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From Stringy Compactifications to Dark Universe: A "Two Birds, One Stone" Approach

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String compactifications generically predict the presence of light scalar moduli, whose late-time coherent oscillations and decay induce an early matter-dominated era, often in tension with constraints from Big Bang Nucleosynthesis (BBN) and Cosmic Microwave Background (CMB) observations. Their decay can both reheat the visible sector and populate hidden sectors, potentially contributing to the dark radiation abundance. In this work, we investigate scenarios where moduli decay into both Standard Model and hidden-sector particles occurs sufficiently early to avoid these conflicts, while simultaneously contributing to the dark radiation abundance, typically parameterized as extra relativistic degrees of freedom, ΔNeff. We construct and solve a system of coupled Boltzmann equations describing modulus decay channels into visible and hidden sectors —particularly axions—and employ a phase-space–based numerical approach to compute the resulting ΔNeff with high precision which can be measured by upcoming CMB stage-4 measurements and any deviations can be detected. In effect, we try to solve Cosmological Moduli Problem as well as the stringent bounds on ΔNeff by one decay mechanism which we study in detail, lepton-photon axion interaction after modulus thermal decays into SM particles. Thus, choosing a unified approach to both longstanding problems and connecting ultraviolet string theory dynamics to precision cosmological probes.

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