Triggering of explosive reconnection in a thick current sheet by temperature anisotropy boosted tearing mode

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論文の内容の要旨

Triggering of explosive reconnection in a thick current sheet by temperature anisotropy boosted tearing mode

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It has been widely believed that collisionless magnetic reconnection is triggered when a current sheet thickness thins and becomes comparable to the ion inertial scale. Here we challenge this argument by performing two-dimensional kinetic simulations of magnetic reconnection triggering in anti-parallel current sheets. In the simulations, the current sheet subject to reconnection is filled with plasmas having temperature anisotropy ($T_\perp/T_\parallel = 2$, where $T_\perp$ and $T_\parallel$ are temperatures perpendicular and parallel to the local magnetic field, respectively,) and its thickness ($D = L/\lambda_i$, where L is the half-thickness of the current sheet and λ_i is the ion inertial length,) is larger than unity. Previous studies showed that the growth rate of the tearing mode enhanced by the anisotropy and the current sheet with $D = 1$, in which the ordinary tearing mode is not effective in triggering vigorous reconnection, is destabilized by the temperature anisotropy boosted tearing mode.

What we newly show here is that the temperature anisotropy boosted tearing mode seeds explosive magnetic reconnection even in thicker initial current sheets more than an order of magnitude of the ion scale. The highlighted results are: (1) the ion-to-electron mass ratio is not an issue in this study allowing us to explore the unprecedented large-D case mentioned above, and (2) the maximum reconnection rate is independent of the initial sheet thickness and peaks at ~ 0.2 (in the widely used normalized unit). We also discuss not only the physical process through which but also the border of the parameter space in which the nonlinear tearing mode evolves into explosive magnetic reconnection and show that the anisotropic ion tearing mode plays an important role for the triggering of explosive magnetic reconnection.

In addition to the explosive reconnection triggering via the tearing mode boosted by the initially prepared temperature anisotropy, we also show the explosive reconnection triggering via the mode boosted by the spontaneously generated temperature anisotropy by compression of thick current sheets. A one-dimensional pre-study shows that the compression is more effective to make the plasma anisotropy than to thin the current sheet thickness. When the lobe magnetic field is amplified by a factor of 2, the plasma temperature anisotropy inside the current sheet reaches 2 but the current sheet thickness is reduced only by $1/\sqrt{2}$ because of the decrease in the ion inertial scale. If a current sheet thickness needs to be comparable to the ion inertial scale for reconnection triggering, the initial thickness cannot be more than a few ion scale for reconnection to set-in. On the other hand, the temperature anisotropy of 2 is effective for the triggering in thicker sheets. Two-dimensional compression shows that the explosive magnetic reconnection takes place even in the large-D case. The maximum reconnection rate reaches 0.2 (in a proper normalization), which is comparable to the incomressive cases.

The explosive reconnection triggering is frequently discussed with the mode coupling effects between the ordinary tearing instability and other current driven instabilities having unstable wave lengths are out of the reconnection plane. The lower hybrid drift instability (LHDI), which is enhanced by inhomogeneity of the plasma pressure at the edges of a current sheet, shows the most effective coupling with the tearing instability because of its nonlinear thinning effect of the current sheet thickness and its plasma heating perpendicular to the magnetic field at the current sheet center. We perform the two-dimensional simulations of the thick current sheet compression in the orthogonal plane to the reconnection plane, in which reconnection and the tearing mode are excluded but the LHDI is included. The results are as follows: (1) the compression makes the gradient of the plasma density steeper, which helps the LHDI to grow up to a significant amplitude in the sheet even with initially $D = 4$, and (2) in the sheet thicker than an order of magnitude of the ion scale, however, the compression is too weak to modify the profile of the current sheet to enhance the LHDI enough.

From the systematic series of simulations mentioned above, we conclude that the temperature anisotropy boosted tearing mode is effective to trigger magnetic reconnection having the explosive nature even in the current sheet thicker than one order of magnitude of the ion scale without any support of LHDI.