The degenerate gravitino scenario

Lotfi Boubekeur
University of Valencia & IFIC

LB, K-Y Choi, R. R. de Austri & O. Vives, arXiv:1002.0340, JCAP 1004:005,2010.

The gravitino

Spin 3/2 particle $\psi_\mu \longleftrightarrow g_{\mu\nu}$

Cosmological problems due to $1/M_{Pl}$ couplings

- Too much gravitinos (Weinberg '82)
- Even with inflation, re-created at reheating. (Ellis etal, ...)
- Number prop. to T_{RH} .
- Bound on reheating temperature in leptogenesis. $T_{\rm RH} \lesssim 10^9\ \rm GeV$
- Decay upsets BBN predictions.

Is it possible to relax these constraints?

The gravitino

In gravity-mediated, scenario typically co-exists with Neutralino.

Typical decay lifetimes O(10^2-10^6) sec

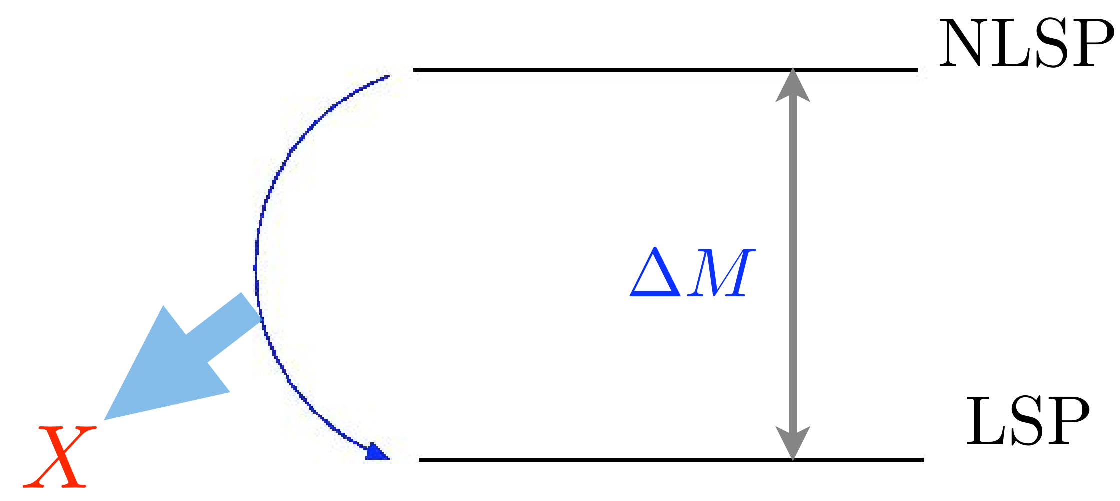
$$\text{NLSP} \to \text{LSP} + X \quad (X = \text{hadrons or } \gamma)$$

puts too much energy in the plasma

$$E_X = m_{\text{NLSP}} - m_{\text{LSP}}$$

BBN (Photodissociation + hadronization)

Hadronization constraints are the most stringent. (Moroi etal.)



To suppress hadronic showers, consider the "degenerate gravitino scenario"

$$\Delta M = m_{\text{NLSP}} - m_{\text{LSP}} \equiv \delta \, m_{\text{LSP}} \ll m_{\text{LSP}}$$

Relic Abundance

Total relic density should match observed one

$$\Omega_{\mathrm{CDM}}\ h^2 = \Omega_{\mathrm{LSP}}^{\mathrm{TP}}\ h^2 + \frac{1}{1+\delta}\Omega_{\mathrm{NLSP}}^{\mathrm{TP}}\ h^2 \simeq 0.11$$

Define the parameter

$$\omega \equiv \frac{Y_{\mathrm{NLSP}}}{Y_{\mathrm{CDM}}} = 1 - \frac{\Omega_{\mathrm{LSP}}^{\mathrm{TP}}\ h^2}{\Omega_{\mathrm{WMAP}}\ h^2}$$

which quantifies how many LSPs are produced non-thermally through NLSP decay.

The released EM energy is defined

$$\xi_{\mathrm{em}} \equiv \delta\ m_{\mathrm{LSP}}\ B_{\mathrm{em}}\ Y_{\mathrm{NLSP}}$$

which can be written as

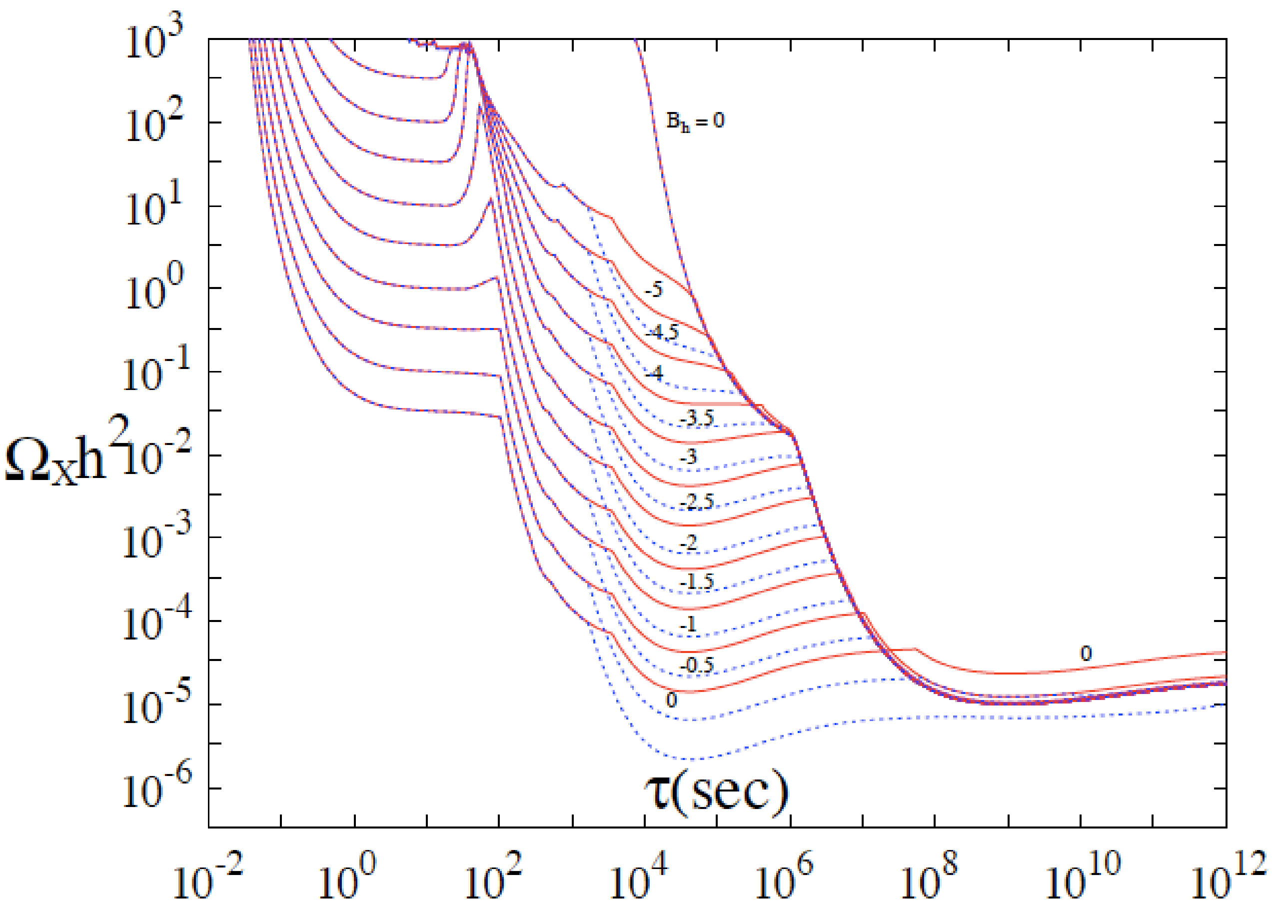
$$\xi_{\mathrm{em}} \simeq 4.1 \times 10^{-10}\mathrm{GeV}\left(\frac{\Omega_{\mathrm{WMAP}} h^2}{0.11}\right)\omega\, B_{\mathrm{em}}\, \delta$$

BBN

Since the mass difference is small $\Delta M < m_Z$ to suppress hadronic decays

- we can take $B_{\rm had} \simeq 0$.
- we consider only 2-body decays.

We can use the results of Jedamzik, arXiv:hep-ph/0604251.



BBN

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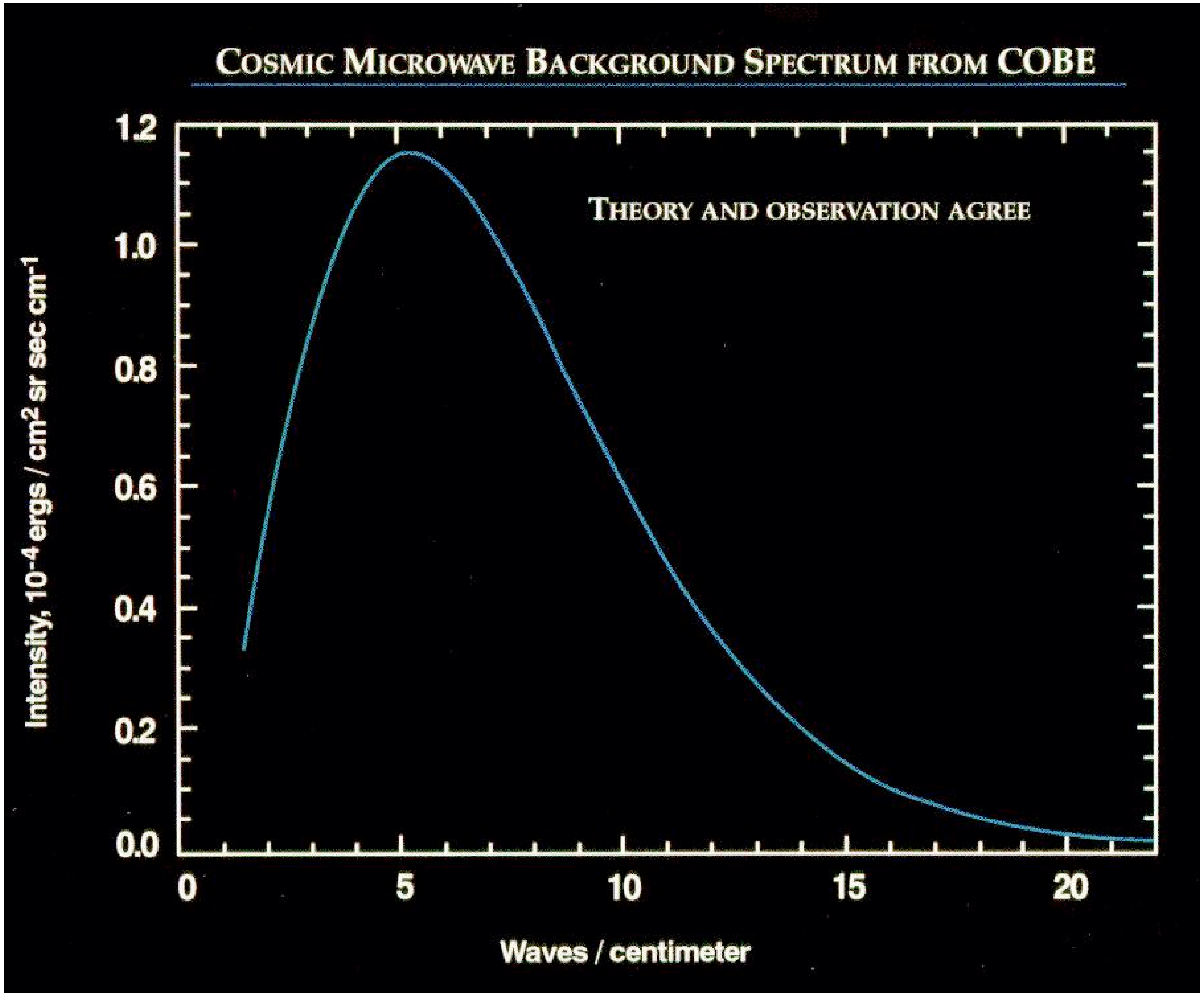
Furthermore the lifetime increases as ΔM^{-3}, we need to consider additional constraints

- CMB: for $\tau_{\rm NLSP} \gtrsim 10^7\,{\rm sec} \Longrightarrow 1\,{\rm GeV} \lesssim \Delta M \lesssim 10\,{\rm GeV}$
- Diffuse gamma rays background: for much longer lifetimes.

CMB



COSMIC MICROWAVE BACKGROUND SPECTRUM FROM COBE
THEORY AND OBSERVATION AGREE
Intensity, 10-4 ergs / cm2 sr sec cm-1
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
5
10
15
20
Waves / centimeter

CMB

Spectrum very well described by a Bose-Einstein distribution

$$f_\gamma(E) = \frac{1}{e^{E/(kT)+\mu} - 1},$$

where $|\mu| < 9 \times 10^{-5}$ from FIRAS.

For $\tau_{\rm NLSP} \lesssim 8.8\ 10^9$ sec

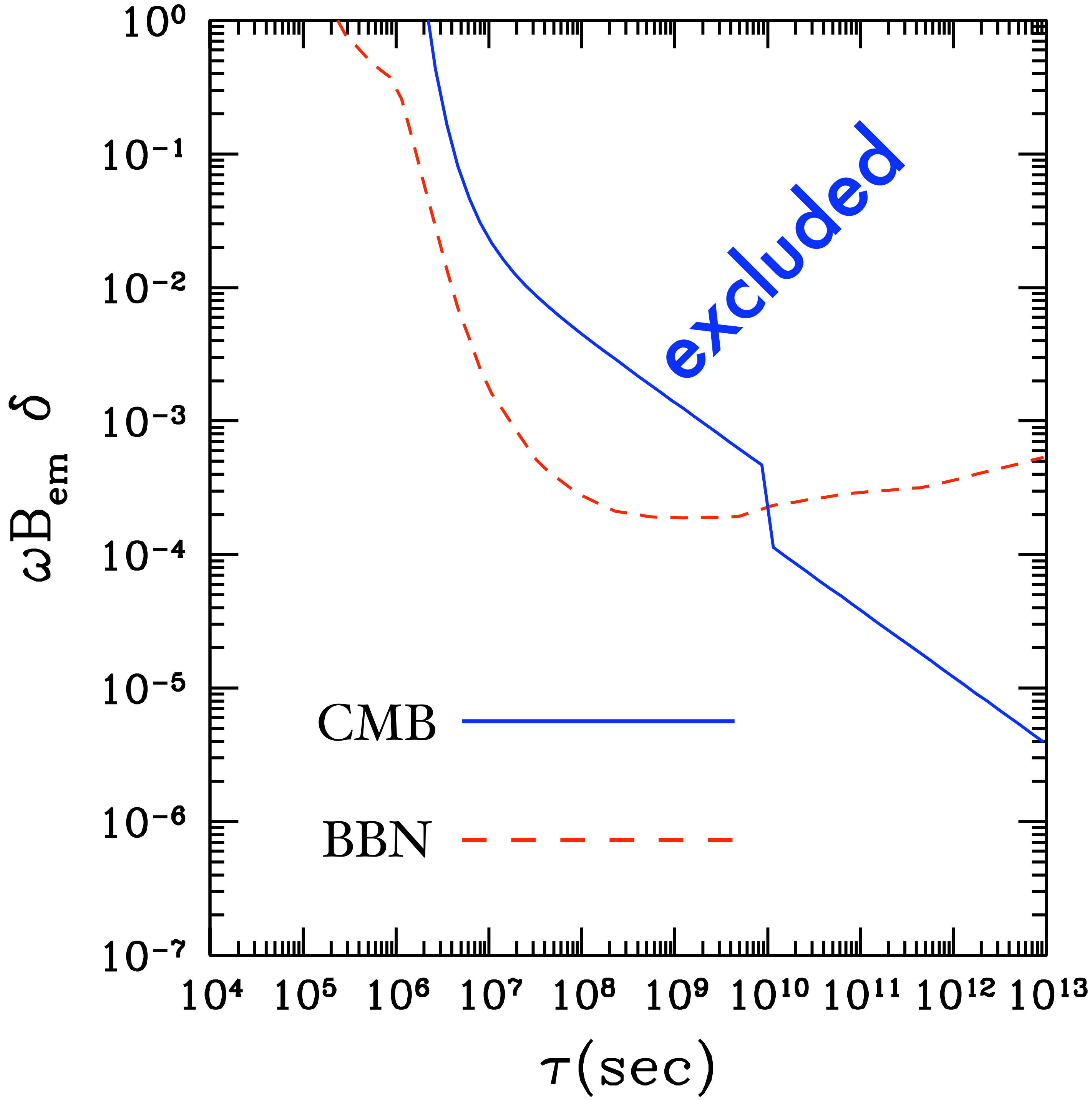
$$\xi_{\rm em} < 1.59 \times 10^{-8}\, e^{(\tau_{dC}/\tau_{\rm NLSP})^{5/4}} \left(\frac{1 \rm sec}{\tau_{\rm NLSP}}\right)^{1/2} {\rm GeV}$$

where $\tau_{dC} \simeq 6.085 \times 10^6$ sec

For $\tau_{\rm NLSP} \gtrsim 8.8\ 10^9$ sec

$$\xi_{\rm em} \lesssim 4.42 \times 10^{-9} {\rm GeV} \sqrt{\frac{1 \, \rm sec}{\tau_{\rm NLSP}}}.$$

BBN + CMB



excluded
CMB
BBN
$\omega B_{em}\ \delta$
τ(sec)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{4} 10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11} 10^{12} 10^{13}

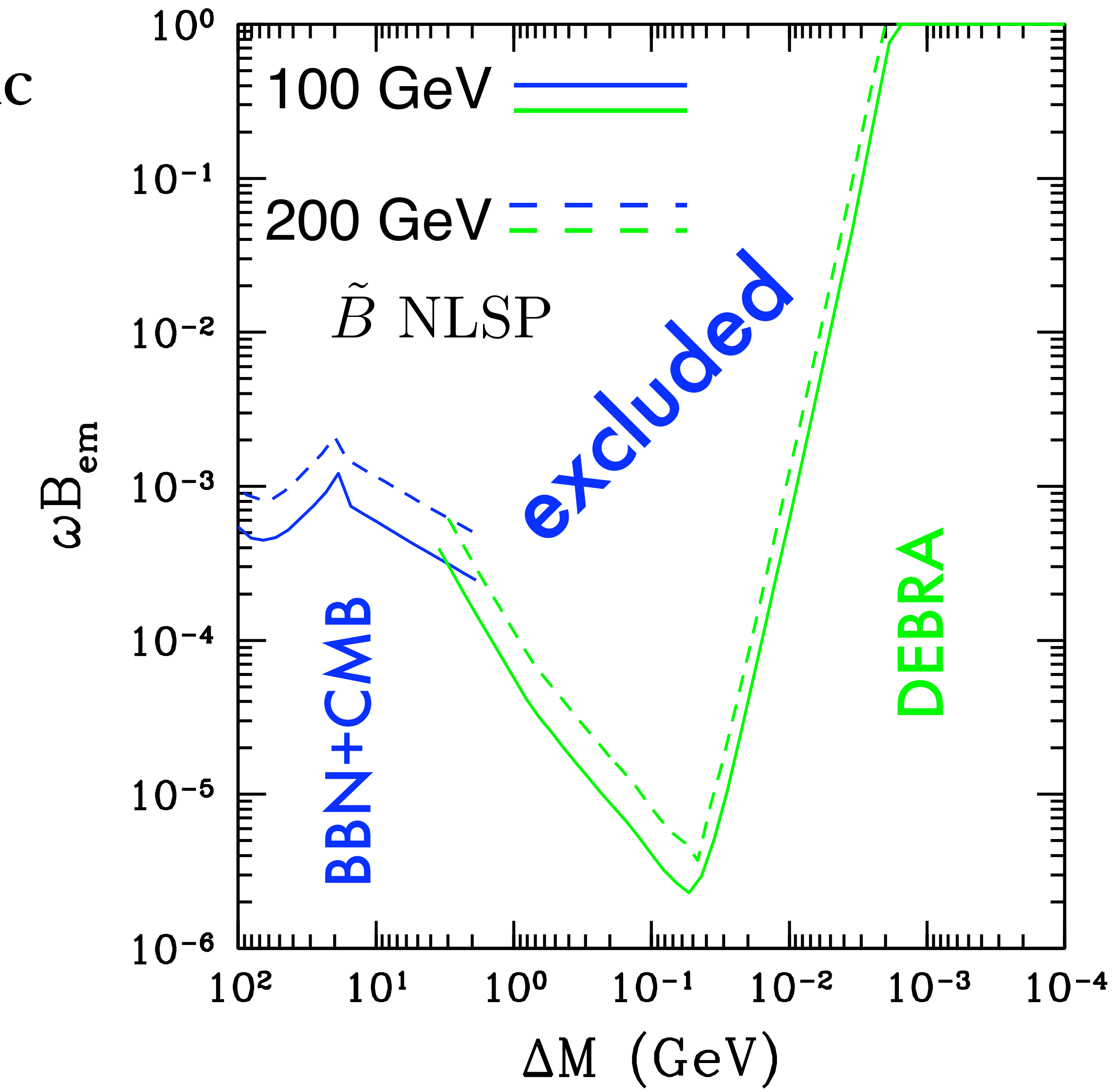
Diffuse Gamma Rays

$$\frac{d\Phi}{dE_\gamma} = \frac{c}{4\pi}\int_{t_i}^{t_0} \frac{dt}{\tau_{\rm NLSP}} \frac{\rho_c\,\Omega_{\rm WMAP}\,\omega\,B_{\rm em}}{m_{\rm NSLP}}\, e^{-t/\tau_{\rm NLSP}}\,\delta(E_\gamma - aE_{\rm em}),$$

Compare expected diffuse extragalactic gamma rays flux with data from

1. SPI
2. COMPTEL
3. EGRET

Yuksel & Kistler '07



NB: Galactic center gamma rays bounds are of the same order.

The reheating temperature

Combining these bounds, get limits on T_{RH}

Gravitino LSP

$$T_{\rm RH} = 4.1 \times 10^9\,\mathrm{GeV}\left(\frac{m_{3/2}}{100\,\mathrm{GeV}}\right)\left(\frac{1\,\mathrm{TeV}}{M_3}\right)^2 (1-\omega)\,.$$

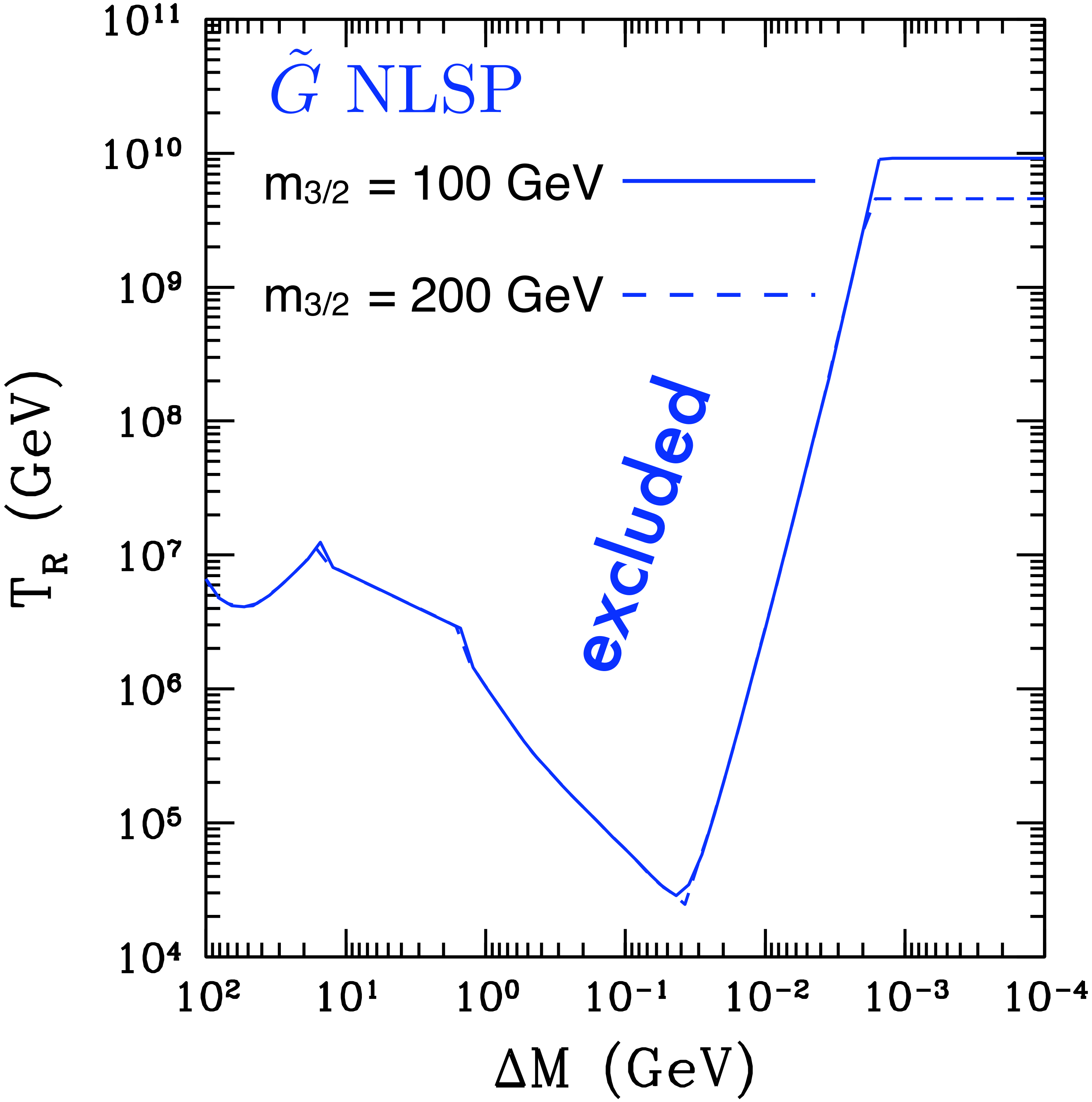
T_{RH} is always $O(10^9)$ GeV provided $\omega < 1$ and the sum of relic densities LSP + NLSP = total CDM.

Gravitino NLSP

$$T_{\rm RH} \simeq 4.1 \times 10^9\,\mathrm{GeV}\left(\frac{m_{3/2}}{100\,\mathrm{GeV}}\right)\left(\frac{1\,\mathrm{TeV}}{M_3}\right)^2 \omega \left(\frac{1}{1+\delta}\right)\,.$$

T_{RH} is $O(10^9)$ GeV, provided $\omega \simeq 1$ and $\delta \ll 1$ and the sum of relic densities LSP + NLSP = total CDM.

The reheating temperature



Gravitino-stau degeneracy

Long-lived negatively charged particle X^-

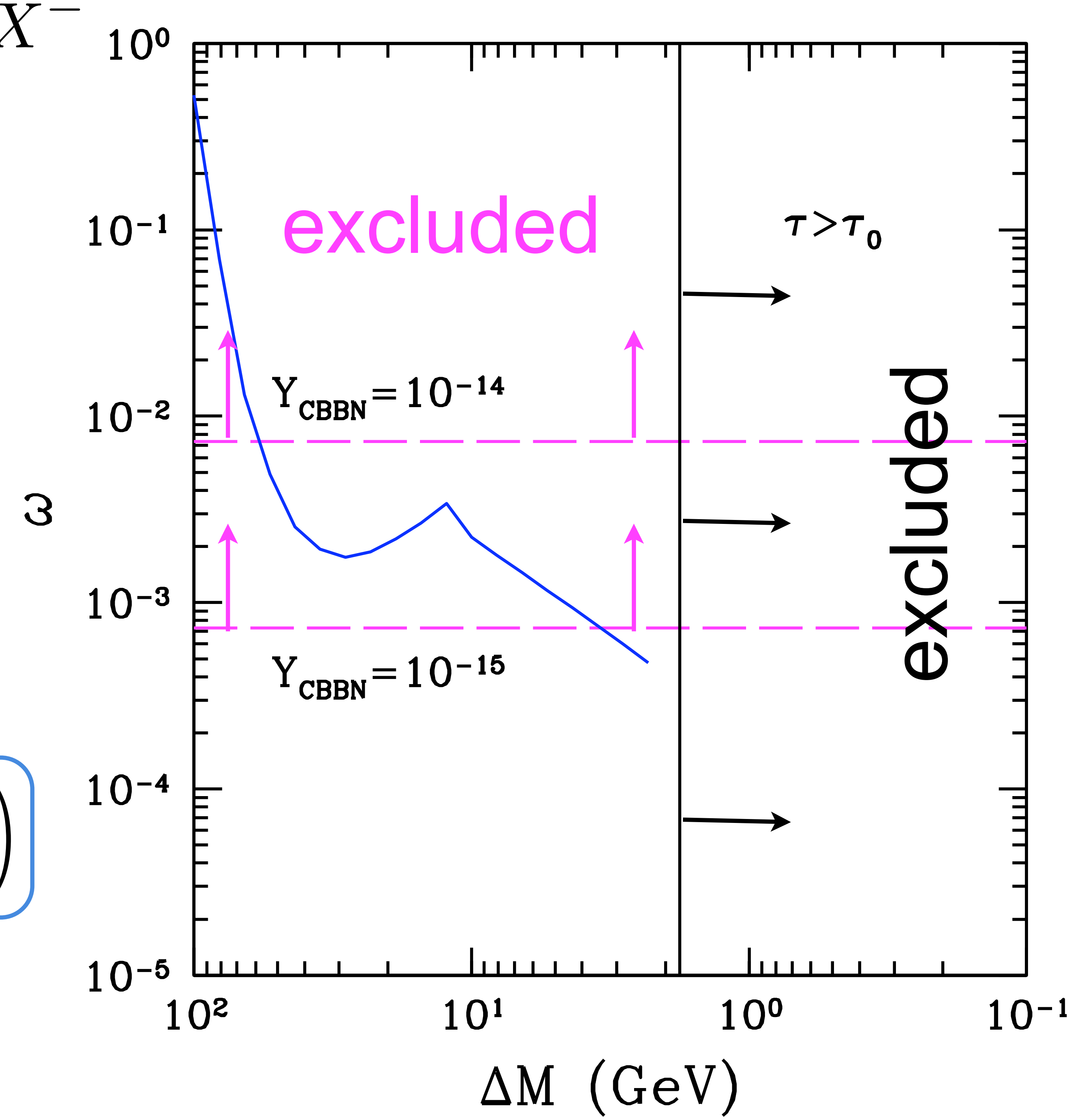
modifies BBN → Catalyzed BBN

Can solve the Li^7 problem.

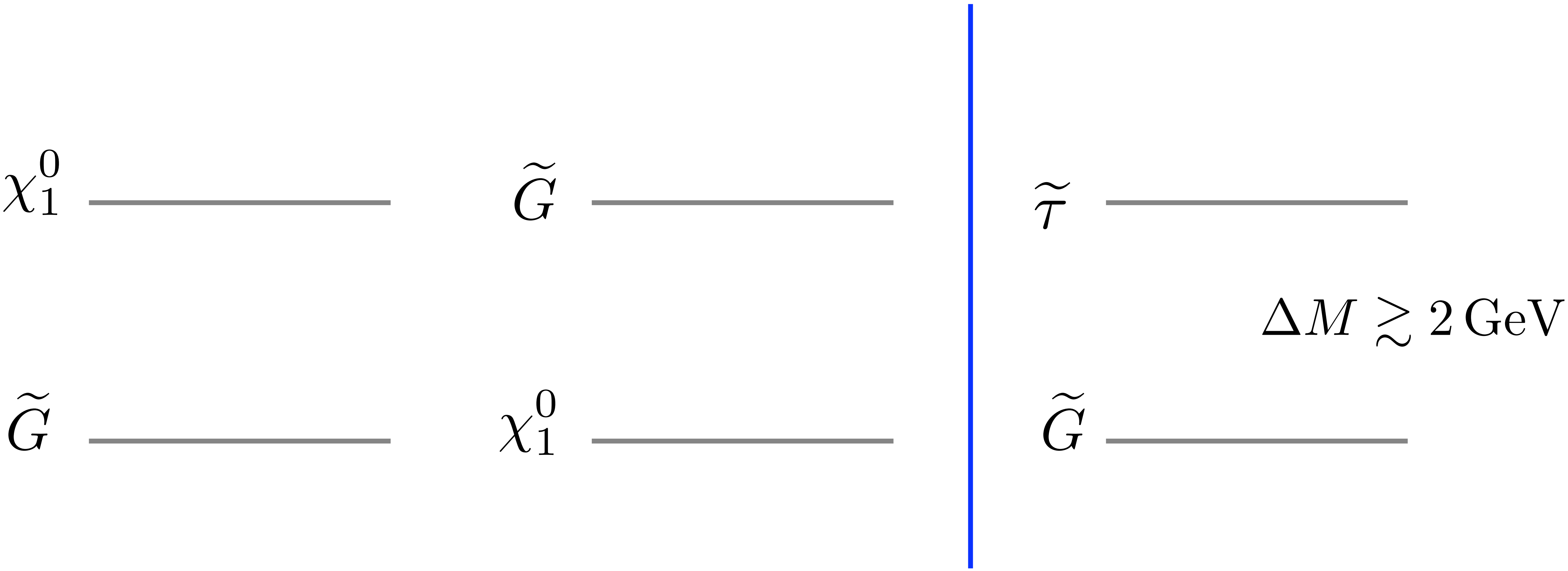
Conservative bound:

$$Y_{X^-} < 10^{-14} - 10^{-15}$$

$$\omega \lesssim 2.44 \times 10^{-3} \left(\frac{m_{\rm LSP}}{100\,{\rm GeV}} \right) \left(\frac{Y_{\rm CBBN}}{10^{-14}} \right)$$



....in the CMSSM

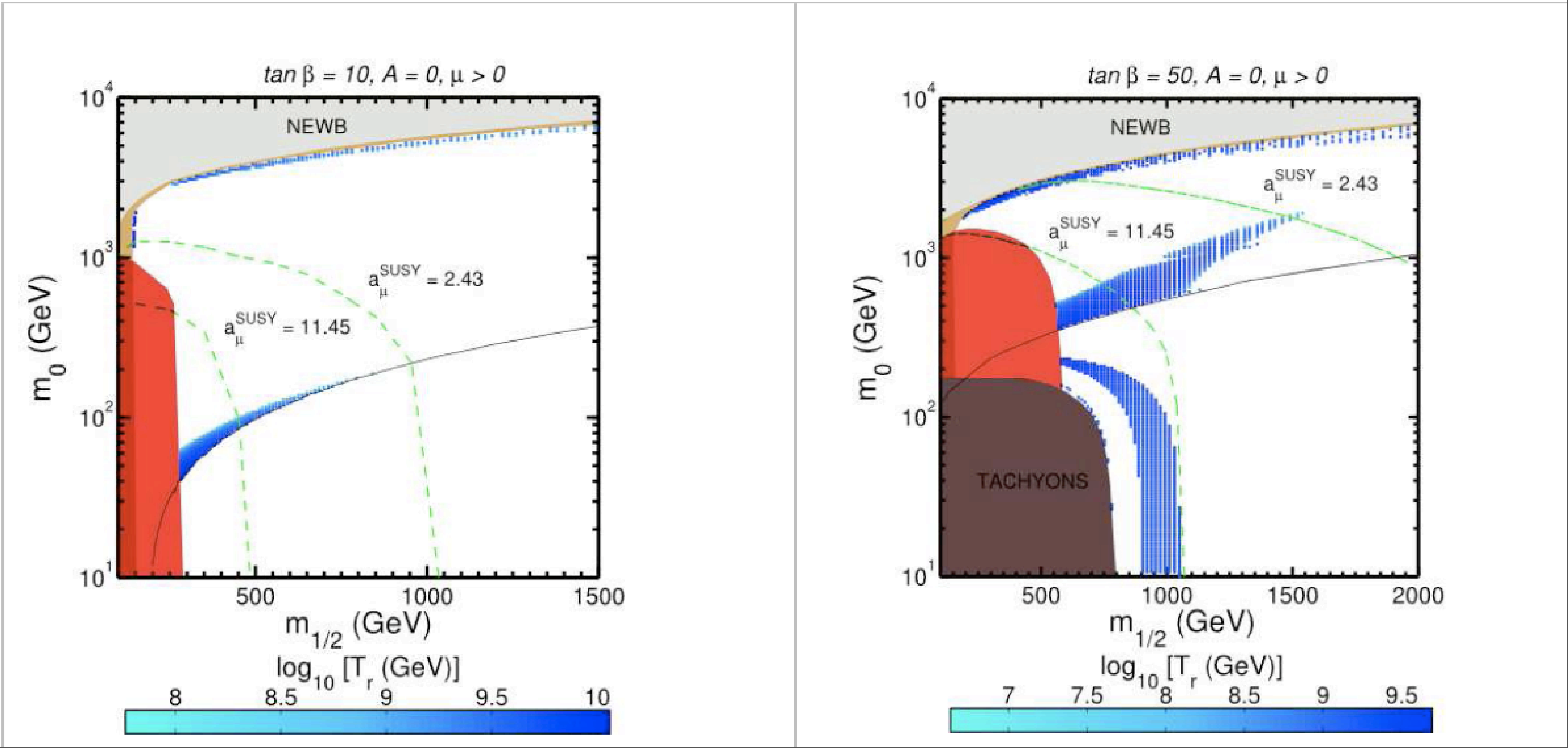


NB: stau abundance today is strongly constrained through “heavy water data”

$$\omega \leq 2.2 \times 10^{-27}\,(m_{\widetilde{\tau}}/100\,\mathrm{GeV})$$

....in the CMSSM

Scan over usual CMSSM parameters $\{m_0,\ m_{1/2},\ A_0,\ \mathrm{sgn}(\mu),\ \tan\beta\}$ plus the gravitino mass $m_{3/2}$



Conclusions

Yes, it is possible to relax constraints on gravitinos.

The price to pay:

1. degeneracy between the gravitino and the LOSP.

- Coannihilation.
- Inelastic DM.

2. Suppressed LOSP abundance $\omega \ll 1$.

➡ A possible way-out to the gravitino impasse in thermal leptogenesis scenarios.

Experiments:

$\widetilde{G} - \chi_1^0$ CDM relic density inferred from direct detection $\neq$ relic density from colliders.

$\widetilde{G} - \widetilde{\tau}$ Charged slow tracks + null results in direct detection.