Gravitino dark matter with constraints from Higgs boson mass and sneutrino decays

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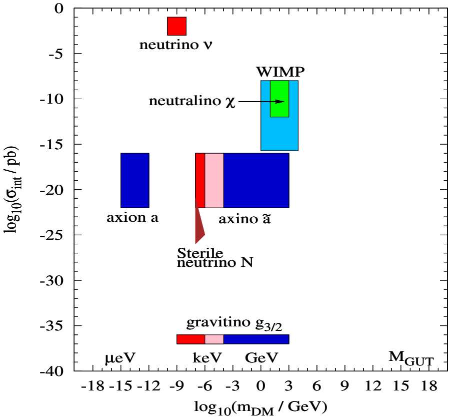
L. Roszkowski, ST, K. Turzyński, K. Jedamzik JHEP **1303** (2013) 013

Well motivated Particle Dark Matter



K.-Y. Choi, J. E. Kim, L. Roszkowski: astro-ph/1307.3330

- neutrino – hot DM
- neutralino
- "generic" WIMP
- axion
- gravitino $\tilde{G}$
- axino $\tilde{a}$

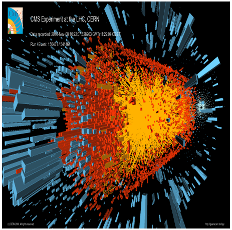
- vast ranges of interactions and masses
- different production mechanisms in the early Universe
- need to go beyond the Standard Model
- WIMP candidates testable in the near future
- axino/gravitino EWIMPs/superWIMPs not directly testable, but some hints from LHC may be possible

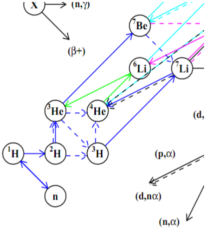
Gravitino $\tilde{G}$: superpartner of graviton, Majorana spin $\frac{3}{2}$ fermion

extremely weakly interacting (EWIMP) –

its interactions are suppressed by $M_{\rm Pl} \sim 10^{18}$GeV

Various energy scales in gravitino phenomenology





inflation → **time**

reheating of the Universe

$T_R \overset{?}{>} \sim 10^9$ **GeV**
generation of baryon asymmetry

$\sim 10^3$ **GeV**
colliders

$\sim 10^{-5}$ **GeV**
nucleosynthesis (BBN)

Non-Thermal Production
late decays of next-to-LSP

Gravitino relic density:

$$\Omega_{\tilde{G}}^{\mathrm{NTP}} \mathbf{h}^2 = \frac{\mathbf{m}_{\tilde{G}}}{\mathbf{m}_{\tilde{\nu}}} \Omega_{\tilde{\nu}} \mathbf{h}^2$$

Thermal production
scatterings of superparticles
in the thermal plasma

For low $\Omega_{\tilde{\nu}} \mathbf{h}^2$ **TP** is dominant.

$$\Omega_{\tilde{G}}^{\mathrm{TP}} \mathbf{h}^2 \simeq \left(\frac{\mathbf{T_R}}{10^8 \mathrm{GeV}}\right)\left(\frac{1 \mathrm{GeV}}{\mathbf{m}_{\tilde{G}}}\right) \sum_{\mathbf{r}=1}^{3} \gamma_{\mathbf{r}}(\mathbf{T_R}) \left(\frac{\mathbf{M_r}}{900 \mathrm{GeV}}\right)^2$$

where $\gamma_1 = 0.2$, $\gamma_2 = 0.5$, $\gamma_3 = 0.5$ at $T_R = 10^9$ GeV.

M. Bolz, A. Brandenburg, W. Buchmuller; hep-ph/0012052

J. Pradler, F. D. Steffen; hep-ph/0608344

V. S. Rychkov, A. Strumia; hep-ph/0701104

$$0.112 = \Omega_{\tilde{G}}^{total} h^2 \simeq \Omega_{\tilde{G}}^{\mathrm{TP}} h^2 \quad \Rightarrow \quad T_R$$

T_R **is maximized for low gaugino masses (**M_r**) and large** $m_{\tilde{G}}$**.**

Why not sneutrino DM?

- for lower $m_{\tilde{\nu}}$ – too low relic density
- for higher $m_{\tilde{\nu}}$ – excluded by DM direct detection experiments e.g. Heidelberg-Moscow exp.

T. Falk, K. A. Olive, M. Srednicki; hep-ph/9409270

Why sneutrino next-to-LSP with gravitino DM?

- $\tilde{\nu}$ low yield at freezeout $\rightarrow$ better than bino $\tilde{B}$

$\Omega_{\tilde{G}} h^2$ – bigger contribution from thermal production $\Rightarrow$ $T_R \nearrow$

thermal leptogenesis $T_R > \sim 2 \times 10^9$ (2×10^8) GeV

G. F. Giudice, A. Notari, M. Raidal, A. Riotto, A. Strumia; hep-ph/0310123
(S. Davidson, E. Nardi, Y. Nir: hep-ph/0802.2962)

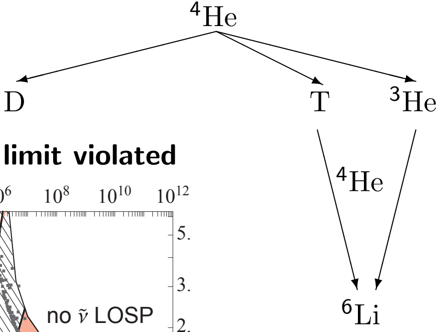
- dominant sneutrino to gravitino decay $\tilde{\nu} \rightarrow \nu \tilde{G}$

$\rightarrow$ better than stau $\tilde{\tau}$

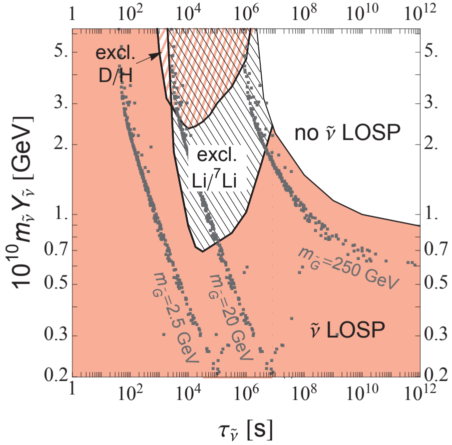
Weak BBN bounds (mainly from subdominant 3- an 4-body decays)

Higgs mass ~ 126 GeV $\Rightarrow$ max $T_R \searrow$

Relevant BBN constraints for $\tilde{\nu}$ next-to-LSP:



D/H upper limit violated



^{6}Li/^{7}Li upper limit violated

Dominant 2-body decays $\tilde{\nu}_\tau \to \nu_\tau \, \tilde{G}$

weak EM cascades

Subdominant 3- and 4- body decays
hadronic and EM cascades

T. Kanzaki, M. Kawasaki, K. Kohri, T. Moroi; hep-ph/0705.1200

Considered constraints:

- $2.3 \times 10^{-5} \le \mathrm{D/H} \le 4 \times 10^{-5}$
- $^3\mathrm{He/D} < 1.4$
- $0.24 \le Y_p \le 0.260$

K. Jedamzik; hep-ph/0604251

- $^6\mathrm{Li}/^7\mathrm{Li} \le 0.1$ or 0.66

K. Jedamzik, M. Lemoine, G. Moultaka; hep-ph/0508141

- Large Scale Structures (LSS) formation
- CMBR distortions (limit on chemical potential)

W. Hu, J. Silk; *Phys. Rev. Lett.* 70 (1993) 2661

http://www.slac.stanford.edu/xorg/hfag/rare/2012/radll/index.html

- $2.82 \times 10^{-4} \le \mathrm{BR}(b \to s\gamma) \le 4.04 \times 10^{-4}$
- $5 \times 10^{-5} \le \mathrm{BR}(B_u \to \tau\nu_\tau) \le 2.82 \times 10^{-4}$ — HFAG; hep-ex/1207.1158
- $12.92\mathrm{ps}^{-1} \le \Delta M_{B_s} \le 22.52\mathrm{ps}^{-1}$ — PDG; *Phys. Rev.* D86 (2012) 010001
- $\mathrm{BR}(B_s \to \mu^+\mu^-) = (3.2 \pm 1.2 \pm 0.3) \times 10^{-9}$ — LHCb; hep-ex/1211.2674
- $m_h = (125.8 \pm 0.6 \pm 2)$ GeV — CMS-PAS-HIG-12-045
- squark masses above LHC limits

How to get $m_{\tilde{\nu}} < m_{\tilde{\tau}_1}, m_{\chi_1}$ in unified models?

↙ ↘

Unified SUSY scenarios (common $m_0, m_{1/2}$)

$S_0 = m^2_{H_u} - m^2_{H_d} + \ldots < 0$

e.g. Non-Universal Higgs Model (NUHM)

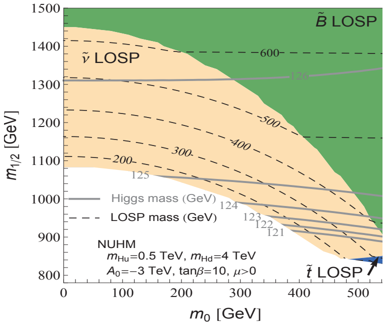
⇓

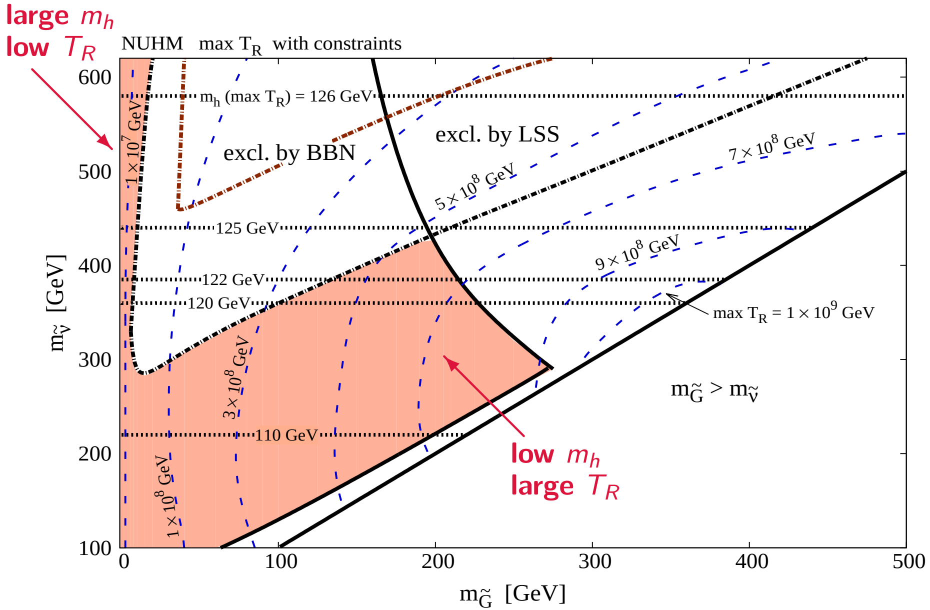
Parameters of the model:

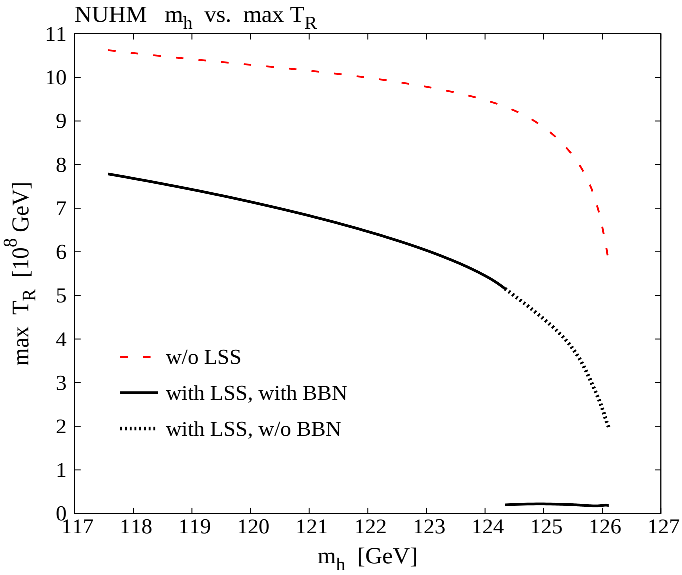
$m_0, m_{1/2}, m_{H_u}, m_{H_d}, \tan\beta, A_0, \mathrm{sgn}\mu$

non-universal gaugino masses

$M_2 < M_1$




large m_h
low T_R
NUHM max T_R with constraints
m_h (max T_R) = 126 GeV
125 GeV
122 GeV
120 GeV
110 GeV
excl. by BBN
excl. by LSS
1×10^7 GeV
1×10^8 GeV
3×10^8 GeV
5×10^8 GeV
7×10^8 GeV
9×10^8 GeV
max $T_R = 1 \times 10^9$ GeV
$m_{\tilde{G}} > m_{\tilde{\nu}}$
low m_h
large T_R
$m_{\tilde{\nu}}$ [GeV]
$m_{\tilde{G}}$ [GeV]
600
500
400
300
200
100
0
100
200
300
400
500


NUHM m_h vs. max T_R
max T_R [10^8 GeV]
m_h [GeV]
w/o LSS
with LSS, with BBN
with LSS, w/o BBN
0
1
2
3
4
5
6
7
8
9
10
11
117
118
119
120
121
122
123
124
125
126
127

Conclusions:

- Models with gravitino DM are strongly constrained by BBN and struggle to get high reheating temperature T_R
- Taking sneutrino as next-to-LSP improves the situation...
- ...but, with the light Higgs boson of mass ~ 126 GeV, this scenario looks disfavoured
- NUHM: lower $m_{\tilde{G}} \Rightarrow$ desired m_h, but too low T_R
- NUHM: higher $m_{\tilde{G}} \Rightarrow$ max $T_R \nearrow$, but too low m_h