Do supermassive black holes merge to form binary systems?

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Penn State Professor of Astronomy and Astrophysics Micheal Eracleous at Kitt Peak National Observatory in Tuscon, Arizona. Credit: Micheal Eracleous

At the center of most galaxies are black holes so massive—up to several billion times the mass of our sun—that they have earned the descriptor "supermassive." Compare this to your run-of-the-mill stellar-mass black hole, a measly 10 to 100 times our sun's mass. Understanding these supermassive black holes will help astronomers understand the origin and evolution of galaxies. One open question is whether they can form binaries.

Stellar-mass black holes form binary systems, two black holes orbiting each other, if they form from the collapse of a binary star system, or possibly when two black holes capture each other in their gravitational pull. They spiral in, eventually merging in an event so powerful that it sends a ripple through space and time known as a gravitational wave. A few years ago, the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves from such an event for the first time.

Theoretically then, the merging of two galaxies could result in a binary black hole of the supermassive variety, but so far astronomers have not unequivocally detected one of these events. Penn State Professor of Astronomy and Astrophysics Michael Eracleous is in the forefront of the hunt.

"About ten years ago, several papers were published claiming to have detected binary supermassive black holes," he said. "I had done some work on binary supermassive black holes as a graduate student, so I felt compelled to embark on a project to gather a lot of data to be able to make a counterpoint to the claims of those papers. Once I got into it, I saw how connected it was to galaxy evolution."

"When I came to Penn State, I knew that the department was a perfect fit for the type of research that I do," he said. "I've made some great connections with my colleagues here, and now I know that if I'm ever stuck, all it takes is a cup of coffee and a conversation to clear things up."

So how do you look for something you've never seen?

"In much of astronomy, observation comes first—we see something and that informs our theory," said Eracleous. "For binary supermassive black holes, theory is driving the observations. Until we find one, the questions are "Should they exist?" and "Should we look for them?" And the answer to both questions is definitely "Yes.'"

A major difference between supermassive black holes and stellar-mass black holes is gas. When stellar-mass black holes form after a star explodes in a supernova, most of the gas is driven away. But supermassive black holes are thought to carry gases with them. These gases emit light signals that can be detected by large telescopes equipped with spectrographs here on Earth, such as the 11-meter Hobby-Eberly Telescope (HET).

Eracleous explained that the gases are detected by the spectrograph as emission lines of a particular wavelength and they could hold the key to identifying a supermassive binary. As the black holes orbit one another, the emission lines from these gases shift due to the Doppler effect. The emission lines from one black hole are shifted to longer wavelengths, and those from the other are shifted to shorter wavelengths. So scientists expect two separate emission lines, one from each black hole.

"If we could follow the emission lines over the course of an orbit, we would see them crossing back and forth as the signals from each black hole shifted one way and then the other," said Eracleous.

Of course, the actual search is not that straightforward. Practicalities like limited availability of time on the large telescopes necessary to make these observations mean astronomers can't just watch and wait to see the telltale signs of a supermassive binary. But they don't need to. Instead, they identify candidates from an initial survey and make regular check-ins to see if the spectra from these candidates have changed as would be expected based on theoretical models.

"Using the Hobby-Eberly Telescope to make these observations makes our life easier because we don't even need to go to the observatory to collect the data," said Eracleous. "The HET is operated by resident astronomers who make the observations and send us the data."

The process is slow, but Eracleous explained that once they find one binary supermassive black hole, the search should accelerate.

"The first confirmed binary supermassive black hole will be like the Rosetta Stone," he said. "It will tell us which of our models were right and which were wrong. It will allow us to refine our next searches and we should be able to find more."

Astronomers are already developing the technology for those next searches. Eracleous is involved in the planning for the Laser Interferometer Space Antenna (LISA). LISA is to LIGO what a supermassive black hole is to a stellar-mass black hole. Where LIGO consists of two four-kilometer-long lasers at right angles to each other, LISA's three spacecrafts will be connected by lasers that travel 2.5 million kilometers forming an equilateral triangle. LISA's scale and the fact that it is space based means that it can detect low-wavelength gravitational waves away from noise sources here on Earth.

"LISA will be tuned to find gravitational waves like those that would result from a supermassive black hole merger," said Eracleous.

For Eracleous, Penn State's Department of Astronomy and Astrophysics has provided the supportive environment necessary for his search.

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