Big Bang Nucleosynthesis and the Abundance of ^{6}Li

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Outline

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Why ^{6}Li?

- Next highest predicted abundance after D, ^{3}He, ^{4}He and ^{7}Li.
- Main production reaction $\mathrm{D}\,(\alpha,\gamma)^6\,\mathrm{Li}$ measured in Basel (G. Testa).
- Potential probe of the baroynic density ρ_b.

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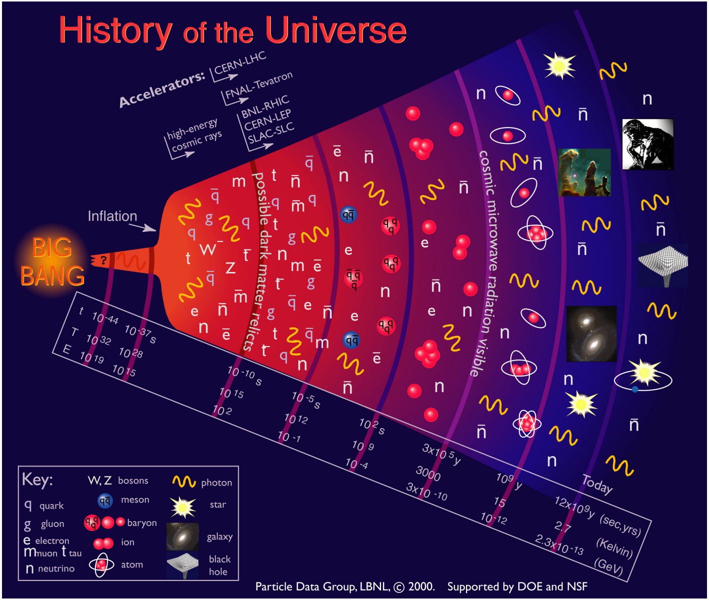
The Big Bang


History of the Universe
Accelerators:
CERN-LHC
FNAL-Tevatron
BNL-RHIC
CERN-LEP
SLAC-SLC
high-energy cosmic rays
Inflation
BIG BANG
possible dark matter relics
cosmic microwave radiation visible
t 10-44 10-37 s
T 10 32 10 28
E 10 19 10 15
10 -10 s
10 15
10 2
10 -5 s
10 12
10 -1
10 2 s
10 9
10 -4
3x10 5 y
3000
3x10 -10
10 9 y
15
10 -12
Today
12x10 9 y (sec,yrs)
2.7 (Kelvin)
2.3x10 -13 (GeV)
Key:
W, Z bosons
photon
q quark
meson
star
g gluon
baryon
galaxy
e electron
ion
m muon t tau
black hole
n neutrino
atom
Particle Data Group, LBNL, © 2000. Supported by DOE and NSF

Framework of BBN Calculation

Assumptions:

- Universe is homogeneous and isotropic (Cosmological Principle)
- Adiabatic expansion (→cosmological parameter $\eta = \frac{\rho_b}{\rho_\gamma} = \text{const.}$)
- No degenerate or exotic particles

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BBN Calculation

- Solving Reaction Network (changes in abundances of a nucleus are determined by reactions creating and destroying said nucleus)

$$\dot{Y}_i = \underbrace{\sum_j N^i_j \lambda_j Y_j}_{decays} + \underbrace{\sum_{j,k} \frac{N^i_{j,k}}{1+\delta_{jk}} \rho N_A < \sigma v >_{j;k} \; Y_j Y_k}_{two-particle\ reactions}$$

$\rightarrow$ solving a system of coupled differential equations

- Self-consistent calculation (time-evolution of temperature and density is calculated using the Friedmann equations)
  $\rightarrow$ only free parameter: η

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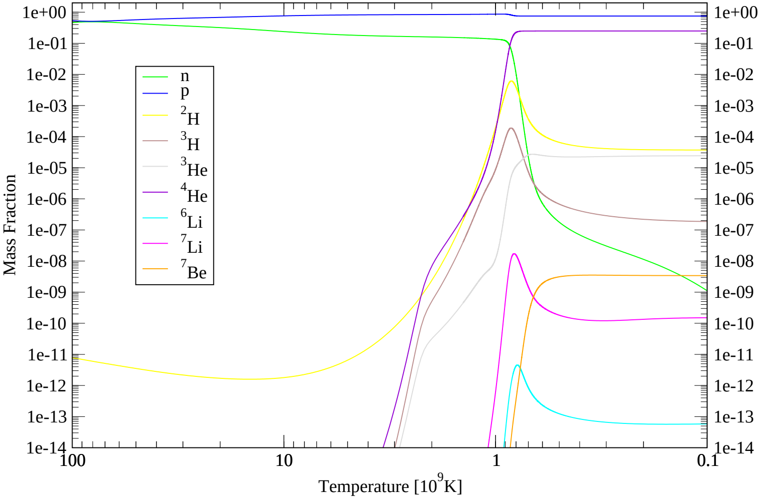
Results of BBN Calculation



Calculation vs Observation

Calculation:

$$
\begin{aligned}
Y_p &\sim 0.248 \\
\mathrm{D/H} &\sim 2.64 \cdot 10^{-5} \\
{}^3\mathrm{He/H} &\sim 1.06 \cdot 10^{-5} \\
{}^7\mathrm{Li/H} &\sim 4.22 \cdot 10^{-10} \\
{}^6\mathrm{Li}/{}^7\mathrm{Li} &\sim 10^{-5}
\end{aligned}
$$

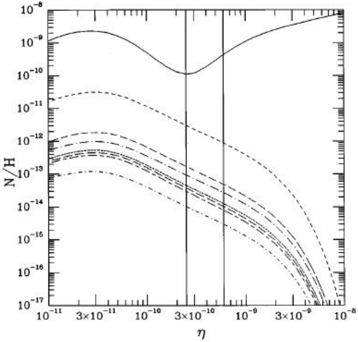
Observation:

$$
\begin{aligned}
Y_p &\sim 0.249 \pm 0.009 \text{ (Olive \& Skillman 2004)} \\
\mathrm{D/H} &\sim 2.78^{+0.44}_{-0.38} \text{ (Kirkmann et al. 2003)} \\
{}^3\mathrm{He/H} &\sim - \\
{}^7\mathrm{Li/H} &\sim 1.23^{+0.68}_{-0.32} \cdot 10^{-10} \text{ (Ryan et al. 2000)} \\
{}^6\mathrm{Li}/{}^7\mathrm{Li} &\sim 10^{-2}
\end{aligned}
$$

Outline

Focus on ^{6}Li

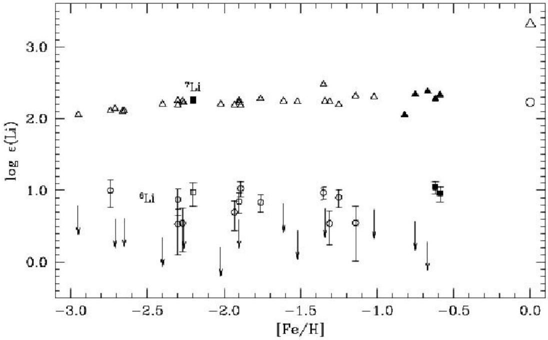
- ^{6}Li abundance falls rapidly with increasing baryon density →potentially sensitive probe of ρ_b →determines $\eta = \frac{\rho_b}{\rho_\gamma}$



Nollett et al (1997)

Observation of Primordial ^{6}Li

- Atmospheres of metal-poor warm dwarf stars
- Spite-plateau (Spite & Spite 1984): ^{7}Li abundance independent of metallicity for [Fe/H]<-1.5
- Possibly plateau for ^{6}Li



Lambert (2004)

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Reasons for Discrepancy

- Nuclear reaction Network incomplete or reaction rates contain errors.
  - $\mathrm{D}\left(\alpha,\gamma\right)^6\mathrm{Li}$- rate relatively uncertain, but very unlikely to resolve huge discrepancy.
- Systematic errors in the observational abundance analysis.

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- The ^{6}Li and ^{7}Li abundances in metal-poor stars are not those of the primordial gas.
  - Destruction of Lithium isotopes in standard stellar models incomplete
  - Consider non-standard processes (rotationally induced mixing, diffusion, mass loss through stellar wind)
- Standard physics incorporated in the BBN predictions is incomplete.
  - radiative or hadronic decay of exotic particles during or after BBN
    $\rightarrow$decay products process primordial products and change abundances
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Summary

- BBN predictions of ^{6}Li differ from observations by $\sim$3 dex.
- Different theories to resolve this difference exist but still have to be verified.