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The Effect of He4 Fusion on Primordial Deuterium

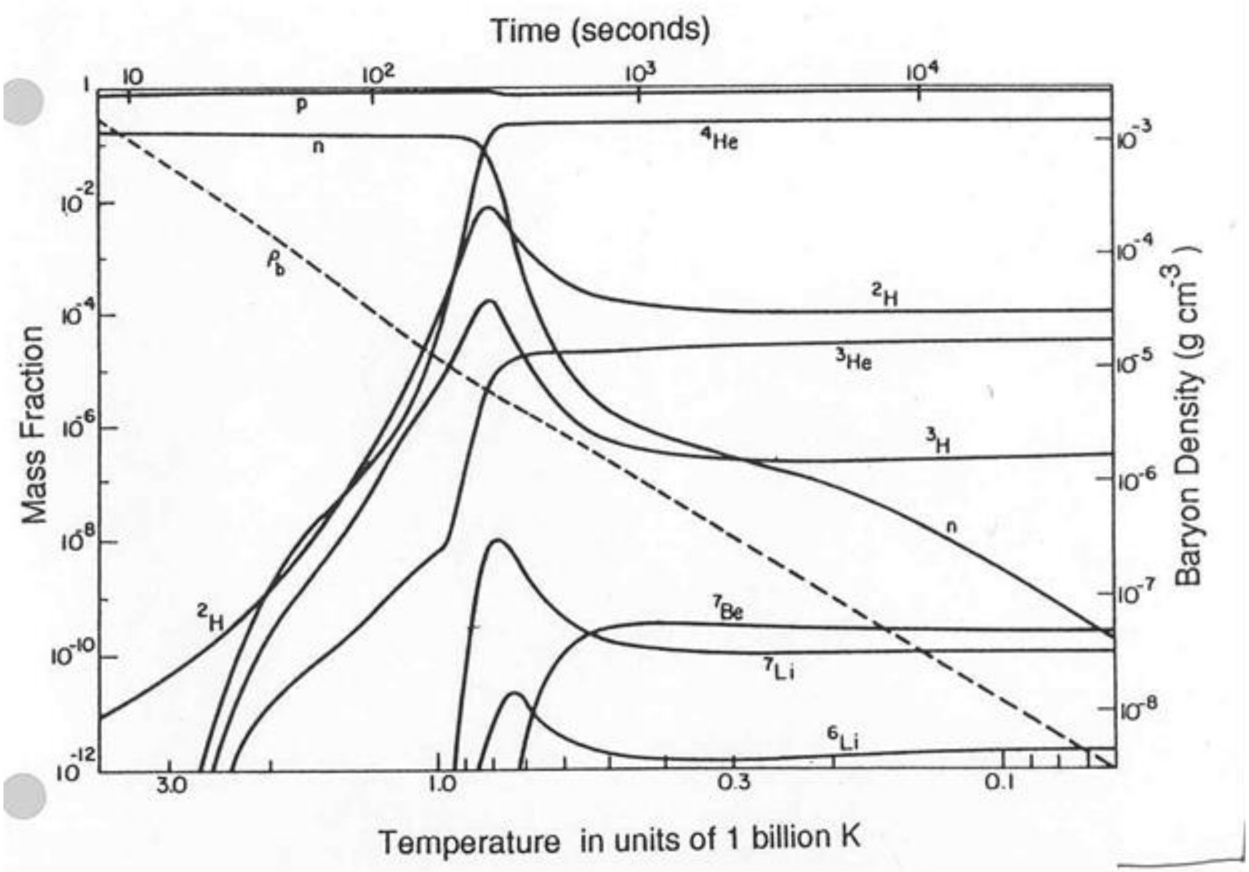
Abstract

It is well known that approximately 23% to 25% of atoms found throughout space are He4 atoms. The distribution uniformity indicates that these atoms were formed in the very early universe. In addition, trace amounts of Deuterium, Lithium 3 and Beryllium 7 are also uniformly distributed. These elements are evidence of a process known as primordial nucleosynthesis that has been well studied and documented by G. Gamow, H. Bethe and A. Sakarov.

The author explored a cosmology based on values found in a model of the proton [5][7]. The related expansion curve is similar to the concordance model [4] with WMAP parameters [3]. Temperature histories that include He4 fusion energy all increase in temperature after fusion leading to potential difficulties explaining measured primordial deuterium. The first goal of the work below is to determine when residual primordial deuterium originated.

The author's expansion model starts at a kinetic energy of 9.8 MeV/particle and has omega mass=0.5, omega dark mass=0.5 and dark energy=0. The associated temperature history decreases initially but as He4 fusion occurs, the temperature increases before finally decreasing to 2.73 K due to expansion. Surprisingly, literature was found [8] that does not account for fusion energy of He4. In addition, there are claims [4][6] that residual deuterium is a sensitive test that rules out cosmologies that contain more than 0.04 baryon fraction. The second goal of this work is to investigate the claim that conventional mass is only 4% of the observed universe, with the remainder "missing".

Conventional Primordial Nucleosynthesis

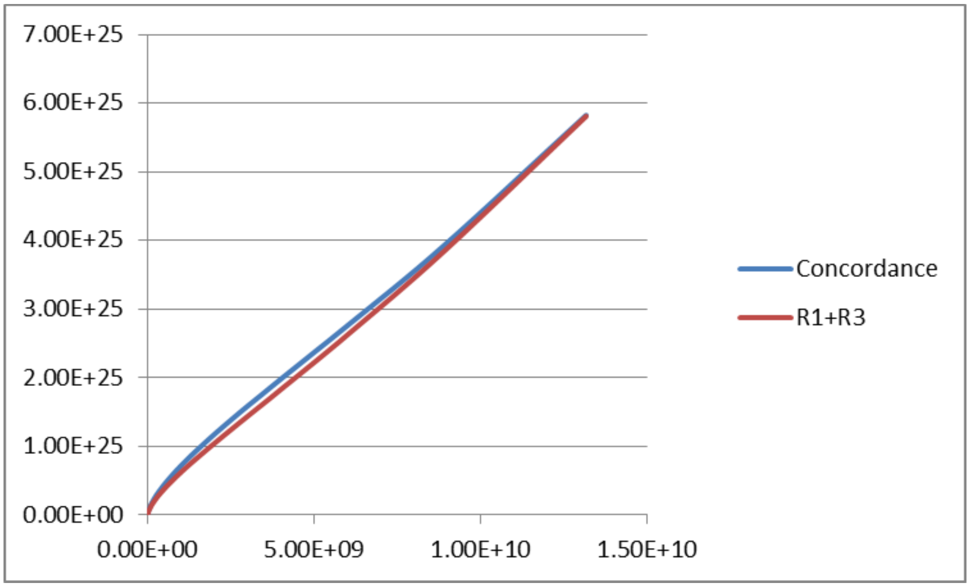


http://burro.astr.cwru.edu/Academics/Astr222/Cosmo/Early/nucleosynth_fig.jpg

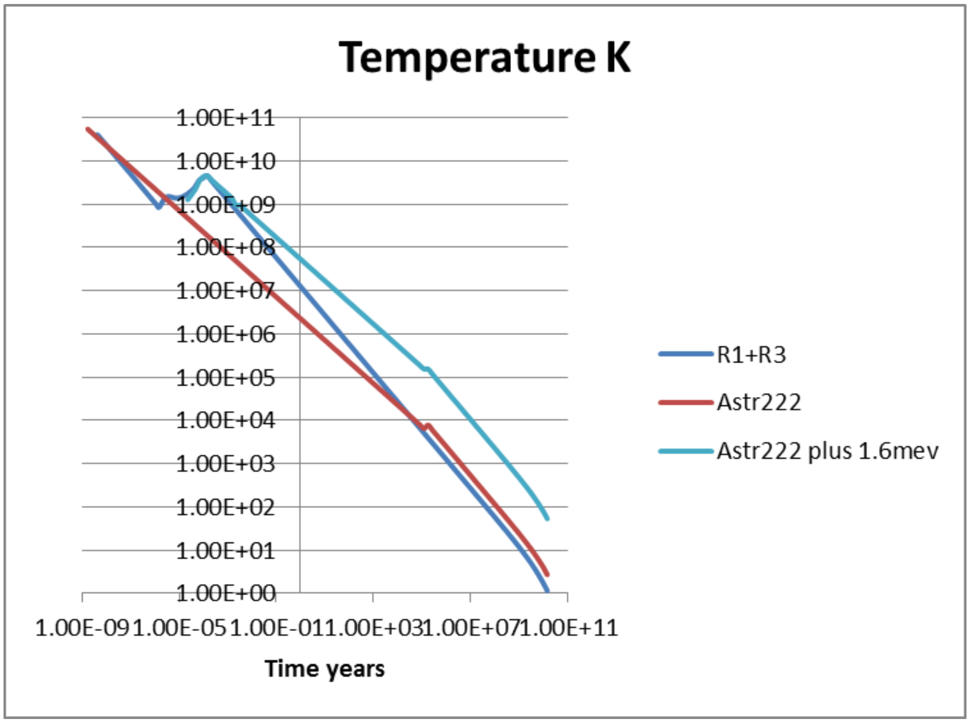
The temperature in the graph above is about 3e9 K at 12 seconds. The kinetic energy associated with this temperature is 1.5*B*T=0.39 MeV, where B is Boltzmann's constant 8.62e-11 MeV/K. One can see from the smoothly decreasing temperature in the horizontal axis that as Helium 4 fuses, there is no increase in temperature. The energy associated with He4 fusion is 7.07*0.23=1.61 MeV. This amount of energy should increase the temperature to about 1.55e10 about 200 seconds into expansion. Further, in the graph above, neutrons are decaying to protons with a half-time of approximately 866 seconds. Decay releases energy and again, no increase in temperature is shown in the graph.

The expansion curve for the above graph can be simulated with the following information from Peebles and other literature: Early expansion, according to the concordance model, is driven by photon and neutrino density and maintains the relationship kinetic energy (KE) = (2.7/t)^.5 with t initial=0.002 seconds. This slope, according to some literature, is maintained until decoupling of matter and radiation at approximately 100K years into the expansion. The temperature can be calculated from kinetic energy with T= (KE/(1.5*B). With these relationships, the temperature at 0.002 seconds is 2.5e11 K. Expansion ratio z can be calculated since T=2.73*z. The final radius is 6.33e25 meters [7] and initial z=2.5e11/2.7=1e11 giving initial radius=6.33e25/1e11=6e14 m. This initial radius does not quite agree with the concordance radius R=5.90e13*(t)^(2/3) but the difference does not affect the results. With z, the initial radius and slope the radius at larger values of time could be determined.

After equality, both cosmologies follow similar curves ending at 6e25 meters. A small difference in size at 1e5 years is not apparent in the curves shown below for expansion to 14 B years.



Temperature history for expansion models

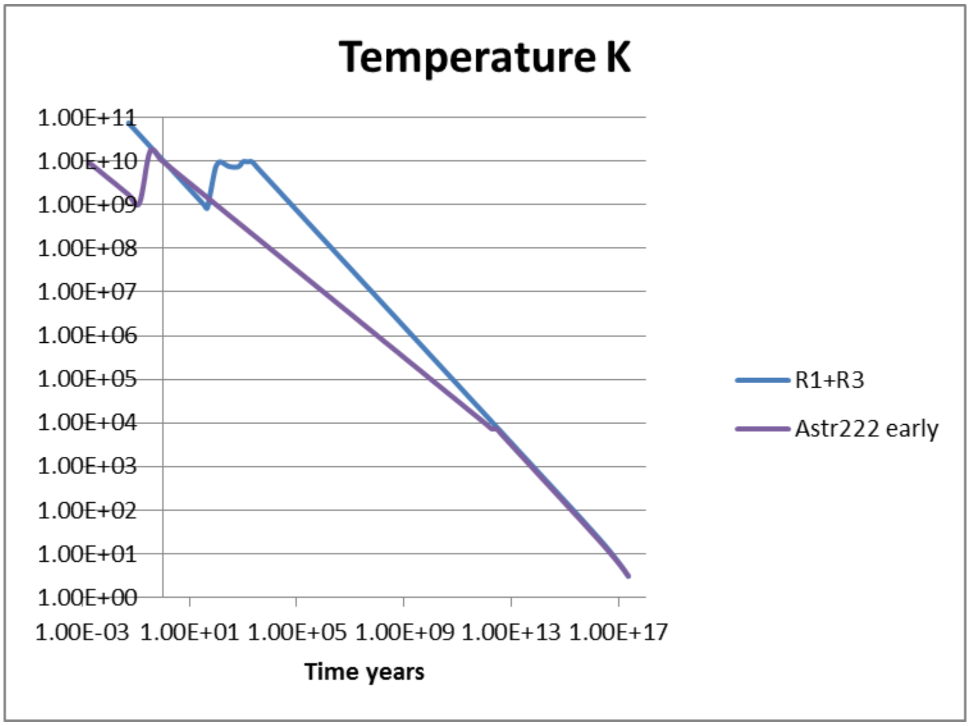


The temperature history associated with three expansion models is shown above. The red curve labelled "Astr222" is an attempt to simulate the results of reference 12. The red curve does not increase at the point where He4 fusion occurs. The early slope is lower than the R1+R3 model but after decoupling, the slope (t^(2/3)) falls appropriately to 2.73 K.

For comparison, the author's R1+R3 expansion model [2][7] is included in the graph. The temperature history includes the effect of 23% He4 fusion energy (0.23*7.07=1.61 MeV). The author's proposed R1+R3 cosmology model follows R proportional to t^(2/3) throughout expansion and has a steeper temperature curve (shown in dark blue), although the temperature before the increase occurs is very similar to the Astr222 history. After fusion and the addition of 1.6 MeV of fusion energy, the dark blue R1+R3 temperature history falls with expansion to the accepted 2.73 K.

An attempt was made to include the He4 fusion energy in the Astr222 approach. The temperature history shown in light blue is about the same temperature as R1+R2 at the beginning. When fusion occurs, the temperature curve increases. After the increase, it once again decreases and follows the lower slope until decoupling of matter and radiation occurs. At about 100 thousand years, it follows the t^(2/3) slope but at the end, the temperature is 200 K, well above the accepted temperature of 2.73K.

This lead to a further attempt to use the lower slope relationship: The curve below starts at a lower temperature of about 1e9 K where He4 fusion starts.



For this alternative, fusion occurs at 0.1 seconds, the low slope can be maintained and the temperature at the end is 2.73 K. Although this appears to be possible the author notes that it is not part of the literature and is concerned that the low slope section of the curve may not be correct physics. WMAP analysis [3] gives parameters that apply uniformly throughout the expansion curve and the slope is the higher R=5.89e13*t^(5/3) relationship.

Photodisintegration of Deuterium

It is well known that Deuterium readily fuses to Helium4 after the temperature falls to approximately 1e9 K. Initial deuterium fraction is limited by photo disintegration [4][6]. However, temperature histories that include He4 fusion energy all increase in temperature. Calculations show that this photo disintegrates any remaining deuterium. Again, one goal of this work is to determine when residual primordial deuterium might have originated.

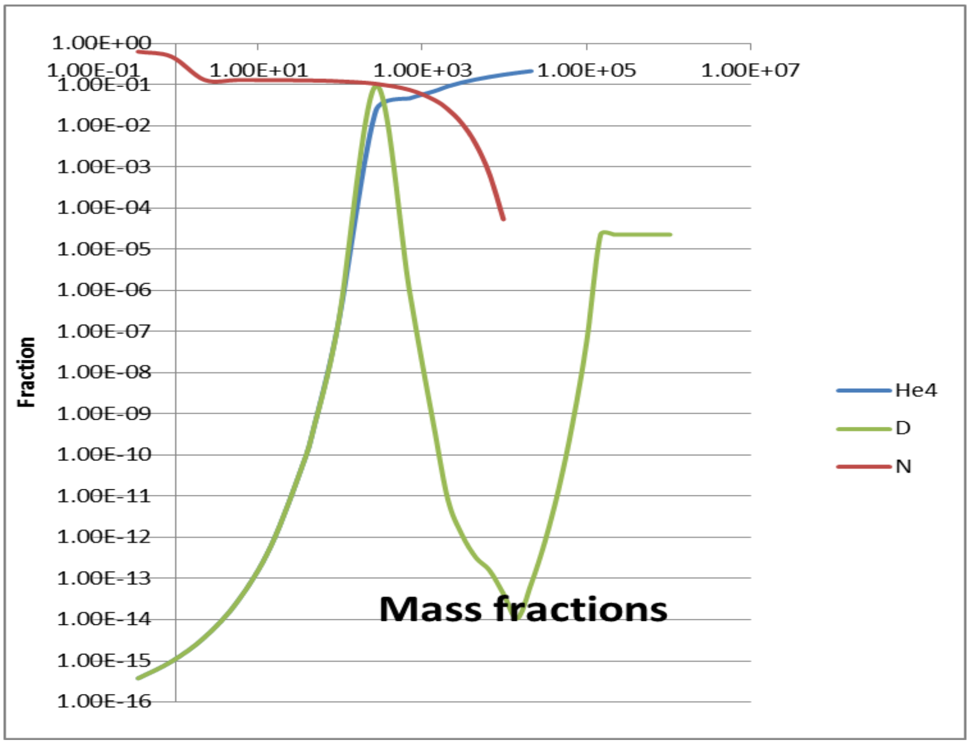
The SAHA equation [4] is utilized to give early deuterium fraction.

SAHA=(D*N)/(p'*n')=-(25.82-LN((Ob)*(T/1e10)^(3/2))-2.58/(T/1e10))

Where: D=deuterium, N=total number of particles, p'=protons and n'=neutrons.

The conventional analysis utilizes Omega b (Ob) =0.044h^2=.0213, where h=0.697 (this is equivalent to 2.26e-18/sec Hubble's constant WMAP). Literature [6] states that the initial number of total initial neutrons and protons (N) is approximately 0.1*exp(180). Neutrons decay to protons with the relationship:

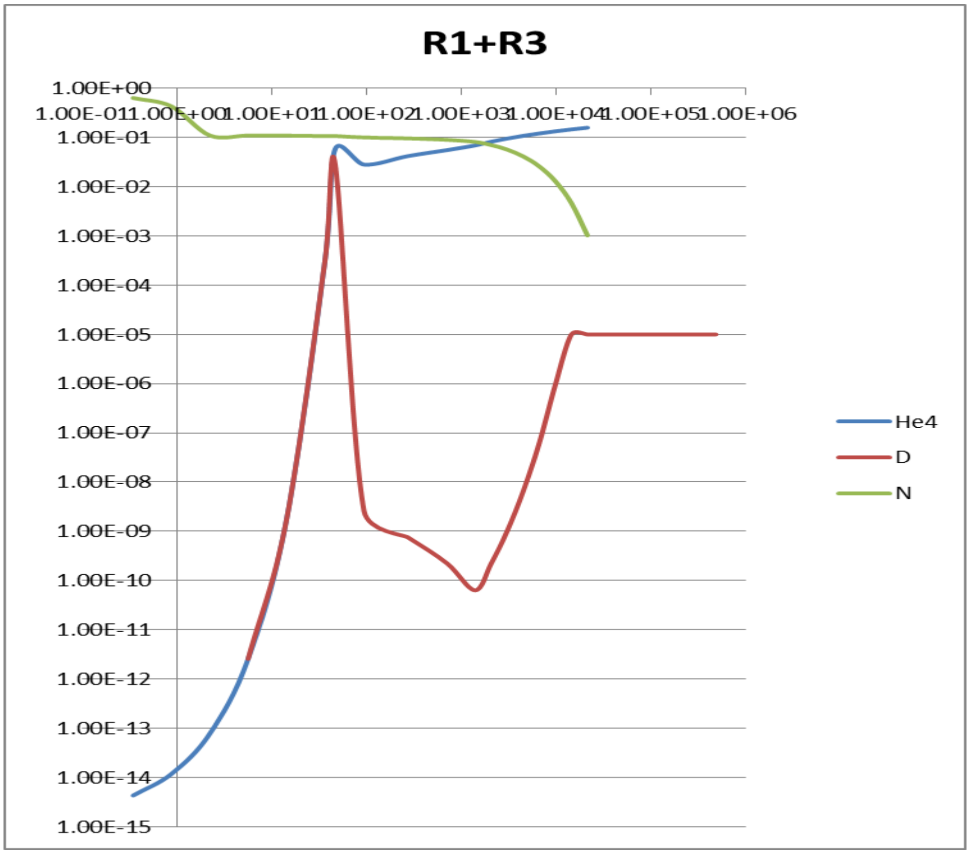
p'/N=(1-EXP(-0.693*t/866))
Multiply the above ratio by N to get p'.
The number of neutrons decreases with time and n'=N*exp(-.693*t/866).
The SAHA equation yields an initial value D N/(p'n')= 5.43e-12 for t=0.002 seconds. With n' and p' above the initial deuterium number D = 5.2e60.
As temperature decreases, D N/(p'n') =1.0. At this condition, literature states that the deuterium D rapidly converts to He4. The resulting graph of Helium and D fractions follows:



Helium4 abundance is shown in blue and increases to 0.23. Neutrons decay and are shown in red. Deuterium, shown in green, is discussed in detail later. As He4 fuses, the deuterium is photo disintegrated and follows the green curve, indicating that it almost completely destroyed.

He4 formation in the R1+R3 model

The author's R1+R3 model starts with 7.35e-14*exp(60)=8.4e12 meters. The kinetic energy given by the associated proton model is 9.8 MeV at this radius. The corresponding temperature from the equation:
T=9.8 MeV/(1.5*8.6e-11) = 7.56e10 K.
Instead of using Omega baryons=0.044h^2, the author uses protons=0.5*exp(180) and Omega baryons=0.5*.697^2=0.242. This results in the following graph for D2 and He4 formation:

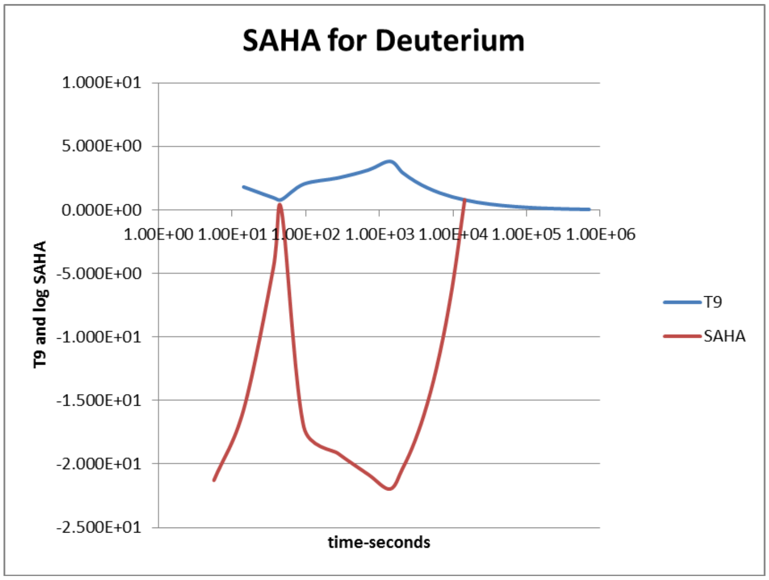


Again, the SAHA equation is used to give the D formation. The analysis and values are similar to the concordance model above. Again, the He4 formation depends on Deuterium production. The kinetic energy follows a slightly different curve but the same Omega baryons gives about the same 0.23 equilibrium He4 formation. Also, neutron decay is very similar and again the D fraction photo disintegrates (the red curve above) until the temperature once again falls.

D formation by rich N Fusion

The graphs above for Deuterium show clearly that the deuterium content is almost fully destroyed by the temperatures involved after He4 fusion. The question remains, where does the measured residual deuterium originate?

A graph of the SAHA criteria [4] for deuterium formation is shown below. The SAHA criteria used is the natural logarithm of the SAHA value. As the SAHA criteria increased to 0, He4 fused and T9 (the temperature divided by 1e9 K) increased. With the addition of fusion energy, the SAHA criteria became negative again and caused photo disintegration of deuterium. The temperature finally fell due to expansion and the SAHA criteria rose to 0 where deuterium was again formed. It is this deuterium that we measure uniformly throughout space at an abundance level of 5e-5 and it is not limited by the photon/baryon ratio.



Fusion in stars is from hydrogen. The hydrogen contributes protons that must be converted to neutrons by energetic electrons. This is quite a different situation than exists for the first few minutes following primordial He4 formation. In this environment there were still a large fraction of neutrons that had not decayed. The rich neutron environment fuses to Deuterium when photo-disintegration is allowed again. The same equations apply as before, i.e. the SAHA equation gives the fraction of deuterium. The above plot shows this in red above and agrees substantially with the deuterium residual abundance we measure.

The author analyzed the effect of Omega mass and photon/baron ration on the abundance of He4 and deuterium. The SAHA equation yields the value 1.0 at a slightly different time with different SAHA parameters but this has neither an effect on the temperature value nor an effect on abundance calculations. There is no reason to believe that the photon/baryon fraction demands a maximum baryon fraction 0.04.

Conclusions

Primordial fusion of He4 releases a significant amount of energy and must be included when determining temperature curves associated with expansion. After formation of He4, the temperature rises and photo disintegrates the deuterium. Subsequently, the temperature decreases and deuterium is once again produced. The author's calculations for the deuterium abundance agree with measured values.

Reference 7 concludes that the number of protons is 0.5*exp(180) and the number of proton like mass dark particles is 0.5*exp(180). There is no reason to question this based on primordial nucleosynthesis.

References:

1. Barbee, Gene. H., A top down approach to fundamental interactions, FQXi essay June 2012, revised Feb 2014, viXra:1307.0082. Reference Microsoft ® spreadsheet entitled Unifying concepts.xls, Barbee.
2. Barbee, Gene. H., Application of information in the proton mass model to cosmology, viXra:1307.0090 revised Nov 2013. Reference Microsoft ® spreadsheet entitled simple1c.xls, Barbee.
3. Bennett, C.L. et al. First Year Wilkinson Microwave Anisotropy Probe (WMAP) Observations: Preliminary Maps and Basic Data, Astrophysical Journal, 2001
4. Peebles, P.J.E., Principles of Physical Cosmology, Princeton University Press, 1993.
5. Barbee, Gene H., On the Source of the Gravitational Constant, Prespacetime Journal, Volume 5 No 3, April, 2014. Originally viXra:1307.0085. Reference Microsoft ® excel spreadsheet entitled Why G Constant.xls.
6. Bergstom, L. and Goobar, A., Cosmology and Particle Astrophysics, 2nd Edition, Springer-Praxis Books in Astrophysics and Astronomy, 2004.
7. Barbee, Gene H., *On Expansion Energy, Dark Energy and Missing Mass*, Prespacetime Journal pending publication, Volume 5 No 5, May, 2014.
8. http://burro.astr.cwru.edu/Academics/Astr222/Cosmo/Early/nucleosynth_fig.jpg.