Numerical study of 3D MagnetoHydroDynamics : nonlinear Alfven waves and recurrences

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Understanding plasma turbulence is key to control the disruption of plasma in experimental devices consequently improving the confinement of plasma. Predicting extreme events occuring in astrophysical objects and stellar matter are of fundamental interest. Also one of the best suited models to explain various large or intermediate scale events in plasma is magnetohydrodynamics (MHD). The magnetic field lines coupled with the plasma flow offer completely new dynamics and energy transfer between modes.

A MPI-parallel three dimensional pseudo-spectral "direct numerical simulation" (DNS) code has been developed in-house that governs the dynamics of plasma within the framework of single fluid MHD model. In collaboration with NVIDIA, the code has been GPU parallelised for NVLink based GPU-nodes. [Rupak Mukherjee *et. al.* Proceedings of 25th International Conference on High Performance Computing Workshops (HiPCW), 2018; arXiv:1810.12707]

In the presence of weak resistivity, the MHD model is known to predict irreversible conversion of magnetic energy into fluid kinetic energy (i.e. reconnection) as well as conversion of kinetic energy into mean large scale magnetic field (i.e. dynamo). Therefore it is interesting to ask oneself, for a given fluid type and magnetic field strength, are there fluid flow profiles which do neither - that is, neither does the flow generate mean magnetic field nor the magnetic field energy is converted to flow energy; instead there are nearly reversible coherent nonlinear oscillations. From our DNS results we have shown that both in two and three dimensions, non-dispersive nonlinear oscillation persists for a wide range of initial flow speeds or Alfven Mach number. The frequency of such oscillation could be mapped with Alfven frequency of the system. A finite mode Galerkin representation of the two dimensional MHD equations in analytically carried out to verify the possibility of such energy exchange phenomena and we found good agreement between our analytical and DNS results. [Rupak Mukherjee, R Ganesh, Abhijit Sen; arXiv:1811.00744]

For three dimensional chaotic flows at Alfven resonance, we find that for two different initial conditions, one flow reconstructs the initial fluid and magnetic flow profile and the other does not. We call the phenomena as "Recurrence" and argue the explanation of the event checking boundedness of Rayleigh quotient measuring the effective number of active degrees of freedom in a high dimensional system. [Rupak Mukherjee, R Ganesh, Abhijit Sen; Physics of Plasmas 26, 022101 (2019); arXiv:1811.00754]

Both the above observations show energy cascading between kinetic as well as magnetic field variables and thus are expected to have fundamental relevance in controlling the plasma disruptions in terrestrial plasma devices where the confinement is achieved through magnetic fields.