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Electrostatic shock waves driven by electron vortices in laser–plasma interactions

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Structure and transportation of electron vortices in near-critical density plasmas driven by ultrashort intense laser pulses have been studied by multi-dimensional particle-in-cell simulations. Dimensional features of electron vortices are revealed. In two-dimensional geometry, two electron vortices and a quasi-static magnetic dipole are closely coupled. In three-dimensional geometry, a moving electron vortex ring associated with a closed magnetic ring moves in near-critical density plasmas. Such structure can transport some energy to the region where the laser pulse cannot reach. It is found that the motion of plasma ions makes the vortex magnetic energy dissipate quickly. These studies provide possible connection of electron vortices in nature with laser plasma experiments.

Nonlinear structures such as shock waves and vortices widely exist in nature and the Universe. They have also been separately observed in laser–plasma interactions. We show for the first time that two perpendicularly propagated collisionless electrostatic shock waves (CESs) can be excited by a moving electron vortex (EV). The latter is driven by an ultrashort intense laser pulse propagating through a sandwich nonuniform underdense plasma slab and is found to move perpendicularly to the density gradient. Two CESs are observed on both sides of the passing route of the EVs. The left-side CES is induced by a high-density electron layer, which originates from the vortex front and is compressed and accelerated during the EV motion. The right-side CES is induced by supersonic ions accelerated by the EVs directly. Ion acceleration by such CESs along the directions perpendicular to the vortex propagation is also observed. This study reveals the transformation of nonlinear structures and provides new routes for laser energy dissipation in plasmas.

References

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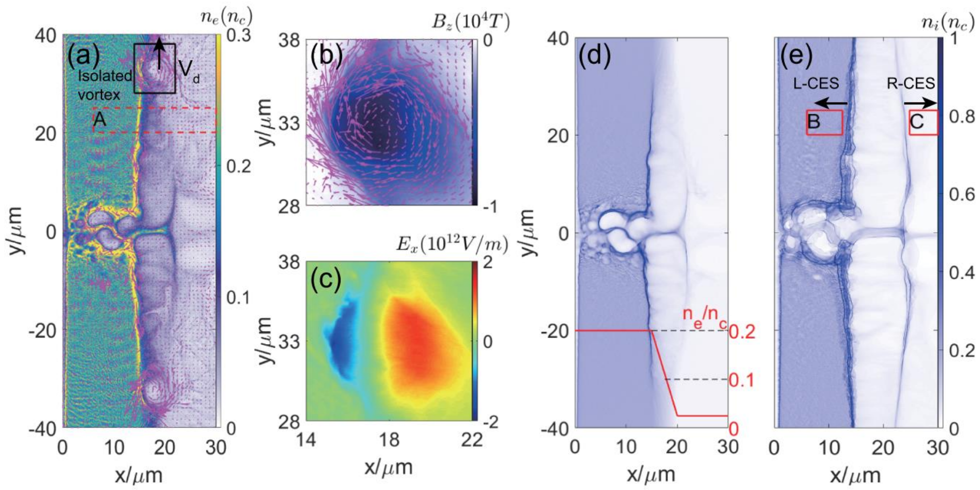

Figure 1. (a) Distributions of electron density n_e and the electric current vector (purple arrows) at t = 150T$_0$. The isolated EV with a drift velocity V_d is marked by a black solid rectangle. The black arrow represents the vortex motion direction. (b) Distributions of the magnetic field (B_z) and electric current vector (purple arrows). (c) Distribution of the longitudinal electric field E_x inside the EV. Distributions of ion density at different times (d) t = 150T$_0$ and (e) t = 300T$_0$. Two shock fronts represented by a leftward collisionless electrostatic shock wave (L-CES) and a rightward CES (R-CES) can be clearly seen, with black arrows showing their motion directions.