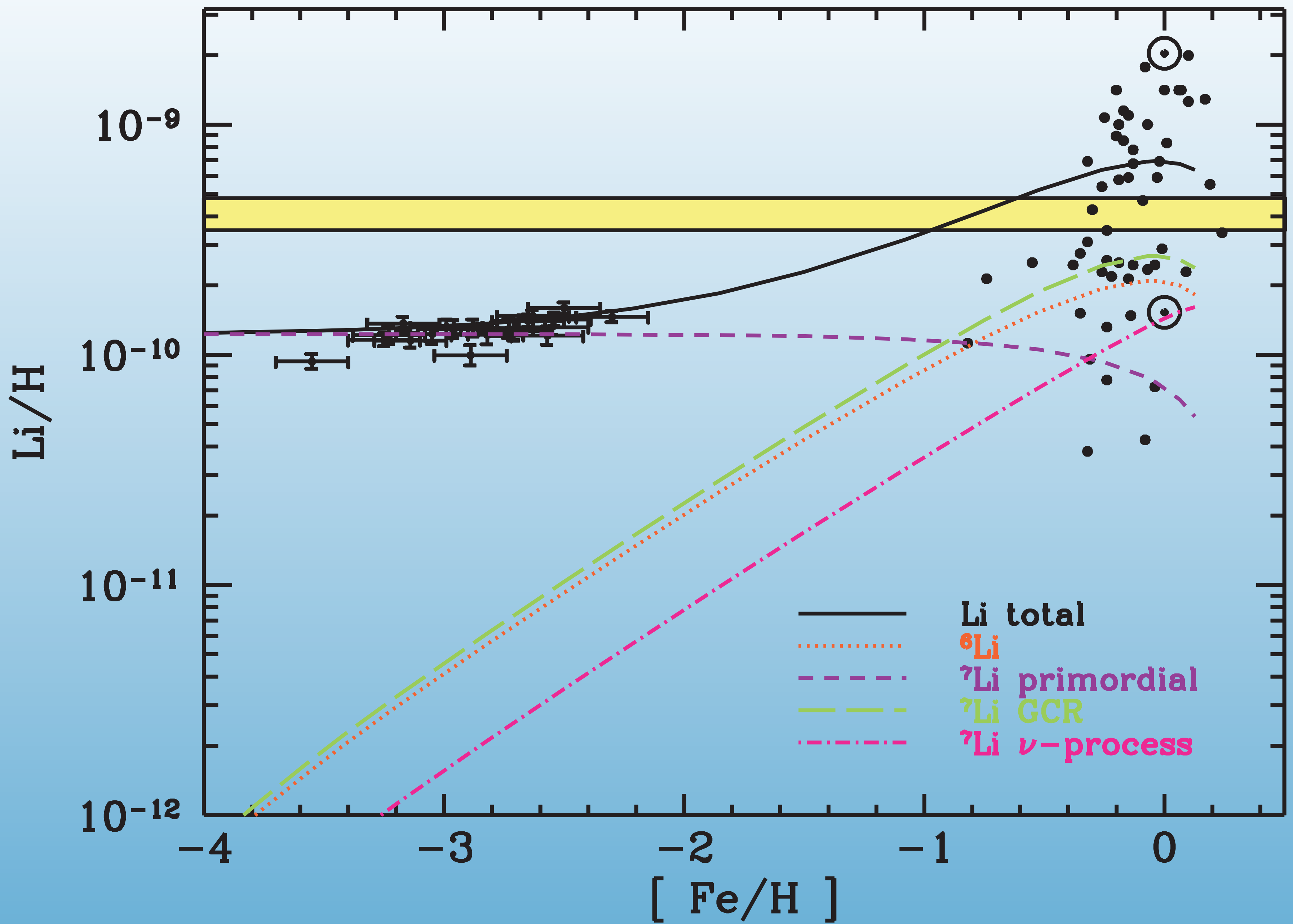
How to best reconcile Big Bang Nucleosynthesis with Li abundance determinations?

Exotic BBN



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

Ryan et al.

Possible sources for the discrepancy

- Nuclear Rates
  - Restricted by solar neutrino flux
  - Role of resonances

Discussed by Coc

- Stellar Depletion

Discussed by Richard, Korn, Lind

- Stellar parameters

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

Discussed by Ryan

Possible sources for the discrepancy

- Stellar Depletion

Discussed by Richard, Korn, Lind

- Stellar parameters

Discussed by Ryan

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

- Particle Decays

Limits on Unstable particles due to

Electromagnetic/Hadronic Production and Destruction of Nuclei

3 free parameters

$\zeta_X = n_X m_X/n_\gamma = m_X Y_X \eta$, m_X ,

and τ_X

- Start with non-thermal injection spectrum (Pythia)

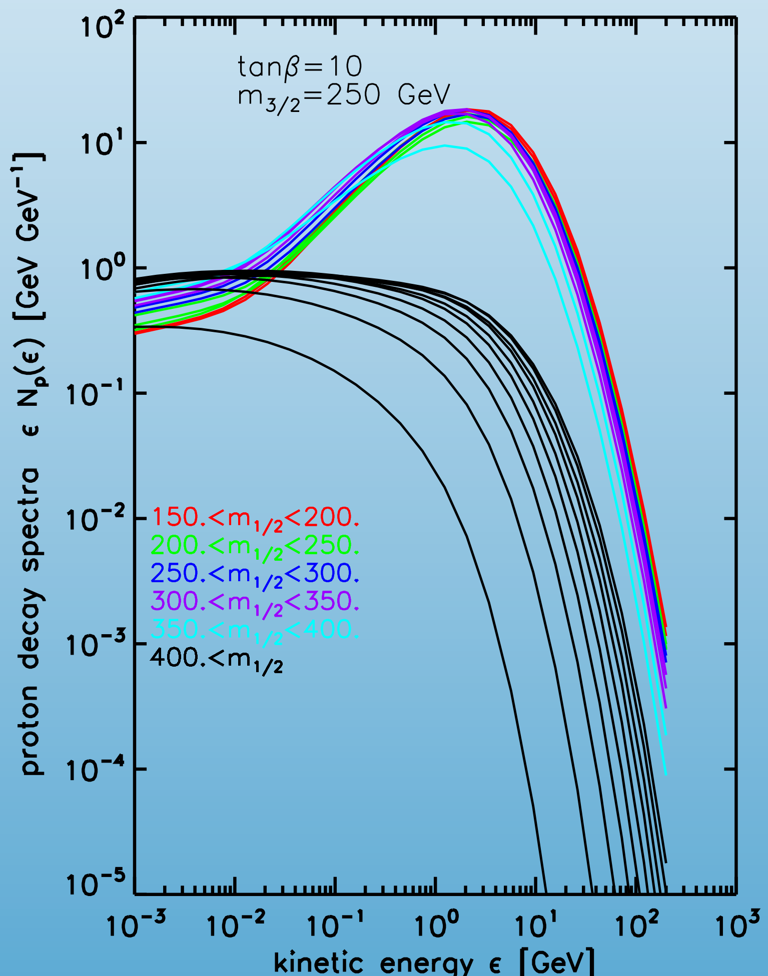
- Evolve element abundances including thermal (BBN) and non-thermal processes.

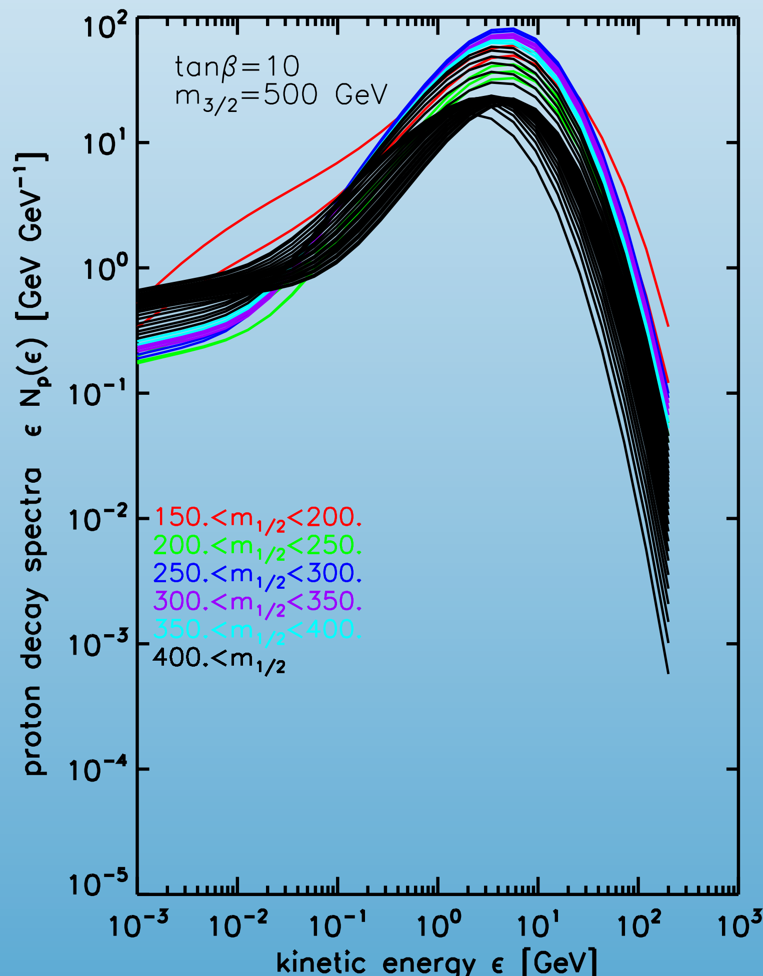
E.g., Gravitino decay

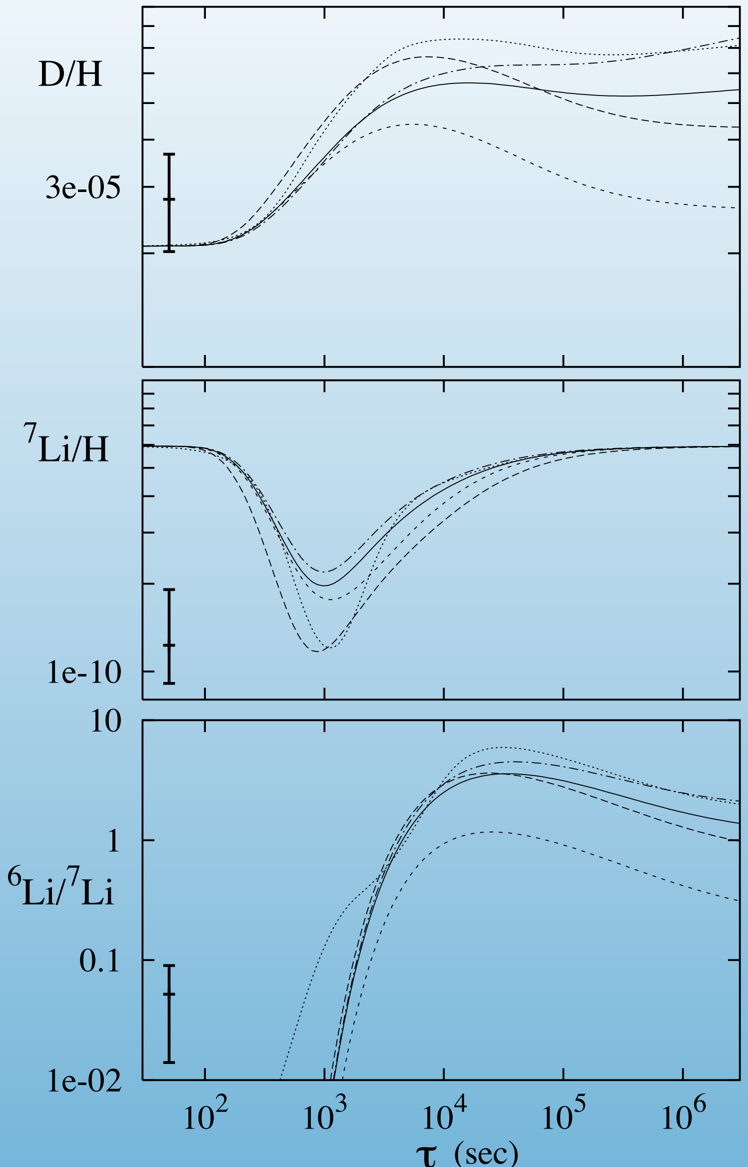
Cyburt, Ellis, Fields, Luo, Olive, Spanos

$$\widetilde{G} \to \tilde{f}\, f, \widetilde{G} \to \tilde{\chi}^+ W^-(H^-), \widetilde{G} \to \tilde{\chi}_i^0\, \gamma(Z), \widetilde{G} \to \tilde{\chi}_i^0\, H_i^0 \widetilde{G} \to \tilde{g}\, g.$$

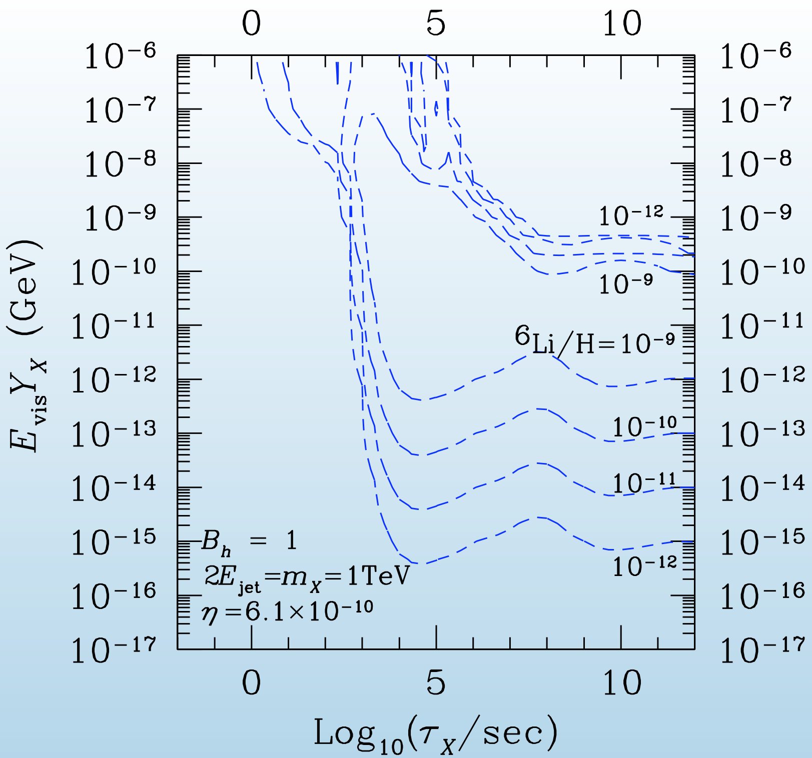
plus relevant 3-body decays

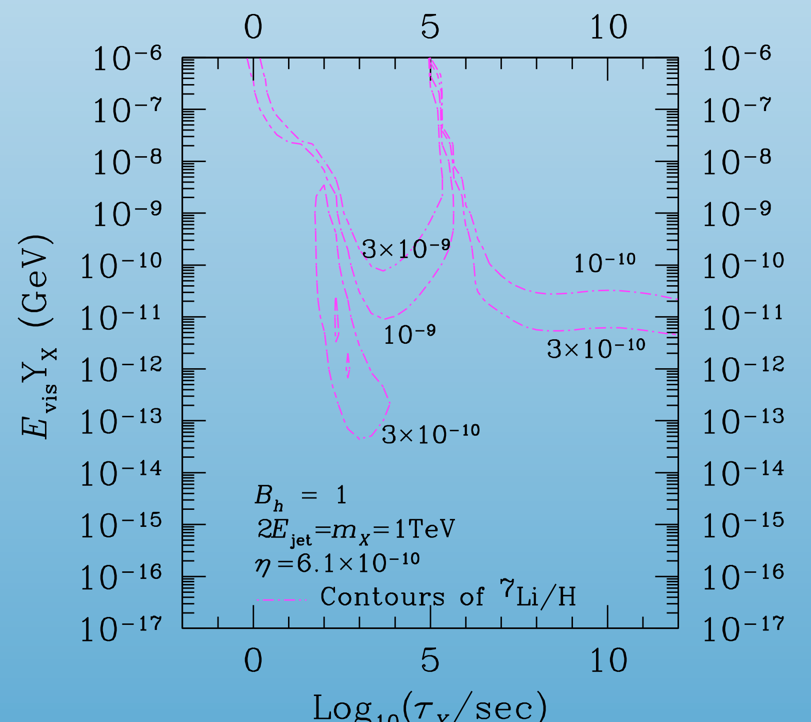




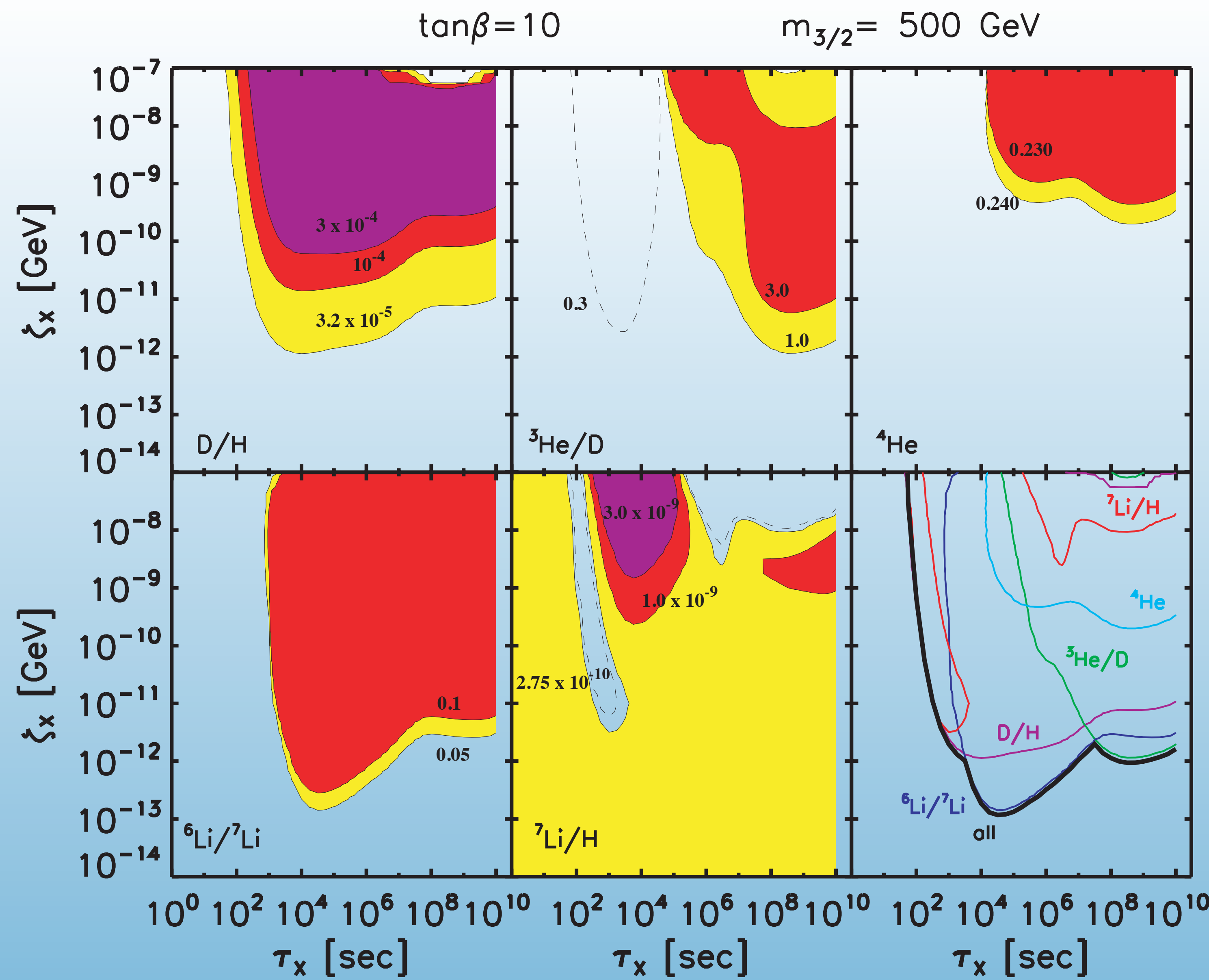


Jedamzik



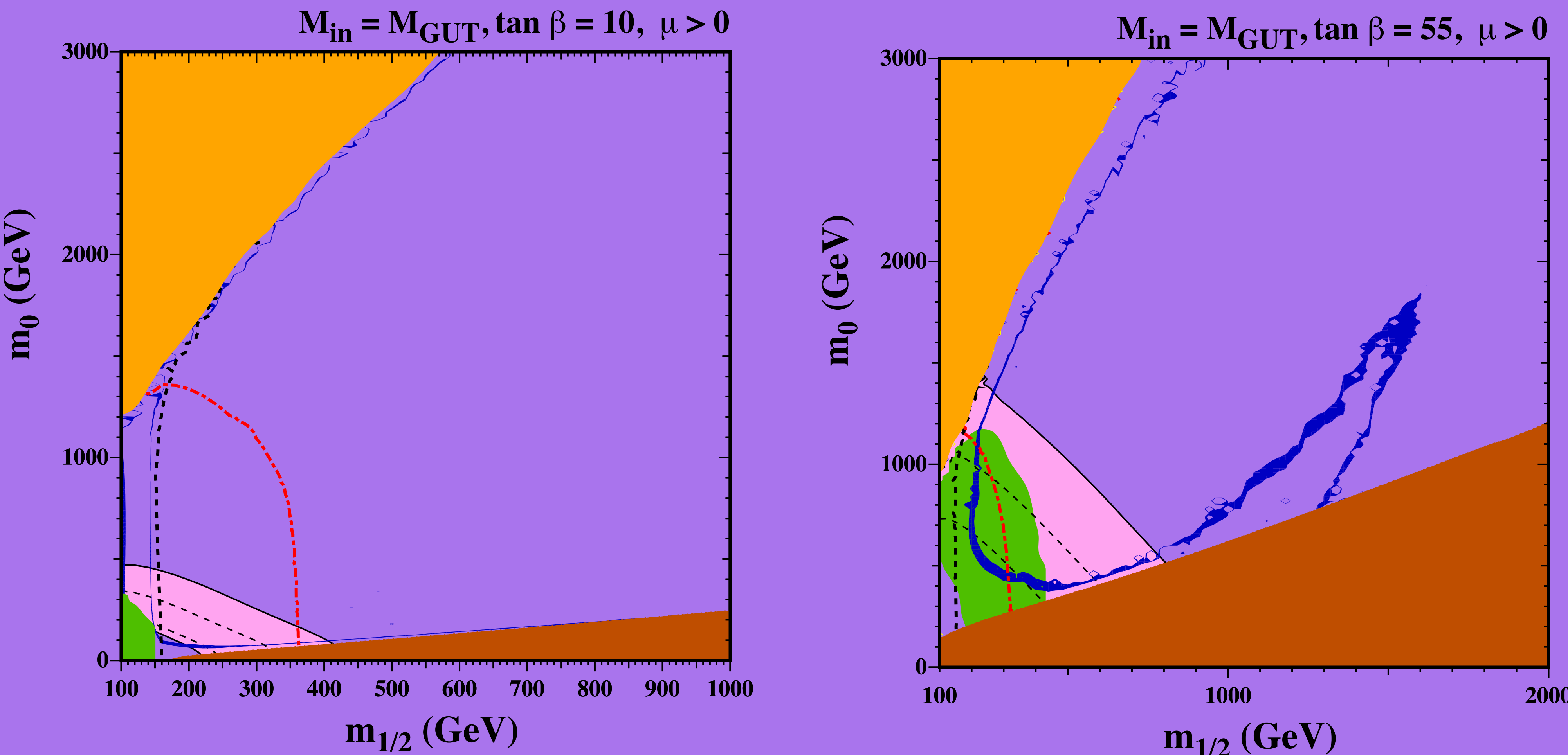


Kawasaki, Kohri, Moroi



Based on $m_{1/2}$ = 300 GeV, tan β =10 ; B_h ~ 0.2

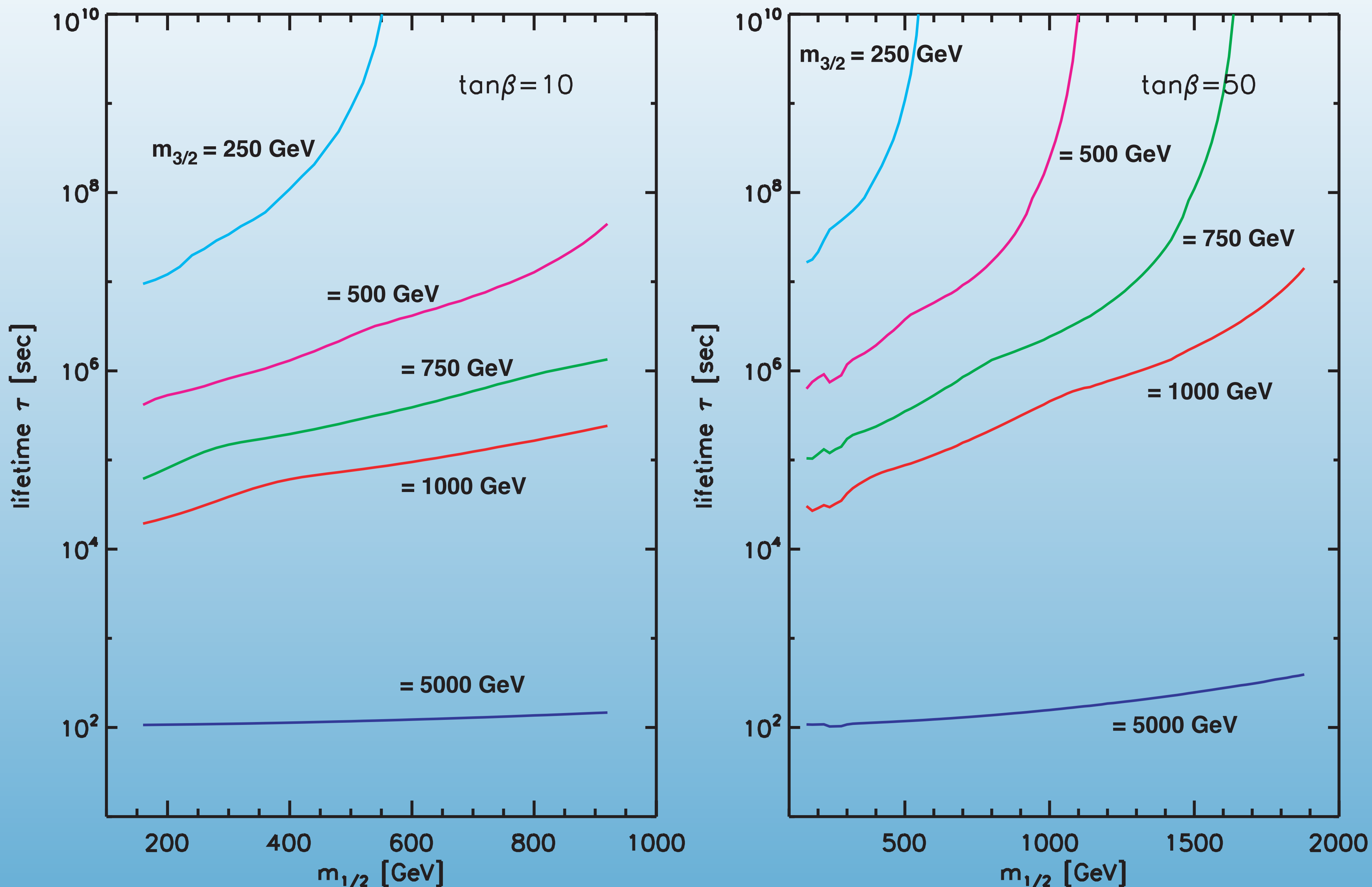
CMSSM



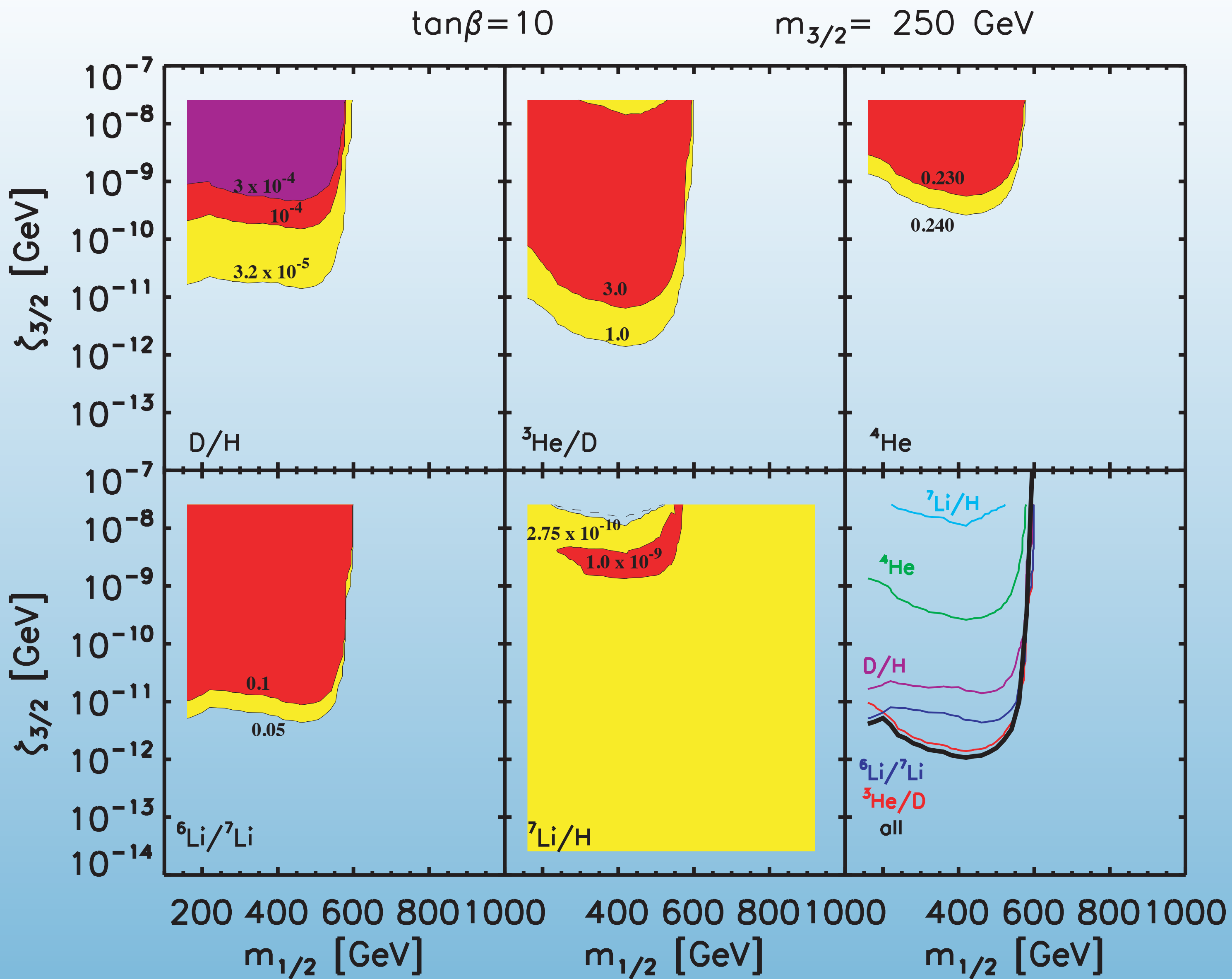
M_in = M_GUT, tan β = 10, μ > 0
m_0 (GeV)
m_1/2 (GeV)
3000
2000
1000
0
100
200
300
400
500
600
700
800
900
1000
M_in = M_GUT, tan β = 55, μ > 0
m_0 (GeV)
m_1/2 (GeV)
3000
2000
1000
0
100
1000
2000

EOSS

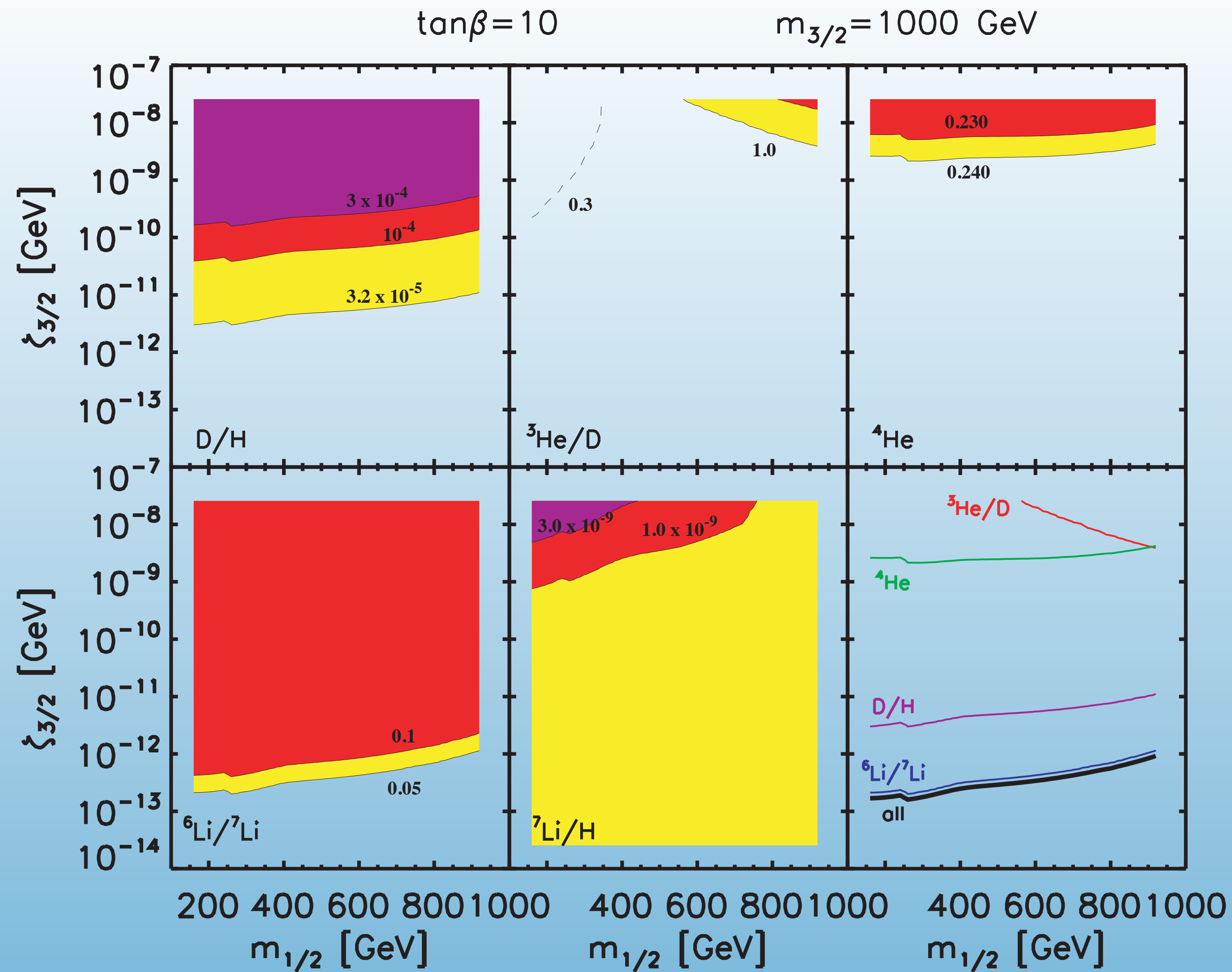
Gravitino Decays and Li



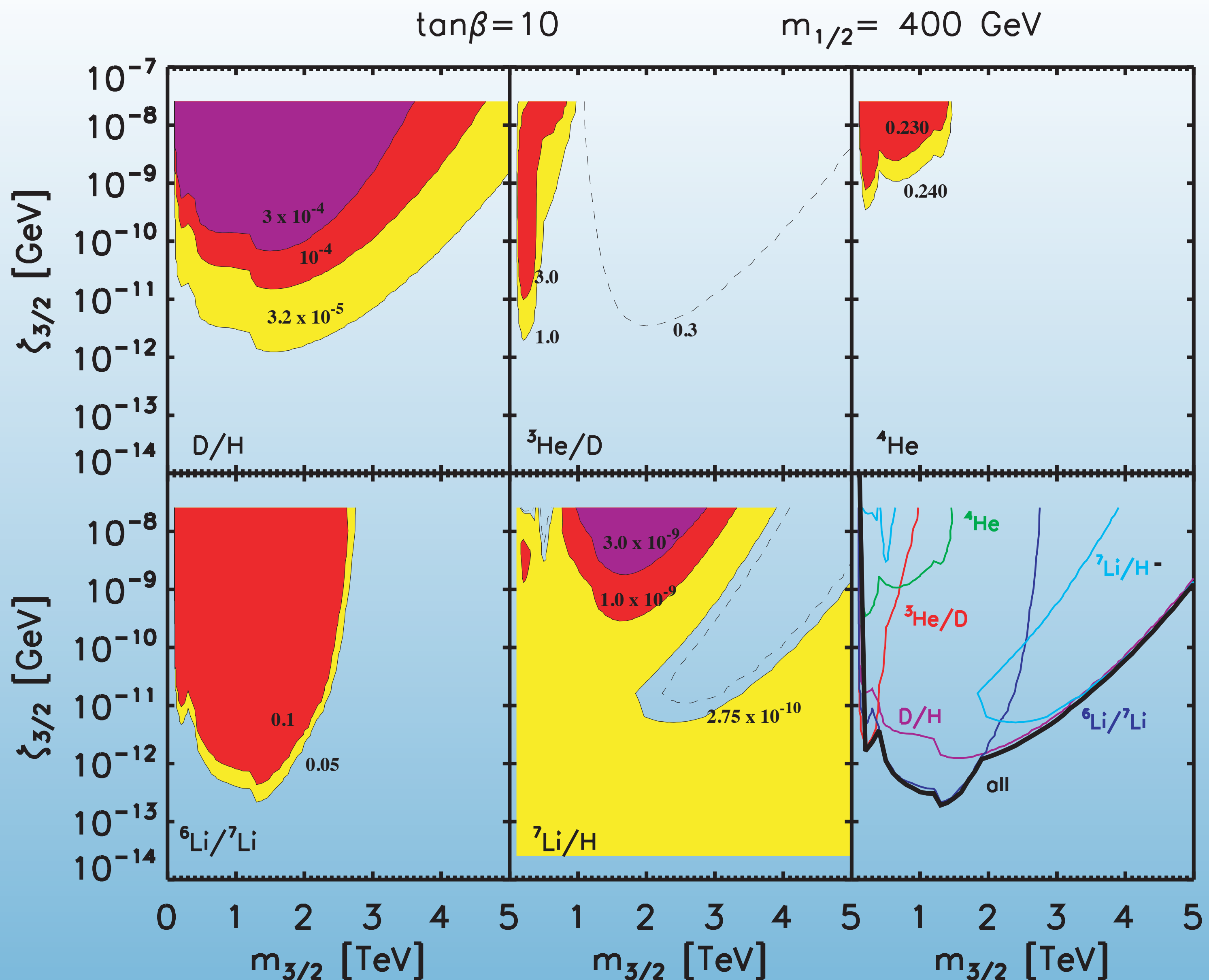
Cyburt, Ellis, Fields, Luo, Olive, Spanos



co-annihilation strip, tan β =10 ; $m_{3/2}$ = 250 GeV



co-annihilation strip, tan β =10 ; $m_{3/2}$ = 1000 GeV



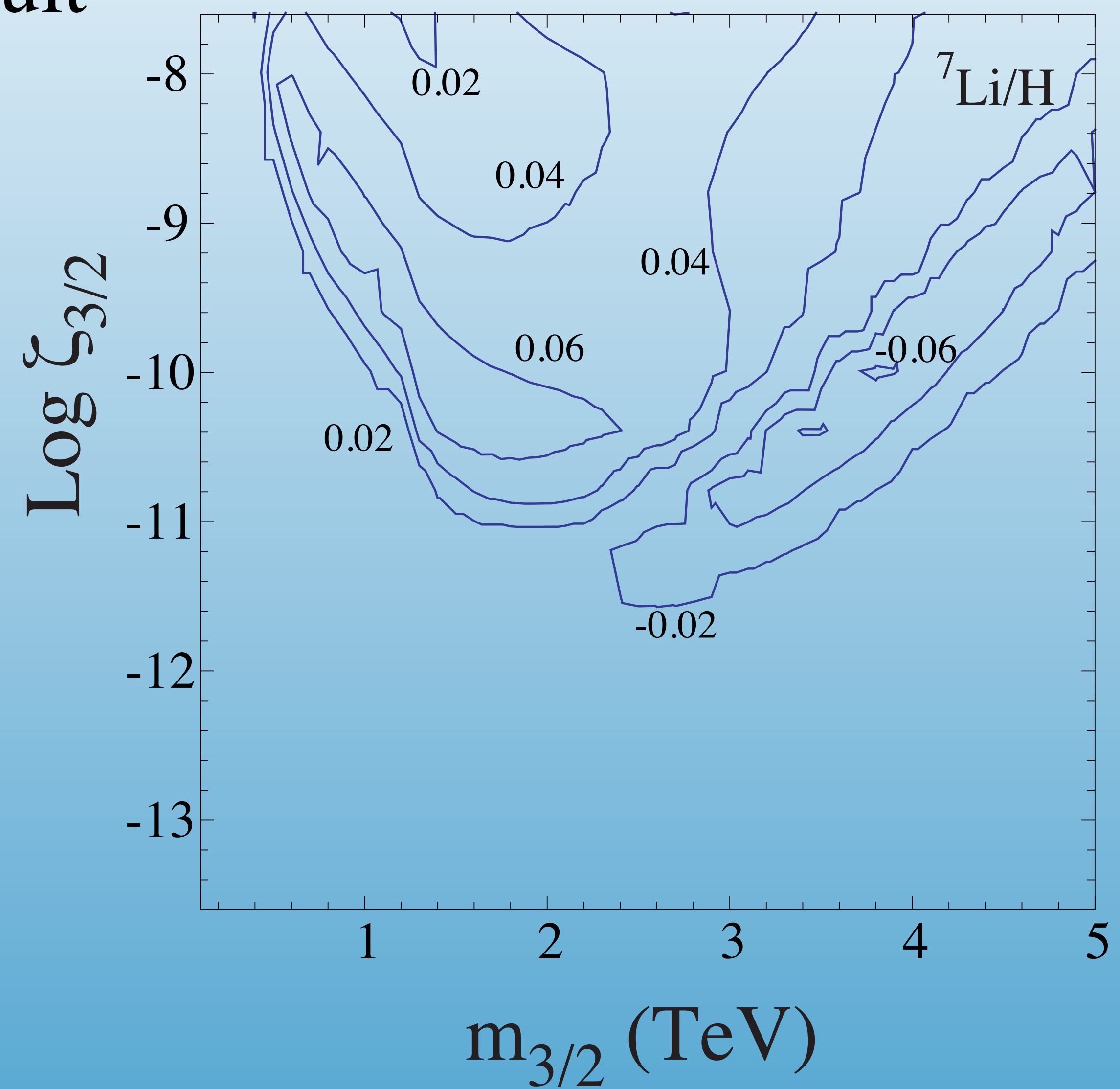
Benchmark point C, tan β =10 ; $m_{1/2}$ = 400 GeV

Uncertainties

There are only a few non-thermal rates which affect the result

$p^4\mathrm{He} \to np^3\mathrm{He}$	20%
$p^4\mathrm{He} \to ddp$	40%
$p^4\mathrm{He} \to dnpp$	40%
$t^4\mathrm{He} \to {}^6\mathrm{Li}n$	20%
${}^3\mathrm{He}^4\mathrm{He} \to {}^6\mathrm{Li}p$	20%
$n^4\mathrm{He} \to npt$	20%
$n^4\mathrm{He} \to ddn$	40%
$n^4\mathrm{He} \to dnnp$	40%
$p^4\mathrm{He} \to ppt$	20%
$n^4\mathrm{He} \to nn^3\mathrm{He}$	20%

$(n^4\mathrm{He} \to npt)$



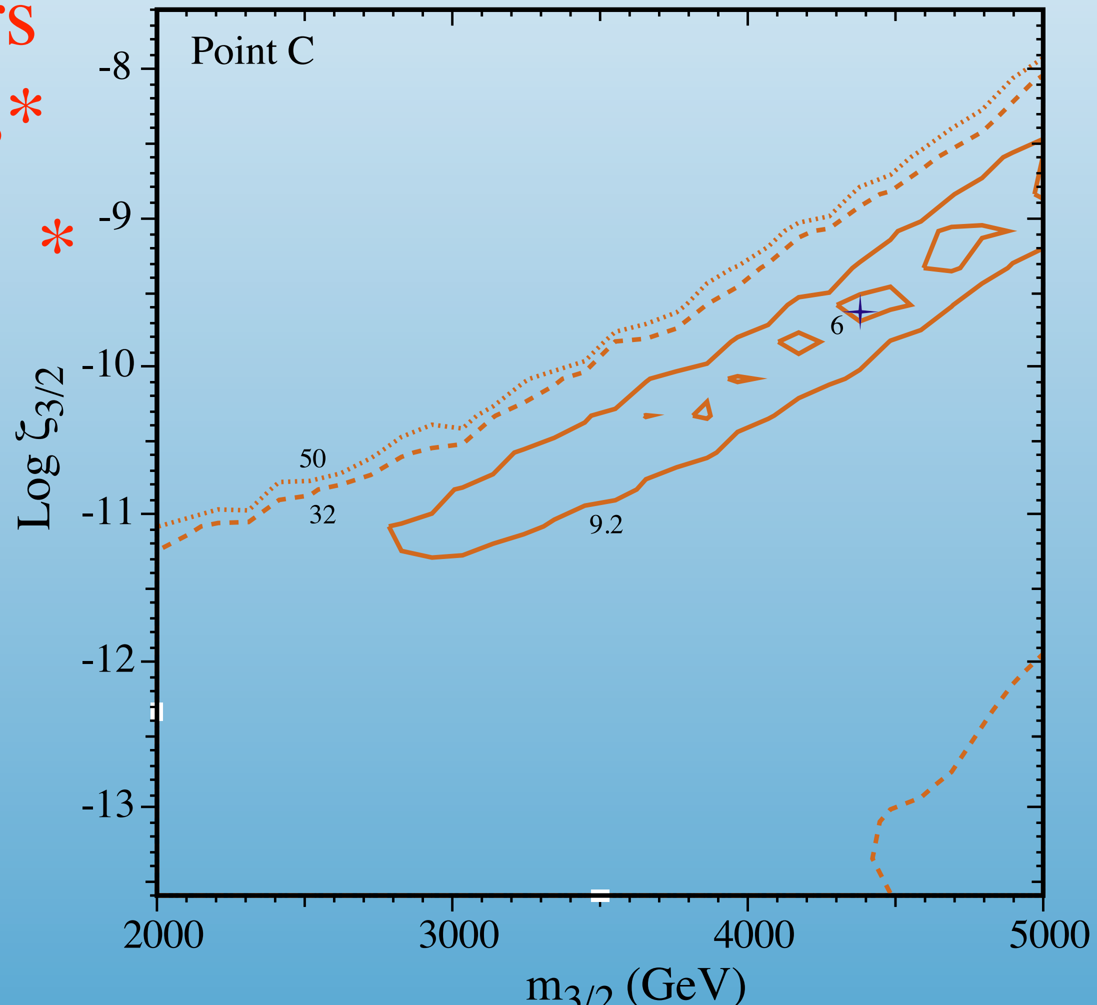
How well can you do

$$\chi^2 \equiv \left(\frac{Y_p - 0.256}{0.011}\right)^2 + \left(\frac{\frac{D}{H} - 2.82 \times 10^{-5}}{0.27 \times 10^{-5}}\right)^2 + \left(\frac{\frac{^7\mathrm{Li}}{H} - 1.23 \times 10^{-10}}{0.71 \times 10^{-10}}\right)^2 + \sum_i s_i^2,$$

SBBN: $\chi^2 = 31.7$ - field stars

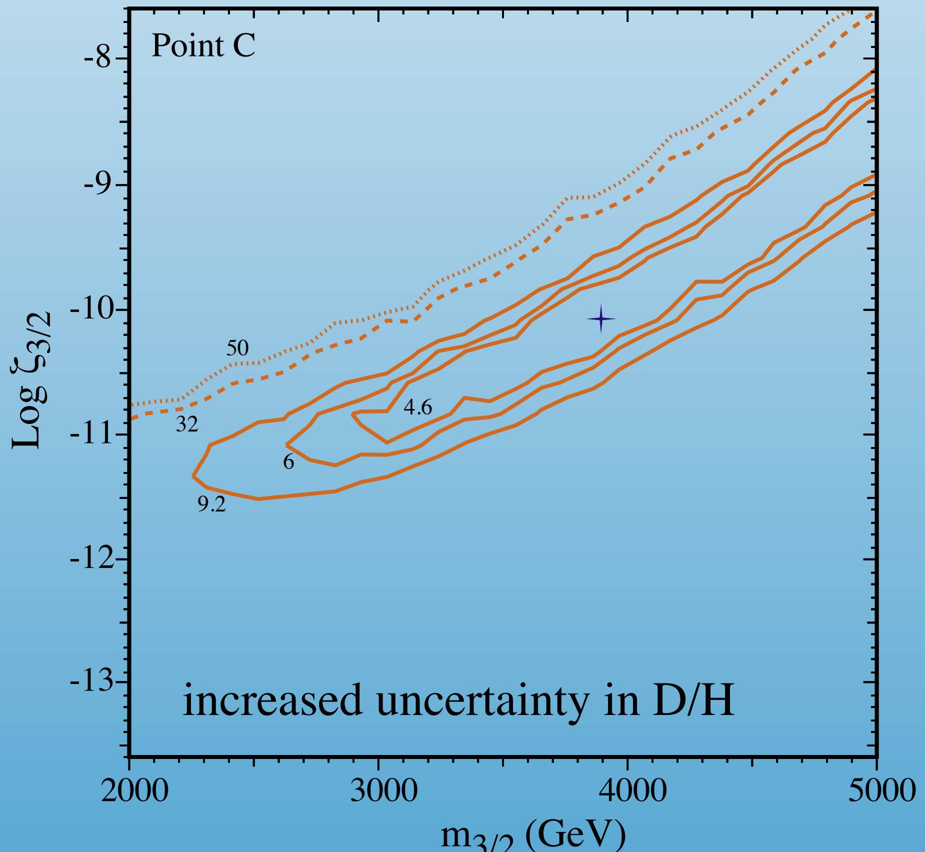
SBBN: $\chi^2 = 21.8$ - GC stars*

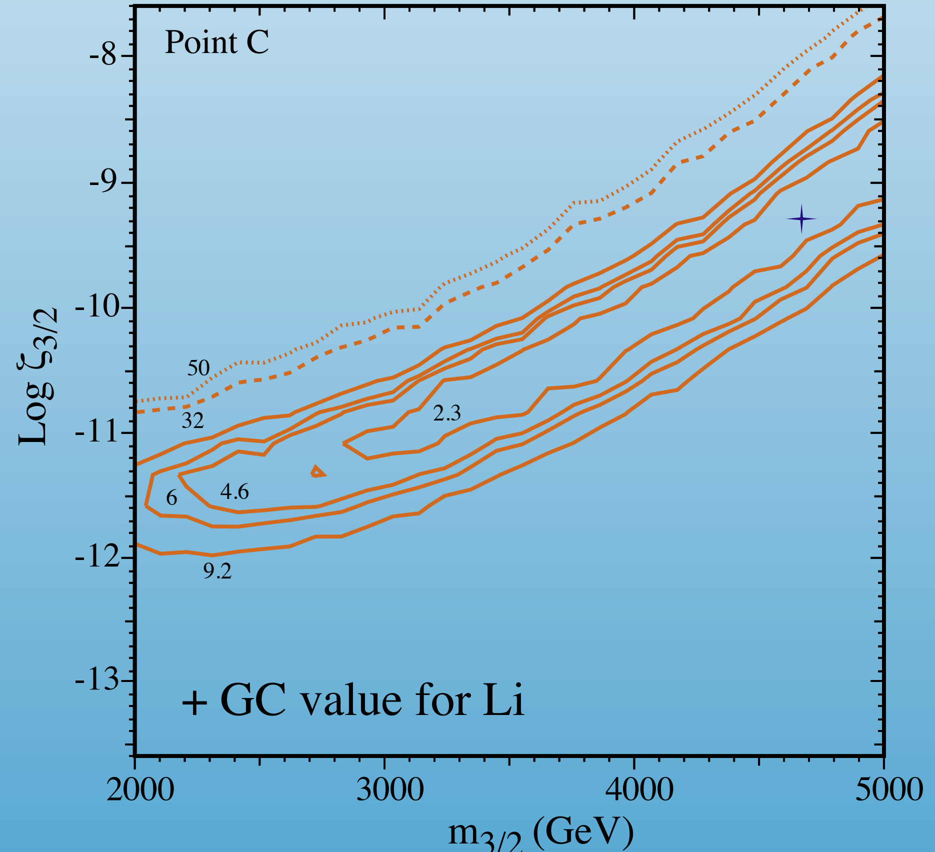
NGC 6397 appears to have a higher Li content than field stars of the same metallicity. This needs to be confirmed by a homogeneous analysis of field stars, with the same models and methods. This may or may not be related to the fact that this cluster is nitrogen rich, compared to field stars of the same metallicity (Pasquini et al. 2008).



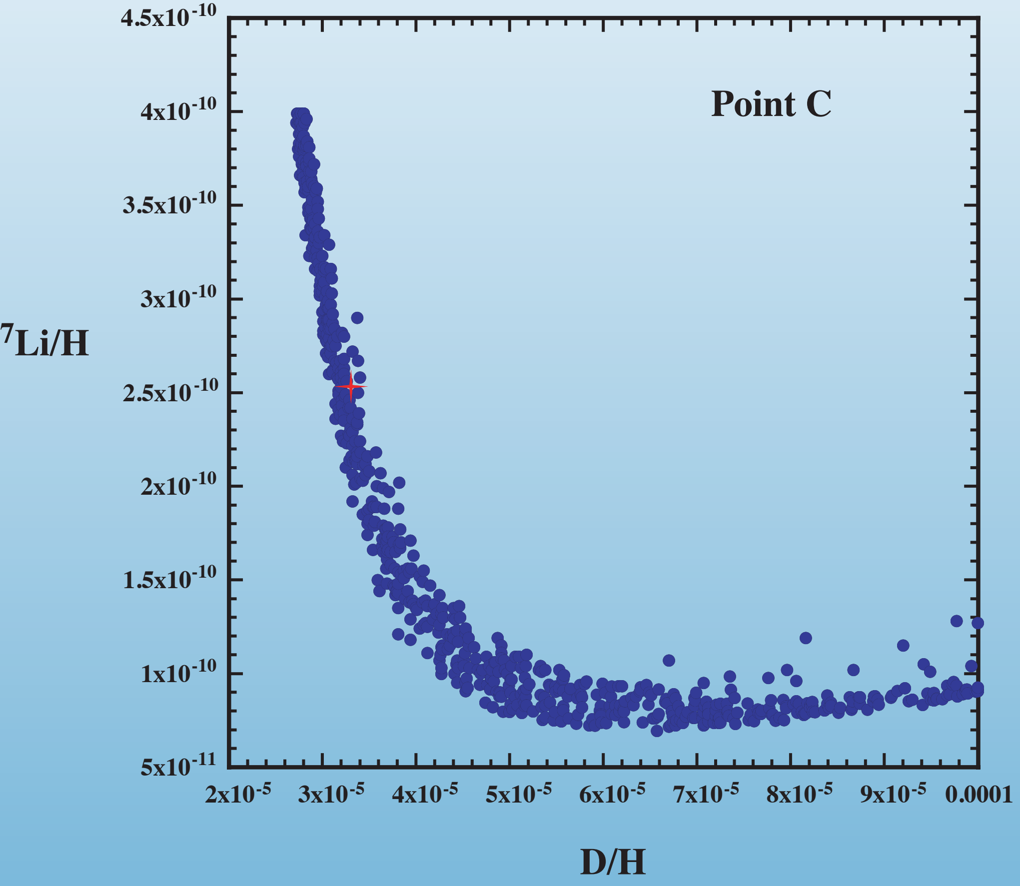
* from Gonzales Hernandez et al.

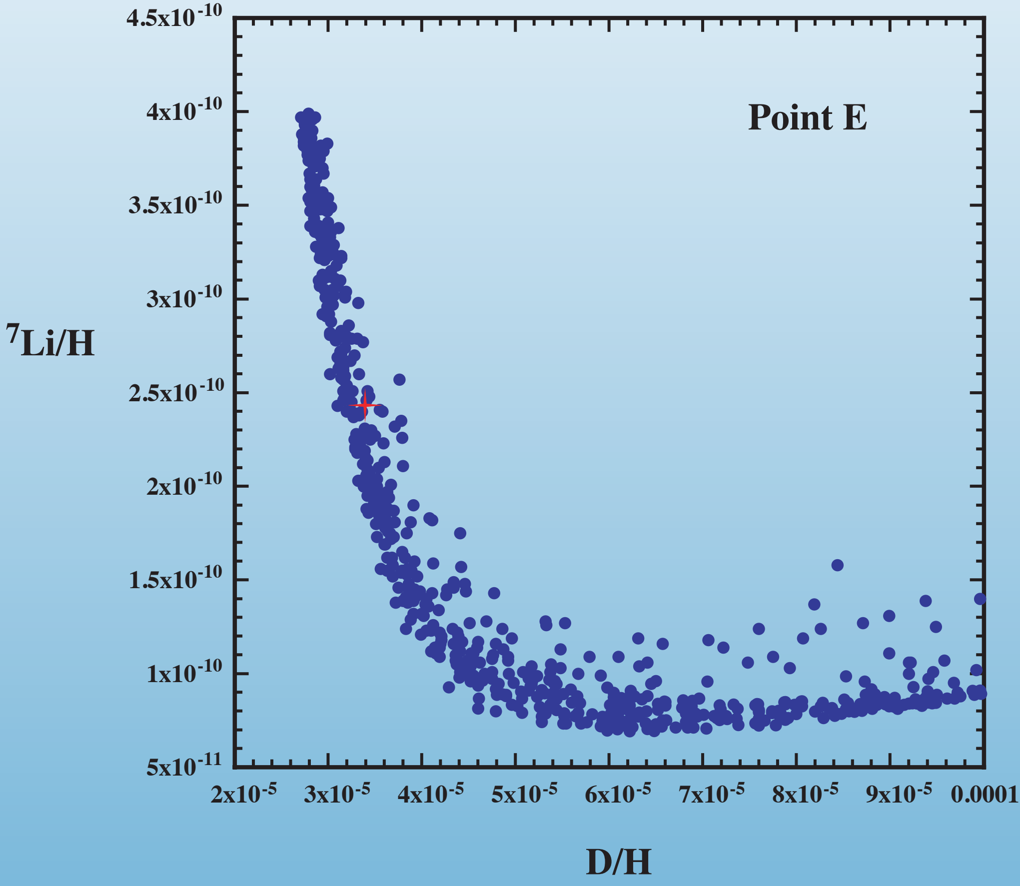
	$m_{3/2}$[GeV]	$\text{Log}_{10}(\zeta_{3/2}/[\text{GeV}])$	Y_p	D/H $(\times 10^{-5})$	^{7}Li/H $(\times 10^{-10})$	$\sum s_i^2$	χ^2
BBN	——	——	0.2487	2.52	5.12	——	31.7
C	4380	−9.69	0.2487	3.15	2.53	0.26	5.5
E	4850	−9.27	0.2487	3.20	2.42	0.29	5.5
L	4380	−9.69	0.2487	3.21	2.37	0.26	5.4
M	4860	−10.29	0.2487	3.23	2.51	1.06	7.0
C	4680	−9.39	0.2487	3.06	2.85	0.08	2.0
M	4850	−10.47	0.2487	3.11	2.97	0.09	2.7
C	3900	−10.05	0.2487	3.56	1.81	0.02	2.8
C	4660	−9.27	0.2487	3.20	2.45	0.16	1.1





General feature of “fixing” Li: Increased D/H

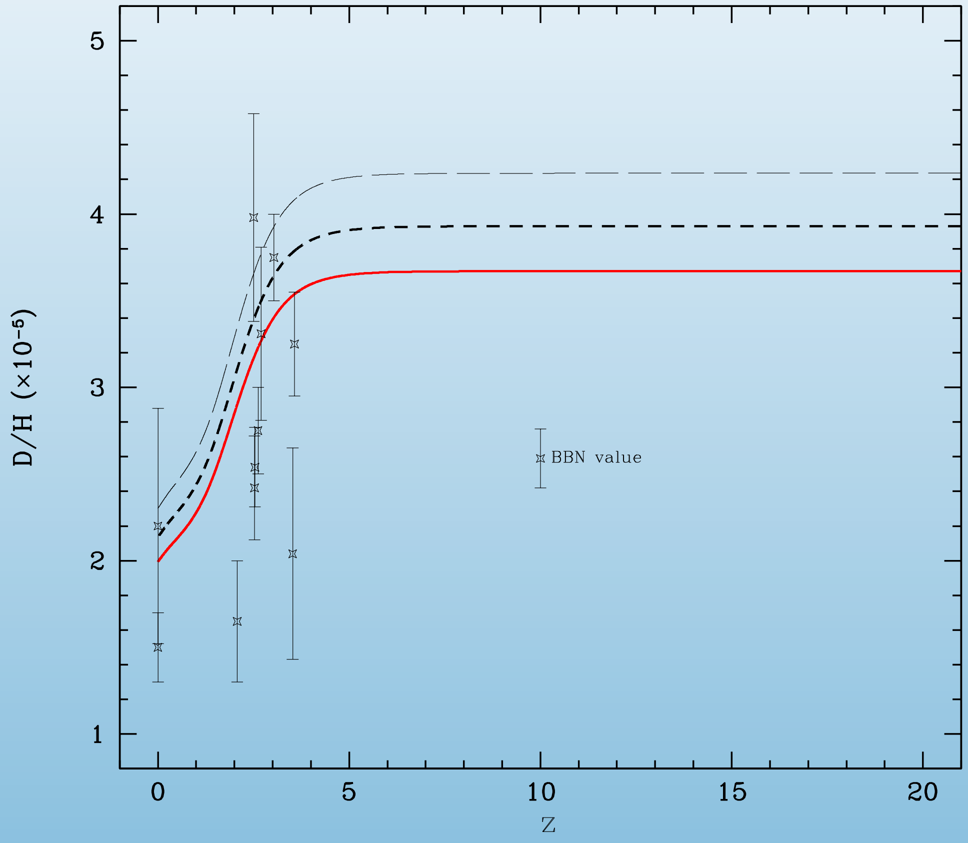


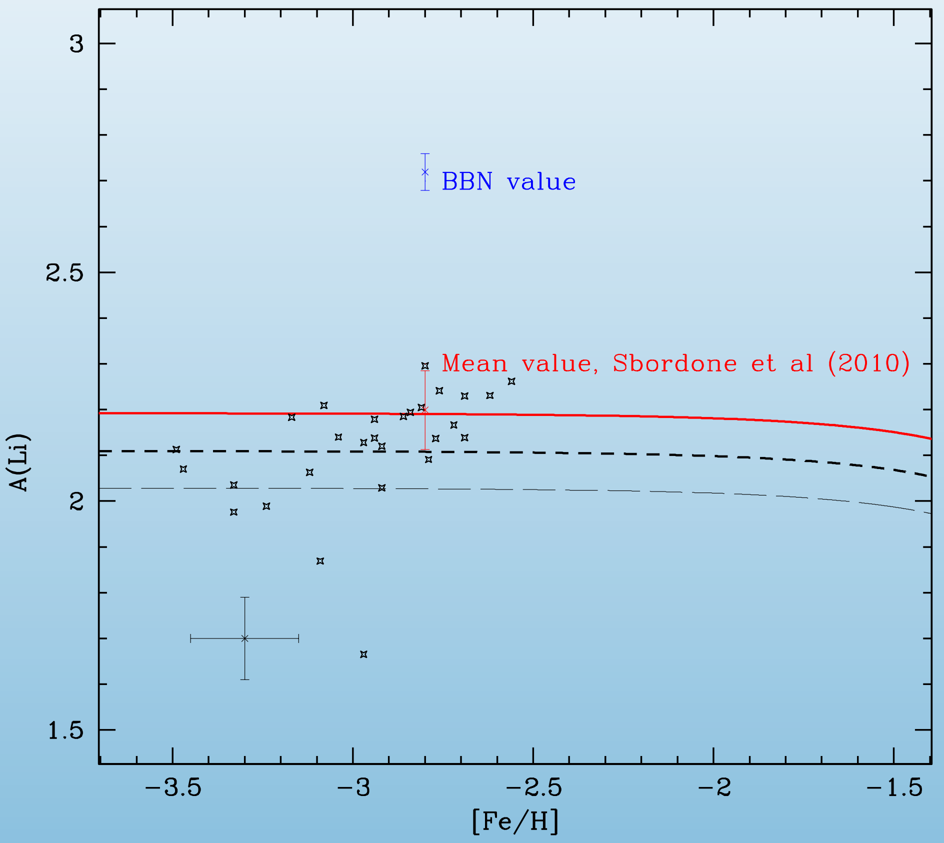


Cyburt, Ellis, Fields, Luo, Olive, Spanos

Olive, Petitjean, Vangioni, Silk

Evolution of D, Li





With post BBN processing of Li, D/H reproduces upper end of absorption data - dispersion due to in situ chemical destruction

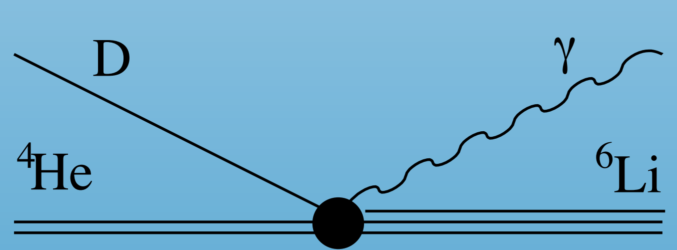
Olive, Petitjean, Vangioni, Silk

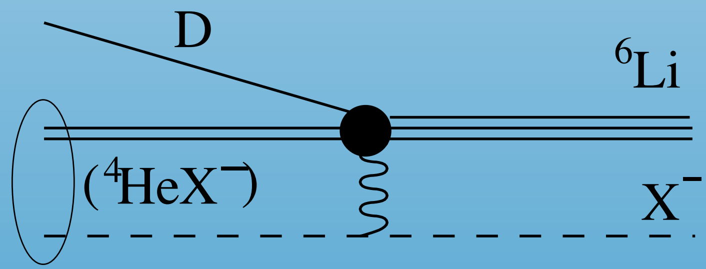
Effects of Bound States

- In SUSY models with a $\tilde{\tau}$ NLSP, bound states form between ^{4}He and $\tilde{\tau}$

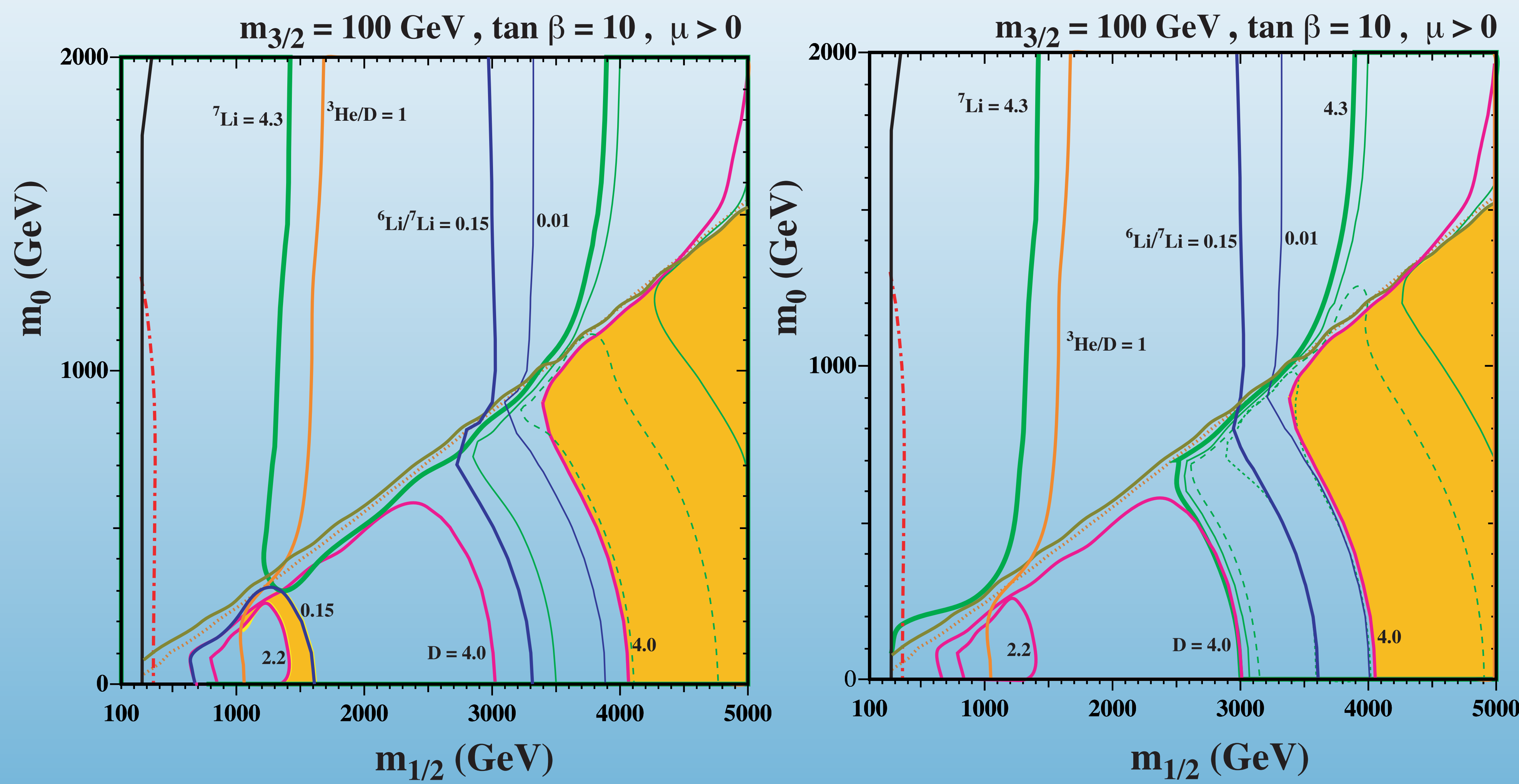
- The ^{4}He (D, γ) ^{6}Li reaction is normally highly suppressed (production of low energy γ)

- Bound state reaction is not suppressed

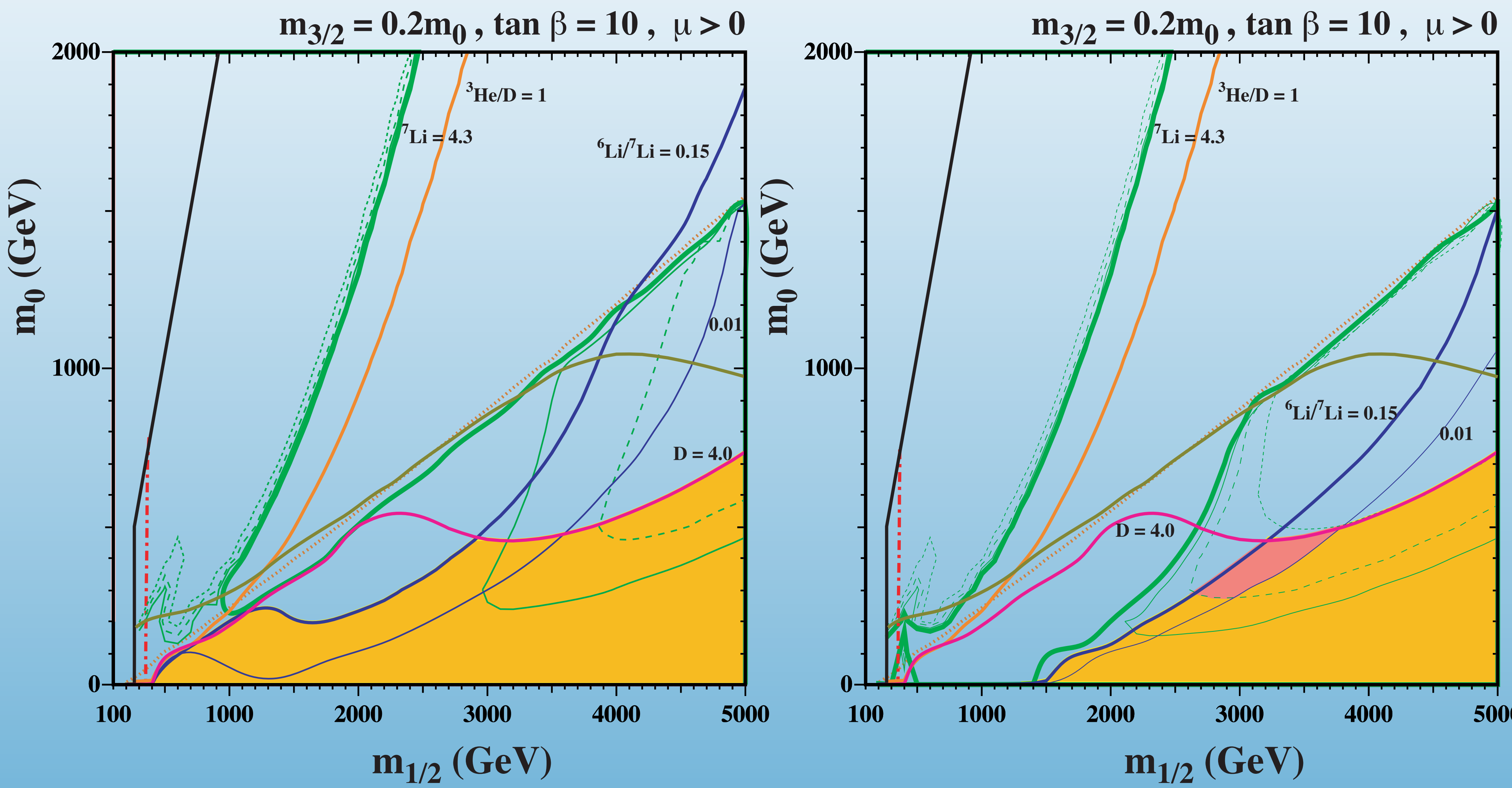




Pospelov



Cyburt, Ellis, Fields, KO, Spanos



Cyburt, Ellis, Fields, KO, Spanos

A ^{6}Li Plateau?

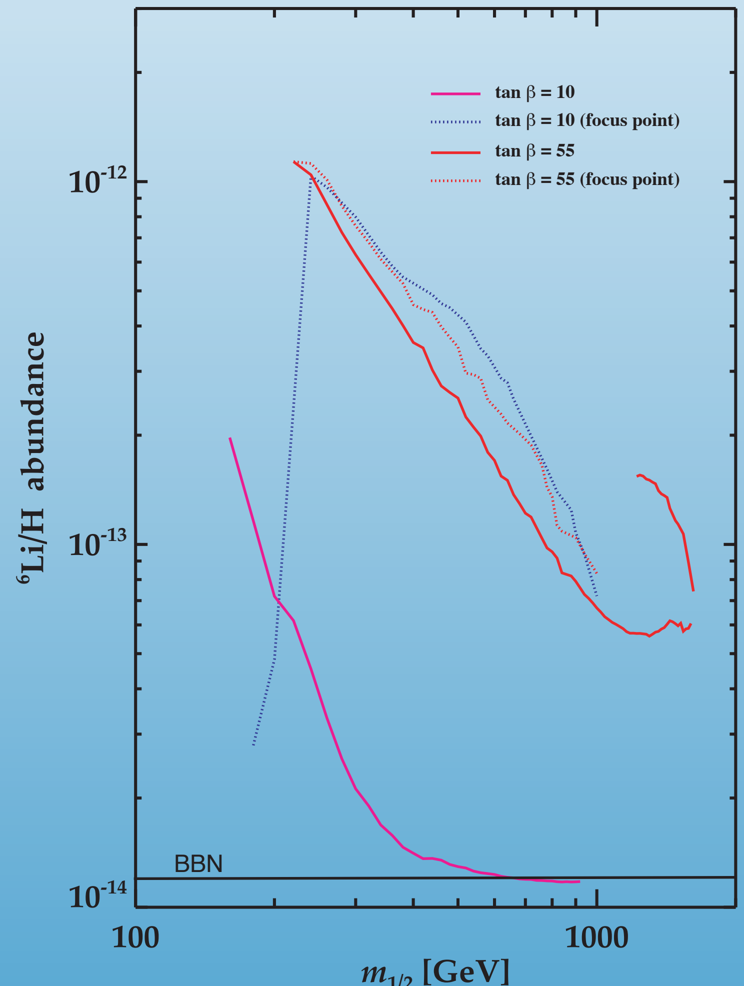
Observers may not see one, but theorist do predict one!

BBN: ^{6}Li/H ~ 10^{-14}

Thomas et al.
Vangioni et al.

Dark Matter:

Jedamzik



Ellis et al.

Axion Condensation

- Axion dark matter forms a Bose-Einstein condensate through gravitational self-interactions.

Interactions between cold axion fluid cool photon gas:

$$\eta_{10,\mathrm{BBN}} = \left(\frac{2}{3}\right)^{3/4} \eta_{10,\mathrm{WMAP}} = 4.57 \pm 0.11$$

$\Rightarrow$ Li/H ~ 2 x 10^{-10} but D/H ~ 4.5 x 10^{-5}

Erken, Sikivie, Tam, Yang

Possible sources for the discrepancy

- Stellar parameters

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

Discussed by Ryan

- Particle Decays

- Variable Constants

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

Limits on α from BBN

Contributions to Y come from n/p which in turn come from Δm_N

Contributions to Δm_N:

Kolb, Perry, & Walker
Campbell & Olive
Bergstrom, Iguri, & Rubinstein

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

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

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

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

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

Coupled Variations

Campbell and Olive

Langacker, Segre, and Strassler

Dent and Fairbairn

Calmet and Fritzsch

Damour, Piazza, and Veneziano

Recall,

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

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

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

R ~ 30, but very model dependent

Dine et al.

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

$$\frac{\Delta v}{v} \sim 80\frac{\Delta\alpha_U}{\alpha_U} \qquad \frac{\Delta v}{v} = S\frac{\Delta\alpha}{\alpha}$$

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

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

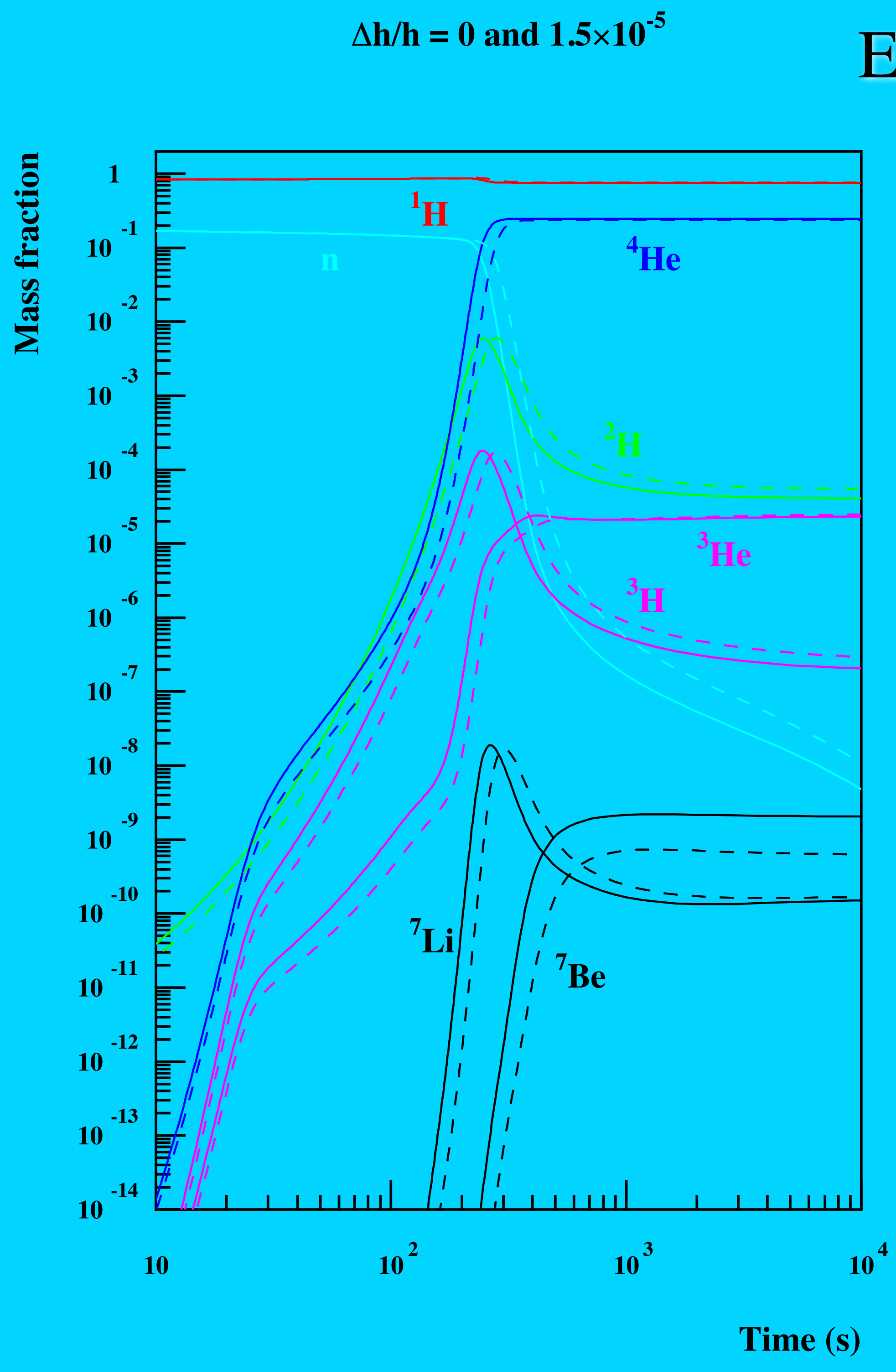
$$\frac{\Delta B_D}{B_D} = -[6.5(1+S) - 18R]\frac{\Delta\alpha}{\alpha}$$

$$\frac{\Delta Q}{Q} = (0.1 + 0.7S - 0.6R)\frac{\Delta\alpha}{\alpha}$$

$$\frac{\Delta \tau_n}{\tau_n} = -[0.2 + 2S - 3.8R]\frac{\Delta\alpha}{\alpha},$$

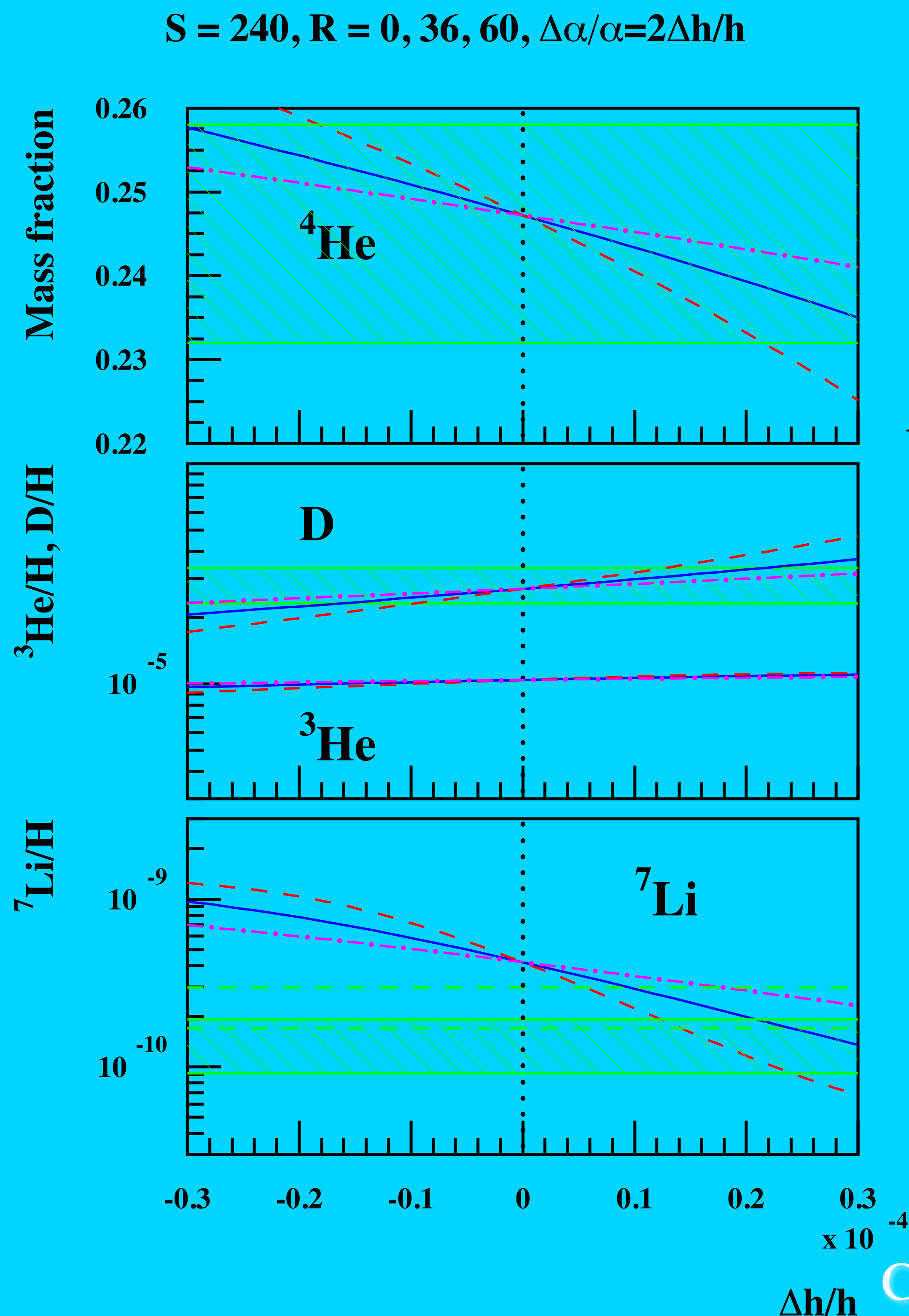
Coc, Nunes, Olive, Uzan, Vangioni
Dmitriev & Flambaum

Effect of variations of h (S = 160)



Notice effect on ^{7}Li

Coc, Nunes, Olive, Uzan, Vangioni

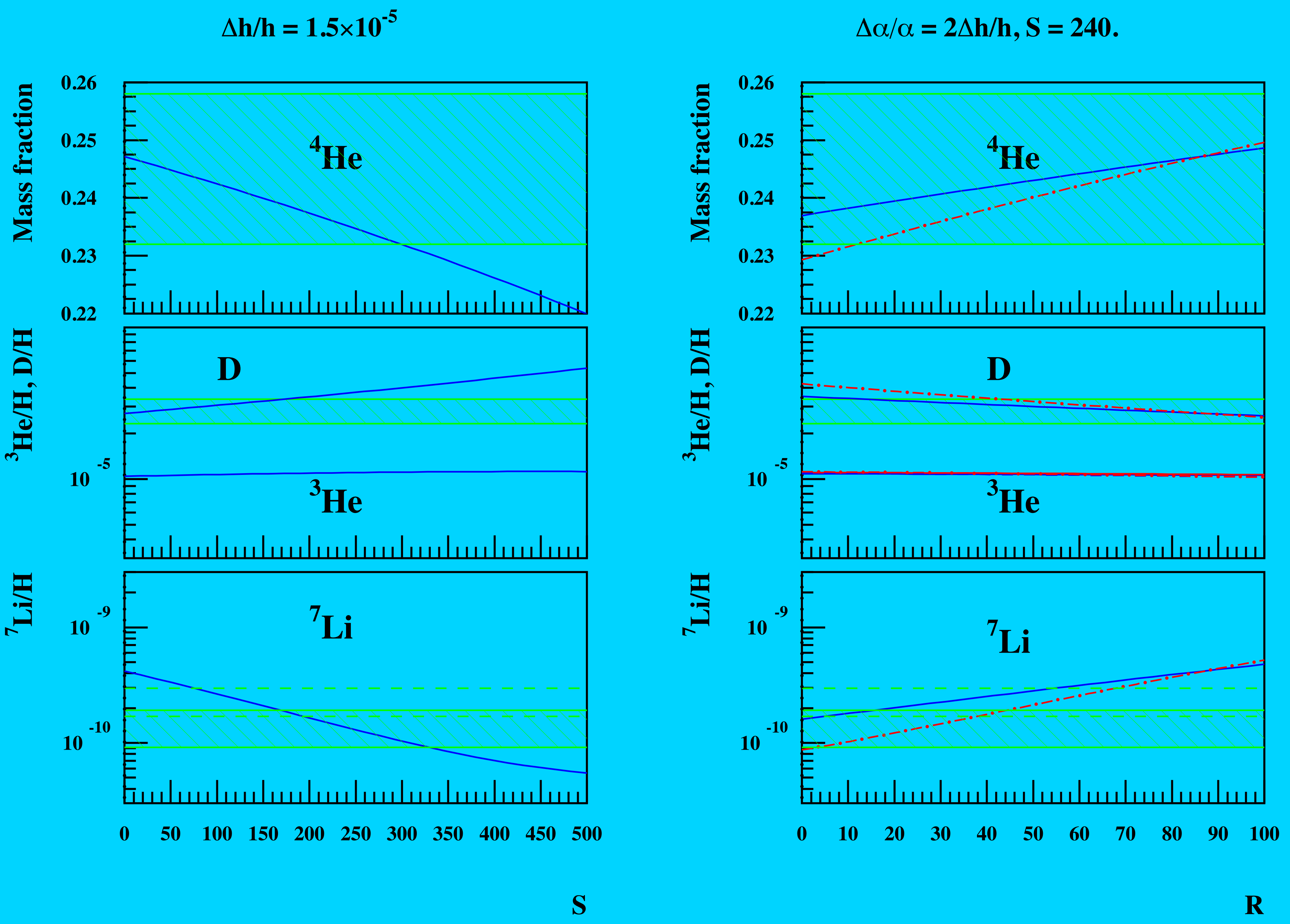


For S = 240, R = 36,

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

Coc, Nunes, Olive, Uzan, Vangioni

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

Summary

- D, He are ok -- issues to be resolved
- Li: Problematic
  - BBN ^{7}Li high compared to observations
- 'Exotic Solutions':
  - Particle Decays?
  - Axion Condensate??
  - Variable Constants???