Gravitino, dark matter candidate and BBN

Rencontre de Physique des Particules - IPN Lyon

Sean Bailly

LAPTH, Annecy

En collaboration avec :

Karsten Jedamzik & Gilbert Moultaka (LPTA, Montpellier)

26 janvier 2010

Composition of the Universe :

- Dark energy : 74%
- Matter
  - Dark matter : 22%
  - Ordinary matter : 4%

Problems in the matter sector

- Nature of dark matter and relic density
- Lithium problems in big bang nucleosynthesis

Solutions studied in the framework of supersymmetric models beyond the standard model with R-parity conservation

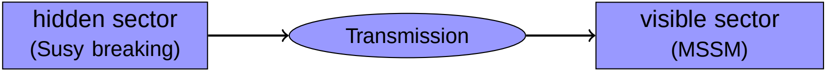
- Gravitino lightest supersymmetric particle (LSP)
- Stau next-to-lightest supersymmetric particle

Particle physics framework (1/2)

Beyond the standard model : supersymmetry

- Symmetry between fermions and bosons
- Each standard model particle has a superpartner
  - lepton tau $\longrightarrow$ stau $\tilde{\tau}$
  - no superpartner observed $\longrightarrow$ broken symmetry
- R-parity conservation

Supersymmetry breaking



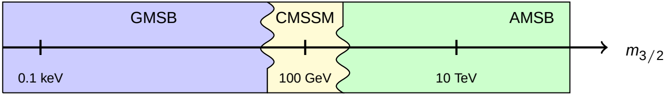
- Gravity mediated supersymmetry breaking : CMSSM
- Gauge mediated supersymmetry breaking : GMSB

Local symmetry : supergravity

- Gravitationnal sector : graviton and superpartner gravitino (spin 3/2)
- Broken supersymmetry $\rightarrow$ massive gravitino

$$m_{3/2} = \frac{F}{\sqrt{3}M_{\mathrm{Pl}}}$$

where $\sqrt{F}$ is the scale of supersymmetry breaking



Hybrid models $\Rightarrow$ Gravitino mass free parameter

Many observations can be explained by dark matter :

- Galaxy profiles
- Clusters
- Large scale structure formation
- CMB power spectrum

Relic density measured by WMAP, Komatsu et al., arXiv:0803.0547

$$\Omega_{DM} h^2 = 0.105^{+0.021}_{-0.030}$$

But... what is dark matter ?

SUSY candidates : neutralino, sneutrino, gravitino, . . .

Gravitino relic density

- Non-thermal production : decay of supersymmetric particle
- Thermal production : scattering processes during reheating

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

Non-thermal relic density

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

$$\Omega_{3/2}^{\mathrm{NTP}}h^2 = \frac{m_{3/2}}{m_{\tilde{\tau}}}\Omega_{\tilde{\tau}}h^2$$

Relic density of stau

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

- After inflation : reheating T_R
- Scattering processes with gravitino production
- Examples :

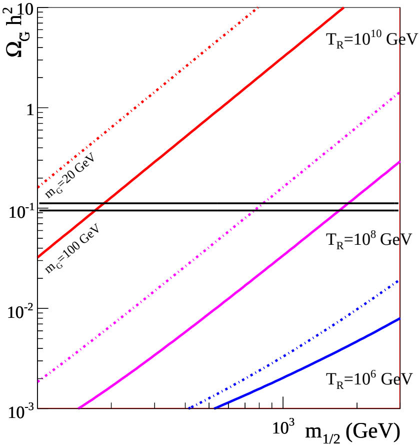
$$\begin{aligned} g + g &\longrightarrow \tilde{g} + \tilde{G} \\ g + \tilde{g} &\longrightarrow g + \tilde{G} \\ &\ldots \end{aligned}$$

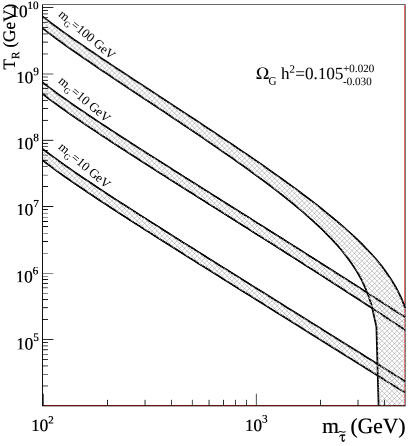
- Gravitino thermal relic density : Pradler, Steffen, hep-ph/0608344

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

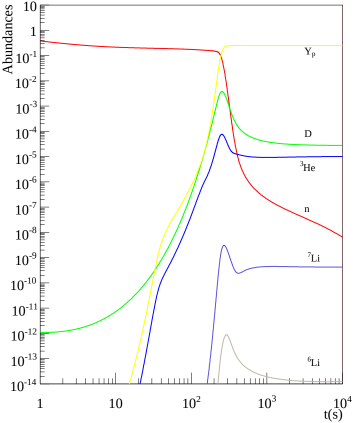
Gravitino relic density

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




m_G =100 GeV
m_G =10 GeV
m_G =10 GeV
$\Omega_G h^2=0.105^{+0.020}_{-0.030}$
T_R (GeV)
10^{10}
10^9
10^8
10^7
10^6
10^5
10^2
10^3
$m_{\tilde{\tau}}$ (GeV)

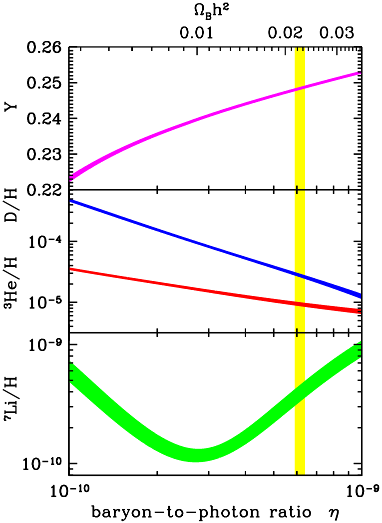
Big bang nucleosynthesis : SBBN (1/2)



- WMAP measurement

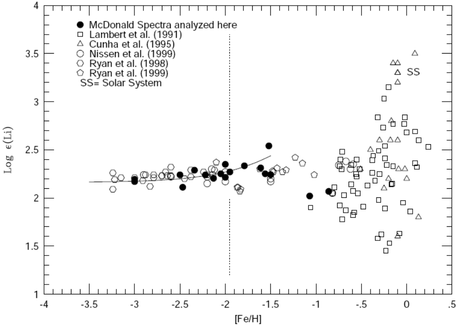
$$\eta = \frac{n_b}{n_\gamma} = (6.225 \pm 0.170) \times 10^{-10}$$

Good agreement for D, ^{4}He



Élement	SBBN	Observations
$\left(\frac{^6Li}{H}\right)$	$10^{-14} - 10^{-15}$	$(3-5)\times 10^{-12}$
$\left(\frac{^7Li}{H}\right)$	$(4.26^{+0.91}_{-0.86})\times 10^{-10}$	$(1.2-1.9)\times 10^{-10}$

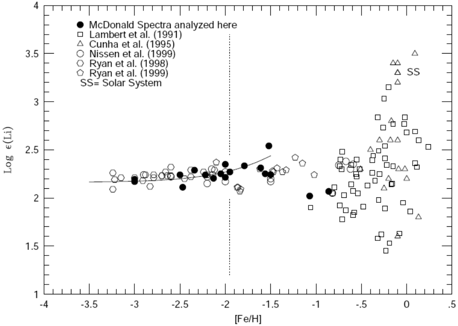
- Post BBN evolution ? Observations difficulties ?
- Problem with SBBN ?



- Spite plateau : primordial abundance

Élement	SBBN	Observations
$\left(\frac{^6Li}{H}\right)$	$10^{-14} - 10^{-15}$	$(3-5) \times 10^{-12}$
$\left(\frac{^7Li}{H}\right)$	$(4.26^{+0.91}_{-0.86}) \times 10^{-10}$	$(1.2-1.9) \times 10^{-10}$

- Post BBN evolution ? Observations difficulties ?
- Problem with SBBN ?



- Spite plateau : primordial abundance

- Unstable massive stau decay with a lifetime $\tau_X \sim 10^2 - 10^6$ s
- Decay to standard model particles
- Injection of photons and nucleons
  - photodisintegration : $^7\mathrm{Li} + \gamma \to {}^6\mathrm{Li} + n$
  - spallation : $^4\mathrm{He} + n \to {}^3\mathrm{He} + 2n$ followed by $^3\mathrm{He} + {}^4\mathrm{He} \to {}^6\mathrm{Li} + n$
- Modification of abundances

Required calculations :

- Relic density
- Hadronic branching ratio and energy
- Electromagnetic branching ratio and energy

- Stau decay dominated by two-body decay : $\tau \simeq 1/\Gamma(\tilde{\tau} \to \tau\tilde{G})$

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

- Lepton tau decay $\to$ electromagnetic decay

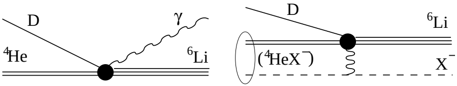
$$B_{\rm em} = \frac{\Gamma(\tilde{\tau} \to \tau\tilde{G})}{\Gamma_{\rm tot}} \simeq 1 \qquad \text{and} \qquad E_{\rm em} = \frac{1}{2}E_\tau = \frac{1}{2}\left(\frac{m_{\tilde{\tau}}^2 - m_{3/2}^2}{2m_{\tilde{\tau}}}\right)$$

- Hadronic decay : four-body decay

$$\begin{aligned} \tilde{\tau} &\to \tau\tilde{G}Z/\gamma \to \tau\tilde{G}q\bar{q} \\ \tilde{\tau} &\to \tau\tilde{G}h \to \tau\tilde{G}q\bar{q} \\ \tilde{\tau} &\to \tau\tilde{G}W \to \nu_\tau\tilde{G}q\bar{Q} \end{aligned}$$

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

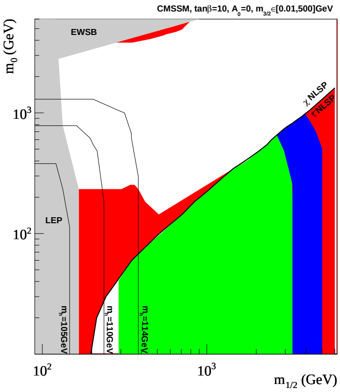
- Negatively charged particle : bound state formation
- Reaction catalysis Pospelov, hep-ph/0605215

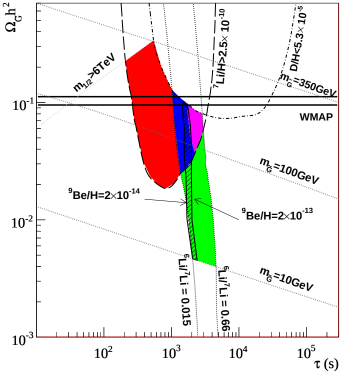


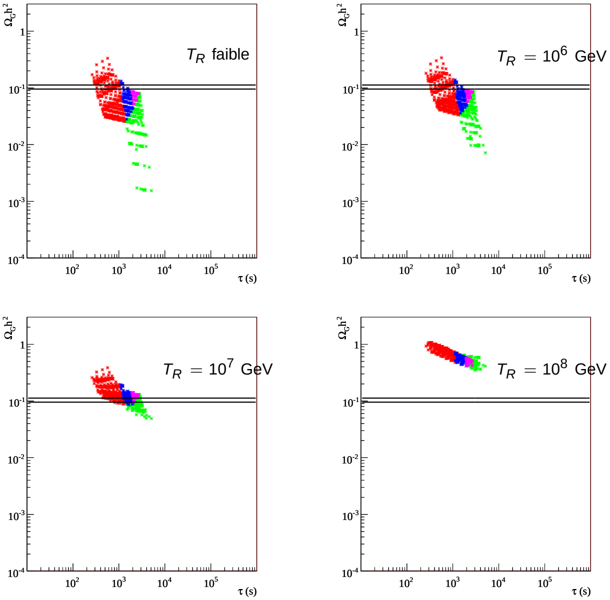
- $\sigma_{\rm CBBN} \simeq 10^8 \times \sigma_{\rm SBBN}$: forte contrainte sur l'abondance de lithium-6

BBN code (Jedamzik, hep-ph/0604251) taking into account all bound states (cross-sections in Kamimura et al., arXiv:0809.4772) effects and decay effects

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






T_R faible
$T_R = 10^6$ GeV
$T_R = 10^7$ GeV
$T_R = 10^8$ GeV
$\Omega_G h^2$
τ (s)
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^2
10^3
10^4
10^5

Conclusions

- Supersymmetry with gravitino LSP and stau NLSP
- Gravitino candidate for dark matter : thermal and non-thermal production
- Decay of stau during BBN : solutions for lithium problems

- $m_{\tilde{\tau}} \sim 1$ TeV
- $m_{\tilde{G}} \sim 100$ GeV
- $T_R \lesssim 10^7$ GeV