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DISPATCH · BLACK HOLE RINGDOWN · 2 MIN

# Direct waves in black hole ringdowns are of limited use as probes of the event horizon

Simulated black hole mergers show a prompt 'direct wave' in the ringdown signal, but its frequency deviates from the horizon value, limiting its use as a probe of the horizon.

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Photo: Nasa Hubble Space Telescope

When two black holes spiral together and merge, the gravitational waves they emit end in a phase called the ringdown, as the newly formed black hole settles down. That part of the signal is usually described in terms of quasinormal modes, the characteristic tones a disturbed black hole rings with, much as a struck bell has its own pitch. A study by Richard Dyer, Adrian Ka-Wai Chung and Christopher J. Moore, published in Physical Review Letters in 2026, examines a second ingredient that sits alongside those tones: the direct wave.

The direct wave, as the authors describe it, is a prompt signal that propagates from the plunging object to the observer, and it exists alongside the quasinormal modes in the ringdown. It has been suggested that its properties are tied to the event horizon, the boundary beyond which nothing can escape. If that link held, it would bring two benefits: the direct wave would be simpler to model, and it might offer a new observational handle on the shape of the horizon.

The paper puts that idea, which the authors call the horizon mode model, to the test. Rather than using detector data, they work with numerical-relativity waveforms, simulated gravitational-wave signals obtained by solving Einstein's equations of gravity numerically. To pull the direct wave out of these signals, they adapt techniques originally developed for studying quasinormal modes.

The results cut both ways. According to the study, the direct wave can be identified across a range of ringdown start times, the point from which an analyst chooses to treat the signal as ringdown. The authors present this as a demonstration that the horizon mode model is useful. But the direct wave's frequency does not match the value the event horizon would set; it deviates from it. That mismatch, the authors conclude, limits how far the direct wave can serve as a probe of the horizon.

The abstract leaves several questions open. It does not say how large the frequency deviation is, how many simulated mergers were analysed, or which combinations of black hole masses and spins they cover, so it is not possible to judge from it whether the mismatch is uniform or depends on the system. The work is also based entirely on simulations rather than on signals recorded by gravitational-wave observatories. What it does establish is narrower but concrete: the direct wave appears to be a real, identifiable feature of simulated ringdowns, while its frequency does not track the horizon value as neatly as had been suggested.


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