Title: Scalar-tensor gravity, changing couplings and BBN

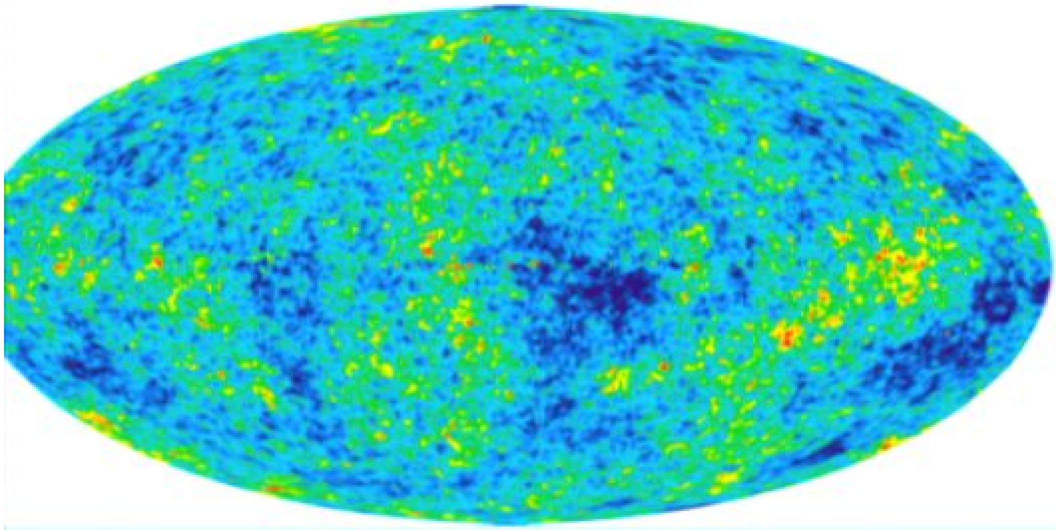
Date: Jun 01, 2008 11:20 AM

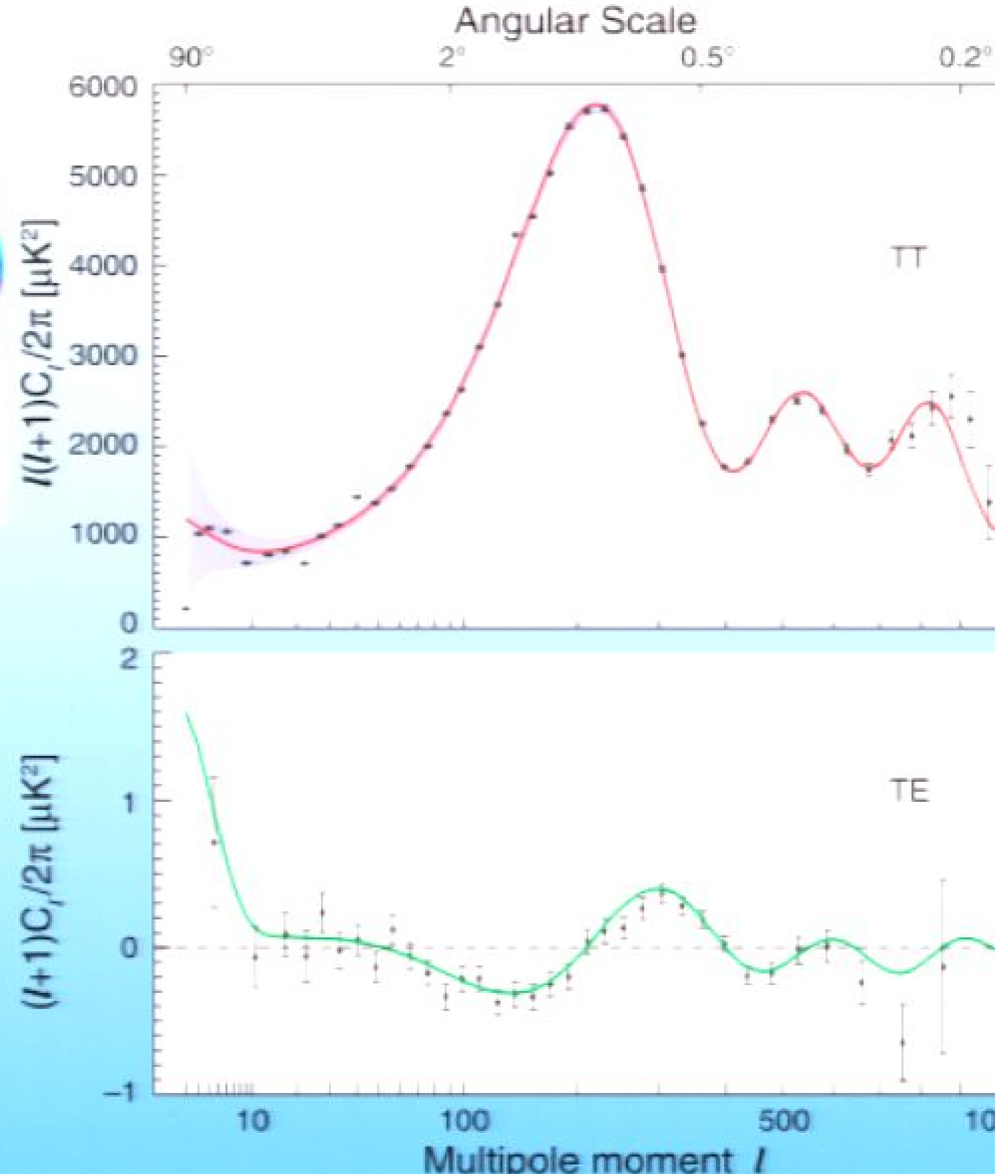
URL: http://pirsa.org/08060025

Abstract:

Big Bang Nucleosynthesis and the Variation of Fundamental Couplings

- BBN and the WMAP determination of η, $\Omega_B h^2$
- Observations and Comparison with Theory
  - D/H - ^{4}He - ^{7}Li
- Variations of Fundamental parameters
- Sensitivity to BBN
  - Δm_N - τ_n B_D

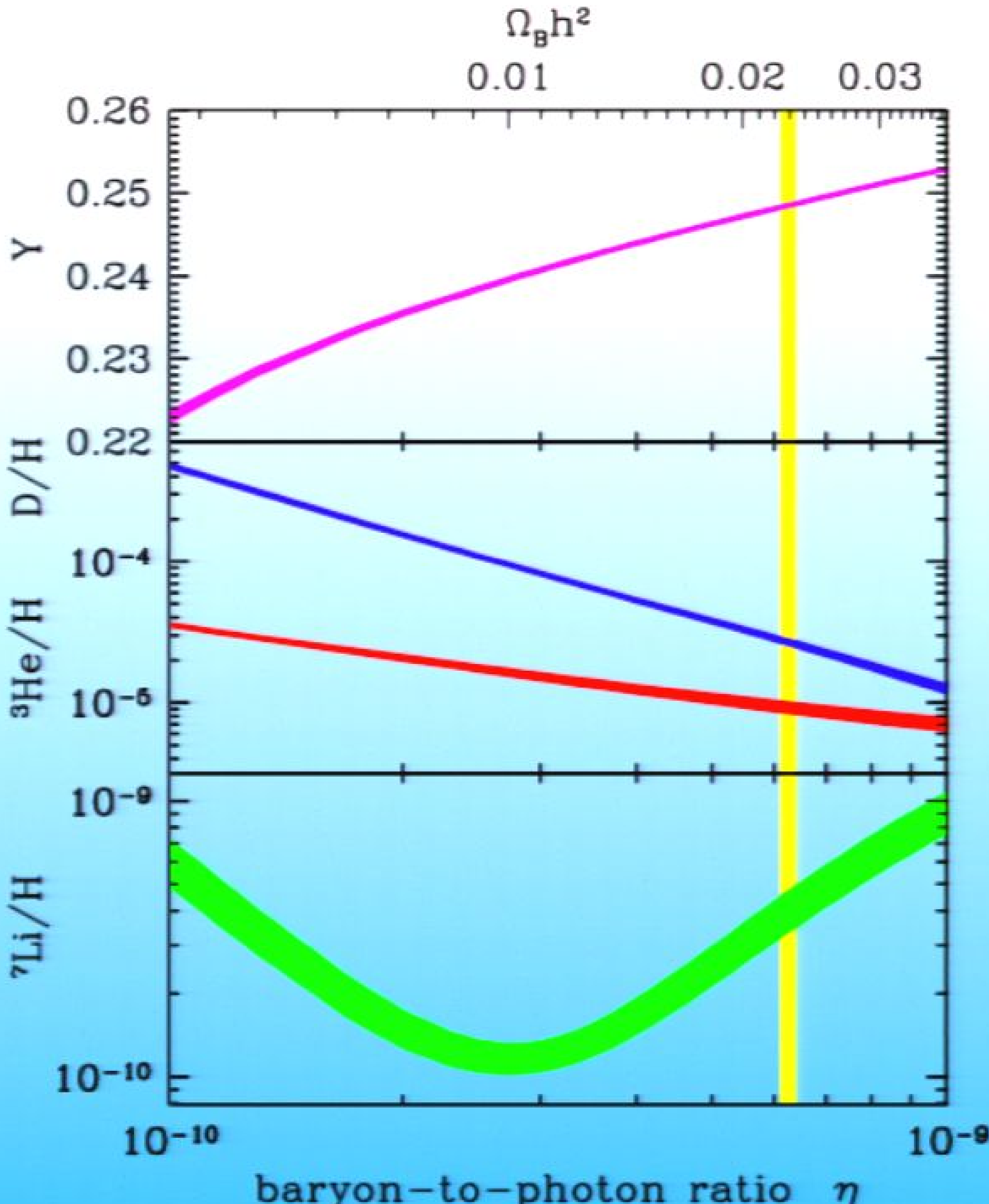




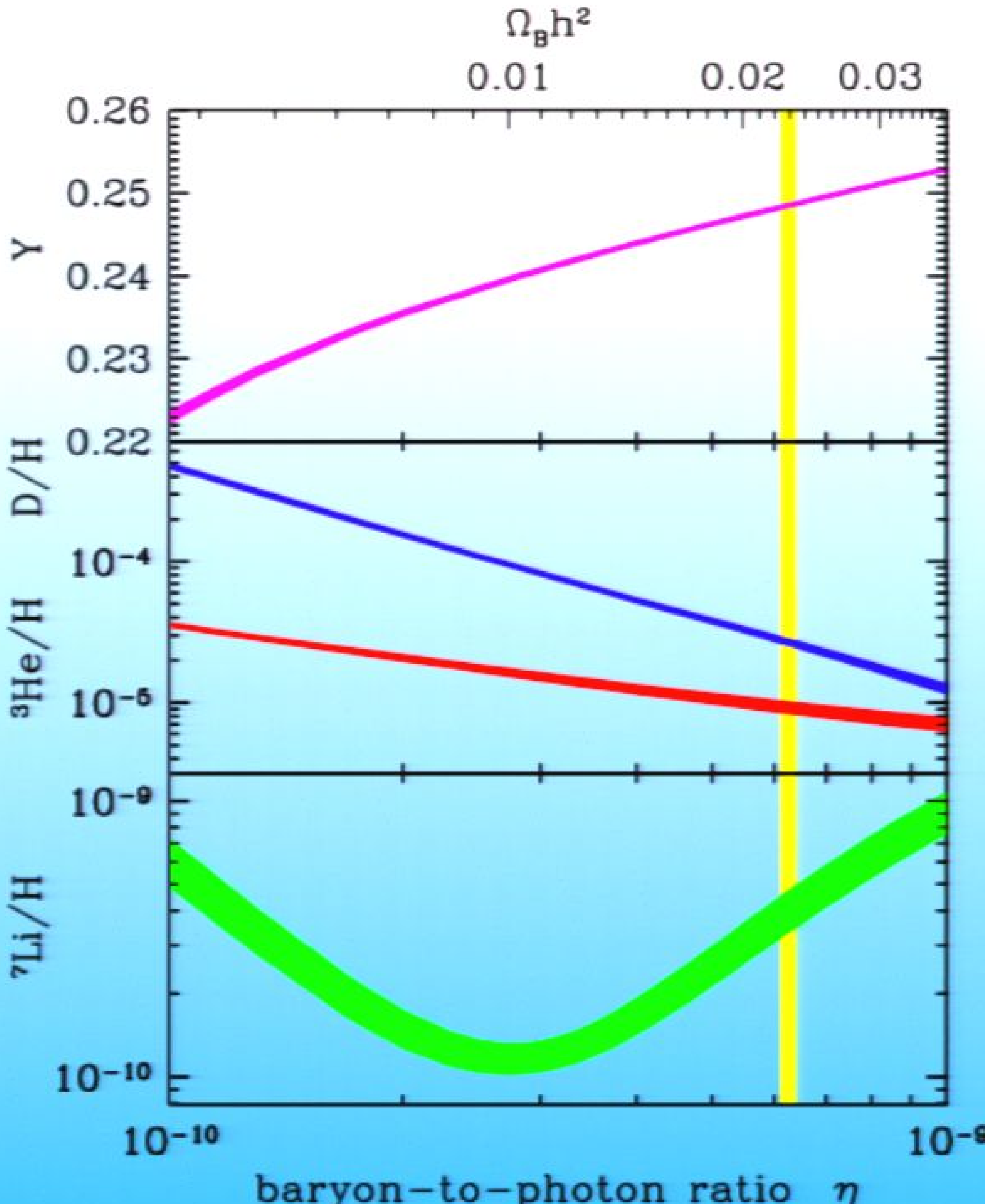
WMAP best fit

$$\Omega_B h^2 = 0.0227 \pm 0.0006$$

$$\eta_{10} = 6.22 \pm 0.16$$

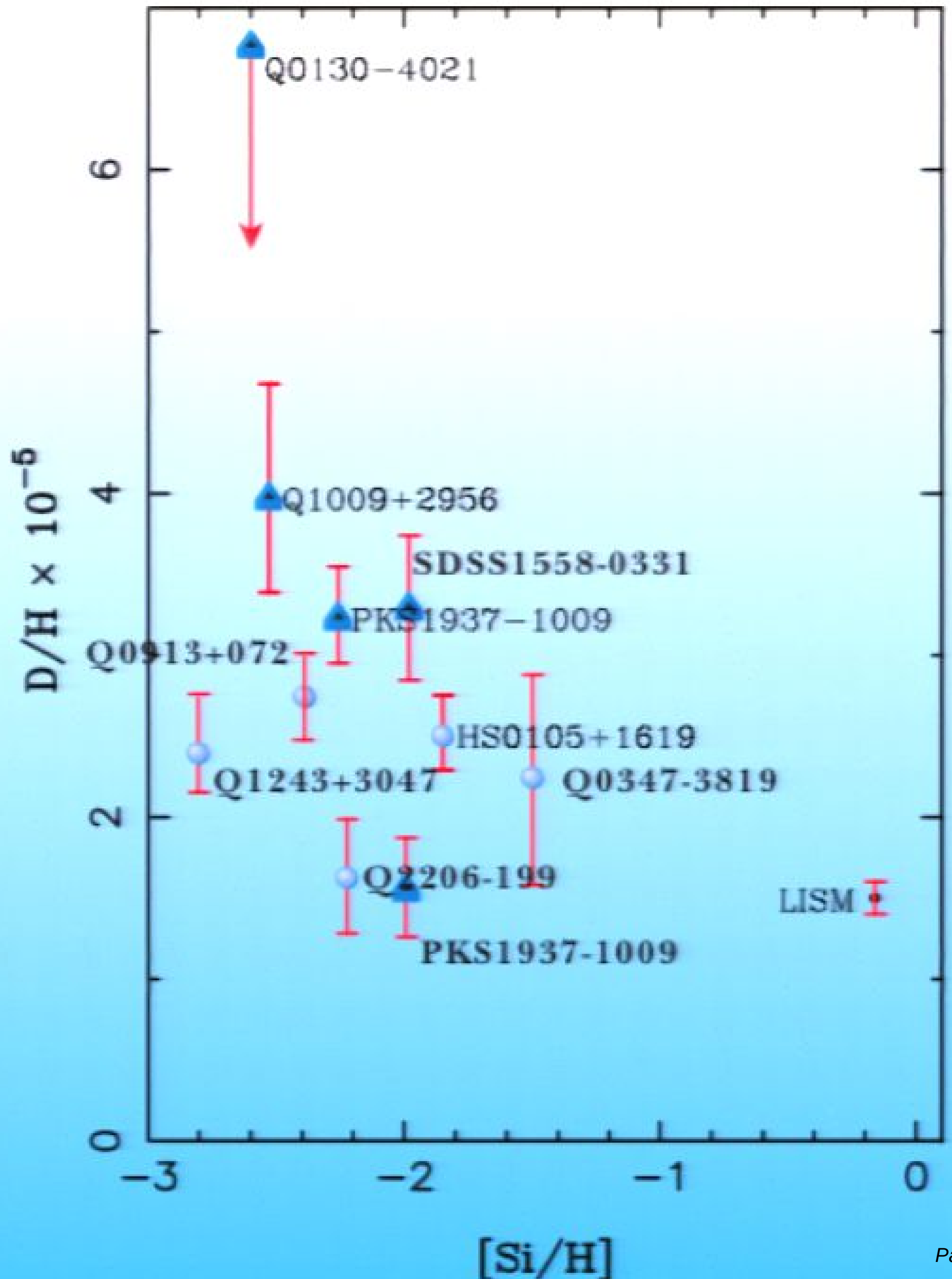


$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
Y
0.24
0.23
0.22
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon-to-photon ratio η



$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon-to-photon ratio η

D/H abundances in Quasar apsorption systems



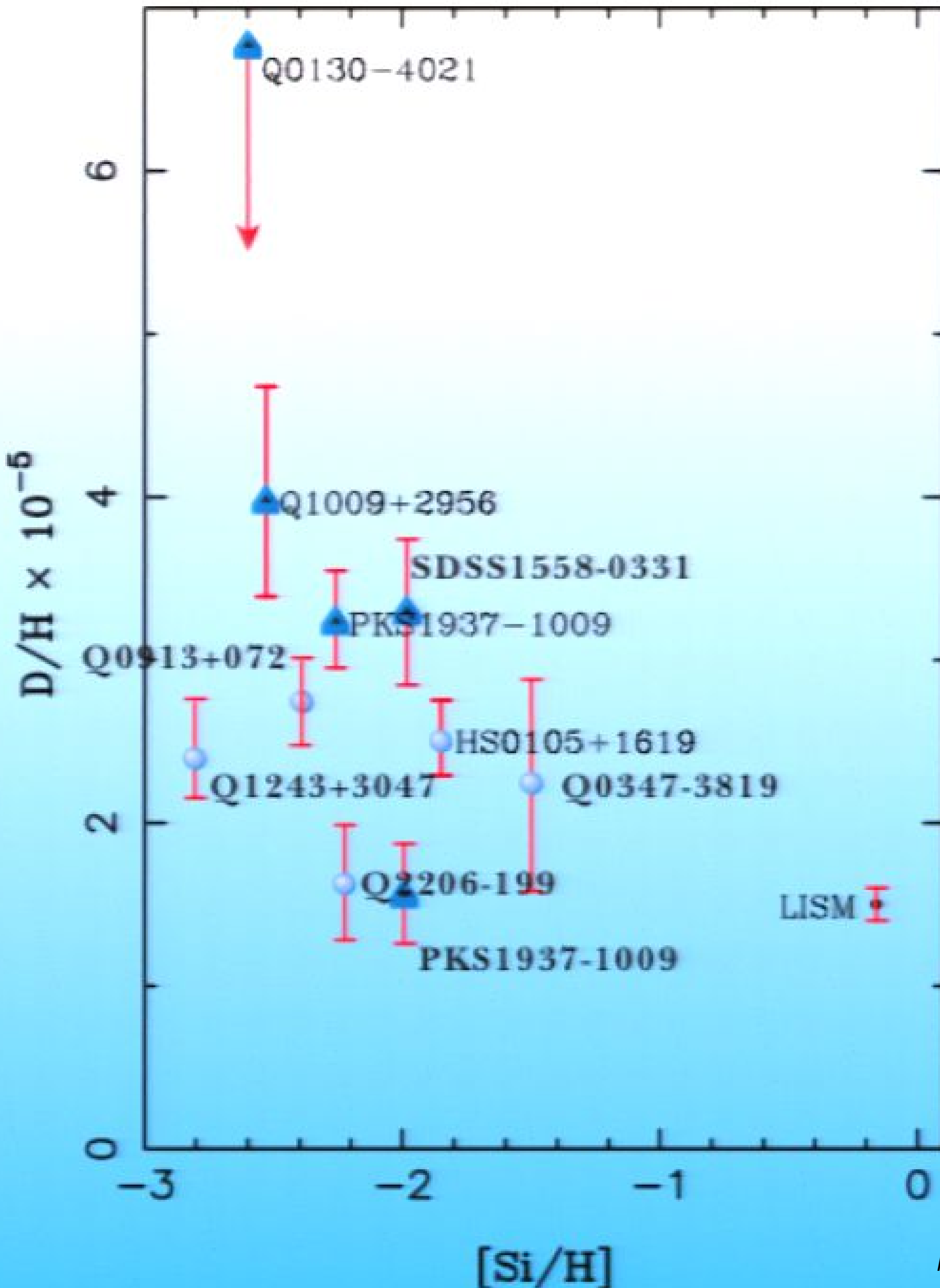
D/H abundances in Quasar apsorption systems

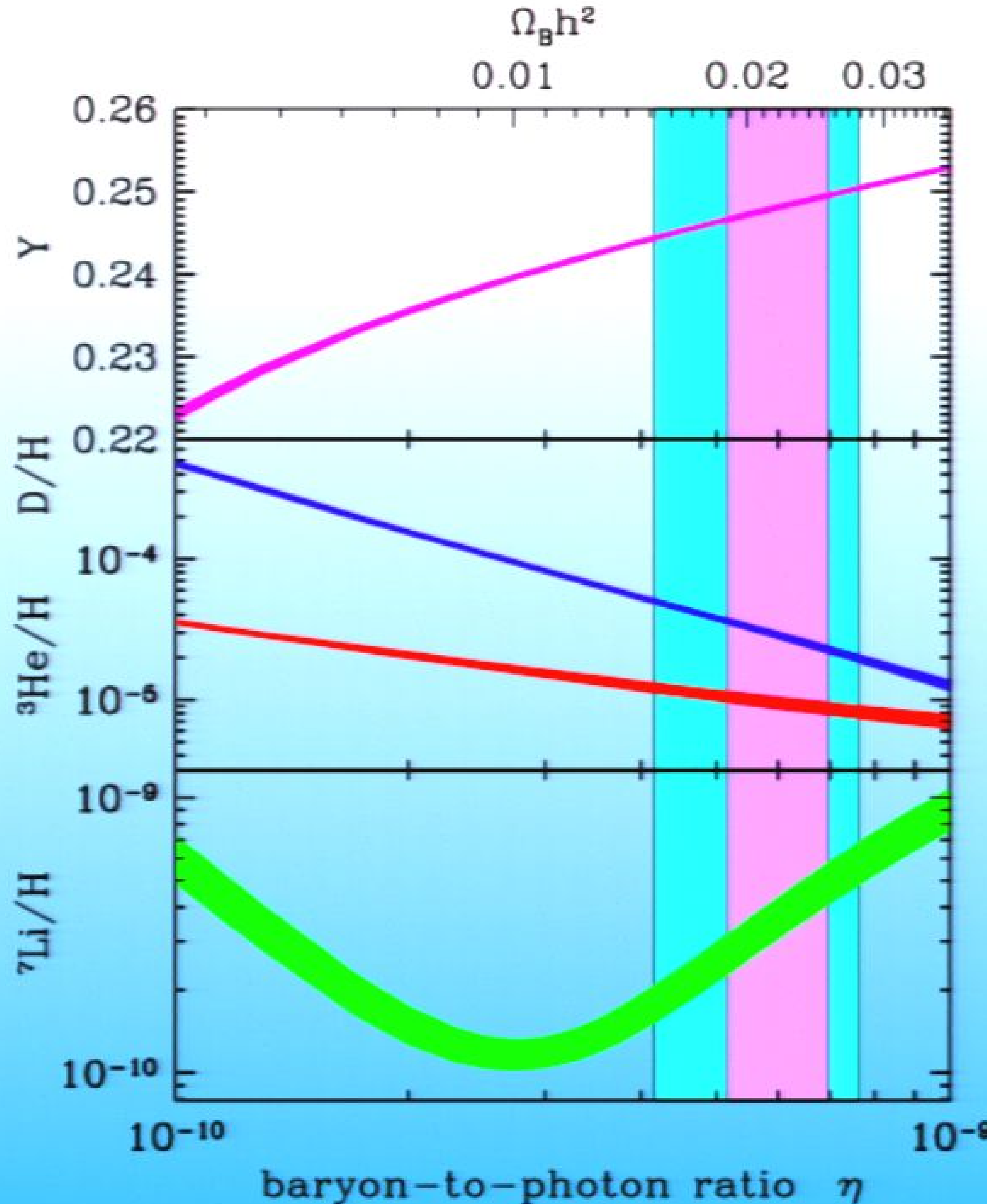
BBN Prediction:

$$10^5\, D/H = 2.74^{+0.26}_{-0.16}$$

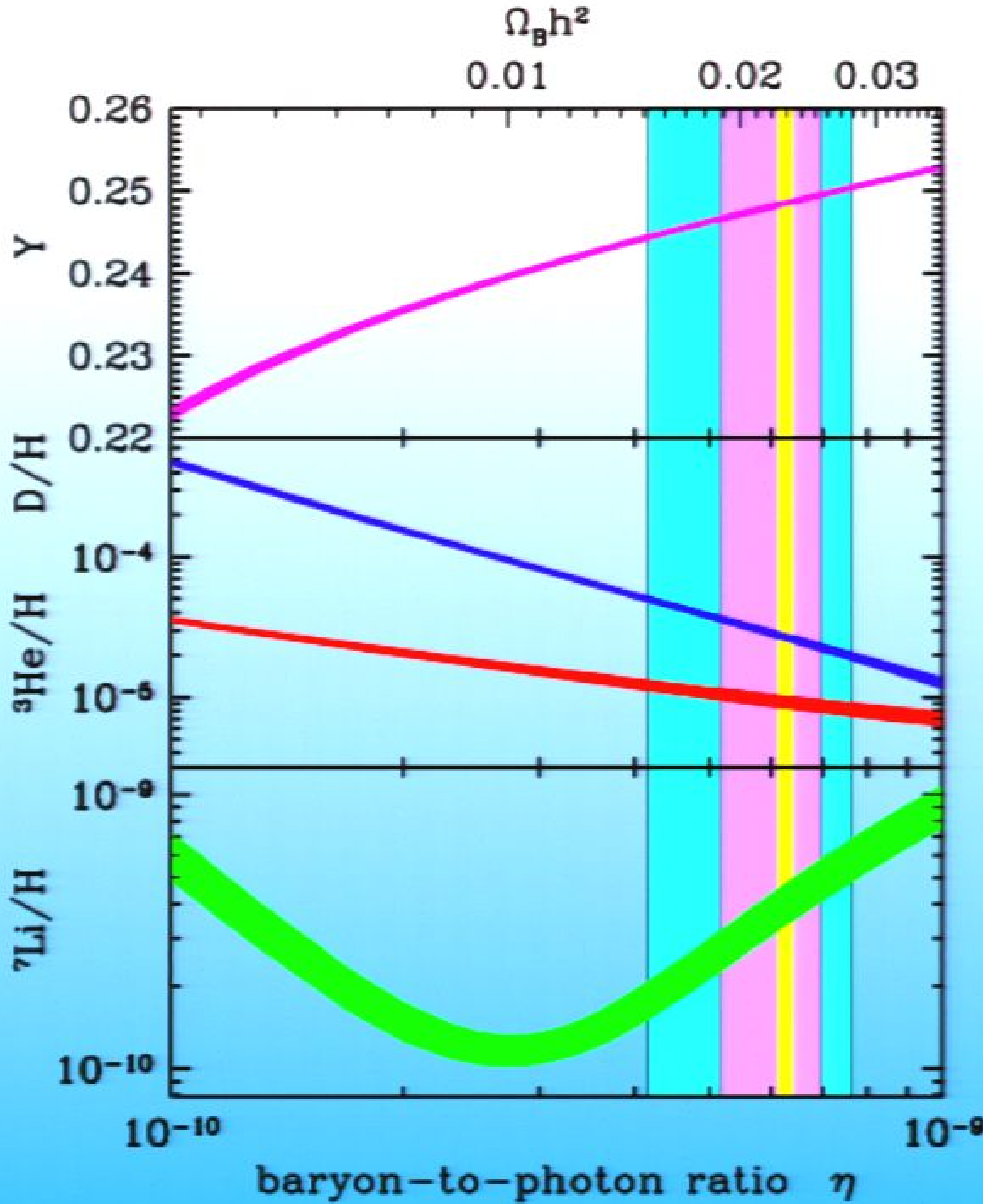
Obs Average:

$$10^5\, D/H = 2.82 \pm 0.21$$

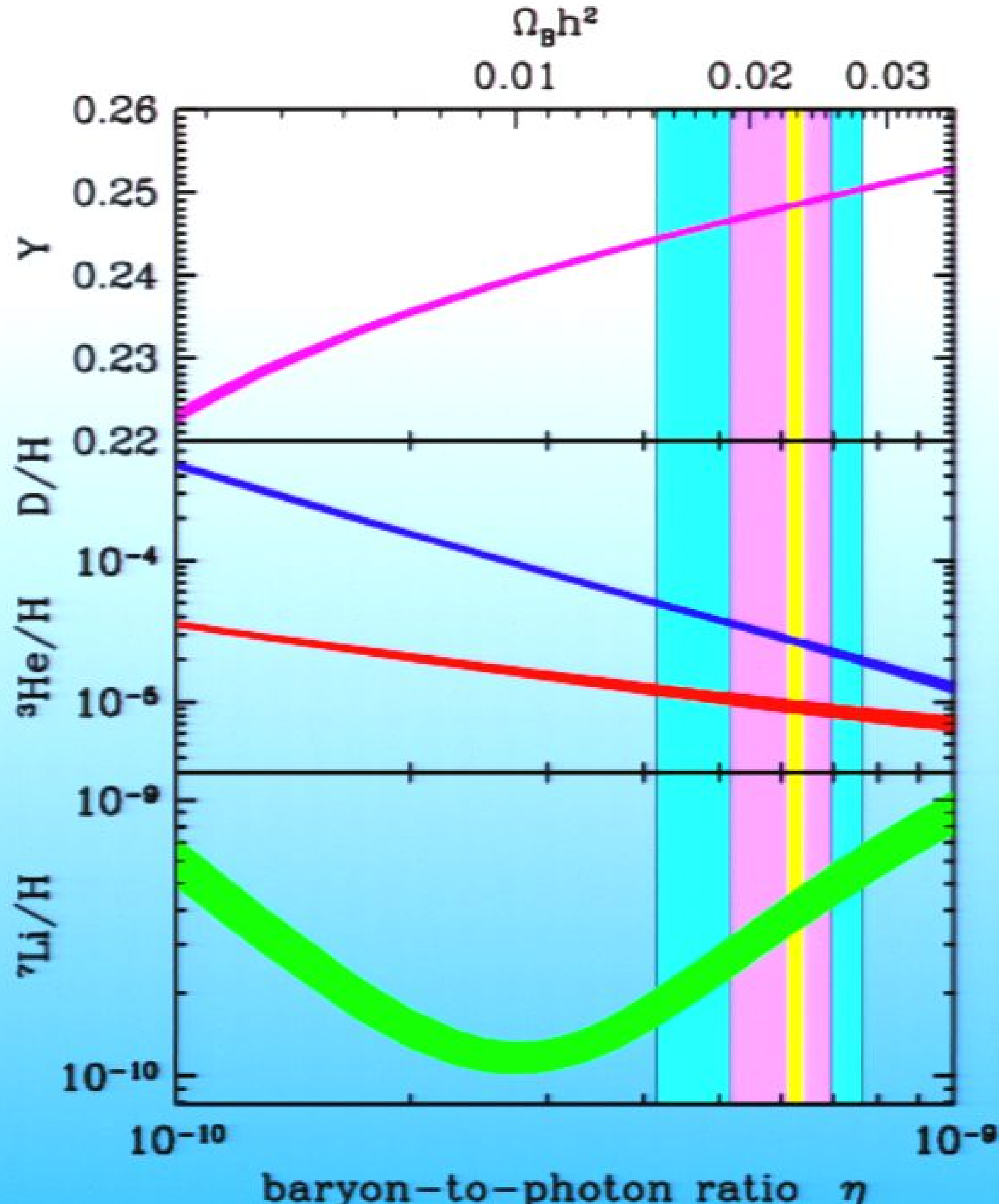




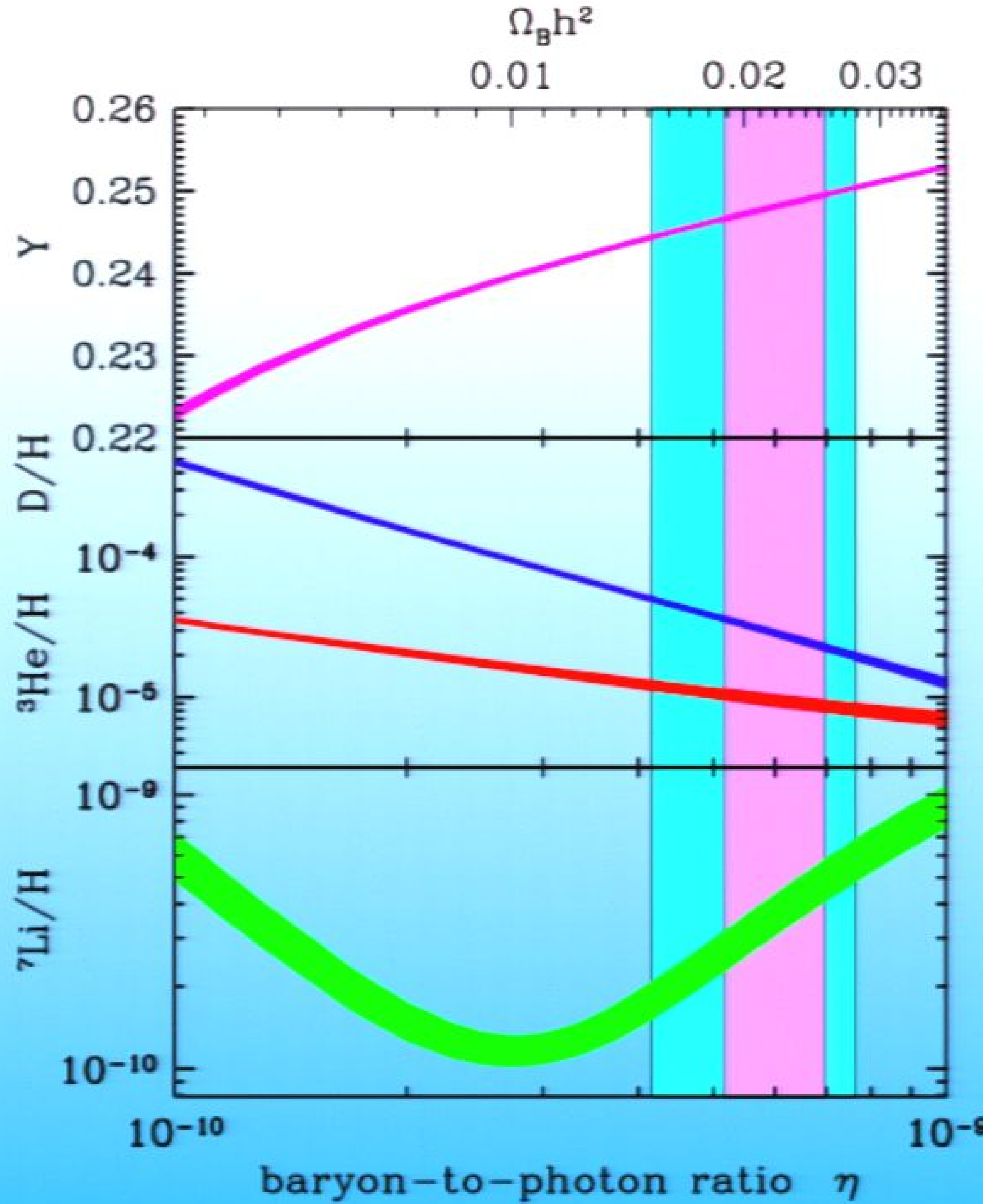
$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon-to-photon ratio η



$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η

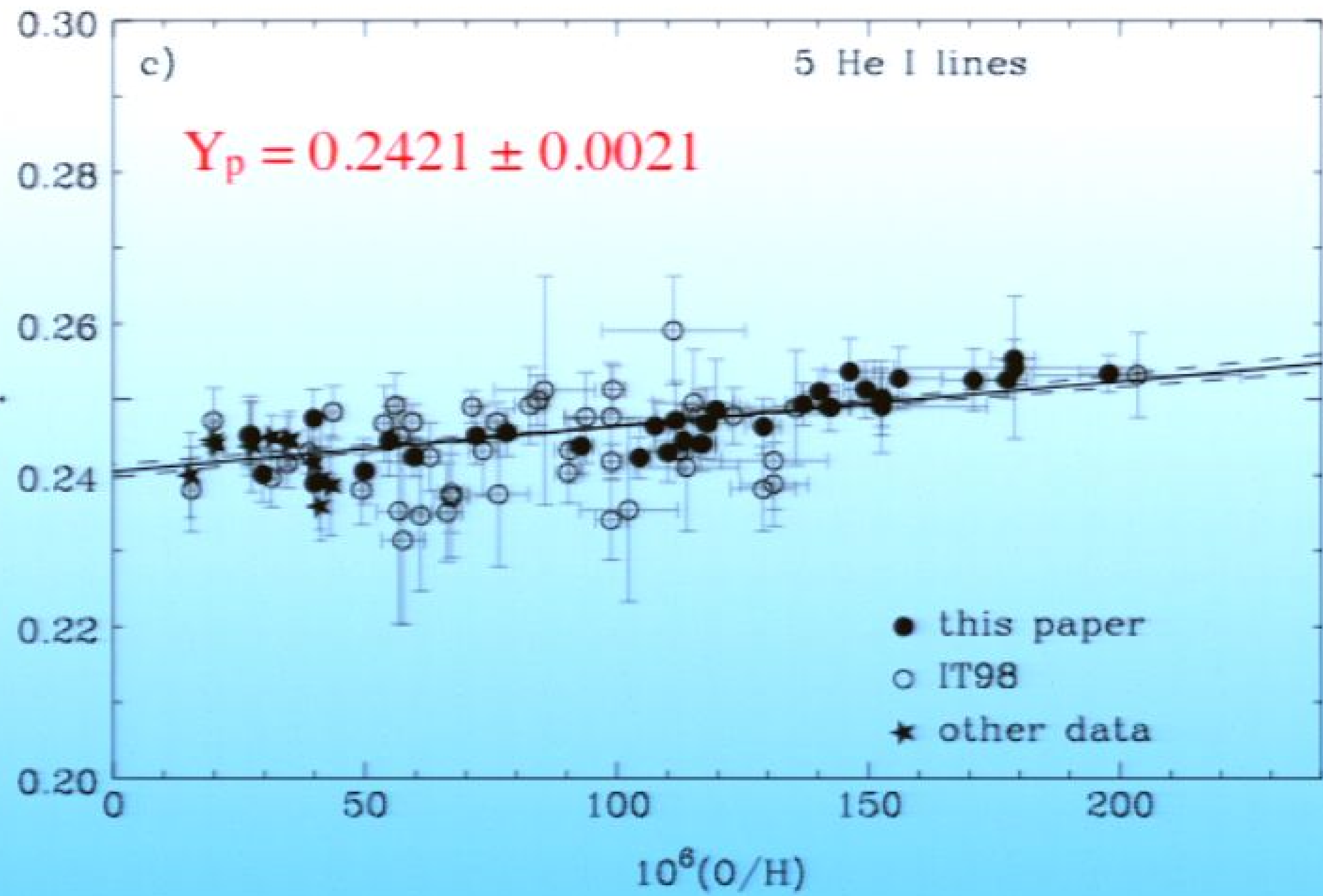


$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon–to–photon ratio η



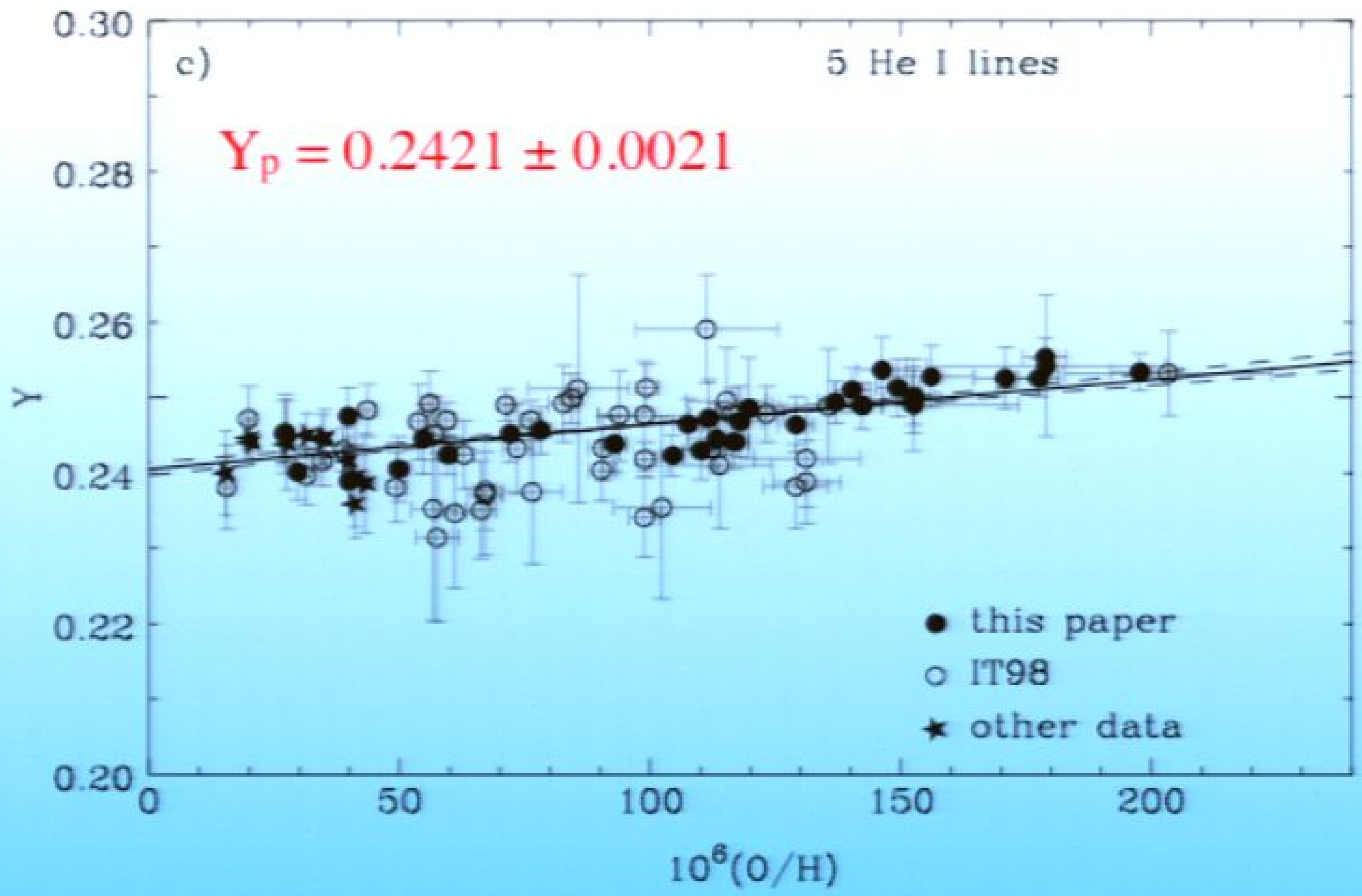
$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon-to-photon ratio η

^{4}He



Izotov & Thuan

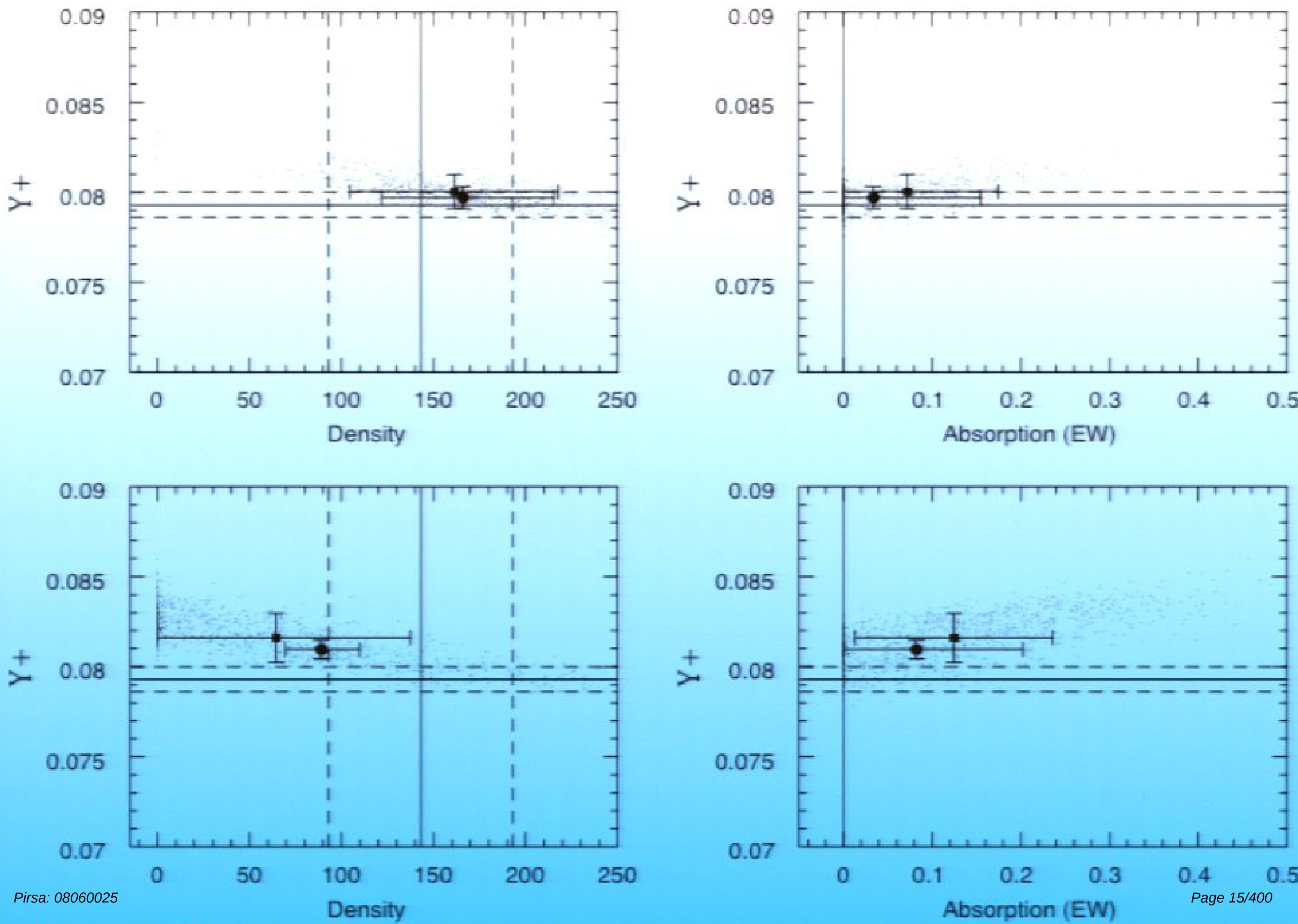
^{4}He



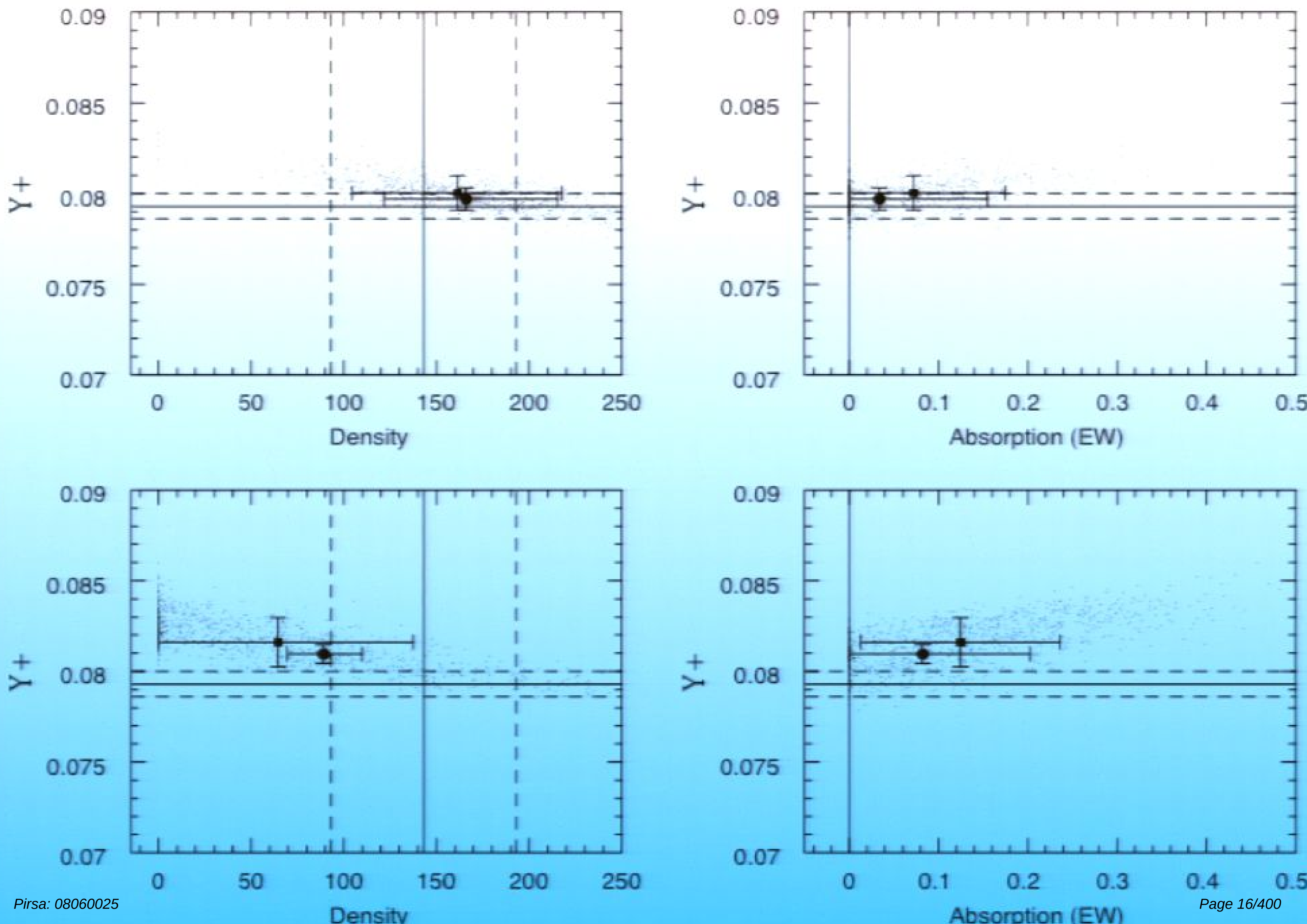
Izotov & Thuan

Method:

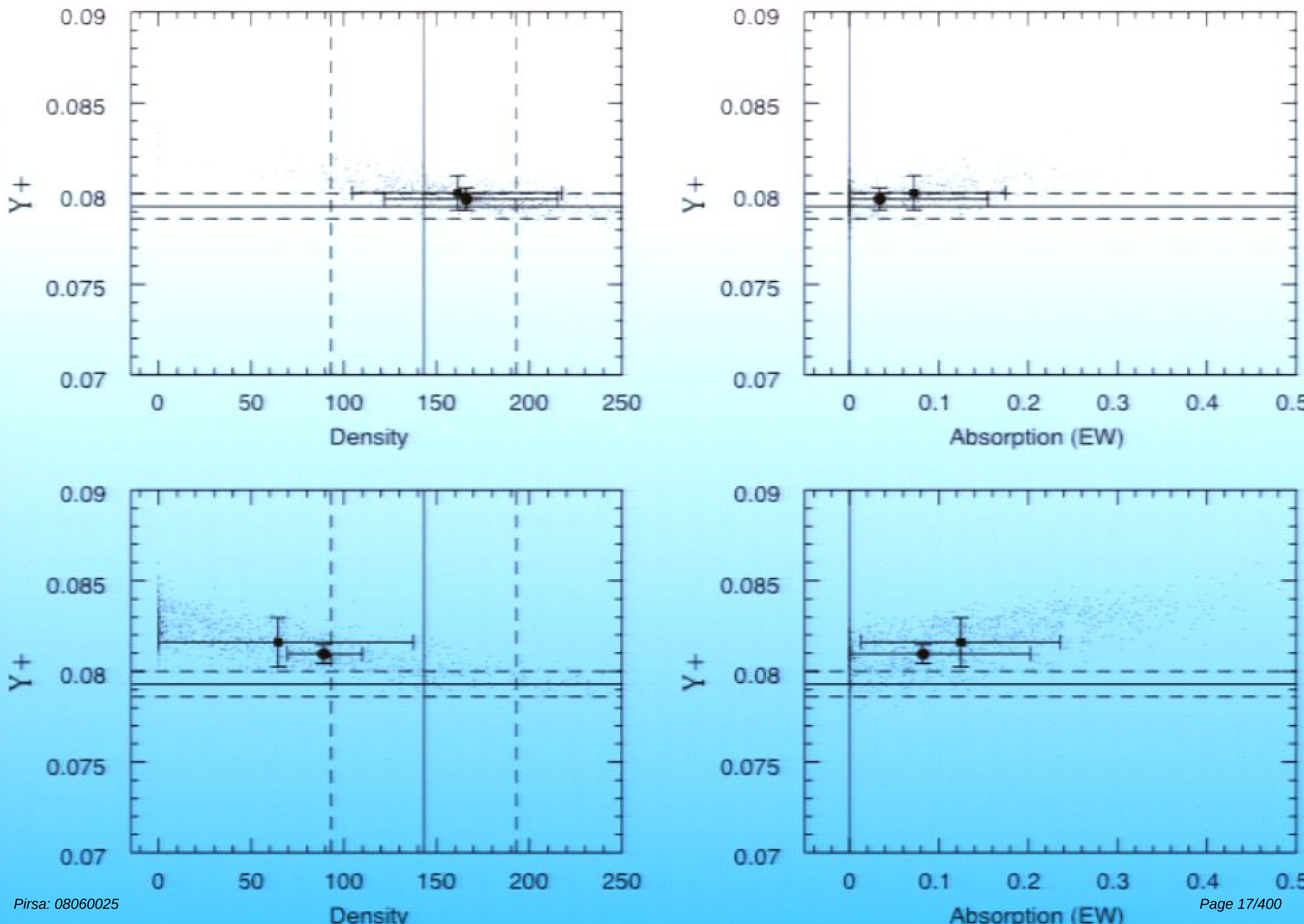
- Intensity and Eq. Width for H and He
- Determine H reddening and underlying absorption
- Use 6 He emission lines to determine physical parameters:
  - denisty, optical depth, temperature, underlying He absorption, ^{4}He abundance
- Severe degeneracies revealed by Monte Carlo anaysis



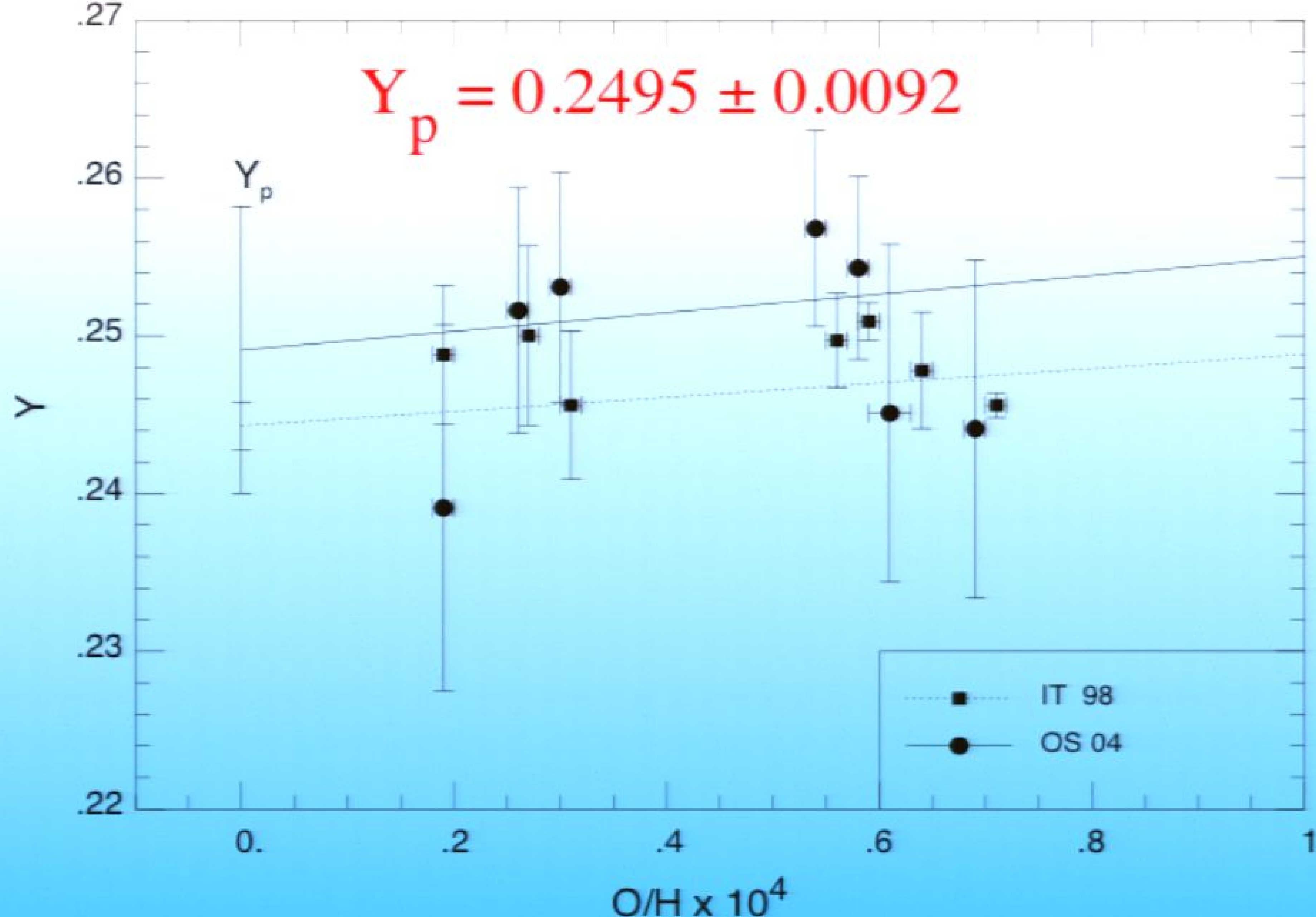
KAO + Skillman

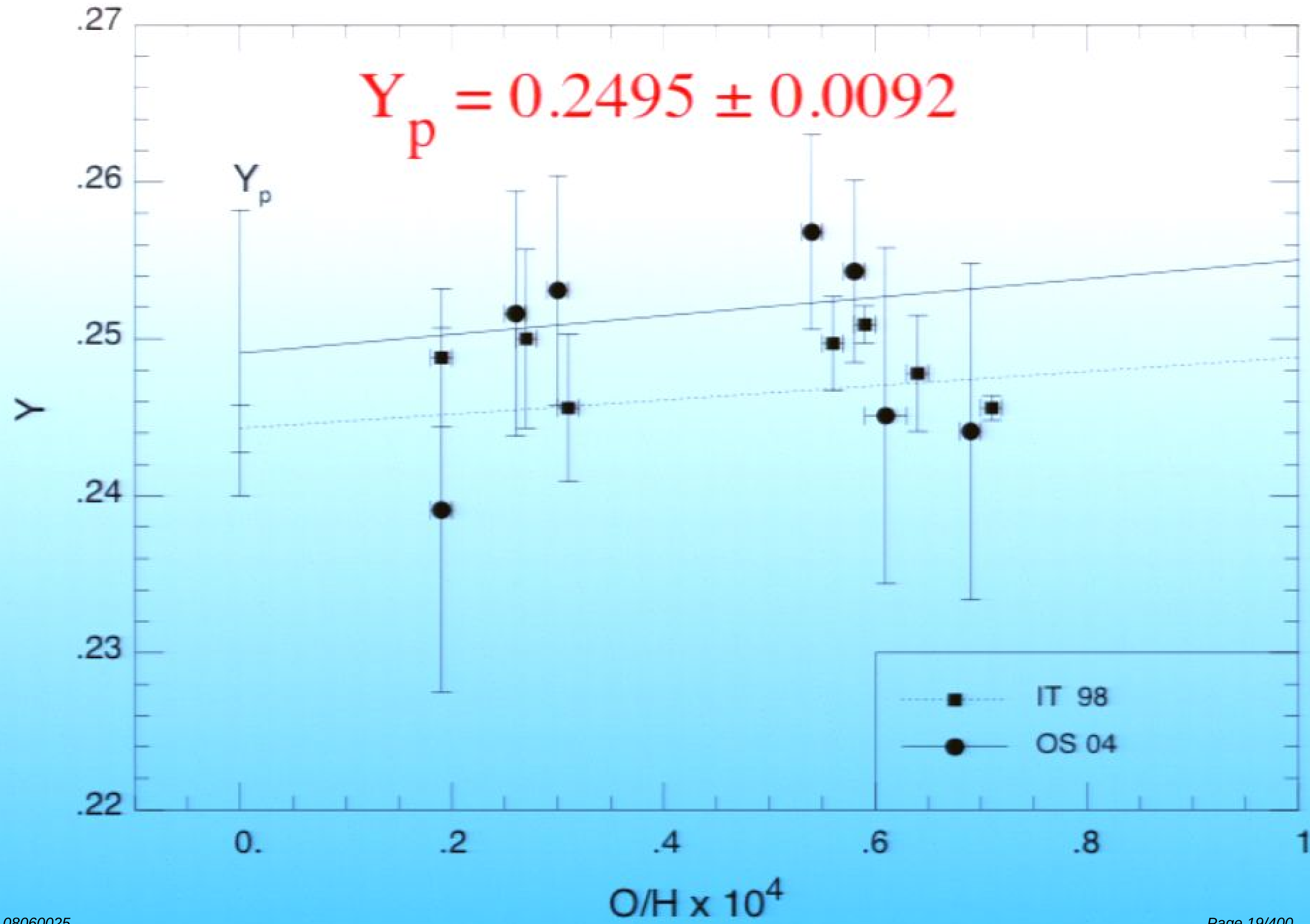


KAO + Skillman



KAO + Skillman


$Y_p = 0.2495 \pm 0.0092$
.27
.26
.25
.24
.23
.22
Y_p
Y
0.
.2
.4
.6
.8
1
O/H x 10^4
IT 98
OS 04



$Y_p = 0.2495 \pm 0.0092$
Y_p
.27
.26
.25
.24
.23
.22
Y
0.
.2
.4
.6
.8
1
O/H x 10^4
IT 98
OS 04

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

^{4}He Prediction: 0.2484 ± 0.0005
Data: Regression: 0.2495 ± 0.0092
Mean: 0.2520 ± 0.0030

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

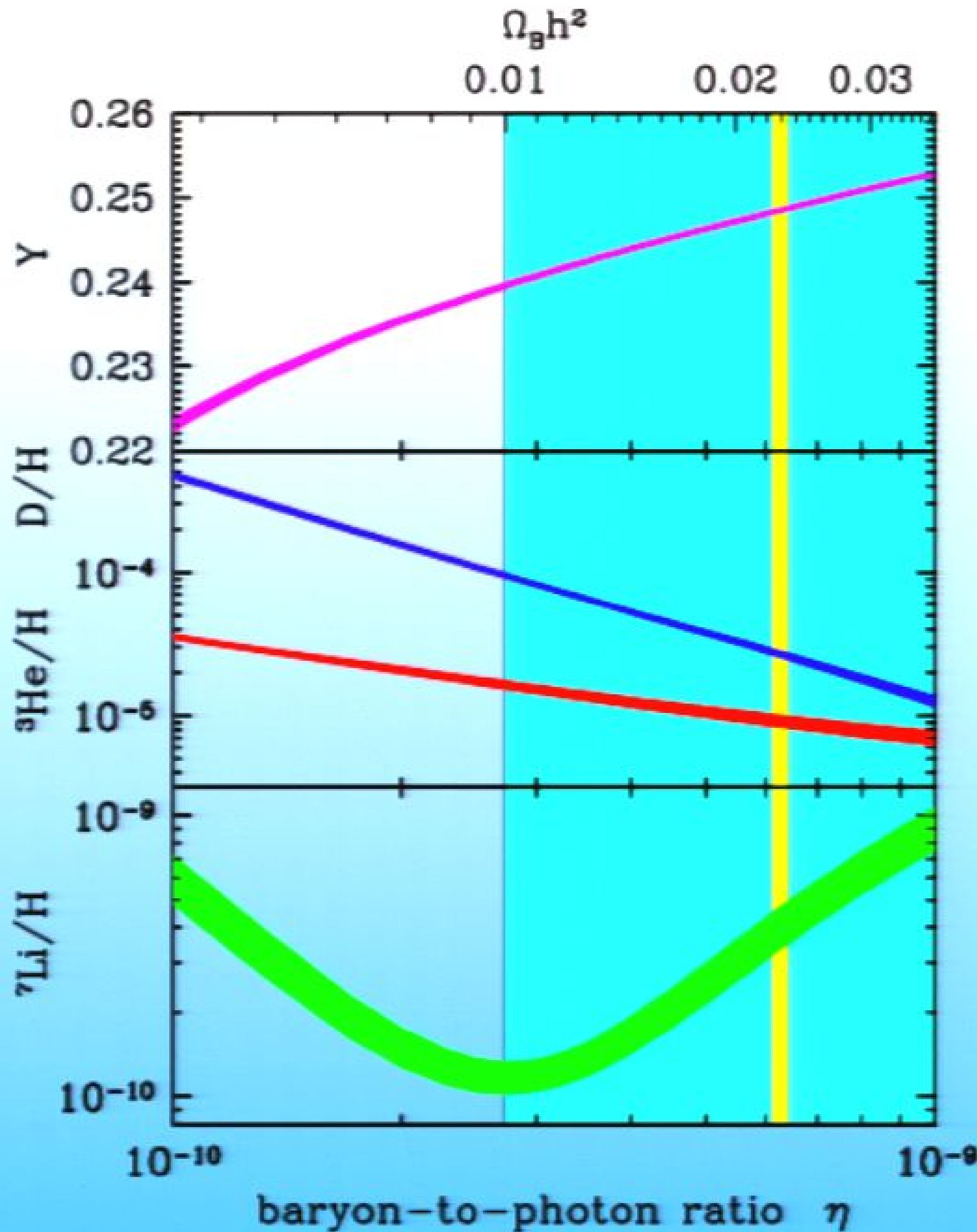
- (Preliminary) no new degeneracies but previous degeneracies remain.

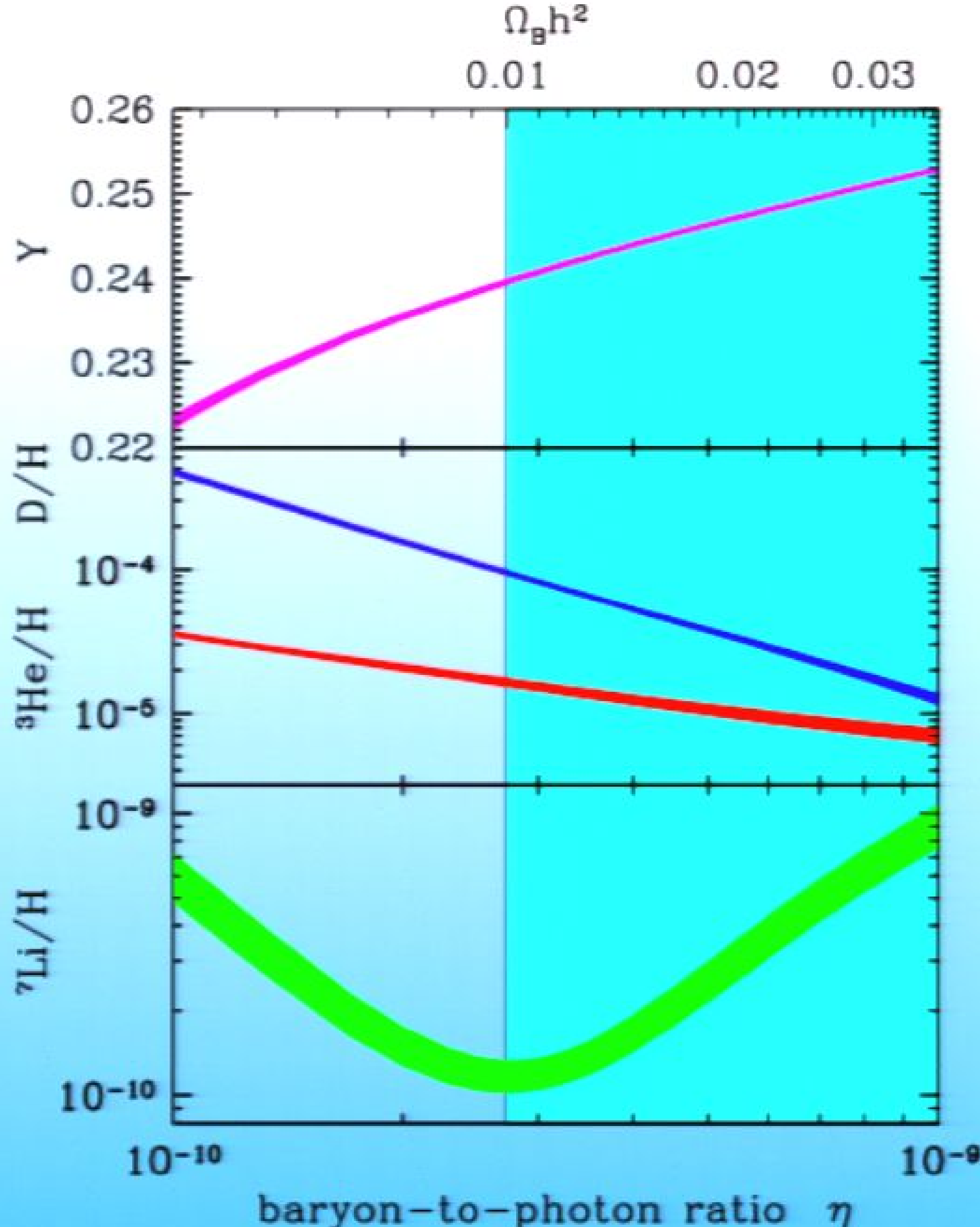
Aver, Olive, Skillman

^{4}He Prediction: 0.2484 ± 0.0005

Data: Regression: 0.2495 ± 0.0092

Mean: 0.2520 ± 0.0030

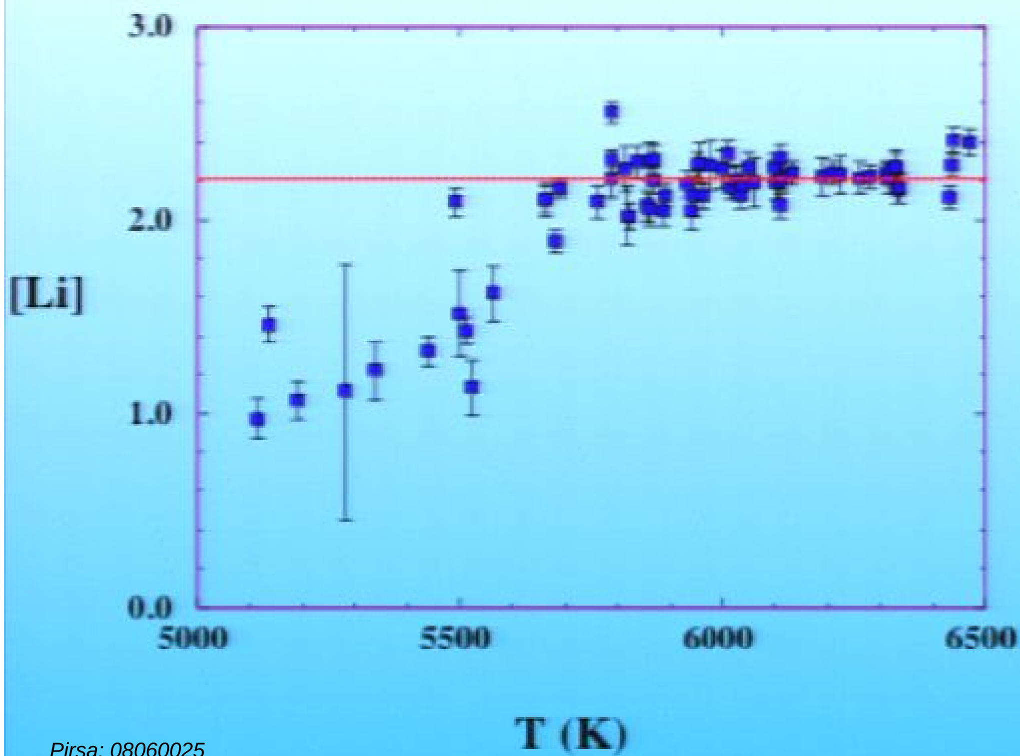

$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon–to–photon ratio η

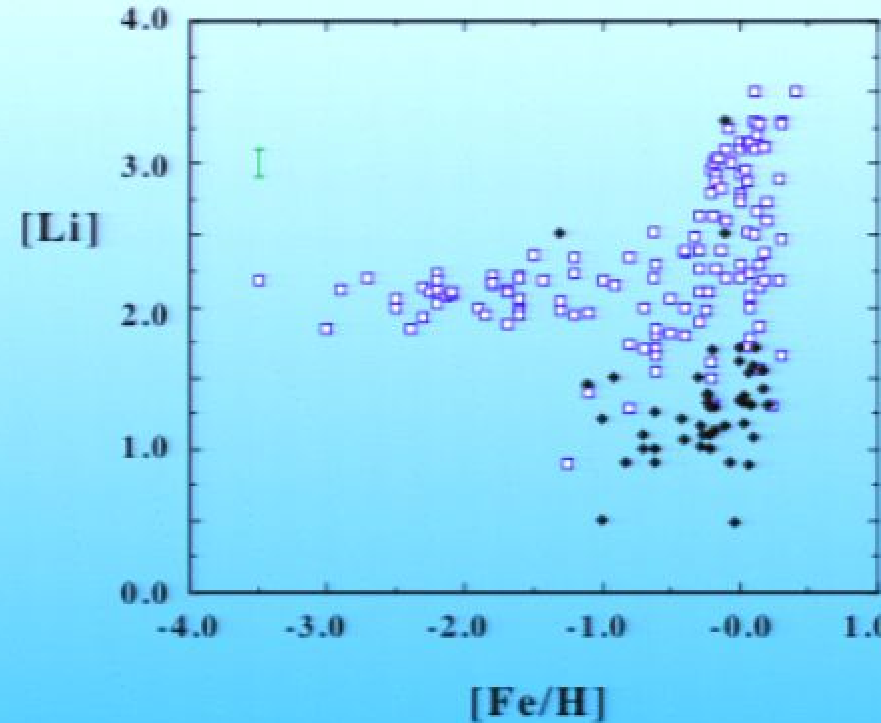


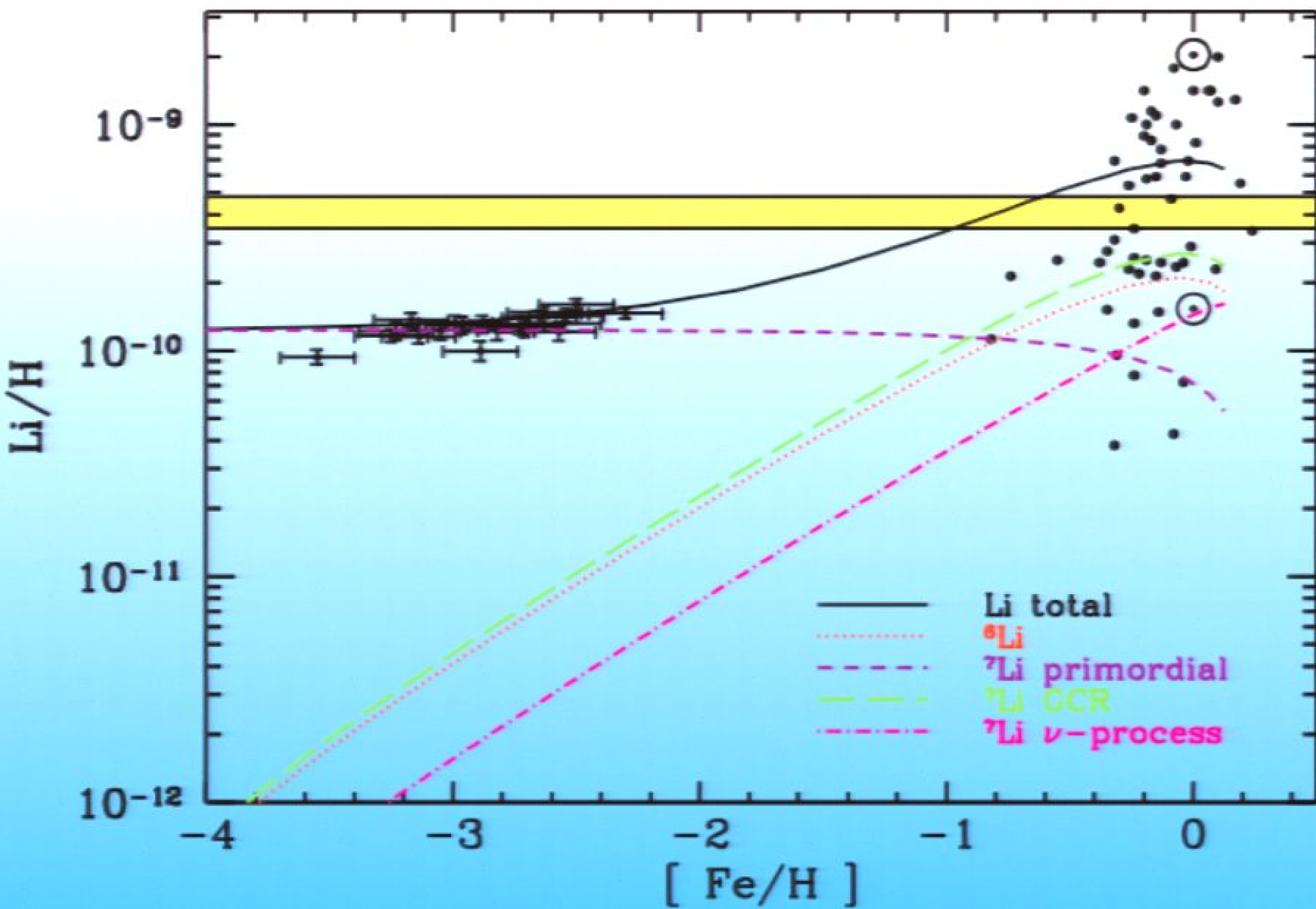
$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η

Li/H

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



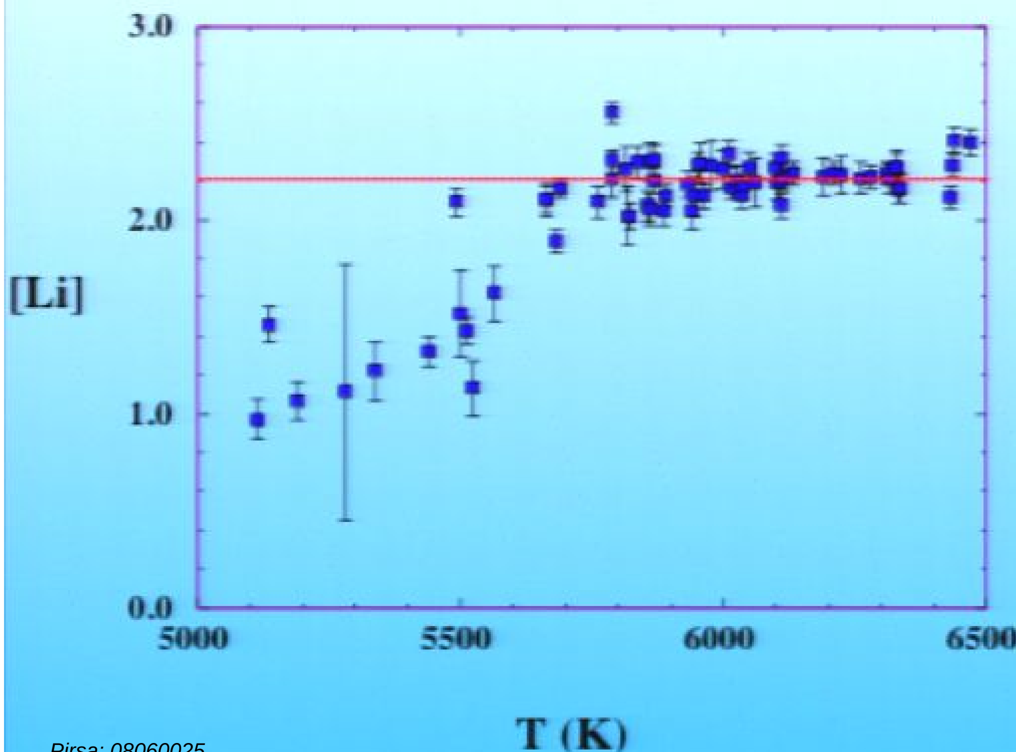


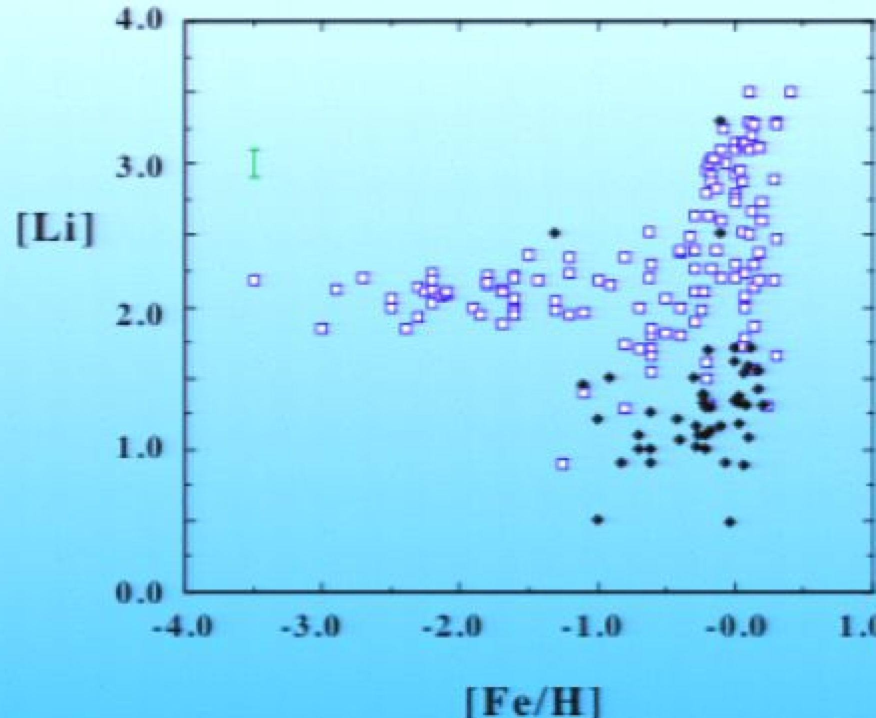


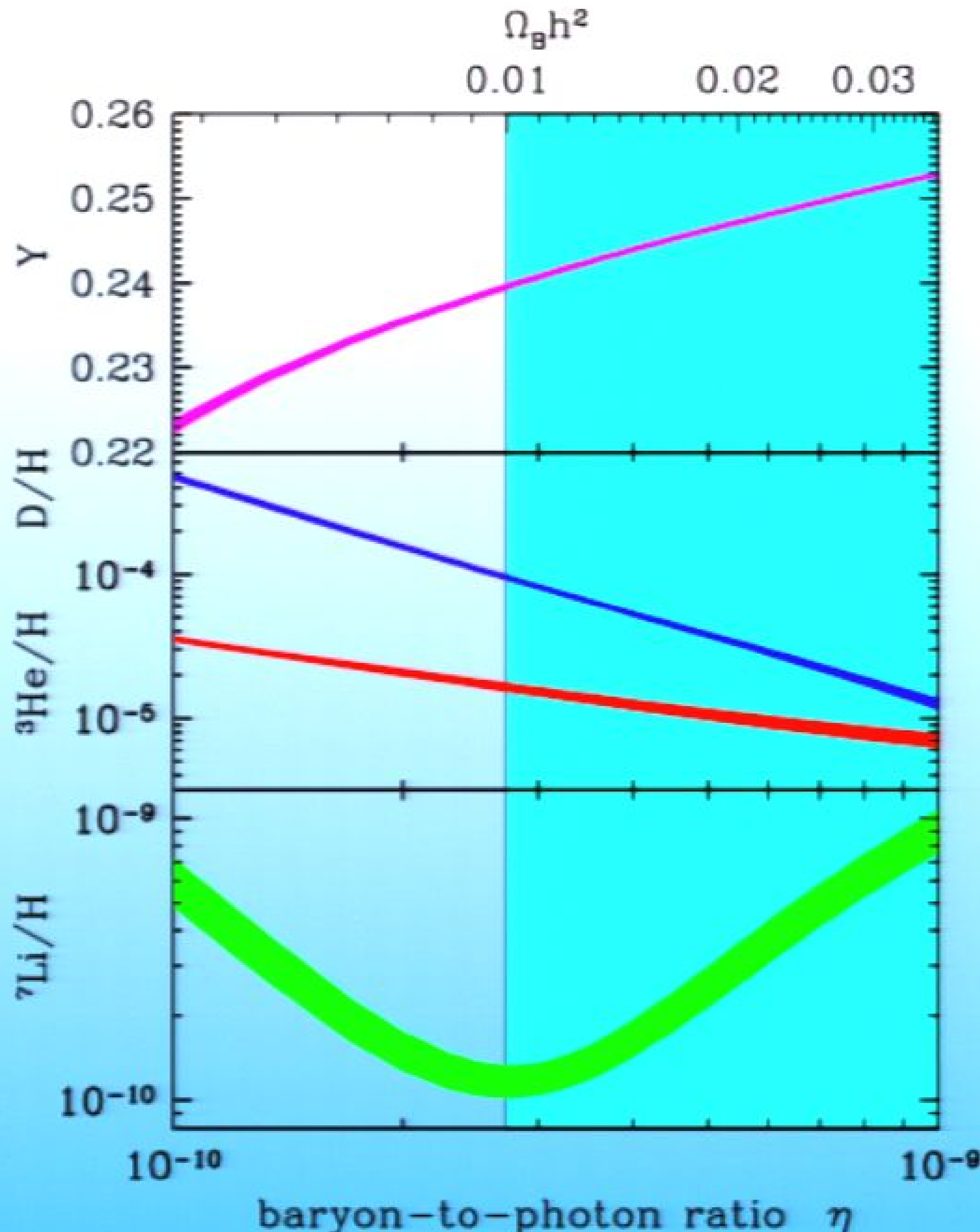
Li/H
[Fe/H]
10^{-9}
10^{-10}
10^{-11}
10^{-12}
−4
−3
−2
−1
0
Li total
^{6}Li
^{7}Li primordial
^{7}Li GCR
^{7}Li ν−process

Li/H

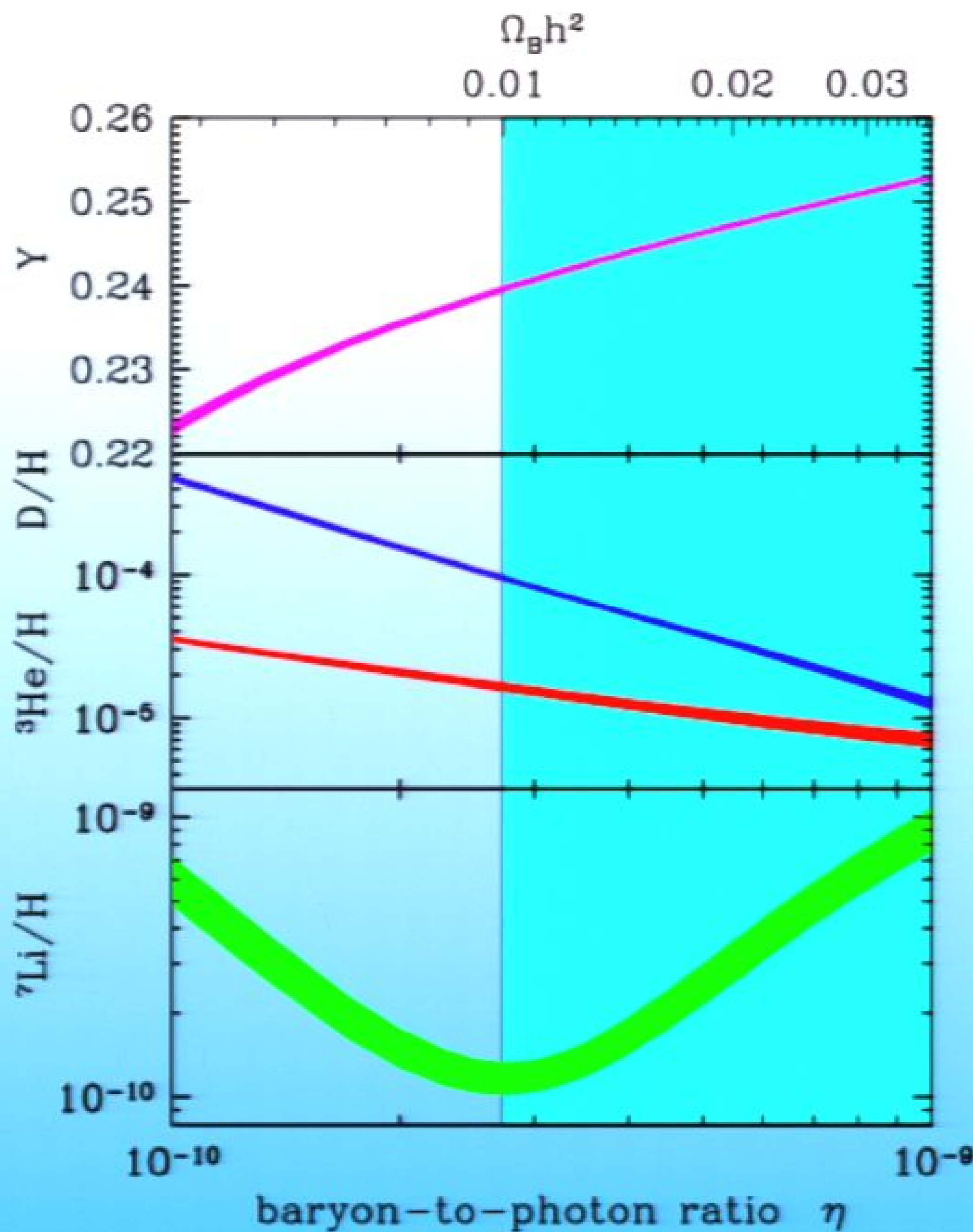
Measured in low metallicity dwarf halo stars (over 100 observed)



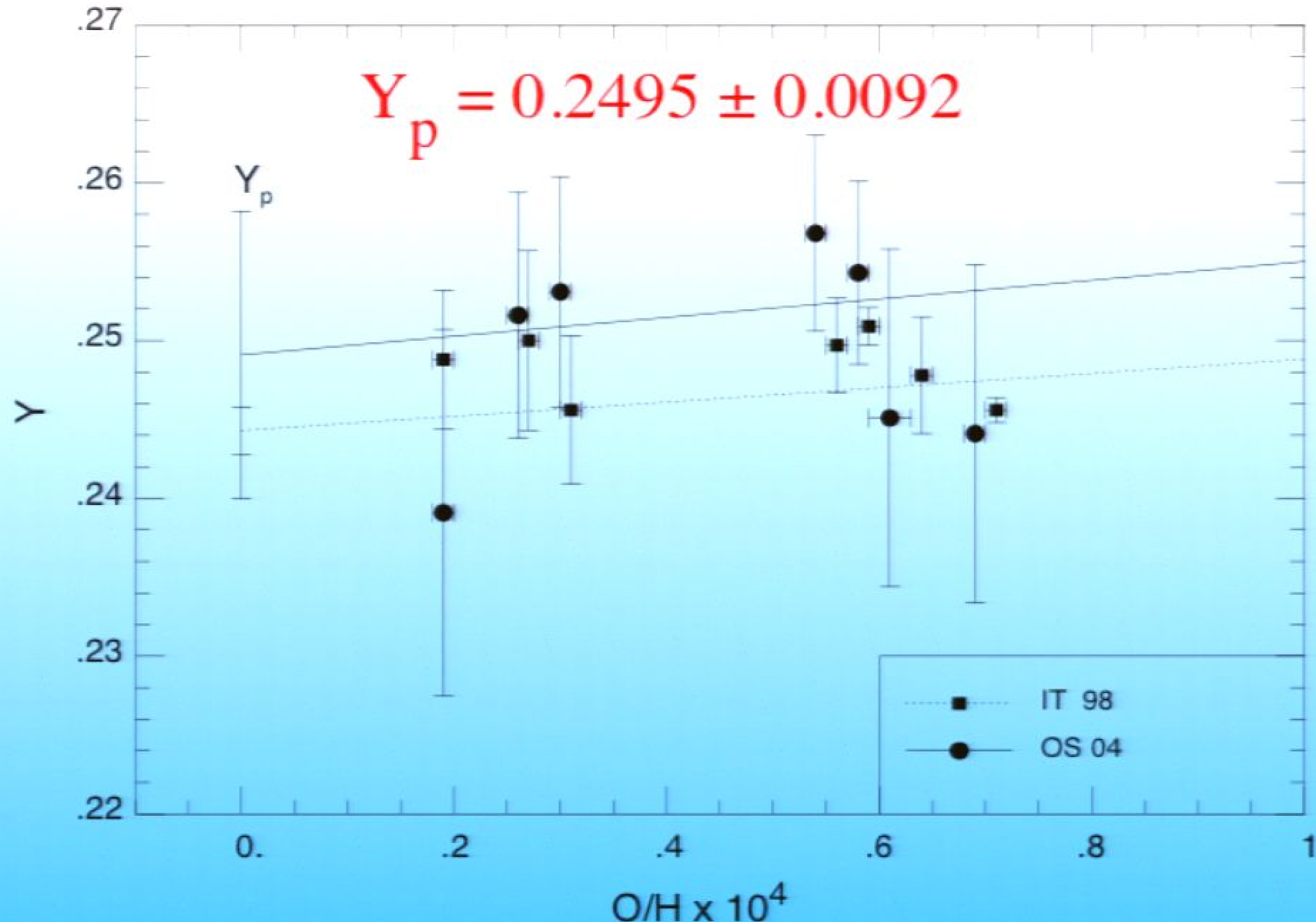




$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η



$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η



$Y_p = 0.2495 \pm 0.0092$
.27
.26
.25
.24
.23
.22
Y_p
Y
0.
.2
.4
.6
.8
1
O/H x 10^4
IT 98
OS 04

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

^{4}He Prediction: 0.2484 ± 0.0005
Data: Regression: 0.2495 ± 0.0092
Mean: 0.2520 ± 0.0030

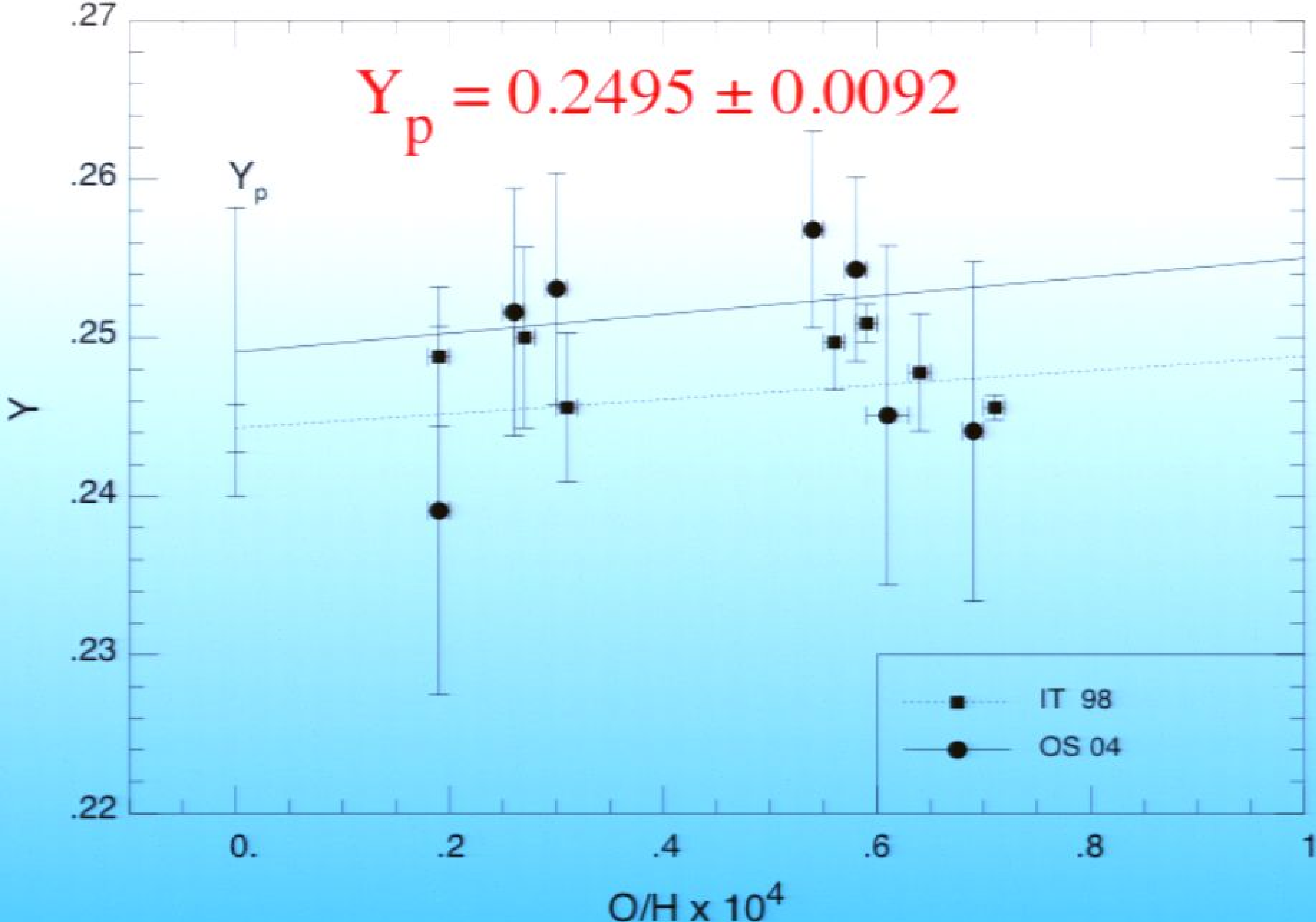
Self-consistent H and He

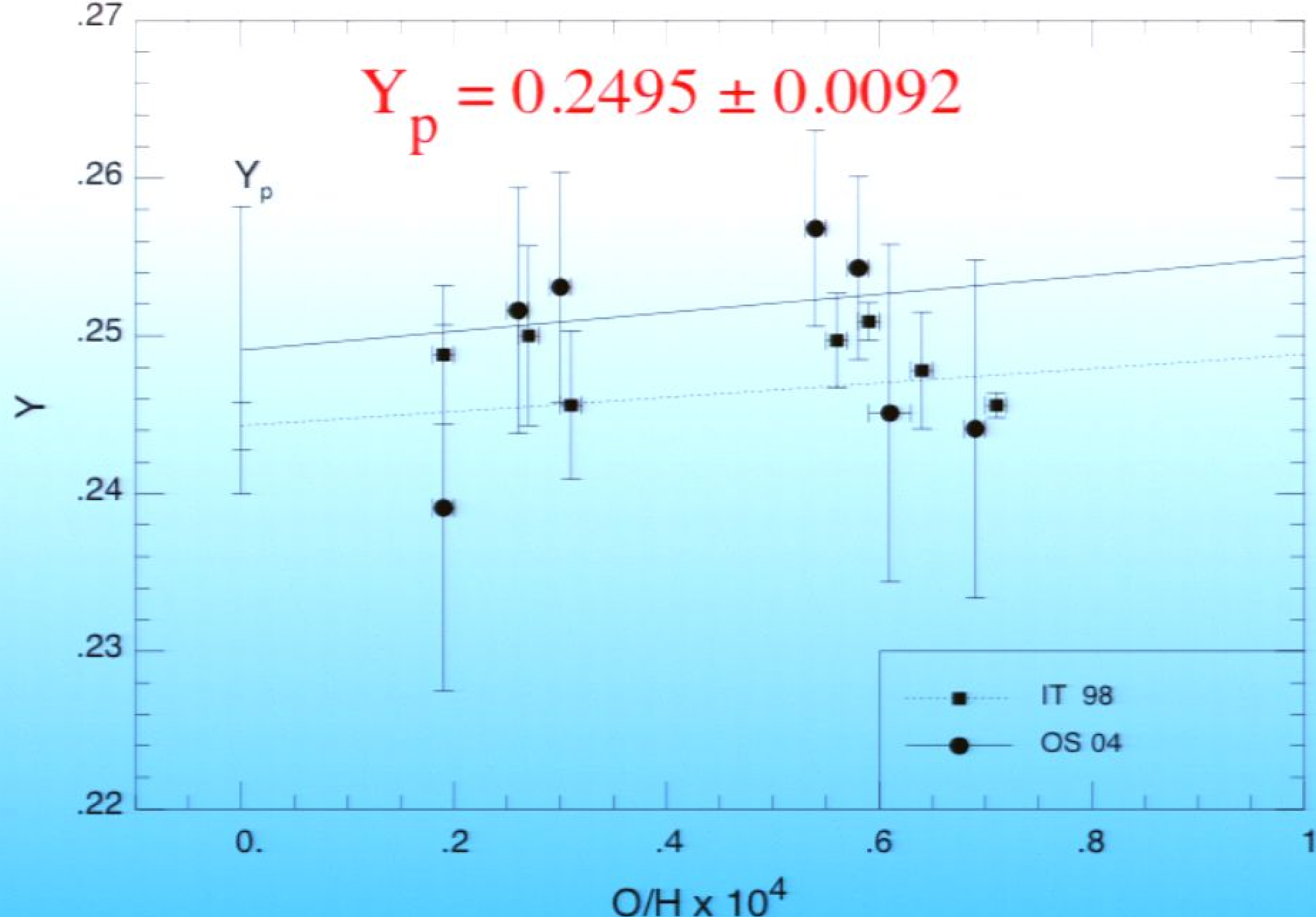
- Determine H and He properties from 9 lines (6 He and 3 H) using MC
- (Preliminary) no new degeneracies but previous degeneracies remain.

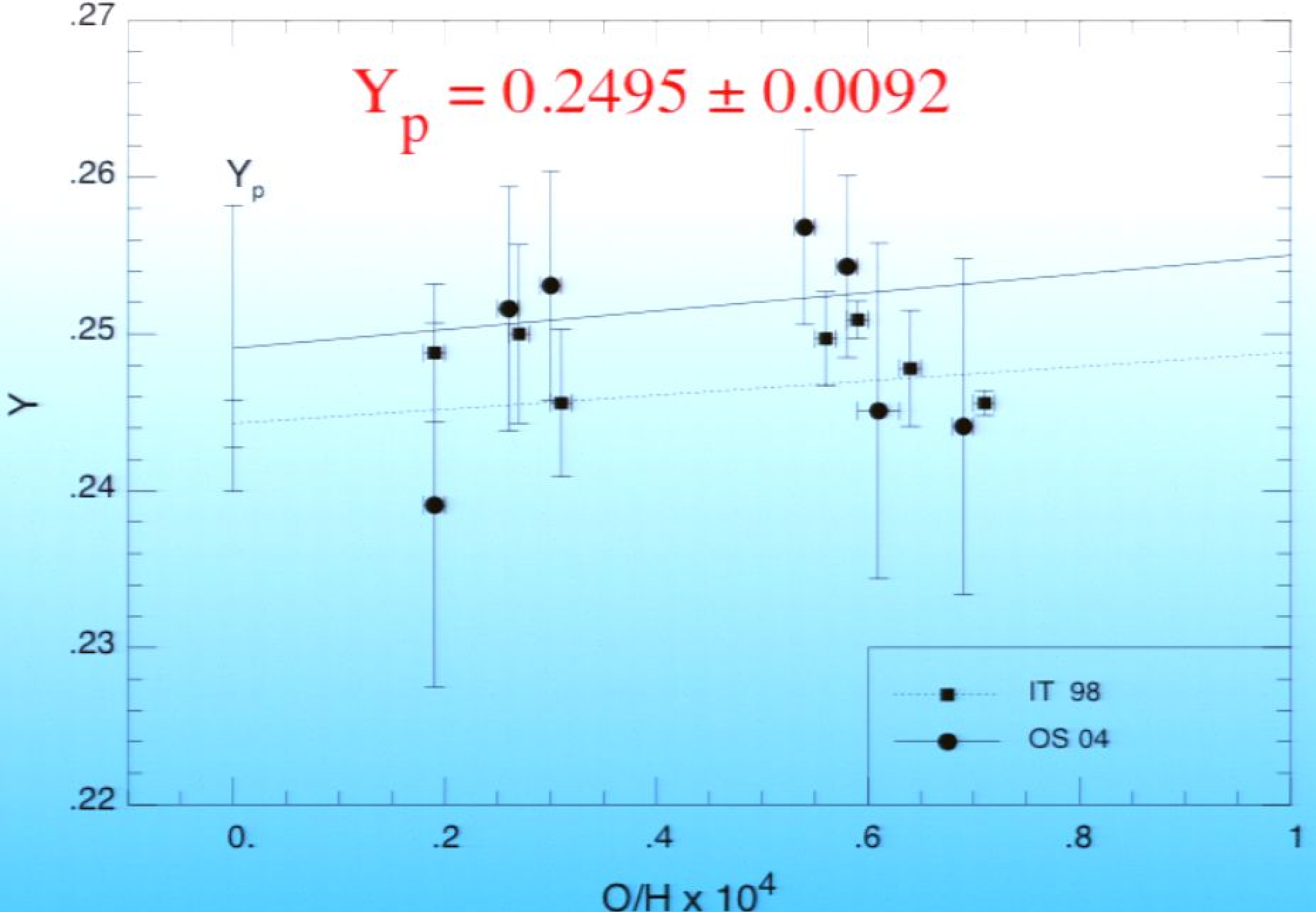
Aver, Olive, Skillman

^{4}He Prediction: 0.2484 ± 0.0005
Data: Regression: 0.2495 ± 0.0092
Mean: 0.2520 ± 0.0030

$$Y_p = 0.2495 \pm 0.0092$$




$Y_p = 0.2495 \pm 0.0092$
Y_p
.27
.26
.25
.24
.23
.22
Y
0.
.2
.4
.6
.8
1
O/H x 10^4
IT 98
OS 04


$Y_p = 0.2495 \pm 0.0092$
.27
.26
.25
.24
.23
.22
Y_p
Y
0.
.2
.4
.6
.8
1
O/H x 10^4
IT 98
OS 04

Self-consistent H and He

- Determine H and He properties from 9 lines (6 He and 3 H) using MC

- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

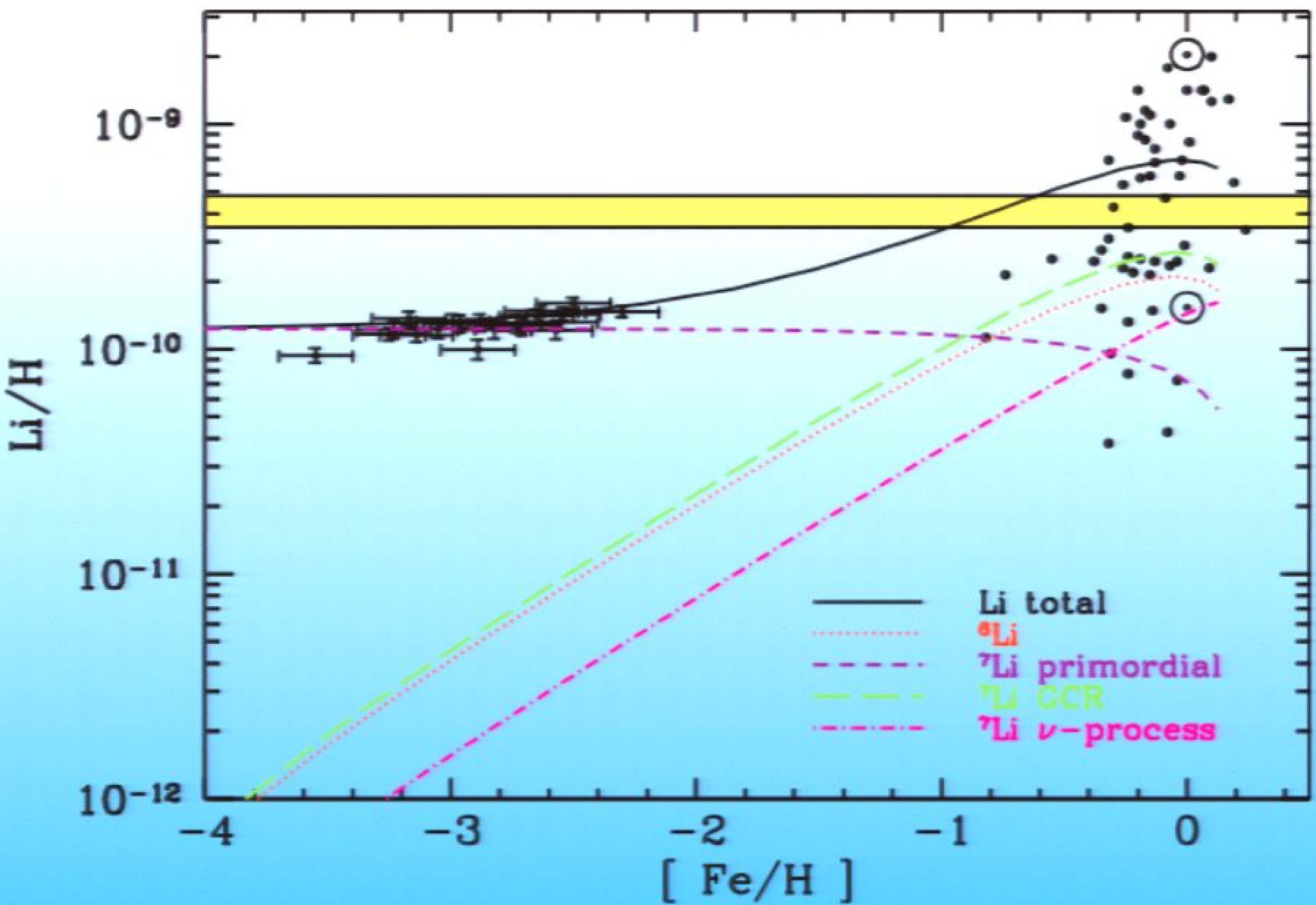
^{4}He Prediction: 0.2484 ± 0.0005
Data: Regression: 0.2495 ± 0.0092
Mean: 0.2520 ± 0.0030

Self-consistent H and He

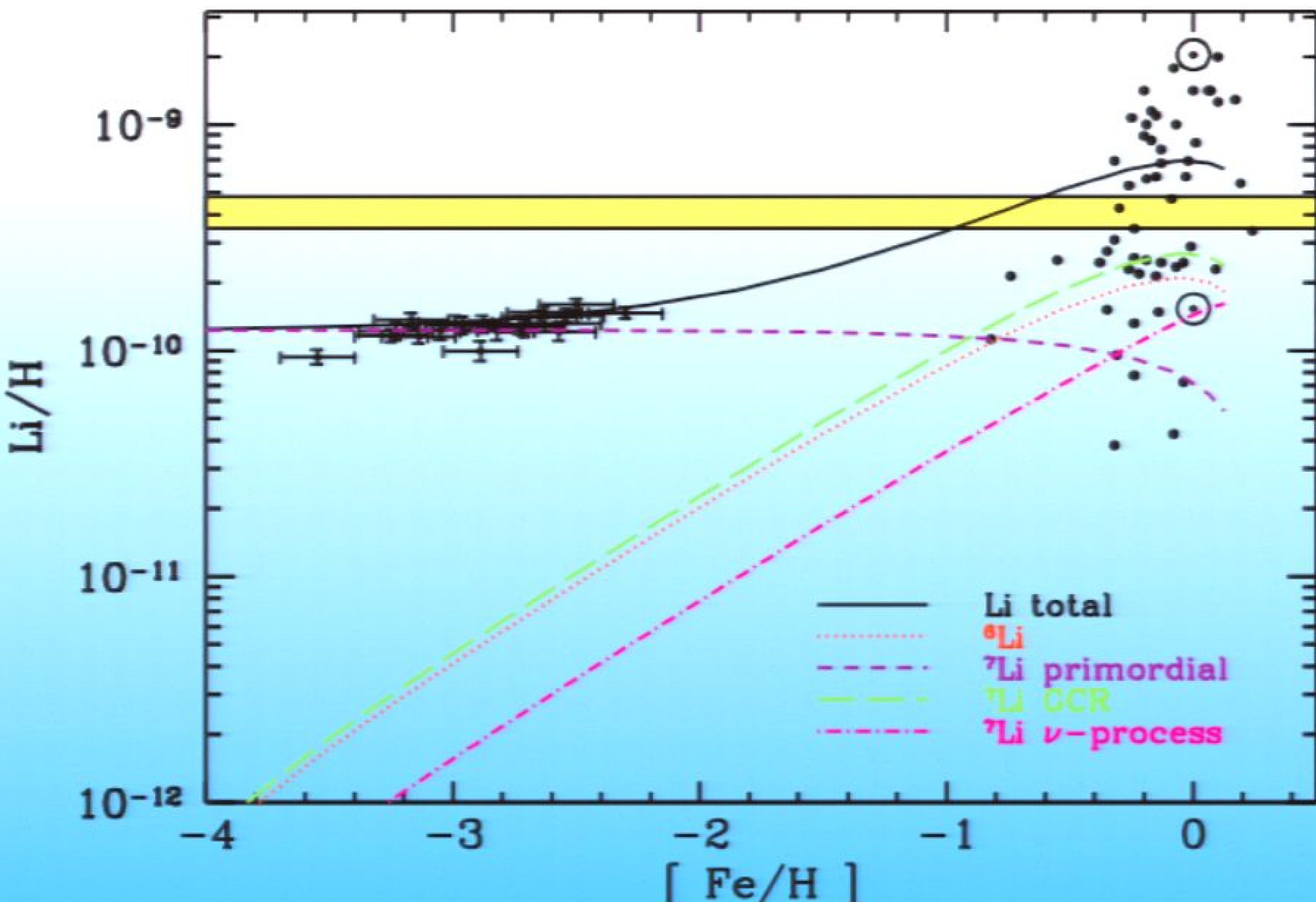
- Determine H and He properties from 9 lines (6 He and 3 H) using MC
- (Preliminary) no new degeneracies but previous degeneracies remain.

Aver, Olive, Skillman

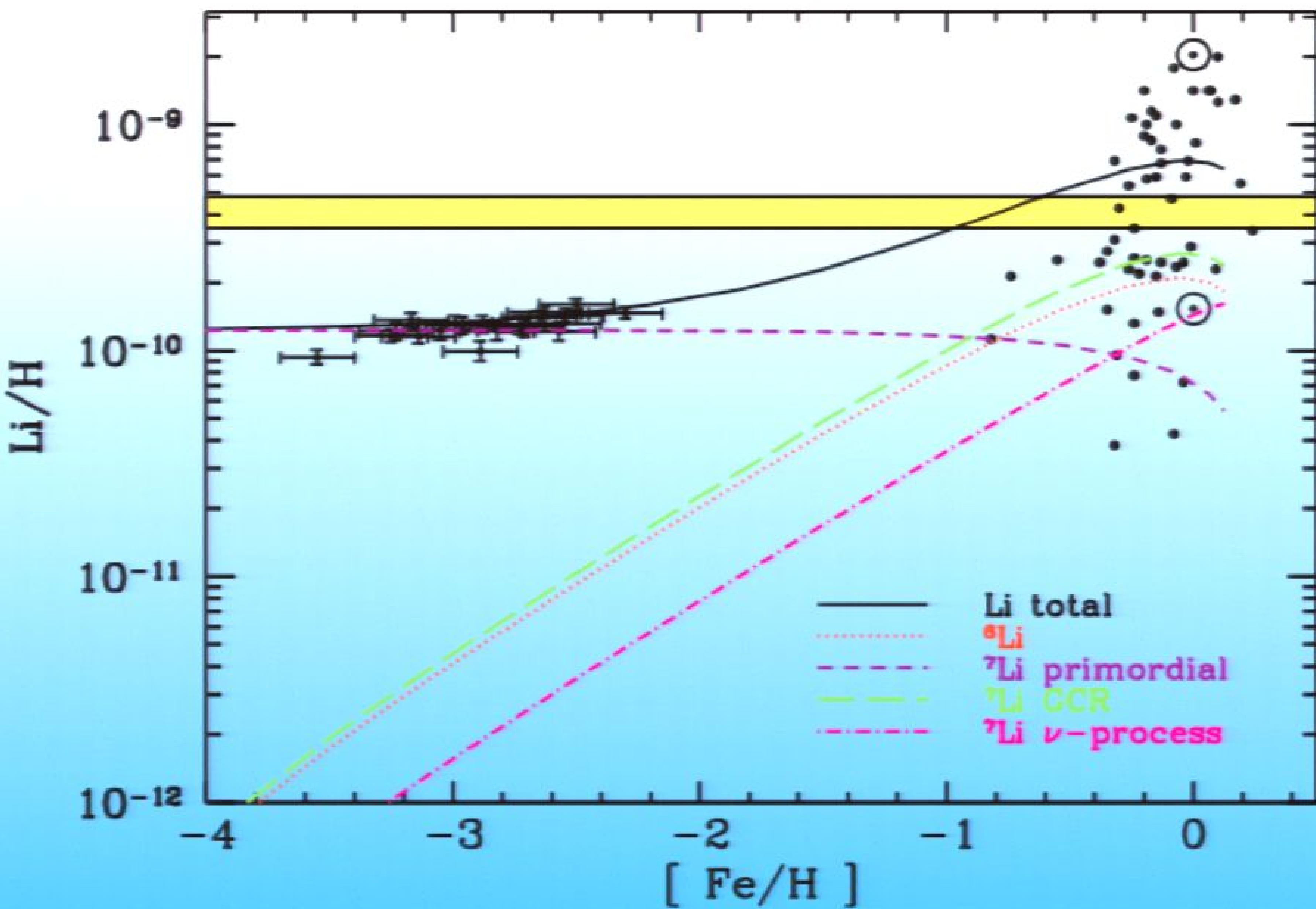
^{4}He Prediction: 0.2484 ± 0.0005
Data: Regression: 0.2495 ± 0.0092
Mean: 0.2520 ± 0.0030



10^{-9}
10^{-10}
10^{-11}
10^{-12}
Li/H
−4
−3
−2
−1
0
[Fe/H]
Li total
^{6}Li
^{7}Li primordial
^{7}Li GCR
^{7}Li ν−process



Li/H
10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
−4
−3
−2
−1
0
[Fe/H]
Li total
⁶Li
⁷Li primordial
⁷Li GCR
⁷Li ν−process



10⁻⁹
10⁻¹⁰
10⁻¹¹
10⁻¹²
Li/H
−4
−3
−2
−1
0
[Fe/H]
Li total
⁶Li
⁷Li primordial
⁷Li GCR
⁷Li ν−process

Possible sources for the discrepancy

Possible sources for the discrepancy

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

Possible sources for the discrepancy

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

- Nuclear Rates
  - Restricted by solar neutrino flux

Possible sources for the discrepancy

- Stellar Depletion
  - lack of dispersion in the data, ^{6}Li abundance
  - standard models (< .05 dex), models (0.2 - 0.4 dex)
- Nuclear Rates
  - Restricted by solar neutrino flux
- Stellar parameters

Possible sources for the discrepancy

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

Vauclaire & Charbonne
Pinsonneault et al.
Richard, Michaud, Rich

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

Reappraising the Spite Lithium Plateau: Extremely Thin and Marginally Consistent with WMAP

Jorge Meléndez[1] and Iván Ramírez[2]

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

$$[Li] = 2.37 \pm 0.1$$

$$Li/H = 2.34 \pm 0.54 \times 10^{-10}$$

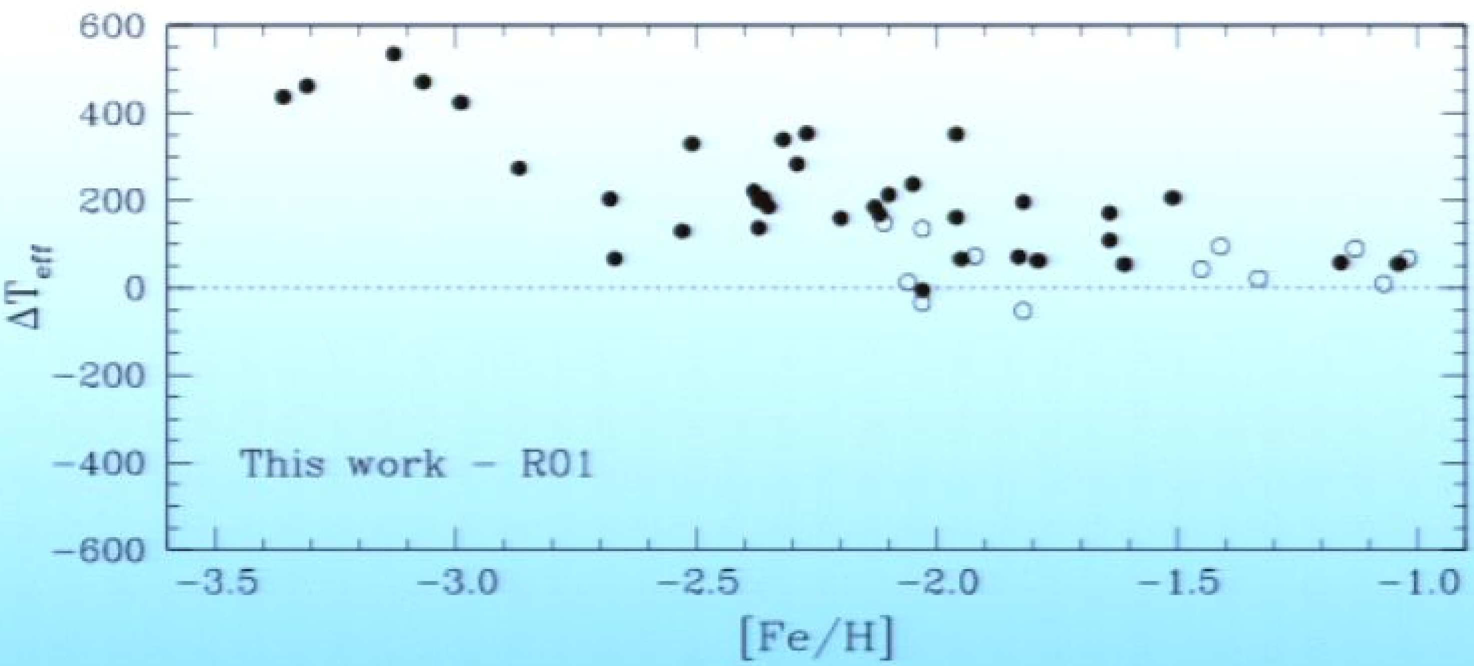
Reappraising the Spite Lithium Plateau: Extremely Thin and Marginally Consistent with WMAP

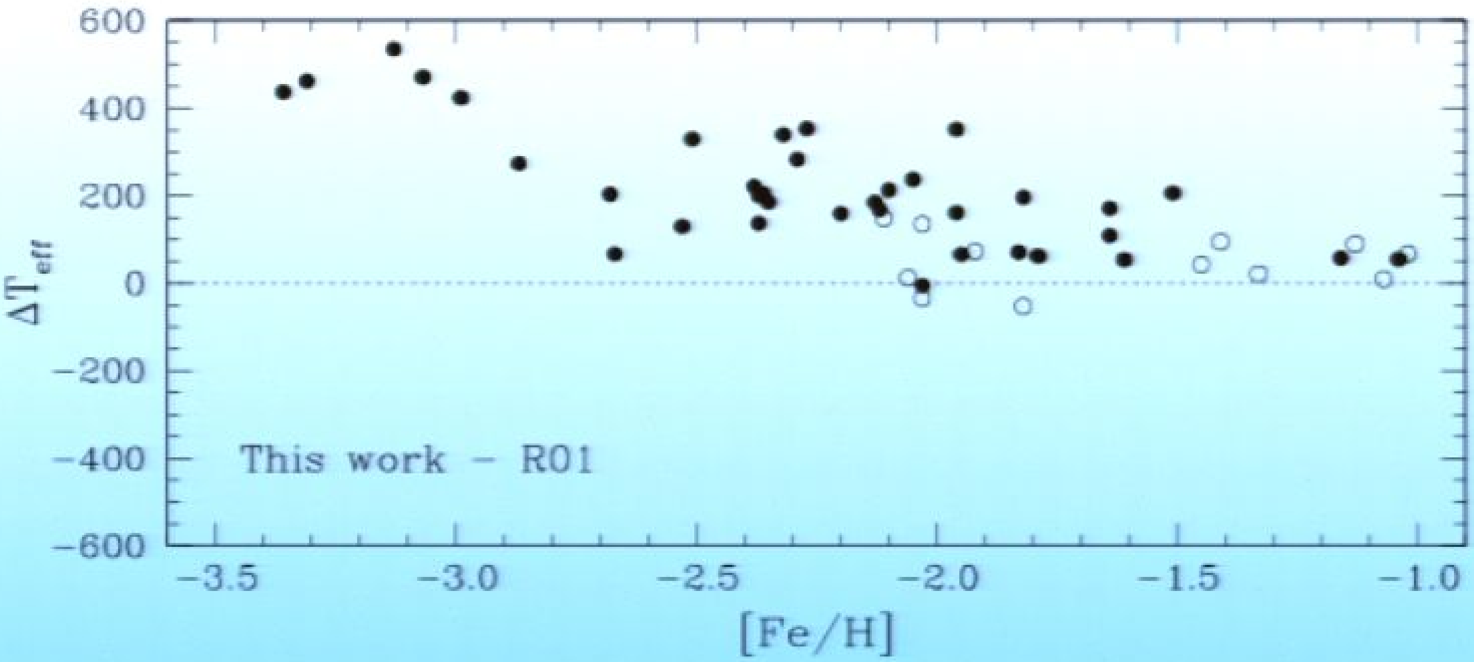
Jorge Meléndez[1] and Iván Ramírez[2]

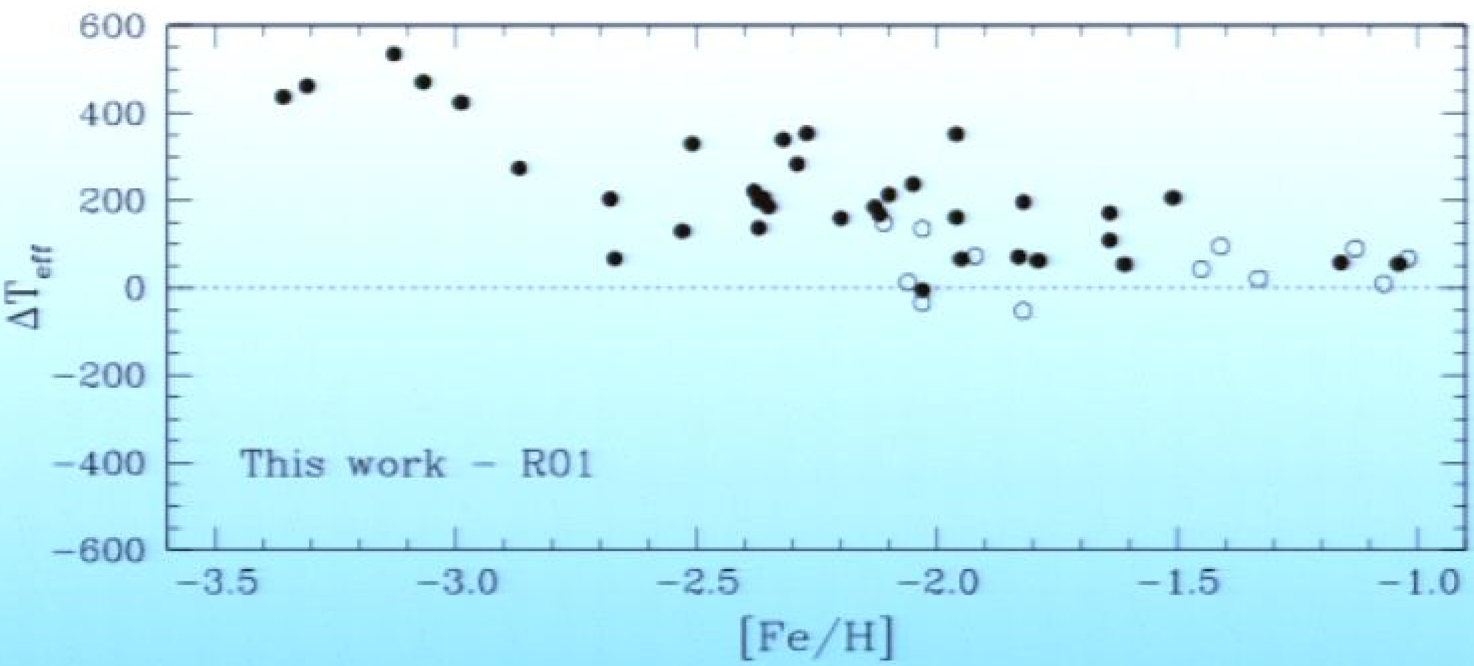
New evaluation of surface temperatures in 41 halo stars with systematically higher temperatures (100-300 K)

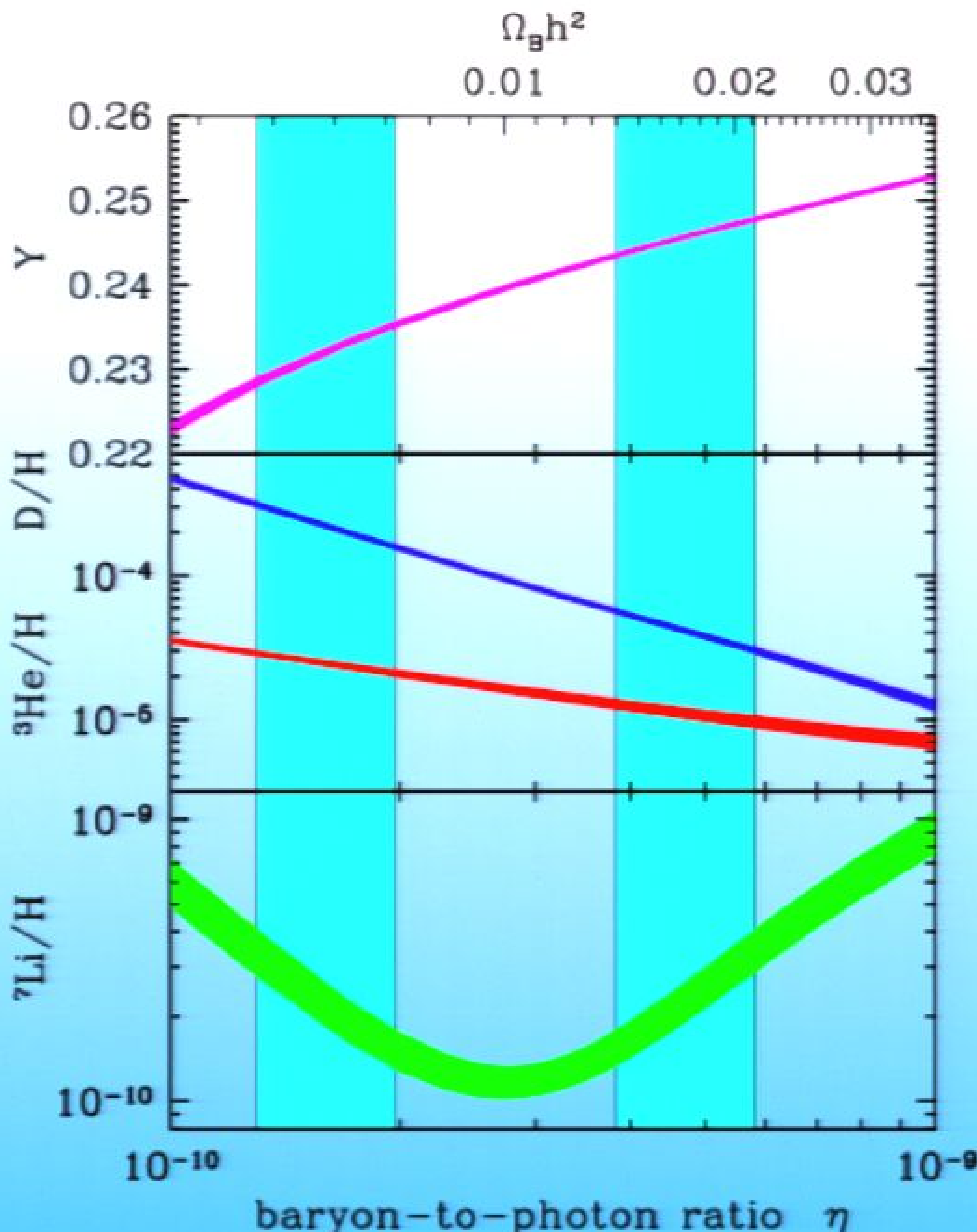
$$[\mathrm{Li}] = 2.37 \pm 0.1$$

$$\mathrm{Li/H} = 2.34 \pm 0.54 \times 10^{-10}$$

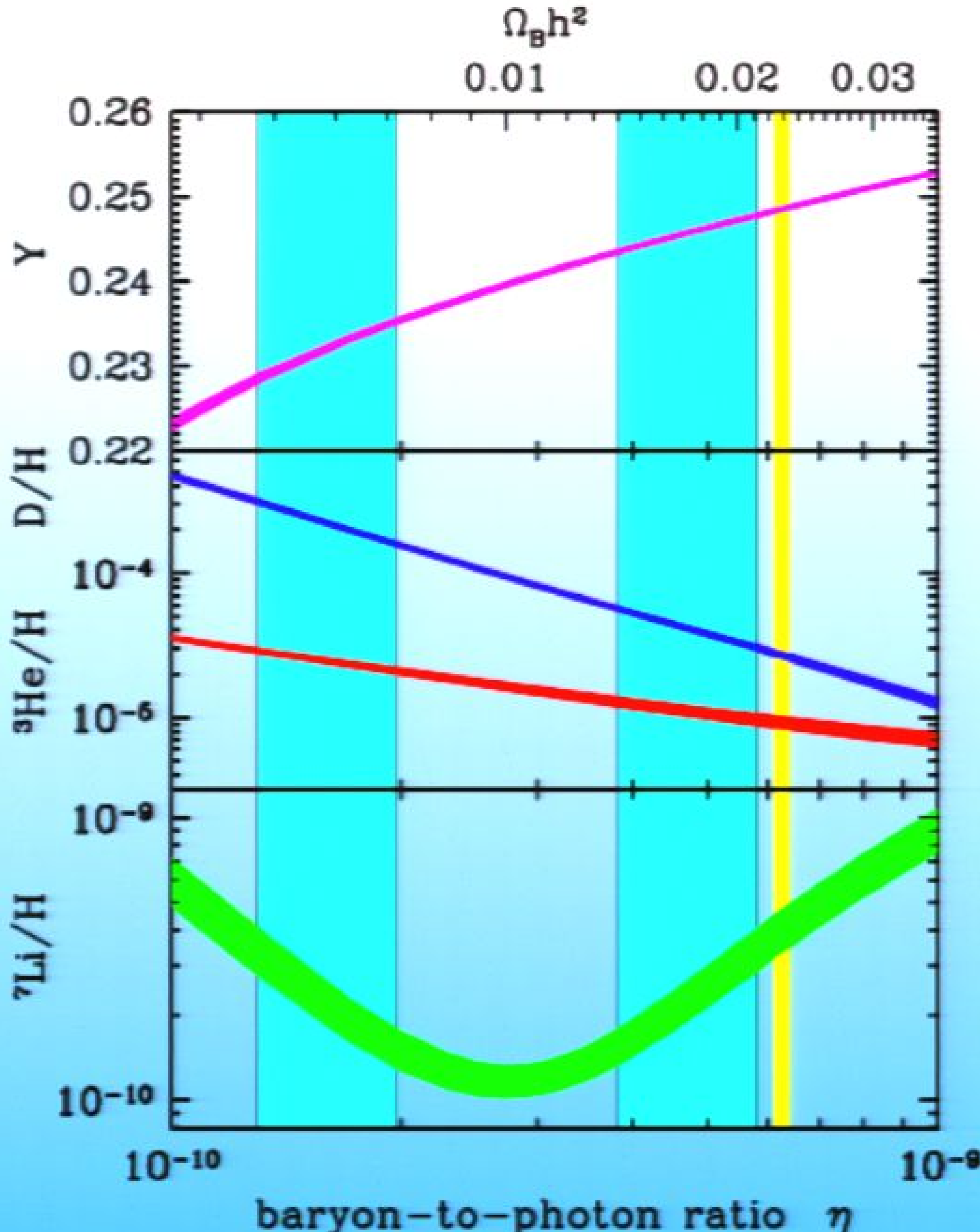

600
400
200
0
−200
−400
−600
ΔT_{eff}
This work − R01
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
[Fe/H]


600
400
200
0
−200
−400
−600
ΔT_{eff}
This work − R01
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
[Fe/H]

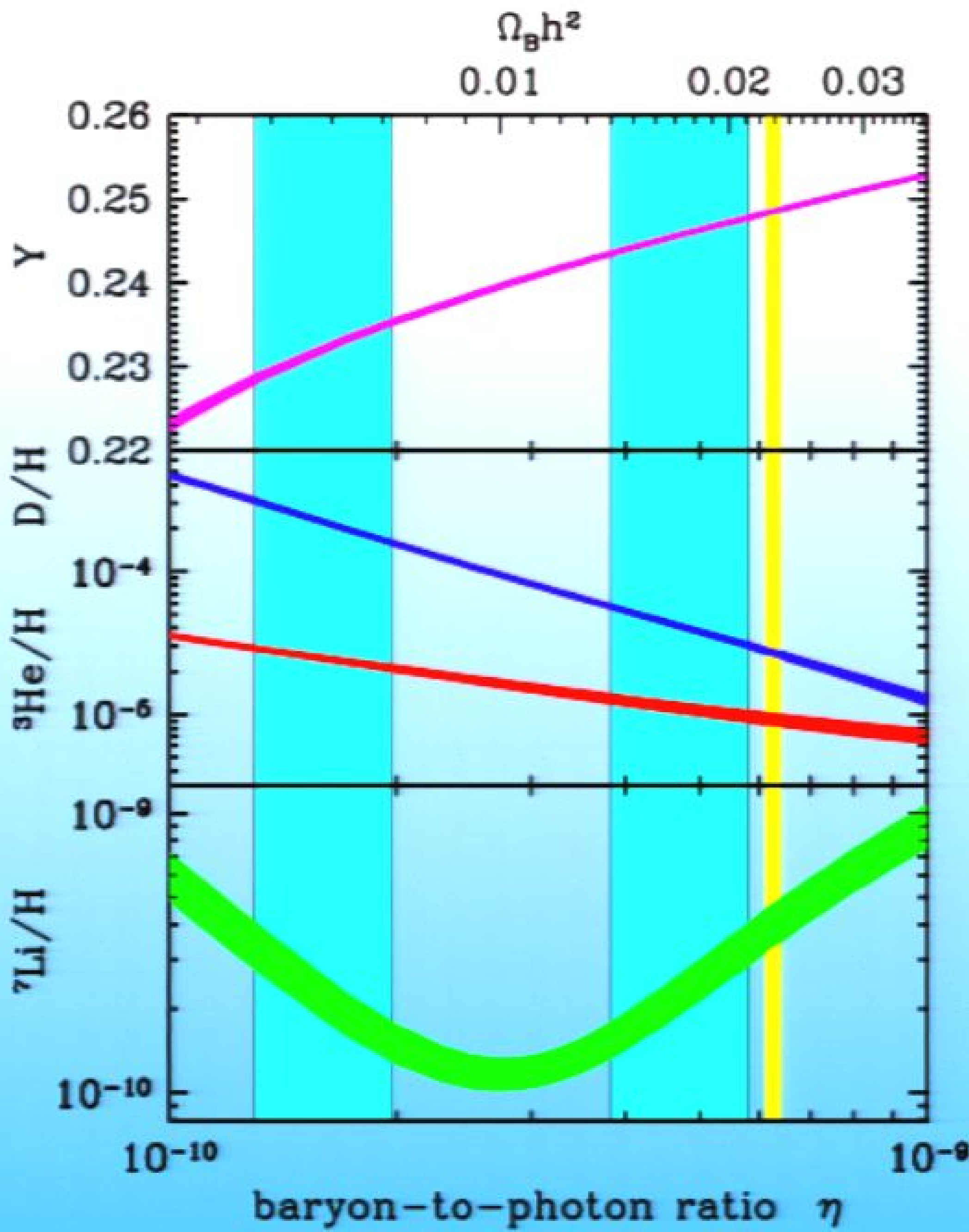

600
400
200
0
−200
−400
−600
ΔT_eff
This work - R01
−3.5
−3.0
−2.5
−2.0
−1.5
−1.0
[Fe/H]



$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η

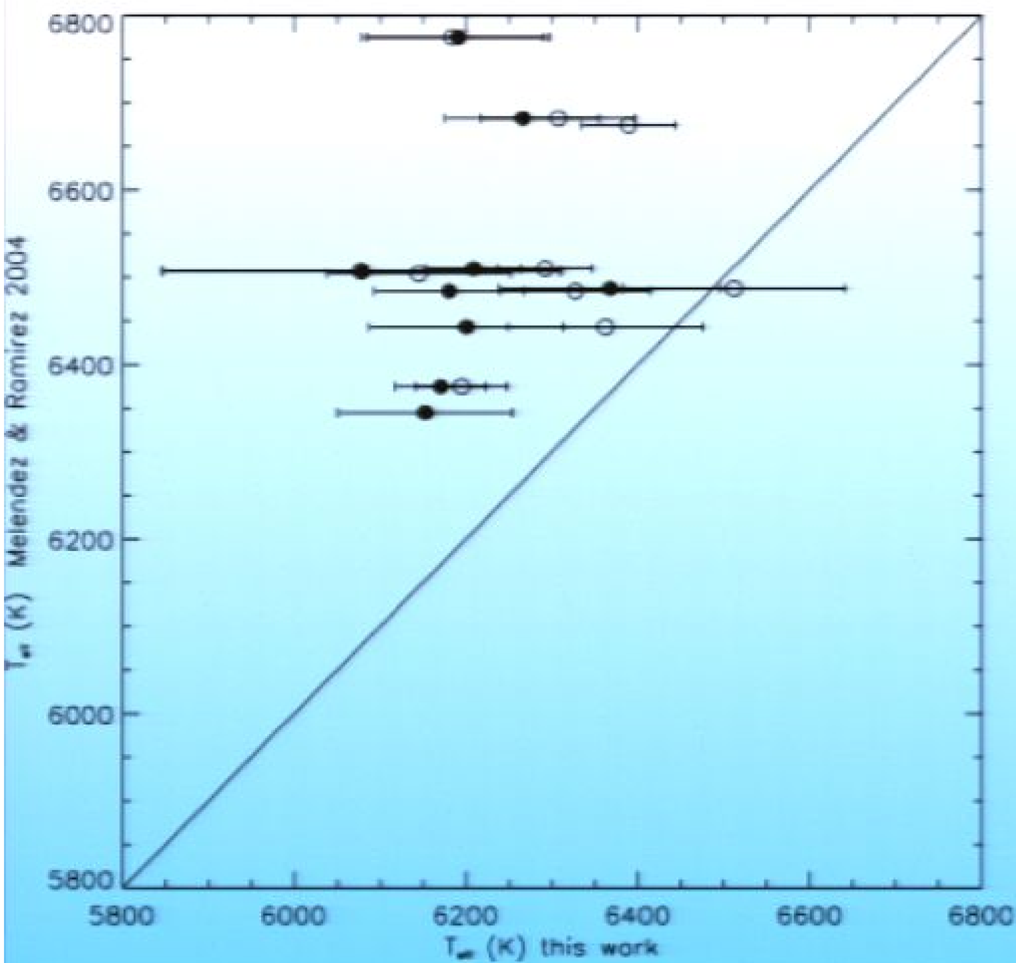


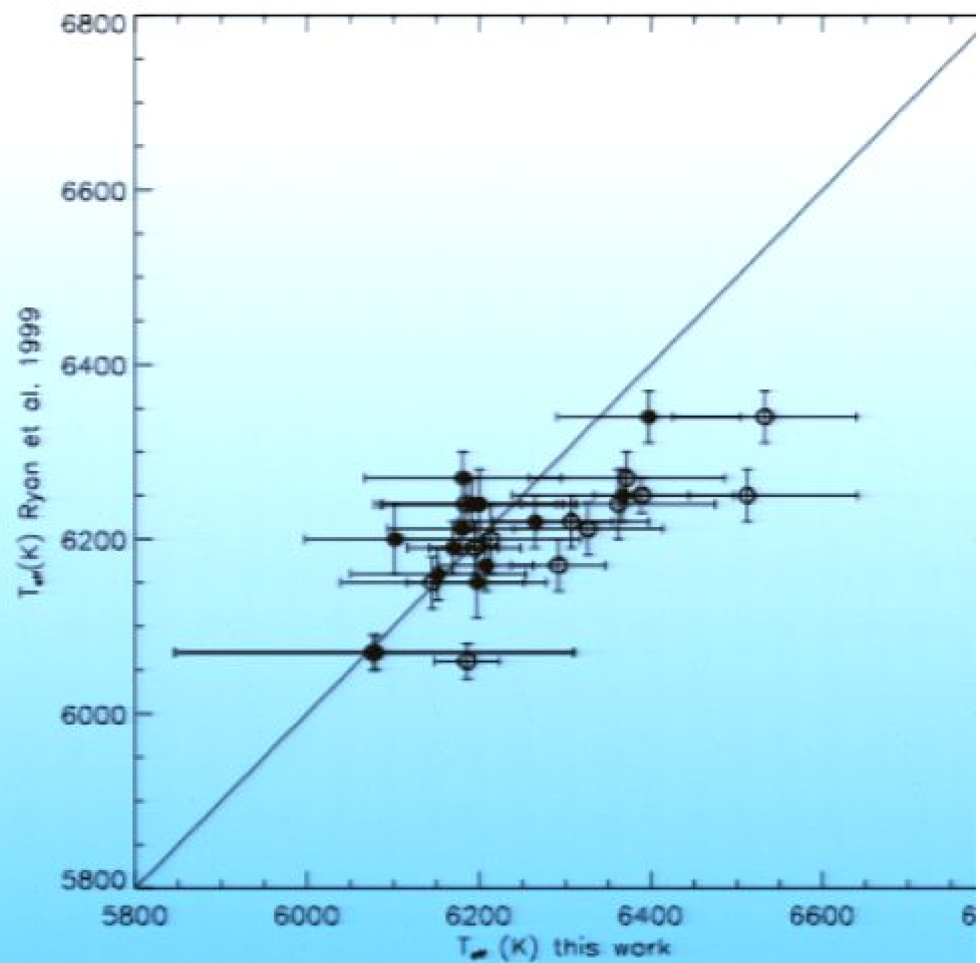
$\Omega_B h^2$
0.01
0.02
0.03
0.26
0.25
0.24
0.23
0.22
Y
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon−to−photon ratio η



$\Omega_B h^2$
0.01
0.02
0.03
Y
0.26
0.25
0.24
0.23
0.22
D/H
10^{-4}
^{3}He/H
10^{-5}
10^{-9}
^{7}Li/H
10^{-10}
10^{-10}
10^{-9}
baryon-to-photon ratio η

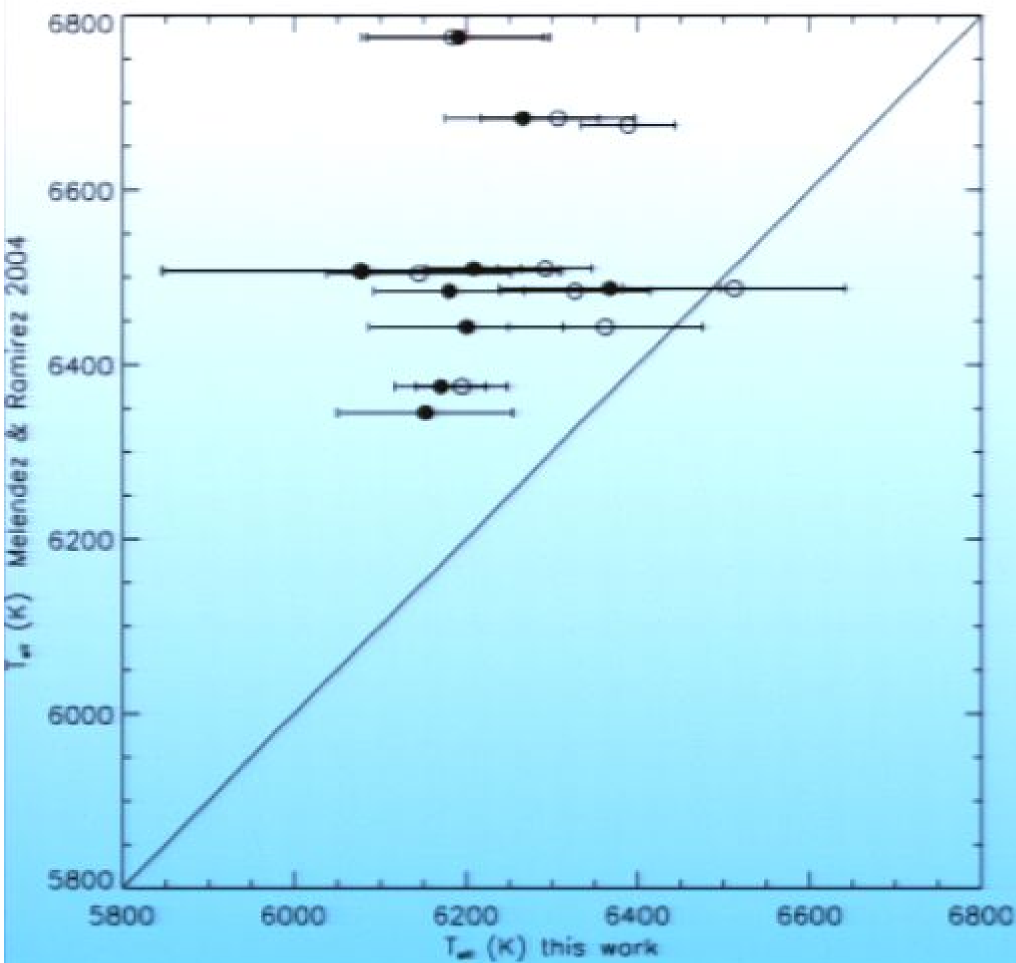
Recent dedicated temperature determinations (excitation energy technique)

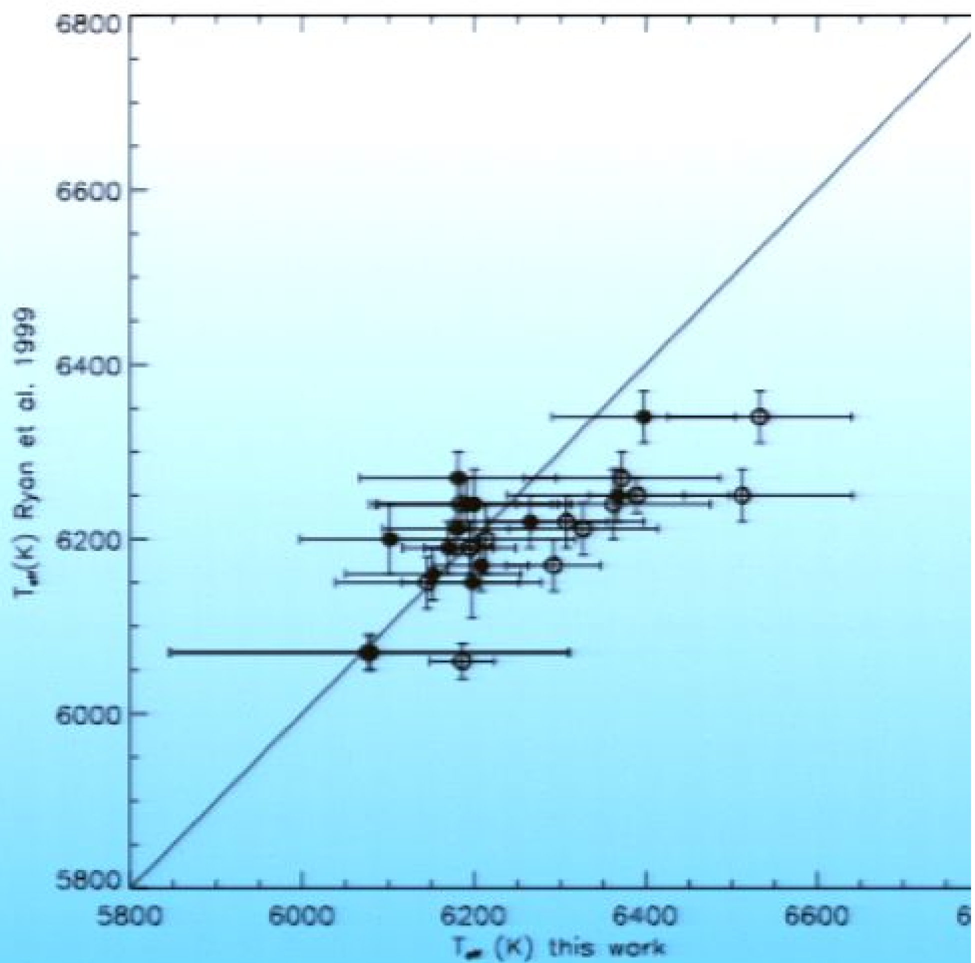




Hosford, Ryan, Garcia-Perez, Norris, Olive

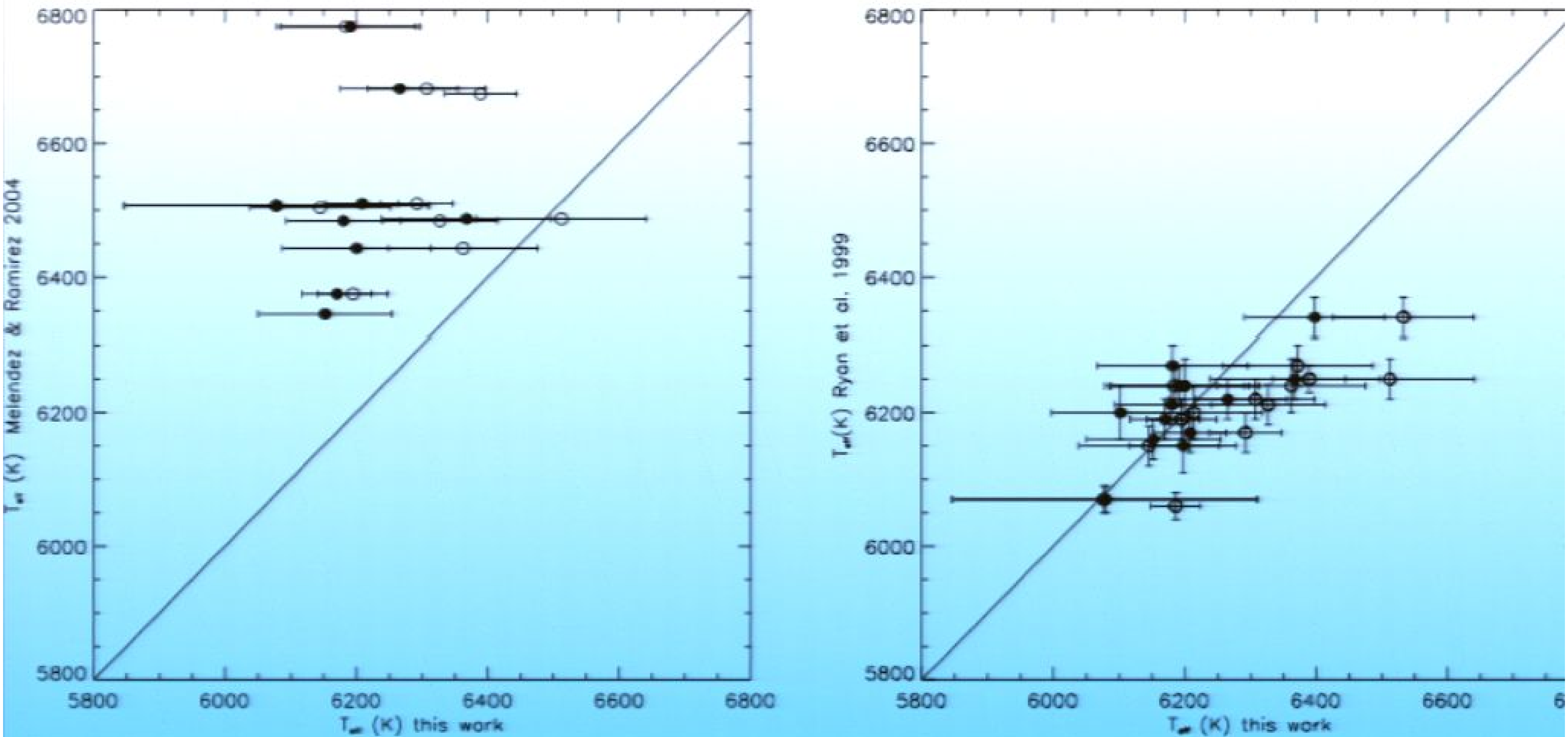
Recent dedicated temperature determinations (excitation energy technique)





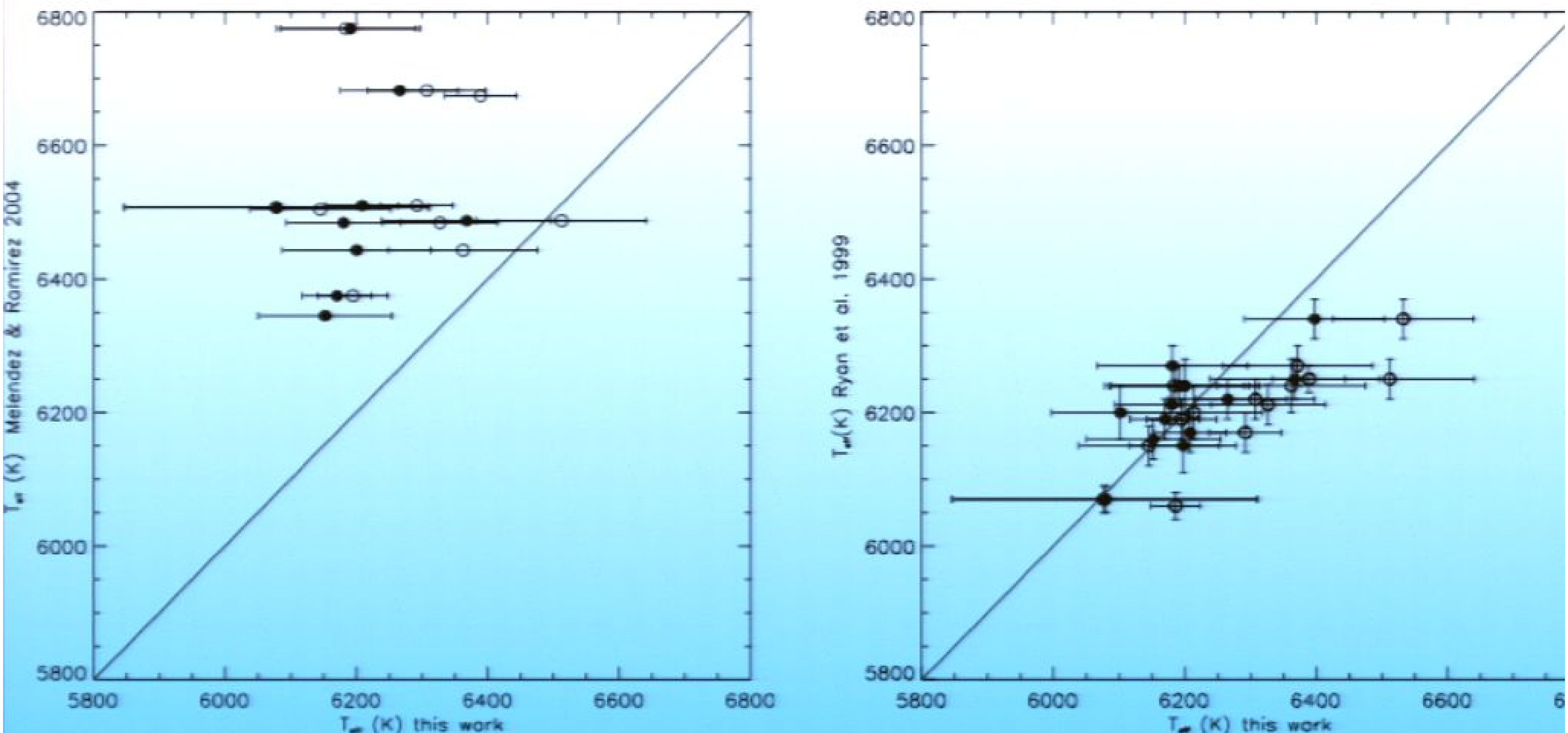
Hosford, Ryan, Garcia-Perez, Norris, Olive

Recent dedicated temperature determinations (excitation energy technique)



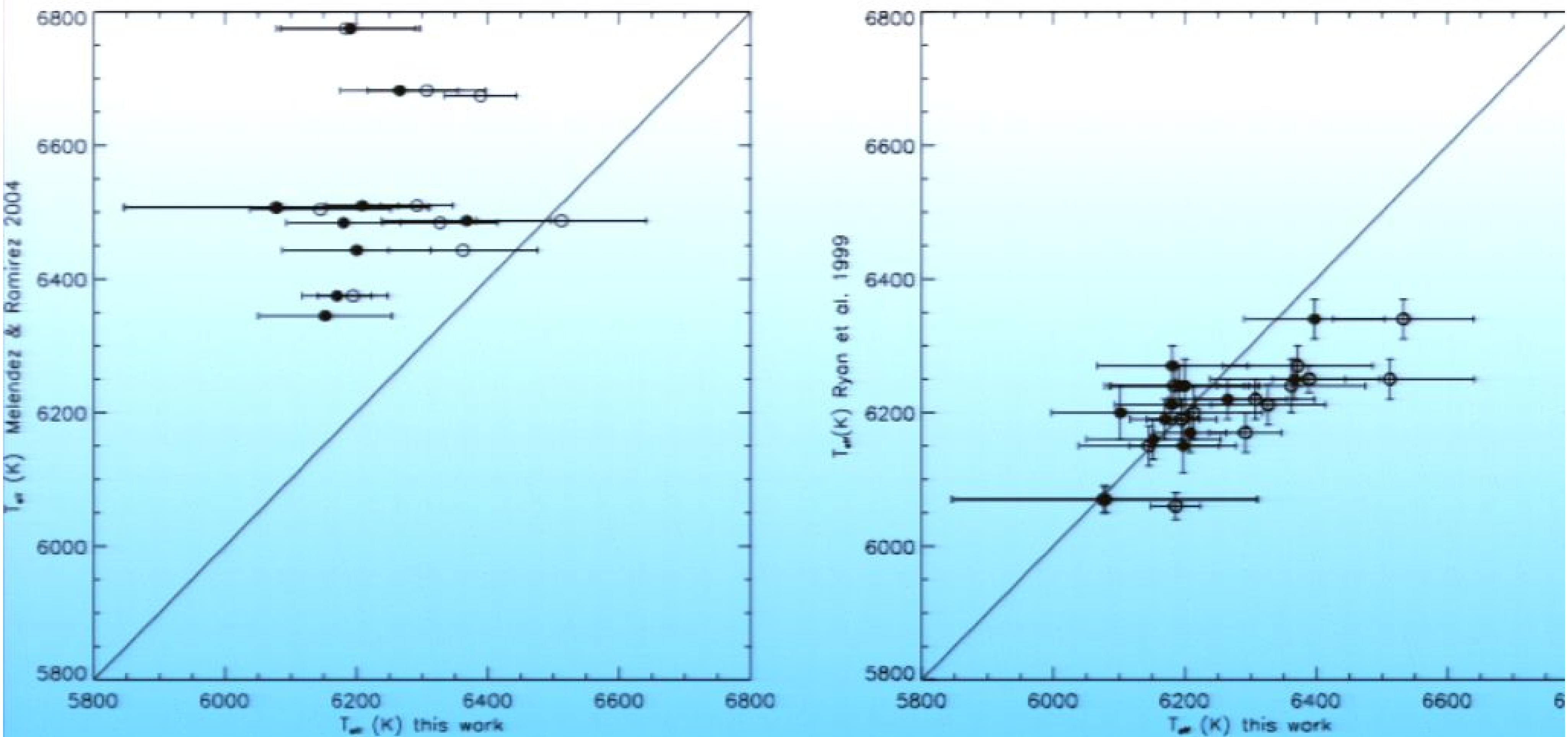
Hosford, Ryan, Garcia-Perez, Norris, Olive

Recent dedicated temperature determinations (excitation energy technique)



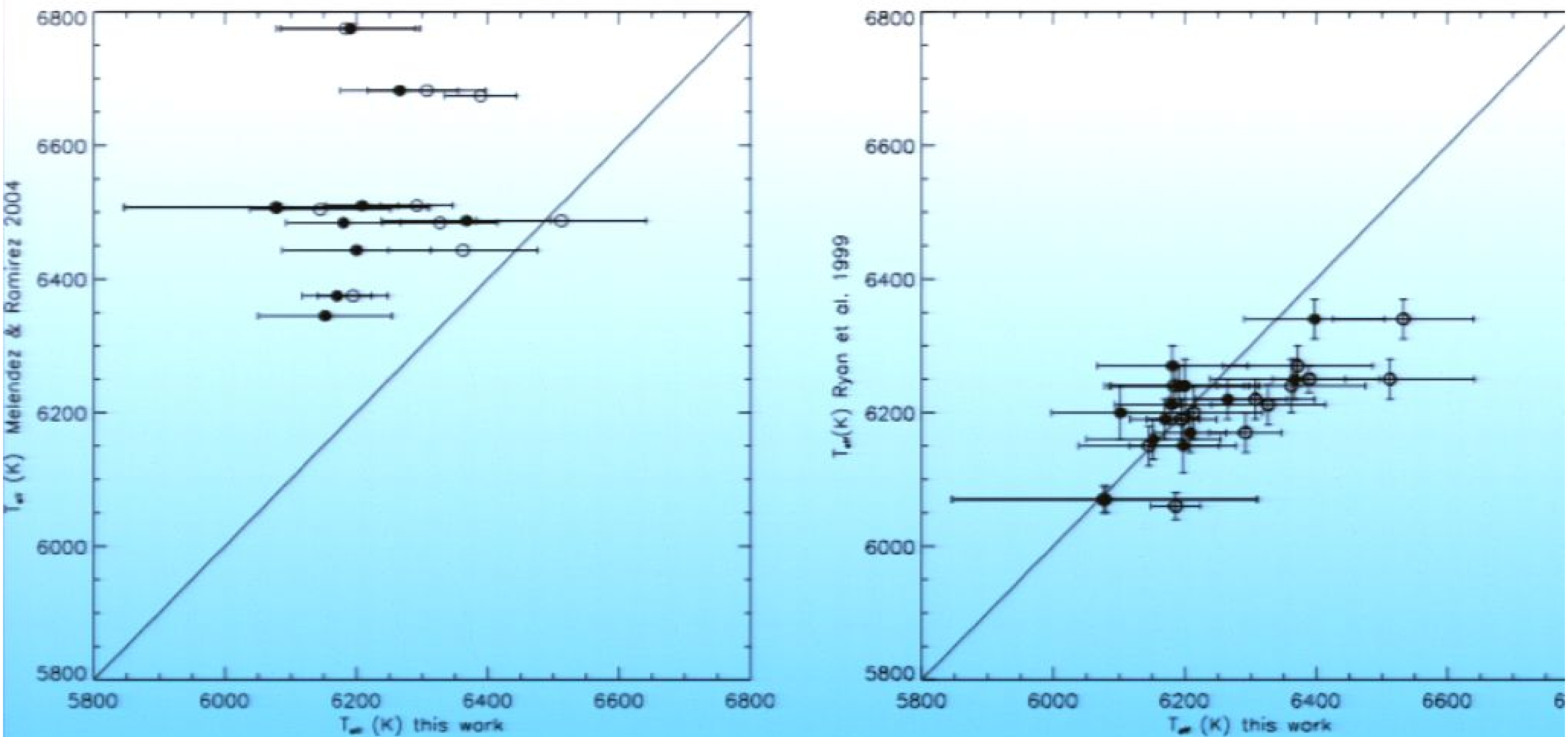
Hosford, Ryan, Garcia-Perez, Norris, Olive

Recent dedicated temperature determinations (excitation energy technique)



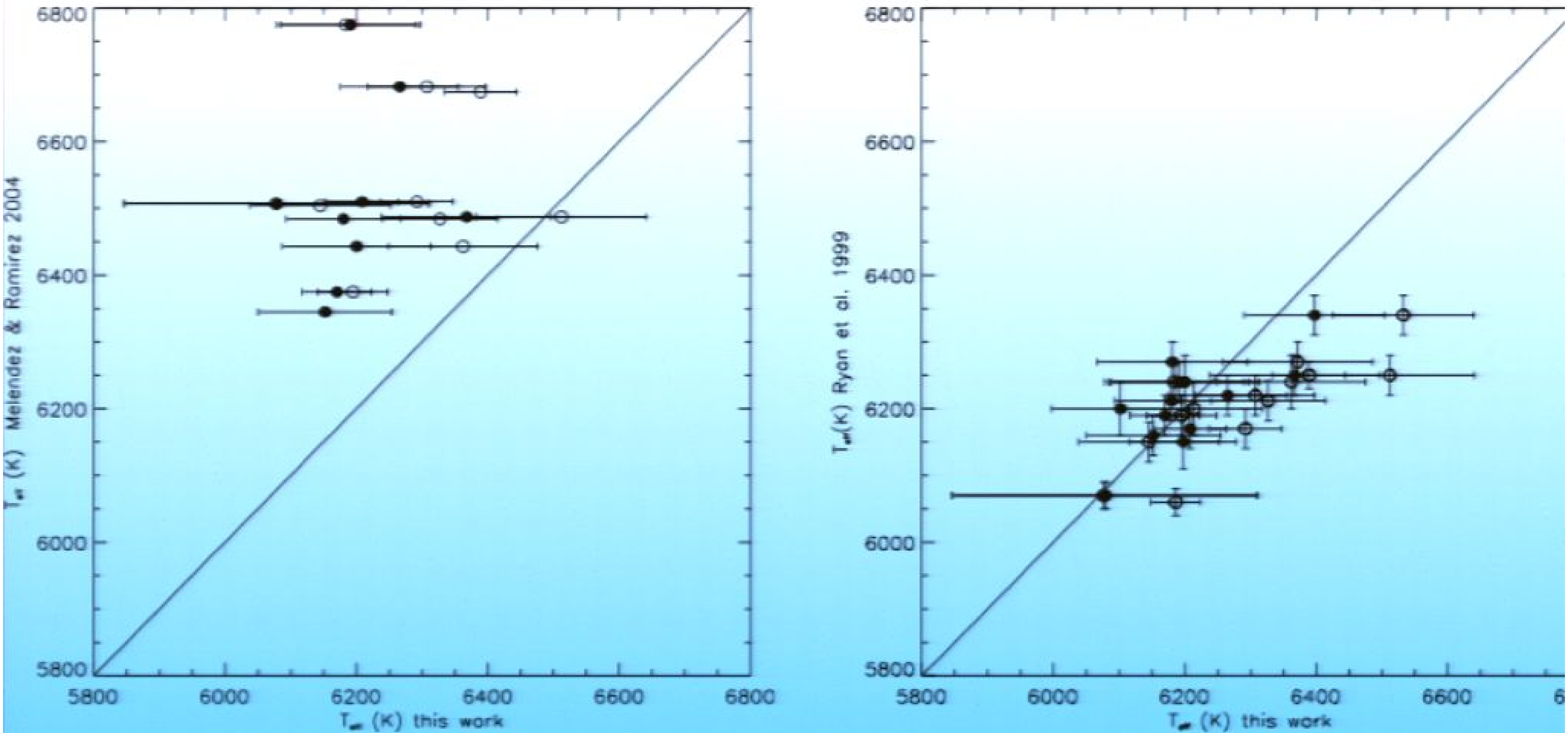
Hosford, Ryan, Garcia-Perez, Norris, Olive

Recent dedicated temperature determinations (excitation energy technique)



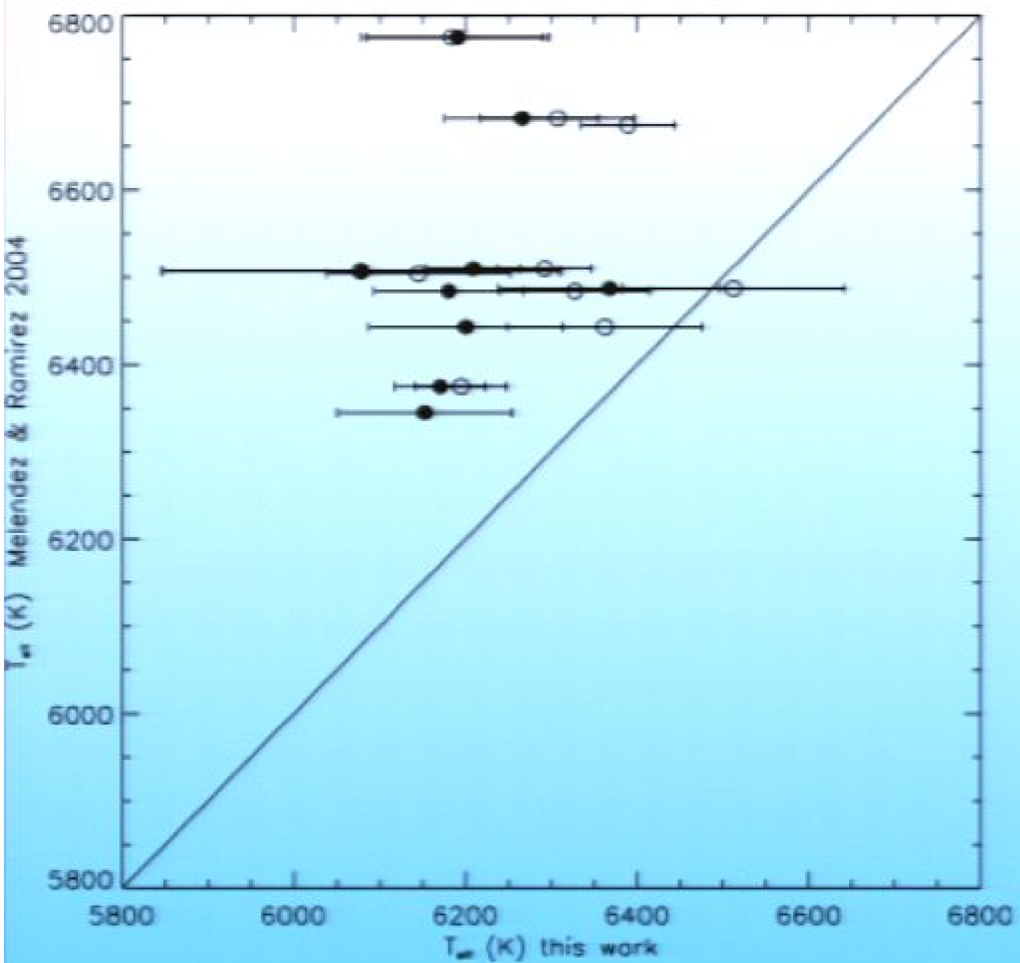
Hosford, Ryan, Garcia-Perez, Norris, Olive

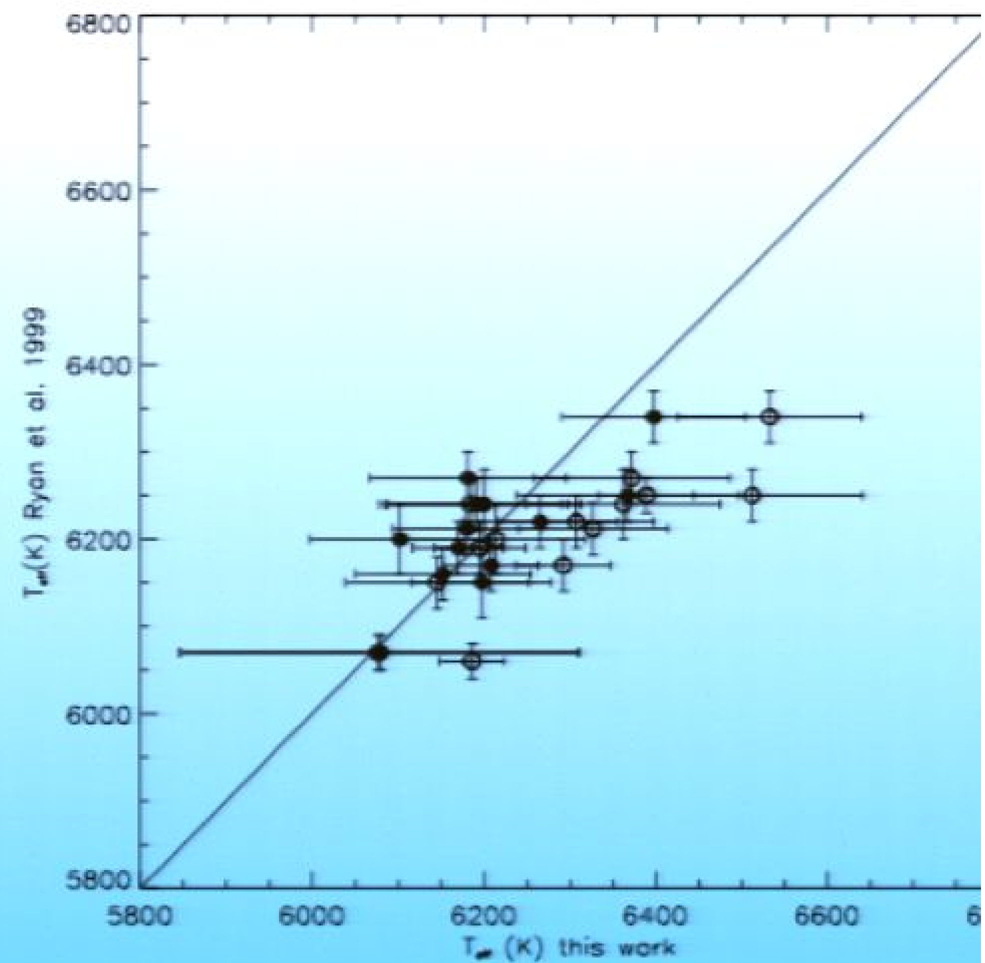
Recent dedicated temperature determinations (excitation energy technique)



Hosford, Ryan, Garcia-Perez, Norris, Olive

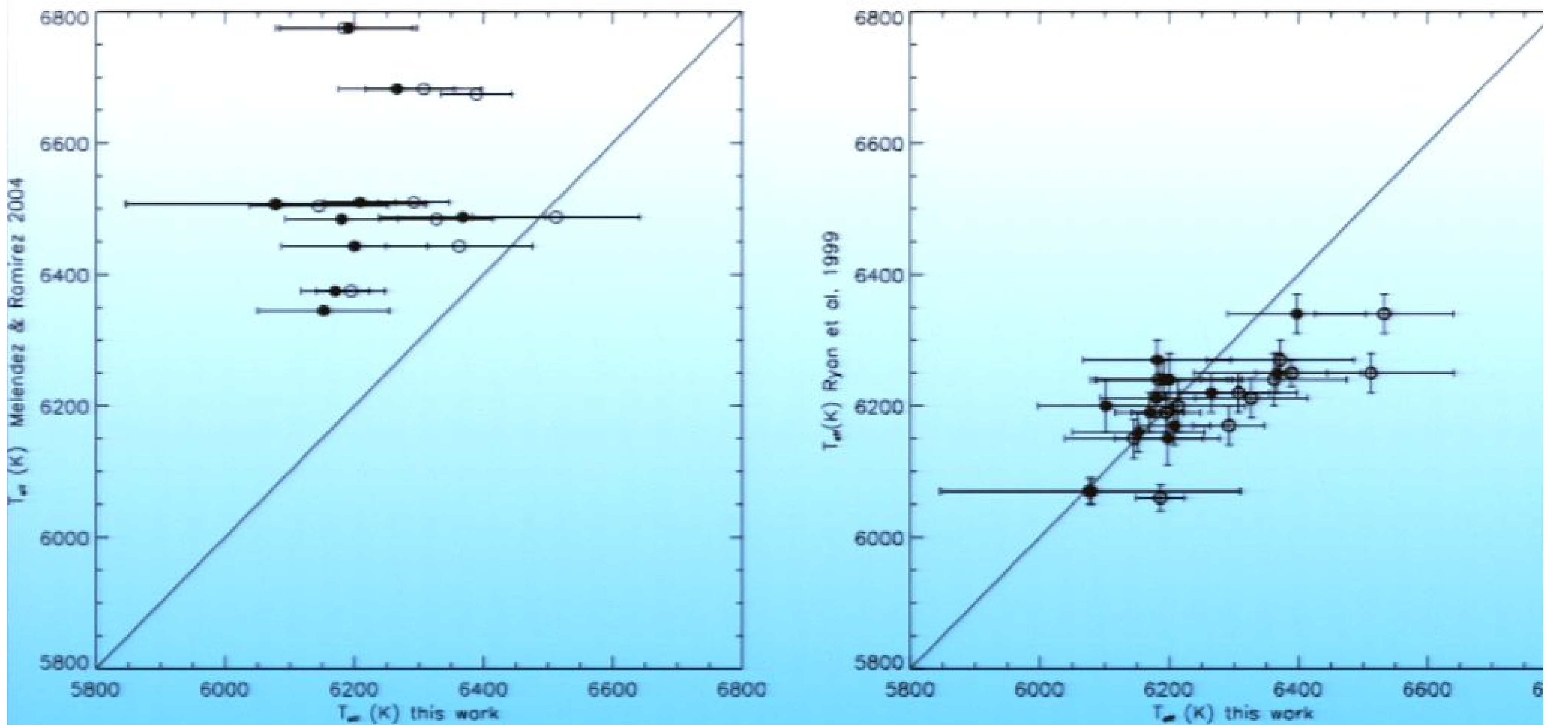
Recent dedicated temperature determinations (excitation energy technique)





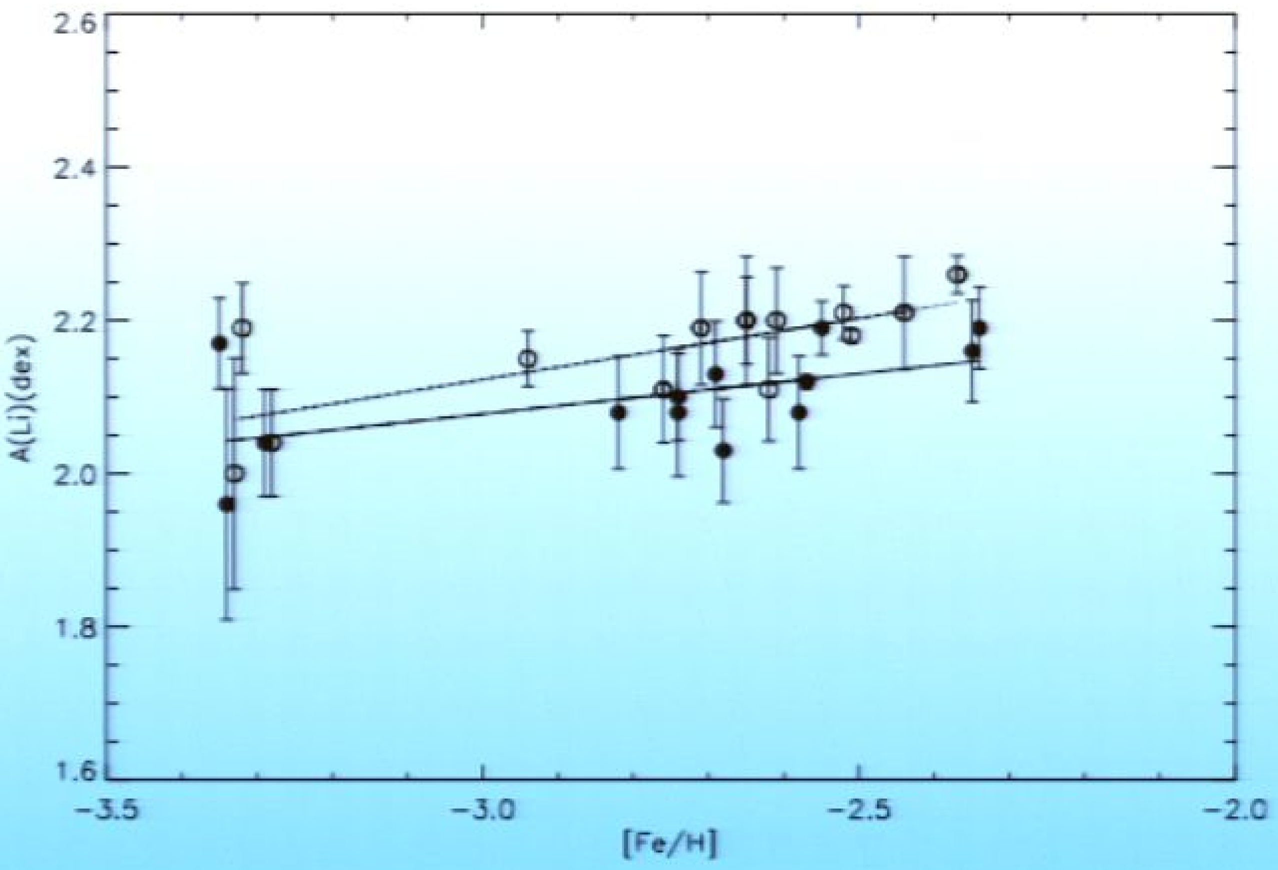
Hosford, Ryan, Garcia-Perez, Norris, Olive

Recent dedicated temperature determinations (excitation energy technique)



Hosford, Ryan, Garcia-Perez, Norris, Olive

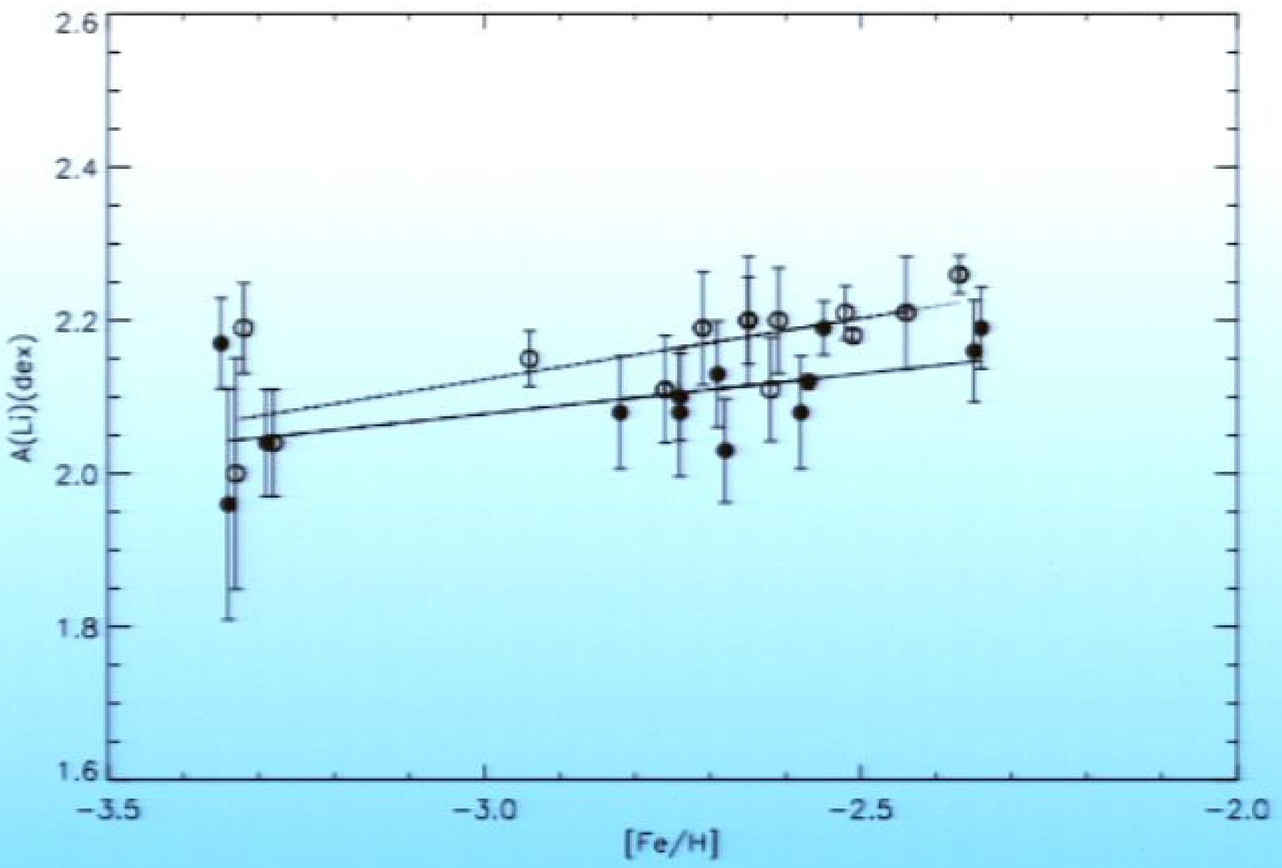
Resulting Li:



$$[\text{Li}] = 2.16 \pm 0.07 \text{ MS}$$
$$= 2.10 \pm 0.07 \text{ SGB}$$

Hosford, Ryan, Garcia-Perez, Norris, Olive

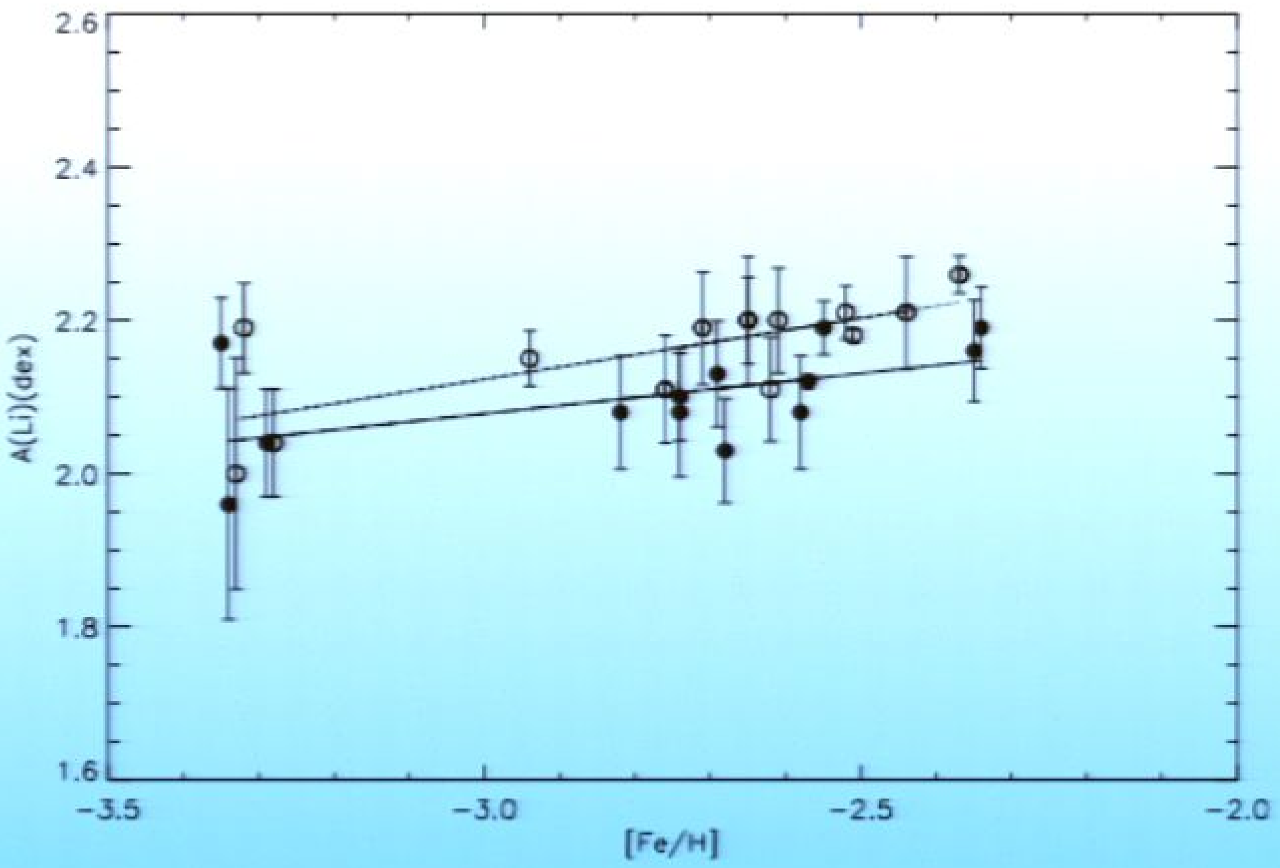
Resulting Li:



$$[Li] = 2.16 \pm 0.07 \text{ MS}$$
$$= 2.10 \pm 0.07 \text{ SGB}$$

Hosford, Ryan, Garcia-Perez, Norris, Olive

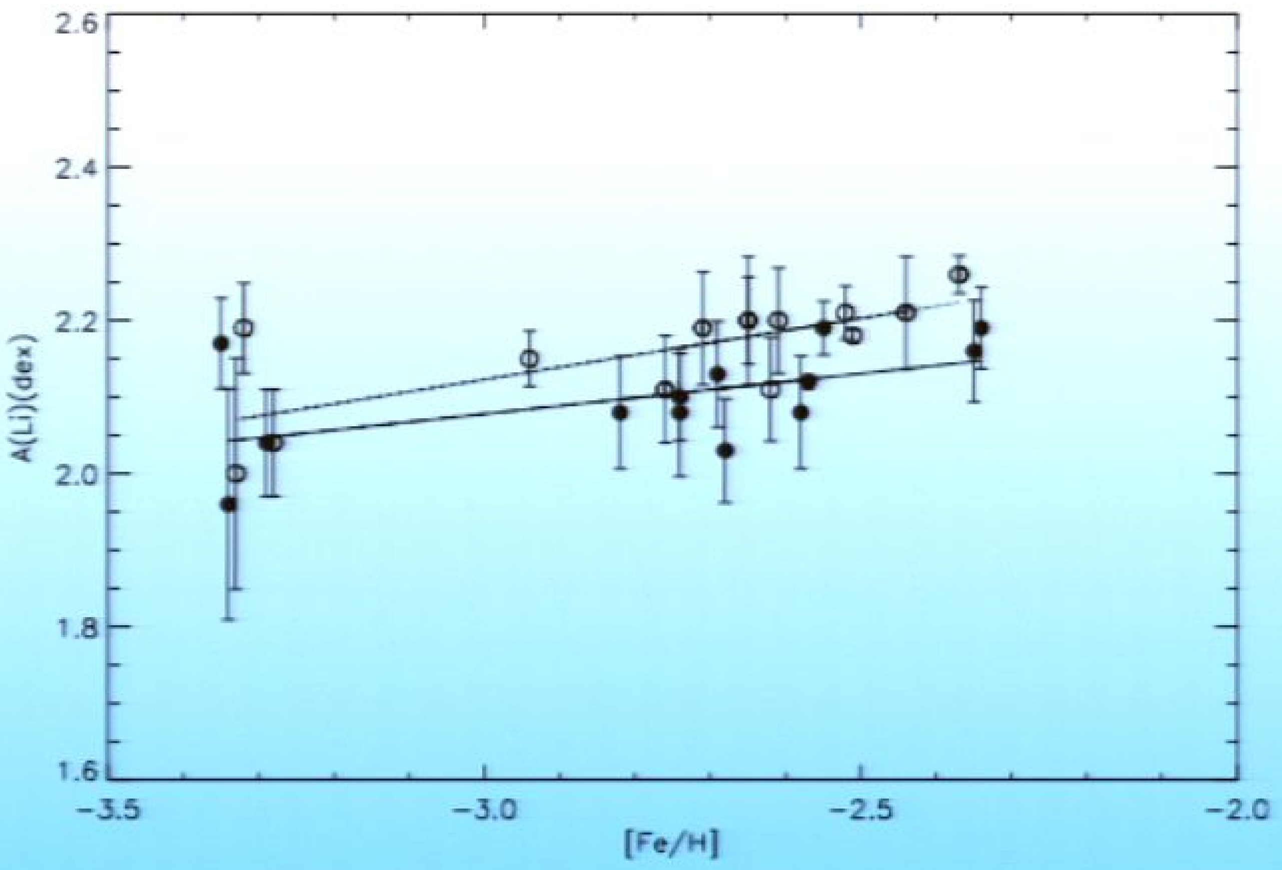
Resulting Li:



$$[Li] = 2.16 \pm 0.07 \text{ MS}$$
$$= 2.10 \pm 0.07 \text{ SGB}$$

Hosford, Ryan, Garcia-Perez, Norris, Olive

Resulting Li:



$[Li] = 2.16 \pm 0.07$ MS

$= 2.10 \pm 0.07$ SGB

Hosford, Ryan, Garcia-Perez, Norris, Olive

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux

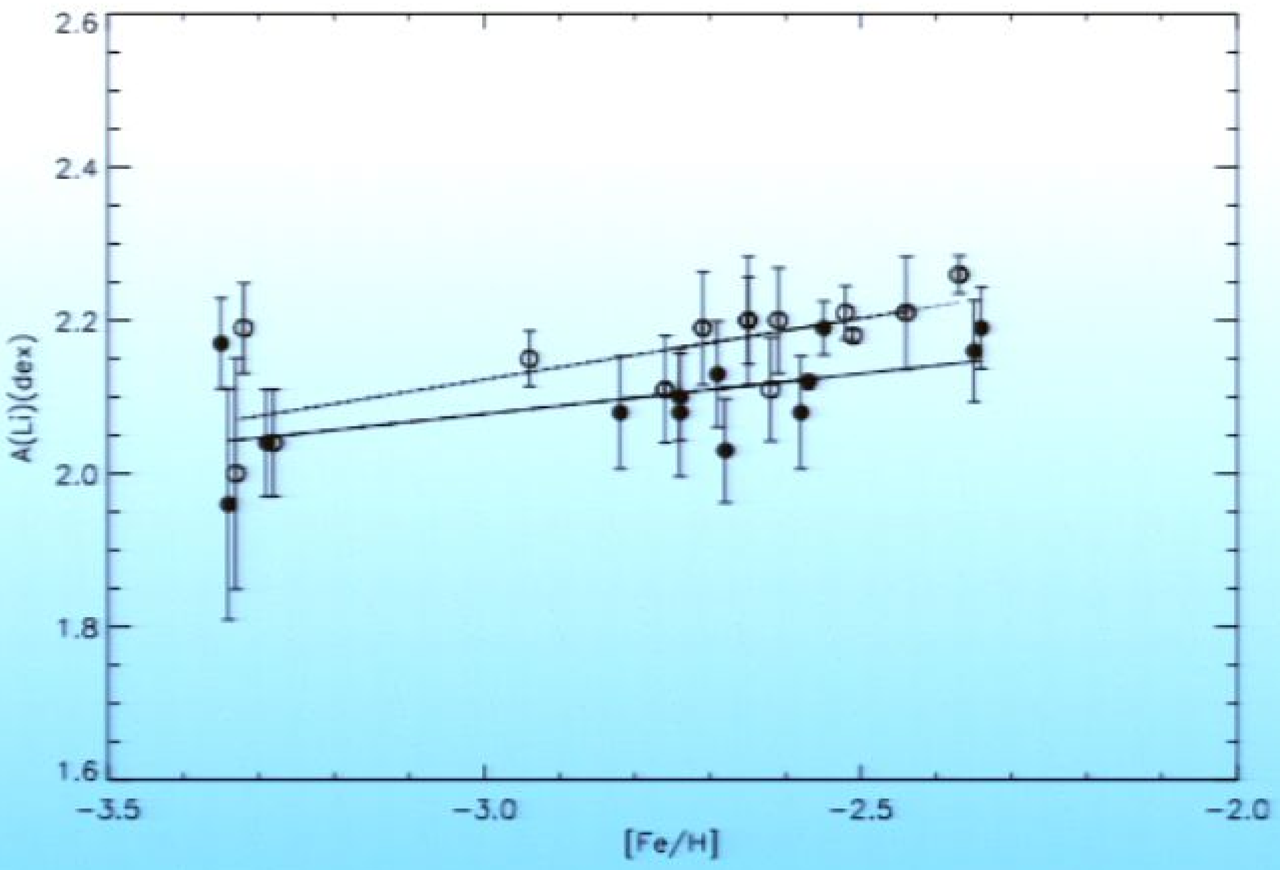
Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays

Resulting Li:



$$[Li] = 2.16 \pm 0.07 \text{ MS}$$
$$= 2.10 \pm 0.07 \text{ SGB}$$

Hosford, Ryan, Garcia-Perez, Norris, Olive

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{d\ln g} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays

Possible sources for the discrepancy

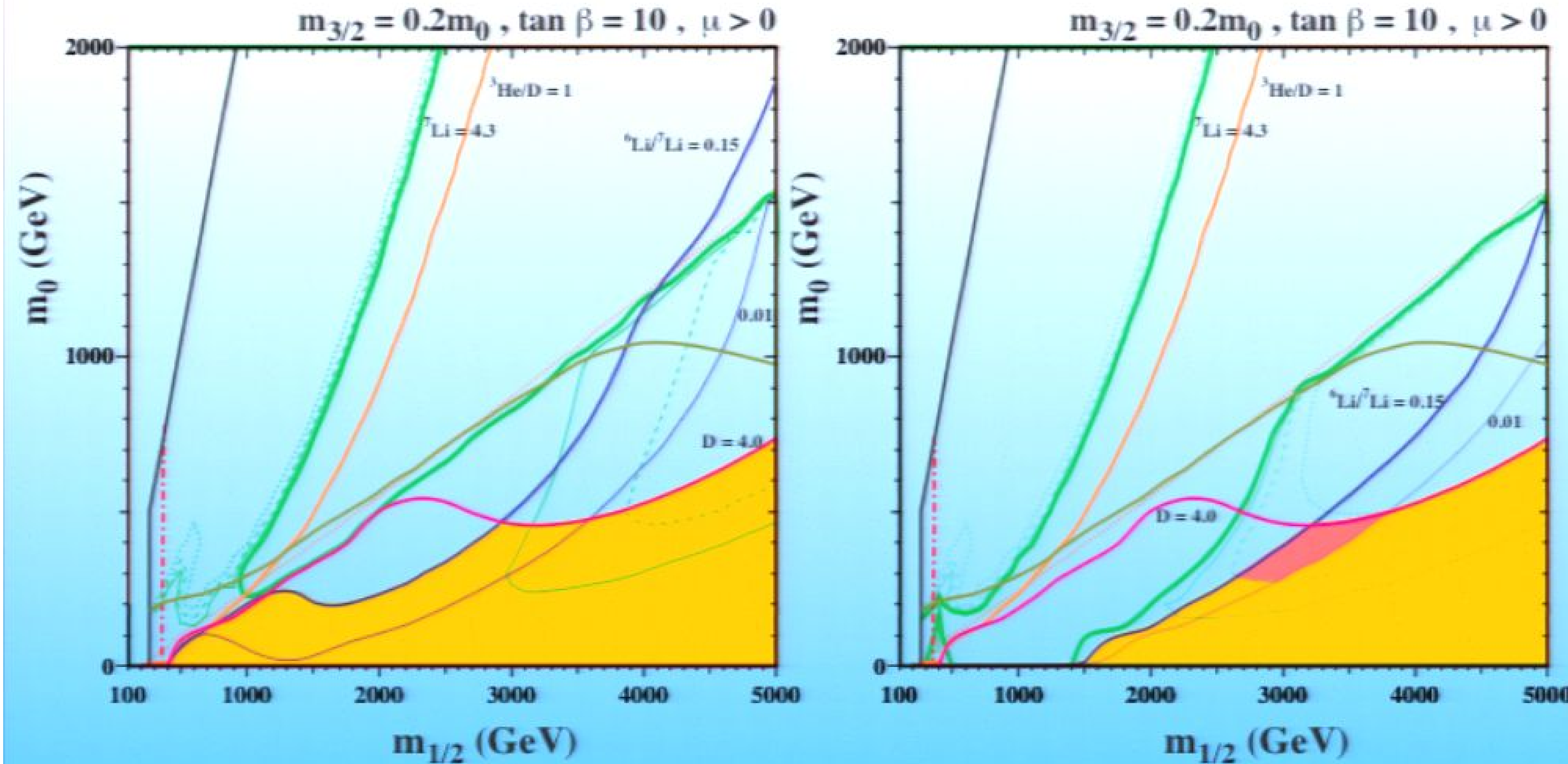
- Nuclear Rates
  - Restricted by solar neutrino flux

Coc et al.
Cyburt, Fields, KAO

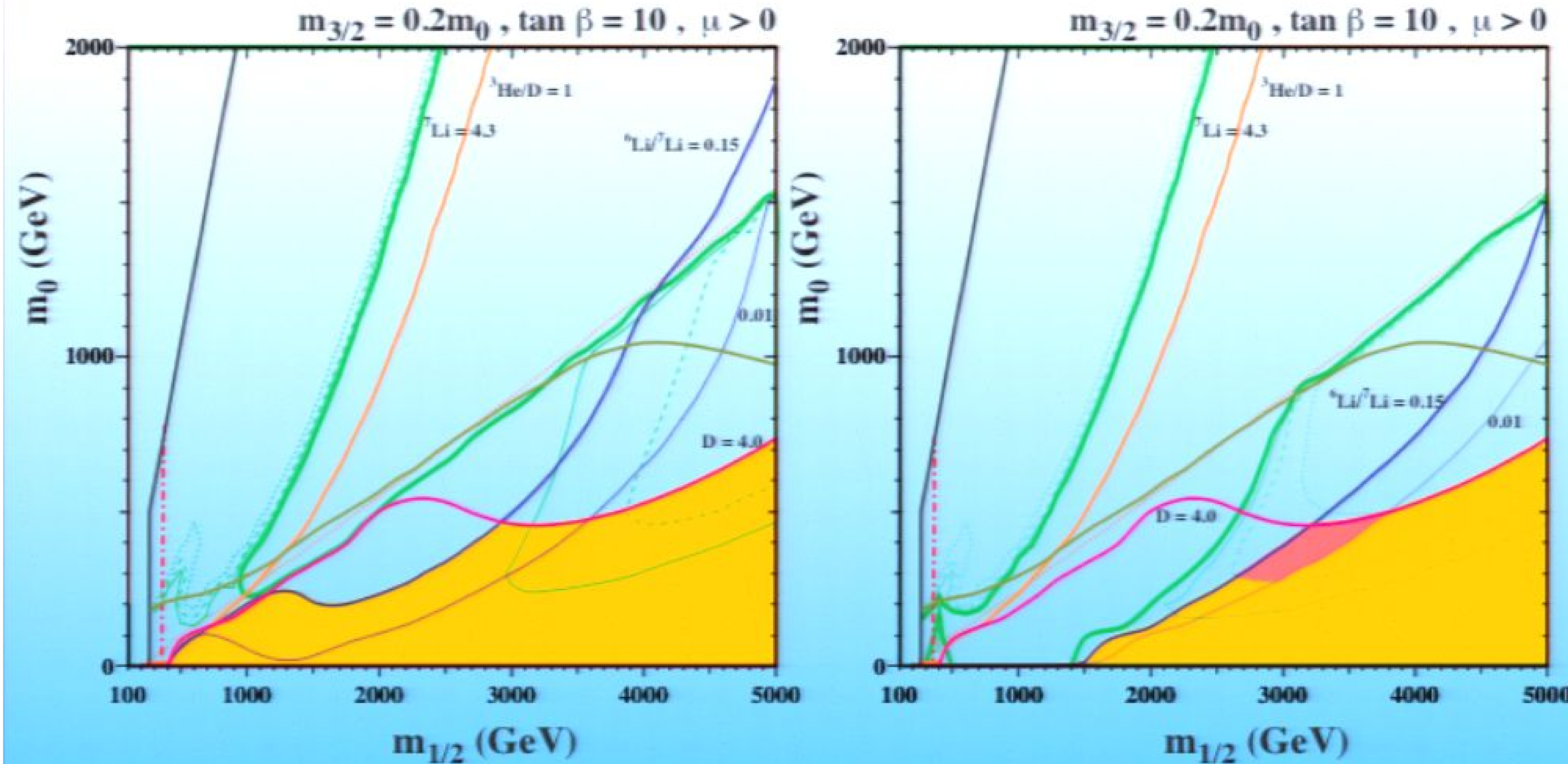
- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

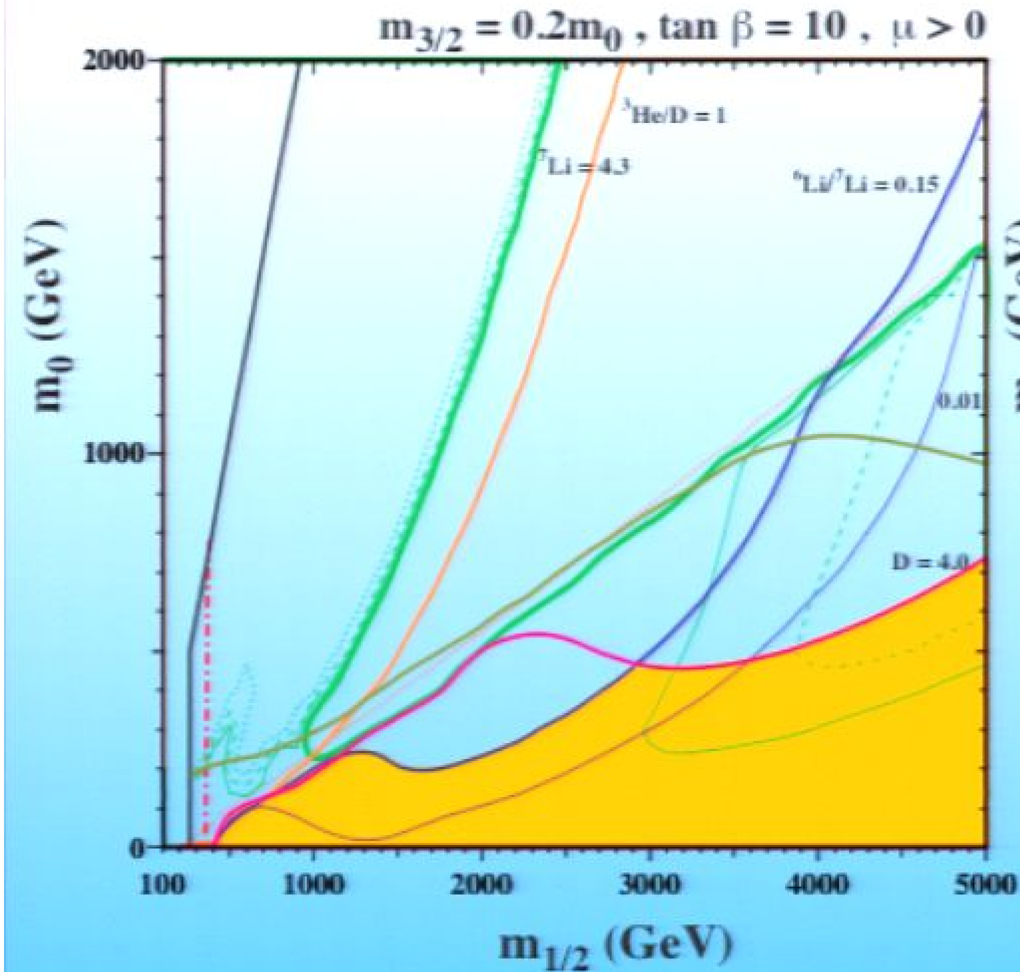
- Particle Decays

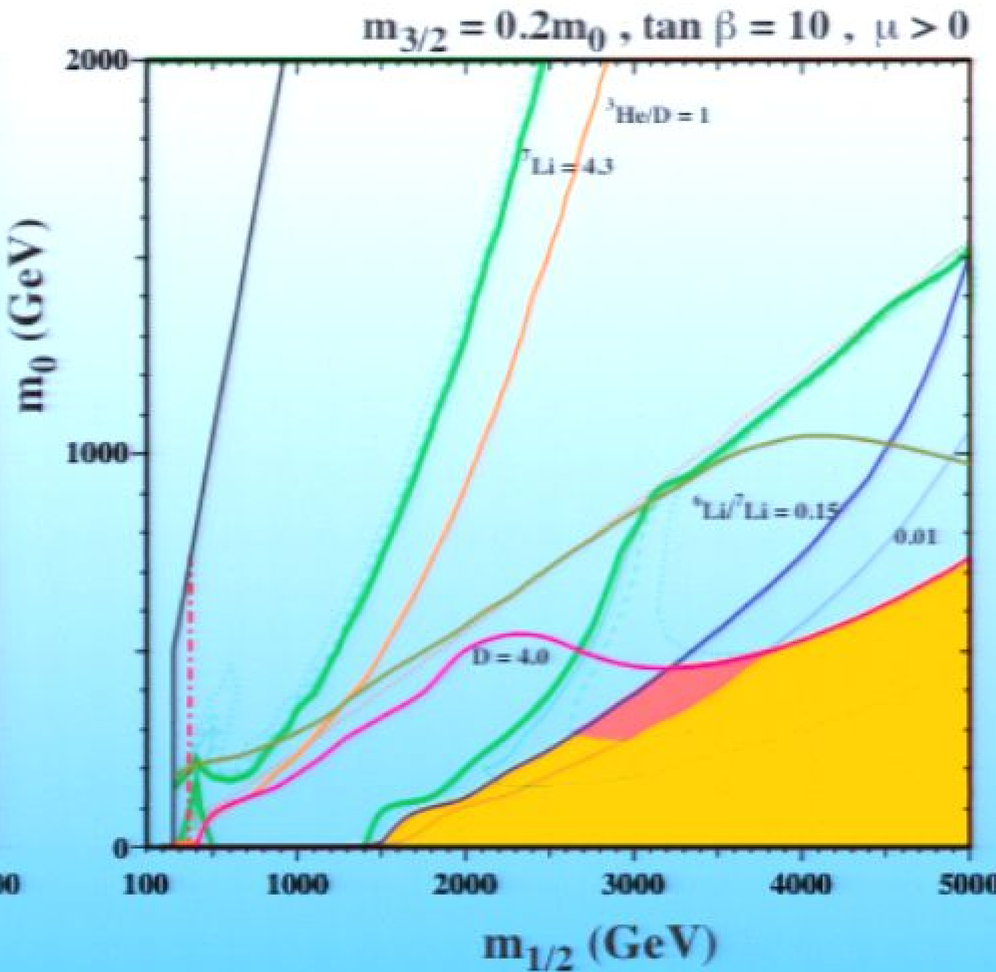


Cyburt, Ellis, Fields, KO, Spano

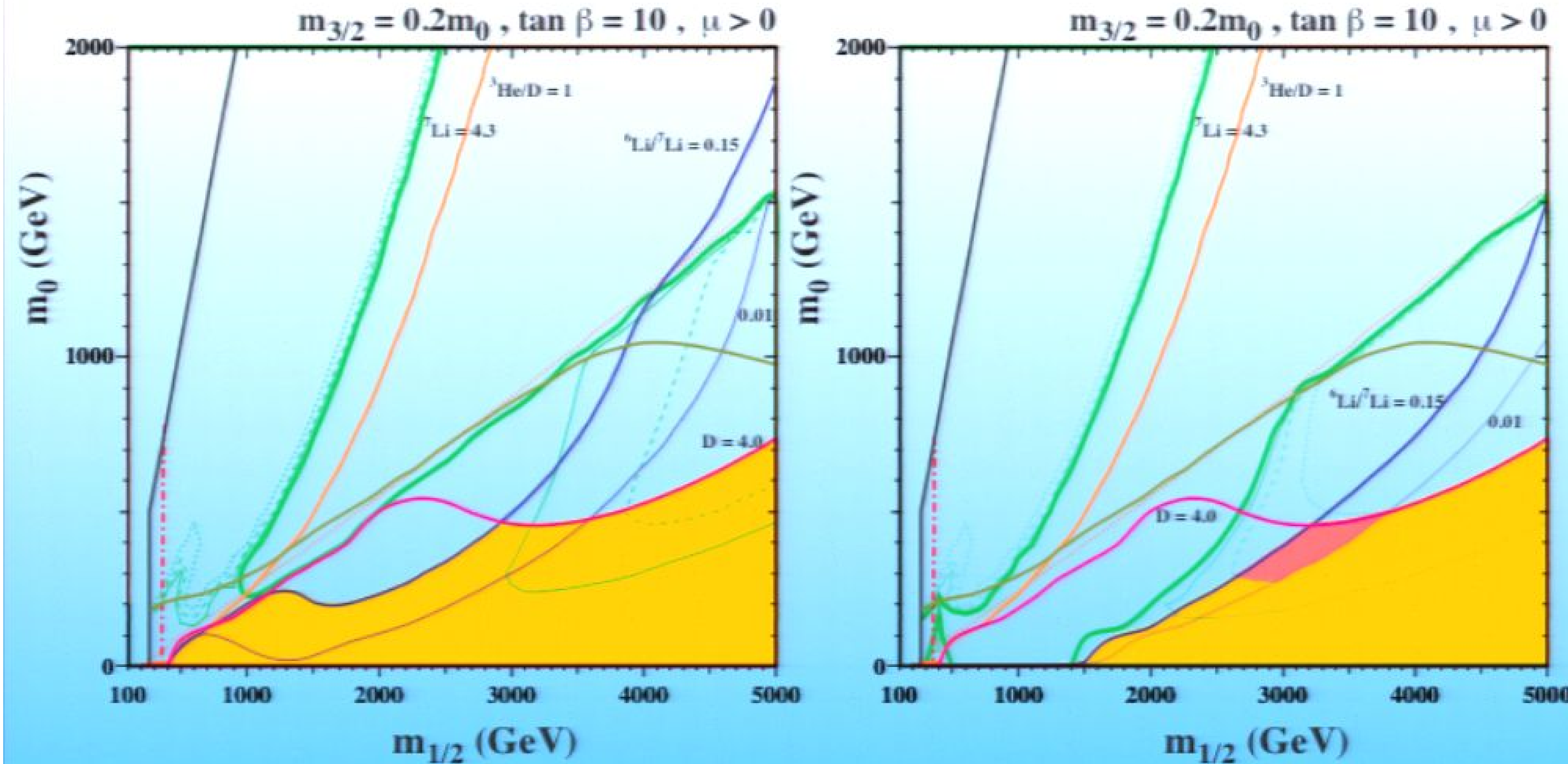


Cyburt, Ellis, Fields, KO, Spanc

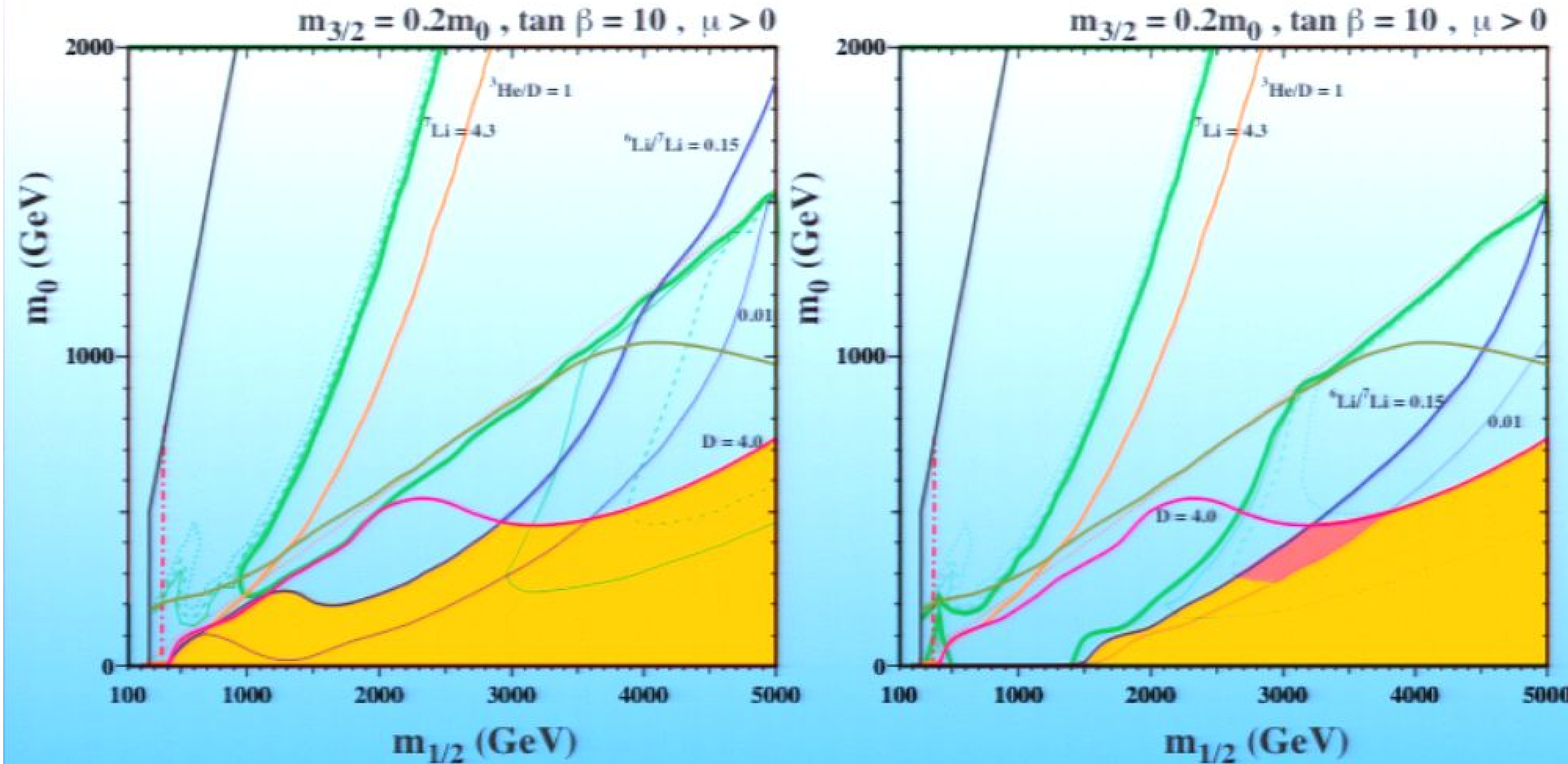




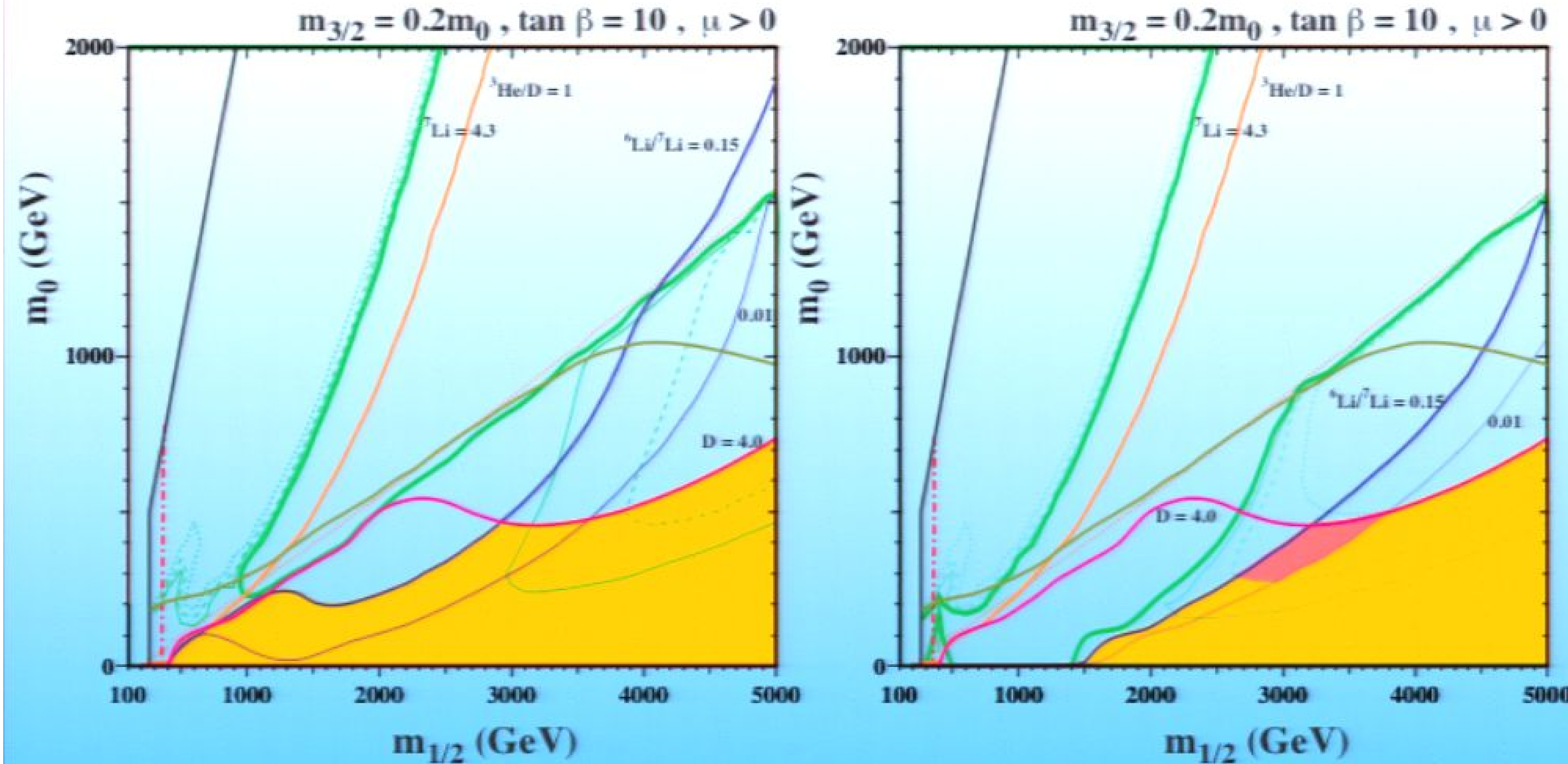
Cybutr, Ellis, Fields, KO, Span



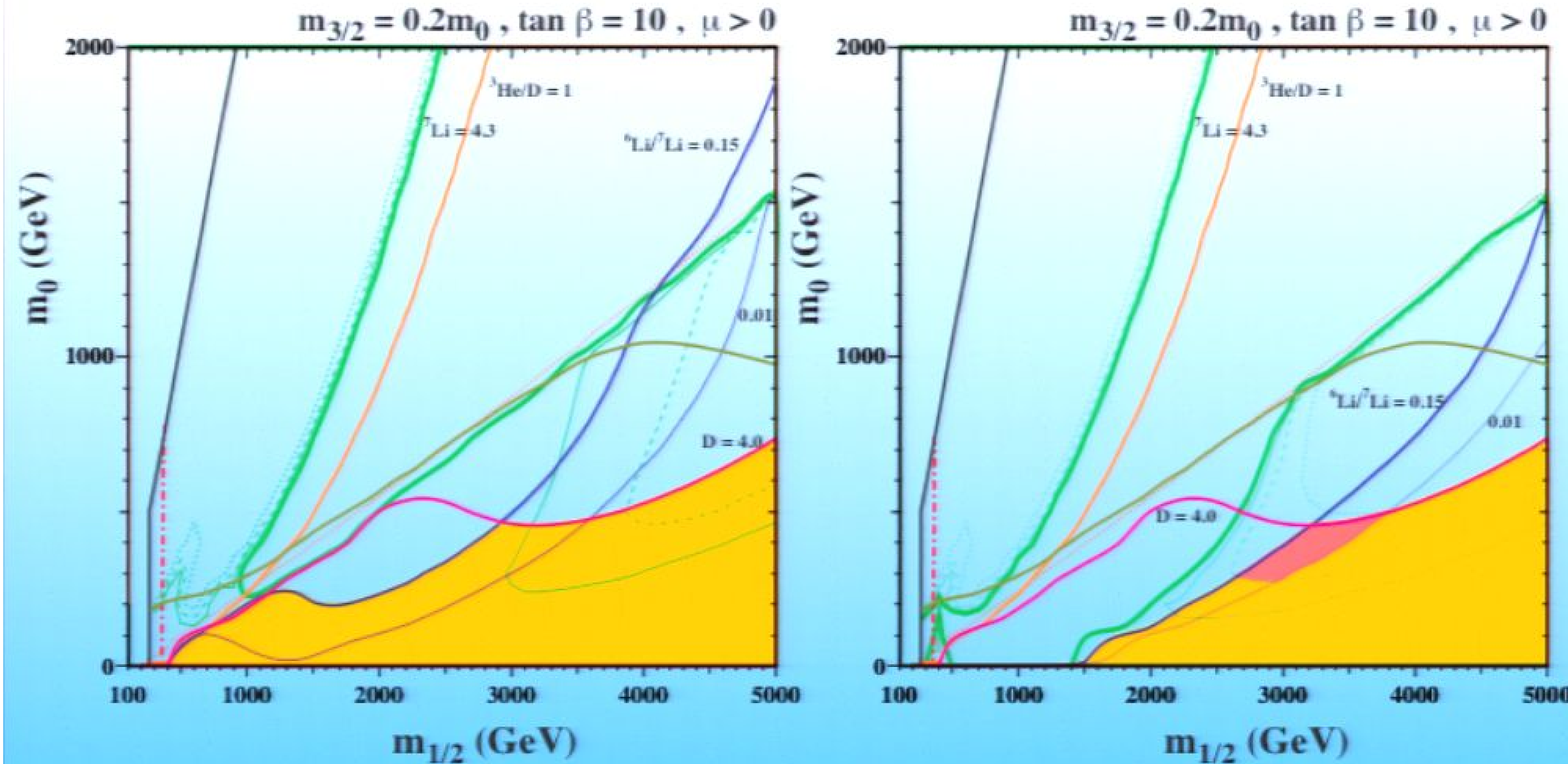
Cyburt, Ellis, Fields, KO, Spanc



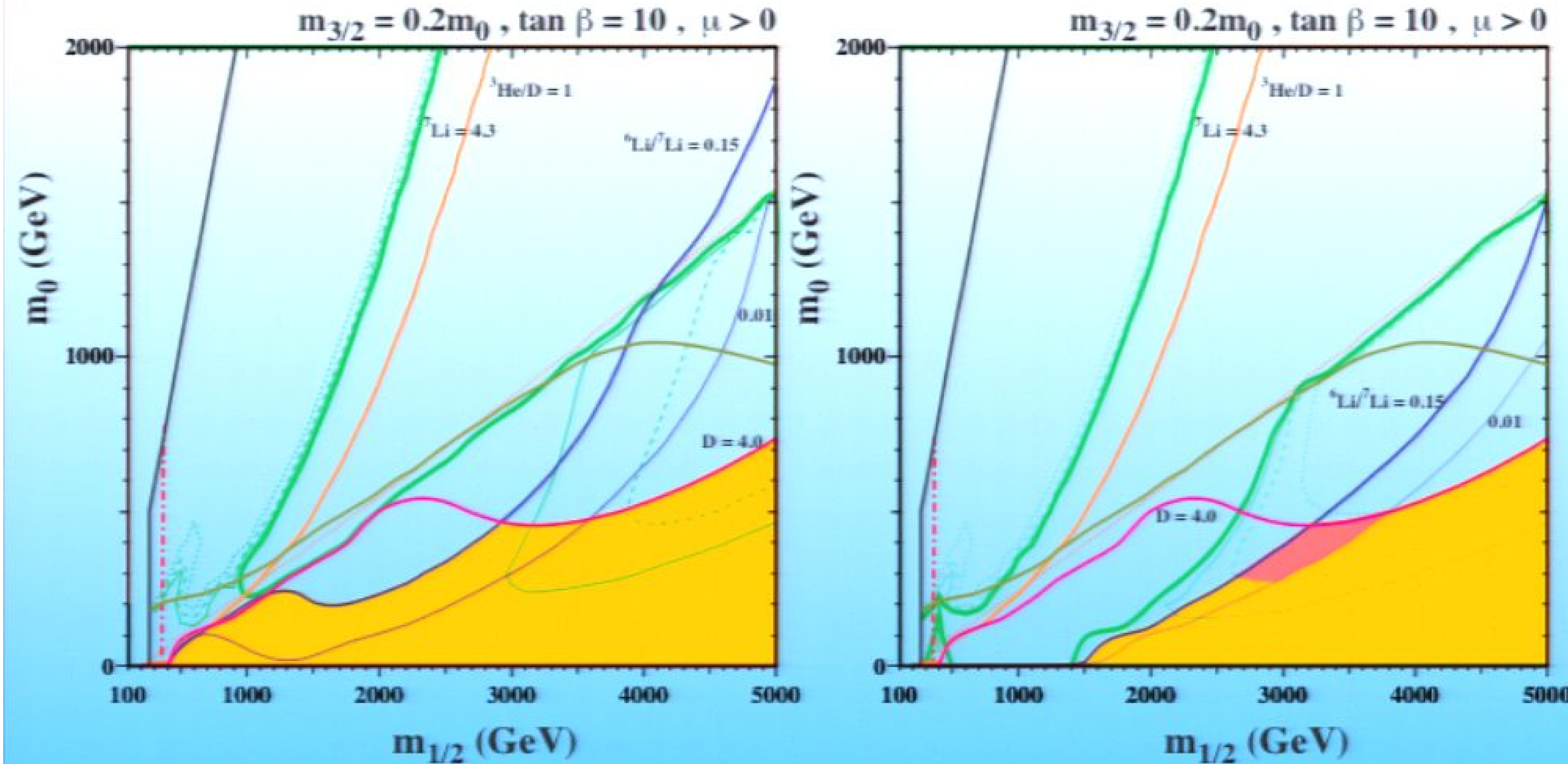
Cyburt, Ellis, Fields, KO, Spanc



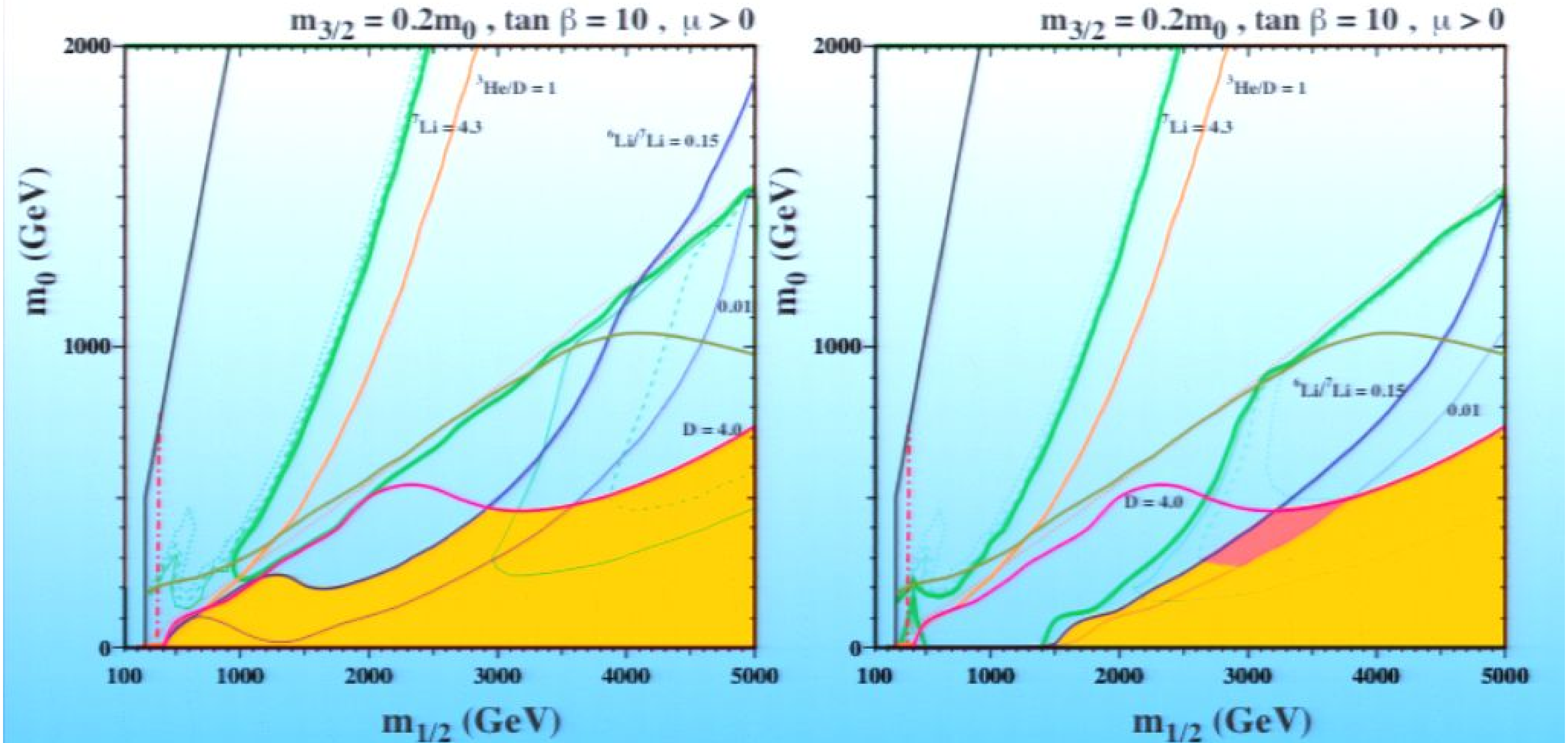
Cyburt, Ellis, Fields, KO, Spanc



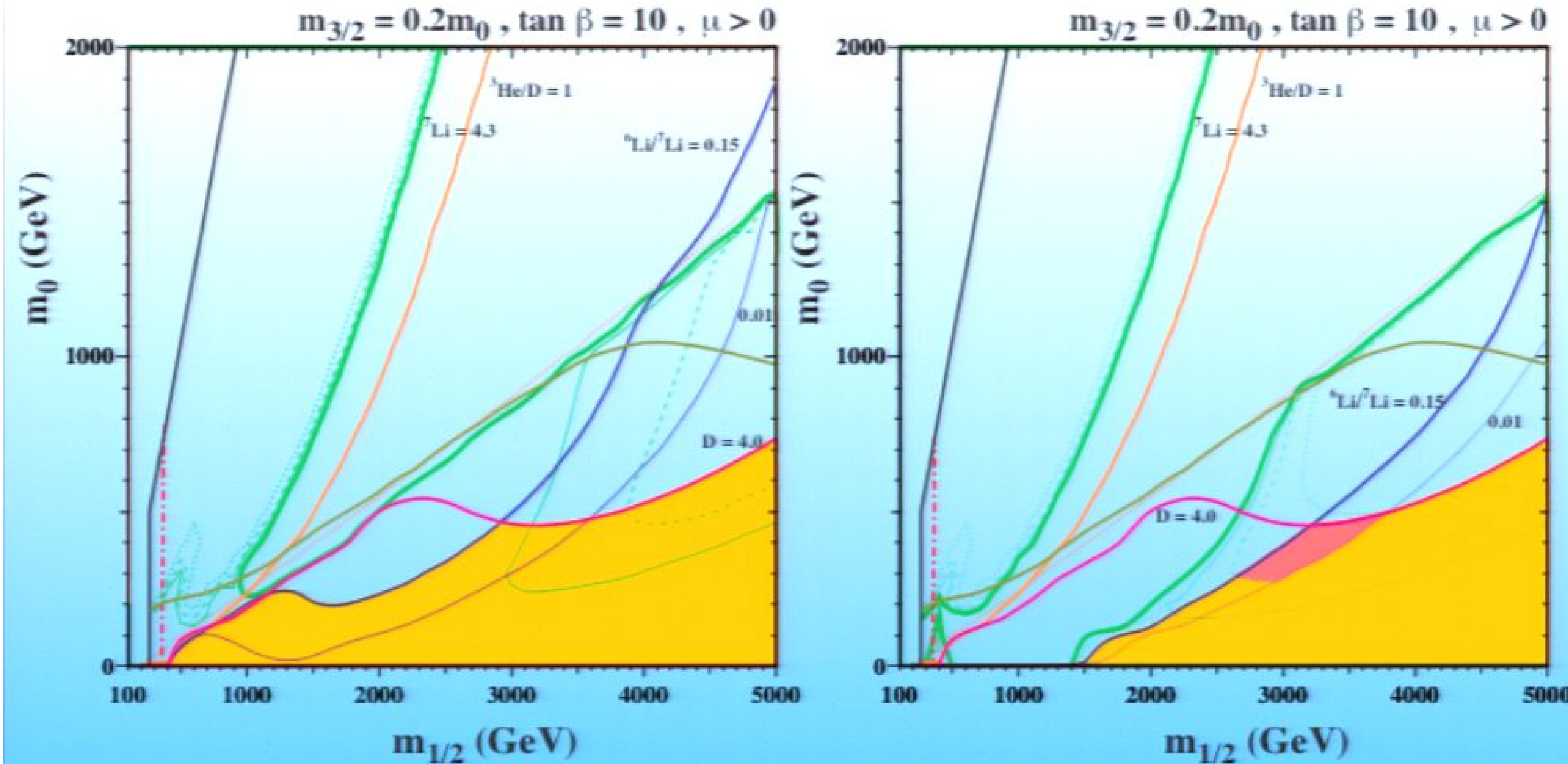
Cyburt, Ellis, Fields, KO, Spano



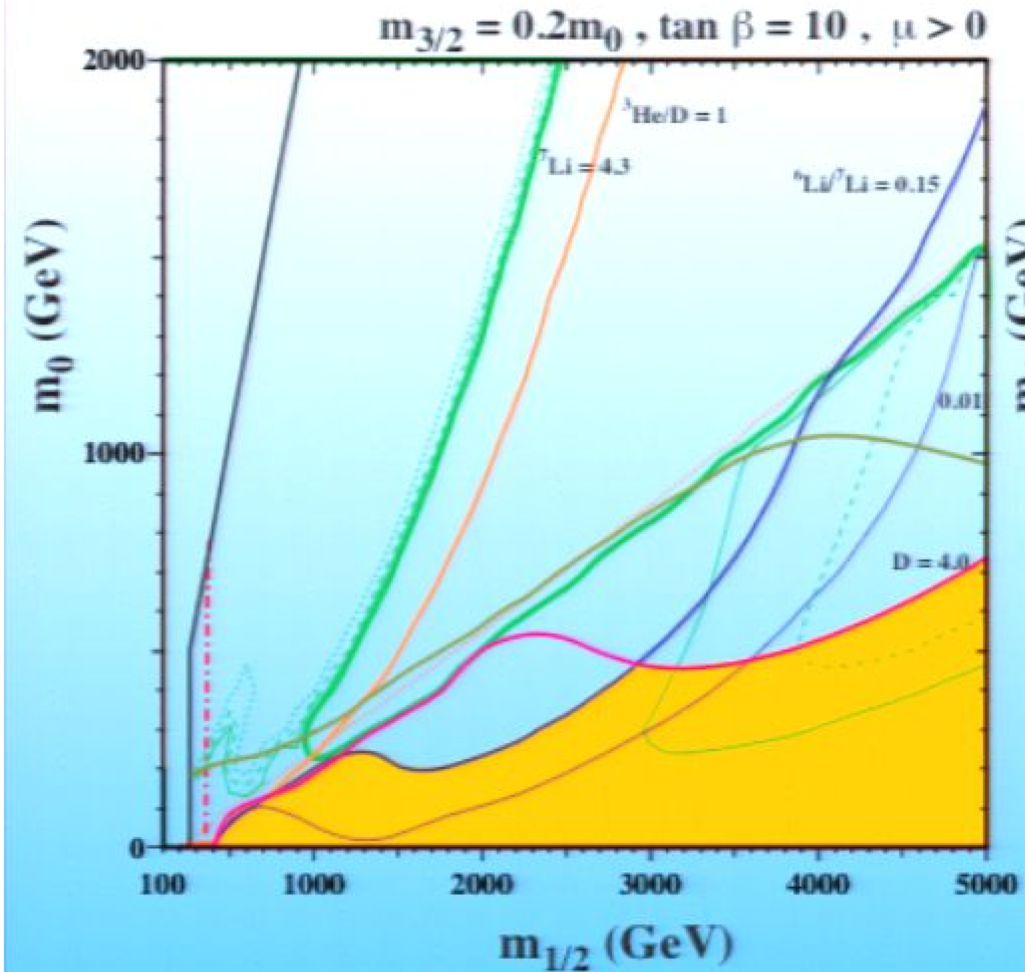
Cyburt, Ellis, Fields, KO, Spanc

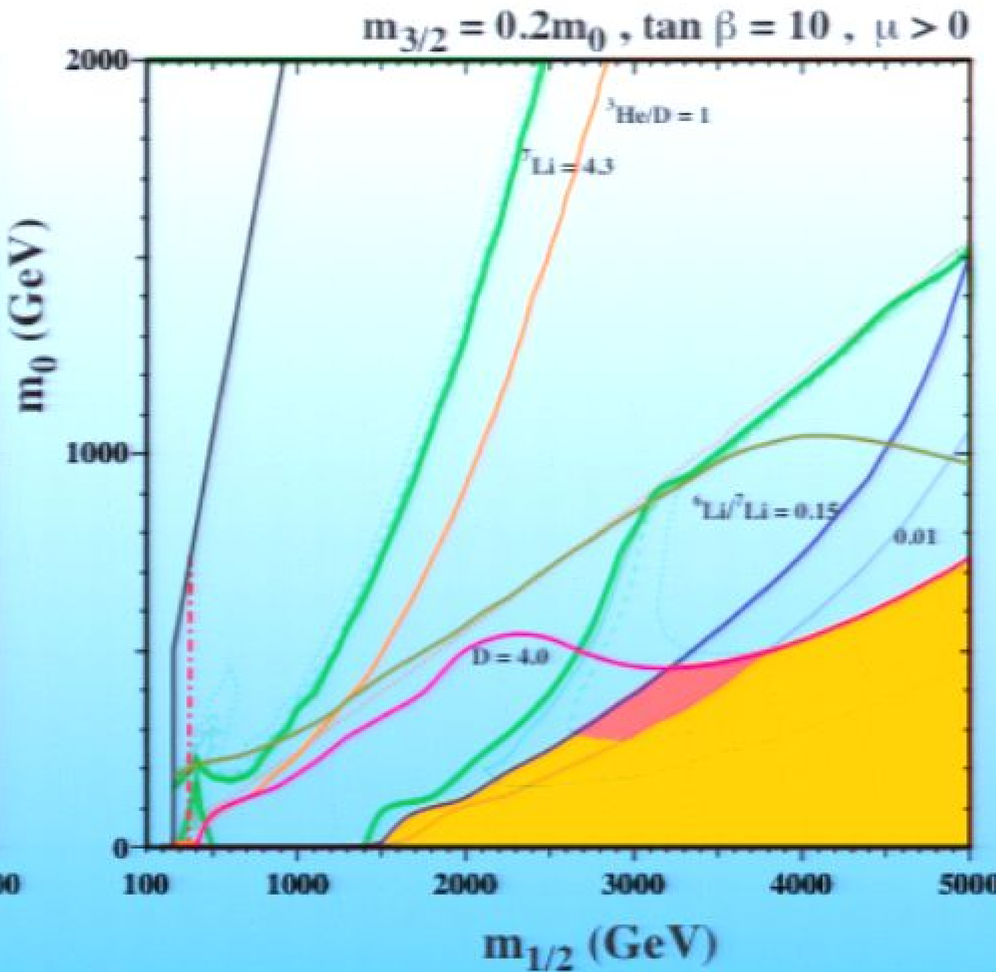


Cyburt, Ellis, Fields, KO, Spanc

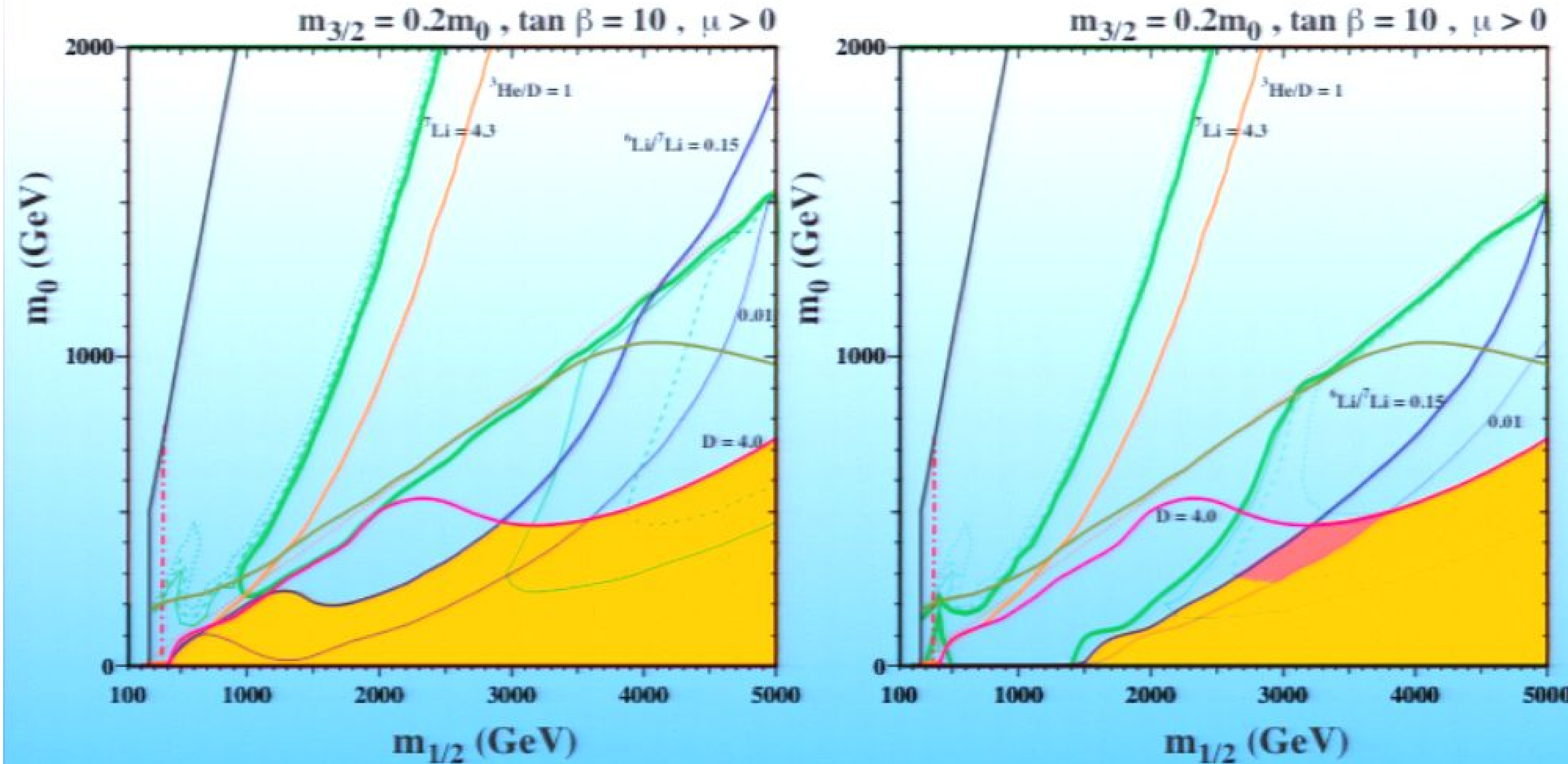


Cybürt, Ellis, Fields, KO, Spano

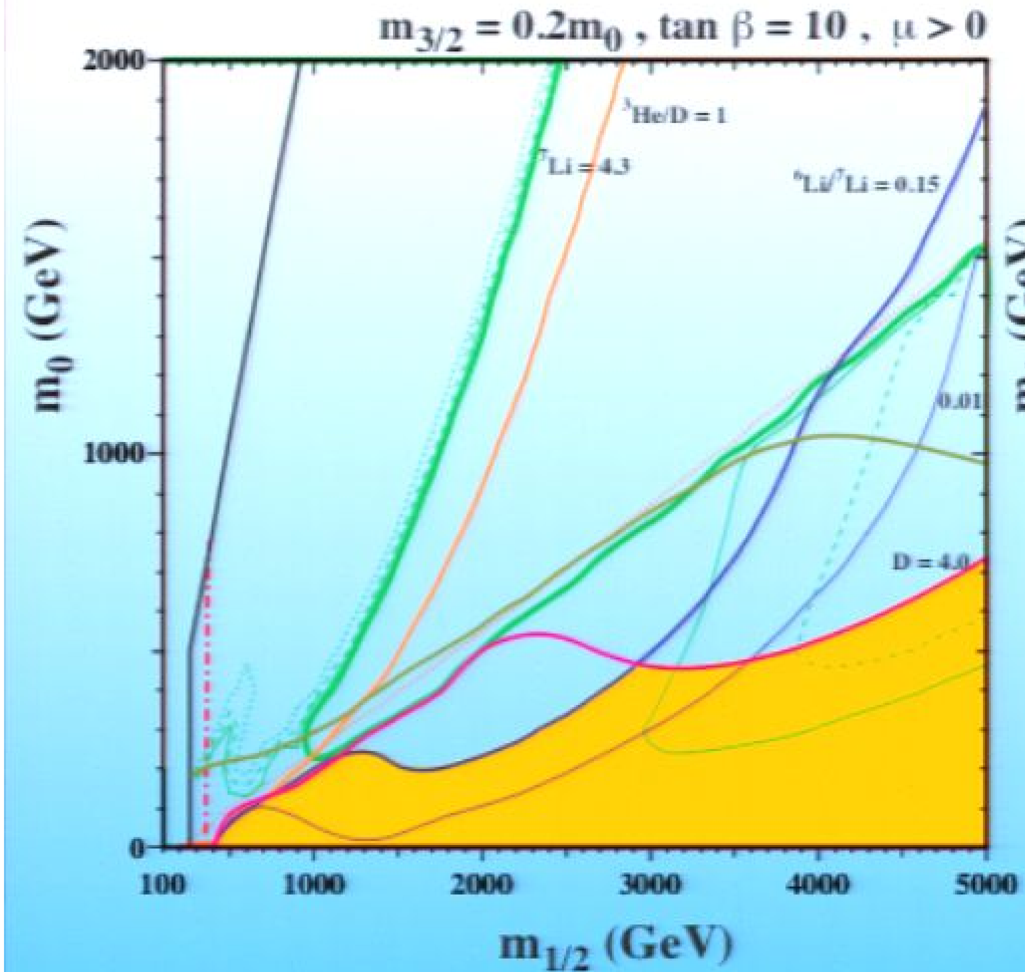


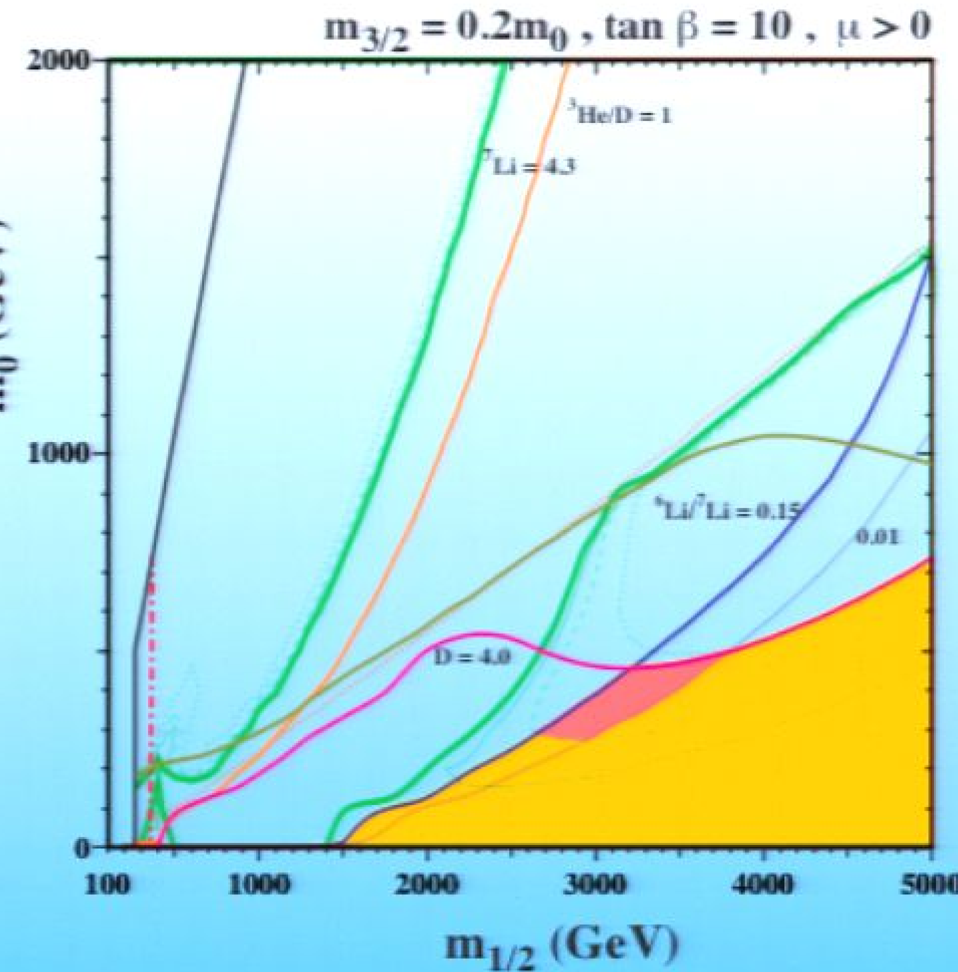


Cyburt, Ellis, Fields, KO, Span

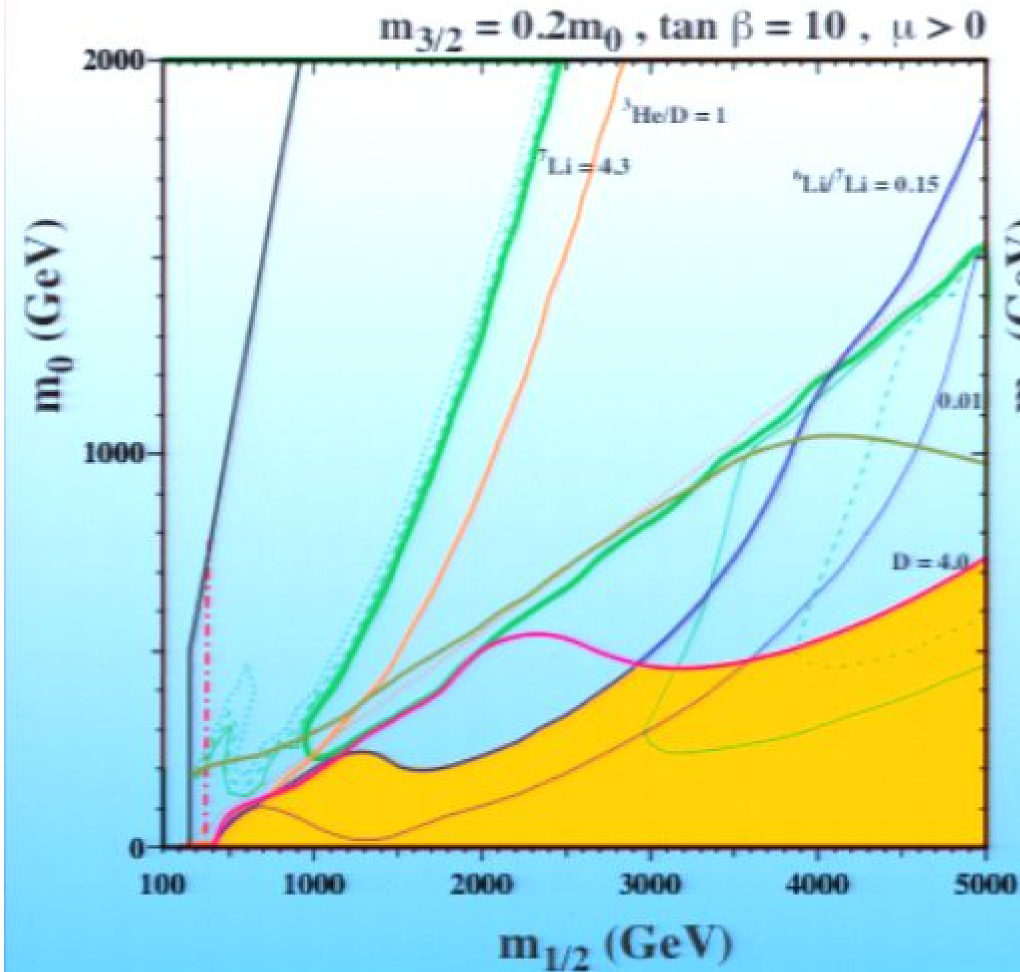


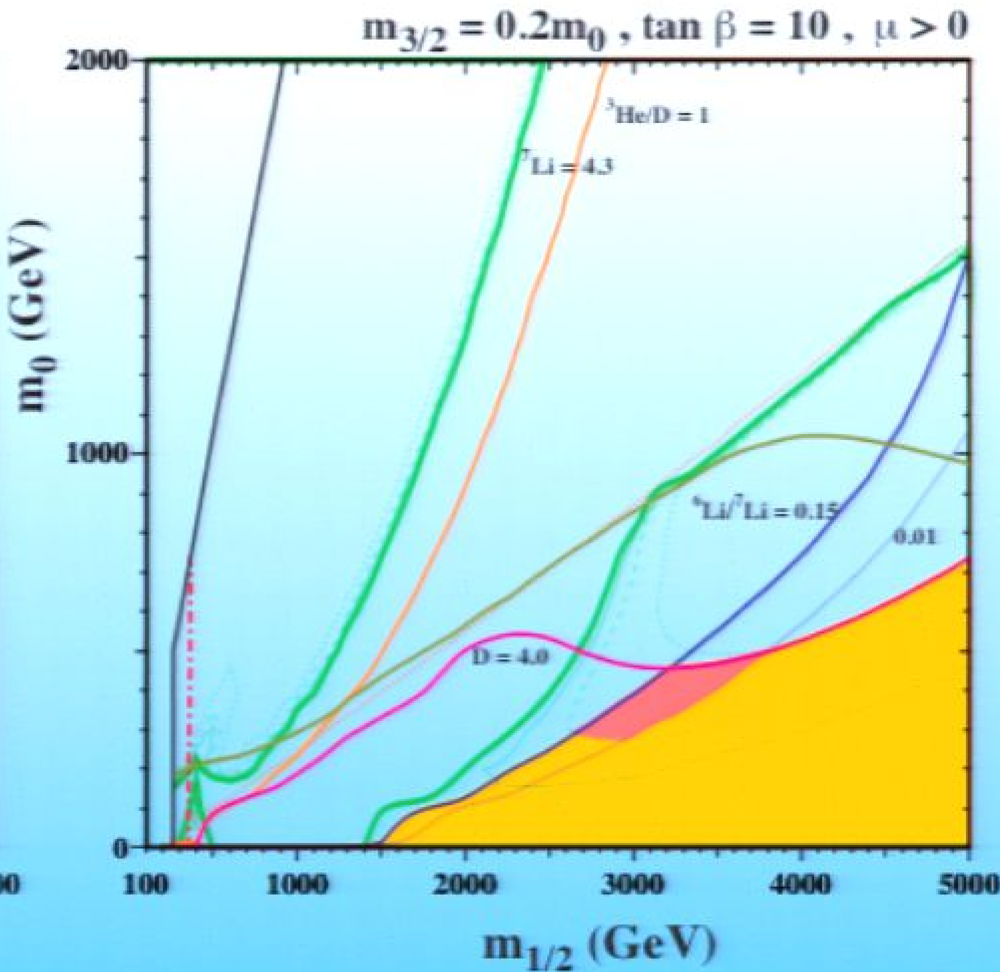
Cyburt, Ellis, Fields, KO, Spanc



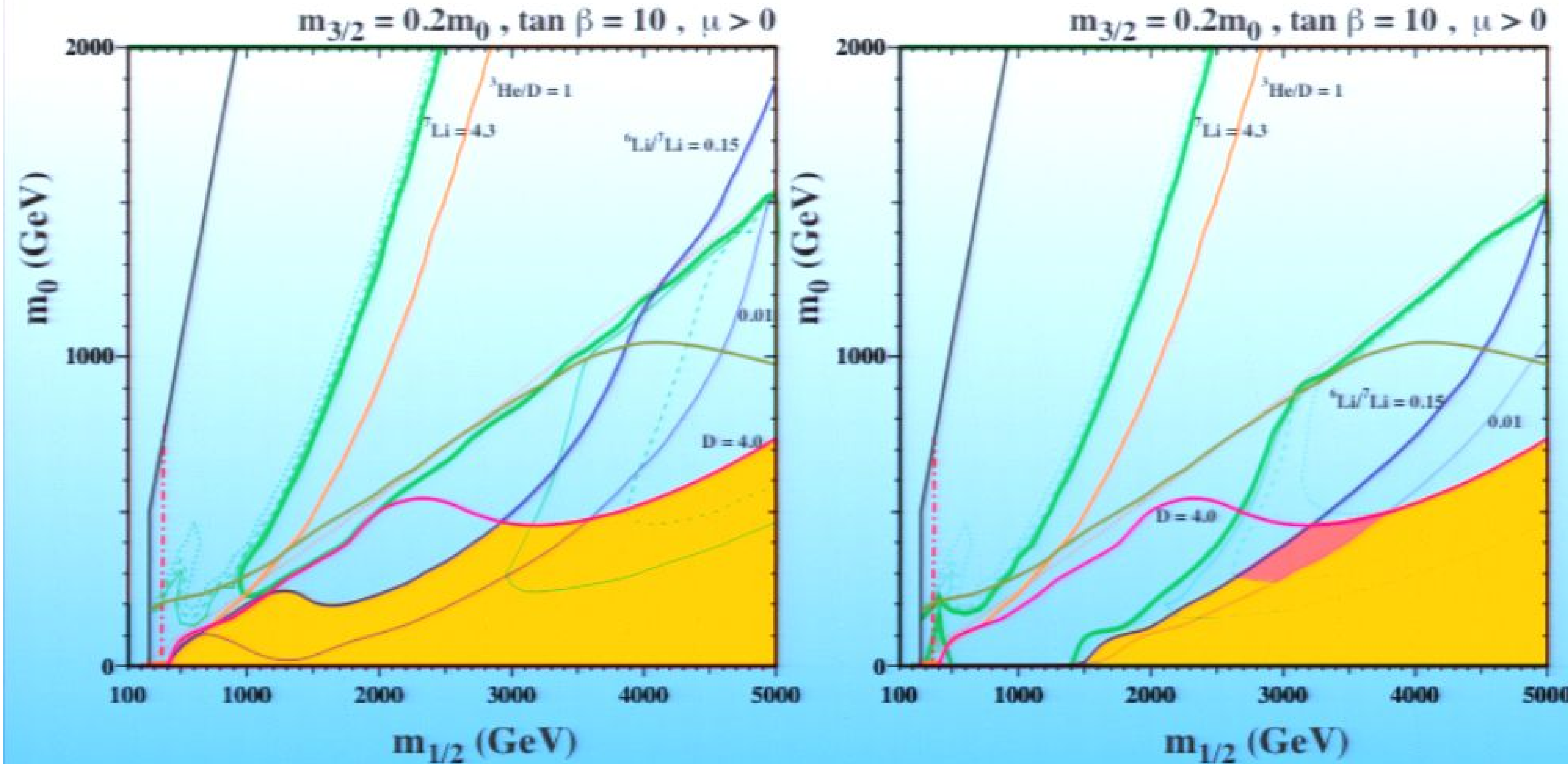


Cyburt, Ellis, Fields, KO, Spanc

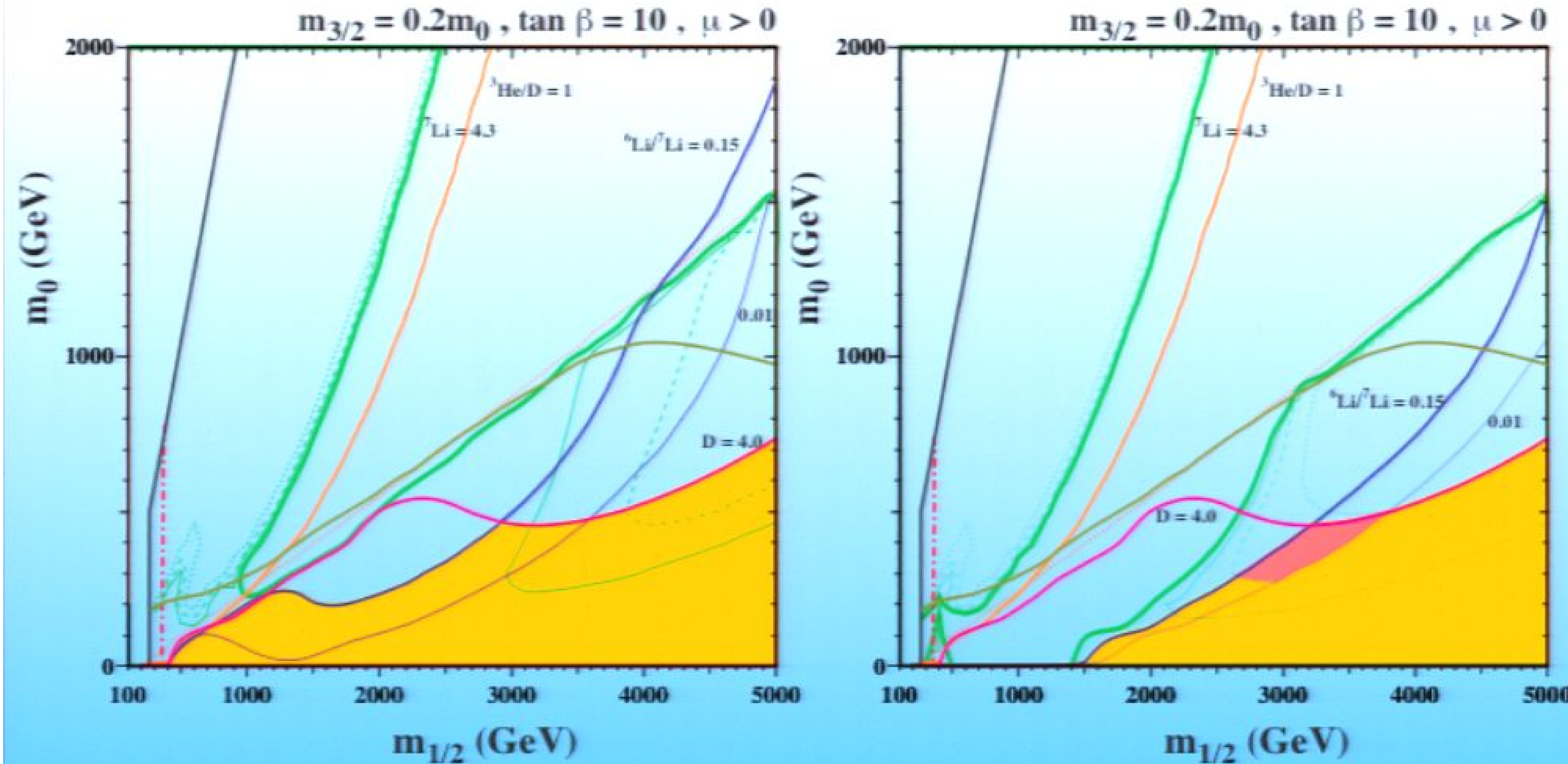




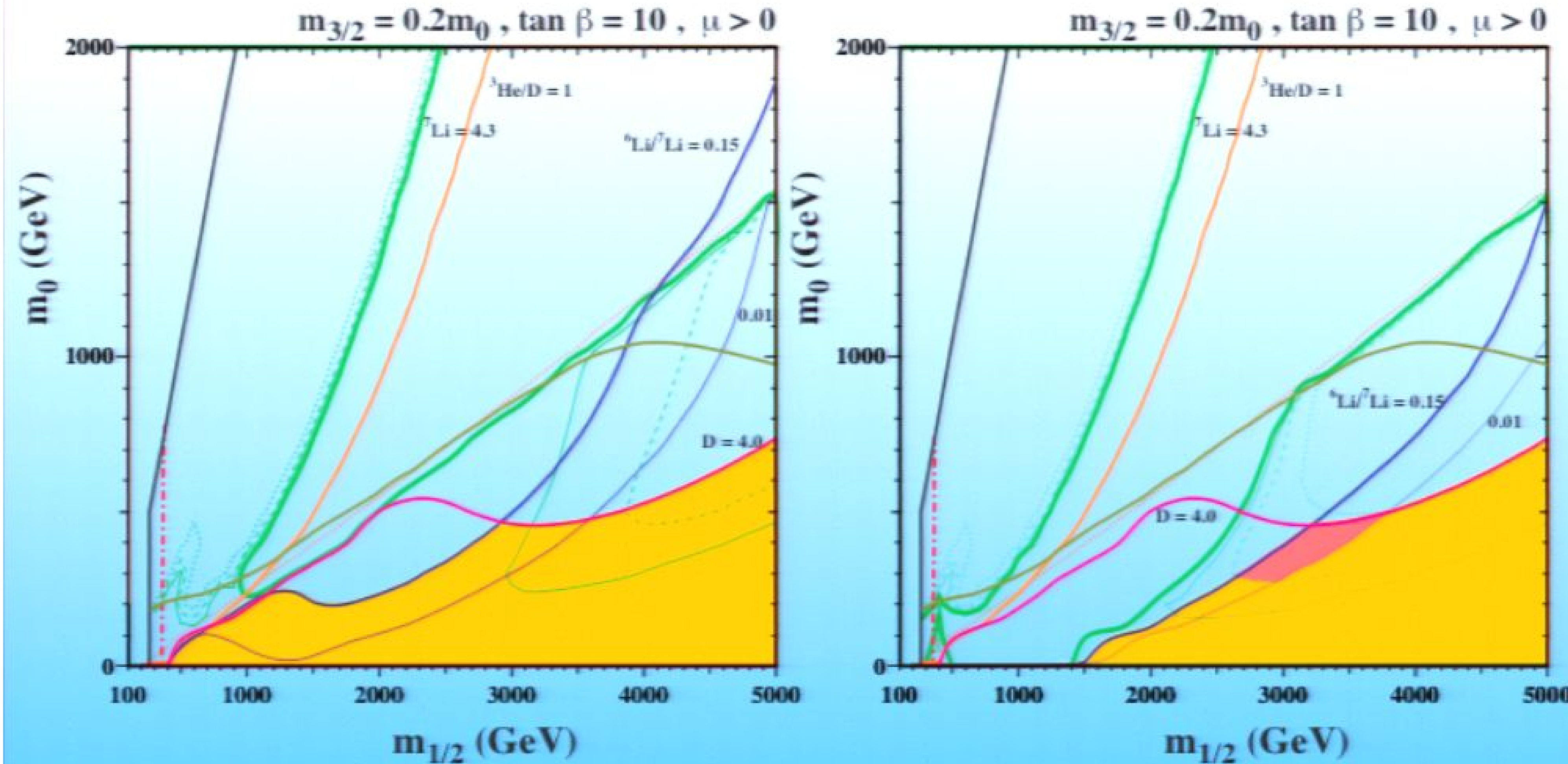
Cybort, Ellis, Fields, KO, Spanc



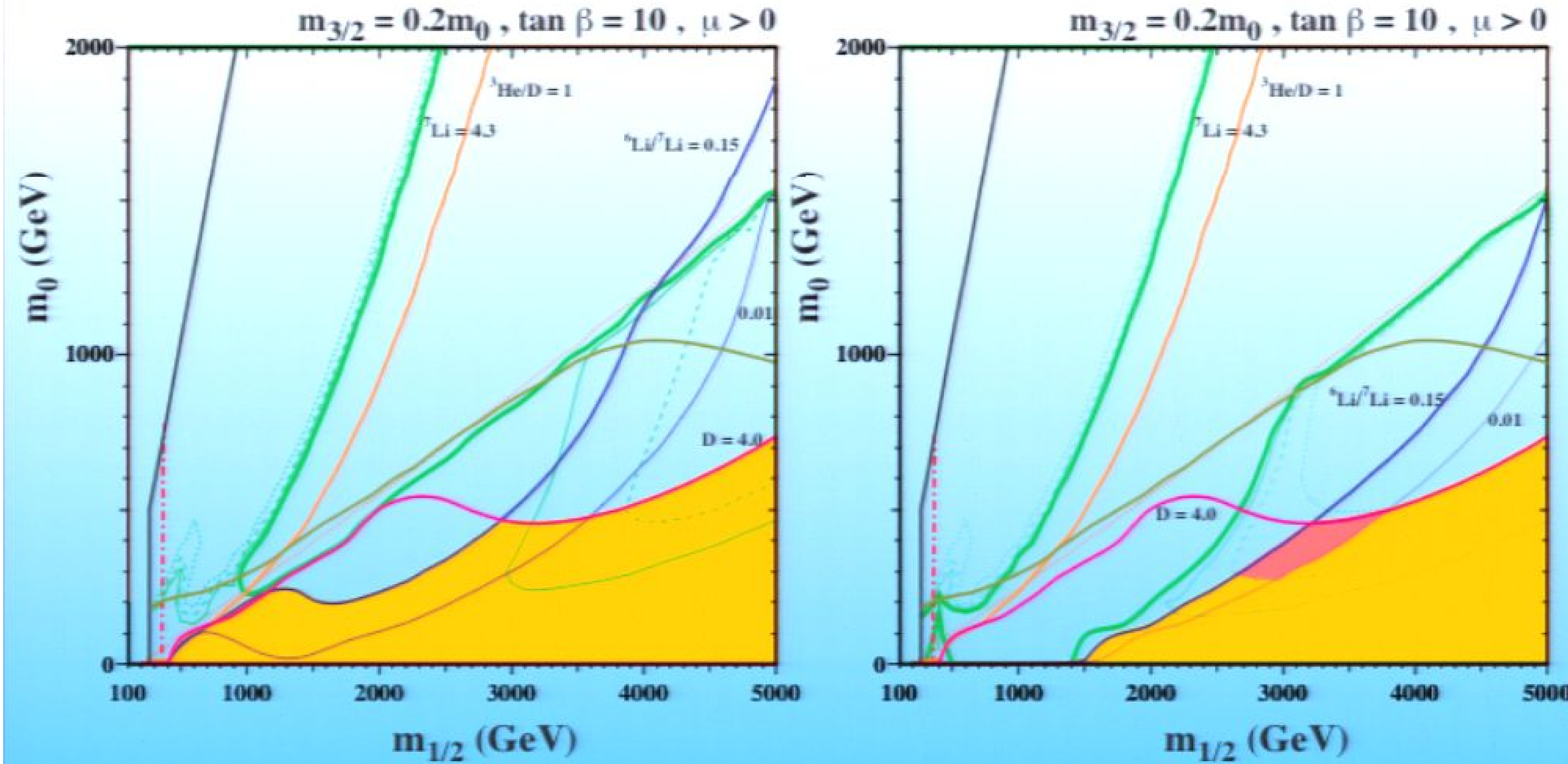
Cyburt, Ellis, Fields, KO, Spanc



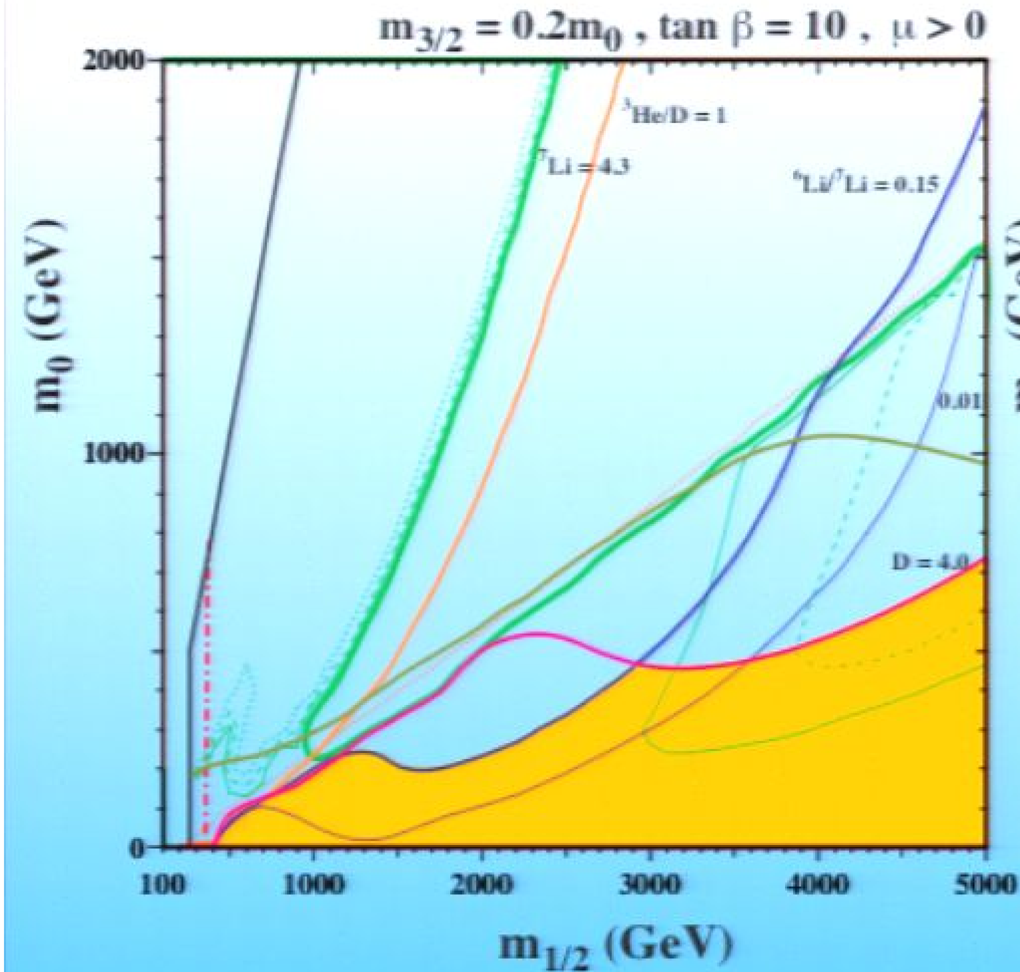
Cyburt, Ellis, Fields, KO, Spano

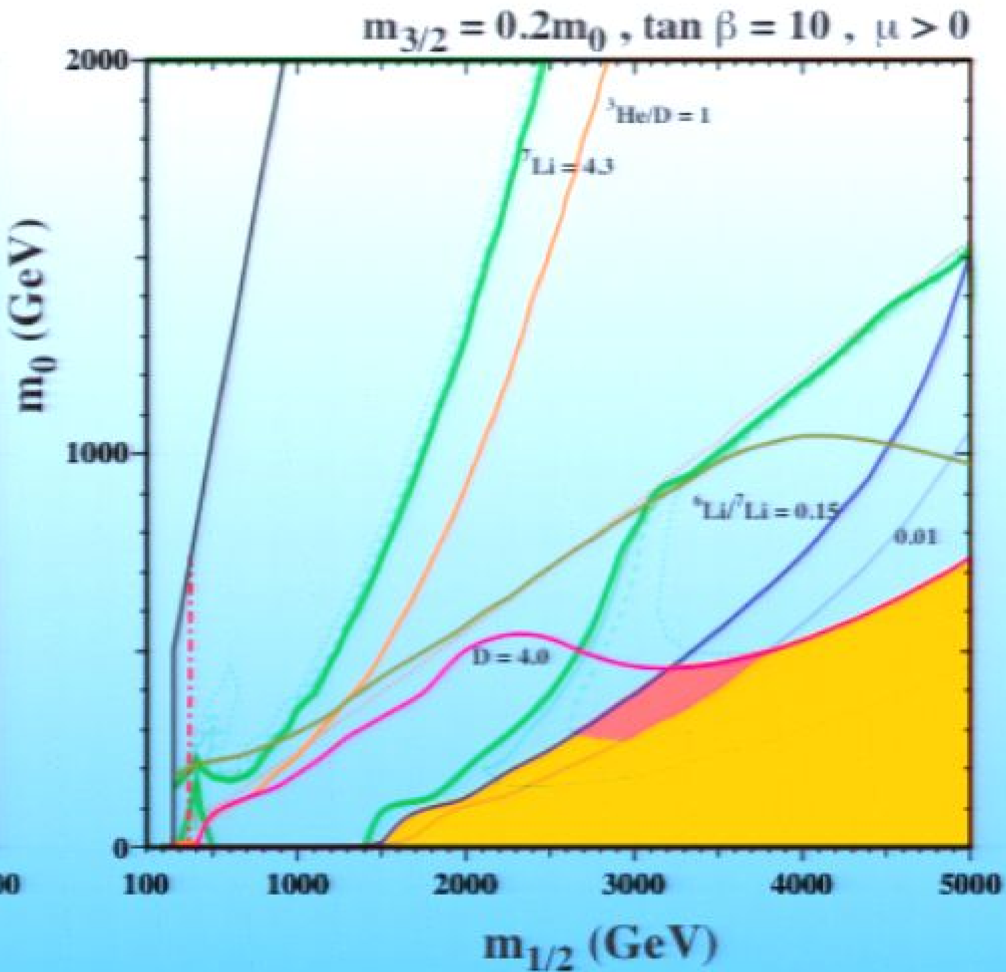


Cyburt, Ellis, Fields, KO, Spanos

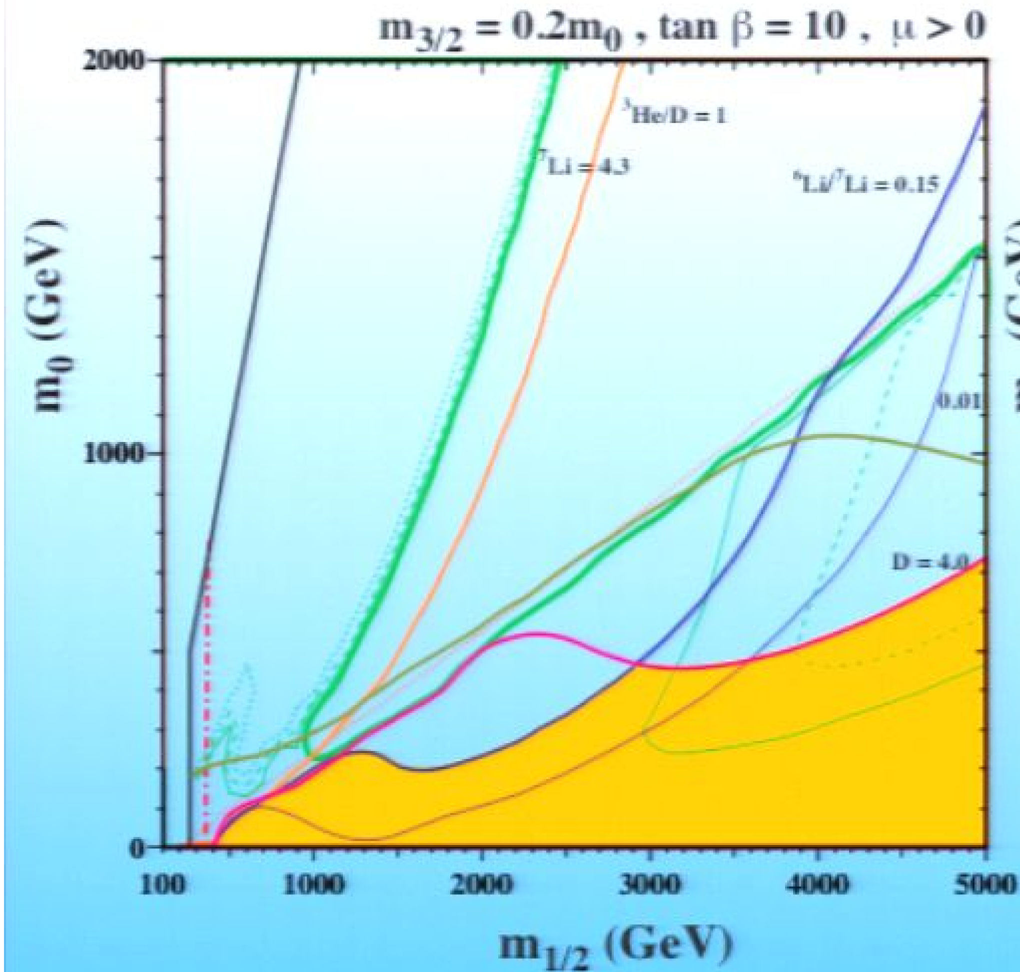


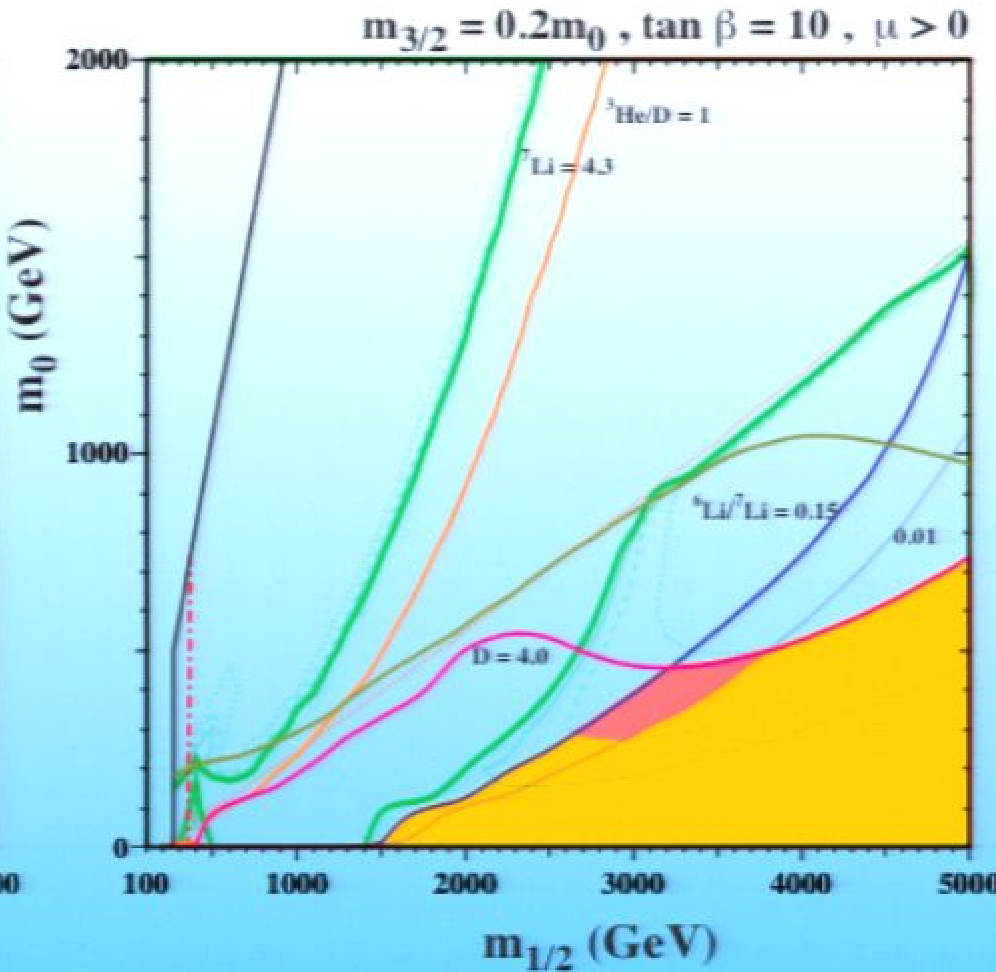
Cybурt, Ellis, Fields, KO, Spanc



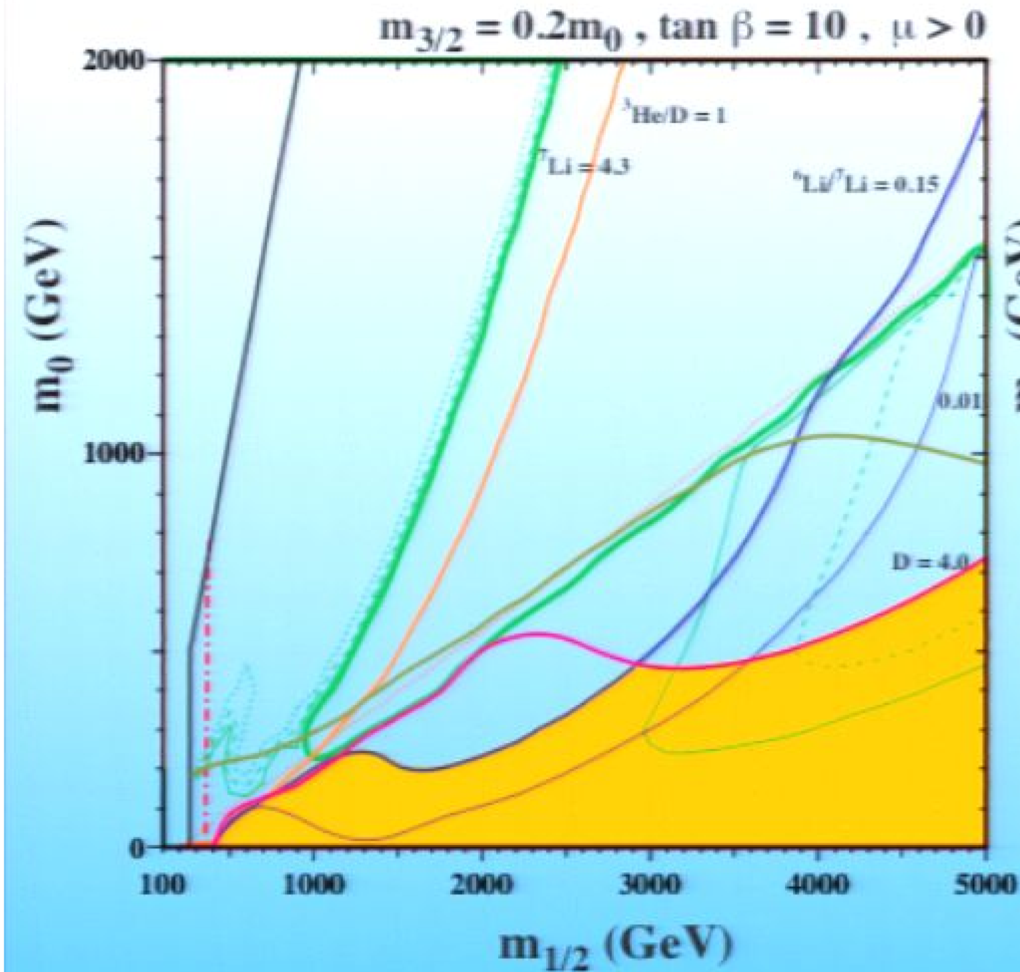


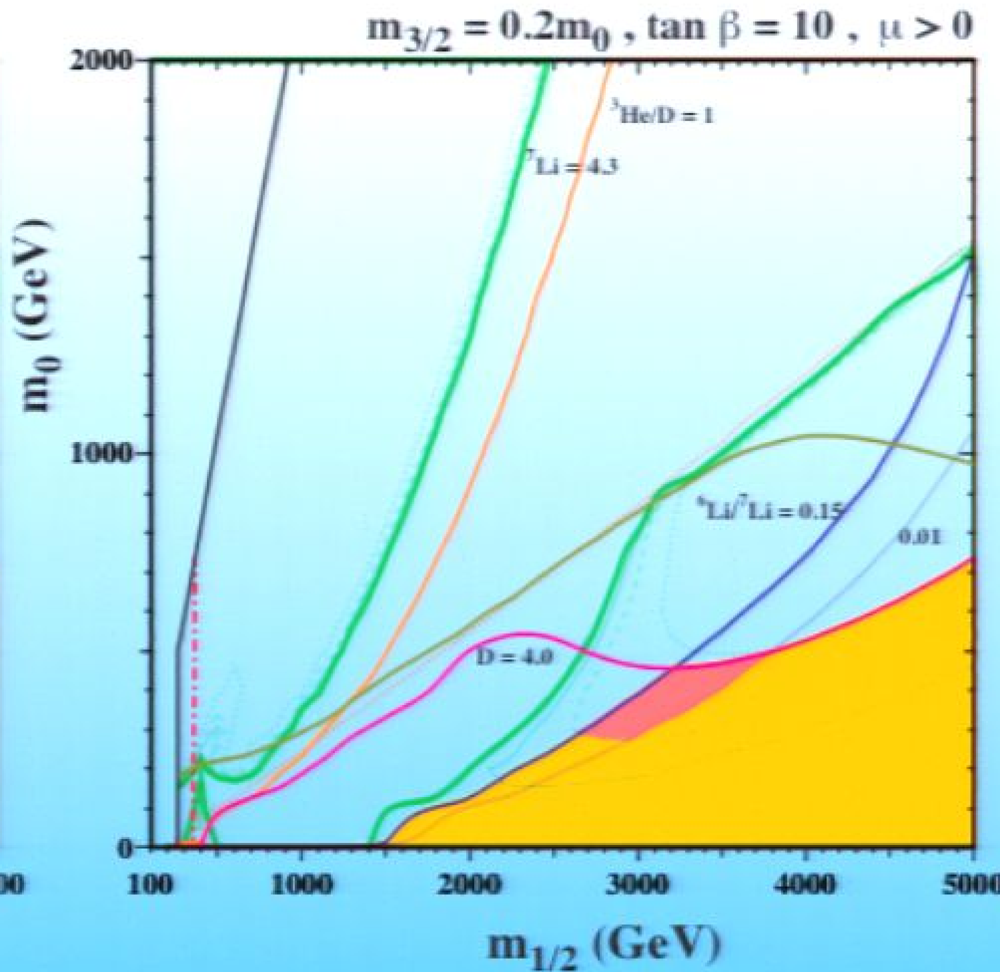
Cyburt, Ellis, Fields, KO, Spano



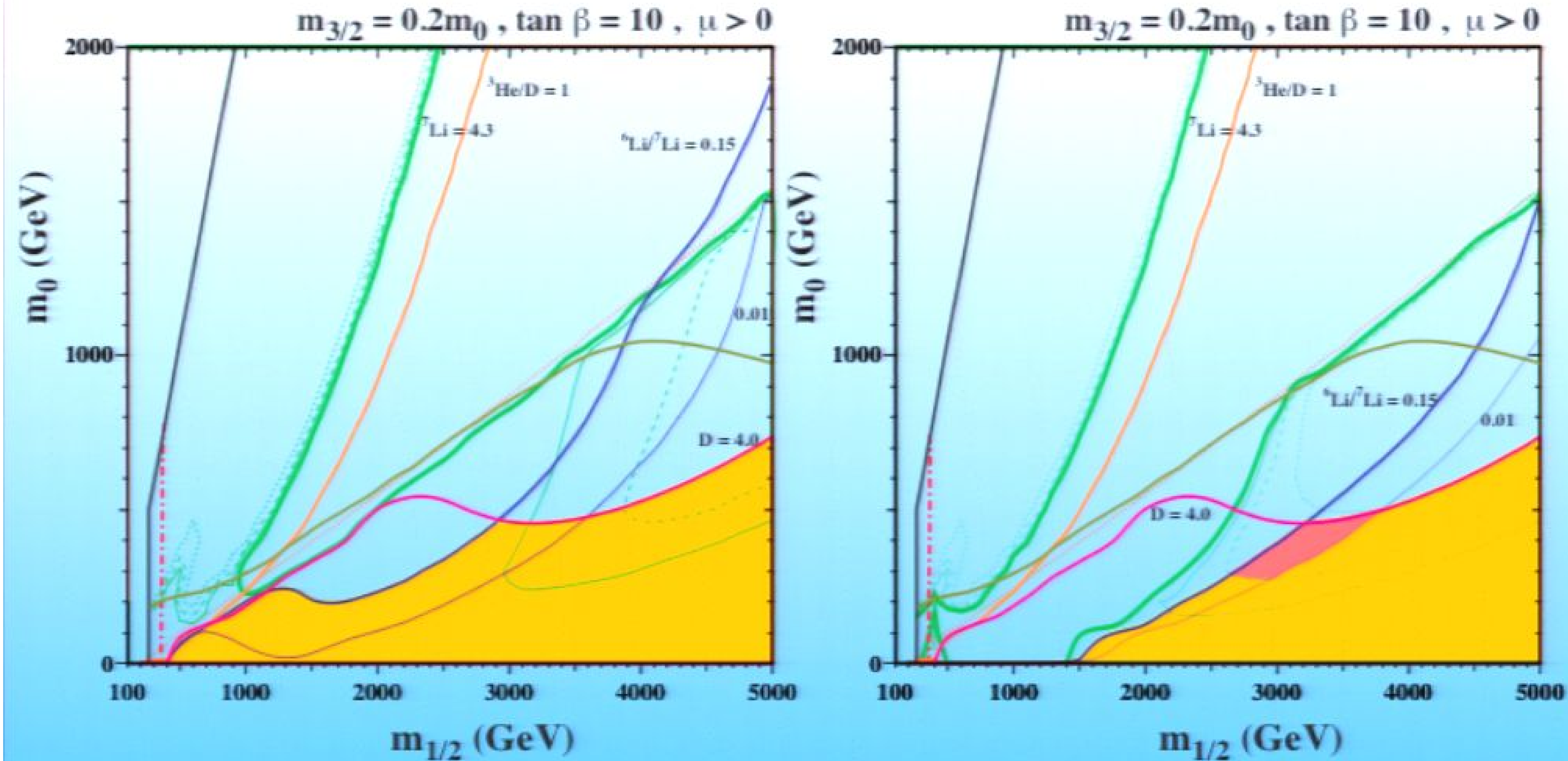


Cyburt, Ellis, Fields, KO, Spanc

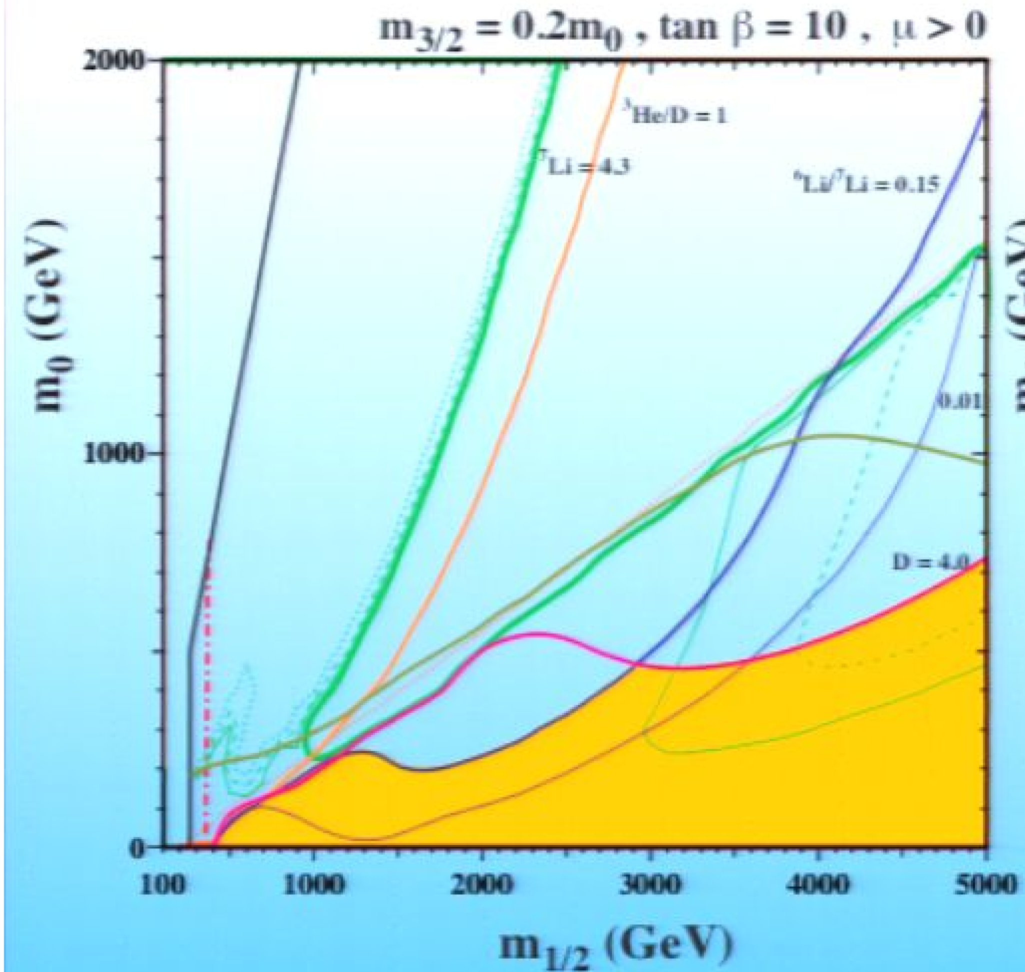


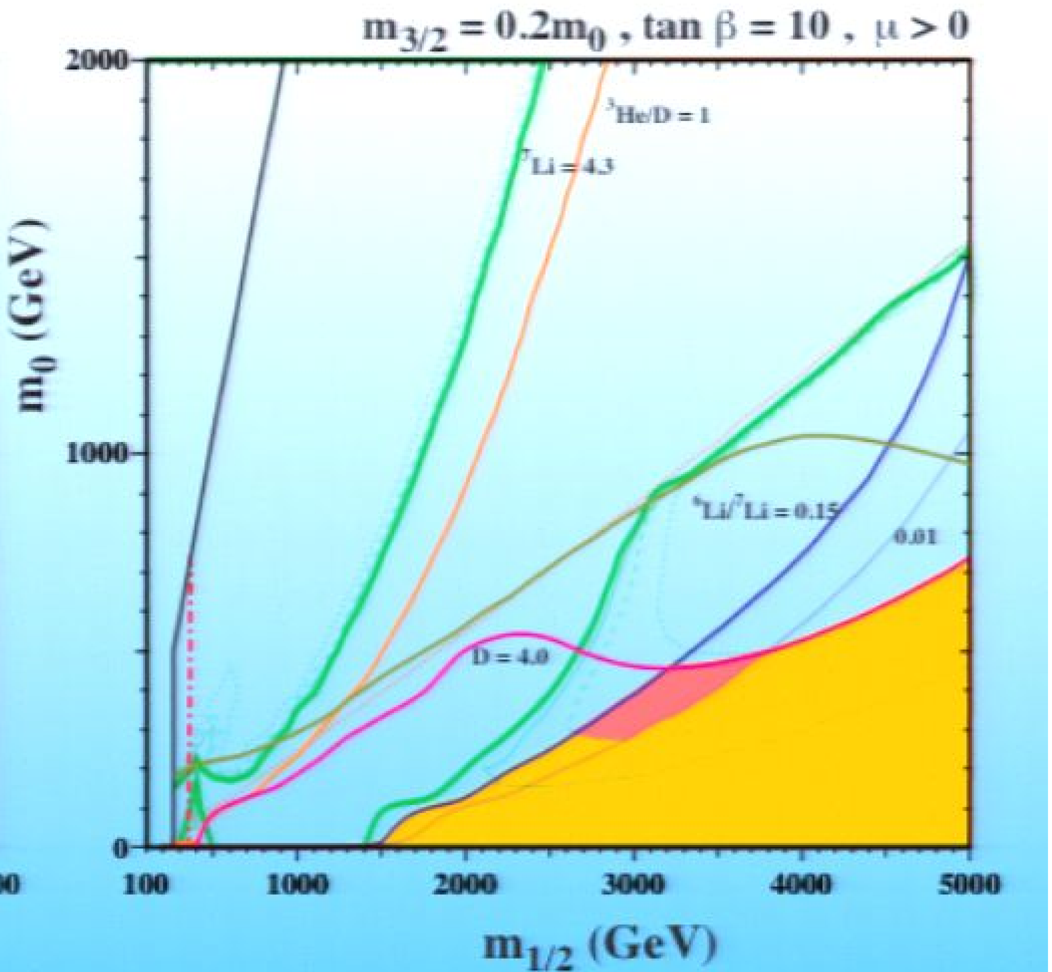


Cybfurt, Ellis, Fields, KO, Spanc

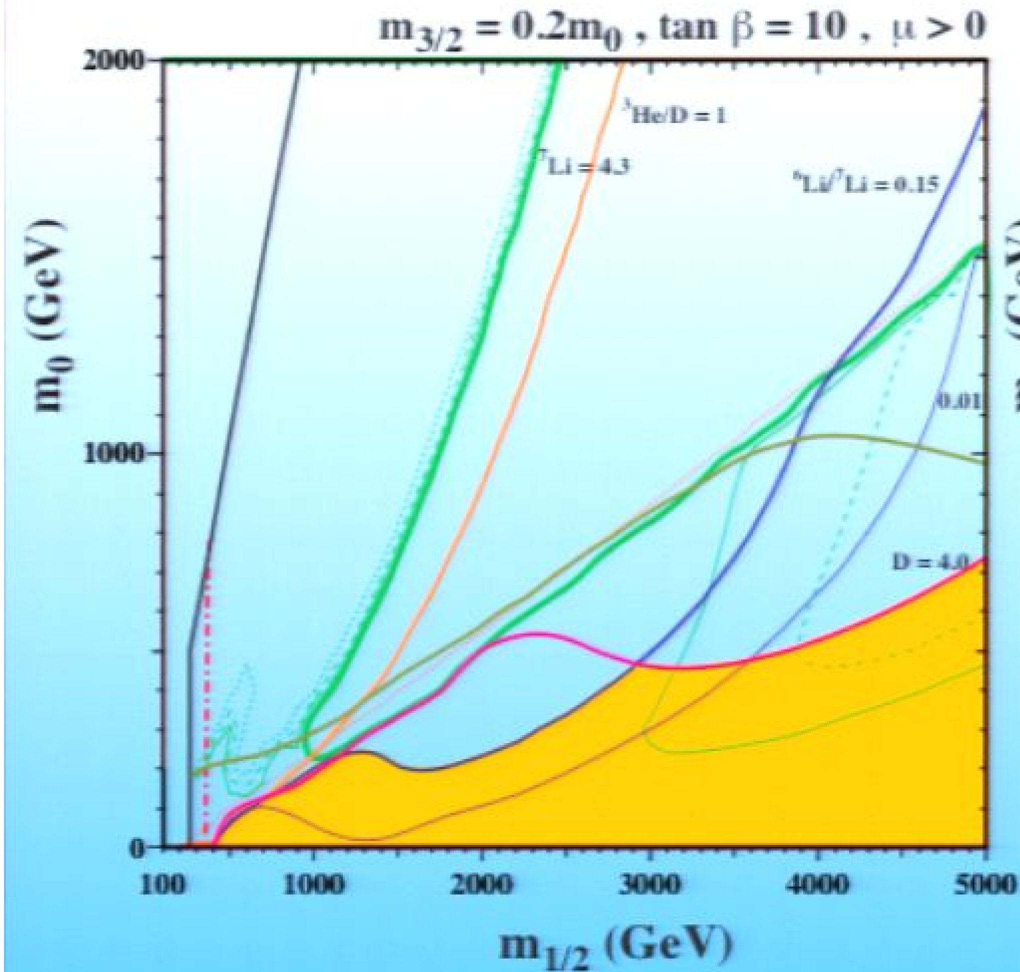


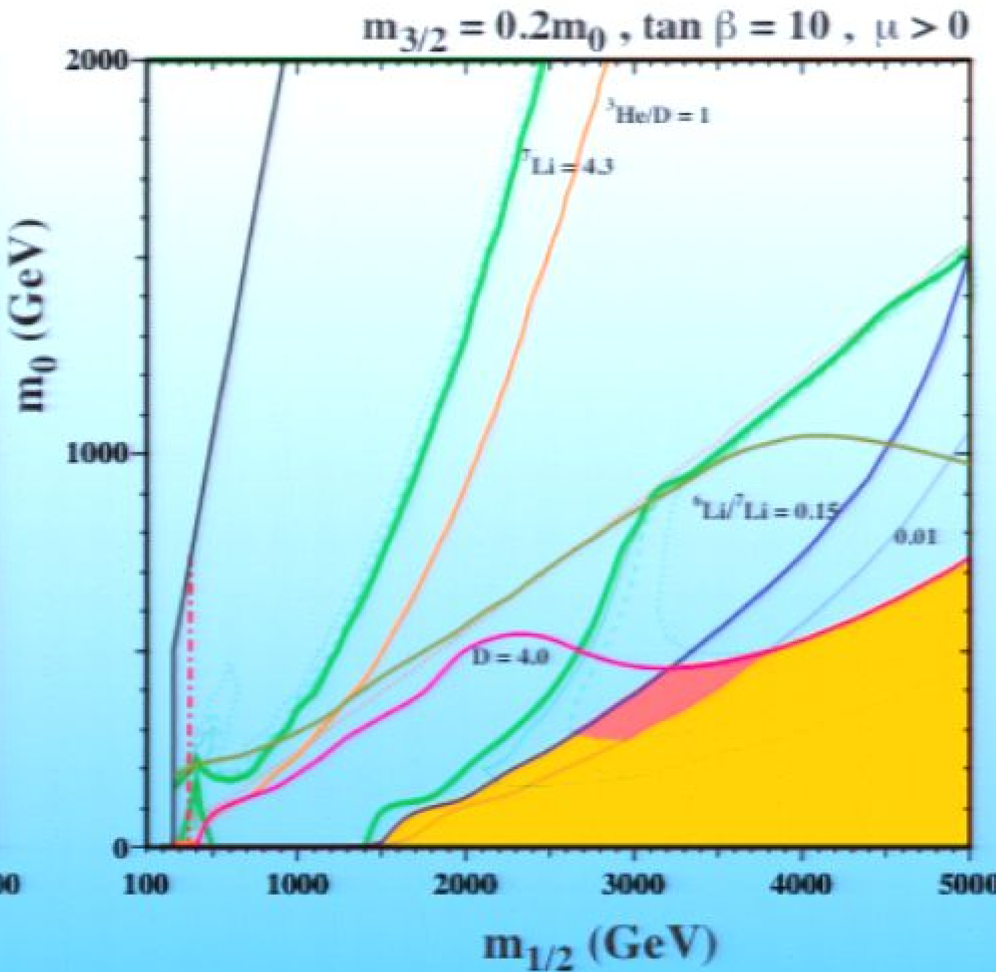
Cyburt, Ellis, Fields, KO, Spanc



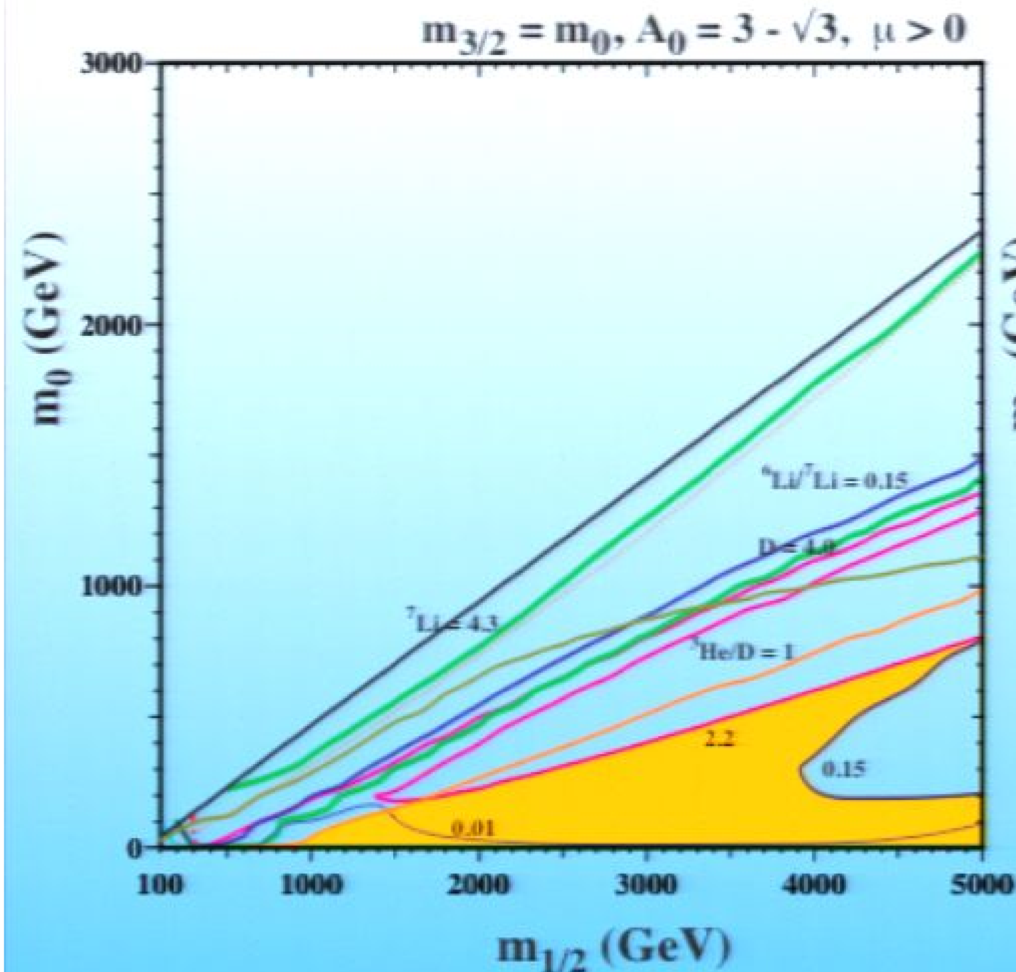


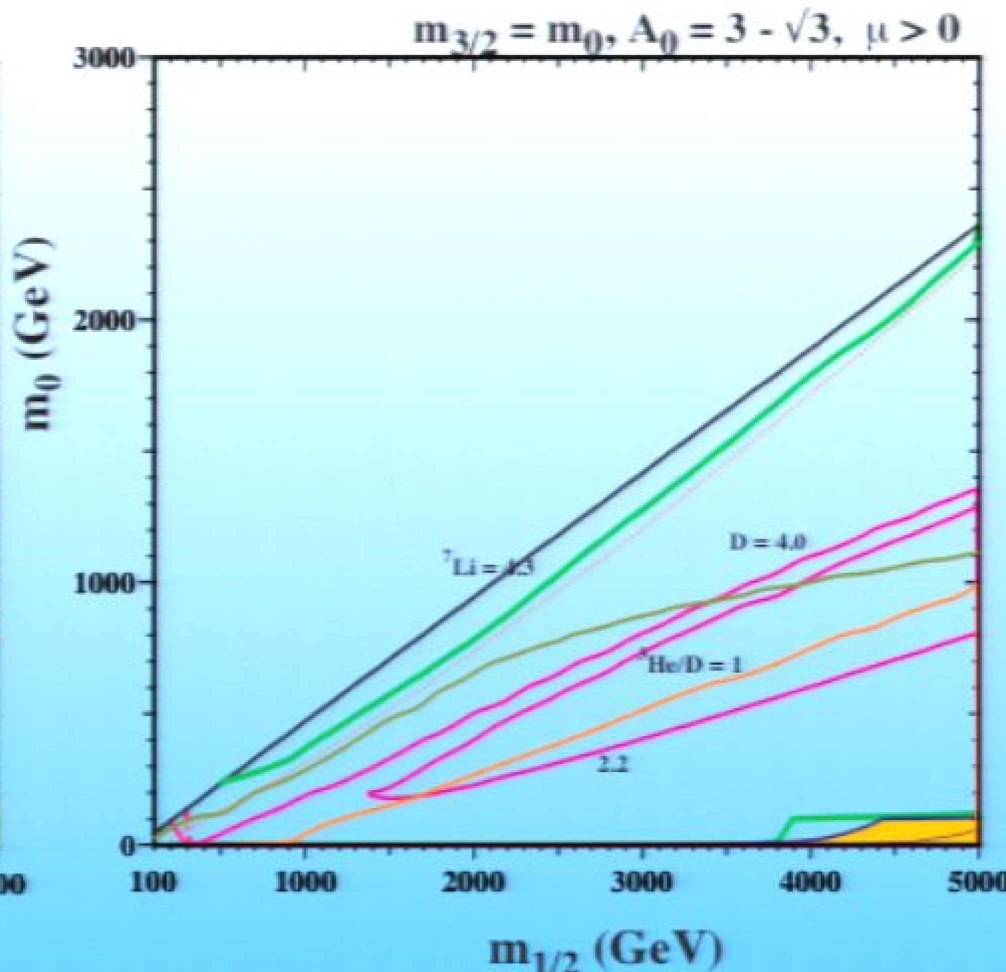
Cyburt, Ellis, Fields, KO, Spanos



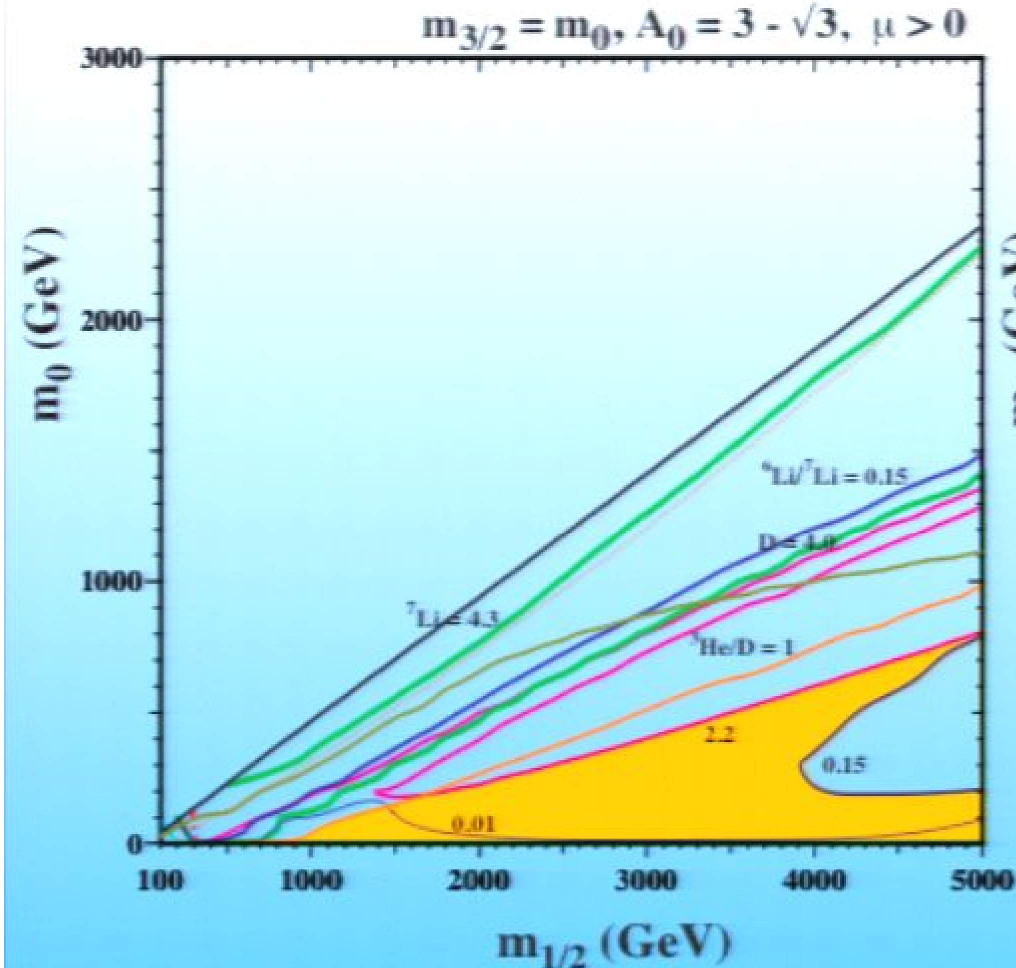


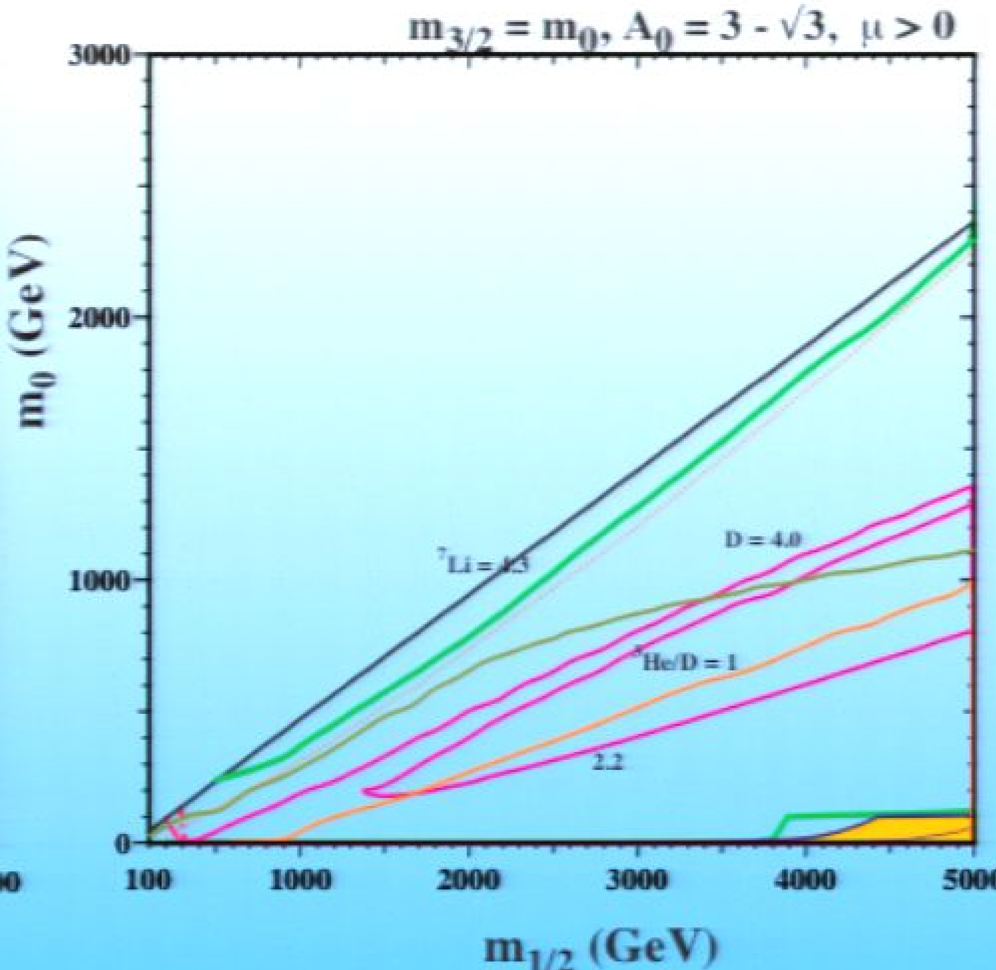
Cyburt, Ellis, Fields, KO, Spanc



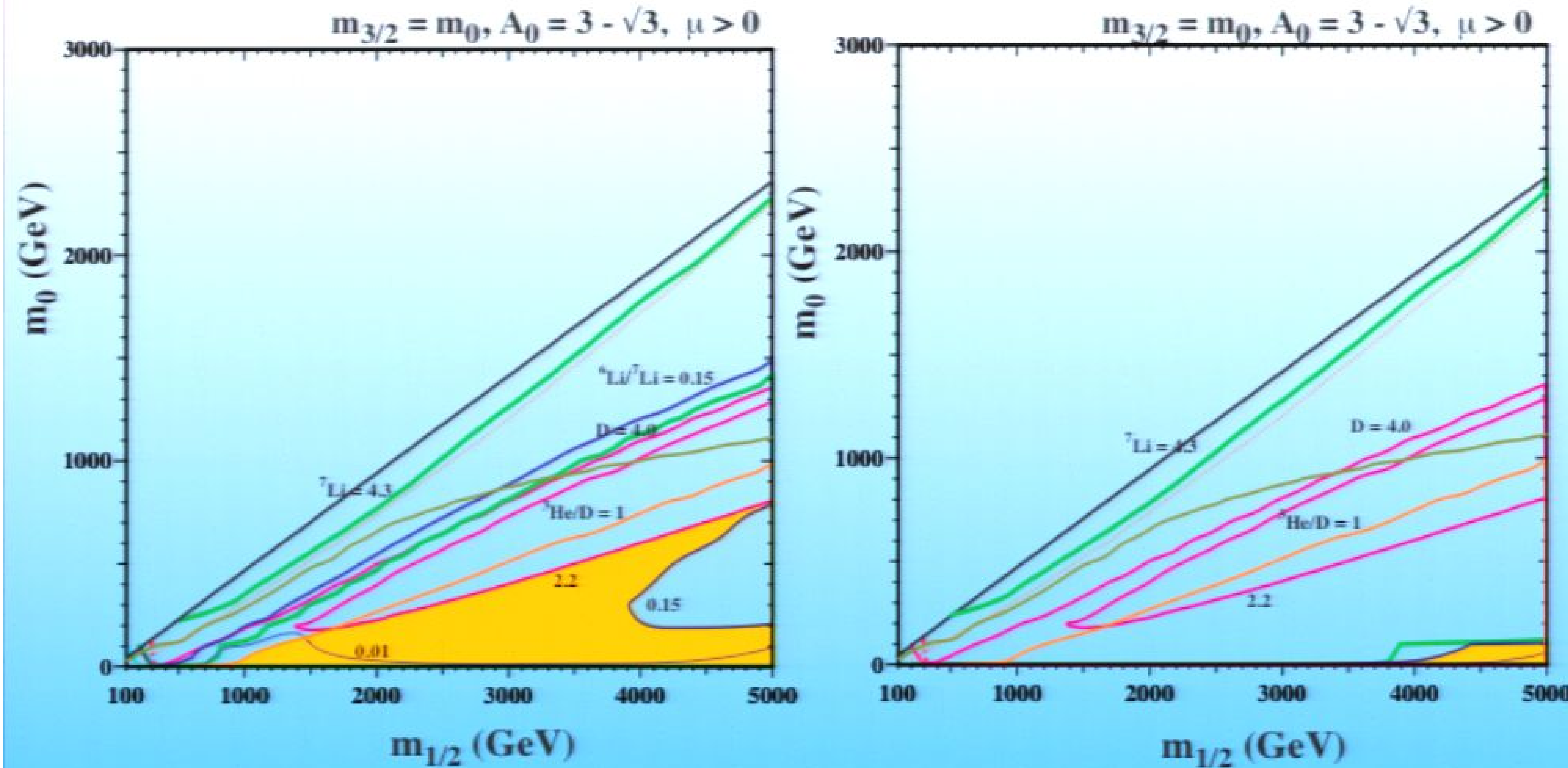


Cyburt, Ellis, Fields, KO, Spanc

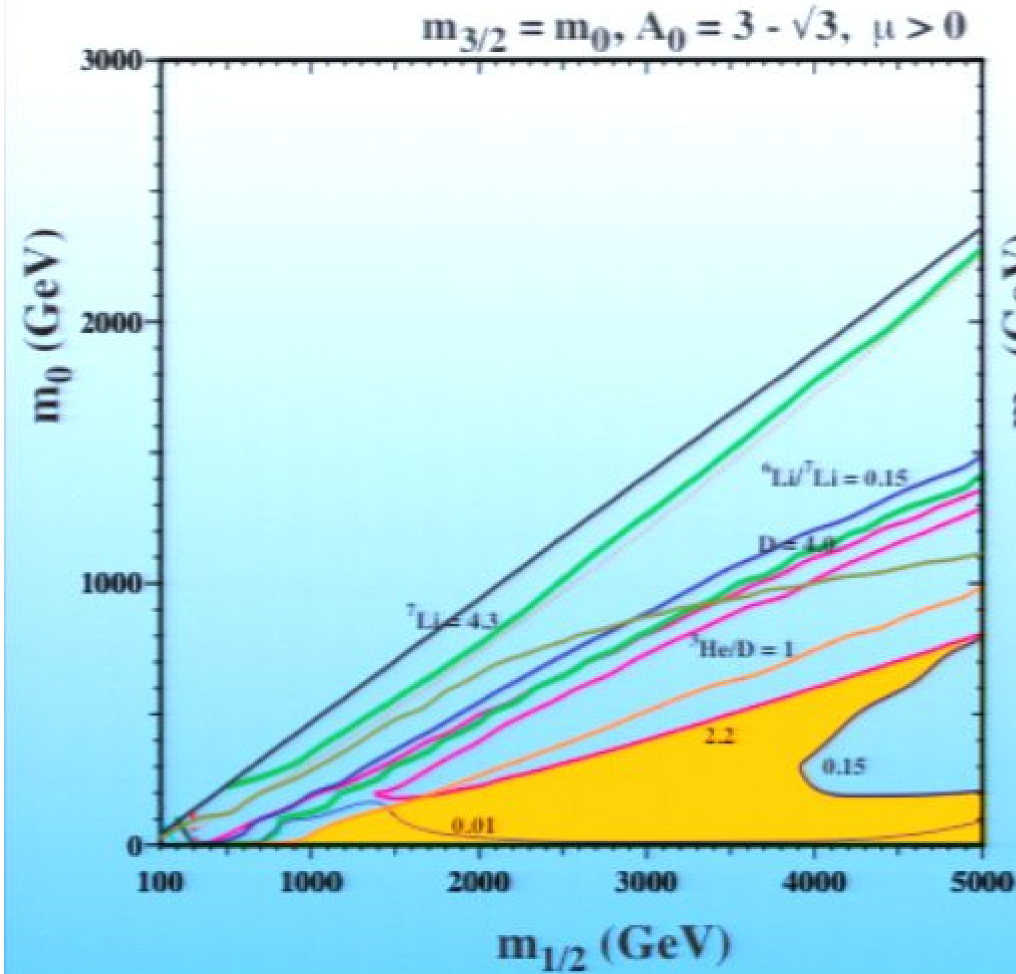


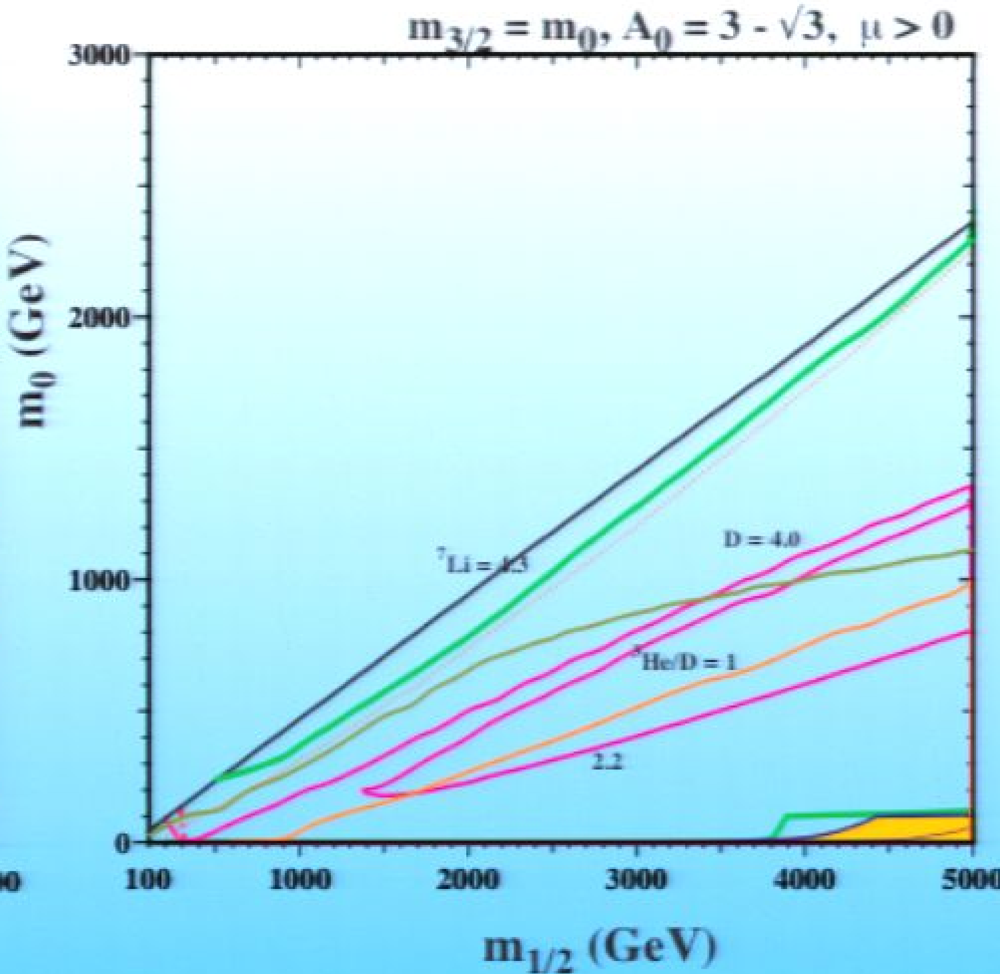


Cyburt, Ellis, Fields, KO, Spanc

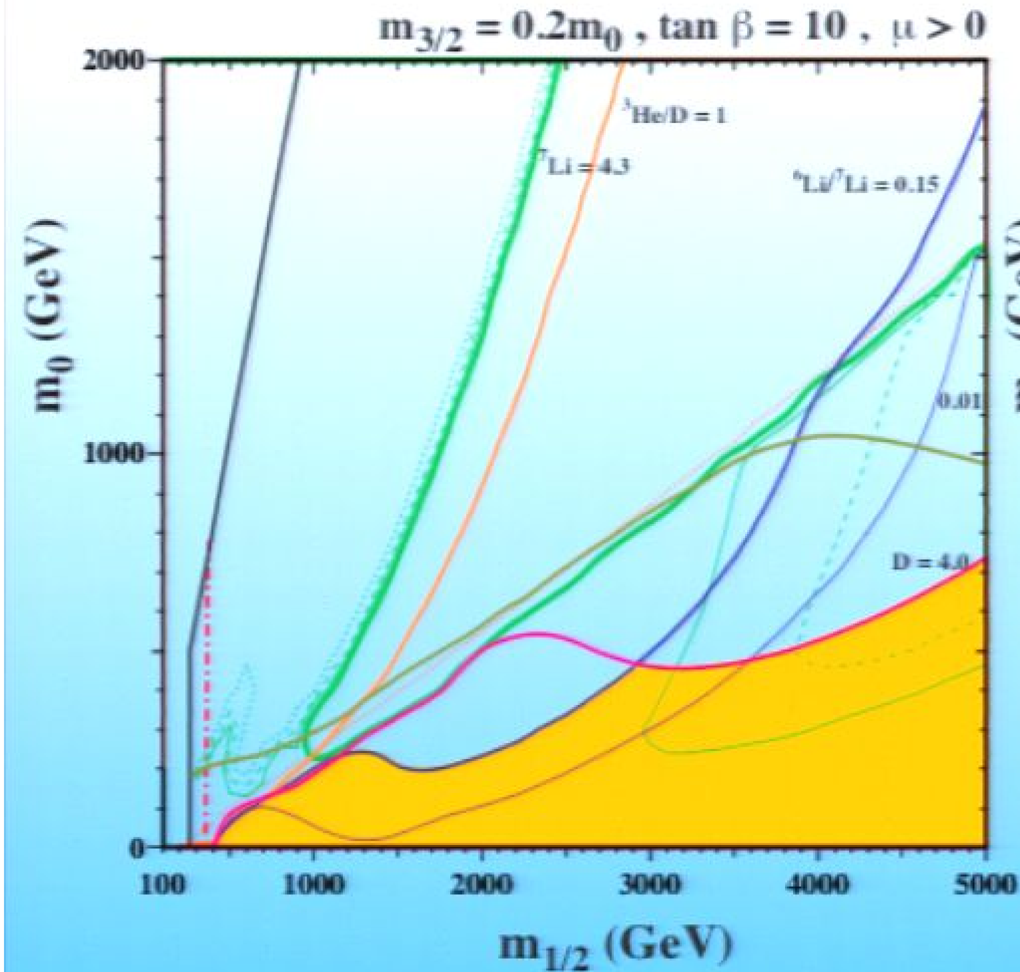


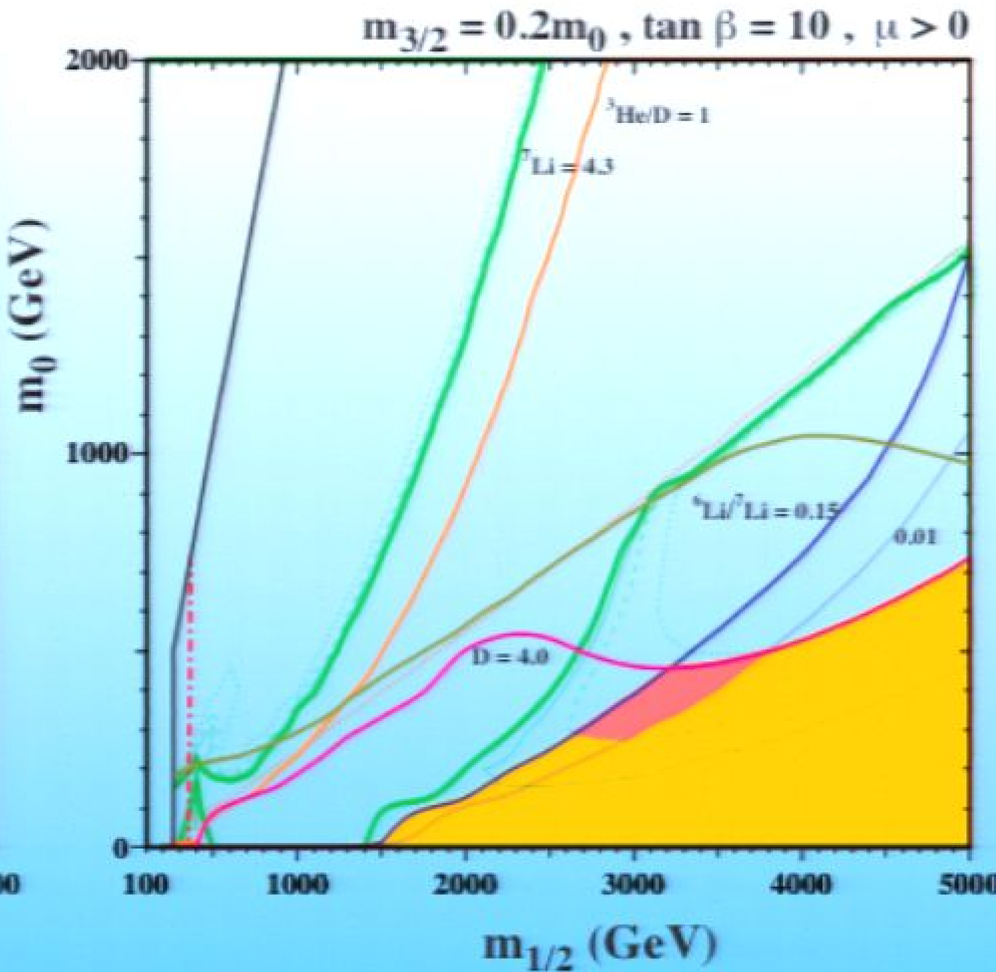
Cyburt, Ellis, Fields, KO, Spanos



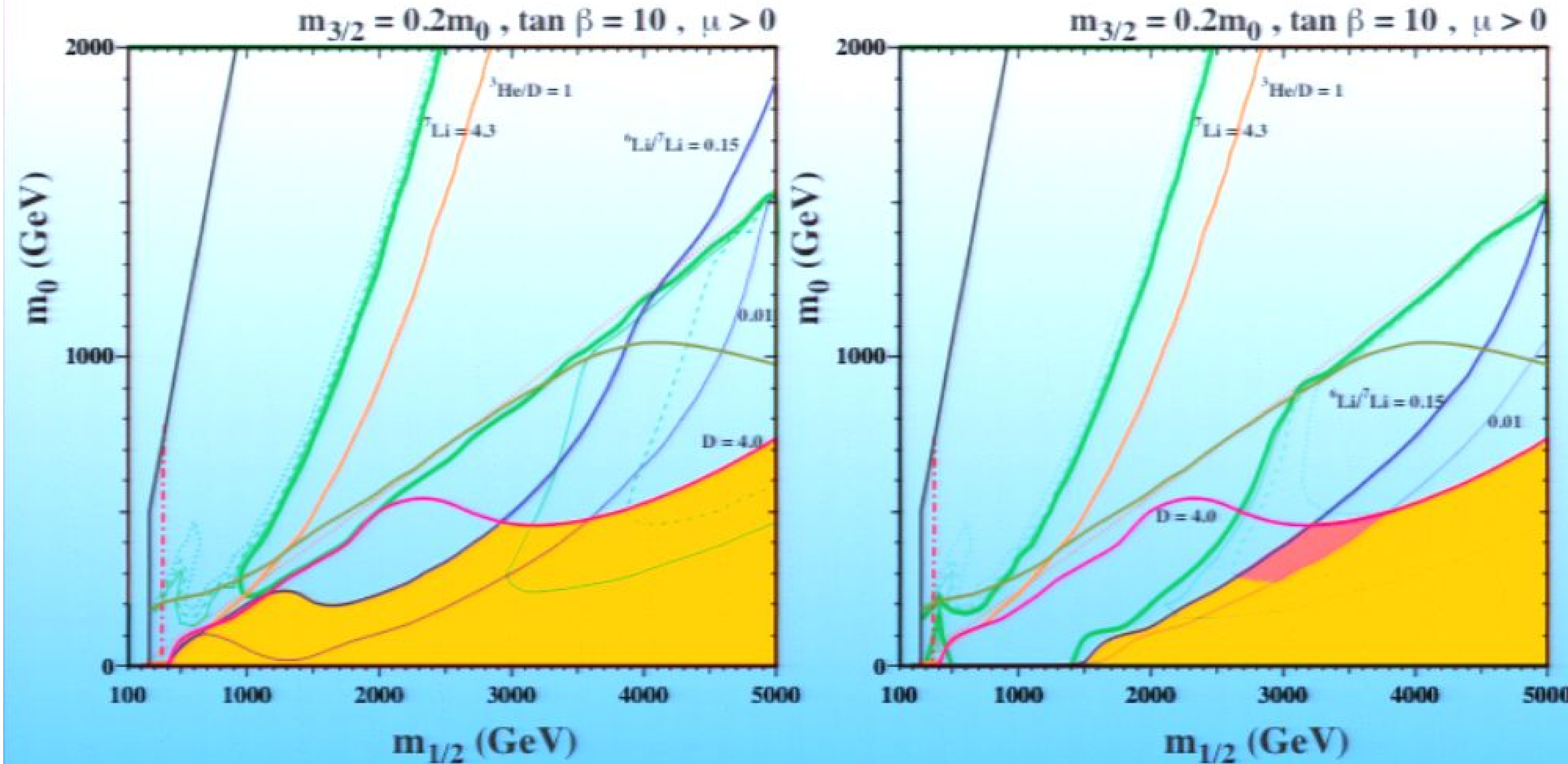


Cyburt, Ellis, Fields, KO, Spanc

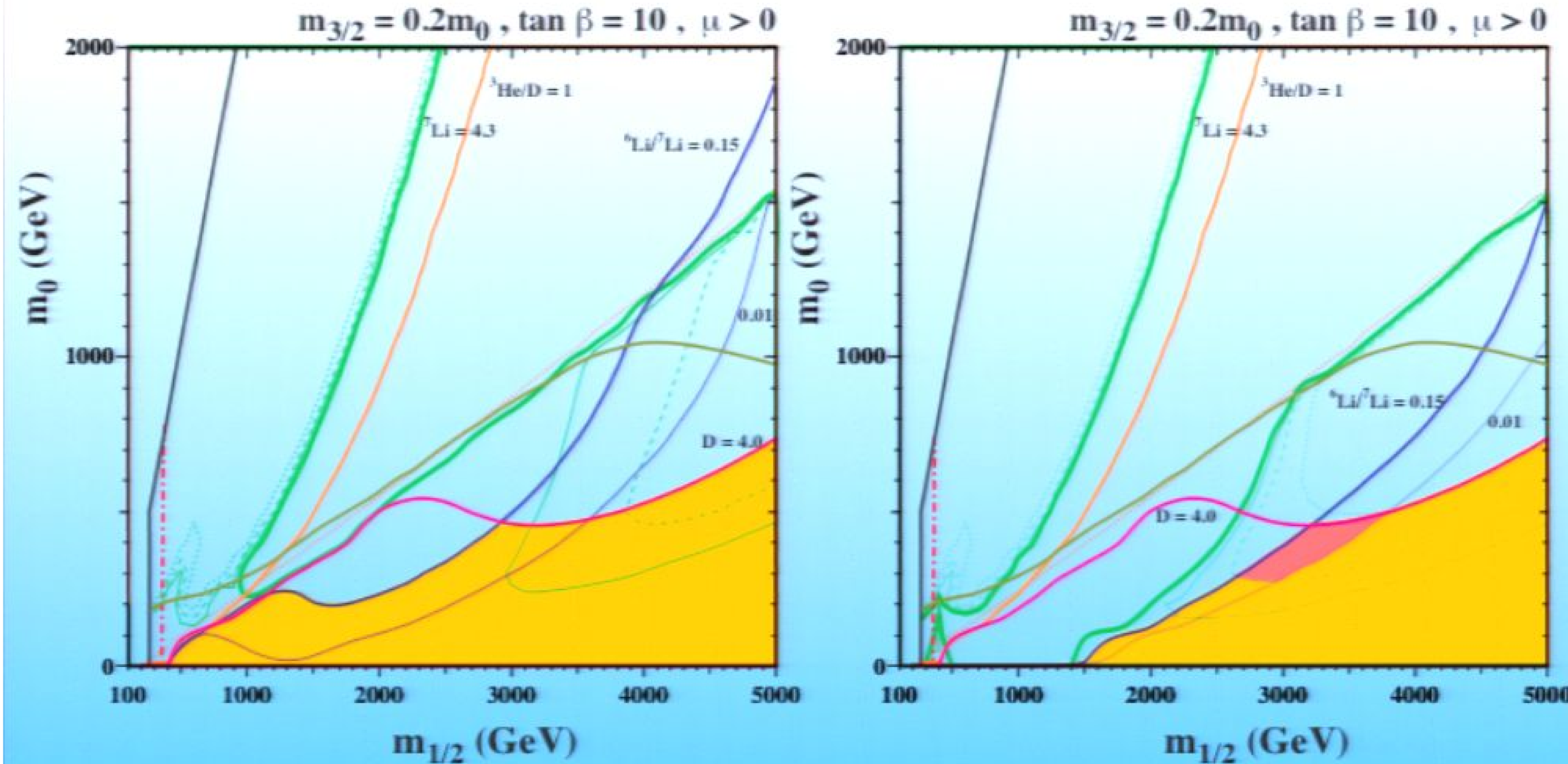




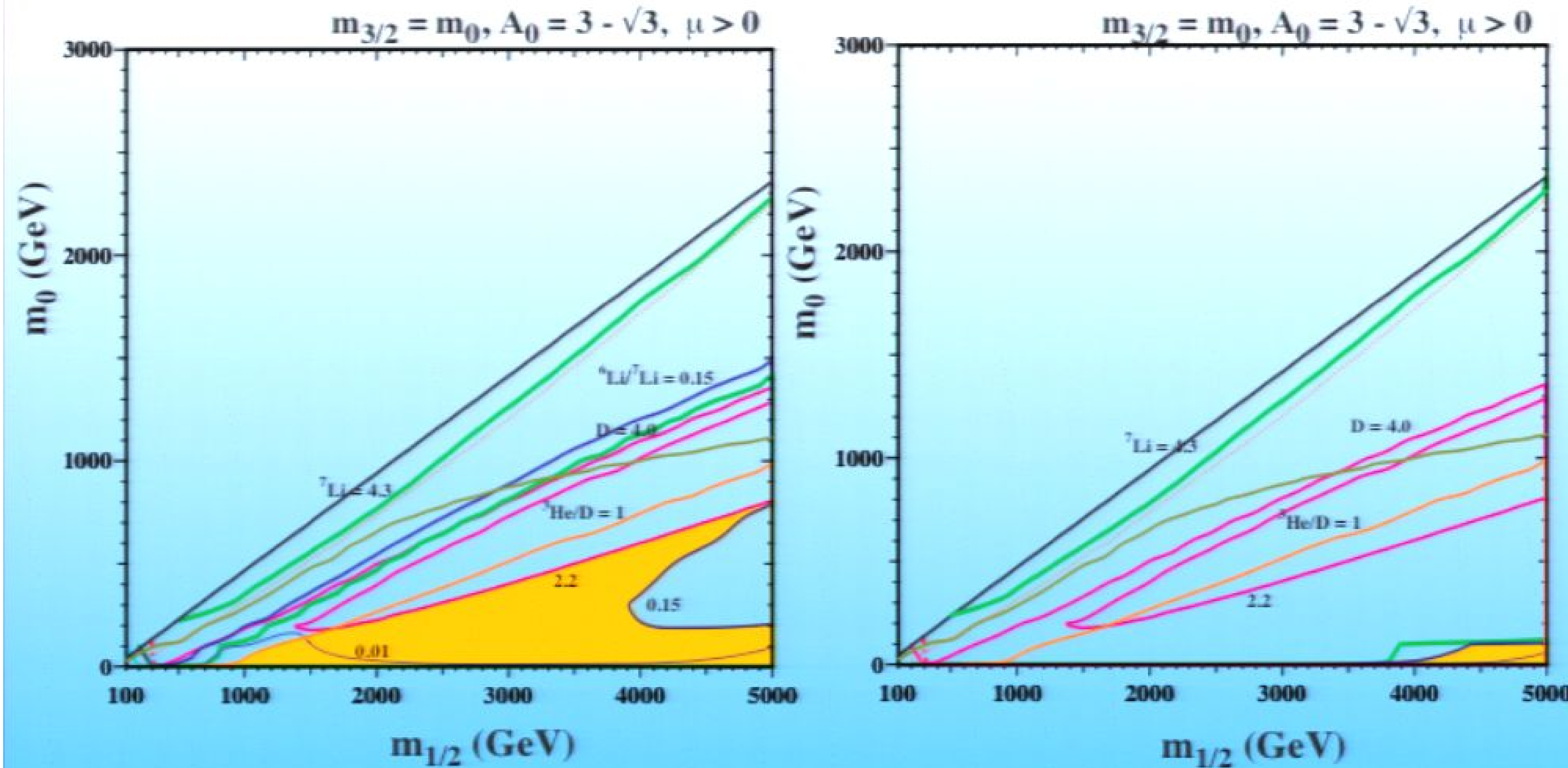
Cybcurt, Ellis, Fields, KO, Spanc



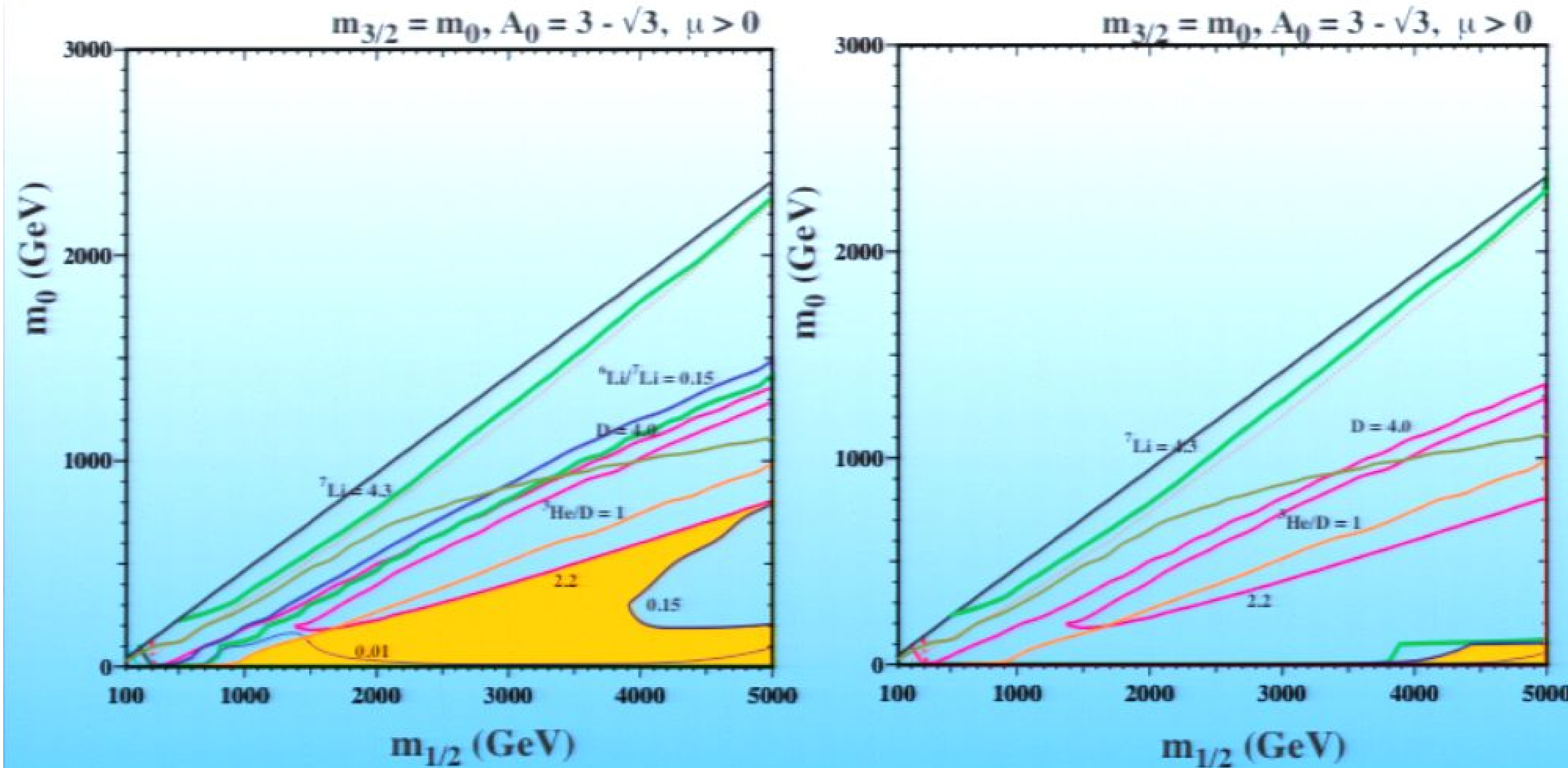
Cyburt, Ellis, Fields, KO, Spanc



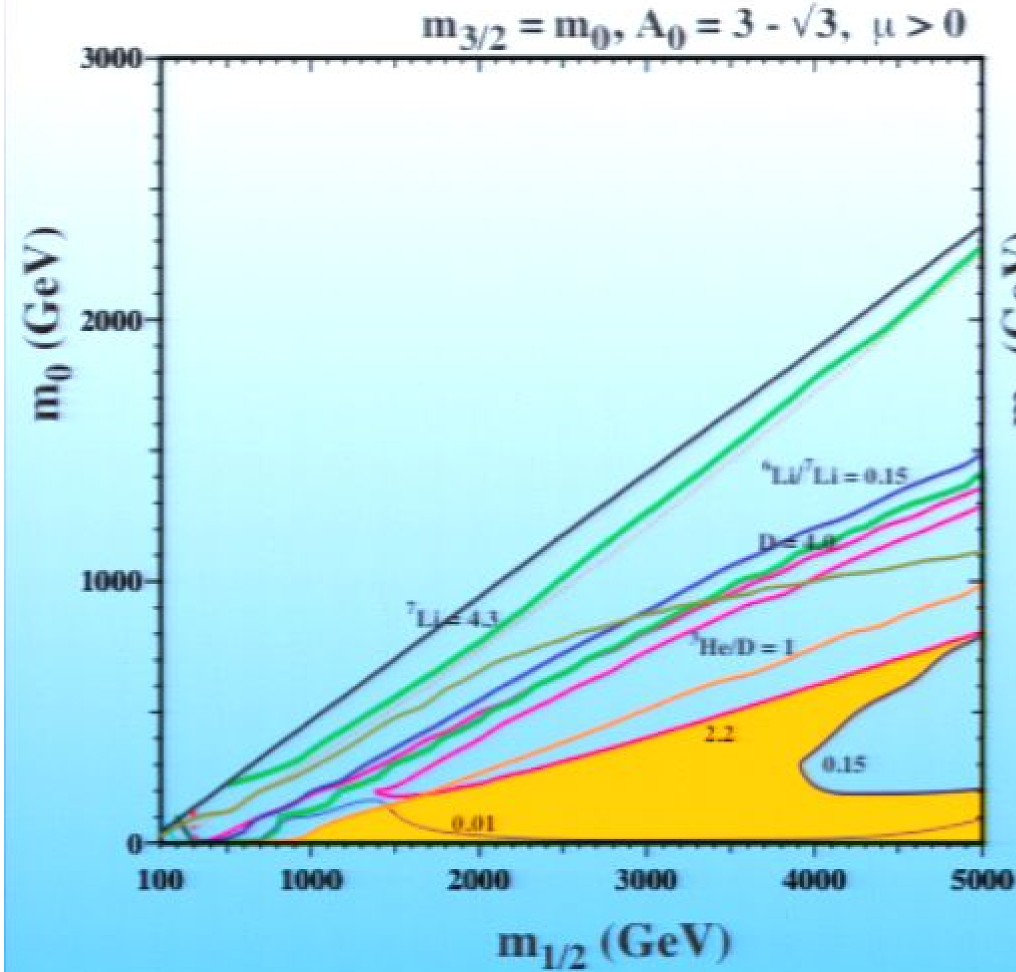
Cyburt, Ellis, Fields, KO, Spano

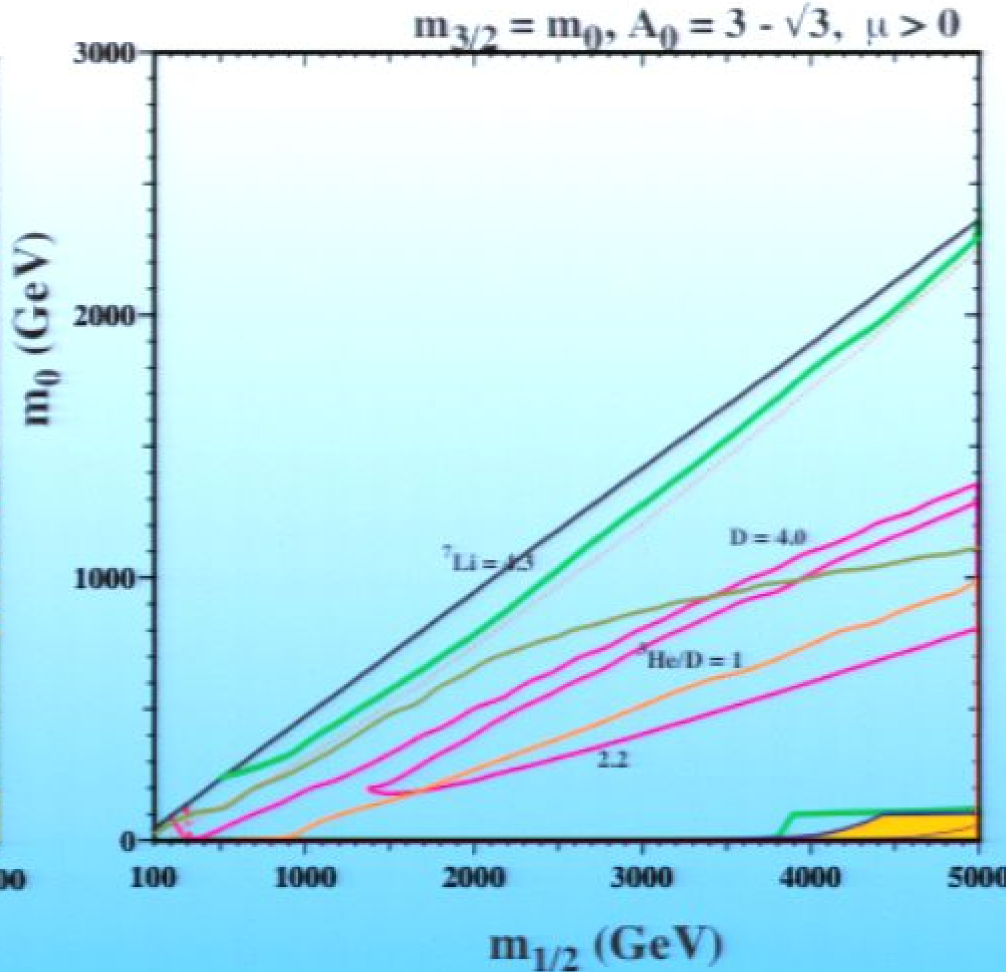


Cyburt, Ellis, Fields, KO, Spano

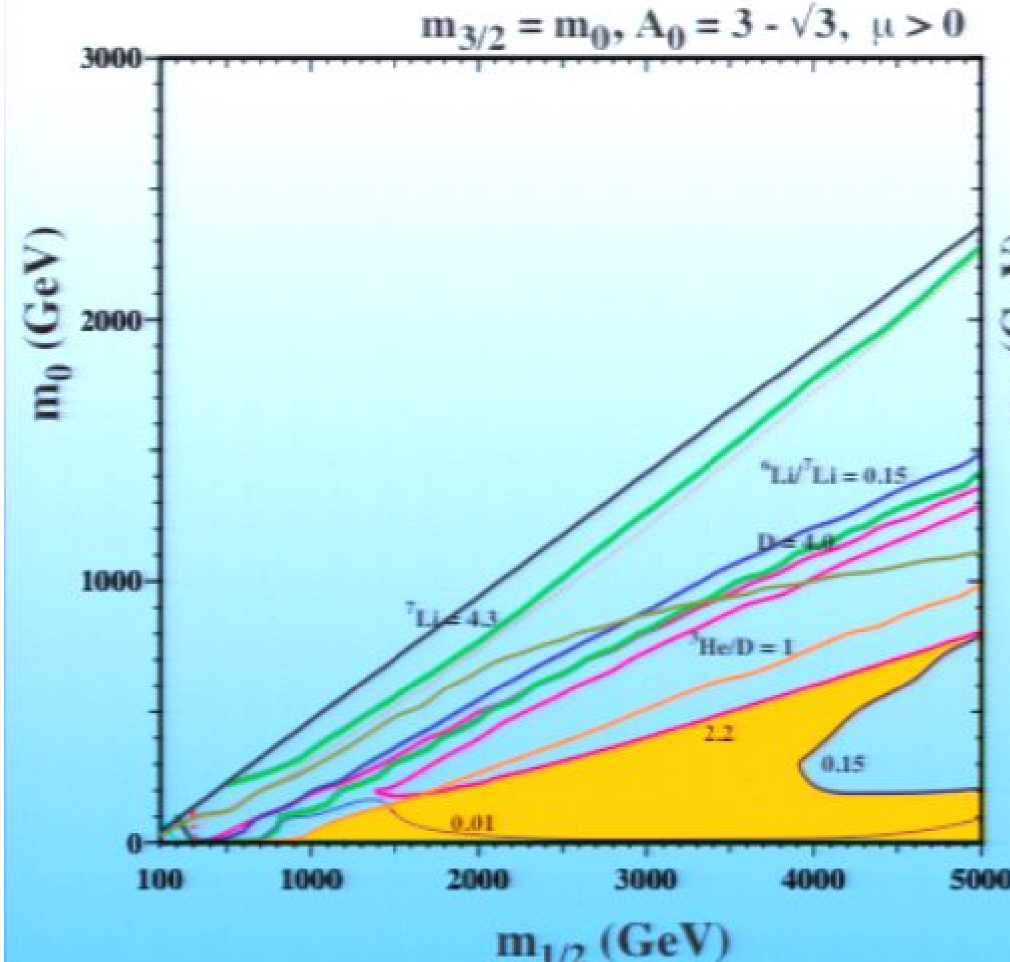


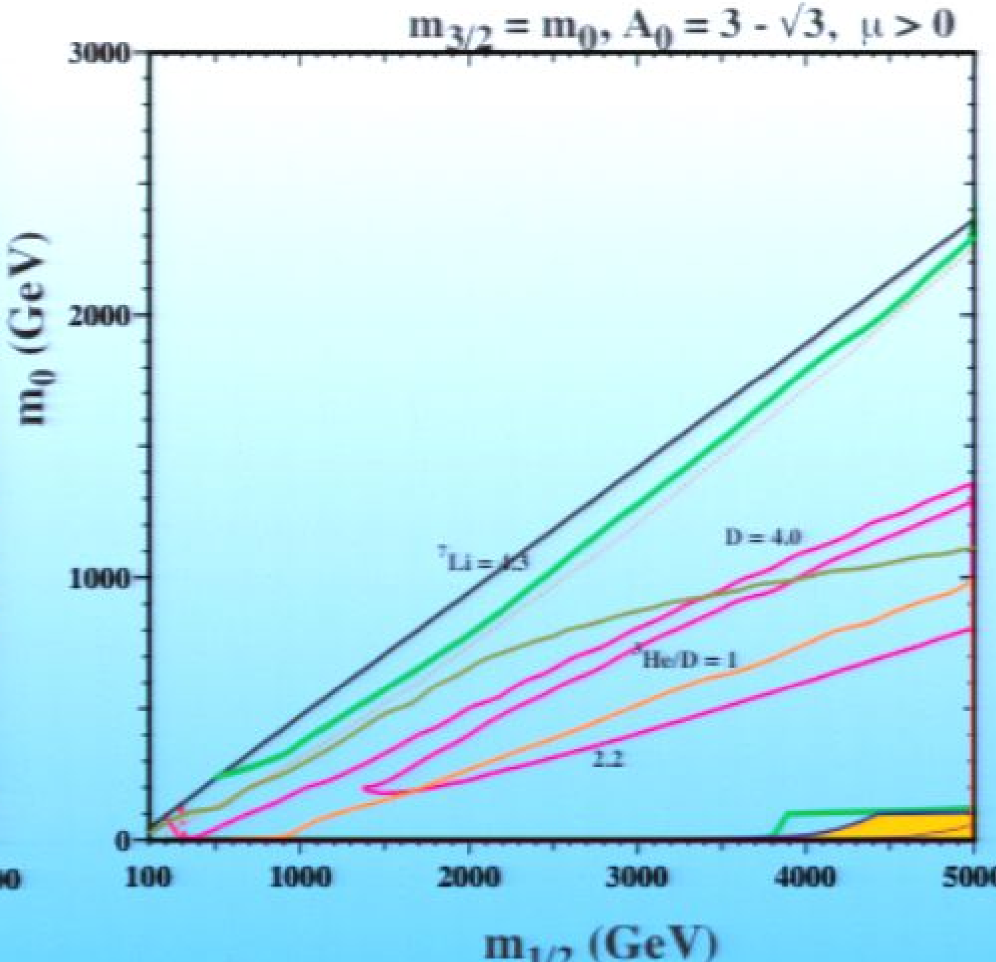
Cyburt, Ellis, Fields, KO, Spanc



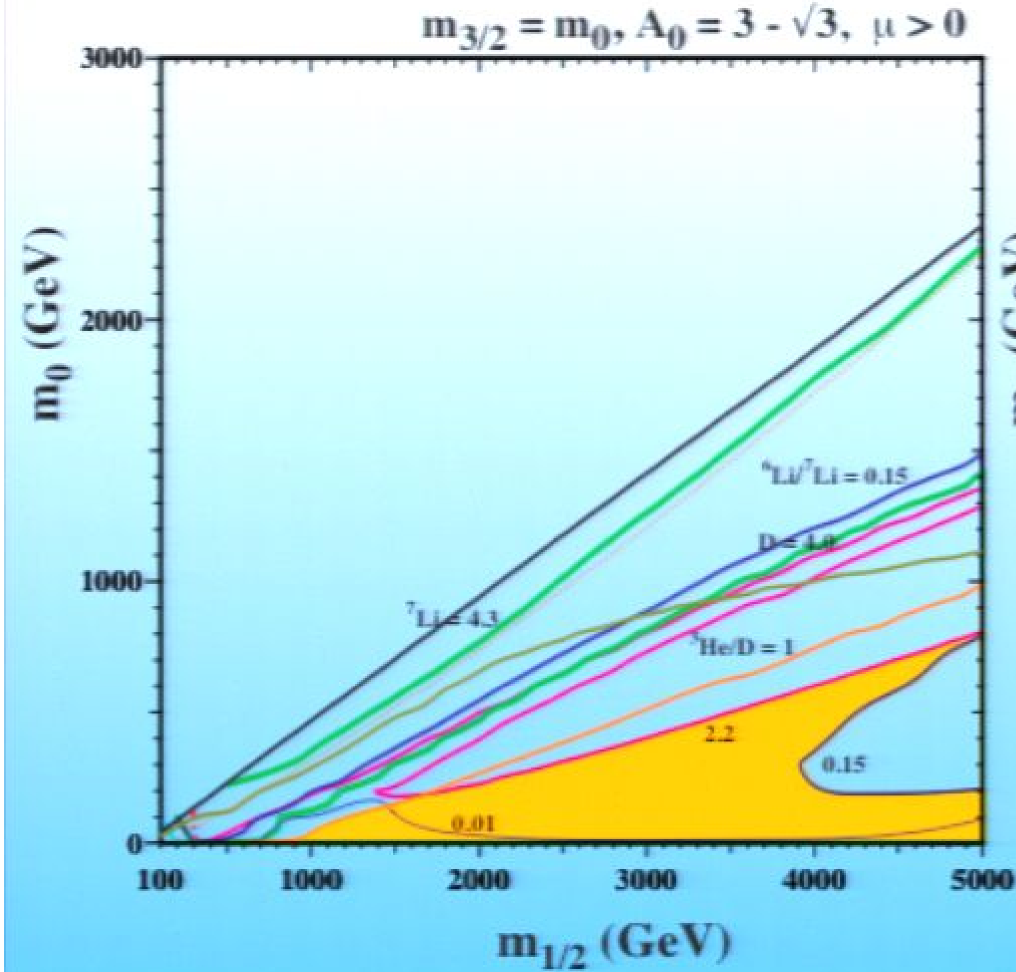


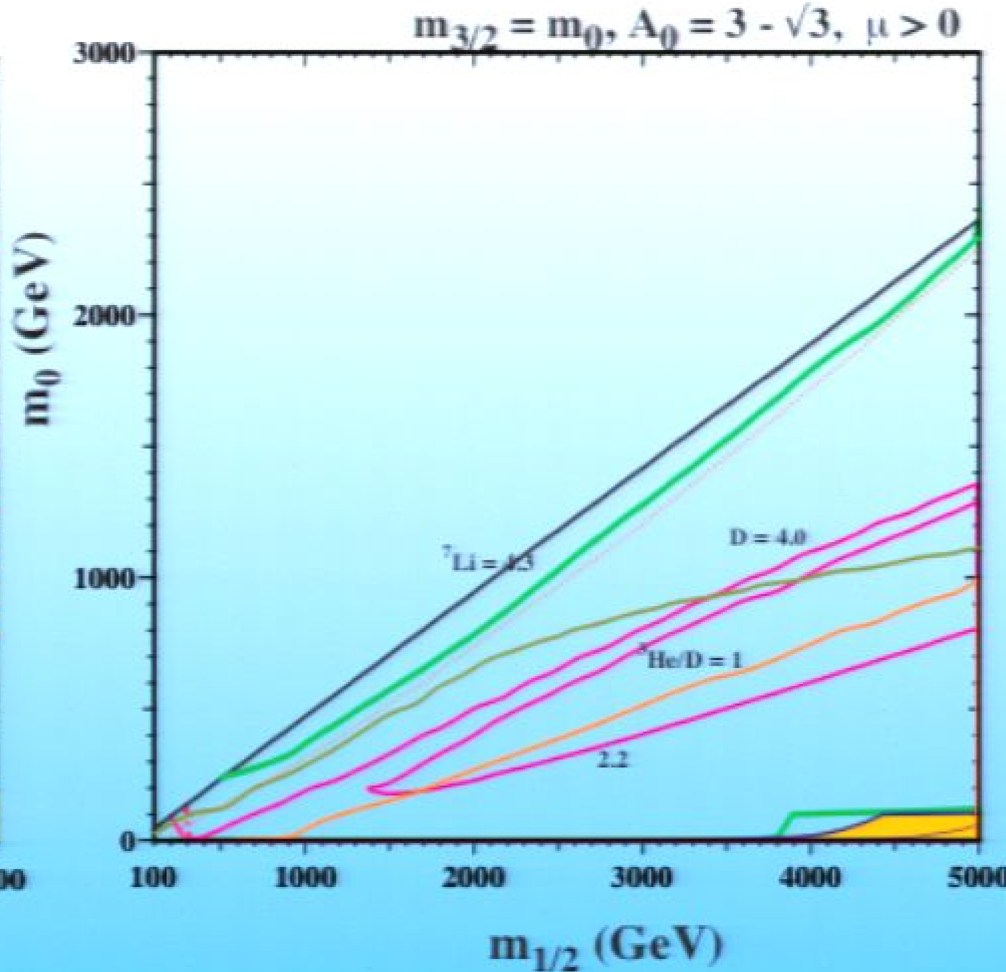
Cyburt, Ellis, Fields, KO, Spano



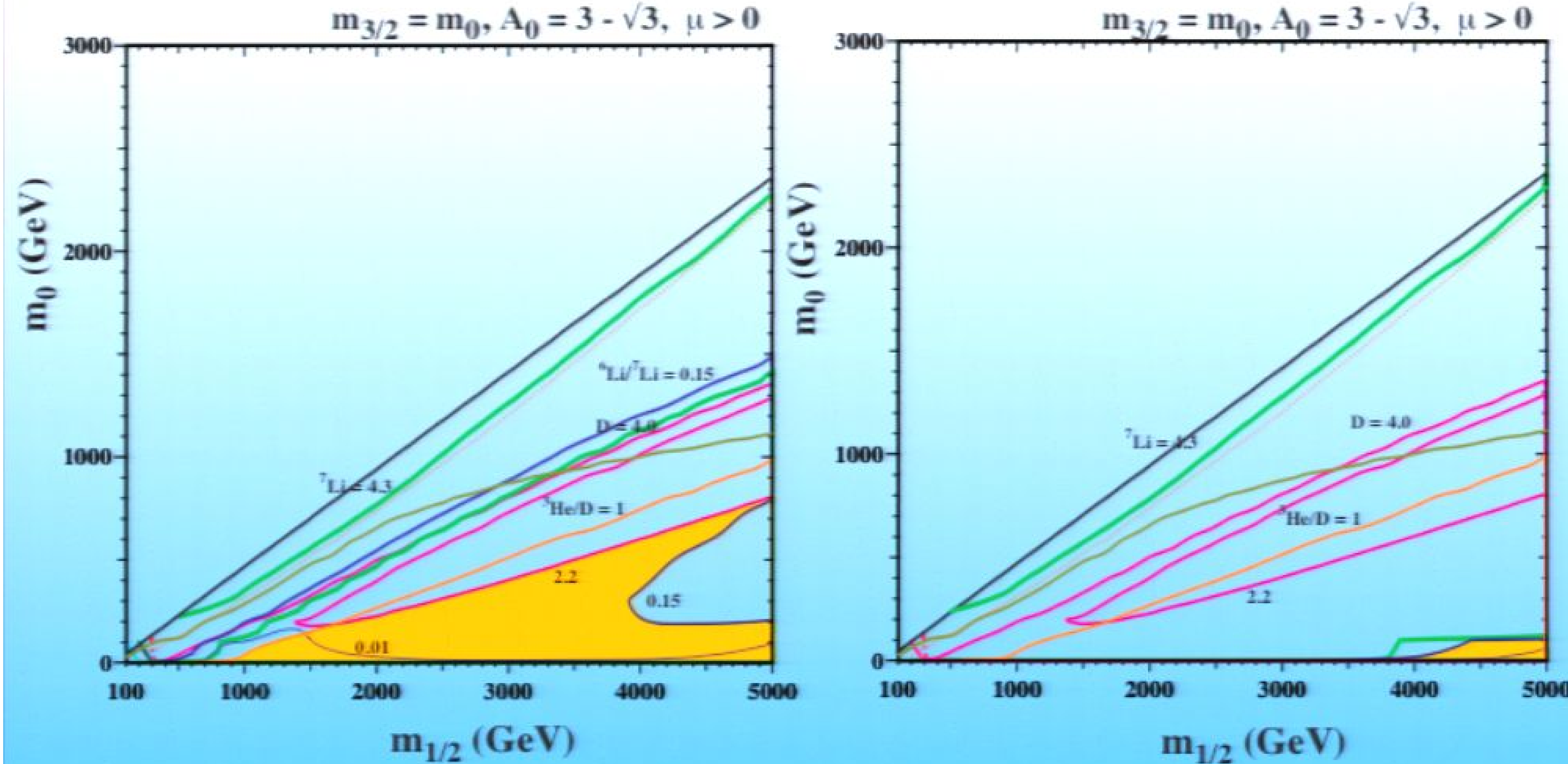


Cyburt, Ellis, Fields, KO, Spanc





Cyburt, Ellis, Fields, KO, Spanc



Cyburt, Ellis, Fields, KO, Spano

Possible sources for the discrepancy

- Stellar parameters

$$\frac{dLi}{dlng} = \frac{.09}{.5} \qquad \frac{dLi}{dT} = \frac{.08}{100K}$$

- Particle Decays
- Variable Constants

How does a Fundamental Constant Change?

$\mathcal{L} \sim \phi R$ $\qquad \langle\phi\rangle = \frac{1}{16\pi G_N} = \frac{M_P^2}{16\pi}$

$\mathcal{L} \sim \phi F^2$ $\qquad \langle\phi\rangle = \frac{1}{4e^2} = \frac{1}{16\pi\alpha}$

How does a Fundamental Constant Change?

$$\mathcal{L} \sim \phi R \qquad \langle \phi \rangle = \frac{1}{16\pi G_N} = \frac{M_P^2}{16\pi}$$

$$\mathcal{L} \sim \phi F^2 \qquad \langle \phi \rangle = \frac{1}{4e^2} = \frac{1}{16\pi\alpha}$$

How does a Fundamental Constant Change?

$$\mathcal{L} \sim \phi R \qquad \langle\phi\rangle = \frac{1}{16\pi G_N} = \frac{M_P^2}{16\pi}$$

$$\mathcal{L} \sim \phi F^2 \qquad \langle\phi\rangle = \frac{1}{4e^2} = \frac{1}{16\pi\alpha}$$

Does this ever happen?

e.g. JBD Theory

$$S = \int d^4x\sqrt{g}\left[\phi R - \frac{\omega}{\phi}\partial_\mu\phi\partial^\mu\phi + \mathcal{L}_m\right]$$

$$\mathcal{L}_m = -\frac{1}{4e^2}F^2 - \frac{1}{2}\partial_\mu y\partial^\mu y - V(y)$$

$$-\overline{\Psi}\, \not{D}\Psi - m\overline{\Psi}\Psi + \Lambda$$

with a conformal rescaling,

$$S = \int d^4x \sqrt{\overline{g}} \Big[\overline{R} - (\omega + \tfrac{3}{2}) \frac{(\partial_\mu \phi)^2}{\phi^2}$$

$$- \frac{1}{2} \frac{(\partial_\mu y)^2}{\phi} - \frac{V(y)}{\phi^2} - \frac{\overline{\Psi} \not{D} \Psi}{\phi^{3/2}}$$

$$- \frac{m \overline{\Psi} \Psi}{\phi^2} - \frac{1}{4e^2} F^2 + \frac{\Lambda}{\phi^2} \Big]$$

now, $M_p(G_N)$, and α are fixed but particle masses scale with ϕ,

$$m \sim 1/\phi^{1/2}$$

the same is true for the Higgs expectation value,

$$G_F \sim \frac{1}{v^2} \sim 1/\phi$$

with a conformal rescaling,

$$S = \int d^4x\sqrt{\overline{g}}\left[\overline{R} - (\omega + \tfrac{3}{2})\frac{(\partial_\mu \phi)^2}{\phi^2}\right.$$

$$-\frac{1}{2}\frac{(\partial_\mu y)^2}{\phi} - \frac{V(y)}{\phi^2} - \frac{\overline{\Psi}\not{D}\Psi}{\phi^{3/2}}$$

$$\left. - \frac{m\overline{\Psi}\Psi}{\phi^2} - \frac{1}{4e^2}F^2 + \frac{\Lambda}{\phi^2}\right]$$

now, $M_p(G_N)$, and α are fixed but particle masses scale with ϕ,

$$m \sim 1/\phi^{1/2}$$

the same is true for the Higgs expectation value,

$$G_F \sim \frac{1}{v^2} \sim 1/\phi$$

Limits on the variations of α

- Cosmology
  - BBN
  - CMB
- The Oklo Reactor
- Meteoritic abundances
- Atomic clocks

Limits on the variations of α

- Cosmology
  - BBN
  - CMB
- The Oklo Reactor
- Meteoritic abundances
- Atomic clocks

Limits on the variations of α

- Cosmology
  - BBN
  - CMB
- The Oklo Reactor
- Meteoritic abundances
- Atomic clocks

BBN Concordance

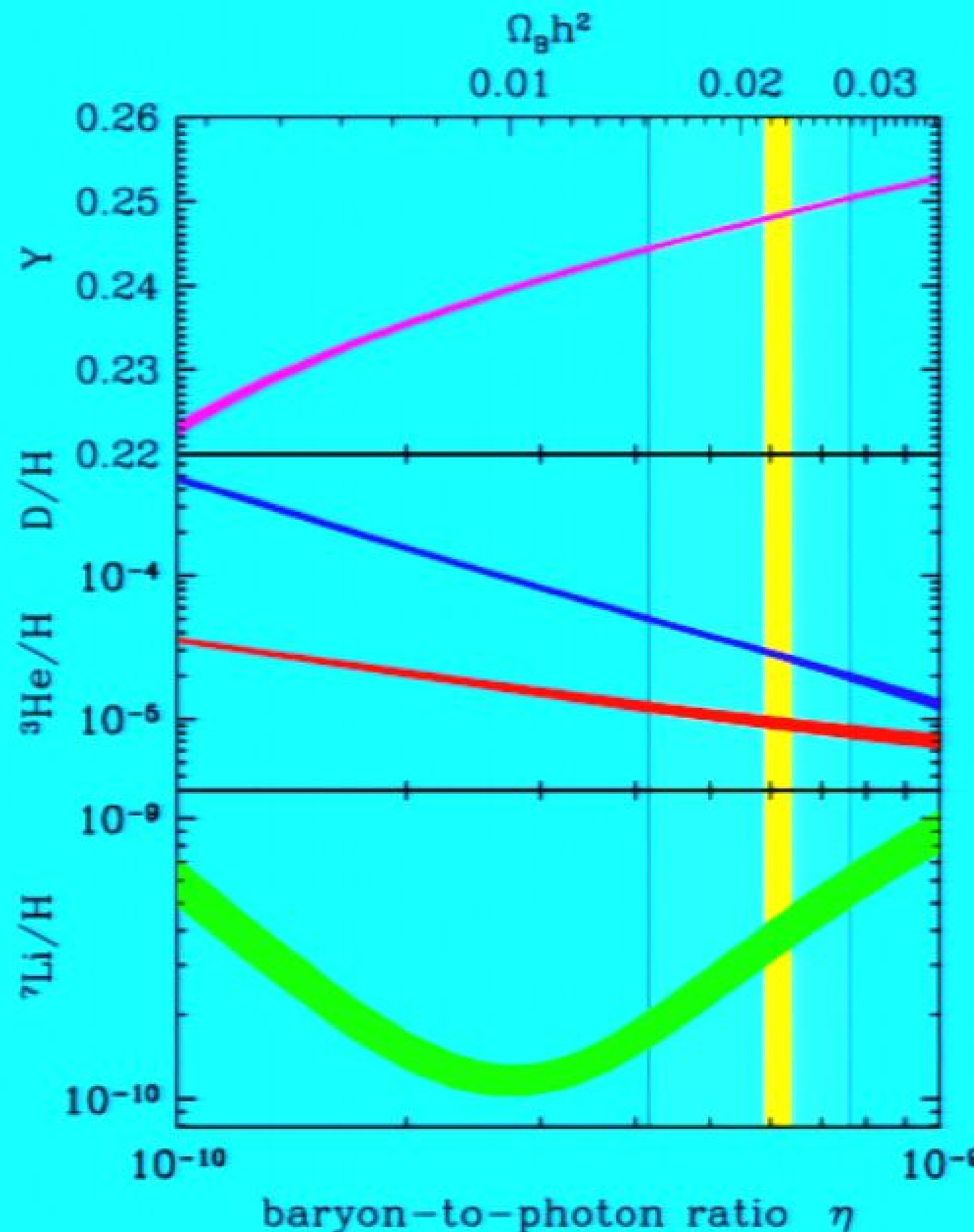
- Concordance rests on balance between interaction rates and expansion rate.

- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters

Cyburt, Fields, KAO

BBN Concordance

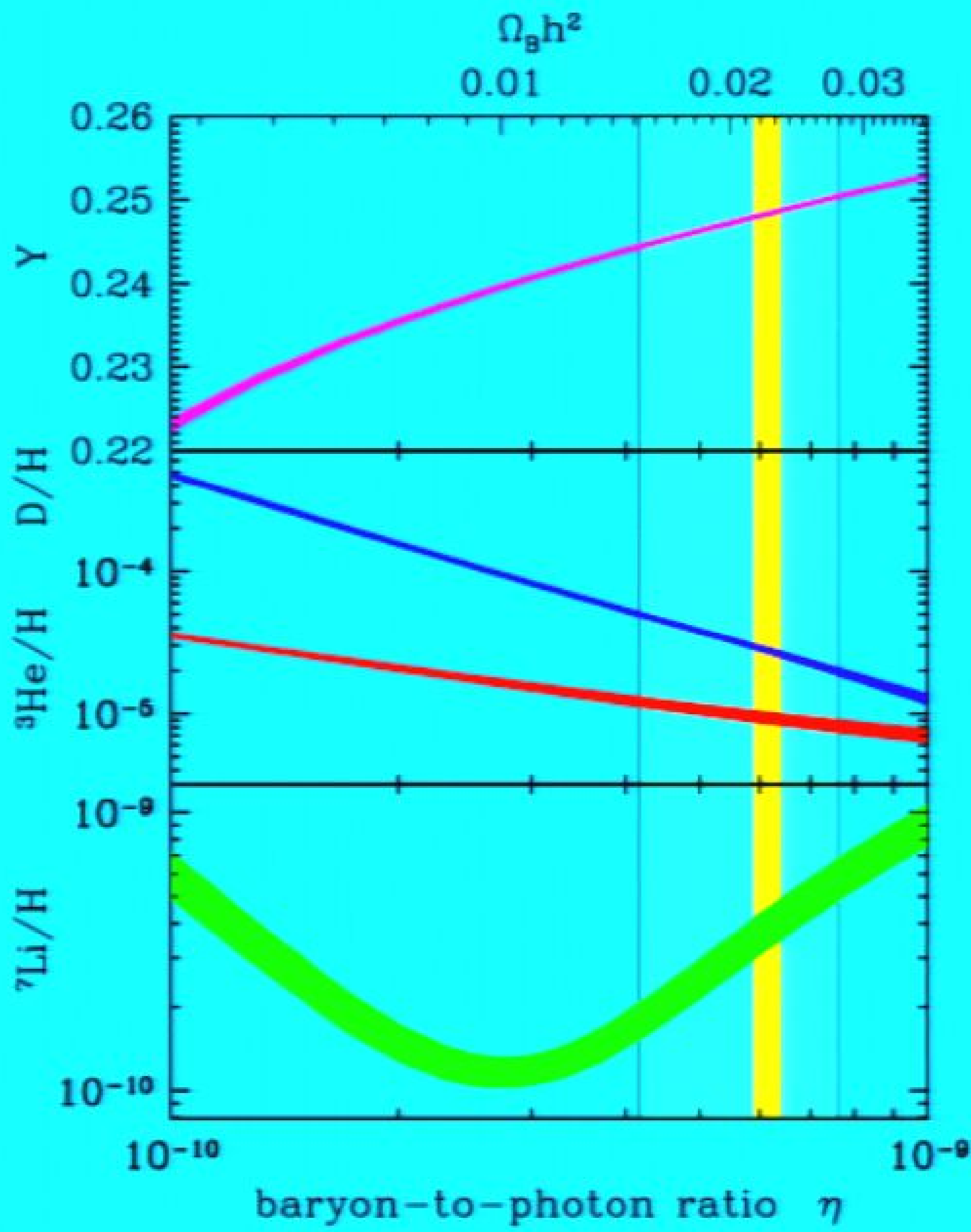
- Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

BBN Concordance

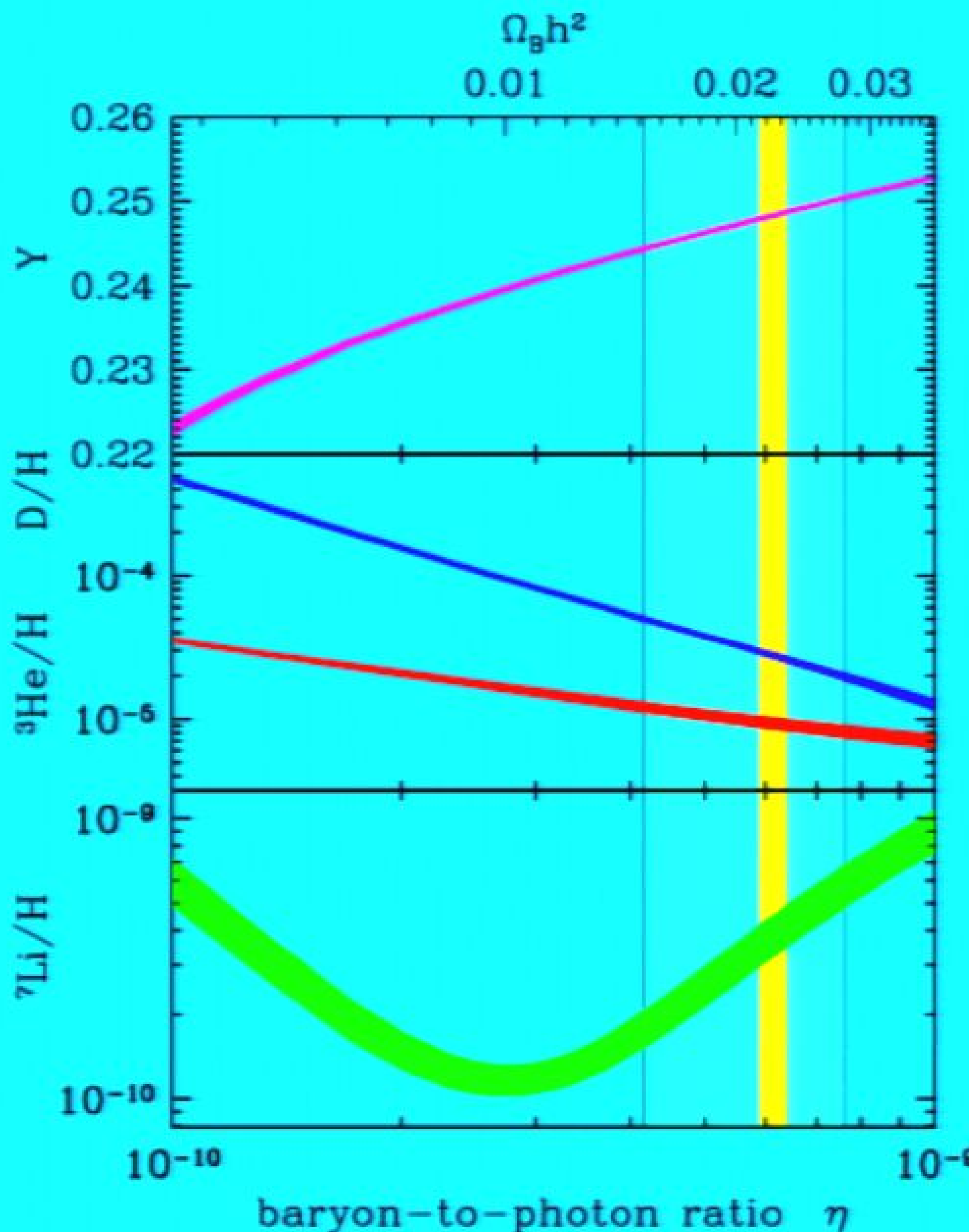
- Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

BBN Concordance

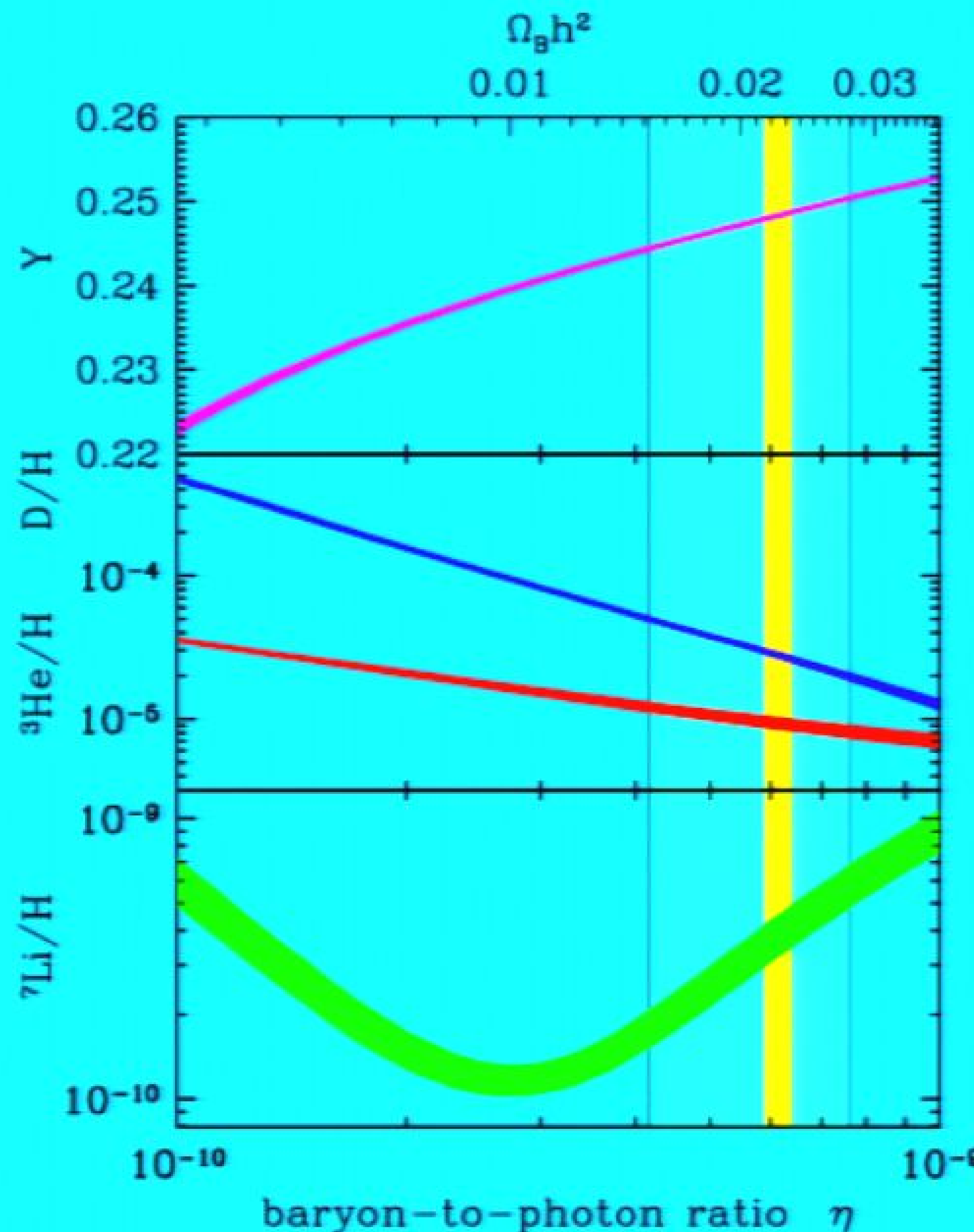
- Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

BBN Concordance

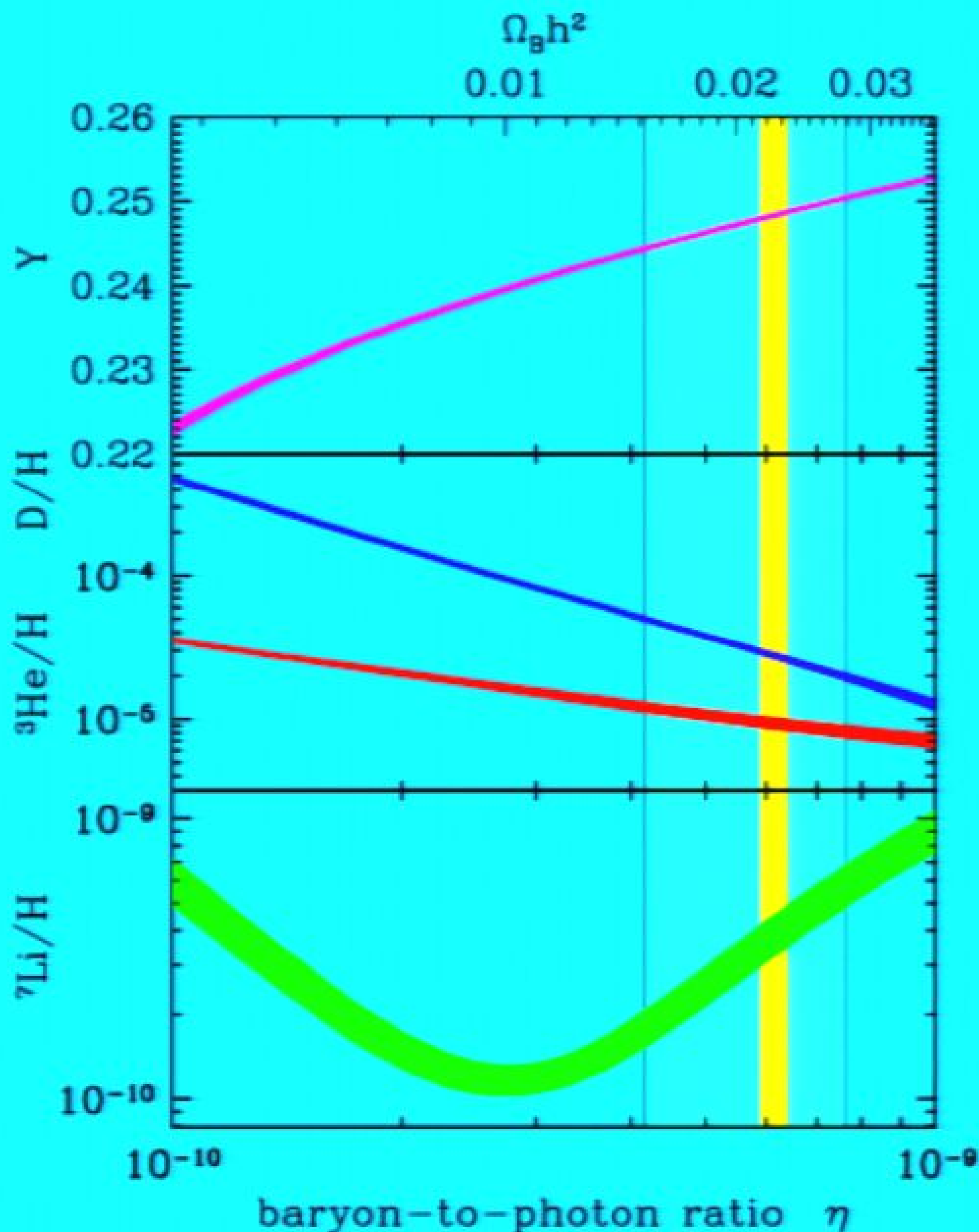
- Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

BBN Concordance

- Concordance rests on balance between interaction rates and expansion rate.
- Allows one to set constraints on:
  - Particle Types
  - Particle Interactions
  - Particle Masses
  - Fundamental Parameters



Cyburt, Fields, KAO

How could varying α affect BBN?

$$G_F^2 T^5 \sim \Gamma(T_f) \sim H(T_f) \sim \sqrt{G_N N} T_f^2$$

Recall in equilibrium,

$$\frac{n}{p} \sim e^{-\Delta m/T}$$ **fixed at freezeout**

Helium abundance,

$$Y \sim \frac{2(n/p)}{1+(n/p)}$$

If T_f is higher, (n/p) is higher, and Y is higher

How could varying α affect BBN?

$$G_F^2 T^5 \sim \Gamma(T_f) \sim H(T_f) \sim \sqrt{G_N N} T_f^2$$

Recall in equilibrium,

$$\frac{n}{p} \sim e^{-\Delta m/T}$$ **fixed at freezeout**

Helium abundance,

$$Y \sim \frac{2(n/p)}{1+(n/p)}$$

If T_f is higher, (n/p) is higher, and Y is higher

How could varying α affect BBN?

$$G_F^2 T^5 \sim \Gamma(T_f) \sim H(T_f) \sim \sqrt{G_N N} T_f^2$$

Recall in equilibrium,

$$\frac{n}{p} \sim e^{-\Delta m/T}$$ **fixed at freezeout**

Helium abundance,

$$Y \sim \frac{2(n/p)}{1+(n/p)}$$

If T_f is higher, (n/p) is higher, and Y is higher

How could varying α affect BBN?

$$G_F^2 T^5 \sim \Gamma(T_f) \sim H(T_f) \sim \sqrt{G_N N} T_f^2$$

Recall in equilibrium,

$$\frac{n}{p} \sim e^{-\Delta m/T} \qquad \text{fixed at freezeout}$$

Helium abundance,

$$Y \sim \frac{2(n/p)}{1+(n/p)}$$

If T_f is higher, (n/p) is higher, and Y is higher

Contributions to ΔY:

Kolb, Perry, and Walker
Campbell and Olive
Bergstrom, Iguri, and Rubenstein

$$\frac{\Delta Y}{Y} \simeq \frac{1}{1+n/p}\frac{\Delta(n/p)}{(n/p)}$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

Contributions to Δm_N:

$$\Delta m_N \sim a\alpha_{em}\Lambda_{QCD} + bv$$

electromagnetic	weak
-0.8 MeV	2.1 MeV

Changes in α, Λ_{QCD}, and/or v
all induce changes in Δm_N and hence Y

Contributions to ΔY:

Kolb, Perry, and Walker
Campbell and Olive
Bergstrom, Iguri, and Rubenstein

$$\frac{\Delta Y}{Y} \simeq \frac{1}{1+n/p}\frac{\Delta(n/p)}{(n/p)}$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

Contributions to Δm_N:

$$\Delta m_N \sim a\alpha_{em}\Lambda_{QCD} + bv$$

electromagnetic	weak
-0.8 MeV	2.1 MeV

Changes in α, Λ_{QCD}, and/or v
all induce changes in Δm_N and hence Y

Contributions to ΔY:

Kolb, Perry, and Walker
Campbell and Olive
Bergstrom, Iguri, and Rubenstein

$$\frac{\Delta Y}{Y} \simeq \frac{1}{1+n/p} \frac{\Delta(n/p)}{(n/p)}$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

Contributions to Δm_N:

$$\Delta m_N \sim a\alpha_{em}\Lambda_{QCD} + bv$$

electromagnetic	weak
-0.8 MeV	2.1 MeV

Changes in α, Λ_{QCD}, and/or v
all induce changes in Δm_N and hence Y

Limits:

Campbell & Olive
see also Ichikawa & Kawasaki
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Limits:

Campbell & Olive
see also Ichikawa & Kawasaki
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Limits:

Campbell & Olive
see also Ichikawa & Kawasaki
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Limits:

Campbell & Olive
see also Ichikawa & Kawasak
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Limits:

Campbell & Olive
see also Ichikawa & Kawasaki
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha} \text{ and } \frac{\Delta\alpha}{\alpha} < \text{few } \times 10^{-4}$$

Limits:

Campbell & Olive
see also Ichikawa & Kawasa[cut off]
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Limits:

Campbell & Olive
see also Ichikawa & Kawasl
Nollett & Lopez

$$\frac{\Delta Y}{Y} \lesssim \frac{\pm 0.012}{0.24} = \pm 0.05$$

$$\frac{\Delta(n/p)}{(n/p)} \simeq \frac{\Delta m_N}{T_f}\left(\frac{\Delta T_f}{T_f} - \frac{\Delta^2 m_N}{\Delta m_N}\right)$$

If the dominant contribution from $\Delta\alpha$ is in Δm_N then:

$$\frac{\Delta Y}{Y} \simeq \frac{\Delta^2 m_N}{\Delta m_N} \sim \frac{\Delta\alpha}{\alpha} < 0.05$$

If $\Delta\alpha$ arises in a more complete theory the effect may be greatly enhanced:

$\frac{\Delta Y}{Y} \simeq O(100)\frac{\Delta\alpha}{\alpha}$ **and** $\frac{\Delta\alpha}{\alpha} <$ **few** $\times 10^{-4}$

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N}$, τ_{N}, B_D

Coc, Nunes, Olive, Uzan, Vangioni

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangioni

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangioni

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangion

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangioni

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangion

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_N, \tau_N, B_D$

Coc, Nunes, Olive, Uzan, Vangioni

Quantities of importance for BBN

- Q = Δ m_N nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\frac{1+3\,g_A^2}{2\pi^3}G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \qquad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d-h_u)}{h_d-h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- Q = Δ m_N nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\frac{1+3\,g_A^2}{2\pi^3}G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \quad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\frac{\Delta v}{v} + 1.5\frac{\Delta h_e}{h_e} - 10.4\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- Q = Δ m_N nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\,\frac{1+3\,g_A^2}{2\pi^3}\,G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \qquad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- $Q = \Delta m_N$ nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\frac{1+3\,g_A^2}{2\pi^3}G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \quad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- $Q = \Delta m_N$ nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\,\frac{1+3\,g_A^2}{2\pi^3}\,G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right],$$ (

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- $Q = \Delta m_N$ nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\,\frac{1+3\,g_A^2}{2\pi^3}\,G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \qquad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Quantities of importance for BBN

- $Q = \Delta m_N$ nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\frac{1+3\,g_A^2}{2\pi^3}G_F^2\,m_e^5\left[\sqrt{q^2-1}(2q^4-9q^2-8) + 15\ln(q+\sqrt{q^2-1})\right], \quad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\frac{\Delta v}{v} + 1.5\frac{\Delta h_e}{h_e} - 10.4\frac{\Delta(h_d-h_u)}{h_d-h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$

Approach:

Consider possible variation of Yukawa, h,
or fine-structure constant, α

Include dependence of Λ on α; of v on h, etc.

Consider effects on: $Q = \Delta m_{N,}\ \tau_{N,}\ B_D$

Coc, Nunes, Olive, Uzan, Vangioni

- B_D binding energy of deuterium

Using a potential model,

Dimitriev & Flambau

$$\frac{\Delta B_D}{B_D} = -48\,\frac{\Delta m_\sigma}{m_\sigma} + 50\,\frac{\Delta m_\omega}{m_\omega} + 6\,\frac{\Delta m_N}{m_N}\,.$$

and the dependence on Λ, by dimensional grounds,

$$\Delta B_D/B_D = -7\Delta\Lambda/\Lambda$$

But there is also a dependence on quark masses.

- B_D binding energy of deuterium

Using a potential model,

Dimitriev & Flambau

$$\frac{\Delta B_D}{B_D} = -48\,\frac{\Delta m_\sigma}{m_\sigma} + 50\,\frac{\Delta m_\omega}{m_\omega} + 6\,\frac{\Delta m_N}{m_N}.$$

and the dependence on Λ, by dimensional grounds,

$$\Delta B_D/B_D = -7\Delta\Lambda/\Lambda$$

But there is also a dependence on quark masses.

- B_D binding energy of deuterium

Using a potential model,

Dimitriev & Flambau

$$\frac{\Delta B_D}{B_D} = -48\,\frac{\Delta m_\sigma}{m_\sigma} + 50\,\frac{\Delta m_\omega}{m_\omega} + 6\,\frac{\Delta m_N}{m_N}.$$

and the dependence on Λ, by dimensional grounds,

$$\Delta B_D/B_D = -7\Delta\Lambda/\Lambda$$

But there is also a dependence on quark masses.

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Σ 45 GeV or (4 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)}\frac{\alpha_{3q}}{m_q} + \frac{2}{27}f_{TG}^{(p)}\sum_{c,b,t}\frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)}\frac{\alpha_{3q}}{m_q} + \frac{2}{27}f_{TG}^{(p)}\sum_{c,b,t}\frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A - Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Σ 45 GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)}\frac{\alpha_{3q}}{m_q} + \frac{2}{27}f_{TG}^{(p)}\sum_{c,b,t}\frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

$\Sigma = 45$ GeV or (4 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Σ = 45 GeV or 64 GeV

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A-Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Z f_p + (A - Z) f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)} \frac{\alpha_{3q}}{m_q} + \frac{2}{27} f_{TG}^{(p)} \sum_{c,b,t} \frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p | m_q \bar{q} q | p \rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)}\frac{\alpha_{3q}}{m_q} + \frac{2}{27}f_{TG}^{(p)}\sum_{c,b,t}\frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$

and $\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v} \right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19\frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052\frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76\frac{\Delta\Lambda}{\Lambda} + 0.24\left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \mathrm{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19\frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052\frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76\frac{\Delta\Lambda}{\Lambda} + 0.24\left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right) \frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \dfrac{B_u - B_s}{B_d - B_s} = \dfrac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24\left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \mathrm{MeV}$

and $$z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19\frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052\frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76\frac{\Delta\Lambda}{\Lambda} + 0.24\left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7$ MeV

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19 \frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052 \frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76 \frac{\Delta \Lambda}{\Lambda} + 0.24 \left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi}$$

r = 6-10

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\,\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1+\frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1+\frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1+\frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi}$$ r = 6-10

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3}\right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)}\right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t}\right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3}\right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)}\right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t}\right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Coupled Variations

Campbell and Olive
Langacker, Segre, and Strassler
Dent and Fairbairn
Calmet and Fritzsch
Damour, Piazza, and Veneziano

Recall,

$$\alpha_s(M_{UV}^2) \equiv \frac{g_s^2(M_{UV}^2)}{4\pi} = \frac{4\pi}{b_3 \ln(M_{UV}^2/\Lambda^2)}$$

$$\Lambda = \mu \left(\frac{m_c\, m_b\, m_t}{\mu^3} \right)^{2/27} \exp\left(-\frac{2\pi}{9\alpha_s(\mu)} \right)$$

$$\frac{\Delta\Lambda}{\Lambda} = R\,\frac{\Delta\alpha}{\alpha} + \frac{2}{27}\left(3\,\frac{\Delta v}{v} + \frac{\Delta h_c}{h_c} + \frac{\Delta h_b}{h_b} + \frac{\Delta h_t}{h_t} \right)$$

R ~ 30, but very model dependent

Dine et al.

Net sensitivities due to Λ

$$\frac{\Delta B_D}{B_D} = -13\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right) + 18R\,\frac{\Delta\alpha}{\alpha}\,,$$

$$\frac{\Delta Q}{Q} = 1.5\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right) - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha}\,,$$

$$\frac{\Delta \tau_n}{\tau_n} = -4\,\frac{\Delta v}{v} - 8\,\frac{\Delta h}{h} + 3.8(1+R)\,\frac{\Delta\alpha}{\alpha}\,.$$

Net sensitivities due to Λ

$$\frac{\Delta B_D}{B_D} = -13\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right) + 18R\,\frac{\Delta\alpha}{\alpha}\,,$$

$$\frac{\Delta Q}{Q} = 1.5\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right) - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha}\,,$$

$$\frac{\Delta\tau_n}{\tau_n} = -4\,\frac{\Delta v}{v} - 8\,\frac{\Delta h}{h} + 3.8(1+R)\,\frac{\Delta\alpha}{\alpha}\,.$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80\frac{\Delta \alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80\frac{\Delta \alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t **will induce large changes in** v

$$\frac{\Delta v}{v} \sim 80 \frac{\Delta \alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80 \frac{\Delta \alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80 \frac{\Delta \alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta\alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80\frac{\Delta\alpha_U}{\alpha_U}$$

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

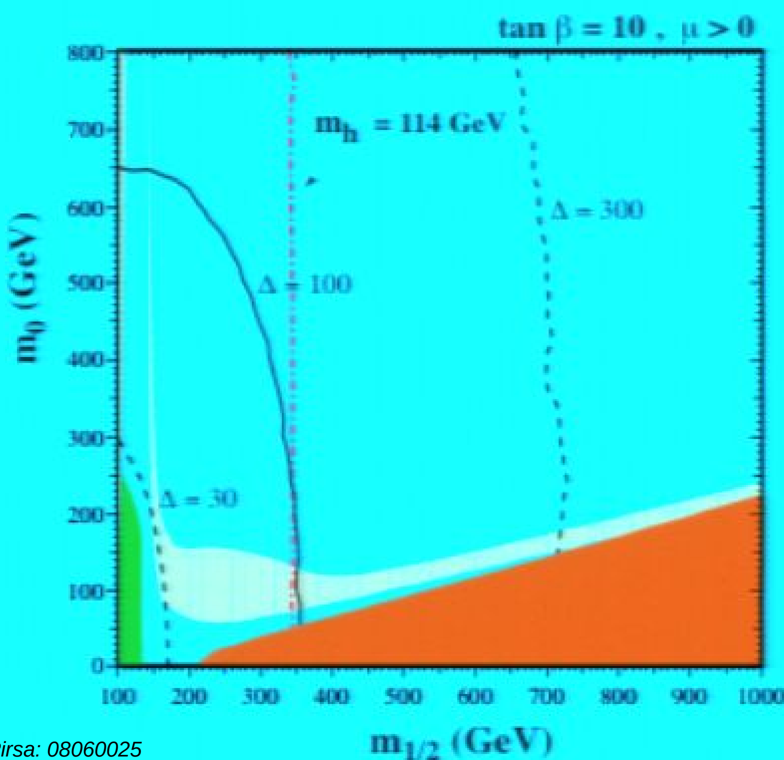
Thus small changes in h_t
will induce large changes in v

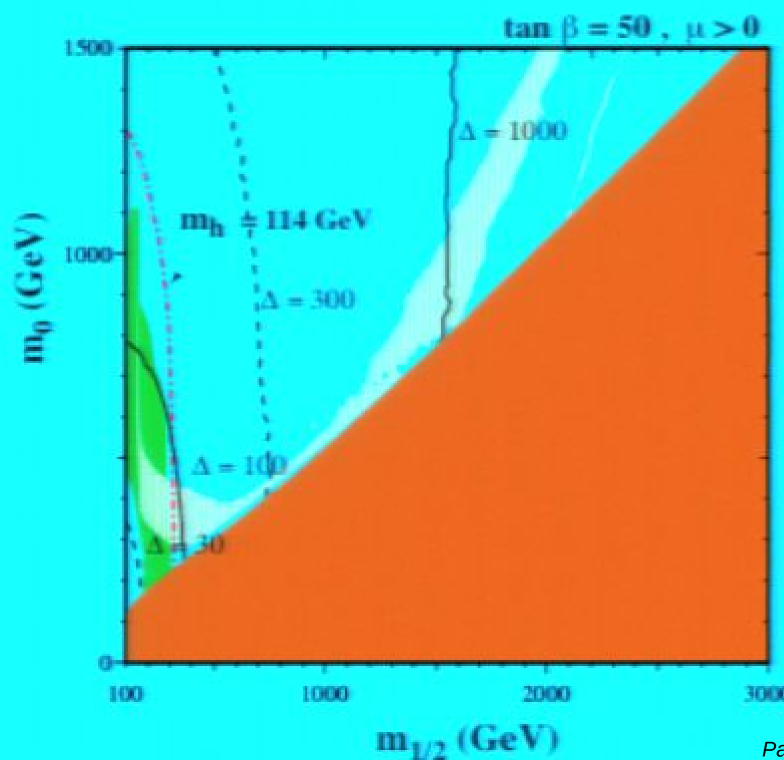
$$\frac{\Delta v}{v} \sim 80\frac{\Delta \alpha_U}{\alpha_U}$$

Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

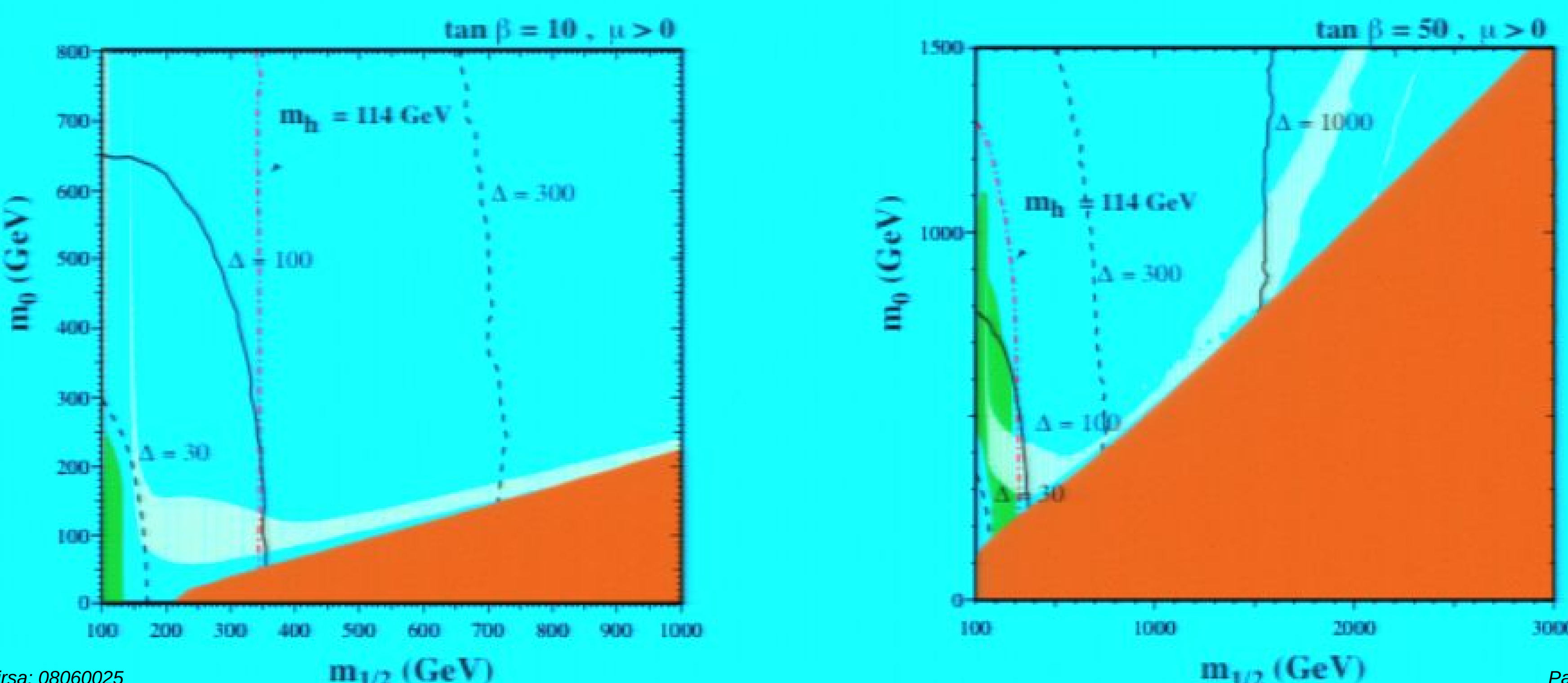




Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

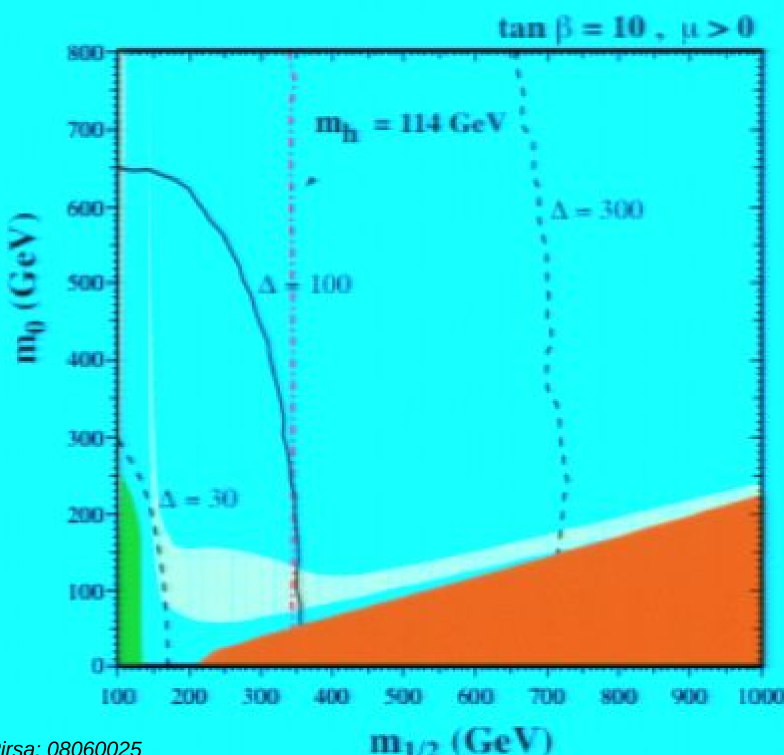
$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

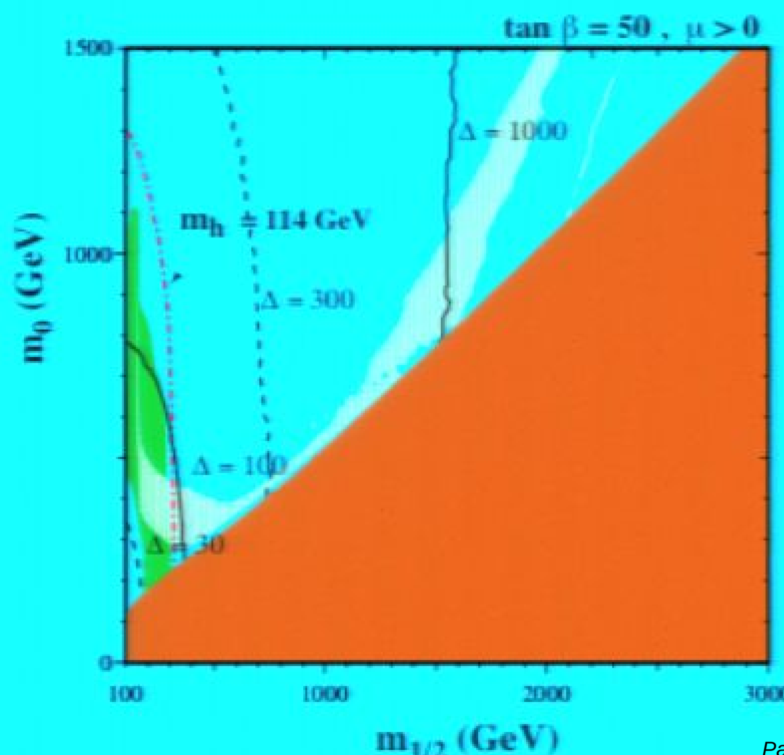


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \ \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

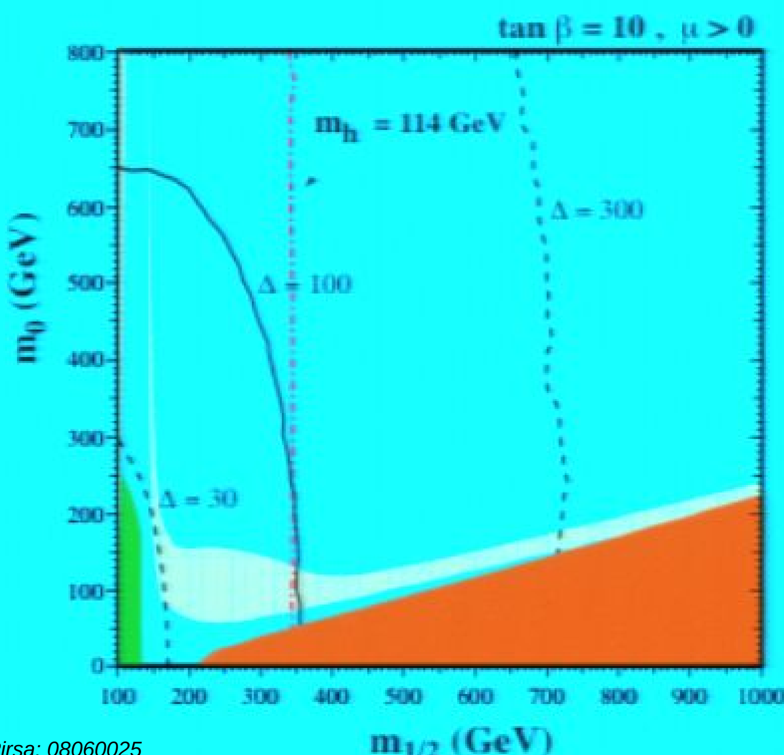


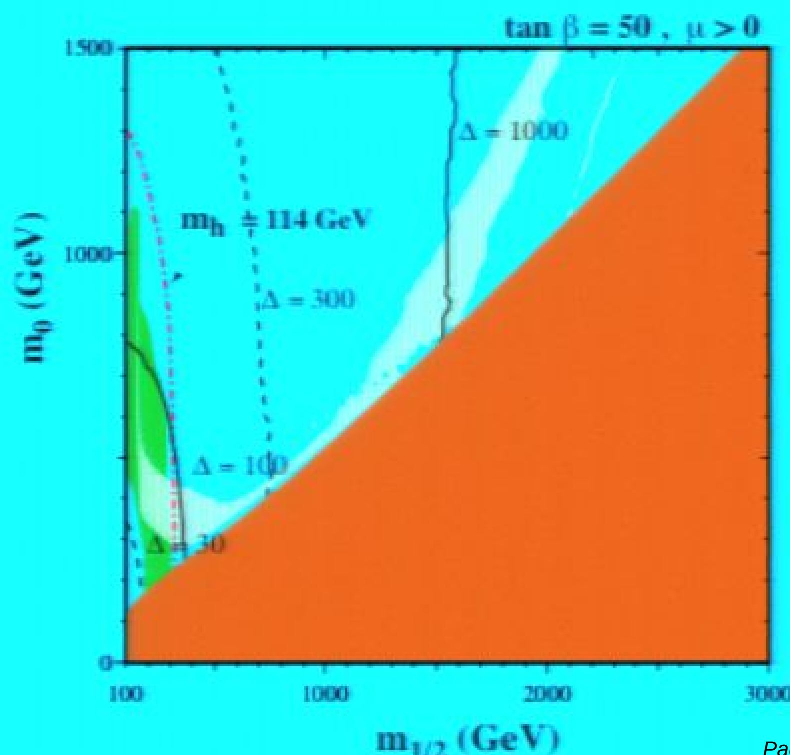


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

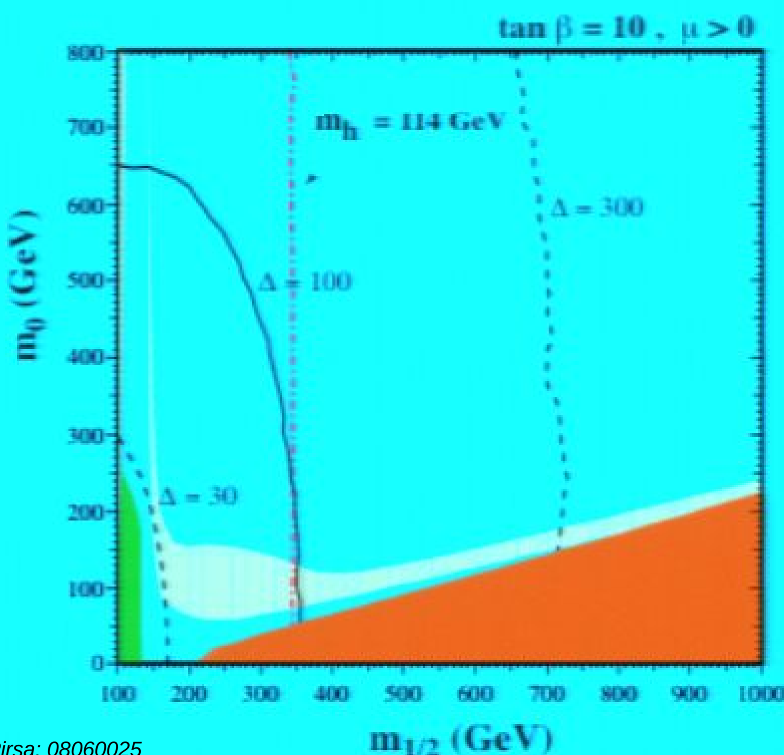


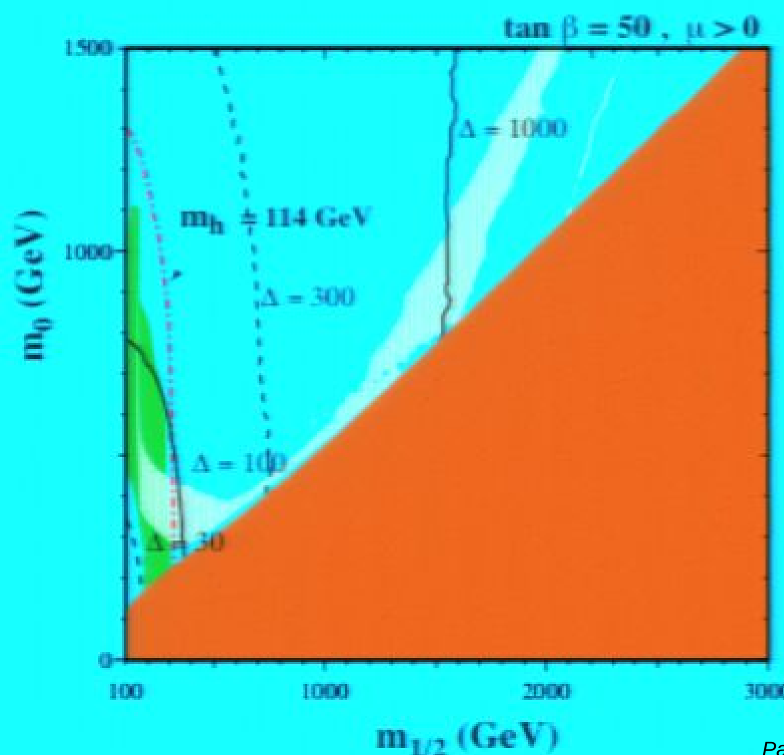


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \ \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

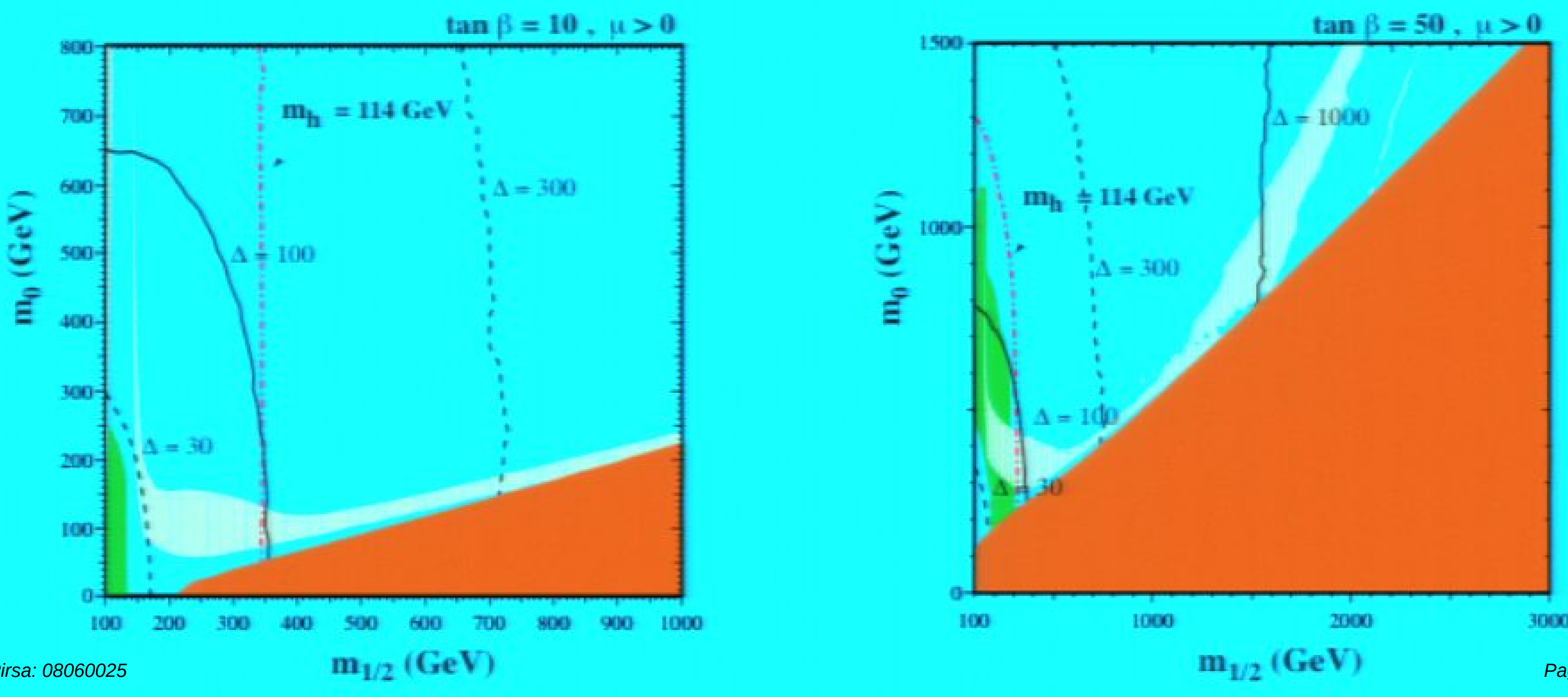




Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h}$,

related SUSY finetuning parameters

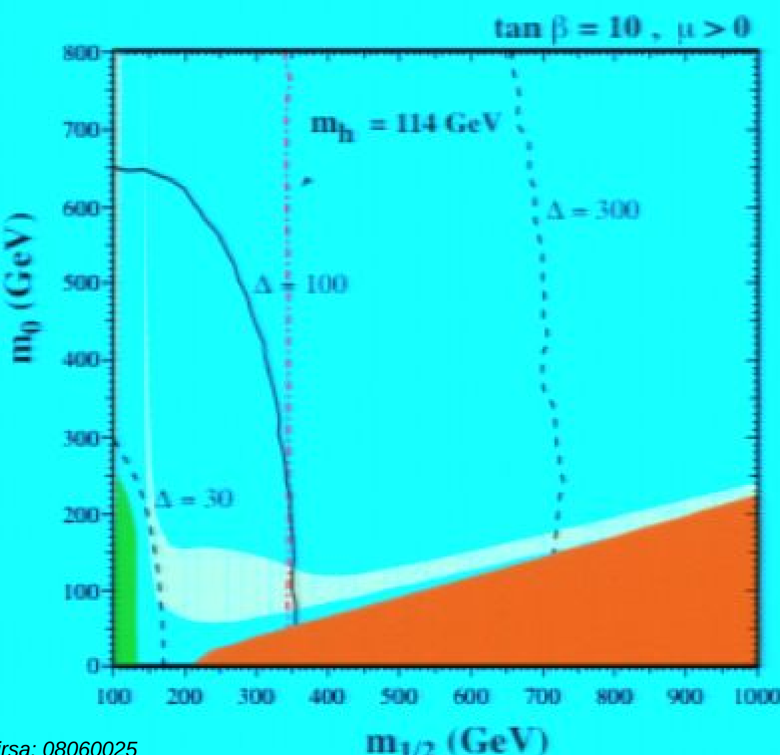
$$\Delta = \sqrt{\sum_i \ {\Delta_i}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

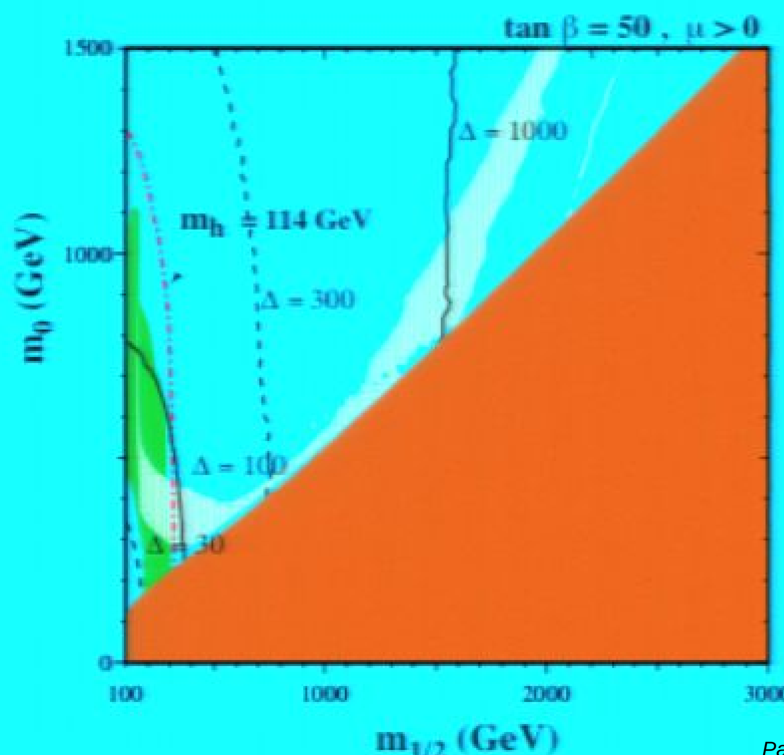


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

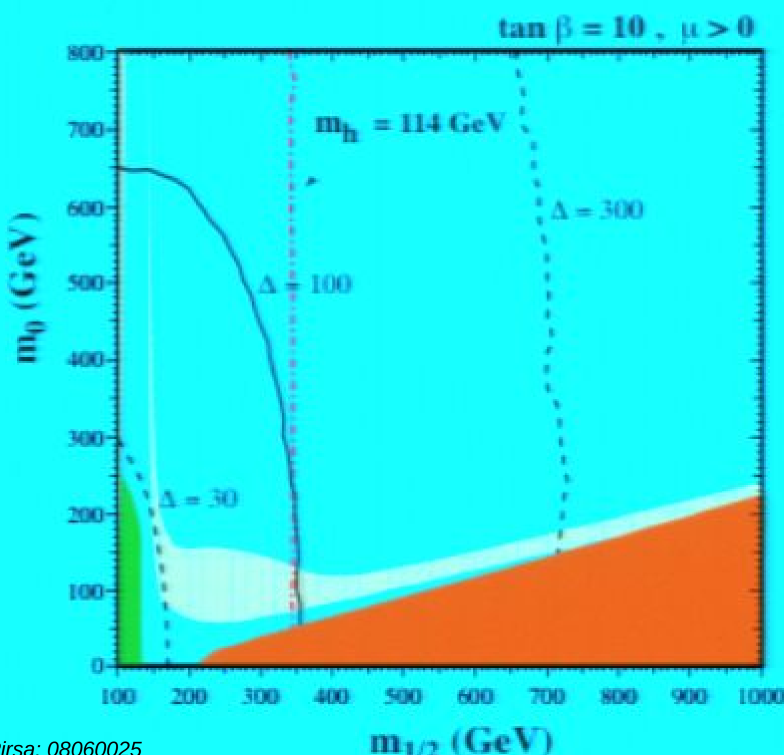


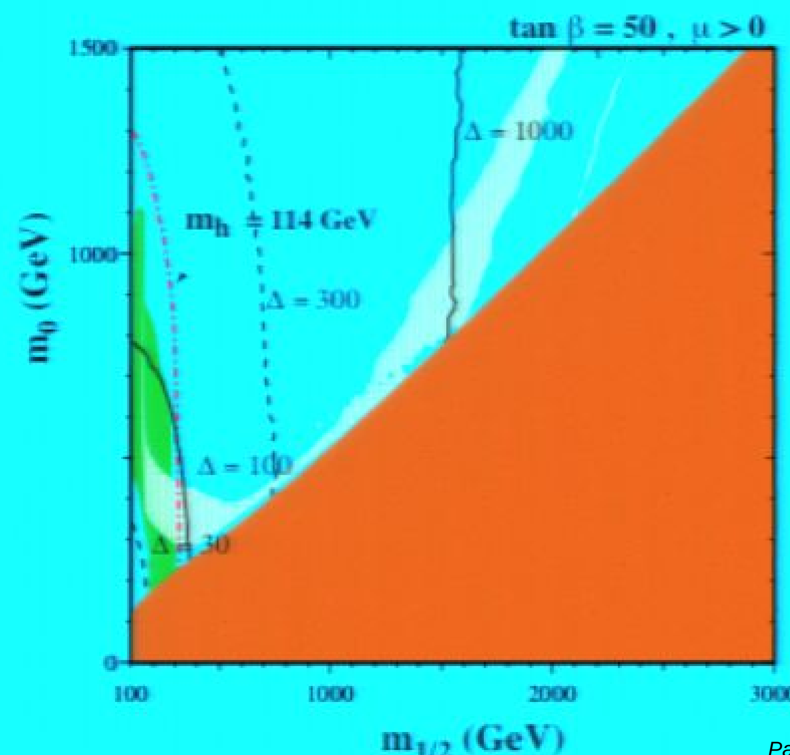


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

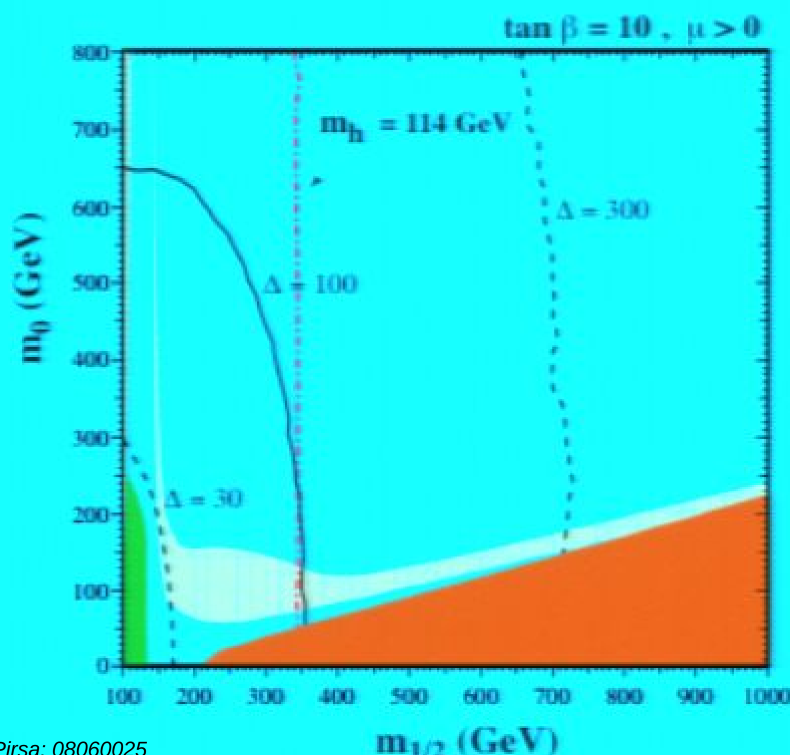


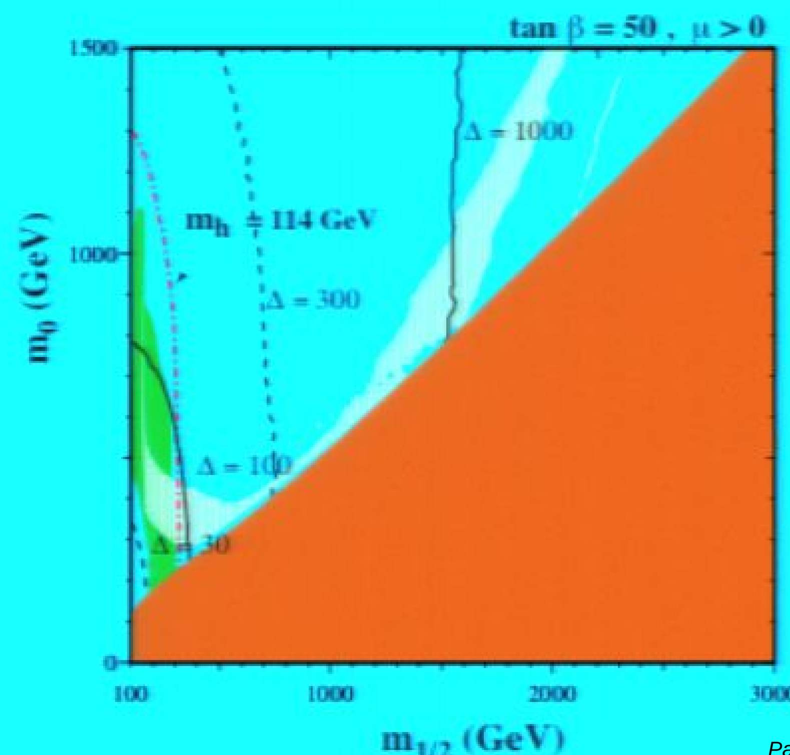


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S\,\frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}\,, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

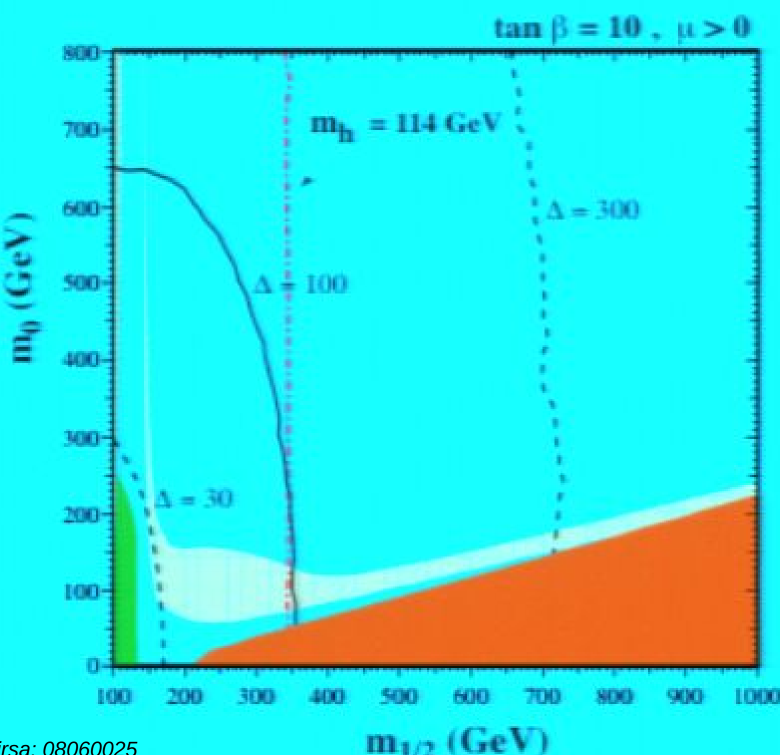


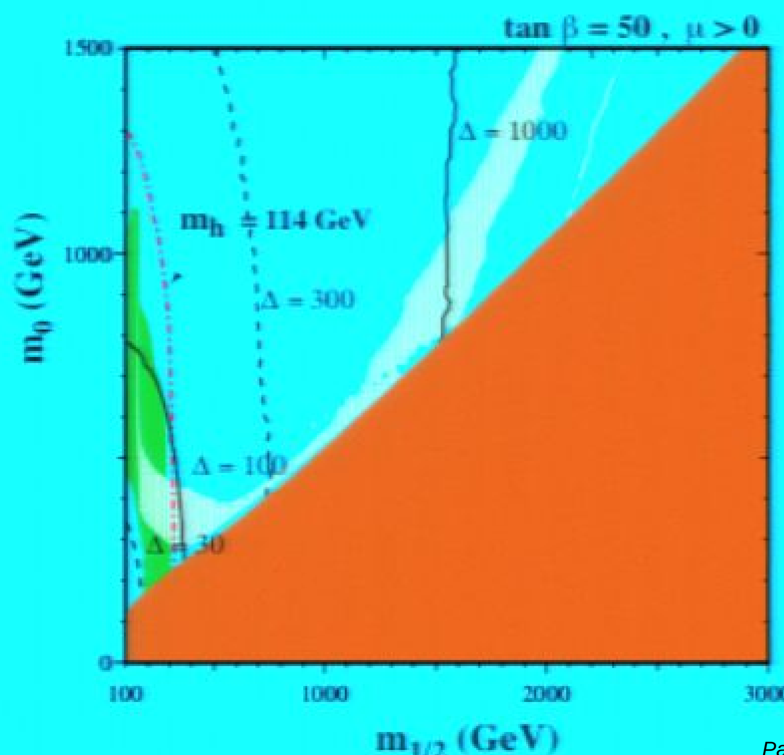


Define another sensitivity parameter $\quad \frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h} \, ,$

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \ \Delta_i{}^2}\,, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

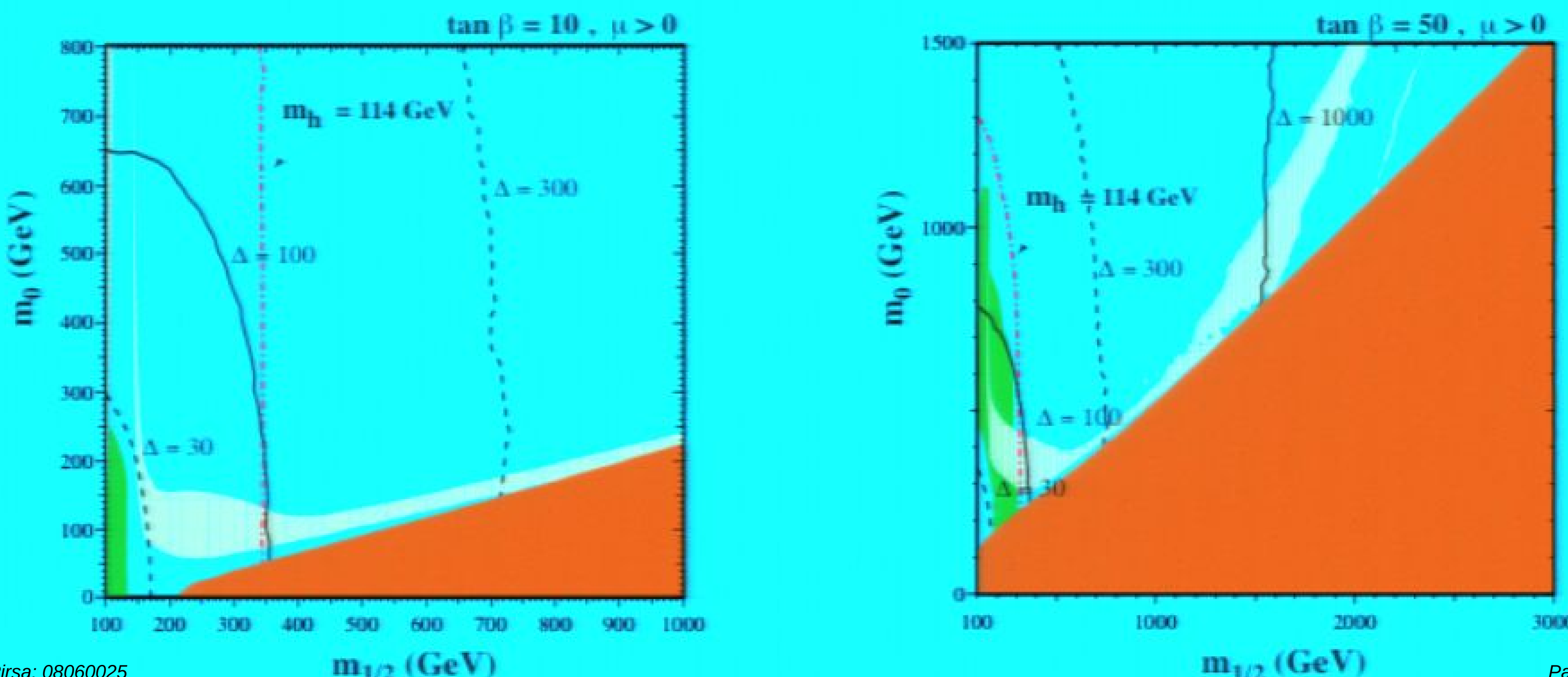




Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

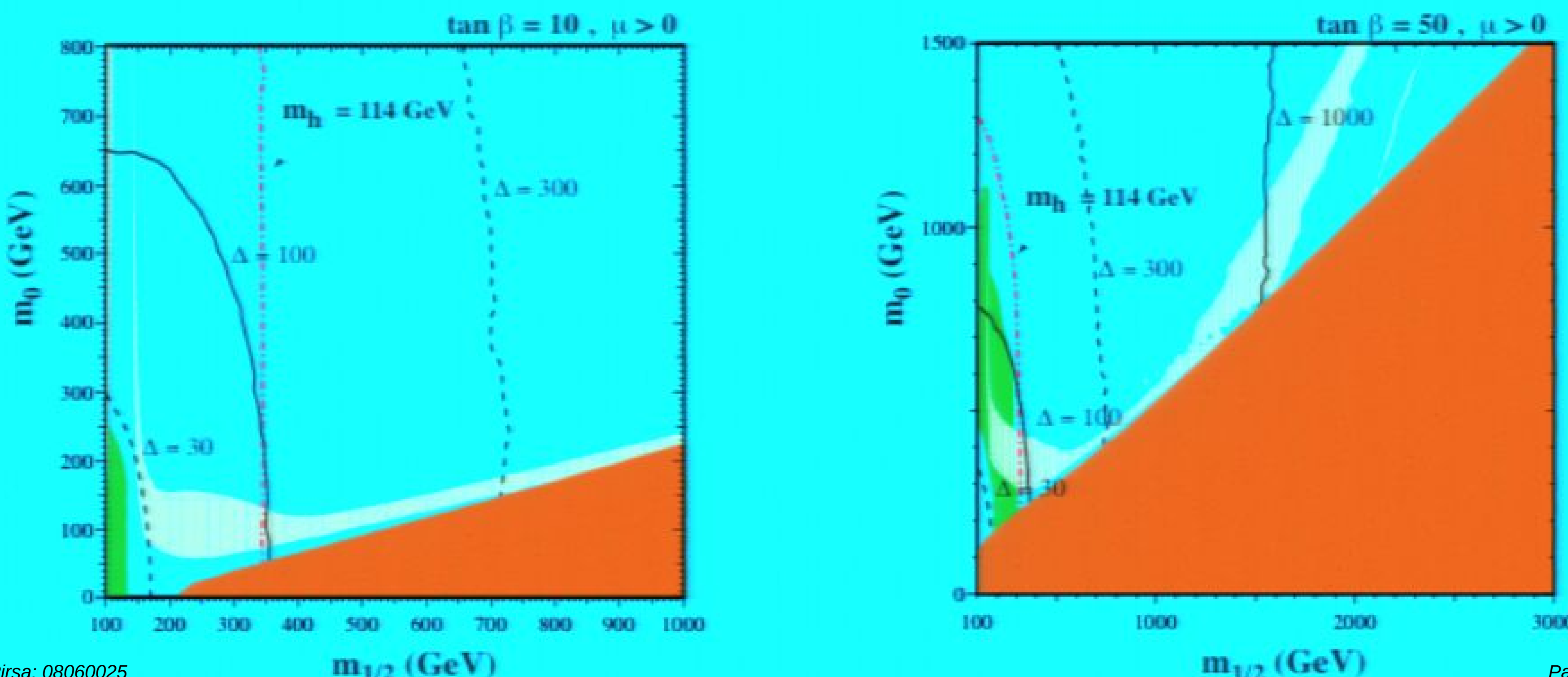
$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$



Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \, \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$



With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta\alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha}\,, \\
\frac{\Delta\tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta\alpha}{\alpha}\,.
\end{aligned}$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$
\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}
$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

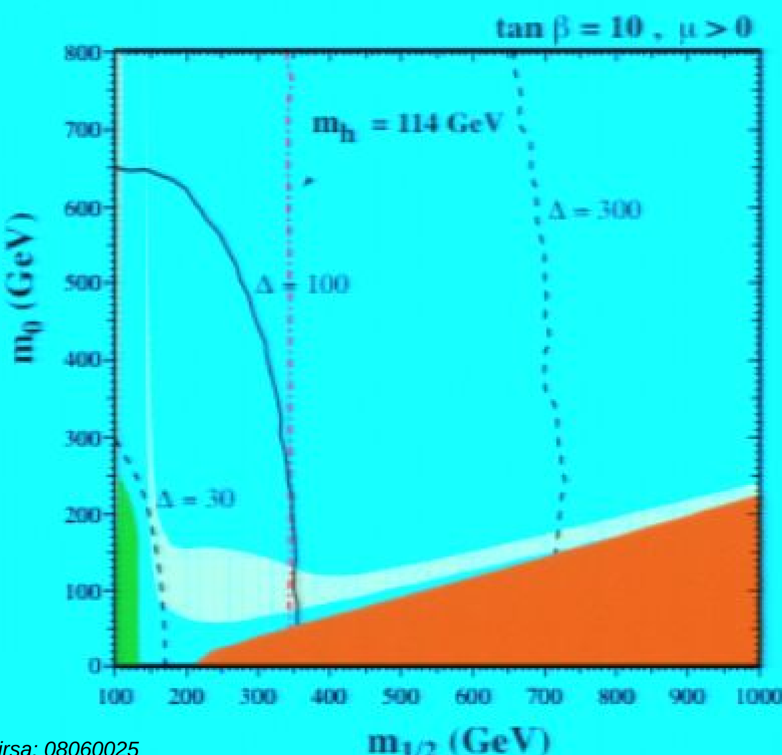
Putting both relations together:

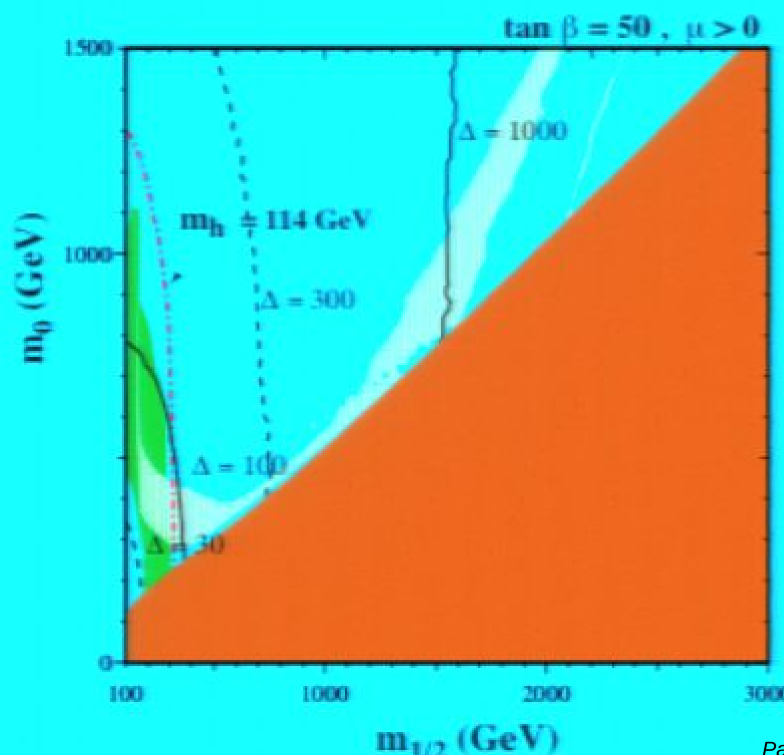
$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta\alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha}\,, \\
\frac{\Delta\tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta\alpha}{\alpha}\,.
\end{aligned}$$

Define another sensitivity parameter $\qquad \dfrac{\Delta v}{v} \equiv S\,\dfrac{\Delta h}{h}\,,$

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \ \Delta_i{}^2}\,, \qquad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

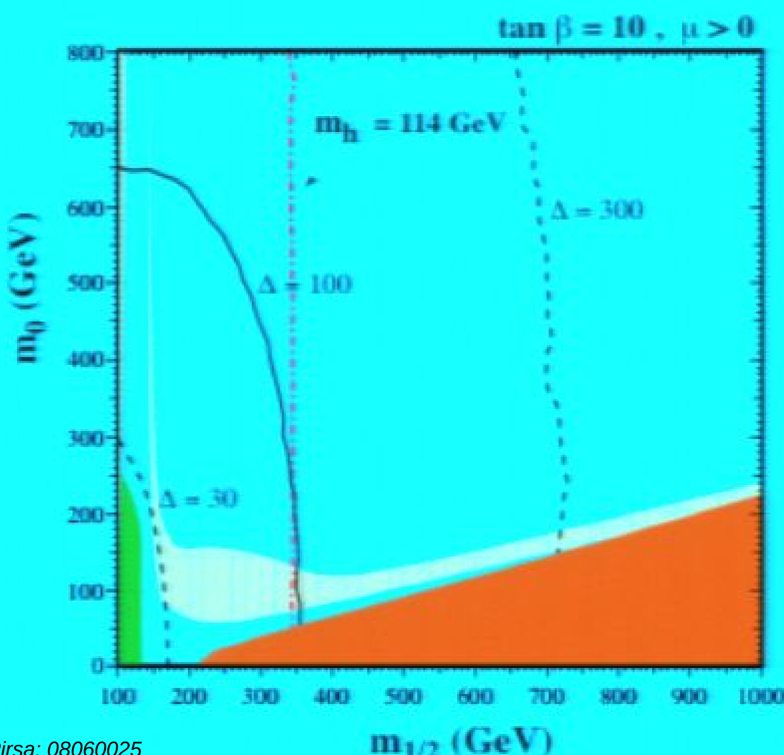


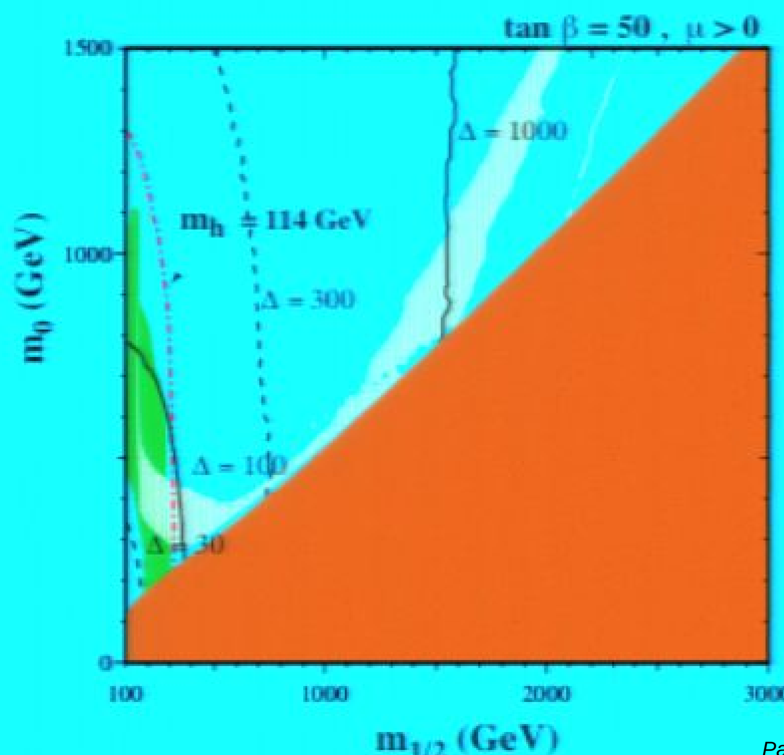


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$

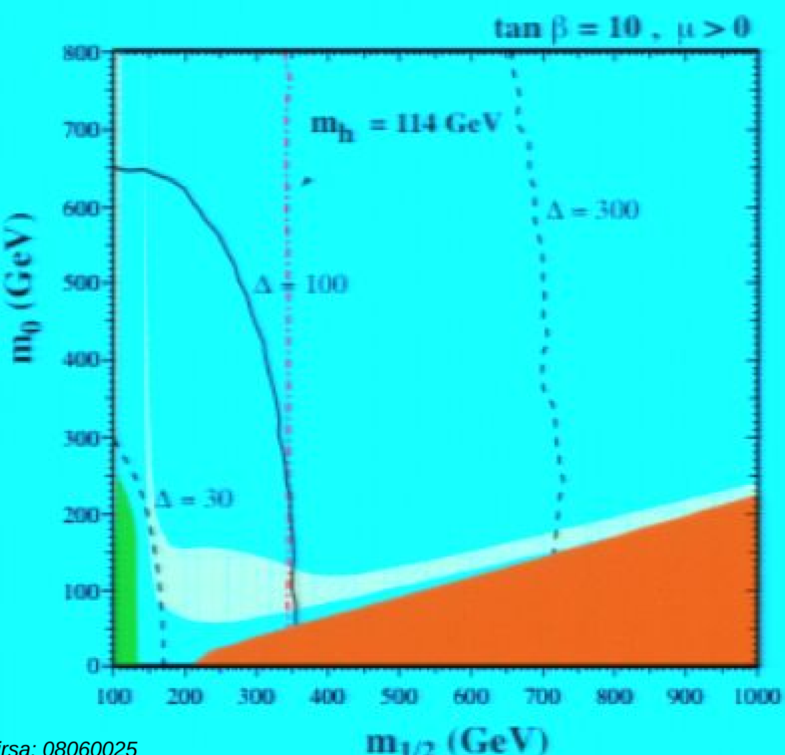


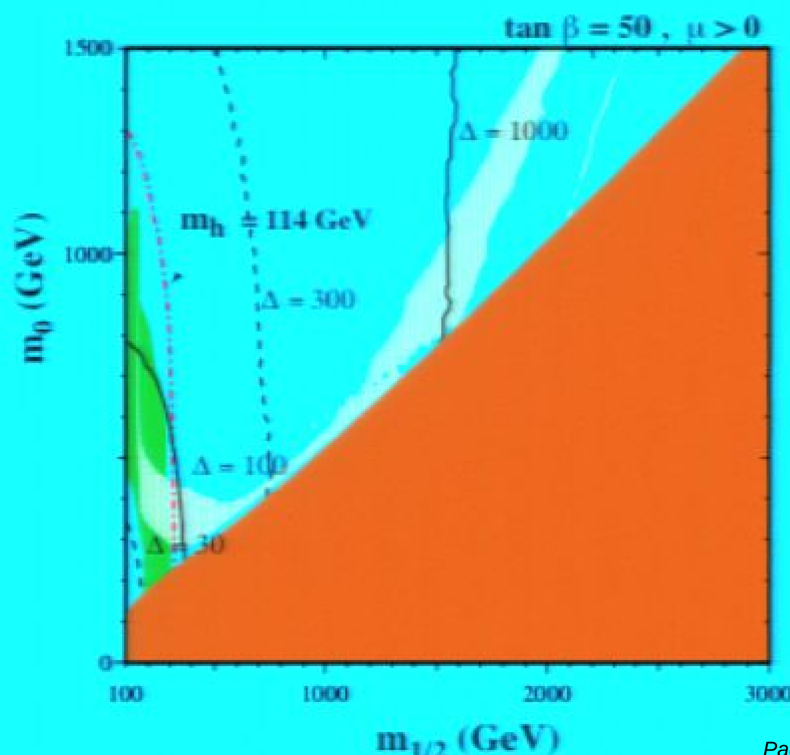


Define another sensitivity parameter $\frac{\Delta v}{v} \equiv S \frac{\Delta h}{h}$,

related SUSY finetuning parameters

$$\Delta = \sqrt{\sum_i \Delta_i{}^2}, \quad \Delta_i \equiv \frac{\partial \ln m_W}{\partial \ln a_i}$$





With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$
\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}
$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}$$

With, $\Delta \sim 100 - 400\ (1000)$, $\Delta_t \sim 80 - 250\ (500)$

Putting both relations together:

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$\begin{aligned}\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\ \frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\ \frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.\end{aligned}$$

$$\frac{\Delta B_D}{B_D} = (0.2-0.4r)(1+S)\,\frac{\Delta h}{h} + (1+0.5r)R\,\frac{\Delta \alpha}{\alpha} \quad \text{from } m_\pi$$

With, $\Delta \sim 100 - 400\ (1000)$, $\Delta_t \sim 80 - 250\ (500)$

Putting both relations together:

$$\begin{aligned}\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta\alpha}{\alpha}\\ \frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha},\\ \frac{\Delta\tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta\alpha}{\alpha}.\end{aligned}$$

$$\frac{\Delta B_D}{B_D} = (0.2-0.4r)(1+S)\,\frac{\Delta h}{h} + (1+0.5r)R\,\frac{\Delta\alpha}{\alpha}$$ from m_π

and with $\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta\alpha_U}{\alpha_U}$

$$\begin{aligned}\frac{\Delta B_D}{B_D} &= -[6.5(1+S) - 18R]\frac{\Delta\alpha}{\alpha}\\ \frac{\Delta Q}{Q} &= (0.1 + 0.7S - 0.6R)\frac{\Delta\alpha}{\alpha}\\ \frac{\Delta\tau_n}{\tau_n} &= -[0.2 + 2S - 3.8R]\frac{\Delta\alpha}{\alpha},\end{aligned}$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}.
\end{aligned}$$

$$\frac{\Delta B_D}{B_D} = (0.2-0.4r)(1+S)\,\frac{\Delta h}{h} + (1+0.5r)R\,\frac{\Delta \alpha}{\alpha} \quad \text{from } m_\pi$$

and with $\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -[6.5(1+S) - 18R]\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= (0.1 + 0.7S - 0.6R)\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta \tau_n}{\tau_n} &= -[0.2 + 2S - 3.8R]\frac{\Delta \alpha}{\alpha},
\end{aligned}$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta\alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta\alpha}{\alpha}\,, \\
\frac{\Delta\tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta\alpha}{\alpha}\,.
\end{aligned}$$

$$\frac{\Delta B_D}{B_D} = (0.2-0.4r)(1+S)\,\frac{\Delta h}{h} + (1+0.5r)R\,\frac{\Delta\alpha}{\alpha}$$ from m_π

and with $\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta\alpha_U}{\alpha_U}$

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -[6.5(1+S) - 18R]\frac{\Delta\alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= (0.1 + 0.7S - 0.6R)\frac{\Delta\alpha}{\alpha} \\
\frac{\Delta\tau_n}{\tau_n} &= -[0.2 + 2S - 3.8R]\frac{\Delta\alpha}{\alpha}\,,
\end{aligned}$$

With, $\Delta \sim 100$ - 400 (1000), $\Delta_t \sim 80$ - 250 (500)

Putting both relations together:

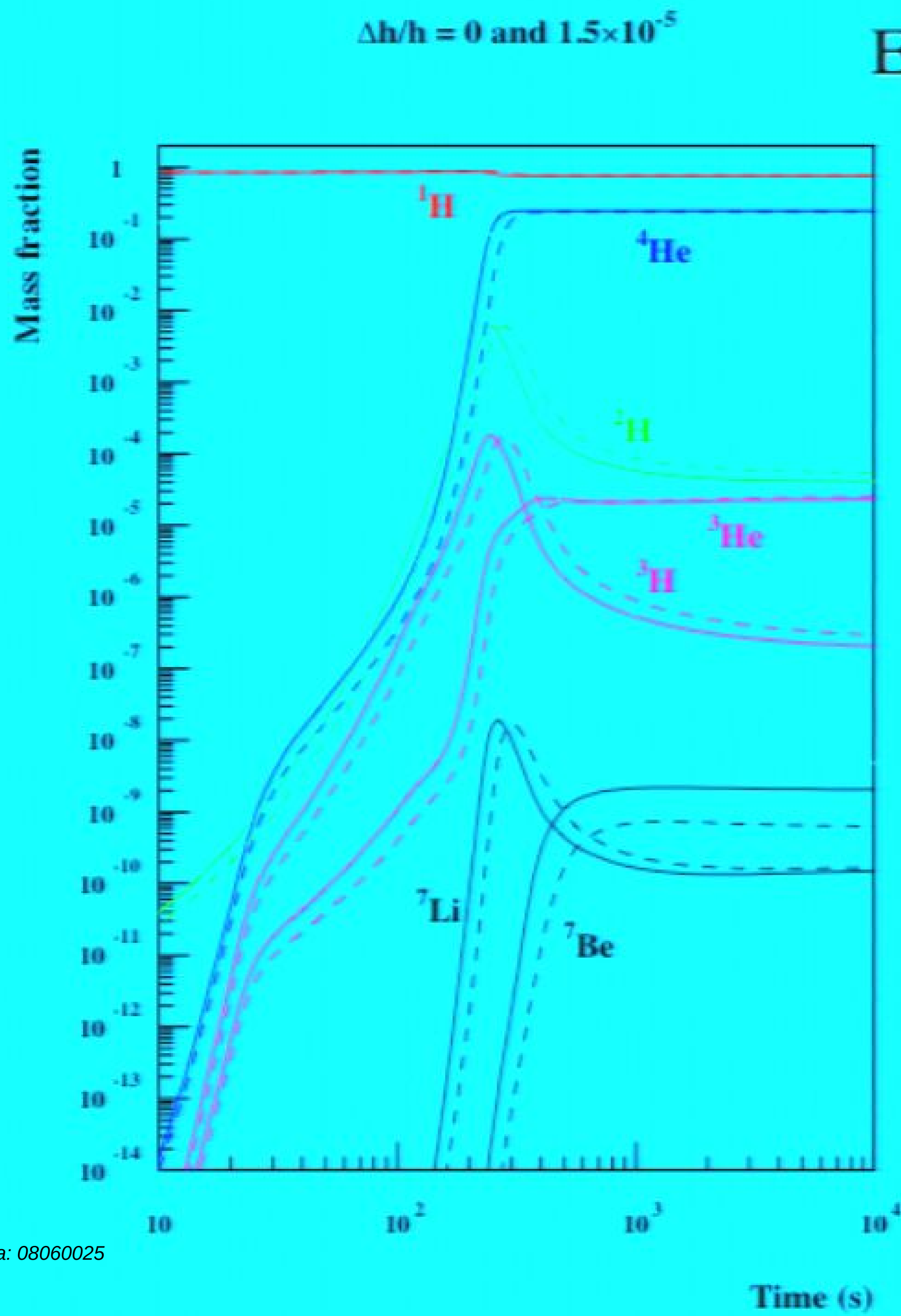
$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13(1+S)\,\frac{\Delta h}{h} + 18R\,\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= 1.5(1+S)\,\frac{\Delta h}{h} - 0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -(8+4S)\frac{\Delta h}{h} + 3.8(1+R)\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}$$

$$\frac{\Delta B_D}{B_D} = (0.2-0.4r)(1+S)\,\frac{\Delta h}{h} + (1+0.5r)R\,\frac{\Delta \alpha}{\alpha}$$ from m_π

and with $\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta \alpha_U}{\alpha_U}$

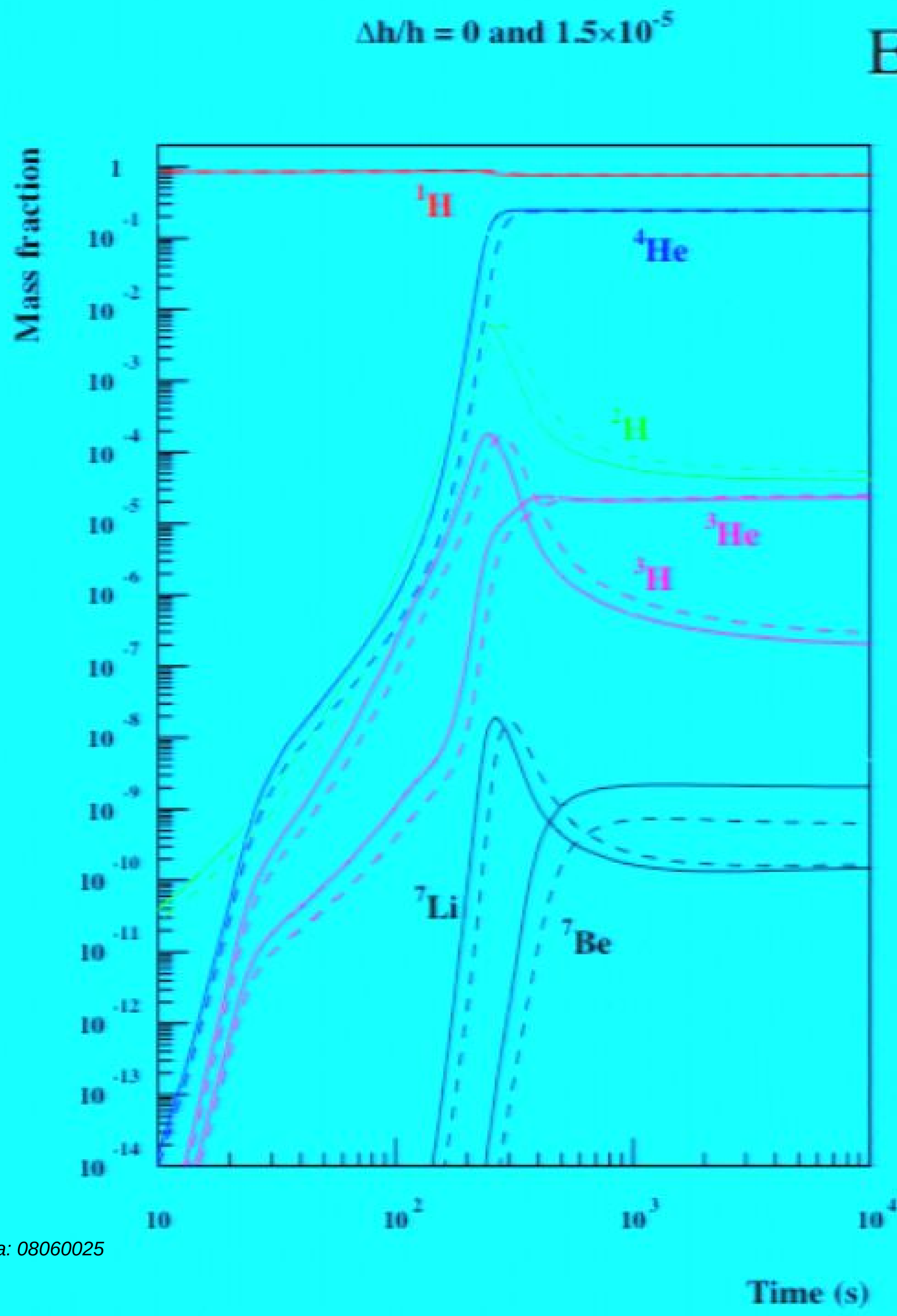
$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -[6.5(1+S) - 18R]\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta Q}{Q} &= (0.1 + 0.7S - 0.6R)\frac{\Delta \alpha}{\alpha} \\
\frac{\Delta \tau_n}{\tau_n} &= -[0.2 + 2S - 3.8R]\frac{\Delta \alpha}{\alpha}\,,
\end{aligned}$$

Effect of variations of h (S = 160)



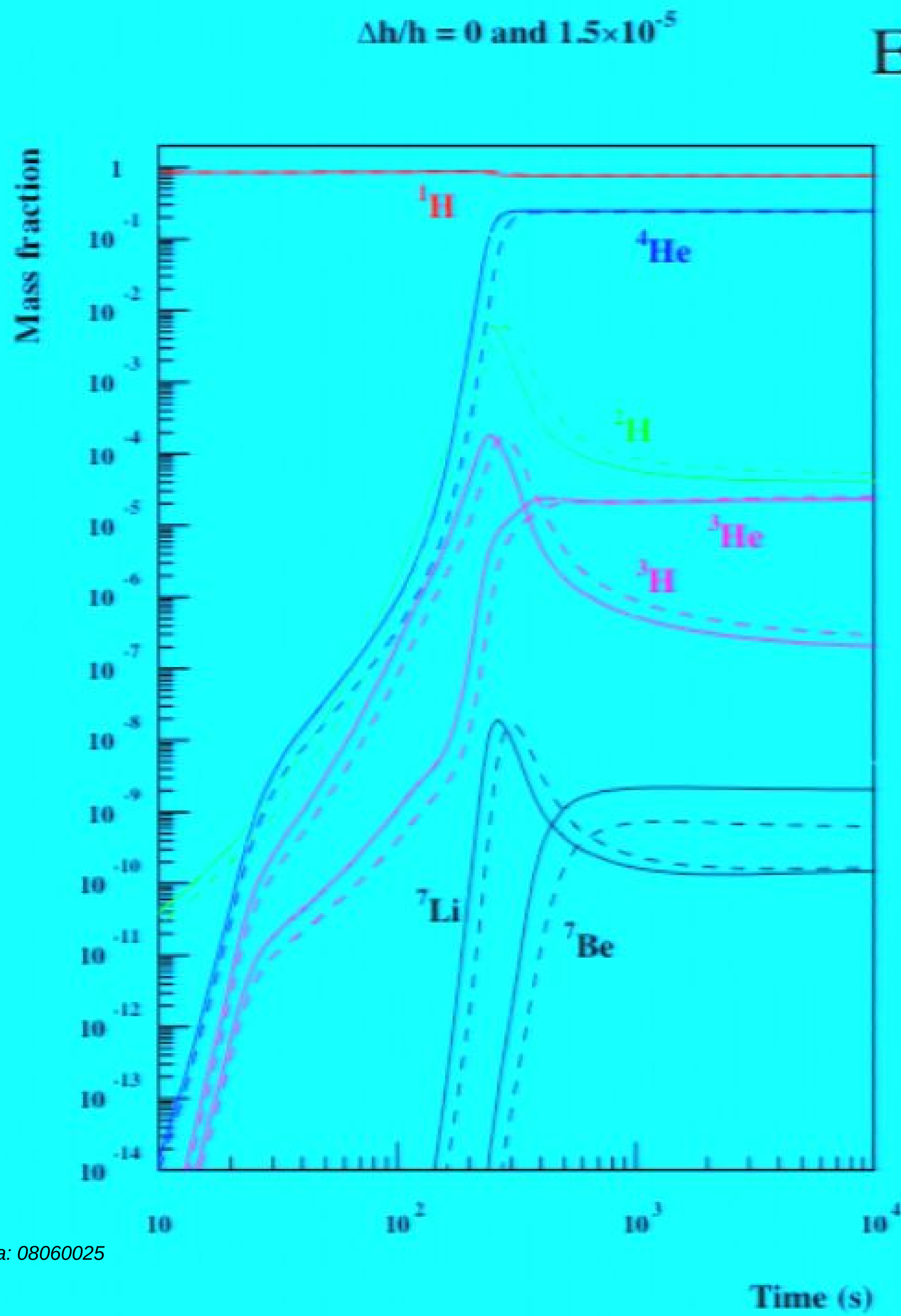
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



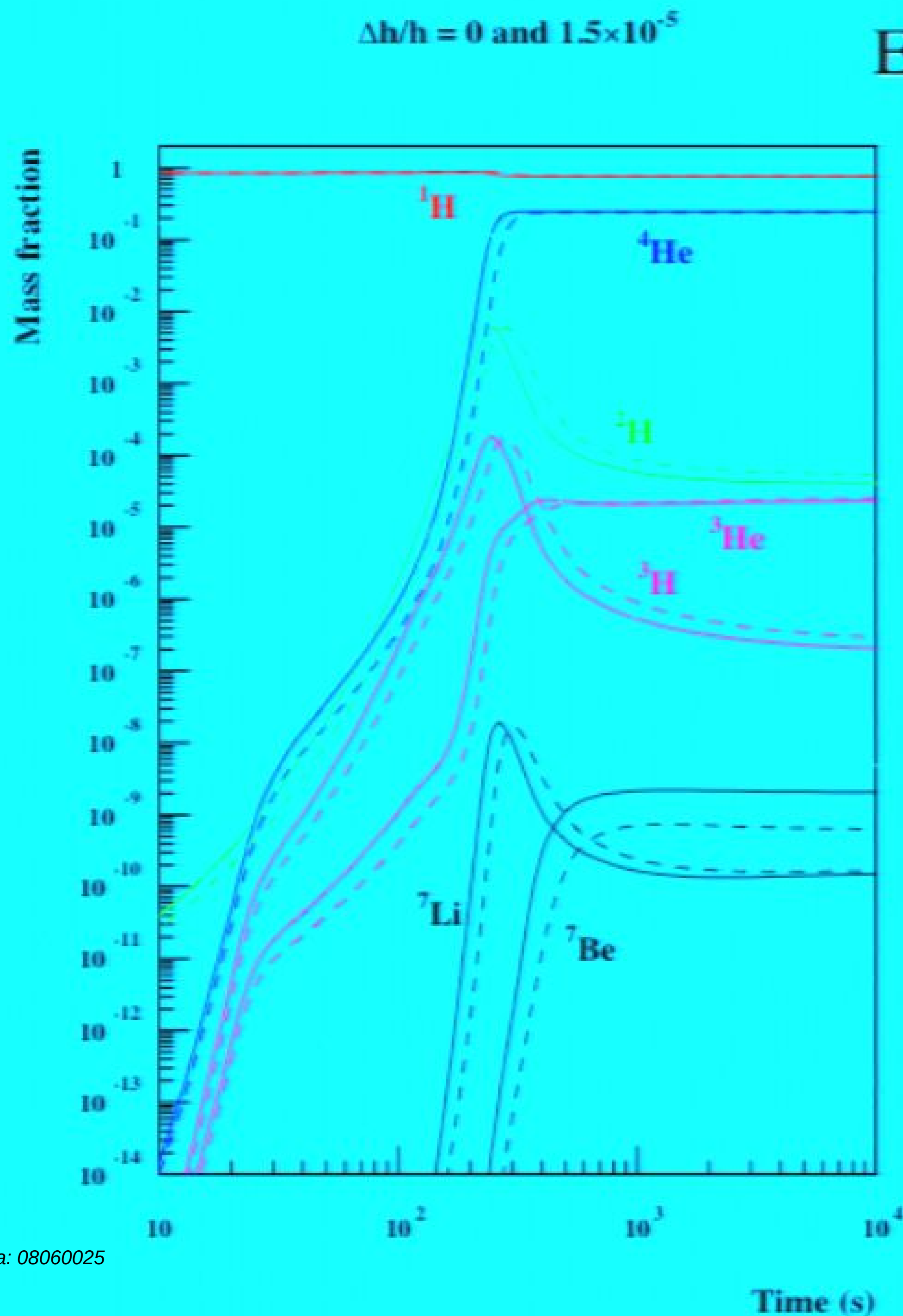
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



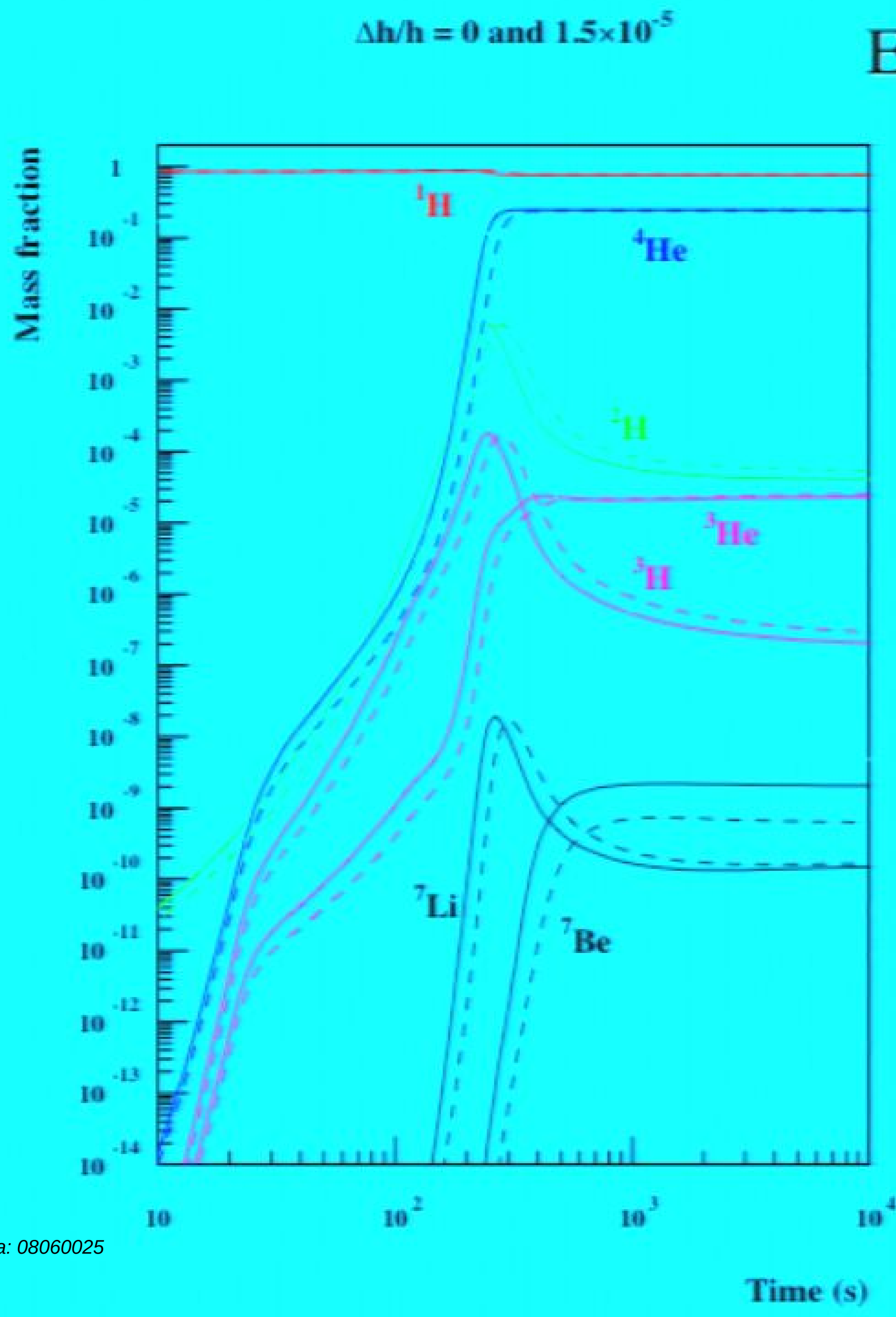
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



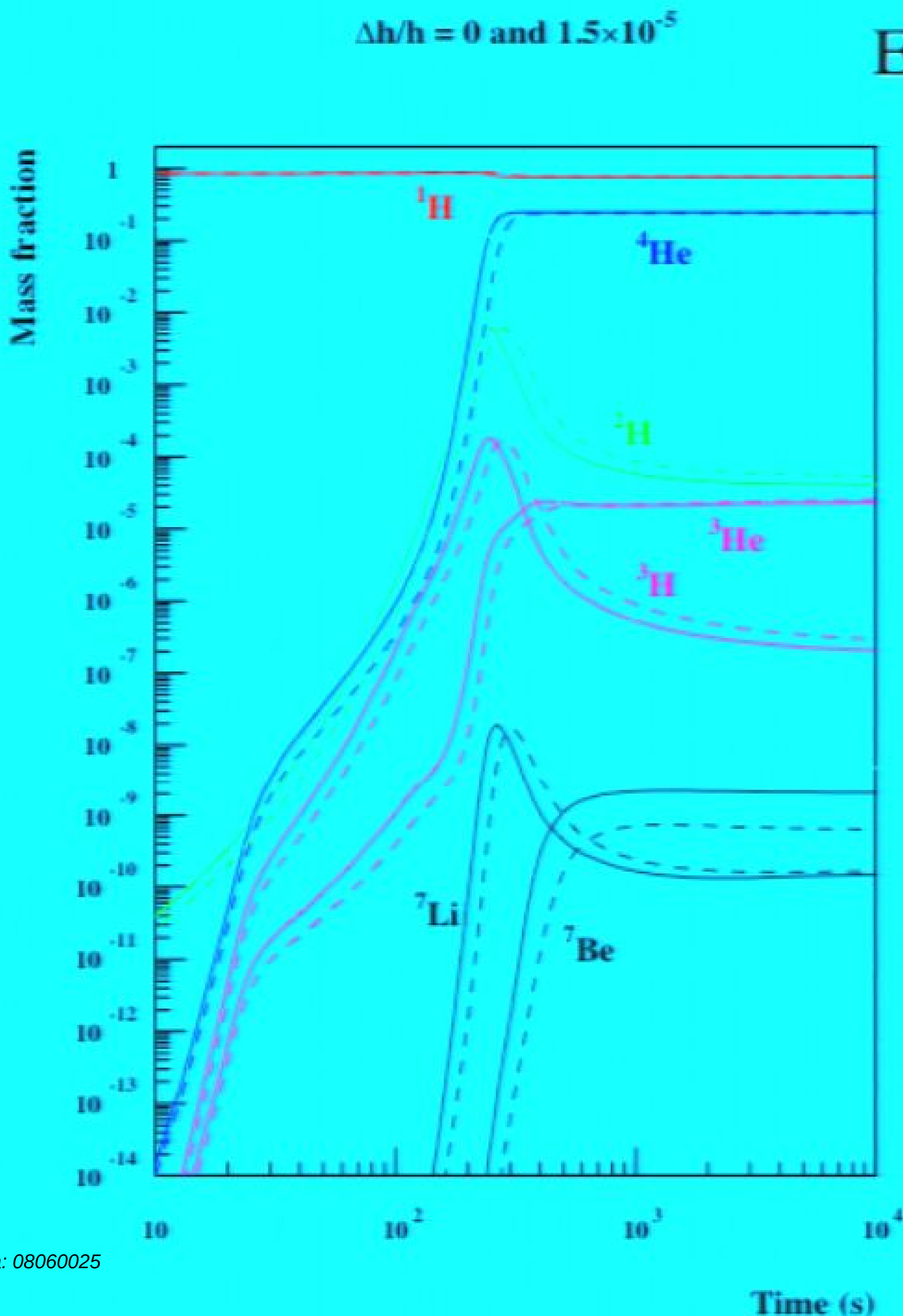
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



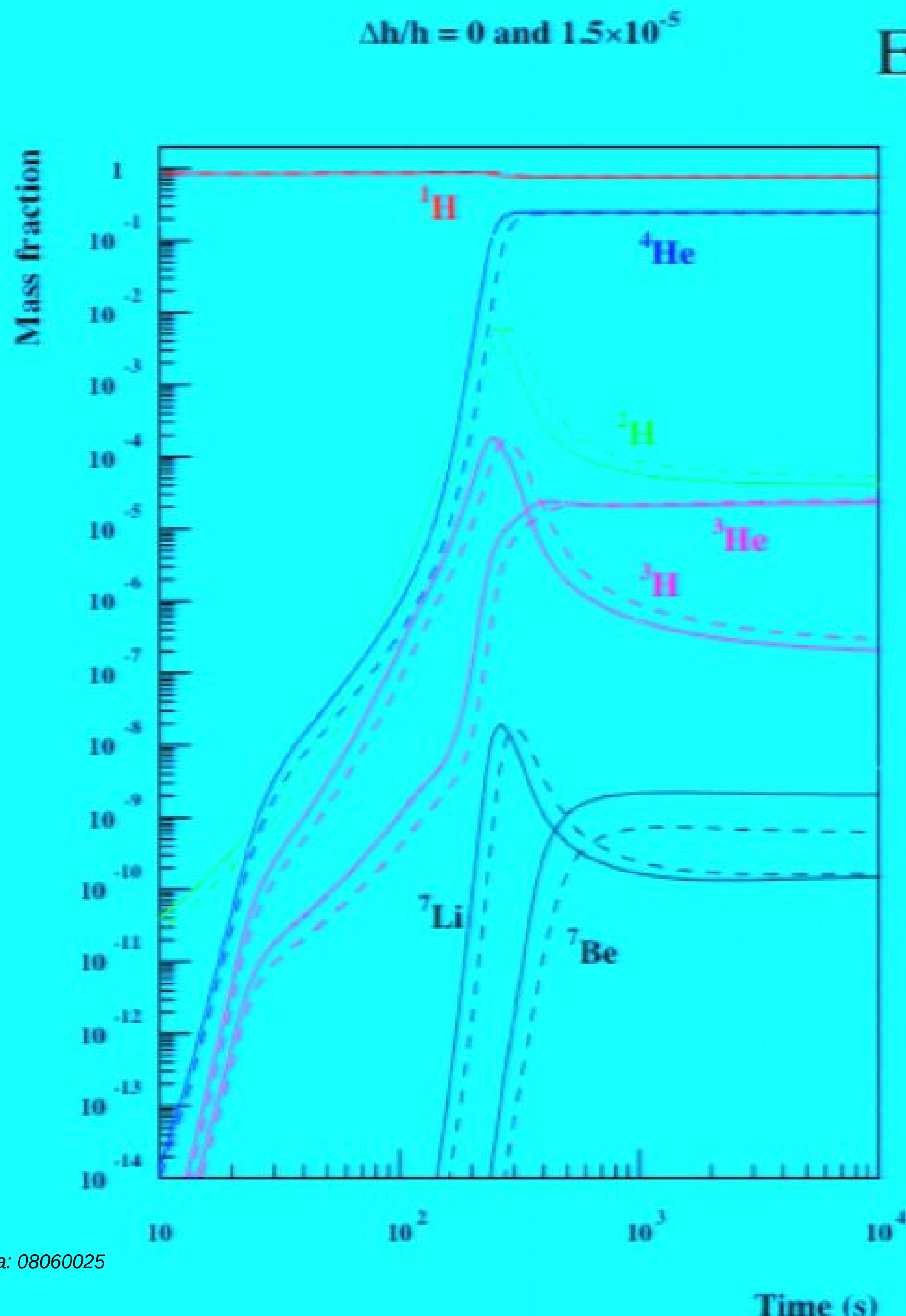
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



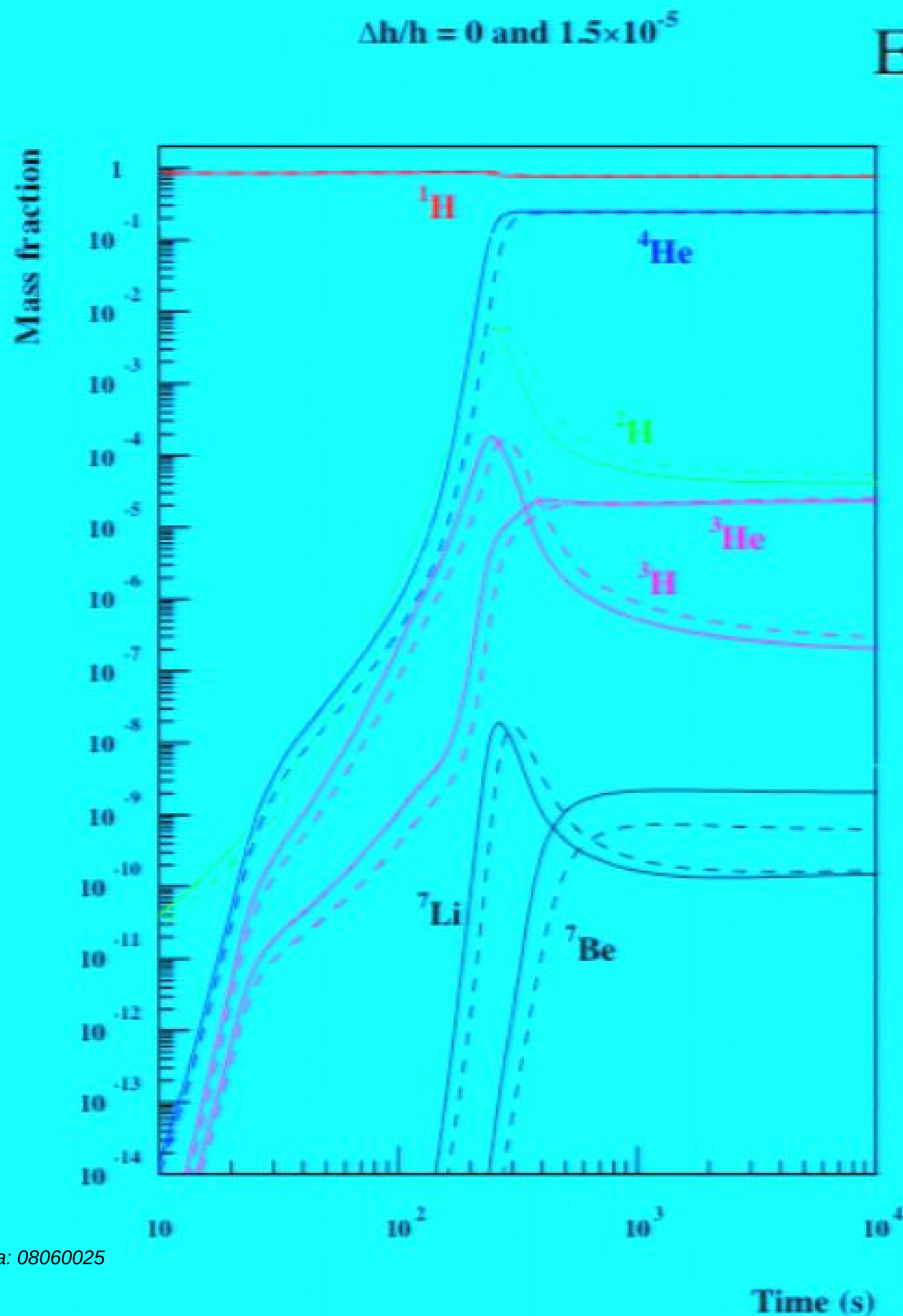
Notice effect on ^{7}Li

Effect of variations of h (S = 160)



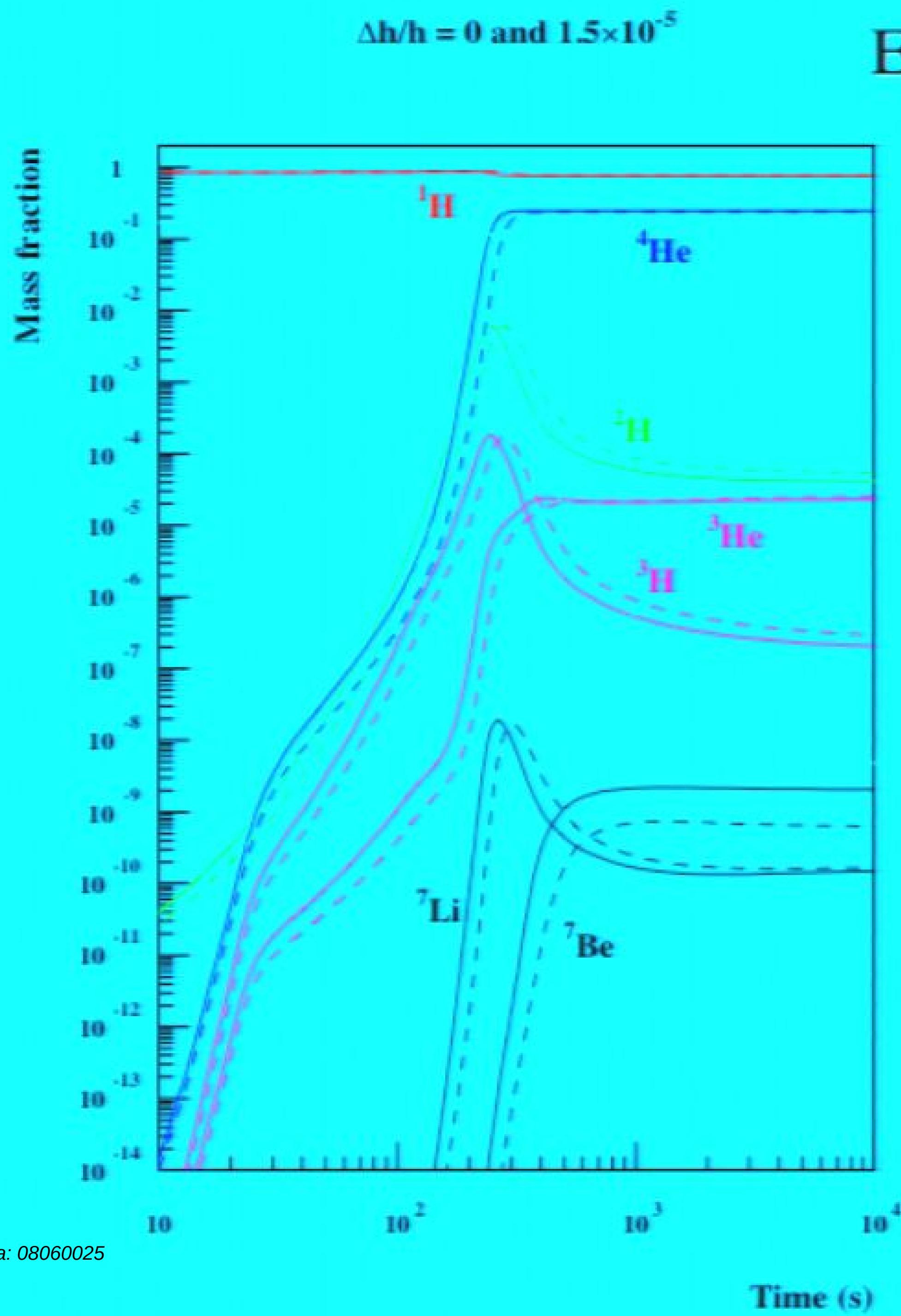
Notice effect on ^7Li

Effect of variations of h (S = 160)

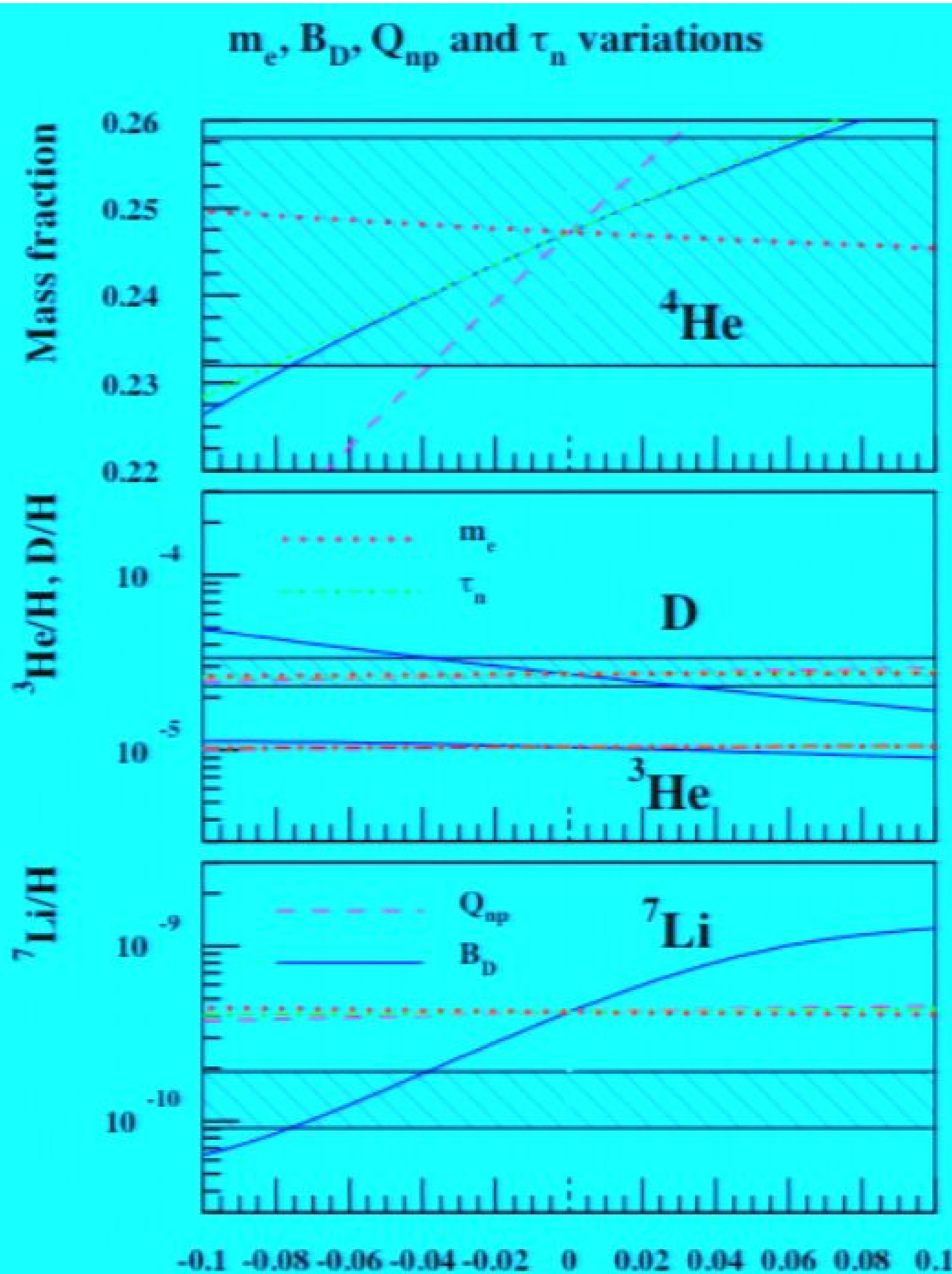


Notice effect on ^{7}Li

Effect of variations of h (S = 160)

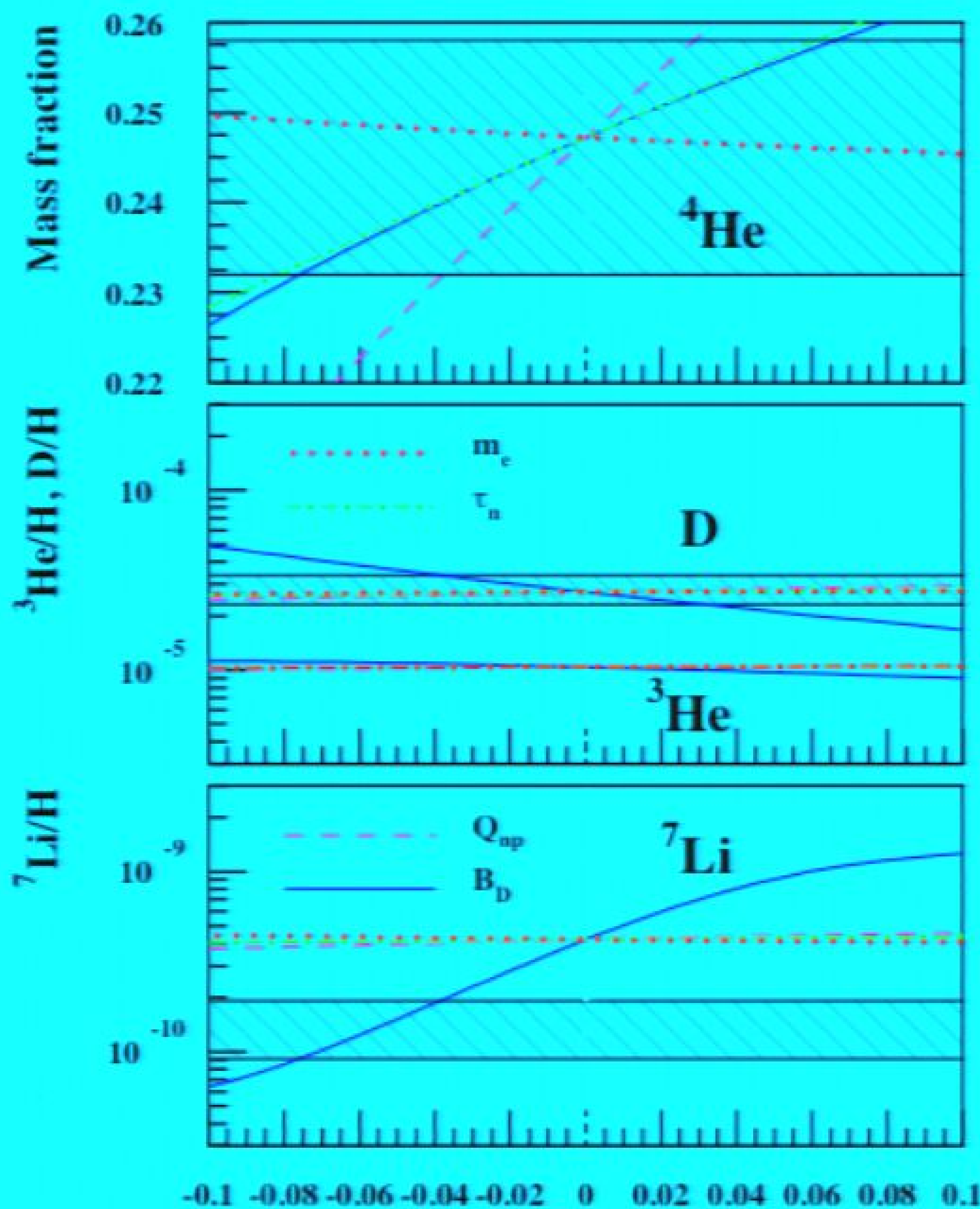


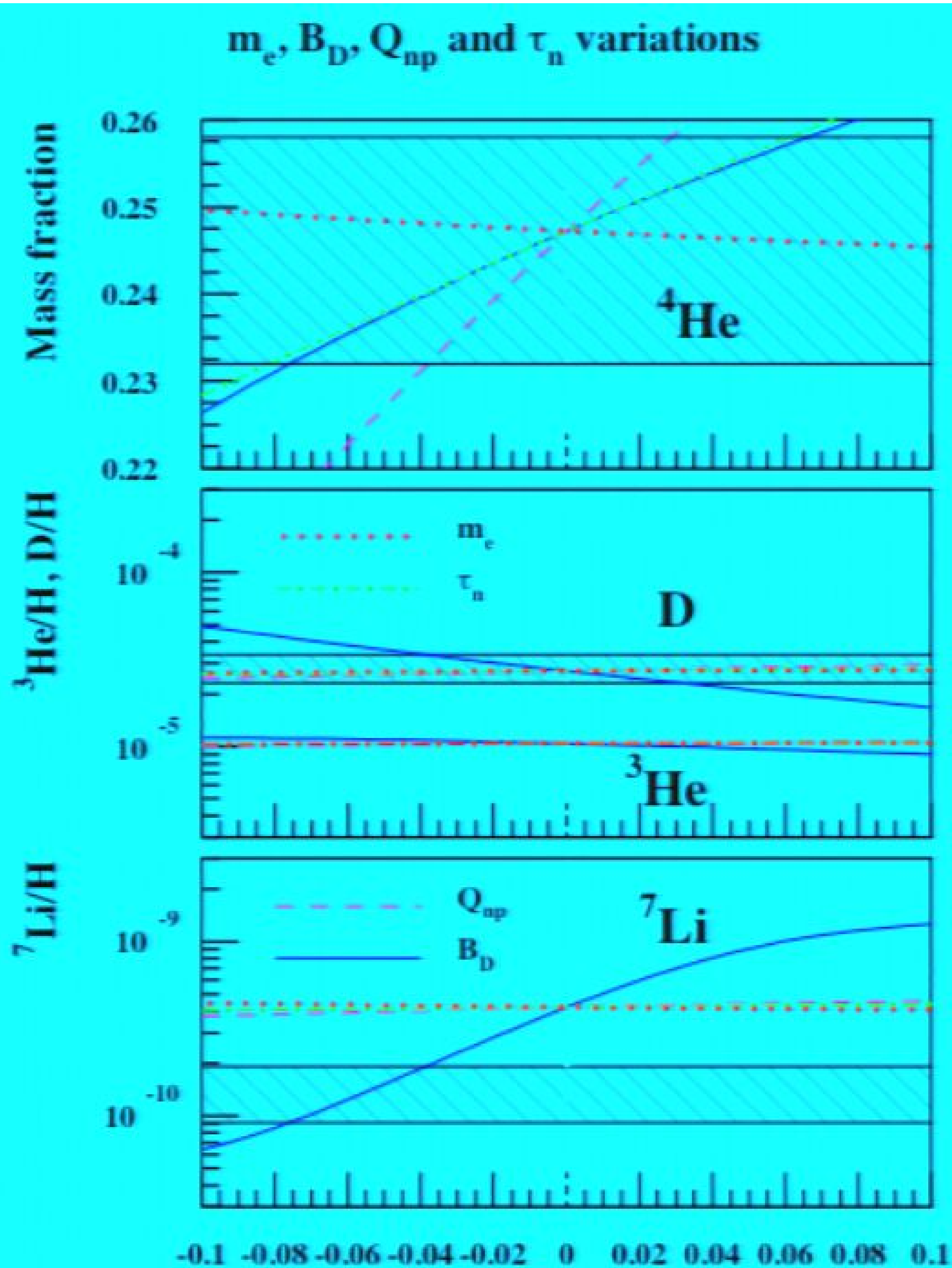
Notice effect on ^{7}Li



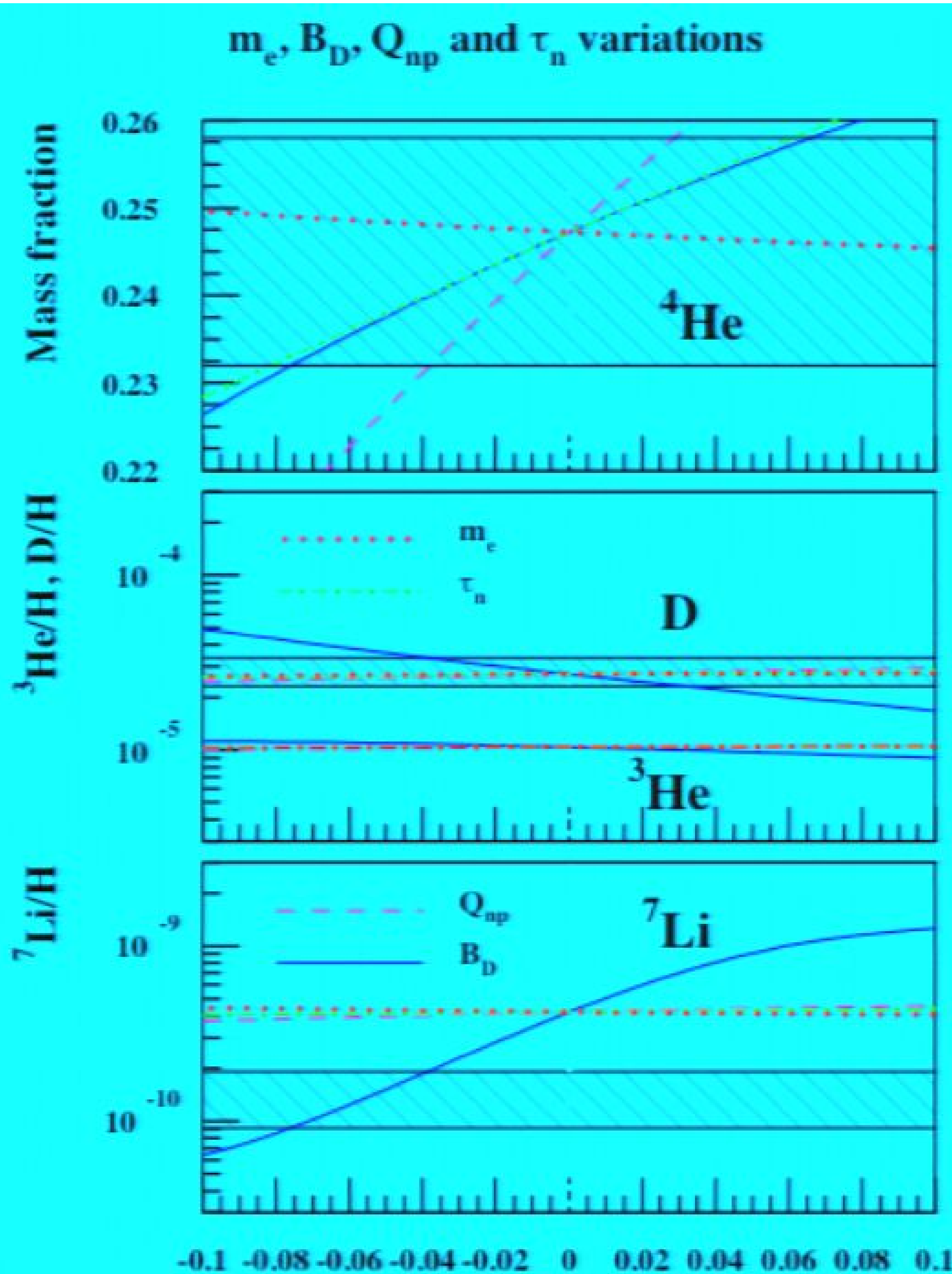
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

m_e, B_D, Q_{np} and τ_n variations

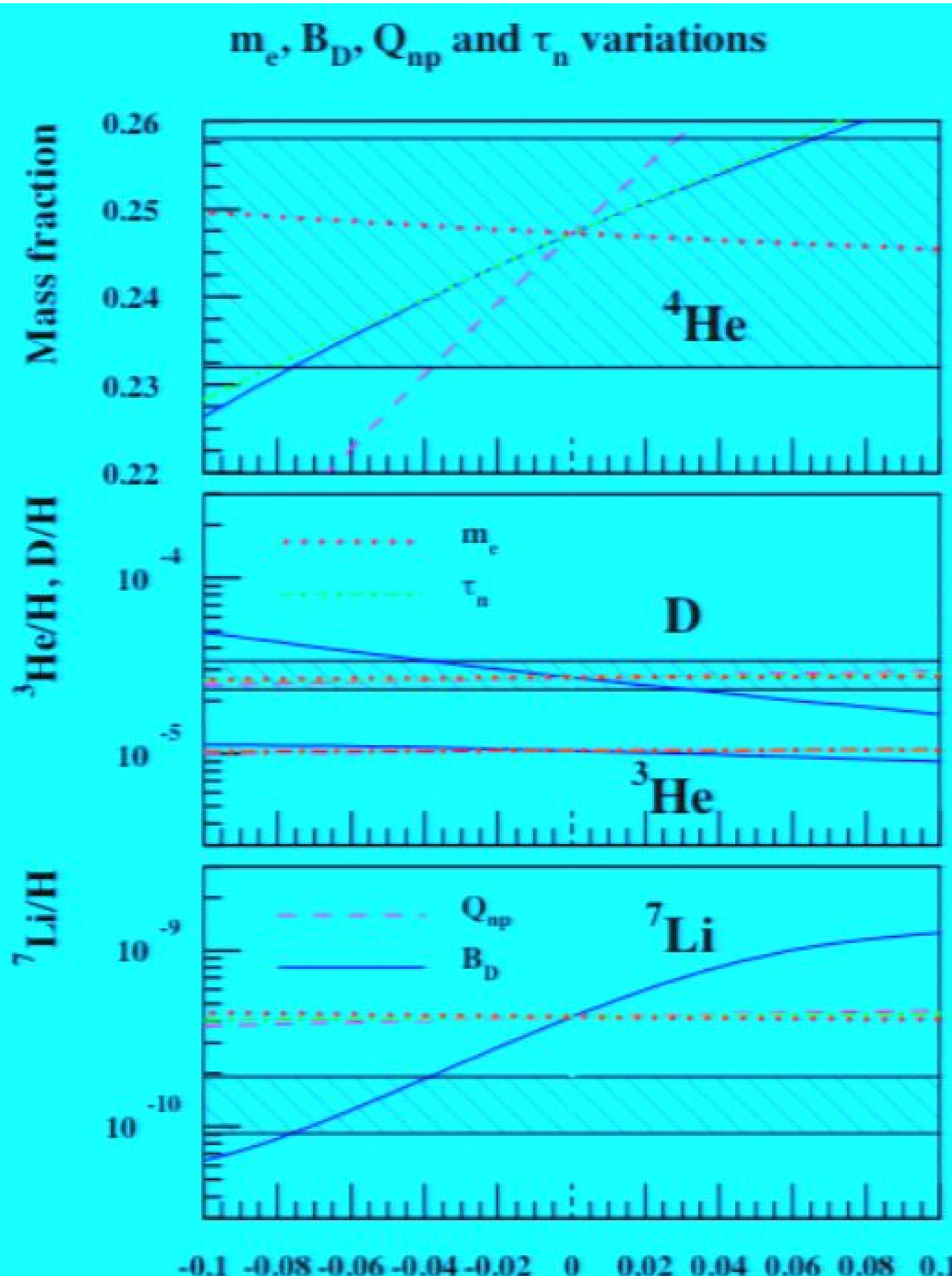




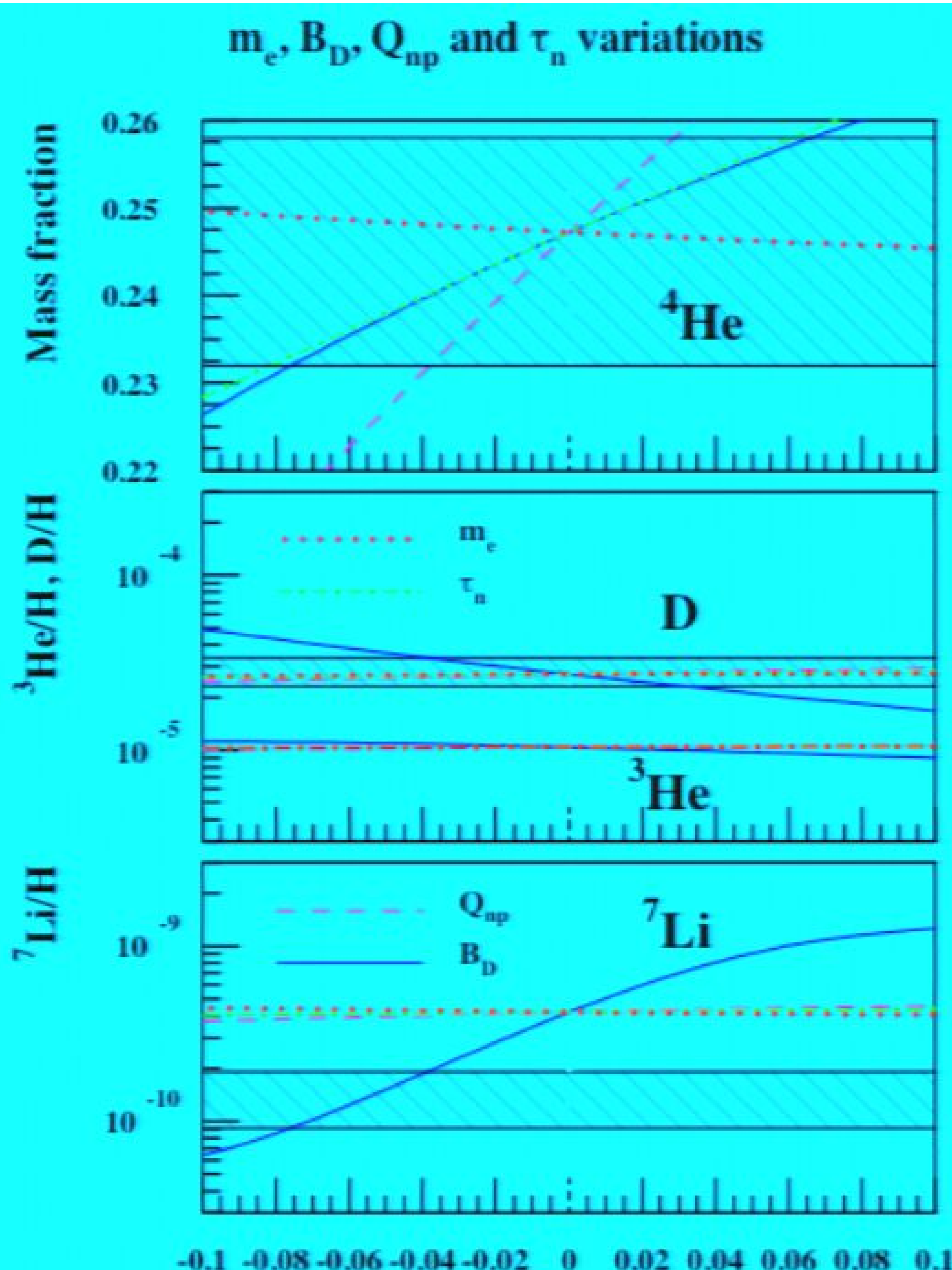
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
10 -4
10 -5
m_e
τ_n
D
3He
7Li/H
10 -9
10 -10
Q_np
B_D
7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

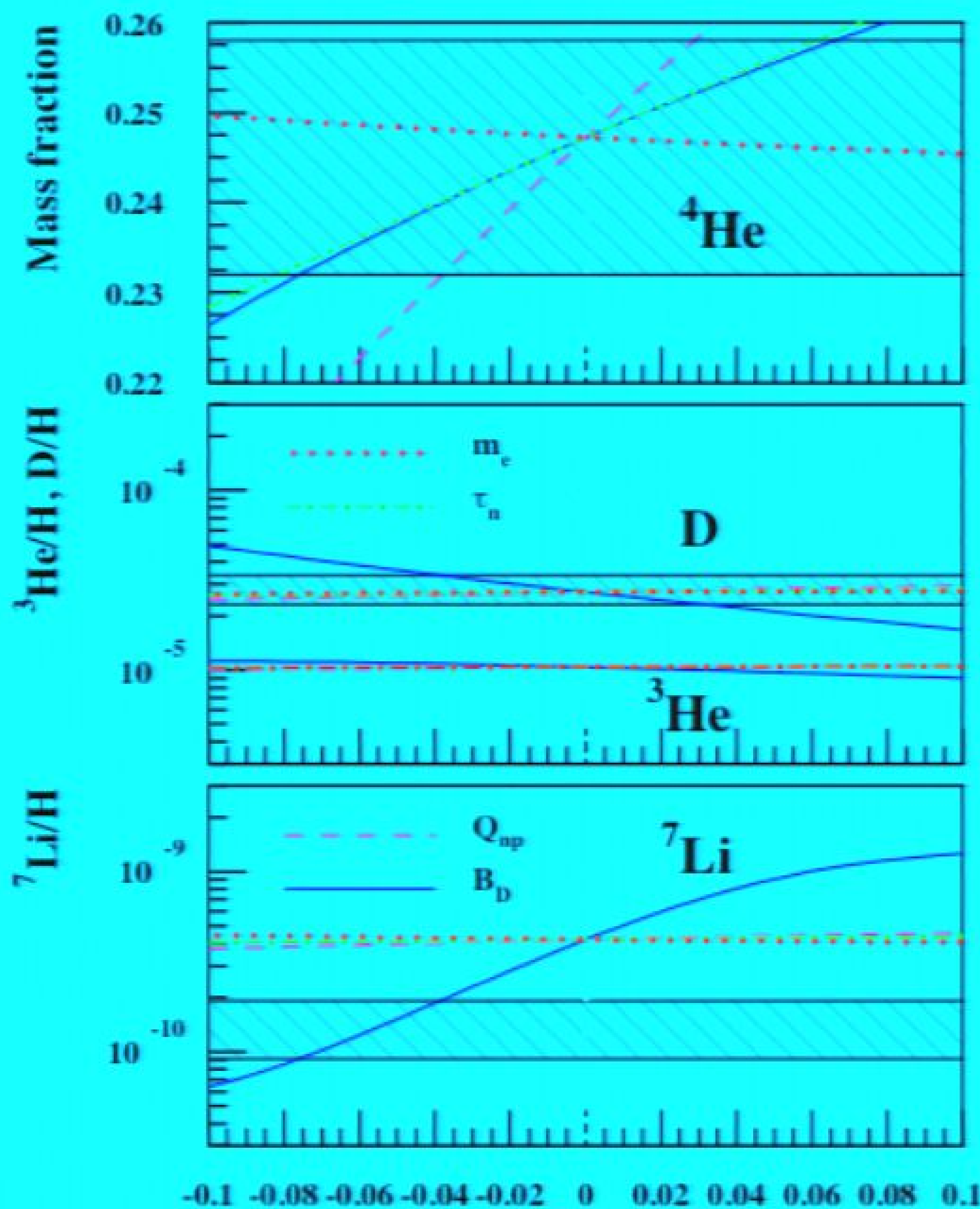


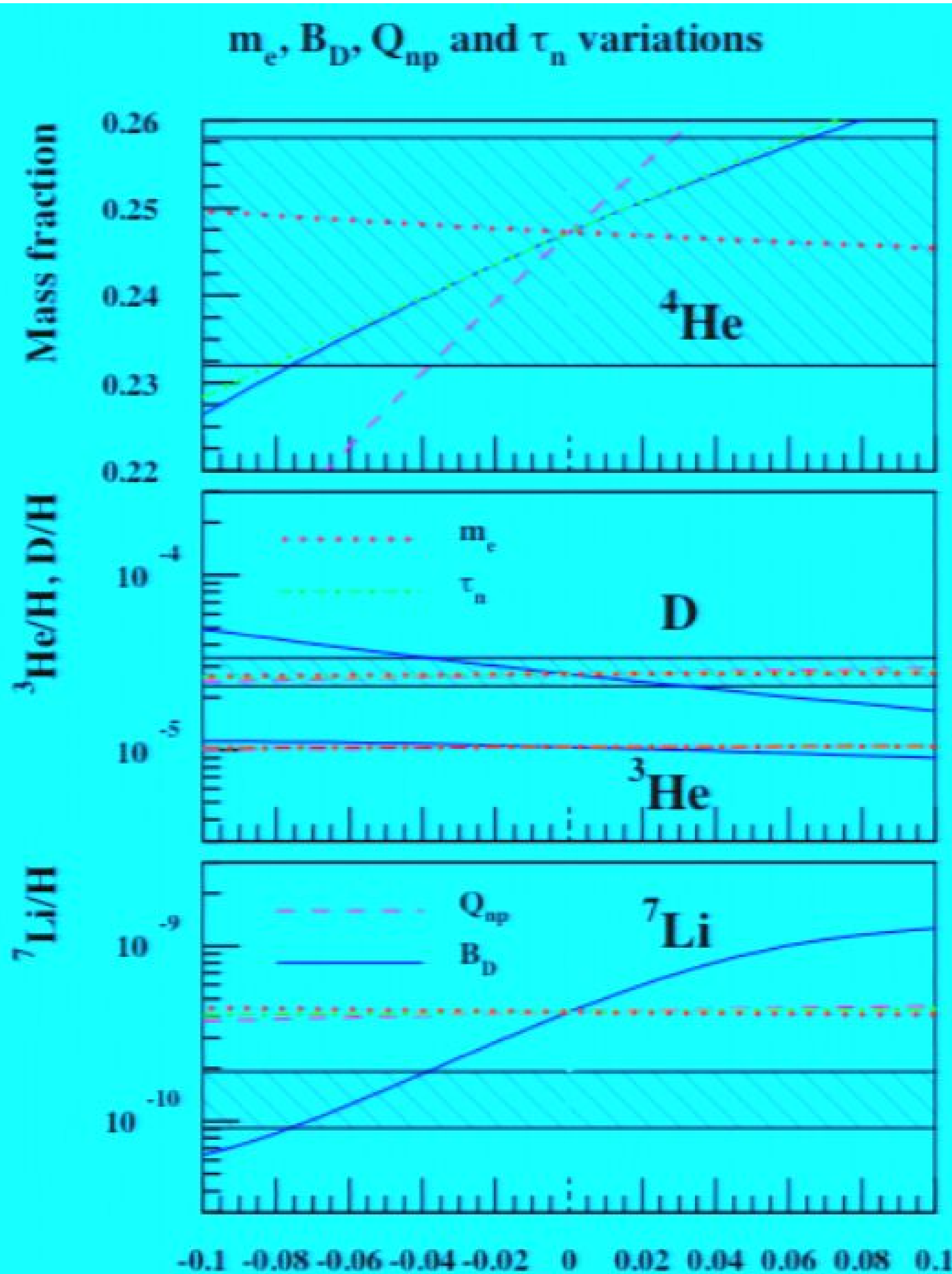
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

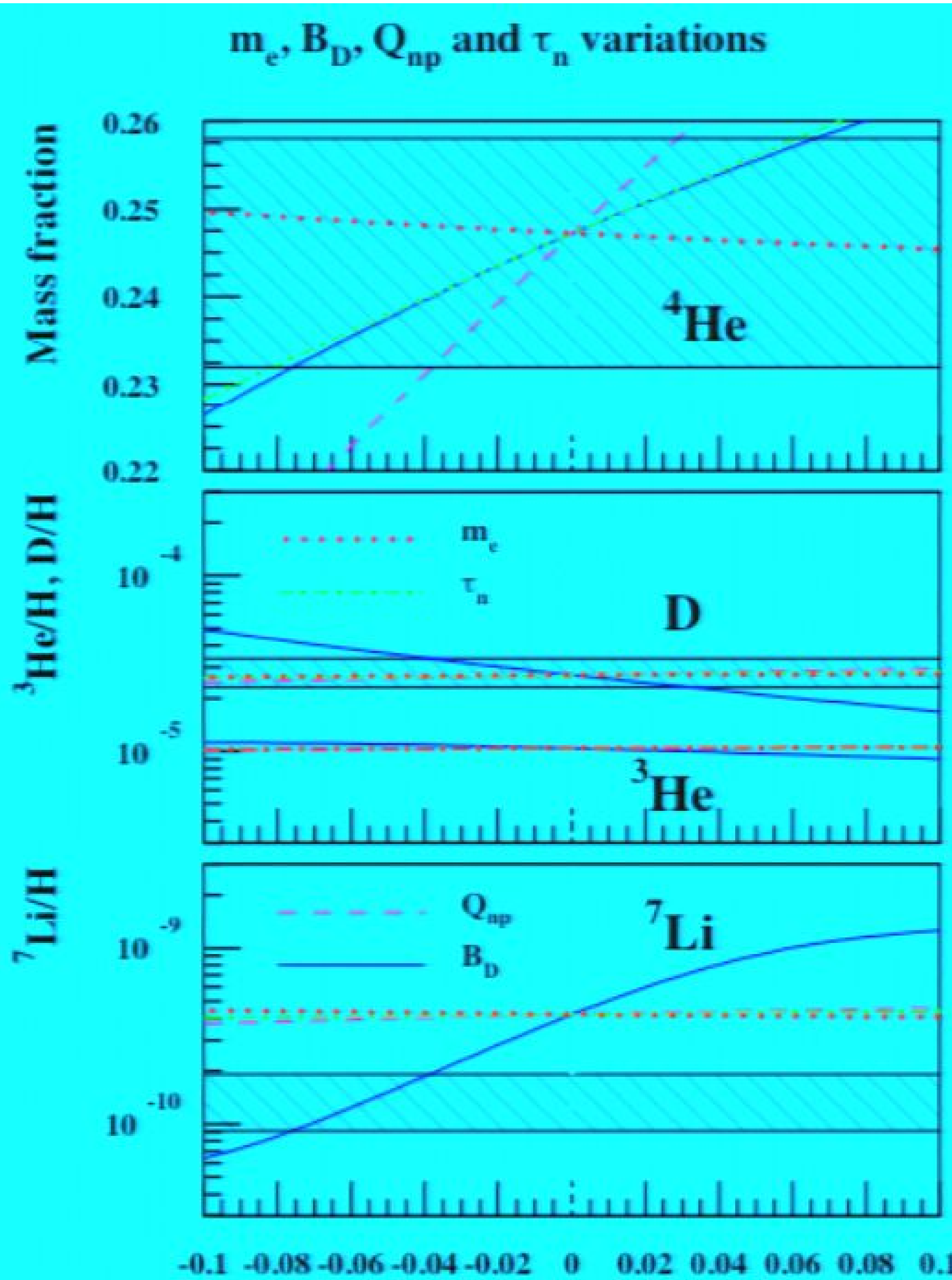


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

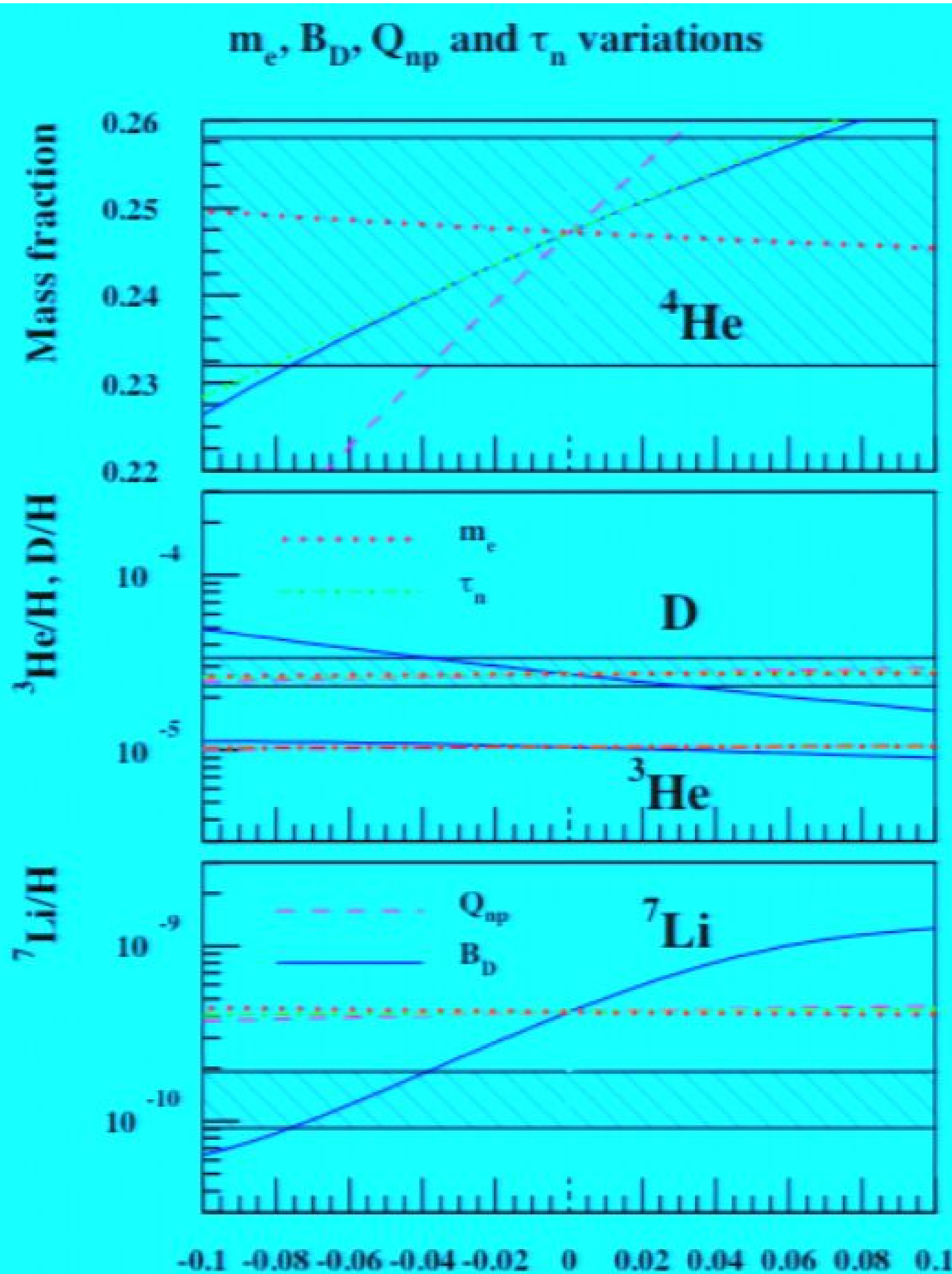
m_e, B_D, Q_{np} and τ_n variations




m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
10^-4
10^-5
m_e
τ_n
D
3He
7Li/H
10^-9
10^-10
Q_np
B_D
7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

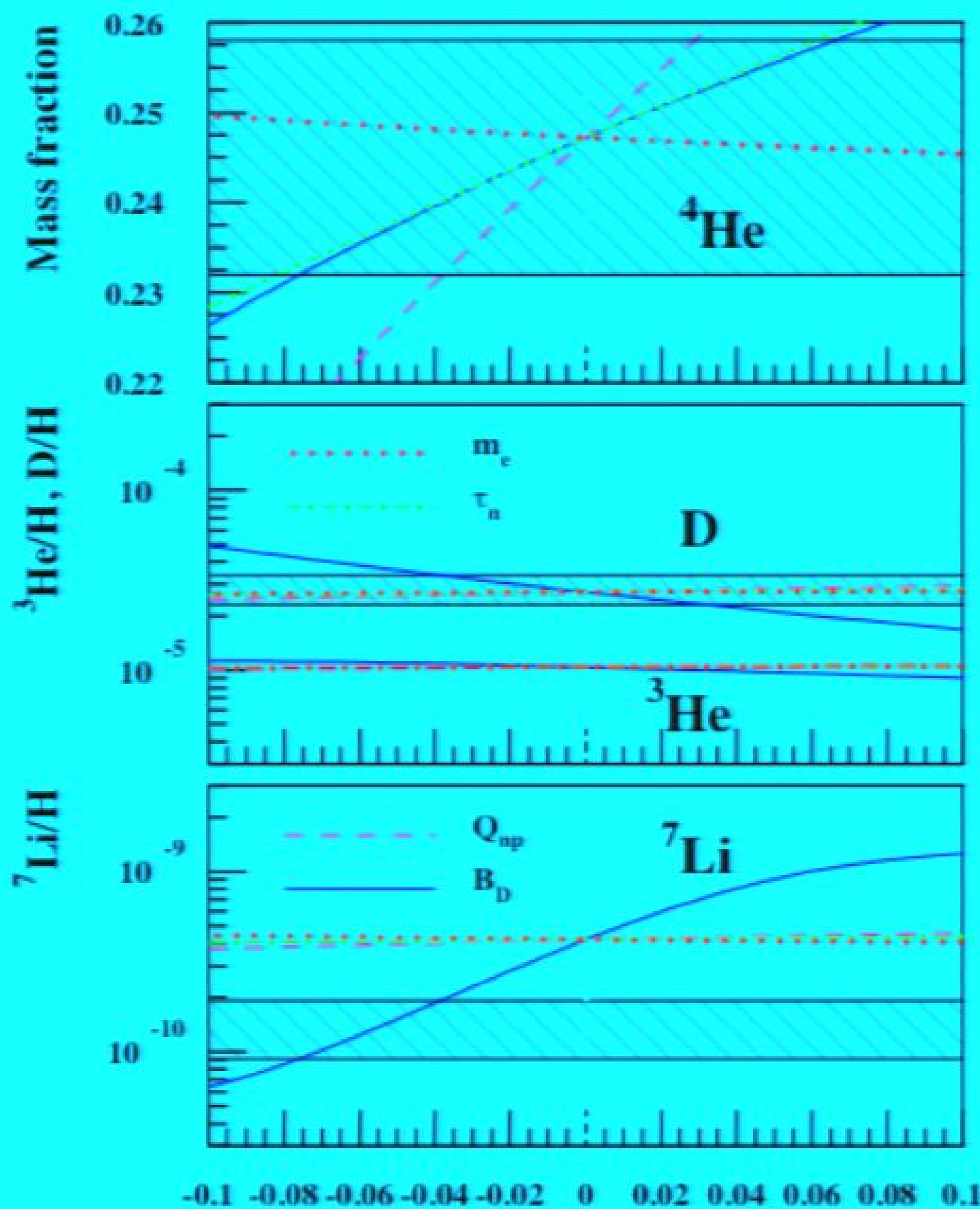


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

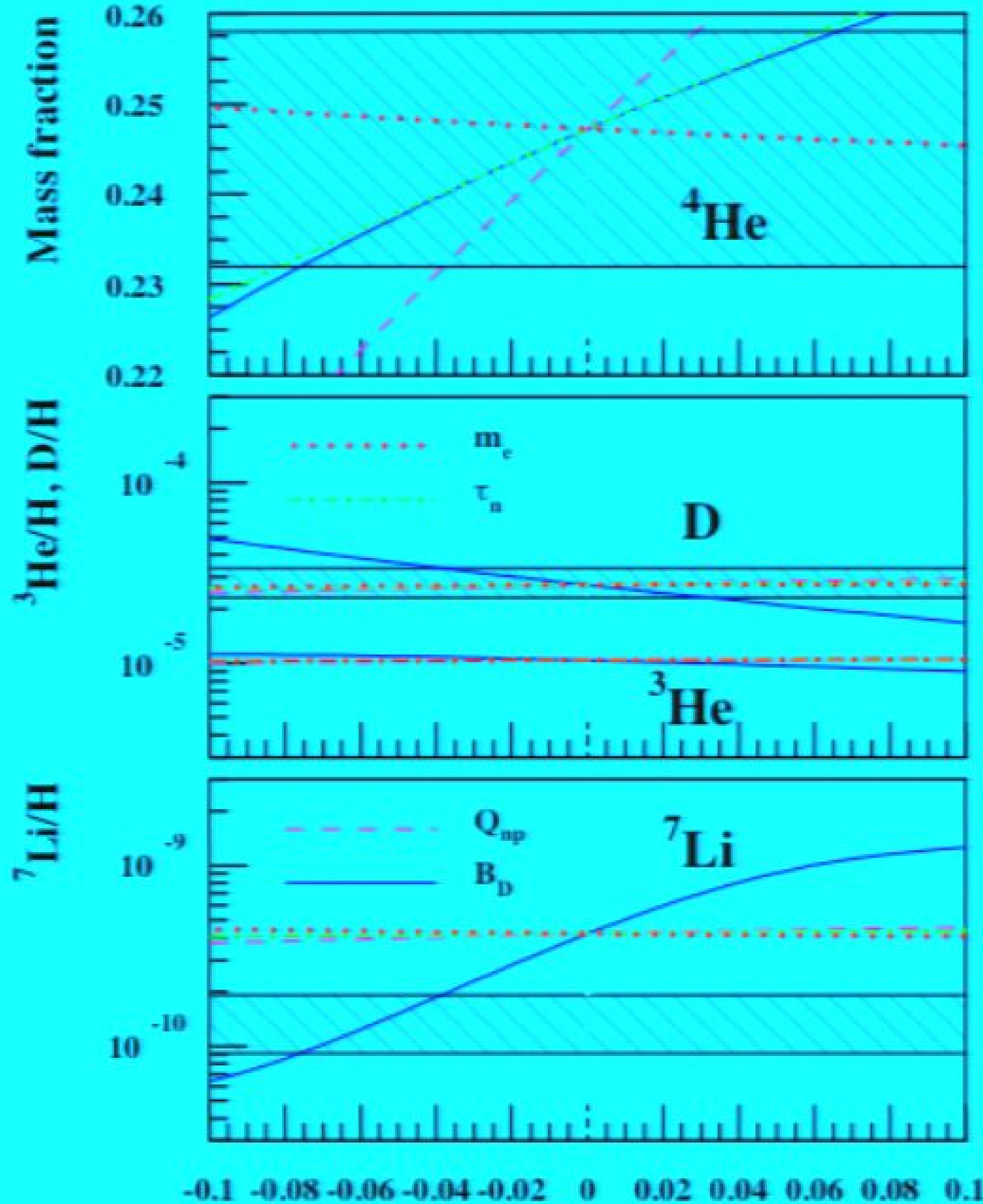


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

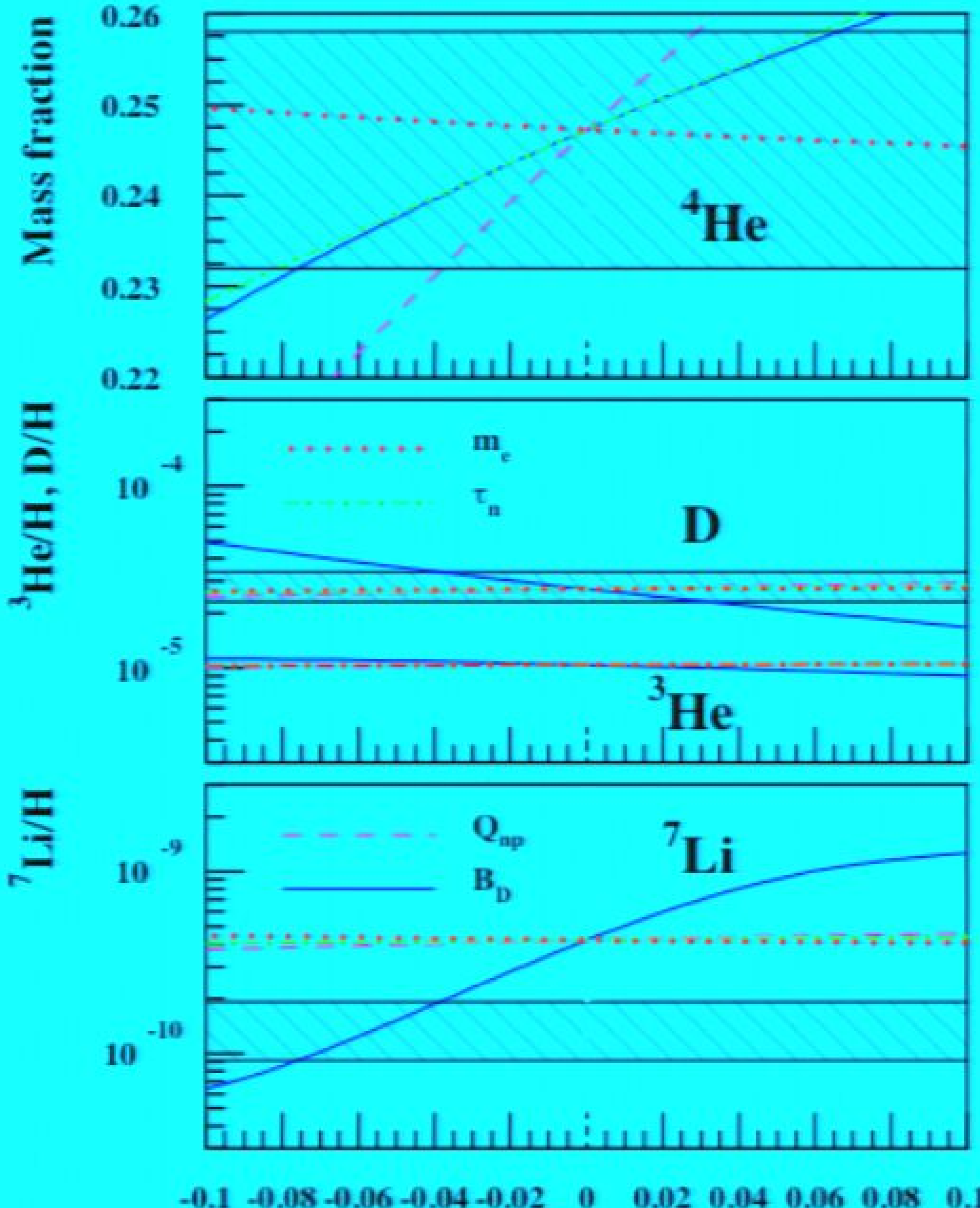
m_e, B_D, Q_{np} and τ_n variations



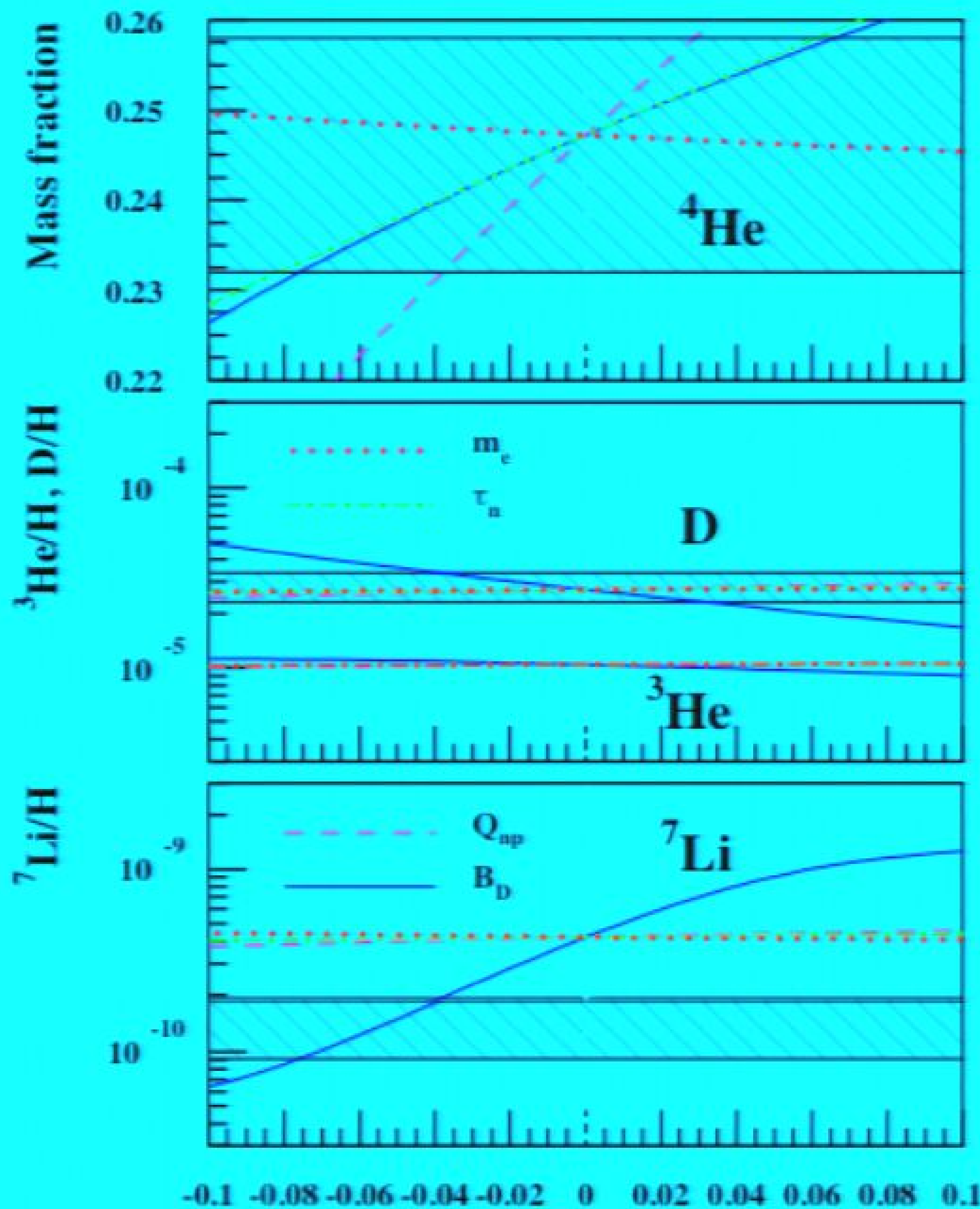
m_e, B_D, Q_{np} and τ_n variations

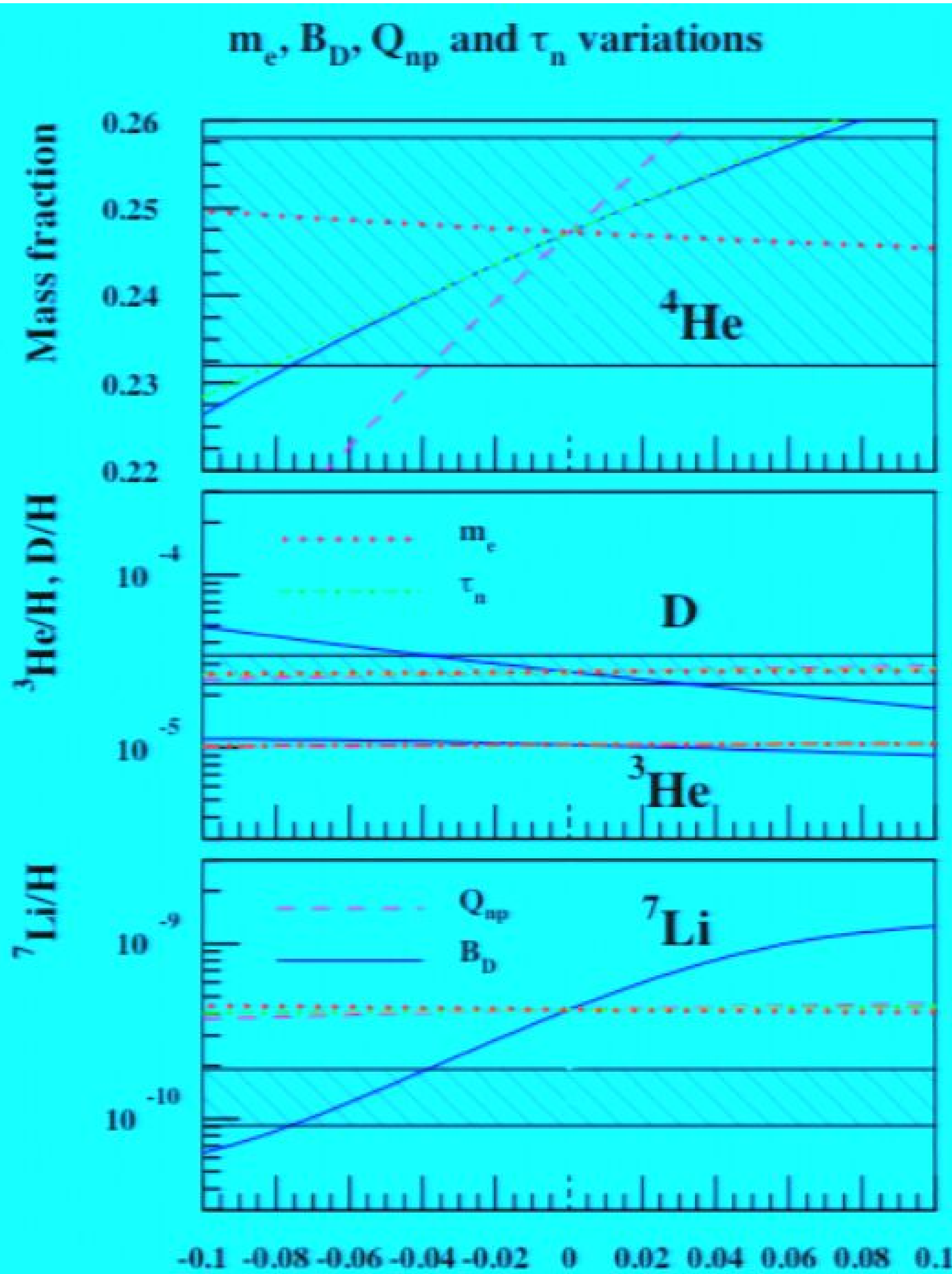


m_e, B_D, Q_{np} and τ_n variations

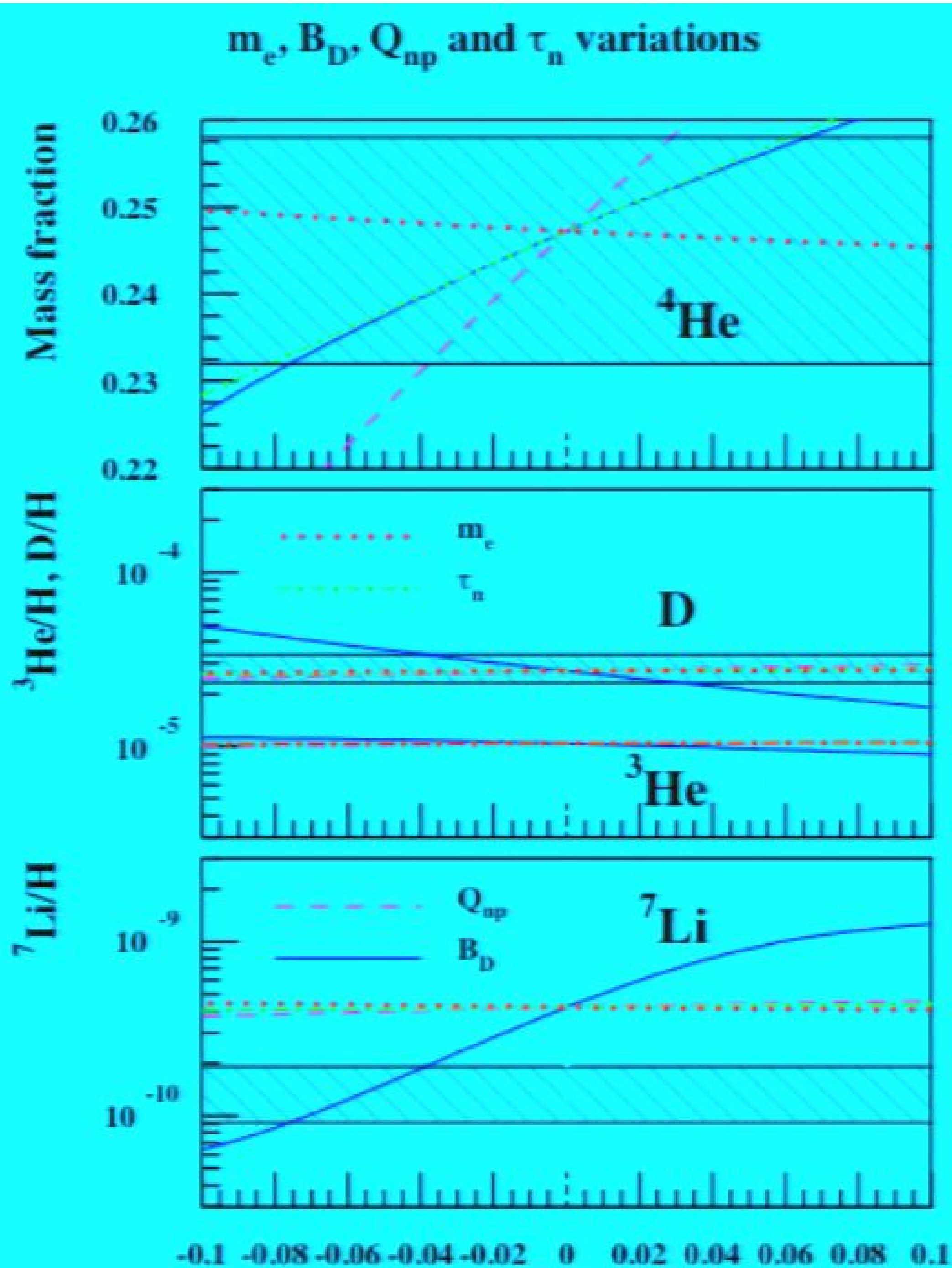


m_e, B_D, Q_{np} and τ_n variations

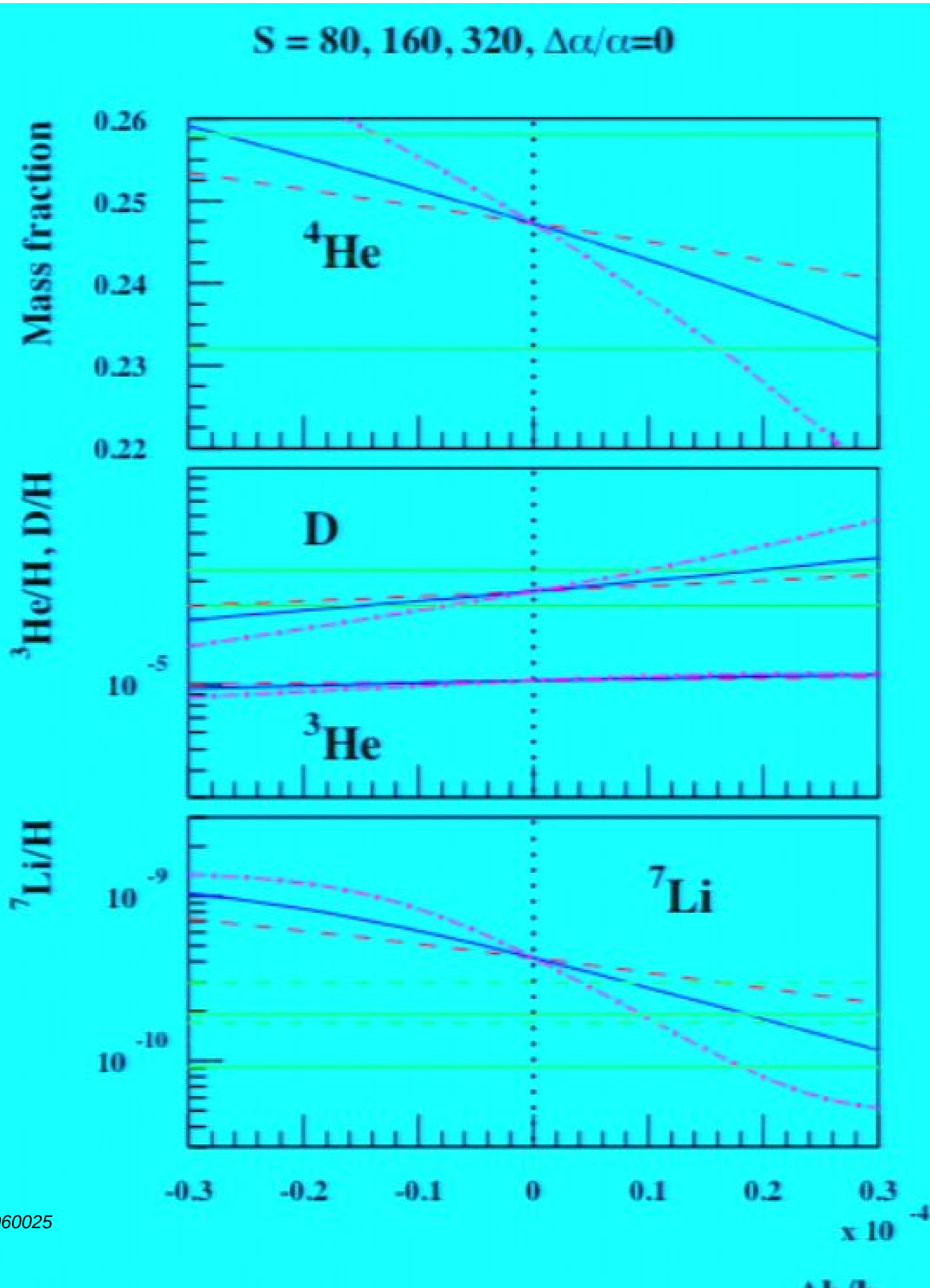




m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^4He
$^3He/H$, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^3He
$^7Li/H$
10^{-9}
10^{-10}
Q_{np}
B_D
^7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

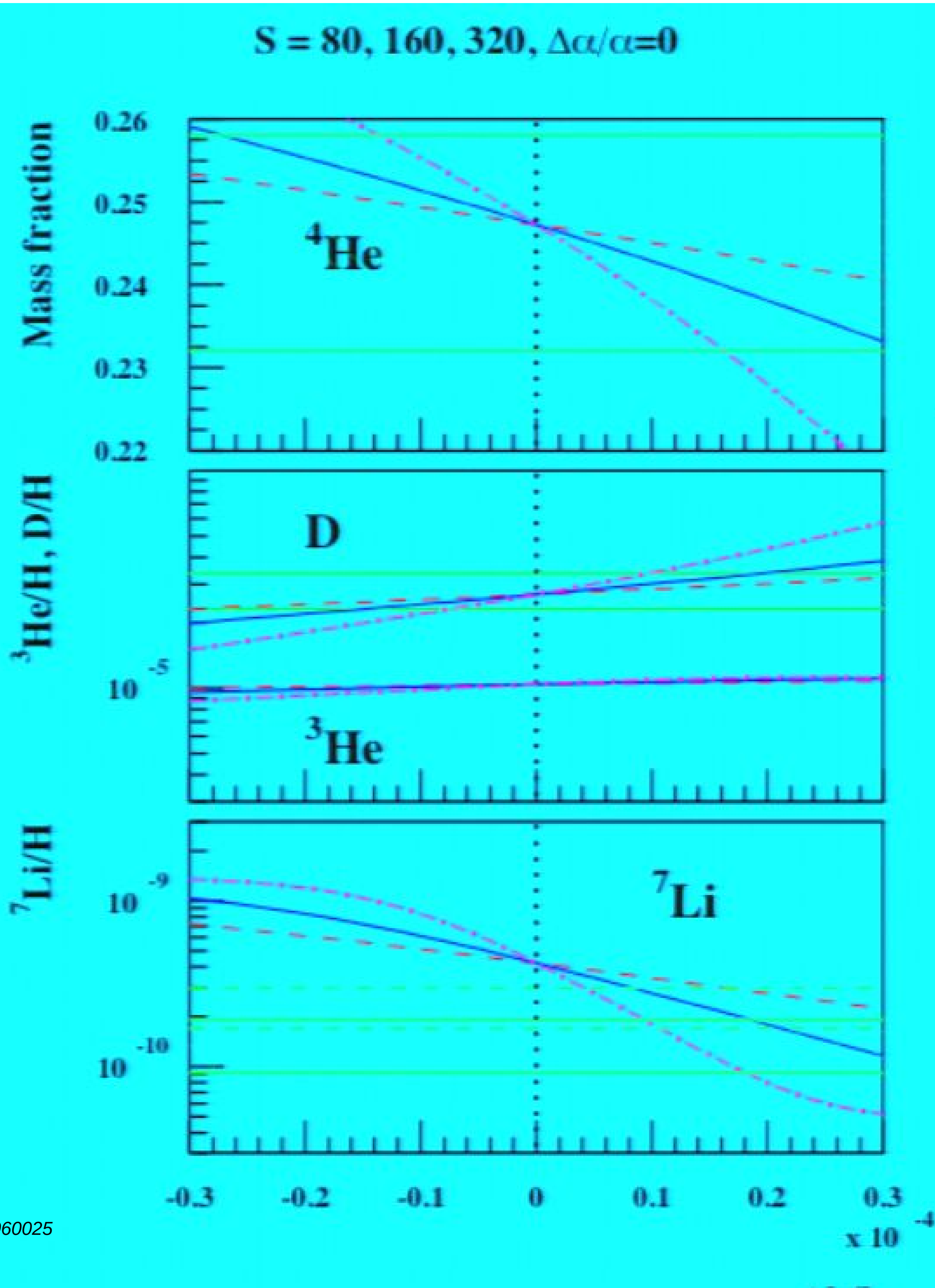


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



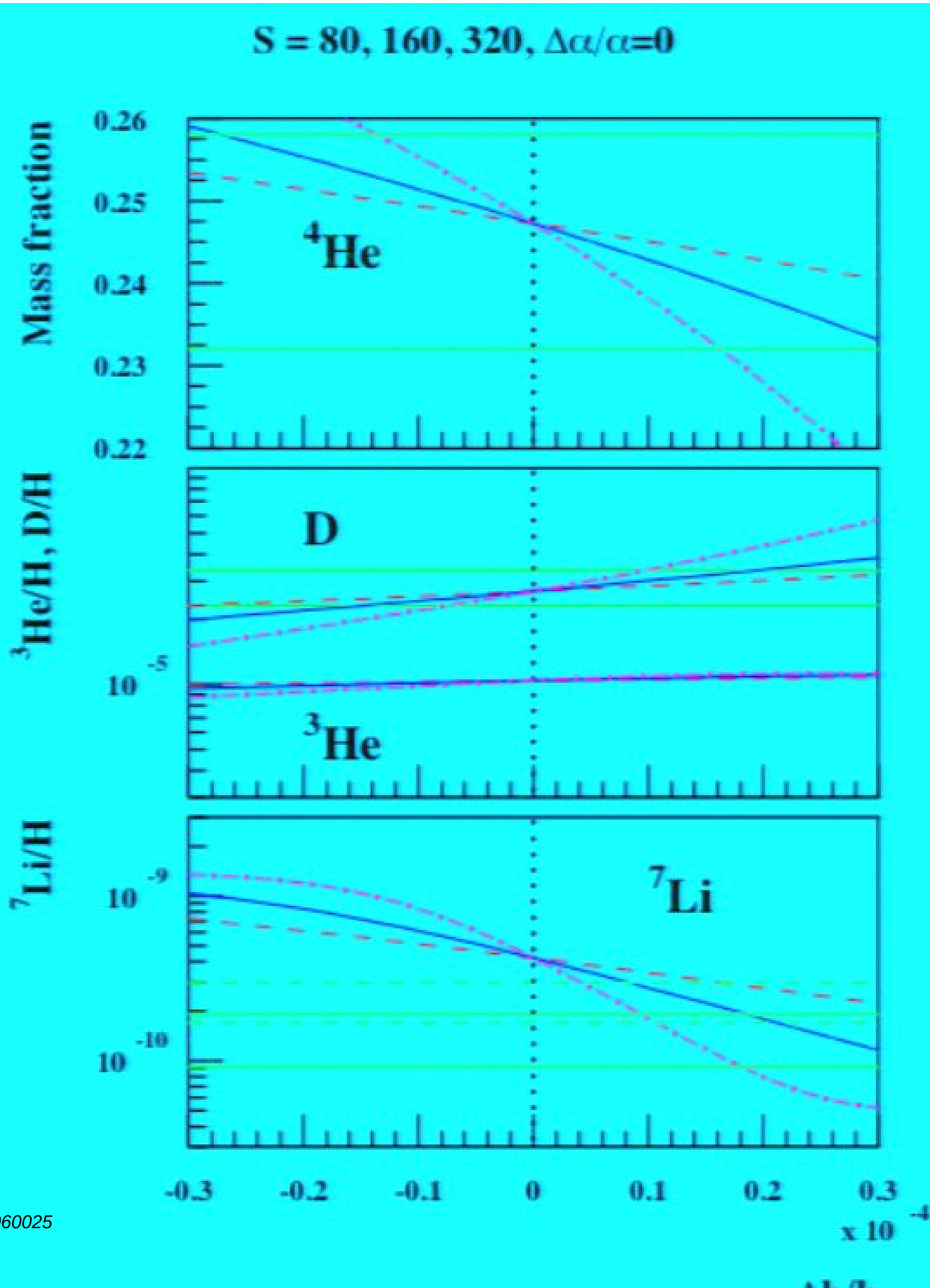
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



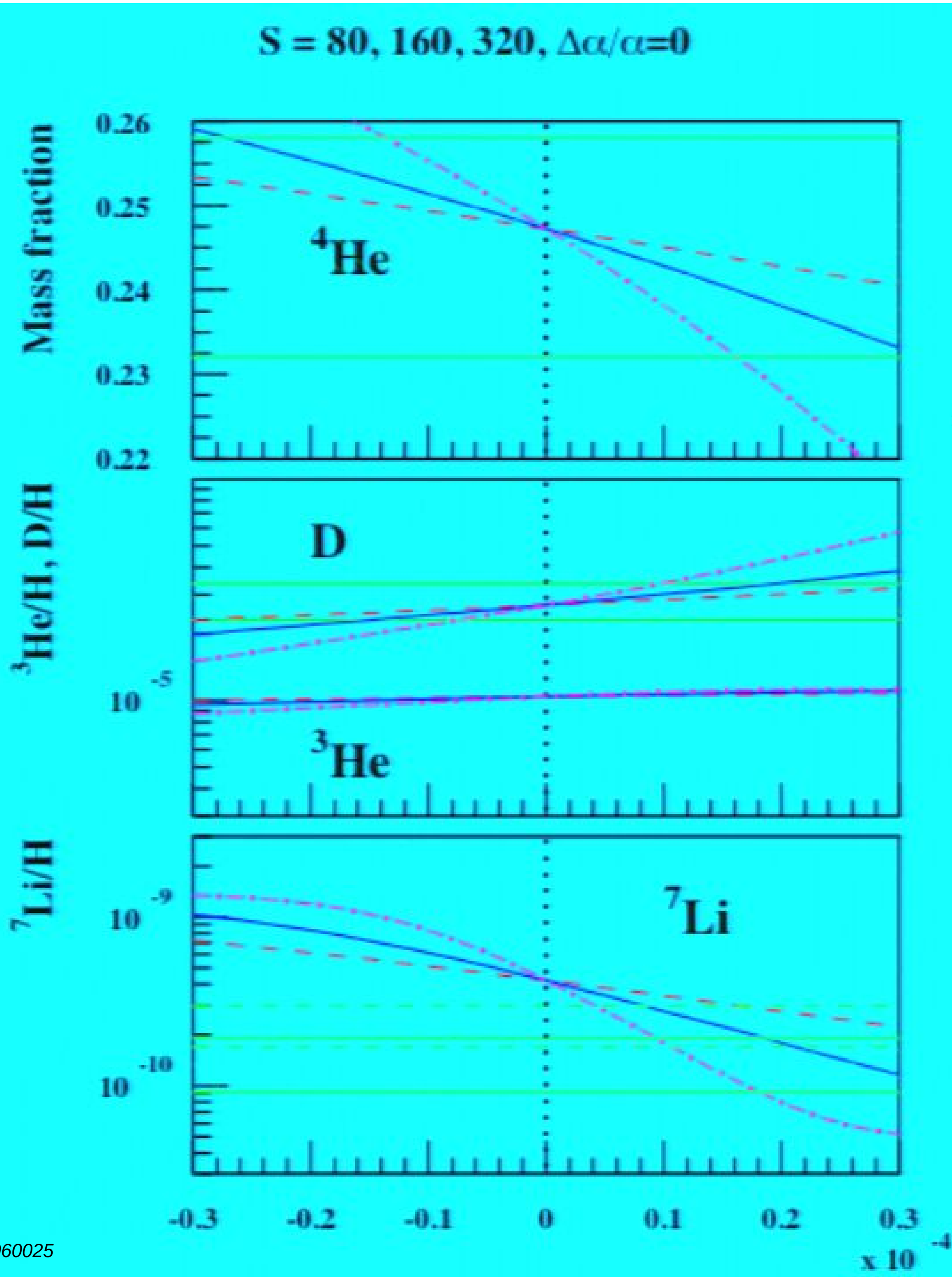
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



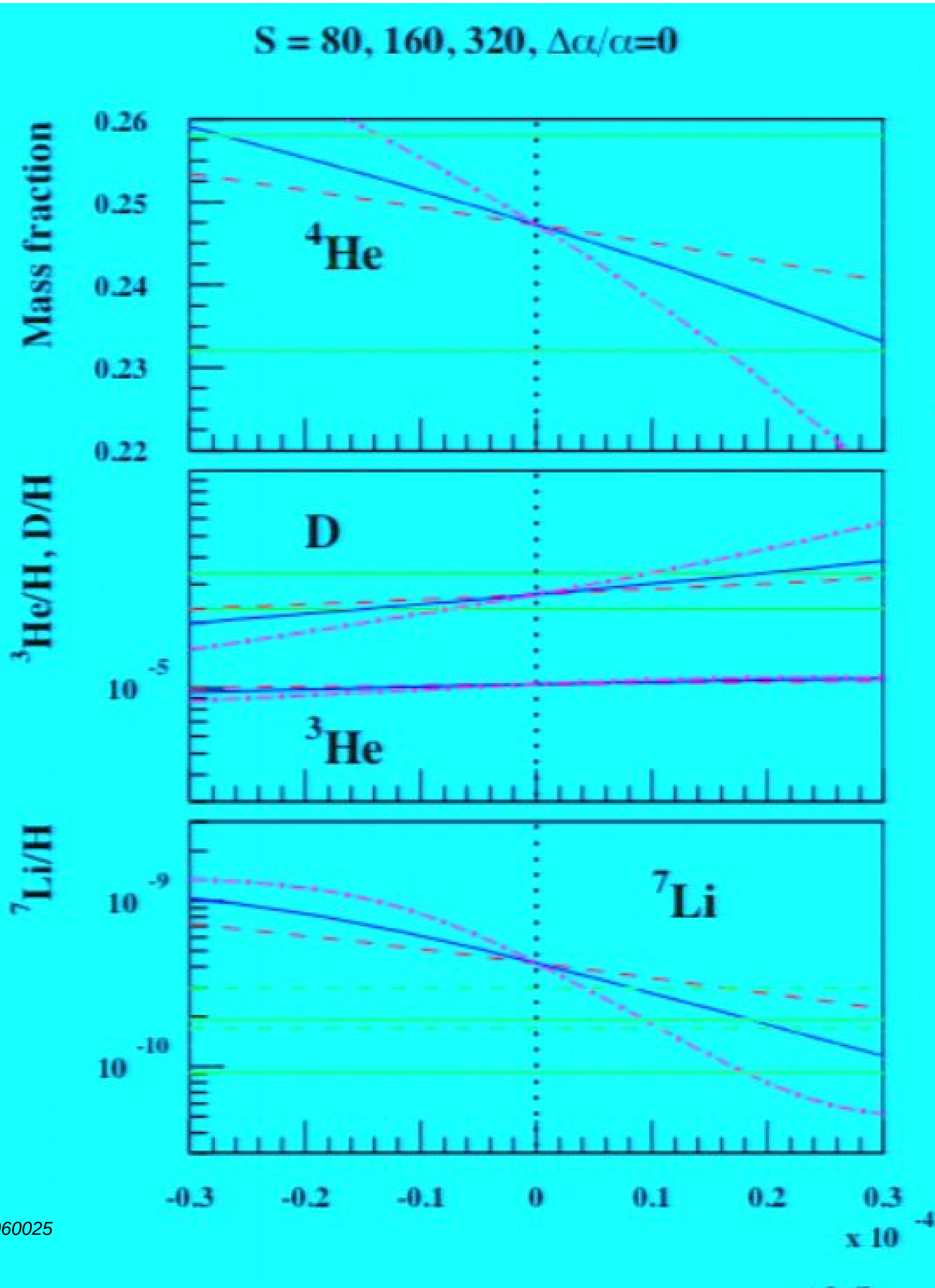
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



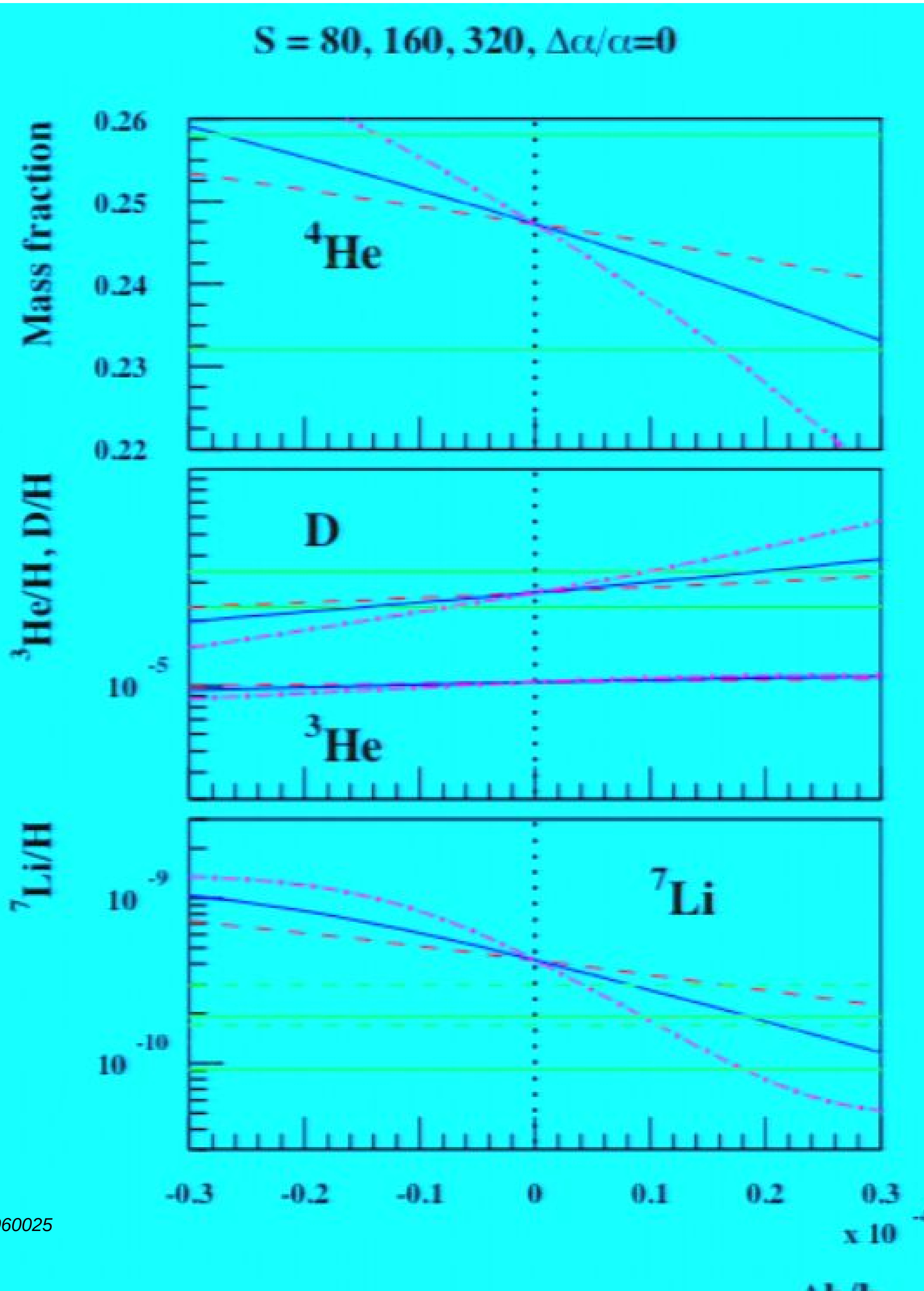
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



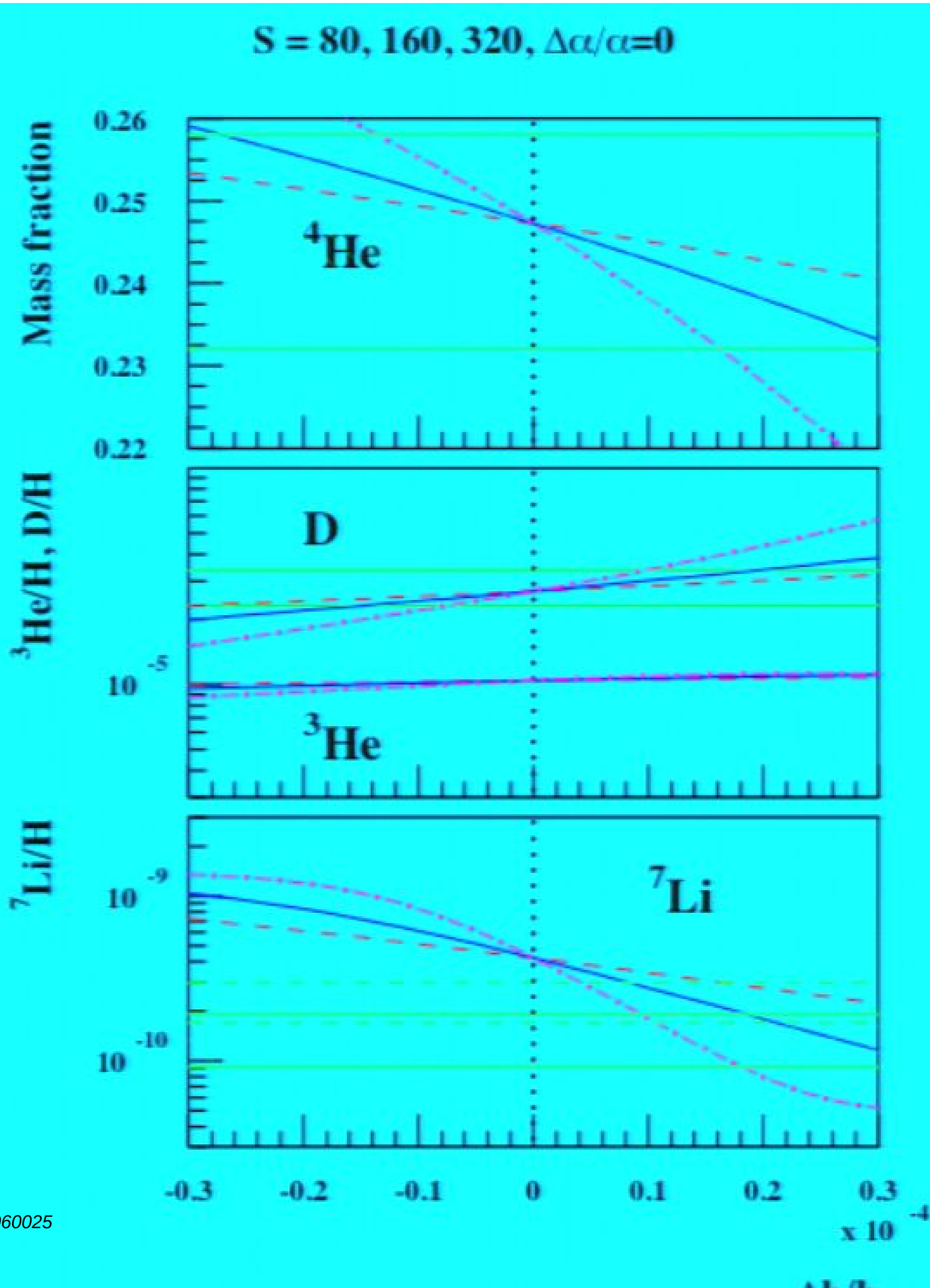
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



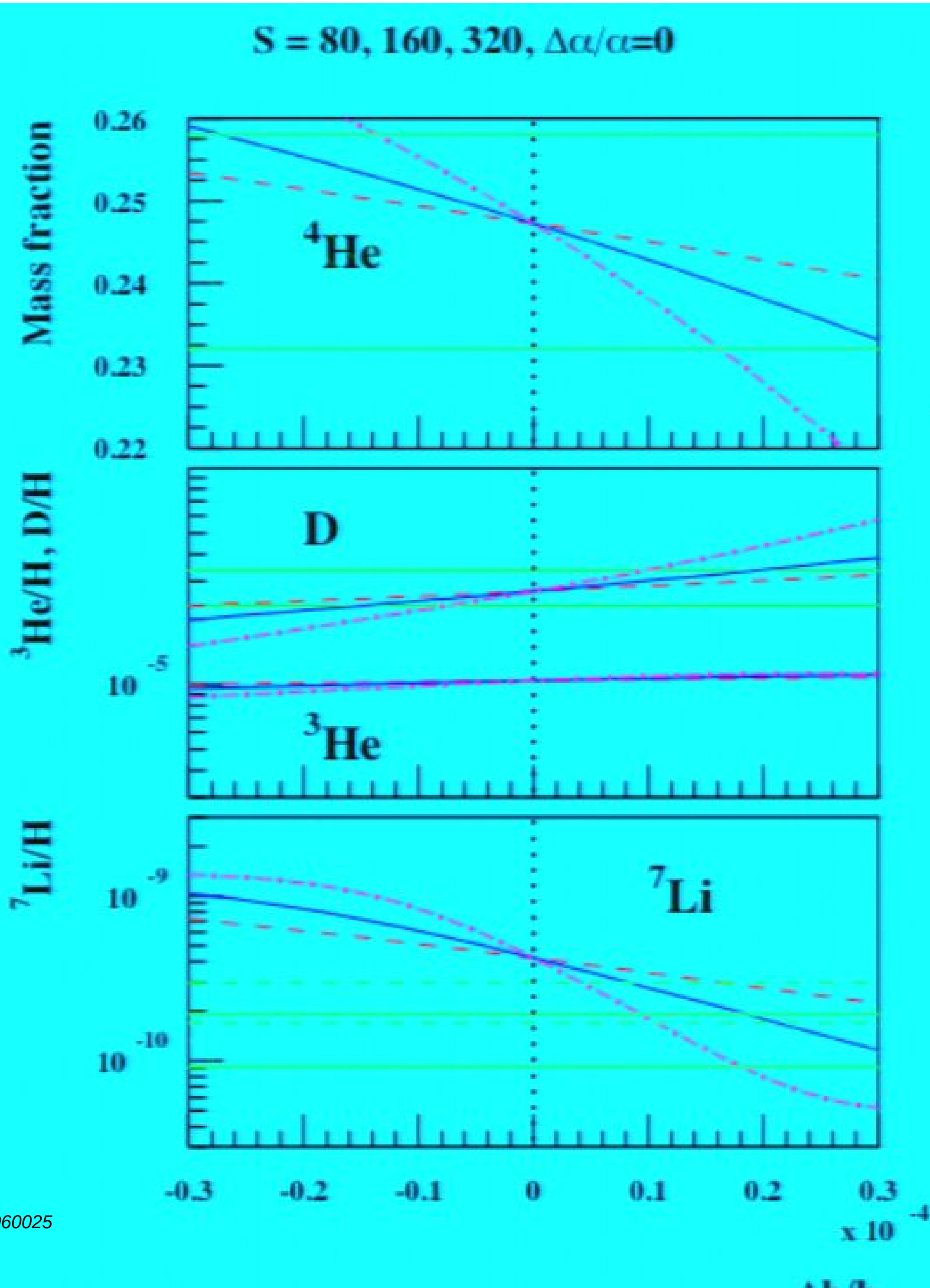
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



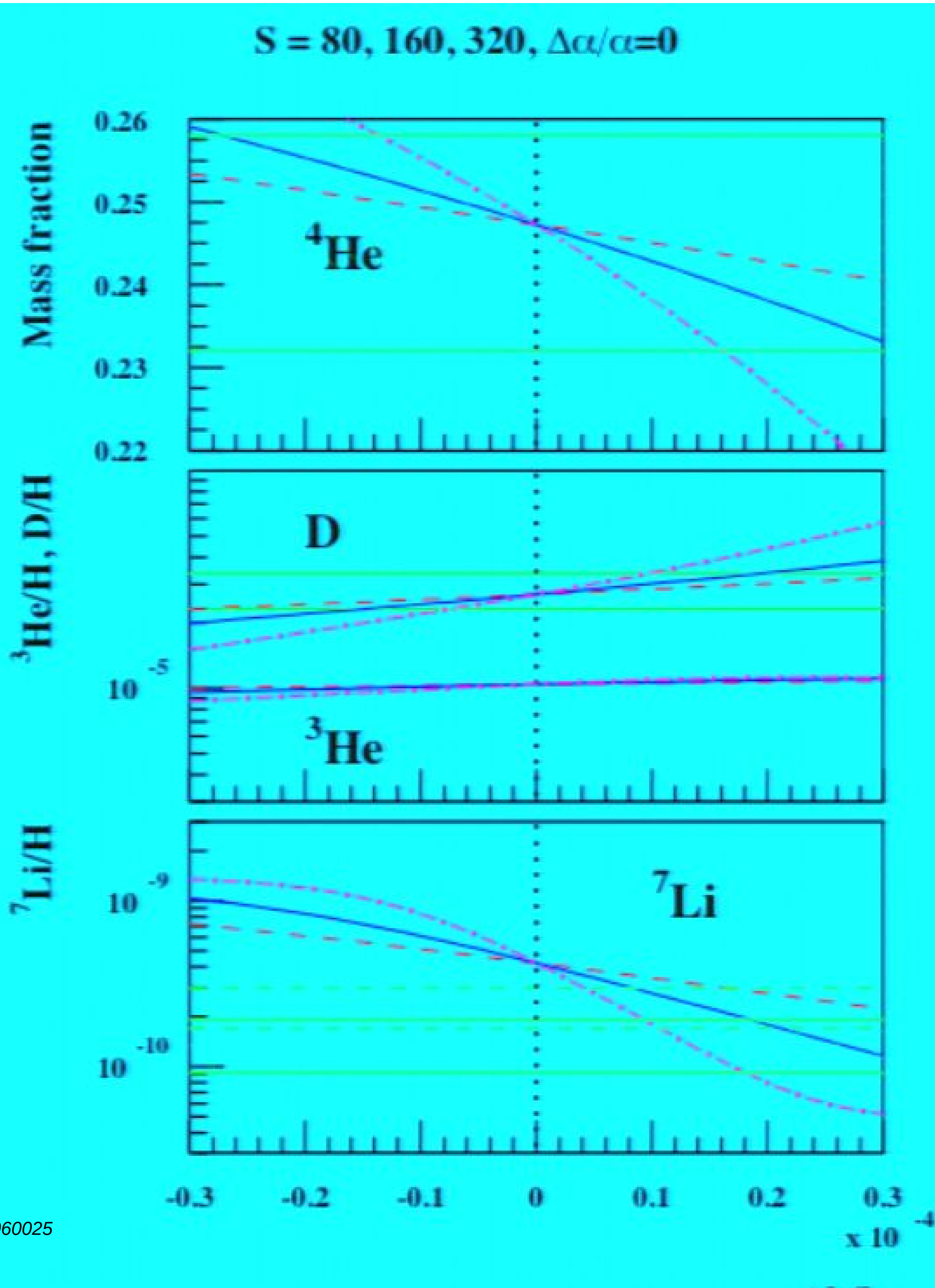
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



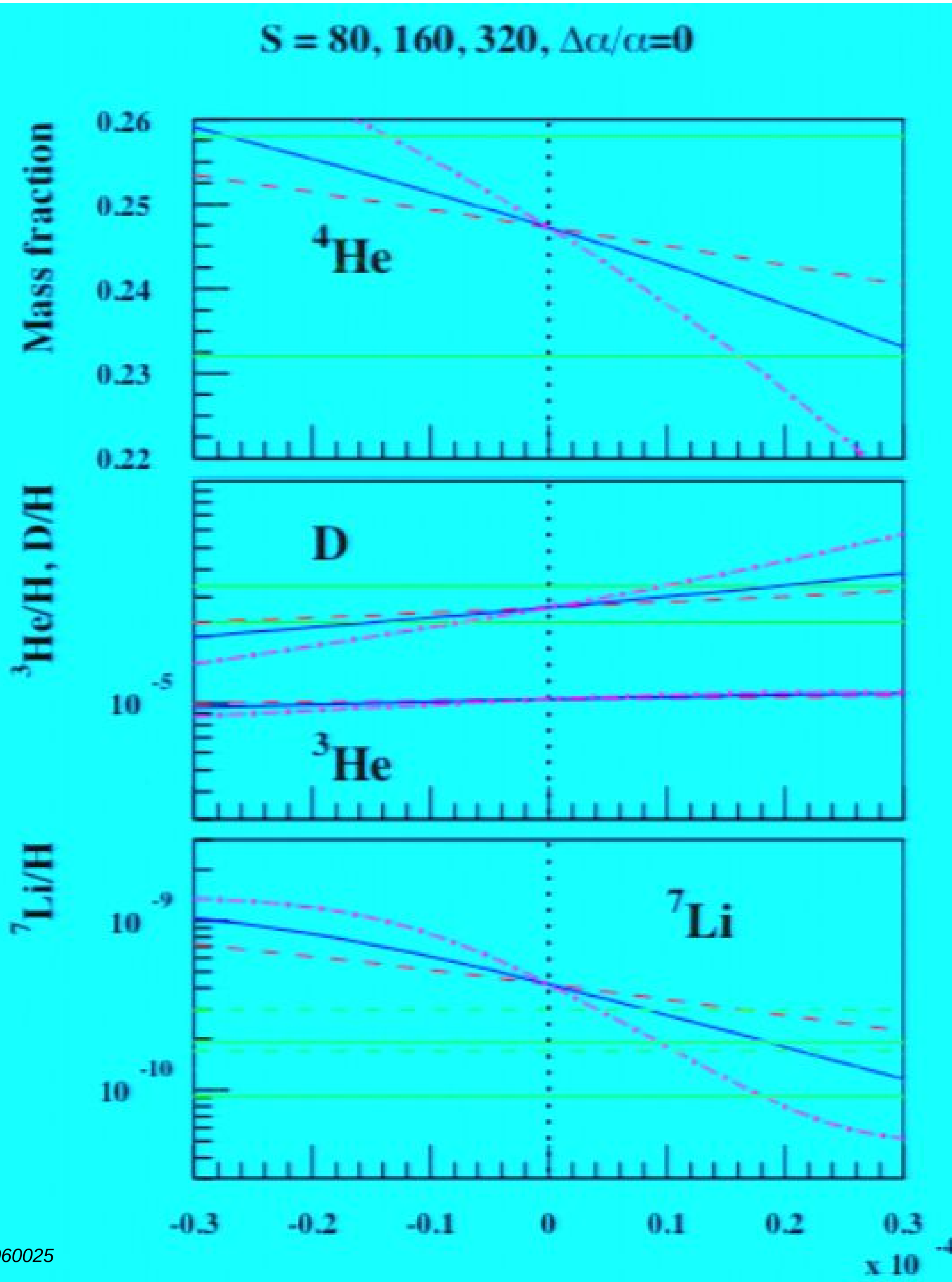
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



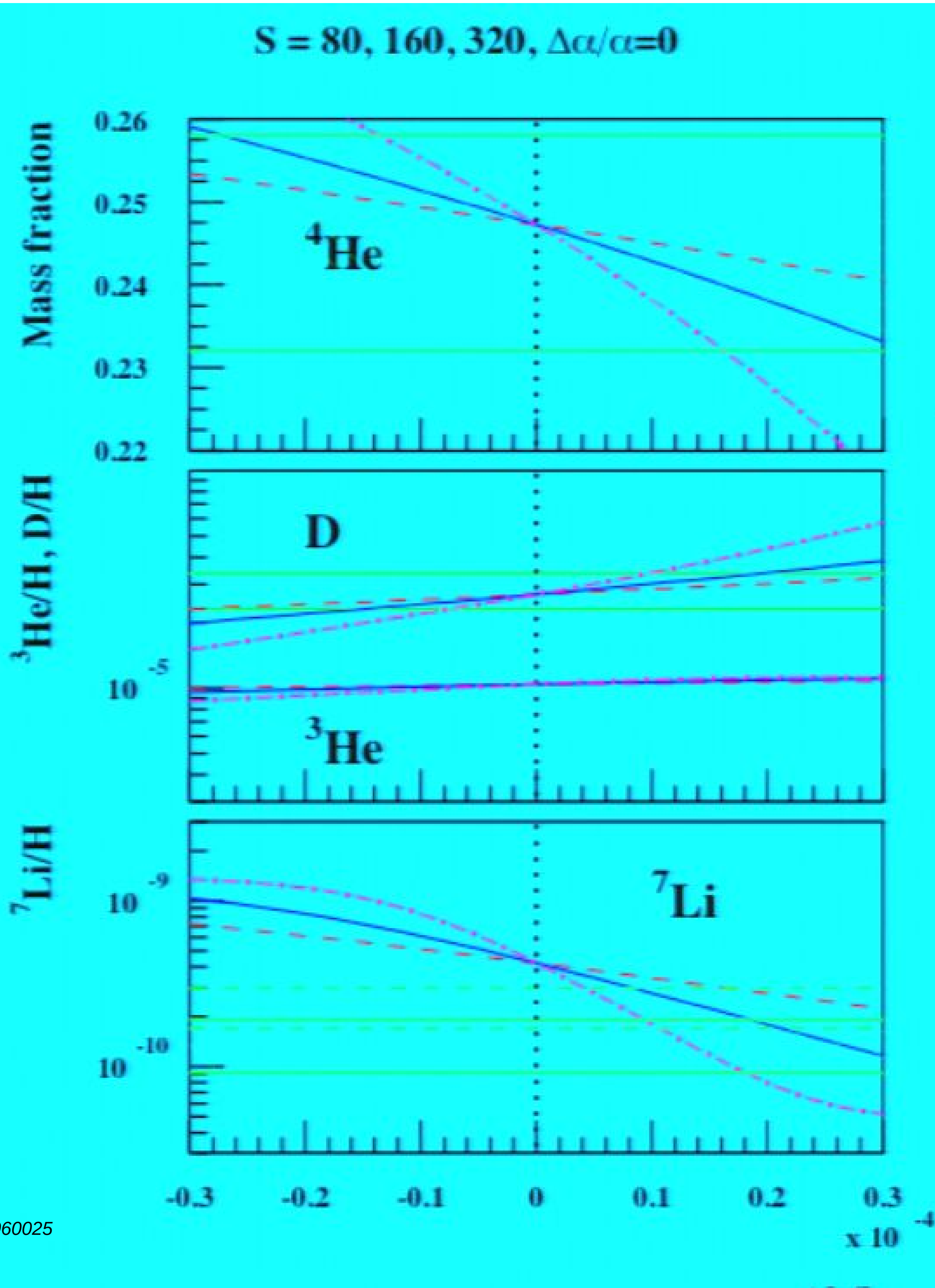
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



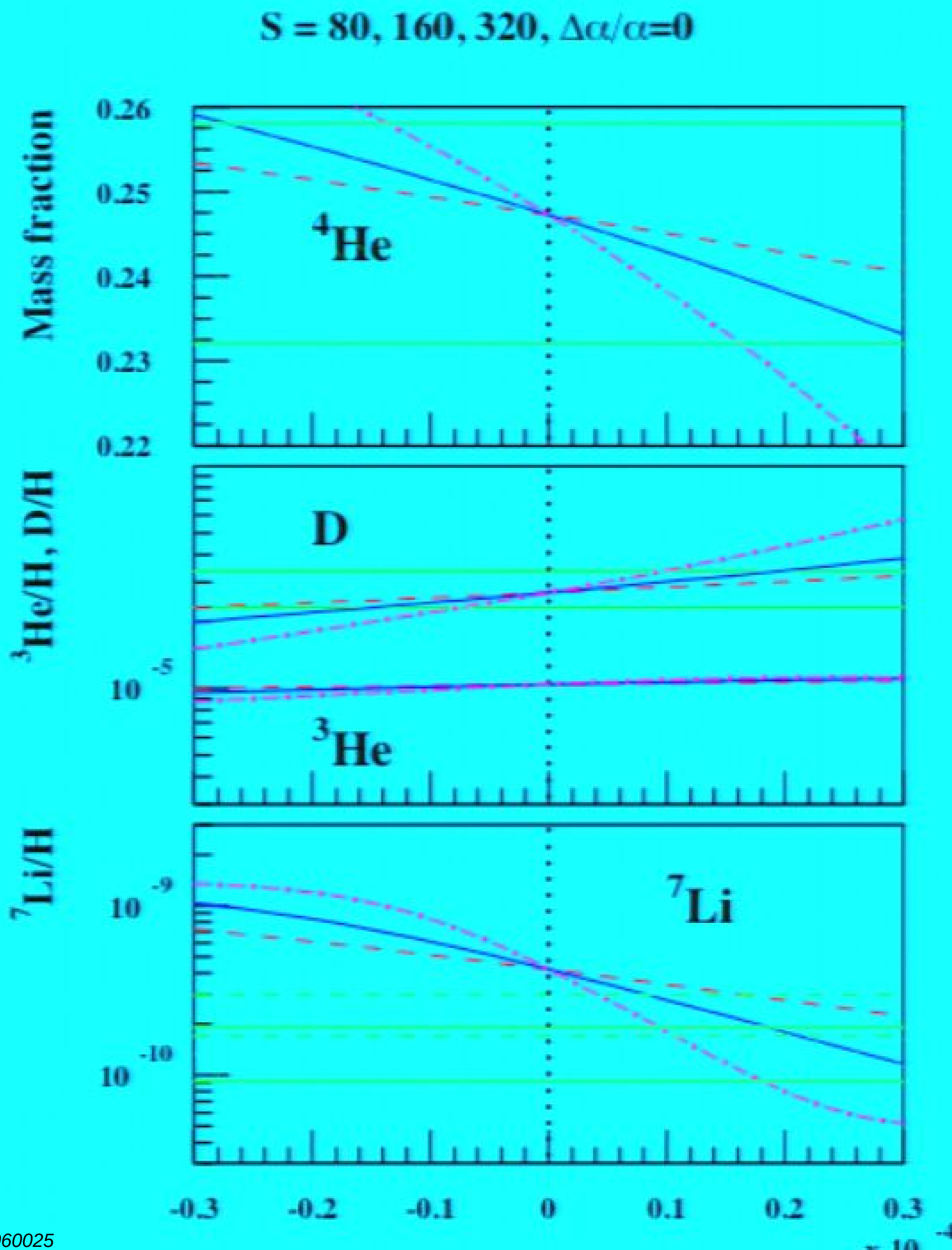
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



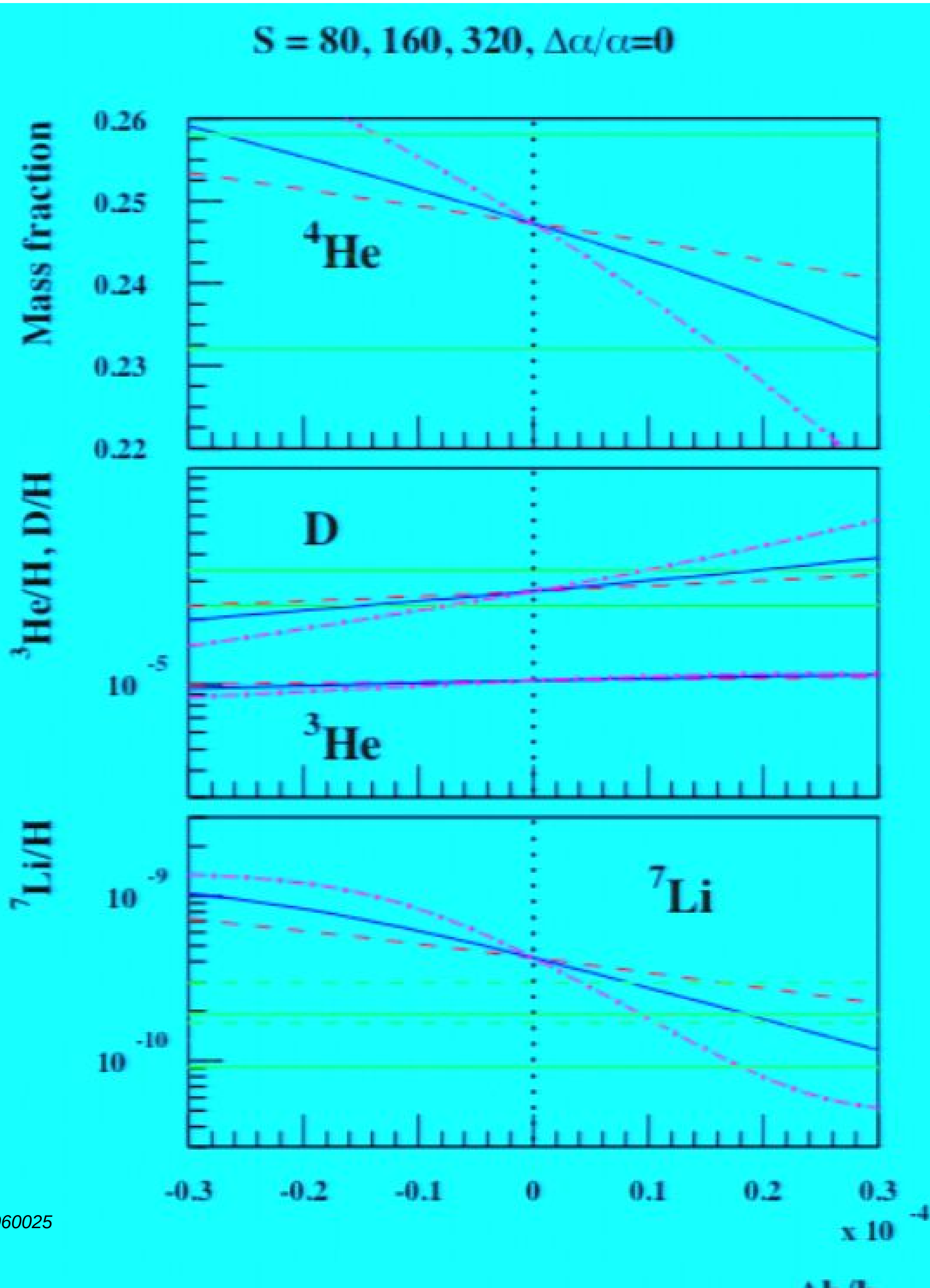
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



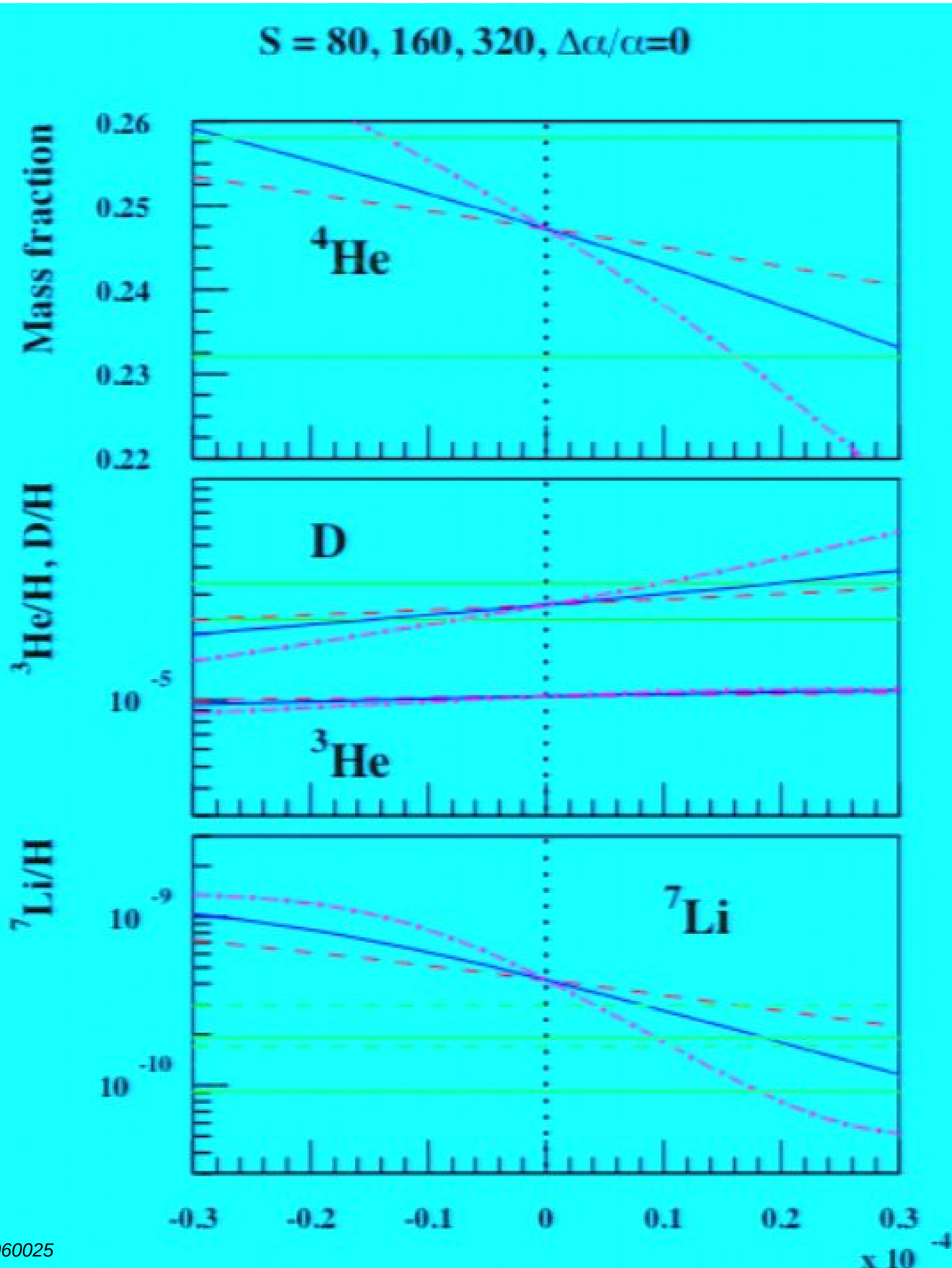
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



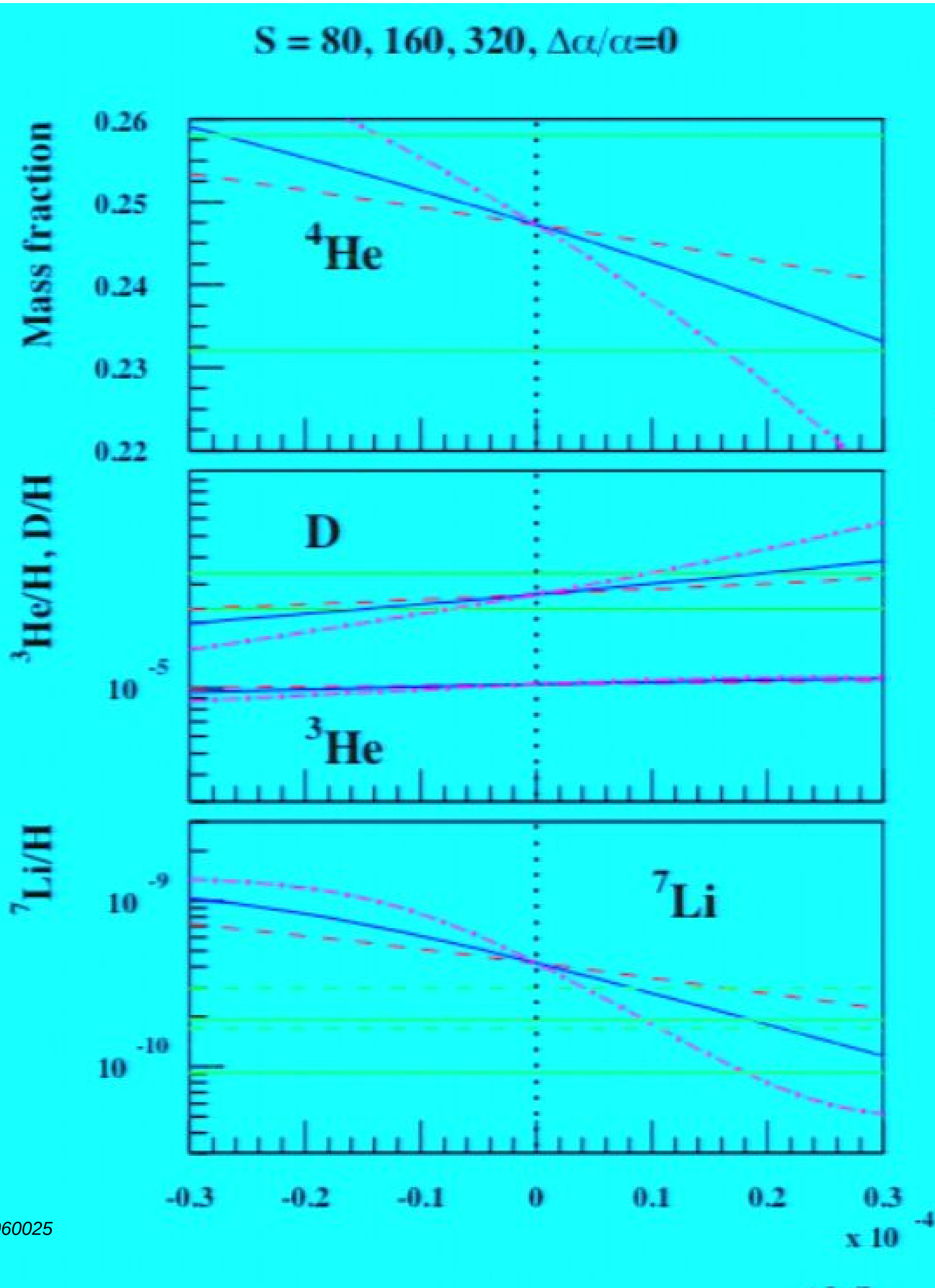
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



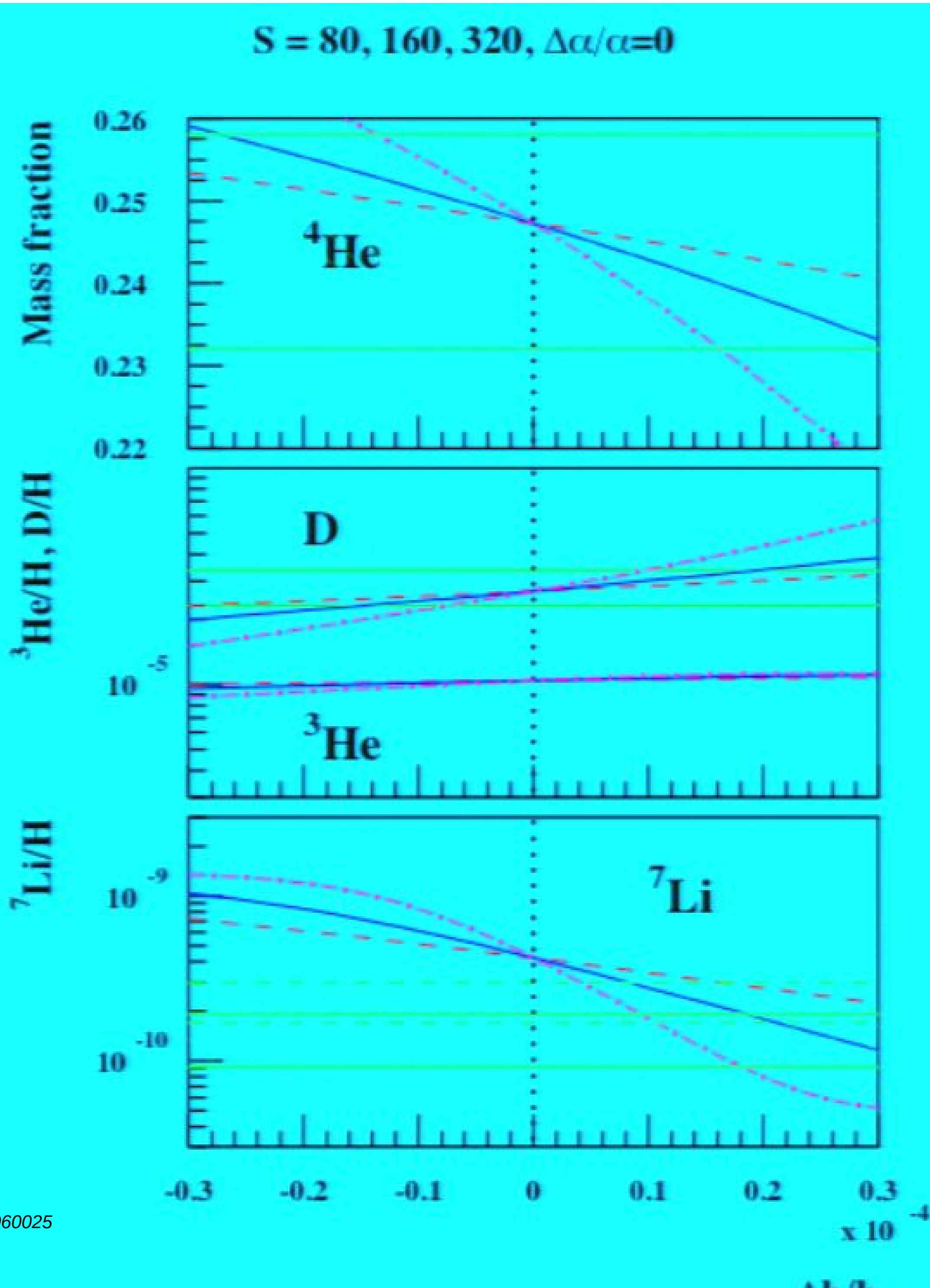
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



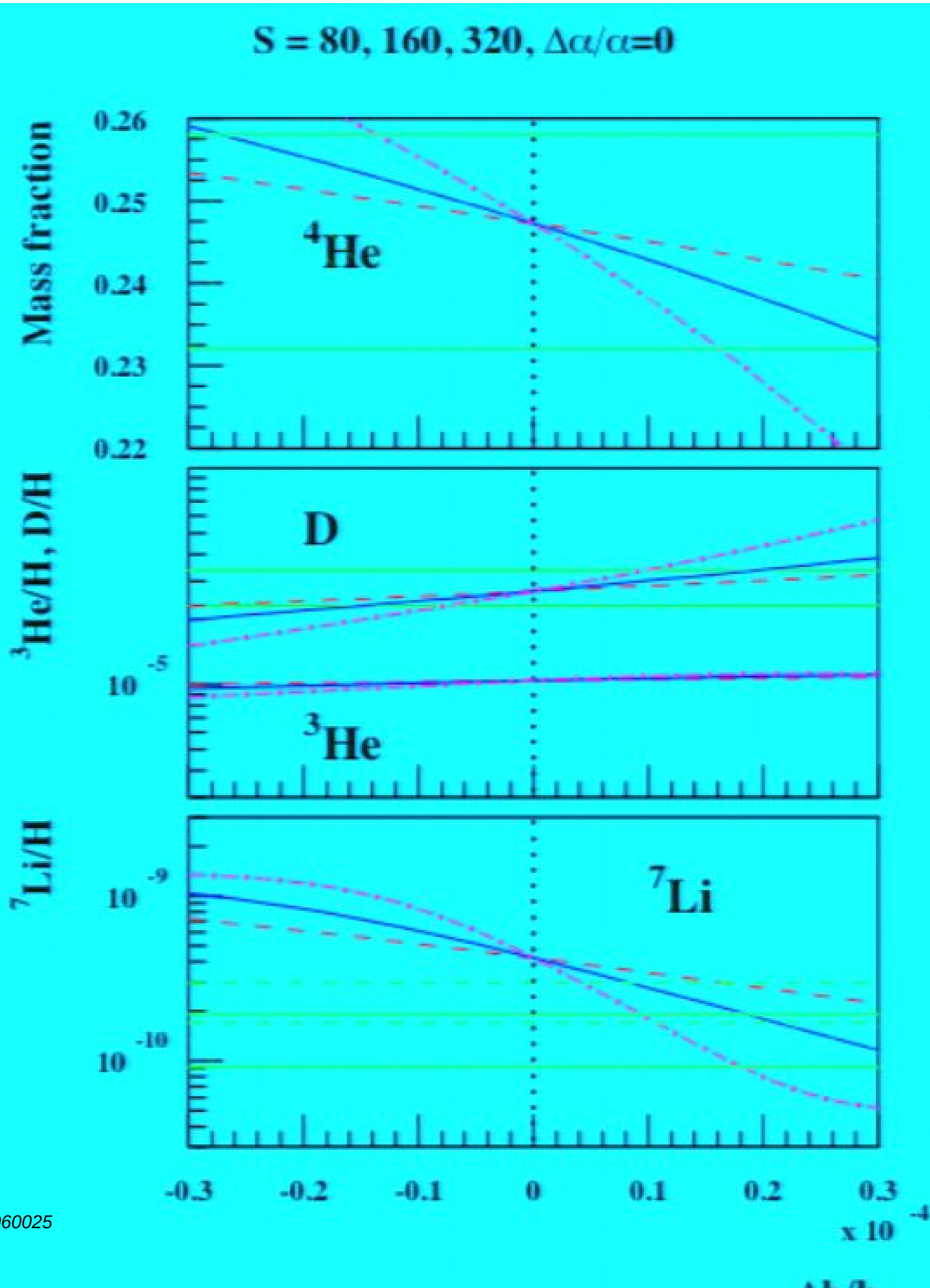
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



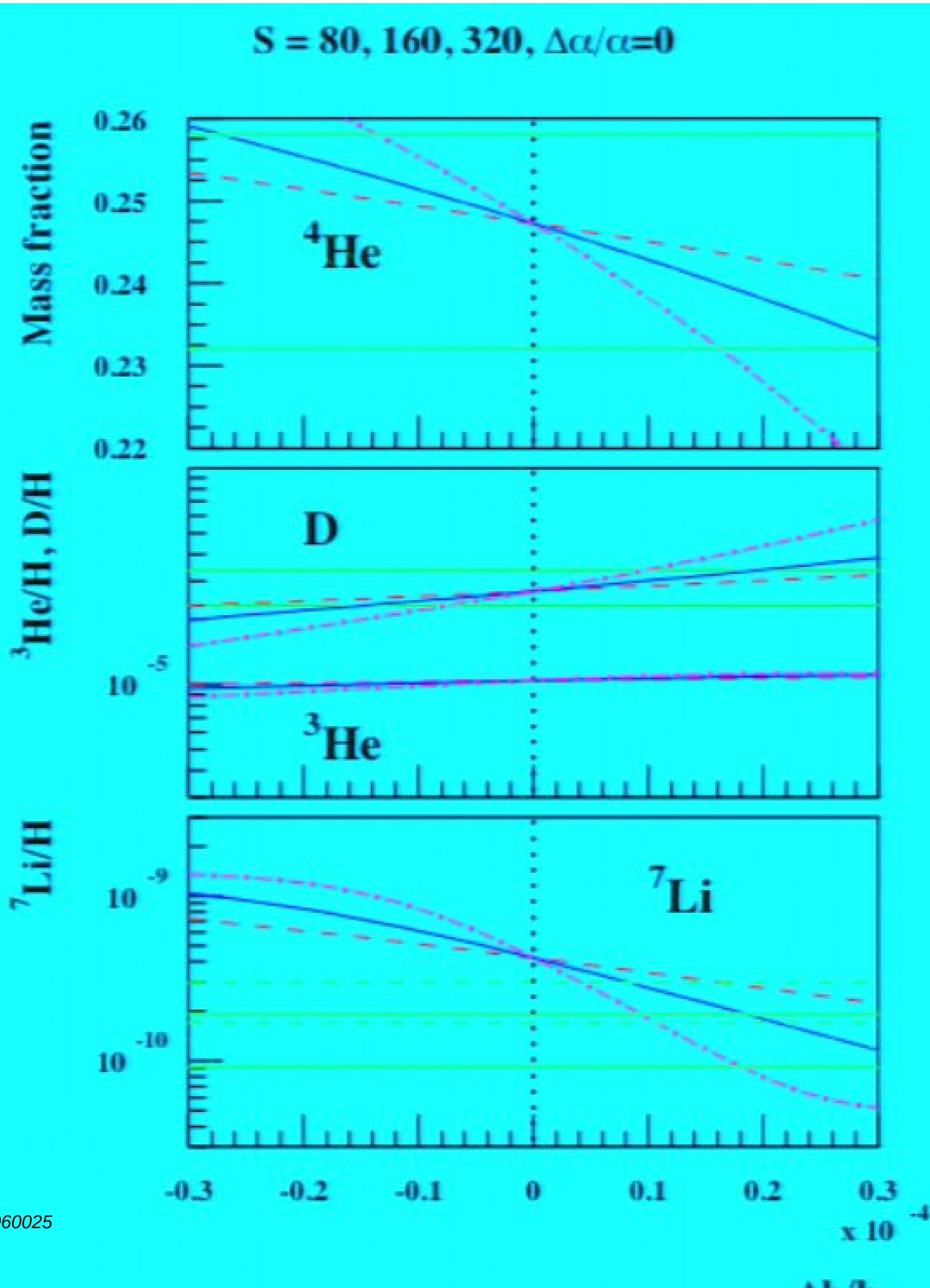
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



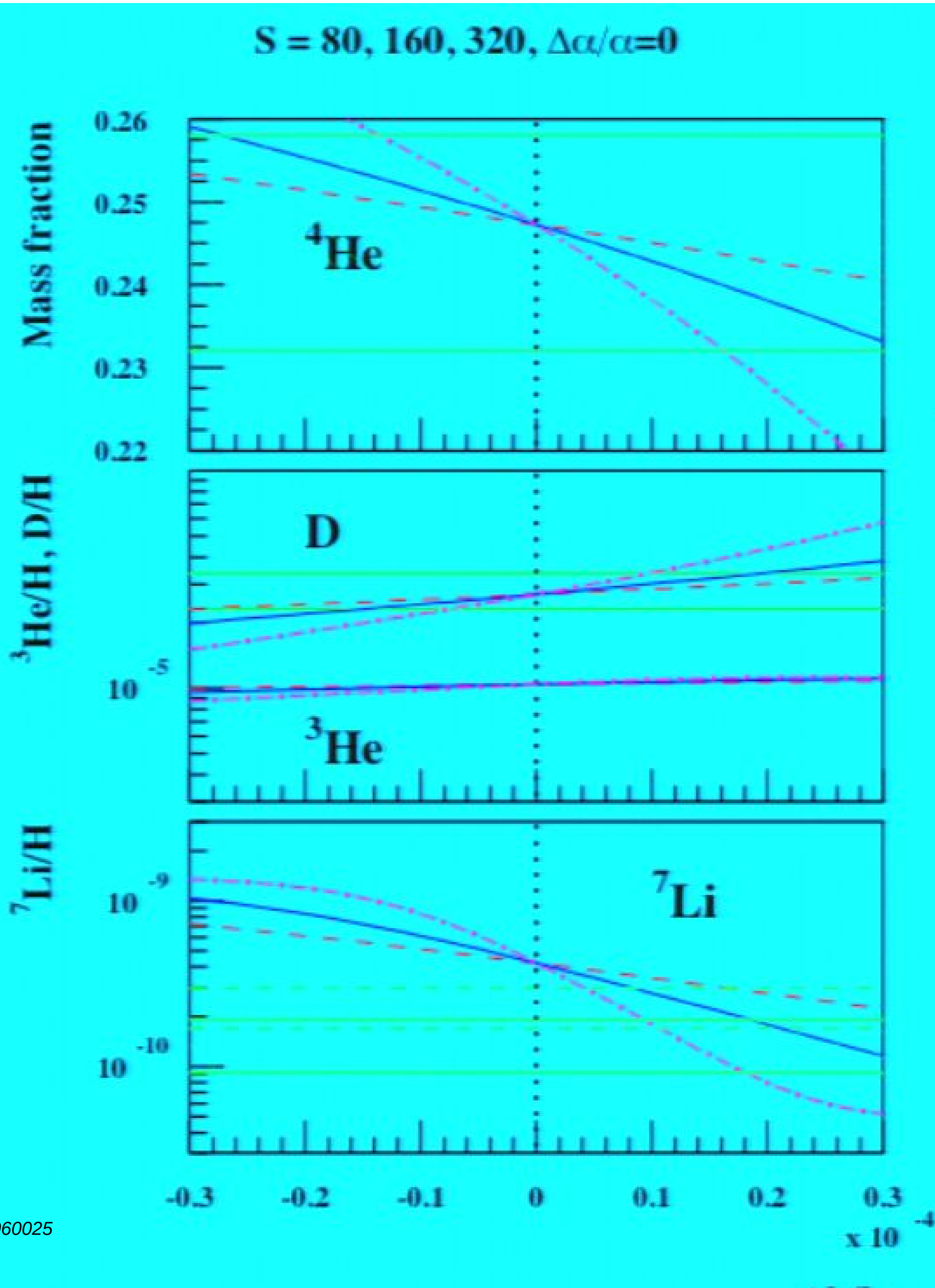
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



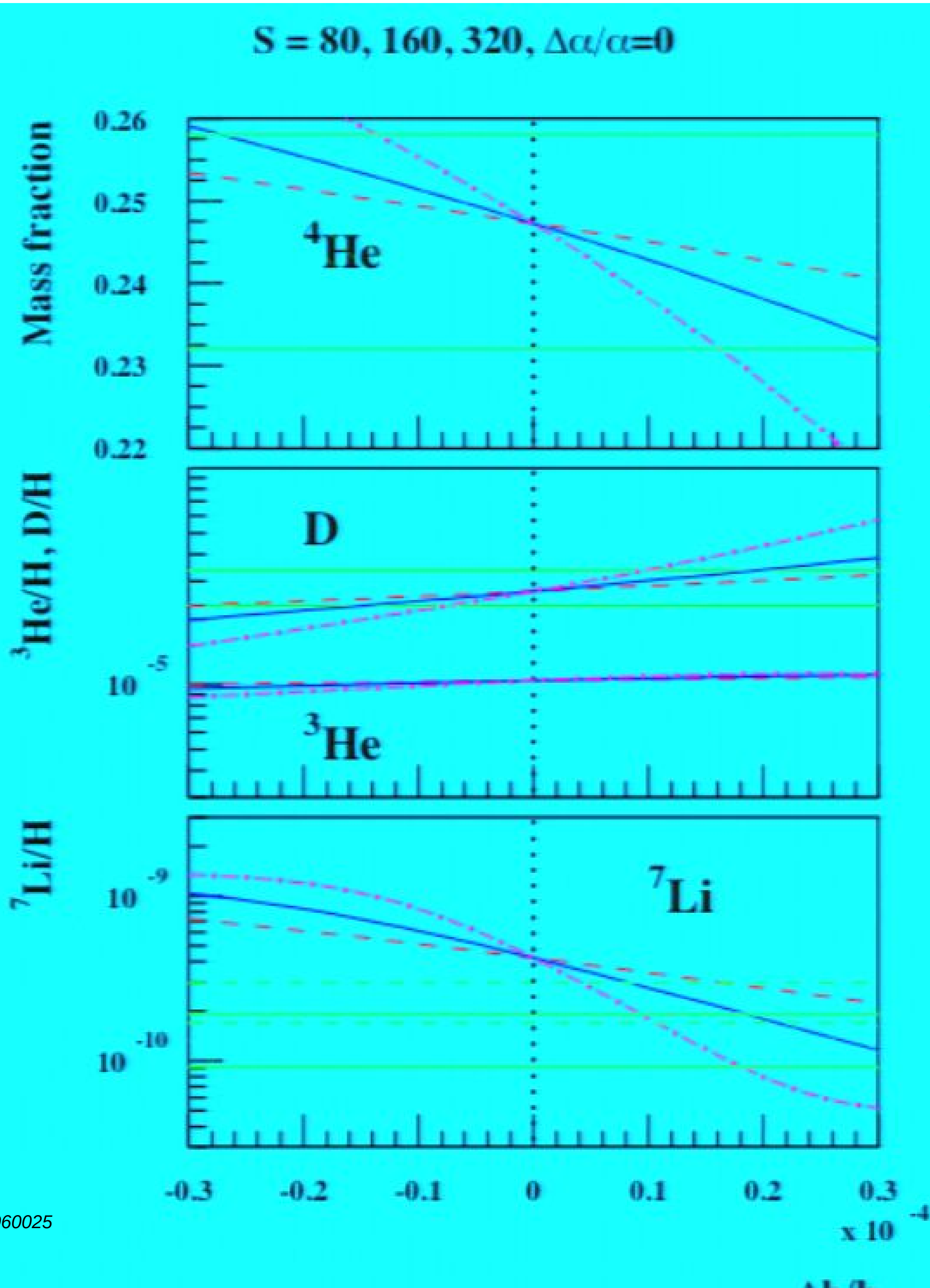
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



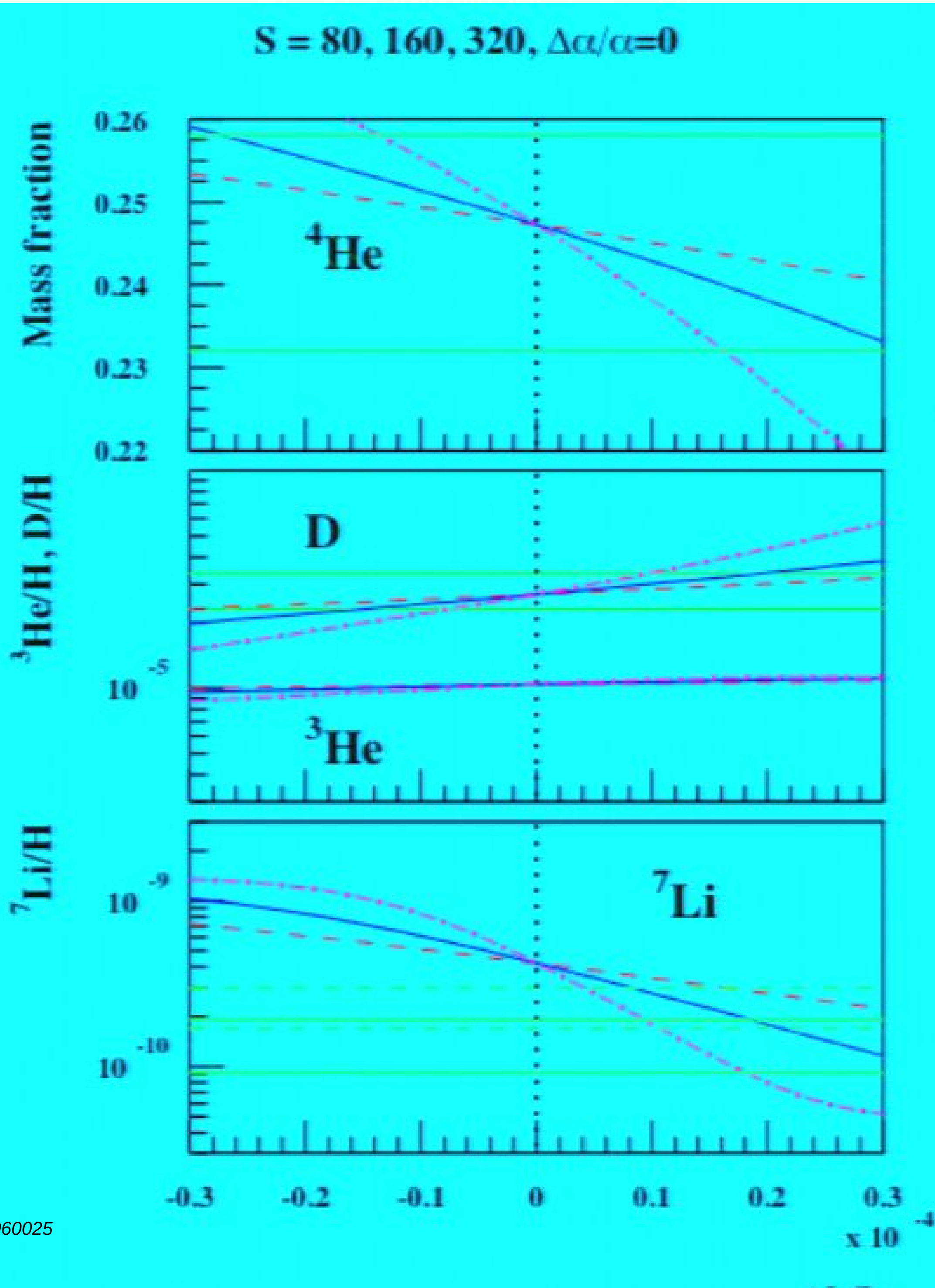
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



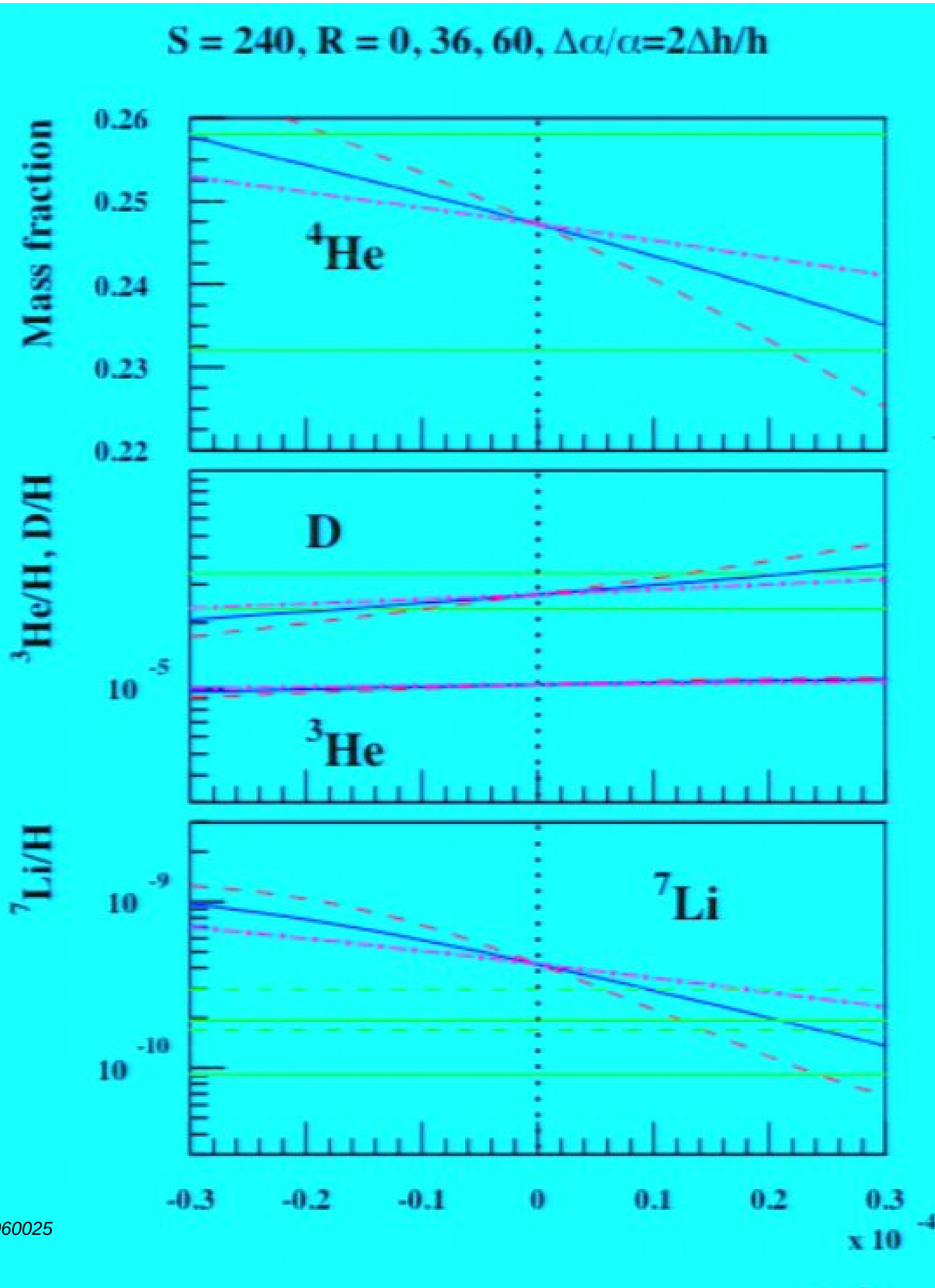
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



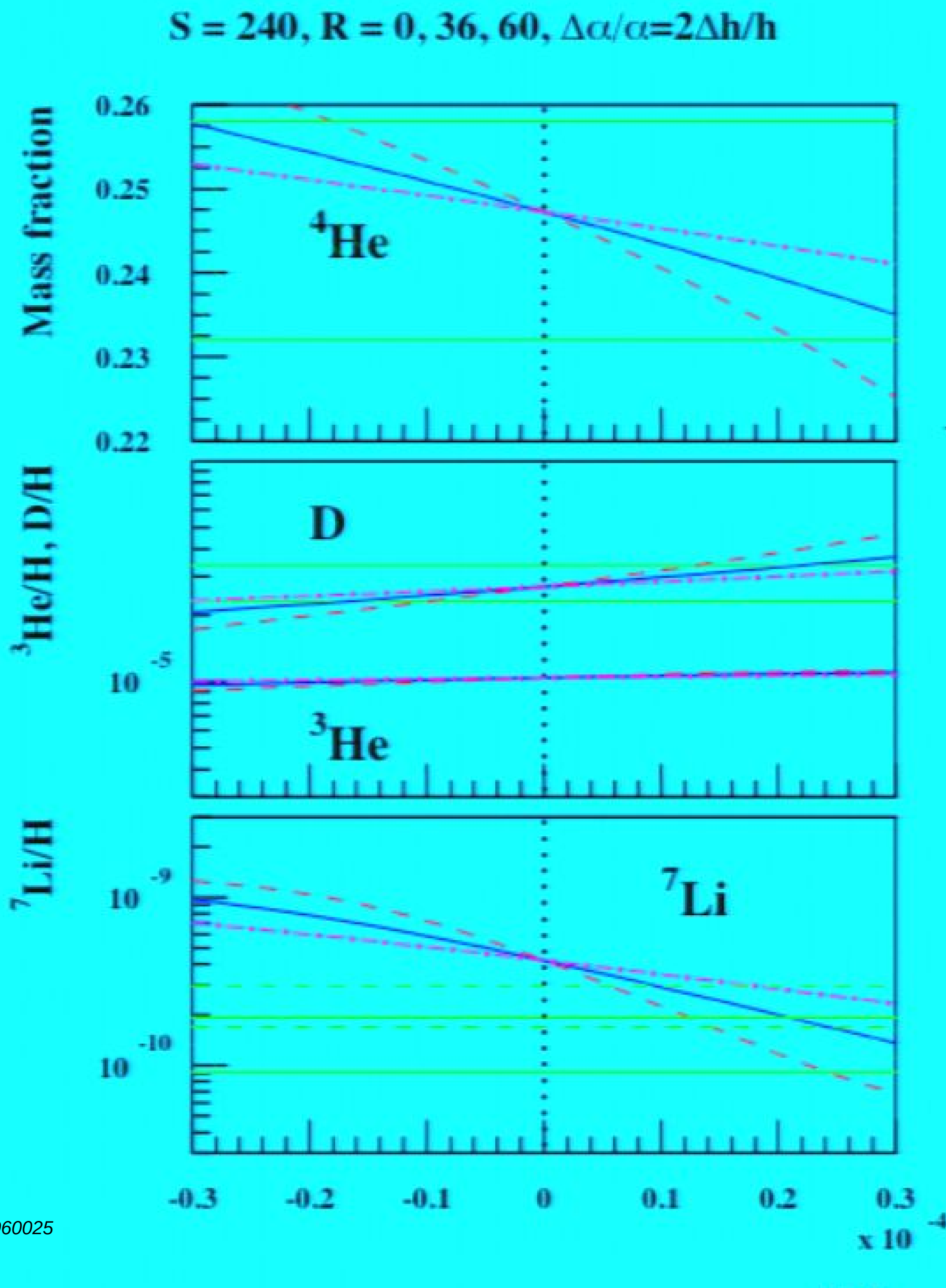
For S = 160,

$$-1.5 \times 10^{-5} < \frac{\Delta h}{h} < 1.9 \times 10^{-5}.$$



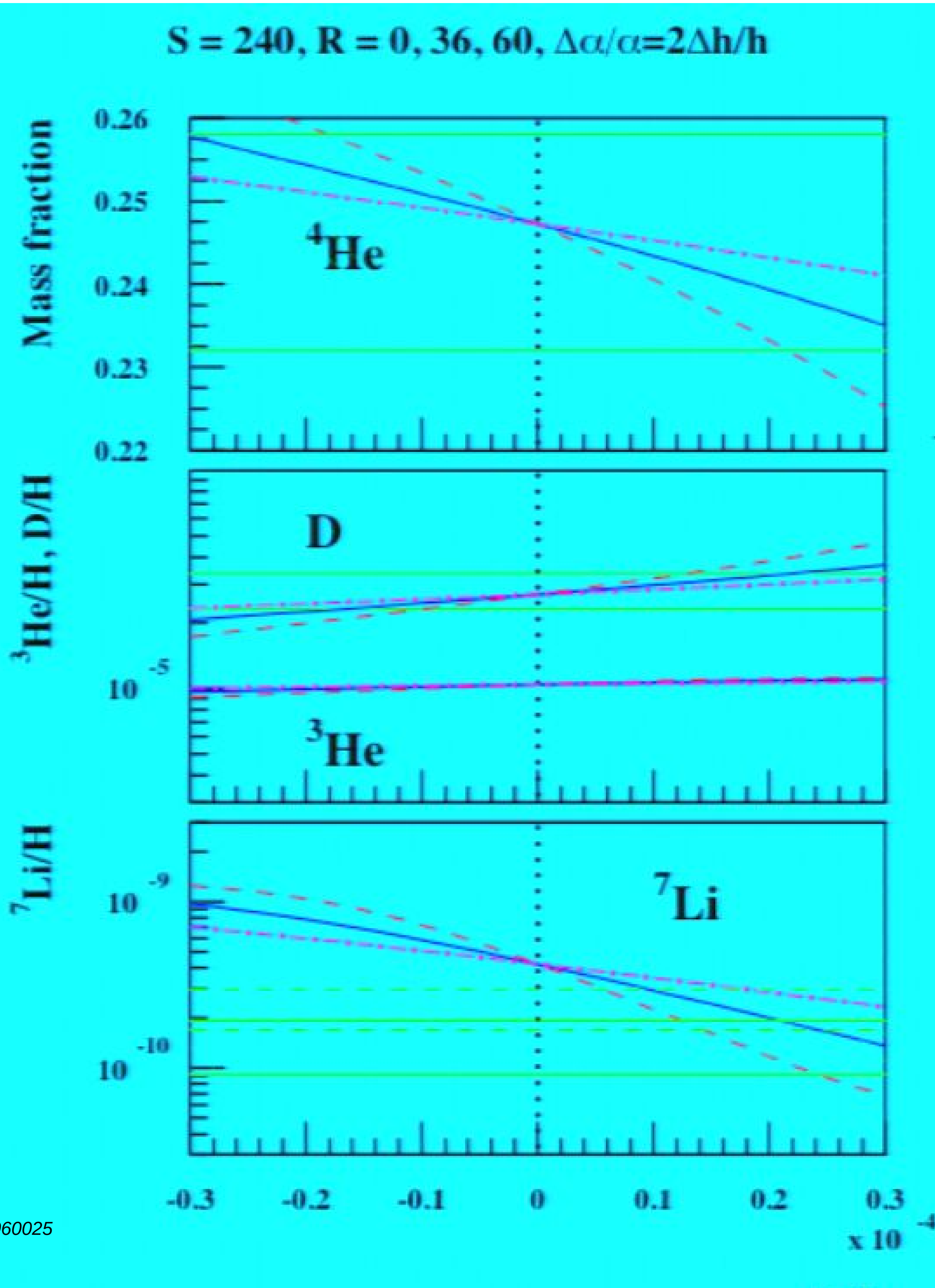
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



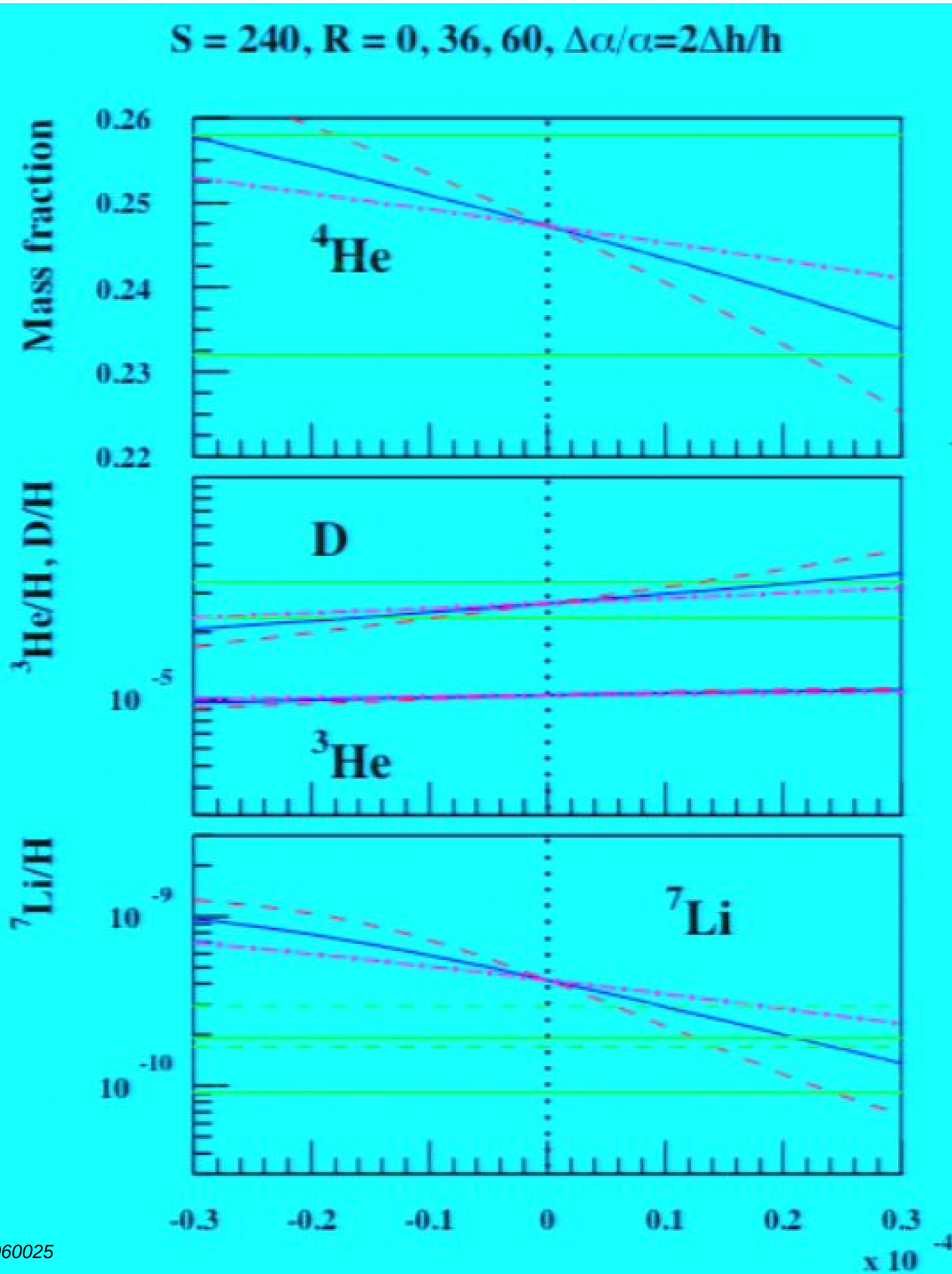
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



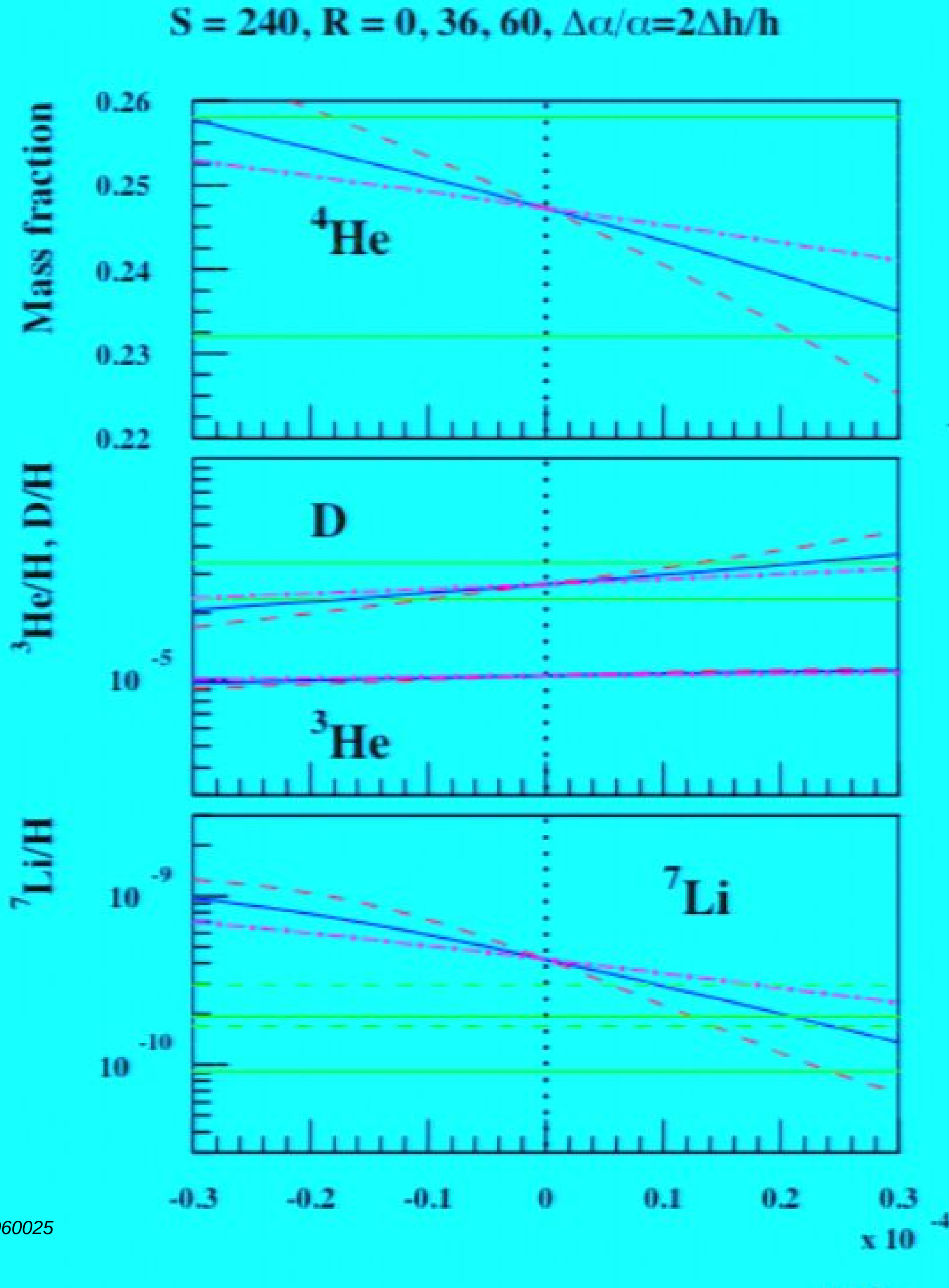
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



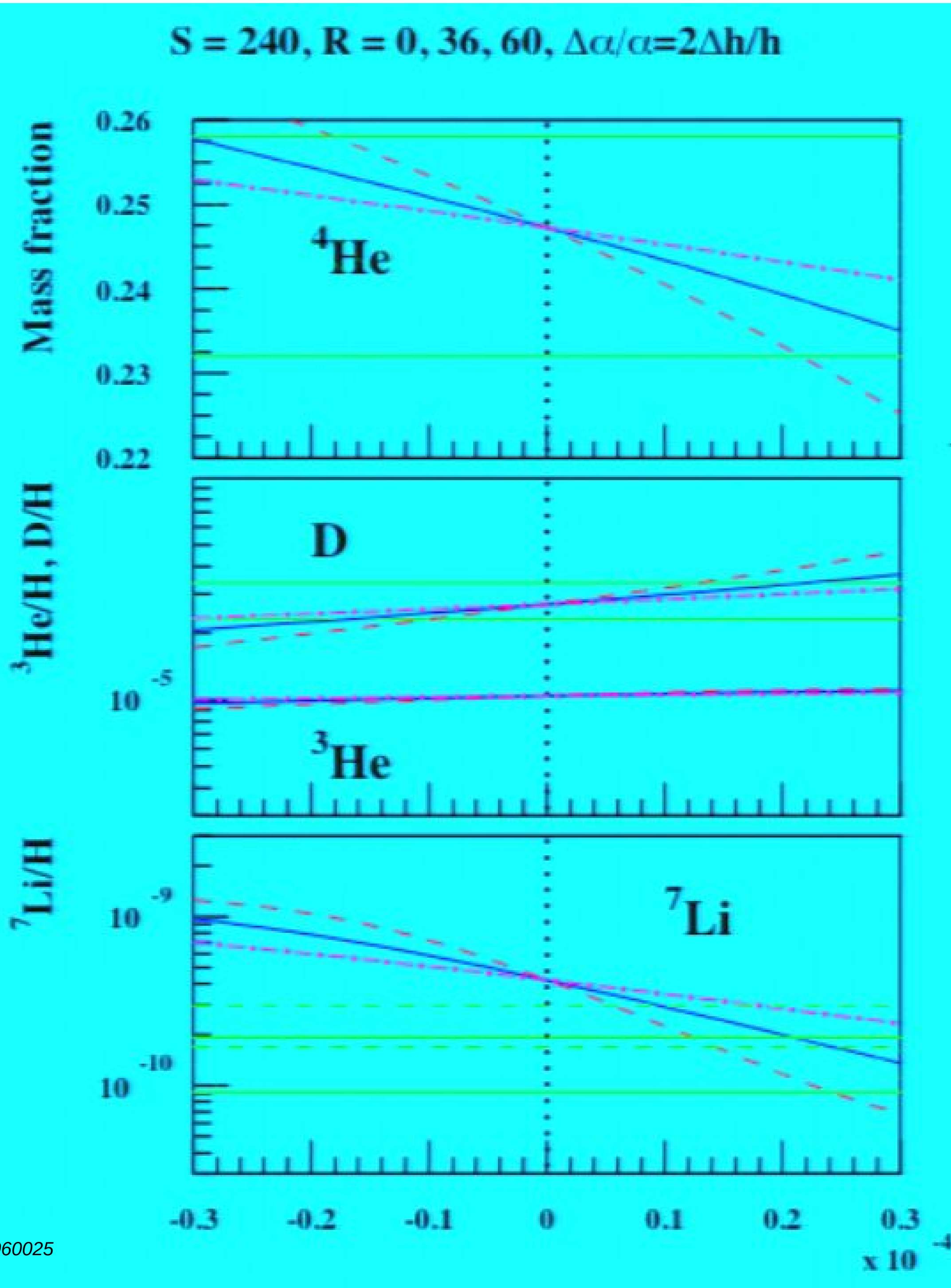
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



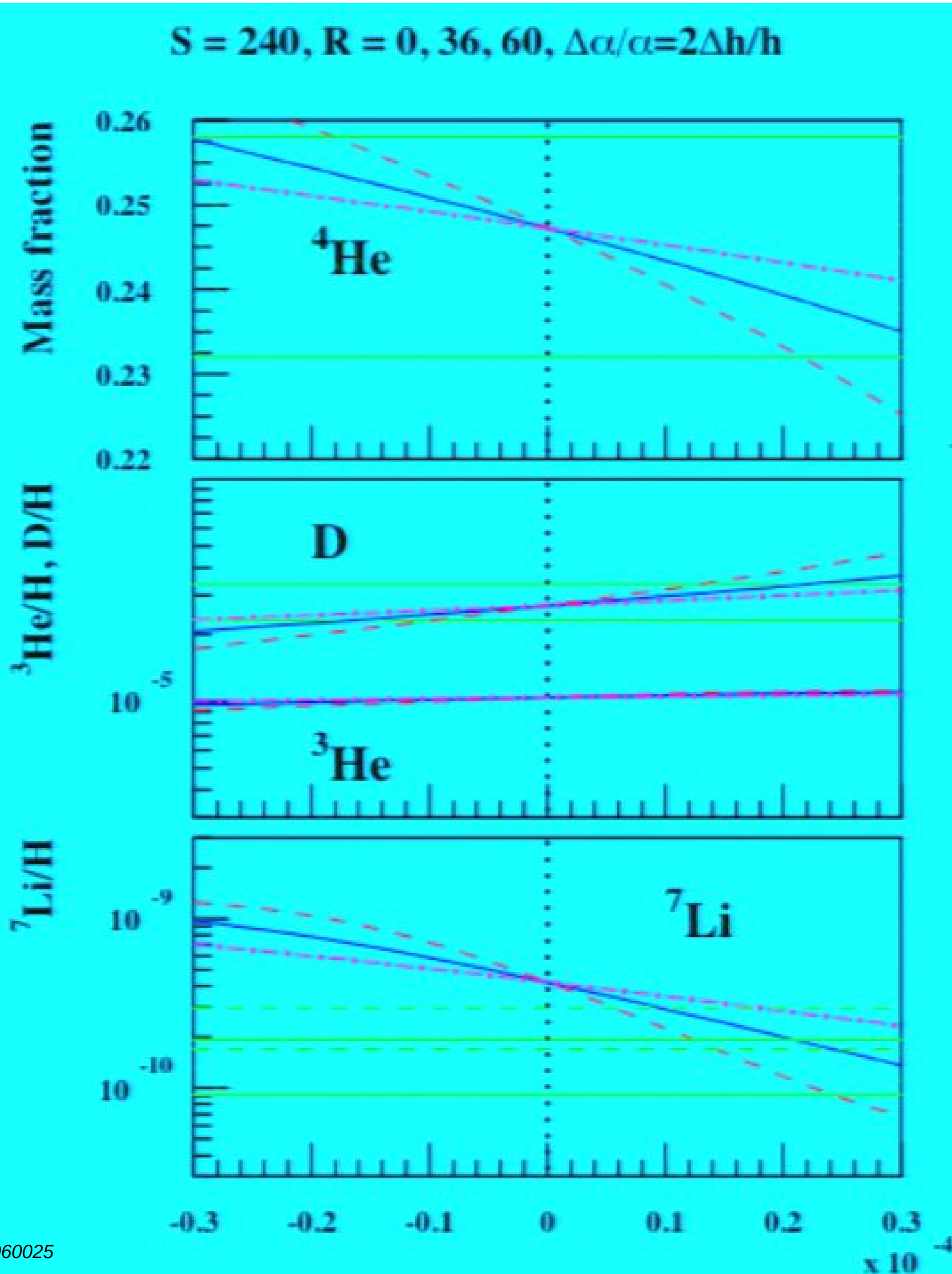
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



For S = 240, R = 36,

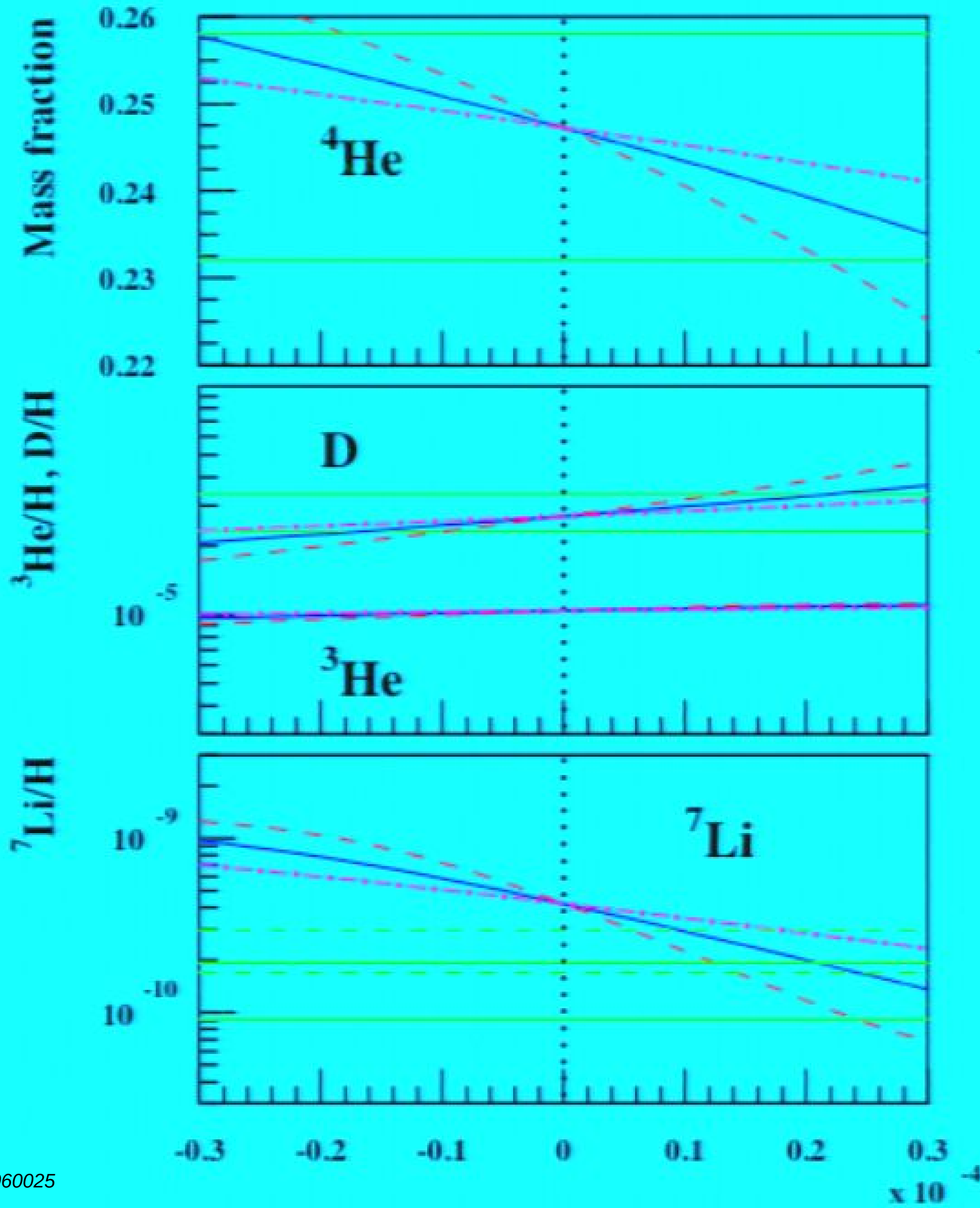
$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



For S = 240, R = 36,

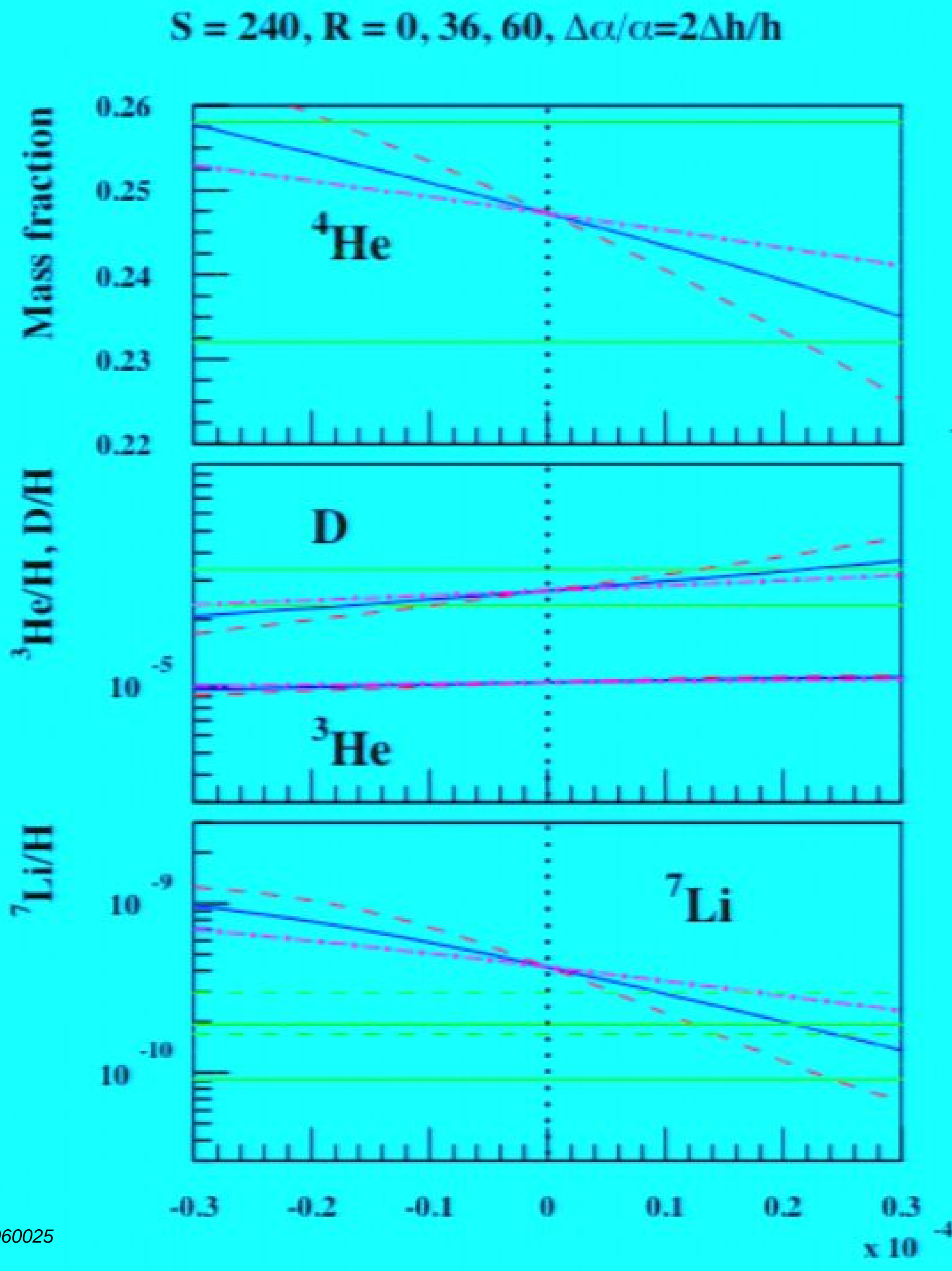
$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$

S = 240, R = 0, 36, 60, Δα/α=2Δh/h



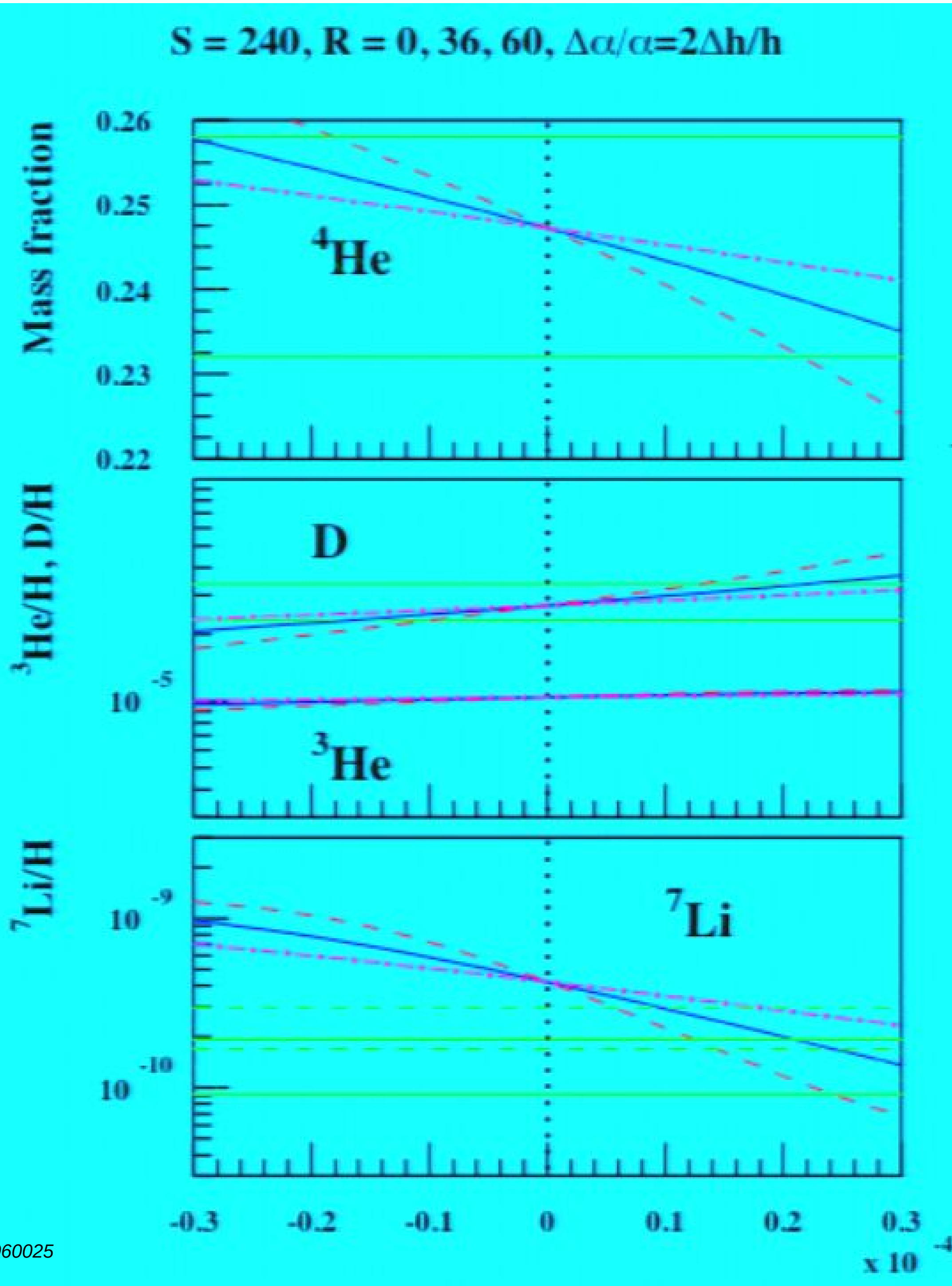
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



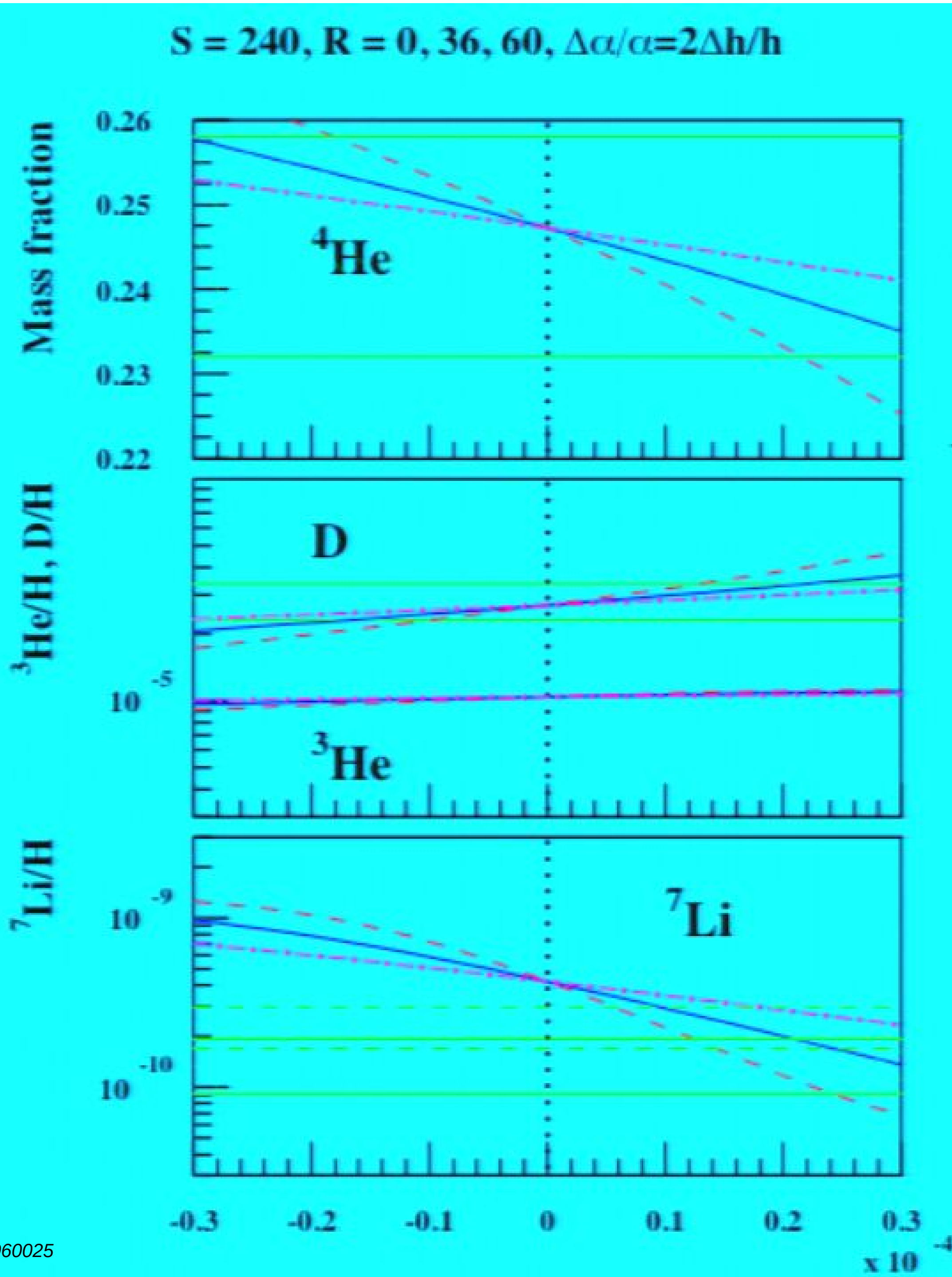
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



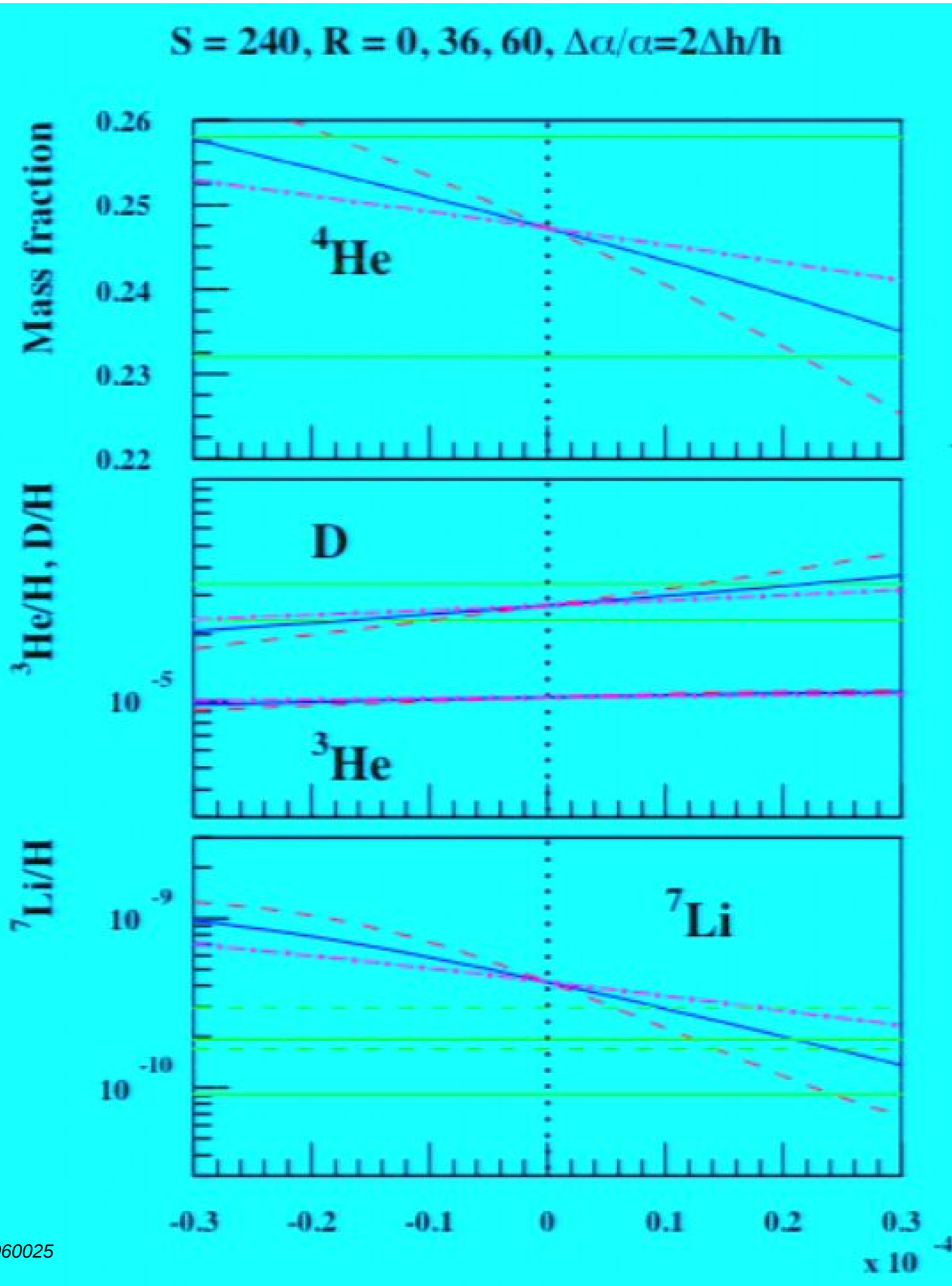
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



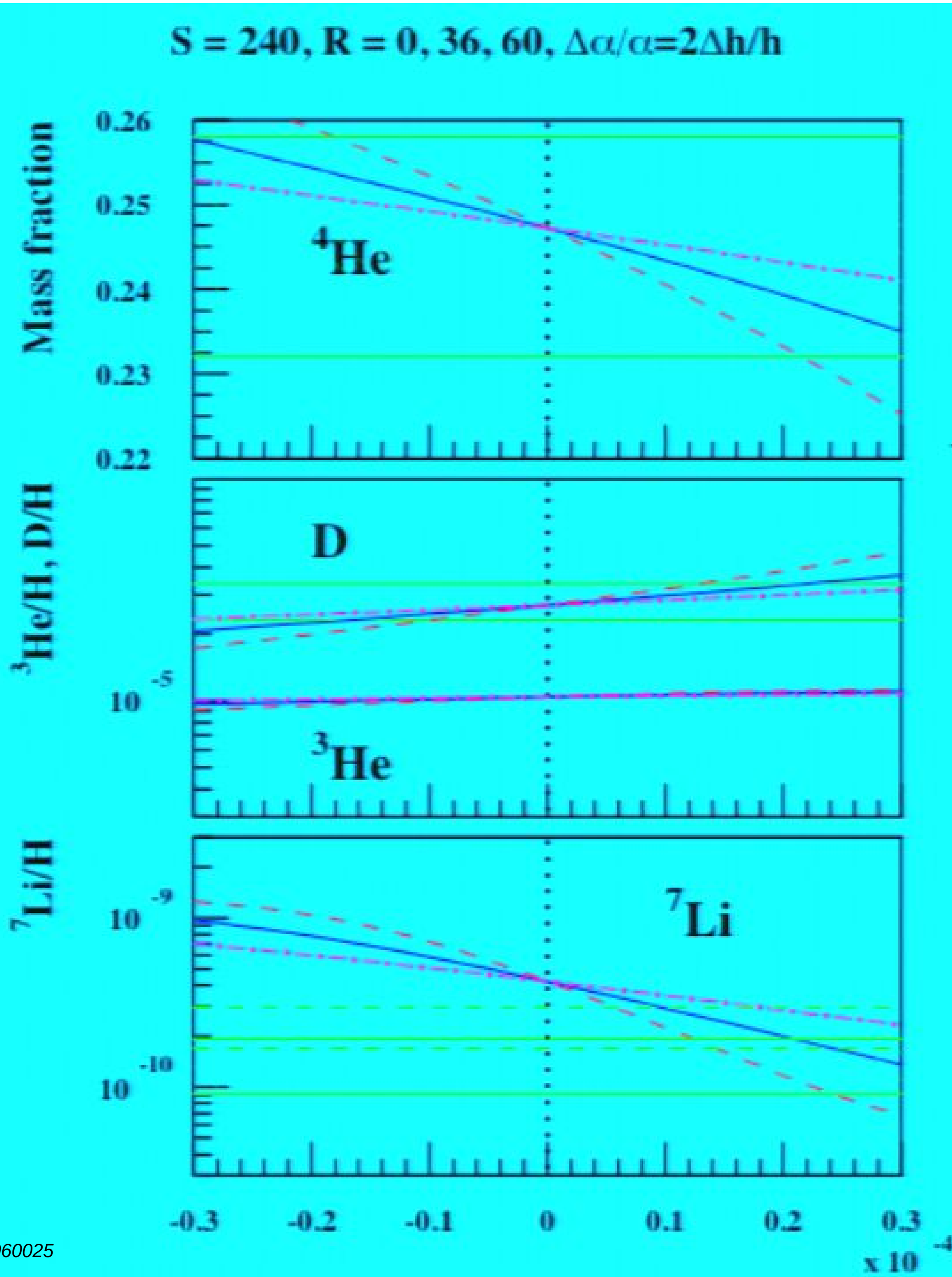
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



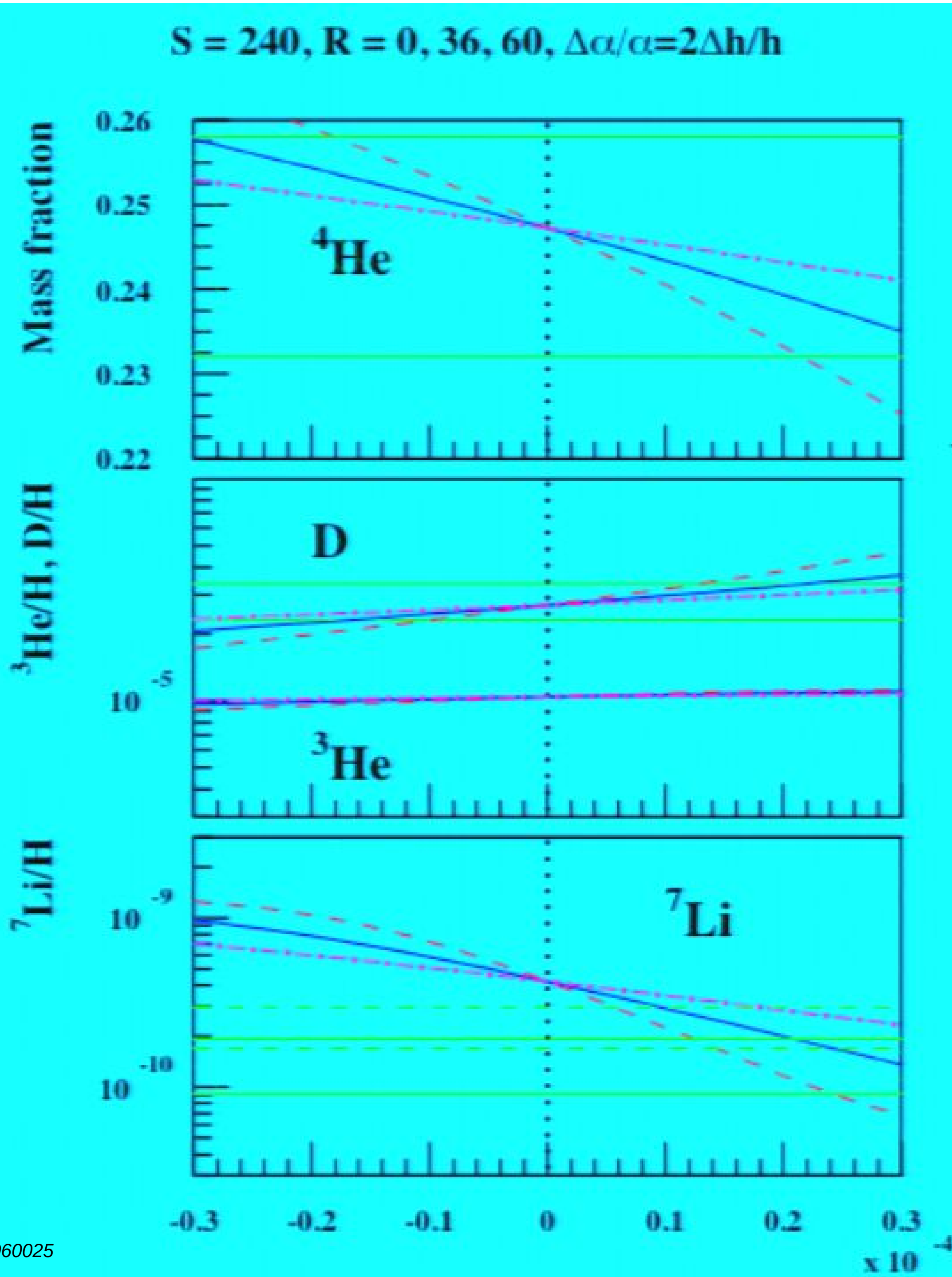
For S = 240, R = 36,

$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



For S = 240, R = 36,

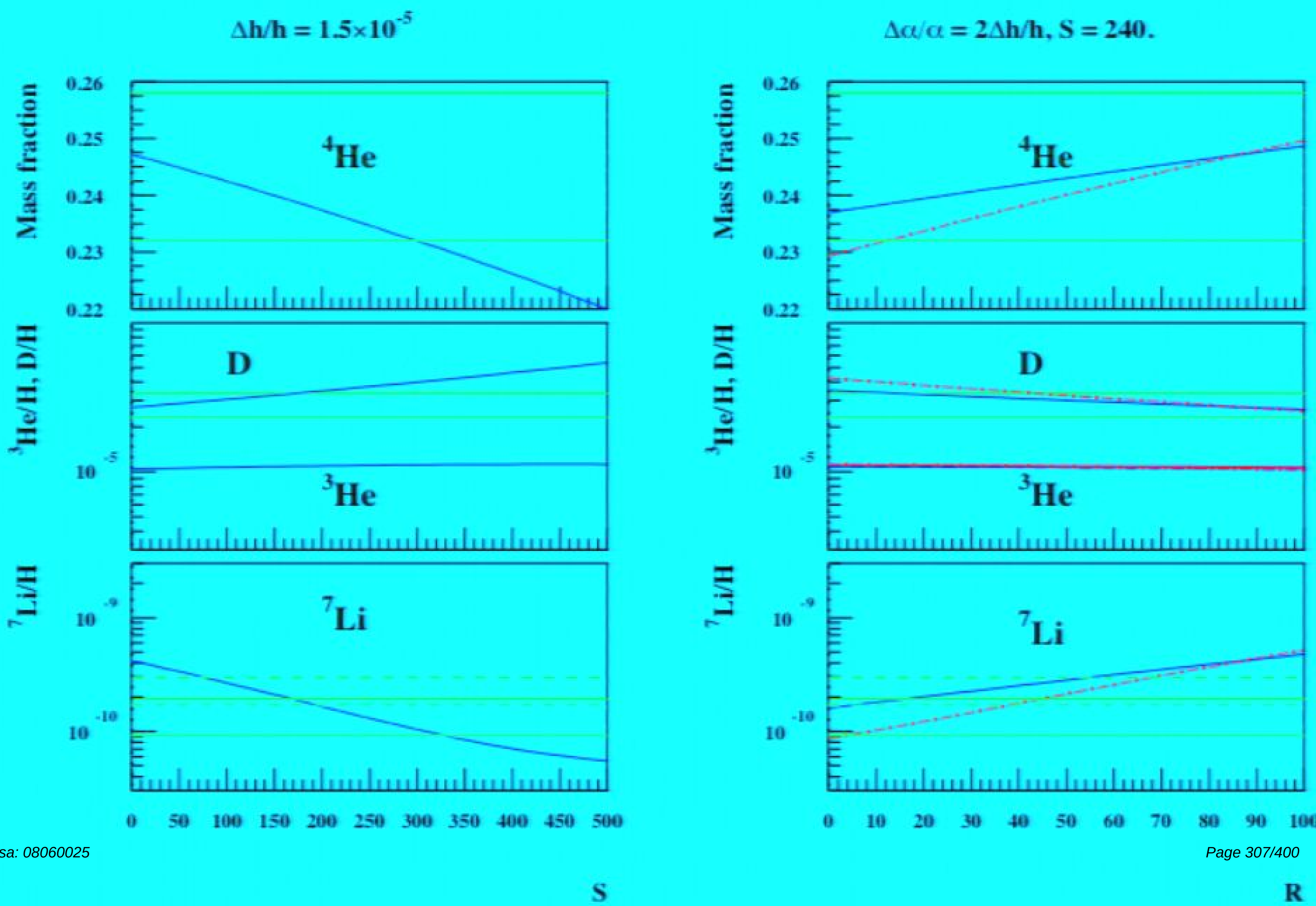
$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$



For S = 240, R = 36,

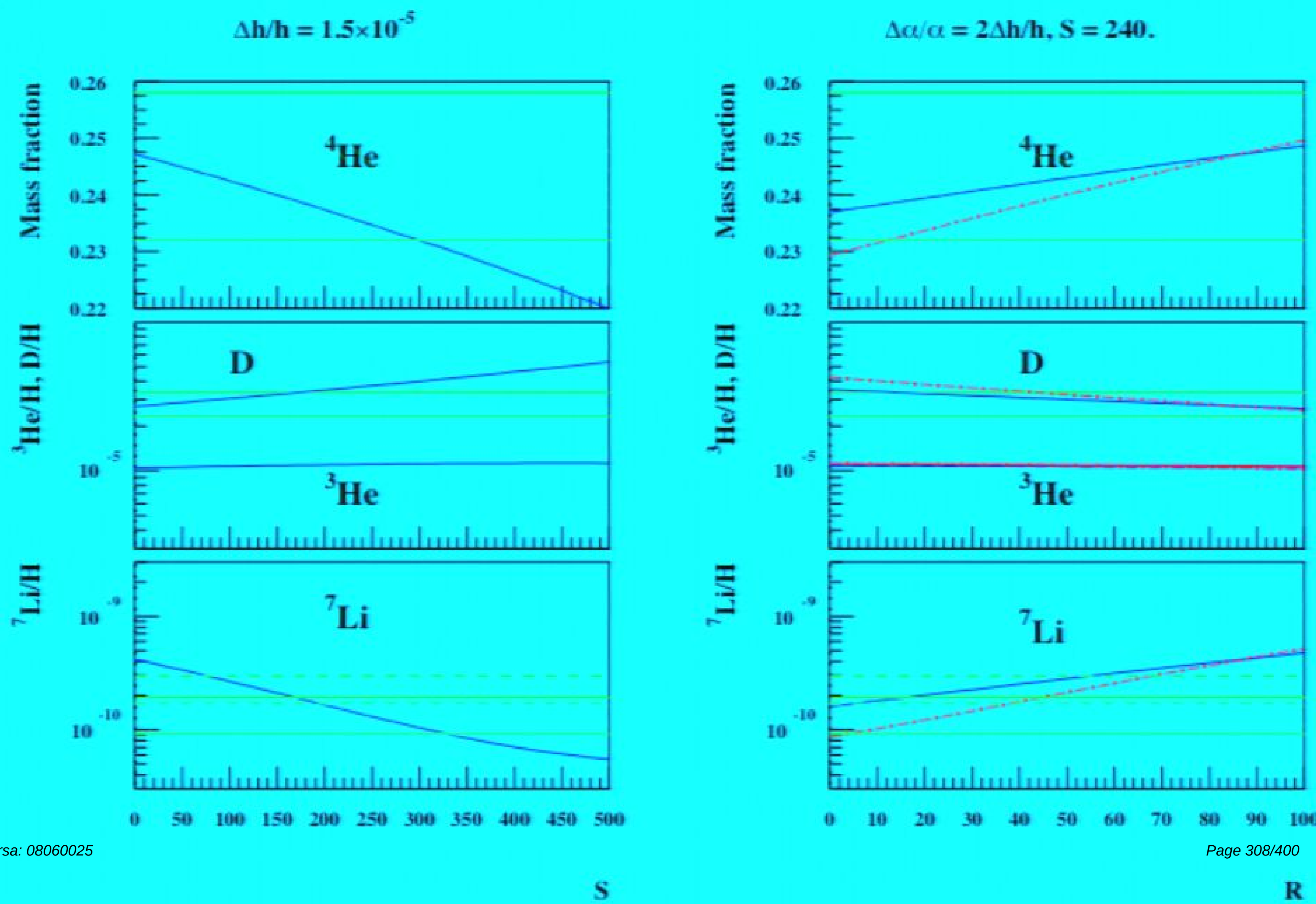
$$-1.6 \times 10^{-5} < \frac{\Delta h}{h} < 2.1 \times 10^{-5}$$

Finally,



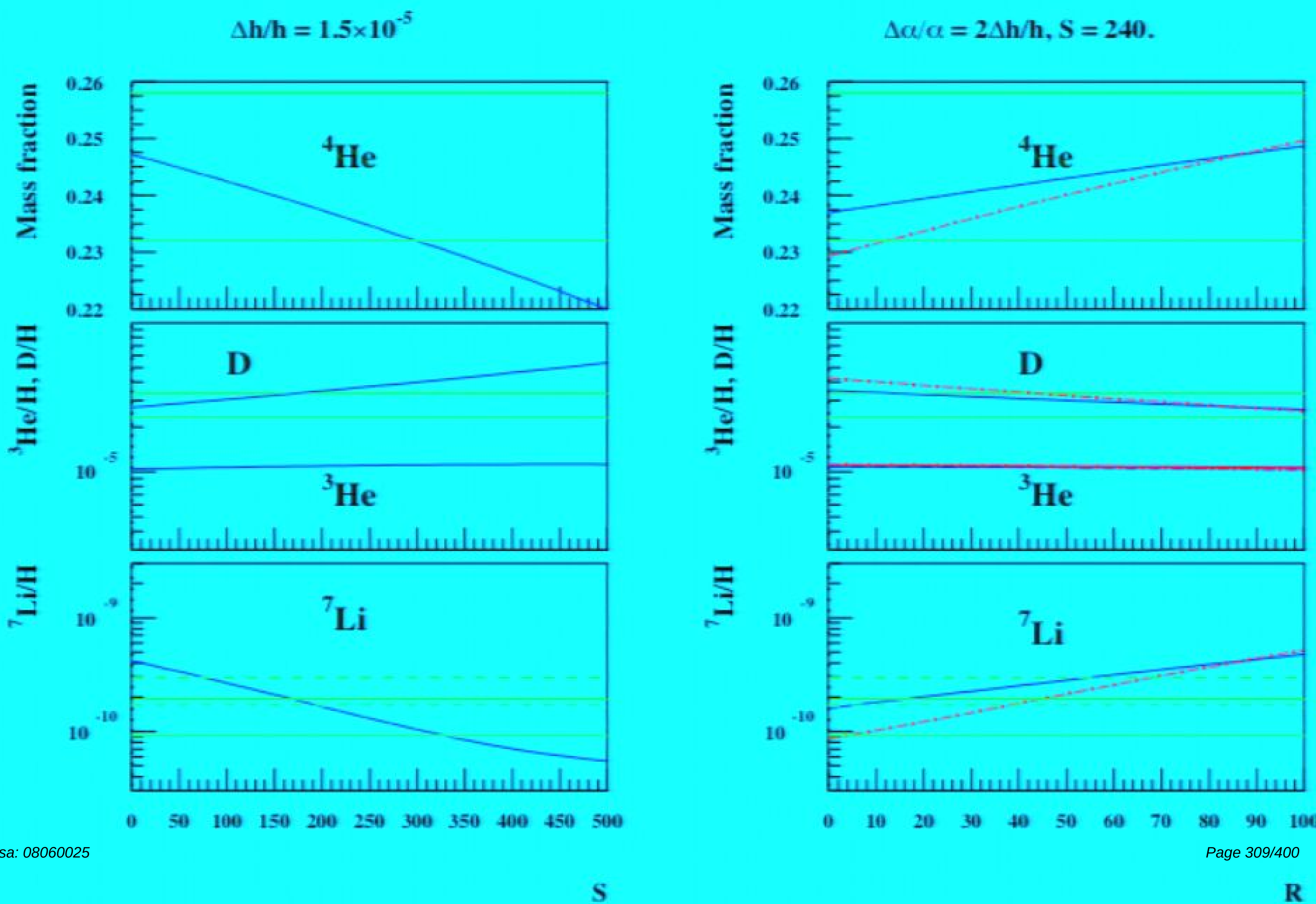
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
10^-9
10^-10
7Li
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
60
70
80
90
S
R

Finally,



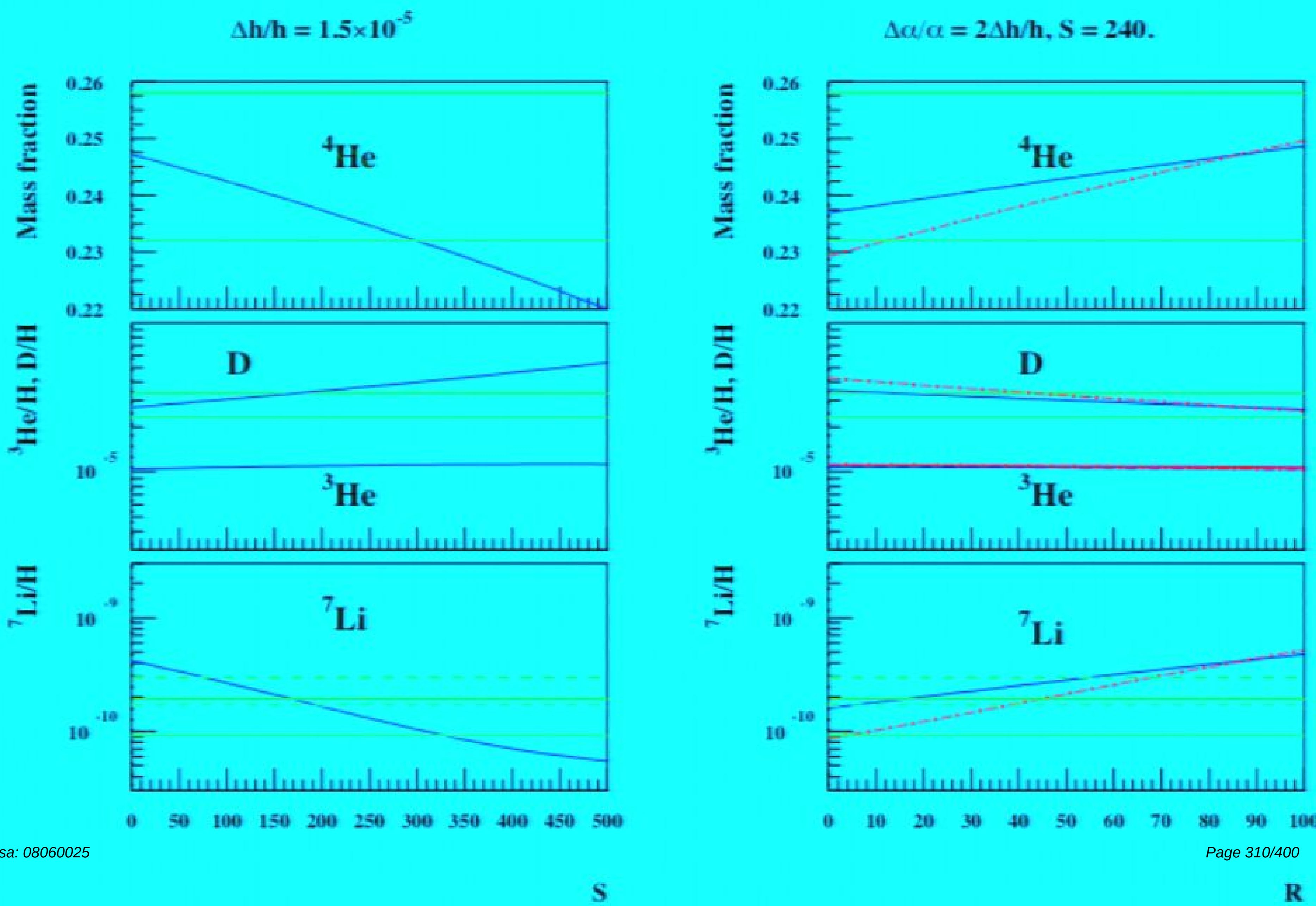
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



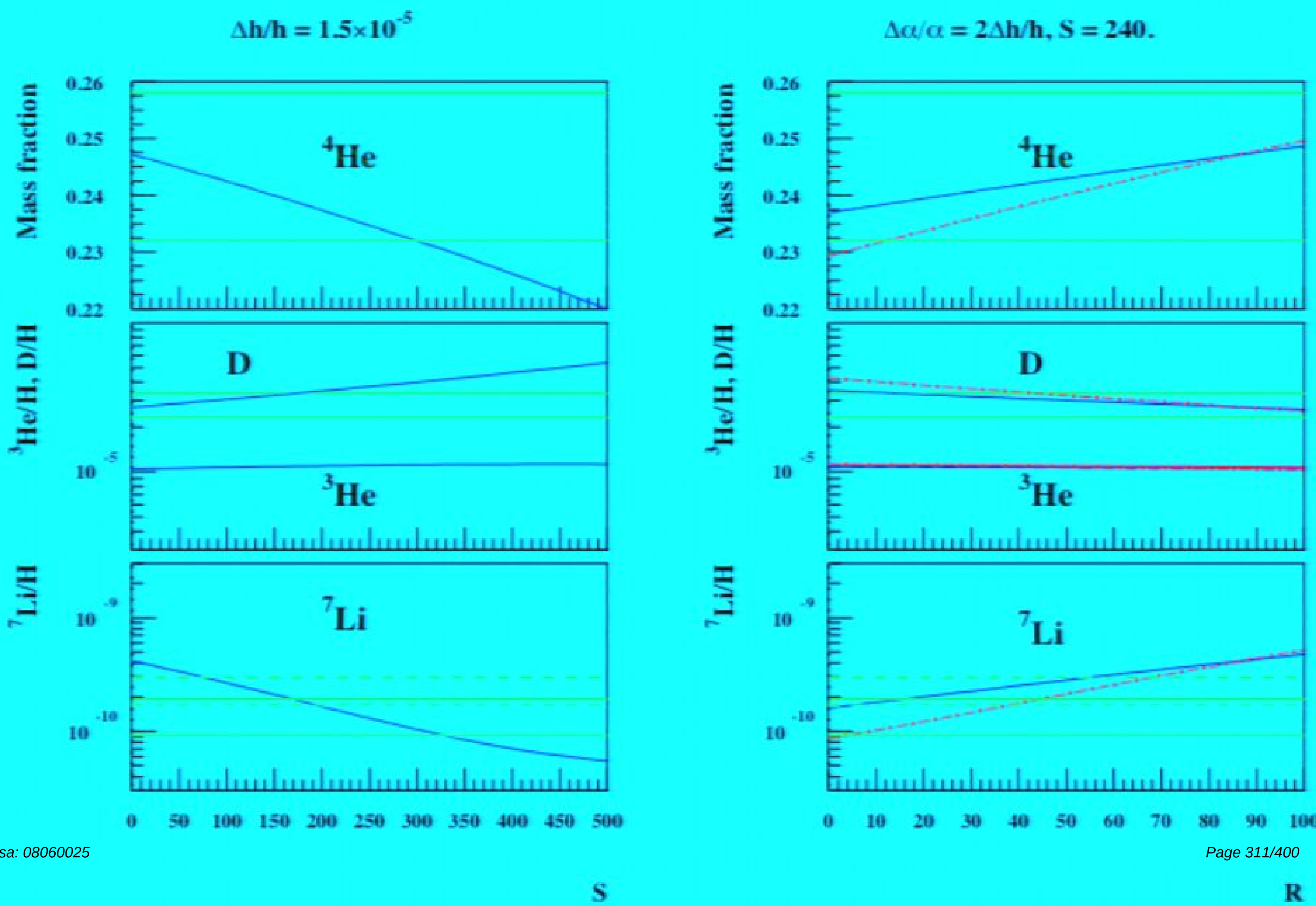
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10 -5
3He
7Li/H
10 -9
7Li
10 -10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



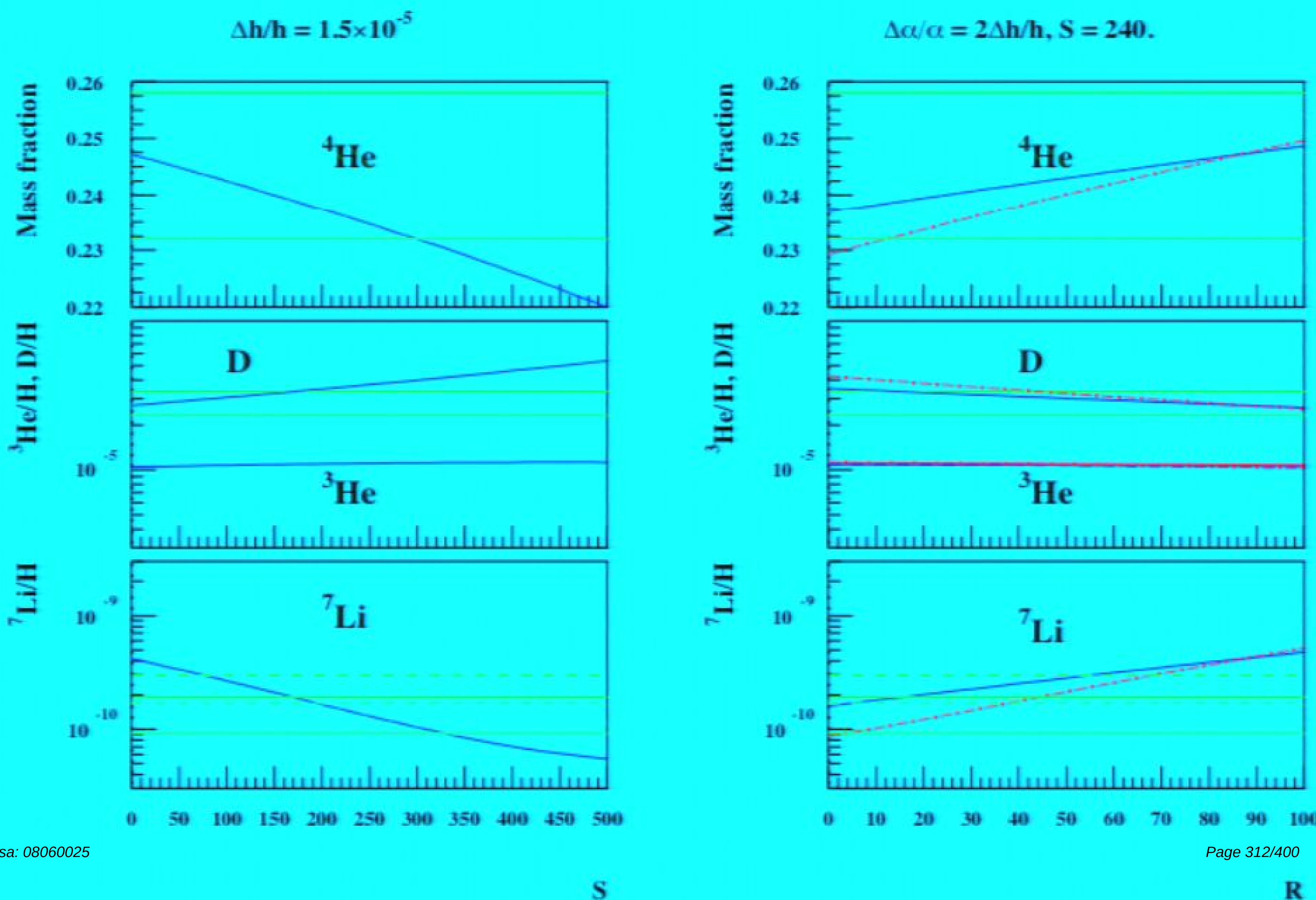
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
^{4}He
D
^{3}He/H, D/H
^{3}He
^{7}Li/H
^{7}Li
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



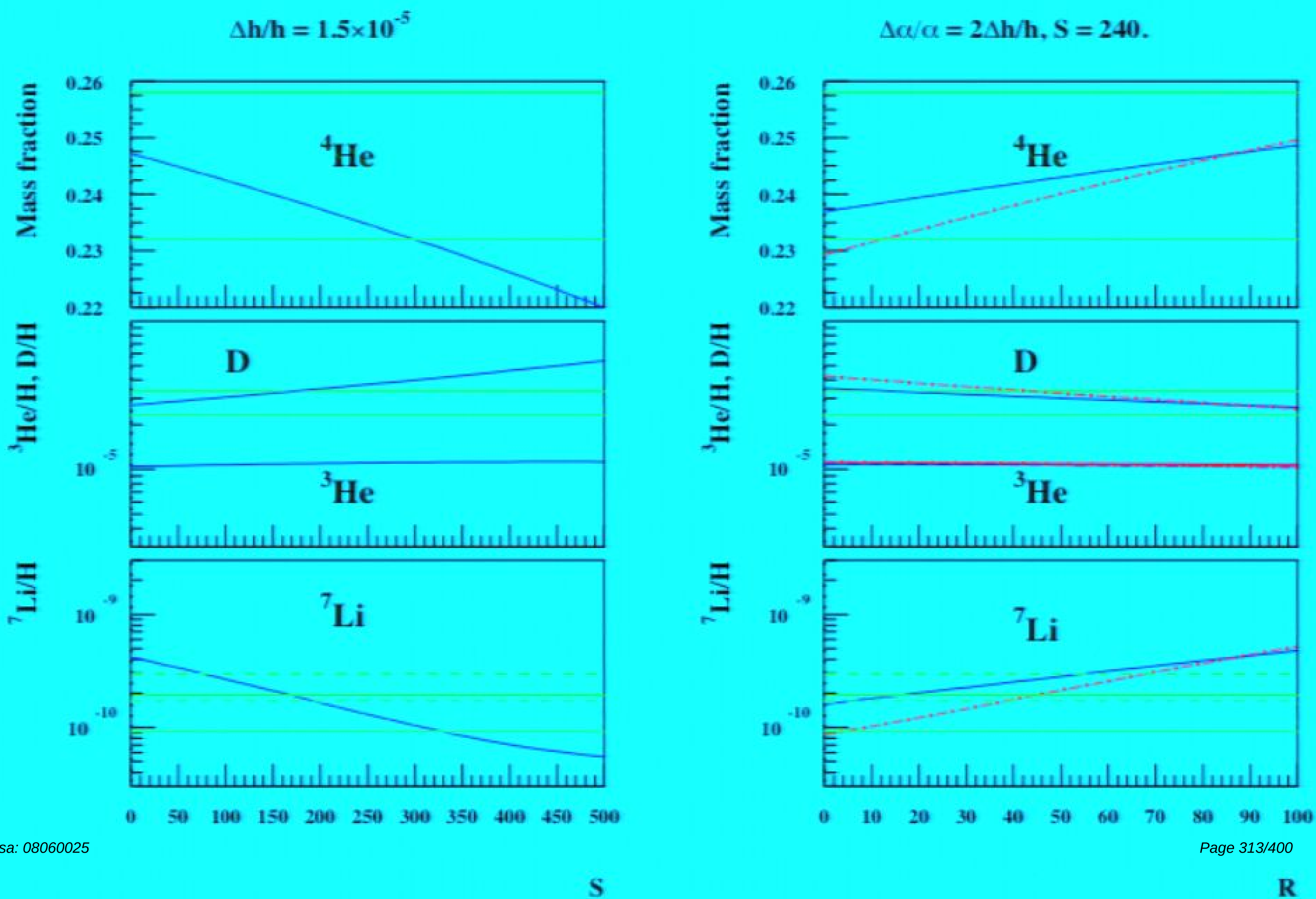
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
⁴He
D
³He/H, D/H
³He
⁷Li/H
⁷Li
S
R

Finally,



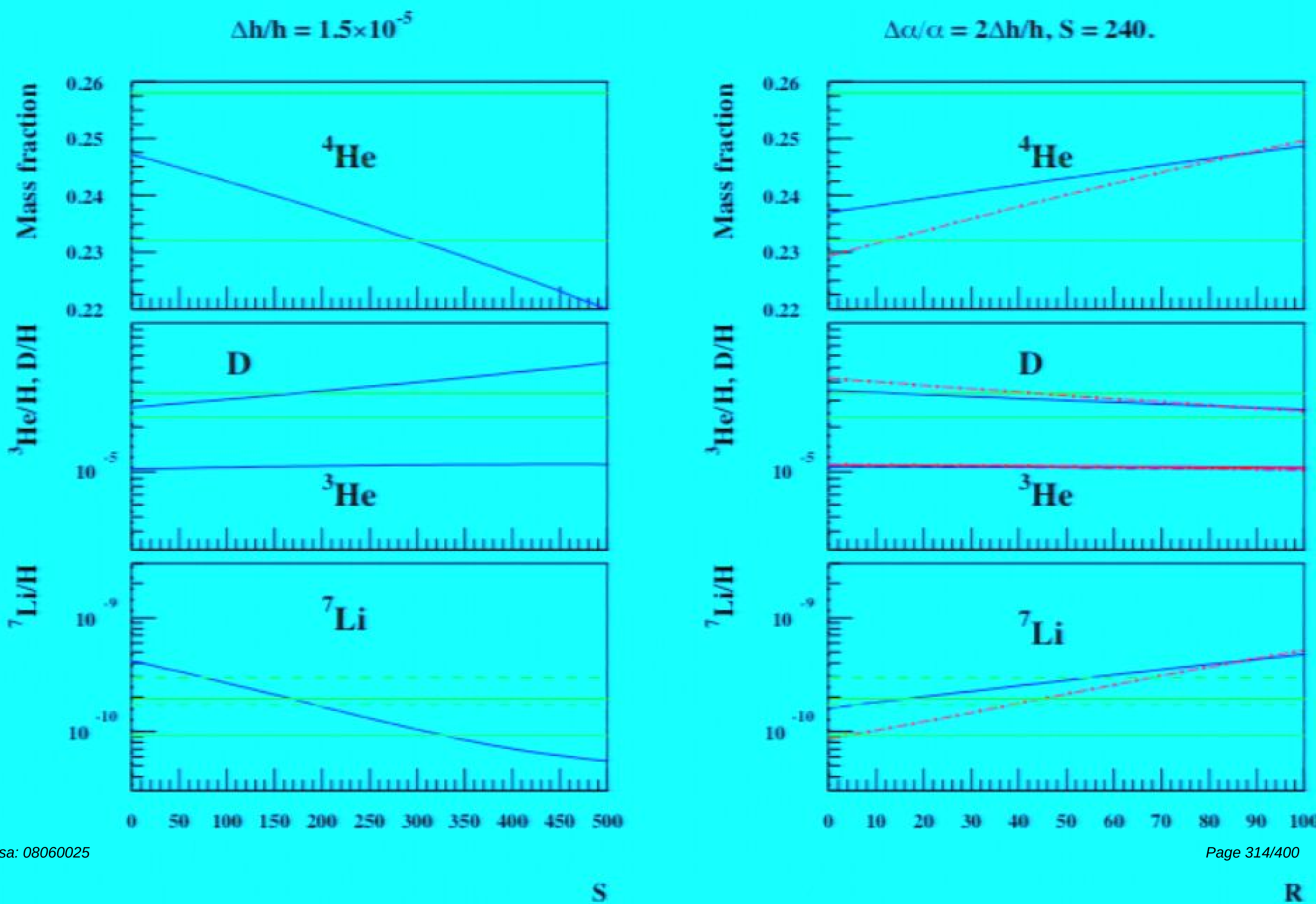
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h, S = 240.$
Mass fraction
^{4}He
^{3}He/H, D/H
D
^{3}He
^{7}Li/H
^{7}Li
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



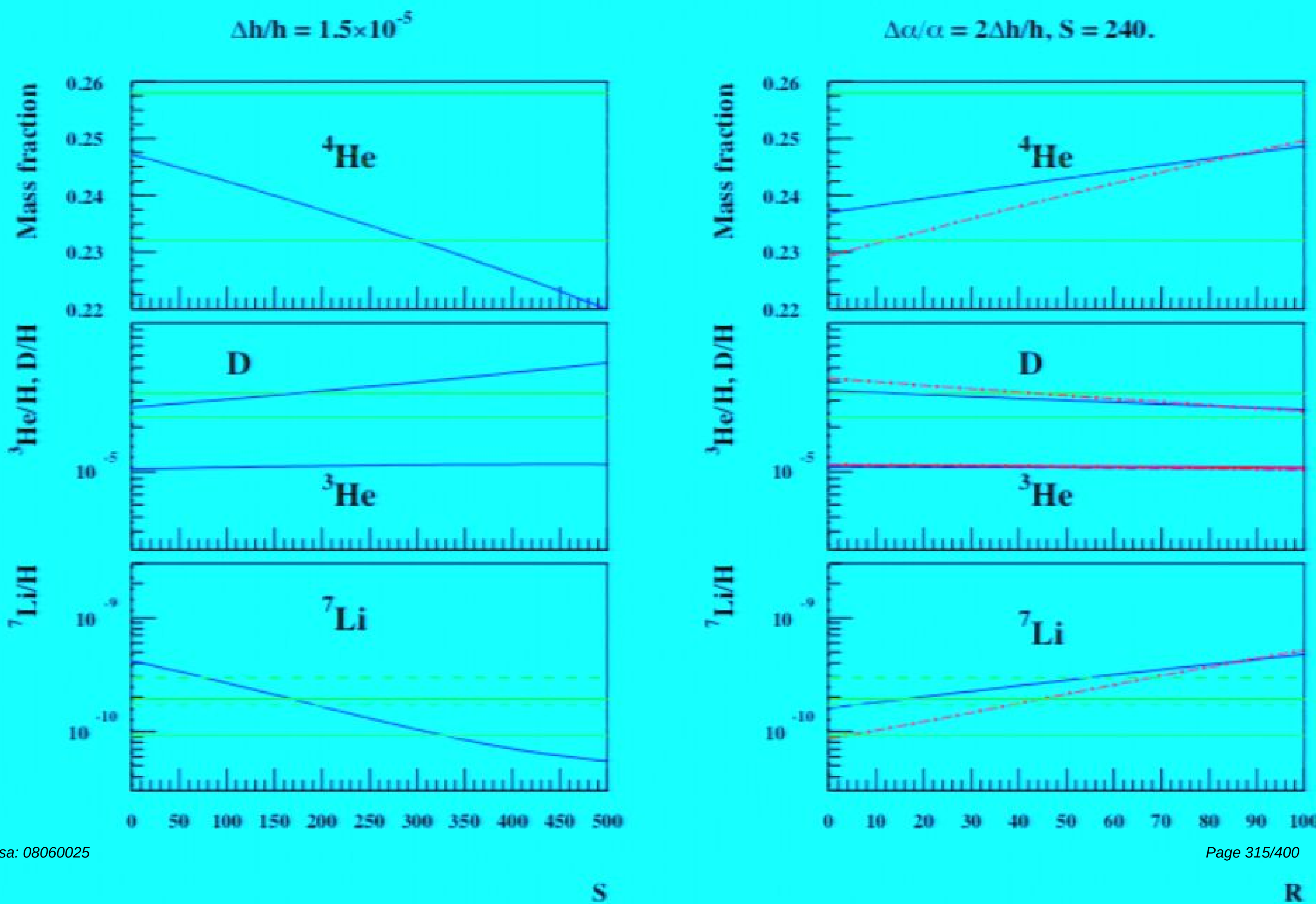
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
10^-9
10^-10
7Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



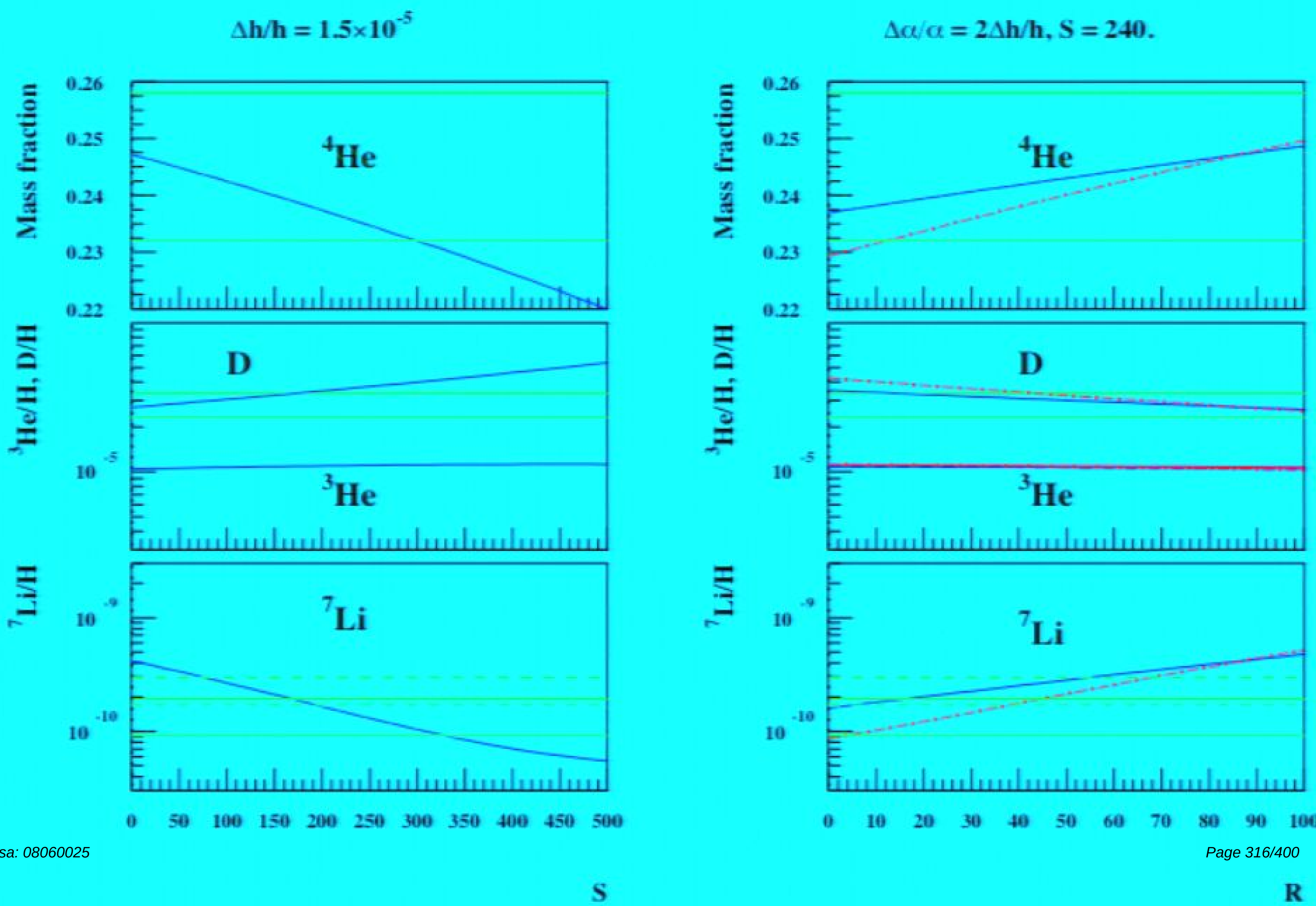
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
7Li
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



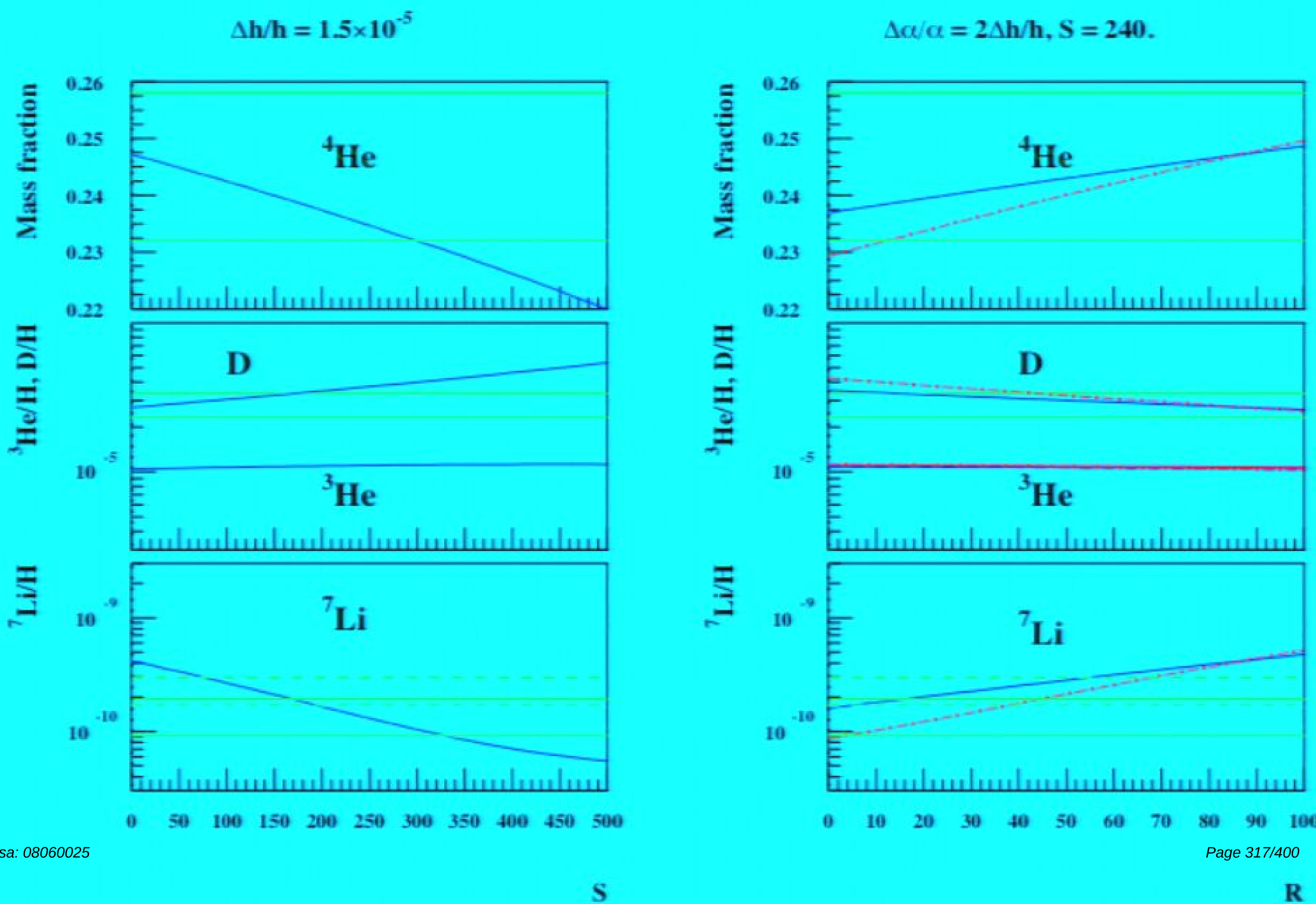
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10 -5
3He
7Li/H
7Li
10 -9
10 -10
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
60
70
80
90
S
R

Finally,



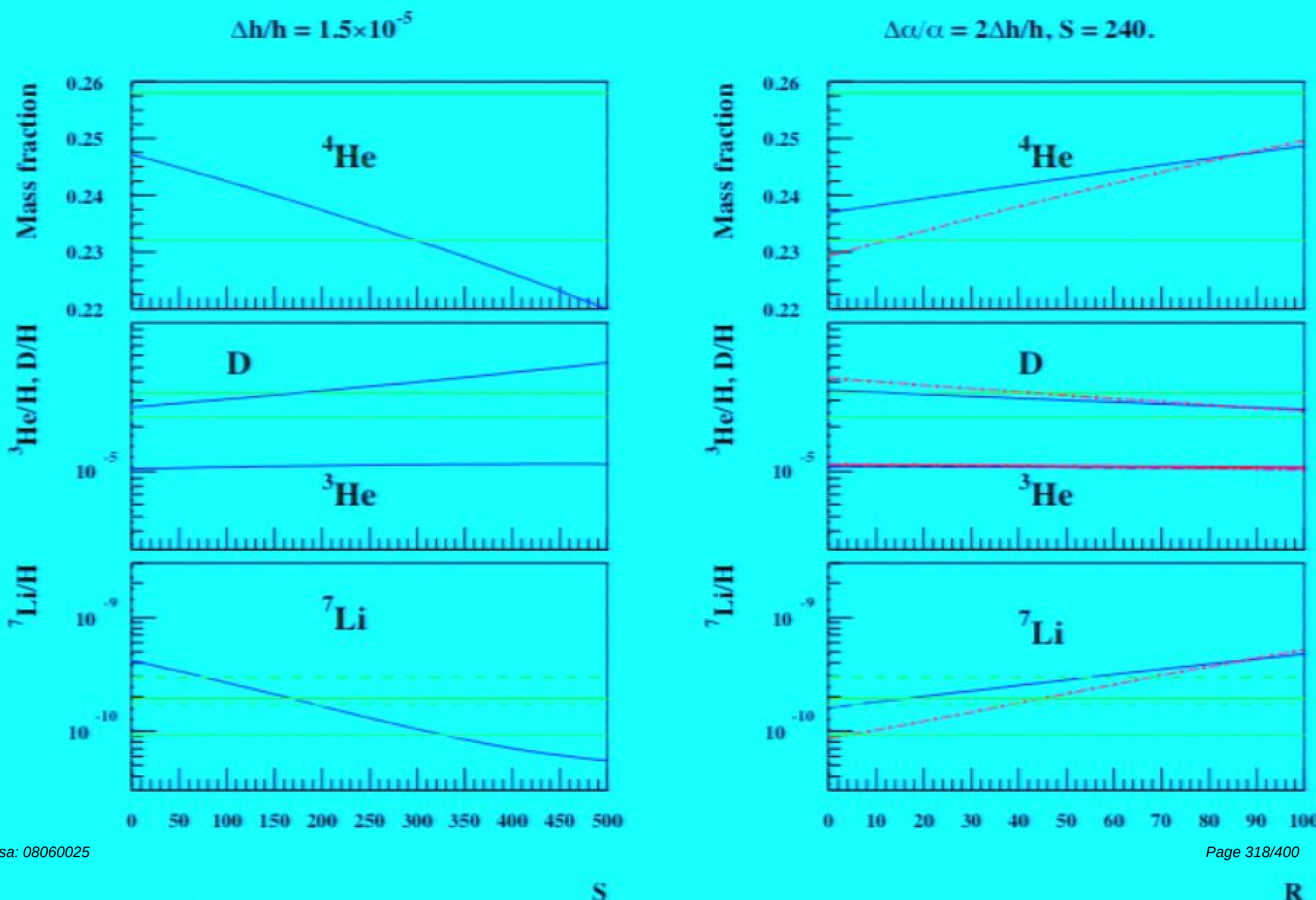
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
7Li
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,

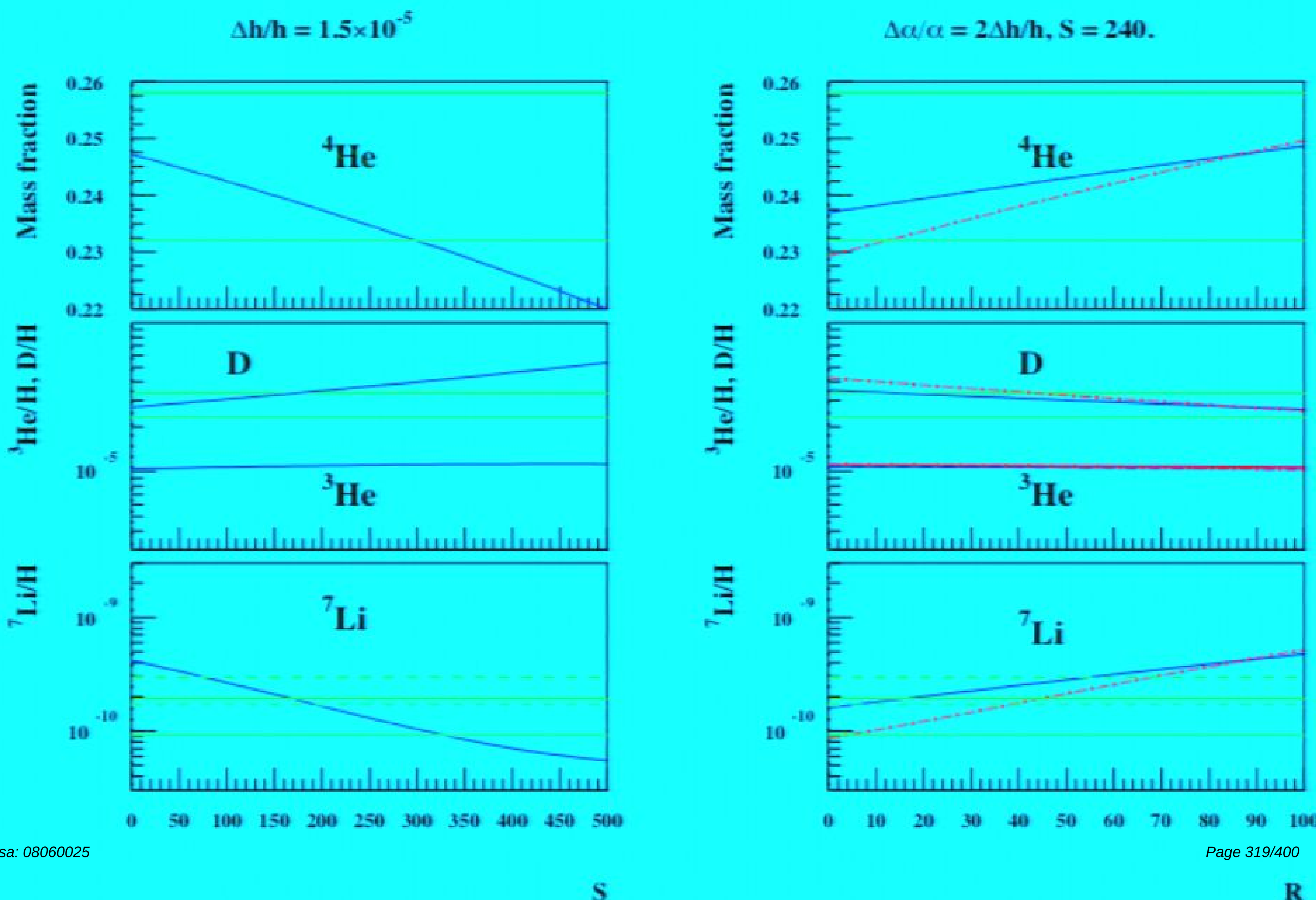


$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h, S = 240.$
Mass fraction
^{4}He
0.26
0.25
0.24
0.23
0.22
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
^{7}Li
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,

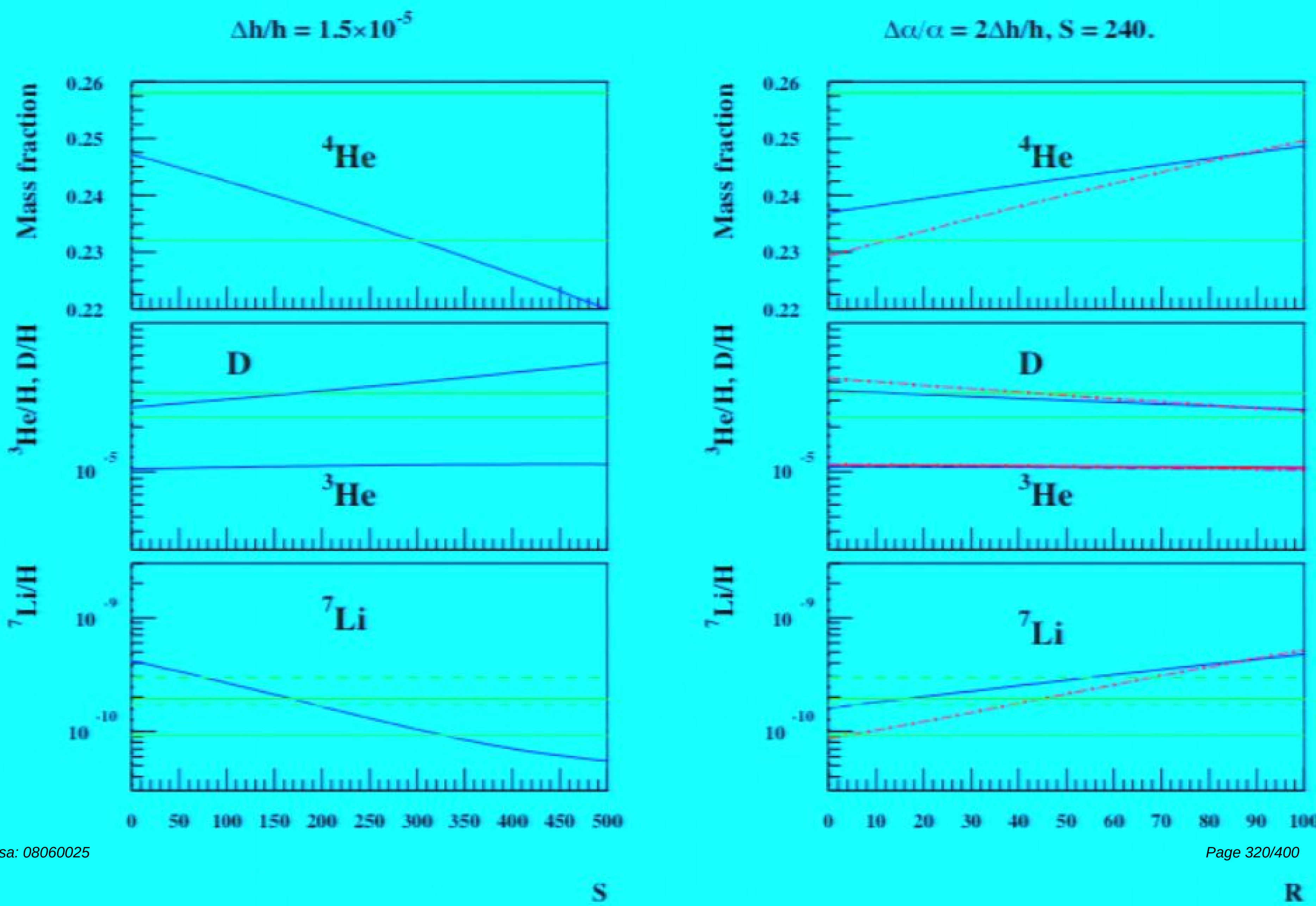

Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
D
3He
7Li
3He/H, D/H
10^-5
7Li/H
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



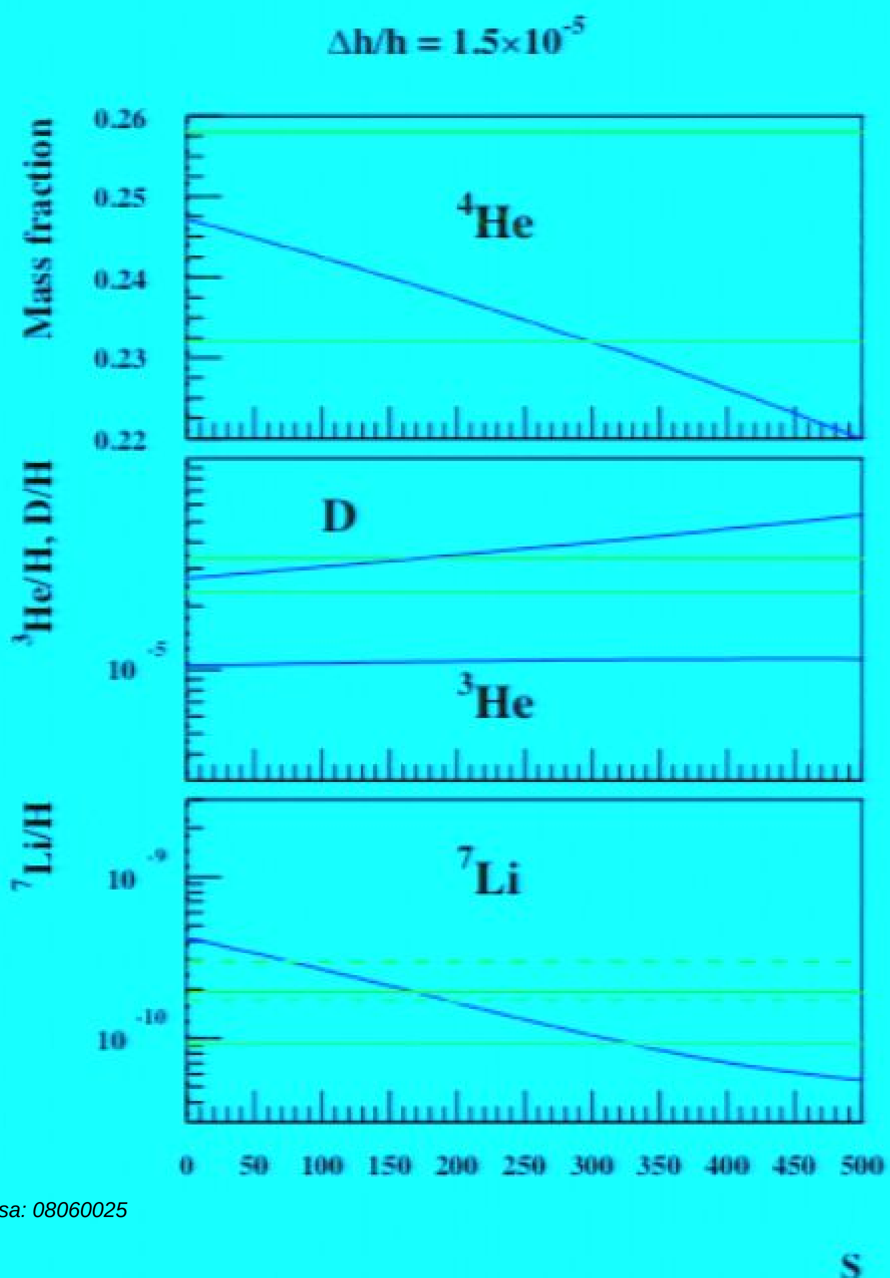
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
7Li
10^-9
10^-10
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
60
70
80
90
S
R

Finally,

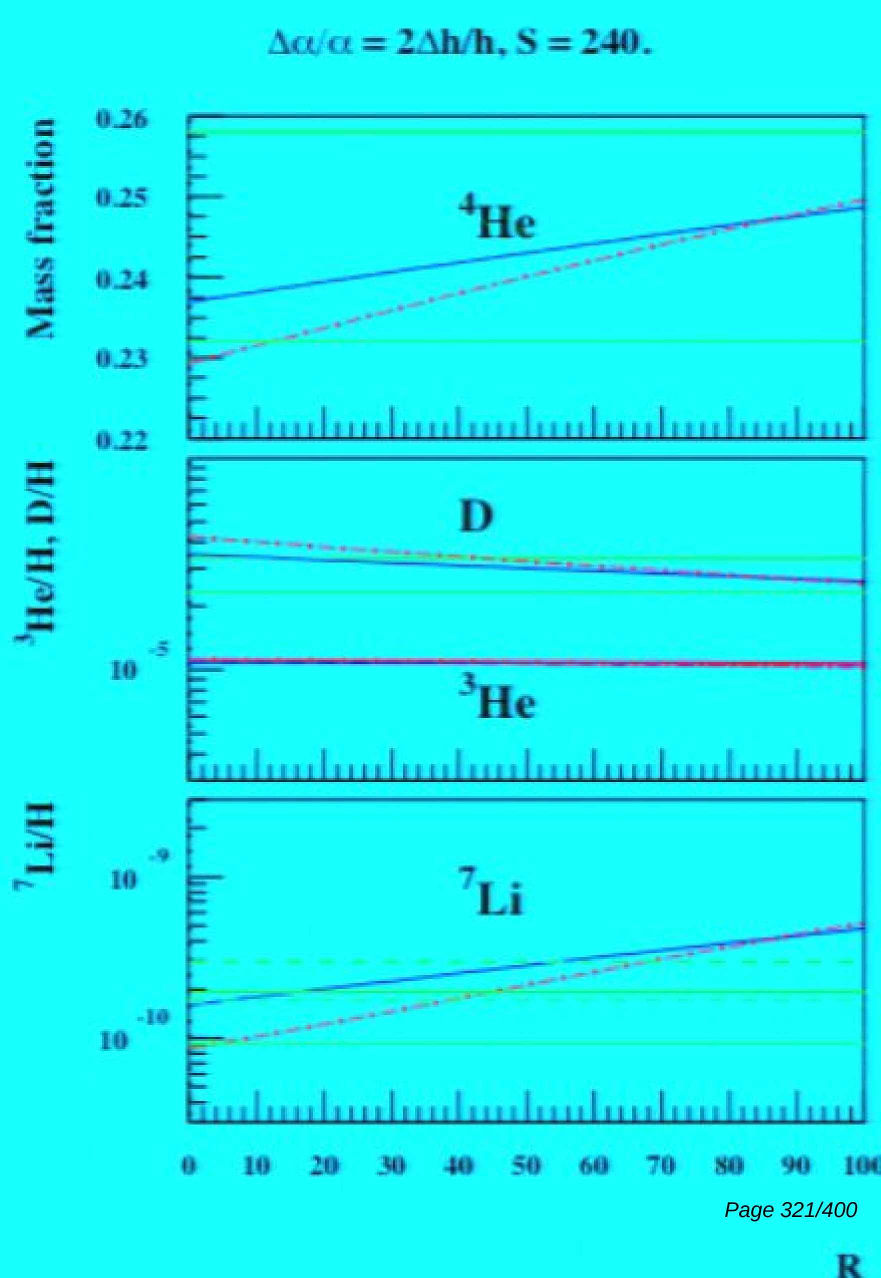


$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
^{4}He
D
^{3}He/H, D/H
^{3}He
^{7}Li/H
^{7}Li
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,

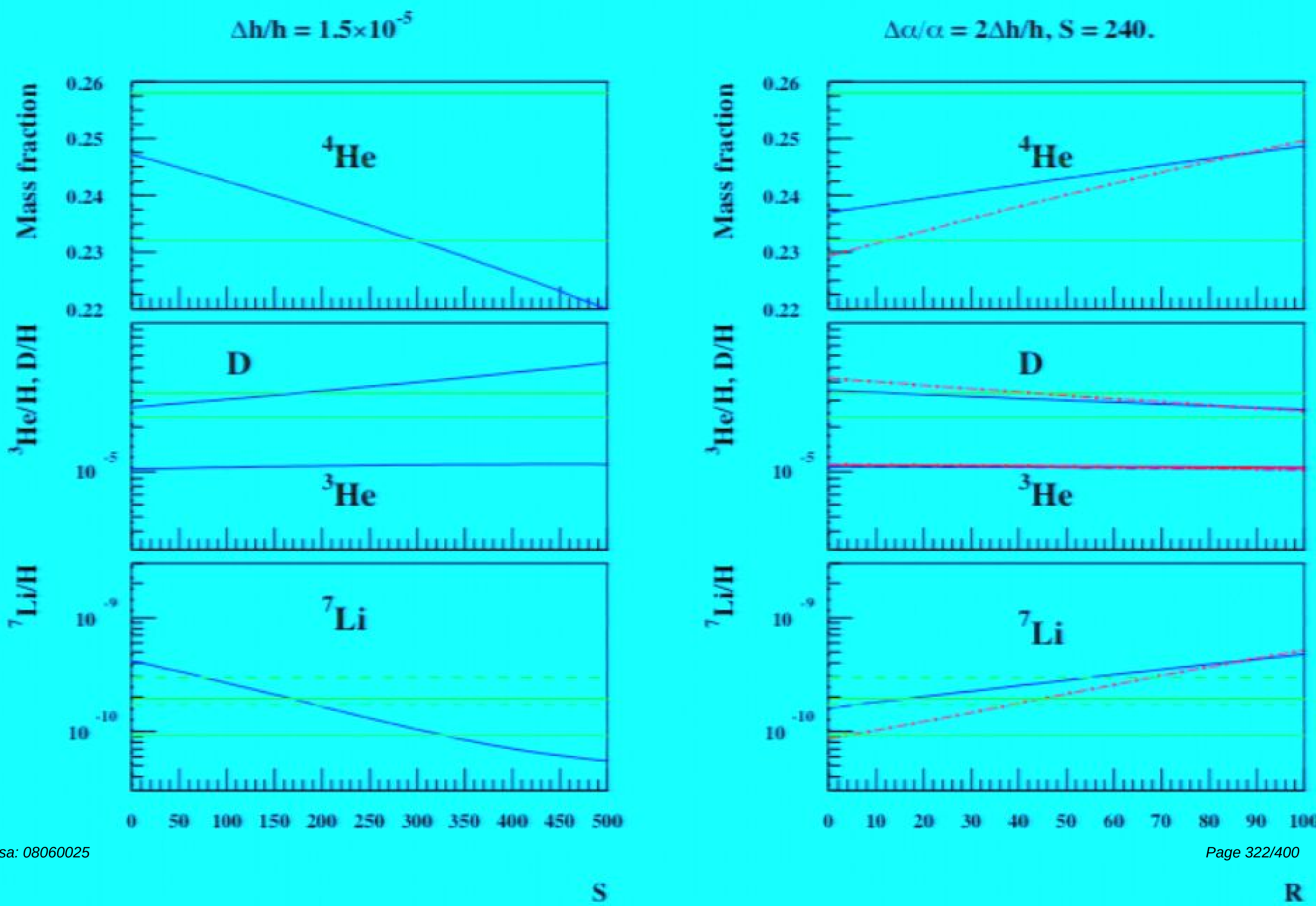


Δh/h = 1.5×10^-5
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
D
3He/H, D/H
10 -5
3He
7Li/H
10 -9
10 -10
7Li
0
50
100
150
200
250
300
350
400
450
500
S



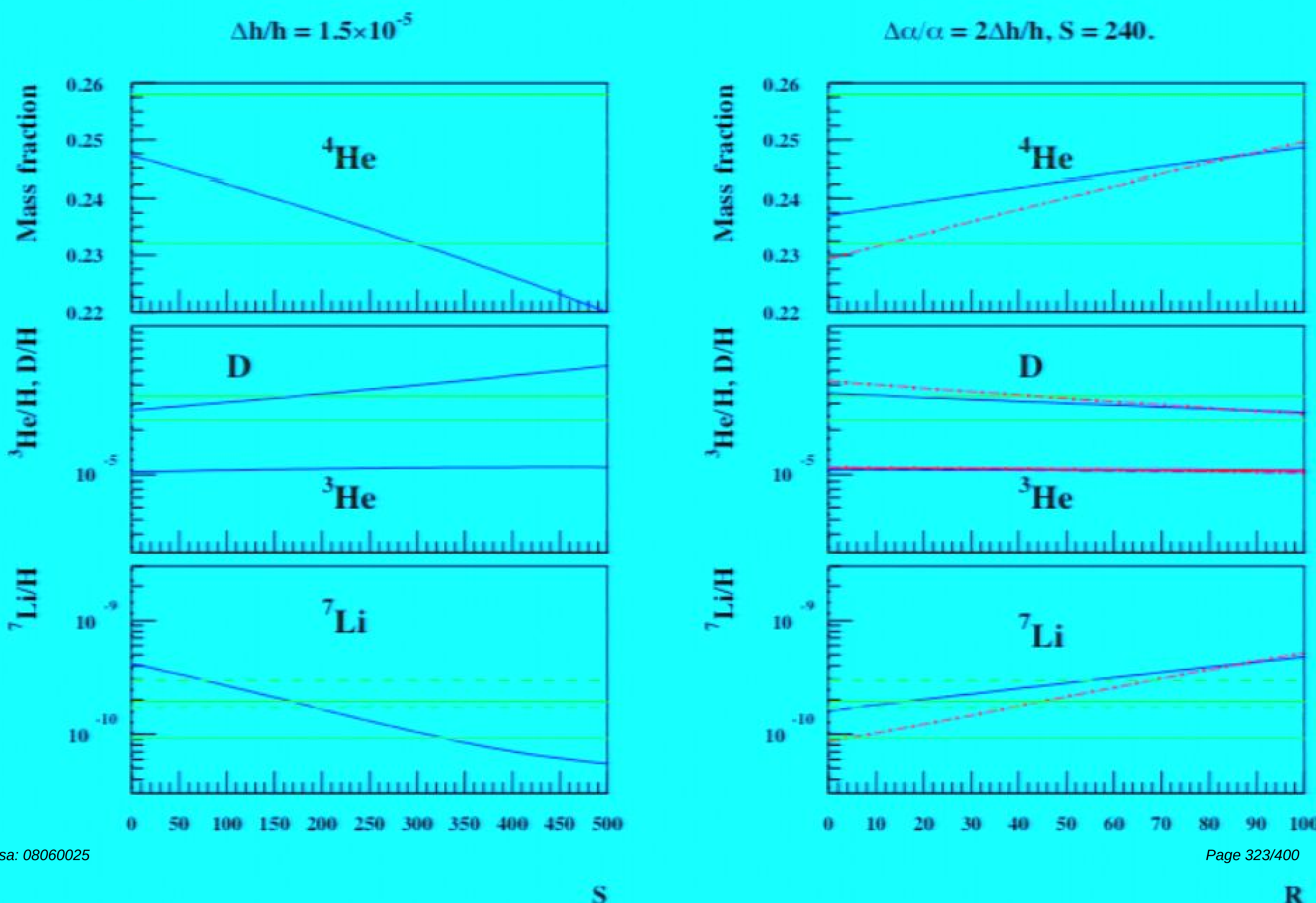
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
D
3He/H, D/H
10 -5
3He
7Li/H
10 -9
10 -10
7Li
0
10
20
30
40
50
60
70
80
90
100
R

Finally,



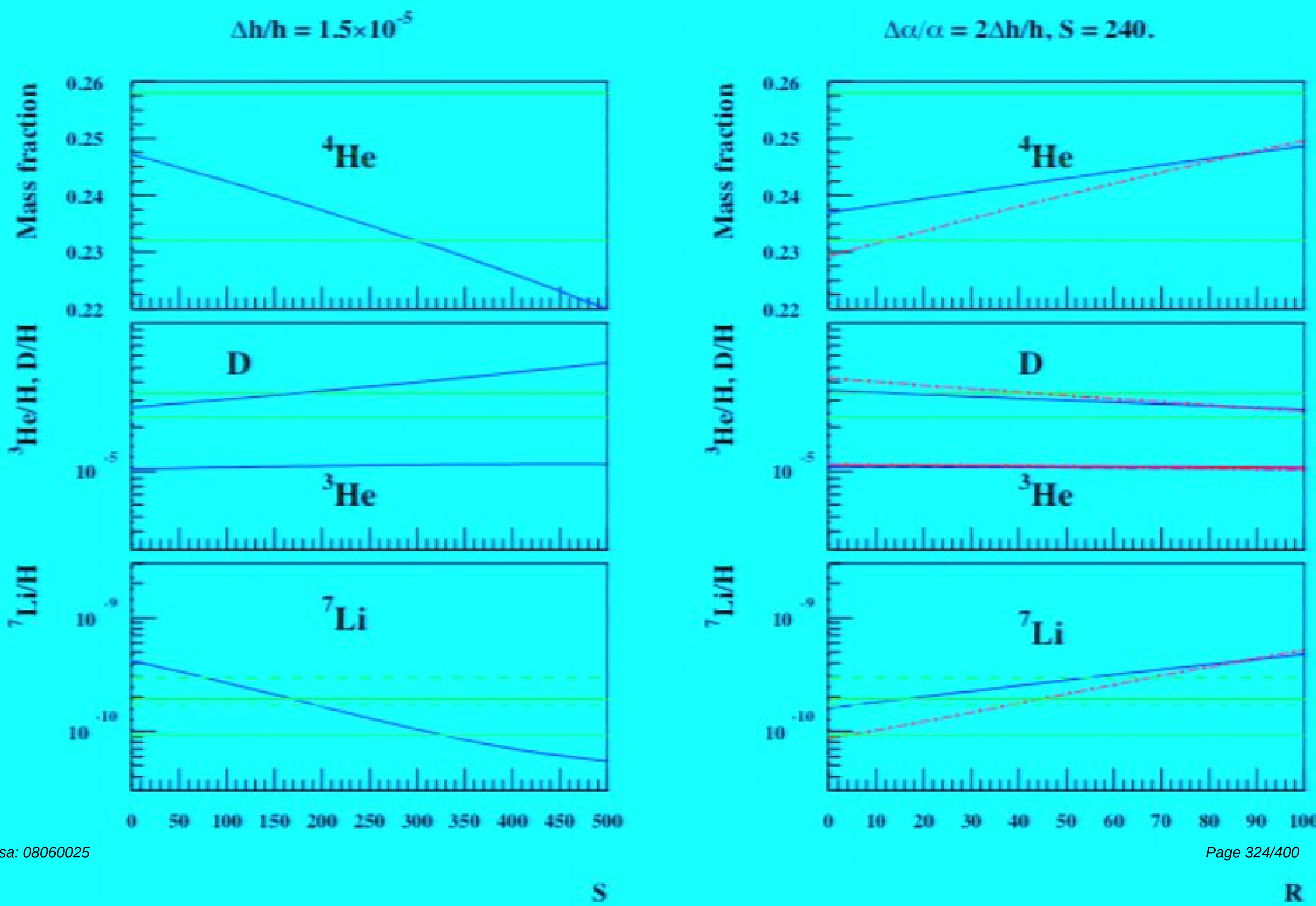
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10 -5
3He
7Li/H
10 -9
10 -10
7Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



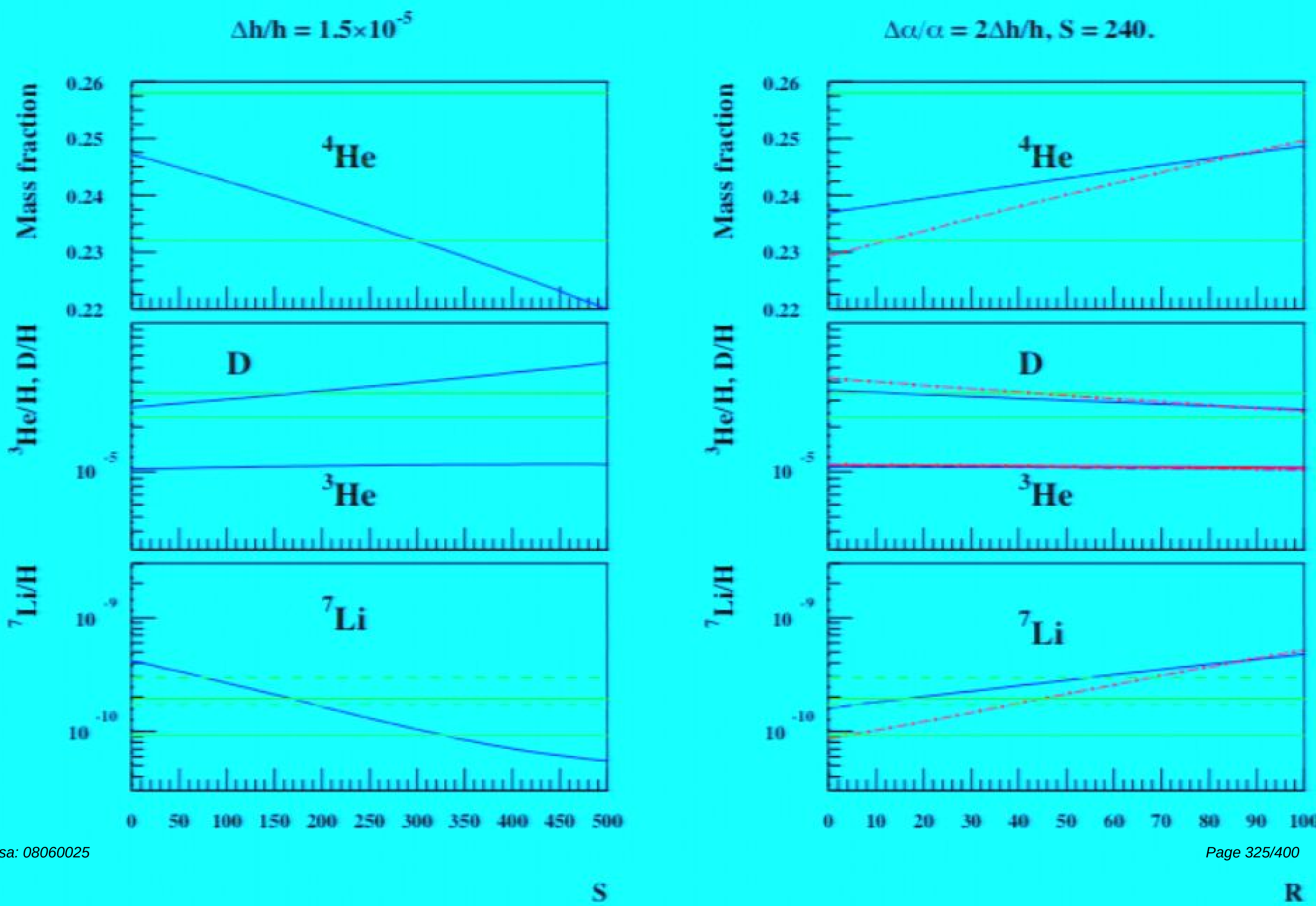
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
7Li
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



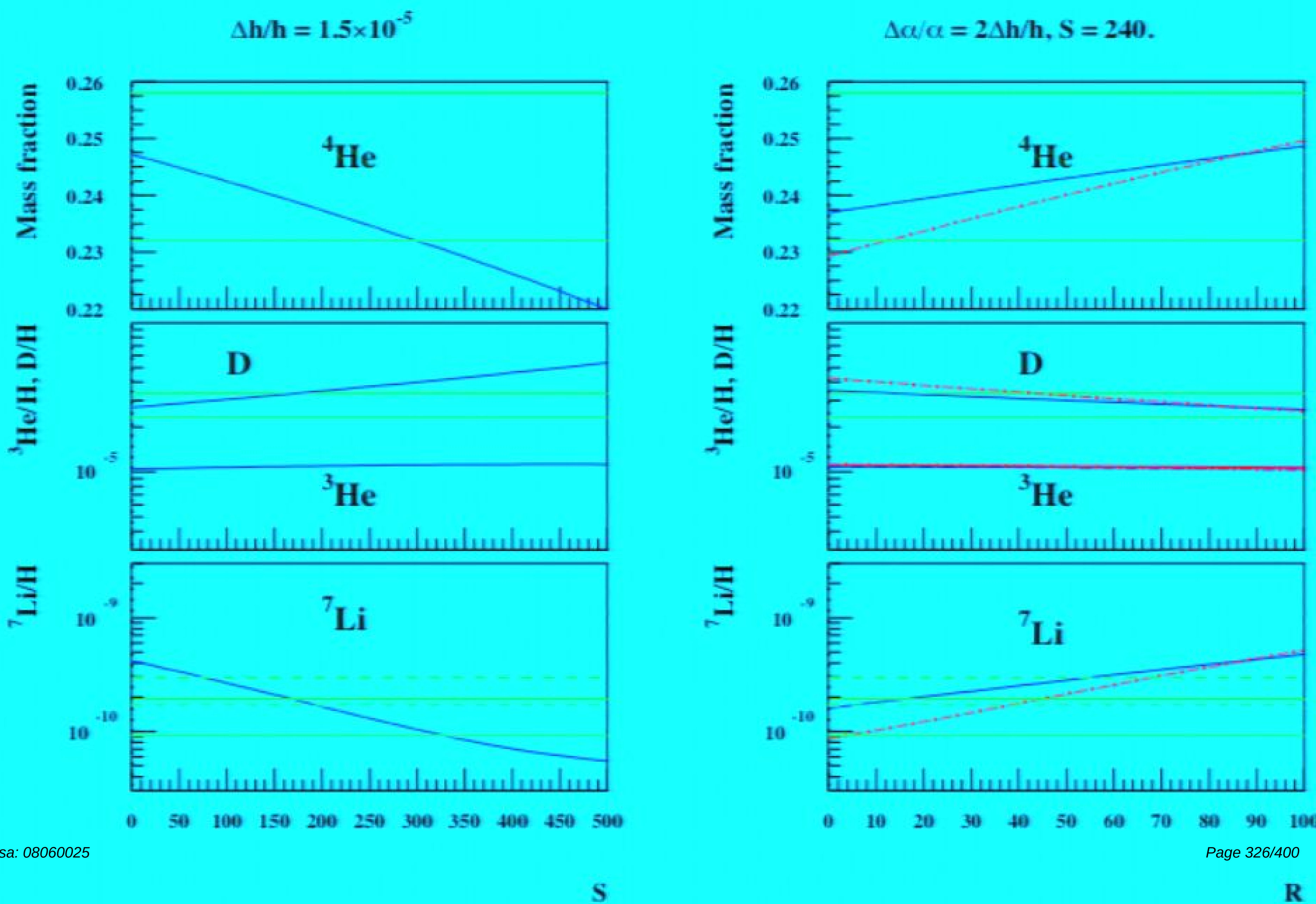
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



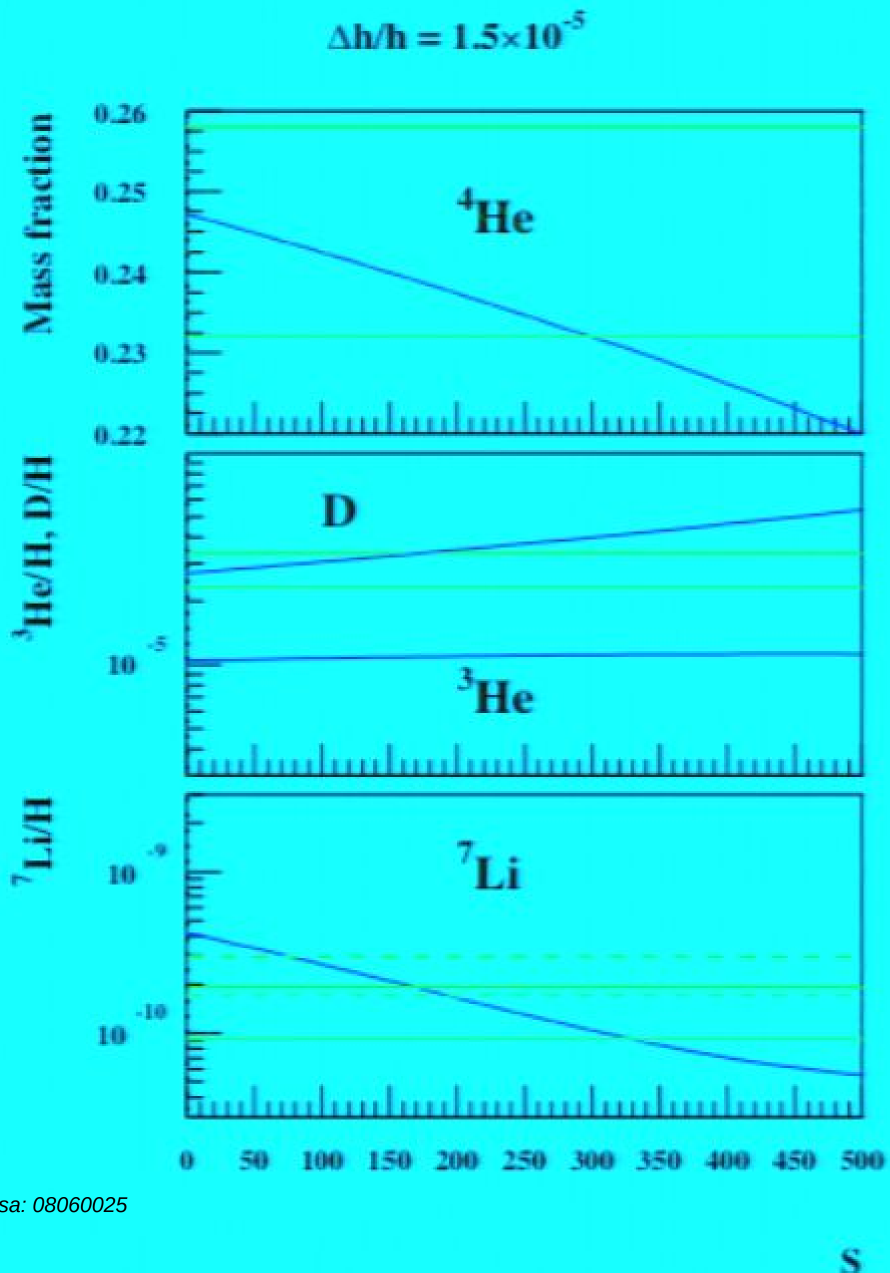
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
⁴He
³He/H, D/H
D
10^-5
³He
⁷Li/H
⁷Li
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
S
0 10 20 30 40 50 60 70 80 90 100
R

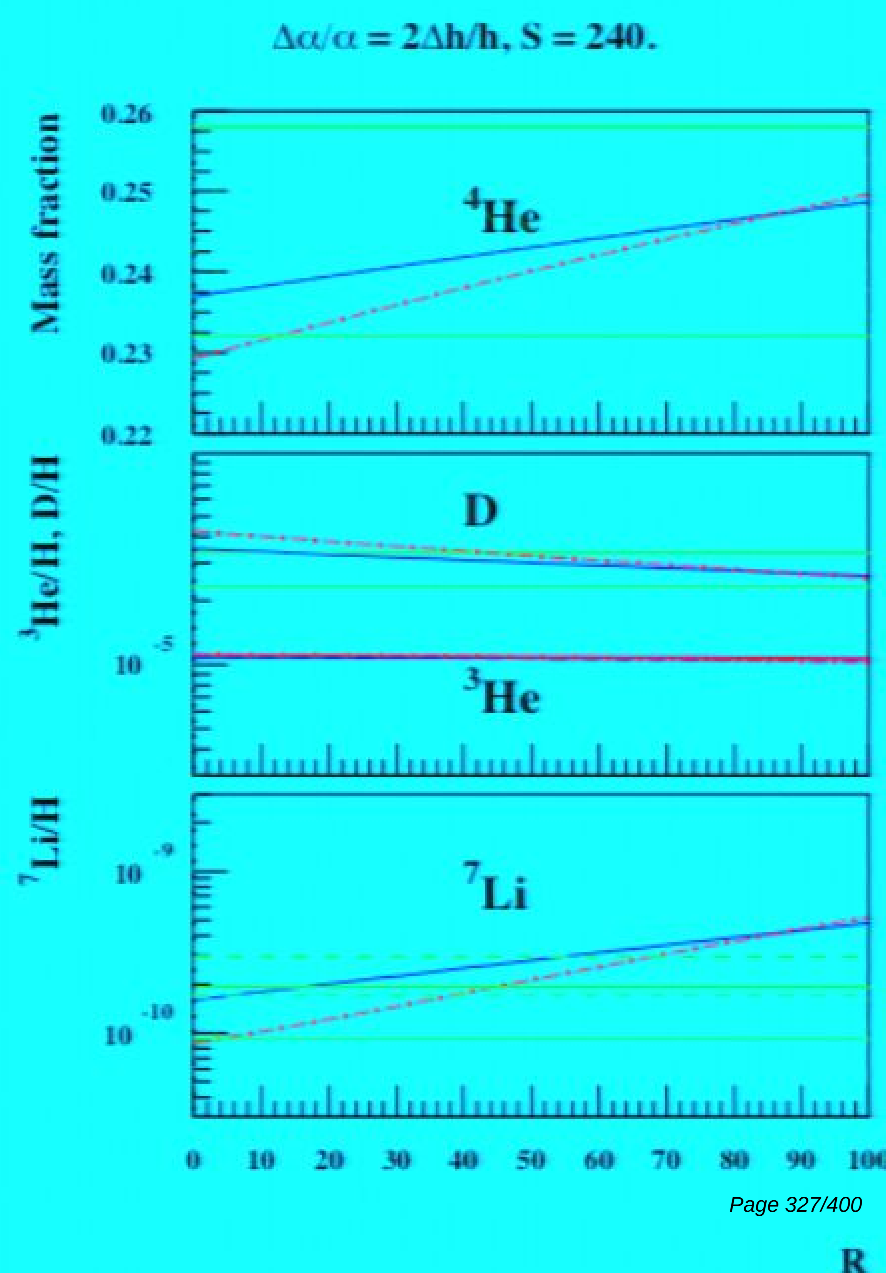
Finally,



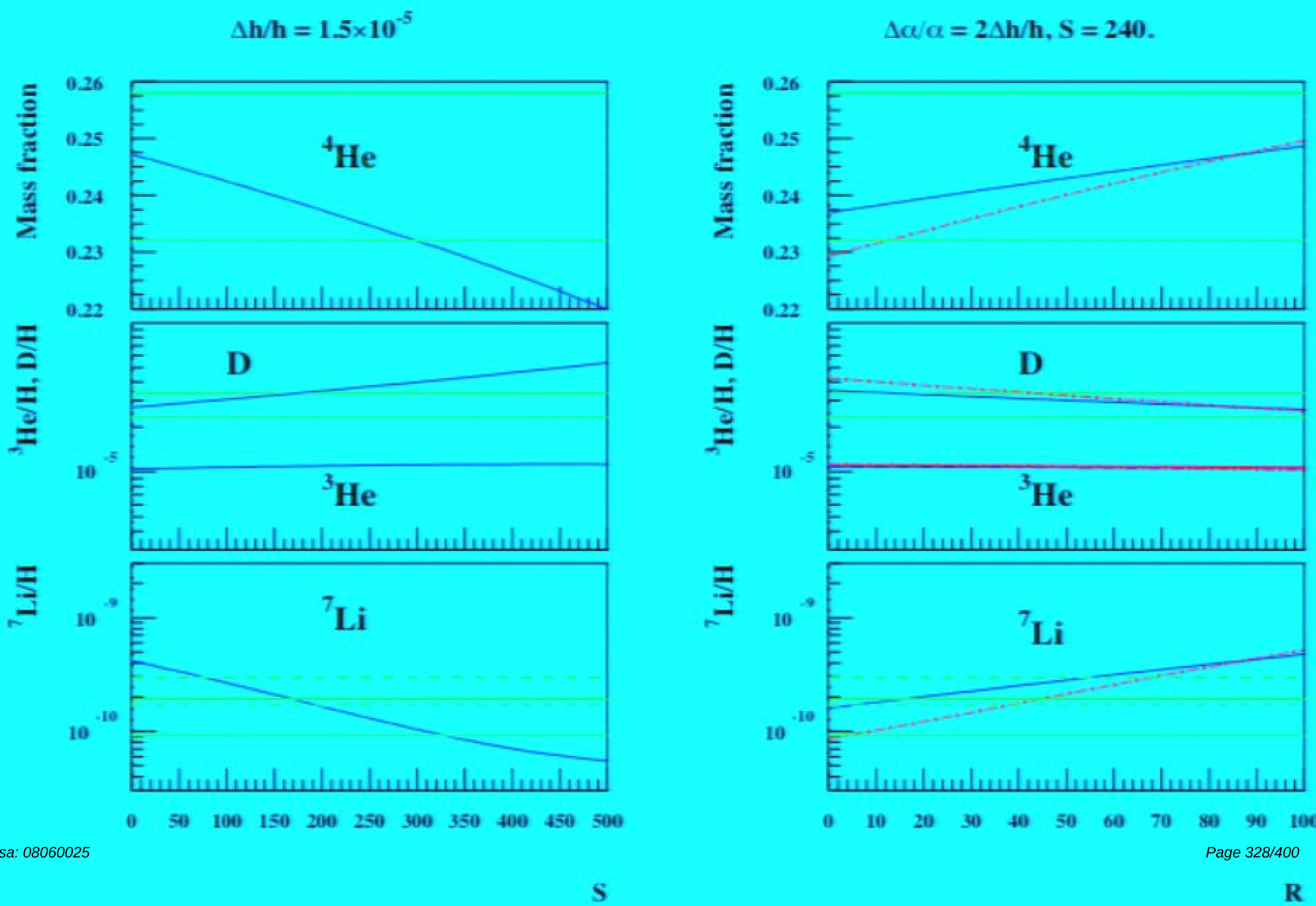
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
10^-9
10^-10
7Li
0
50
100
150
200
250
300
350
400
450
500
10
20
30
40
60
70
80
90
S
R

Finally,


$\Delta h/h = 1.5\times10^{-5}$
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
S

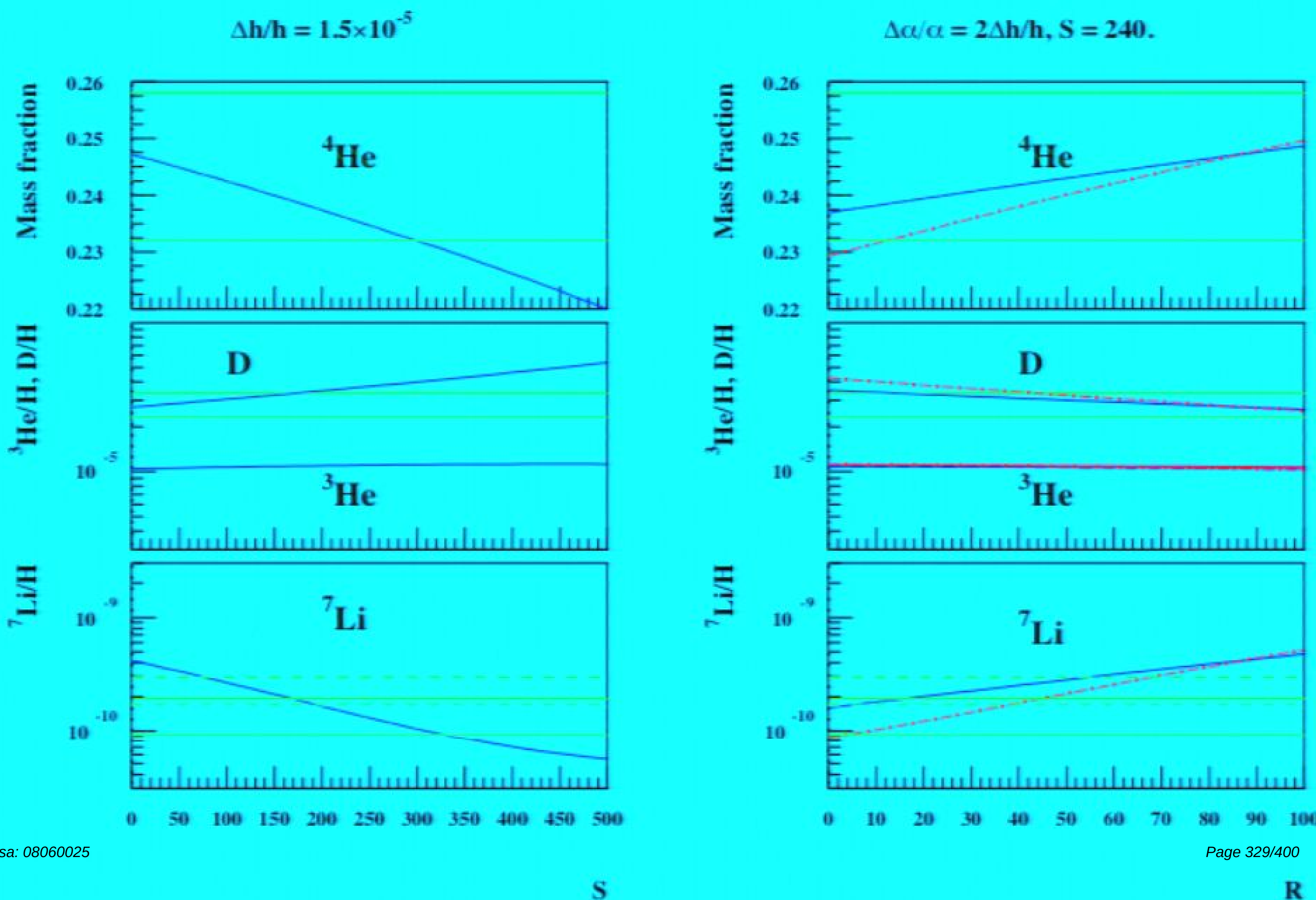

$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 10 20 30 40 50 60 70 80 90 100
R

Finally,



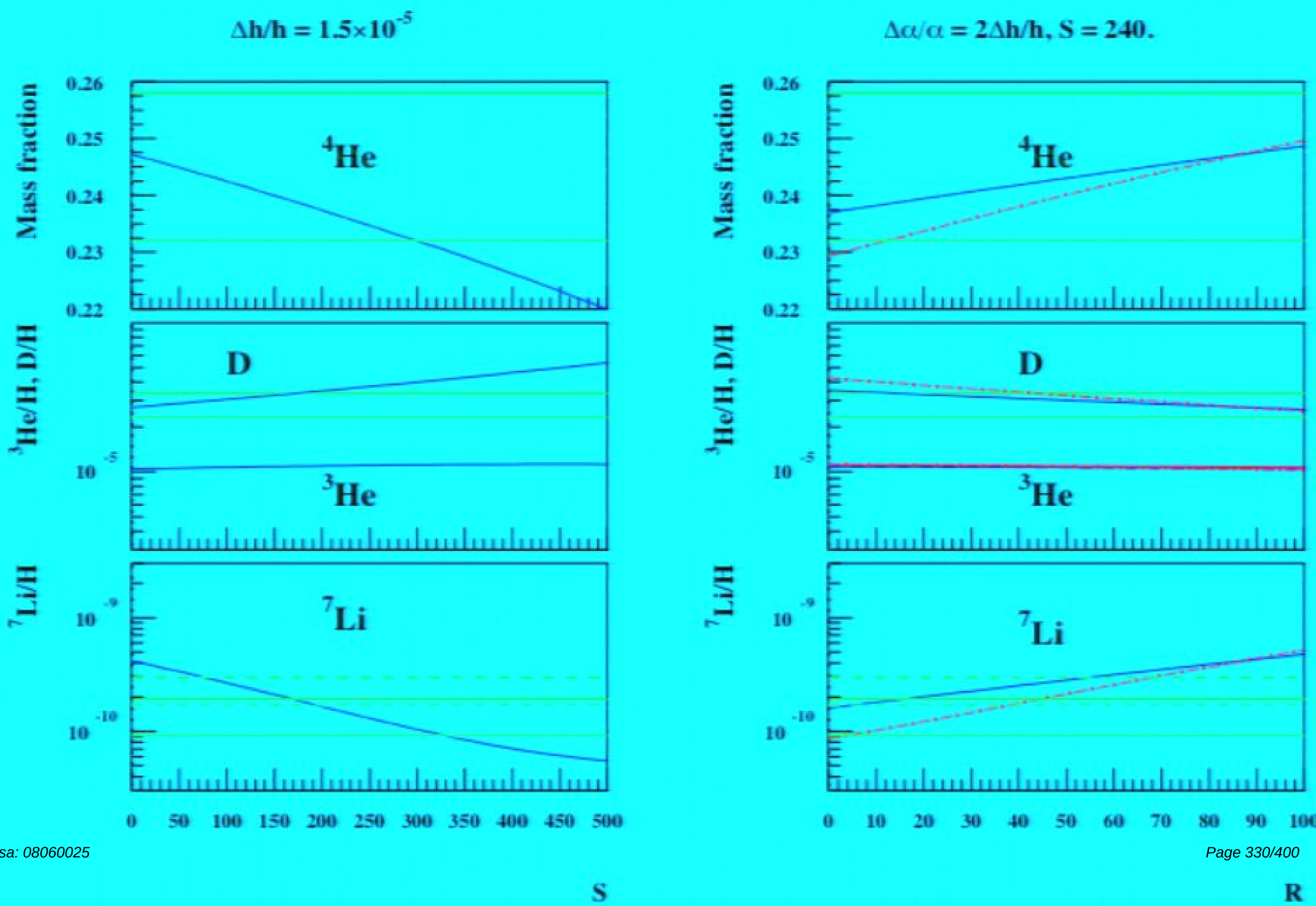
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



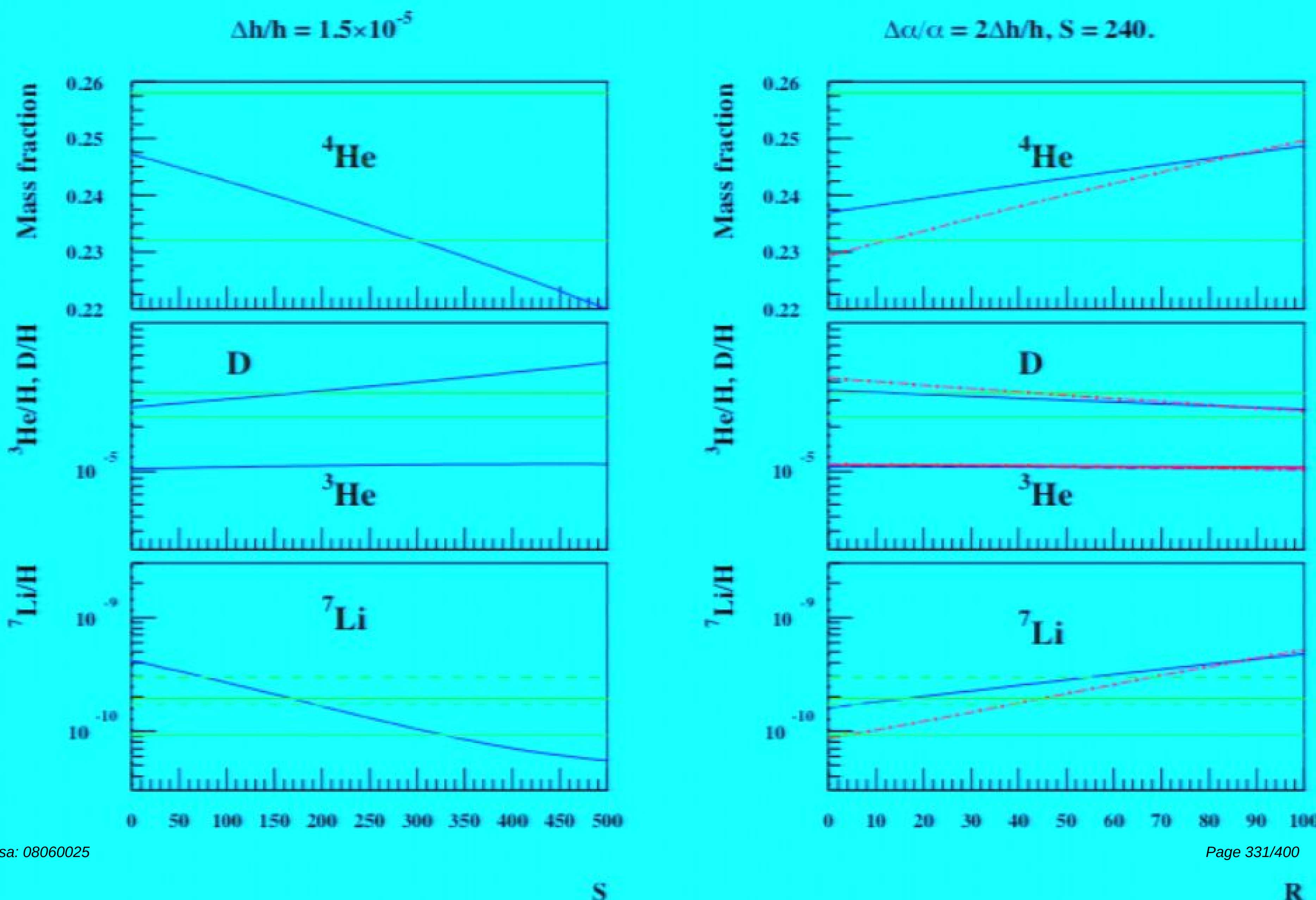
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
^{4}He
D
^{3}He/H, D/H
^{3}He
^{7}Li/H
^{7}Li
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



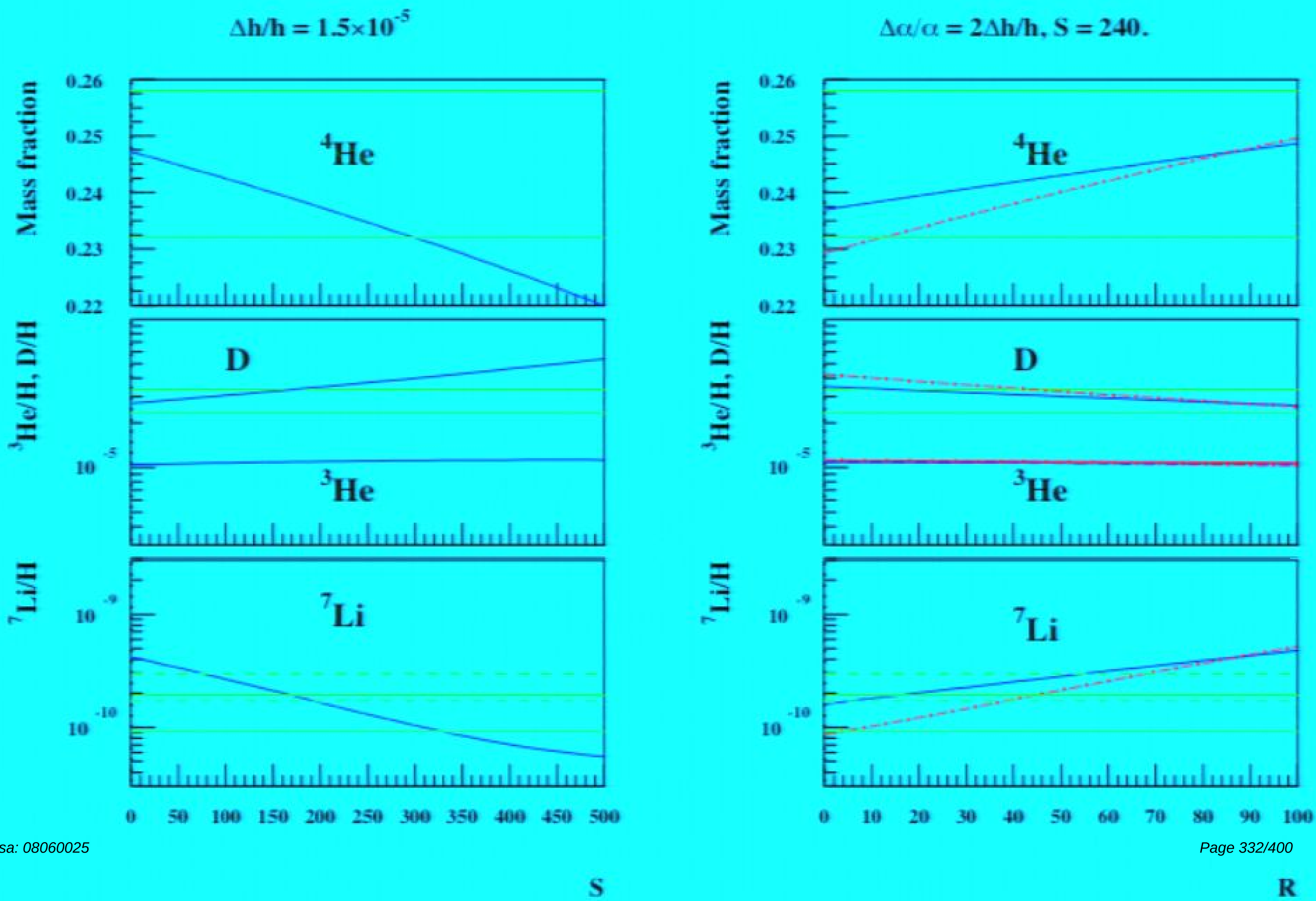
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
^{4}He
D
^{3}He
^{7}Li
^{3}He/H, D/H
^{7}Li/H
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



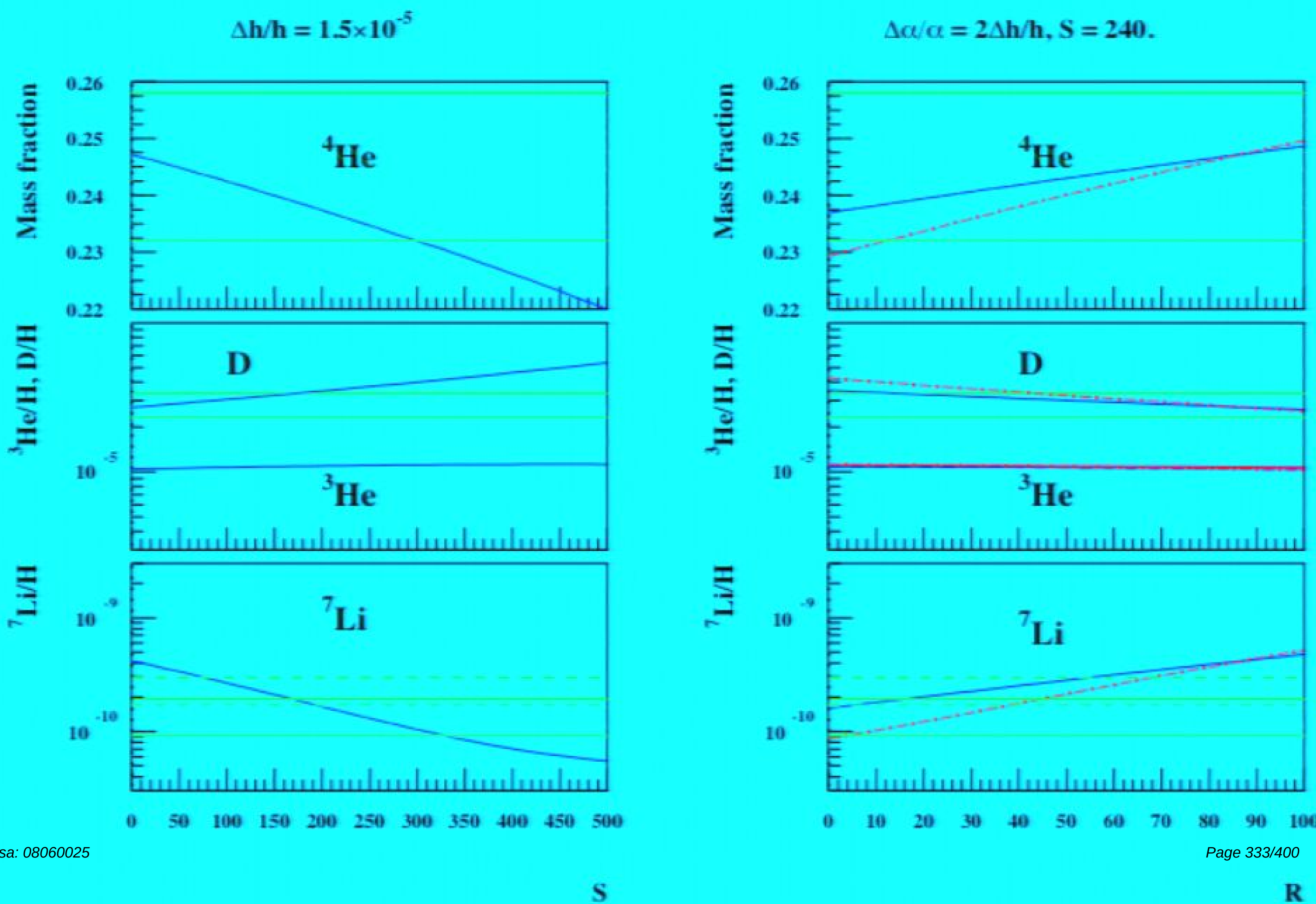
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
4He
3He/H, D/H
D
3He
7Li/H
7Li
0.26
0.25
0.24
0.23
0.22
10^-5
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



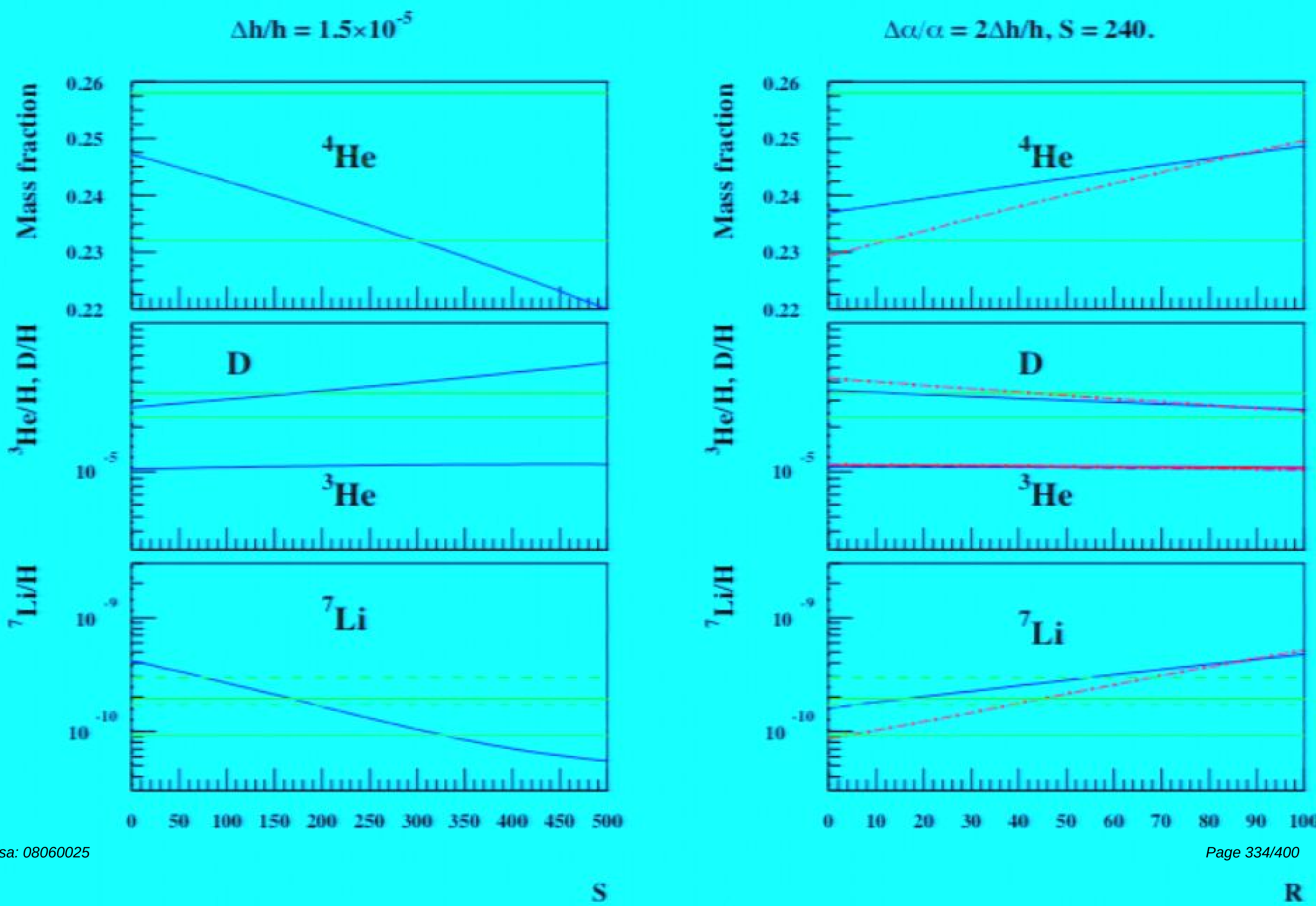
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
^{4}He
D
^{3}He
^{7}Li
^{3}He/H, D/H
^{7}Li/H
0.26
0.25
0.24
0.23
0.22
10^{-5}
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



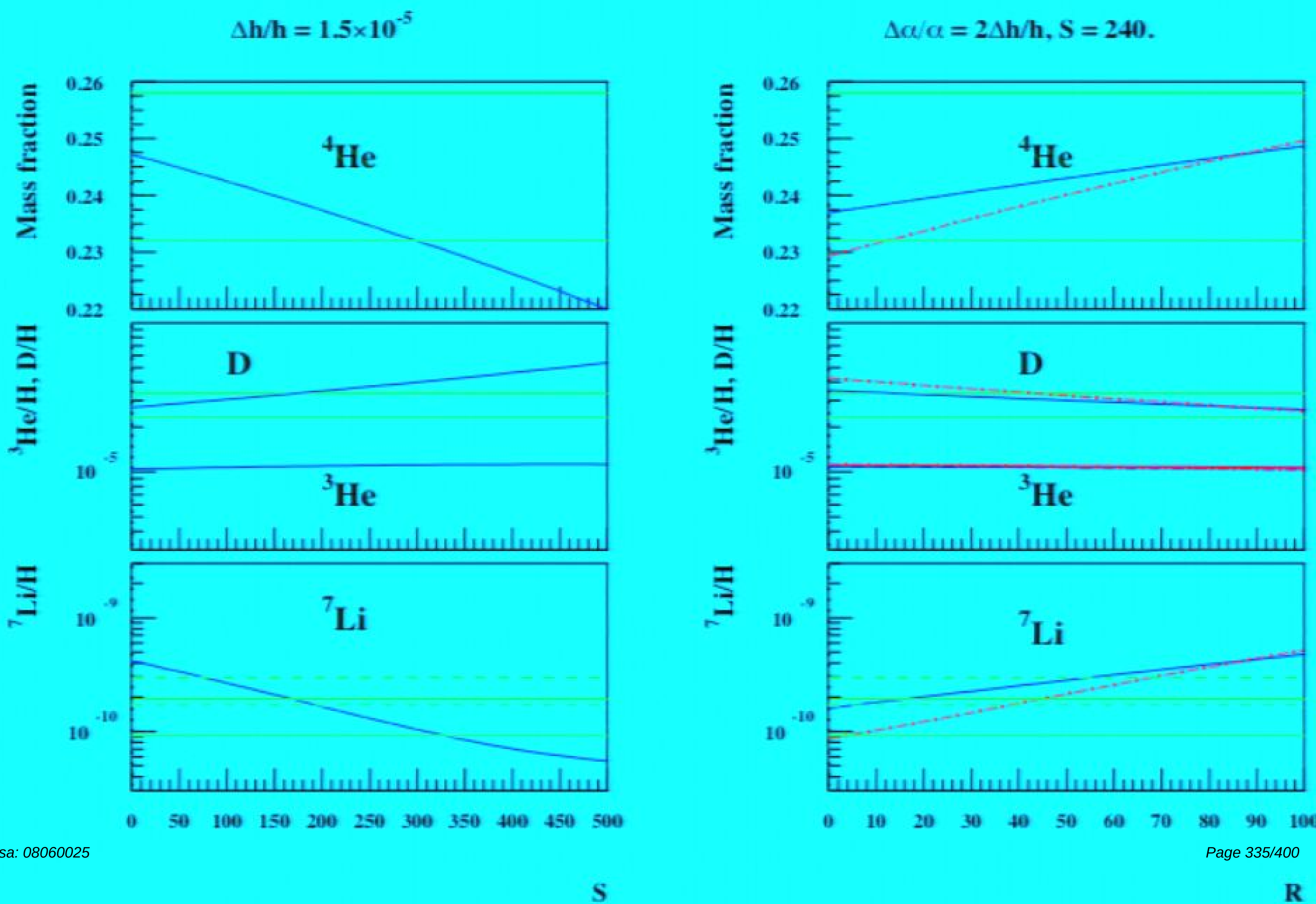
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
S
0 10 20 30 40 50 60 70 80 90 100
R

Finally,



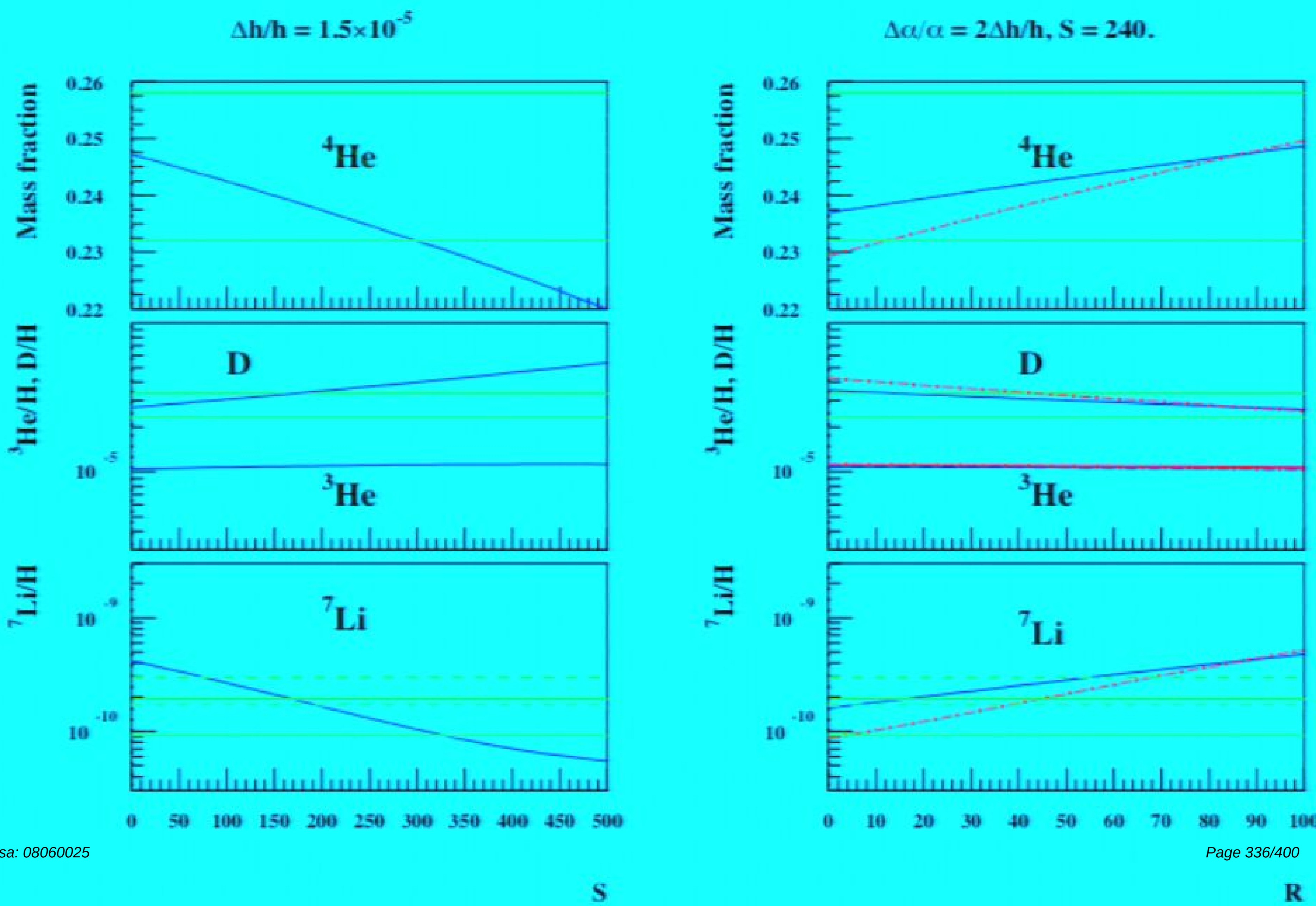
$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
^{7}Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



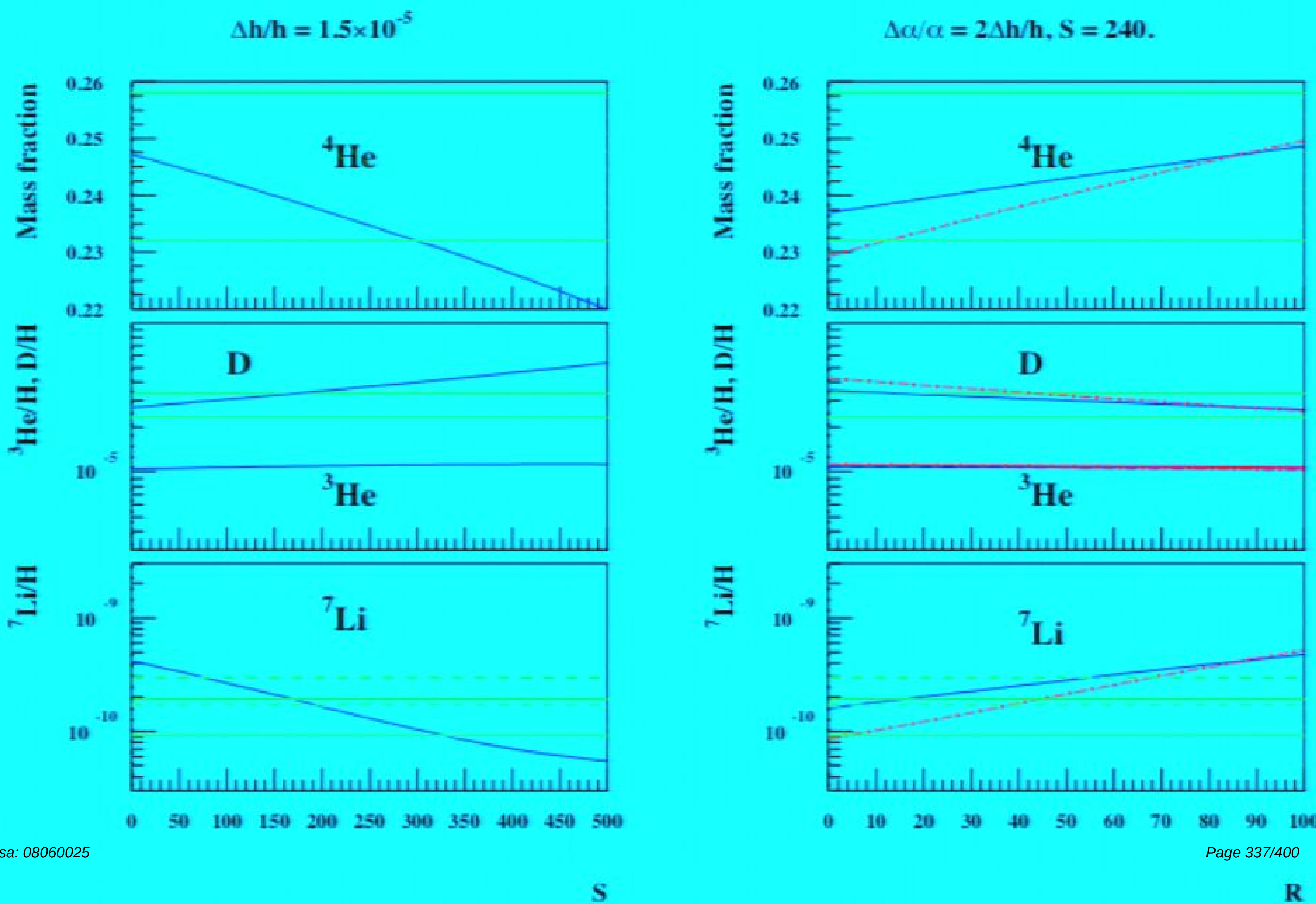
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10 -5
3He
7Li/H
10 -9
10 -10
7Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



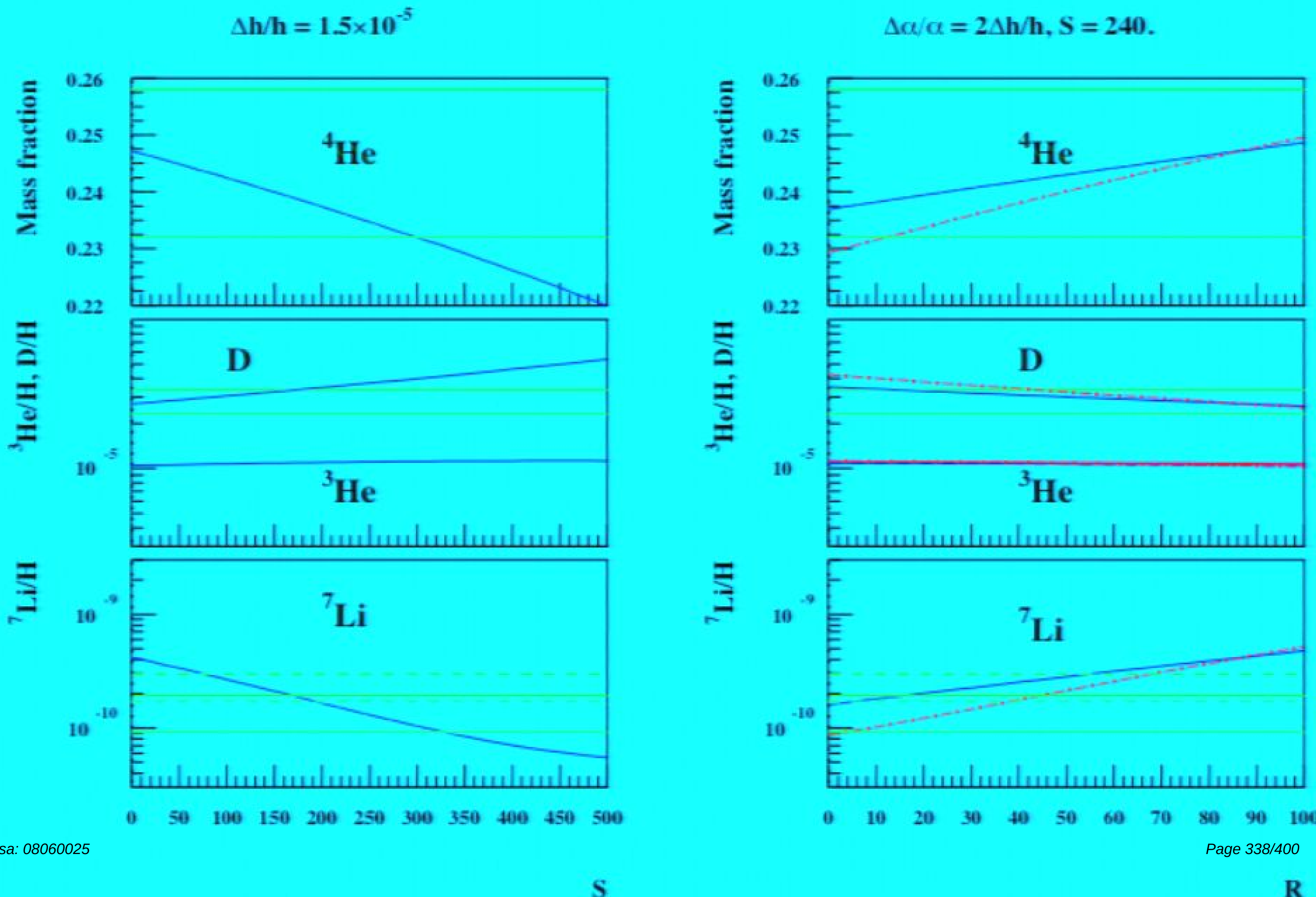
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
10^-9
10^-10
7Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



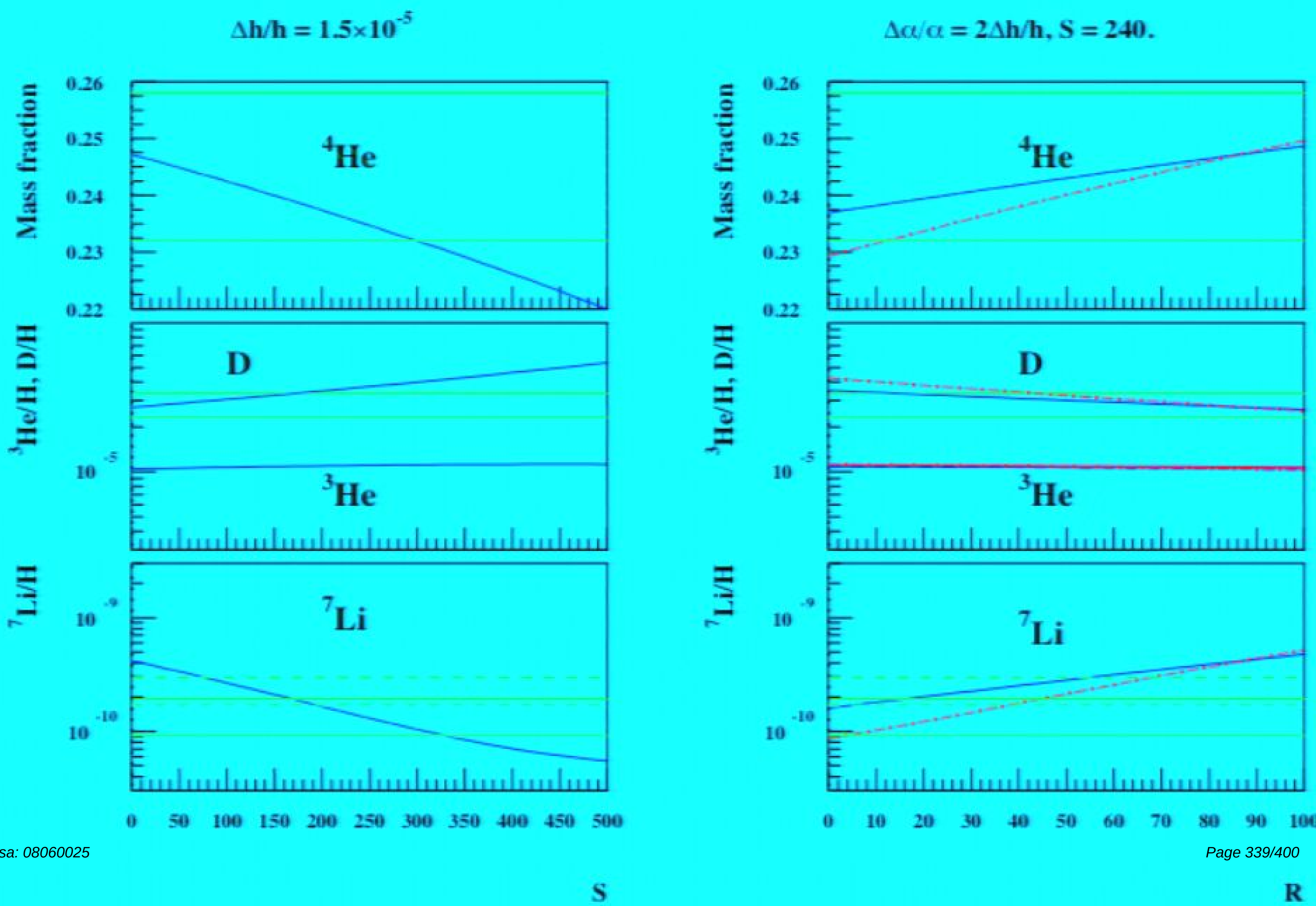
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
10^-9
10^-10
7Li
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



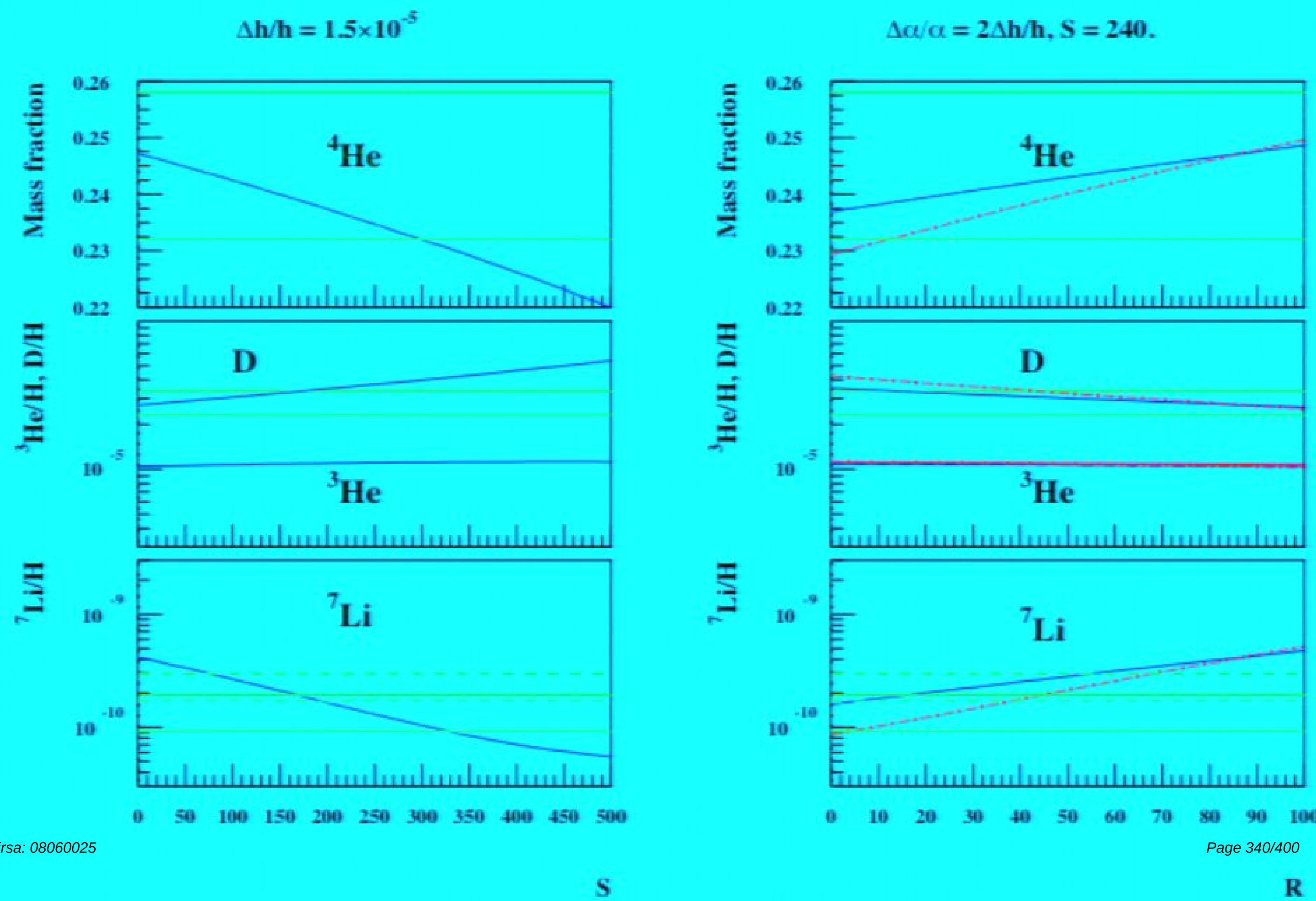
Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
D
10^-5
3He
7Li/H
7Li
10^-9
10^-10
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Finally,



Δh/h = 1.5×10^-5
Δα/α = 2Δh/h, S = 240.
Mass fraction
⁴He
³He/H, D/H
D
³He
⁷Li/H
⁷Li
S
R

Finally,



$\Delta h/h = 1.5\times10^{-5}$
$\Delta\alpha/\alpha = 2\Delta h/h$, S = 240.
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
^{7}Li
10^{-9}
10^{-10}
0 50 100 150 200 250 300 350 400 450 500
0 10 20 30 40 50 60 70 80 90 100
S
R

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^7Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

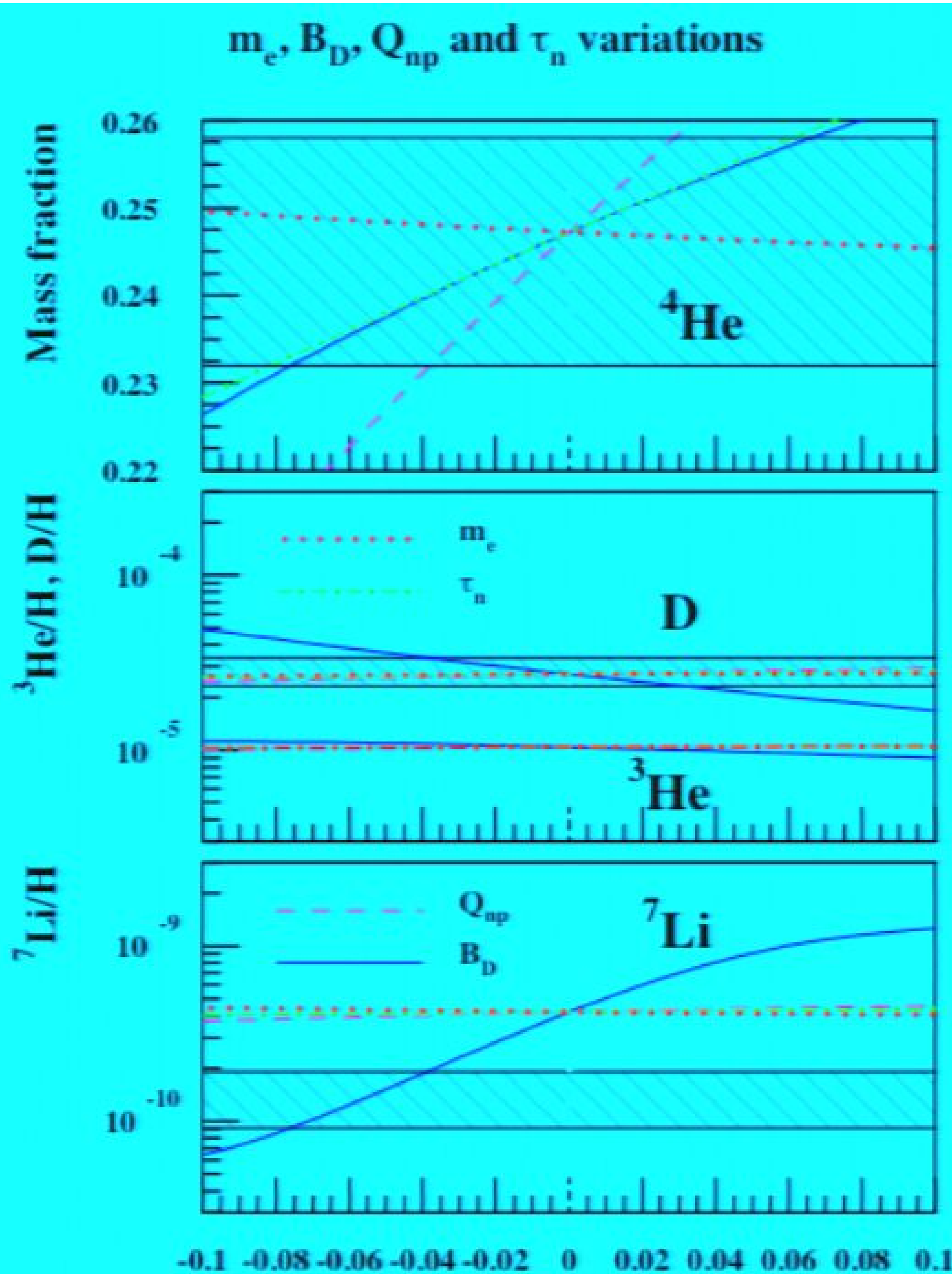
- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

Summary

- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^{7}Li problem?

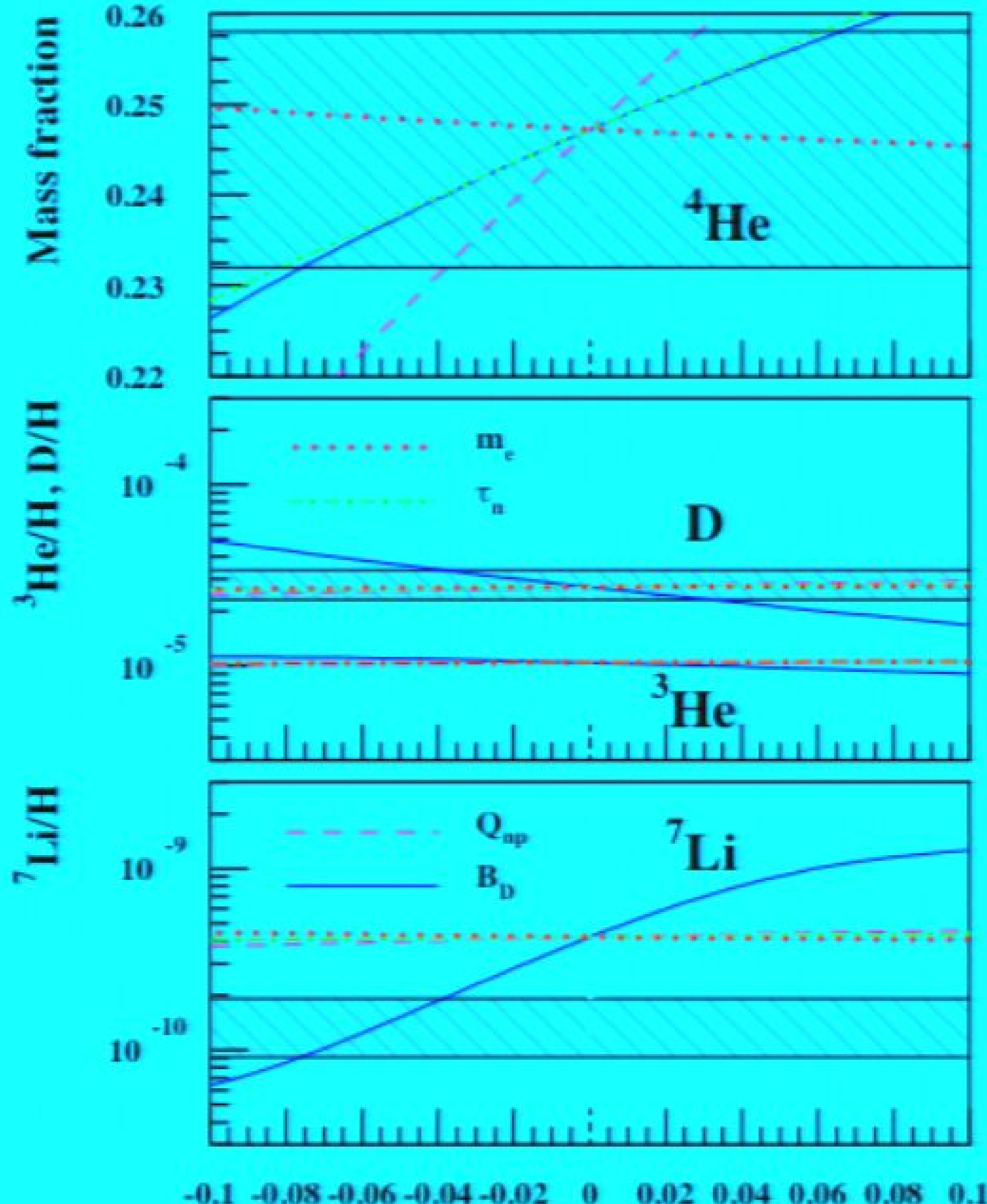
Summary

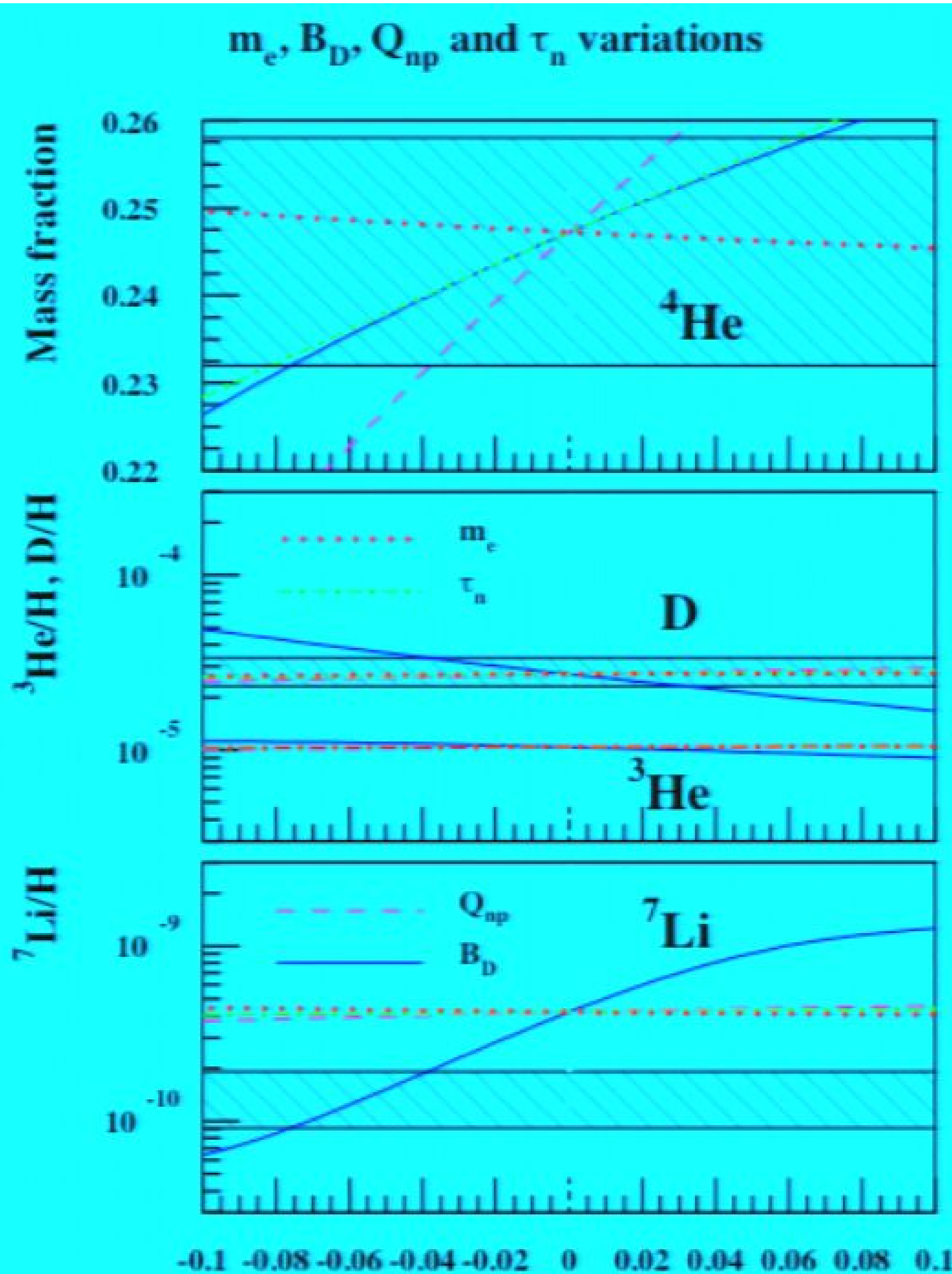
- While possible, there are many constraints on the variations of α
- BBN constraints (when coupled variations are considered) are of order 10^{-5}
- Solution to ^7Li problem?



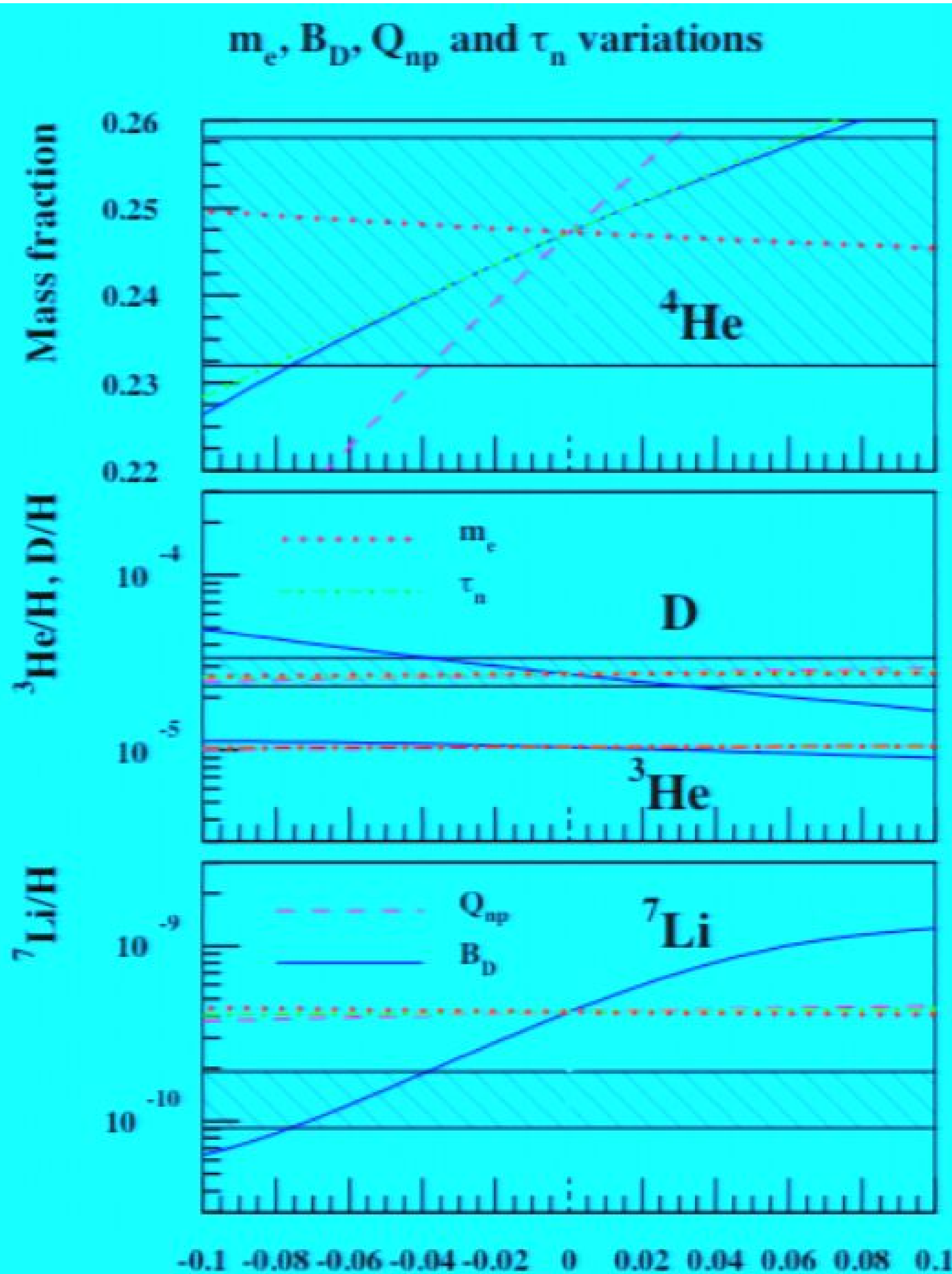
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

m_e, B_D, Q_{np} and τ_n variations

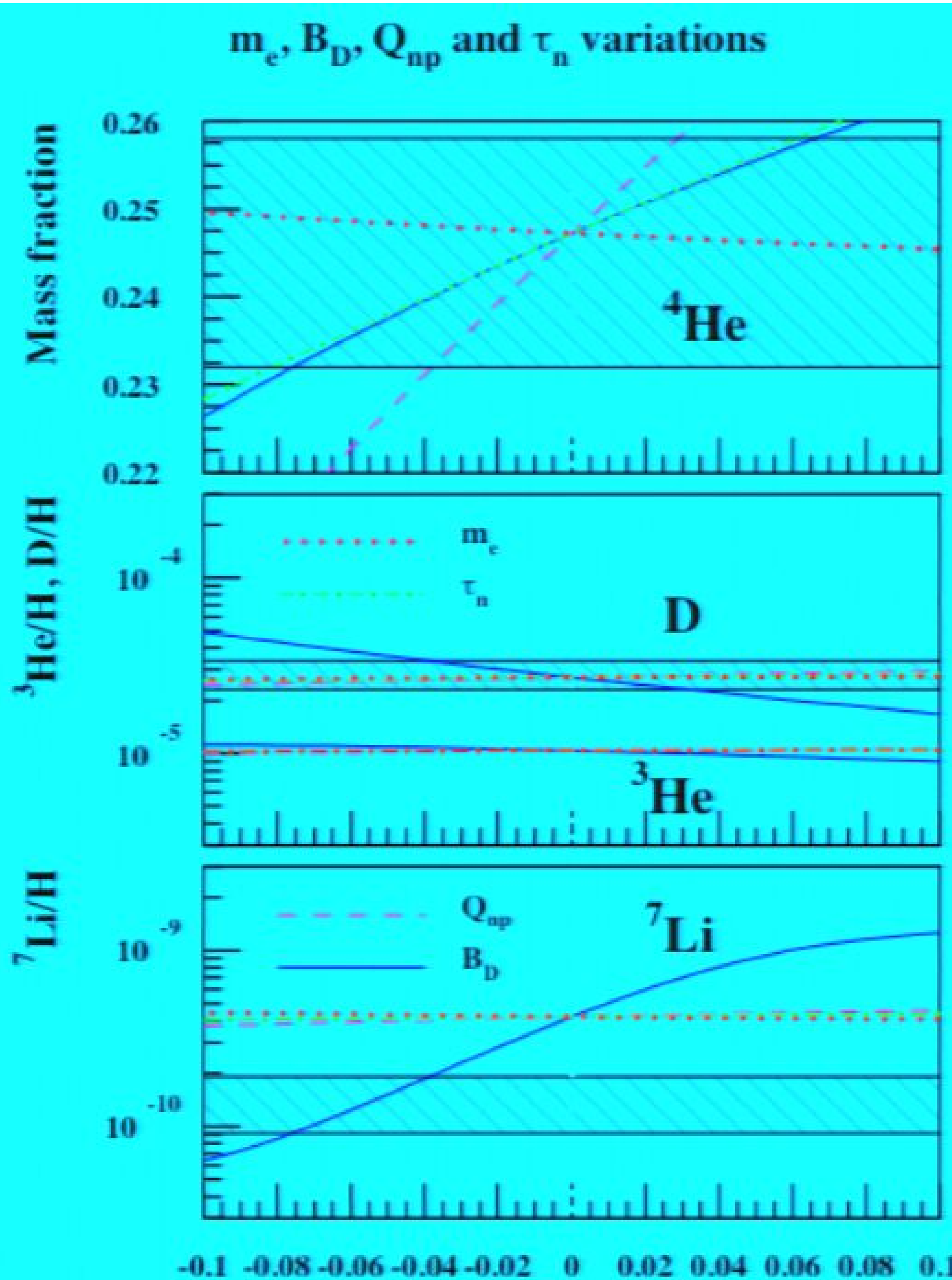




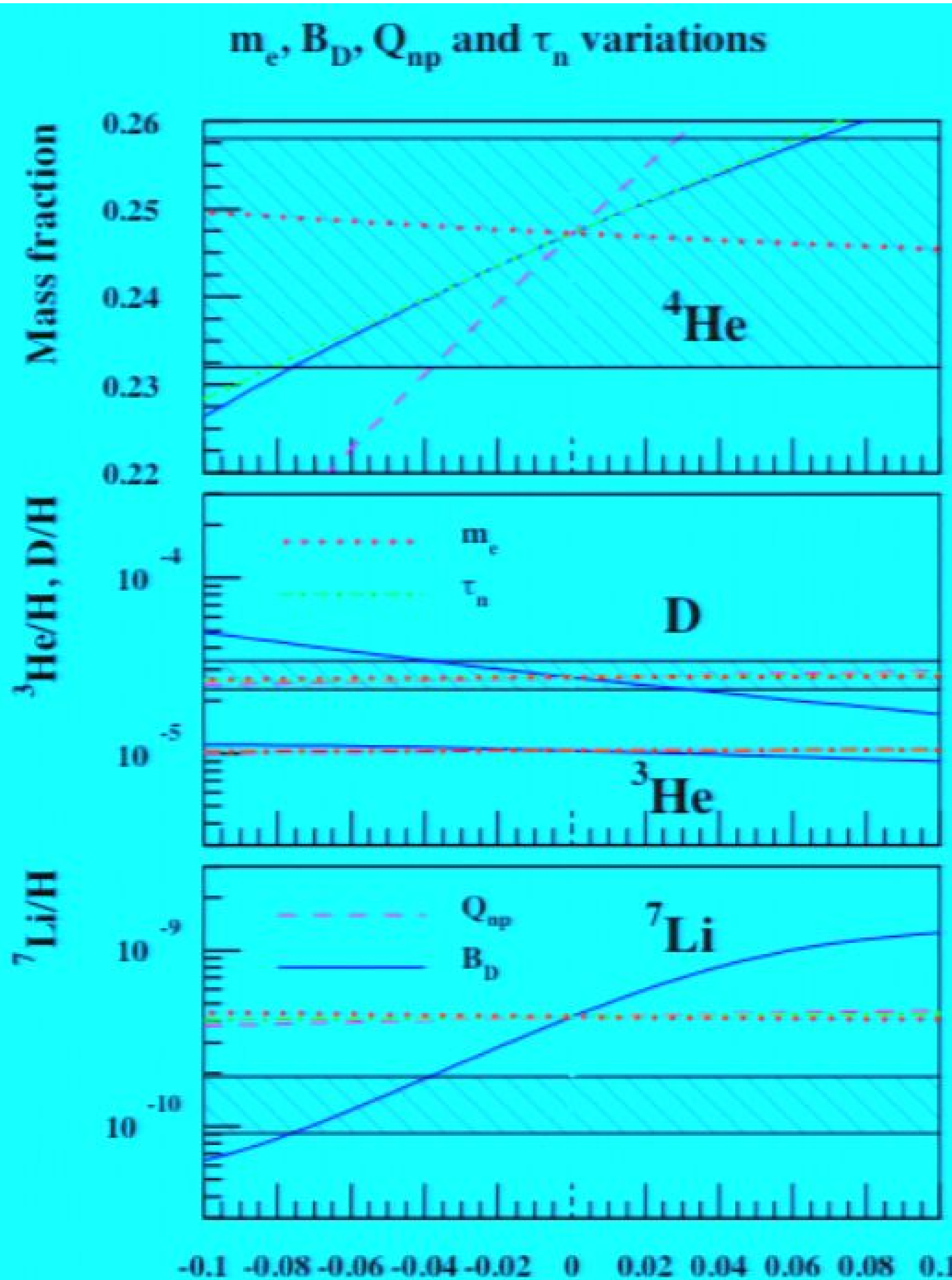
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

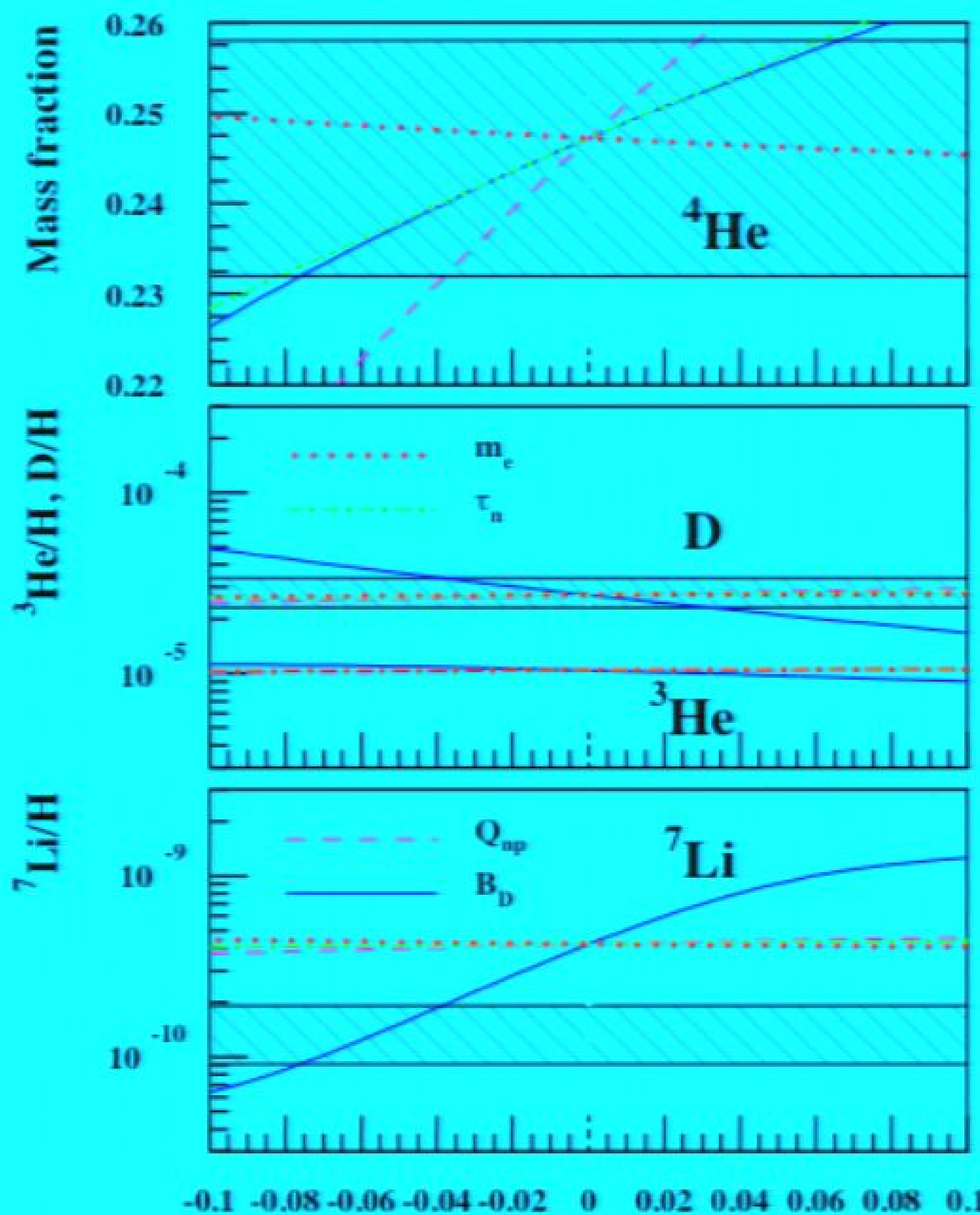


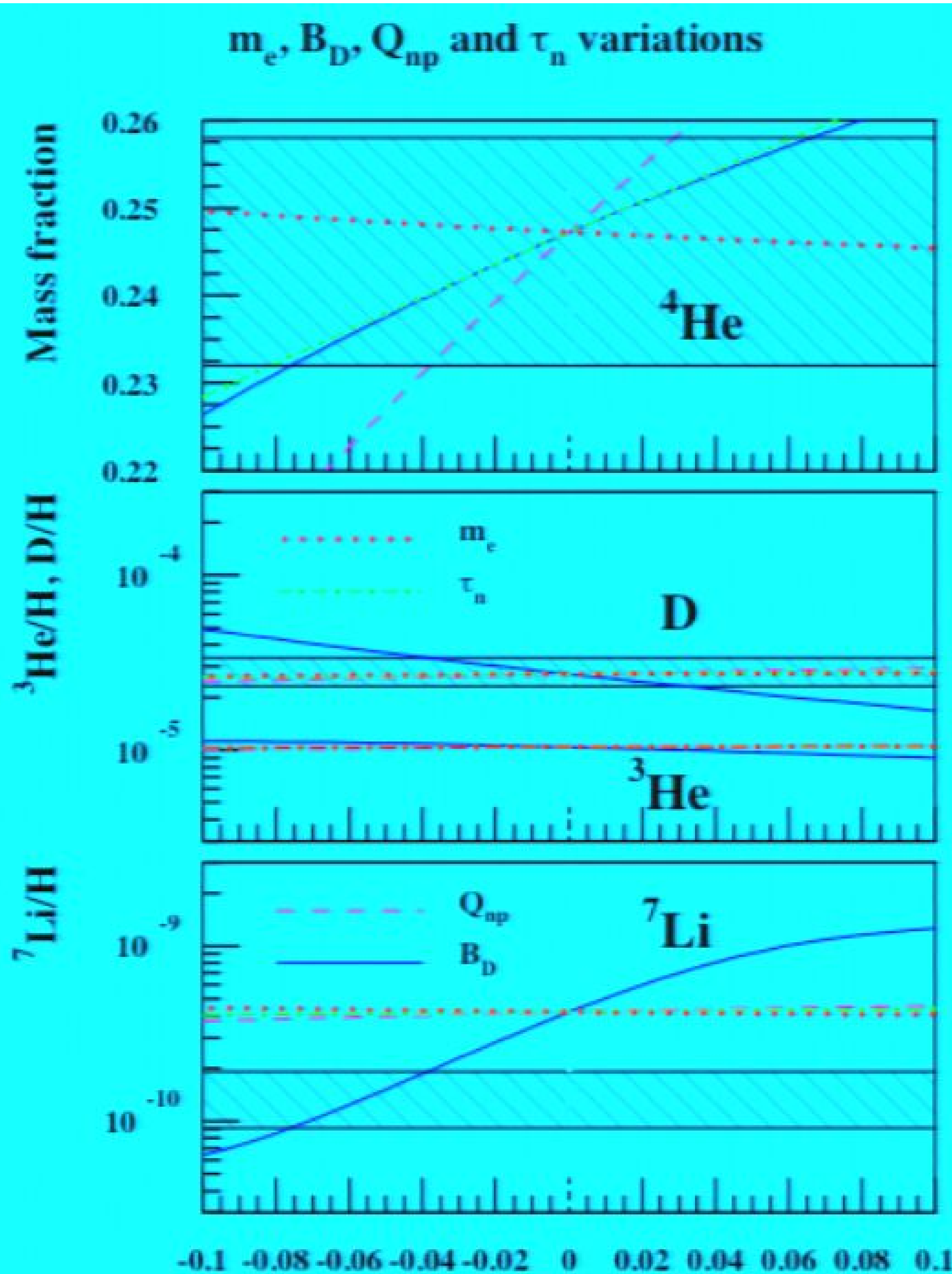
m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
10 -4
10 -5
m_e
τ_n
D
3He
7Li/H
10 -9
10 -10
Q_np
B_D
7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

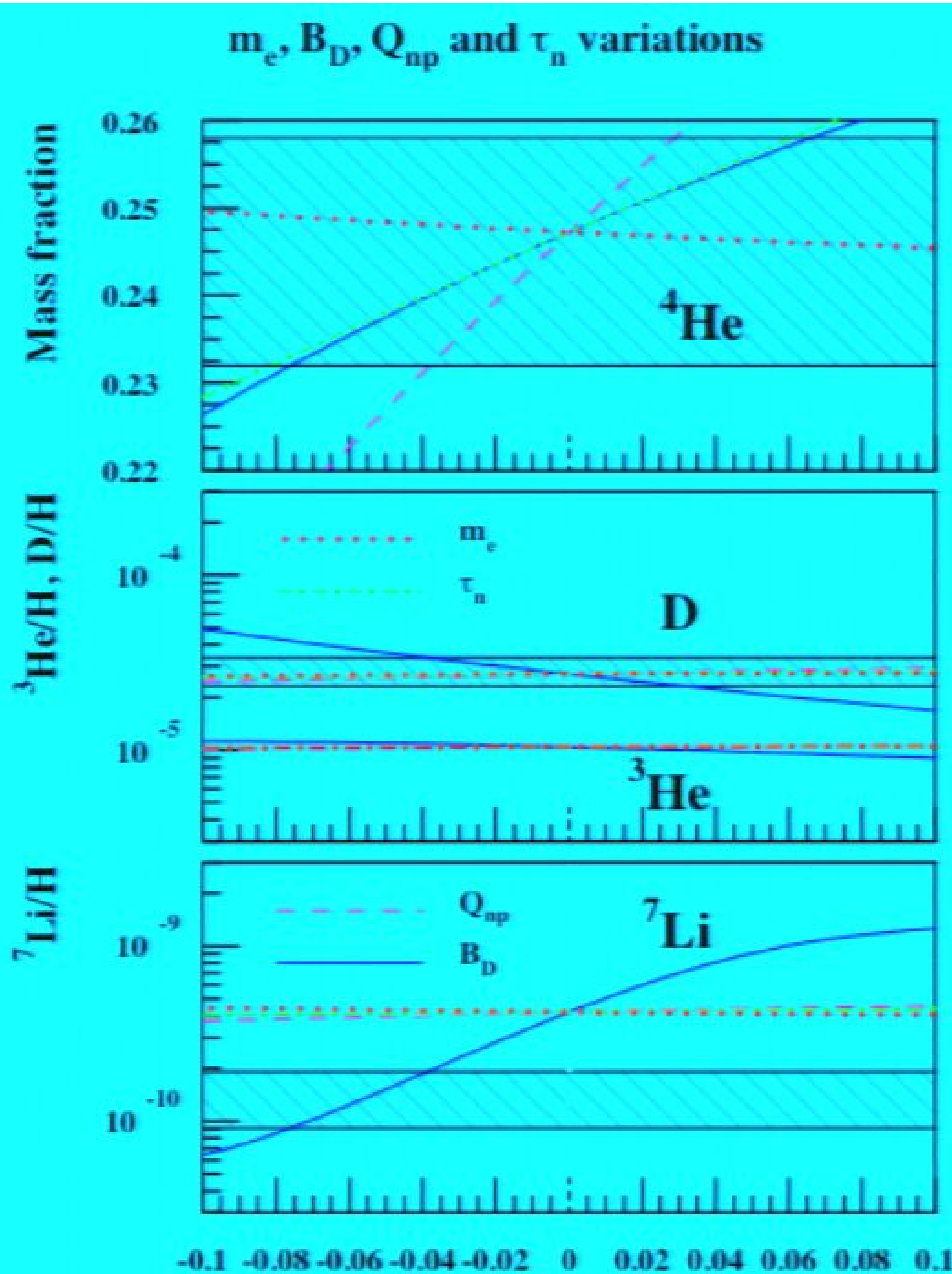


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

m_e, B_D, Q_{np} and τ_n variations

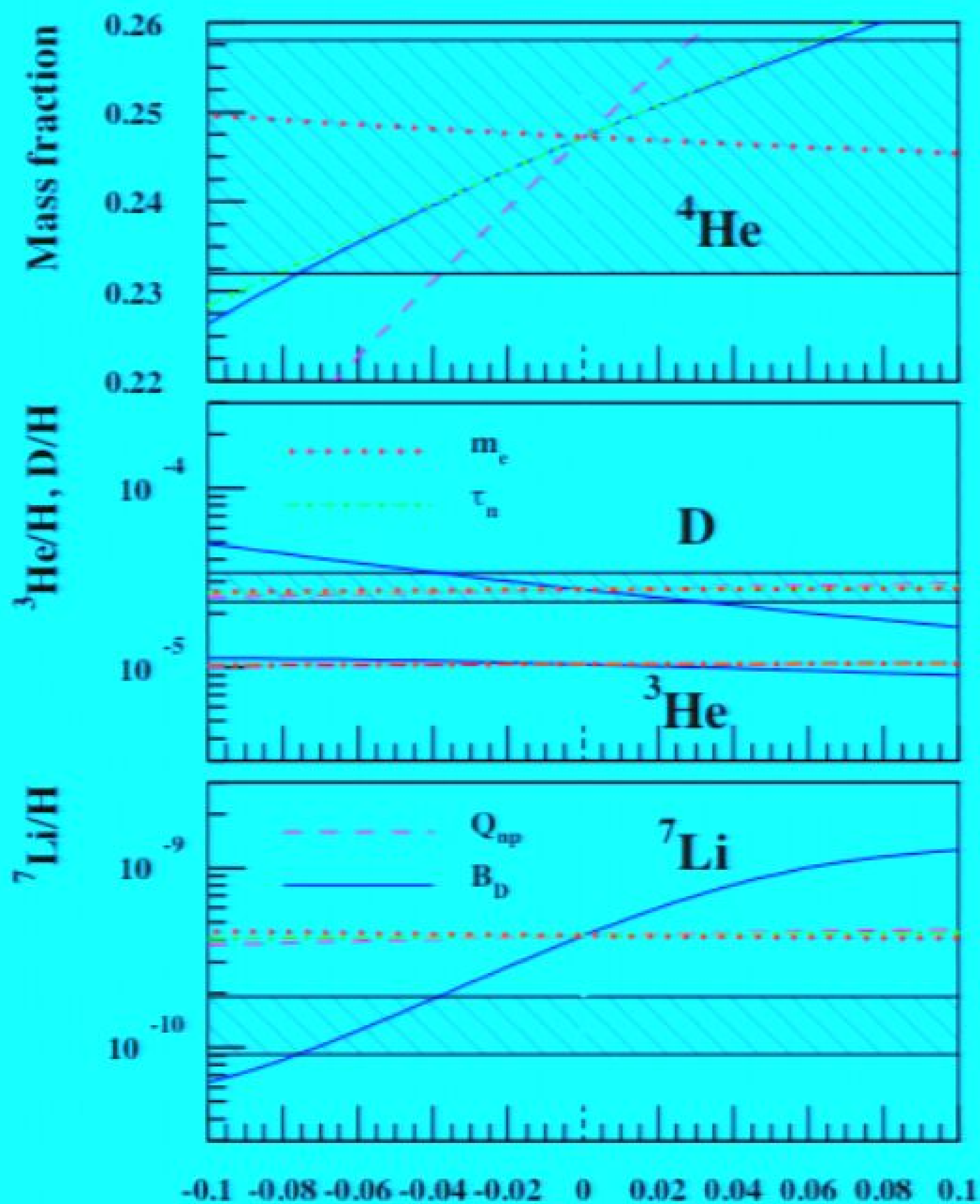



m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

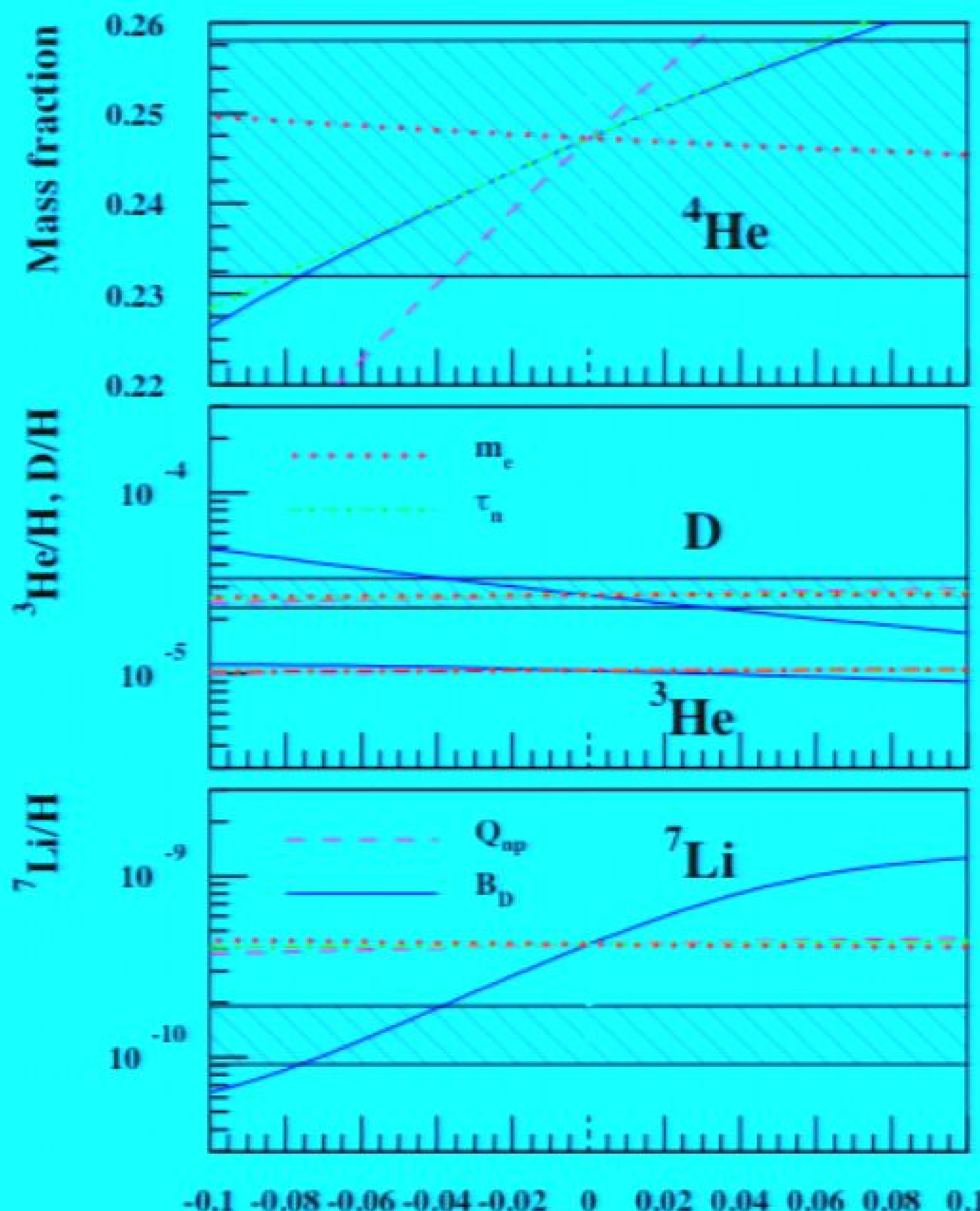


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
^{4}He
^{3}He/H, D/H
m_e
τ_n
D
^{3}He
^{7}Li/H
Q_{np}
B_D
^{7}Li
0.26
0.25
0.24
0.23
0.22
10^{-4}
10^{-5}
10^{-9}
10^{-10}
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

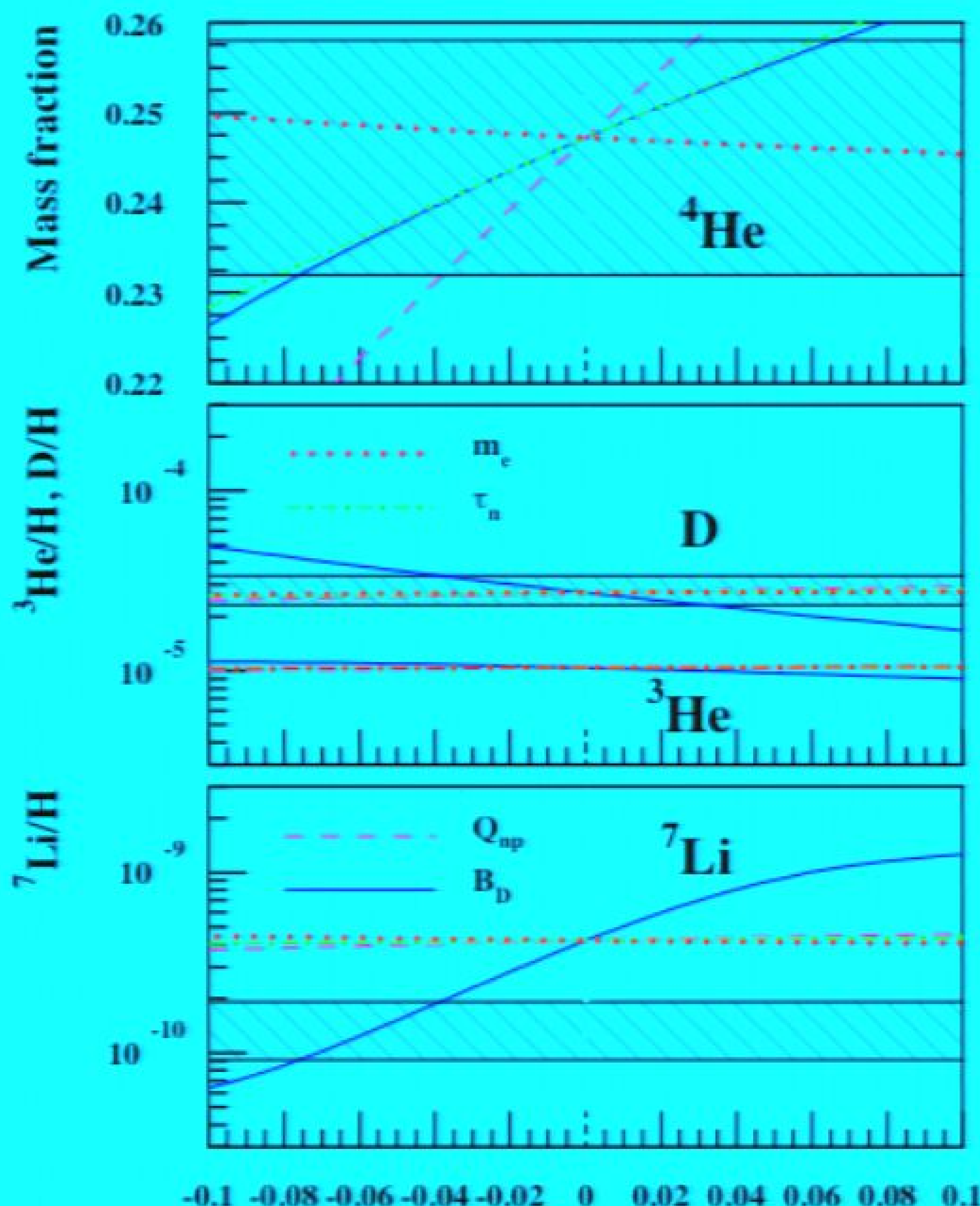
m_e, B_D, Q_{np} and τ_n variations

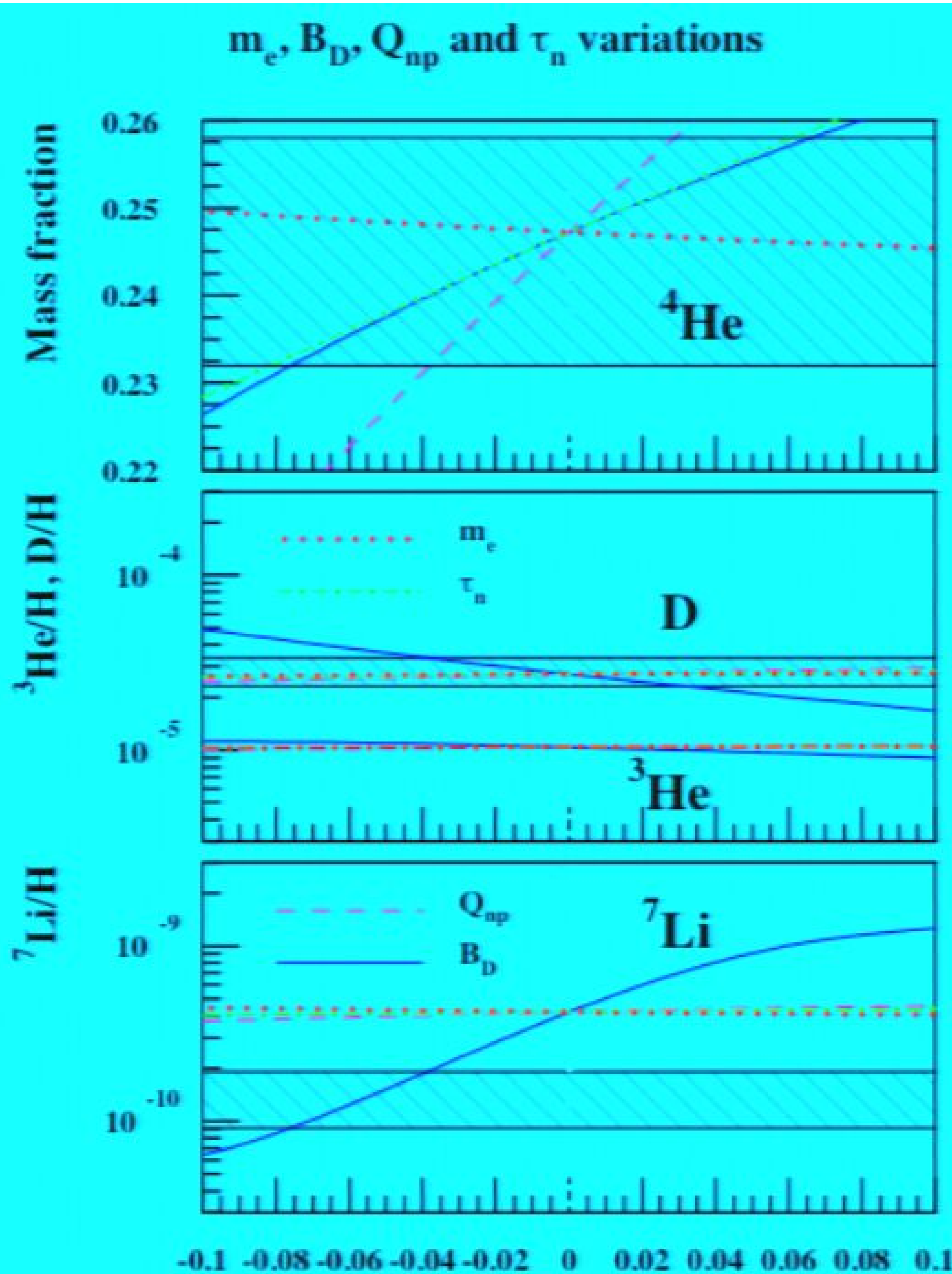


m_e, B_D, Q_{np} and τ_n variations

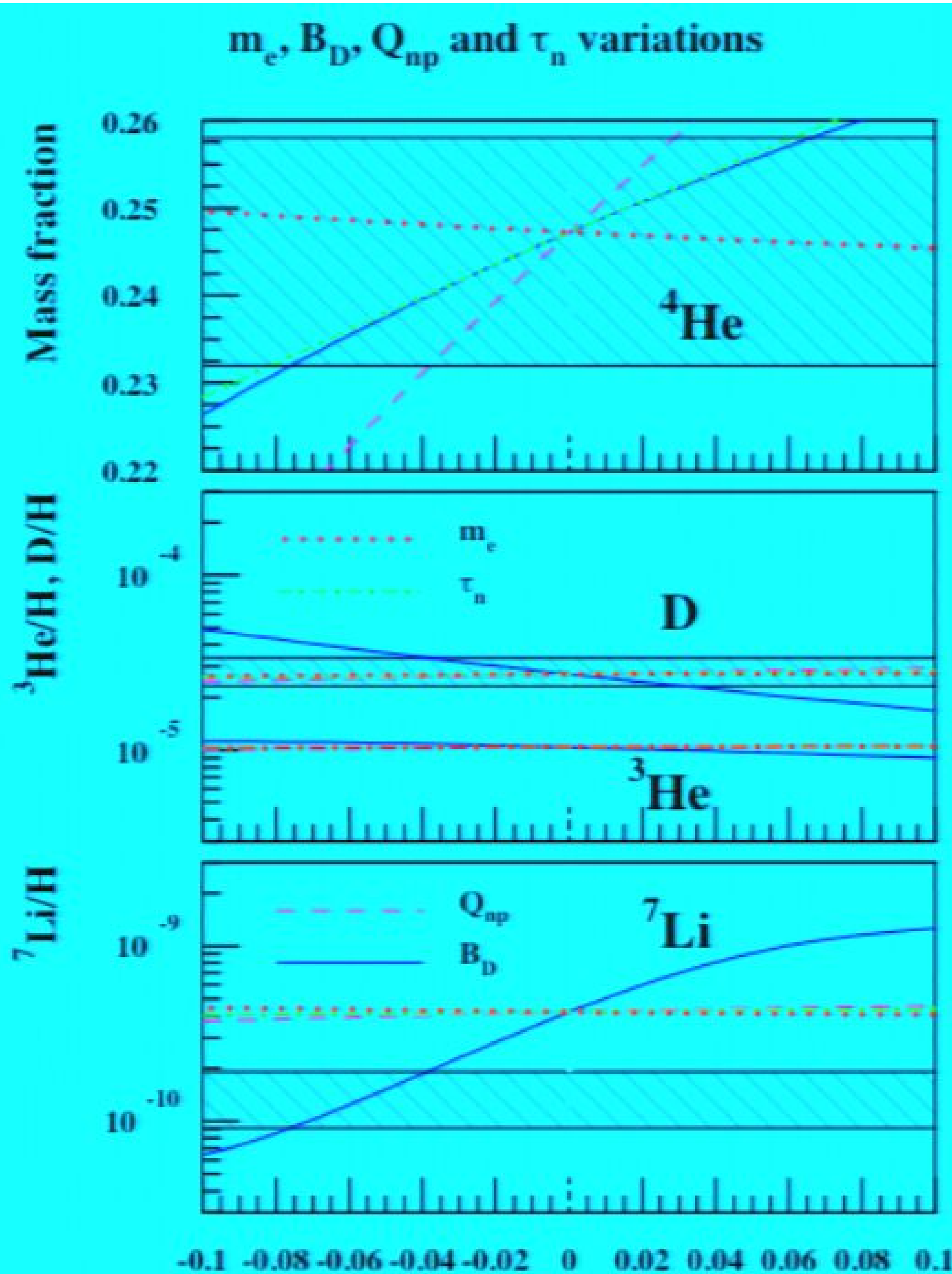


m_e, B_D, Q_{np} and τ_n variations

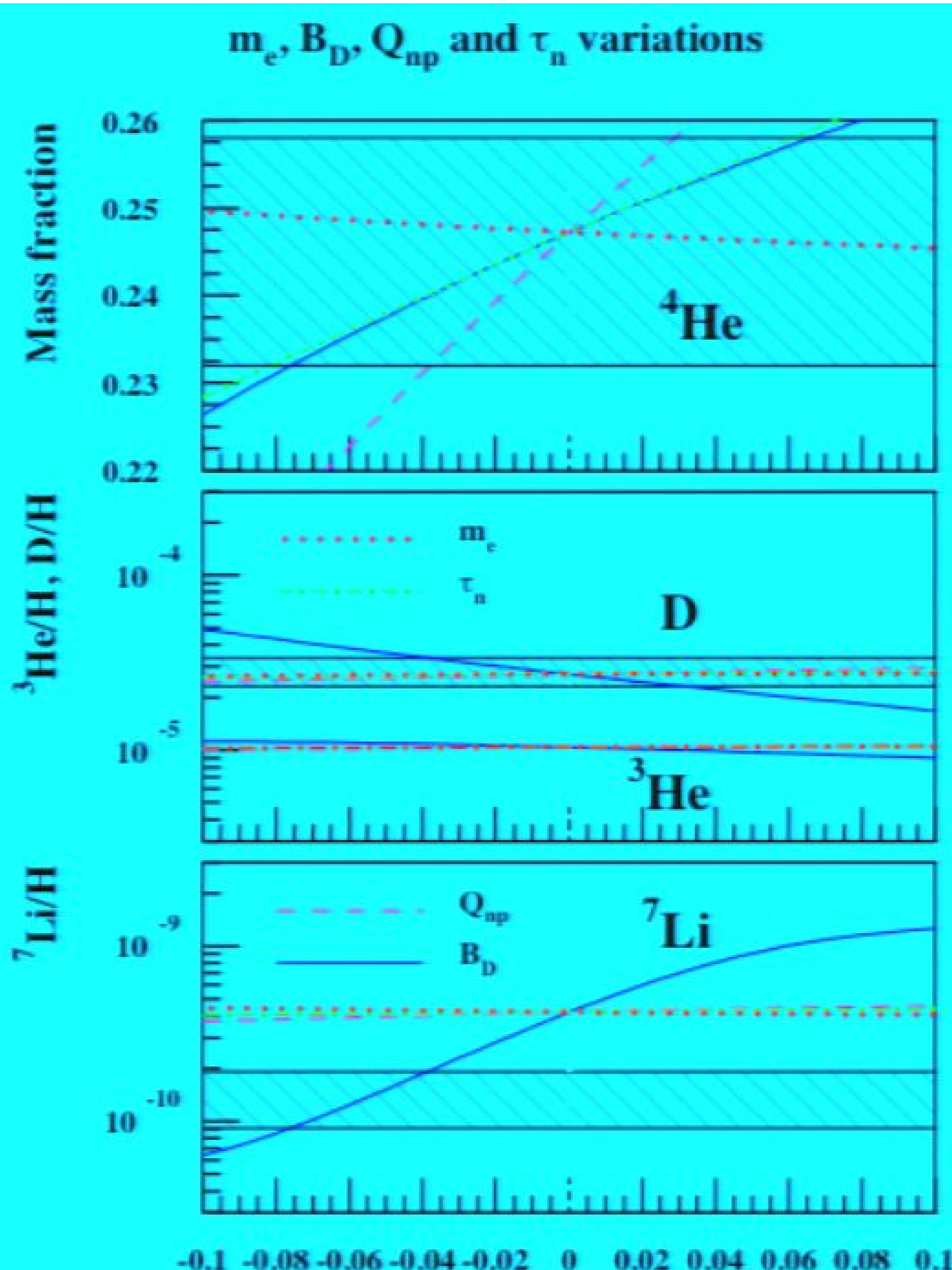


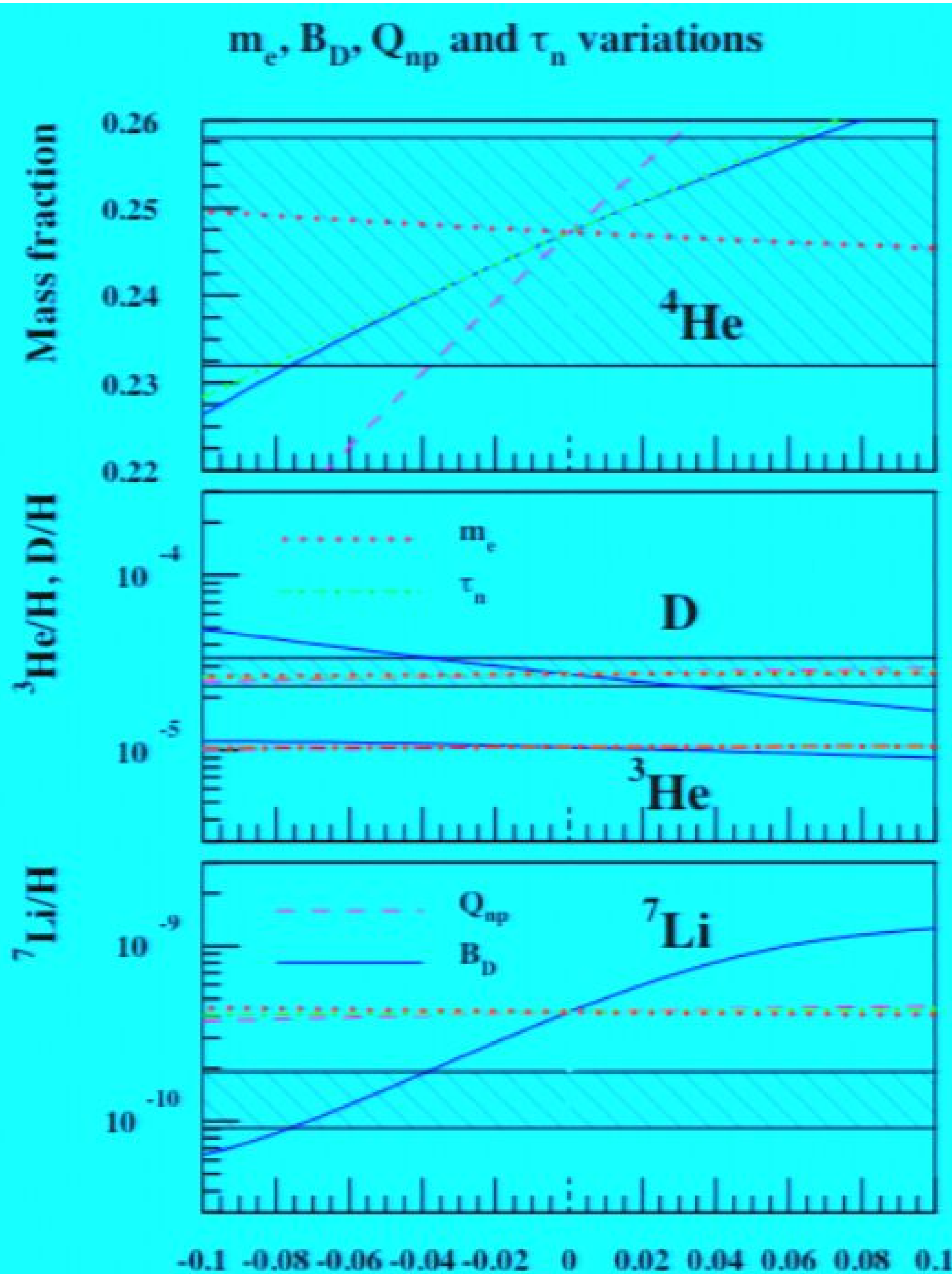


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
^{4}He
^{3}He/H , D/H
D
^{3}He
^{7}Li/H
^{7}Li
m_e
τ_n
Q_{np}
B_D
0.26
0.25
0.24
0.23
0.22
10^{-4}
10^{-5}
10^{-9}
10^{-10}
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



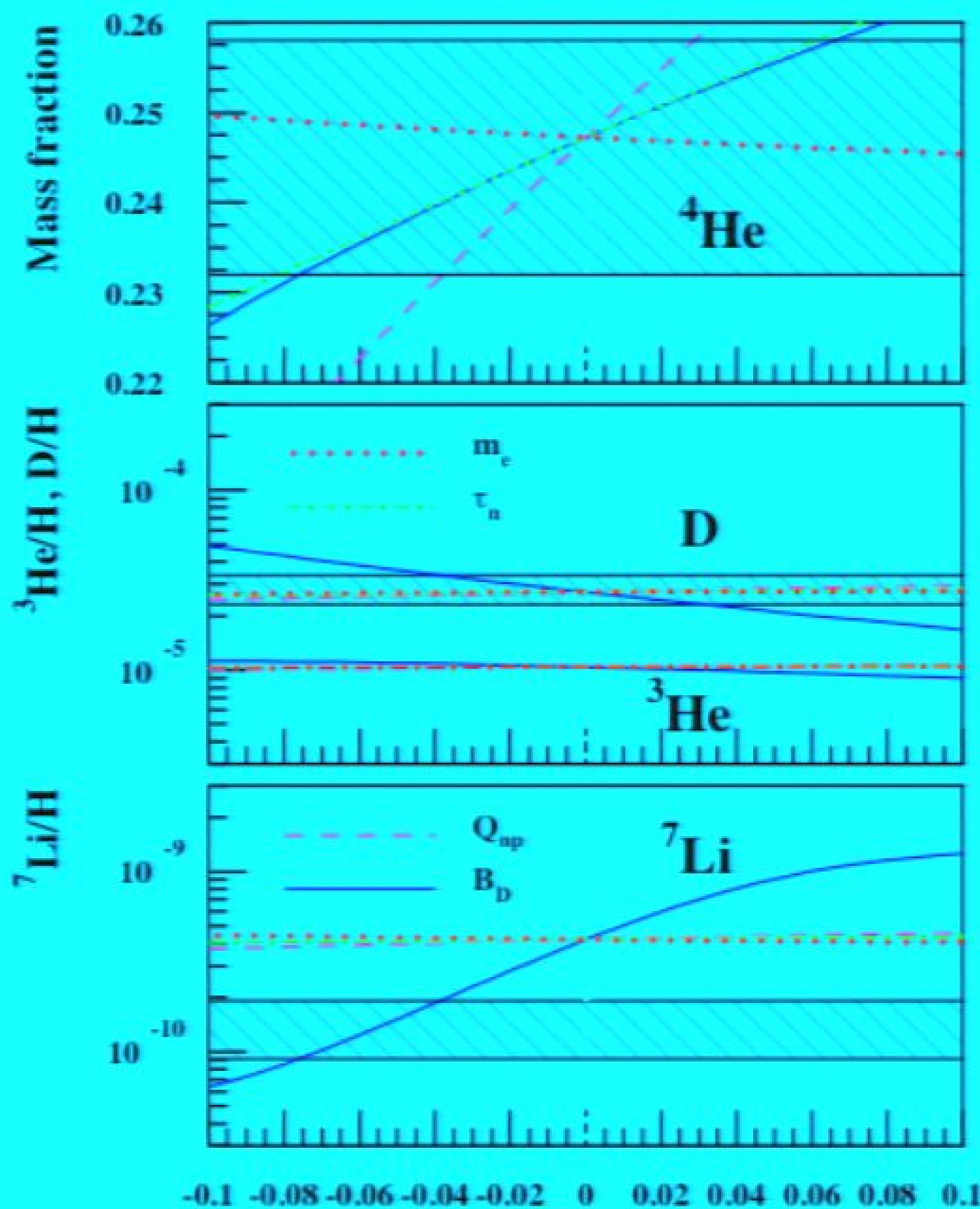
m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
⁴He
³He/H, D/H
10⁻⁴
10⁻⁵
m_e
τ_n
D
³He
⁷Li/H
10⁻⁹
10⁻¹⁰
Q_np
B_D
⁷Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

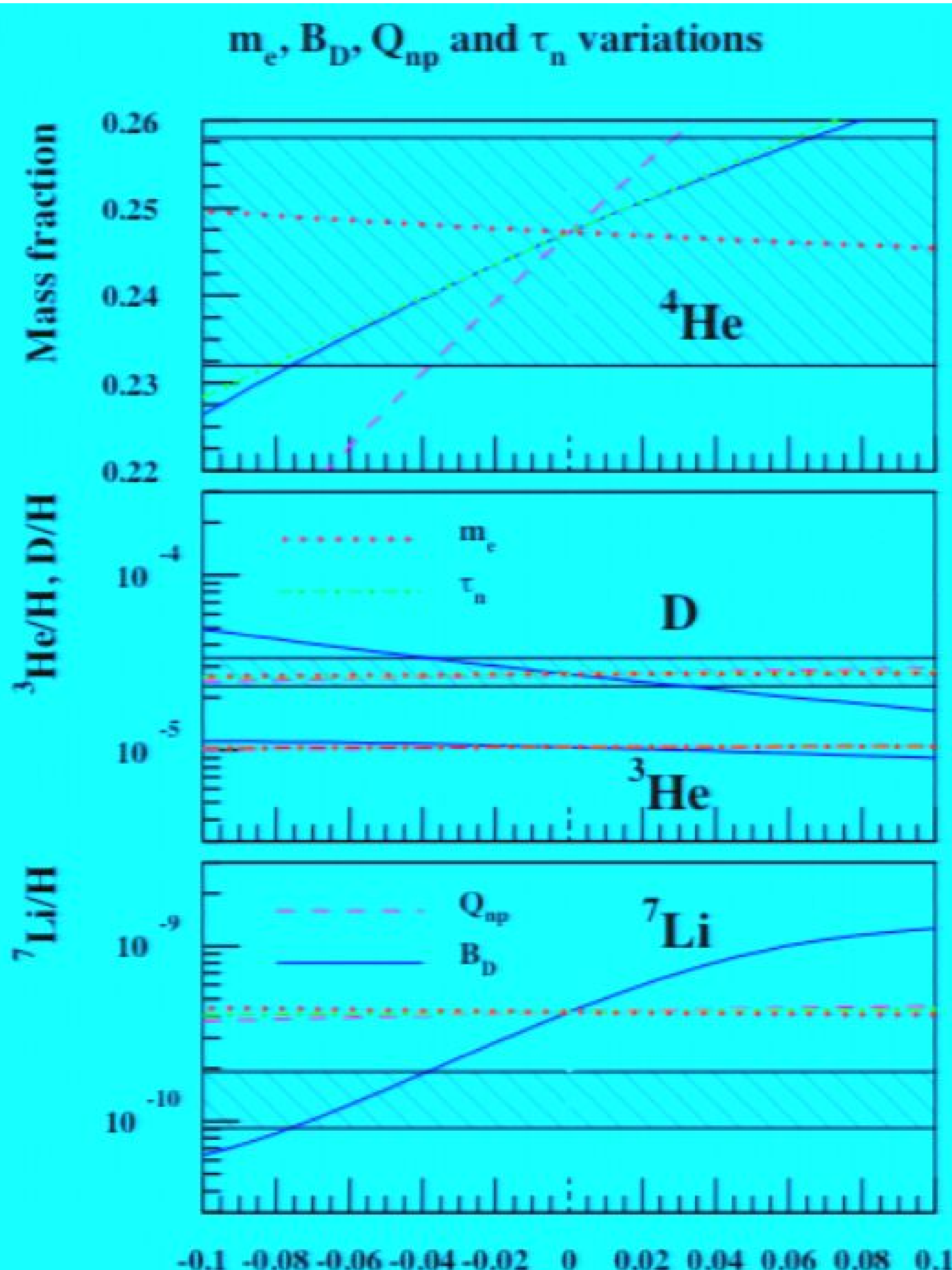

m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

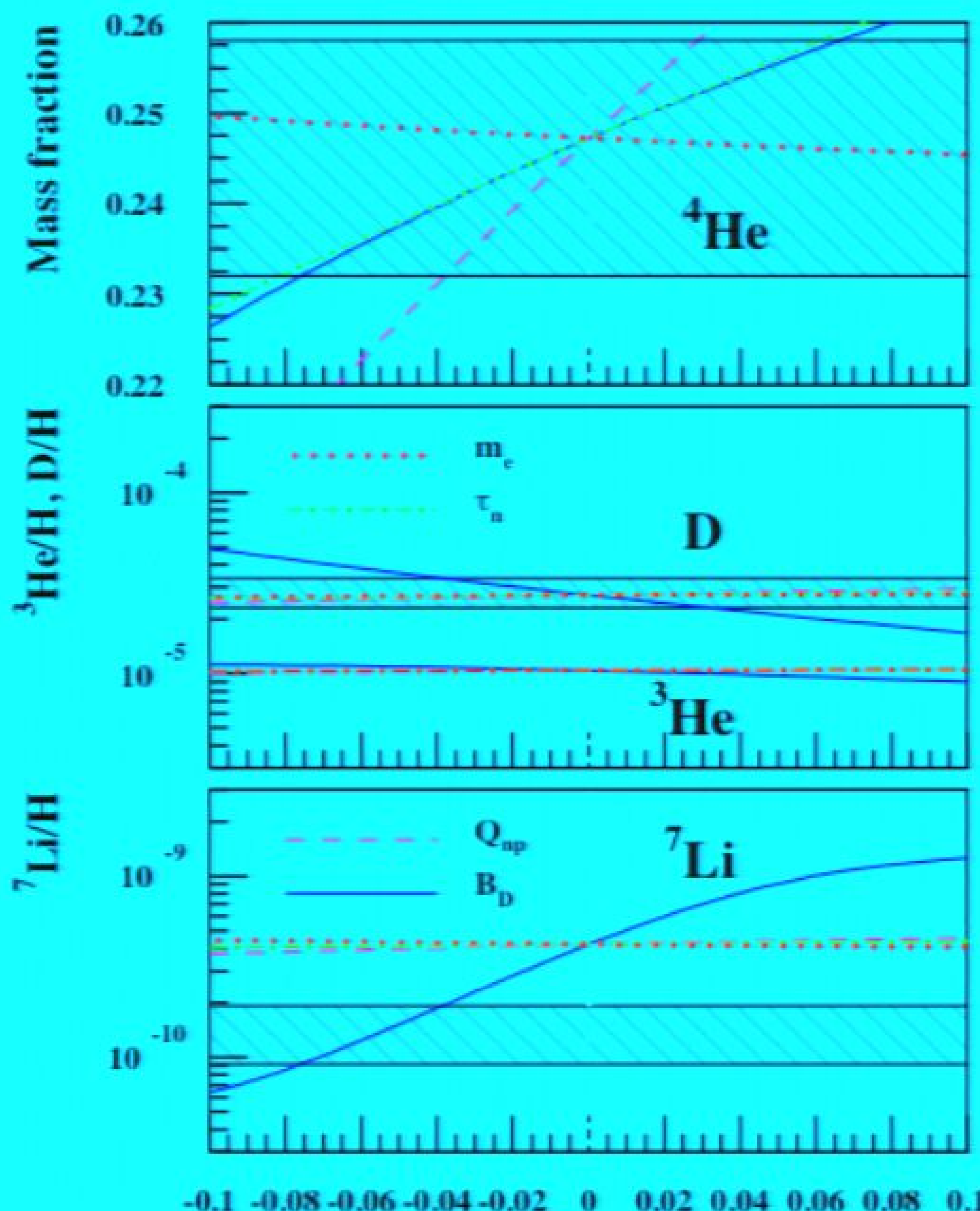
m_e, B_D, Q_{np} and τ_n variations



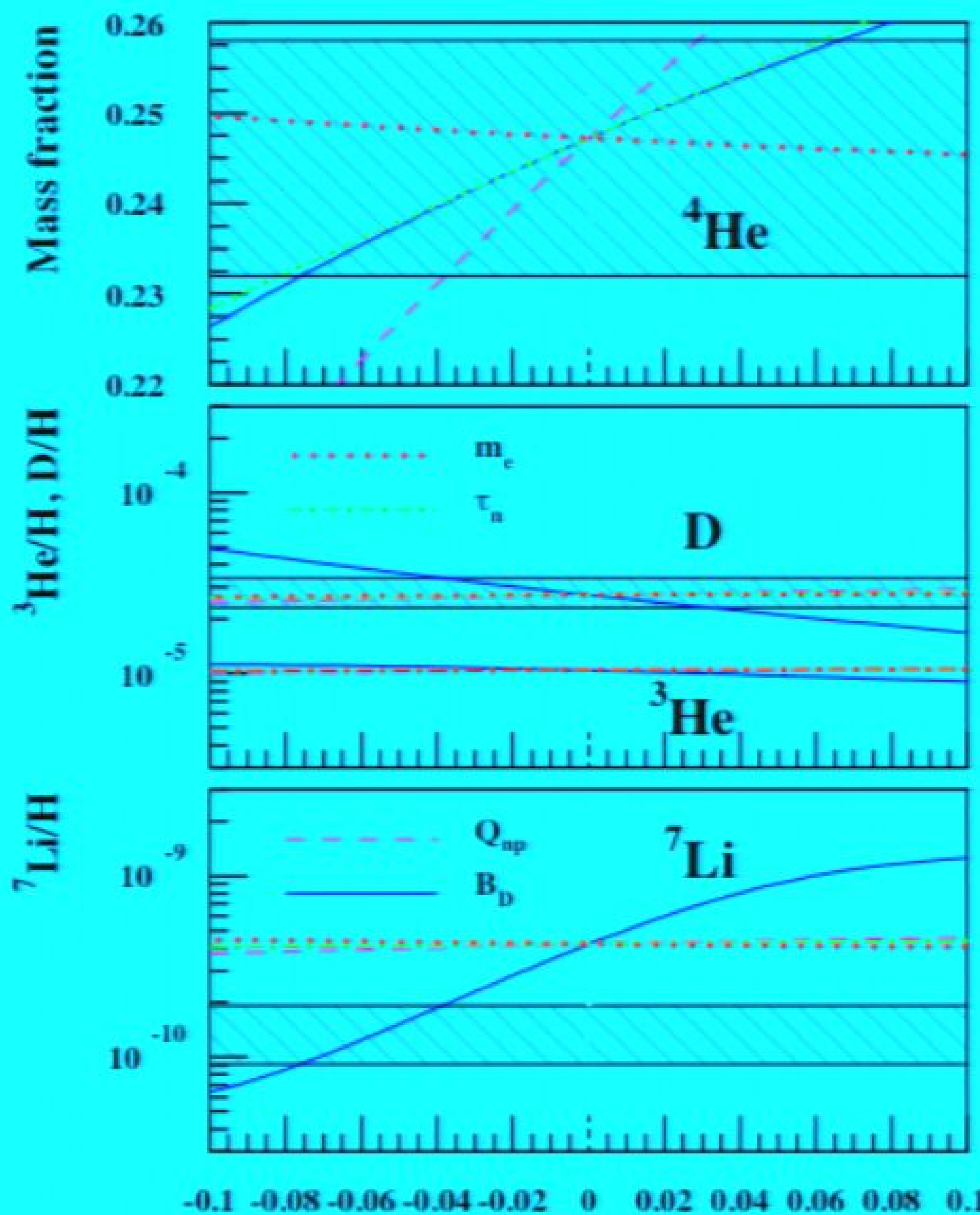


m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

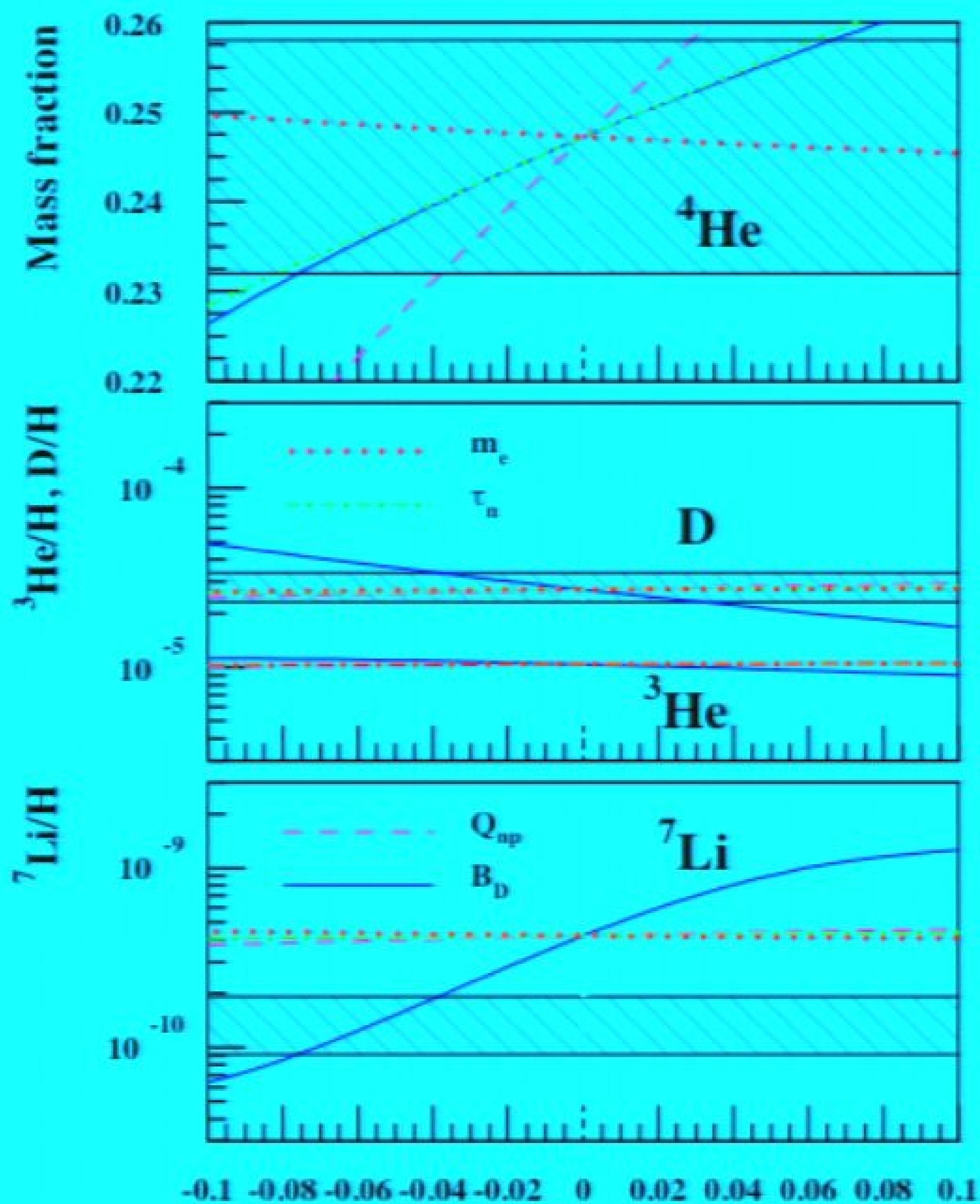
m_e, B_D, Q_{np} and τ_n variations

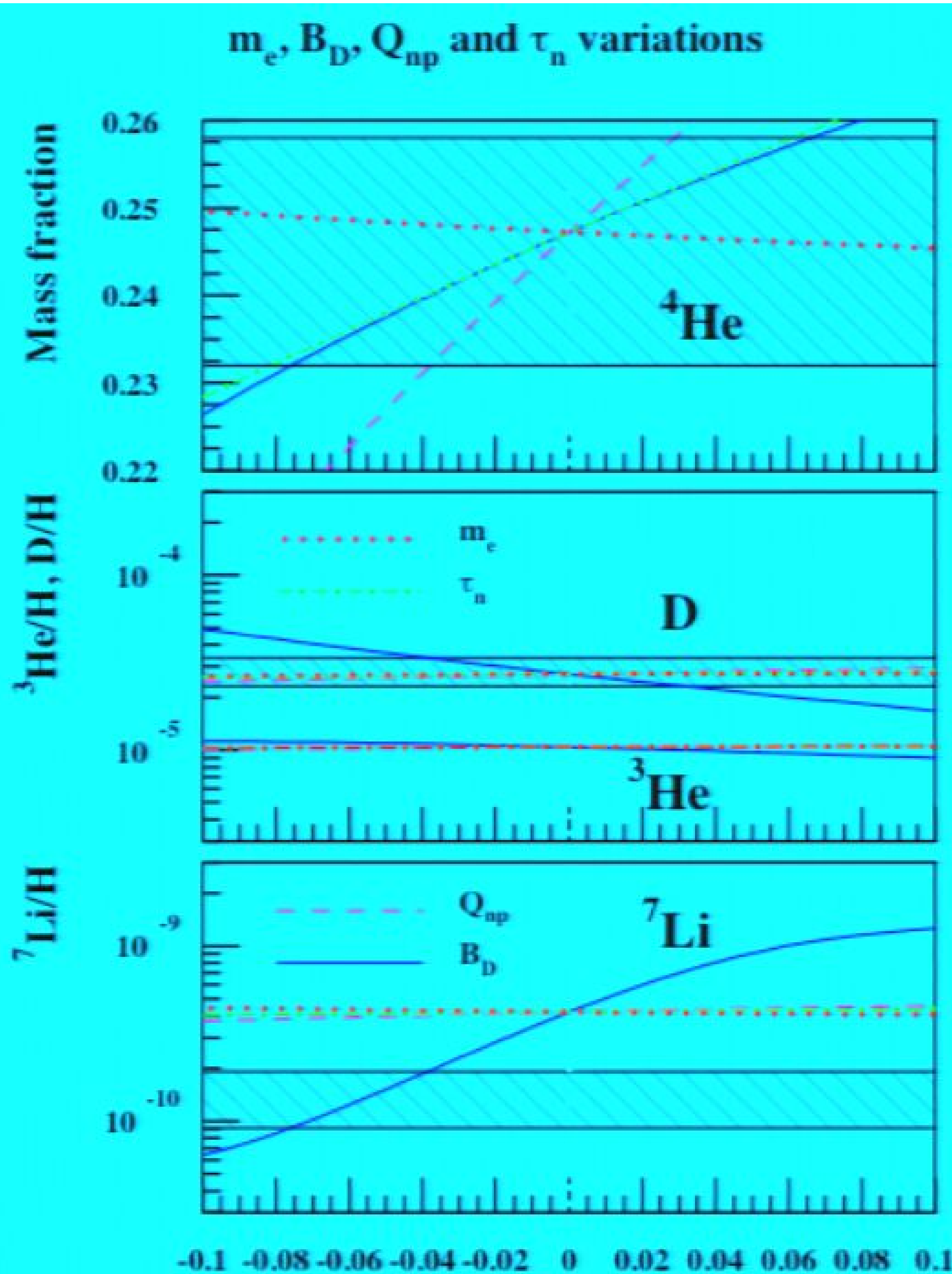


m_e, B_D, Q_{np} and τ_n variations

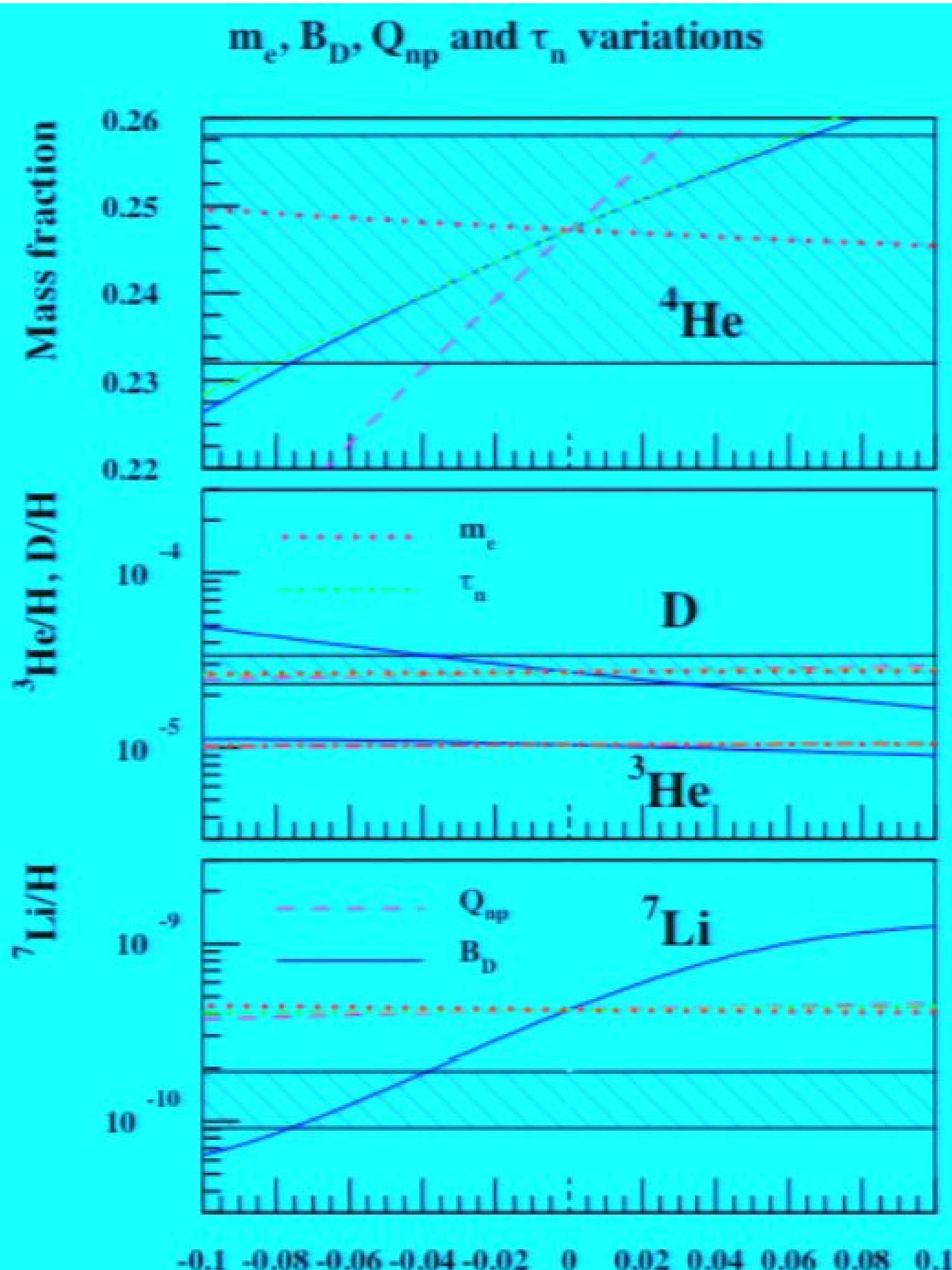


m_e, B_D, Q_{np} and τ_n variations

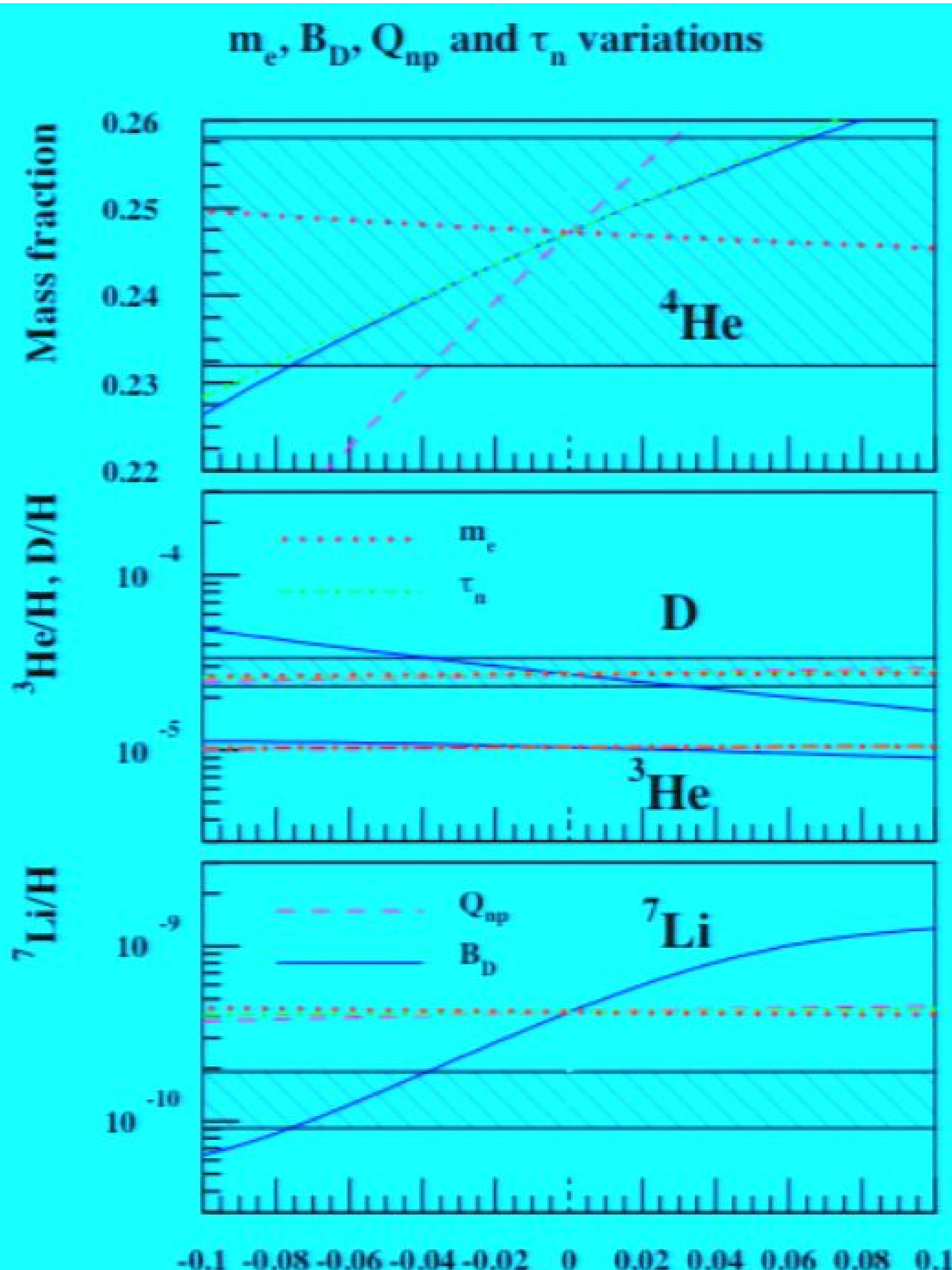




m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

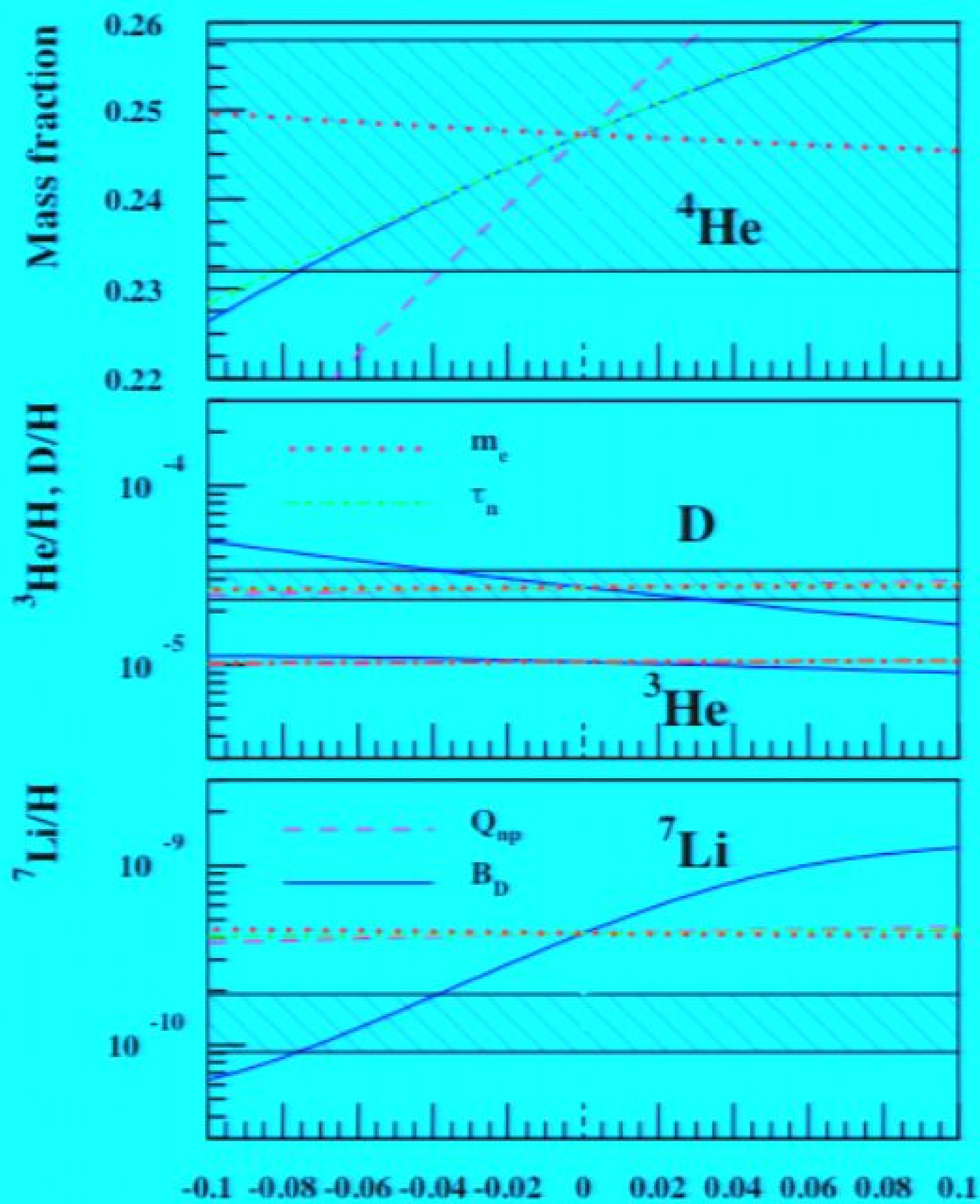


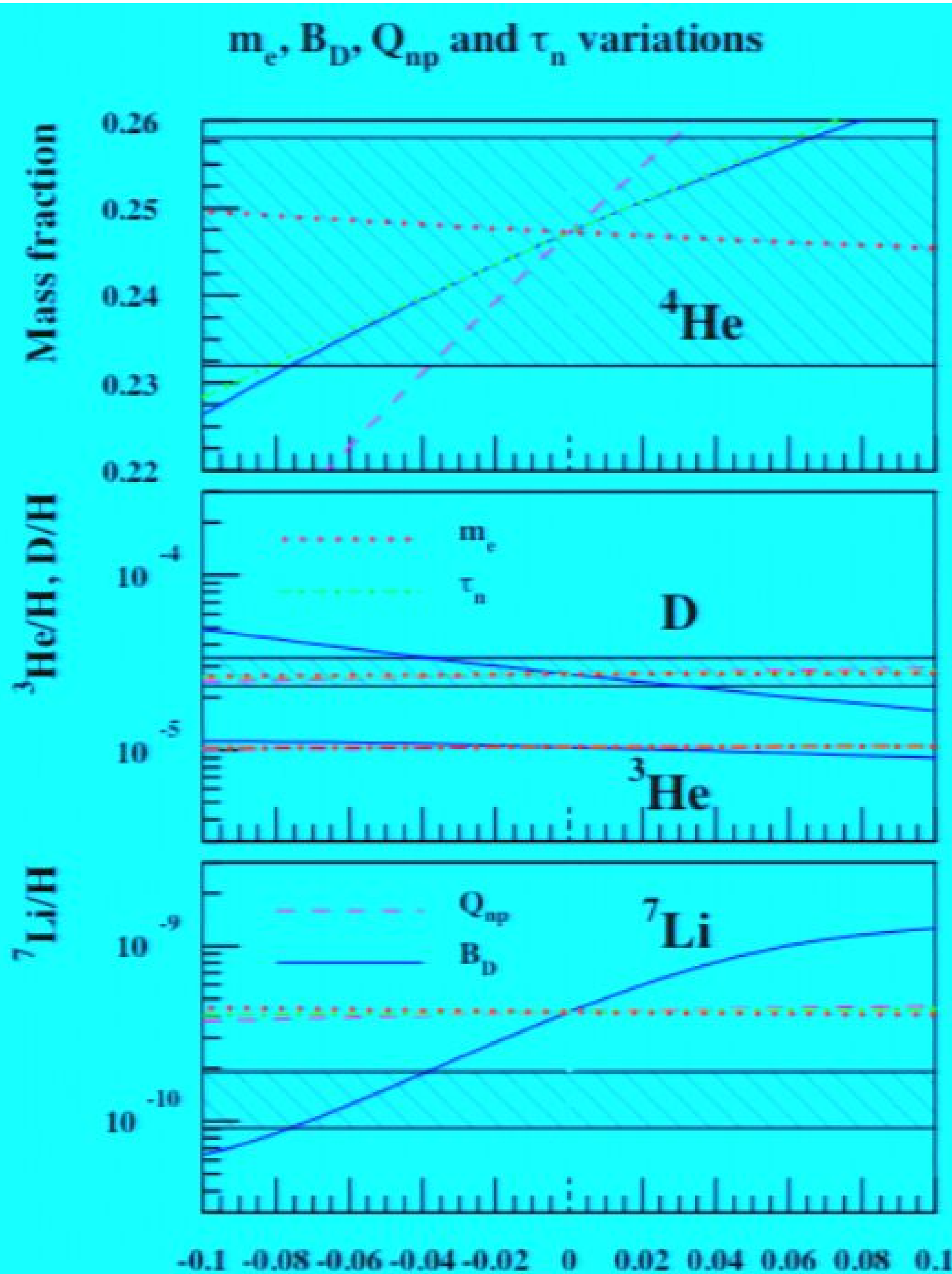
m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1



m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
10^-4
10^-5
m_e
τ_n
D
3He
7Li/H
10^-9
10^-10
Q_np
B_D
7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

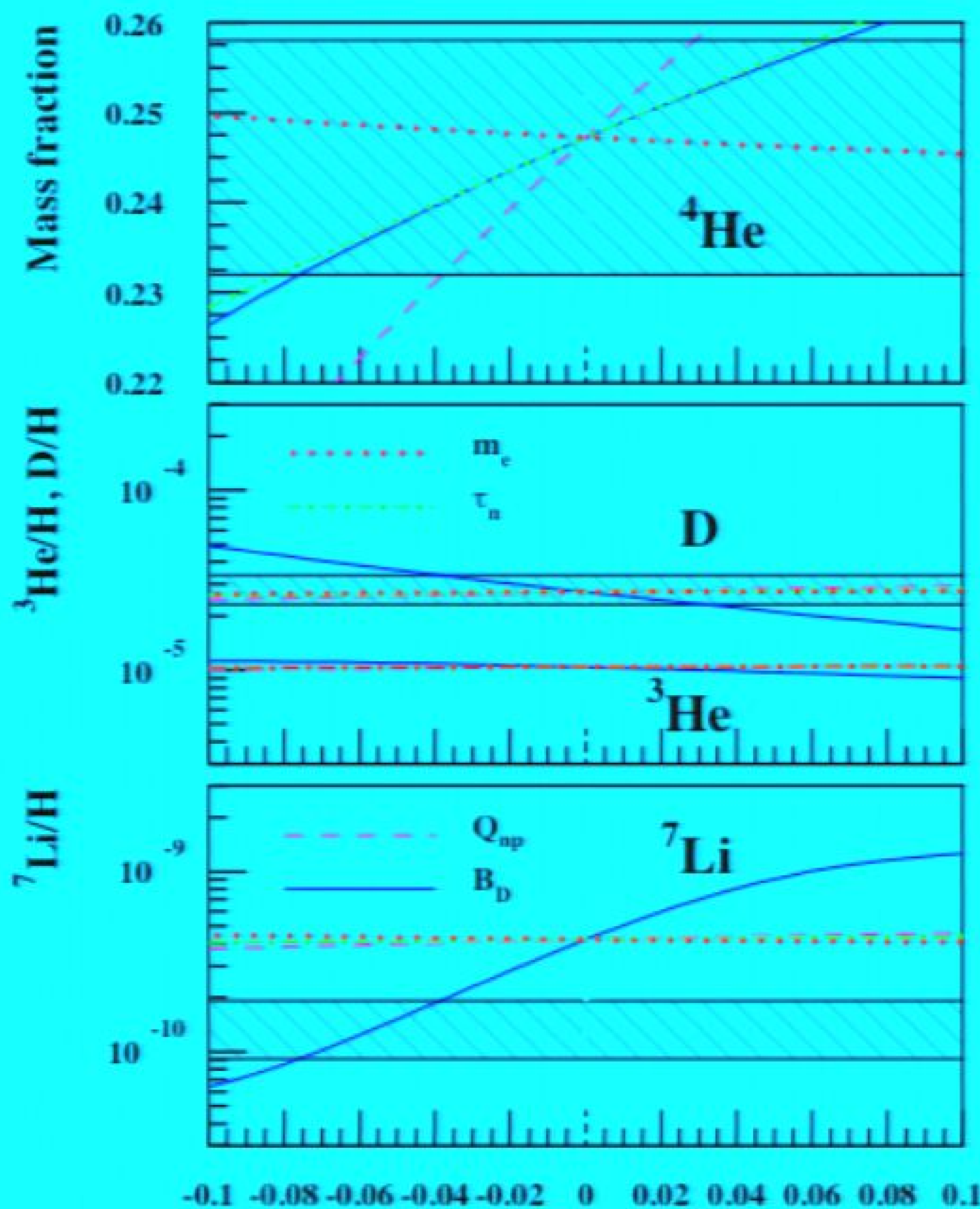
m_e, B_D, Q_{np} and τ_n variations

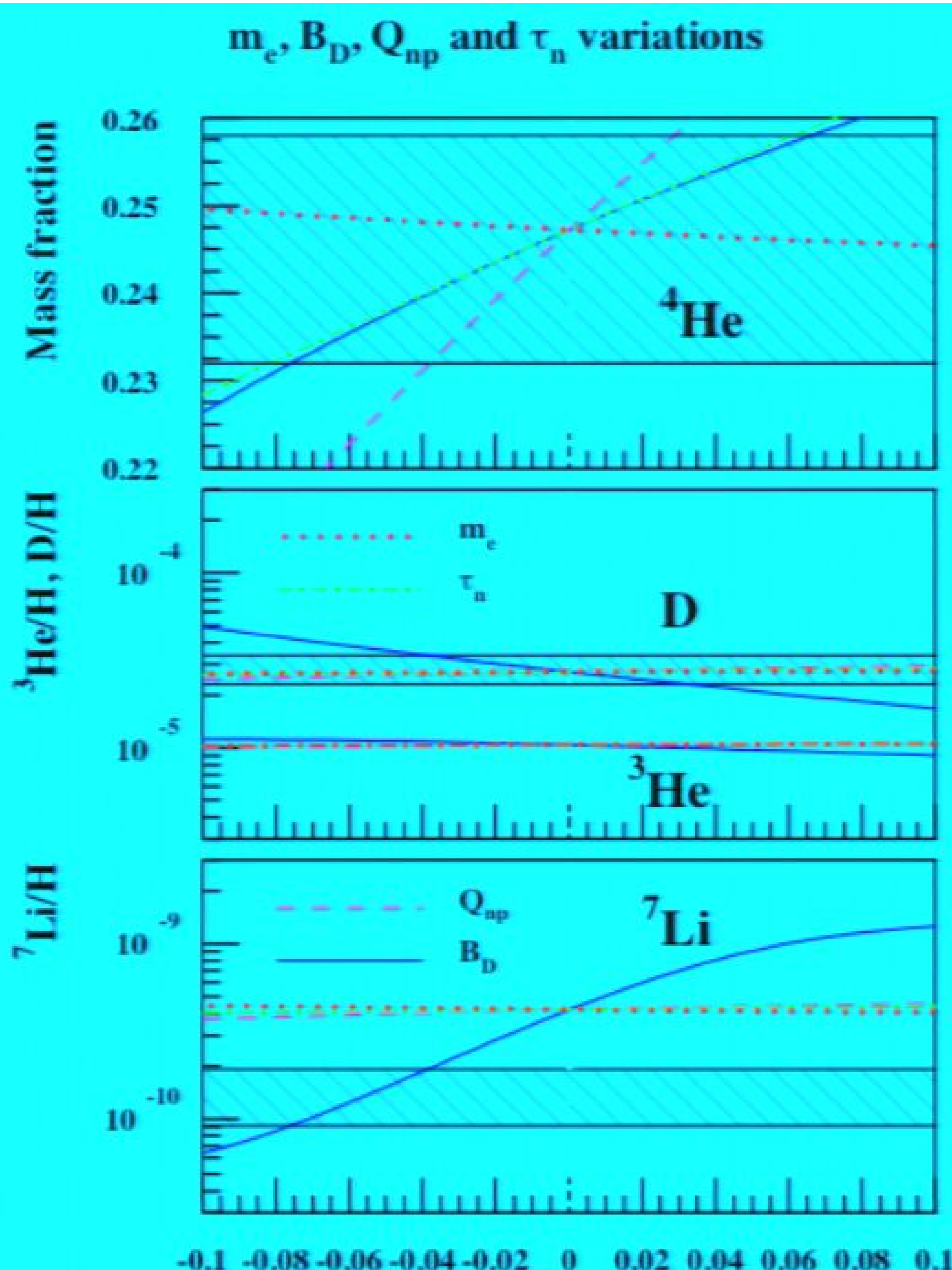




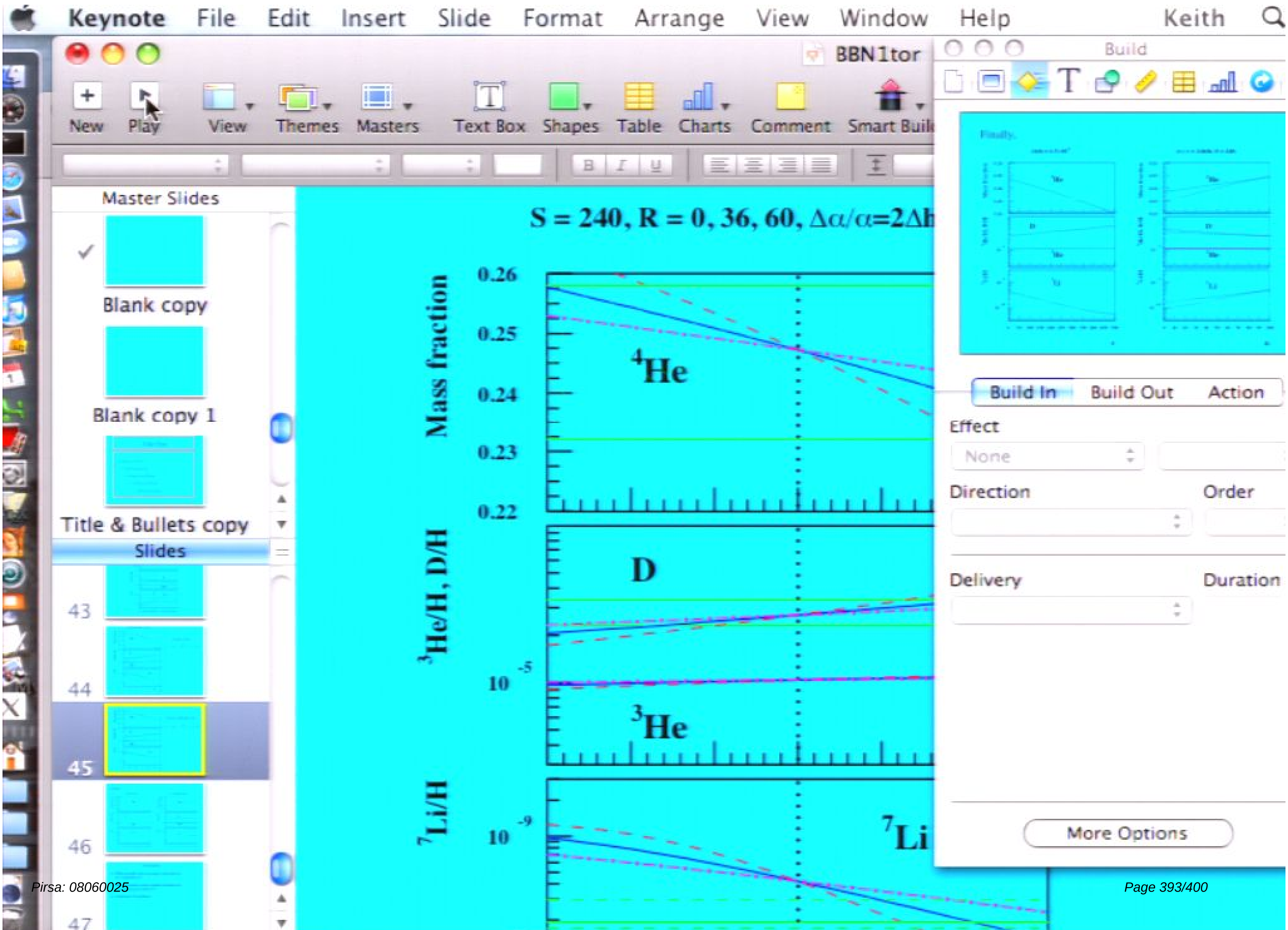
m_e, B_D, Q_np and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
4He
3He/H, D/H
10 -4
10 -5
m_e
τ_n
D
3He
7Li/H
10 -9
10 -10
Q_np
B_D
7Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

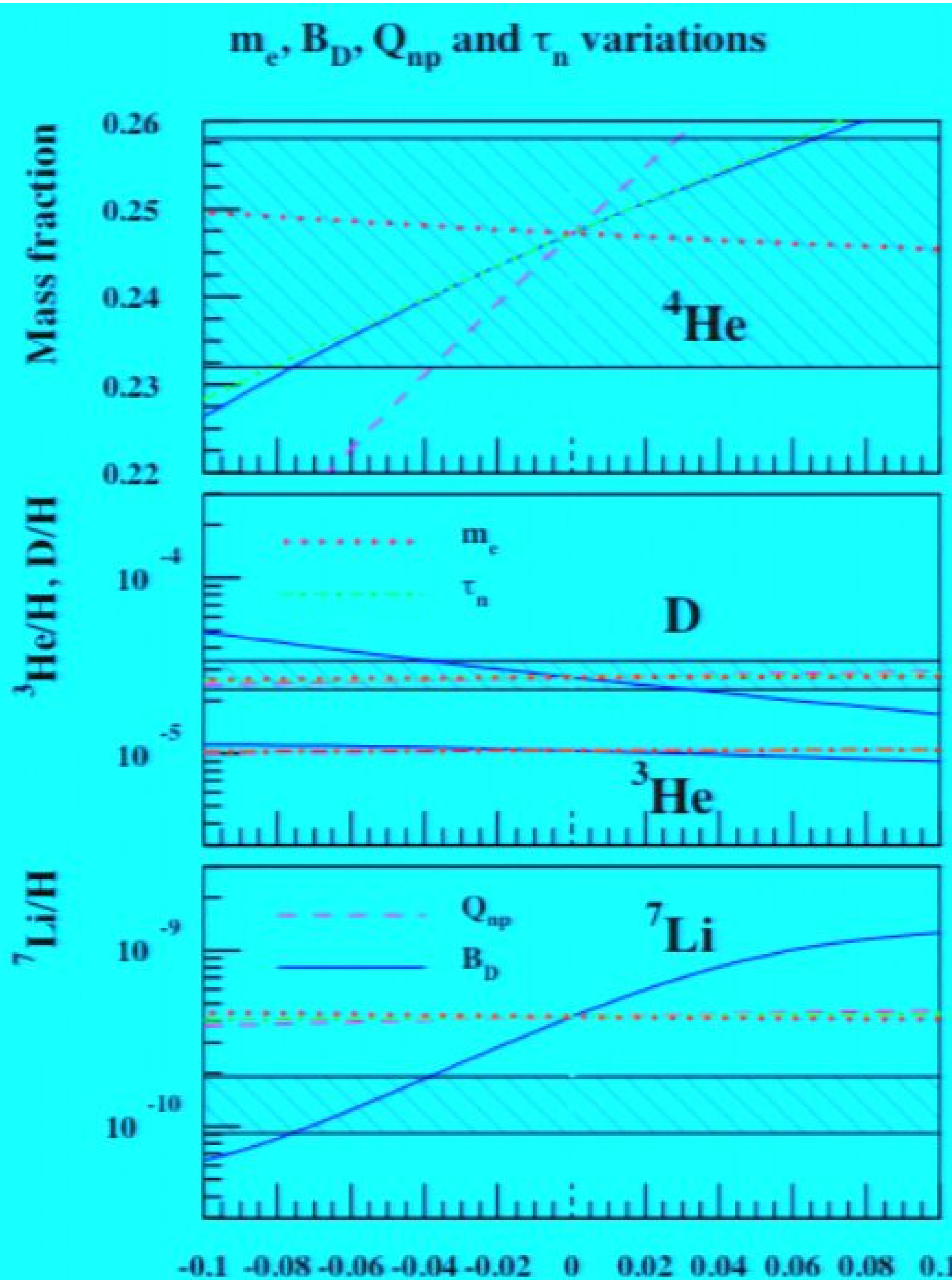
m_e, B_D, Q_{np} and τ_n variations





m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1


Keynote
File
Edit
Insert
Slide
Format
Arrange
View
Window
Help
Keith
BBN1tor
New
Play
View
Themes
Masters
Text Box
Shapes
Table
Charts
Comment
Smart Buil
Master Slides
Blank copy
Blank copy 1
Title & Bullets copy
Slides
43
44
45
46
47
S = 240, R = 0, 36, 60, Δα/α=2Δh
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
D
10^{-5}
^{3}He
^{7}Li/H
10^{-9}
^{7}Li
Build
Build In
Build Out
Action
Effect
None
Direction
Order
Delivery
Duration
More Options



m_e, B_D, Q_{np} and τ_n variations
Mass fraction
0.26
0.25
0.24
0.23
0.22
^{4}He
^{3}He/H, D/H
10^{-4}
10^{-5}
m_e
τ_n
D
^{3}He
^{7}Li/H
10^{-9}
10^{-10}
Q_{np}
B_D
^{7}Li
-0.1 -0.08 -0.06 -0.04 -0.02 0 0.02 0.04 0.06 0.08 0.1

Fermion Masses:

$$m_f \propto h_f v \qquad G_F \propto 1/v^2$$

Also expect variations in Yukawas,

$$\frac{\Delta h}{h} = \frac{1}{2}\frac{\Delta\alpha_U}{\alpha_U}$$

But in theories with radiative electroweak symmetry breaking

$$v \sim M_P \exp(-2\pi c/\alpha_t)$$

Thus small changes in h_t
will induce large changes in v

$$\frac{\Delta v}{v} \sim 80\frac{\Delta\alpha_U}{\alpha_U}$$

Net sensitivities due to Λ

$$\begin{aligned}
\frac{\Delta B_D}{B_D} &= -13\left(\frac{\Delta v}{v}+\frac{\Delta h}{h}\right)+18R\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta Q}{Q} &= 1.5\left(\frac{\Delta v}{v}+\frac{\Delta h}{h}\right)-0.6(1+R)\,\frac{\Delta \alpha}{\alpha}\,, \\
\frac{\Delta \tau_n}{\tau_n} &= -4\,\frac{\Delta v}{v}-8\,\frac{\Delta h}{h}+3.8(1+R)\,\frac{\Delta \alpha}{\alpha}\,.
\end{aligned}$$

Repeat calculation for contribution of quark masses to σ and ω

Dimitriev & Flambaum

$$\frac{\Delta B_D}{B_D} = 18\,\frac{\Delta\Lambda}{\Lambda} - 17\left(\frac{\Delta v}{v} + \frac{\Delta h_s}{h_s}\right)$$

contributions from u and d are negliglible

Alternative:

Use dependence from pion mass

Beane & Savage
Yoo & Scherrer

$$\frac{\Delta B_D}{B_D} = -r\,\frac{\Delta m_\pi}{m_\pi} \qquad r = 6\text{-}10$$

$$\frac{\Delta B_D}{B_D} = \left(1 + \frac{r}{2}\right)\frac{\Delta\Lambda}{\Lambda} - \frac{r}{2}\left(\frac{\Delta v}{v} + \frac{\Delta h}{h}\right)$$

Strangeness contribution $y = 2B_s/(B_u + B_d)$

with $\Sigma(1-y) = 36 \pm 7 \quad \text{MeV}$

and $z \equiv \frac{B_u - B_s}{B_d - B_s} = \frac{m_{\Xi^0} + m_{\Xi^-} - m_p - m_n}{m_{\Sigma^+} + m_{\Sigma^-} - m_p - m_n} = 1.49$

giving $$\frac{\Delta m_N}{m_N} = \left(\frac{m_s B_s}{m_N}\right)\frac{\Delta m_s}{m_s} \simeq 0.19\frac{\Delta m_s}{m_s}.$$

and $$\frac{\Delta m_N}{m_N} \simeq 0.052\frac{\Delta m_q}{m_q}.$$

$$\frac{\Delta m_p}{m_p} \simeq 0.76\frac{\Delta \Lambda}{\Lambda} + 0.24\left(\frac{\Delta h}{h} + \frac{\Delta v}{v}\right)$$

Spin-independent Neutralino-p cross section

The scalar cross section

$$\sigma_3 = \frac{4m_r^2}{\pi}\left[Zf_p + (A-Z)f_n\right]^2$$

where

$$\frac{f_p}{m_p} = \sum_{q=u,d,s} f_{Tq}^{(p)}\frac{\alpha_{3q}}{m_q} + \frac{2}{27}f_{TG}^{(p)}\sum_{c,b,t}\frac{\alpha_{3q}}{m_q}$$

and

$$m_p f_{Tq}^{(p)} \equiv \langle p|m_q\bar{q}q|p\rangle \equiv m_q B_q$$

determined by

$$\sigma_{\pi N} \equiv \Sigma = \frac{1}{2}(m_u + m_d)(B_u + B_d)$$

will take:

Σ = 45 GeV or 64 GeV

Quantities of importance for BBN

- $Q = \Delta m_N$ nucleon mass difference

$$Q \equiv m_n - m_p = a\,\alpha\,\Lambda + (h_d - h_u)\,v\,,$$

$$\frac{\Delta Q}{Q} = -0.6\left[\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right] + 1.6\left[\frac{\Delta(h_d - y_u)}{h_d - h_u} + \frac{\Delta v}{v}\right]$$

- τ_n neutron lifetime

$$\tau_n^{-1} = \frac{1}{60}\,\frac{1 + 3\,g_A^2}{2\pi^3}\,G_F^2\,m_e^5\left[\sqrt{q^2 - 1}(2q^4 - 9q^2 - 8) + 15\ln(q + \sqrt{q^2 - 1})\right], \qquad ($$

$$\frac{\Delta\tau_n}{\tau_n} = -4.8\,\frac{\Delta v}{v} + 1.5\,\frac{\Delta h_e}{h_e} - 10.4\,\frac{\Delta(h_d - h_u)}{h_d - h_u} + 3.8\left(\frac{\Delta\alpha}{\alpha} + \frac{\Delta\Lambda}{\Lambda}\right).$$