Three-dimensional MHD and Hall-MHD spontaneous reconnection

Andrey Beresnyak

Naval Research Laboratory

ABSTRACT: Magnetic reconnection is a topological change in large-scale magnetic field structure, which is also associated with dissipation of magnetic energy. It is observed on the Sun where it causes particle acceleration and the bursts of X-rays known as solar flares. It is also suspected to be the source of high-energy particles in magnetically-dominated astrophysical environments, such as AGN jets and pulsars. The basic puzzle of reconnection is that it is observed to be "fast", with opposite polarity magnetic field flowing in with the speed, which is a sizable fraction of the Alfven speed, which also means a sizable dissipation of magnetic energy per unit time, per unit area. A common explanation, often found in the literature, is that reconnection rate is universally determined by microphysics, e.g. plasma properties. The number 0.1 (reconnection rate in units of Alfven speed) is often quoted as such a universal rate for electron-proton plasma. The problem is that this connection of large-scale properties (e.g. the speed of inflow into the current layer) with microphysics is at odds with the well-known and popular limit known as MHD. Indeed, the resistive reconnection in MHD was thought to be very slow (v_A/S^1/2). Recently this result has been updated by findings that large-scale current layer disrupt itself, creates turbulence and reconnects "quickly". This MHD reconnection rate is around 0.02, however, much smaller than plasma reconnection rate of 0.1. Should we conclude that MHD is inapplicable to current layers, i.e. inapplicable to most magnetized plasma environments and that we always need subgrid plasma models? I tried to resolve this by systematic parameter study of spontaneous reconnection in Hall-MHD limit. Hall-MHD is a minimal description of electron-proton plasma that also manifested reconnection rate around 0.1. The issue with previous plasma and Hall-MHD numerical studies, we think, was that the size of the layer was always fixed relative to the plasma ion skin depth d_i. My study includes scaling of reconnection rate with respect to changing size of the layer. By looking at this scaling we may find out what happens in the limit of very large scales. Is it MHD or something else? Going to large box size in terms of d_i is numerically challenging because Hall-MHD contains fast electron dynamics which limits the timestep. We pushed the limits of what is currently possible in three-dimensional numerics, performing simulations as large as 2304x4608^2 and making of order of a million timesteps. This peta-scale numerics is possible with our pseudospectral code 1CARU5 on IBM BG/Q platform. Aside from evolving Hall-MHD the code also calculates evolution of two passive scalars advected by ion and electron fluids, which shows how mixing in the layer is different for electrons and ions. I will show preliminary

results of the calculations. Of particular interest to me is whether turbulence locality will hold in Hall-MHD case so that the large-scale dynamics could be disconnected from microphysics, and so the use of MHD limit will be justified. If not, we live in a plasma Universe which is much more complex that we previously thought.