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Kelvin-Helmholtz Vortices and Secondary Instabilities in Super-Magnetosonic Regimes

In this project we have built a two-fluids, 3D numerical code, parallelized with MPI, for the study of the non linear dynamics of a magnetized, collisionless plasma. The boundary conditions are periodic along the y and z directions and open along x where we extended the transparent boundary condition scheme previously developed in 2D (1). The code advances in time using the third order accurate Adam-Bashforth algorithm. It uses Fast Fourier Transform routines for spatial derivative along the periodic directions and sixth order Compact Finite Difference Scheme with Spectral like resolution for spatial derivative along the inhomogeneous x-direction. Numerical stability is achieved by means of filters, a spectral filter along the periodic y and z-directions and a sixth order spectral like filtering scheme along the inhomogeneous x-direction. A more performant version of the same code, in particular concerning the scaling on parallel machines, has been recently made using sixth order explicit finite differences schemes along all directions to limit the communications to nearby processors (local stencil). The code has been used to investigate the problem of the interaction of the solar wind with the magnetosphere at low latitude. The main application is the development of large-scale Kelvin-Helmholtz vortices and the consequent non linear dynamics, including 3D magnetic reconnection events already observed in the 2D limit (2). The results obtained in 3D are very preliminary and these investigations will be continued in a recently approved ISCRA A project. In the following, instead, we will summarize 2D results obtained during this project running on the SP6 IBM Machine at Cineca.

We have performed large-scale numerical simulations in order to study the non-linear magnetized dynamics of a plasma in the presence of a shear flow driving the development of KH instability. This instability eventually leads to the formation of a "large scale" vortex chain. Many physical processes are then at play and naturally generate small-scale structures leading to a multi-scale system where the coupling between large and small scales is self-consistent. Depending on which process dominates, the system evolves differently, from the formation of a mixing layer, to classical hydrodynamics vortex pairing, to the formation of magnetic islands, shock structures, etc. Our simulations model the interaction of the solar wind flow with the Magnetosphere at low latitude. The 2D results presented here concern the problem of the transition to super-magnetosonic regimes where shock structures are generated by the K-H vortices and play a very important role on the mixing of the two plasmas. Indeed, variations of the large-scale fields connecting the upstream and downstream regions strongly influence possible onset of secondary instabilities. Shock structures could also have an impact on the acceleration of ion populations. In Figure 1, left frame, by means of passive tracers, we give an example of the formation of the K-H vortex chain, the advection of the magnetic field line by the flow and the onset of secondary instabilities. The solar wind and magnetospheric plasmas are represented by yellow and blue color, respectively, while the
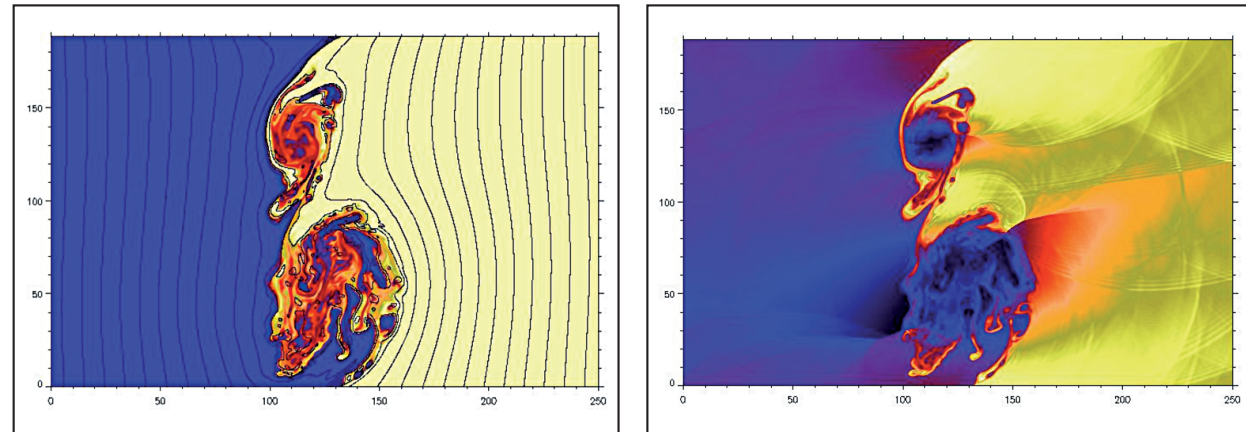

Fig. 1. – Left frame: passive tracers representing the solar wind and the magnetosheric plasmas, yellow and blue color, respectively, at $t = 460$. Black lines represent the magnetic in-plane field lines. Right frame: the plasma density at the same time instant.

black lines represent the magnetic field. In the right frame, by showing the plasma density at the same time instant, we observe the presence of several shock structures.

The results of the study of the transition to the super-magnetosonic regime have been published in Refs. (3) and (4) and presented in many International Conferences as invited paper or posters.

Bibliography

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