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Observation of a multimode quasi-normal spectrum from a perturbed black hole

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When two black holes merge, the late stage of gravitational wave emission is a superposition of exponentially damped sinusoids. According to the black hole no-hair theorem, this ringdown spectrum depends only on the mass and angular momentum of the final black hole. An observation of more than one ringdown mode can test this fundamental prediction of general relativity. Here we provide strong observational evidence for a multimode black hole ringdown spectrum using the gravitational wave event GW190521, with a Bayes factor of ~ 40 preferring two fundamental modes over one. The dominant mode is the $\ell=m=2$ harmonic, and the sub-dominant mode corresponds to the $\ell=m=3$ harmonic. We estimate the redshifted mass and dimensionless spin of the final black hole as 330^{+30}_{-40} Solar masses and $0.87^{+0.05}_{-0.10}$ respectively. The detection of the two modes disfavors a binary progenitor with equal masses; the mass ratio is constrained to $0.4^{+0.2}_{-0.3}$. We find that the final black hole is consistent with the no hair theorem and constrain the fractional deviation from general relativity of the sub-dominant mode's frequency to be $-0.01^{+0.07}_{-0.11}$.

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