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A Numerical Framework for Seismic and Suspension Thermal Noise Modelling in Advanced and Next-Generation Gravitational-Wave Detectors

Seismic and suspension thermal noise set fundamental limits on the low-frequency sensitivity of ground-based gravitational-wave detectors. The aim of this work was to develop a Python-based numerical framework capable of modelling these noise sources in a manner consistent with published noise sensitivity budgets for Advanced LIGO and other ground-based detectors. Transfer-function models were implemented to estimate seismic and suspension thermal noise contributions using frequency-domain and spectral analysis techniques. Fused-silica suspension fibres were represented using a simplifying segmentation approach, in which the fibre was divided into uniform-width sections, enabling efficient estimation of oscillation modes, material loss mechanisms, thermoelastic noise, and horizontal–vertical coupling. Thermal noise estimates were obtained using the fluctuation–dissipation theorem, with additional corrections accounting for wire flexure and effective oscillation-length effects. Model outputs were validated through comparison with published Advanced LIGO noise budget curves, showing good agreement across the relevant frequency range. The modular structure of the framework allowed systematic exploration of key suspension design parameters, including fibre geometry and test-mass properties, and enabled extension to representative configurations for advanced and next-generation detectors, including A# and Cosmic Explorer.

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