Interferometric Characterization of Laboratory Plasma Astrophysical Jets Produced by a 1-μs Pulsed Power Driver

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***Abstract*— A high current driver based on microsecond LTD technology has been used to perform laboratory plasma astrophysics studies using a conical wire array load coupled a 950 kA, 1.2-μs pulsed power generator. A plasma jet is generated as a result of the on-axis shock formed by the ablation streams from the wires of a conical tungsten wire-array load together with conservation of the axial momentum. The aim of this paper is to produce a scaled-down laboratory simulation of astrophysical Herbig–Haro plasma jets occurring during star formation along with some of their interactions with the interstellar medium, such as a crosswind. Due to the relatively long duration of the current pulse delivered by the driver, the jet develops on a 2-μs timescale and grows up to 100 mm. A time-resolved laser interferometer has been fielded to measure the plasma areal electron density as a function of time in and around the plasma jets. The setup consists of a continuous diode-pumped solid state laser (5 W–532 nm), a Mach–Zehnder interferometer and fast gated visible multiframe camera.**

***Index Terms*— Astrophysics, plasma density, plasma diagnostics.**

THE OEDIPE generator at the CEA Gramat, France, delivers 950 kA in 1.2 μs in a conical wire array load. It is a small current driver based upon the technology developed for the 5.5 MA, 1-μs SPHINX machine [1]. The configuration of the load is as follows: the height of the truncated cone is 20 mm; the anode and cathode diameter are 40 and 70 mm, respectively, corresponding to an opening angle of 37°. The load is made of 16 tungsten wires of 25-μm diameter. The plasma jet generated by the on-axis shock [3] from the wire-array ablation streams is subjected to an interaction with a crosswind. A 20-μm thickness, 1×1 cm^2 target foil is located 40 mm away from the wire-array anode. It makes an angle of 18° with respect to the jet propagation axis. The upper tip of the foil is 6 mm away from the jet axis. The load and jet radiation heat up and ablate the foil, which generates a plasma wind moving toward the path of the jet prior to the arrival of the jet. We probe the jet-wind interaction with a 2-D time-resolved Mach–Zehnder interferometer to infer the electron densities of both the jet and the wind. A 40-mm diameter laser beam is directed into the experiment chamber. The 2-D interferogram probes an area, which spatially exceeds the dimensions of the plasma to keep reference fringes for absolute fringe shift calculation. The raw data are processed [4] using a fringe tracking application for both the background and dynamic interferograms. The known phases $\phi = 2\pi$N of all the fringes are 2-D-interpolated on the image matrix. This way, the phase shift induced by the plasma is obtained. This phase shift depends on the refractive index of the probed medium, which is proportional to the electron density integrated along the probe axis ($\int \eta e dl$). The plasma flowing from the foil is assumed to be invariant for 1 cm along the laser beam axis in front of the foil. Density is inferred on that basis from the areal density. The jet areal electron density is given without conversion to volume density. The electron densities measured in the interaction region are $\sim$1.3.10^{18} e-.cm-3 for the plasma wind and 4.10^{17} e-.cm-2 for the plasma jet. Analysis of the interferograms in the interstream region, shown in Fig. 1, reveals that the wind inferred from the target foil has an asymmetric expansion. The interaction with the wind causes a substantial jet deviation, which differs from the typical curvature of astrophysical jet-wind scenario. We believe that a low density plasma flow, which is undetectable with our interferometer setup (Ne $<$ 10^{17} cm-3), precedes the jet and interacts with the plasma foil. This plasma is generated earlier in time in the load region either by explosion of the wires or wire ablation with low degree of on-axis collimation. Therefore, the wind is first pushed by this low density plasma and the interferogram exhibits a sharp shock-like fringe shift as a result of this interaction. A modified crosswind device will be applied in future work to generate a more representative wind flow. The plasma jet parameters inferred from the experiments (velocity and radius of the jet of $\sim$90 km.s-1 and 1.5 mm) are intended to be consistent with Herbig–Haro object characteristics scaled-down to the laboratory. 3-D radiative MHD simulation results obtained for this load configuration using the GORGON code provide the plasma jet parameters that are not obtained experimentally. The reproducible jets produced on this microsecond current driver pave the way for relevant laboratory astrophysics experiments in which measurements will be carried out over extended space and time scales compared with shorter pulse generators.

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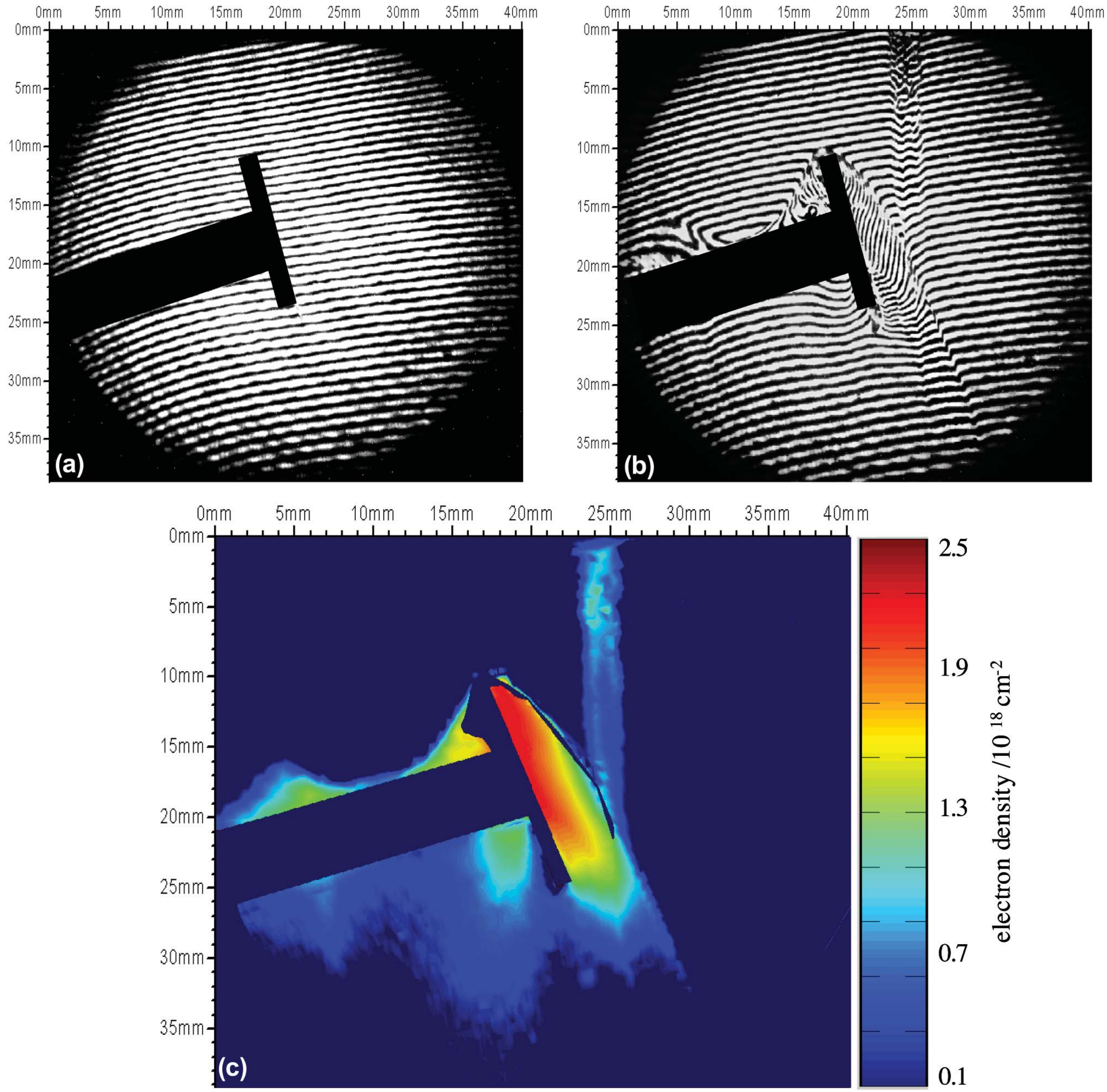

Fig. 1. Example of end-on interferograms captured during a 16 wire tungsten conical array crosswind experiment, 45 mm underneath the anode. (a) Before the shot and (b) 1400 ns after start of current. (c) 2-D areal electronic density raw map of (b) with (a) providing zero fringe.

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