Cahill’s Cosmological Model Exacerbates The Primordial Lithium Problem And Creates New Problems For Primordial Deuterium And Helium

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(Dated: February 24, 2010)

In a recent article R. T. Cahill claims that the cosmological model based on his “new physics of a dynamical 3-space” resolves the CMB-BBN $^7$Li and $^4$He abundance anomalies. In this note it is shown that this conclusion is wrong, resulting from a misunderstanding. In fact, primordial nucleosynthesis in this non-standard cosmological model exacerbates the $^7$Li problem and creates new problems for primordial $^4$He and deuterium.

I. INTRODUCTION

In a series of papers [1–4] R. T. Cahill proposed a non-standard cosmological model based on his “new physics of a dynamical 3-space”. In his most recent paper [4] Cahill shows that this model predicts a slower evolution of the early, radiation-dominated (RD) Universe and he misinterprets this result to infer that the radiation (e.g., the CMB photons) is hotter than the baryons (nucleons), leading to an early-Universe ratio of baryons to photons which is different from the present (and, compared to standard cosmologies). In fact, in his, as in other cosmologies, after the \( e^\pm \) pairs have annihilated in the early Universe, prior to Big Bang Nucleosynthesis (BBN), the numbers of CMB photons and of baryons in every comoving volume are preserved and the ratio of baryons to photons, \( \eta_B \equiv n_B/n_\gamma \), remains constant during the subsequent evolution of the Universe. The baryon-to-photon ratio has nothing to do with how fast or slow the Universe is expanding. In this note it is shown that since in Cahill’s cosmology the early Universe expands more slowly (compared to the standard cosmology), the predicted relic abundance of $^7$Li increases, while the predicted primordial abundances of D and $^4$He decrease, in comparison to the predictions of standard BBN (SBBN).

In §II the early, RD evolution of the Universe in Cahill’s cosmology [4] is described and the source of Cahill’s misinterpretation of the implication of the model’s slower evolution is identified. In §III the primordial abundances of D, $^4$He, and $^7$Li are calculated in this non-standard BBN (nSBBN) model and they are compared to the observationally-inferred relic abundances. Our results are summarized and our conclusions presented in §IV.

II. A MISUNDERSTANDING OF THE RADIATION-DOMINATED EVOLUTION OF THE UNIVERSE

According to Cahill [4], the expansion rate (the Hubble parameter, \( H' \)) of the early, RD Universe in his cosmological model is related to the energy density in “radiation” (e.g., in all massless and/or extremely relativistic particles) by

\[
\frac{H'(z)^2}{H_0^2} = \frac{\Omega_R}{2} (1 + z)^4,
\]

where \( \Omega_R \) is the usual radiation density parameter and \( z \) is the redshift. It is the factor of 1/2 in eq. 1 which distinguishes the early evolution of the Universe in this model from the standard model result: \( H^2/H_0^2 = \Omega_R (1 + z)^4 \).

In the standard model, as well as in Cahill’s, the relation between the Hubble parameter and the age of the Universe during the RD epoch is: \( H t = 1/2 \). As a result, the age of the Universe at a fixed redshift (or temperature) in Cahill’s model is larger than in the standard cosmology: \( t'/t = H'/H' = \sqrt{2} \). Cahill’s Universe expands more slowly than the standard cosmology (i.e., it takes longer for the Universe to cool to a fixed temperature). At a fixed time after the beginning of the expansion, Cahill’s Universe is hotter than the standard cosmology. Cahill misinterprets this to draw the incorrect conclusion that in his model the photons are hotter than the baryons (resulting in a smaller baryon to photon ratio). Independent of how fast the Universe expands, the numbers of CMB photons and of baryons (nucleons) in every comoving volume of the Universe are preserved (resulting from baryon number conservation for the baryons and from entropy conservation for the CMB photons). The ratio (by number) of baryons to photons is unchanged in Cahill’s model (compared to the standard cosmology).
III. BBN ABUNDANCES IN A MORE SLOWLY EXPANDING EARLY UNIVERSE

In Cahill’s model, the early Universe expands more slowly than it does in the standard cosmology. The early, RD evolution of the two models may be compared by comparing their expansion rates (Hubble parameters). Their ratio, the expansion rate factor, \( S = \frac{H'}{H} \), introduced by Kneller & Steigman (2004) \([5]\), is

\[
S = \frac{H'}{H} = 1/\sqrt{2}.
\]  

\( S < 1 \) corresponds to a more slowly evolving Universe. In this case there is more time to bridge the gap at mass-5 and build the primordial abundance of \(^7\text{Li}\), increasing (not decreasing) its relic abundance compared to the prediction of SBBN \((S = 1)\). The slower expansion also allows more time to burn deuterium to \(^3\text{He}\) and \(^4\text{He}\), reducing the relic D abundance and, with more time available for neutrons to decay, the primordial \(^4\text{He}\) mass fraction is reduced too.

Kneller & Steigman (2004) \([5]\) provide simple fitting formulae for the BBN light element yields when \( S \neq 1 \), and these have been updated in Steigman (2007) \([6]\). Although the very small value of \( S \) for Cahill’s model is somewhat outside of the range of values where the fits are as accurate as quoted in references \([5, 6]\), they still provide sufficiently accurate quantitative estimates for the relic abundances in this non-standard BBN (nSBBN) model.

**Deuterium**

For deuterium the nSBBN-predicted relic abundance \([6]\) is \( y_{DP} = 10^5(D/H)_P = 1.7 \) (or, \( \log y_{DP} = 0.22 \)), to be compared with the observationally-inferred value \([7]\) of \( y_{DP} = 2.8 \) (or, \( \log y_{DP} = 0.45 \)). The primordial D abundance predicted by Cahill’s model is too low by a factor of \( \sim 1.7 \).

**Helium-4**

Unquantified (and often unidentified) systematic errors plague the \( \text{H} \text{II} \) region observational data used to infer the primordial abundance of \(^4\text{He}\) (see, e.g., Steigman (2007) \([6]\) for a review). Given this state of affairs, a few good (well observed and analyzed) \( \text{H} \text{II} \) regions may be of more value than hundreds of \( \text{H} \text{II} \) regions with lower quality data and analysis (see, e.g., the discussion in Steigman (2009) \([8]\)). For example, from the analysis of Olive & Skillman \([9]\), \( Y_P \leq 0.250 \pm 0.003 \), while from similar data set, analyzed carefully by Peimbert, Luridiana, & Peimbert \([10]\), \( Y_P \leq 0.252 \pm 0.004 \). These upper bounds to the \(^4\text{He}\) mass fraction, with their more realistic errors, are consistent with the estimate, \( Y_P = 0.247 \pm 0.001 \) (or, using new emissivities, \( Y_P = 0.252 \pm 0.001 \)) from Izotov, Thuan, & Stasinska (2007) \([11]\). In stark contrast, in Cahill’s model the \(^4\text{He}\) nSBBN-predicted relic mass fraction is \( Y_P = 0.202 \). The cosmological model proposed by Cahill creates a new, very serious \(^4\text{He}\) anomaly.

**Lithium-7**

The lithium abundances derived from observations of the very most metal-poor halo and globular cluster stars in the Galaxy \([12–15]\) lie well below the SBBN-predicted value \(([\text{Li}]_{\text{P.SBBN}} = 12+\log([\text{Li}]/\text{H})_{\text{P.SBBN}} \approx 2.7)\). The discrepancy between the predictions and the observations is a factor of \( \sim 3 - 5 \) (see, e.g., \([6, 8]\) and references therein). In his most recent paper \([4]\), Cahill claims that his new cosmological model resolves the lithium abundance anomaly. In fact, for this nSBBN model, the predicted relic lithium abundance, \([\text{Li}]_P \approx 2.8\), is \( \sim 30\% \) larger than for SBBN, exacerabting, not resolving, the primordial lithium problem.

Because of the slower early evolution of the Universe in this model, the BBN-predicted abundances of D and \(^4\text{He}\) are too small and that of \(^7\text{Li}\) is too large, to be consistent with the observational data. The relic abundances of D, \(^4\text{He}\), and \(^7\text{Li}\) provide the nails in the coffin of this model.

IV. SUMMARY AND CONCLUSIONS

During its early evolution the cosmological model proposed by Cahill \([1–4]\) evolves more slowly than does the standard cosmological model. In this model the slow, early evolution results in relic D and \(^4\text{He}\) abundances far too small to be consistent with the relic abundances inferred from the observational data. And, with more time available to synthesize \(^7\text{Li}\), the \(^7\text{Li}\) relic abundance is even larger than that predicted by SBBN, thus exacerbating the lithium problem. As a consequence of these conflicts it must be concluded that the cosmological model proposed by Cahill is incompatible with the observationally-inferred abundances of the light nuclides produced during BBN. Cahill’s model is not a viable cosmological model.
Acknowledgments

The research of GS is supported at The Ohio State University by a grant from the US Department of Energy. I am pleased to acknowledge an informative exchange of emails with R. T. Cahill.

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