Particle energization in laser-driven magnetized shocks and associated instabilities

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The origin of the high-energy non-thermal particles flying through the Universe is still an open question. Well-known sources are collisionless shock waves and their associated instabilities. By interacting with the ambient medium, these shocks, the collisions between them, together with the turbulence induced from the associated instabilities, can transfer their bulk kinetic energy to non-thermal particles through electromagnetic fields. Here we show that super-critical magnetized collisionless shocks, the collision between them, as well as the magnetic Rayleigh-Taylor instability (MRTI), can be produced in the laboratory by coupling high-power lasers with external magnetic fields. More importantly, high-energy non-thermal protons have been measured during these processes, providing the first direct evidence of early stage non-thermal proton energization by the collisionless shocks and the turbulence induced by the MRTI. Both kinetic Particle-in-cell (PIC) and extended magnetohydrodynamics (MHD) simulations (as well as the integrated MHD-PIC one) have been used to identify the ion energization mechanisms and to reproduce the experimental observations. This platform opens the door to future laboratory experiments, in the regime of magnetized high-energy-density plasma (HEDP), investigating the possible transition to other mechanisms, and shed light on the related astrophysical phenomena.