Gravitino, dark matter candidate and BBN

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SB, K. Jedamzik, G. Moultaka Phys.Rev.D80:063509,2009.
SB, K.Y. Choi, K. Jedamzik, L. Roszkowski JHEP 0905:103,2009.
SB, to appear very soon !

- Supersymmetric scenario with R-parity conservation
- A very very interesting dark matter candidate : gravitino
  - No direct detection
  - No indirect detection
- A nice probe for early Universe
  - Dark matter production
  - Big Bang Nucleosynthesis
  - Study in non-standard cosmological scenarios

Introduction

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Gravitino dark matter (1/2)

Non-thermal production

- All SUSY particle decay to NLSP
- Decay of NLSP to gravitino

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

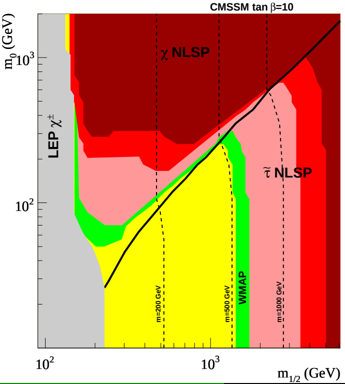
CMSSM

- Parameters :

$$m_{1/2}, \quad m_0, \quad A_0 = 0$$
$$\tan\beta = 10, \quad \mu > 0$$

- gravitino mass : $m_{3/2}$
- NLSP : neutralino or stau
- stau relic density :

$$\Omega_{\tilde\tau} h^2 = (2.2 - 4.4) \times 10^{-1} \left(\frac{m_{\tilde\tau}}{1\ \rm TeV}\right)^2$$



Thermal production

- After inflation : reheating T_R

$$\frac{dn_{3/2}}{dt} + 3Hn_{3/2} = C_{3/2}$$

- $C_{3/2}$: scattering processes with gravitino production
- Examples :

$$\begin{aligned} g + g &\rightarrow \tilde{g} + \tilde{G} \\ g + \tilde{g} &\rightarrow g + \tilde{G} \\ &\ldots \end{aligned}$$

- Gravitino thermal relic density : Pradler, Steffen '06

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

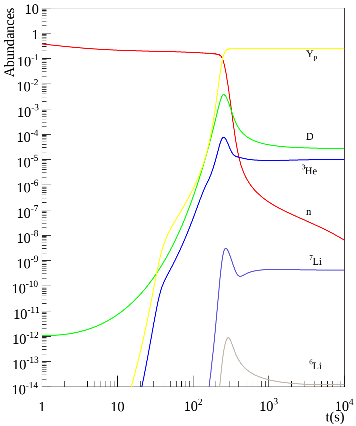
Standard BBN

- Production of light elements in the early Universe
- Predictive model : one parameter
- WMAP measurement

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

Observations

- Good agreement for D, ^{4}He
- Discrepancies for lithium isotopes



Élement	SBBN	Observations
$\left(\frac{^6\text{Li}}{\text{H}}\right)$	$10^{-14} - 10^{-15}$	$(3 - 5) \times 10^{-12}$
$\left(\frac{^7\text{Li}}{\text{H}}\right)$	$(5.24^{+0.71}_{-0.67}) \times 10^{-10}$	$(1.2 - 1.9) \times 10^{-10}$

- Post BBN evolution ?
- Observation difficulties ?
- Stellar mechanisms
- Problem with SBBN ?

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Decay of relic particle

Stau with a lifetime $\tau_X \sim 10^2 - 10^6$ s

- Decay to standard model particles : injection of photons, electrons and nucleons
- Non-thermal reactions
- Modification of abundances

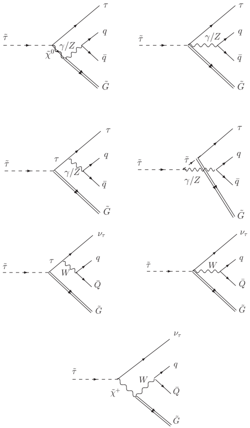
Calculation procedure

- Spectrum : SuSpect
- Relic density : MicrOMEGAs
- Lifetime and electromagnetic branching ratio and energy : CalcHEP

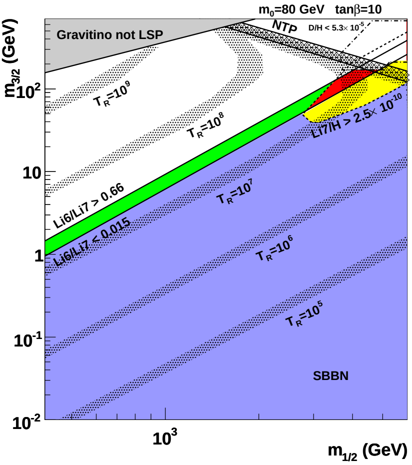
$$\tilde{\tau} \to \tau \tilde{G}$$

- Hadronic branching ratio and energy

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



■ : SBBN, ■ : ^{6}Li, ■ : ^{7}Li, ■ : both problems



solutions : $m_{\tilde{\tau}} \sim 1 - 1.8$ TeV, $m_{3/2} \sim 60 - 120$ GeV, $T_R \sim 10^7$ GeV

Non-standard cosmology

- This scenario is also a probe for non-standard cosmology
- No constraint before BBN on the composition of the Universe
- Dark component with positive energy density Arbey, Mahmoudi

$$\rho_D(T) = \kappa_D \rho_{\mathrm{rad}}(T_{\mathrm{BBN}}) \left(\frac{T}{T_{\mathrm{BBN}}} \right)^{n_D}$$

- BBN is a radiative dominated era

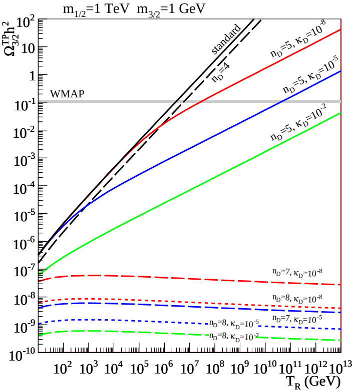
$$0 < \kappa_D < 1 \qquad \text{and} \qquad 4 \leq n_D \leq 8$$

- The Hubble parameter reads

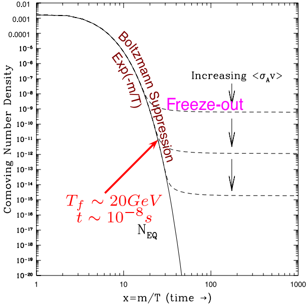
$$H^2 = \frac{8\pi G}{3} (\rho_B + \rho_D)$$

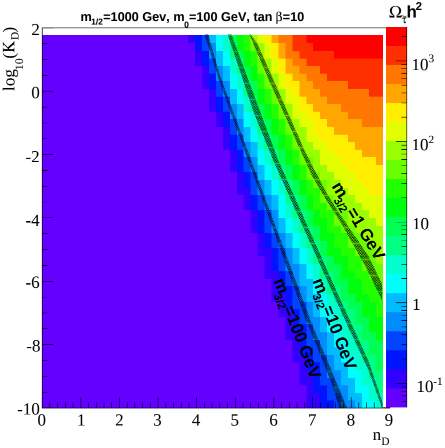
$$\Omega_{3/2}^{\rm TP}h^2 = \Omega_{3/2}^{\rm stand,TP}h^2 \times {}_2F_1\left(1/N, 1/2; 1+1/N; -\kappa_D\left(\frac{T_R}{T_{\rm BBN}}\right)^N\right)$$

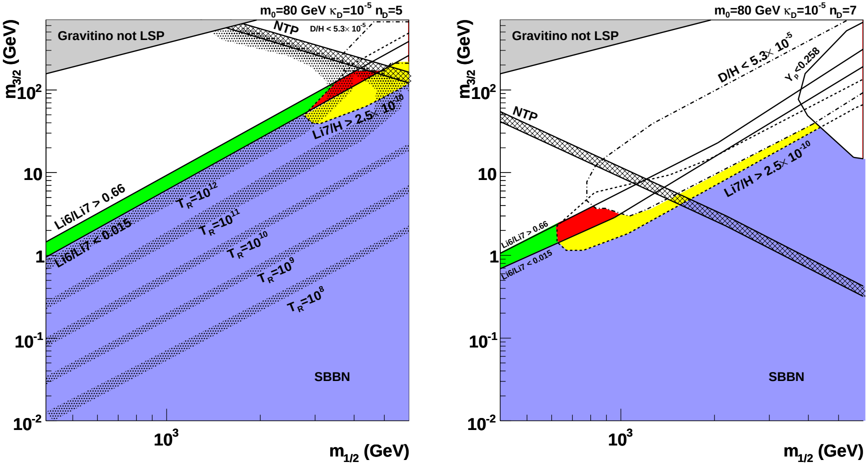
$\Rightarrow$ Suppression of gravitino production



- Freeze-out occurs earlier due to larger Hubble parameter
- Larger stau abundance







m_0=80 GeV $\kappa_D=10^{-5}$ n_D=5
Gravitino not LSP
NTP
D/H < 5.3× 10^{-5}
Li7/H > 2.5× 10^{-10}
Li6/Li7 > 0.66
Li6/Li7 < 0.015
$T_R=10^{12}$
$T_R=10^{11}$
$T_R=10^{10}$
$T_R=10^{9}$
$T_R=10^{8}$
SBBN
$m_{3/2}$ (GeV)
$m_{1/2}$ (GeV)
m_0=80 GeV $\kappa_D=10^{-5}$ n_D=7
Gravitino not LSP
D/H < 5.3× 10^{-5}
Y_p <0.258
NTP
Li7/H > 2.5× 10^{-10}
Li6/Li7 > 0.66
Li6/Li7 < 0.015
SBBN
$m_{3/2}$ (GeV)
$m_{1/2}$ (GeV)

Conclusion

- Solutions for dark matter compatible with WMAP
- Solutions for SBBN and lithium problems
- Non-standard cosmological scenario changes constraints on reheating temperature and required masses to solve lithium problems
- Collider perspective : lighter spectrum may be reachable at LHC 14 TeV run. If SUSY events are produced, quite clear signal as the stau is stable in detector and would be seen as a muon with slow velocity