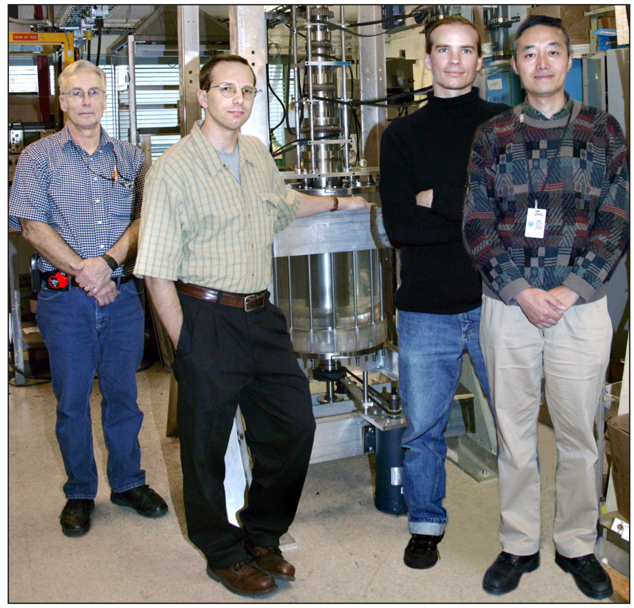
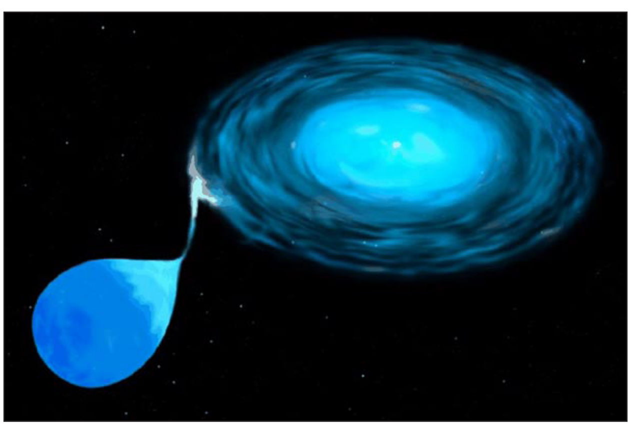
MRI Experiment Underway at PPPL

The formation process of stars and planets remains one of the big questions in astrophysical science. Currently, scientists do not understand the required conditions and the accretion, or matter collection process, involved in star and planet formation. But the Magnetorotational Instability (MRI) experiment at PPPL may shed light on this mystery. Staffing the MRI project are PPPL physicist Hantao Ji, postdoc Michael Burin, graduate students Ethan Schartman, Wei Liu, with technical and engineering support from Robert Cutler, Steve Raftopoulos, Phil Heitzenroeder, Chang Jun, and Lew Morris. They are working in collaboration with Professor Jeremy Goodman of the Princeton University Observatory. The work is being funded jointly by DOE, NSF, and NASA.

"The Earth must have sufficient angular momentum so that it does not fall into the Sun under the influence of gravity. We also know that galaxies and solar systems have a preferred direction of rotation. Consequently, matter forming these systems must also have had net angular momentum, which must have been overcome by gravity for the matter to coalesce. The angular momentum prevents matter from falling into the star directly, so an accretion disk is formed, which consists of matter losing it angular momentum and swirling into the core of the star. For example, when our Sun was formed, the accretion process was very efficient in casting off angular momentum, because most of the material comprising our solar system ended up in the Sun," noted Ji. Since angular momentum must be conserved, the lost amounts must be efficiently transported elsewhere. But how does this happen, and where does the angular momentum go?



At the MRI experiment are, from the left, Bob Cutler, Michael Burin, Ethan Schartman, and Hantao Ji.



Accretion occurs in a binary star system when one star is paired with a sufficiently compact star such as a white dwarf, a neutron star, or a black hole. An accretion disk may form as the stellar envelop of the first star is captured by the denser star. (courtesy Space Telescope Science Institute)

Unique Apparatus

Star formation occurs in deep space and therefore is not directly observable, so the accretion process has been described only in theoretical models and in their resulting computer simulations. The unique PPPL MRI apparatus will be the first anywhere to attempt a direct test of this widely postulated physical process in accretion disks. The project's primary mission is to test the plausibility of a 1991 theory that indicates magnetorotational instability (MRI), a disruptive plasma process, plays a major role in accretion. Unlike most PPPL experiments, MRI will not use an actual plasma. Hantao Ji and Jeremy Goodman came up with a way to physically simulate an accretion disk with material "standing in" for the plasma, dust, and other materials.

The system they are building consists of two concentric cylinders, each 28 centimeters in length, free to rotate

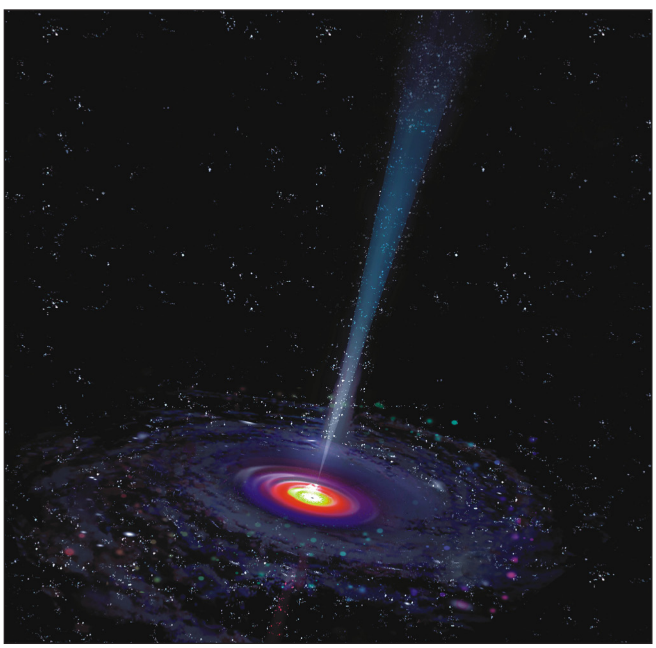
Photo of the MRI apparatus showing the elaborate driving mechanisms for the concentric cylinders.

independently about a common axis. The inner cylinder has a radius of 7 centimeters and is made of steel, and the outer cylinder has a radius of 20.3 centimeters and is of made of plastic to allow visual inspection. During a typical experiment, the space between the cylinders will be filled with a liquid metal, chosen because it is easy to maintain and interacts with the magnetic field in ways similar to plasma. The researchers have chosen a mixture of 67% gallium, 20.5% indium and 12.5% tin. The inner and outer cylinders will rotate independently in the same direction, but at significantly different speeds, 4000 rpm and 533 rpm, respectively. What makes this project a significant engineering challenge is the requirement to have two rotating disks at each end of the cylinders. The disks must be driven at different speeds by separate motors through six concentric pipes.

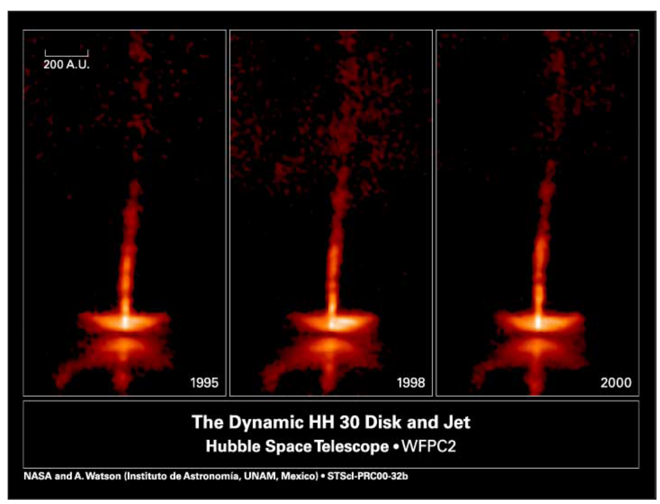
Measuring Differences

Experiments will be conducted with and without a magnetic field parallel to the axis of the cylinders. Researchers will measure the differences in the torque on the cylinders between both conditions. The magnetorotational instability, when it occurs in the liquid metal, will cause angular momentum to be transferred from the inner cylinder toward the outer cylinder, resulting in an increase in torque-couplings between cylinders. This is equivalent to the transfer of angular momentum outward in an accretion disk, allowing matter to fall toward its center, forming a star. This result would support the hypothesis that magnetorotational instability is responsible for the transport of angular momentum.

Accretion disks also form around massive black holes in the center of many galaxies and in binary star systems (see diagrams). Results from the PPPL experiments will help astrophysicists better understand these phenomena. Understanding transport phenomena in plasmas is important for basic plasma physics in general, and also for fusion plasmas in particular.



Accretion disk around a massive black hole often thought to exist in the center of many galaxies. (NASA)



Edge-on views of an accretion disk around a young star at three different times. (Space Telescope Science Institute)

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