Spectral methods for multi-scale plasma physics simulations

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ABSTRACT

The Vlasov-Maxwell (VM) equations are extremely challenging numerically because of their high dimensionality, nonlinearities and the wide disparity of spatial and temporal scales.

In this work, we present a spectral method for the VM equations based on a decomposition of the plasma phase-space density in Hermite or Legendre modes. It leads to a truncated system for the expansion coefficients (i.e. moments). Its most important feature is that, with a suitable spectral basis, the low-order moments are akin to the typical moments (mass, momentum, energy) of a fluid/macroscopic description of the plasma, while the kinetic/microscopic physics can be retained by adding more moments. In addition, spectral convergence, stability and exact conservation laws in the limit of finite time step can be proven [1].

Selected results illustrating the properties and the potential of the method will be presented. A comparison between PIC and the spectral method on standard electrostatic test problems shows that the spectral method can be orders of magnitude faster/more accurate than PIC [2]. Some attempts to optimize the spectral decomposition in velocity space [3] and multi-dimensional fully electromagnetic tests with efficient preconditioning techniques [1, 4] will also be presented.

With the 'built-in' fluid/kinetic coupling and favorable numerical properties, spectral methods might offer an optimal way to perform accurate large-scale simulations including microscopic physics.

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