The Gravitino-Stau Scenario and BBN

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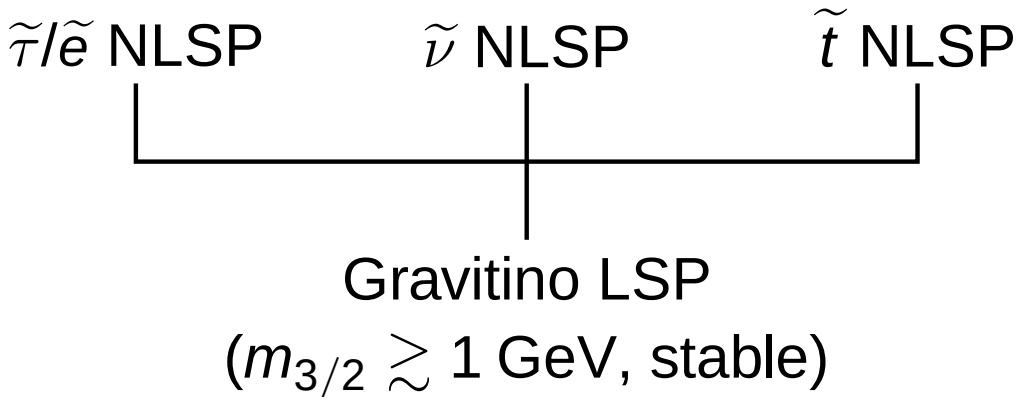
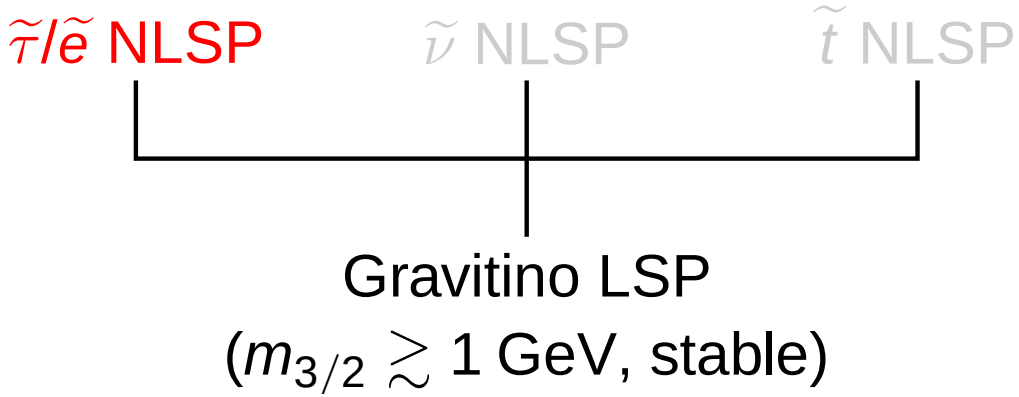
Overview


$\widetilde{\tau}/\widetilde{e}$ NLSP
$\widetilde{\nu}$ NLSP
$\widetilde{t}$ NLSP
Gravitino LSP
($m_{3/2} \gtrsim 1$ GeV, stable)

Overview



- Cosmological constraints: dark matter, BBN, CMB
- Catalyzed BBN $\rightsquigarrow$ rather heavy NLSP
- Concrete example: gaugino mediation

Cosmological Constraints I: Dark Matter

- Observed cold dark matter density:

$$0.094 < \Omega_{\mathrm{DM}} h^2 < 0.136 \quad (95\%\ \mathrm{C.L.})$$

Hamann, Hannestad, Sloth, Wong, Phys. Rev. **D75** (2007)

- Density of gravitinos: $\Omega_{3/2} = \Omega_{3/2}^{\mathrm{th}} + \Omega_{3/2}^{\mathrm{infl}} + \dfrac{m_{3/2}}{m_{\mathrm{NLSP}}} \Omega_{\mathrm{NLSP}}$
  - $\Omega_{3/2}^{\mathrm{th}} \propto T_{\mathrm{R}}$ (reheating temperature)
  - $\Omega_{3/2}^{\mathrm{infl}}$ from inflaton decays
  - Ω_{NLSP} determined by thermal relic density
    Calculated using micrOMEGAs

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

Cosmological Constraints II: BBN

- Late NLSP decays problematic in early universe
  - Energetic decay products destroy nuclei produced in Big Bang Nucleosynthesis

    Jedamzik, Phys. Rev. **D74** (2006)
  - Distortions of the Cosmic Microwave Background (less constraining than BBN)

    Lamon, Durrer, Phys. Rev. **D73** (2006), Steffen, JCAP **09** (2006)

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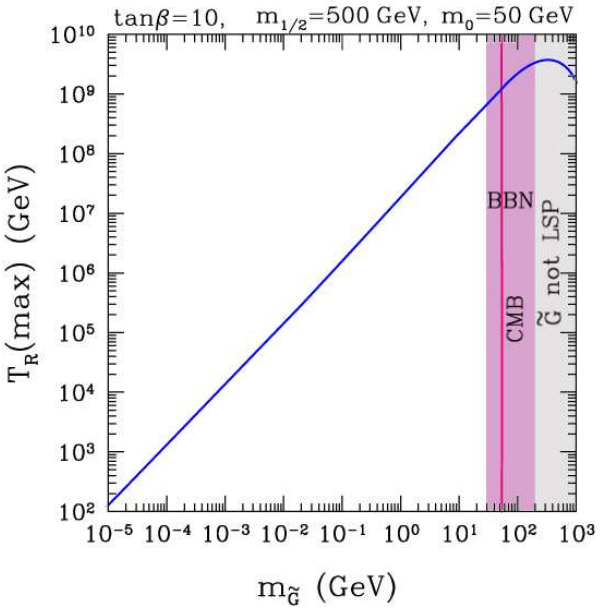
- Charged NLSPs form bound states with nuclei
  $\rightsquigarrow$ BBN reaction rates change $\rightsquigarrow$ Overproduction of ^{6}Li

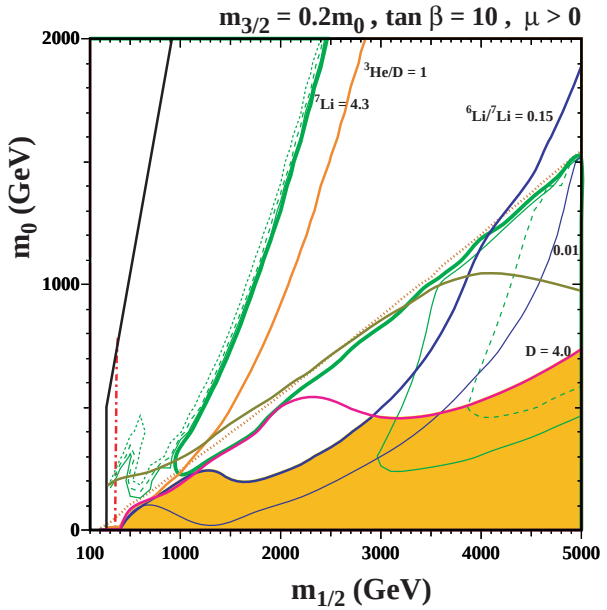
  Pospelov, Phys. Rev. Lett. **98** (2007)

Stau NLSP Decays

- Dominant decay: $\widetilde{\tau} \longrightarrow \widetilde{G}\tau \rightsquigarrow$ Electromagnetic energy
- Hadrons from $\widetilde{\tau} \longrightarrow \tau\widetilde{G}q\overline{q}$
- CMSSM:



Cerdeño, Choi, Jedamzik, Roszkowski, Ruiz de Austri, JCAP **06** (2006)



Cyburt, Ellis, Fields, Olive, Spanos, JCAP **11** (2006)

- Gaugino mediation: $m_{3/2} \lesssim 30\,\text{GeV}$ for $m_{1/2} = 500\,\text{GeV}$

Buchmüller, Covi, J.K., Schmidt-Hoberg, JCAP **11** (2006)

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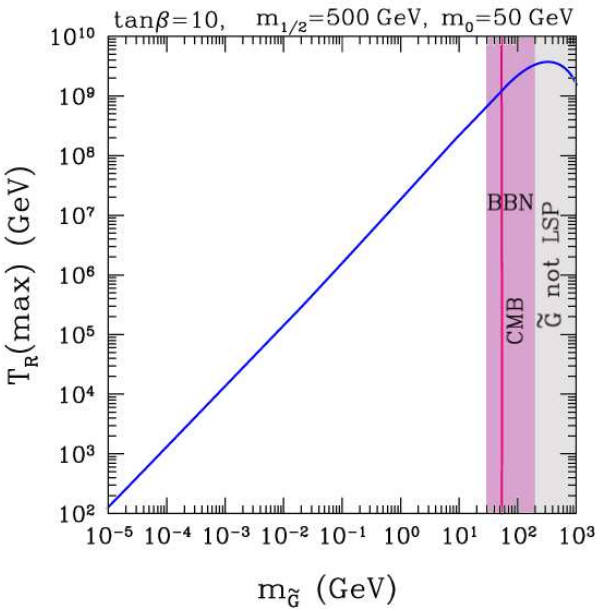

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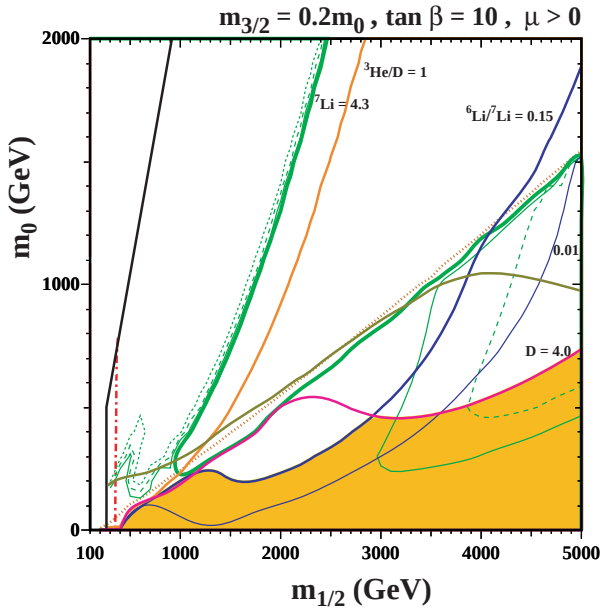

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$\Rightarrow$ Stau NLSP allowed by constraints from decays

Bound State Effects

- $\widetilde{\tau}^-$ form bound states with nuclei

  $\rightsquigarrow$ $\tau_{\widetilde{\tau}} \gtrsim 5 \cdot 10^3$ s excluded

  Pospelov, Phys. Rev. Lett. **98** (2007),
  Cyburt, Ellis, Fields, Olive, Spanos, JCAP **11** (2006),
  Hamaguchi, Hatsuda, Kamimura, Kino, Yanagida, Phys. Lett. **B650** (2007),
  Bird, Koopmans, Pospelov, `hep-ph/0703096`,
  Kawasaki, Kohri, Moroi, Phys. Lett. **B649** (2007),
  Jedamzik, Phys. Rev. **D77** (2008), JCAP **03** (2008),
  Pradler, Steffen, `arXiv:0710.2213`,
  Kawasaki, Kohri, Moroi, Yotsuyanagi, `arXiv:0804.3745`

- E.g. example from gaugino mediation: $\tau_{\widetilde{\tau}} \gtrsim 10^5$ s $\Rightarrow$ excluded
- Easiest way out: heavier staus $\Rightarrow$ shorter lifetime

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$\Rightarrow$ Heavy stau NLSP allowed

Heavy Stau NLSPs

- Stau lifetime $\tau_{\tilde{\tau}} \propto m_{3/2}^2 / m_{\tilde{\tau}}^5$
- Maximum stau NLSP mass $m_{\tilde{\tau}} \sim m_{\chi_1^0} \sim M_1 \sim 0.4\, m_{1/2}$
  - $\rightsquigarrow$ Lower bound on unified gaugino mass in CMSSM

$$m_{1/2} \gtrsim 400\ \text{GeV} \left(\frac{m_{3/2}}{1\ \text{GeV}} \right)^{2/5}$$

Pradler, Steffen, arXiv:0710.2213

- Mininum gravitino mass $m_{3/2} > c\, m_{1/2}$
  - $\rightsquigarrow$ Absolute lower bound

$$m_{1/2} \gtrsim 1\ \text{TeV} \left(\frac{c}{0.01} \right)^{2/3}$$

J.K., Schmidt-Hoberg, JCAP **01** (2008) [arXiv:0710.4528]

Gaugino Mediation

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

Boundary conditions at the compactification scale $1/R \sim M_{\mathrm{GUT}}$:

- Gauge couplings $g_1 = g_2 = g_3 = g \simeq 1/\sqrt{2}$
- Gaugino masses $M_1 = M_2 = M_3 = m_{1/2}$
- Gravitino mass $m_{3/2} > 0.01\, m_{1/2}$
- Squark and slepton masses $\simeq 0$
- Trilinear couplings $A \simeq 0$
- Soft Higgs masses $m_{h_1}^2, m_{h_2}^2 \neq 0$
- $\tan\beta$
- $\mathrm{sign}(\mu) = +1$

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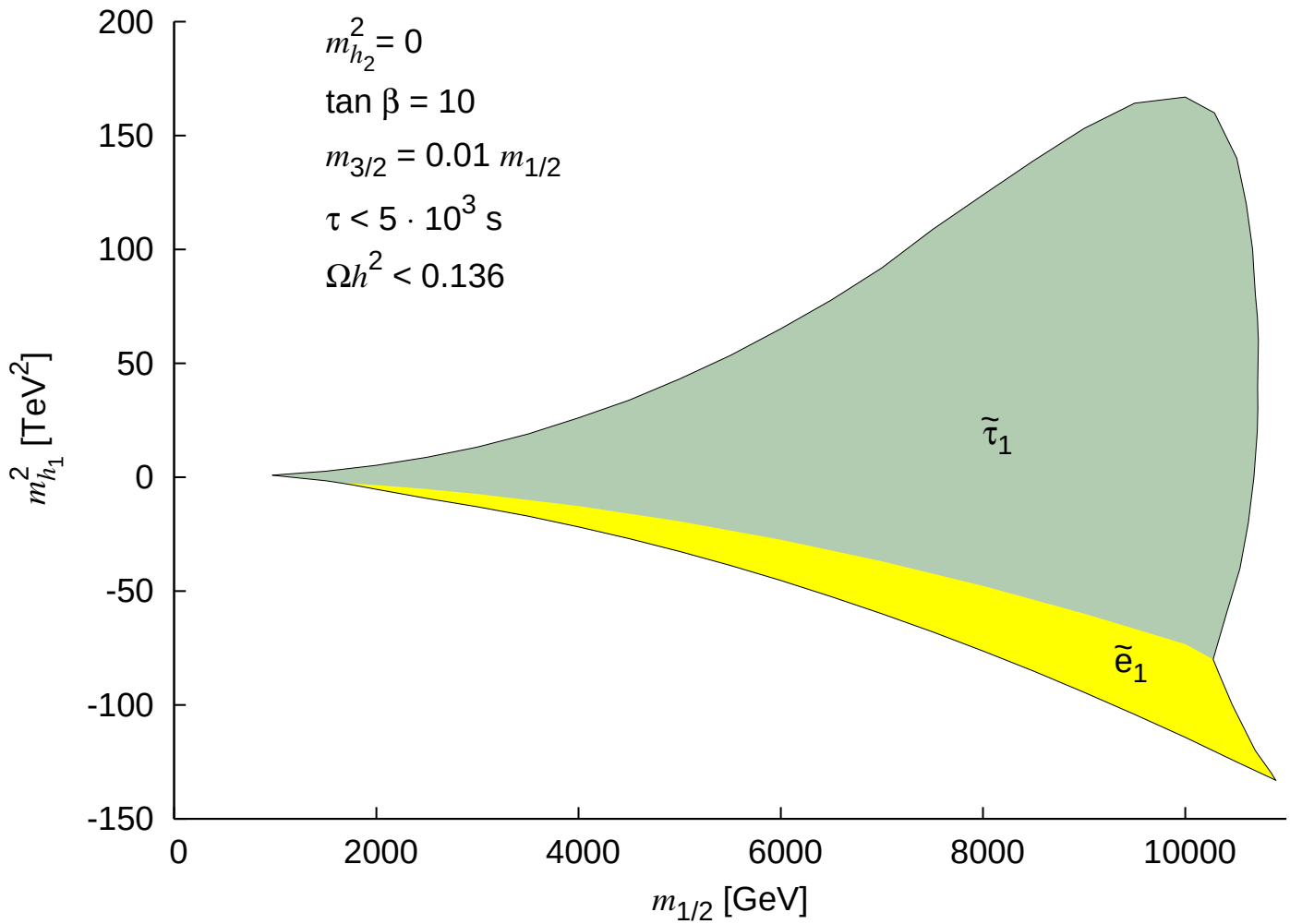
Running generates non-zero masses at low energies
Calculated using SOFTSUSY

Allanach, Comput. Phys. Commun. **143** (2002)

Allowed Parameter Space with Charged Slepton NLSP



J.K., Schmidt-Hoberg, JCAP **01** (2008)

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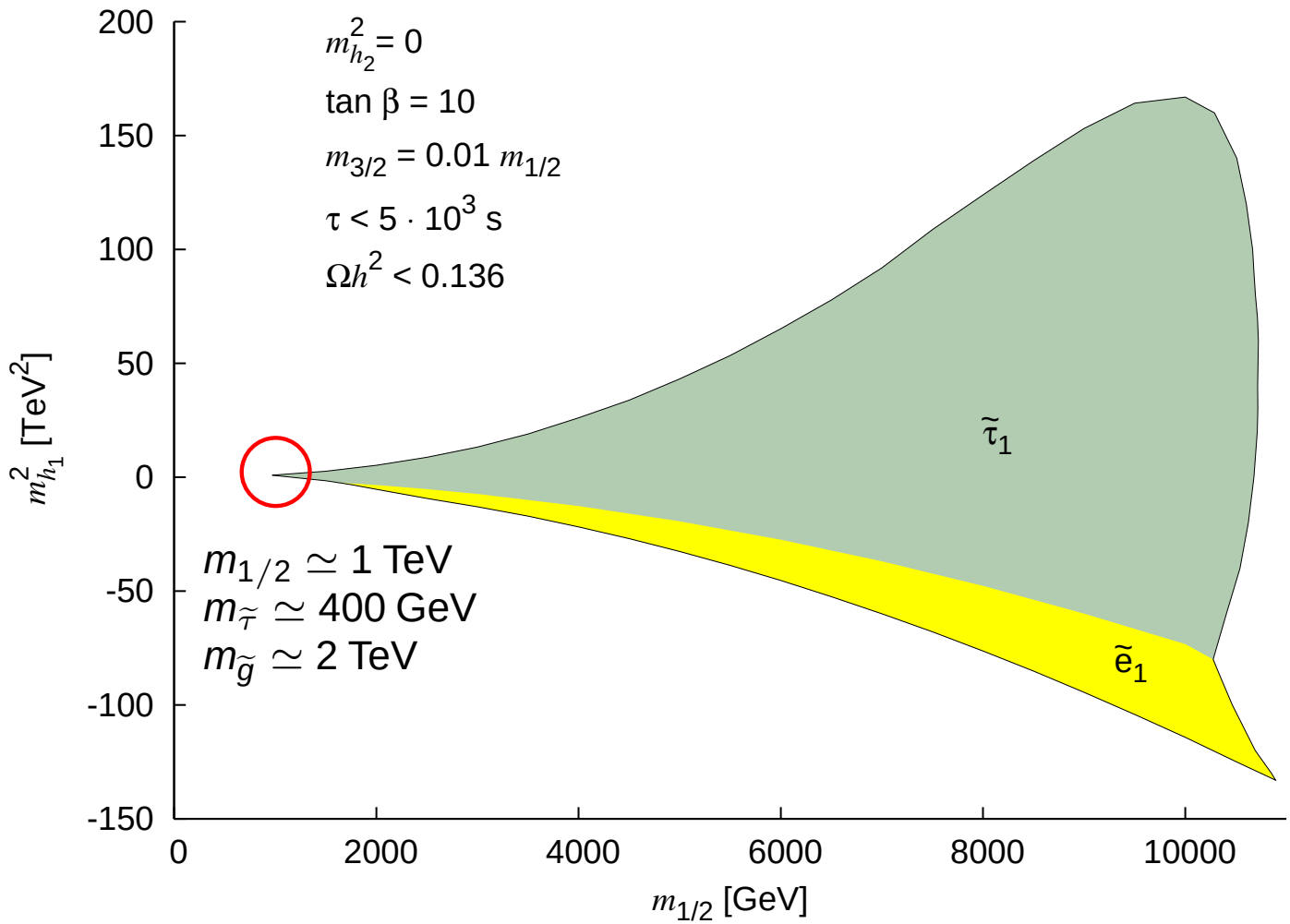

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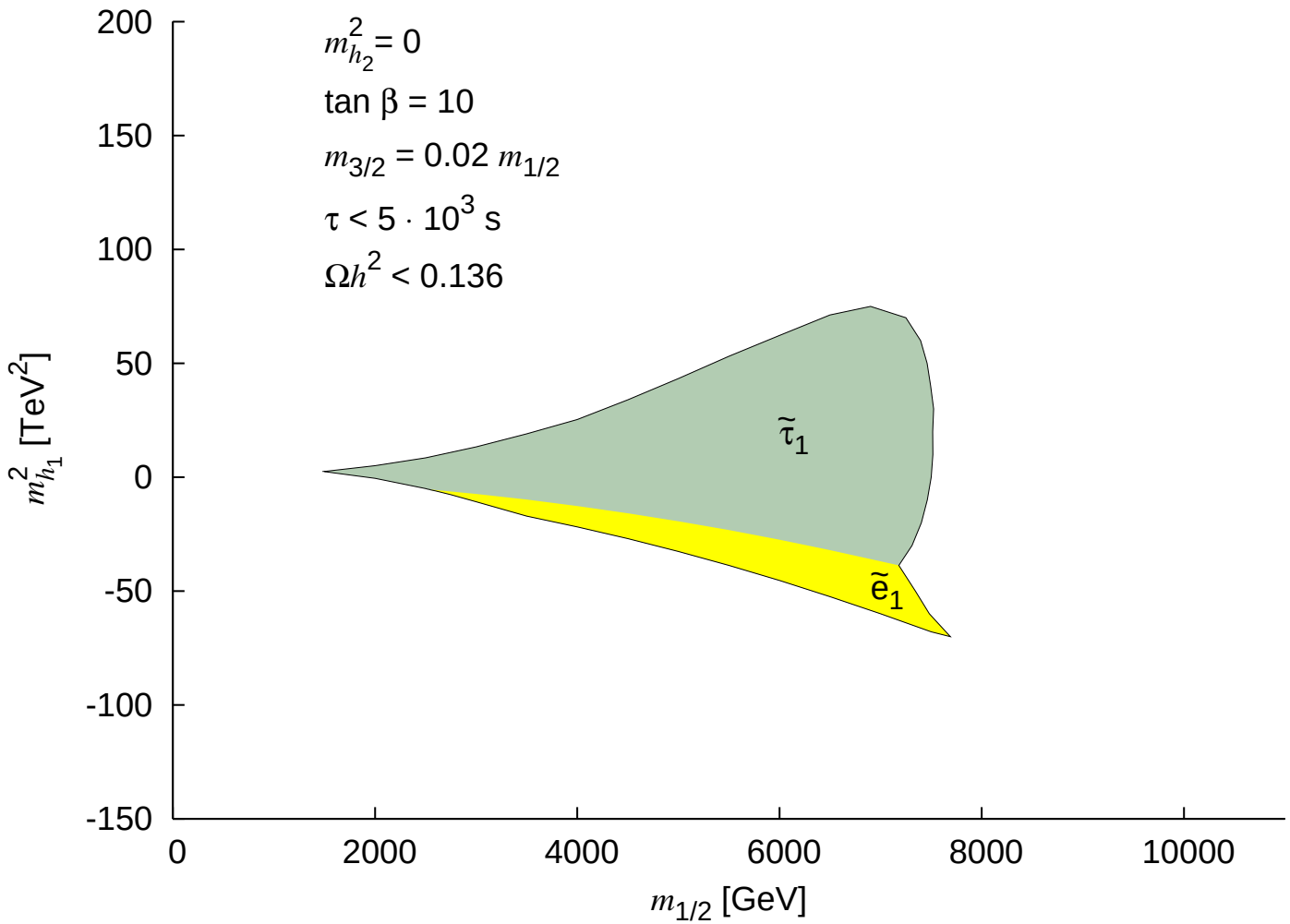

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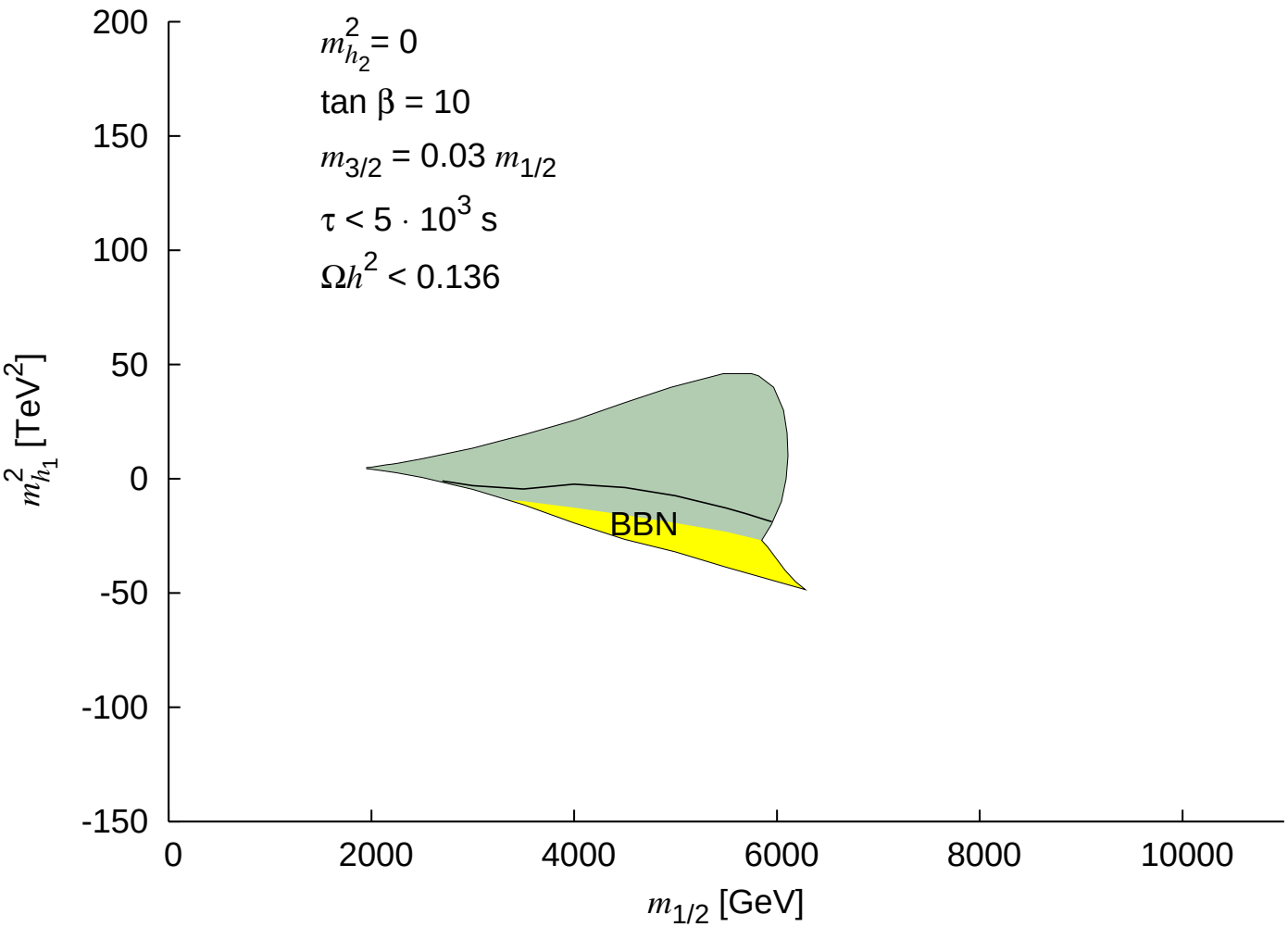

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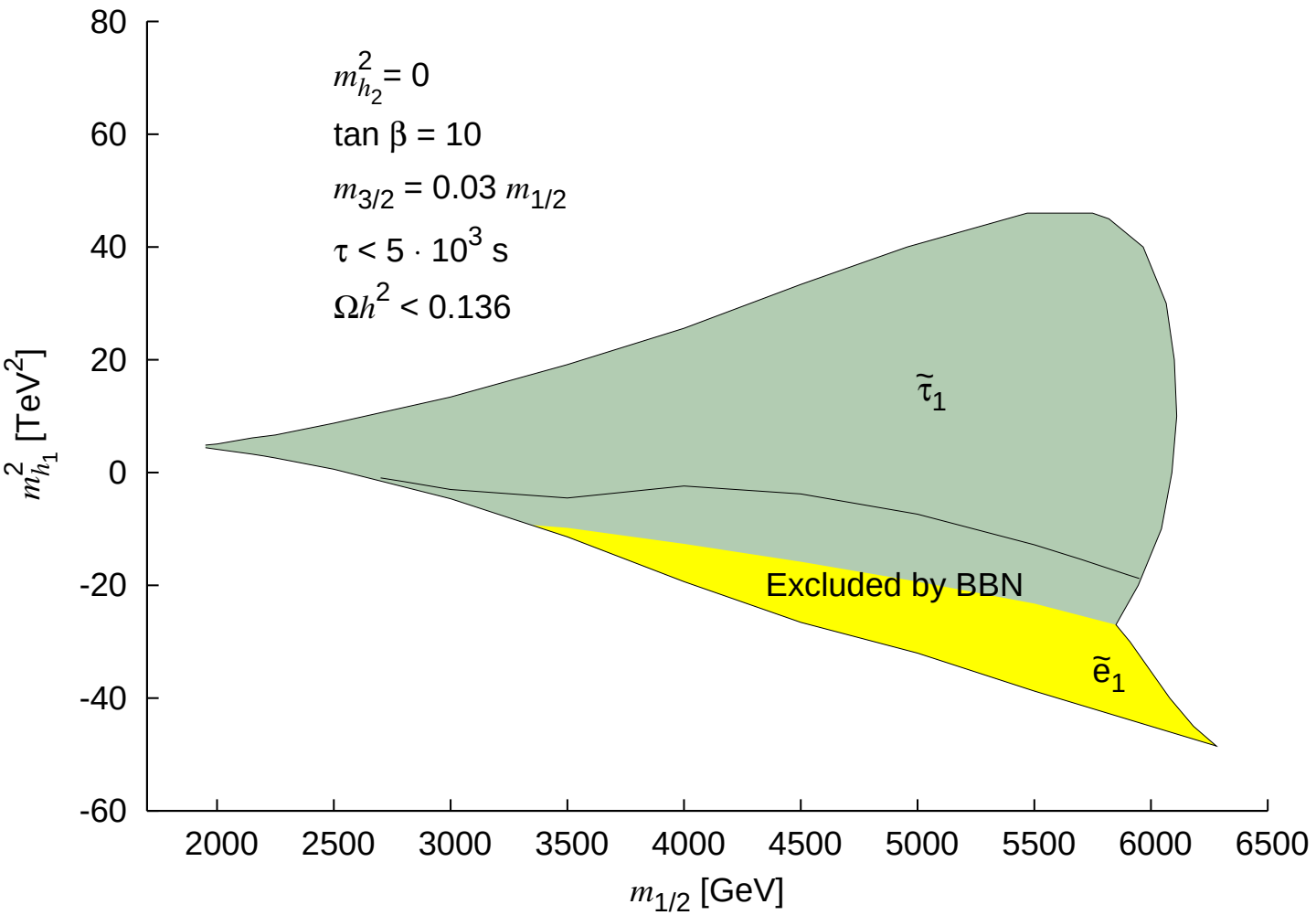

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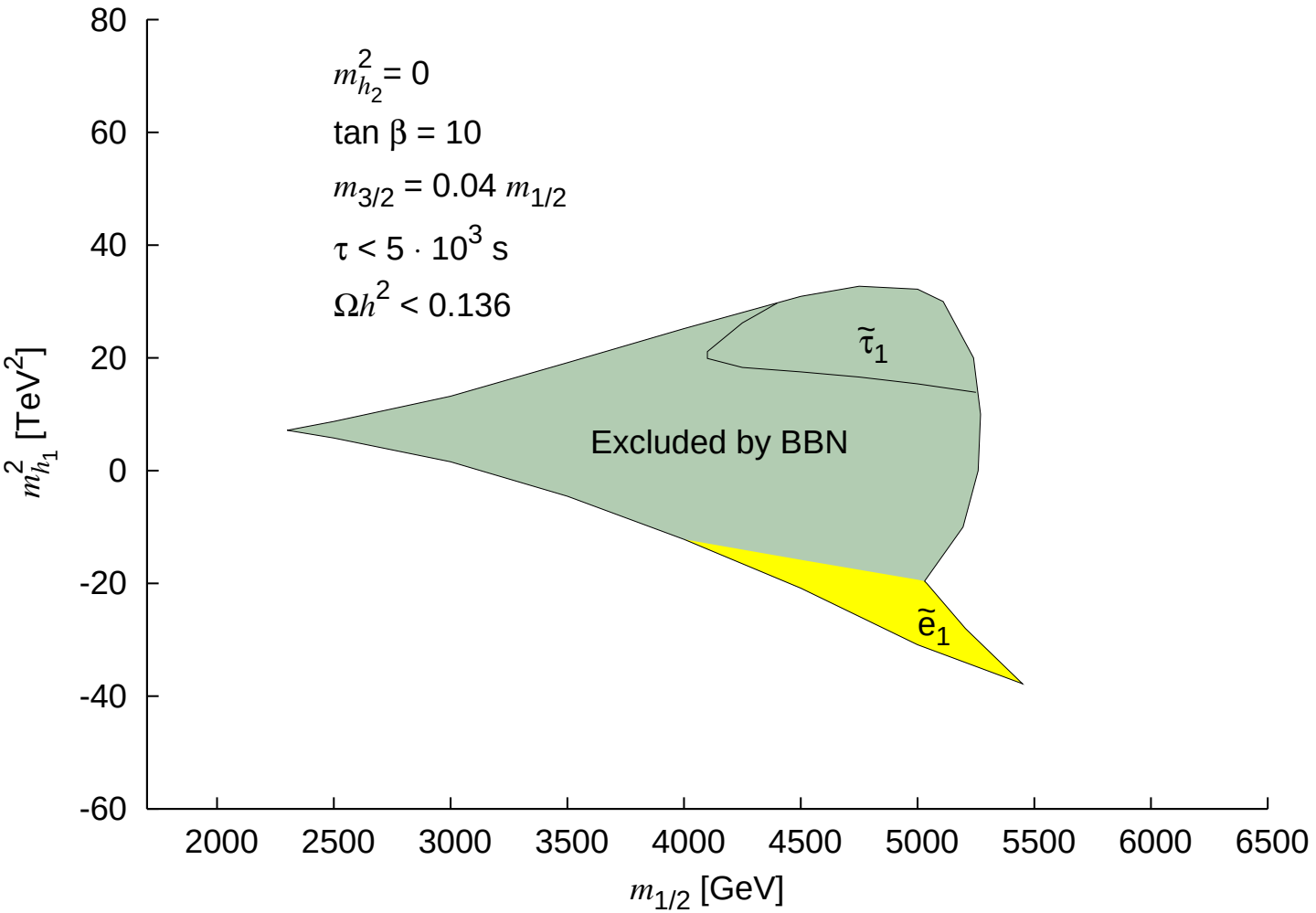

J.K., Schmidt-Hoberg, JCAP **01** (2008)

Example Spectra

c	0.01	0.02	0.03
$m_{1/2}^{\min}$	960	1500	1900
$\widetilde{g}$	2100	3100	4000
Other $\widetilde{q}$	1800	2700	3400
$\widetilde{t}_1$	1500	2200	2800
$\chi_2^{\pm}, \chi_3^0, \chi_4^0$	1100	1600	2000
$\chi_2^0, \chi_1^{\pm}$	760	1200	1500
$\widetilde{\nu}, \widetilde{\tau}_2, \widetilde{e}_{\mathrm{L}}, \widetilde{\mu}_{\mathrm{L}}$	610	930	1200
$\widetilde{e}_{\mathrm{R}}, \widetilde{\mu}_{\mathrm{R}}$	420	660	860
$\widetilde{\tau}_1, \chi_1^0$	410	640	830
$\widetilde{G}$	9.6	30	57

Conclusions

- Considered gravitino LSP ($m_{3/2} \gtrsim 1\,\text{GeV}$), charged slepton NLSP
- Cosmological constraints: dark matter density, BBN, (CMB)
- Bound state effects (Catalyzed BBN) $\Rightarrow$ lower bound on $m_{1/2}$
- Gaugino mediation: gravitino-stau scenario allowed for
  $m_{1/2} \gtrsim 1\,\text{TeV}$,
  $0.01\, m_{1/2} \lesssim m_{3/2} \lesssim 0.05\, m_{1/2}$