Moduli Stabilization
and
Moduli-Induced Gravitino Problem

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What is Moduli?

Scalar Fields in SUGRA/Superstring

○ Flat direction — almost massless

Mass is given by stabilization and related to SUSY/Non-Perturb.

\[ m_\phi \sim m_{\text{soft}} \]

○ Weak Interaction — Planck suppressed

Decay rate:

\[ \Gamma_X = \frac{c}{4\pi} \frac{m_\phi^3}{M_P^2} \]
Cosmological Moduli Problem

[Coughlan, Fischler, Kolb, Raby & Ross; Banks, Kaplan & Nelson; Carlos, Casas, Quevedo & Roulet]

Problem of Light and Long-Lived Scalar Field

- develop a large VEV during inflationary period and dominate energy of universe
- decay can upset success of BBN very easily
- constraint on $\tau_\phi$
  \[ \tau_\phi < O(0.1) \text{ sec} \]
... Many Solutions Proposed

- **Heavy Moduli Scenario** [Ellis,Nanopoulos&Quiros]
  ...
  ... depends on moduli stabilization

- Enhanced Symmetry Points [Dine,Nir&Shadmi]
- Large Hubble-Induced Mass [Linde]
- Weak scale inflation [Randall&Thomas;Lyth&Stewart]
- Domain wall [Kawasaki&Takahashi]

and more...
Heavy Moduli Scenario: \( m_\phi \gtrsim 100 \text{ TeV} \)

Mass is determined by moduli stabilization

- Gaugino condensation (e.g. KKLT)
  \[ m_\phi \sim O(10) \times m_{3/2} \]

- Racetrack
  \[ m_\phi \sim O(10^2) \times m_{3/2} \]

cf. Gravitino mass is bounded from above

\[ m_{3/2} \lesssim 100 \text{ TeV} \]
Heavy Moduli Scenario: $m_\phi \gtrsim 100$ TeV

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Modulus decay is NOT protected by symmetry

**Moduli-Induced Gravitino Problem**

cf. Gravitino mass is bounded from above

$m_{3/2} \lesssim 100$ TeV
Branching Ratios of Moduli Decay

Radiations e.g. dilatonic coupling, \( \frac{\lambda_G}{M_P} \int d^2 \theta \phi WW \)

\[ \Gamma(\text{gauge boson}) \sim \Gamma(\text{gaugino}) \sim \frac{3|\lambda_G|^2 m_\phi^3}{2\pi M_P^2}, \]

Gravitino Production

\[ \Gamma(\phi \rightarrow 2\psi_{3/2}) \sim \frac{|\kappa|^2 m_\phi^3}{288\pi M_P^2}, \]

\[ B_{3/2} \sim B_{\text{LSP}} \sim B_{\text{rad}} \]

indep. of \( m_\phi \)

\[ \kappa = O(1) \]

[ME, Takahashi&Hamaguchi; Nakamura&Yamaguchi]
[cf. Brignole, Casas, Espinosa&Navarro]
**Gravitino Production Rate**: $B_{3/2} \sim |\kappa|^2$

Generically $\kappa = O(1)$ at vac. in mass-eigenstate basis, where $z$ is SUSY breaking field

- **Kaehler mixing**: $K \sim \kappa \phi^{\dagger} z z + h.c.$
  
  $\phi$ and $z$ are not protected by sym. at vac.

- **mass of SUSY breaking field** (e.g. DSB)
  
  $m_Z > m_\phi \quad \rightarrow \quad \kappa \sim \nabla_\phi G_z \sim O(1)$

  cf. (accidentally) minimal Kaehler & $m_Z < m_\phi$

  $\kappa \sim m_{3/2}/m_\phi < O(1)$

[Dine, Kitano, Morrise & Shirman; ME, Takahashi & Hamaguchi]
Cosmological Bounds

$\Omega_{\text{LSP}} h^2 > 0.13$

$\Omega_{3/2} h^2 > 0.13$

BBN bound from NLSP decay

WDM

allowed

unstable gravitino

speed up effect

stable gravitino

$B_{3/2}$

$B_{3/2}$

$10^5$

$10^4$

$10^3$

$10^2$

$10^1$

$10^0$

$10^{-1}$

$10^{-2}$

$10^{-3}$

$10^{-4}$

$10^{-5}$

$10^{-6}$

$m_{\phi} = 10^3 \text{ TeV}$

[ME, Takahashi & Hamaguchi]
Cosmological Bounds

$\phi = 10^3 \text{ TeV}$

Heavy Moduli Scenario is Cosmologically Disfavored!!

Moduli-Induced Gravitino Problem

Inflation case is talked by Takahashi

[ME, Takahashi & Hamaguchi]
Possible Solutions of MIG Problem

- dilution  *e.g.* thermal inf., Q-ball, …
  
  the field should be free from MIG problem

- heavy Gravitino: $m_{3/2} \gtrsim 10^{3-4} \text{ TeV}$
  
  SUSY med. by superconformal anomaly

- super-heavy moduli
  
  supersymmetric stabilization

- suppress $\kappa$ at vac.
  
  symmetry-preserved stabilization mechanism
Summary

Heavy moduli field is generically plagued with the Moduli-Induced gravitino problem.

Solution:

- moduli stabilization mechanism which preserves symmetry @ vac.,
- / we require subtleties for the other sector.