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Experimental observation of instability cascade from ideal MHD to kinetic scale culminating in magnetic reconnection[1]

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Magnetic reconnection underlies the critical dynamics of magnetically confined plasmas both in nature and in the lab. Reconnection necessarily involves processes outside ideal MHD, a model in which magnetic field lines are frozen into the plasma frame and so cannot reconnect even if energetically favorable. Finite resistivity, the most obvious non-ideal MHD mechanism that might enable reconnection, gives dynamics far too slow to explain observations. Consequently, contemporary models invoke microscale dynamics beyond the scope of MHD. However, these models do not in general explain how MHD couples to the required microscale, nor why magnetic reconnection is typically observed to be very sudden, i.e., impulsive. We present detailed experimental observations that identify a macro to microscale cascade of instabilities giving rise to impulsive reconnection. High-speed imaging of a magnetized plasma jet shows that about 20 μs after initiation the jet develops an ideal MHD kink instability; the initially straight jet becomes an exponentially growing helix. Images also show that one segment of this helix develops a localized, sharply defined, fast Rayleigh-Taylor (RT) instability with short axial wavelength. The observed RT growth rate agrees with the theoretically predicted RT growth rate calculated using the effective gravity produced by the measured kink-induced lateral acceleration. The fast-growing RT destroys the jet segment on which it resides in about 1-2 μs, thereby accomplishing an impulsive localized reconnection. The jet radius has shrunk to the ion skin depth scale (i.e., non-MHD scale) when the RT instability occurs. These observations clearly demonstrate an “instability of an instability” which achieves impulsive reconnection via a coupling of the ideal MHD scale to the ion skin depth scale.

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