

WIMP Meets ALP: Coherent Freeze-Out of Dark Matter

The microscopic nature of dark matter is the major open question in science. Weakly-Interacting Massive Particles (WIMPs) and Axion-Like Particles (ALPs) are the two most theoretically motivated dark matter candidates. Thousands of papers consider them separately. We point out that if both species are present in the theory, even a tiny (Planck-suppressed) interaction between them could lead to drastic modifications of their dynamics in the early universe.

Specifically, we consider the cosmological history of a fermionic WIMP coupled to a light ALP via a quadratic coupling. Although the coupling is too feeble to thermalize the ALP, coherent forward scattering between the two sectors induces temperature-dependent mass shifts that substantially modify both WIMP freeze-out and ALP misalignment dynamics, giving rise to a novel coherent freeze-out mechanism. At high temperatures, the WIMP thermal bath spontaneously breaks the symmetry of the ALP potential, displacing the field to a new vacuum. The resulting back-reaction reduces the WIMP effective mass and significantly delays its freeze-out. Depending on the strength of the coupling, symmetry restoration occurs via either a first-order phase transition (FOPT) or a crossover. In the FOPT regime, dark matter consists solely of WIMPs, whose delayed freeze-out permits annihilation cross sections up to three orders of magnitude above the standard value, while still yielding the correct relic density. In the crossover regime, both WIMP and ALP can contribute to dark matter. Remarkably, we find an “ALP miracle”: a Planck-suppressed quadratic coupling yields an ALP abundance comparable to the observed dark matter density, largely independent of its initial displacement and mass.

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