Gravitational 'kick' may explain the strange shape at the center of Andromeda

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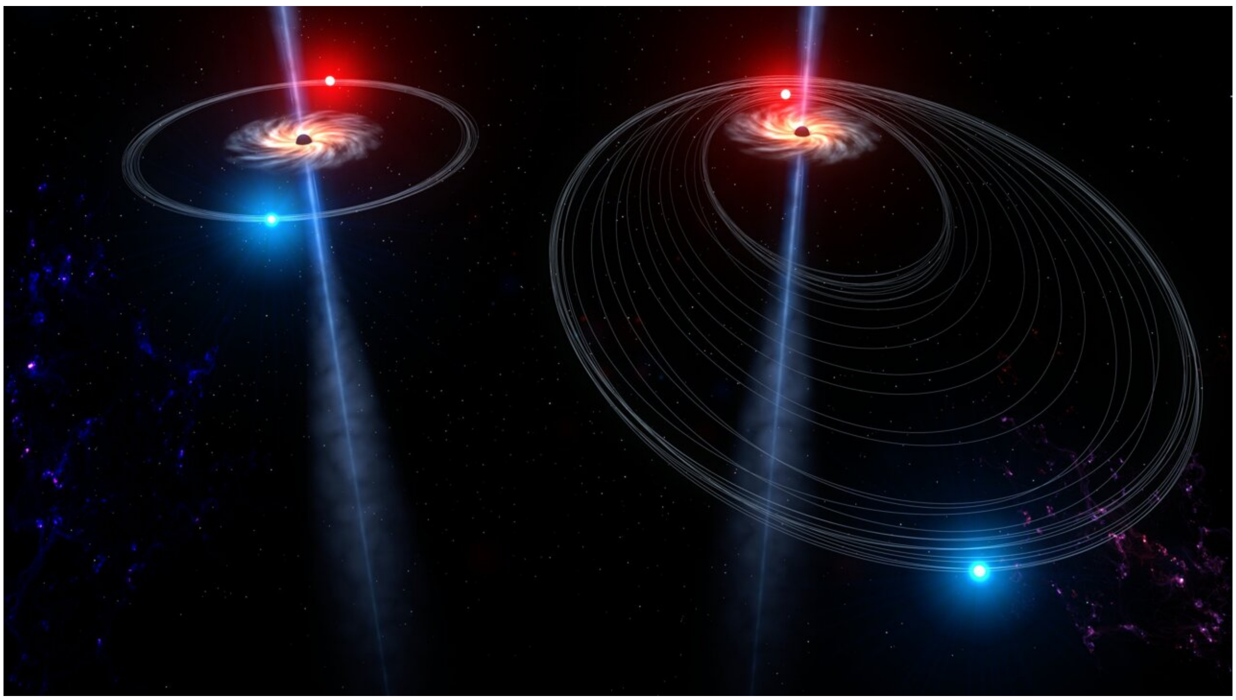

Graphic showing the orbit of stars around a supermassive black hole before, left, and after, right, a gravitational "kick." Credit: Steven Burrows/JILA

When two galaxies collide, the supermassive black holes at their cores release a devastating gravitational "kick," similar to the recoil from a shotgun. New research led by CU Boulder suggests that this kick may be so powerful it can knock millions of stars into wonky orbits.

The research, published Oct. 29 in *The Astrophysical Journal Letters*, helps solve a decades-old mystery surrounding a strangely-shaped cluster of stars at the heart of the Andromeda Galaxy. It might also help researchers better understand the process of how galaxies grow by feeding on each other.

"When scientists first looked at Andromeda, they were expecting to see a supermassive black hole surrounded by a relatively symmetric cluster of stars," said Ann-Marie Madigan, a fellow of JILA, a joint research institute between CU Boulder and the National Institute of Standards and Technology (NIST). "Instead, they found this huge, elongated mass."

Now, she and her colleagues think they have an explanation.

In the 1970s, scientists launched balloons high into Earth's atmosphere to take a close look in ultraviolet light at Andromeda, the galaxy nearest to the Milky Way. The Hubble Space Telescope followed up on those initial observations in the 1990s and delivered a surprising finding: Like our own galaxy, Andromeda is shaped like a giant spiral. But the area rich in stars near that spiral's center doesn't look like it should—the orbits of these stars take on an odd, ovalish shape like someone stretched out a wad of Silly Putty.

And no one knew why, said Madigan, also an assistant professor of astrophysics. Scientists call the pattern an "eccentric nuclear disk."

In the new study, the team used computer simulations to track what happens when two supermassive black holes go crashing together—Andromeda likely formed during a similar merger billions of years ago. Based on the team's calculations, the force generated by such a merger could bend and pull the orbits of stars near a galactic center, creating that telltale elongated pattern.

"When galaxies merge, their supermassive black holes are going to come together and eventually become a single black hole," said Tatsuya Akiba, lead author of the study and a graduate student in astrophysics. "We wanted to know: What are the consequences of that?"

Bending space and time

He added that the team's findings help to reveal some of the forces that may be driving the diversity of the estimated two trillion galaxies in the universe today—some of which look a lot like the spiral-shaped Milky Way, while others look more like footballs or irregular blobs.

Mergers may play an important role in shaping these masses of stars: When galaxies collide, Akiba said, the black holes at the centers may begin to spin around each other, moving faster and faster until they eventually slam together. In the process, they release huge pulses of "gravitational waves," or literal ripples in the fabric of space and time.

"Those gravitational waves will carry momentum away from the remaining black hole, and you get a recoil, like the recoil of a gun," Akiba said.

He and Madigan wanted to know what such a recoil could do to the stars within 1 parsec, or roughly 19 trillion miles, of a galaxy's center. Andromeda, which can be seen with the naked eye from Earth, stretches tens of thousands of parsecs from end to end.

It gets pretty wild.

Galactic recoil

The duo used computers to build models of fake galactic centers containing hundreds of stars—then kicked the central black hole to simulate the recoil from gravitational waves.

Madigan explained the gravitational waves produced by this kind of disastrous collision won't affect the stars in a galaxy directly. But the recoil will throw the remaining supermassive black hole back through space—at speeds that can reach millions of miles per hour, not bad for a body with a mass millions or billions of times greater than that of Earth's sun.

"If you're a supermassive black hole, and you start moving at thousands of kilometers per second, you can actually escape the galaxy you're living in," Madigan said.

When black holes don't escape, however, the team discovered they may pull on the orbits of the stars right around them, causing those orbits to stretch out. The result winds up looking a lot like the shape scientists see at the center of Andromeda.

Madigan and Akiba said they want to grow their simulations so they can directly compare their computer results to that real-life galaxy core—which contains many times more stars. They noted their findings might also help scientists to understand the unusual happenings around other objects in the universe, such as planets orbiting mysterious bodies called neutron stars.

"This idea—if you're in orbit around a central object and that object suddenly flies off—can be scaled down to examine lots of different systems," Madigan said.

More information: Tatsuya Akiba et al, On the Formation of an Eccentric Nuclear Disk following the Gravitational Recoil Kick of a Supermassive Black Hole, *The Astrophysical Journal Letters* (2021).

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