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In a pair of merging supermassive black holes, a new method for measuring the void

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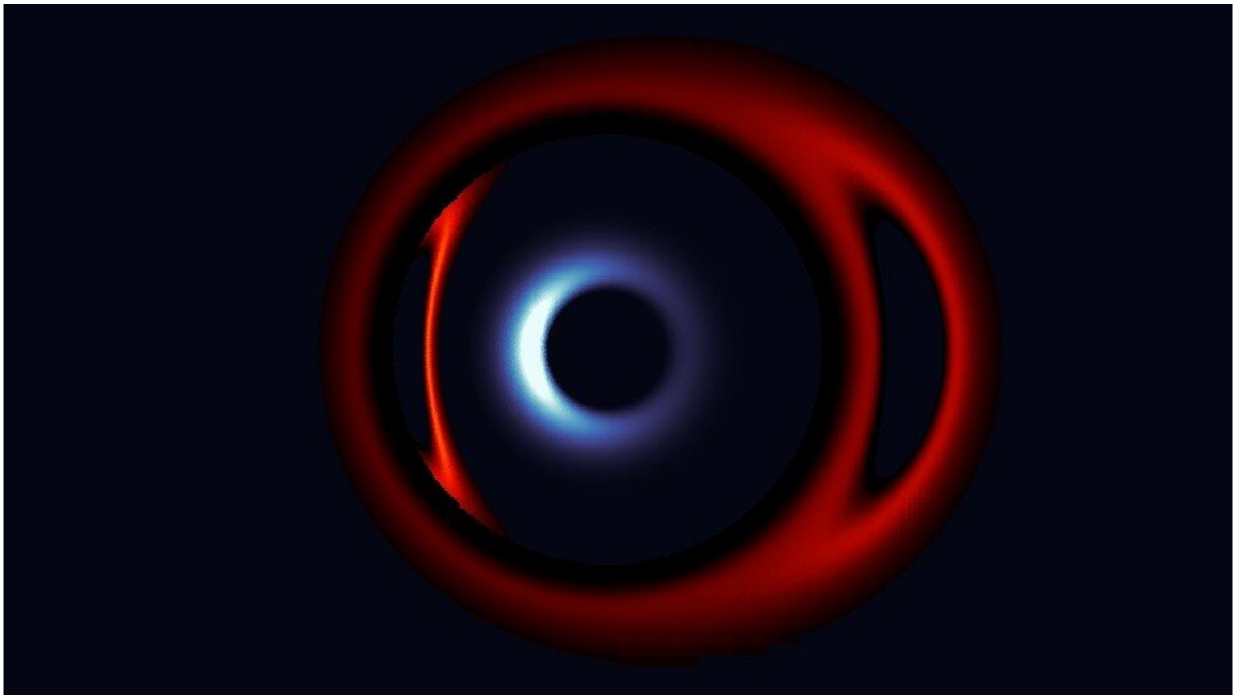


In this simulation of a supermassive black hole merger, the blue-shifted black hole closest to the viewer amplifies the red-shifted black hole in the back through gravitational lensing. The researchers discovered a distinct dip in brightness when the closest black hole passed in front of the shadow of its counterpart, an observation that could be used to measure the size of both black holes and test alternative theories of gravity. Credit: Jordy Davelaar

Three years ago, the first ever image of a black hole stunned the world.

A black pit of nothingness enclosed by a fiery ring of light. That iconic image of the black hole at the center of galaxy Messier 87 came into focus thanks to the Event Horizon Telescope, a global network of synchronized radio dishes acting as one giant telescope.

Now, a pair of Columbia researchers have devised a potentially easier way of gazing into the abyss. Outlined in complementary studies in *Physical Review Letters* and *Physical Review D*, their imaging technique could allow astronomers to study black holes smaller than M87's, a monster with a mass of 6.5 billion suns, harbored in galaxies more distant than M87, which at 55 million light-years away, is still relatively close to our own Milky Way.

The technique has just two requirements. First, you need a pair of supermassive black holes in the throes of merging. Second, you need to be looking at the pair at a nearly side-on angle. From this sideways vantage point, as one black hole passes in front of the other, you should be able to see a bright flash of light as the glowing ring of the black hole farther away is magnified by the black hole closest to you, a phenomenon known as gravitational lensing.

The lensing effect is well known, but what the researchers discovered here was a hidden signal: a distinctive dip in brightness corresponding to the "shadow" of the black hole in back. This subtle dimming can last from a few hours to a few days, depending on how massive the black holes, and how closely entwined their orbits. If you measure how long the dip lasts, the researchers say, you can estimate the size and shape of the shadow cast by the black hole's event horizon, the point of no exit, where nothing escapes, not even light.

"It took years and a massive effort by dozens of scientists to make that high-resolution image of the M87 black holes," said the study's first author, Jordy Davelaar, a postdoc at Columbia and the Flatiron Institute's

Center for Computational Astrophysics. "That approach only works for the biggest and closest black holes—the pair at the heart of M87 and potentially our own Milky Way."

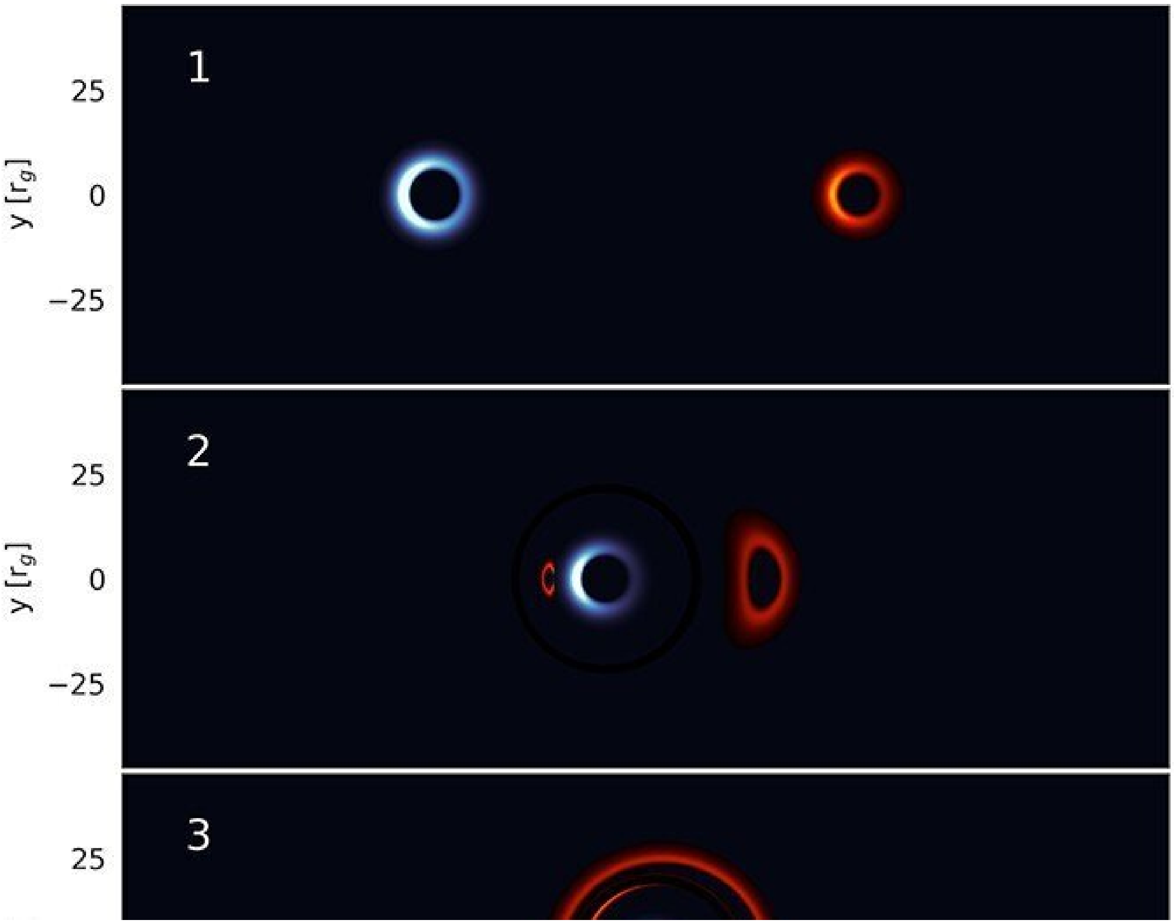
He added, "with our technique, you measure the brightness of the black holes over time, you don't need to resolve each object spatially. It should be possible to find this signal in many galaxies."

The shadow of a black hole is both its most mysterious and informative feature. "That dark spot tells us about the size of the black hole, the shape of the space-time around it, and how matter falls into the black hole near its horizon," said co-author Zoltan Haiman, a physics professor at Columbia.

Black hole shadows may also hold the secret to the true nature of gravity, one of the fundamental forces of our universe. Einstein's theory of gravity, known as general relativity, predicts the size of black holes. Physicists, therefore, have sought them out to test alternative theories of gravity in an effort to reconcile two competing ideas of how nature works: Einstein's general relativity, which explains large scale phenomena like orbiting planets and the expanding universe, and quantum physics, which explains how tiny particles like electrons and photons can occupy multiple states at once.

The researchers became interested in flaring supermassive black holes after spotting a suspected pair of supermassive black holes at the center of a far-off galaxy in the early universe. NASA's planet-hunting Kepler space telescope was scanning for the tiny dips in brightness corresponding to a planet passing in front of its host star. Instead, Kepler ended up detecting the flares of what Haiman and his colleagues claim are a pair of merging black holes.

They named the distant galaxy "Spikey" for the spikes in brightness triggered by its suspected black holes magnifying each other on each full rotation via the lensing effect. To learn more about the flare, Haiman built a model with his postdoc, Davelaar.



In this simulation of a pair of merging supermassive black holes, the black hole closest to the viewer is approaching and thus appears blue (frame 1), amplifying the red-shifted black hole in back through gravitational lensing. As the closest black hole amplifies the light of the black hole farther away (frame 2), the viewer sees a bright flash of light. But when the closest black hole passes in front of the abyss, or shadow, of the farthest black hole, the viewer sees a slight dip in brightness (frame 3). This brightness dip (3) shows up clearly in the light-curve data below the images. Credit: Jordy Devalaar

They were confused, however, when their simulated pair of black holes produced an unexpected, but periodic, dip in brightness each time one orbited in front of the other. At first, they thought it was a coding mistake. But further checking led them to trust the signal.

As they looked for a physical mechanism to explain it, they realized that each dip in brightness closely matched the time it took for the black hole closest to the viewer to pass in front of the shadow of the black hole in back.

The researchers are currently looking for other telescope data to try and confirm the dip they saw in the Kepler data to verify that Spikey is, in fact, harboring a pair of merging black holes. If it all checks out, the technique could be applied to a handful of other suspected pairs of merging supermassive black holes among the 150 or so that have been spotted so far and are awaiting confirmation.

As more powerful telescopes come online in the coming years, other opportunities may arise. The Vera Rubin Observatory, set to open this year, has its sights on more than 100 million supermassive black holes. Further black hole scouting will be possible when NASA's gravitational wave detector, LISA, is launched into space in 2030.

"Even if only a tiny fraction of these black hole binaries has the right conditions to measure our proposed effect, we could find many of these black hole dips," Davelaar said.

More information: Jordy Davelaar et al, Self-Lensing Flares from Black Hole Binaries: Observing Black Hole Shadows via Light Curve Tomography, *Physical Review Letters* (2022). DOI: 10.1103/PhysRevLett.128.191101

Jordy Davelaar et al, Self-lensing flares from black hole binaries:

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Provided by Columbia University

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