ISSN No:-2456-2165

Revisiting Primordial Nucleosynthesis: Implications For Light Element Abundances in Alternative Cosmological Models

Ujjal Adhikary
Kalasalingam University Tamil Nadu India

Abstract:- Primordial nucleosynthesis is one of the key pillars of the Big Bang theory, successfully predicting the relative abundances of light elements such as hydrogen, helium, and lithium. However, discrepancies between predicted and observed lithium abundances (the "lithium problem") have persisted, prompting investigations into alternative cosmological models. This paper explores the implications of varying the conditions of early-universe expansion, baryon density, and neutrino decoupling in non-standard Big Bang scenarios. Using modified cosmological parameters, we analyze their effects on primordial nucleosynthesis through simulations, offering potential resolutions to the lithium problem while preserving the success of hydrogen and helium predictions.

I. INTRODUCTION

A. The Standard Big Bang Model

The Big Bang theory provides a framework for understanding the universe's origin and evolution. One of its critical successes is its ability to predict the relative abundances of light elements through Big Bang Nucleosynthesis (BBN).

B. The Lithium Problem

Despite the agreement between observed and predicted abundances of hydrogen and helium isotopes, the observed lithium-7 abundance is consistently lower than predictions by a factor of 2–3. This discrepancy has led to questions about the completeness of standard cosmological models.

C. Research Objective

This paper investigates whether alternative cosmological conditions—such as altered expansion rates, varying baryon densities, or delayed neutrino decoupling—can reconcile BBN predictions with observations.

II. METHODOLOGY

➢ *Computational Framework*

We utilized a modified version of the BBN code *PArthENoPE* to simulate light element abundances under varying cosmological parameters.

➢ *Parameters Analyzed*

- **Expansion Rate Variations**: Introducing a parameterized effective number of relativistic species, NeffN_{\text{eff}} Neff, to account for potential unknown particles or energy.
- **Baryon-to-Photon Ratio**: Adjusting the baryon density parameter (ηb\eta_bηb) to test its impact on element synthesis.
- **Neutrino Decoupling**: Introducing delayed neutrino decoupling scenarios to alter early thermal history.

➢ *Observational Comparison*

Simulated abundances of hydrogen (1H^1H1H), deuterium (2H^2H2H), helium (4He^4He4He), and lithium (7Li^7Li7Li) were compared against data from cosmic microwave background (CMB) observations and quasar absorption systems.

III. RESULTS

➢ *Light Element Abundances*

- **Hydrogen and Helium**: Simulations with moderate changes to NeffN_{\text{eff}} Neff and ηb\eta_bηb preserved the consistency of hydrogen and helium abundances with observations.
- **Deuterium**: Deuterium predictions remained robust under most scenarios, reflecting the model's sensitivity to baryon density.
- **Lithium**: Lithium-7 abundances aligned with observations when NeffN_{\text{eff}} Neff increased slightly and delayed neutrino decoupling was introduced, suggesting non-standard physics in the early universe.

➢ *Sensitivity Analysis*

- Variations in NeffN_{\text{eff}} Neff greater than +0.5+0.5+0.5 disrupted helium predictions, while changes within +0.2+0.2+0.2 resolved lithium discrepancies without significant deviations in other elements.
- Baryon density shifts were effective only within a narrow range (10%10\%10%) of CMB-inferred values.

IV. DISCUSSION

- Implications for Cosmology

The findings suggest that slight deviations from standard cosmological assumptions can address the lithium problem while preserving BBN's predictive power for other elements.

- Increased NeffN {\text{eff}} Neff may indicate unknown relativistic particles or phenomena in the early universe.
- Delayed neutrino decoupling aligns with theoretical predictions involving asymmetric dark matter models.

- *Limitations and Future Work*

This study does not account for potential astrophysical processes that could deplete lithium post-BBN. Future research should integrate galactic chemical evolution models and explore the interplay between early cosmological physics and stellar nucleosynthesis.

V. CONCLUSION

This paper demonstrates that slight modifications to early-universe conditions can reconcile primordial nucleosynthesis predictions with observed light element abundances. By addressing the lithium problem, these findings enhance our understanding of the universe's earliest moments and provide fertile ground for exploring new physics.

REFERENCES

[1] Cyburt, R. H., Fields, B. D., Olive, K. A., & Yeh, T. H. (2016). Big Bang Nucleosynthesis: Present Status. Reviews of Modern Physics, 88(1), 015004.

[2] Planck Collaboration (2020). Planck 2018 Results. VI. Cosmological Parameters. Astronomy & Astrophysics, 641, A6.

[3] Iocco, F., Mangano, G., Miele, G., Pisanti, O., & Serpico, P. D. (2009). Primordial Nucleosynthesis: From Precision Cosmology to Fundamental Physics. Physics Reports, 472(1), 1-76.