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Bringing stars and galaxies down to Earth: a new perspective in astrophysics

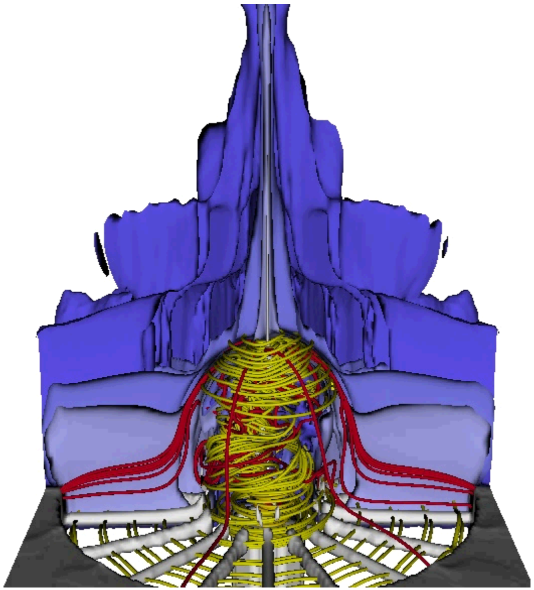
Laboratory experiments produce scaled-down versions of the powerful jets seen in space.

PHILADELPHIA, Pennsylvania, Oct. 30, 2006 – Scientists from both sides of the Atlantic have developed a new technique to produce in the laboratory centimeter-sized versions of the powerful jets of plasma observed in young stars, active galaxies and in supernovae explosions. The results provide new insights into the physics of jet formation and open the door to laboratory studies of some complex space phenomena.

Jets are some of the most remarkable objects in the universe. Observed in a variety of systems, they transport energy and matter in narrow channels over huge distances. In newly-born stars, surrounded by a rotating disc-like region of gas, the production of jets seems to be fundamental to the evolution of the star itself. Jets are partly responsible in allowing mass to accrete from the disc onto the star by removing the excess of angular momentum that is transported by the in-falling gas. In active galaxies, jets are also a signature of an evolutionary phase but in this case it is a black hole that accretes material and powers the jets over galactic distances.

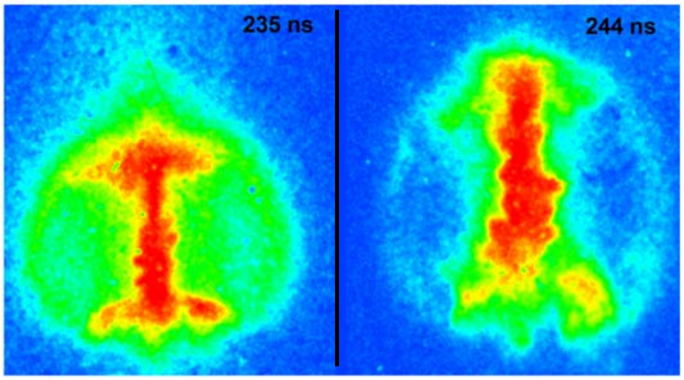
A critical, yet debated role is played by the magnetic fields which launch the jets and dynamically connect them to the discs. Although there is consensus on the importance of fields and rotation, the actual jet formation mechanism and whether it is common to all jets is still largely unknown.

A recent approach to study some of the jet physics is to re-create in the laboratory the scaled physical conditions and phenomena that take place in space. In addition, developments in high-performance computer simulations have also been fundamental in determining the possible connections between the laboratory experiments, the astrophysical observations and the theoretical models.



The image shows surfaces of constant density from a three-dimensional simulation of a laboratory jet. The cut-through shows the inside of the magnetic bubble and the current flow (red tubes). The magnetic field loops (yellow tubes) wrap around the jet filling the cavity. The wire array can be seen in the lower part of the image.

Using the MAGPIE pulsed-power generator at Imperial College London, the new technique delivers a millionth-of-a-second pulse of current to an array of micron-sized metallic wires. The experiment is designed to reproduce the interaction of magnetic field loops with a plasma environment, a common feature in many astrophysical models of jet formation. The laboratory experiments, coupled with state-of-the-art simulations, show that the sudden release of energy produces inside the hot plasma a magnetic bubble enveloped by a relatively thin shock-layer. Magnetic field and pressure distributions confine the magnetic bubble into a cylinder-like structure that grows taller in time: a "magnetic tower."



The image shows two snap shots of the soft x-rays emitted by the magnetic tower during an experiment. The strong emission (*in red*) comes from the jet which forms inside the magnetic bubble. The "walls" of the magnetic bubble are visible in the form of an almost circular, weaker emission (*light blue and green*) surrounding the jet. The magnetic tower can be seen to grow in time.

Within the magnetic bubble itself a current-carrying jet appears with the magnetic field lines tightly wrapped around it. The plasma is accelerated to speeds of over half a million miles an hour and compressed to temperatures of a million degrees; then, instabilities in the jet and the "bursting" of the magnetic bubble lead to the break-up of the system. Surprisingly, it was observed in both experiments and simulations that well collimated "blobs" of plasma are left behind, forming a relatively narrow channel of energy and mass reminiscent of the clumpy structure observed in many astrophysical jets.

Further additions of important physical effects, such as poloidal magnetic fields and rotation are under development and have resulted in the first rotating jets ever produced in the laboratory.

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The Evolution of Magnetic Tower Jets in the Laboratory and in Astrophysics

Invited Session NI2: Space and Astrophysical Plasmas: Energetic Phenomena
10:00 AM–10:30 AM Wednesday, November 1, 2006
Philadelphia Marriott Downtown - Grand Salon CDE