**Introduction**

Turbulence in magnetized plasmas is an inherently multiscale process which transfers energy from the large to the small scales. The energy spectrum is a power law in the inertial range, at low wavenumbers; at kinetic scales (high wavenumbers) the spectrum steepens and the process becomes dissipative.

In the solar wind, a “turbulence laboratory” (1), breaks in the turbulent spectra are observed at both the ion (2) and the electron (3) scales; they are supposed to be due to particle interaction with Alfven waves (4), to proton cyclotron damping (5), to electron or ion Landau damping (6).

Particle In Cell (PIC) simulations are a precious tool in understanding energy dissipation at kinetic scales. However, the cost of the simulations soon becomes prohibitive because both large fluid scales (where the turbulent cascade is initiated) and kinetic ion and electron scales (where dissipation kicks in) need to be resolved.

We propose to reduce these costs by using the recently developed semi-implicit adaptive PIC Multi Level Multi Domain (MLMD) method, already successfully tested with simulations of kinetic instabilities and magnetic reconnection (7).

The MLMD method is a semi-implicit and adaptive method for PIC simulations of plasmas. Computational resources are saved by simulating the domain at different levels with different spatial and temporal resolution between the levels.

A MLMD simulation with realistic mass ratio between the species and a refinement jump (RF) of 14 between the levels is 70 times faster than a “traditional” single level one (see (7)).

Turbulence originated by the Lower Hybrid Drift Instability - LHDI (8) is simulated with the MLMD method and a realistic mass ratio between the species. With the MLMD method, we can simulate the large (tens of electron skin depths) domain needed for the evolution of the instability with the local high resolution (tenths of electron skin depths) required to observe the break of the inertial range at a moderate computing cost.

**Conclusions**

The Multi Level Multi Domain method is used to simulate turbulence originated by the LHDI.

We verified that the end of the inertial range is due to ion interaction with LH waves.

The MLMD method proves effective in simulating kinetic turbulence: the slope of the inertial range is seamlessly continued in the refined grid, which registers the beginning of the dissipative regime.

Increasing the $k$ resolution of a factor $n$ multiplies the cost of a standard simulation by $n^3$; the cost is only doubled for a MLMD simulation.

References


**MLMD simulations of turbulence of LHDI origin**

In MLMD simulations of turbulence of LHDI origin with different Refinement Factors RFs (jumps in spatial resolution) between the grids:

- the cascade initiated on the coarse grid continues on the refined grid with the same slope — the grid interlocking is excellent, the combined data set can be used for the calculation of the slope

- in the $k$ range of validity of the refined grid only (the CG values are affected by smoothing), a change in slope is observed (red vertical line)

- the wavenumber of the slope change, $k_d=30$, is in the “relaxation” RG range and is the same notwithstanding the different RF — it’s a physical process, not an artifact of the method

Using the resonance criterium from (6), $C=R^2\Omega_i/c_i$, LH frequencies, $c$ the thermal velocity of ions and $k_d=30$, the end of the slope in the inertial range appears to be due to ion interaction with LH waves.

**On the use of smoothing in turbulent simulations**

Smoothing (9) is often used in PIC simulations to curb numerical noise and suppress numerical instabilities.

Using smoothing introduces an artificial knee in the energy spectrum which may be mistaken, in turbulent simulations, for the beginning of the dissipative range.

We empirically established that the $k$ parameter of the spectrum, with $k_{min}=(/d)x$, is affected by smoothing and cannot be deemed reliable.

This finding increases even more the necessity of a method to reduce the cost of PIC simulations.

**References**