Astrophysicists use X-ray fingerprints to study eating habits of giant black holes

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Georgia Tech astrophysicists have provided an important test of a long-standing theory that describes the extreme physics occurring when matter spirals into massive objects known as black holes. Here, David Ballantyne poses with a NASA illustration of a black hole. Credit: Georgia Tech Photo: Gary Meek

By studying the X-rays emitted when superheated gases plunge into distant and massive black holes, astrophysicists at the Georgia Institute of Technology have provided an important test of a long-standing theory that describes the extreme physics occurring when matter spirals into these massive objects.

Matter falling into black holes emits tremendous amounts of energy which can escape as visible light, ultraviolet light and X-rays. This energy can also drive outflows of gas and dust far from the black hole, affecting the growth and evolution of galaxies containing the black holes. Understanding the complex processes that occur in these active galactic nuclei is vital to theories describing the formation of galaxies such as the Milky Way, and is therefore the subject of intense research.

Though light cannot escape from black holes themselves, black holes with accretion disks – which are swirling clouds of matter about to enter the black hole – are among the most luminous objects in galaxies. By studying how the radiation and accretion disk interact, astrophysicists can learn much about the extreme gravitational fields, magnetic forces and radiation processes close to these black holes.

"We reviewed data collected from space telescopes over the past few years and found that the more rapidly a black hole was gobbling up material, the more highly ionized the accretion disk was," said David Ballantyne, an assistant professor in Georgia Tech's School of Physics. "The simple theory of accretion disks predicts this, but the relationship we saw between the ionization and rate of accretion was different from what the theory predicted."

The large difference between the observed and theoretical relationships – a linear dependence on the rate of accretion as opposed to a cubic dependence – is not surprising for a phenomenon that can't exactly be tested under controlled laboratory conditions. In a paper published online June 3 in *The Astrophysical Journal,* Ballantyne describes the research and speculates about possible reasons for the difference between observations and theory. The research, which will appear in the Journal's June 20 issue, was supported in part by the National Science Foundation (NSF).

"As in many areas of science, especially astronomy, we end up needing more data – many more high-quality observations to better define this relationship," he added.

Astrophysicists don't have a detailed understanding of how the accretion process works, why black holes grow at different rates – or what makes them stop growing. These questions are important because the growth of active galactic nuclei – the black holes and their surrounding accretion disks – has broader effects on the galaxies of which they are part.

"The rapid accretion phase releases a lot of energy, not only in radiation, but also in outflows that drive gas out of a galaxy, which can shut off star formation and hold back the growth of the galaxy," said Ballantyne, a scientist in Georgia Tech's Center for Relativistic Astrophysics. "We could potentially learn something fundamental about the flow of energy through the accretion disk very close to the black hole. We could learn about the viscosity of this matter and how efficiently radiation transport takes place. These are very important questions in astrophysics."

X-rays are believed to originate from innermost portion of active galactic nuclei. As they pass through matter on its way into the black hole, the X-rays are altered by the materials in ways that astrophysicists can measure. In their study, Ballantyne and his collaborators were interested in studying the ionization state of the matter – which is related to the illumination – and were able to do so by analyzing the "fingerprint" the ionization left on the X-rays.

"From laboratory work, we understand the physics of how gas interacts with X-ray radiation because that's basically an atomic physics problem," he explained. "We can model what these fingerprints might look like on the X-rays, and compare that to the actual data to help us understand what's going on."

Because of their high energy and short wavelength, X-rays pass through many materials, such as human bodies, with little attenuation. This makes them ideal for examining processes in active galactic nuclei. Longer wavelengths, such as ultraviolet and visible light, are absorbed by intergalactic dust, or are difficult to distinguish from light originating in stars. However, X-rays do get absorbed by dense objects, such as bones – and crucially for this study – accretion disks.

Ballantyne and his collaborators Jon McDuffie and John Rusin studied ten X-ray observations reported by other scientists from eight different active galactic nuclei. The observations were made using such space telescopes as Chandra and XMM.

To be useful, they used only measurements of X-ray emissions from the innermost and hottest portion of the accretion disk, and only where the mass of the black holes – which range from a million to a billion times the size of our sun – had high quality estimates.

In pursuing the study, Ballantyne hopes to maintain the involvement of Rusin, a student from South Cobb High School in Marietta, near Atlanta. Rusin became involved when he contacted Georgia Tech to inquire about astrophysics projects.

"He helped us with data acquisition and was a really big help," said Ballantyne. "I treated him just like an undergraduate student. I'm pleased to know that he has decided to attend Georgia Tech."

The next step in the research will be to gather additional information from other studies of active galactic nuclei to see if the linear relationship Ballantyne's group measured holds up. The work may also lead to other techniques for learning about black holes and the accretion process.

"Black holes themselves are very simple, but what goes on around them can be very complex," Ballantyne said. "There is still a lot to be learned about how black holes get fueled, and how some accrete slowly while others grow rapidly. The astrophysics of black holes is actually very important in determining what our universe looks like."

Provided by Georgia Institute of Technology

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