Gravitino Production in Early Universe

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This Talk

- Gravitinos are produced from scalar, i.e. inflaton, decay via gravitational effects.
- Direct and perturb. - different from thermal/preheating production.
- This talk clarifies underlying physics.
  - How generic it is?
  - How significant (for cosmology)?
(talk by Takahashi for inflation models)
Gravitino: overview

- R-parity odd
- Massive below SUSY breaking scale
- Absorb goldstino (fermion of SUSY field)
- Decay is Planck-suppressed

SUGRA = global SUSY + gravity

<table>
<thead>
<tr>
<th>SM</th>
<th>SUSY</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B, W, g$</td>
<td>$\tilde{B}, \tilde{W}, \tilde{g}$</td>
</tr>
<tr>
<td>$\ell, e, q, d, u$</td>
<td>$\tilde{\ell}, \tilde{e}, \tilde{q}, \tilde{d}, \tilde{u}$</td>
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<tr>
<td>$H_u, H_d$</td>
<td>$\tilde{H}_u, \tilde{H}_d$</td>
</tr>
<tr>
<td>graviton</td>
<td>gravitino</td>
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</tbody>
</table>
Gravitino Spoils SBBN

- BBN is spoiled by unstable gravitino

\[ X = \text{gravitino} \]

\[ \text{bounded} \]

[Gravitino Spoils SBBN by Kawasaki, Kohri, Moroi]
Abundance Bounded

- BBN is spoiled by unstable gravitino
- Overclose universe by stable LSP
- Initial gravitino abundance to be constrained

\[ m_X Y_X \lesssim 4.4 \times 10^{-10} \text{GeV} \]
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Production?
Thermal Production

- Thermal scattering of SM/SUSY particles
- Increase as $T_R \uparrow$

\[ Y_{3/2}^{(th)} \sim 10^{-12} \left( \frac{T_R}{10^{10}\text{GeV}} \right) \]

up to corrections

Example:
\[ g + g \rightarrow \tilde{g} + \psi_{3/2} \]
Thermal Production

- Thermal scattering of SM/SUSY particles
- Increase as $T_R \uparrow$

$Y_{3/2} \sim 10^{-12} \left( \frac{T_R}{10^{10} \text{GeV}} \right)$

cf. BBN bound

$Y_{3/2} \lesssim 10^{-(15-16)}$

for gravity-mediation
Thermal Production

- Thermal scattering of SM/SUSY particles
- Increase as $T_R \uparrow$
- Total decay rate of inflaton should be suppressed.
  \[ c \sim \frac{1}{M_P} \]
- Gravity effects should affect reheating

\[ Y_{3/2}^{(th)} \sim 10^{-12} \left( \frac{T_R}{10^{10}\text{GeV}} \right) \]

up to corrections

ex. $g + g \rightarrow \tilde{g} + \psi_{3/2}$

\[ Y_{3/2} \lesssim 10^{-(15-16)} \]

for gravity-mediation

\[ \text{cf. BBN bound} \]

\[ \text{up to corrections} \]
Gravitational Interaction

• We discuss inflaton decay in SUGRA

• Universal
  – SUSY breaking sector as well as inflaton inevitably couples to gravity.

• Less depend on details of model
  – Generic interaction rate
Gravity-Induced Inflaton Decay

Gravity supermultiplet

inflaton

SUSY

goldstino
Gravity-Induced Inflaton Decay

Gravity supermultiplet
\( \{ h_{\mu\nu}, \psi^{3/2}, b_\mu, \Phi \} \)

auxiliary field
\( b_\mu : U(1)_R \)
\( \Phi : \text{conformal} \)
Gravity-Induced Inflaton Decay

Gravity supermultiplet
\[ \{ h_{\mu\nu}, \psi_{3/2}, b_\mu, \Phi \} \]

inflaton

\[ \langle \phi \rangle \]

SUSY

conformal-/R-breaking
\[ m_\phi < \Lambda_{\text{SUSY}} \]

SUSY broken

\[ Z \rightarrow 2\psi_{3/2} \]

[ME, Hamaguchi, Takahashi; Kawasaki, Takahashi, Yanagida]
$m_\phi < \Lambda_{\text{SUSY}}$

[SUSY broken]

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[ME, Hamaguchi, Takahashi; Kawasaki, Takahashi, Yanagida]
$m_\phi < \Lambda_{\text{SUSY}}$

[SUSY broken]

Production rate

$\Gamma \simeq \frac{1}{32\pi} \left( \frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}$

[ME, Hamaguchi, Takahashi; Kawasaki, Takahashi, Yanagida]
$m_\phi > \Lambda_{\text{SUSY}}$

- Previous channel is suppressed
  - SUSY is restored - no conformal/R breaking
  - cancellation works even if SUSY is broken
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- Disaster of elementally-singlet Z
  - Polonyi problem
  - large gravitino production by $\delta K \sim |\phi|^2 z z$
\( m_\phi > \Lambda_{\text{SUSY}} \)

- Previous channel is suppressed
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- Disaster of elementally-singlet Z
  - Polonyi problem
  - large gravitino production by \( \delta K \sim |\phi|^2 zz \)
- Assign gauge charge for Z (e.g. in DSB)
\[ m_\phi > \Lambda_{\text{SUSY}} \]

- Conformal-/R-symmetries are anomalous at quantum level (c.f. AMSB)

[ME, Takahashi, Yanagida]
Conformal-/R-symmetries are anomalous at quantum level (c.f. AMSB)

\[ m_\phi > \Lambda_{\text{SUSY}} \]

\[ \langle \phi \rangle \sim \psi^{3/2} \]

massless in SUSY lim.
renormalizable coupling

[ME, Takahashi, Yanagida]
Conformal-/R-symmetries are anomalous at quantum level (c.f. AMSB)

\[ m_\phi > \Lambda_{\text{SUSY}} \]

Production rate

\[ \Gamma \sim \frac{\alpha^2}{256\pi^3} \left( \frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2} \]

[ME, Takahashi, Yanagida]
Production Rate

- Gravitinos are produced as long as $\langle \phi \rangle \neq 0$
- Direct pair gravitino for $m_\phi < \Lambda_{\text{SUSY}}$

\[
\Gamma \sim \frac{1}{32\pi} \left( \frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m_\phi^3}{M_P^2}
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- Anomaly-induced decay for $m_\phi > \Lambda_{\text{SUSY}}$

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[ME in collaboration w/ Hamaguchi, Kawasaki, Takahashi, Yanagida]
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[ME in collaboration w/. Hamaguchi, Kawasaki, Takahashi, Yanagida]
Gravitino Produced

Inflaton

$T_R$

Radiation

Thermal Gravitino
Gravitino Produced

\[ \Gamma_{3/2} \sim \left( \frac{\langle \phi \rangle}{M_P} \right)^2 \frac{m^3_\phi}{M_P^2} \]

\[ T_R \]

Radiation

Inflaton

Thermal Gravitino

Gravitino
Inflation Models

A: $m_{3/2} = 1$TeV, $B_h = 1$

B: $m_{3/2} = 1$TeV, $B_h = 10^{-3}$

C: $m_{3/2} = 100$TeV

D: $m_{3/2} = 1$GeV

+ : new(single); 1TeV
* : new(single); 100TeV
+ : new(multi)
- : hybrid
- : smooth hyb.
- : chaotic (w/o $Z_2$)

Talk by Takahashi

[ME, Takahashi, Yanagida]
Moduli Decay

- mass of scalar is light
  - $Y_{3/2}$ REDUCED
- VEV is at Planck scale
  - $Y_{3/2}$ INCREASES
- Very low reheating temperature
  - $Y_{3/2}$ INCREASES
- Problem becomes much WORSE
Moduli Decay

- mass of scalar is light
  - $Y_{3/2}$ REDUCED
- VEV is at Planck scale

Gravitino production is serious

- Very low reheating temperature
  - $Y_{3/2}$ INCREASES
- Problem becomes much WORSE
Natural Reheating

• Inflaton decays into MSSM sector w/o introducing special couplings by hand.

• Tree-level processes
  
  Majorana neutrino mass (leptogenesis)
  
  Top Yuakwa coupling w/\[ K \sim |\phi|^2 |Q|^2 \]

• Gluon(ino) production via anomalies

• Universe may be reheated. (ex. string-inspired inflation)
Summary

• Gravitinos are produced via gravitational effects.

• We obtained generic production rates.

• Crucially change conventional picture of reheating process.

• Inflation/moduli models are constrained.
  (see talk by Takahashi for inflation)

• Universe may be reheated naturally.
STOP
Decay into SM sector

- Inflaton decays into SM sector w/o introducing special couplings by hand.
- Tree-level processes
- Majorana neutrino mass
- Top Yukawa coupling w/
- Gluon (ino) production via anomalies
- Universe can be reheated

\[ K \sim |\phi|^2 |Q|^2 \]

via Yt coupling at tree-level w/ minimal Kahler
Relaxation of Problem

• Vanishing VEV: symmetries at vac.
  cf. most inf. models do NOT
  but chaotic w/ Z2

• Dilution: introduce new fields
  gravitino/LSP again, so NOT really solved

• Special SUSY breaking: need discussion