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Nonlinear Explosive Magnetic Reconnection for a Thick Current Sheet

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Magnetic reconnection has received great attention in various plasma environments of the Earth's magnetosphere, laboratory plasmas, and astrophysical objects such as pulsar magnetospheres and magnetars [1, 2, 3, 4]. It is known that the magnetic energy stored in a plasma sheet with an anti-parallel magnetic field component can be efficiently converted into not only the bulk flow energy but also the energies of plasma heating and nonthermal particle acceleration by reconnection. However, our understanding of the onset of fast reconnection remains an important and debated topic. In the last couple of decades, based on satellite observations and computer simulation studies, our understanding of reconnection dynamics has gradually accumulated for a "thin" plasma sheet with a thickness of the order of the ion gyro-radius, and it is argued that fast energy dissipation can occur for such a thin plasma sheet. However, the mechanism of fast energy dissipation of reconnection for a "thick" plasma sheet is still a controversial issue, and has remained an intriguing enigma for more than half a century. In this presentation, we focus on the interplay between nonlinear explosive reconnection and collisionless inertia resistivity in magnetic diffusion region in the course of reconnection.

According to the linear theory of collisionless tearing modes, the growth rate $\gamma_l \tau_{\mathrm{A}}$ normalized by the Alfvén transit time of a plasma sheet is known to be proportional to $(r_{\mathrm{g}}/\lambda)^{3/2}$, where r_{g} and λ are the gyro-radius of the thermal particle and the thickness of the current sheet, respectively. The linear theory suggests that the energy dissipation for a thick plasma sheet with $r_{\mathrm{g}} \ll \lambda$ is extremely slow. To overcome the difficulty of the fast energy dissipation for a thick plasma sheet in a collisionless plasma, [5] proposed the explosive reconnection mechanism by focusing on the time evolution of the collisionless inertia resistivity in association with the growth of the reconnecting magnetic field. They considered the enhancement of the inertia resistivity due to the magnetized particles by the reconnecting magnetic field around the X-type neutral line, and estimated that the nonlinear growth rate $\gamma_{\mathrm{G}} \tau_A$ was of the order of $(r_{\mathrm{g}}/\lambda)^{1/2} b_1$, where $b_1 = B_1/B_0$ is the ratio of the reconnection magnetic field B_1 to the magnetic field B_0 outside of the plasma sheet. This nonlinear reconnection suggests not only much faster energy dissipation than in the linear stage, but also an explosive nature of growth, namely, $b_1(t) = b_1(t_0)/(1-(t-t_0)\gamma_l)$, where t_0 is the start time of the nonlinear reconnection. The nonlinear explosive growth, however, still depends on the initial plasma thickness of r_{g}/λ, and the time scale is of the order of γ_l^{-1}. Therefore, the fast reconnection issue for a thick current sheet remains unresolved.

In this presentation, based on high-resolution two-dimensional PIC simulation, we propose a new mechanism of nonlinear reconnection in which the energy dissipation can occur in the time scale of the Alfvén transit time, namely, our proposal gives the growth rate $\gamma_{\mathrm{nl}} \tau_A \sim (r_{\mathrm{g}}/\lambda)^0 b_1$ and the amplitude $b_1(t) \simeq b_1(0)/(1-(t-t_0)/\tau_{\mathrm{A}})$ in the early nonlinear phase. The crucial factor of our mechanism is the enhancement of the inertia resistivity due to the effects of both thinning of the current sheet and the reconnecting magnetic field during reconnection. As the key process, we show that the current sheet shrinks quickly to a thickness of the gyro-radius. The theoretical model to explain the nonlinear explosive reconnection is also discussed.

References

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