The Primordial Lithium Problem

Bruno Carrazedo, nº49380

Primordial Universe
Faculdade de Ciências da Universidade de Lisboa

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Introduction

- H, He and Li were the first and lightest elements created, according to the Big Bang Nucleosynthesis theory.
- Primordial abundances were in accordance with the theory, except for the lithium case, which measured values 3-4 times smaller than predictions.

Big Bang Nucleosynthesis: The Theory

- Nuclides originated between $\sim$1 s and $\sim$3 min after BB in a radiation dominated epoch.
- The baryon-to-photon ratio triggered these reactions:

$$\eta \equiv \frac{\eta_b}{\eta_\gamma} = (6.19 \pm 0.15) \times 10^{-10} \tag{1}$$

with η being the only free parameter that controls the quantity of primordial formed light elements in standard BBN

Big Bang Nucleosynthesis: The Theory

- At t $\leq$ 1 s after the Big Bang (and T $\geq$ 1 MeV), cosmic baryons started taking the form of free nucleons, which interact through the reactions:

$$n + \nu_e \rightleftharpoons p + e^- \tag{2}$$

$$p + \bar{\nu}_e \rightleftharpoons n + e^+ \tag{3}$$

Neutron and proton abundances are balanced into an equilibrium ratio:

$$\frac{n}{p} = e^{-(m_n - m_p)/T} \tag{4}$$

Big Bang Nucleosynthesis: The Theory

- At T $\approx$ 1 MeV there is a "freeze out" of the previous reactions.
- Around 0.07 MeV, deuterium grows rapidly in quantity, starting strong nuclear reactions that originate the lightest elements, as shown in Figure 1.

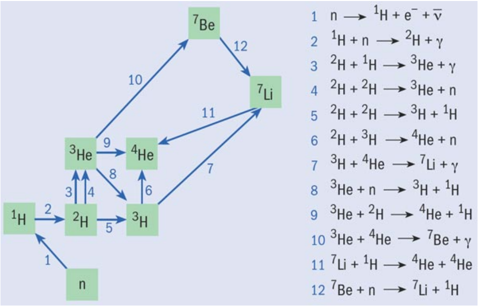

Figure 1: Major Big Bang Nucleosynthesis reactions summarized.

BBN: Ligh Element Observations

- Hydrogen makes up $\sim$92% of the atoms in the Universe, helium $\sim$8% and lithium composes only 10^{-10} times the amount of hydrogen.
- Hydrogen and helium quantities match BBN's predictions. However lithium does not:
  $^7Li/H = (1.6 \pm 0.3) \times 10^{-10}$ observations vs $(5.62 \pm 0.25) \times 10^{-10}$ predictions, a $\sim 5\sigma$ discrepancy.

BBN: Ligh Element Observations

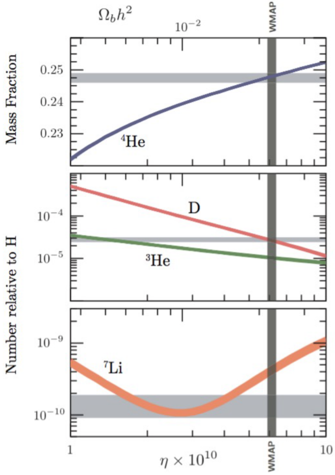

Figure 2: Big Bang Nucleosynthesis amount and mass fraction predictions dependency on the photon-to-baryon ratio ($\eta \times 10^{10}$) for the primordial light element isotopes formed. Also known as Schramm plot.

- Lithium abundance is measured by observing the atmosphere of halo stars (Population II) present in our galaxy.
- Figure 3 shows that the ^7Li isotope has almost no correlation with the metallicity of the stars (for $-3 \leq [Fe/H] \leq -1.5$). This is known as the Spite plateau.

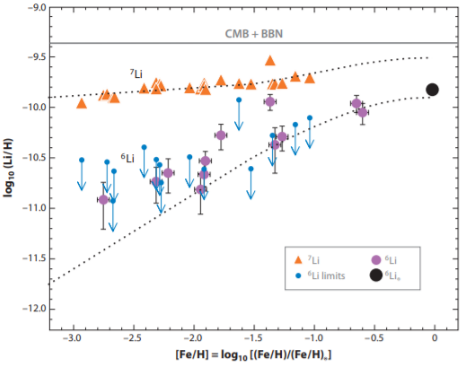

Figure 3: Lithium quantities in a sample of metal-poor halo stars form the Milky Way

BBN: Ligh Element Observations

- Another plateau (for ^6Li). But observations of this isotope are much harder to get:
- $\frac{^6Li}{^7Li} \approx 0.05$

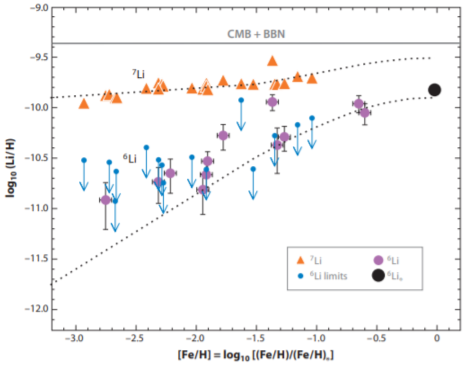

Figure 3: Lithium quantities in a sample of metal-poor halo stars form the Milky Way

BBN: The Lithium Problem Emerges

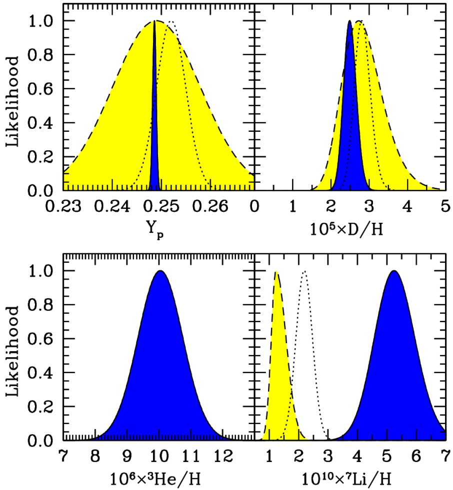

Figure 4: Comparison of the likelihood abundance distributions of the three light elements from the BBN theory to the WMAP observations.

The data disagreement in the ${}^7Li$ values constitutes the lithium problem.

Solutions: Astrophysics

Assuming standard cosmology and particle physics are correct and nuclear physics calculation of mass-7 production is also correctly done:

- Great dependence of observed lithium amount on the surface temperature of the star $\rightarrow$ recent temperature estimates in accordance with previous values.
- Possible lithium destruction in stars $\rightarrow$ difficult to correctly replicate in models.
- Lithium diffusion or turbulent mixing inside the star due to convective zones $\rightarrow$ systematic discrepancies between lithium abundances in globular star clusters.
- Stars with very low metallicity ($[Fe/H] \leq -3$) have much more scattered Li/H abundances $\rightarrow$ the same is not noticed in stars with more metallicity.

Solutions: Nuclear Physics - New and revised reactions

Assuming that the primordial lithium abundance measured is correct and that standard cosmology and particle physics are also correct:

- Incorrect reaction rates or unaccounted ones that should have been considered $\rightarrow$ well demystified calculations and reactions replicable in laboratory.
- Error in $^3He +^4 He \rightarrow {}^7Be + \gamma$ cross section measurement $\rightarrow$ current values needed for predicted and observed solar neutrino amounts spectacular correlation.
- $^7Be\ (d, \alpha)\ \alpha p$ beryllium destruction reaction with calculated cross section that could be higher by a factor of $\sim$100 $\rightarrow$ new calculations with a $\sim$10 factor below the original obtained value.

Solutions: Nuclear Physics - Resonances

- $^{7}Be + d \;\rightarrow\; ^{9}B^{*}$(16.71 MeV) and $^{7}Be + t \;\rightarrow\; ^{10}B^{*}$(18.80 MeV) reactions don't have well defined cross sections and could become the most dominant ways of ^{7}Be destruction if corrections to it promote $^{7}Be + d$ and/or $^{7}Be + t$ channels, which would solve the lithium problem easily.

Conclusion

In the end, more experimental and observational data and maybe better equipment is needed to accept or refute these solution proposals and eventually solve the lithium problem.