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Magnetic reconnection in turbulent space and astrophysical plasmas

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The energy accumulated in magnetized plasmas is released mainly via magnetic reconnection. Hot and dilute space and astrophysical plasmas usually are collisionless, i.e. their Knudsen number (the ratio of mean free path over the characteristic length scales) is typically much larger than unity. Hence, energy cannot efficiently be dissipated via binary particle-particle collisions and their usually huge corresponding magnetic Reynolds numbers $R_m = \mu_o L V / \eta$ indicate negligible current dissipation (μ_o denotes the vacuum magnetic permeability, L the characteristic length scale, V the characteristic flow velocity, η the resistivity). The conjecture is that micro-turbulence allows effective reconnection [1].
On the other hand, in the probing ground for collisionless turbulent magneto-plasmas recent CLUSTER- and MMS spacecraft observations have revealed that, e.g., in the strongly turbulent plasmas of the magnetosheath of the Earth's magnetosphere small-scale current sheets are formed, also in the solar wind and perhaps also in the interstellar medium (ISM) of large-Reynolds-number, weakly magnetized (plasma $\beta = 2 \mu_o n k_B T / B^2$ of the order of unity) plasmas.
Based on fluid approaches it has been conjectured in the past that reconnection in such turbulent plasmas might be highly efficient [2]. Those predictions where based on ideal MHD arguments, i.e. they omitted the question of energy dissipation missing the point of addressing the physical process of energy release.
Recently the mechanisms of dissipation in turbulent collisionless plasmas were investigated by kinetic [3-6] and hybrid code simulations. It appears that after initiating macroscopic, fluid-scale turbulence kinetic-scale current sheets (CSs) form (see Fig.1) In the absence of collisional dissipation and for vanishing (neglected) electron inertia these current sheets thin down to the scale of the numerical grid resolution. It could be shown that the thinning, small-scale CSs become the sites of energy dissipation [7]. With the CSs consequently thinning down the sheet currents primarily flow parallel to the external magnetic field (out of the plane shown in Fig. 1). The perpendicular electron flow velocity, though of the same order of magnitude as the perpendicular ion bulk flow velocity, varies faster through the CSs. The parallel electron vorticity consequently exceeds the parallel (external magnetic field-aligned) ion vorticity.
At the same time the variation of the plasma number density through the current sheets is negligibly small.
The primary source of free energy for instabilities of CSs sheets formed in collisionless plasma turbulence is, therefore, the electron flow shear both in the directions parallel and perpendicular to the external magnetic field. The (half-)thickness of the current sheets formed in the turbulent plasma decreases until the electron inertia comes into play. The immediate consequences of the electron-scale shear flow instabilities of the electron-scale CS for magnetic reconnection were investigated in the framework of the electron-MHD approximation.

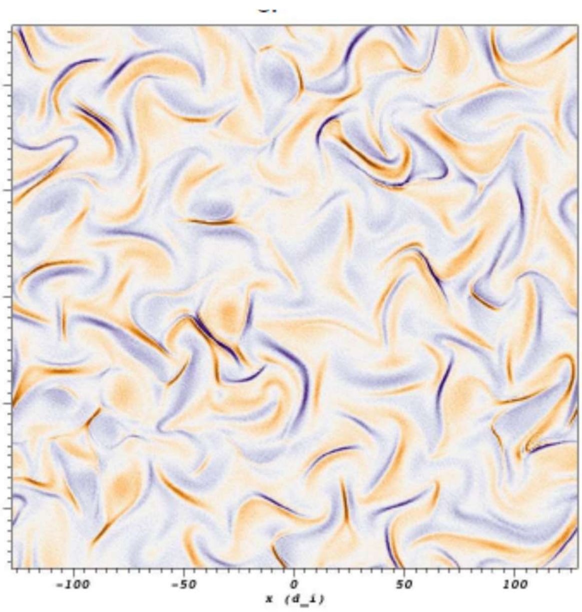

Fig. 1. Current densities illustrating the formation kinetic scale current sheets in collisionless turbulent plasmas [7].

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