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Detectability of the phase transition gravitational waves in the DFSZ axion model

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In recent years, an increasing number of studies have focused on using gravitational waves to explore axions and the dynamics of Peccei-Quinn symmetry breaking at high energy scales in the early universe. To accurately quantify the capability of specific gravitational wave experiments to probe the axion properties, it is crucial to perform precise calculations of gravitational wave signals based on given axion models and to conduct detailed detectability analysis tailored to the experimental configurations. Therefore, in this work, we consider the widely-studied DFSZ axion model and, for the first time, perform precise calculations of the phase transition dynamics parameters and associated gravitational wave signals. Our results demonstrate that the DFSZ model allows a strong first-order phase transition for the Peccei-Quinn symmetry-breaking process at high energy scales exceeding 10^9 GeV. Moreover, by calculating the signal-to-noise ratio of the gravitational waves and comparing it with the thresholds of the Cosmic Explorer detector, we find that these signals are observable by the Cosmic Explorer with the energy scale range from 10^9 GeV to 10^{12} GeV. Notably, through Fisher Matrix analysis, we find that if Cosmic Explorer detectors observe these gravitational waves, the bubble wall velocity will be the first parameter to be determined. This study demonstrates that gravitational wave detection offers a powerful approach to investigating axion dynamics complementary to other experiments.

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