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ORIGINAL ARTICLE

# Observations of magnetic flux compression in jet impact experiments

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**Abstract** The astrophysical jet experiment at Caltech generates a $T = 2$–$5$ eV, $n = 10^{21}$–$10^{22}$ m$^{-3}$ plasma jet using coplanar disk electrodes linked by a poloidal magnetic field. A 100 kA current generates a toroidal magnetic field; the toroidal field pressure inflates the poloidal flux surface, magnetically driving the jet. The jet travels at up to 50 km/s for ∼20–25 cm before colliding with a cloud of initially neutral gas. We study the interaction of the jet and the cloud in analogy to an astrophysical jet impacting a molecular cloud. Diagnostics include magnetic probe arrays, a 12-channel spectroscopic system and a fast camera with optical filters. When a hydrogen plasma jet collides with an argon target cloud, magnetic measurements show the magnetic flux compressing as the plasma jet deforms. As the plasma jet front slows and the plasma piles up, the density of the frozen-in magnetic flux increases.

**Keywords** Astrophysical jets and outflows · Laboratory astrophysics · Flux compression · Magnetic compression · Molecular cloud

## 1 Introduction

Accretion disks with high-speed jets are observed in astrophysical systems over a wide range of length scales (De Young 1991). Models of jet formation include a magnetic field linking the central body and the surrounding disk (Lynden-Bell 2006). The disk provides material that is both collimated and accelerated by the magnetic field. The jet may then interact with the surrounding medium. The Caltech astrophysical jet experiment produces magnetically driven (Kumar 2009), collimated jets by creating analogous boundary conditions in a laboratory setting (Hsu and Bellan 2002). An inner disk cathode and surrounding annulus anode are linked by a dipole magnetic field. The electrodes are initially in vacuum; gas that forms the jet material is supplied at the electrodes. The gas breaks down into a plasma that then evolves and expands freely into the chamber. Wall effects are minimal, as the jet length scale is about 25% that of the chamber. Past experiments showed jet morphology to be consistent with the Kruskal-Shafranov limit for kink instability onset (Hsu and Bellan 2004). We report here results of recent experiments designed to mimic an astrophysical jet interacting with the surrounding medium. Specifically, a localized, initially neutral cloud of gas is placed in the path of the jet in analogy to an astrophysical jet impacting a molecular cloud. The gas used to form the plasma and the neutral gas in the cloud can be independently selected so that different species can be used to distinguish cloud and jet dynamics.

## 2 Experimental setup

The Caltech experimental apparatus is comprised of coplanar, concentric electrodes (Fig. 1). The inner electrode diameter is 20 cm, the outer electrode diameter is 50 cm. An ∼15 cm diameter, 110 turn coil mounted behind the electrodes supplies a variable strength (usually ∼0.1 T) dipole magnetic field. Prior to plasma breakdown, the background magnetic field coil is pulsed and neutral gas is injected at 8 locations on each electrode. At breakdown, a 120 μF capacitor bank charged to 5 kV breaks the gas down into plasma in 8 radially arranged filamentary arches. The arches lie along the poloidal magnetic field lines, so that the electrodes are

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