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(Non-)Perturbative Dynamics of Light QCD Axion Cosmologies

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The QCD axion, which solves the strong CP problem and constitutes a dark matter candidate, remains one of the most motivated signals of physics beyond the Standard Model. In the canonical scenario, the QCD axion mass-coupling relation fixes the interaction strength below the reach of most experiments, which target lighter or more strongly coupled axions. However, no fundamental principle demands this canonical relation. If a light QCD axion were discovered, the so-called Z_N model—invoking N exact Standard Model copies coupled by the QCD axion—would be one of the few natural explanations. Yet in a Z_N scenario only a fraction of the possible cosmological evolutions yield a solution to the strong CP problem—first assumed to be 1/N. Moreover, these scenarios are generically susceptible to non-perturbative dynamics that modify the axion relic abundance. The dynamics we uncover are expected to play a similar role in other light-axion cosmologies, including tuned Z_N models. We present the first perturbative statistical treatment of the CP-solution probability, and the first non-perturbative lattice simulations for the Z_N axion. Together, they reveal a significant reduction in the probability of solving the strong CP problem relative to the 1/N expectation, and an O(1) suppression of the axion dark matter abundance.

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