongly turbulent. The surprise, however, is that the turbulence driven by an electron sheared-flow instability completely dominates traditional streaming instabilities and the associated turbulent driven anomalous viscosity balances the reconnection electric field and therefore breaks field lines. The turbulence modestly enhances the rate of reconnection. This instability was not seen in earlier simulations because of the limited scale size of earlier computational domains. The instability is electromagnetic, is part of the whistler branch and therefore falls below the electron cyclotron frequency. The ions play no significant role. A second surprise is that a guide field is required for the instability to exist so that reconnection with a guide field exhibits stronger turbulence that anti-parallel reconnection. Signatures of this turbulence that could be explored in laboratory reconnection experiments and satellite observations are discussed.