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Gravitational-wave Tomography of the Moon: Constraining Lunar Structure with Calibrated Gravitational Waves

The recent success of gravitational-wave (GW) astronomy together with renewed plans for lunar geophysical instrumentation has revived interest in using the Moon as a resonant detector for mid-frequency (mHz-Hz) GWs. In realistic observational scenarios, the GW strain amplitude is expected to be constrained independently by networks of GW detectors, which motivates an inverse, tomographic question: to what extent can measurements of the Moon's seismic response to known GWs be used to infer its internal structure? In this work, we develop a first-principles, perturbative framework that maps spherically symmetric perturbations of the elastic and density structure to measurable changes in observables, especially GW-driven modal amplitudes of the Moon. The formalism combines (i) a normal-mode representation of the elastic response, (ii) first-order perturbation theory for eigenvalues and eigenfunctions, and (iii) a linearized observation model that links frequency and amplitude observables to model parameters (bulk and shear moduli, density, and interface locations) and their perturbations. We show that the estimation errors of the Moon's elastic parameters can be reduced by about an order of magnitude with observations of calibrated GWs.

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