Spinning Black Hole Pushes the Limit

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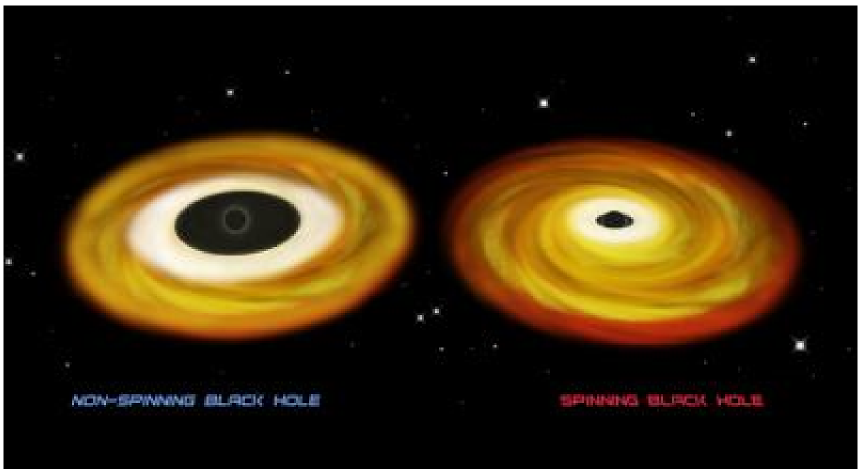

This illustration shows a swirling disk of accreting gas orbiting a black hole, with the bulk of the X-rays pouring out of the inner, white-shaded region of the disk. One remarkable prediction of Einstein's relativity theory is the existence of a smallest radius for the disk, inside of which the gas suddenly plunges into the hole with no time to radiate away its energy. For the non-spinning black hole shown at left, this inner radius is large, which leaves a big dark hole cut out of the center of the hot disk of gas. For the fast-spinning black hole shown at right, the gas can orbit very near the event horizon, and thus only a small portion of the inner disk is missing. Therefore, the radius of the hole is a direct measure of the spin. Credit: NASA/NASA/CXC/M.Weiss

The existence of black holes is perhaps the most fascinating prediction of Einstein's General Theory of Relativity. When any mass, such as a star, becomes more compact than a certain limit, its own gravity becomes so strong that the object collapses to a singular point, a black hole. In the popular mind, this immense gravity well is a place where strange things happen. And now, a Center for Astrophysics-led team has measured a stellar-mass black hole spinning so rapidly - turning more than 950 times per second - that it pushes the predicted speed limit for rotation.

"I would say that this regime of gravity is as far from direct experience and knowing as the subatomic world itself," says CfA astronomer Jeffrey McClintock.

Applying a technique to measure spin developed jointly by McClintock and CfA astrophysicist Ramesh Narayan, the team used NASA's Rossi X-ray Timing Explorer satellite data to provide the most direct determination yet of black hole spin.

McClintock and Narayan led an international group consisting of Rebecca Shafee, Harvard University Physics Department; Ronald Remillard, Kavli Center for Astrophysics and Space Research, MIT; Shane Davis, University of California, Santa Barbara, and Li-Xin Li, Max-Planck Institute for Astrophysics, Germany, in this research. The results are published in today's issue of the *Astrophysical Journal*.

"We now have accurate values for the spin rates of three black holes," says McClintock. "The most exciting is our result for the microquasar GRS1915+105, which has a spin that is between 82% and 100% of the theoretical maximum value."

"This result has major implications for explaining how black holes emit jets, for modeling possible sources of gamma-ray bursts, and for the detection of gravitational waves," says theorist Narayan.

Why do astronomers care about spin?

"In astronomy, a black hole is completely described by just two numbers that specify its mass and how rapidly it is rotating," says McClintock. "We know of nothing else this simple except for a fundamental particle like an electron or a quark."

Although astronomers have been successful at measuring black hole mass, they have found it much more difficult to measure the second fundamental parameter of a black hole, its spin.

"Indeed, until this year, there was no credible estimate of spin for any black hole," says Narayan.

A black hole's gravity is so strong that, as the black hole spins, it drags the surrounding space along. The edge of this spinning hole is called the event horizon. Any material crossing the event horizon is pulled into the black hole.

"The black hole spin frequency we measured is the rate at which space-time is spinning, or is being dragged, right at the black hole's event horizon," says Narayan.

The high-speed black hole, GRS 1915, is the most massive of the 20 X-ray binary black holes for which masses are presently known, weighing about 14 times as much as the Sun. It is well known for unique properties such as ejecting jets of matter at nearly the speed of light and rapid variations in its X-ray emission.

Over the last few decades, dozens of black holes have been discovered in X-ray binary systems. An X-ray binary is a system in which two objects orbit around each other, with gas from one - a normal star like the Sun - being transferred steadily to the other - in this case, a black hole. The gas spirals onto the black hole by a process called accretion. As it spirals in, it heats up to millions of degrees and radiates X-rays. The team used the

X-ray spectrum of the black hole's accretion disk to determine its spin.

The technique is based on a key prediction of relativity theory: gas that accretes onto a black hole radiates only down to a certain radius that lies outside the black hole - outside its event horizon. Inside this radius, the gas falls into the hole too quickly to produce much radiation. The critical radius depends on the black hole spin, so measuring this radius provides a direct estimate of the spin. The smaller the radius is, the hotter the X-rays which are emitted from the disk. The temperature of the X-rays, coupled with the X-ray brightness, gives the radius which, in turn, gives the black hole's spin rate.

"It is really cool to be able to measure something this fundamental," says Rebecca Shafee, who is a graduate student in the Physics Department at Harvard University. "Our method is very simple in concept and easy to understand. We are really lucky to have powerful X-ray observatories such as the Rossi X-ray Timing Explorer in space and telescopes on Earth to carry out the measurements we need."

The search for the cause of gamma-ray bursts, which can be, for a moment, the brightest flash in the universe, may be helped by the team's results. Theoretical astrophysicist Stan Woosley of the University of California, Santa Cruz, has modeled gamma-ray bursts based on the collapse of a massive star. These models, however, depend on the existence of black holes with very high spin, which until now had never been confirmed.

"This is extremely important," Woosley says. "I had no idea such measurements could be made."

The paper concludes that GRS 1915 and the other two black holes studied by the team were born with their high spins. That is, the collapsing core of the original massive star poured its angular momentum down into the black hole.

"Ever since the community figured out many years ago how to measure black hole mass, measuring spin has been the holy grail in this field," says McClintock. "The technique we used on GRS 1915 can be applied to a number of other black hole X-ray binaries. We cannot wait to see what we find!'"

"One of our fond hopes is that the black hole systems that we are studying will also be studied by other groups using their favorite methods of measuring spin," says Narayan. "Once these other methods are developed further and become more reliable, cross-comparison of results from the different methods would be most interesting."

Source: Harvard-Smithsonian Center for Astrophysics

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