Multi-Scale PIC Modeling of High Energy Density Scenarios: from Laboratory to Astrophysics

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Laser-plasma interactions at ultrahigh intensities can lead to a wide range of nonlinear phenomena of interest for many applications such as plasma-based accelerators, laser fusion, or laboratory astrophysics. The numerical simulation of these extreme physical phenomena in multiple dimensions with the inclusion of kinetic effects can pose outstanding challenges due to the different spatial and temporal scales involved. The self-consistent coupling of the different scales has been a long-standing problem.

Following the work on a optimized hybrid algorithm for modeling inhomogeneous plasmas by B. Cohen et al. [J. Comp. Phys. 229, 4591 (2010)], an hybrid algorithm was implemented in OSIRIS 2.0 [F. Fiuza et al., PPCF 53, 074004 (2011)], allowing for the self-consistent modeling of different physical regimes at different scales, and leading to a dramatic change in the computational resources required to model these high energy density scenarios.

The possibility of performing for the first time multi-dimensional full-scale integrated simulations of many of these scenarios will be demonstrated. We will focus on the modeling of fast ignition of fusion targets. Realistic compressed target profiles obtained from hydrodynamic simulations were used to study key questions such as the multipicosecond evolution of laser absorption and beam divergence, the fast electron transport, and its energy deposition in a fully self-consistent manner with the new hybrid-PIC algorithm. Control of electron divergence, capable of providing laser to core energy efficiencies consistent with ignition conditions, will be shown either by changing the laser profile or by using external collimating structures. We will also discuss the application of this hybrid-PIC algorithm to other high energy density systems, in particular to ion acceleration in laser-solid interactions and to shock formation and propagation in the transition between collisional/collisionless media in astrophysical/laboratory relevant conditions.

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