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Inspiral-merger-ringdown waveforms in Einstein-scalar-Gauss-Bonnet gravity within the effective-one-body formalism

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Gravitational waves (GWs) provide a unique opportunity to test general relativity (GR) in the highly dynamical strong-field regime. So far, the majority of the tests of GR with GW signals have been carried out following parametrized, theory-independent approaches. An alternative avenue consists in the development of inspiral-merger-ringdown (IMR) waveform models in specific beyond-GR theories of gravity, by combining analytical and numerical-relativity results. In this work, we provide the first example of a full IMR waveform model in a beyond-GR theory, focusing on Einstein-scalar-Gauss-Bonnet (ESGB) gravity, a theory that has attracted particular attention due to its rich phenomenology for binary black-hole (BH) mergers, thanks to the presence of non-trivial scalar fields. Starting from the state-of-the-art, effective-one-body (EOB) multipolar waveform model for spin-precessing binary BHs SEOBNRv5PHM, we add theory-specific corrections to the EOB Hamiltonian, the GW and scalar energy fluxes, the GW modes, the quasi-normal-mode spectrum and the mass and spin of the remnant BH. We also propose a way to marginalize over the uncertainty in the merger morphology with additional nuisance parameters. By performing Bayesian parameter estimation for the GW events GW190412, GW190814 and GW230529, we are able to place constraints on the fundamental coupling of the theory and to perform Bayesian model selection between ESGB and GR. Our model can be used to improve constraints on modifications of GR with upcoming GW observations, and to provide forecasts for next-generation GW detectors on the ground, such as the Einstein Telescope and Cosmic Explorer.

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