How to feed a black hole

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A special magnetic effect, the so-called magnetorotational instability (MRI), plays a key role in the formation of stars and planetary systems. It is also what feeds the black holes in the center of galaxies. For the first time, this effect has been observed in a laboratory experiment at the Forschungszentrum Dresden-Rossendorf (Germany). These results have recently been published in *Physical Review Letters*.

Everybody remembers the picture of the hungry black hole swallowing all matter in its vicinity. Not even light has a chance to escape. However, closer inspection reveals that feeding a black hole is far from trivial.

Typically, the matter around black holes has organized itself into so-called accretion disks. And just as the Earth is not falling into the sun, the black hole cannot just scarf up the matter encircling it. Before being swallowed by the black hole, the gas in the disk has to be slowed down in order to weaken the centrifugal forces, which keep the gas rotating.

But how does one put the brakes on matter in an accretion disk? Since this problem not only applies to black holes, but also to normal stars, it is of fundamental importance for the formation of cosmic structures.

Balbus and Hawley proposed the solution to this problem in 1991. They showed mathematically that stable rotating flows can be destabilized by external magnetic fields. This effect, now known as magnetorotational instability (MRI), enables sufficient angular momentum transport in accretion disks, which is essential for the mass concentration in stars and black holes.

Laboratory simulation of star formation

For approximately five years, teams throughout the world have tried to create this instability in a laboratory. Two recent papers in the journal *Nature* (November 16, 2006) underlined the urgent need for an experimental demonstration of MRI by showing evidence that hydrodynamics alone is not capable of producing turbulence in accretion disks. At the Forschungszentrum Dresden-Rossendorf the experiment PROMISE (Potsdam Rossendorf Magnetic InStability Experiment) was set-up and carried out as a joint project between scientists from Dresden and from the Astrophysikalisches Institut Potsdam (AIP).

The experimental set-up contains unusual details, such as the use of a simple wastewater tube carrying the coil that produces the vertical magnetic field. Within this tube, there are two co-axial copper cylinders with a two to one ratio in radius. As long as the rotation rate of the outer cylinder is larger than a quarter of the rate of the inner cylinder, the liquid metal flow between them is stable. The flow field is measured with ultrasonic velocity sensors. The interesting point is that this initially stable flow is destabilized by an externally applied spiral magnetic field. For the first time, this experiment allowed the observation of a magnetorotational instability in a laboratory.

The figure shows the measured axial flow as a function of the vertical position and time for three different currents in the coils. In each case, the azimuthal magnetic field is produced by an axial current of 6000 Ampères. In good agreement with numerical simulations, an upward traveling wave is observed only for certain levels of current in the coils. Moreover, the measured frequency of the traveling wave agrees well with the numerical prediction.

The results were published recently in *Physical Review Letters* and *Astrophysical Journal Letters*.

Publications:
Stefani, F., Gundrum, Th., Gerbeth, G., Rüdiger, G., Schultz, M., Szklarski, J., Hollerbach, R., Experimental evidence for magnetorotational instability in a Taylor-Couette flow under the influence of a helical magnetic field,
Phys. Rev. Letters, Vol. 97, Art. No 184502 (2006).

Rüdiger, G., Hollerbach, R., Stefani, F., Gundrum, Th., Gerbeth, G., Rosner, R.,
The traveling wave MRI in cylindrical Taylor-Couette flow: comparing wavelengths and speeds in theory and experiment,
Astrophys. J. Lett., Vol. 649, L145-L147 (2006)

Source: Forschungszentrum Dresden-Rossendorf