In situ spacecraft observations of structured electron diffusion regions during magnetic reconnection

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Magnetic reconnection is a fundamental energy conversion process in plasmas. It occurs in thin current sheets, where a change in the magnetic field topology leads to rapid heating of plasma, plasma bulk acceleration and acceleration of plasma particles. To allow for magnetic field reconfiguration, both ions and electrons must be demagnetized. The ion and electron demagnetization take place in the ion and electron diffusion regions respectively, in both cases at kinetic scales. For the first time, Magnetospheric Multiscale (MMS) spacecraft observations, at inter-spacecraft separation comparable to the electron inertial length, allow for a multi-point analysis of the electron diffusion region (EDR). A key question is whether the EDR has a homogeneous or patchy structure.

Here we report MMS observations at the magnetopause providing evidence of inhomogeneous current densities and energy conversion over a few (~3 \(d_e\)) electron inertial lengths suggesting that the EDR can be structured at electron scales. In particular, the energy conversion is patchy and changing sign in the vicinity of the reconnection site implying that the EDR comprises regions where energy is transferred from the field to the plasma and regions with the opposite energy transition, which is unexpected during reconnection. The origin of the patchy energy conversion appears to be connected to the large \(v_{e,N} \sim v_{e,M}\) directed from the magnetosphere to magnetosheath. These observations are consistent with recent high-resolution and low-noise kinetic simulations of asymmetric reconnection. Patchy energy conversion is observed also in an EDR at the magnetotail, where the inter-spacecraft separation was ~1 \(d_e\). Electric field measurements are different among the spacecraft suggesting inhomogeneities at the electron scale. However, in this case the current density appear homogeneous in the EDR suggesting that
the structuring may be sourced from a different kind of electron dynamics in the magnetotail.

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