Black Hole Found to be Spinning at 50% the Speed of Light

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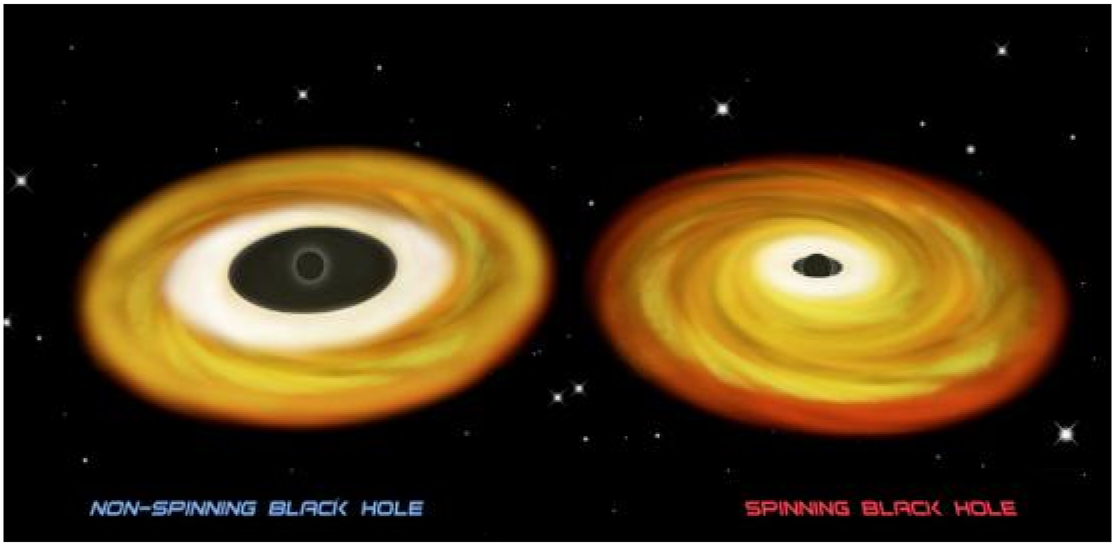

This illustration shows a swirling disk of accreting gas orbiting a black hole, with the bulk of the X-rays pouring out of the inner, white-shaded region of the disk. One remarkable prediction of Einstein's relativity theory is the existence of a smallest radius for the disk, inside of which the gas 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. (Image Credit: NASA/CXC/M.Weiss)

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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. Yet measuring a black hole's spin rate has long eluded scientists. Twisted space is difficult to detect and perhaps even harder to fathom.

Now a group led by Jeff McClintock and Ramesh Narayan of the Harvard-Smithsonian Center for Astrophysics (CfA) in Cambridge, Mass., has a new technique to measure black hole spin, which they describe as surprisingly straightforward and direct. They have accurately measured one black hole's spin and are moving on to others.

In doing so, they hope to accurately test some of Albert Einstein's wildest predictions.

A black hole is an object so dense and with gravity so strong that nothing, not even light, can escape its pull if it ventures too close. Our Milky Way galaxy is dotted with millions of black holes, the majority of which cannot be detected. These black holes are the remains of massive stars, long since extinguished.

When a star at least 10 times more massive than our sun runs out of nuclear fuel to burn, it no longer has the energy to support its own mass. The core implodes in a fraction of a second, creating shock waves that cause the outer shells of the star to explode into space, an event called a SuperNova.

If there's enough mass in the core, nothing can stop its collapse. It just gets denser and denser, tinier and tinier. All the mass folds into a single point of infinite density. There is no longer any star surface left, just a spinning hole in space. The spin from the old star gets converted directly into the spin of the black hole.

The spherical border around this spinning hole is called the event horizon. The radius (distance from the event horizon to the black hole center) is only about 10 to 50 kilometers, or about 5 to 30 miles. Once anything crosses the event horizon, it falls down the slippery slope into the black hole, never to return.

As fantastic as they sound, black holes are commonplace throughout the universe and scientists have much evidence that black holes exist even though they cannot be seen directly.

McClintock and Narayan studied a well-known black hole system called GRS 1915+105, in the constellation Aquila (The Eagle) about 35,000 light-years from Earth. The black hole itself is invisible, but matter pouring into it is exceptionally visible.

GRS 1915+105 is a two-star system. Gas from a "normal" star spills towards the black hole, lured by gravity. The gas spirals into the black hole like water down a drain: It doesn't just fall in all at once but first swirls around the black hole, forming a reservoir of matter called an accretion disk.

Gas in the accretion disk gets quite hot and emits light across a wide range of wavelengths. The inner part of the accretion disk, closest to the black hole, can be particularly bright in X-rays. Not all black holes are in two-star systems, but those that are can reveal themselves this way whenever they snack on gas from a companion star. Isolated black holes, on the other hand, only feed on the thin gas of interstellar space and are therefore very difficult to detect.

The science team, which includes Rebecca Shafee, McClintock's graduate student from Harvard University, focused on the accretion disk of GRS 1915+105 with the NASA's Rossi X-ray Timing Explorer. They concentrated on the inner edge of this disk, a region called the innermost stable circular orbit.

This region, Shafee said, is about 30 kilometers from the black hole center in GRS 1915+105, which is remarkably close. At an innermost stable orbit, gas can hover around the black hole indefinitely unless it is pushed. In between this region and the event horizon is somewhat of a no-man's land. Once matter gets bumped out of the innermost stable orbit, it falls toward the event horizon in less than a millisecond and is gone.

The distance from the innermost stable orbit to the black hole center depends on black hole spin. The faster the spin, the closer that matter can orbit "safely." This is a special property based on Einstein's theory of general relativity.

What McClintock and Narayan have done is accurately measure, for the first time, the distance of the innermost stable orbit to the black hole center. The measurement is based in part on the spectral analysis of the X-ray light. Simply put, when a black hole is spinning very fast, matter can orbit rather close to the event horizon; and as matter gets closer and closer to the black hole, the light it emits gets brighter and brighter. This information---brightness, temperature, velocity---is all encoded in the X-ray light.

From ground-based optical and radio observations, the scientists could determine the mass of the black hole, the angle of the tilt of the accretion disk in relation to us, and its distance from Earth. All these measurements feed into the equation to measure how fast a black hole is spinning.

"The black hole spin frequency we measured is the rate at which spacetime is spinning, or is being dragged, right at the black hole event horizon," said Narayan.

This black hole is about 14 solar masses. This would imply, based on Einstein's math, that the event horizon is at a radius of 42 kilometers assuming no spin or at 21 kilometers assuming maximum spin. In reality, it is in between, at 25 kilometers from the black hole center.

At the point of the event horizon, the black hole is spinning at over 950 times per second. At the event horizon that is 149,000 kilometers per second, or 50 percent the speed of light.

According to theory, the absolute maximum rate at which this black hole could possibly spin-essentially the speed of light - is 1,150 times per second. This means that the black hole is spinning at 98 percent its maximum value. (Note, this is not based on a simple calculation of 950/1150.)

This clocking technique can be applied to any stellar-size black hole, and the team plans to measure the spins of about a dozen other well-studied systems. This would have broad implications for other topics in astrophysics, including understand such mysteries as black hole jets, gamma-ray bursts and gravitational waves.

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

"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.

"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.

"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. "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."

For more info:

http://cfa-www.harvard.edu/press/pr0630.html

http://www.astromart.com/news/news.asp?news_id=432

http://www.nasa.gov/vision/universe/starsgalaxies/spinning_blackhole.html

http://www.cfa.harvard.edu/press/pr0630image.html