Gravitino Dark Matter and General Neutralino NLSP

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Conflict between SUGRA and BBN

- supergravity* (SUGRA) = supersymmetry (SUSY) + general relativity

↷ minimal particle content is MSSM + graviton + gravitino $\Psi_{3/2}$

↷ $\Psi_{3/2}$ is unique and inevitable prediction of
any supersymmetric theory containing gravity!

↷ $\Psi_{3/2}$ can be produced in the early universe and has typically
long lifetimes $\tau_{3/2} \gg 1$ s (i.e. $\tau_{3/2} \propto M_{pl}^2/m_{3/2}^3$)‡

- Big Bang Nucleosynthesis (BBN) predicts successfully the light element abundances in the universe

↷ Maintaining this success reveals bounds on energy (had/em) emitted by particle decays during or after BBN (i.e. for $t \gtrsim t_{BBN} \approx 1$ s)

Decaying gravitinos may spoil the success of BBN

*We assume that SUGRA is an appropriate low-energy approximation of a more fundamental theory.

‡[Pagels & Primack, 1982 and Ellis, Kim & Nanopoulos, 1984]

Gravitino Dark Matter

1) $\Psi_{3/2}$ is superweakly interacting massive particle (sWIMP)
   $\Rightarrow$ if $\Psi_{3/2}$ is the lightest supersymmetric particle (LSP),
   it can be dark matter (DM)
2) If R-parity is conserved, it is stable $\Rightarrow$ no dangerous $\Psi_{3/2}$ decays
3) **But** next-to-LSP (NLSP) becomes long-lived $\tau_{NLSP} \propto M_{pl}^2 m_{3/2}^2 / m_{NLSP}^5$
   $\Rightarrow$ may in turn spoil BBN
4) large $m_{3/2} \gtrsim 100$ GeV preferable to allow high reheating temperature T_{RH}, while $\Omega_{3/2} \lesssim \Omega_{DM} \curvearrowright$ high T_{RH} needed for thermal leptogenesis to produce baryon asymmetry
   [Fukugita & Yanagida, 1986 and Buchmüller, Bari, Plumacher, 2005]

$\Longrightarrow$ Problem is softened*, but investigation is needed to determine lower bounds on m_{NLSP} and upper bounds on $m_{3/2}$

Bounds on m_{NLSP} and $m_{3/2}$

*$\tau_{NLSP}/\tau_{3/2} \propto m_{3/2}^5 / m_{NLSP}^5 \ll 1$, if $\Psi_{3/2}$ is LSP.

Neutralino NLSP

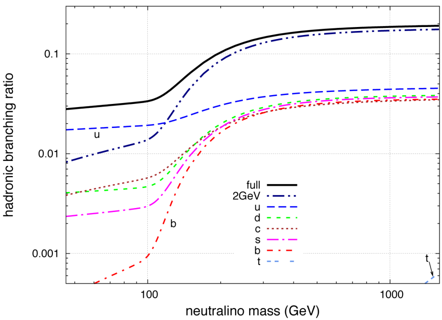
1) neutralino χ is one of the lightest particles within MSSM and thus good NLSP candidate (often χ NLSP $\sim \widetilde{B}$)
2) χ is superposition of bino $\widetilde{B}$, wino $\widetilde{W}$ and Higgsinos $\widetilde{H}_u$, $\widetilde{H}_d$
3) compute relic density $\Omega_\chi h^2 = \frac{\rho_\chi}{\rho_0^{cr}} h^2$ after freeze-out with micrOMEGAs
4) compute all neutralino decay channels $\chi \to \Psi_{3/2} +$ SM particles to determine τ_χ and branching ratios $B_{had/em}$
5) m_{NLSP} in TeV range preferred

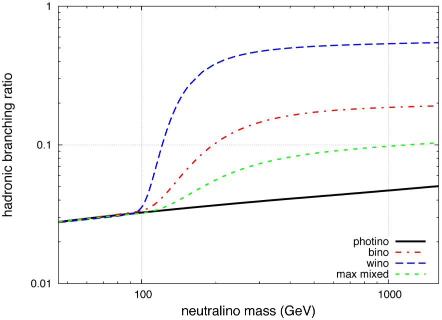
$\Longrightarrow$ Find mass bounds and in particular how these are relaxed for different compositions

Bounds on m_χ and $m_{3/2}$ dependend on the χ composition

earlier work: [Feng, Su & Takayama, 2004], (cmssm) [Ellis, Olive, Santoso & Spanos, 2004 and Bailly, Choi, Jedamzik & Roszkowski, 2009], (charged slepton) [Steffen, 2006] and many more...

Example branching ratios



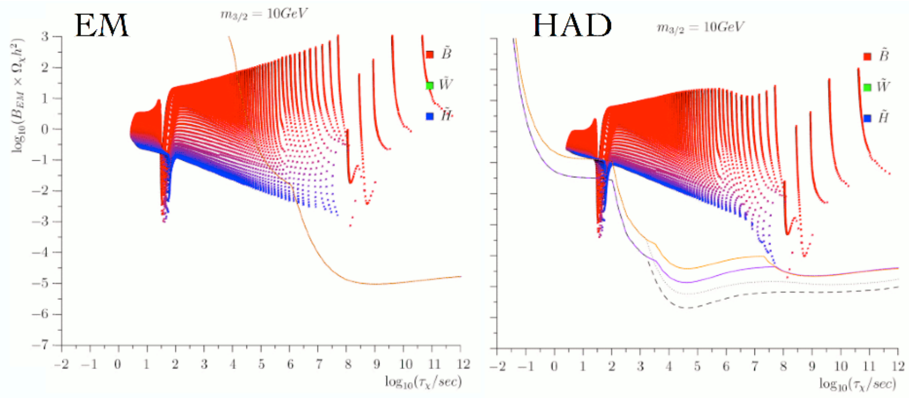


left: branching ratio of $\widetilde{B} \to \Psi_{3/2}\, q\bar{q}$

right: B_{had} for $\widetilde{B}$, $\widetilde{W}$, the maximally mixed case and $\widetilde{\gamma}$

- below Z threshold decay dominated by off-shell γ and light quarks preferred due to IR logarithmic enhancement
- B_{had} after Z threshold increased for any state except $\widetilde{\gamma}$

Example exclusion plot



1) $\widetilde{W}$ and $\widetilde{H}$ with lower number densities $\Rightarrow$ larger allowed $m_{3/2}$
2) at $m_\chi \sim 100$ GeV low B_{had} for $\widetilde{W}$ and $\widetilde{H}$ could allow $m_{3/2} \sim$ few GeV

BBN bounds taken from [Jedamzik, 2006]

Results

3) resonant Higgs annihilation $(m_{3/2})_{max,res} \sim 70 \text{ GeV} \left(\frac{m_\chi}{1.15 \text{ TeV}}\right)^{5/2}$
4) $\chi = \widetilde{\gamma}$ does not relax the hadronic constraints
5) sfermion coannihilation is order of magnitude effect for $\widetilde{B}$ and small effect for $\widetilde{W}$, $\widetilde{H}$
6) changing $\tan\beta$ has small effect

general χ NLSP extends allowed $m_{3/2}$ by about one order of magnitude
substantial hierarchy remains necessary

Conclusions

- thermal leptogenesis and $\Psi_{3/2}$ DM stay hardly reconcilable
  Higgs resonance region with lowered $m_{\widetilde{g}} \sim m_\chi$, $m_{3/2} \sim 70$ GeV
  $\widetilde{W}$ NLSP just above LEP bound with small $m_{\widetilde{g}}$, $m_{3/2}$ of a few GeV
- possibilty of producing $\Omega_{3/2}$ by χ NLSP decays*
  is excluded for LHC region

light χ (except $\widetilde{W}$ with degenerate chargino) would be difficult to reconcile with $\Psi_{3/2}$ DM and thermal leptogenesis with conserved R-parity

*[Feng, Rajarama & Takayama, 2003]

and LHC?

- gluino mass parameter should be smaller than 2 TeV
  $\rightarrow$ main observable E_{miss} in cascade decays as with χDM
- resonant annihilation region needs precise measurements of m_A and m_χ
- $\widetilde{W}$, $\widetilde{H}$ NLSP easier to identify due to nearly degenerate charginos
  $\rightarrow$ difficult to proof $\Omega_\chi \ll \Omega_{DM}$ with LHC alone

$\Longrightarrow$ hard to disentangle χLSP and DM from $\Psi_{3/2}$ DM with χ NLSP

large m_χ and enhanced NLSP annihilation (like Higgs resonance) may be first phenomenological signal for $\Psi_{3/2}$ DM at colliders