Gravitino Decays and the Cosmological Lithium Problem in Light of the LHC Higgs and Supersymmetry Searches

arXiv:1303.0574

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SUSY 2013

Motivation

Use BBN to constrain massive particle decay scenarios

In this work, we take gravitino as the massive decaying particle,
gravitino $\rightarrow$ ... $\rightarrow$ LSP + hadronic and electromagnetic showers

assume LSP = lightest neutralino = DM particle, and R-parity conservation

Try to solve $^7\mathrm{Li}$ problem

$$
\begin{aligned}
\text{standard BBN :} \quad & \left(\frac{^7\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{SBBN}} &=& \quad (5.11^{+0.71}_{-0.62}) \times 10^{-10} \\
\text{observations :} \quad & \left(\frac{^7\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{halo}*} &=& \quad (1.23^{+0.34}_{-0.16}) \times 10^{-10} \\
& \left(\frac{^7\mathrm{Li}}{\mathrm{H}}\right)_{\mathrm{GC}} &=& \quad (2.34 \pm 0.05) \times 10^{-10}
\end{aligned}
$$

Method

SUSY model input (CMSSM, NUHM, subGUT models)

$\downarrow$ RGEs

sparticle masses and couplings

$\downarrow$

gravitino decay spectra

$\downarrow$ `PYTHIA`

hadronic and electromagnetic showers

$\downarrow \zeta_{3/2} \equiv \frac{m_{3/2} n_{3/2}}{n_\gamma}$ and BBN code including non-thermal reactions

light element abundances prediction

$\downarrow$ compare with observations

constraints on $m_{3/2}, \zeta_{3/2}$ and SUSY model parameters, $^7\mathrm{Li}$ solved?

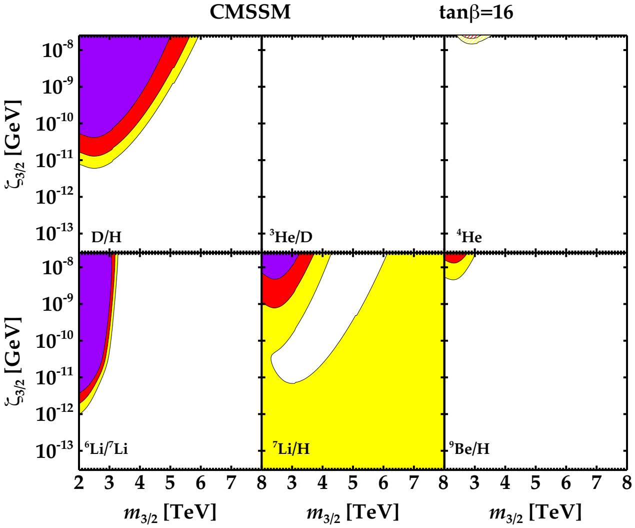
SUSY model studied

ID	Model	Ref	$m_{1/2}$	m_0	A_0	$\tan\beta$	μ	m_χ	$m_{3/2}$	$\zeta_{3/2}$	$\tau_{3/2}$	$\chi^2_{\rm min}$
1	CMSSM	[a]	905	361	1800	16	> 0	395	4560	1.5×10^{-10}	208	2.81
2	CMSSM	[a]	1895	1200	1200	50	> 0	857	5520	1.8×10^{-10}	231	2.86
3	NUHM1	[a]	970	345	2600	15	2600	427	4600	1.2×10^{-10}	220	2.82
4	NUHM1	[a]	2800	1040	2100	39	3800	1288	6200	2.6×10^{-10}	276	3.14
5	CMSSM	[b]	1115	1000	2500	40	> 0	496	4800	1.6×10^{-10}	213	2.87
6	NUHM1	[b]	1175	1500	3000	40	500	499	5000	2.6×10^{-10}	188	2.86
7	NUHM1	[b]	1300	1000	2500	30	-550	550	4700	1.0×10^{-10}	258	2.87
8	subGUT CMSSM	[b]	2040	2200	5500	10	> 0	1554	5400	1.6×10^{-10}	214	2.96
9	subGUT mSUGRA	[b]	2400	4000	Polonyi	36	> 0	1099	6000	1.6×10^{-10}	239	2.91
10	subGUT mSUGRA	[b]	1700	2000	Polonyi	33	> 0	1110	5100	1.6×10^{-10}	219	2.89
12	CMSSM	[a]	905	361	1800	16	> 0	395	4520	1.0×10^{-10}	215	0.52

All mass parameters are in GeV, and the best-fit lifetime $\tau_{3/2}$ is in seconds.
The subGUT CMSSM model assumes $M_{in} = 10^9$ GeV, and the subGUT mSUGRA models assumes $M_{in} = 10^{10}$ GeV.
In the final row, the χ^2 and best-fit values are computed using the ${}^7\mathrm{Li}/\mathrm{H}$ abundance as determined from globular clusters.

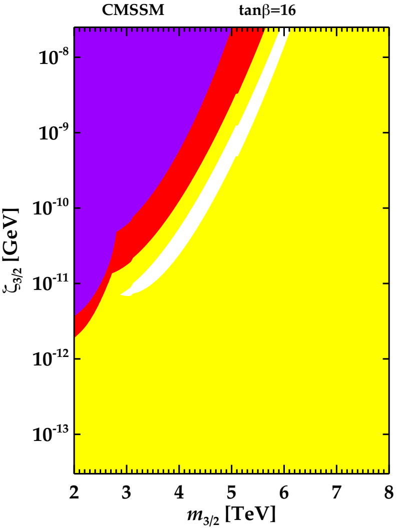
[*a*] Buchmueller *et al.* (1207.7315)
[*b*] Ellis, FL, Olive and Sandick (1212.4476)

An example: model 1



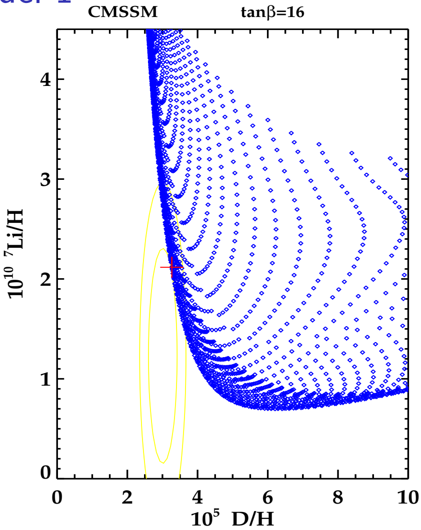
The unshaded regions in the panels are those consistent with the light-element abundance observations, whilst the yellow, red and magenta regions correspond to progressively larger deviations from the central values of the abundances.

An example: model 1



Combine all six panels.

An example: model 1



The blue points show the values found in scans for different values of $m_{3/2}$ and $\zeta_{3/2}$. The ellipses represent the one- and two-σ regions found by combining the D and $^7\mathrm{Li}$ constraints. The red cross marks the best fit.

An example: model 1

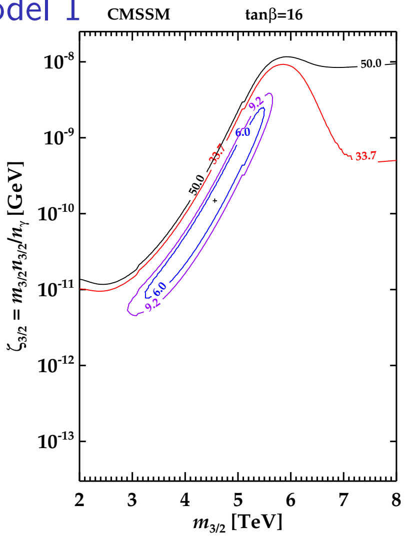
$$\chi^2 \equiv \left(\frac{Y_p - 0.2534}{0.0083}\right)^2 + \left(\frac{\mathrm{D/H} - 3.01 \times 10^{-5}}{0.27 \times 10^{-5}}\right)^2 + \left(\frac{{}^7\mathrm{Li/H} - 1.23 \times 10^{-10}}{0.71 \times 10^{-10}}\right)^2 + \left(\frac{\Omega_\chi^{(3/2)} h^2}{0.0045}\right)^2,$$

where

$$\Omega_\chi^{(3/2)} = \frac{m_\chi}{m_{3/2}} \frac{n_\gamma}{\rho_c} \zeta_{3/2}$$

is the density of neutralinos produced in gravitino decays.

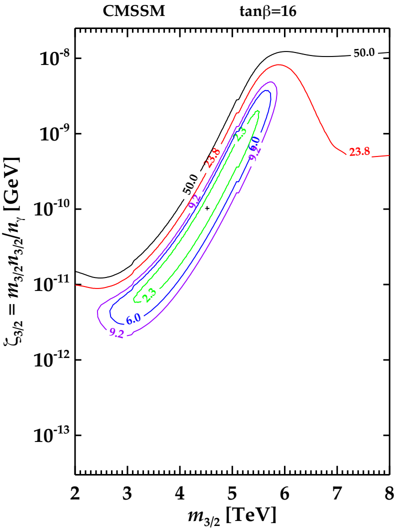
An example: model 1



SBBN = 33.7 (for 3 degrees of freedom)
Best-fit point (marked by a black cross) = 2.81 (for 3 − 2 = 1 d.o.f.)

Significant improvement: 33.7/3 vs. 2.81/1

An example: model 1



If use the globular cluster value for $^{7}\mathrm{Li}/\mathrm{H}$, then

SBBN $= 23.8$, Best-fit point $= 0.52$.

SUSY model studied

ID	Model	Ref	$m_{1/2}$	m_0	A_0	$\tan\beta$	μ	m_χ	$m_{3/2}$	$\zeta_{3/2}$	$\tau_{3/2}$	$\chi^2_{\min}$
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Conclusions

- We see that the best-fit gravitino mass varies between 4.6 and 6.2 TeV, and its abundance in the narrow range between 1.0 and 2.6×10^{-10} GeV. The best-fit gravitino lifetimes fall in an even more narrow range, $\tau_{3/2} \sim 210 - 280$ sec. Thus the models all show a close similarity in the best-fit gravitino abundance and lifetime values.
- In view of this persistence of the massive gravitino solution to the $^7\mathrm{Li}$ problem despite the impact of LHC results on the supersymmetric parameter space, we conclude that the late decays of massive gravitinos provide a robust solution to the cosmological $^7\mathrm{Li}$ problem.

back up

Nuclear reactions of non-thermal particles

	Reaction	Uncertainty ϵ		Reaction	Uncertainty ϵ
1	$p^4\mathrm{He} \to d^3\mathrm{He}$		2	$p^4\mathrm{He} \to np^3\mathrm{He}$	20%
3	$p^4\mathrm{He} \to ddp$	40%	4	$p^4\mathrm{He} \to dnpp$	40%
5	$d^4\mathrm{He} \to {}^6\mathrm{Li}\gamma$		6	$t^4\mathrm{He} \to {}^6\mathrm{Li}n$	20%
7	${}^3\mathrm{He}^4\mathrm{He} \to {}^6\mathrm{Li}p$	20%	8	$t^4\mathrm{He} \to {}^7\mathrm{Li}\gamma$	
9	${}^3\mathrm{He}^4\mathrm{He} \to {}^7\mathrm{Be}\gamma$		10	$p^6\mathrm{Li} \to {}^3\mathrm{He}^4\mathrm{He}$	
11	$n^6\mathrm{Li} \to t^4\mathrm{He}$		12	$pn \to d\gamma$	
13	$pd \to {}^3\mathrm{He}\gamma$		14	$pt \to n^3\mathrm{He}$	
15	$p^6\mathrm{Li} \to {}^7\mathrm{Be}\gamma$		16	$p^7\mathrm{Li} \to {}^8\mathrm{Be}\gamma$	
17	$p^7\mathrm{Be} \to {}^8\mathrm{B}\gamma$		18	$np \to d\gamma$	
19	$nd \to t\gamma$		20	$n^4\mathrm{He} \to dt$	
21	$n^4\mathrm{He} \to npt$	20%	22	$n^4\mathrm{He} \to ddn$	40%
23	$n^4\mathrm{He} \to dnnp$	40%	24	$n^6\mathrm{Li} \to {}^7\mathrm{Li}\gamma$	
25	n (thermal)		26	$n^7\mathrm{Be} \to p^7\mathrm{Li}$	
27	$n^7\mathrm{Be} \to {}^4\mathrm{He}^4\mathrm{He}$		28	$p^7\mathrm{Li} \to {}^4\mathrm{He}^4\mathrm{He}$	
29	$n\pi^+ \to p\pi^0$		30	$p\pi^- \to n\pi^0$	
31	$p^4\mathrm{He} \to ppt$	20%	32	$n^4\mathrm{He} \to nn^3\mathrm{He}$	20%
33	$n^4\mathrm{He} \to nnnpp$		34	$p^4\mathrm{He} \to nnppp$	
35	$p^4\mathrm{He} \to N^4\mathrm{He}\pi$		36	$n^4\mathrm{He} \to N^4\mathrm{He}\pi$	

subGUT

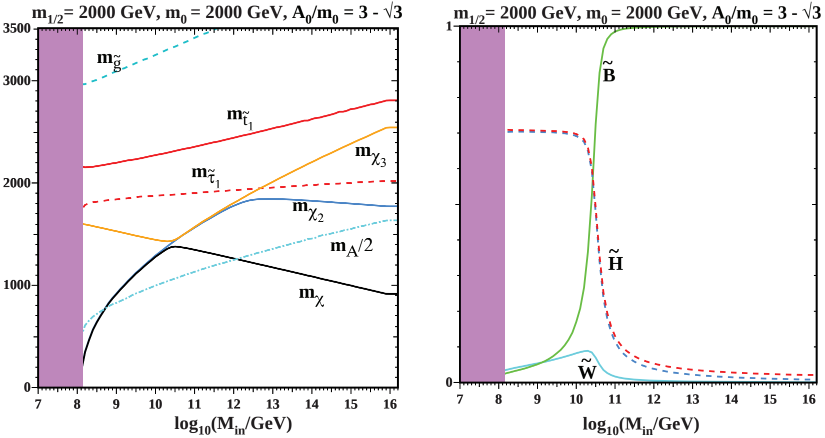

Figure: *The evolution of (left) the sparticle spectrum and (right) the composition of the LSP χ as functions of M_{in} in a specific sub-GUT Polonyi mSUGRA scenario with $m_{1/2} = m_0 = 2000$ GeV.*