Structure and Dynamics of Colliding Plasma Jets

C. K. Li,[1] D. D. Ryutov,[2] S. X. Hu,[3] M. J. Rosenberg,[1] A. B. Zylstra,[1] F. H. Séguin,[1] J. A. Frenje,[1] D. T. Casey,[1]* M. Gatu-Johnson[1], M. E. Manuel,[1†] H. G. Rinderknecht,[1] R. D. Petrasso,[1] P. A. Amendt,[2] H. S. Park,[2] B. A. Remington,[2] S. C. Wilks,[2] R. Betti,[3] D. H. Froula,[3] J. P. Knauer,[3] D. D. Meyerhofer,[3] R. P. Drake,[4] C. C. Kuranz,[4] R. Young,[4] and M. Koenig[5]

[1]*Plasma Science and Fusion Center, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139 USA*
[2]*Lawrence Livermore National Laboratory, Livermore, California 94550 USA*
[3]*Laboratory for Laser Energetics, University of Rochester, Rochester, New York 14623 USA*
[4]*University of Michigan, Ann Arbor, Michigan USA*
[5]*Laboratoire pour l'Utilisation des Lasers Intenses, UMR 7605, CNRS–CEA–Université Paris VI–Ecole Polytechnique, 91128 Palaiseau Cedex, France*

Monoenergetic-proton radiographs of laser-generated, high-Mach-number plasma jets colliding at various angles shed light on the structures and dynamics of these collisions. The observations are compared favorably with results from 2D hydrodynamic simulations of multi-stream plasma jets with collisional electrons and also with results from an analytic treatment of azimuthal magnetic field advection using a plausible model for velocity distribution of the effective electron flow. For collisions of two noncollinear jets, the observed flow structure is similar to the analytic model's prediction of a characteristic feature with a narrow structure pointing in one direction and a much thicker one pointing in the opposite direction. Spontaneous magnetic fields, largely azimuthal around the colliding jets and generated by the well-known $\nabla T_e \times \nabla n_e$ Biermann battery effect near the periphery of the laser spots, are demonstrated to be "frozen in" the plasma (due to high magnetic Reynolds number $R_M \sim 5\times10^4$) and advected along the jet streamlines of the electron flow. These studies provide novel insight into the interactions and dynamics of colliding plasma jets.

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We report on recent experiments for studying the collisions of two identical plasma jets generated by high-power lasers. Modeled with comprehensive numerical simulations and analytic analysis, the measurements have, for the first time, indicated a key aspect of the jet collisions at various angles and the prediction of rapid expansion along the bisector plane, which agree with the analysis of frozen-in magnetic fields that were advected with streamlines of the plasma electron flow, reinforcing our insight into the interactions of colliding plasma jets.

The collision of high-Mach-number plasma jets in the laboratory is attracting increasing attention since such interactions can be used as an important test bed for studying many astrophysical phenomena and basic physics problems in self-organization [1-4]. Exploring the spatial structure and temporal evolution of these colliding jets, as well as their relationship with self-generated electromagnetic fields [5-8], is of essential importance for understanding the underlying physics of plasma jet interactions [9,10].

Although they have very different spatial, temporal, temperature and density scales, laboratory-generated plasma jets and astrophysical jets share a large variety of hydrodynamic similarities [11-18]. As indicated by numerous dimensionless parameters, these similarities suggest common physical processes that govern jet dynamics and allow us to scale laboratory jets to astrophysical conditions under some circumstances [9-18]. For example, recent experiments [2,3,19] and numerical simulations [20] indicate that the collisions of two counter-streaming plasma flows with sufficiently large spatial overlap lead to collisionless shocks mediated by the development of plasma micro-turbulence [21,22]. Such shocks can be scaled to mimic and explain many astrophysical phenomena [2-5, 9-22]. To simulate aspects of accretion disks and out-flows in astrophysics, an array of properly directed plasma jets has been proposed [23,24] to drive and form a differentially rotating, quasi-planar disc in which an azimuthal magnetic field, seeded with a cusp magnetic configuration, will be enhanced. The interactions among these jets in such a specially configured plasma will play a critical role in reproducing this particular astrophysical phenomenon [23,24]. In inertial confinement fusion (ICF) [25], the relevance of plasma jet interactions is evident in the plasma stagnation on a hohlraum axis (a consequence of radial collisions of supersonic high-Z wall blowoff), which is critical to hohlraum x-ray drive symmetry and ICF capsule implosions [25,26].

Laser-produced colliding jets can be supersonic [11-13, 27, 28], with sufficiently high kinetic energies that collisions of ions in one jet with ions in another jet are negligible. In this case, the ion streams interpenetrate each other essentially freely [1, 29]. On the other hand, the electrons (whose thermal velocity is much higher than the flow velocity) form a background common to both streams. As the electron temperature is lower than the ion directed energy by a factor ~ 50 - 100, they are highly collisional. The average velocity of the electrons is established to provide quasi-neutrality. For the case of equal strength streams the stagnation surface along which the magnetic flows from each plasma jet become parallel proves to be a plane which includes what would be the vector sum of the two equal flows and which would be

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[5]*Laboratoire pour l'Utilisation des Lasers Intenses, UMR 7605, CNRS-CEA-Université Paris VI-Ecole Polytechnique, 91128 Palaiseau Cedex, France*

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We report on recent experiments for studying the collisions of two identical plasma jets generated by high-power lasers. The observations have, for the first time, shown key aspects of jet collisions at various angles. In particular, it was seen that plasma flowing into the collision from the two jets forms a stagnation surface along which incoming electrons flow away from the collision. This surface is a plane that bisects the angle formed by the two jets (the "bisector plane"). This and other observations are combined with numerical simulations and analytic models, reinforcing our insight into the interactions of colliding plasma jets.

The collision of high-Mach-number plasma jets in the laboratory is attracting increasing attention since such interactions can be used as a test bed for studying many astrophysical phenomena and basic physics problems in self-organization [1–4]. Exploring the spatial structure and temporal evolution of these colliding jets, as well as their relationship with self-generated electromagnetic fields [5–8], is of essential importance for understanding the underlying physics of plasma jet interactions [9,10].

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