An open window for high reheating temperatures in supersymmetry

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Inflation

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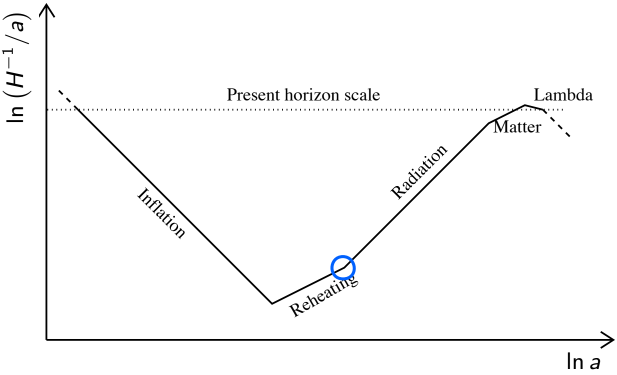
Supersymmetry

Inflation

$\updownarrow$ Reheating Temperature
$\rightarrow$ Gravitino Problem

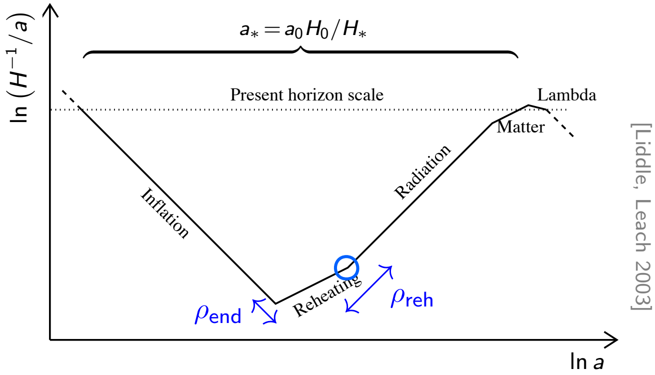
Supersymmetry

Inflation



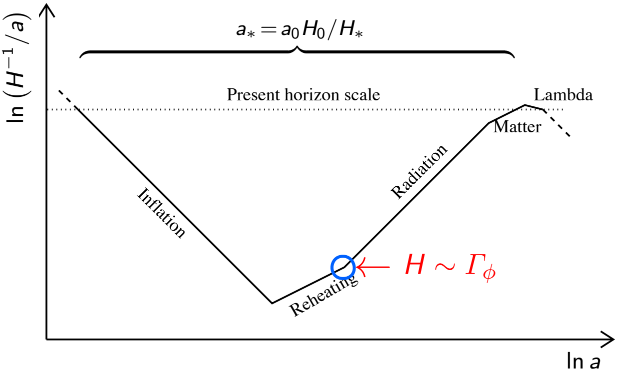
[Liddle, Leach 2003]

Inflation



$a_* = a_0 H_0 / H_*$
Present horizon scale
Lambda
Matter
Radiation
Inflation
Reheating
ρ_{end}
ρ_{reh}
$\ln\left(H^{-1}/a\right)$
$\ln a$
[Liddle, Leach 2003]

Inflation

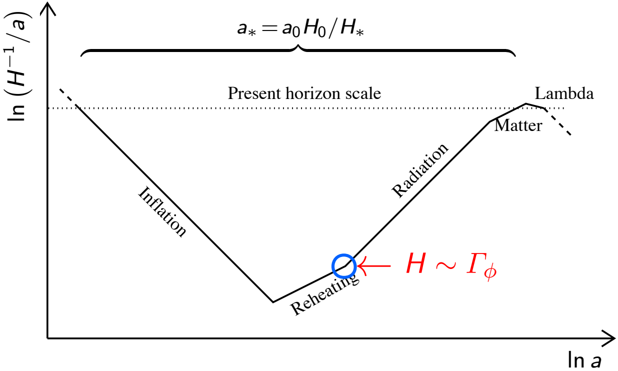


[Liddle, Leach 2003]

E.g. $\Gamma_\phi \sim m_\phi^3 / M_{\rm Pl}^2, \quad \rho_{\rm reh}^{1/4} \sim \sqrt{M_{\rm Pl}\Gamma_\phi}$

$r \sim 0.1 \;\rightarrow\; m_\phi \sim 10^{13}$ GeV $\;\rightarrow\; T_{\rm R} \gtrsim 10^9$ GeV

Inflation



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E.g. $\Gamma_\phi \sim m_\phi^3 / M_{\rm Pl}^2$, $\rho_{\rm reh}^{1/4} \sim \sqrt{M_{\rm Pl} \Gamma_\phi}$

[Fukugita, Yanagida '86]

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[Davidson, Ibarra '02; Buchmüller, Di Bari, and Plümacher '04]

The Gravitino Problem [Weinberg '82, Ellis *et al.* '84]

- Production of $\widetilde{G}$ in the early universe $\Omega_{\widetilde{G}} \sim T_{\mathrm{R}}$

  [Bolz, Buchmüller, Plümacher '98; Bolz, Brandenburg, Buchmüller '00; Pradler, Steffen '07]

- High $\Omega_{\widetilde{G}}$: $\widetilde{G} \to \widetilde{\chi} X$ conflict Big Bang Nucleosynthesis (BBN)

Way out: $\widetilde{G} = \mathrm{LSP} = \mathrm{DM}$

- NLSP $\to \widetilde{G} X$ suppressed: $\tau_{\mathrm{NLSP}} \sim M_{\mathrm{Pl}}^2 m_{\widetilde{G}}^2 / m_{\widetilde{\tau}_1}^5$
- If NLSP $\in$ MSSM: freeze-out!
  $\to$ BBN constraints depend on MSSM param. (not T_{R})
- $\Omega_{\widetilde{G}} \overset{!}{=} \Omega_{\mathrm{DM}}$, $\Omega_{\widetilde{G}} \sim \frac{T_{\mathrm{R}}}{m_{\widetilde{G}}} M_i^2 + (\text{non-therm. contr.})$

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  $\to$ Non-trivial interplay $T_{\mathrm{R}} \leftrightarrow$ MSSM param.

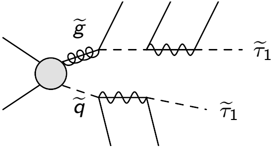
  [Moroi *et al.* '93; Fujii *et al.* '03; Roszkowski *et al.* '04, Pradler *et al.* '06, Olechowski *et al.* '09, Endo *et al.* '10]

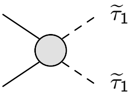
Here: no constraint model (pMSSM), implications from LHC 7/8

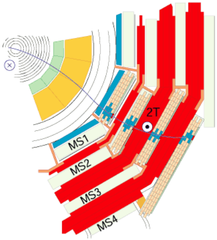
Choice of NLSP

Consider NLSP $= \widetilde{\tau}_1$:

- Direct SUSY searches = searches for heavy stable charged particles (HSCP) (no MET!)
- Clean signature $\rightarrow$ high sensitivity
- E.g. $m_{\widetilde{\tau}_1} \gtrsim 340\,\text{GeV}$ [CMS 2013]
- Great prospects for LHC 13/14







pMSSM Monte Carlo scan [JH, Kersten, Panes, Robens, 1310.2825]

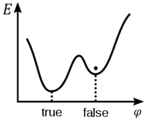
- Monte Carlo scan over $(17+1)$-dim. pMSSM
  A_t, A_b, A_τ; μ, $\tan\beta$, m_A; M_1, M_2, M_3; $\theta_{\tilde{\tau}}$, $m_{\tilde{\tau}_1}$; $\theta_{\tilde{t}}$, $m_{\tilde{t}_1}$, $m_{\tilde{b}_1}$;
  $m_{\tilde{L}_{1,2}}$, $m_{\tilde{e}_{1,2}}$, $m_{\tilde{Q}_{1,2}} = m_{\tilde{u}_{1,2}} = m_{\tilde{d}_{1,2}}$; $m_{\tilde{G}}$
- Interprete Higgs discovery in MSSM:

$$123\,\text{GeV} < m_{h/H} < 128\,\text{GeV}$$ [ATLAS, CMS '12]

- Used tools:
  - Spectrum, Higgs decays and precision observables: SuSpect, FeynHiggs
  - Decay tables: SDecay, Whizard
  - Cross sections: Fast XS estimation based on Prospino and NLL Fast, Whizard
  - Stau abundance and flavor observables: micrOMEGAs

pMSSM scan – constraints [JH, Kersten, Panes, Robens, 1310.2825]

- Interpretation of the HSCP search at the 7 and 8 TeV LHC
  - Consider all SUSY xs (also $pp \to h/H \to \widetilde{\tau}_1\widetilde{\tau}_1$)
  - Estimated $\sigma^{\text{obs}}_{\text{limit}}$ for each point from [CMS Collaboration '13]
- MSSM Higgs searches via HiggsBounds 4.0.0 (HB)
- Flavor and precision observables (FP)
  - $M_W = 80.385 \pm 0.060\,\text{GeV}$ @ 95% C.L. (Exp.+Theo. error)
    [TEW Group '12; Bechtle, Heinemeyer, Stål, Stefaniak, Weiglein Zeune '12]
  - $\text{BR}(B \to X_s\gamma) = (3.43 \pm 0.56) \times 10^{-4}$ @ 95% C.L.
    [Heavy Flavor Averaging Group '12]
  - $\text{BR}(B_s^0 \to \mu^+\mu^-) = (3.2^{+3.2}_{-2.1}) \times 10^{-9}$ @ 95% C.L.
    [LHCb Collaboration '12]
- Constraints from vacuum (meta-)stability (CCB)
  - Constraints on $|\mu \tan\beta|$ [Kitahara, Yoshinaga '13]
  - Constraints on A_τ, A_b, A_t [Casas, Lleyda, Muñoz '96]



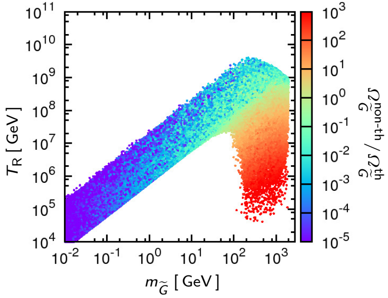
Implications for T_R from Ω_{DM}

- Compute stau yield $Y = n_{\widetilde{\tau}_1}/s$ from MSSM param.
- Non-thermal production: $\Omega_{\widetilde{G}}^{\text{non-th}} \sim Y m_{\widetilde{G}}$
- Gravitino DM: $\Omega_{\widetilde{G}} h^2 \stackrel{!}{=} \Omega_{DM} h^2 = 0.119$ [Planck '13]
  $\Omega_{\widetilde{G}} = \Omega_{\widetilde{G}}^{\text{th}} + \Omega_{\widetilde{G}}^{\text{non-th}}$
- Thermal production:

$$\Omega_{\widetilde{G}}^{\text{th}} \sim \sum_{i=1}^{3} C_i \left(1 + \frac{M_i^2}{3m_{\widetilde{G}}^2}\right) m_{\widetilde{G}} T_R$$

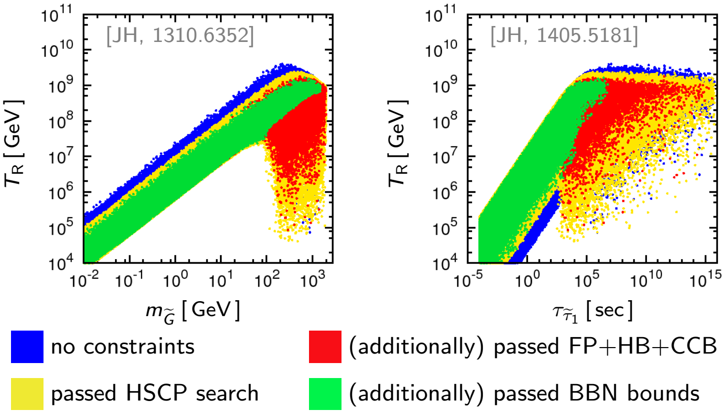
[Bolz, Buchmüller, Plümacher '98/'00; Pradler, Steffen '07]

[JH, 1310.6352]



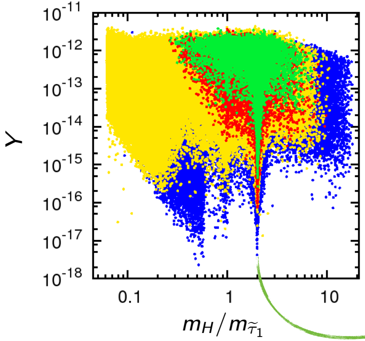
Implications for T_R from BBN and other constraints

- Compute $\tau_{\widetilde{\tau}_1}$, hadronic BRs $\Gamma(\widetilde{\tau}_1 \to \widetilde{G}\tau q\bar{q})$, $\Gamma(\widetilde{\tau}_1 \to \widetilde{G}\nu_\tau q\bar{q}')$
- Apply BBN bounds [Jedamzik '08]

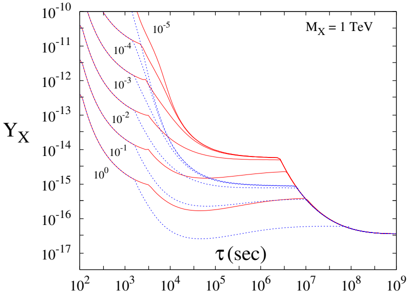


Exceptionally small stau yields

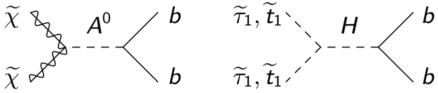
[JH, Kersten, Panes, Robens, 1310.2825]



[Jedamzik '08]



- no constraints
- passed HSCP search
- passed +FP+HB
- passed +CCB bounds



$Y < 10^{-14} \rightarrow m_A \simeq 2m_{\tilde{\tau}_1}$ only

Window for large $T_{\rm R}$

Points with $T_{\rm R} > 10^9\,\text{GeV}$ point to very particular corner:

- Large gravitino masses: $300\,\text{GeV} < m_{\widetilde{G}} < (m_{\widetilde{\tau}_1} - 200\,\text{GeV})$
- Life-times: $10^4\,\text{sec} < \tau_{\widetilde{\tau}_1} < 10^7\,\text{sec}$
- Exceptionally small yields $Y \lesssim 10^{-14}$
- All in H/A resonant region (w EWino/stop or w/o co-ann.)
- Gaugino masses just above exclusion limits, in particular M_2 (running)
- Small stau-gaugino splittings, $m_{\widetilde{\tau}_1} > 800 GeV$

Conclusions

- Sizable tensor-to-scalar ratio can have implications for SUSY
  $\rightarrow$ Gravitino Problem
- Gravitino-stau scenario: high LHC sensitivity
- Chose bottom-up approach (no high scale model)
- Points with $T_{\mathrm{R}} > 10^9\,\mathrm{GeV}$ only in particular window
- Interesting LHC pheno: Testable @ LHC 13

Thank you for your attention!