LiBeB and Big Bang Nucleosynthesis

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Abstract. The dual origin of population II $^7$Li, in both big bang nucleosynthesis and galactic cosmic-ray nucleosynthesis is discussed. It is argued that with additional $^6$Li data, stringent limits on the degree of $^7$Li depletion can be obtained. $^7$Li depletion is also constrained by the concordance of big bang predictions with observational determinations of light element abundances. Stringent limits can also be obtained for a fixed primordial D/H abundance.

1. Introduction

The key link between galactic cosmic-ray and big bang nucleosynthesis (GCRN and BBN) is the production of $^7$Li. Although the big bang produces each of the element isotopes $^6$Li, $^7$Li, $^9$Be, $^{10}$B, and $^{11}$B, their abundances relative to GCRN production are nearly negligible, with the exception of $^7$Li for which BBN is the main source for the abundances determined from the observation of population II halo stars. In contrast, the other LiBeB elements are all formed predominantly in GCRN. Therefore, not only is $^7$Li a common link relating the two processes, but the interpretation of the abundance of $^7$Li in halo stars may require an understanding of both mechanisms.

One of the goals of this paper is to differentiate the sources of $^7$Li and in particular the primordial abundance of $^7$Li. Among the criteria that will be used is the concordance of the primordial $^7$Li abundance with the other light element data ($^4$He and D), as well as the consistency with the galactic evolution of $^6$Li and BeB. BBN produces significant amounts of D, $^3$He, $^4$He, and $^7$Li (see e.g. Olive 1999). Furthermore, in the standard BBN model there is really only one free (undetermined) parameter, the baryon-to-photon ratio, $\eta$. Therefore, we can impose as a constraint the concordance between the predicted abundances of the light elements with the observationally determined abundances (with the exception of $^3$He which is highly dependent on the uncertainties of stellar and galactic evolution). $^7$Li, however, is also produced in spallation and fusion processes associated with cosmic rays. By modeling the evolution of the observed abundances of Be and B, we can determine the associated $^7$Li production (in a given model). As we will see, $^6$Li has the potential to play a key role in this type of investigation, since its GCRN production is very similar to that of $^7$Li and is
much less model dependent. However, the current paucity of data (though we should celebrate the fact there is some data) makes it difficult at this time to draw hard conclusions.

In what follows, we will very briefly review the key essentials of BBN relevant to our discussion here. We will then discuss the relevant LiBeB data and the dual origin for $^7\text{Li}$. The main focus of the paper will be devoted to the question of $^7\text{Li}$ depletion and the limits that can be placed on depletion from BBN and GCRN.

2. Big Bang Nucleosynthesis

As noted above, the standard BBN model is in fact a one-parameter model. The key uncertainty in the prediction of the light element abundances is the the baryon-to-photon ratio, $\eta$. The other parameters normally associated with BBN are now to a large extent fixed. Experiments at LEP have fixed the number of light neutrino flavors, $N_\nu = 3$, and the neutron mean-life is now well measured to be $\tau_n = 886.7 \pm 1.9$ s (see e.g. the Review of Particle Properties, 1998). The predicted abundances of the light elements are shown in Figure 1, which concentrates on the range in $\eta_{10}$ between 1 and 10 ($\eta_{10} = 10^{10}\eta$). The curves for the $^4\text{He}$ mass fraction, $Y$, bracket the computed range based primarily on the uncertainty of the neutron mean-life. Uncertainties in the produced $^7\text{Li}$ abundances have been adopted from the results in Hata et al. (1996). Uncertainties in D and $^3\text{He}$ production are small on the scale of this figure. The boxes correspond to the observed abundances with $2\sigma$ statistical uncertainties and the dashed boxes include systematic uncertainties.

As one can see, the predicted abundances of the light elements are roughly

\[
Y_p \approx 0.23 - 0.25 \\
D/H \approx 3.4 - 20 \times 10^{-5} \\
^3\text{He}/H \approx 1 - 2 \times 10^{-5} \\
^7\text{Li}/H \approx 1 - 2 \times 10^{-10}
\]

(1)

To test the concordance of the BBN predictions with the observations it has become useful to use a maximum likelihood method as described in detail in Fields et al. (1996). Shown in Figure 2a, are individual likelihood distributions for $^4\text{He}$ and $^7\text{Li}$. To obtain these distributions, the observed values of $Y_p = 0.238 \pm 0.002 \pm 0.005$ (Olive, Skillman, & Steigman 1997, Fields & Olive 1998) and $^7\text{Li}/H = (1.6 \pm 0.1) \times 10^{-10}$ (Molaro, Primas, & Bonifacio 1995, Bonifacio & Molaro 1997) were adopted. $^7\text{Li}$ exhibits a two-peaked distribution due to the local minimum in the predicted abundance versus $\eta$. These two elements are shown because of their relative lack of model dependent galactic evolutionary effects, in contrast to D and $^3\text{He}$. In Figure 2b, the total likelihood function is shown (the product of the two distributions). As one can see there is broad agreement (based on $^4\text{He}$ and $^7\text{Li}$) in the range 1.55 < $\eta_{10}$ < 4.45.

In Figure 3a, the total likelihood distribution including a high value of deuterium D/H = $(2.0 \pm 0.5) \times 10^{-5}$ is shown (Songaila et al. 1994, Carswell et al. 1994, Webb et al. 1997, Tytler et al. 1999). Now, the concordance is limited to a narrower range in $\eta$, 1.5 < $\eta_{10}$ < 3.4 as can be seen from the total likelihood
Figure 1.  The light element abundances from big bang nucleosynthesis as a function of $\eta_{10} = 10^{10} \eta$.

distribution shown in Figure 3b.  Similarly, in Figure 4, the distribution is shown for $D/H = 3.4 \pm 0.3 \times 10^{-5}$ (Burles & Tytler, 1998a,b).  Notice the relative scale in the two distributions (3b and 4b).  The low value of $D/H$ is compatible with $^4$He and $^7$Li at the 2 $\sigma$ level in the range $4.2 < \eta_{10} < 5.6$.

In contrast to the isotopes discussed above, big bang nucleosynthesis also produces some $^6$Li, Be, and B.  In the favored range of $1.5 - 4.5$ for $\eta_{10}$, the big bang produces roughly (Thomas et al. 1993),

$$\begin{align*}
^6\text{Li}/H & \approx 2 - 9 \times 10^{-14} \\
^9\text{Be}/H & \approx 0.04 - 2 \times 10^{-17} \\
^{10}\text{B}/H & \approx 0.5 - 3 \times 10^{-19} \\
^{11}\text{B}/H & \approx 0.02 - 1 \times 10^{-16}
\end{align*}$$

(2)

Because these abundances are far below the observed abundances found in Pop II halo stars, ($^6\text{Li}/H \approx \text{few} \times 10^{-12}$, $^9\text{Be}/H \approx 1 - 10 \times 10^{-13}$, and $^{10}\text{B}/H \approx 1 - 10 \times 10^{-12}$), it is generally recognized that these isotopes are not of primor-
dial origin, but rather have been produced in the Galaxy, through cosmic-ray nucleosynthesis.

Figure 2. (a) - Likelihood distribution for each of $^4$He and $^7$Li, shown as a function of $\eta$. The one-peak structure of the $^4$He curve corresponds to the monotonic increase of $Y_p$ with $\eta$, while the two peaks for $^7$Li arise from the minimum in the $^7$Li abundance prediction; (b) - Combined likelihood for simultaneously fitting $^4$He and $^7$Li, as a function of $\eta$.

Figure 3. (a) - As in Figure 2a, with the addition of the likelihood distribution for D/H assuming high D/H; (b) - The total likelihood distribution with high D/H.

3. LiBeB Data

The LiBeB data in population II halo stars is been discussed extensively in these proceedings and therefore, we can be brief here and concentrate on the data as it concerns nucleosynthesis and the question of the primordial abundance of $^7$Li.

The $^7$Li data was reviewed by Molaro, and based on the work of Molaro, Primas & Bonifacio (1995) and Bonifacio & Molaro (1997) as well as more recent results, he argued for a uniform abundance of $^7$Li with a value

$$^7\text{Li}/\text{H} \simeq (1.6 \pm 0.1) \times 10^{-10}$$

absent of any trends with respect to either temperature or metallicity ([Fe/H]).

The $^6$Li abundance (reviewed here by Hobbs) has been improving over time. There are now two stars at low metallicity ([Fe/H] $\sim -2.3$) with measured $^6$Li/H
Figure 4. (a) - As in Figure 2a, with the addition of the likelihood distribution for D/H assuming low D/H; (b) - The total likelihood with low D/H. The dashed curve is the distribution from Figure 3b.

(Smith, Lambert & Nissen 1993,1998, Hobbs & Thorburn 1994,1997, Cayrel et al. 1999):

\[
\begin{align*}
\text{HD84937} & : \quad ^{6}\text{Li}/^{6}\text{Li}_{\text{total}} = 0.054 \pm 0.011 \\
\text{BD26}^\circ3578 & : \quad ^{6}\text{Li}/^{6}\text{Li}_{\text{total}} = 0.05 \pm 0.03
\end{align*}
\]

(4)

corresponding to \( ^{6}\text{Li}/\text{H} \simeq 6 - 10 \times 10^{-12} \). These values, together with the solar abundance \( ^{6}\text{Li} \simeq 1.5 \times 10^{-10} \) lead to strong constraints on the evolution of \(^{6}\text{Li}\) and more importantly on the nucleosynthesis of the LiBeB elements and the depletion of \(^{7}\text{Li}\) as will be discussed below.

The BeB data was discussed by Duncan and Garci-Lopez. The pop II BeB data is summarized by the tables below (Fields & Olive 1999a). The table below represents a compilation of data using a uniform set of stellar parameters (effective temperature, surface gravity, and metallicity) to extract abundances. Results for two methods are shown (see Fields & Olive 1999a for more details).

Table 1. Observed Pop II logarithmic slopes for Be versus Fe and O

| metal tracer | method | metallicity range | Be slope | B slope | B/Be slope |
|--------------|--------|-------------------|----------|---------|------------|
| Fe/H Balmer  | \(-3 \leq [\text{Fe/H}] \leq -1\) | \(1.21 \pm 0.12\) | \(0.65 \pm 0.11\) | \(-0.18 \pm 0.15\) |
| O/H Balmer   | \(-2.5 \leq [\text{O/H}] \leq -0.5\) | \(1.76 \pm 0.28\) | \(1.84 \pm 0.58\) | \(-0.81 \pm 0.44\) |
| Fe/H IRFM    | \(-3 \leq [\text{Fe/H}] \leq -1\) | \(1.30 \pm 0.13\) | \(0.77 \pm 0.13\) | \(0.01 \pm 0.14\) |
| O/H IRFM     | \(-2.5 \leq [\text{O/H}] \leq -0.5\) | \(1.38 \pm 0.19\) | \(1.35 \pm 0.30\) | \(0.00 \pm 0.17\) |

In standard GCRN (Meneguzzi, Audouze, & Reeves 1971), \(^{9}\text{Be}\) is a secondary isotope, and is expected to have a logarithmic slope of 2 with respect to [Fe/H]. In the context of GCRN, B/H is also produced with a slope of 2, but there is an additional source for boron from neutrino spallation in supernovae (Hartmann 1999) which is primary (slope of 1). The [Fe/H] data shown in the table, however, do not reflect the expectations of standard GCRN. As a result, many models have been developed over the last several years to explain this data. For a review of these, see Ramaty (1999).

The apparent failure of GCRN to account for the evolution of BeB vs. [Fe/H] rests upon the assumption that at low metallicity, [O/Fe] is constant. However, new data (discussed here by Garci-Lopez) from Israelian et al. (1998)
indicates that in fact O/Fe is not constant. If we take \([O/Fe] = \omega_{O/Fe}[Fe/H]\), then we would expect up to an additive constant (Fields & Olive 1999a)

\[
[\text{Be}] = 2(1 + \omega_{O/Fe}) [\text{Fe}/\text{H}]
\]  

Now for the Israelian et al. (1998) value of \(\omega_{O/Fe} = -0.31\), we would predict a Be slope which is consistent with the data. Galactic chemical evolution models with a varying O/Fe were presented here by Fields. As we will see below, these models also affect the evolution of \(^6\text{Li}\) in a positive way (Fields & Olive 1999b).

4. Two-component \(^7\text{Li}\)

In order to test big bang nucleosynthesis, it is necessary to establish a primordial abundance of \(^7\text{Li}\). The extraction of the primordial \(^7\text{Li}\) abundance is complicated by two factors: the GCRN production of \(^7\text{Li}\) and the depletion of \(^7\text{Li}\) in halo stars. If we for the moment ignore the depletion, we must still ascertain what fraction of the observed \(^7\text{Li}\) is primordial. In principle, we can use the abundance information on the other LiBeB isotopes to determine the abundance of the associated GCRN produced \(^7\text{Li}\). As it turns out, the boron data is problematic for this purpose, as there is very likely an additional source for \(^{11}\text{B}\), namely \(\nu\)-process nucleosynthesis in supernovae as indicated above. In Walker et al. (1993), and Olive & Schramm (1992), the Be data was used to set a rough upper bound of 20-30% to the fraction of GCRN produced \(^7\text{Li}\) on a star by star basis.

There are in fact many stars for which both \(^7\text{Li}\) and \(^9\text{Be}\) have been detected. Using this subset of the data, one can extract the primordial abundance of \(^7\text{Li}\) in the context of a given model of GCRN. For example, a specific GCRN model, predicts the ratio of Li/Be as a function of [Fe/H]. Under the (plausible) assumption that all of the observed Be is GCRN produced, the Li/Be ratio would yield the GCRN produced \(^7\text{Li}\) and could then be subtracted from each star to give a set of primordial \(^7\text{Li}\) abundances. This was done in Olive & Schramm (1992) where it was found that the plateau was indeed lowered by approximately 0.07 dex. However, it should be noted that this procedure is extremely model dependent. The predicted Li/Be ratio in GCRN models was studied extensively in Fields, Olive & Schramm (1994). It was found that Li/Be can vary between 10 and \(~300\) depending on the details of the cosmic-ray sources and propagation—e.g., source spectra shapes, escape pathlength magnitude and energy dependence, and kinematics.

In contrast, the \(^7\text{Li}/^6\text{Li}\) ratio is much better determined and far less model dependent since both are predominantly produced by \(\alpha-\alpha\) fusion rather than by spallation. The obvious problem however, is the paucity of \(^6\text{Li}\) data. As more \(^6\text{Li}\) data becomes available, it should be possible to obtain a better understanding of the relative contribution to \(^7\text{Li}\) from BBN and GCRN.

5. Li Depletion

Stellar evolution models have predicted depletion factors which differ widely, ranging from essentially no depletion in standard models (for stars with \(T \gtrsim 6\)) to...
5500 K) to a large depletion (Deliyannis et al. 1990, Charbonnel et al. 1992). Depletion occurs when the base of the convection zone sinks down and is exposed to high temperatures, $\sim 2 \times 10^6$ K for $^7$Li and $\sim 1.65 \times 10^6$ K for $^6$Li (Brown & Schramm 1988). In standard stellar models, the depletion of $^7$Li is always accompanied by the depletion of $^6$Li, though the converse is not necessarily true. Below, the consequences of $^7$Li depletion will be examined from both its effect on the galactic evolution of $^6$Li and its effect on the concordance of BBN and the observations of D and $^4$He.

5.1. $^6$Li and depletion

Model results (Fields & Olive 1999b) for $^6$Li vs. Fe appear in Figure 5, for an [O/Fe]-[Fe/H] Pop II slope $\omega_{O/Fe} = -0.31$ (as discussed above) and $\omega_{O/Fe} = 0$ for comparison. We see that GCRN does quite well in reproducing both solar and Pop II $^6$Li when O/Fe is allowed to evolve in Pop II. On the other hand, if O/Fe is constant, then the $^6$Li-Fe slope is steeper and the model underproduces the Pop II $^6$Li. This is consistent with what is obtained for the evolution of BeB (Fields & Olive 1999a,c).

![Figure 5](image)

Figure 5. The $^6$Li evolution as a function of [Fe/H]. **Solid line:** the “revised standard” GCRN model. Here Fe is scaled from the calculated O to fit the observed [O/Fe]-[Fe/H] slope. **Dashed line:** the GCRN model with Fe $\propto$ O in Pop II. The error bars on the points are 2 sigma errors, and the spread in the points connected by lines show the uncertainty due to stellar parameter choices.
It is also useful to compare the evolution of $^6\text{Li}$ with that of Be or B. The problem again is the paucity of data. For HD 84937, data is available for both $^6\text{Li}$ and Be. By comparing the solar ratio of $^6\text{Li}/\text{Be}_\odot = 5.9$ and the value of this ratio for HD84937, $^6\text{Li}/\text{Be} \simeq 80$, it appears that GCRN is consistent (though the observational uncertainties remain large). This data are good enough however, to exclude the possibility of a purely primary (linear) evolution for $[\text{Be}/\text{H}]$ vs. $[\text{Fe}/\text{H}]$ coupled with the expected linear evolution of $^6\text{Li}$ as a primary element due to $\alpha - \alpha$ fusion. In this case one would expect the $^6\text{Li}/\text{Be}$ ratio to be constant, which is clearly not the case.

In standard GCRN (with constant O/Fe at low metallicities), $^9\text{Be}$ is a secondary isotope, and given the linearity of $[^6\text{Li}]$, one should expect that $^6\text{Li}/\text{Be}$ is inversely proportional to Fe/H (i.e., to have a log slope of -1). However, if we take $\omega_{O/Fe} \neq 0$, then we would expect the Be evolution to be governed by Eq. (5) (Fields & Olive 1999a,b) and

$$[^6\text{Li}] = (1 + \omega_{O/Fe}) [\text{Fe}/\text{H}]$$

so that

$$[^6\text{Li}]/\text{Be} = -(1 + \omega_{O/Fe}) [\text{Fe}/\text{H}]$$

The Israeli et al. (1998) value of $\omega_{O/Fe} = -0.31$, implies a dependence which is consistent with the data.

The above comparison of the data as shown in Figure 5 to the models do not take into account any depletion of $^6\text{Li}$. There is still a great deal of uncertainty in the amount of depletion for both $^6\text{Li}$ and $^7\text{Li}$ as well as the relative depletion factor, $D_6/D_7$ (Chaboyer 1994, Vauclair and Charbonnel 1995, Deliyannis et al. 1996, Chaboyer 1998, Pinsonneault et al. 1992, Pinsonneault et al. 1998, Pinsonneault 1999, Vauclair 1999). The observed lithium abundance can be expressed as

$$\text{Li}_{\text{Obs}} = D_7(7\text{Li}_{\text{BB}} + 7\text{Li}_{\text{CR}}) + D_6(6\text{Li}_{\text{BB}} + 6\text{Li}_{\text{CR}})$$

where the $D_{6,7} < 1$ are the $6,7\text{Li}$ depletion factors. The two lithium components due to big bang and cosmic ray production, discussed in the previous section, are shown explicitly here. Given enough $^6\text{Li}$ Pop II data, one could use the observed $^6\text{Li}$ evolution (1) to infer $7\text{Li}_{\text{CR}}$ and thus $7\text{Li}_{\text{BB}}$, and (2) to measure $^6\text{Li}/\text{Be}$ and thereby constrain in more detail the nature of early Galactic cosmic rays both which would lead to a better understanding of Li depletion in general.

In standard stellar models, Brown & Schramm (1988) have argued that $D_6 \sim D_7^\beta$ with $\beta \approx 60$. Clearly in this case any observable depletion of $^7\text{Li}$ would amount to the total depletion of $^6\text{Li}$. Hence the observation of $^7\text{Li}$ in HD84937 has served as a basis to limit the total amount of $^7\text{Li}$ depletion (Steigman et al. 1993, Lemoine et al. 1997, Pinsonneault et al. 1998). There are however, many models based on diffusion and/or rotation which call for the depletion of $^6\text{Li}$ and $^7\text{Li}$ even in hot stars. The weakest constraint comes from assuming that depletion occurs entirely due to mixing, so the destruction of the Li isotopes is the same despite the greater fragility of $^6\text{Li}$. Because $^6\text{Li}/^7\text{Li} \sim 1$ in cosmic-ray nucleosynthesis, the observation of $^6\text{Li}$ does exclude any model with extremely large $^6\text{Li}$ depletion if one requires the preservation of the Spite plateau for $^7\text{Li}$ up to $[\text{Fe}/\text{H}] = -1.3$ (Pinsonneault et al. 1998, Smith et al. 1998). However,
barring an alternative source for the production of $^6$Li, the data are in fact much more restrictive. At the $2\sigma$ level, the model used to produce the evolutionary curve in Figure 5, would only allow a depletion of $^6$Li by 0.15 dex ($D_6 > 0.7$); since $D_7 \geq D_6$, this is also a lower limit to $D_7$.

Further constraints on $D_7$ become available if we adopt a model which relates $^6$Li and $^7$Li depletion. E.g., if we use $\log D_6 = -0.19 + 1.94 \log D_7$ as discussed in Pinsonneault et al. (1998), the data in the context of the given model would not allow for any depletion of $^7$Li. However, given the observation al uncertainties, together with the uncertainties in the stellar parameters it is possible to account for some Li depletion. For example, using the Balmer line stellar parameters, Fields & Olive (1999a) found $\omega_{O/Fe} = -0.46 \pm 0.15$. Using the value of -0.46, it was determined that at $2\sigma$ (with respect to the $^6$Li data) that $\log D_6 > -0.32$ and would still limit $\log D_7 > -0.07$. Even under what most would assume is an extreme O/Fe dependence of $\omega_{O/Fe} = -0.61$, $^6$Li depletion is limited to by a factor of 3.5 and corresponds to an upper limit on the depletion of $^7$Li by 0.2 dex. This is compatible with the upper limit in Lemioine et al. (1997) though the argument is substantially different.

It should be clear at this point, that improved (≡ more) data on $^6$Li in halo stars can have a dramatic impact on our understanding of cosmic-ray nucleosynthesis and the primordial abundance of $^7$Li. Coupled with improved data on the O/Fe ratio in these stars, we would be able to critically examine these models on the basis of their predictions of $^6$Li and $^9$Be.

5.2. Constraints from BBN

It is also in principle possible to constrain the degree of $^7$Li depletion from the concordance of the light elements produced in BBN and the observations. If $^7$Li depletion were significant, then the comparison of BBN predictions to the observed abundances should be based on a $^7$Li abundance which is greater than that determined in pop II halo stars. As a result of the local minimum in the BBN produced $^7$Li abundance (at about $\eta_{10} \sim 3$) the two most likely values of $\eta$ from $^7$Li (the twin peaks in the likelihood distribution of Figure 2a), are split farther apart as is shown in Figure 6a, where the assumed $^7$Li abundance is $^7$Li/H = $(4.1 \pm 0.1) \times 10^{-10}$. This corresponds to a depletion factor of 0.4 dex, which was recently argued to be an upper limit to the $^7$Li depletion (Pinsonneault et al. 1998, Pinsonneault 1999). As one can see, the previous excellent agreement between $^7$Li and $^4$He (seen in Figure 2a) is lost. The lack of agreement is seen more quantitatively by comparing the two likely distributions of Figure 2b and 6b.

When one also considers deuterium, the concordance is further disturbed. For high D/H, where the agreement between D/H and $^4$He is good, there is barely any overlap with Li as can be seen in Figure 7a. The total likelihood function in this case, shown in Figure 7b, can be compared with that in Figure 3b, which shows the likelihood distribution with high D/H and no $^7$Li depletion.

Finally, one can consider the case of low D/H. Here the concordance was never very good. $^7$Li depletion causes the high-$\eta$ peak of the Li distribution to move to the right (to higher values of $\eta$), and for a depletion factor of 0.4 dex as is assumed in Figure 8, the peak of the $^7$Li distribution lies at values of $\eta$ larger than that predicted by low D/H. Clearly for a smaller $^7$Li depletion factor,
good agreement between $^7\text{Li}$ and D/H can be achieved. In this case, $^4\text{He}$ is still somewhat problematic.

Figure 6. (a) - As in Figure 2a, where the assumed primordial $^7\text{Li}$ abundance has been increased to take into account a possible 0.4 dex of depletion; (b) - As in Figure 2b, with the increased primordial $^7\text{Li}$.

Figure 7. (a) - As in Figure 6a, with the addition of the likelihood distribution for D/H assuming high D/H; (b) - The total likelihood distribution with high D/H.

6. Summary

It is apparent that we have a general understanding of the production mechanisms of the LiBeB elements. Their (relative) inferior position on the abundance chart indicates that they are not produced in the normal course of stellar evolution and as is well known the mass gaps at $A = 5$ and 8 prevent them from being produced in sufficient abundance in the big bang. Cosmic-ray nucleosynthesis has been shown to work reasonably well in accounting for the LiBeB abundances. However, several questions remain. Among them is the challenge to separate the BBN and GCRN components of $^7\text{Li}$. This is crucial for testing the concordance of BBN theory with observations. The depletion of $^7\text{Li}$ is another complication that must be resolved. It was argued above, that $^6\text{Li}$ may hold the key to resolving both of these problems. The similar processes (namely $\alpha - \alpha$ fusion) which produce both Li isotopes could allow for a direct determination of GCRN produced $^7\text{Li}$. Due to its fragility, $^6\text{Li}$, if observed in more halo stars could also play a key role in pinning down the $^7\text{Li}$ depletion factor. In addition, the comparison with BeB, would be extremely useful in distinguishing between primary
and secondary models of cosmic-ray nucleosynthesis. While great advances have occurred in obtaining LiBeB data, open questions can only be resolved with new data on these elements.

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