

Uncovering Mysteries of Astrophysical Jet Formation in a Laboratory Plasma Experiment
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Scott Hsu and Paul Bellan, Caltech M/C 128-95, Pasadena, CA 91125

Summary: A laboratory plasma experiment shows how magnetic forces can help explain the formation of astrophysical jets.

Astrophysical jets are one of the truly exotic sights in the universe. How they form is a curious mystery. They are usually associated with accretion disks, which are disks of matter spiraling into a massive central object such as a black hole. The jets are narrow, fast, and extend for extreme distances along the disk axis. Jets and accretion disks are known to accompany widely varying types of astrophysical objects, ranging from infant star systems to binary stars to galactic nuclei. While the mechanism for jet formation is the subject of much debate, many theoretical models predict that jets form as the result of magnetic forces.

Now, plasma physicists at the California Institute of Technology have brought this seemingly remote phenomenon into the laboratory. By using technology developed for creating a magnetic fusion configuration called a spheromak,¹ they have produced plasmas, or ionized gas, which incorporate some of the essential physics of astrophysical jets. Reporting in a recent issue of the *Monthly Notices of the Royal Astronomical Society*,² Scott Hsu and Paul Bellan describe how their work helps explain the magnetic dynamics of these jets. By placing two concentric copper electrodes and a coaxial coil in a large vacuum vessel and driving as much as 150 kilo-Amperes of electric current through a hydrogen plasma, they have succeeded in producing jet-like structures [Fig. 1(a)] that not only resemble those in astronomical images, but also develop remarkable helical instabilities [Fig. 1(b)] that could help explain the wiggled structure observed in some astrophysical jets.

“Photographs clearly show that the jet-like structures in the experiment form spontaneously,” says Bellan, who studies laboratory plasma physics but chanced upon the astrophysical application when he was looking at how plasmas with large internal currents can self-organize. “We originally built this experiment to study spheromak formation, but it also dawned on us that the combination of electrode structure, applied magnetic field, and applied voltage is similar to theoretical descriptions of accretion disks, and so might produce jet-like plasmas.”

The theory Bellan refers to states that jets can be formed when magnetic fields are twisted up by the rotation of accretion disks. Magnetic field lines in plasma are like elastic bands frozen into jello. The electric currents flowing in the plasma (jello) can change the shape of the magnetic field lines (elastic bands) and thus change the shape of the plasma as well. Magnetic forces associated with these currents squeeze both the plasma and its embedded magnetic field into a narrow jet that shoots out along the axis of the disk.

By applying a voltage differential across the gap between the two concentric electrodes, Hsu and Bellan effectively simulate an accretion disk spinning in the presence of a magnetic field. The coil produces magnetic field lines linking the two concentric electrodes in a manner similar to the magnetic field linking the central object and the accretion disk.

The importance of the study, Bellan and Hsu say, is that it provides compelling evidence in support of the idea that astrophysical jets are formed by magnetic forces associated with rotating accretion disks, and it also provides quantitative information on the stability properties of these jets.

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¹P. M. Bellan, *Spheromaks* (Imperial College Press, London, 2000).

²S. C. Hsu and P. M. Bellan, *Mon. Not. R. Astron. Soc.* **334**, 257 (2002).

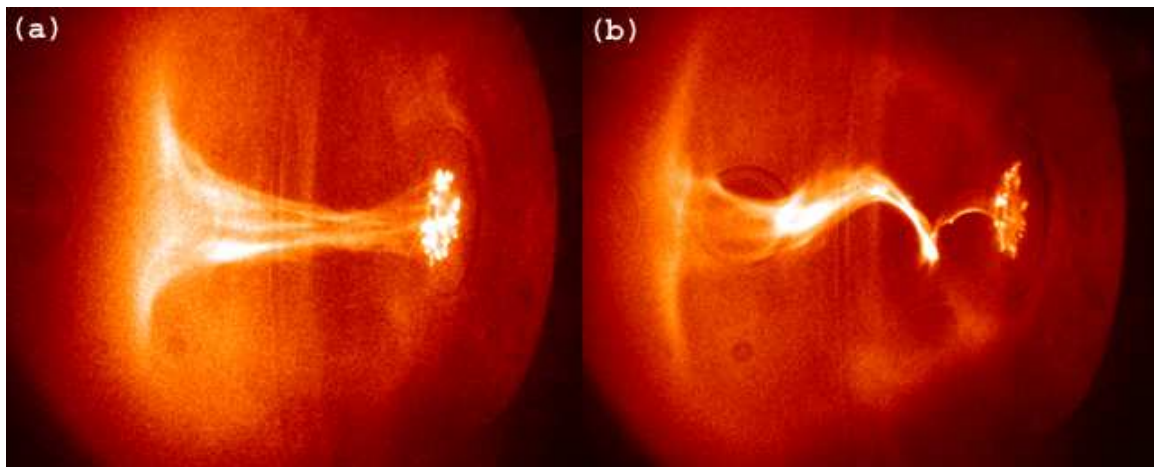


Figure 1: False-color images of laboratory plasmas taken with a high-speed digital camera. Development of (a) jet-like structure and (b) helical instability in the jet structure. (Concentric electrodes appear on right hand side of each image.)