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Probing Physics Beyond the Standard Model: Limits from BBN and the CMB Independently and Combined

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We present new Big Bang Nucleosynthesis (BBN) limits on the cosmic expansion rate or relativistic energy density, quantified via the number N_ν of equivalent neutrino species. We use the latest light element observations, neutron mean lifetime, and update our evaluation for the nuclear rates d + d $\longrightarrow$ ^{3}He + n and d + d $\longrightarrow$ ^{3}H + p. Combining this result with the independent constraints from the cosmic microwave background (CMB) yields tight limits on new physics that perturbs N_ν and the baryon-to-photon ratio η prior to cosmic nucleosynthesis: a joint BBN+CMB analysis gives N_ν = 2.898 ± 0.141, resulting in N_ν < 3.180 at 2σ. The strength of the independent BBN and CMB constraints now opens a new window: we can search for limits on potential *changes* in N_ν and/or η between the two epochs. The present data place strong constraints on the allowed changes in N_ν between BBN and CMB decoupling; for example, we find -0.708 $< N_\nu^{\rm CMB} - N_\nu^{\rm BBN} <$ 0.328 in the case where η and the primordial helium mass fraction Y_p are unchanged between the two epochs; we also give limits on the allowed variations in η or in (η, N_ν) jointly. We discuss scenarios in which such changes could occur. Looking to the future, we forecast the tightened precision for N_ν arising from both CMB Stage 4 measurements as well as improvements in astronomical ^{4}He measurements. We find that CMB-S4 combined with present BBN and light element observation precision can give $\sigma(N_\nu) \simeq$ 0.03. Such future precision would reveal the expected effect of neutrino heating ($N_{\rm eff}$ - 3 = 0.044) of the CMB during BBN, and would be near the level to reveal any particle species ever in thermal equilibrium with the standard model. Improved Y_p measurements can push this precision even further.

Keyword-1

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Keyword-2

Cosmology

Keyword-3

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