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(NASA-TM-82082) CONSISTENCY OF THE STANDARD
MODEL OF PRIMORDIAL NUCLEOSYNTHESIS:
RESPONSE TO THE COMMENT OF OLIVE AND TURNER
(NASA) 5 p HC A02/HF A01

N81-20994

CSSL 03B

Unclas

G3/90 18840



Technical Memorandum 82082

Consistency of the Standard Model of Primordial Nucleosynthesis

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JANUARY 1981

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Space Administration

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Published in *Physical Review Letters*, 46, 517 (Feb. 16, 1980)

Stecker Responds: In my previous paper, I made two points: (A) That arguments constraining the mean density of the universe and the number of neutrino flavors appear unjustified in view of the astrophysical data, and (B) that "the simplest big-bang model for helium production may be untenable." I argued that *prima facie* inconsistencies appear to exist in the present data when related to the orthodox baryon dominated (BD) model, and possibly even in the neutrino dominated (ND) model, which I discussed¹ as an approach to relieving the inconsistencies in the BD case. I believe this point of view to be valid, and that it has been strengthened by recent measurements of low helium abundances in other galaxies which have undergone less stellar nucleosynthesis.²⁻⁴

For this discussion, I use the notation of Olive and Turner with the exception of defining Y_0 as the observationally derived value of Y_p and Y_c as the value calculated with the standard model. The corresponding deuterium abundances will be denoted by X_0^D and X_c^D . Olive and Turner argue that $Y_0 \lesssim 0.25$. The new observations, however, give $Y_0 = 0.216 \pm 0.015$ (ref.2), $Y_0 = 0.216 \pm 0.013$ (ref.3) and 0.216 ± 0.02 (ref.4). Together with the references given previously¹, these analyses support the stronger limit $Y_0 \lesssim 0.23$ used previously. One might argue that scatter in the data would allow a larger value for Y_0 , however, the existence of considerably lower Y_0 value measurements for individual galaxies would suggest the opposite conclusion, since He, once produced, is not readily destroyed. Individual measurements^{2,3} in the range 0.17-0.18 may be evidence for $Y_0 < 0.2$ rather than 0.23.

The calculated value Y_c is a function of several empirical parameters, $Y_c = Y_c(\Omega_N, h, T, \tau_{1/2}, N_\nu)$. Olive and Turner take $N_\nu \gtrsim 2$. However, since $m_{\nu_\tau} \lesssim 250$ MeV, by the well known cosmological arguments⁵, conservatively, $m_{\nu_\tau} \lesssim 100$ eV, unless the τ neutrinos have decayed. However, Cowsik⁶ has determined that the lifetime of ν_τ is greater than the age of the universe. Thus, ν_τ should be included in the model, giving $N_\nu \gtrsim 3$. Then, with $\tau_{1/2} = 10.68 \pm 0.07$ min.⁷ and $T = 2.8 \pm 0.1$ K⁸, one re-

quires $\Omega_N \lesssim 4.1 \times 10^{-3} h^{-2}$ for $Y_C \lesssim 0.23$ and $\Omega_N \lesssim 1.9 \times 10^{-3} h^{-2}$ for $Y_C \lesssim 0.2$. This is clearly inconsistent with the BD case ($\Omega = \Omega_N$) for $\Omega \gtrsim 0.2$ and $h \gtrsim \frac{1}{2}$ (ref.9). Furthermore, $\Omega_N \lesssim 4.1 \times 10^{-3}$ gives a deuterium abundance $X_C^D \gtrsim 6.8 \times 10^{-4}$ for $\eta_\nu \gtrsim 3$ (ref.10). Thus, if we invoke such a low value for Ω_N as to account for Y_0 , we must give up using the standard model to calculate X^D , since $X_0^D = 3.6 \times 10^{-5} < X_C^D$ (ref.11). Using Olive and Turner's lowest value $\eta = 3 \times 10^{-11}$ gives $X_C^D = 2 \times 10^{-3}$, almost two orders of magnitude too large. Of course, we may invoke stellar destruction of D to lower X^D , but this in turn implies more stellar nucleosynthesis, ergo more stellar He and a lower Y_p . We must, at any rate, abandon the use of X_0^D to place theoretical limits on Ω_N .

For the ND case ($\Omega_N \ll \Omega$) one must determine an observational lower limit for Ω_N . From the X-ray observations of hot gas in galaxy clusters¹², one finds $\Omega_N \gtrsim 0.02$, even in the ND case. Such gas should be associated with galaxies in general¹³. Recent evidence of cooler gas associated with the outer parts of galaxy clusters¹⁴ imply an even higher value $\Omega_N \gtrsim 0.06$. Thus, we may have a problem with the standard model even in the ND case, since $Y_0 \lesssim 0.23$ implies $\Omega_N \lesssim 0.004 h^{-2}$. This problem is aggravated for $h \sim 1$ (Aaronson, et al. and Davis et al., ref.9) and, in any case, is in conflict with the deuterium abundances. Further discussion and data regarding all of the relevant parameters of this complex problem will be of utmost importance.

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