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Current sheet formation and reconnection in collisionless turbulent plasmas

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Hot, collisionless plasmas are ubiquitous in astrophysical environments as well as in laboratory (fusion) devices. In the course of the turbulence evolution coherent structures are formed like current sheets (CSs) and plasmoids. Their formation influences the spectral properties of the turbulence and contribute to the dissipation of the turbulent energy, as it has been demonstrated theoretically[1], observationally[2] and numerically[3]. The evolution of these structures is, however, not well understood, yet, in particular the energy dissipation at electron scales.

Since all these processes are strongly nonlinear numerical simulations are the method of choice. In the last decade, mainly 2D hybrid-kinetic simulations concentrated on the turbulence cascade at sub-ion scales[1,3]. 2D fully kinetic turbulence simulations have complemented those findings by determining the statistics of reconnection rates in current sheets and distinguishing between "standard" reconnection events and the newly proposed electron-only reconnection events (without ion coupling)[4,5,6]. In particular it was shown that electron-scale reconnection events are more likely in low rather than high-β turbulence, although the reconnection rates were found to be in both regimes close to the standard normalized reconnection value 0.1.[5]

In 3D turbulence the characterization of current sheets and reconnection is much harder, so there has been less progress. A detection algorithm applied to hybrid-kinetic [7] and fully-kinetic 3D simulations revealed a number of physical signatures of the decaying CSs such as the presence of outflows and parallel electric field [8], in a similar way as detected by spacecrafts in space. [9]

Currently we obtained new results by using the fully kinetic code ACRONYM and the hybrid-kinetic code CHIEF. The latter allows a description of the electrons as an inertial fluid, different from standard hybrid approaches where the electrons are massless. [10,11]

A decaying turbulence is typicall initialized by randomly-phased Alfvén-waves at large, injection scales. In the course of the turbulence cascade CSs are formed which thin down until they dissipate, e.g. via magnetic reconnection, in plasmoids or structures at even smaller (electron-) scales. 2D hybrid kinetic simulations in the limit of massless electrons had shown that current sheet thinning is only limited by the grid resolution [12]. For inertial electrons, however, their inertia determines the limits of thinning and reconnection breakups which proofs the necessity of the consideration of the electron inertia in hybrid fluid-kinetic plasma models [13]

3D hybrid-kinetic turbulence simulations with consider inertial electrons have shown that the CS thinning is limited mainly by the electron inertia (see Fig. 1) [14]. and it was found that, unexpectedly, the electron inertia influences the spectra of the parallel-current fluctuations even well above the electron scales.

A comparison of the results obtained by fully kinetic and by finite-electron-mass hybrid simulations revealed that mainly the electron inertia limits the CS thinning and then almost completely balances the reconnection electric field either by the bulk electron inertia described by an acceleration term in the generalized two-fluid-Ohm's law, to a lesser degree on by the thermal-electron-inertia, described by a fully anisotropic pressure tensor. 2D fully kinetic investigations of the plasma β dependence showed that in finite-guide-field reconnection the CS properties depend lesser on the off-diagonal elements of the pressure tensor for larger β (=2.0, compared, e.g., to β=0.1) compared to the role played by the electron inertia for the reconnection process. Also, for finite β , the CS current densities stay smaller and the reconnection rates are reduced.[15]

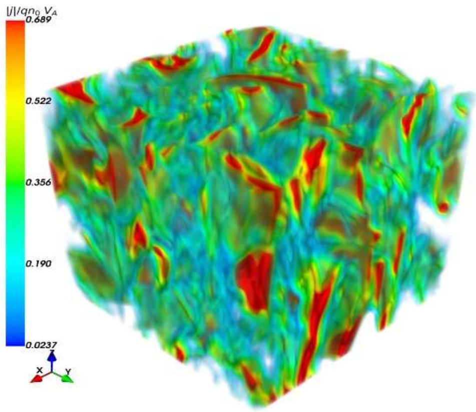

Fig. 1 Volume-rendered structures of the current density obtained by 3D hybrid code simulations with the code CHIEF (ions as particles and electrons as an inertial, i.e. finite-mass fluid). Box size: $(51{,}2\ d_i)^3$ [14]

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