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Classification of g-modes in hybrid neutron stars with sharp phase transitions: novel universal relations for twin stars

We present a systematic analysis of gravity modes (g-modes) in hybrid neutron stars undergoing a sharp first-order phase transition from hadronic to quark matter, modeled using a Maxwell construction. The equation of state is built from the BPS model for the outer crust, smoothly matched to the SLy model in the inner crust and outer core, and finally to a constant-speed-of-sound (CSS) parametrization for the quark matter phase. This approach allows us to explore a wide range of hybrid equations of state that support the existence of twin stars. We compute the g-mode frequencies within the relativistic Cowling approximation, specifically considering the slow phase conversion regime associated with the first-order phase transition. Our results demonstrate that g-modes are highly sensitive to the properties of the phase transition, particularly the jump in energy density at the interface. Adopting a classification scheme introduced in previous works, we organize the equations of state into four categories based on their macroscopic features and transition parameters. Each category exhibits characteristic trends in mass–radius relations, tidal deformabilities, and g-mode frequencies. Most notably, we identify and validate new universal relations that link the g-mode frequency to combinations of stellar observables and transition parameters, such as compactness, tidal deformability, and the relative energy density discontinuity. These universal trends hold across all categories, suggesting a powerful tool for constraining the microphysics of dense matter using future gravitational wave observations of oscillating compact stars.

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