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The effect of quantum decoherence on inflationary gravitational waves

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The theory of inflation provides a mechanism to explain the structures we observe today in the Universe, like, e.g., the Cosmic Microwave Background (CMB) anisotropies, starting from quantum-mechanically generated fluctuations. However, this leaves us with the unanswered question: how did the quantum-to-classical transition, which leads to such structures, occur? During inflation, tensor perturbations interact (at least gravitationally) with other fields, meaning that we need to view these perturbations as an open system that interacts with an environment. In this paper, the evolution of the system is described using a Lindblad equation, leading to the quantum decoherence of the system, which is a possible mechanism to explain the quantum-to-classical transition. We show that this quantum decoherence leads to a scale-dependent increase of the gravitational wave power spectrum, depending on the strength and time dependence of the interaction between the system and the environment. By using current upper bounds on the gravitational wave power spectrum from inflation, obtained from CMB and the LIGO-Virgo-KAGRA constraints, we find an upper bound on the interaction strength. Furthermore, we compute the decoherence criterion, which indicates the minimal interaction strength needed for a specific scale to have successfully decohered by the end of inflation, therefore looking at which scales relic quantum signatures (beyond decoherence) might have survived. Assuming that the CMB modes have completely decohered, this gives a lower bound on the interaction strength. In addition, we look at which scales might not have fully decohered and could still show some quantum signatures. Lastly, we use sensitivity forecasts to study how future gravitational-wave detectors, such as LISA and ET, could constrain the parameter space. Due to the scale-dependence of the power spectrum, LISA could only have a very small impact. However, ET will be able to significantly improve our current constraints for specific scenarios.

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