Proton Imaging of Collisionless Shock Experiments at OMEGA EP

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Abstract

Astrophysical collisionless shocks may play a role in diverse phenomena such as high-energy cosmic ray acceleration and the ubiquitous magnetization of the universe. These shocks are predicted to coalesce from collective plasma effects mediated by electric and magnetic fields. However, the precise mechanisms by which electric and magnetic fields contribute to collisionless shock formation and associated astrophysical phenomena are still largely unknown. Our collaboration (Astrophysical Collisionless Shocks with Lasers, or ASCEL) is studying the signatures of collisionless shock formation in the laboratory. One of our approaches is to use short-pulse laser generated proton imaging at the large-scale OMEGA EP laser facility. Two opposing CH_2 disks spaced 8 mm apart were driven with 2200 J (per target) of 351 nm light over 3 ns to create a millimeter-scale interaction region of two overlapping, high-velocity (1000 km/s) plasmas with moderately low ion densities estimated to be in the range of 10^{18}-10^{19} cm^{-3}. Under these conditions the inter-flow collisional mean free path exceeds the size of the system, a regime that is appropriate for collisionless shock formation. Two 10 ps, 250 J short-pulse laser beams were used to proton radiograph the long pulse plasma from orthogonal views. Proton images reveal electromagnetic field structures that form and then change shape dramatically over several ns. Spherically symmetric structures, prolate filaments, and oblate pancakes are observed. These structures vary in size over a wide range of spatial scales from tens of μm to several mm. Field strengths within the plasma are estimated using a new first-principles analytic toolkit that we have developed to relate electric and magnetic field structures to their proton-beam images.

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