BBN, CMB and Neutrino

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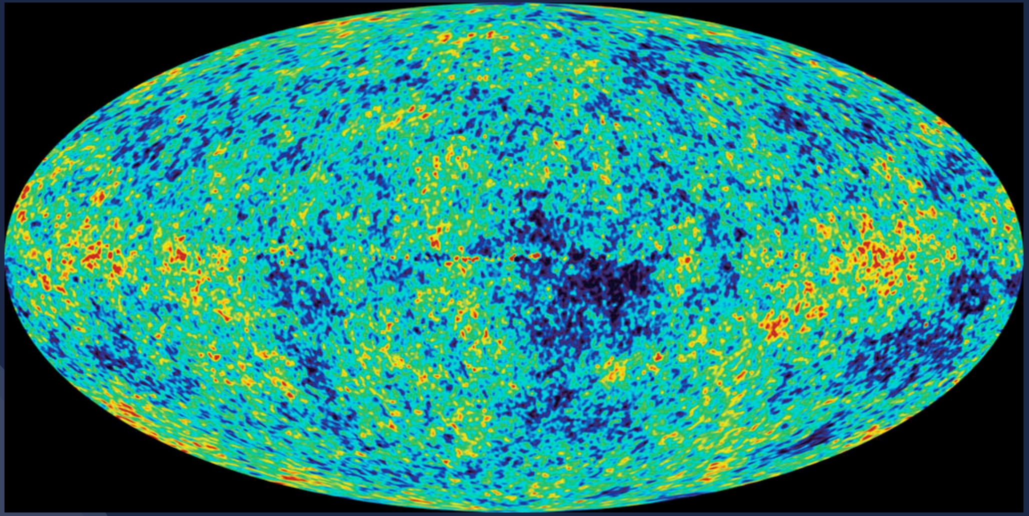
Introduction



http://map.gsfc.nasa.gov/

WMAP Date Release in 2003

WMAP (+ Galaxy Survey + etc)

Support the Standard Framework of Cosmology

Inflation, Lambda-CDM . . .

Determination of Cosmological Parameters

Cosmological Parameters

WMAP only, assuming a falt universe

- Baryon $\omega_b \equiv \Omega_b h^2 = 0.024 \pm 0.001$
- Matter $\omega_m \equiv \Omega_m h^2 = 0.14 \pm 0.02$
- Hubble $h = 0.72 \pm 0.05$
- Spectral Index $n_s = 0.99 \pm 0.04$
- Optical Depth $\tau = 0.166^{+0.076}_{-0.071}$

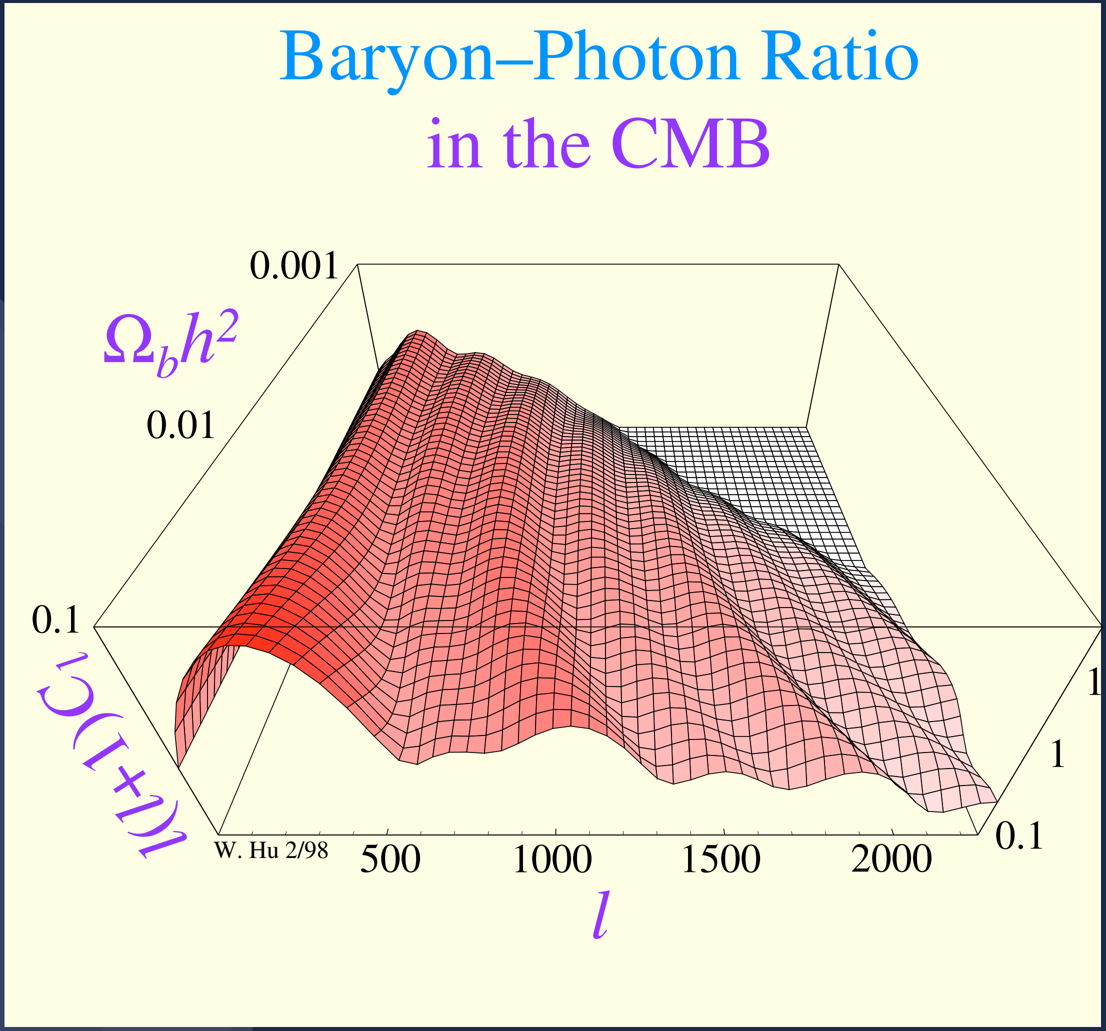
5% accuracy !

Baryon Density

CMB Angular Power Spec. 2nd Peak

$$\eta = n_b/n_\gamma = (6.5^{+0.4}_{-0.3}) \times 10^{-10}$$

Is This Consistent with Big Bang Nucleosynthesis ?



http://background.uchicago.edu/~whu/

Plan of Talk

1. Introduction
2. Big Bang Nucleosynthesis
3. Discrepancy
4. Solutions
5. Conclusuins

Big Bang Nucleosynthesis (BBN)

Standard BBN

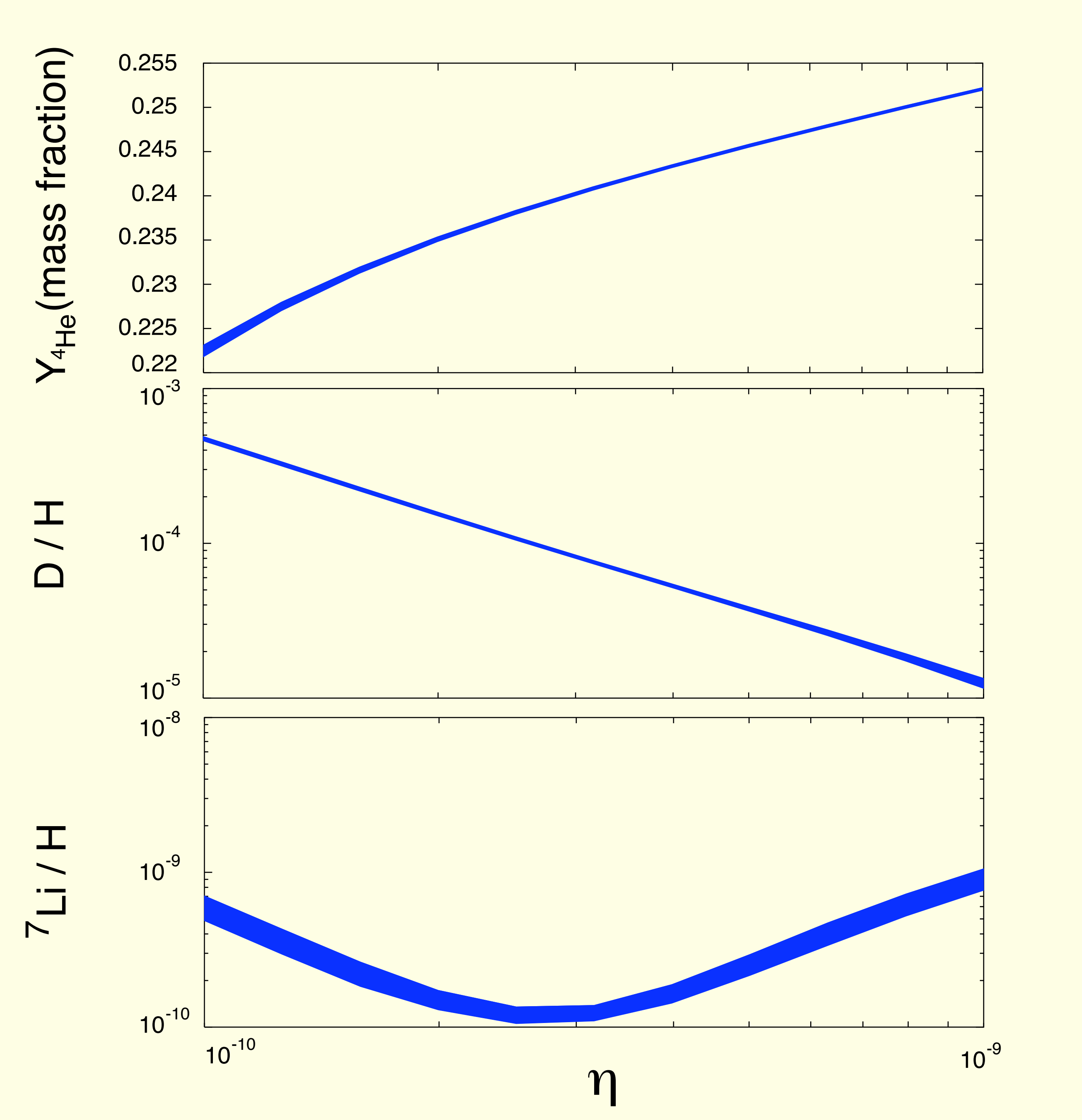
- Theoretical Abundances of Light Elements Only Depend on Baryon-Photon Ratio

$$\eta \equiv \frac{n_b}{n_\gamma}$$

- Primordial Abundances Inferred from Observations

⇒ Determine baryon density

BBN (Theoretical Prediction)



BBN (observational Abundances)

- He4

$$Y_{^4\mathrm{He}} = 0.238 \pm 0.002 \pm 0.005$$ Fields, Olive (1998)

$$Y_{^4\mathrm{He}} = 0.2421 \pm 0.0021$$ Izotov, Thuan (2003)

- D

$$\mathrm{D/H} = (2.78 \pm 0.44) \times 10^{-5}$$ Kirkman et al (2003)

- Li7

$$^7\mathrm{Li/H} = (1.23 \pm 0.34) \times 10^{-10}$$ Ryan et at (2000)

Theory vs Observation

CMB

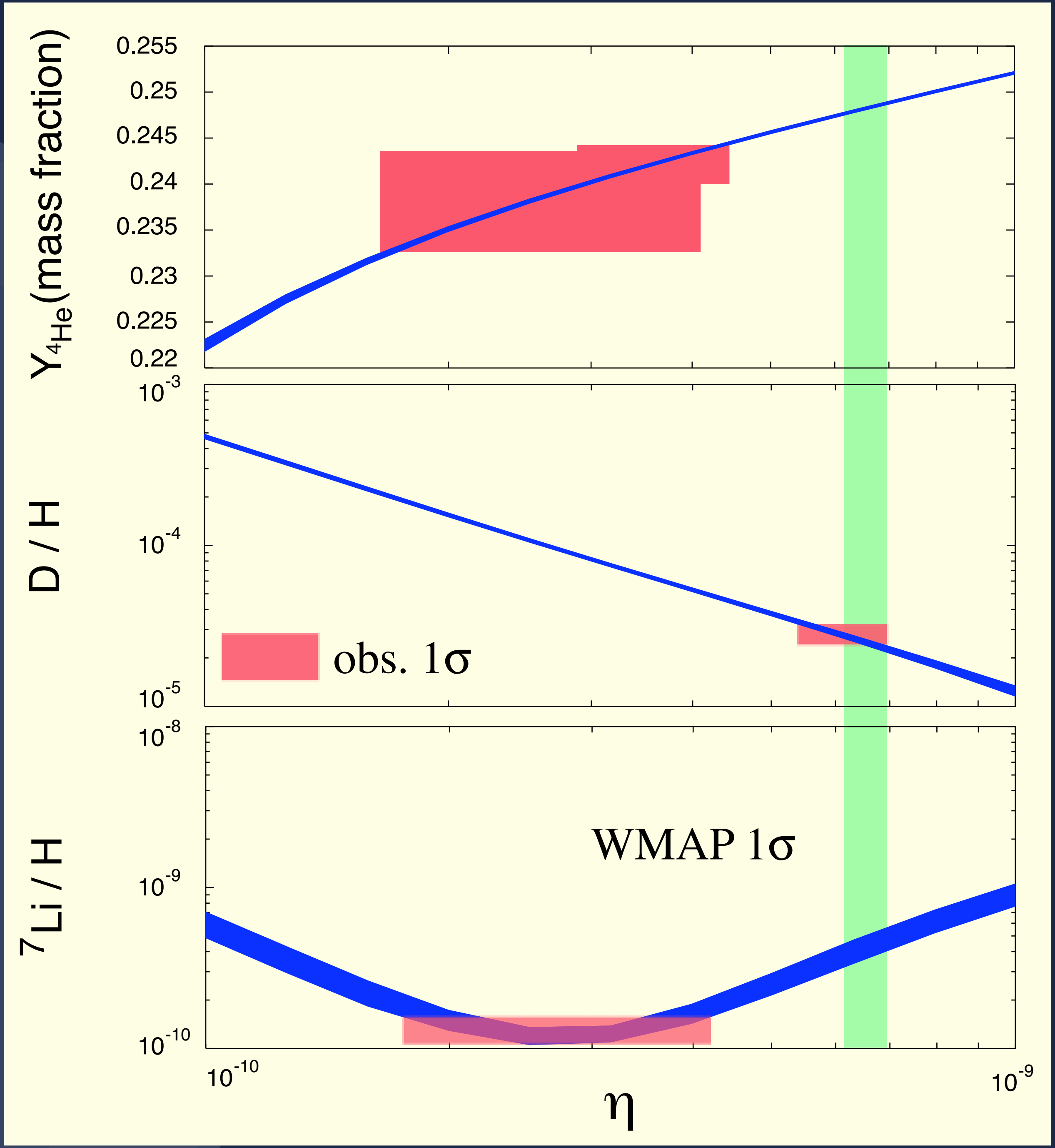
$$\eta = n_b/n_\gamma = (6.5^{+0.4}_{-0.3}) \times 10^{-10}$$

BBN

^{7}Li, ^{4}He

Smaller η is favored

Cyburt et al (2004)
Coc et al (2004)



Inconsistency

He4 and Li7 are produced more than observed

Possible Solutions

- Systematic Errors in Obs
- New Physics
  - Photo-Dissociation of Li7 by Decaying Particle   Feng, Rajaraman, Takayama (2003)
  - Varying Fine Structure Constant
  - Baryon Number Production after BBN
  - . . . .

Varying Coupling Constant

Evidence from QSO Absorption Lines?

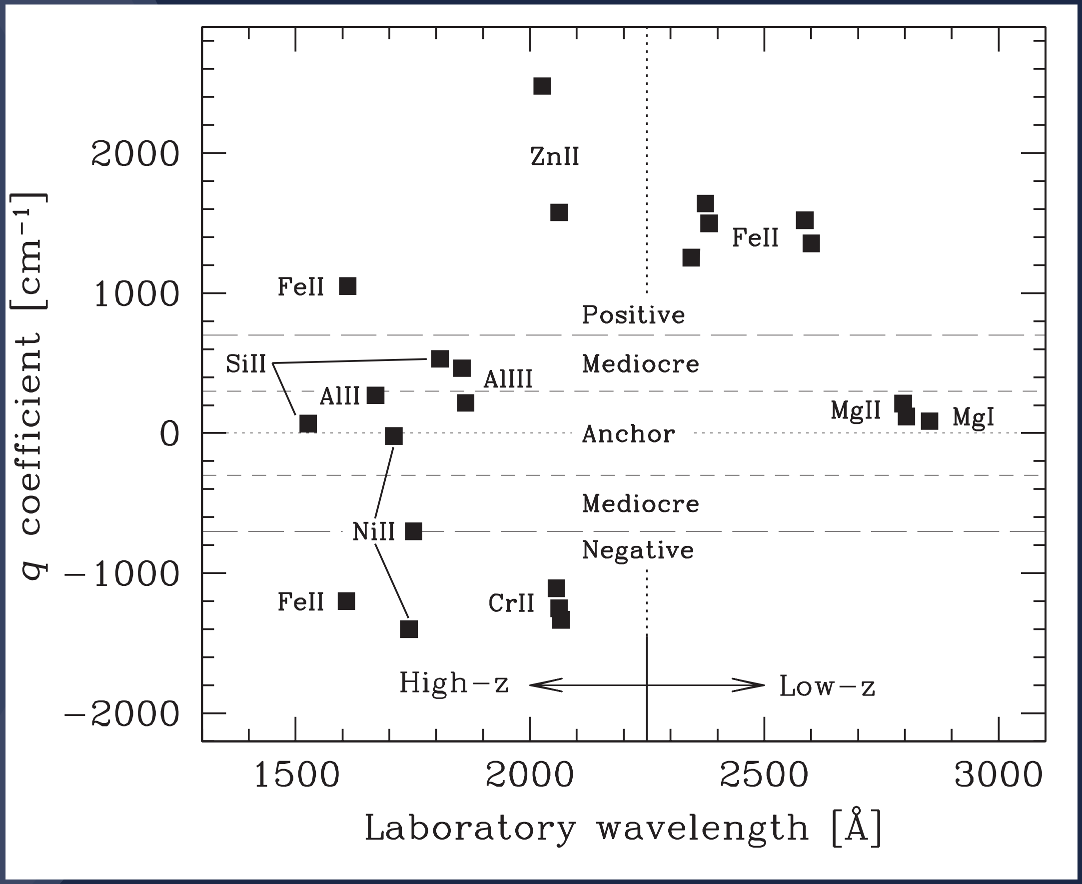
Transition Frequency ω, e.g. ($S_{1/2}$ --> $P_{3/2}$)

$$\omega_i = \omega_{i,0} + q_i \left[\left(\frac{\alpha}{\alpha_0} \right)^2 - 1 \right]$$

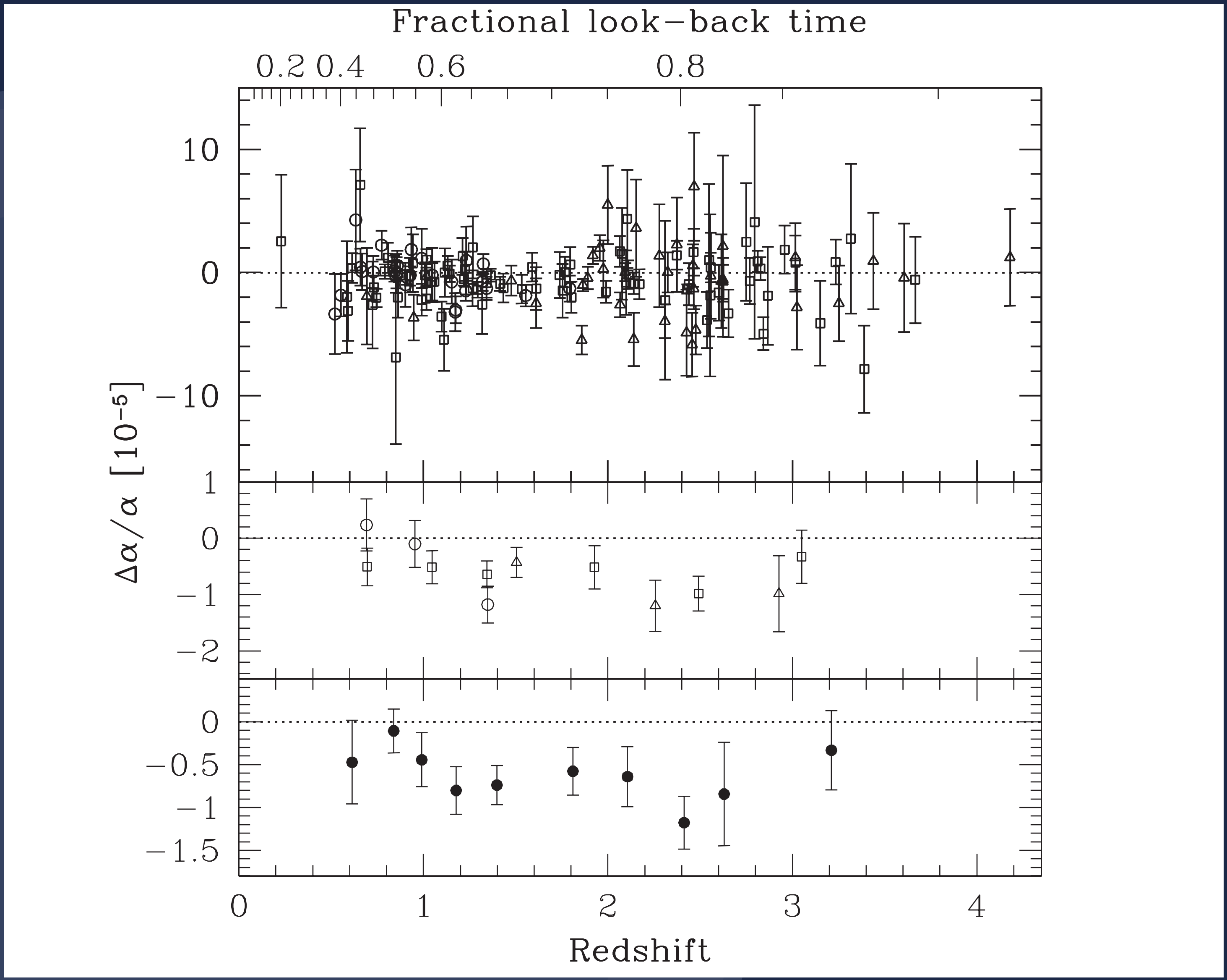
Many Multiplet Method

Dzuba et al (1999) Webb et al (1999)

use different atoms



Evidence for Varying α ?



$$\Delta\alpha/\alpha = (-0.573 \pm 0.113) \times 10^{-5}$$

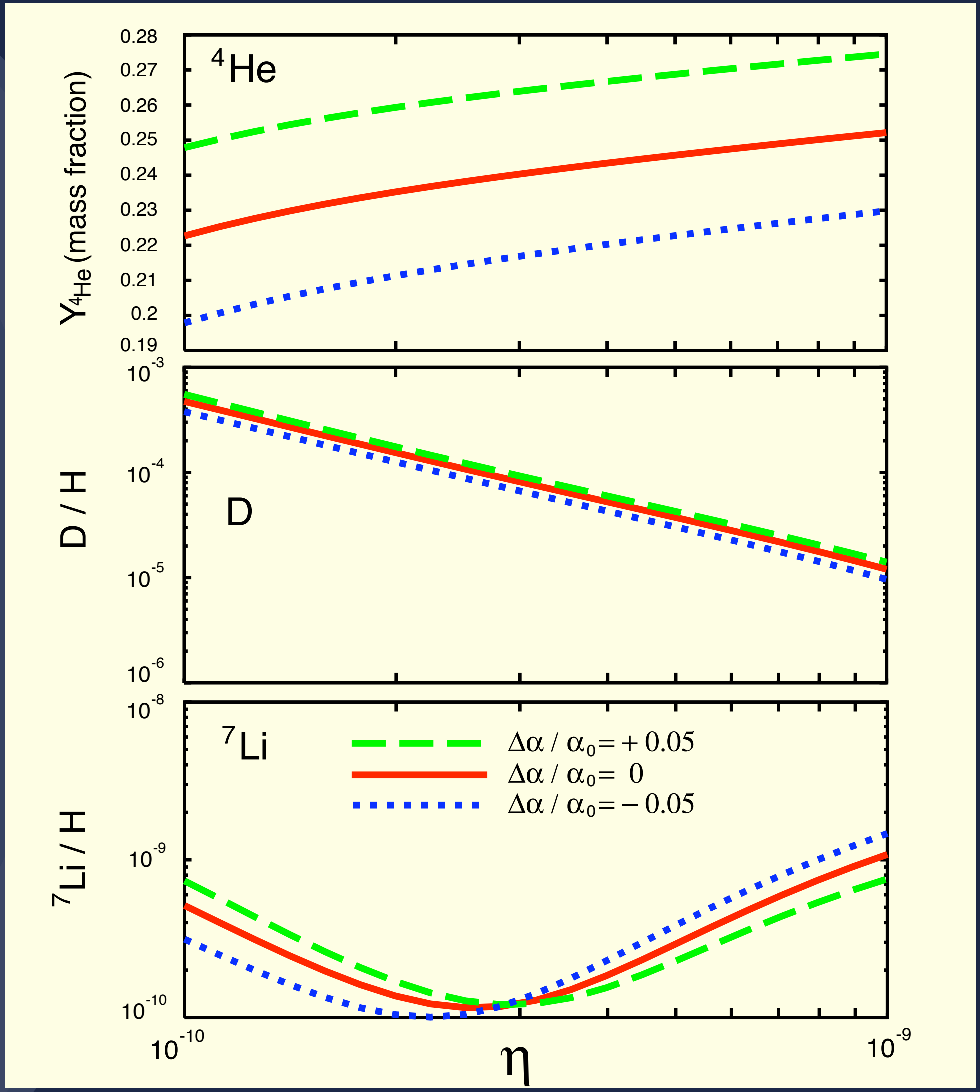
Murphy et al (2003)

Varing α and BBN

Assume Larger Fine Structure Constant at BBN

$$\alpha \nearrow \quad \Rightarrow \quad {}^{7}\mathrm{Li} \searrow$$

Large Coulomb Barrier



But

$${}^{4}\mathrm{He} \nearrow$$

$$\begin{aligned} m_n - m_p &= 2.05 \text{ MeV} \\ &- 0.76(\alpha/\alpha_0) \end{aligned}$$

Gasser, Leutwyler (1982)

$$\Delta m \searrow \quad \Rightarrow \quad n/p \nearrow$$

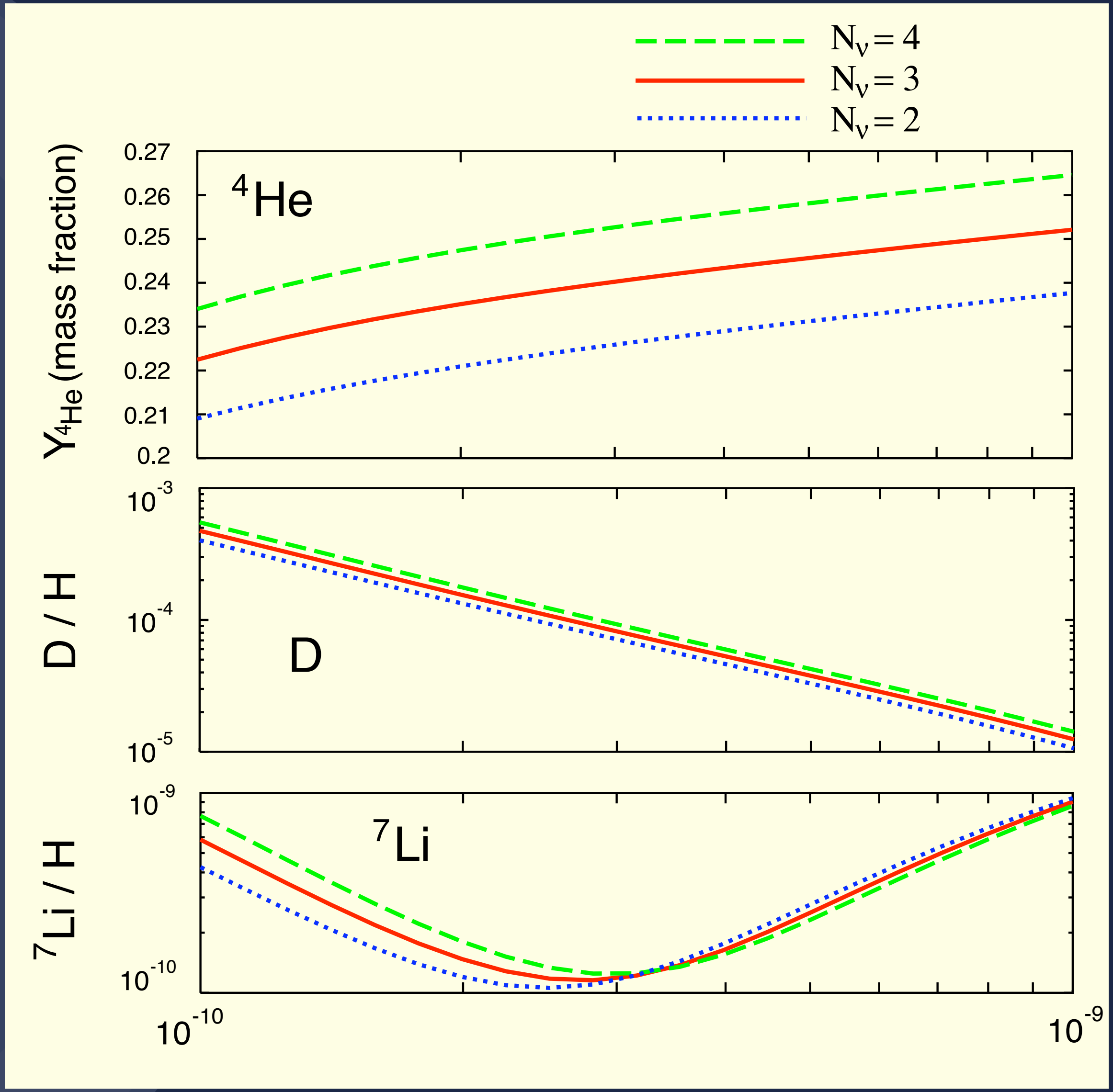
➡ We must reduce He4

Decrease the Abundance of He4

1. Decrease Effective Number of Neutrino N_ν
2. Large Lepton Asymmetry

$$N_\nu \searrow \quad \Rightarrow \quad H \searrow$$

$$\Rightarrow \quad n/p \searrow \quad \Rightarrow \quad {}^4\mathrm{He} \searrow$$



N_ν Decreases ?

- Hot Universe Begins at MeV Scale (Neutrinos are not thermalized)

MK, Kohri, Sugiyama (1999) (2000)

$$N_\nu \searrow$$

- Dark Radiation from Extra-Dimensions

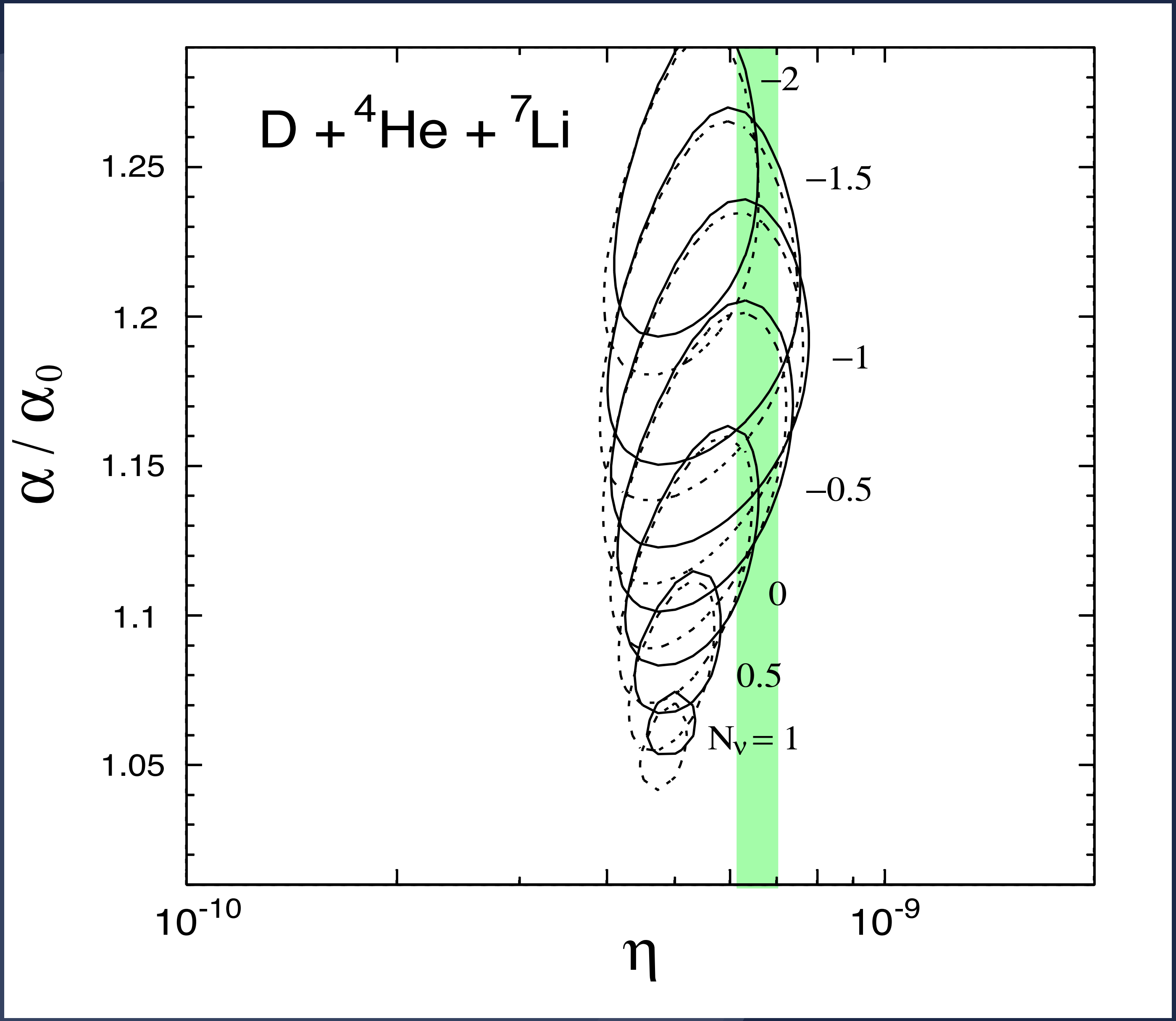
$$H^2 = \frac{8\pi G}{3}\rho + \rho_{dark}$$

$$N_\nu \searrow \text{ or } \nearrow$$

e.g. Rundall & Sundrum Model (1999),
Shiromizu, Maeda, Sasaki (1999)

Larger α and smaller N_ν

Ichikawa, MK hep-ph/0401231



Notice: CMB may also be affected by α and N_ν

2. Large Lepton Asymmetry

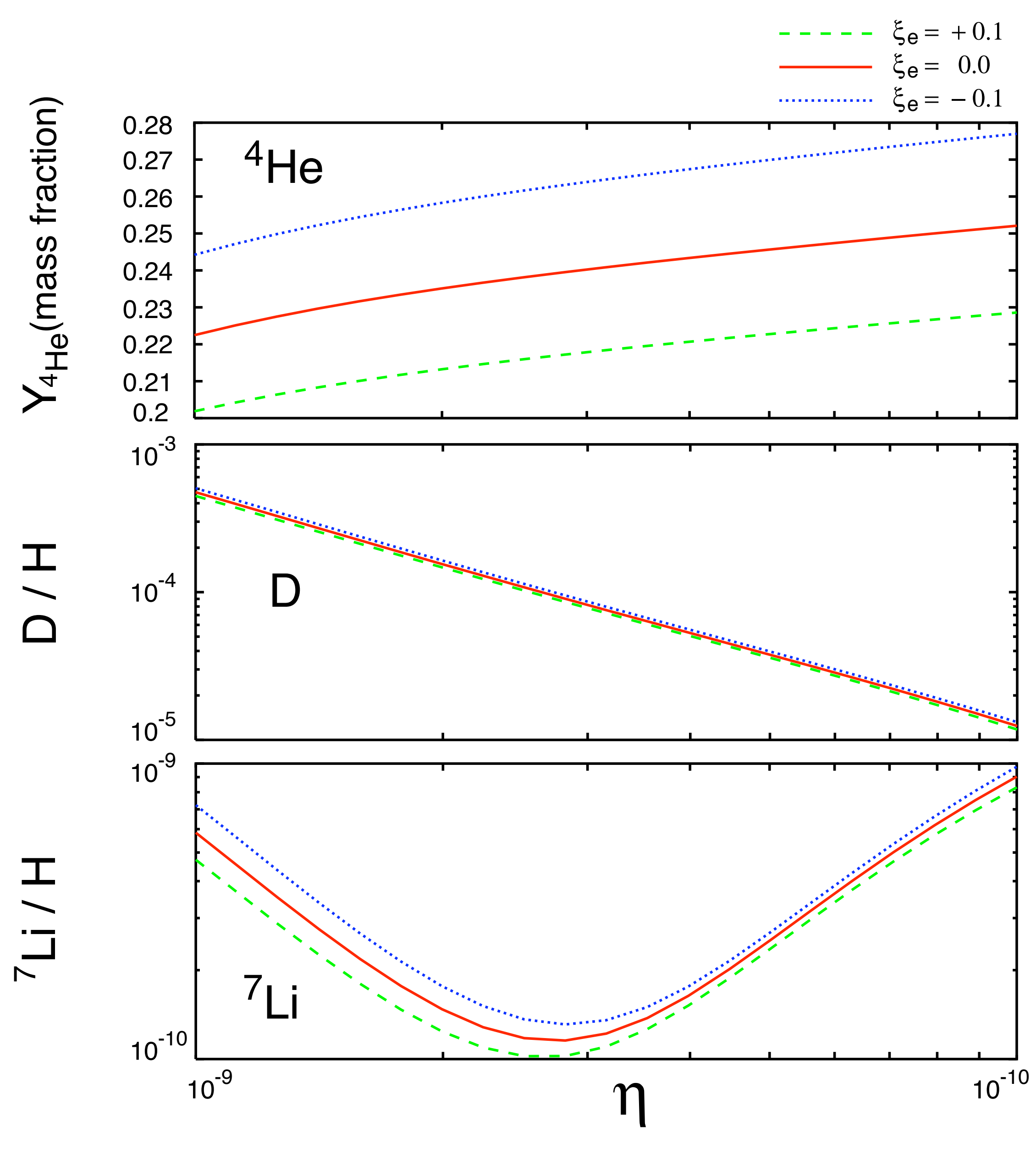
Chemical Potential

$$\xi_e > 0 \;\Rightarrow n_{\nu_e} > n_{\bar{\nu}_e}$$

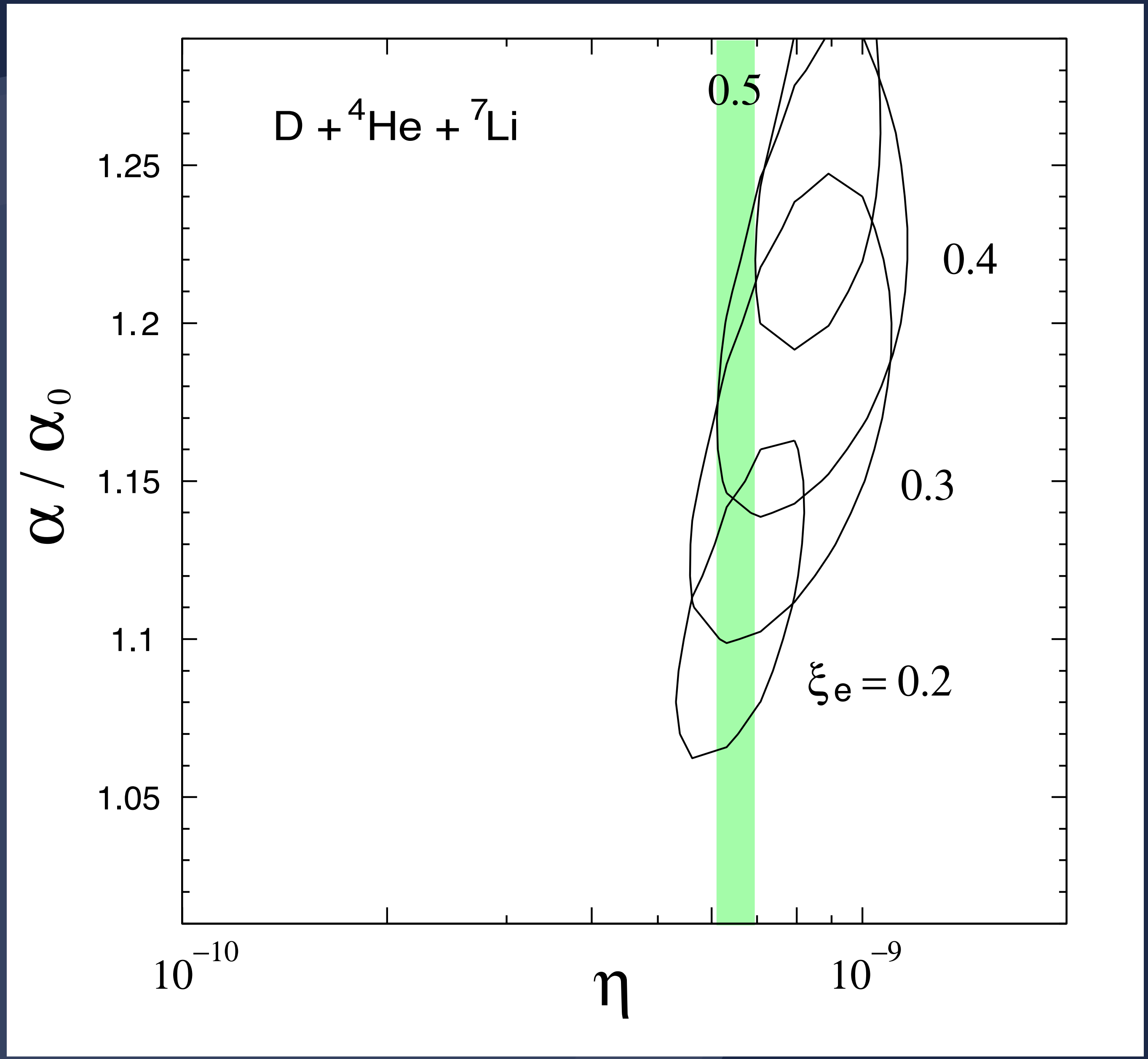
$$\xi_e \sim \frac{n_L}{n_\gamma}$$

$$p + e^- \leftrightarrow n + \nu_e$$

$$\xi_e \nearrow \;\Rightarrow\; {}^4\mathrm{He} \searrow$$



Lager α and Large Lepton Asym.



Notice: CMB may also is affected by α

Inconsistency

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Possible Solutions

- Systematic Errors in Obs
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  - Baryon Number Production after BBN
  - . . . .

Baryon Number Production after BBN

Ichikawa, MK, F.Takahashi astro-ph/0402522

Scheme

Baryogenesis → BBN → Recombination

↑ η_{BBN} (before BBN) ↑ $+\eta_{add}$ (between BBN and Recombination)

$$\eta_0 = \eta_{BBN} + \eta_{add} \simeq 6.5 \times 10^{-10} \quad \text{(WMAP)}$$

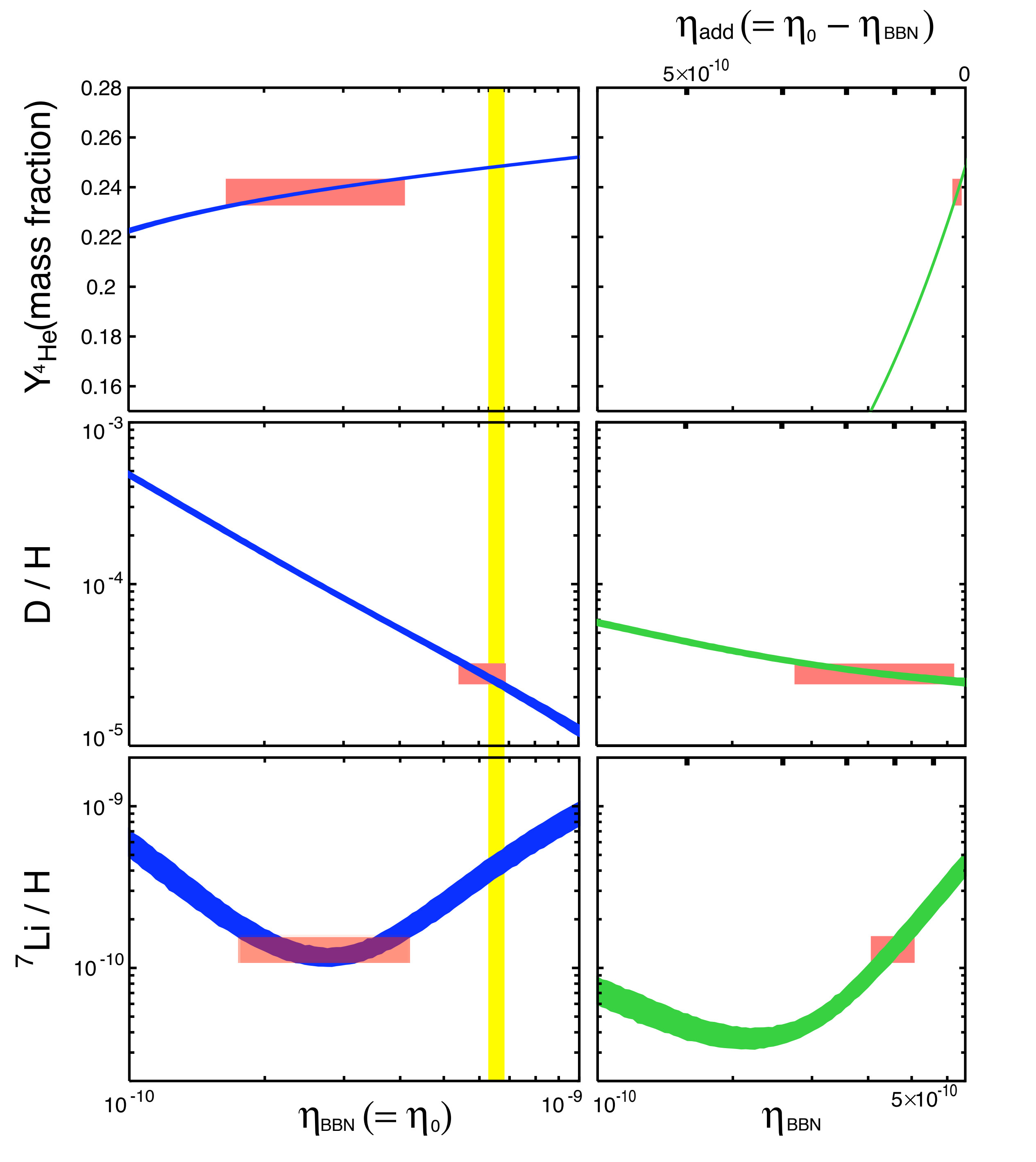
Since Hydrogen Number Density Increases

$$Y^0_{^4\mathrm{He}} = Y^{BBN}_{^4\mathrm{He}}(\eta_{BBN}/\eta_0)$$

$$(\mathrm{D/H})^0 \sim (\mathrm{D/H})^{BBN}(\eta_{BBN}/\eta_0)$$

$$(^7\mathrm{Li/H})^0 \sim (^7\mathrm{Li/H})^{BBN}(\eta_{BBN}/\eta_0)$$

Prediction of Light Element Abundances



Too Small He4

Consistent

Increase the Abundance of He4

Large Lepton Asymmetry

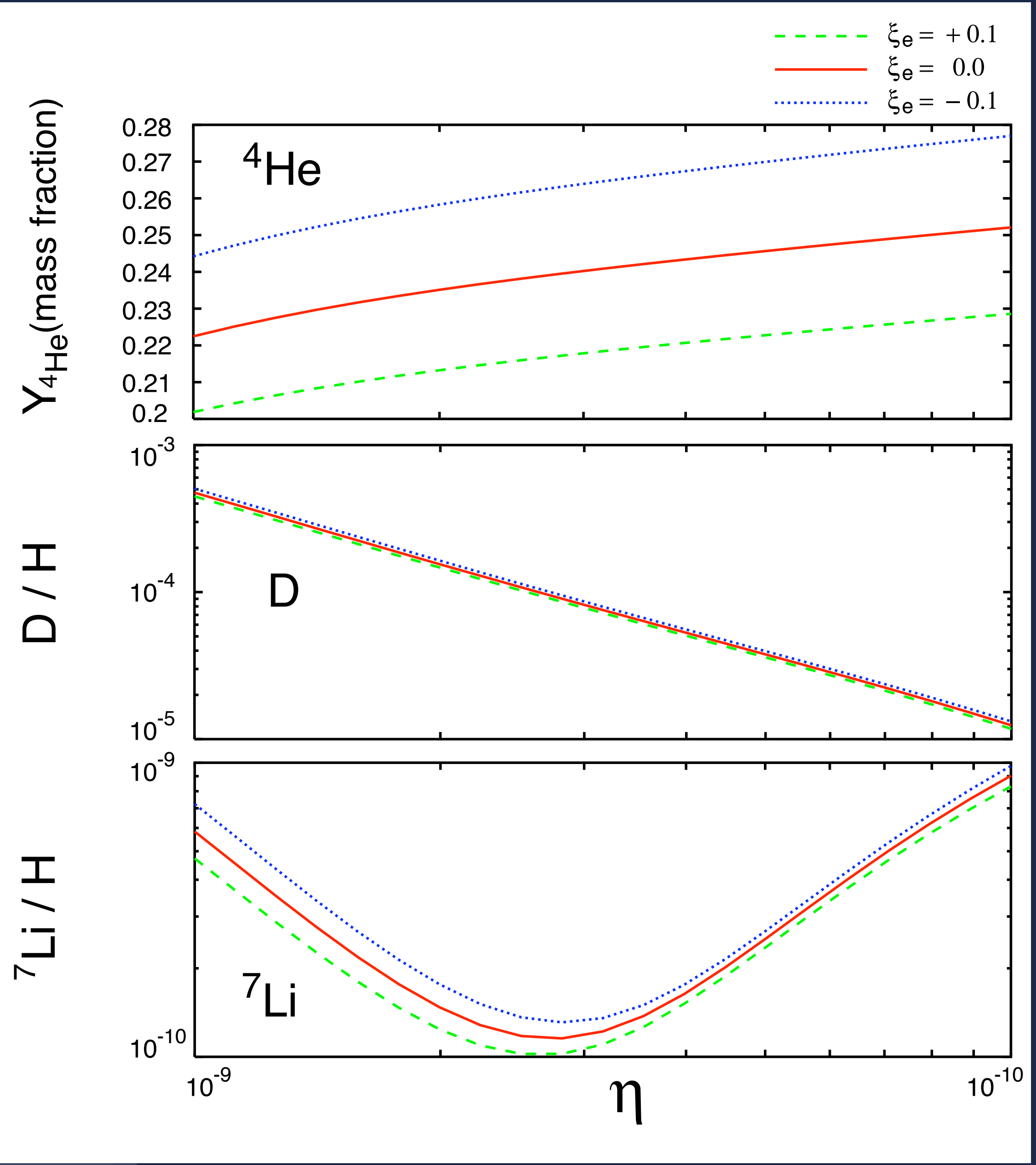
Chemical Potential

$$\xi_e < 0 \Rightarrow n_{\nu_e} < n_{\bar{\nu}_e}$$

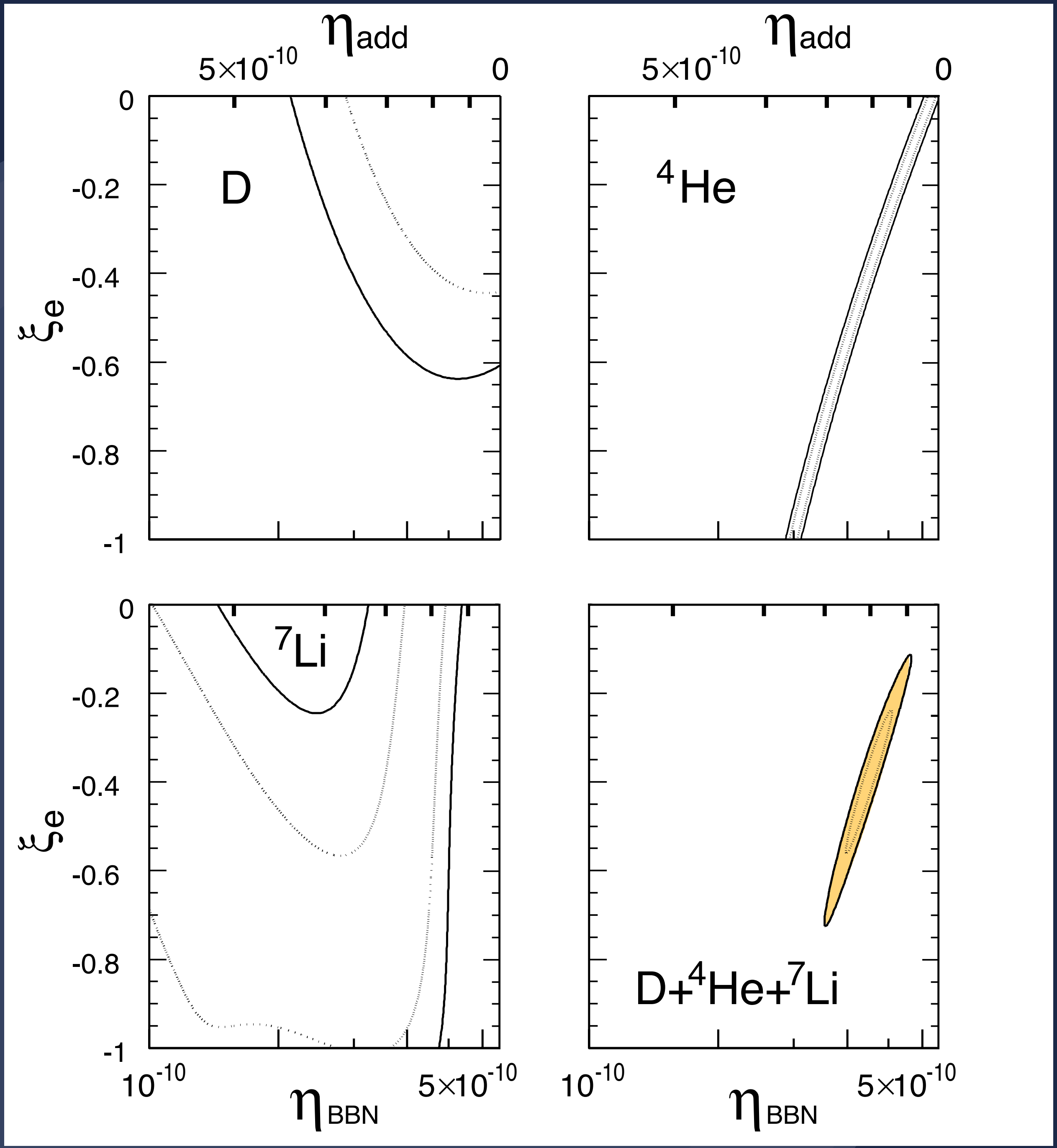
$$\xi_e \sim \frac{n_L}{n_\gamma}$$

$$p + e^- \leftrightarrow n + \nu_e$$

$$\xi_e \searrow \quad \Rightarrow \quad {}^4\text{He} \nearrow$$



Baryon Injection and Large Lepton Asym



Best Solution

$$\eta_{add} = 2 \times 10^{-10}$$
$$\xi_e = -0.4$$

Scenario with use of Q-Balls

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Scheme

Baryogenesis → BBN → Recombination

η_{BBN} ξ_e (at BBN)

$+\eta_{add}$ (at Recombination)

Affleck-Dine

Q-ball Formation with Two Flat Directions (e.g. eLL, and udd)

L-Ball (eLL) → ξ_e η_{BBN}

B-Ball (udd) → η_{add}

Typical Parameters

$$m_{3/2} \simeq 1 \text{ GeV}$$

$$Q_L \sim 10^{21}$$

$$T_{\text{L decay}} \sim 10 \text{ GeV}$$

$$Q_B \sim 10^{25}$$

$$T_{\text{B decay}} \sim 0.01 \text{ MeV}$$

Conclusion

- If we take the observational data seriously, there exists some inconsistency between WMAP and BBN
- Solutions may need exotic assumptions on parameters in BBN such as large lepton asymmetry (neutrino chemical pot.) and extra baryon number injection
- We must understand more about systematic errors in the observations