R-PARITY VIOLATION AND THE COSMOLOGICAL GRAVITINO PROBLEM

—

G. Moreau

Physikalisches Institut, Universität Bonn, Germany

M. Chemtob

Service de Physique Théorique, CEA/Saclay, France

Phys. Rev. **D65** (2002) 024033.

ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES

- Moriond - - 03/2002 -

Introduction

The Cosmological Gravitino Problem

The gravitino ($\Psi_\mu \equiv$ spin 3/2 field of the supersymmetric partner of the graviton) has gravitational interactions.
Ex: Lagrangian of the coupling with matter ($\psi \equiv$ spin 1/2 field, $\phi \equiv$ spin 0 field of the supersymmetric partner):

$$\mathcal{L} = -\frac{1}{\sqrt{2}M_\star}\bar{\psi}_L \gamma^\mu \gamma^\nu \partial_\nu \phi \Psi_{\mu R} \; + \; \text{h.c.},$$

with,

$$M_\star = \frac{M_{Planck}}{\sqrt{8\pi}} = \frac{1}{\sqrt{8\pi G_N}} = 2.4 \; 10^{18} GeV.$$

$\Downarrow$

1) The gravitino-gravitino annihilation reactions of the type $\tilde{G}\tilde{G} \to f f$ go out of equilibrium at early times ($n < \sigma v >= \Gamma < H$, $\Gamma \equiv$ reaction rate, $H \equiv$ universe expansion rate).

2) In particular, this gravitino decoupling occurs at $kT_d > m_{3/2}$ ($m_{3/2} \equiv$ gravitino mass).
$\Rightarrow$ The annihilation reactions of the type $\tilde{G}\tilde{G} \to f f$ are in equilibrium for temperatures $kT > kT_d > m_{3/2}$ at which the inverse reactions $f f \to \tilde{G}\tilde{G}$ ($\equiv$ gravitino production reactions) are also in equilibrium.
$\Rightarrow$ The decrease of the population of a stable gravitino ($\Rightarrow$ gravitino LSP) is not possible.

$\Downarrow$

Large relic number density of the (stable) gravitino.

Potential Solutions

1) Compensation of the important gravitino relic number density by a small gravitino mass: $m_{3/2} < 1keV$.
$\Rightarrow$ Bound on the cosmological energy density $\Omega_0 \lesssim 1$ respected (*H. Pagels and J. R. Primack, Phys. Rev. Lett.* **48** *(1982) 223*).

2) Inflation models: dilution of the gravitino number density during the exponential expansion phase of the universe history.

3) Unstable gravitino (life time sufficiently short):

• *Gravitino $\neq$ LSP*
Decay of the gravitino into superpartners (ex: $\tilde{G} \to \tilde{l}^{\pm} l^{\mp}$).
$\Rightarrow$ The LSP number density conflicts with the data on the universe energy density (*L. M. Krauss, Nucl. Phys.* **B277** *(1983) 556*).

• *Gravitino = LSP & Violation of the R-parity symmetry*
Decay of the gravitino into Standard Model particles via the R-parity violating ($\not{R}_p$) interactions, which couple an odd number of superpartners:

$$W_{\not{R}_p} = \sum_{i,j,k} \Big(\frac{1}{2} \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2} \lambda''_{ijk} U^c_i D^c_j D^c_k + \mu_i H L_i \Big).$$

Lagrangian of the trilinear interactions associated to the λ, λ' and λ'' terms of the superpotential:

$$\begin{aligned}
\mathcal{L}_{\not{R}_p} = \Sigma_{ijk} \Big[& - \lambda_{ijk} \ \tfrac{1}{2} \Big(\tilde{\nu}_{iL} \bar{e}_{kR} e_{jL} + \tilde{e}_{jL} \bar{e}_{kR} \nu_{iL} + \tilde{e}^{\star}_{kR} \bar{\nu}^c_{iR} e_{jL} - (i \leftrightarrow j) \Big) \\
& - \lambda'_{ijk} \ \Big(\tilde{\nu}_{iL} \bar{d}_{kR} d_{jL} + \tilde{d}_{jL} \bar{d}_{kR} \nu_{iL} + \tilde{d}^{\star}_{kR} \bar{\nu}^c_{iR} d_{jL} \\
& \qquad - \tilde{e}_{iL} \bar{d}_{kR} u_{jL} - \tilde{u}_{jL} \bar{d}_{kR} e_{iL} - \tilde{d}^{\star}_{kR} \bar{e}^c_{iR} u_{jL} \Big) \\
& - \lambda''_{ijk} \ \tfrac{1}{2} \Big(\tilde{u}^{\star}_{iR} \bar{d}_{jR} d^c_{kL} + 2 \tilde{d}^{\star}_{jR} \bar{u}_{iR} d^c_{kL} \Big) \Big] + \text{h.c.}
\end{aligned}$$

Does the scenario containing an unstable LSP gravitino decaying via $\not R_p$ trilinear interactions constitute effectively a solution to the cosmological gravitino problem ?

Plan:

I) Constraints in a scenario characterised by an unstable gravitino and supposed to solve the cosmological gravitino problem.

II) Results of the calculations of gravitino decay rates involving the $\not R_p$ trilinear couplings.

III) Quantitative discussion (based on I & II and the experimental bounds on the $\not R_p$ coupling constants) aimed at determining whether the scenario of an unstable LSP gravitino, decaying through $\not R_p$ trilinear couplings, provides a natural solution with respect to the cosmological gravitino problem.

Conclusion (& comparison with the results of the study on $\not R_p$ bilinear terms)

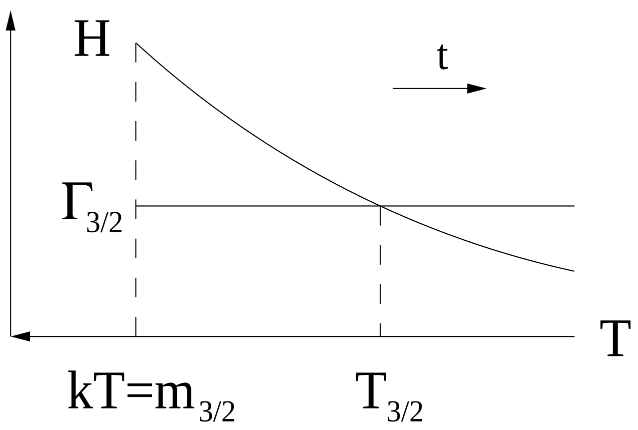
I) Temperatures characteristic of a model with an unstable gravitino and their constraints

Scenario Containing an Unstable Gravitino

Maximum Gravitino Decay Rate:

$$\Gamma^{max}_{3/2} \approx \Gamma(\tilde{G} \to \tilde{f} f) \sim m^3_{3/2}/M^2_{Planck}.$$

For $kT = m_{3/2}$, $H(T) \approx \frac{\sqrt{m_{3/2}}}{M_{Planck}}(kT)^{3/2} = m^2_{3/2}/M_{Planck}$.



$\Rightarrow$ **Equilibrium** ($\Gamma_{3/2} \geq H(T)$) **reached at** $kT_{3/2} < m_{3/2}$**.**

$\Downarrow$

1) Decay of the gravitinos at the temperature $kT_{3/2}(< m_{3/2})$ at which they cannot be reproduced in collisions.
$\Rightarrow$ The gravitino decays can effectively decrease the quantity of gravitinos.

2) Determination of the equilibrium temperature $T_{3/2}$ at which gravitinos decay:

$$\Gamma_{3/2} = H(T) \quad \text{with} \quad H(T) \approx \sqrt{\frac{8\pi G_N}{3}\rho_{3/2}}.$$

$$\rho_{3/2} = \frac{3\zeta(3)}{\pi^2}\frac{g(T)}{g(T_d)} m_{3/2}(kT)^3,$$

where $\zeta(3) = 1.20206\ldots$ (*Riemann* function), $g(T) \equiv$ statistical factor counting the number of massless degrees of freedom (particles such that $m \ll kT$), $T_d \equiv$ gravitino decoupling temperature.

$$\boxed{kT_{3/2} \approx \left(\frac{\pi}{8\zeta(3)}\frac{g(T_d)}{g(T_{3/2})}\right)^{1/3}\left(\Gamma_{3/2}^2 M_{Planck}^2/m_{3/2}\right)^{1/3}.}$$

At $T = T_{3/2}$, most of the gravitinos decay. After this, the gravitino decay energy *thermalises* and the temperature increases from $T_{3/2}$ to $T'_{3/2}$:

$$(kT'_{3/2})^4 \approx \frac{90\zeta(3)}{\pi^4}\frac{m_{3/2}(kT_{3/2})^3}{g(T_{3/2})}.$$

(energy density conservation)

$$\boxed{kT'_{3/2} \approx \left(\frac{45}{4\pi^3}\right)^{1/4}\frac{g(T_d)^{1/4}}{g(T_{3/2})^{1/2}}\sqrt{\Gamma_{3/2}M_{Planck}}.}$$

Constraints on a Scenario Containing an Unstable Gravitino and Solving the Cosmological Gravitino Problem

• The absence of a large gravitino relic number density is guaranteed by a decay of the gravitinos, previous to the present epoch:

$$kT'_{3/2} > 2.75K \quad (= 2.36\ 10^{-10} MeV).$$

• Elevation of the temperature after thermalisation of the gravitino decay energy:

$$\frac{T'_{3/2}}{T_{3/2}} \approx \frac{45^{1/4}\sqrt{2}\zeta(3)^{1/3}}{\pi^{13/12}}\left(\frac{g(T_{3/2})}{g(T_d)^{-1/2}}\right)^{-1/6}\left(m_{3/2}/\sqrt{\Gamma_{3/2}M_{Planck}}\right)^{1/3}$$
$$> \frac{45^{1/4}\sqrt{2}\zeta(3)^{1/3}}{\pi^{13/12}}\left(\frac{g(T_{3/2})}{g(T_d)^{-1/2}}\right)^{-1/6}\left(M_{Planck}/m_{3/2}\right)^{1/6}.$$

⇒ Increase of the entropy density: $s = (2\pi^2/45)g(T)(kT)^3$.
⇒ Decrease of the baryon number: $B = n_B/s$,
$n_B \equiv$ baryon number density.

$$\left(\underline{\underline{\text{Ex:}}}\ m_{3/2} = 10^{13}GeV \Rightarrow \frac{T'_{3/2}}{T_{3/2}} \sim 10 \Rightarrow \frac{s'}{s} \sim 10^3 \Rightarrow \frac{B'}{B} \sim 10^{-3}\right)$$

⇒ **If** the thermalisation of gravitino decay energy occurs after the *nucleosynthesis*
⇒ B during the nucleosynthesis > present B.
⇒ Production (via nucleosynthesis) of too much *Helium* and too little *Deuterium*, compared to the constraints on the primordial abundances derived from the observationnal data (*S. Weinberg, Phys. Rev. Lett.* **48** *(1982) 1303*).

⇒ If the gravitinos decay before the present epoch, the thermalisation temperature must be higher than the nucleosynthesis temperature:

$$kT'_{3/2} > 0.4MeV.$$

II) Rates of the gravitino decay via $R\!\!\!/_p$ trilinear couplings

Does a given scenario containing an unstable gravitino represent a solution of the cosmological gravitino problem ?

$$\Leftrightarrow \; kT'_{3/2} > 0.4MeV \; ?$$

$\hookrightarrow$ **Calculation of the decay rates ($\Gamma_{3/2}$) in this scenario.**
$\Rightarrow$ **Thermalisation temperature ($T'_{3/2}$).**

Considered scenario $\equiv$ Gravitino LSP decaying via $R\!\!\!/_p$ trilinear interactions.

Gravitino Decay Channels

In the considered scenario, the gravitino decay channels, having the largest rates, are the decays into 3 Standard Model fermions via the exchange of a virtual scalar superpartner:

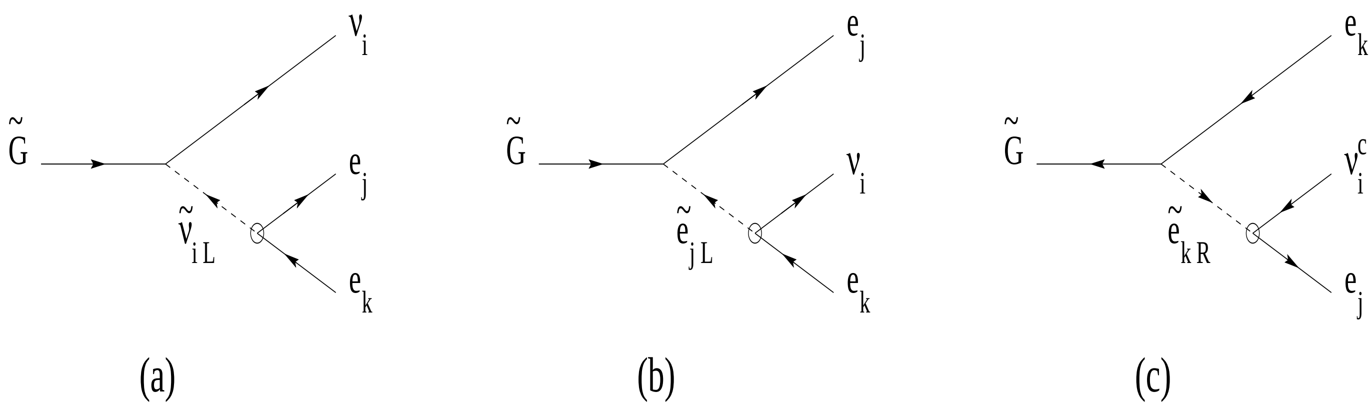


Figure 1: *Feynman* diagrams of the dominant gravitino decays involving the interactions $\lambda_{ijk} L_i L_j E^c_k$ (represented by circles). The arrows denote the momentum of the associated particles. The charge conjugated processes are easily deduced from these ones.

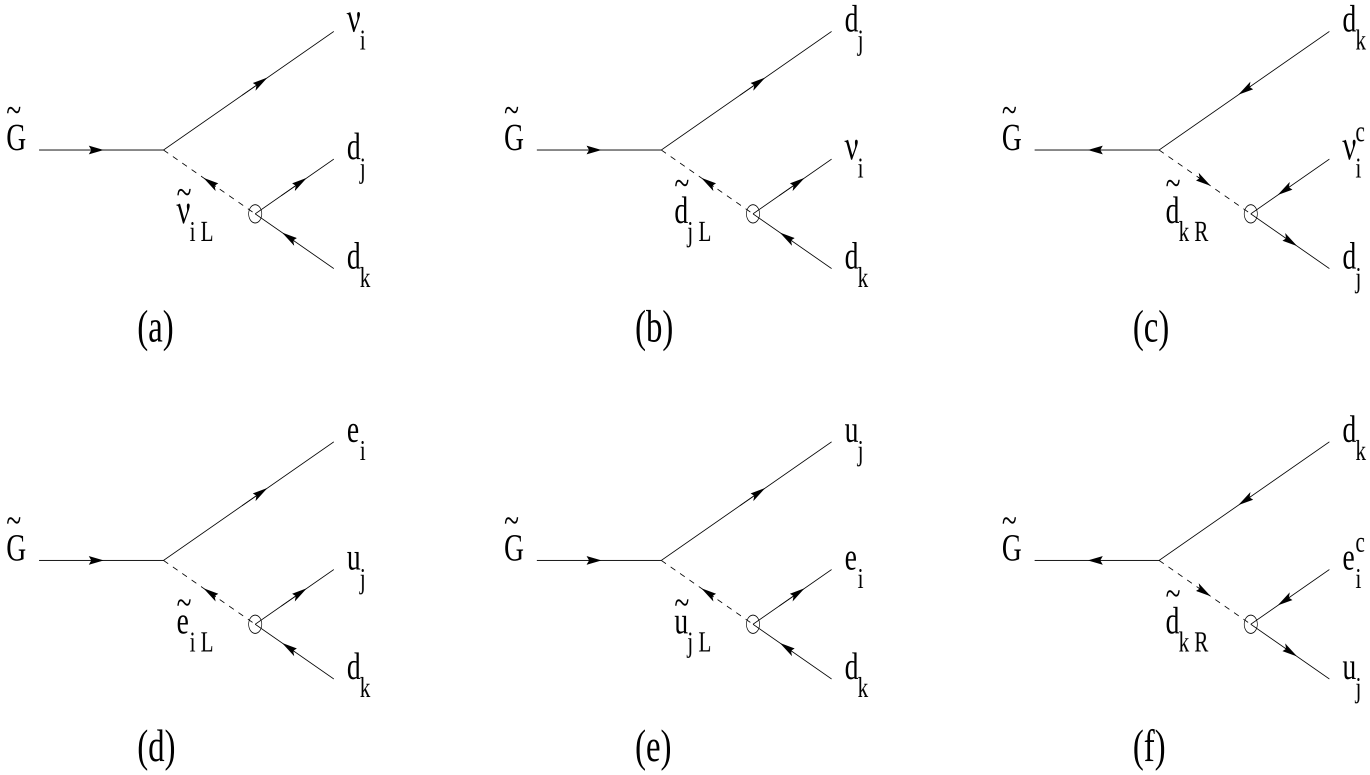


Figure 2: *Feynman* diagrams of the decays through the interactions $\lambda'_{ijk} L_i Q_j D^c_k$.

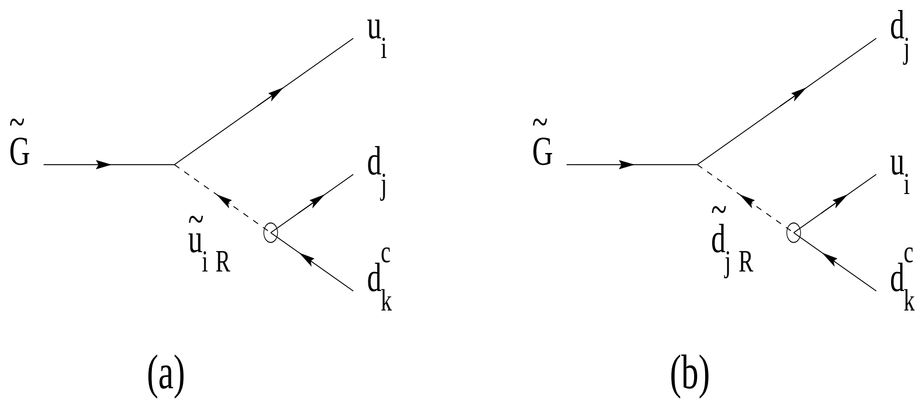


Figure 3: *Feynman* diagrams of the decays through the interactions $\lambda''_{ijk} U^c_i D^c_j D^c_k$.

Analytical Results of the Decay Rate Calculations

(final state ordinary fermion masses neglected with respect to the masses of the gravitino and the exchanged scalar superpartners ⇒ simplified expressions)

$$\mathbf{\Gamma(\tilde{G} \overset{\lambda_{ijk}}{\to} \nu_i e_j \bar{e}_k)} = \frac{1}{96(2\pi)^3}\frac{\lambda^2_{ijk}}{m^3_{3/2}M^2_\star}\Big[\Omega(m_{\tilde{\nu}_{iL}}) + \Omega(m_{\tilde{e}_{jL}}) + \Omega(m_{\tilde{e}_{kR}})$$
$$+\Xi(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{kR}}) + \Xi(m_{\tilde{e}_{jL}}, m_{\tilde{e}_{kR}}) + \Xi(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{jL}})$$
$$+\Sigma(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{kR}}) + \Sigma(m_{\tilde{e}_{jL}}, m_{\tilde{e}_{kR}}) + \Sigma(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{jL}}) + \Sigma(m_{\tilde{e}_{jL}}, m_{\tilde{\nu}_{iL}})$$
$$+\Delta(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{kR}})[Sp(\frac{m^2_{\tilde{\nu}_{iL}}}{m^2_{\tilde{\nu}_{iL}}+m^2_{\tilde{e}_{kR}}-m^2_{3/2}}) - Sp(\frac{m^2_{\tilde{\nu}_{iL}}-m^2_{3/2}}{m^2_{\tilde{\nu}_{iL}}+m^2_{\tilde{e}_{kR}}-m^2_{3/2}})]$$
$$+\Delta(m_{\tilde{e}_{jL}}, m_{\tilde{e}_{kR}})[Sp(\frac{m^2_{\tilde{e}_{jL}}}{m^2_{\tilde{e}_{jL}}+m^2_{\tilde{e}_{kR}}-m^2_{3/2}}) - Sp(\frac{m^2_{\tilde{e}_{jL}}-m^2_{3/2}}{m^2_{\tilde{e}_{jL}}+m^2_{\tilde{e}_{kR}}-m^2_{3/2}})]$$
$$+\Delta(m_{\tilde{\nu}_{iL}}, m_{\tilde{e}_{jL}})[-Sp(-\frac{m^2_{\tilde{e}_{jL}}}{m^2_{\tilde{\nu}_{iL}}}) - Sp(-\frac{m^2_{\tilde{\nu}_{iL}}}{m^2_{\tilde{e}_{jL}}})$$
$$+Sp(\frac{m^2_{3/2}-m^2_{\tilde{e}_{jL}}}{m^2_{\tilde{\nu}_{iL}}}) + Sp(\frac{m^2_{3/2}-m^2_{\tilde{\nu}_{iL}}}{m^2_{\tilde{e}_{jL}}})]\Big],$$

$$\mathbf{\Omega(m)} = \frac{1}{48}\Big(60m^6 - 162m^4m^2_{3/2} + 140m^2m^4_{3/2} - 37m^6_{3/2}$$
$$+12(m^2 - m^2_{3/2})^3(5\frac{m^2}{m^2_{3/2}} - 1)\log(1 - \frac{m^2_{3/2}}{m^2})\Big),$$
$$\mathbf{\Xi(m_1, m_2)} = \frac{1}{48}\Big(84m_1^2m_2^2m^2_{3/2} + 7m^6_{3/2}$$
$$+m_1^2(-12m_1^4 + 24m_2^4 + 42m_1^2m^2_{3/2} - 40m^4_{3/2})$$
$$+m_2^2(-12m_2^4 + 24m_1^4 + 42m_2^2m^2_{3/2} - 40m^4_{3/2})$$
$$+(\frac{2m_2^2m_1^4 - m_1^6}{m^2_{3/2}} + 4m_1^4 - 4m_2^2m^2_{3/2} - 5m_1^2m^2_{3/2} + 2m^4_{3/2} + 2m_1^2m_2^2)$$
$$12m_1^2\log(1 - \frac{m^2_{3/2}}{m_1^2}) + 12m_2^2\log(1 - \frac{m^2_{3/2}}{m_2^2})$$
$$(\frac{2m_1^2m_2^4 - m_2^6}{m^2_{3/2}} + 4m_2^4 - 4m_1^2m^2_{3/2} - 5m_2^2m^2_{3/2} + 2m^4_{3/2} + 2m_1^2m_2^2)\Big),$$
$$\mathbf{\Delta(m_1, m_2)} = -m_1^2m_2^2(\frac{m_1^2m_2^2}{2m^2_{3/2}} + m_1^2 + m_2^2 - m^2_{3/2}),$$
$$\mathbf{\Sigma(m_1, m_2)} = \Delta(m_1, m_2)\log(1 - \frac{m^2_{3/2}}{m_1^2})\log(1 + \frac{m_1^2}{m_2^2} - \frac{m^2_{3/2}}{m_2^2}).$$

$$\mathbf{\Gamma(\tilde{G} \stackrel{\lambda'_{ijk}}{\rightarrow} \nu_i d_j \bar{d}_k)} = \mathbf{\Gamma(\tilde{G} \stackrel{\lambda_{ijk}}{\rightarrow} \nu_i e_j \bar{e}_k)} \begin{cases} \lambda_{ijk} \rightarrow \lambda'_{ijk} \\ m_{\tilde{\nu}_{iL}} \rightarrow m_{\tilde{\nu}_{iL}} \\ m_{\tilde{e}_{jL}} \rightarrow m_{\tilde{d}_{jL}} \\ m_{\tilde{e}_{kR}} \rightarrow m_{\tilde{d}_{kR}} \\ \times N_c = 3 \end{cases}$$

$$\mathbf{\Gamma(\tilde{G} \stackrel{\lambda'_{ijk}}{\rightarrow} e_i u_j \bar{d}_k)} = \mathbf{\Gamma(\tilde{G} \stackrel{\lambda_{ijk}}{\rightarrow} \nu_i e_j \bar{e}_k)} \begin{cases} \lambda_{ijk} \rightarrow \lambda'_{ijk} \\ m_{\tilde{\nu}_{iL}} \rightarrow m_{\tilde{e}_{iL}} \\ m_{\tilde{e}_{jL}} \rightarrow m_{\tilde{u}_{jL}} \\ m_{\tilde{e}_{kR}} \rightarrow m_{\tilde{d}_{kR}} \\ \times N_c = 3 \end{cases}$$

$$\mathbf{\Gamma(\tilde{G} \stackrel{\lambda''_{ijk}}{\rightarrow} u_i d_j d_k)} = \frac{N_c!}{96(2\pi)^3} \frac{\lambda''^2_{ijk}}{m^3_{3/2} M^2_\star} \Big[\Omega(m_{\tilde{u}_{iR}}) + 4\Omega(m_{\tilde{d}_{jR}})$$
$$+2\Xi(m_{\tilde{u}_{iR}}, m_{\tilde{d}_{jR}}) + 2\Sigma(m_{\tilde{u}_{iR}}, m_{\tilde{d}_{jR}}) + 2\Sigma(m_{\tilde{d}_{jR}}, m_{\tilde{u}_{iR}})$$
$$+2\Delta(m_{\tilde{u}_{iR}}, m_{\tilde{d}_{jR}})[-Sp(-\frac{m^2_{\tilde{d}_{jR}}}{m^2_{\tilde{u}_{iR}}}) - Sp(-\frac{m^2_{\tilde{u}_{iR}}}{m^2_{\tilde{d}_{jR}}})$$
$$+Sp(\frac{m^2_{3/2} - m^2_{\tilde{d}_{jR}}}{m^2_{\tilde{u}_{iR}}}) + Sp(\frac{m^2_{3/2} - m^2_{\tilde{u}_{iR}}}{m^2_{\tilde{d}_{jR}}})]\Big].$$

Gravitino Life Time

(all masses taken into account)

For $1 > (\frac{m_{3/2}}{\tilde{m}})^2 > 0$ and with $\hat{\lambda}_{ijk} = \lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}$:

$$\tau(\tilde{G} \stackrel{\hat{\lambda}_{ijk}}{\to} f_i f_j f_k) \approx 10^9 - 10^{11} \left(\frac{1}{\hat{\lambda}^2_{ijk}}\right)\left(\frac{1TeV}{m_{3/2}}\right)^3 sec.$$

Typically, for $\hat{\lambda}_{ijk} = 10^{-1}$ and $m_{3/2} = 10^2 GeV$:

$\tau(\tilde{G} \stackrel{\hat{\lambda}_{ijk}}{\to} f_i f_j f_k) \approx 10^{14} - 10^{16} sec < t_0 \simeq 3.2\, 10^{17} sec$ (age of the universe).

III) Numerical results of the $T'_{3/2}$ calculations

Results of $\Gamma_{3/2}$ $\boxed{\Rightarrow}$ values of $T'_{3/2} \approx \sqrt{\Gamma_{3/2} M_{Planck}}$.
$\Gamma_{3/2} = \Gamma_{3/2}(\hat{\lambda}_{ijk}, m_{3/2}, \tilde{m})$ $\boxed{\Rightarrow}$ $T'_{3/2} = T'_{3/2}(\hat{\lambda}_{ijk}, m_{3/2}, \tilde{m})$
($\hat{\lambda}_{ijk} = \lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk}$, $\tilde{m} \equiv$ univ. mass of superpartners).

One Single Dominant Coupling Constant of type λ_{ijk}

$\lambda_{233} = 0.06(\frac{m_{\tilde{\tau}_R}}{100GeV})$ ($\equiv$ present low-energy experimental bound on λ_{233} obtained at colliders, under the hypothesis of one single dominant coupling among a set of $\not{R}_p$ couplings).

The limit on λ_{233} is one of the less severe constraints on the λ_{ijk}.
$\Rightarrow$ Maximisation of $\Gamma_{3/2}$ and thus of $T'_{3/2}$.

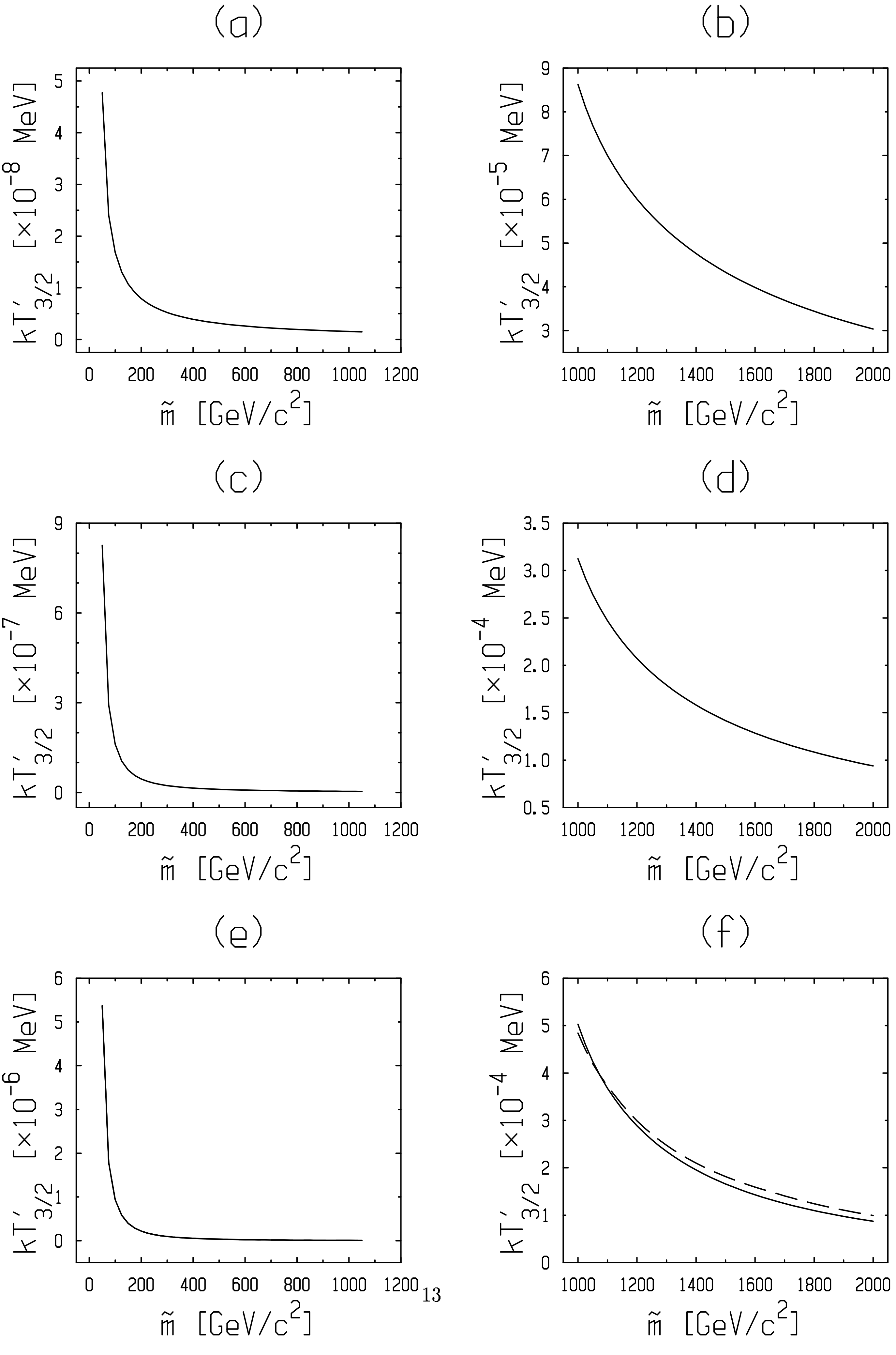
$$\boxed{\tilde{m} < \mathcal{O}(TeV) \Rightarrow kT'_{3/2} \ll 0.4MeV.}$$

One Single Dominant Coupling Constant of type λ'_{ijk}

$\lambda'_{331} = 0.48$ for $m_{\tilde{q}} = 100GeV$ ($\equiv$ present low-energy experimental bound on λ'_{331} obtained at colliders, under the hypothesis of one single dominant coupling among a set of $\not{R}_p$ couplings).

The limit on λ'_{331} is one of the less severe constraints on the λ'_{ijk}.
$\Rightarrow$ Maximisation of $\Gamma_{3/2}$ and thus of $T'_{3/2}$.

$$\boxed{\tilde{m} < \mathcal{O}(TeV) \Rightarrow kT'_{3/2} \ll 0.4MeV.}$$


(a)
(b)
(c)
(d)
(e)
(f)
kT′3/2 [×10−8 MeV]
kT′3/2 [×10−5 MeV]
kT′3/2 [×10−7 MeV]
kT′3/2 [×10−4 MeV]
kT′3/2 [×10−6 MeV]
kT′3/2 [×10−4 MeV]
m̃ [GeV/c2]
0 200 400 600 800 1000 1200
1000 1200 1400 1600 1800 2000
0 1 2 3 4 5
3 4 5 6 7 8 9
0 3 6 9
0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 1 2 3 4 5 6

One Single Dominant Coupling Constant of type λ''_{ijk}

$\lambda''_{213} = 1.25$ for $M_{SUSY} \approx 1TeV$ ($\equiv$ bound on λ''_{213} derived from the perturbativity condition: $\lambda''^2_{213}/4\pi < 1$, up to the grand unification scale, in the hypothesis of one single dominant coupling among a set of $R\!\!\!/_p$ couplings).

The limit on λ''_{213} is one of the less severe constraints on the λ''_{ijk}.
$\Rightarrow$ Maximisation of $\Gamma_{3/2}$ and thus of $T'_{3/2}$.

$$kT'_{3/2} > 0.4MeV \Rightarrow m_{3/2} \gtrsim 80TeV.$$

"Optimistic" Scenario

Let us consider a type of scenario in which several $R\!\!\!/_p$ coupling constants are *simultaneously* dominant, and, are equal to their present limit (obtained under the hypothesis of one single dominant coupling among a set of $R\!\!\!/_p$ couplings).

Present constraints on the $R\!\!\!/_p$ couplings $\Rightarrow$ Scenario of this type leading to the *maximum* $\Gamma_{3/2}$, and hence to the *maximum* $T'_{3/2}$, (for $m_{3/2} = 1TeV$ and $\tilde{m} = 1.5TeV$) $\equiv$ Scenario containing the following simultaneously dominant $R\!\!\!/_p$ coupling constants:

$$\lambda'_{132},\ \lambda'_{211},\ \lambda'_{223},\ \lambda'_{311},\ \lambda_{121} \text{ and } \lambda_{233}.$$

Present limits (hypothesis of single $R\!\!\!/_p$ coupling dominance):
$\lambda'_{132} < 0.34(m_{\tilde{q}} = 100GeV)$, $\lambda'_{211} < 0.06(m_{\tilde{d}_R}/100GeV)$,
$\lambda'_{223} < 0.18(m_{\tilde{b}_R}/100GeV)$, $\lambda'_{311} < 0.10(m_{\tilde{d}_R}/100GeV)$,
$\lambda_{121} < 0.05(m_{\tilde{e}_R}/100GeV)$, $\lambda_{233} < 0.06(m_{\tilde{\tau}_R}/100GeV)$.

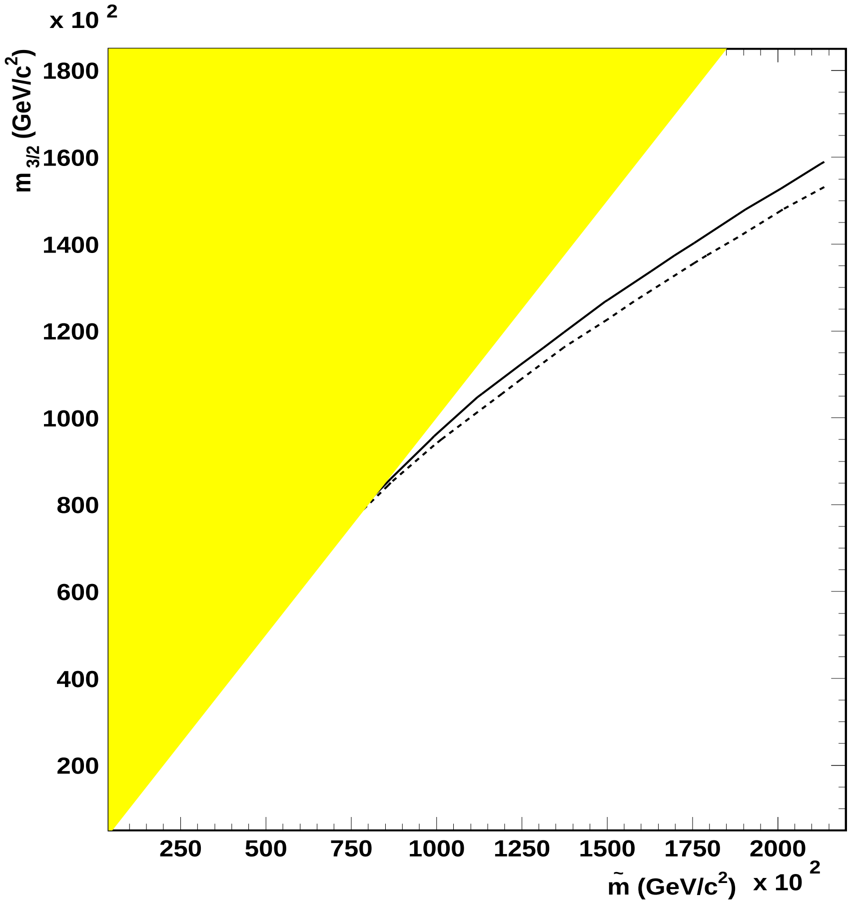


Figure 4: Domains of the $m_{3/2}(GeV/c^2)$-$\tilde{m}(GeV/c^2)$ plane (gravitino versus superpartner mass) in which $kT'_{3/2} > 0.4MeV$. The region situated above the plain line corresponds to $kT'_{3/2} > 0.4MeV$ in case **the dominant $\not R_p$ coupling constant is** $\lambda''_{213} = 1.25$. The domain situated above the dashed line corresponds to $kT'_{3/2} > 0.4MeV$ in case **the dominant $\not R_p$ coupling constants are** $\lambda'_{132} = 1.04$, $\lambda'_{211} = 1$, $\lambda'_{223} = 1.12$, $\lambda'_{311} = 1.12$, $\lambda_{121} = 1$ **and** $\lambda_{233} = 1$. All these $\not R_p$ coupling constants have been set to their perturbativity limit, obtained from the requirement of perturbativity up to the gauge group unification scale, since in the whole intervale of $\tilde{m}$ covered by the figure, this latter limit is more severe than the corresponding present low-energy experimental bound. Finally, the colored region corresponds to the situation $m_{3/2} > \tilde{m}$ which must be considered within a scenario where $\tilde{G} \neq LSP$.

The number of $R\!\!\!/_p$ coupling constants simultaneously dominant is limited by the:

- Conditions under which are obtained the bounds used.

- Experimental constraints on the products of $R\!\!\!/_p$ coupling c^{sts}.

<u>Ex:</u>

Experimental limits on the proton life time
$\Rightarrow$ $\lambda'_{ijk}\lambda''_{i'j'k'} < 10^{-9}$ $(m_{\tilde{q}} < 1TeV)$.
$\Rightarrow$ No λ''_{ijk} coupling constant can be added to the list of $R\!\!\!/_p$ coupling constants simultaneously dominant given above.

$$kT'_{3/2} > 0.4MeV \Rightarrow m_{3/2} \gtrsim 80TeV.$$

Conclusion

If the light elements (Atomic Number < 7) have effectively been produced by the nucleosynthesis, the temperature reached after thermalisation of the gravitino decay energy ($T'_{3/2}$) must be *higher* than the nucleosynthesis temperature ($\approx 0.4 MeV$).

Now, in the scenario considered (gravitino LSP decaying via $\not R_p$ trilinear couplings):

$$\left.\begin{array}{r} \tilde{m} < \mathcal{O}(TeV) \\ \lambda_{ijk}, \lambda'_{ijk}, \lambda''_{ijk} < \text{Present Limits} \end{array}\right\} \Rightarrow \boxed{kT'_{3/2} \ll 0.4 MeV.}$$

&

Study of *Takayama* and *Yamaguchi*: Decay $\tilde{G} \to \gamma\nu$ of a gravitino LSP via the $\not R_p$ *bilinear* couplings.

↪ For values of the $\not R_p$ bilinear coupling constants allowing an interpretation of the observed atmospheric ν anomaly, and, for a mass of the photino of $80 GeV$:

$$\tau(\tilde{G} \to \gamma\nu) \approx 8.3\ 10^{26} \left(\frac{1GeV}{m_{3/2}}\right)^3 sec.$$

$$\Rightarrow \tau(\tilde{G} \to \gamma\nu) < t_{Nucl.} \sim 10^2 sec \Leftrightarrow m_{3/2} (\equiv m_{LSP}) \gtrsim 2\ 10^8 GeV:$$

conflicts with $\tilde{m} < \mathcal{O}(TeV)$.

⇓

The scenario of a gravitino LSP, unstable due to the violation of the R-parity symmetry, seems to be ruled out of the realistic solutions for the cosmological gravitino problem.