# *Gravitino Dark Matter*
# *and*
# *Light element abundances*

Cyburt, Ellis, Fields, Olive

**SUSY07 July 30, Karlsruhe**

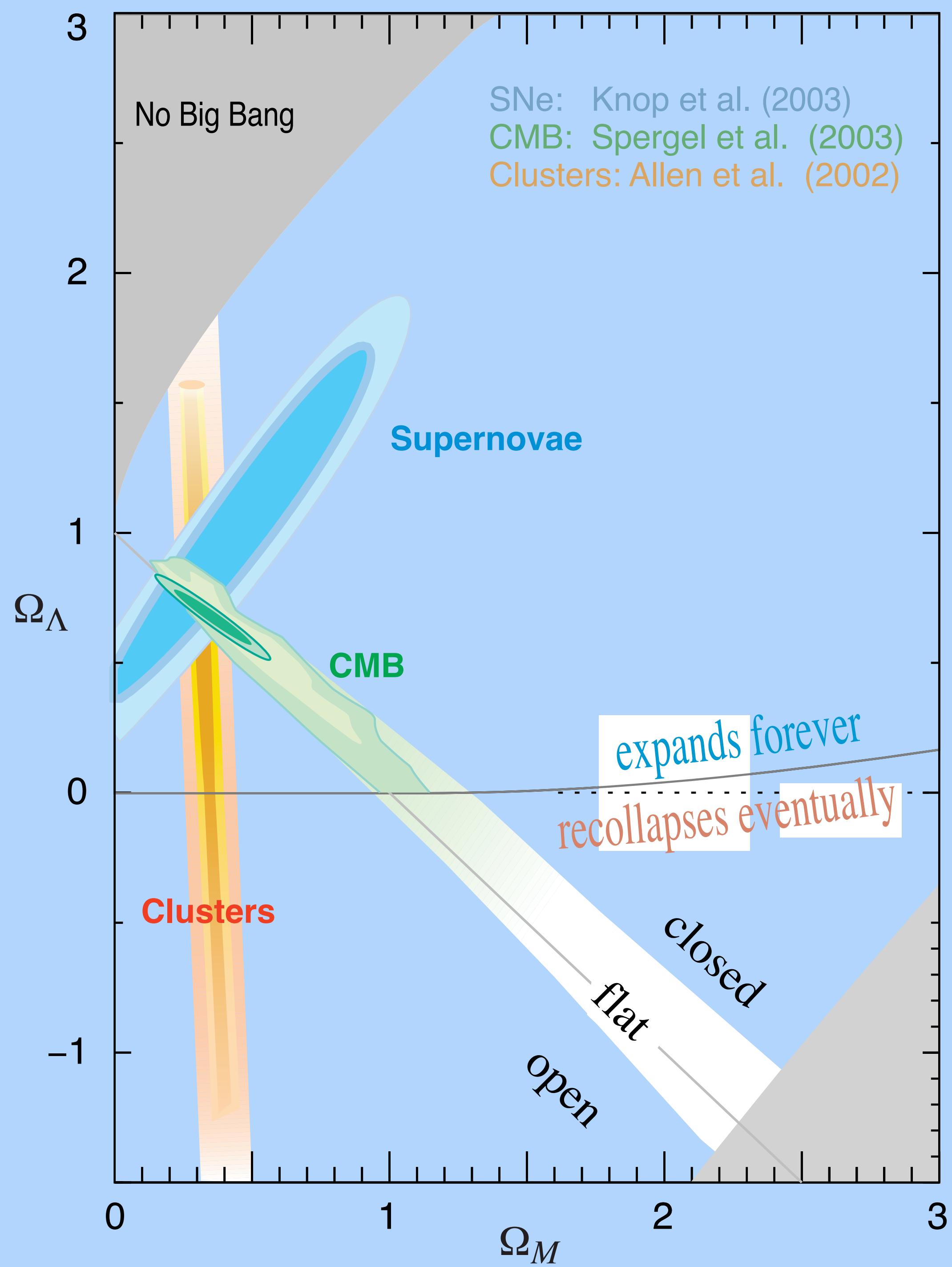
**Vassilis Spanos**

*University of Patras*

*MEXT-CT2004-014297*

# Outline

- Cosmological data and Big-Bang Nucleosynthesis (BBN) constraints
- Lithium puzzle
- A possible explanation and consequences for particle physics and cosmology
- Summary-Prospects




$$\Omega_{tot} = 1.02 \pm 0.02 \qquad \rho_c = \frac{3H_0^2}{8\pi G}$$

$$\Omega_m\, h_0^2 = 0.127 \pm 0.008$$

$$\Omega_B\, h_0^2 = 0.0223 \pm 0.0007$$

$$\Longrightarrow$$

$$\Omega_{DM}\, h_0^2 = \Omega_m\, h_0^2 - \Omega_B\, h_0^2 = 0.104 \pm 0.008$$

This value of $\Omega_B$ agrees quite well with the BBN predictions for the abundance of $^4$**He**, **D**, $^3$**He**, but not so good ... with $^7$**Li** and $^6$**Li**

# Big Bang Nucleosynthesis

## Light Elements observed abundances:

- $^{4}$**He** observed in extragalactic HII regions:

  abundance by mass ~ **25%**

- $^{7}$**Li** observed in the atmosphere of dwarf halo stars:

  abundance by number ~ $\mathbf{10^{-10}}$

- **D** in quasars absorption systems (and locally):

  abundance by number ~ $\mathbf{3 \times 10^{-5}}$

- $^{3}$**He** observed in solar wind, meteorites, and in ISM:

  abundance by number ~ $\mathbf{10^{-5}}$

## Neutrino decoupling prepares the beginning of BBN

$$n + \nu_e \leftrightarrow p + e^-$$
$$n + e^+ \leftrightarrow p + \bar{\nu}_e$$
$$n \leftrightarrow p + e^- + \bar{\nu}_e$$

## BUT ... BBN begins after the D formation

$$p + n \rightarrow D + \gamma \qquad \Gamma_{prod} \sim n_B \sigma$$

Deuterium bottleneck

$$p + n \leftarrow D + \gamma \qquad \Gamma_{dest} \sim n_\gamma \sigma e^{-E_B/T}$$

Nucleosynthesis begins when

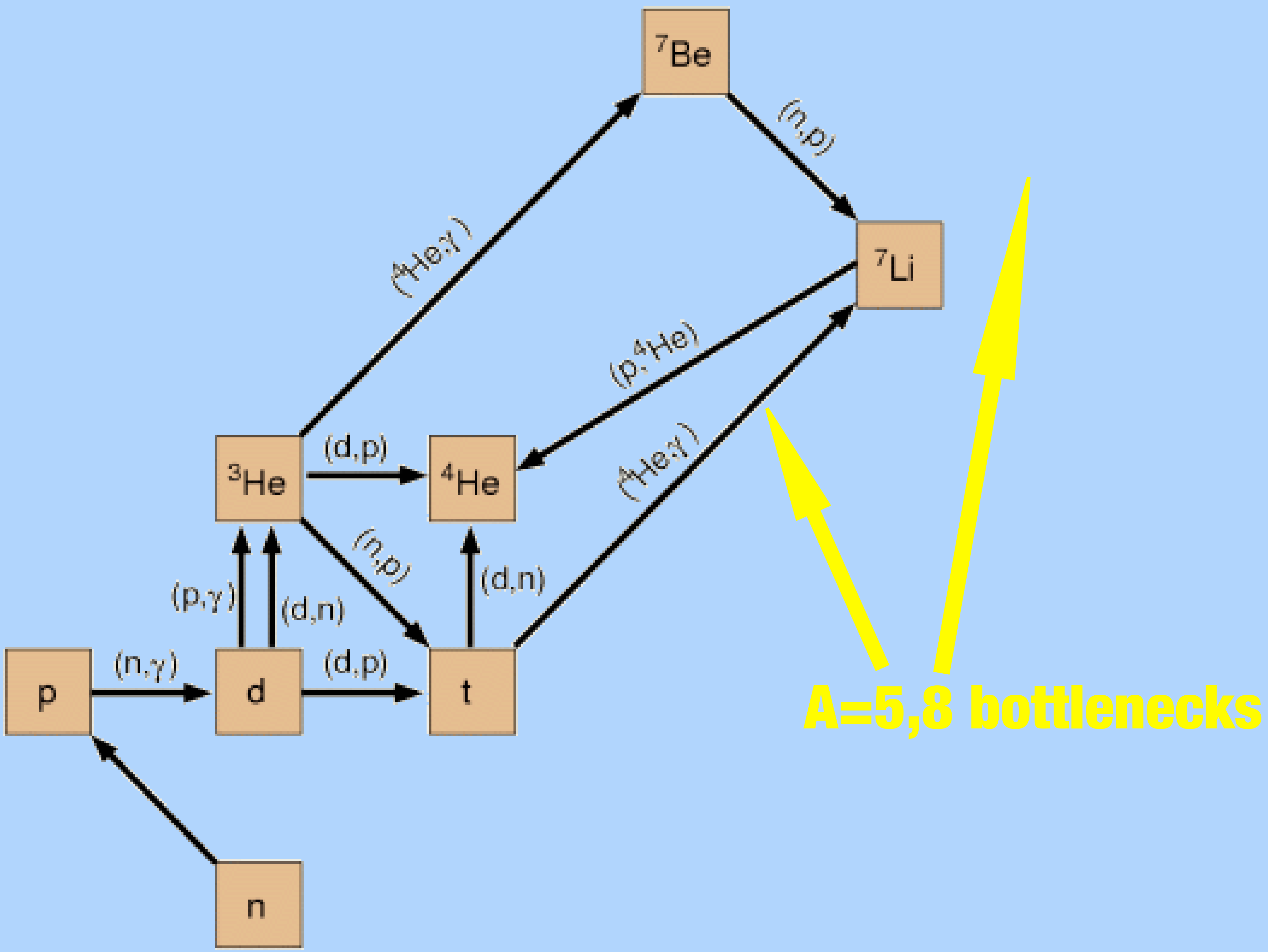
$$\Gamma_{prod} \sim \Gamma_{dest} \Rightarrow \frac{n_\gamma}{n_b} e^{-E_B/T} \sim 1 \Rightarrow T_{BBN} \sim 100\,\mathrm{KeV} \;\; (t_{BBN} = 180\,\mathrm{s})$$

At this time $n/p \simeq \frac{1}{7}$

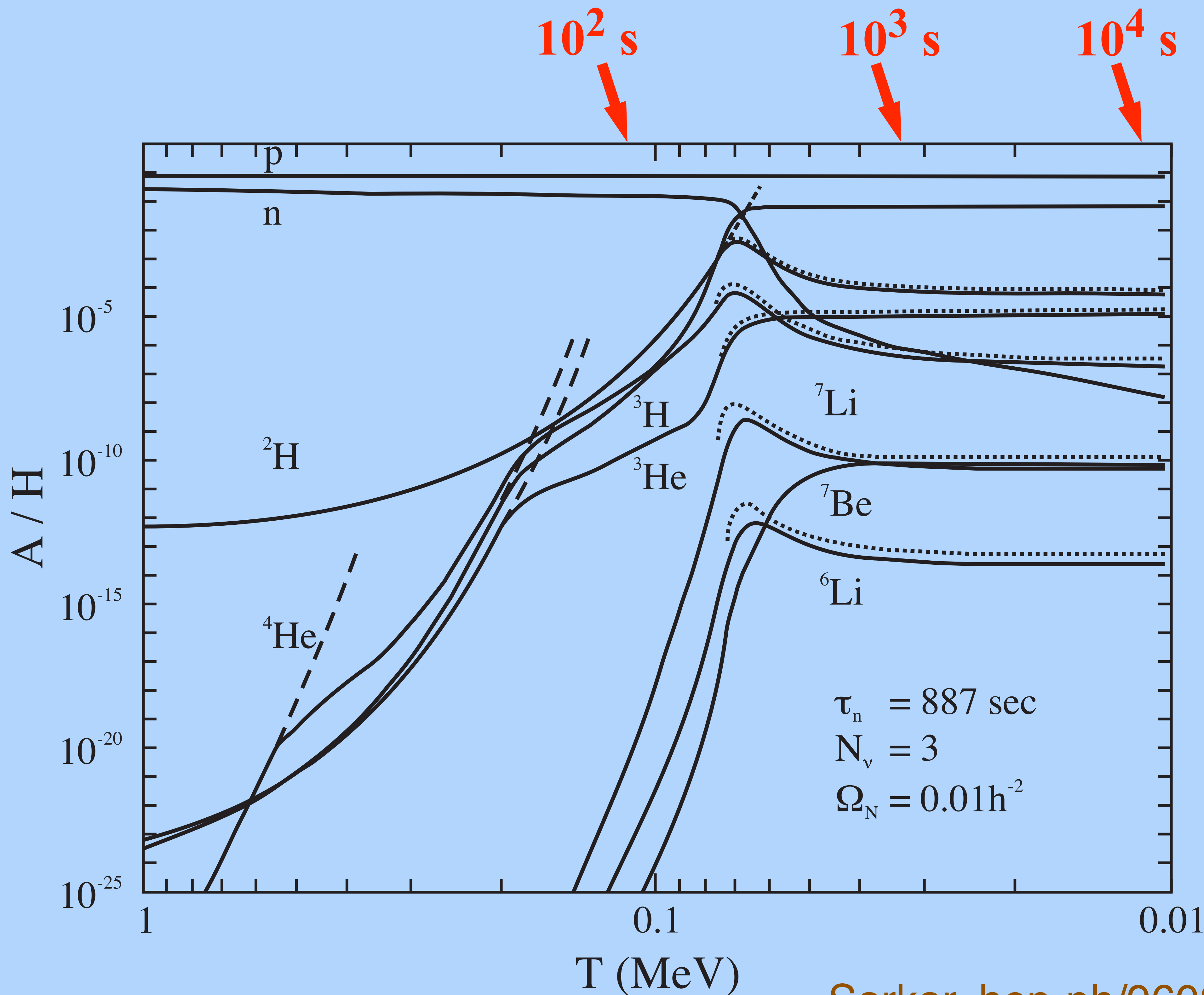
## BBN ends when there are no more neutrons

BBN is completed when all neutrons present at $t_{BBN} = 180\,\mathrm{s}$ have been cooked into nuclei.
This happens at $t \sim 1000\,\mathrm{s}$.

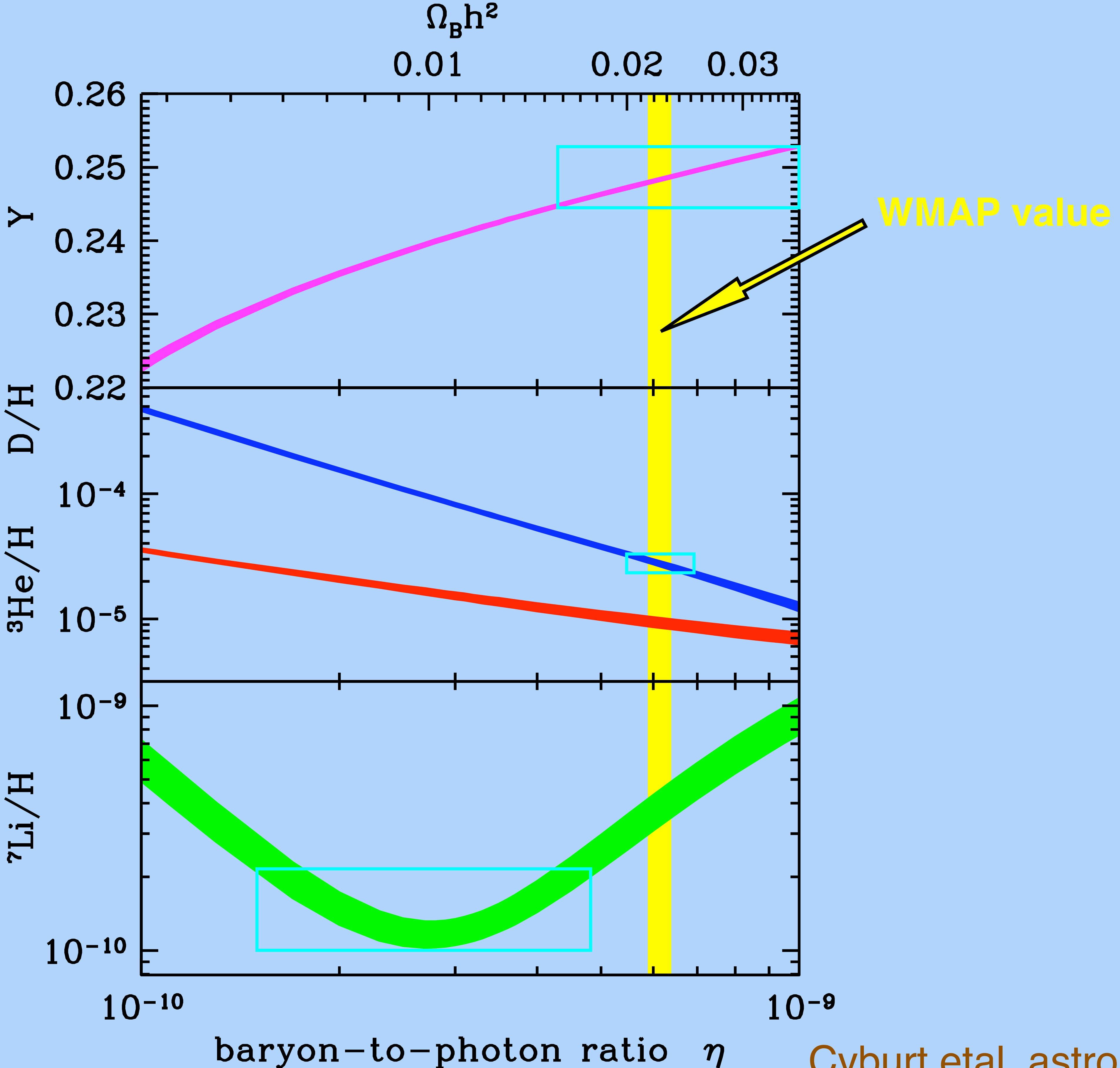
# *Main BBN reactions*



# *Light elements production*




Sarkar, hep-ph/9602260



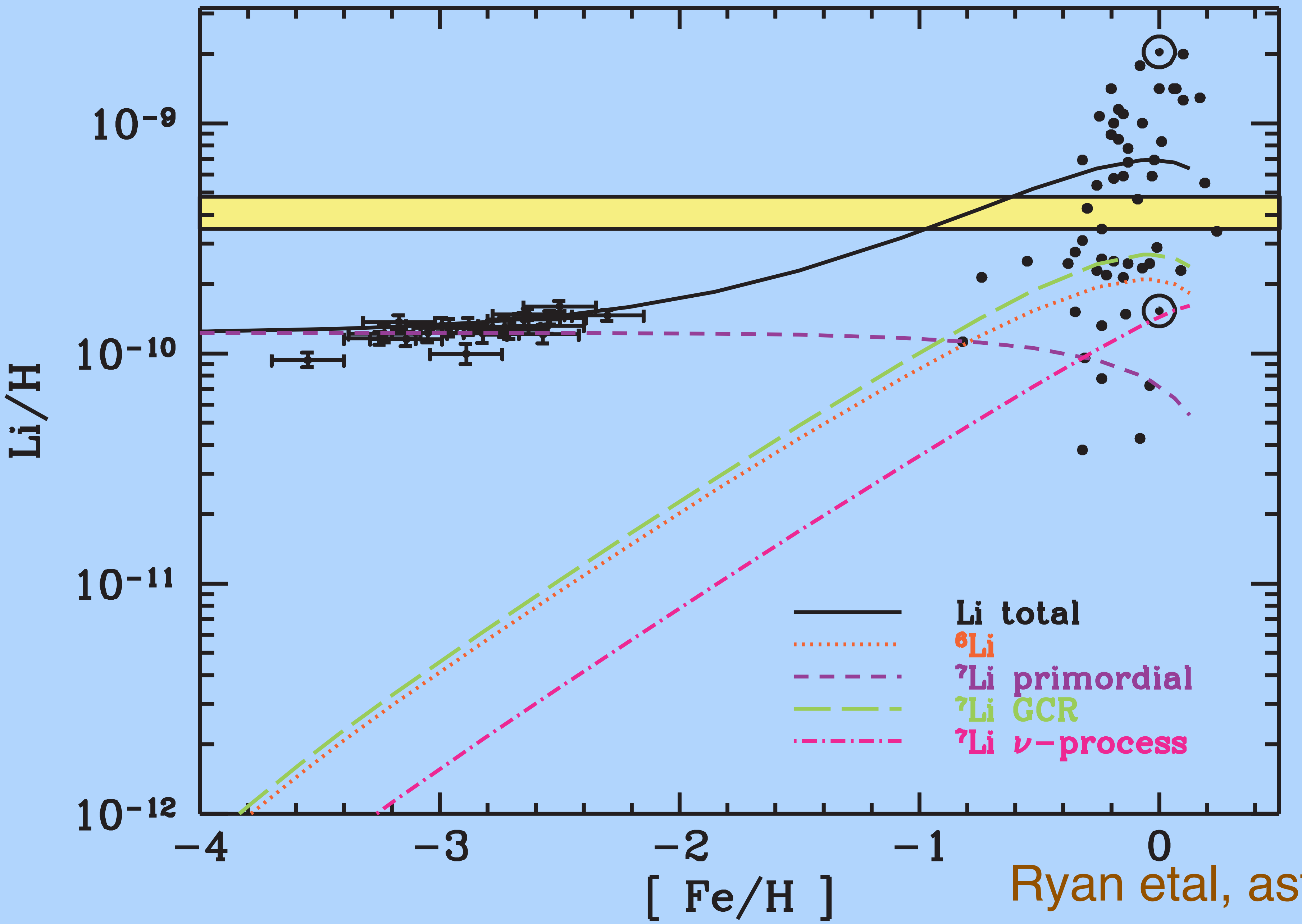

Cyburt etal, astro-ph/0211258

# Li problem

$^7$Li data **3 time less** than BBN prediction

$^6$Li data **1000 time more** than BBN prediction

pre-Galactic PopIII stars can explain $^6$Li




Ryan etal, astro-ph/9905211

# *Possible solutions*

**for $^7$Li isotope**

- Stelar parameters like *T*, *g*

  Can account for a factor of 2

- Nuclear rates, for example $^3He(\alpha,\gamma)^7Be$

  Restricted by solar model

- Particle decays during and after BBN

# *SUSY Candidates for Dark Matter*

- Sneutrino (constrained severely by LEP2 data and direct data)
- Neutralino
- Gravitino, *the supersymmetric partner of graviton the mediator of gravity*

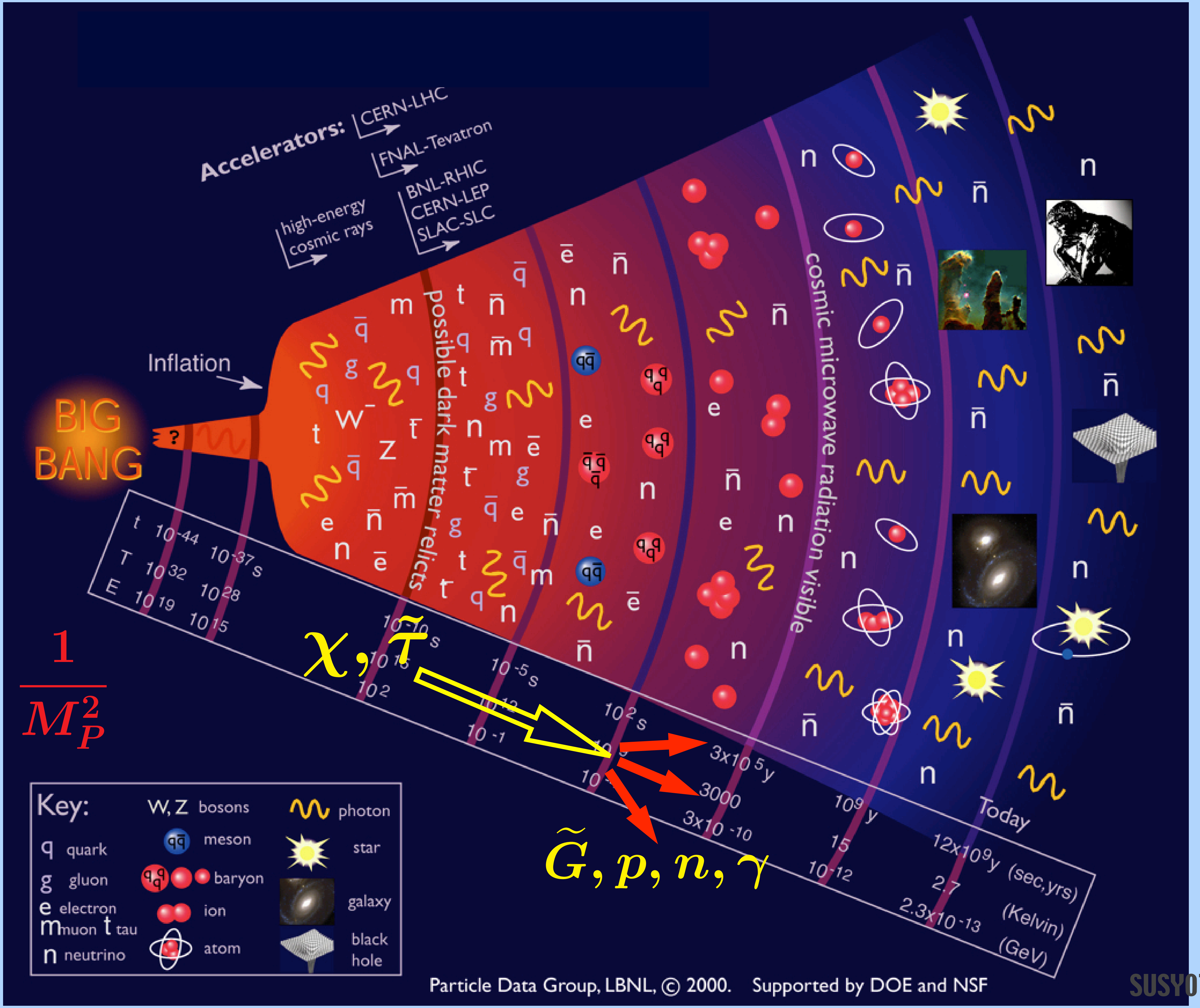
# Gravitino DM scenarios in SUSY models

- Usually the LSP is either the neutralino or stau, and neutralino is the DM particle
- If gravitino is the LSP, the NSP is either neutralino or stau (for large $A_0$, stop can also play the role of NSP Y. Santoso's talk for details)
- In this case we must consider the effect of the "late" gravitational decays NSP $\longrightarrow$ LSP + X, eg $\chi \longrightarrow \widetilde{G}\,\gamma$ or $\tilde{\tau} \longrightarrow \widetilde{G}\,\tau$

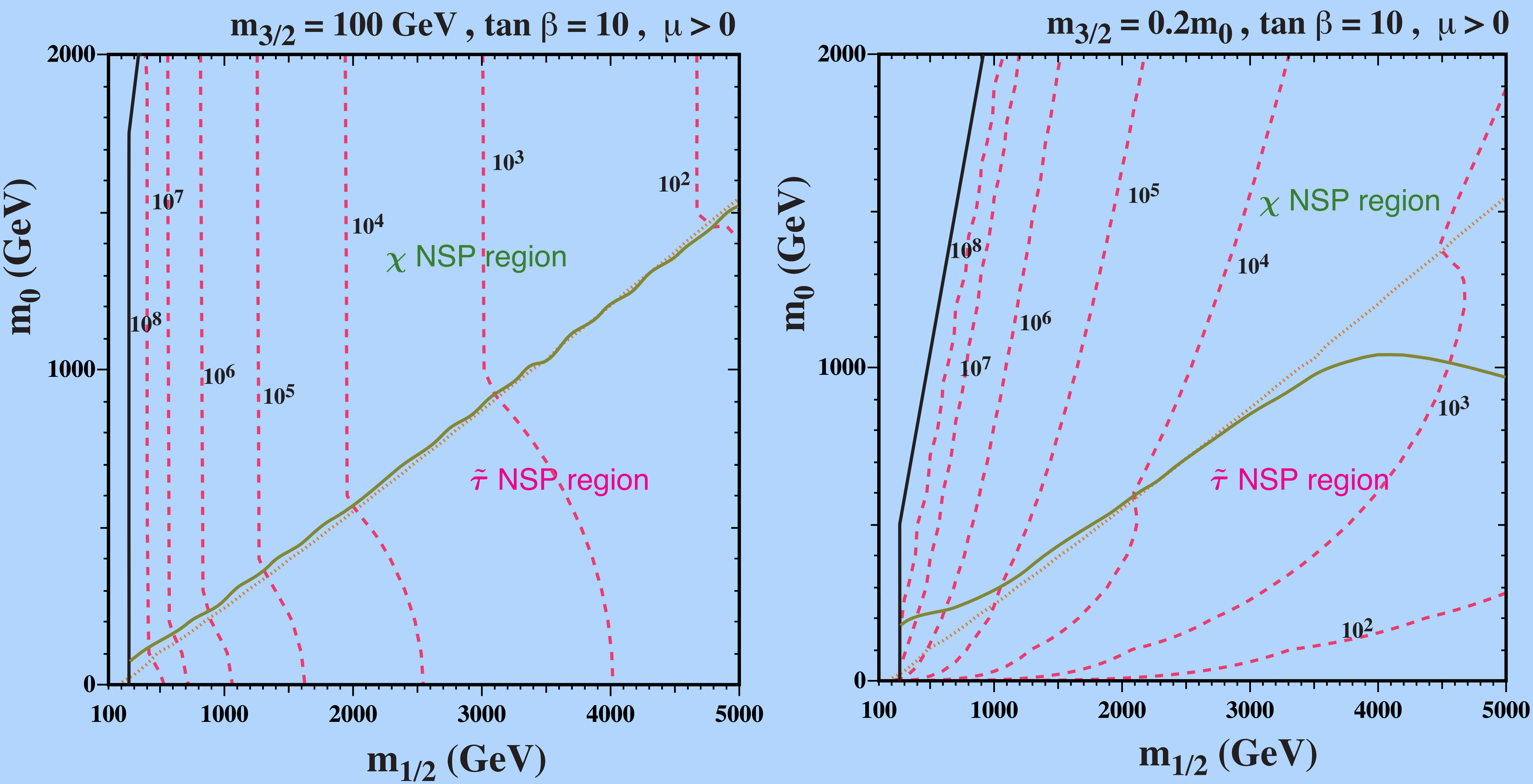
$$\Gamma_{\chi\to\tilde{G}\,\gamma} \simeq \frac{1}{48\pi}\frac{1}{M_P^2}\frac{m_\chi^5}{m_{3/2}^2} \Longrightarrow \tau \lesssim \mathcal{O}(10^8)s$$

# .. if gravitino is the LSP

$$\Gamma_{\chi,\tilde{\tau}} \sim \frac{1}{M_P^2}$$



# *NSP lifetimes in s*



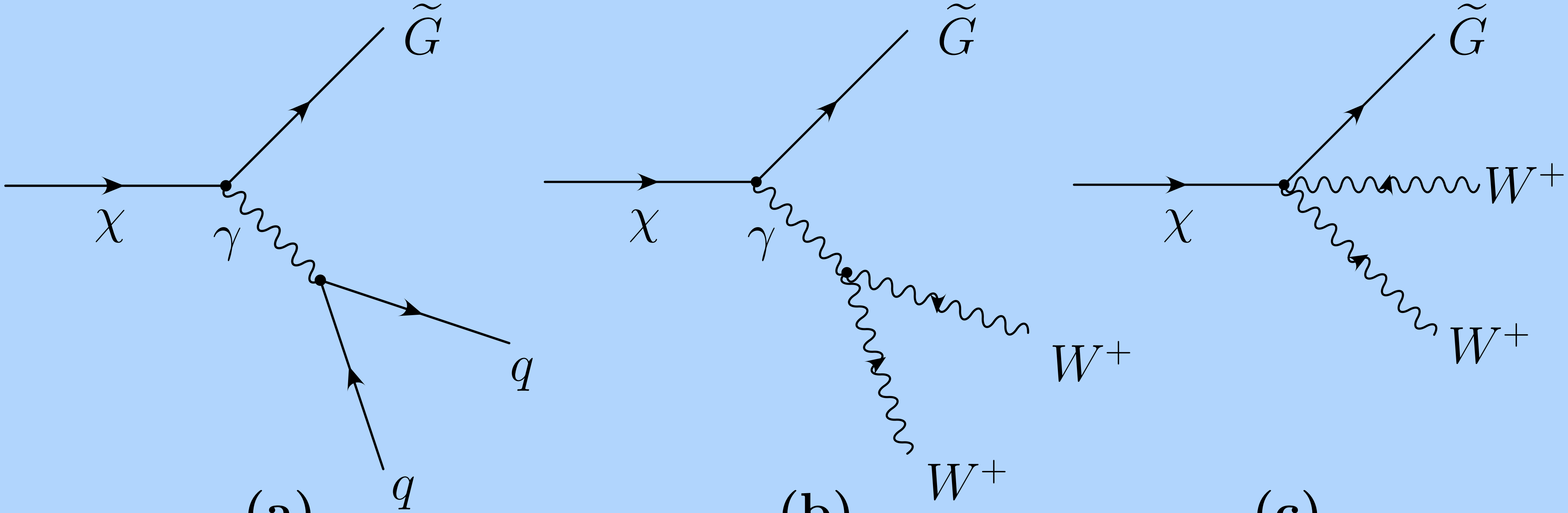
# NSP decays

**$\chi$ NSP**

$$\chi \to \widetilde{G}\,\gamma$$

$$\chi \to \widetilde{G}\,Z$$

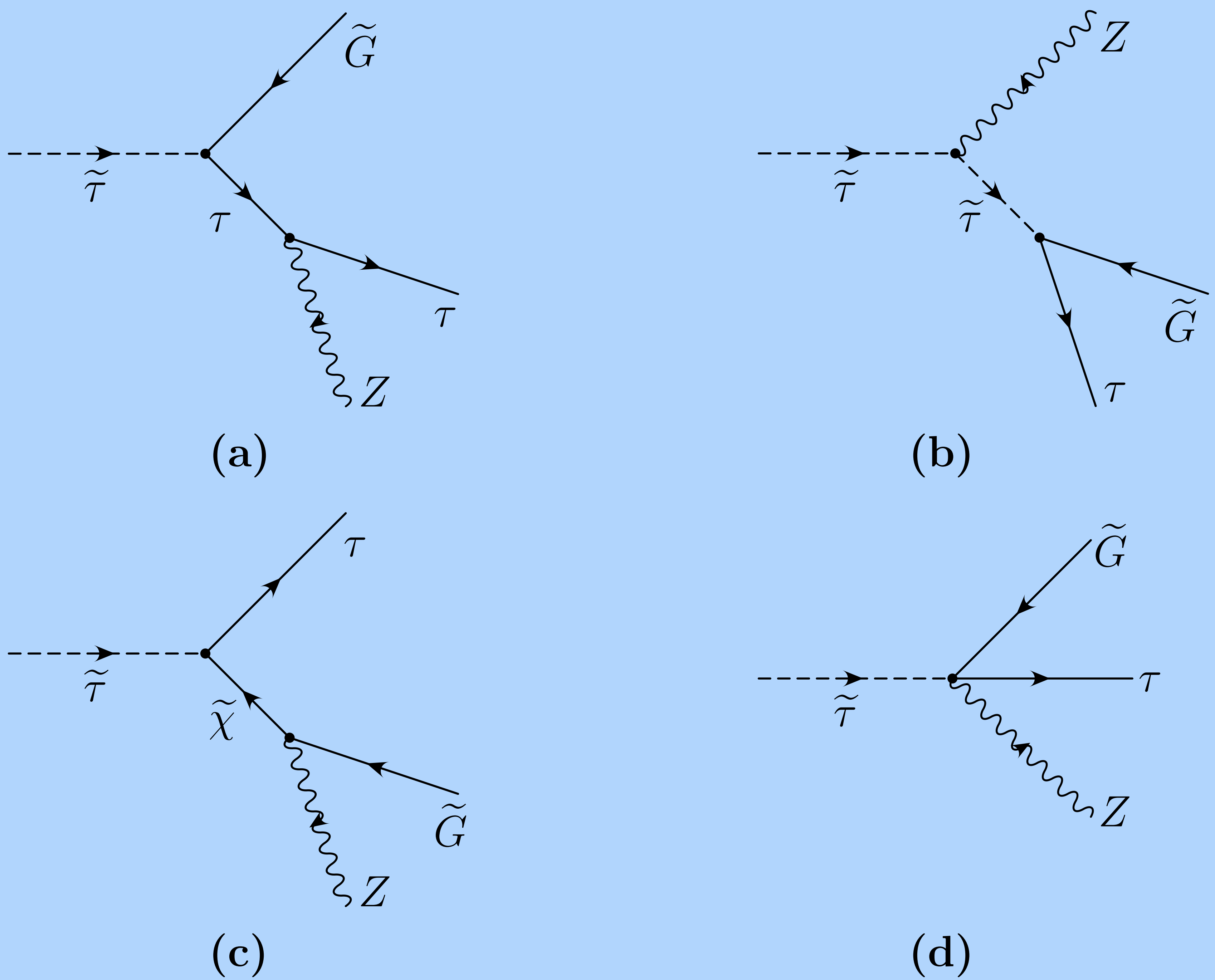
$$\chi \to \widetilde{G}\,H_i$$




(a) (b) (c)

## $\tilde{\tau}$ NSP

$$\tilde{\tau} \longrightarrow \widetilde{G}\,\tau$$



# Method

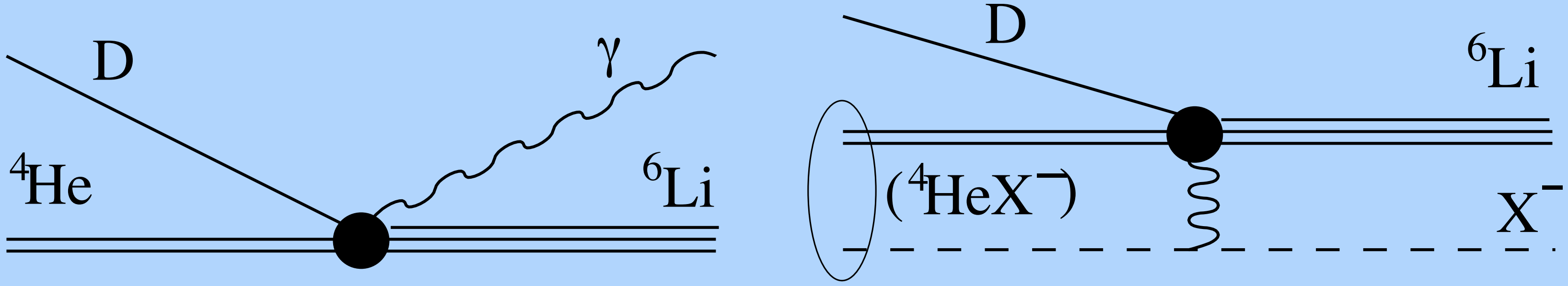
- Calculate the partial and the total widths for the NSP decays
- Calculate the NSP relic density, that eventually will become gravitino relic density
- Employ PYTHIA event generator to simulate the EM and HD products of Z, Higgs bosons, quarks and taus
- Incorporate in  the BBN code the effects of the EM and HD injections
- Estimate for each point of the SUSY parameter space the light element abundances

# Bound-state effects for stau NSP

* $\tilde{\tau}$ NSP can form bound states with various nuclei, $^4\mathrm{He}$, $^7\mathrm{Li}$ and $^7\mathrm{Be}$

* The presence of these bound states changes the light elements abundance in two ways:

1. reduces the Coulomb barrier of the nuclear reactions
2. enhances particular channels, for example $^4\mathrm{He}(\boldsymbol{d},\gamma)^6\mathrm{Li}$




$\sigma \sim \lambda^5$

Pospelov, hep-ph/0605215

Similar for $^3\mathrm{He}(\alpha,\gamma)^7\mathrm{Be}$ $^7\mathrm{Li}(p,\gamma)^8\mathrm{Be}$

# *Procedure*

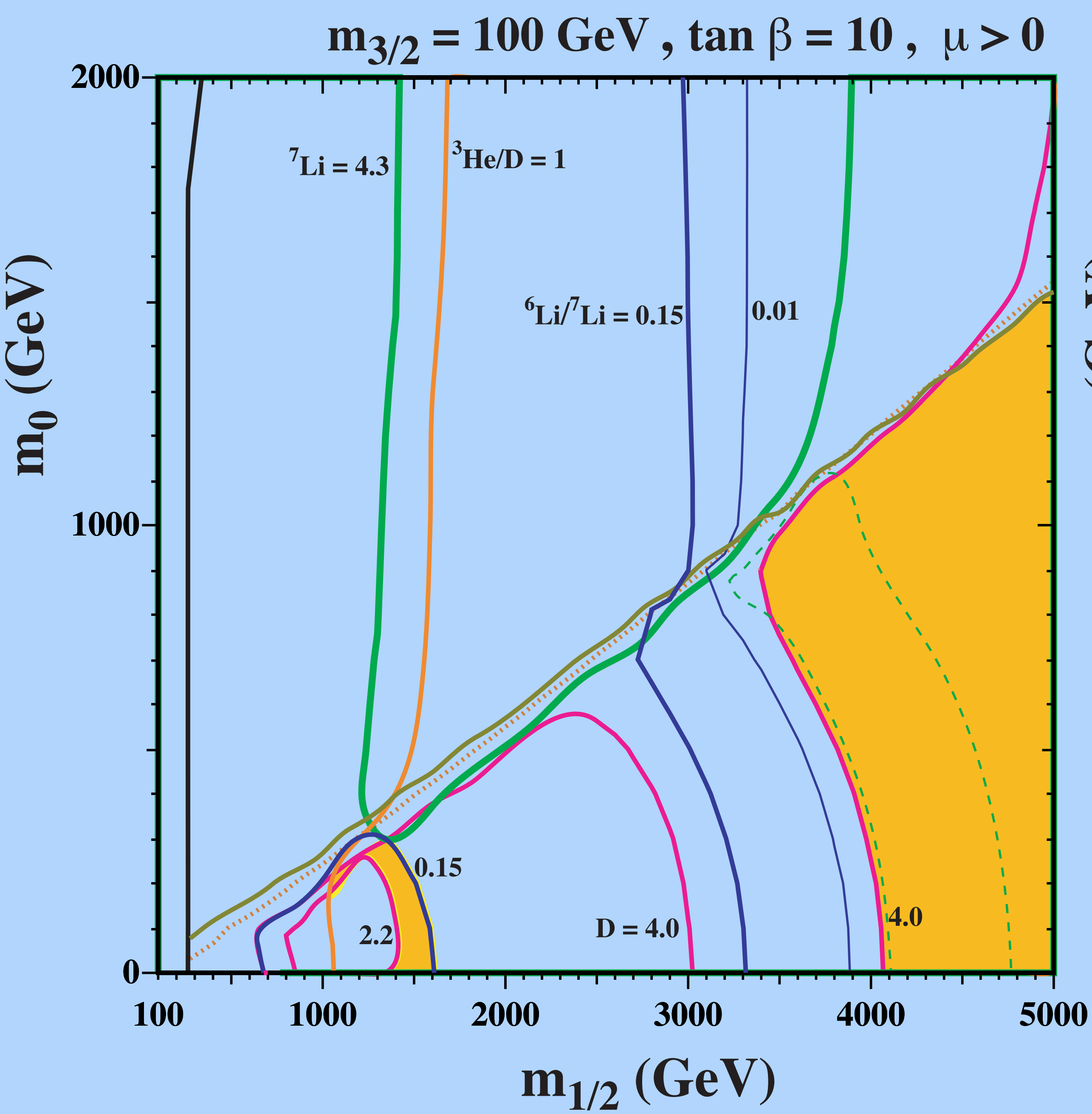
- Solve numerically the corresponding Boltzmann eqs for the BS abundances
  Kohri, Takayama, hep-ph/0605243

- We apply this for BS effects associated with **$^{4}$He**, **$^{7}$Li** and **$^{7}$Be** nuclei

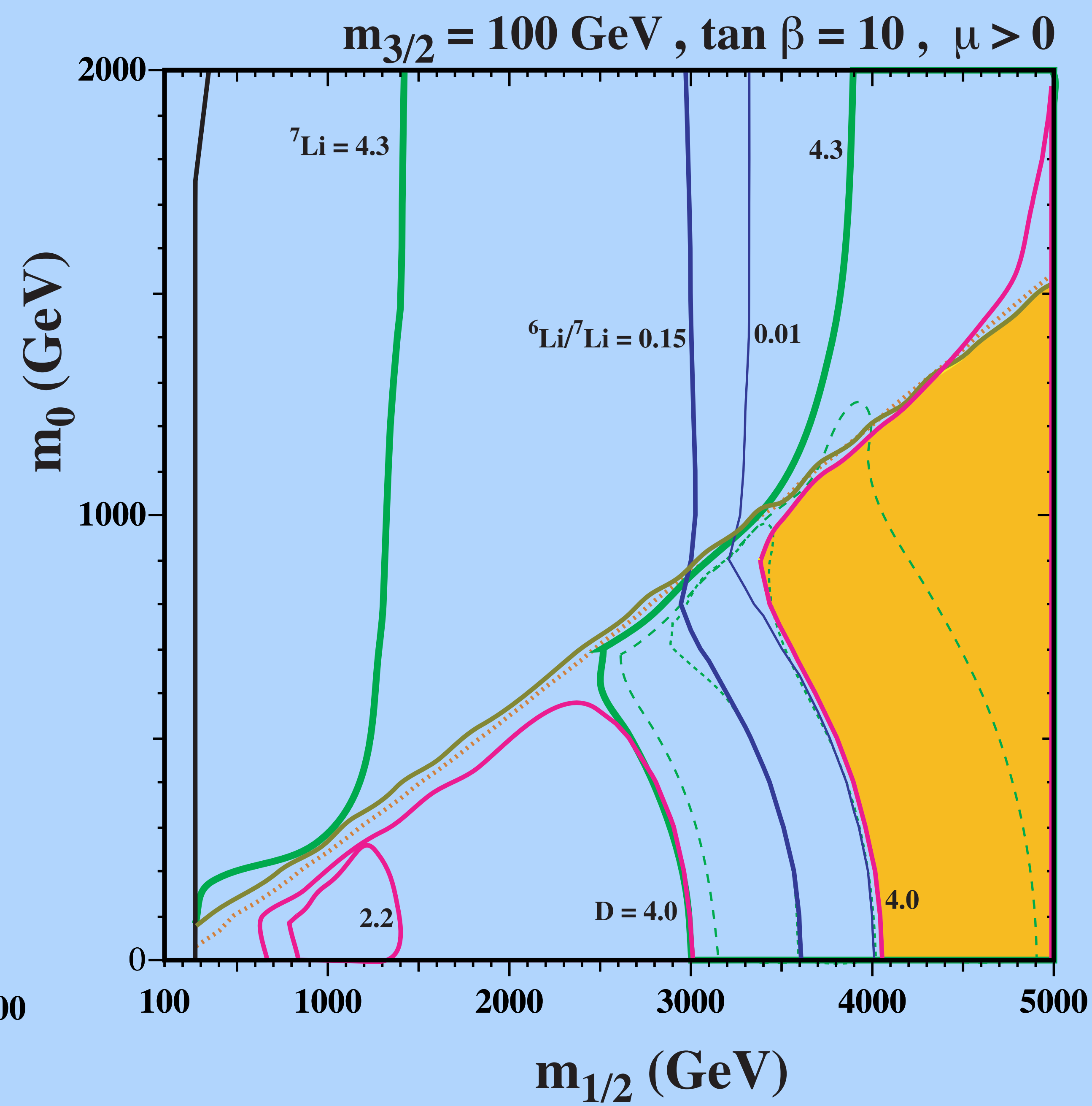
- The BS effects affect significantly the values of various cross-sections and consequently the light elements abundances.

Rich Cyburt, John Ellis, Brian Fields, Keith Olive, VS, JCAP 0611 (2006) 014

## w/o BS



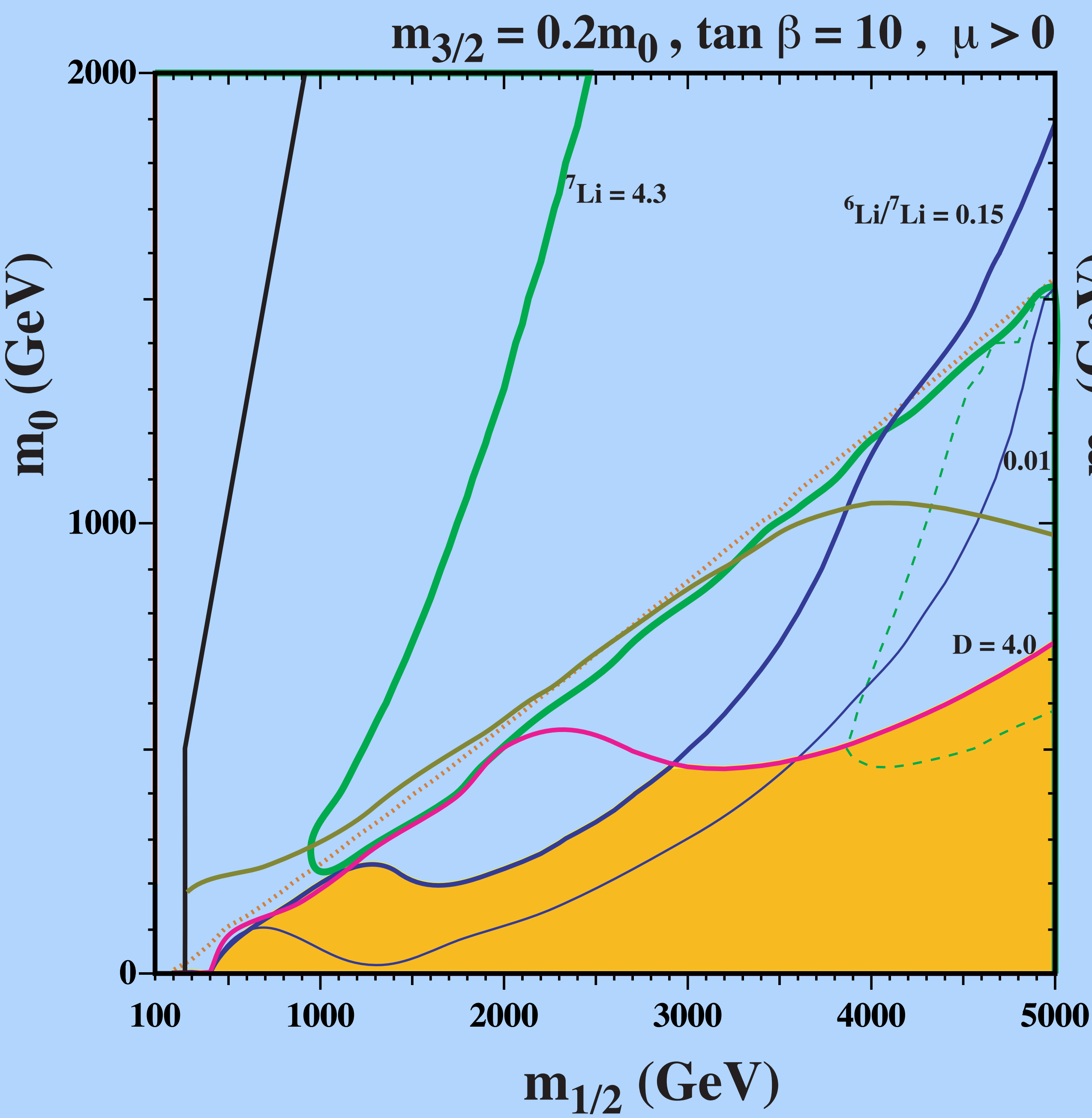

## w/ BS



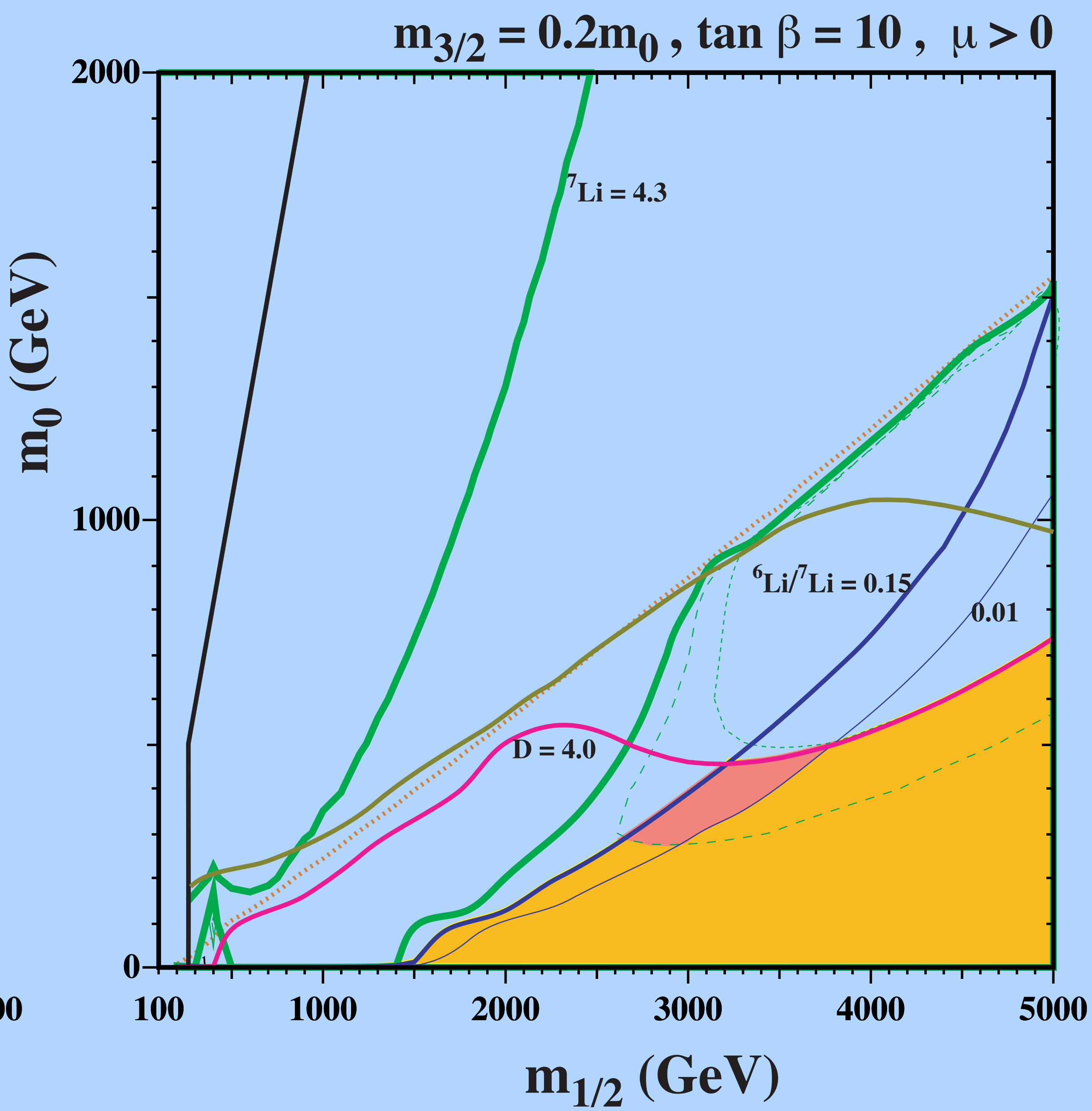

**Compatible with BBN**

Rich Cyburt, John Ellis, Brian Fields, Keith Olive, VS, JCAP 0611 (2006) 014

## w/o BS




## w/ BS

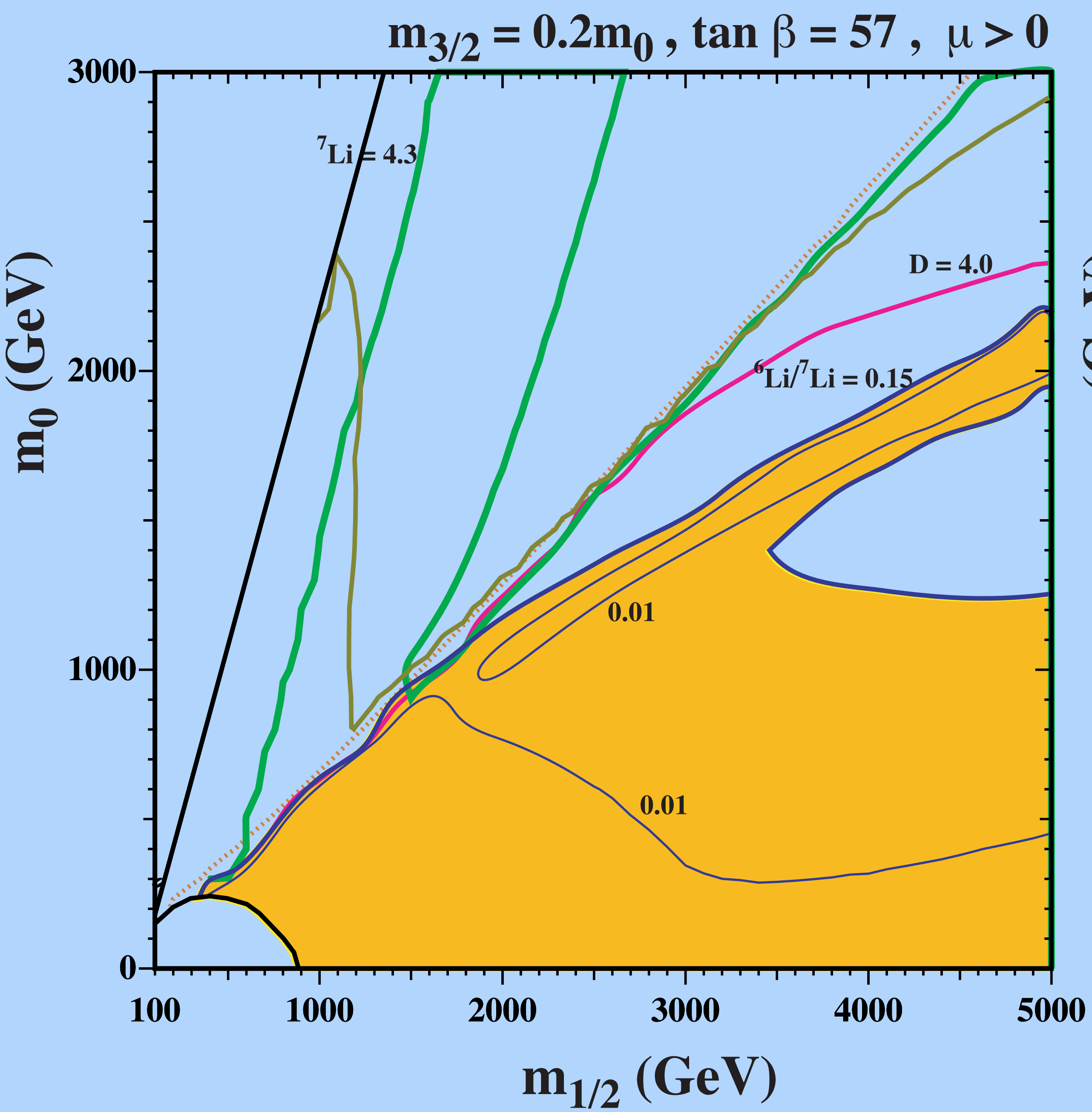



**Compatible with BBN**

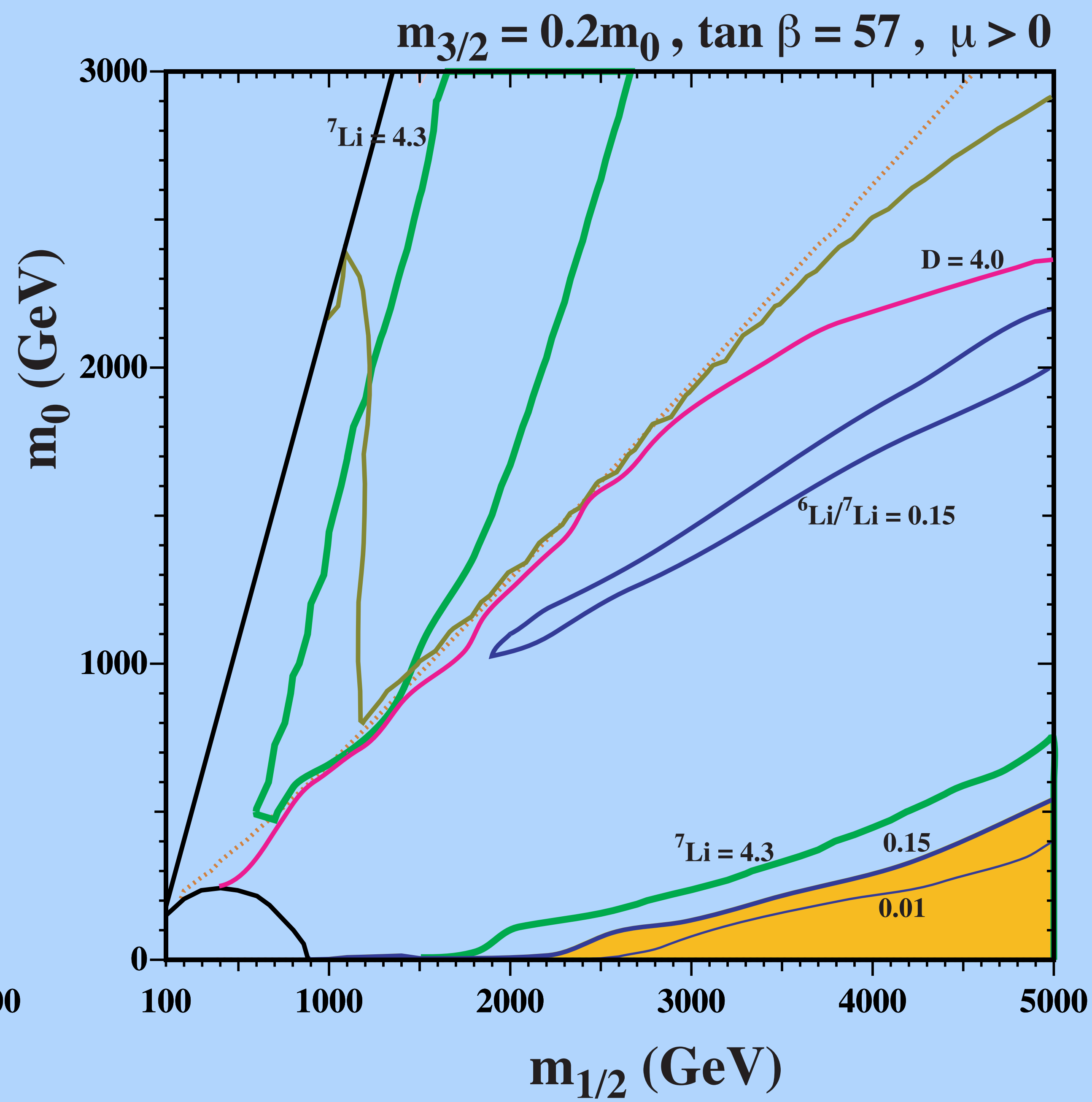
**Solution of Li problem**

Rich Cyburt, John Ellis, Brian Fields, Keith Olive, VS, JCAP 0611 (2006) 014

## w/o BS



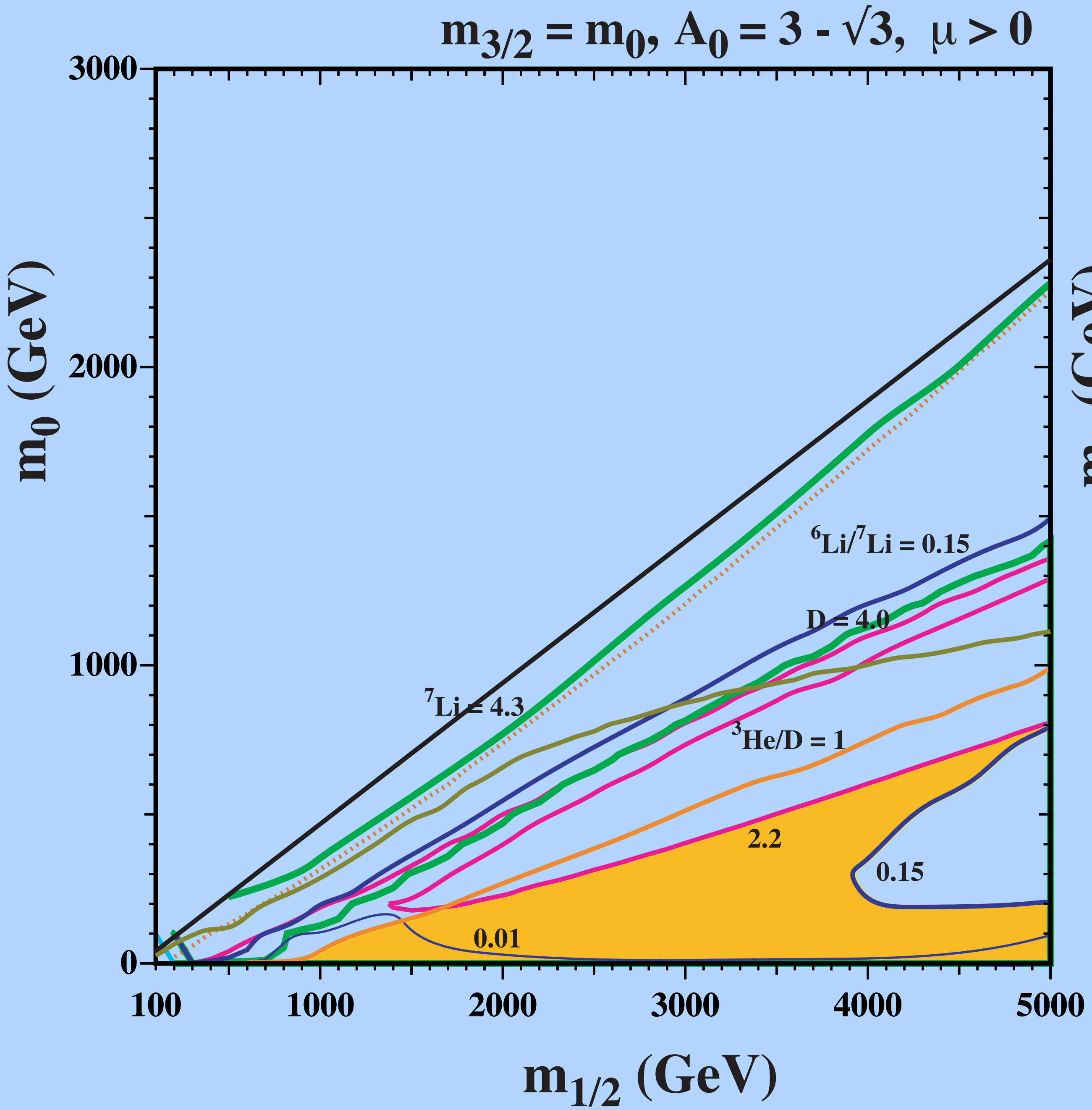

## w/ BS



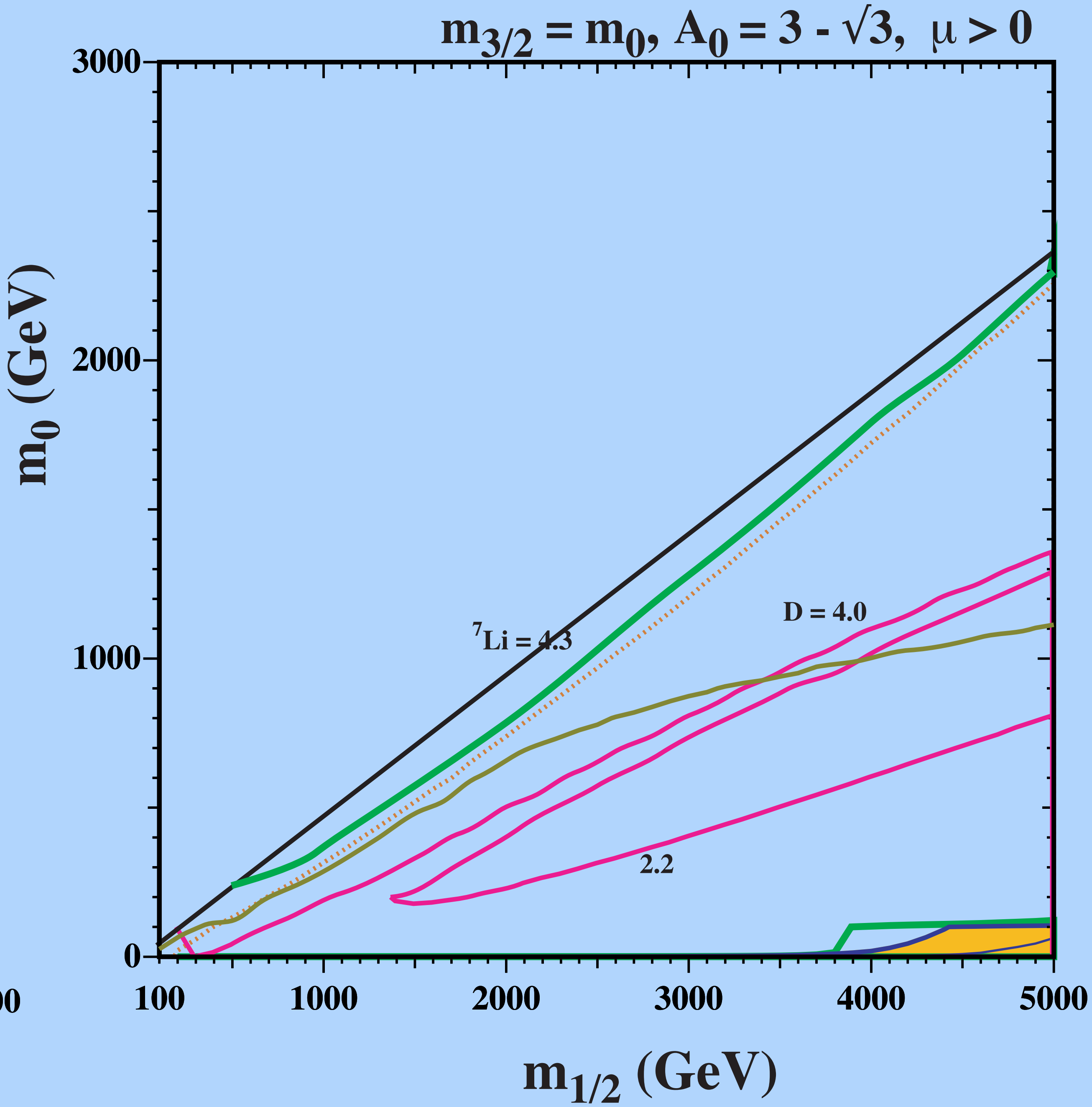

Compatible with BBN

Rich Cyburt, John Ellis, Brian Fields, Keith Olive, VS, JCAP 0611 (2006) 014

## w/o BS




## w/ BS




Compatible with BBN

# Summary-Prospects

- We present a new BBN calculation including the effects of the EM and HD decays of the NSP
- Including the bound-states effects in the stau NSP case
- NSP decays probably can not solve the lithium problem
- The bound states effects for the stau NSP case are important and exclude regions of the parameter space with lifetimes longer than $10^4$ *s*. And can explain the lithium isotopes discrepancies for $\tau \lesssim 1000$ *s* !
- Work in progress and for the future:
  - Unstable gravitino effects of neutralino DM models
  - detailed scan of the parameter space
  - SUSY searches at LHC