The black hole always chirps twice: Scientists find clues to decipher the shape of black holes

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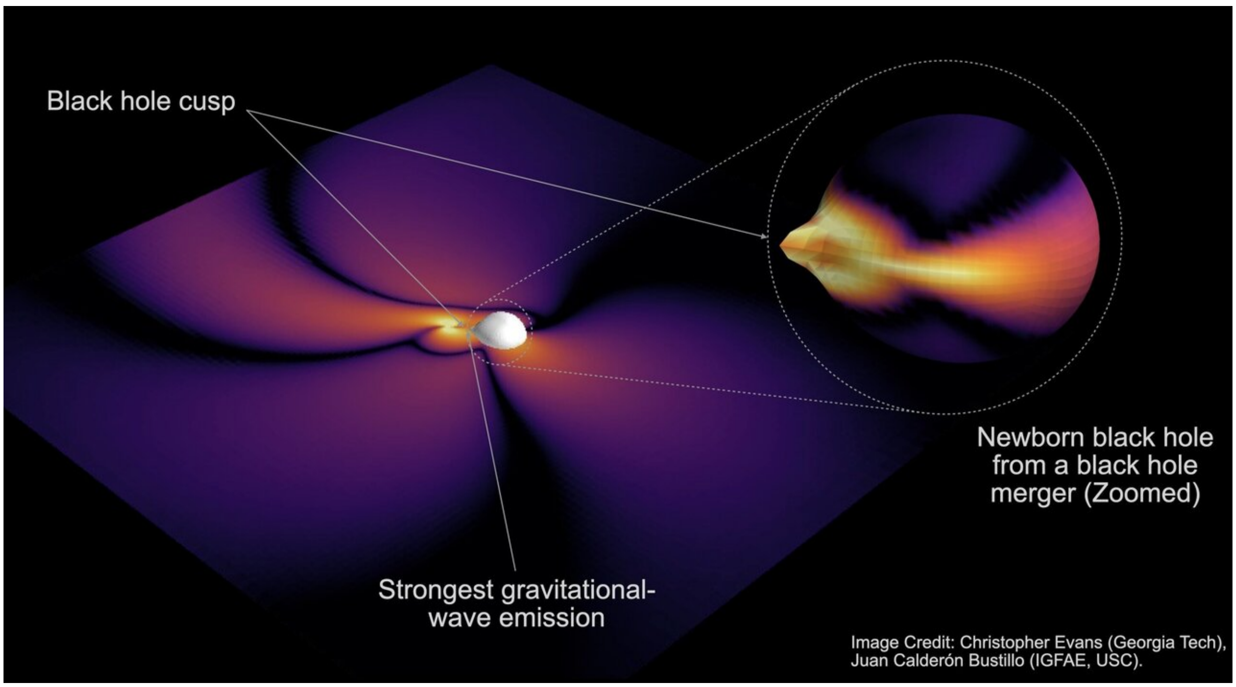

Black hole cusp. Credit: ARC Centre of Excellence for Gravitational Wave Discovery

A team of gravitational wave researchers led by the ARC Center of Excellence for Gravitational Wave Discovery (OzGrav) report that when two black holes collide and merge, the remnant black hole "chirps" not once, but multiple times, emitting gravitational waves—intense ripples in the fabric space and time—that reveal information about its shape. Their study has been published in *Communications Physics*.

Black holes are among the most fascinating objects in the universe. At their surface, known as the event horizon, gravity is so strong that not even light can escape. Usually, black holes are silent objects that swallow anything that falls too closely to them; however, when two black holes collide and merge, they produce one of the most catastrophic events in universe: In a fraction of a second, a highly deformed black hole forms and releases tremendous amounts of energy as it settles to its final state. This phenomenon gives astronomers a unique chance to observe rapidly changing black holes and explore gravity in its most extreme form.

Although colliding black holes do not produce light, astronomers can observe the detected gravitational waves they create—ripples in the fabric of space and time. Scientists speculate that, after a collision, the behavior of the remnant black hole is key to understanding gravity and should be encoded in the emitted gravitational waves.

In the article published in *Communications Physics*, the scientists, led by OzGrav alumnus Prof. Juan Calderón Bustillo, reports how gravitational waves encode the shape of merging black holes as they settle into their final form.

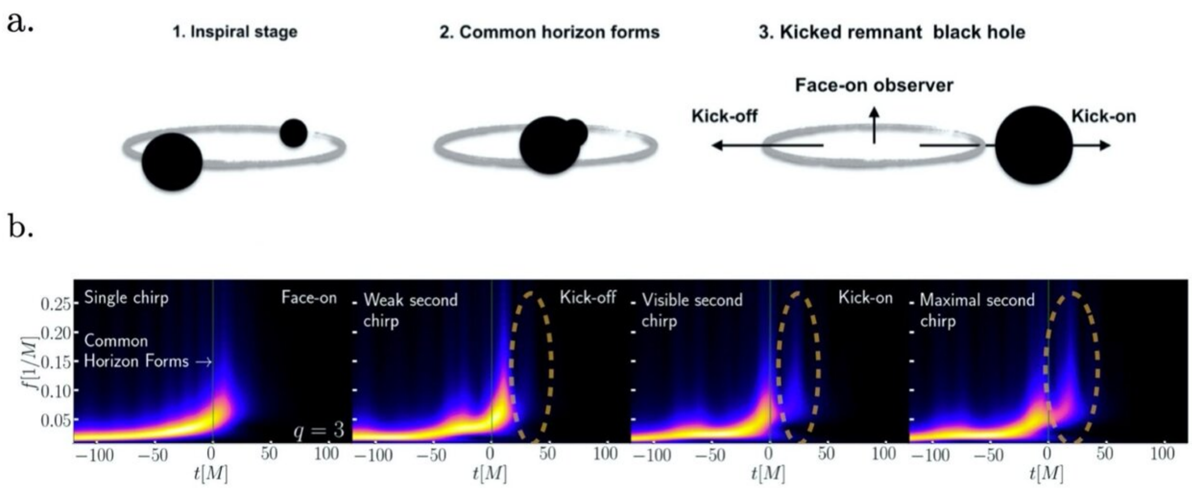

Fig. 1. a: The stages of a black hole merger. First, both black holes orbit each other, slowly approaching, during the inspiral stage.. Second the two black holes merge, forming a distorted black hole. Finally, the black hole reaches its final form. b: Frequency of the gravitational-wave signals observed from the top of the collision (leftmost) and from various positions on its equator (rest) as a function of time. The first signal shows the typical “chirping” signal, in which the frequency raises as a function of time. The other three show that, after the collision (at t=0) the frequency drops and rises again, producing a second “chirp”. Credit: C. Evans, J. Calderón Bustillo

Graduate student and co-author Christopher Evans from the Georgia Institute of Technology (U.S.) says, "We performed simulations of black-hole collisions using supercomputers and then compared the rapidly changing shape of the remnant black hole to the gravitational waves it emits. We discovered that these signals are far more rich and complex than commonly thought, allowing us to learn more about the vastly changing shape of the final black hole."

The gravitational waves from colliding black holes are simple signals known as "chirps." As the two black holes approach each other, they emit a signal of increasing frequency and amplitude that indicates the speed and radius of the orbit. Prof. Calderón Bustillo says, "The pitch and amplitude of the signal increases as the two black holes approach faster and faster. After the collision, the final remnant black hole emits a signal with a constant pitch and decaying amplitude—like the sound of a bell being struck." This principle is consistent with all gravitational-wave observations so far when studying the collision from the top.

However, the study found something completely different happens if the collision is observed from the "equator" of the final black hole. "When we observed black holes from their equator, we found that the final black hole emits a more complex signal, with a pitch that goes up and down a few times before it dies," says Prof. Calderón Bustillo. "In other words, the black hole actually chirps several times."

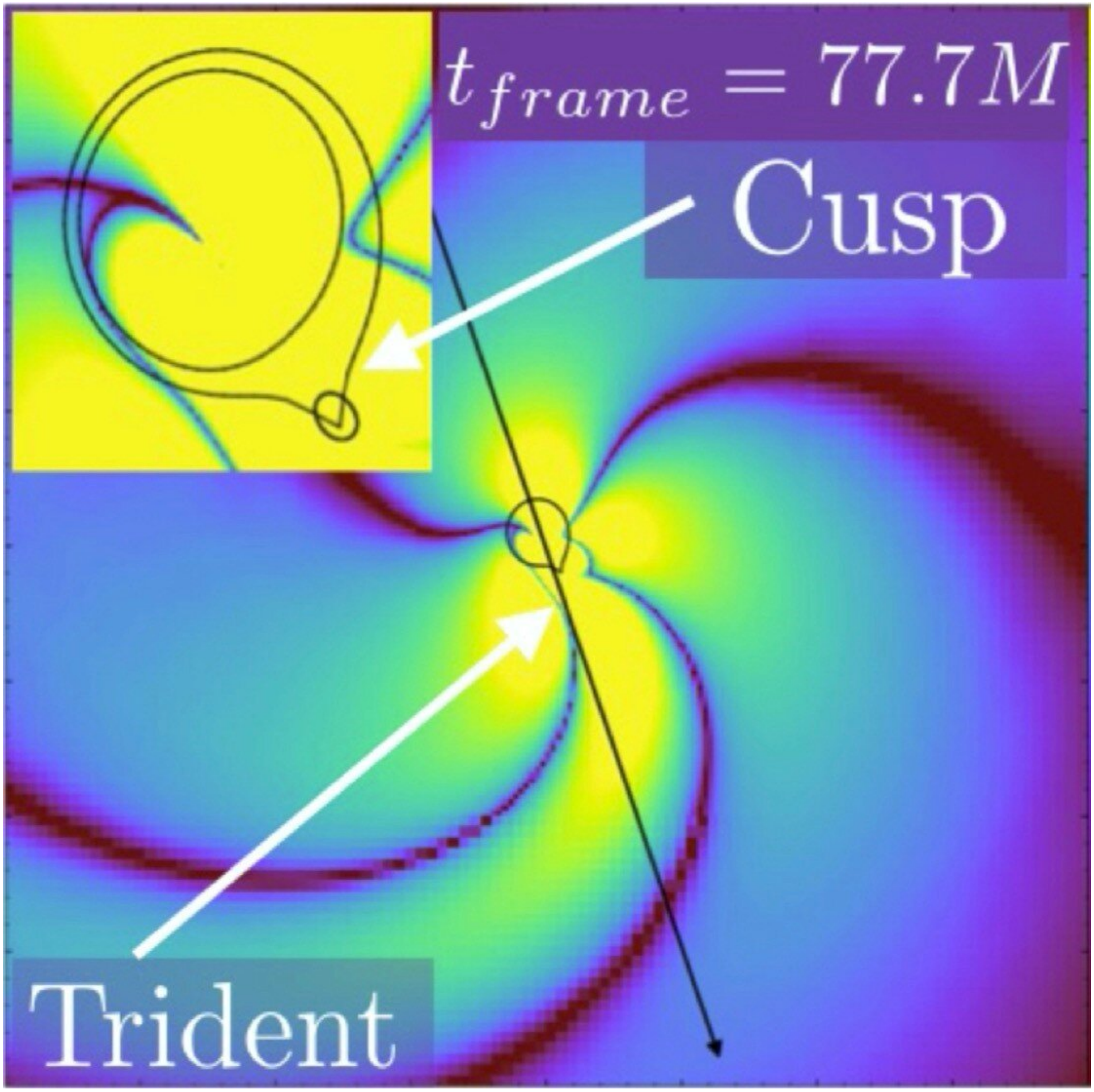

Fig. 2. Detail of the shape of the remnant black hole after a black hole collision, with a 'chestnut shape'. Regions of strong gravitational-wave emission (in yellow) cluster near its cusp. This black hole spins making the cusp point to all observers around it. Credit: C. Evans, J. Calderón Bustillo

The team discovered that this is related to the shape of the final black hole, which acts like a kind of gravitational-wave lighthouse: "When the two original parent black holes are of different sizes, the final black hole initially looks like a chestnut, with a cusp on one side and a wider, smoother back on the other," says Bustillo. "It turns out that the black hole emits more intense gravitational waves through its most curved regions, which are those surrounding its cusp. This is because the remnant black hole is also spinning and its cusp and backside repeatedly point to all observers, producing multiple chirps."

Co-author Prof. Pablo Laguna, former chair of the School of Physics at Georgia Tech and now professor at the University of Texas at Austin, said, "While a relation between the gravitational waves and the behavior of the final black hole has been long conjectured, our study provides the first explicit example of this kind of relation."

More information: *Communications Physics* (2020). 10.1038/s42005-020-00446-7

Provided by ARC Centre of Excellence for Gravitational Wave Discovery