Studying how black holes grow

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The whirlpool galaxy, m51, is one of many galaxies with supermassive black holes at their core. The galaxy has a central black hole of about one million solar masses. Image: NASA

Black holes are some of the most exotic objects in the universe. They are the final evolutionary stage of giant stars much larger than the sun. When these stars explode, their cores collapse down to the size of large asteroid. That produces gravitational fields so intense that not even light can escape, reaching a point where space and time as we know them cease to exist.

So it isn't a surprise that Kelly Holley-Bockelmann became fascinated with black holes when she was a young girl. What is exceptional is that she sustained this interest and pursued a career in astronomy. She's now a member of the small cadre of researchers who are applying the latest computer simulation techniques to study how black holes interact with their environment.

Now, the assistant professor of physics and astronomy has received nearly $1.1 million over five years from the National Science Foundation to use computer simulations to study how "supermassive" black holes grow. Astronomers have found these gigantic black holes, weighing in at millions to billions of solar masses, lurking at the cores of most galaxies. For example, the black hole that has been detected at the core of our own Milky Way galaxy has a mass of about four million times that of the sun.

Due to the availability of Recovery Act funds, Holley-Bockelmann received the largest Faculty Early Career Development grant that NSF has ever awarded in astronomy. According to NSF, CAREER awards support exceptionally promising college and university junior faculty who are committed to the integration of research and education and are likely to become the academic leaders of the 21st century. They are considered NSF's most prestigious honor for junior faculty members.

Holley-Bockelmann will use the award to address one of the fundamental mysteries that surrounds the supermassive black holes. "We don't have a real, detailed understanding of how supermassive black holes grow. The first stars in galaxies began forming about 300 million years after the Big Bang, and the first quasars show up about 700 million years later. Quasars are the enormously bright nucleus of a galaxy, and we think they're powered by the vigorous accretion of gas onto a supermassive black hole. This means that supermassive black holes must have evolved in a surprisingly short period. The question is, how did they grow so big so fast?" Holley-Bockelmann says.

Understanding how supermassive black holes form is important because these objects have played a major role in the evolution of the universe.

Specifically, they appear to have had a major impact on the development of galaxies, such as affecting the rate at which they produce new stars.

Scientists believe that the most straightforward way black holes can grow is by engorging enormous amounts of dust and gas. Under the influence of the black hole's gravity, any gas and dust in its vicinity is pulled into a flattened disk around its equator that is called an accretion disk. The material in the disk is heated and compressed. As dust particles and gas molecules repeatedly collide, some lose energy and spiral down into the black hole while others gain energy and escape.

This approach, however, can't account for the speed of black hole growth. Stellar black holes tend to be very small, only a few kilometers in diameter. Even if a black hole is surrounded by an abundant supply of dust and gas, it can only ingest so much material at a time, just as a hungry person can only swallow one mouthful at a time. "On a diet of dust and gas, it takes a black hole about 40 million years to roughly double its mass. That isn't fast enough to account for the evolution of the largest supermassive black holes," says Holley-Bockelmann.

Another way that black holes might gain mass is by merging. When two supermassive black holes meet they can combine into a single, larger black hole. However, the astrophysicists who model the behavior of black holes have encountered two basic problems with this mechanism.

One involves the kick that black holes gain when they merge. The latest simulations of these events have found that when small supermassive black holes merge the resulting black hole receives an average kick of about 200 kilometers per second, which is fast enough to sling it out of a protogalaxy. (By contrast, the escape velocity of the Milky Way galaxy is 700 kilometers per second.) If the merger process routinely flings black holes out into the far reaches of a galaxy, it means they are less likely to be available for repeated mergers than if they stay concentrated near the galactic core. The astronomer will be exploring how such gravitational recoil influences the evolution of supermassive black holes.

A second difficulty is that in simulations, supermassive black holes circling around each other refuse to close the final distance and combine. This is called the final parsec problem. "We can get them very close, but they always stall," says Holley-Bockelmann.

She will be testing the idea that collisions between galaxies that have massive black holes in their cores may create an environment that is particularly conducive to such mergers. For example, one mechanism to get a pair of black holes to merge is to shoot some stars past them. These interloper stars steal some of the energy from the binary orbit, causing the black holes to move closer together. When two galaxies collide they tend to form a squished football shape that can make stars move back and forth through the galactic center, making them repeatedly available to steal energy from black hole pairs.

Holley-Bockelmann will also use part of her grant to support the Fisk-Vanderbilt Master-to-Ph.D. Bridge Program — a partnership with historically black Fisk University designed to encourage underrepresented minorities and women to pursue careers in physics and other sciences. She is following in the footsteps of Associate Professor of Physics and Astronomy Keivan Stassun, who received a CAREER Award in 2004 and used it to start the Bridge program.

In the last five years the program has proven exceptionally successful. It has attracted 31 underrepresented minority students with a retention rate of 97 percent and so is poised to become the nation's top source of Ph.D.s in physics and astronomy awarded to underrepresented minorities. In the last few months, the program has received $3.7 million from several federal programs to support and expand its efforts.

Holley-Bockelmann, who is an adjunct professor at Fisk, will hire two Bridge graduates to assist in her black hole studies. Her grant is also providing "time-release" for a Fisk instructor so he can finish up his doctoral degree. In addition, she is hiring an additional post-doctoral fellow to assist in her black hole studies and a graduate student to serve as a computational guru for the Bridge program. She will also teach a "computational boot camp" for entering graduate students and supervise a program using rocketry to train Fisk students pursuing high school teacher certification which will be field tested in local schools.

"As a first generation college student, and a woman astronomer, it's important for me to help students realize that they can be a scientist no matter where they come from or what they look like, as long as they love science enough to put in the hard work.," Holley-Bockelmann says.

Provided by Vanderbilt University

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