Astro 596/496 NPA
Lecture 18
Oct. 5, 2009

Announcements:

- Problem Set 3 due Friday
- PS 1 graded–good job!
- **Fermilab Tour**
  this Saturday, Oct 10, 8am to ~ 7pm
  `www: Fermitour info`

Last time: BBN observations–light element abundances

- good news: cosmo principle → primordial abundances universal
  same everywhere after "first 3 min"
- bad news: can't observe universe then
  but much later, after star-formation has begun
  must measure & correct for lite element "pollution"

Q: how?

Lithium-7

Note: solar system (meteorites) show $(\mathrm{Li/H})_\odot \sim 10^9 \gg (\mathrm{LI/H})_p$.
Is this trouble?

best candidates: low-metal stars in our Galaxy
"population II" or "halo" or "spheroid" stars

old stars → low mass ($\sim 1 M_\odot$)
low metallicity: $[\mathrm{Fe/H}] < -1.5$ down to -4
where:

- $[\mathrm{Fe/H}] = \log_{10}[(\mathrm{Fe/H})_\star/(\mathrm{Fe/H})_\odot]$, with
- "units" of "decimal ($\log_{10}$) exponent" $\equiv$ "dex"

But there's a worry: recall PS 2
Li is low in solar photosphere–what does this imply?

trouble: Li has low binding: "fragile"
PS 2: burned when $T \gtrsim 2.5 \times 10^6$ K $\ll T_{\rm core,\odot}$
$\Rightarrow$ if surface material dragged into interior, can burn Li

stellar envelope convection $\rightarrow$ Li depletion
but: convection zone depth $\downarrow$ as $T_{\rm eff}$ $\uparrow$
$\Rightarrow$ pick hottest $\gtrsim 5800$ K (MS, subgiants)
no (?) Li depletion

measure Li I via absorption
`www: solar spectrum around 6707Å`
`www: halo star spectra`

^{7}Li **Results**

Spite & Spite (1984): first Li in Pop II
- $(\mathrm{LI/H})_{\mathrm{II}} \sim 10^{-10}$
- Li flat at low [Fe/H]: “Spite plateau”

★ if undepleted → primordial!

Plateau data:

`www: Li vs Fe`

$$\left(\frac{\mathrm{Li}}{\mathrm{H}}\right)_p = (1.23 \pm 0.06 \pm 0.40\ {}^{+0.60}) \times 10^{-10} \qquad (1)$$

statistical errors: many stars → small

systematics: dominate
- ± 0.40 due to stellar atmosphere modelling
- $+0.30$ due to possible Li burning (depletion) constrained by observations of fragile ^{6}Li

Helium-3

measure in ISM (H II regions)
via hyperfine emission ("21 cm")
spin-spin coupling $E_{\text{hf}} \propto S_e \cdot S_A$

good news:
since $S(^4\text{He}) = 0$, $S(^3\text{He}) = 1/2$,
only ^{3}He has signal: no ^{4}He "noise"!

`www: Rood et al` ^{3}He

bad news:
(1) ^{3}He only available at high metallicities
(2) (low mass) stellar nuke uncertain:
are stars net ^{3}He producers or destroyers?

Q: how to proceed?

Give up! ...for now, anyway

Do not use ^{3}He for BBN testing

but can turn problem around:
BBN predicts primordial ^{3}He
$\longrightarrow$ infer sign of, and degree of,
Galactic ^{3}He processing

Assessing BBN: Theory vs Observations

(Standard) BBN theory has a free parameter: $n_B/n_\gamma = \eta$
different lite element predictions for different η
Q: so how to compare with observations?
is it even possible to test the theory?

What uncertainties are there in the standard *theory?*

What uncertainties are there in the obs?

How can we account for these uncertainties when comparing theory and observations?

If theory & obs agree*, what would this mean:*
qualitatively? quantitatively?
If they disagree*, what would this mean?*

Assessing BBN: Theory vs Observations

BBN Theory:

all elements dependent on η

the only free parameter in standard ("vanilla") calculation

$\Rightarrow$ for each η value, 4 lite elements: "overconstrained"

a priori η is unknown, but homogeneous U $\rightarrow$ one value today

`www: Schramm plot`

Lite Elt Observations:

1. measure *one* element: find η
2. measure *more* elements: each picks an η

   $\Rightarrow$ do they agree? test of BBN & of cosmology!

∞

Assessing BBN: Procedure

Combine observations (+ errors!)
statistical errors only:
• ^{4}He and D agree
• ^{7}Li likes lower η
include systematics:
Concordance!
`www: Schramm plot w/ data boxes`

lite elts fit if η in range

$$3.4 \times 10^{-10} \leq \eta \leq 6.9 \times 10^{-10} \tag{2}$$

Have extrapolated hot big bang to $t \sim 1$ s
predict lite elts → agrees w/ theory
big bang model works back to $t \sim 1$ s, $z \sim 10^{10}$!

lends confidence to extrapolation $t < 1$ s