# Nuclear Physics I: Nuclear Astrophysics
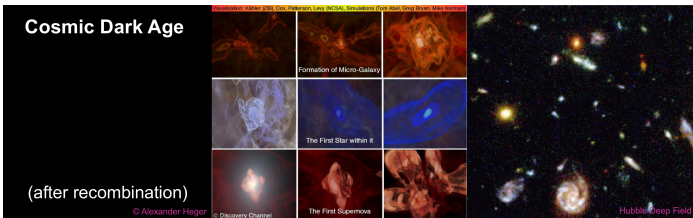## PHYS 8801

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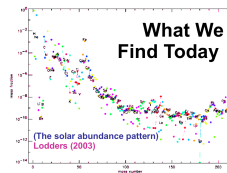
Nuclear Physics I: Nuclear Astrophysics, Spring 2012

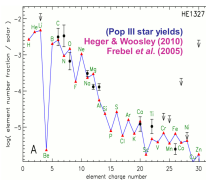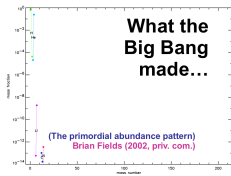# Agenda

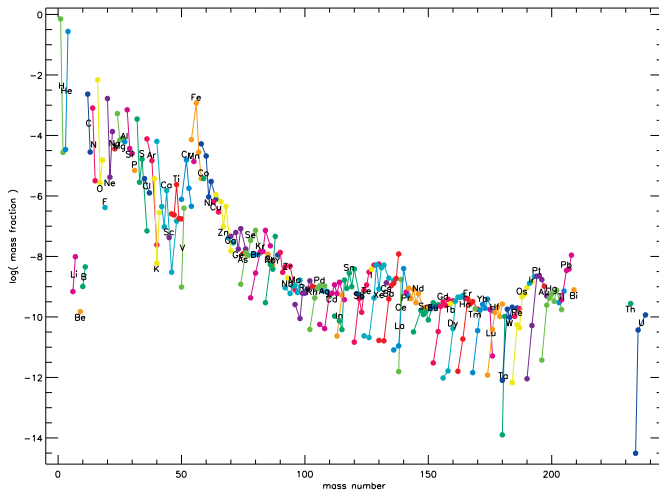1. Nucleosynthesis Overview

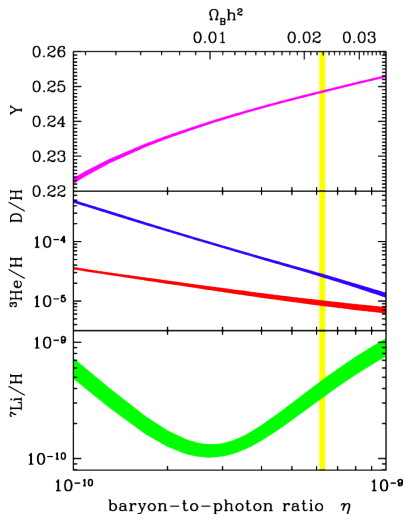2. Big Bang Nucleosynthesis

# The Origin of the Elements



**time**

# The Origin of the Elements

# Nucleosynthesis as function of baryon-photon ratio

# BBN Nucleosynthesis Network



1. $n \longrightarrow {}^1H + e^- + \bar{\nu}$
2. ${}^1H + n \longrightarrow {}^2H + \gamma$
3. ${}^2H + {}^1H \longrightarrow {}^3He + \gamma$
4. ${}^2H + {}^2H \longrightarrow {}^3He + n$
5. ${}^2H + {}^2H \longrightarrow {}^3H + {}^1H$
6. ${}^2H + {}^3H \longrightarrow {}^4He + n$
7. ${}^3H + {}^4He \longrightarrow {}^7Li + \gamma$
8. ${}^3He + n \longrightarrow {}^3H + {}^1H$
9. ${}^3He + {}^2H \longrightarrow {}^4He + {}^1H$
10. ${}^3He + {}^4He \longrightarrow {}^7Be + \gamma$
11. ${}^7Li + {}^1H \longrightarrow {}^4He + {}^4He$
12. ${}^7Be + n \longrightarrow {}^7Li + {}^1H$
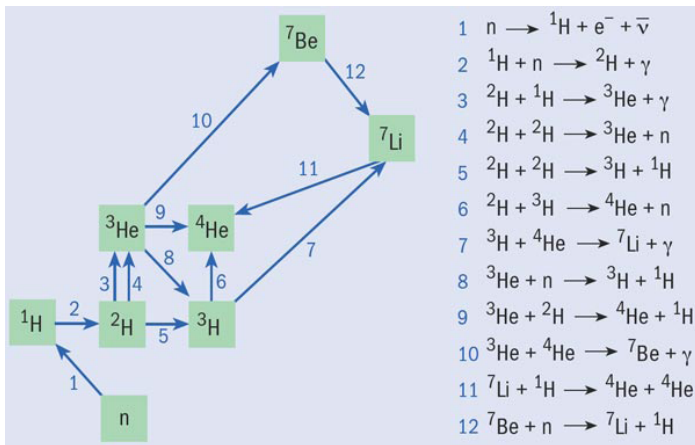
# BBN Nucleosynthesis Network
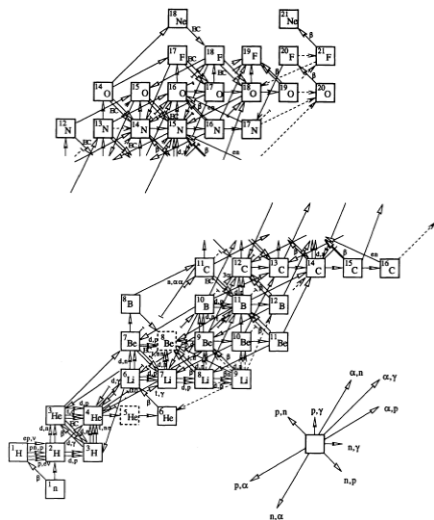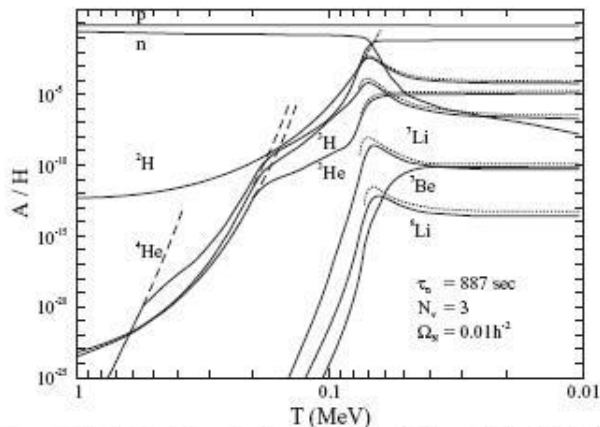


Fig. 1.—Reaction network used in the code. Estimated reactions are shown with dashed lines.

# BBN Nuclear Gaps

# BBN Nucleosynthesis



Evolution of the abundances of primordially synthesized light elements with
temperature according to the Wagoner (1973) numerical code as upgraded by Kawano
(1992). The dashed lines show the values in nuclear statistical equilibrium while the
dotted lines are the 'freeze-out' values as calculated analytically by Esmailzadeh et al
(1991).

# BBN Nucleosynthesis
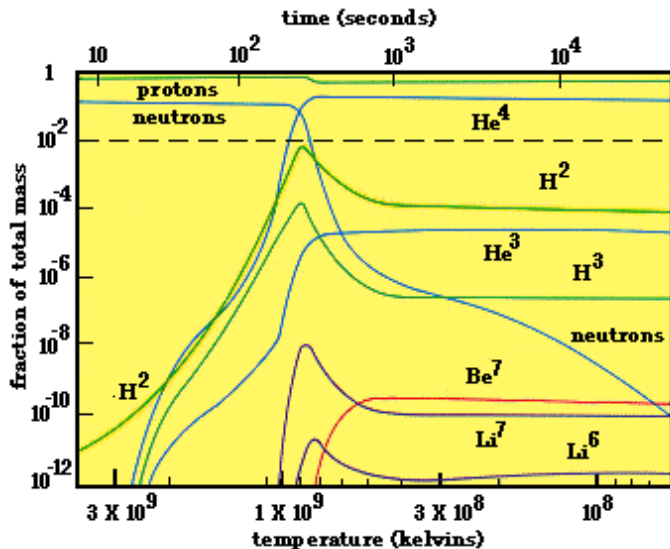
# BBN Nucleosynthesis Results

| | Theory | Observation |
|---|---|---|
| $D$ | $3.6 * 10^{-5 \pm 0.06} \left( \dfrac{\eta}{5.5 * 10^{-10}} \right)^{-1.6}$ | $2.78 \pm 0.44 * 10^{-5}$ <br> $> 1.5 \pm 0.1 * 10^{-5}$ <br> $< 6.7 * 10^{-5}$ |
| $^3He$ | $1.2 * 10^{-5 \pm 0.06} \left( \dfrac{\eta}{5.5 * 10^{-10}} \right)^{-0.63}$ | $1.5 \pm 0.5 * 10^{-5}$ |
| $^4He$ | $0.245 \pm 0.014(N_\nu - 3) \pm 0.0002(\tau_n - 887) \pm 0.009 \ln\left( \dfrac{\eta}{5.5 * 10^{-10}} \right)$ | $0.2443 \pm 0.0015$ <br> $0.2391 \pm 0.0020$ <br> $0.249 \pm 0.004$ |
| $^7Li$ | $1.2 * 10^{-10 \pm 0.06} \left( \dfrac{\eta}{5.5 * 10^{-10}} \right)^{-2.38}$ | $1.23^{+0.68}_{-0.32} * 10^{-10}$ |

# Observed D/H in quasars

| QSO | $z_{em}$ | $z_{abs}$ | $\log N(\text{H\,I})$ (cm$^{-2}$) | [O/H][b] | $\log(\text{D/H})$ |
|---|---|---|---|---|---|
| HS 0105+1619 | 2.640 | 2.53600 | $19.42 \pm 0.01$ | $-1.70$ | $-4.60 \pm 0.04$ |
| Q0913+072 | 2.785 | 2.61843 | $20.34 \pm 0.04$ | $-2.37$ | $-4.56 \pm 0.04$ |
| Q1009+299 | 2.640 | 2.50357 | $17.39 \pm 0.06$ | $< -0.67$[c] | $-4.40 \pm 0.07$ |
| Q1243+307 | 2.558 | 2.52566 | $19.73 \pm 0.04$ | $-2.76$ | $-4.62 \pm 0.05$ |
| SDSS J155810.16−003120.0 | 2.823 | 2.70262 | $20.67 \pm 0.05$ | $-1.47$ | $-4.48 \pm 0.06$ |
| Q1937−101 | 3.787 | 3.57220 | $17.86 \pm 0.02$ | $< -0.9$ | $-4.48 \pm 0.04$ |
| Q2206−199 | 2.559 | 2.07624 | $20.43 \pm 0.04$ | $-2.04$ | $-4.78 \pm 0.09$ |

# Li Problem