NON-LINEAR DYNAMICS AND PRIMORDIAL BLACK HOLE FORMATION DURING KINATION

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The physics of the early universe may have included phases that differ from the standard radiation-dominated picture, with important consequences for the growth of fluctuations and the formation of compact objects. One such phase is kination, in which the expansion is driven by the kinetic energy of a scalar field. During kination, the evolution of density perturbations is altered in a scale-dependent way, potentially leading to strong non-linear effects and gravitational collapse.

In this work, the evolution of the scalar perturbations during a kination-dominated era was studied by solving the fully non-linear Einstein equations using numerical relativity. The dynamics of both sub-horizon and super-horizon perturbations were followed to identify the regimes where linear theory remains valid and where non-linear behaviour becomes essential.

Sub-horizon modes were well described by perturbative methods. Super-horizon perturbations were found to undergo significant non-linear growth, and in some cases lead to gravitational collapses and the formation of primordial black holes. Physical initial conditions required for such collapses were found numerically. These conditions have significant implications for primordial black hole production and post-inflationary reheating scenarios. The results highlight the importance of non-linear gravitational dynamics in non-standard cosmological epochs and provide a concrete framework for assessing the observable consequences.

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[1] C. Cheng, P. Giannadakis, L. Heurtier, and E. A. Lim, “Non-linear Dynamics and Primordial Black Hole Formation During Kination,” arXiv.org, 2025. https://arxiv.org/abs/2507.19166 (accessed Feb. 07, 2026).