Lithium Update
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- 2 Lithium Problems
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  - BBN overproduction of $^7\text{Li}$
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  - GCRN underproduction of $^6\text{Li}$
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    • claims to solve both problems
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  - Cosmological Cosmic Rays
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Lithium Solutions?
- Post BBN Particle Decay
  • claims to solve both problems
- Cosmological Cosmic Rays
  • massive Pop III CR production of $^6\text{Li}$
Big Bang Nucleosynthesis

- Production of the Light Elements: D, $^3$He, $^4$He, $^7$Li
  - $^4$He observed in extragalactic HII regions:
    abundance by mass = 25%
  - $^7$Li observed in the atmospheres of dwarf halo stars:
    abundance by number = $10^{-10}$
  - D observed in quasar absorption systems (and locally):
    abundance by number = $3 \times 10^{-5}$
  - $^3$He in solar wind, in meteorites, and in the ISM:
    abundance by number = $10^{-5}$
WMAP best fit
(WMAPext + 2dFGRS +
Lyman α +running sp.
index )

\[ \Omega_B h^2 = 0.0224 \pm 0.0009 \]

\[ \eta_{10} = 6.14 \pm 0.25 \]
D/H abundances in Quasar absorption systems
$^4\text{He}$

Measured in low metallicity extragalactic HII regions ($\sim 100$) together with O/H and N/H

\[ Y_P = Y(O/H \rightarrow 0) \]

$^4\text{He}$ is Primordial!
$Y_p = 0.2495 \pm 0.0092$
Li/H

Measured in low metallicity dwarf halo stars (over 100 observed)
Li Woes

- Observations based on
  - “old”: Li/H = 1.2 x 10^{-10} Spite & Spite +
  - Balmer: Li/H = 1.7 x 10^{-10} Molaro, Primas & Bonifacio
  - IRFM: Li/H = 1.6 x 10^{-10} Bonifacio & Molaro
  - IRFM: Li/H = 1.2 x 10^{-10} Ryan, Beers, KAO, Fields, Norris
  - Hα (globular cluster): Li/H = 2.2 x 10^{-10} Bonifacio et al.
  - Hα (globular cluster): Li/H = 2.3 x 10^{-10} Bonifacio
  - λ6104: Li/H ~ 3.2 x 10^{-10} Ford et al.

- Li depends on T, ln g, [Fe/H], depletion, post BBN-processing, ...

- Strong systematics
Problem 1: BBN $^7\text{Li}$ too high
Possible sources for the discrepancy

- **Stellar Depletion**
  - lack of dispersion in the data, $^6\text{Li}$ abundance
  - standard models (< .05 dex), models (0.2 - 0.4 dex)

- **Nuclear Rates**
  - Restricted by solar neutrino flux

- **Stellar parameters**

  \[
  \frac{d\text{Li}}{d\ln g} = \frac{0.09}{0.5} \quad \frac{d\text{Li}}{dT} = \frac{0.08}{100K}
  \]

  Vauclaire & Charbonnel
  Pinsonneault et al.
  Coc et al.
  Cyburt, Fields, KAO
Reappraising the Spite Lithium Plateau: Extremely Thin and Marginally Consistent with WMAP

Jorge Meléndez¹ and Iván Ramírez²

New evaluation of surface temperatures in 41 halo stars with systematically higher temperatures (100-300 K)

\[[\text{Li}] = 2.37 \pm 0.1\]

\[\text{Li/H} = 2.34 \pm 0.54 \times 10^{-10}\]
Fig. 2.—Temperatures obtained in this work minus the temperatures from R01 (for stars within the temperature range 2100 K). Filled circles: plateau stars (Teff > 6000 K); open circles: stars with Teff < 6000 K.
Fig. 1.—Upper panel: A Li of the Spite plateau stars (T eff > 6000 K) as a function of [Fe/H].

\[ \langle A_{\text{Li}} \rangle = 2.37 \text{ dex} \ (\sigma = 0.06 \text{ dex}) \]

T eff > 6000 K
D, He and Li

Figure 7: As in Figure 6, including the constraints from 4 He medium (pink) shading and 7 Li medium-light (green) shading.

Cyburt, Ellis, Fields, KAO
“All”

\[ \eta = 6 \times 10^{-10} \]

\[ \tau_x = 10^8 \text{ sec} \]

Cyburt, Ellis, Fields, KAO
Regions in the plane with Li/H < 3 x 10^{-10}

Blue: D/H > 1.3 x 10^{-5}
Red: D/H > 2.2 x 10^{-5}
Regions in the plane with $\text{Li/H} < 3 \times 10^{-10}$

Blue: $\text{D/H} > 1.3 \times 10^{-5}$
Red: $\text{D/H} > 2.2 \times 10^{-5}$
Blue: D/H > 1.3 x 10^{-5}
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Blue: D/H > 1.3 x 10^{-5}
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Blue: D/H > 1.3 x 10^{-5}
Red: D/H > 2.2 x 10^{-5}

Require $^3$He/D < 1

Ellis, KAO, Vangioni
Ellis, KAO, Vangioni
The cross sections for different nuclei are shown on the graph. The x-axis represents the logarithm of the lifetime of the nucleus ($\tau_X$) in seconds, while the y-axis represents the logarithm of the energy ($\xi_X$) in GeV. The curves are labeled with different isotopes: 

- $^6$Li, $^7$Li
- $^6$Li/$^7$Li
- $^4$He
- $^3$He/D
- $^6$Li
- $^7$Li

Ellis, KAO, Vangioni
$^6\text{Li}$

In the happy but not too distant past:

$^6\text{Li} \ (\@ \ [\text{Fe/H}] \sim -2.3)$:

- HD 84937: $^6\text{Li}/\text{Li} = 0.054 \pm 0.011$
- BD 26°3578: $^6\text{Li}/\text{Li} = 0.05 \pm 0.03$

cf. BBN abundance of about $^6\text{Li}/\text{H} = 10^{-14}$

or $^6\text{Li}/\text{Li} < 10^{-4}$
These data nicely accounted for by Galactic Cosmic Ray Nucleosynthesis

Fields and Olive Vangioni et al.
Problem 2: There appears to be a $^6$Li plateau

Data from Asplund et al and Inoue
Solution 1: Particle Decays

Jedamzik

Kawasaki, Kohri, Moroi
Solution 1: Particle Decays

Kawasaki, Kohri, Moroi
FIG. 1: Parameter space in the GUT–scale unified supersymmetric scalar mass $m_0$–gaugino mass $\tan \beta = 10$, $\mu > 0$, $A_0 = 0$, for the points shown in Fig. 1 and 2. The colour coding is that of Fig. 1.
Solution 1 plagued by the overproduction of D/H.
Solution 2: Cosmological Cosmic Rays (to Problem 2 only)

- Cosmic Chemical Evolution
- Early Reionization and Massive Stars
- Cosmic Ray Production and Propagation in an expanding Universe

\[
\frac{\partial N_{l, H}(E, z)}{\partial t} = \int \sigma_{\alpha \alpha \rightarrow l}(E, E') n_{\text{He}}(z) \Phi_{\alpha, H}(E', z) \, dE'
\]

\[
\Phi_{\alpha, H}(E, z) = \frac{\phi_{\alpha}(E)}{n^0_H} \frac{\beta'}{\beta} \frac{\phi_{\alpha}(E_s')}{\phi_{\alpha}(E)} \left| \frac{dz}{dt} \right|_{z_s} \exp(-\xi) \frac{1}{|\partial z^* / \partial E'|_{E_s'}}
\]

\[
\phi_{\alpha}(E) = \mathcal{F} 12.5 K_{\alpha p}(E + E_0) \{E(E + 2E_0)\}^{-(\gamma+1)/2}
\]
\[ \mathcal{E}_{\text{SN}}(z) = (1 + z)^3 \int_{\max(8M_\odot, m_{\text{min}(t)})}^{m_{\text{sup}}} dm \phi(m) \psi(t - \tau(m)) \mathcal{E}_{\text{CR}}(m). \]

\[ \mathcal{E}_{\text{CR}}(m) = \frac{\epsilon E_{cc}(m)}{100} \quad \epsilon = 0.04 - 0.15 \]

Rollinde, Vangioni, Olive
Summary

- D, He are ok -- issues to be resolved

- Li: 2 Problems
  - BBN $^7$Li high compared to observations
  - BBN $^6$Li low compared to observations
    $^6$Li plateau?

- Important to consider:
  - Depletion
  - Li Systematics - T scale
  - Particle Decays?
  - PreGalactic production of $^6$Li