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Studying astrophysical particle acceleration with laser-driven plasmas[1]

FREDERICO FIUZA, SLAC National Accelerator Laboratory

The acceleration of non-thermal particles in plasmas is critical for our understanding of explosive astrophysical phenomena, from solar flares to gamma ray bursts. Particle acceleration is thought to be mediated by collisionless shocks and magnetic reconnection. The microphysics underlying these processes and their ability to efficiently convert flow and magnetic energy into non-thermal particles, however, is not yet fully understood. By performing for the first time ab initio 3D particle-in-cell simulations of the interaction of both magnetized and unmagnetized laser-driven plasmas, it is now possible to identify the optimal parameters for the study of particle acceleration in the laboratory relevant to astrophysical scenarios. It is predicted for the Omega and NIF laser conditions that significant non-thermal acceleration can occur during magnetic reconnection of laser-driven magnetized plasmas. Electrons are accelerated by the electric field near the X-points and trapped in contracting magnetic islands. This leads to a power-law tail extending to nearly a hundred times the thermal energy of the plasma and that contains a large fraction of the magnetic energy. The study of unmagnetized interpenetrating plasmas also reveals the possibility of forming collisionless shocks mediated by the Weibel instability on NIF. Under such conditions, both electrons and ions can be energized by scattering out of the Weibel-mediated turbulence. This also leads to power-law spectra that can be detected experimentally. The resulting experimental requirements to probe the microphysics of plasma particle acceleration will be discussed, paving the way for the first experiments of these important processes in the laboratory. As a result of these simulations and theoretical analysis, there are new experiments being planned on the Omega, NIF, and LCLS laser facilities to test these theoretical predictions.

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