Gravitino, dark matter candidate and BBN

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April 18 2011, GDR Terascale, IPN Lyon

SB, K. Jedamzik, G. Moultaka, Phys.Rev.D80:063509,2009.
SB, K.Y. Choi, K. Jedamzik, L. Roszkowski, JHEP 0905:103,2009.
SB, JCAP 1103:022,2011.

Two problems

- Dark matter relic density
- Lithium production in Big Bang Nucleosynthesis (BBN)

A simple framework

- Extension of the Standard Model: Supersymmetry
- Lightest Supersymmetric Particle (LSP): gravitino

In this scenario

- The gravitino is a good candidate for dark matter
- The decay of the Next-to-LSP to the LSP during BBN can solve the lithium problem

However

- Requirements: low reheating temperature and heavy mass spectrum
- Non-standard cosmology with a modified Hubble parameter

Supersymmetry with gravitino LSP

Broken symmetry and supergravity

- Explicit breaking terms included in effective SUSY lagrangian
- CMSSM: $m_{1/2}, \quad m_0, \quad A_0, \quad \tan\beta, \quad \text{sgn}\,\mu$
- If supersymmetry is a broken local symmetry: supergravity
- Super-Higgs mechanism: $\tilde{G}$ becomes massive

R-parity conservation

$$P_R = (-1)^{3B+L+2S}$$

The gravitino LSP is stable
We focus on a scenario $\tilde{\tau}$ NLSP

Non-thermal production from $\tilde{\tau}$ NLSP decay

- All SUSY particles decay to NLSP
- NLSP freeze-out
- NLSP decays to LSP

$$\Omega^{\mathrm{NTP}}_{3/2} h^2 = \frac{m_{3/2}}{m_{\mathrm{NLSP}}} \Omega_{\mathrm{NLSP}} h^2$$

Thermal production from scattering processes during reheating

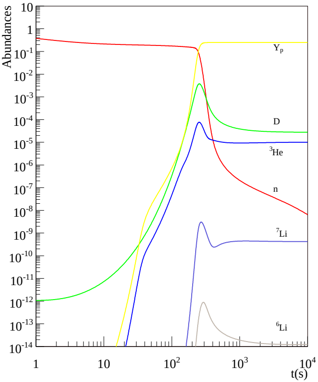
Bolz et al. (2001), Pradler & Steffen (2007)

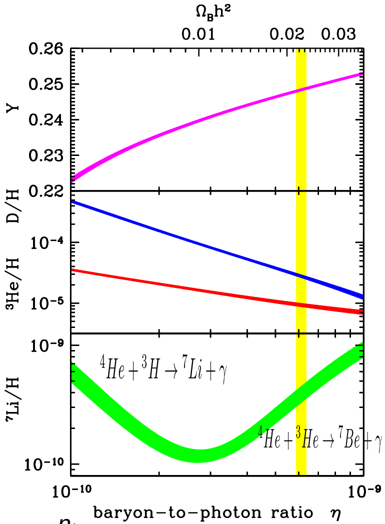
$$g + g \to \tilde{g} + \tilde{G}, \qquad q + g \to \tilde{q} + \tilde{G} \qquad q + q \to \tilde{g} + \tilde{G} \ldots$$

$$\Omega^{\mathrm{TP}}_{3/2} h^2 \simeq 0.32 \left(\frac{10 \text{ GeV}}{m_{3/2}} \right) \left(\frac{m_{1/2}}{1 \text{ TeV}} \right)^2 \left(\frac{T_R}{10^8 \text{ GeV}} \right)$$

Gravitino relic density

$$\Omega_{3/2} h^2 = \Omega^{\mathrm{TP}}_{3/2} h^2 + \Omega^{\mathrm{NTP}}_{3/2} h^2$$





$$\eta = \frac{n_b}{n_\gamma} = (6.225 \pm 0.170) \times 10^{-10}$$

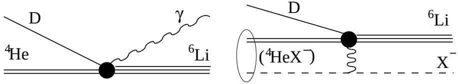
Element	SBBN	Observations
$\left(\frac{D}{H}\right)$	$(2.60 \pm 0.16) \times 10^{-5}$	$(2.68^{+0.27}_{-0.25}) \times 10^{-5}$
$\left(\frac{^3He}{H}\right)$	$(1.05 \pm 0.04) \times 10^{-5}$	$(1.1 \pm 0.2) \times 10^{-5}$
Y_p	0.2487 ± 0.0006	0.242 ± 0.002
$\left(\frac{^6Li}{H}\right)$	$10^{-14} - 10^{-15}$	$(3 - 5) \times 10^{-12}$
$\left(\frac{^7Li}{H}\right)$	$(4.26^{+0.91}_{-0.86}) \times 10^{-10}$	$(1.2 - 1.9) \times 10^{-10}$

Decay of massive particles during BBN

- Injection of non-thermal photons and nucleons
- ^{6}Li production: $n(^{4}\mathrm{He}, pn)^{3}\mathrm{H}(\alpha, n)^{6}\mathrm{Li}$
- ^{7}Li destruction: $^{7}\mathrm{Be}(n, p)^{7}\mathrm{Li}(p, \alpha)^{4}\mathrm{He}$
- Abundance change is constrained by observations

Catalyzed BBN

- Negatively charged X particles: bound state formation
- Reactions catalyzed Pospelov (2006)



- $\sigma_{\mathrm{CBBN}} \simeq 10^{8} \times \sigma_{\mathrm{SBBN}}$

Calculation of new abundances from stau decay (1/2)

Requirements

- Mass spectrum: SuSpect
- Stau NLSP relic density: micrOMEGAs
- Stau lifetime: dominated by two-body decay
- Description of decay: electromagnetic and hadronic cascades

Electromagnetic cascade: two-body decay

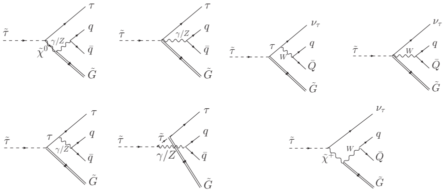
$$\Gamma(\tilde{\tau} \to \tau \tilde{G}) = \frac{1}{48\pi} \frac{m_{\tilde{\tau}}^5}{M_{\mathrm{Pl}}^2 m_{3/2}^2} \left(1 - \frac{m_{3/2}^2}{m_{\tilde{\tau}}^2}\right)^4$$

$$B_{\mathrm{em}} = 1 - B_{\mathrm{had}} \simeq 1 \qquad \text{and} \qquad E_{\mathrm{em}} = \alpha \left(\frac{m_{\mathrm{NLSP}}^2 - m_{3/2}^2}{2m_{\mathrm{NLSP}}}\right) \qquad \alpha \simeq \frac{1}{2}$$

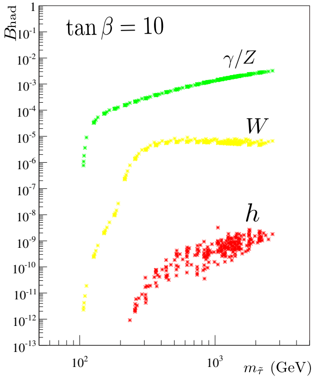
Hadronic cascade: four-body decay using CalcHEP Steffen (2006)

$$B_{\rm had}(\tilde{\tau} \to \tau \tilde{G} q \bar{q}; m_{q\bar{q}}^{\rm cut}) = \frac{\Gamma(\tilde{\tau} \to \tau \tilde{G} q \bar{q})}{\Gamma_{\rm tot}}$$

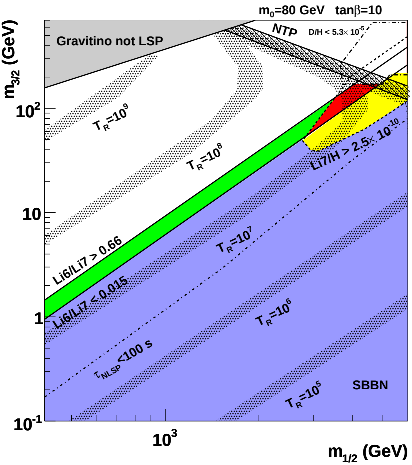
$$\Gamma(\tilde{\tau} \to \tau \tilde{G} q \bar{q}; m_{q\bar{q}}) = \int_{m_{q\bar{q}}}^{m_{\tilde{\tau}} - m_{3/2} - m_{\tau}} dm_{q\bar{q}} \frac{d\Gamma(\tilde{\tau} \to \tau \tilde{G} q \bar{q})}{dm_{q\bar{q}}}$$



$E_{\rm had}$ calculated using a similar procedure



■ : ^{6}Li solution ■ : ^{7}Li solution ■ : ^{6}Li and ^{7}Li solution



Red region: $m_{1/2} = [3 - 5]$ TeV corresponding to stau masses $m_{\tilde{\tau}} = [1 - 1.8]$ TeV and gravitino masses $m_{3/2} = 60 - 120$ GeV

Modified Hubble parameter

$$H^2 = \frac{8\pi G}{3}\left(\rho_m + \rho_{\rm rad} + \rho_D\right)$$

Addition of a dark component in the pre-BBN Universe Arbey & Mahmoudi (2008)

$$\rho_D(T) = \rho_D(T_{\rm BBN})\left(\frac{T}{T_{\rm BBN}}\right)^{n_D}$$

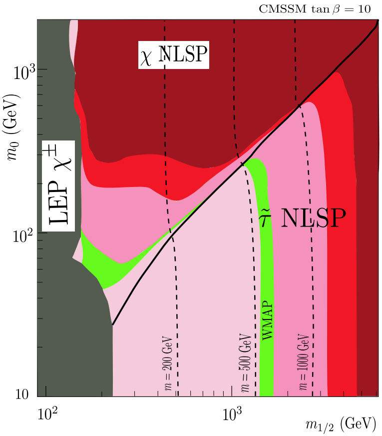
with $T_{\rm BBN} = 10$ MeV

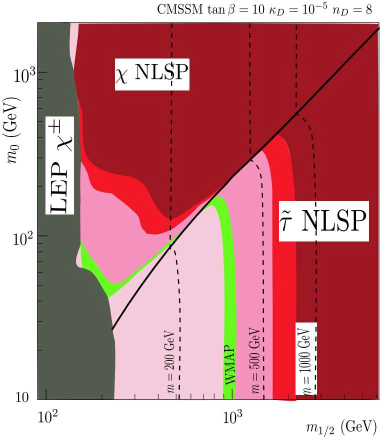
As we require a radiation dominated era for the beginning of BBN, we introduce the parameter

$$\kappa_D = \frac{\rho_D(T_{\rm BBN})}{\rho_{\rm rad}(T_{\rm BBN})} \ll 1$$

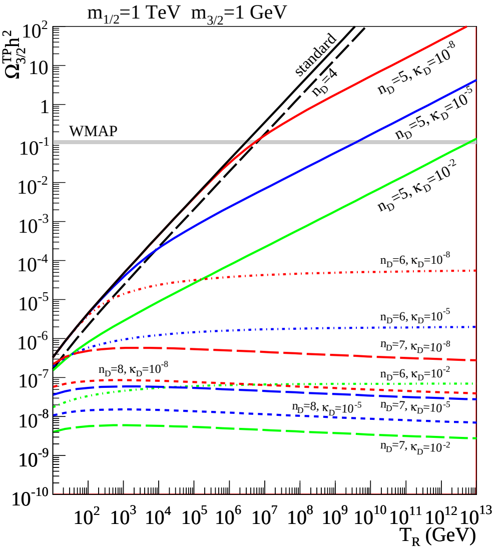
where the radiation density $\rho_{\rm rad}(T) = g_{\rm eff}(T)\frac{\pi^2}{30}T^4$

Since the Hubble parameter is larger as in the standard scenario, the NLSP freeze-out occurs earlier

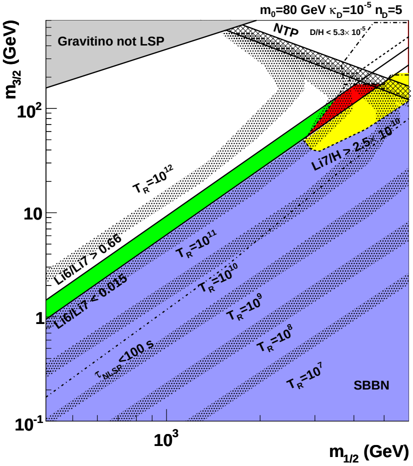


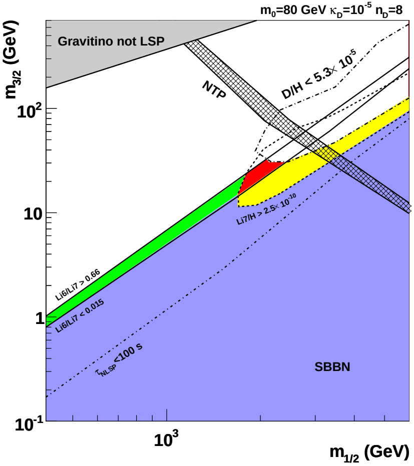


The thermal contribution is suppressed compared to the standard scenario



For a given mass, more NLSP particles decay during BBN





Conclusion

Dark matter

- Gravitino good cadidate
- Non-thermal production and thermal production

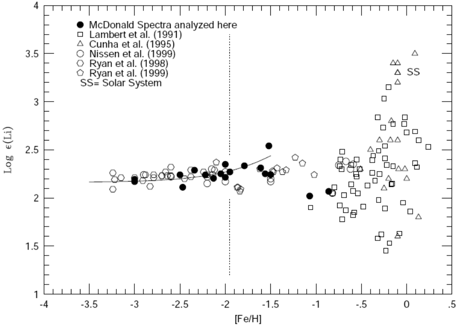
Lithium problems

- Scenario to solve the lithium problems
- SBBN puts constraints on the model

Modified Hubble parameter

- Solution for the reheating temperature
- Lighter mass spectrum
- Constraints on the pre-BBN era

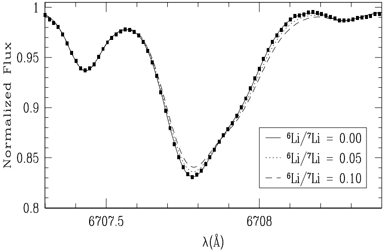
More slides. . .

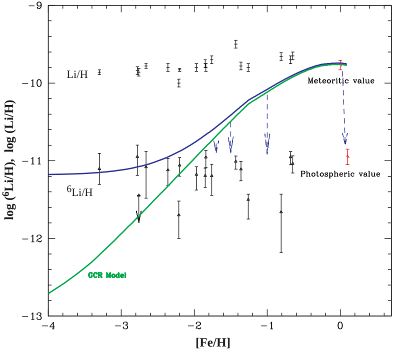


Spite plateau points to a primordial abundance which disagrees with SBBN

Many possible origin of discrepancy
Particle decay during BBN Moroi et al. (1993), Feng et al. (2003), Cerdeno et al. (2005)

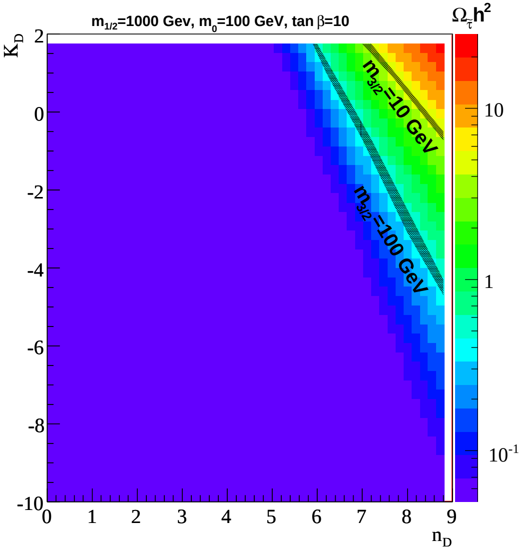
Debate on the existence of plateau ?





Many possible origin of discrepancy
Particle decay during BBN

Rollinde et al. (2006)



m1/2=1000 Gev, m0=100 GeV, tan β=10
Ωτ̃h2
KD
2
0
-2
-4
-6
-8
-10
0 1 2 3 4 5 6 7 8 9
nD
10
1
10-1
m3/2=10 GeV
m3/2=100 GeV

Thermal production (1/2)

$$Y_{3/2}(T_{\rm BBN}) = \sum_{\alpha=1}^{3}\left(1+\frac{M_\alpha^2}{3m_{3/2}^2}\right) y'_\alpha g_\alpha^2 \ln\left(\frac{k_\alpha}{g_\alpha}\right)\int_{T{\rm BBN}}^{T_R}\frac{dT}{\left[1+\kappa_D\left(\frac{T}{T_{\rm BBN}}\right)^{n_D-4}\right]^{1/2}}$$

For κ_D, we recover the standard value Y_{PS}

- $n_D = 4$

$$Y_{3/2}(T_{\rm BBN}) = \frac{1}{1+\kappa_D} Y_{\rm PS}(T_{\rm BBN})$$

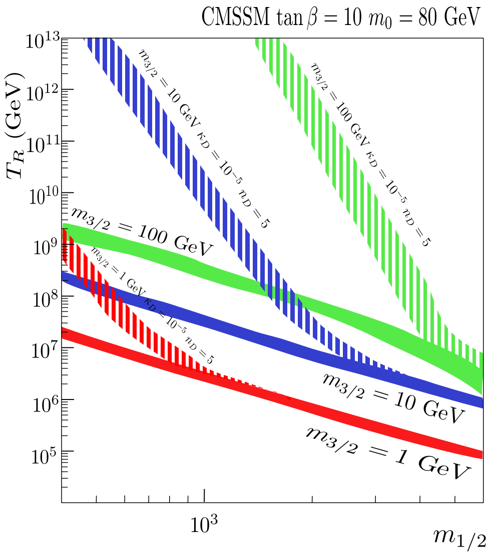
- $n_D > 4$

$$Y_{3/2}(T_{\rm BBN}) = Y_{\rm PS}(T_{\rm BBN}) \times {}_2F_1\left(1/N, 1/2; 1+1/N; -\kappa_D\left(\frac{T_R}{T_{\rm BBN}}\right)^N\right)$$

Relic density

$$\Omega_{3/2}^{\rm TP} h^2 = 2.742\times 10^8\left(\frac{m_{3/2}}{1\ {\rm GeV}}\right) Y_{3/2}(T_{\rm BBN})$$

The thermal contribution is suppressed compared to the standard scenario


CMSSM $\tan\beta = 10$ $m_0 = 80$ GeV
T_R (GeV)
$m_{1/2}$
$m_{3/2} = 10$ GeV $\kappa_D = 10^{-5}$ $n_D = 5$
$m_{3/2} = 100$ GeV $\kappa_D = 10^{-5}$ $n_D = 5$
$m_{3/2} = 100$ GeV
$m_{3/2} = 1$ GeV $\kappa_D = 10^{-5}$ $n_D = 5$
$m_{3/2} = 10$ GeV
$m_{3/2} = 1$ GeV