Cosmological Constraints on Gaugino Mediation

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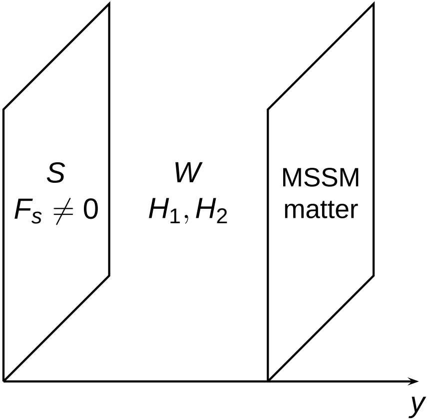
Based on
W. Buchmüller, L. Covi, J.K., K. Schmidt-Hoberg, JCAP **11** (2006) 007

Outline

Gaugino-Mediated Supersymmetry Breaking

Kaplan, Kribs, Schmaltz, Phys. Rev. **D62** (2000)
Chacko, Luty, Nelson, Ponton, JHEP **01** (2000)



Mass Spectrum of Superparticles

Boundary conditions at the compactification scale $M_c \sim M_{\rm GUT}$:

- Gauge couplings $g_1 = g_2 = g_3 = g \approx 1/\sqrt{2}$
- Gaugino masses $M_1 = M_2 = M_3 = m_{1/2}$
- Gravitino mass $m_{3/2} \gtrsim 10\,\text{GeV}$
- Squark and slepton masses ≈ 0
- Trilinear couplings $A \approx 0$
- Soft Higgs masses $m^2_{\tilde{h}_1}, m^2_{\tilde{h}_2} > 0$
- $\tan\beta$

(See Evans, Morrissey, Wells, hep-ph/0611185 for the case $m^2_{\tilde{h}_i} < 0$)

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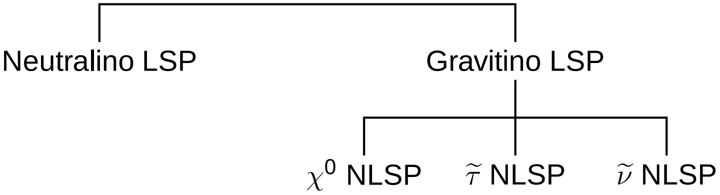
Possible Scenarios



Overview

Issues to consider:

- Dark matter density
- Big Bang Nucleosynthesis
- Cosmic Microwave Background

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$\rightsquigarrow$ Constraints on particle abundances $Y \equiv \frac{n}{s}$

Standard assumption:

Long-lived $\chi^0, \widetilde{\tau}, \widetilde{\nu}$ freeze out with thermal relic density

Calculated using microMEGAS

Belanger, Boudjema, Pukhov, Semenov, Comput. Phys. Commun. **149** (2002), Comput. Phys. Commun. **174** (2006)

Gravitinos: $Y_{3/2} \propto T_\mathrm{R}$ (reheating temperature) $\Rightarrow$ free parameter

1. Introduction

2. Constraints from Cosmology
   - Neutralino Dark Matter
   - Gravitino Dark Matter

3. Summary

Neutralino LSP

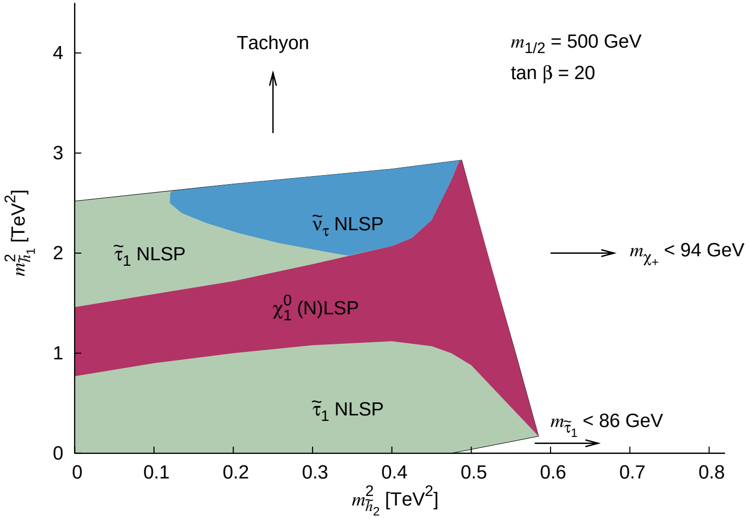
- No constraints from BBN and CMB, if T_{R} small enough
- Observed cold dark matter density:

$$0.106 < \Omega_{\mathrm{DM}} h^2 < 0.123 \quad (3\sigma \text{ C.L.})$$

Seljak, Slosar, McDonald, JCAP **10** (2006)

- $\Omega_{\chi^0} h^2 < 0.106$ not excluded

Neutralino LSP



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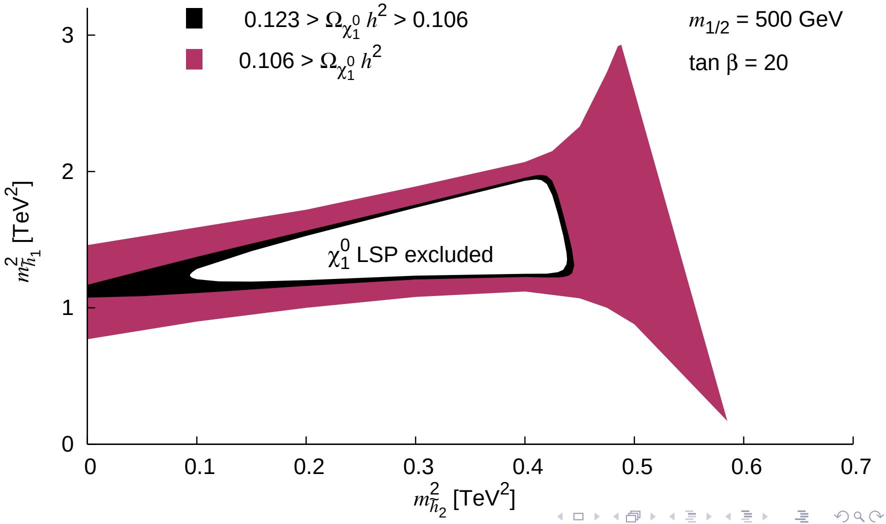

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$\Rightarrow$ Neutralino LSP allowed

Direct detection:

- χ_1^0 usually bino-like $\Rightarrow$ impossible
- Sizable gaugino-higgsino mixing for large $m^2_{\tilde{h}_2}$
  $\Rightarrow$ maybe possible in next generation of experiments

Gravitino LSP

- For $m_{1/2} = 500$ GeV, 10 GeV $\lesssim m_{3/2} \lesssim$ 100 GeV:
  Correct dark matter density for
  $$10^8 \text{ GeV} \lesssim T_R \lesssim 10^9 \text{ GeV}$$
- Non-thermal production negligible here
- CMB less constraining than BBN

  Lamon, Durrer, Phys. Rev. **D73** (2006), Steffen, JCAP **09** (2006)
- BBN constraints satisfied?

BBN and Long-Lived Particles

- Late NLSP decays into gravitino
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- Bounds depend on NLSP lifetime (here: $\tau_{\mathrm{NLSP}} \gtrsim 10^5\,\mathrm{s}$)

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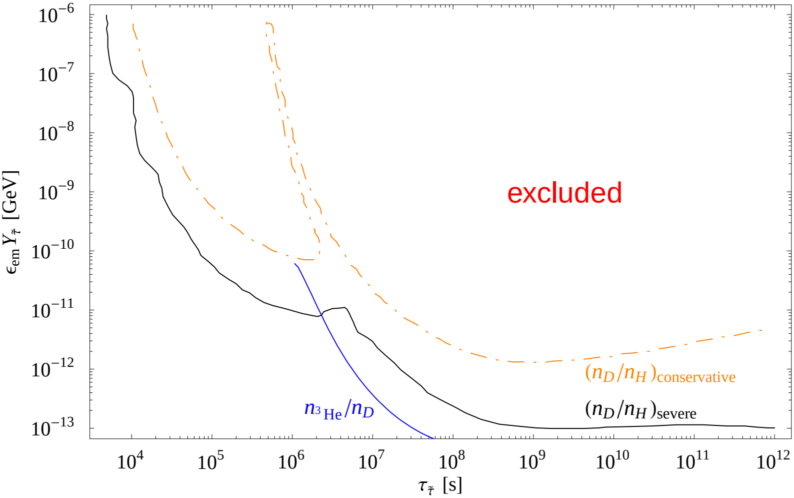
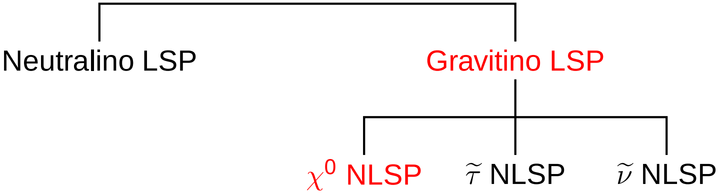
- Electromagnetic and hadronic energy release $\epsilon_{\mathrm{em,had}} Y_{\mathrm{NLSP}}$ bounded from above
- Bounds depend on NLSP lifetime (here: $\tau_{\mathrm{NLSP}} \gtrsim 10^5\,\mathrm{s}$)
- Used constraints from D and ^{4}He abundance given in Steffen, JCAP **09** (2006) (Based on Cyburt, Ellis, Fields, Olive, Phys. Rev. **D67** (2003), Kawasaki, Kohri, Moroi, Phys. Rev. **D71** (2005))
- To take into account experimental uncertainties: Consider conservative and severe constraints
- In addition: Constraint from ratio $n_{^3\mathrm{He}}/n_{\mathrm{D}}$ from Jedamzik, Phys. Rev. **D74** (2006)
- ^{6}Li, ^{7}Li not used (large systematic uncertainties)

BBN and Long-Lived Particles



Neutralino NLSP



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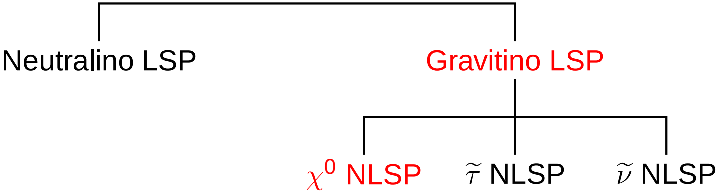

- Hadronic energy release too large, if $\chi_1^0 \to Z\widetilde{G}$ possible
  Feng, Su, Takayama, Phys. Rev. **D70** (2004),
  Cerdeño, Choi, Jedamzik, Roszkowski, Ruiz de Austri, JCAP **06** (2006)
- Small hadronic branching ratio, if this decay not possible
  $\rightsquigarrow$ Severe hadronic constraints satisfied
- Conservative electromagnetic constraints violated

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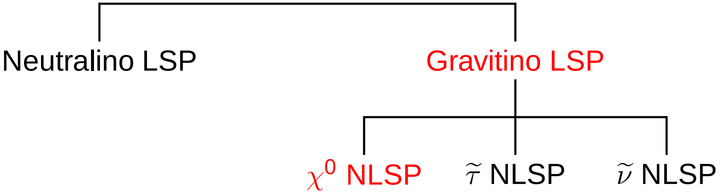

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$\Rightarrow$ Neutralino NLSP excluded

Stau NLSP

- Hadronic energy release small (mainly from $\widetilde{\tau} \to \tau \widetilde{G} q \overline{q}$)

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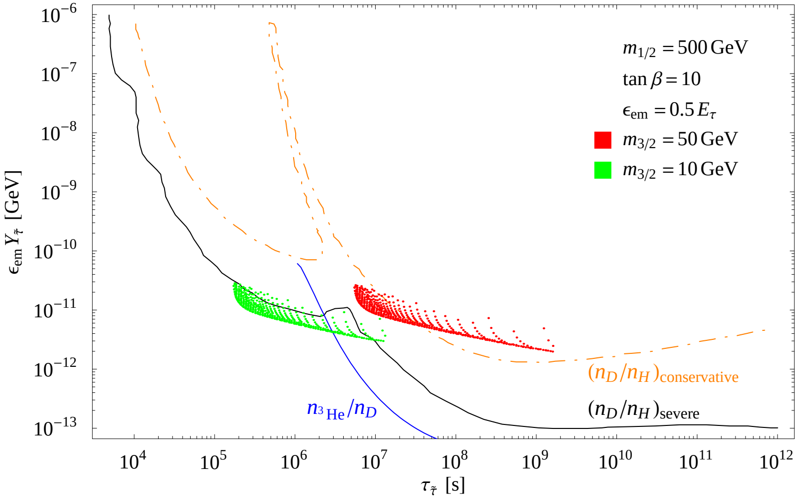
  $\Rightarrow$ Severe hadronic constraints satisfied
- Electromagnetic constraints: $\widetilde{\tau} \to \tau \widetilde{G}$ dominant
- τ energy partly ends up in neutrinos
  $\Rightarrow \epsilon_{\rm em} = x E_\tau \;,\; 0.3 < x < 1$

Stau NLSP


$m_{1/2} = 500\,\mathrm{GeV}$
$\tan\beta = 10$
$\epsilon_{\mathrm{em}} = 0.5\,E_\tau$
$m_{3/2} = 50\,\mathrm{GeV}$
$m_{3/2} = 10\,\mathrm{GeV}$
$(n_D/n_H)_{\mathrm{conservative}}$
$(n_D/n_H)_{\mathrm{severe}}$
$n_{^3\mathrm{He}}/n_D$
$\epsilon_{\mathrm{em}}\,Y_{\tilde\tau}$ [GeV]
$\tau_{\tilde\tau}$ [s]
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{4}
10^{5}
10^{6}
10^{7}
10^{8}
10^{9}
10^{10}
10^{11}
10^{12}

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- Conservative constraints allow most of parameter space for $m_{3/2} = 50\,\text{GeV}$
- Severe constraints and ^{3}He bound require lighter gravitino
- Larger $m_{1/2}$: Better agreement with BBN

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- Larger $m_{1/2}$: Better agreement with BBN

$\Rightarrow$ Stau NLSP may be allowed

Catalysed BBN: The Sword of Damocles

- $\widetilde{\tau}^-$ form bound states with nuclei $\Rightarrow$ Reaction rates change

  Pospelov, hep-ph/0605215
- Massive overproduction of Li
- $\tau_{\widetilde{\tau}} > 10^4$ s excluded in CMSSM

  Cyburt, Ellis, Fields, Olive, Spanos, JCAP **11** (2006)
- If this holds in general: Stau NLSP excluded

  (Loophole: entropy production after stau decoupling)

Sneutrino NLSP

- Dominant decay: $\widetilde{\nu} \to \nu \widetilde{G}$
- ν can annihilate with background neutrinos
  $\rightsquigarrow$ Charged leptons and pions
- Hadronic energy release from $\widetilde{\nu} \to \nu \widetilde{G} q \overline{q}$
  $\rightsquigarrow$ More stringent constraint
- $\widetilde{\nu}$ NLSP with thermal abundance and $m_{\widetilde{\nu}} \lesssim 300$ GeV allowed
  Kanzaki, Kawasaki, Kohri, Moroi, Phys. Rev. **D75** (2007)
- For $m_{1/2} = 500$ GeV: $m_{\widetilde{\nu}} \lesssim 200$ GeV

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- ν can annihilate with background neutrinos
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- $\tilde{\nu}$ NLSP with thermal abundance and $m_{\tilde{\nu}} \lesssim 300\,\text{GeV}$ allowed
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- For $m_{1/2} = 500\,\text{GeV}$: $m_{\tilde{\nu}} \lesssim 200\,\text{GeV}$

$\Rightarrow$ Sneutrino NLSP allowed

Summary

Gaugino Mediation

$\Downarrow$

- Neutralino LSP
- Gravitino LSP
  - ~~χ^0 NLSP~~
  - $\widetilde{\tau}$ NLSP
  - $\widetilde{\nu}$ NLSP