Magnetic Island Merging: Two-dimensional MHD Simulation and Test-Particle Modeling

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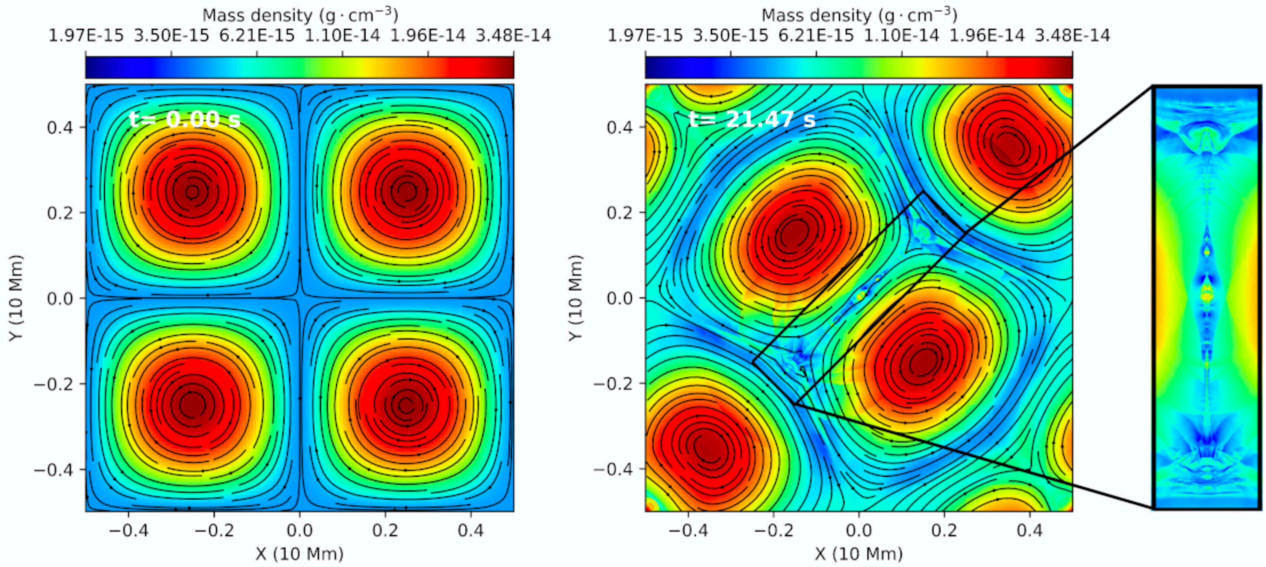

Figure 1 Density distribution with magnetic field lines (black arrows) overlaid.

We investigate particle acceleration process during magnetic reconnection when magnetic islands merge using a combined magnetohydrodynamic (MHD) and test-particle method in a parallel adaptive mesh refinement (AMR) framework that is incorporated in MPI-AMRVAC code [1]. The MHD simulation starts with two pairs of force-free magnetic islands in a two-dimensional periodic box with an "X"-point located in the midst of the four islands, as shown in the left panel of Figure 1. A perturbation to the velocity field is given to the system, which drives one pair of islands move towards each other while the other pair of islands are pushed away from one another. The "X"-point is locally unstable to the perturbation and collapses, producing a current sheet in-between with enhanced current and mass density as illustrated in the right panel of Figure 1. Five cases are run with different global Lundquist numbers ranging from 4.5×10^3 to 10^7. In all five cases, the newly formed current sheets experience the Sweet-Parker reconnection stage. We demonstrate that the primary Sweet-Parker sheet is fragmented into multiple plasmoids if the Lundquist number of the current sheet is greater than a critical value 6×10^5, which is larger than previously predicted value by other researchers of about 10^4 [2]. An effective spatial resolution of 600 m in both directions is achieved by the AMR technique, which is in-between the electron mean free path of about 100 km and the ion Larmor radius of about 1m. Various waves and shocks are excited in front of magnetic islands when the magnetic islands move in the current sheet. These waves propagate outside the current sheet and across whole simulation domain. The current sheet thus plays a role of wave generator. These waves may lead to secondary effects in the plasma, like heating and particle acceleration. We notice that the magnetic islands usually present complex internal structures. Termination shocks are identified in the region where the reconnection outflow hits the island. Turbulent and chaotic flow patterns are also observed inside the islands. For test-particle simulations, we run the particle in a fixed MHD snapshot at a specific instant of time as well as along a time-evolutionary MHD simulation. Particles are revealed to be reflected back and forth between shocks in the current sheet and gain energy. Turbulent flow patterns inside the current sheet is also an efficient particle accelerator. The conservation of adiabatic invariants of particle motion is inspected. The particle spectral evolution is investigated, too.

References

[1] "MPI-AMRVAC 2.0 for solar and astrophysical applications", C. Xia, J. Teunissen, I. El Mellah, E. Chane & R. Keppens, 2018, ApJ Suppl. **234**, 30 (26 pp) doi:10.3847/1538-4365/aaa6c8

[2] "Scaling laws of resistive magnetohydrodynamic reconnection in the high-Lundquist-number, plasmoid-unstable regime", Y.-M. Huang, A. Bhattacharjee, 2010, Phys. Plasmas. **17**, Issue 6, pp. 062104-062104-8 doi:10.1063/1.3420208