A framework for microscopic/macroscopic simulations of magnetized plasmas

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The Vlasov-Maxwell (VM) equations are central to many problems in space physics. However, these equations are extremely hard to solve numerically because of their high dimensionality, nonlinearities, and the huge disparity between microscopic and system spatiotemporal scales. While several reduced methods have been developed in certain limits, a comprehensive approach capable of obtaining accurate solutions in all parameters regimes remains elusive. From an application standpoint, this is a longstanding challenge for space weather research, which has so far prevented the development of an operational space-weather global model that includes microscopic physics.

In this talk, we will present a spectral method for the VM equations based on a decomposition of the plasma phase-space density in Hermite or Legendre modes (G.L. Delzanno, J. Comp. Phys., 301, 338-356, 2015; J. Vencels, G.L. Delzanno, et al., J. Physics, 719, 012022, 2016). Its most important aspect 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. The method features favorable numerical properties (such as spectral convergence and exact conservation laws in the limit of finite time step) and a comparison against the Particle-In-Cell (PIC) on standard electrostatic test problems shows that it can be orders of magnitude faster/more accurate than PIC. With the 'built-in' fluid/kinetic coupling, spectral methods might offer an optimal way to perform accurate simulations of macroscopic phenomena including microscopic physics. Some applications relevant to space physics, such as wave generation from electron beams in magnetized plasmas or simulations of solar wind turbulence, will be presented to illustrate the properties of the method.