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Magnetic Bubble Expansion as an Experimental Model for Extra-Galactic Radio Lobes

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I. Introduction

It is generally thought that energies (including magnetic fields) in jets and lobes of radio galaxies observed on large scales are supplied from the central black hole at the center of the massive galaxies. The past modeling of these systems has focused on the assumption that such outflows are dominated by their kinetic energy (see [1] for a recent review). Recent observations, however, suggest that these systems could be magnetically dominated[2]. Newly proposed models of extra-galactic radio lobes including the effects of magnetic energy and helicity have been proposed[3], but numerical and observational efforts alone cannot adequately test these nonlinear plasma physics jet/lobe models -- laboratory experiments are needed in order to properly assess their accuracy.

The Plasma Bubble Expansion Experiment (PBEX) has begun laboratory experiments and coordinated nonlinear MHD simulations to address outstanding nonlinear plasma physics issues related to how magnetic energy and helicity carried by extra-galactic jets interacts with the intergalactic medium to form radio lobe structures. The primary objective is to investigate in a laboratory plasma experiment how a magnetized, higher pressure plasma ("bubble") relaxes as it propagates into a lower density plasma ("background"). Experiments are being conducted in the 4 meter long, 50 cm diameter HelCat (Helicon-Cathode) linear plasma device at the University of New Mexico. A pulsed magnetized coaxial gun (~ 10 kV, ~ 100 kA, ~ 2 mWb) forms and injects magnetized plasma bubbles perpendicularly into a lower pressure weakly magnetized background plasma formed by a helicon and/or hot cathode source in HelCat. Ideal MHD simulations show that an MHD shock develops ahead of the bubble as it propagates, and that the bubble develops asymmetries due to the background field[4].

II. Experimental Setup

The experiment uses a coaxial plasma gun[5] to form and launch a higher pressure magnetized plasma into a lower pressure background plasma created by the HelCat plasma experiment[6]. Fig. 1 shows the conceptual layout. The coaxial gun is mounted on one side wall of a large cylindrical vacuum chamber. The principle of the gun operation is as follows: First current is driven through an external coil, providing bias magnetic flux $\Phi_{\mathbf{bias}}$. Next, a gas puff valve injects a large quantity of neutral gas (typically 2-4 μg Argon or Helium) into the gap between inner and outer electrodes in a short burst (a few microseconds). The main gun cap-bank then discharges, initiating Paschen breakdown along the bias B-field between electrodes to form the plasma. At the same time, field-aligned current injects toroidal flux into the plasma, and **J×B** forces accelerate the plasma out of the gun. Eventually, the bias B-field reconnects as plasma leaves the gun, forming a plasma bubble with closed flux surfaces.

Diagnostics include multi-tip Langmuir probes for density and temperature measurements, b-dot probes to measure 3D magnetic field structure, and soon a fast framing camera. The background plasma and bubble can be either Argon or Helium, independently of each other. The background plasma magnetic field can also be independently adjusted.

III. Results

Measurements with a Langmuir probe having multiple tips radially displaced allow an estimate of bubble density vs. distance from the gun at different times (Fig. 2). Knowing the probe tip separations and time delays, this shows that the bubble propagates away from the gun at v ~ 0.5 cm/μs when Argon is used. Helium shows similar results with v ~ 1.5 cm/μs due to Helium's lighter mass. Both velocities are of the same magnitude as the sound speed. After calibrating the probe against a microwave interferometer in a helicon plasma, absolute densities in the bubble were $n_e \sim 1\text{-}2\text{x}10^{20}$ m^{-3} in Argon with similar densities in Helium. Estimates of T_e from triple probe measurements found $T_e \sim 7 – 10$ eV (in Argon), depending on the voltage driving the gun current. Figure 3 shows preliminary data from bubble propagation into a background plasma, indicating that the background plasma does affect the bubble propagation. Further experiments including detailed magnetic field measurements are underway.

IV. Summary

Plasma processes are important for extra-galactic jet/radio lobe formation and evolution. Numerical and observational efforts alone cannot adequately test nonlinear plasma physics in jet/lobe models, laboratory experiments are needed. The model problem of a magnetized plasma bubble ("radio lobe") interacting with a lower pressure background plasma ("inter-galactic medium") is being studied using MHD modeling at Los Alamos National Laboratory in conjunction with laboratory experiments at the University of New Mexico with first measurements currently underway. Detailed experimental measurements in close collaboration with numerical modeling will explore in detail the key plasma physics underlying new astrophysical models of extra-galactic jets and radio lobes.

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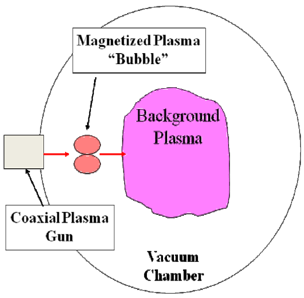

Figure 1 Schematic layout of plasma bubble injection experiment.

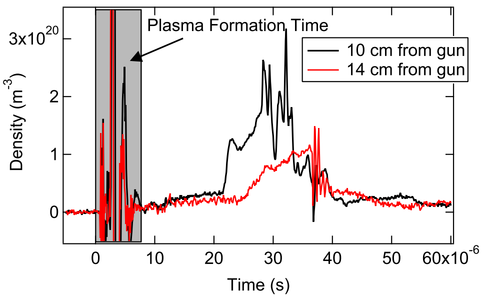

Figure 2 Plasma density at different distances from the gun shows bubble propagation. Argon plasma data shown.

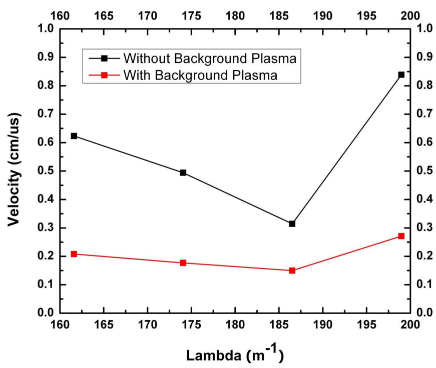

Figure 3 Plasma bubble propagation behavior with and without background plasma. Lambda is a common coaxial gun operating parameter proportional to the ratio of gun current to bias flux.