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QCD axion mass prediction from Adaptive Mesh Refinement simulations

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If the PQ symmetry is broken after inflation then the QCD axion mass that gives rise to the observed dark matter (DM) abundance can in principle be calculated precisely. In practice it remains a computational challenge to accurately predict the DM contribution from nonlinear features of the PQ field such as axion strings, which introduce a large hierarchy of scales between their width and the Hubble length. In this work we employ adaptive mesh refinement (AMR) to simulate the post-inflationary axion field beginning before the PQ phase transition and into the scaling regime, building off of the framework of Buschmann et al. Nature Commun. 2022, which predicted the axion mass to be in the range (40,180) microelectronvolts. We improve the accuracy and precision of the mass prediction by running larger simulations further into the scaling regime and by closely examining sources of systematic uncertainty. For example, for the first time we account for axions produced during domain wall formation and string-network collapse using the AMR simulation framework. Our work leads to a narrow axion mass prediction that directly informs experiments such as ADMX, HAYSTAC, MADMAX, and ALPHA, which target axion DM in the mass range of interest. Moreover, our work helps determine the relevant initial conditions for investigating small-scale structure formation in the post-inflationary scenario.

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