Axionic Mirage Mediation

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1. Outline

- **Mixed modulus-anomaly mediation of SUSY breaking (mirage mediation)**

  simple and attractive scenario

  Choi,Falkowski,Nilles, Olechowski 05
  Endo,MY,Yoshioka 05
  Choi,Jeong,Okumura 05

- **little hierarchy among masses**:

  Moduli X — gravitino (compensator Φ) — sparticles

  $F_X \sim m_{3/2}^2/m_X$ << $F_\Phi = m_{3/2}$

  m_X >> $m_{3/2}$ >> m_{soft}

- **Relatively heavy moduli**

  ← A consequence of a simple exponential factor

  $W \sim A \exp[- bX] +$ constant

  typical example: KKLT set-up

- **This scenario seemed to provide a solution to cosmological moduli problem and gravitino problem.**

However life is not that easy!

Moduli-Induced Gravitino Problem

Endo,Hamaguchi, Takahashi 06
Nakamura,MY 06

- Moduli decay into Gravitino Pair
  - significant branching ratio ~0.01 generically

- *Dangerous Decay Chain*

  Moduli→ Gravitino →(Sparticles) → Neutralino LSP

- Too many LSPs are produced!
  - (even after considering the effect of neutralino annihilation)

Another Problem: μ/B-problem

- common problem when gravitino is heavy (anomaly mediation)

- If μ is generated in SUSY way, B-parameter (Higgs mixing parameter) becomes $F_\phi = m_{3/2}$ (mass dimension)

- μ as well as B should be generated in a non-trivial way (related with SUSY breaking).

OUR PROPASAL

- ***Axionic (Extension of) Mirage Mediation*** solves
  the moduli-induced gravitino problem and
  the μ/B problem simultaneously.

- **Idea:**
  - Use of Pomarol-Rattazzi (to generate μ/B parameters)
    + its axionic extension (similar to Abe-Moroi-MY)
  - μ and B are dynamically generated.
  - **Axino LSP** avoids overabundance thanks to small mass.

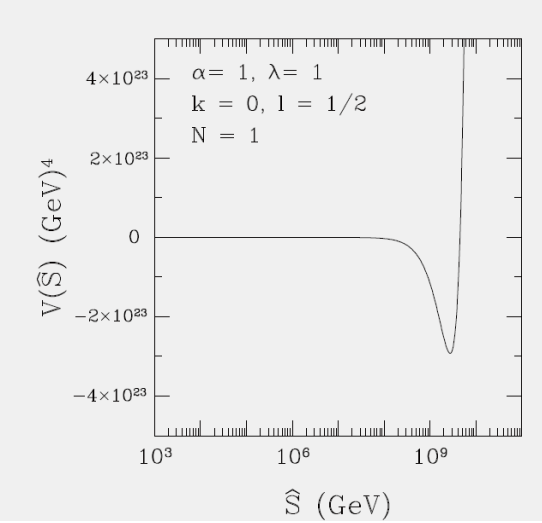
2. The Model

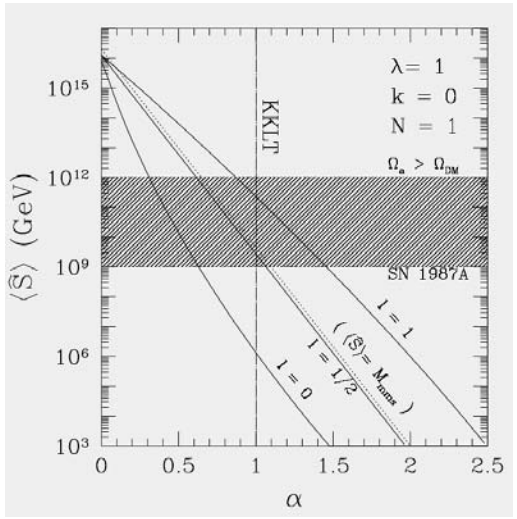
Nakamura,Okumura, MY 08

Axion multiplet *S*: gauge singlet with PQ charge 2.

Coupling to “mesesenger” $W = \lambda S \Psi \bar{\Psi}$

Potential of *S:* generated at loop level





$$\alpha \equiv \frac{m_{3/2}}{(F_X/2X_R)\ln(M_{\rm Pl}/m_{3/2})}$$

PQ scale can naturally fall into the axino window.

F term of S field becomes non-supersymmetric

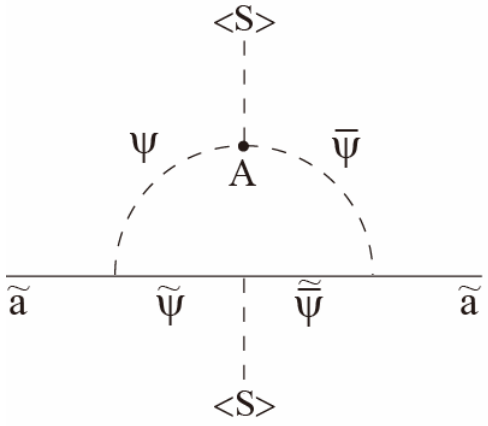
$$F_S/S \approx -F_\Phi$$

deflection (Pomarol-Rattazzi)

Axino Mass

$$m_{\tilde{a}} = \frac{1}{8\pi^2}\left(\frac{1}{2}\frac{\partial\gamma_S(|\hat{S}|)}{\partial X^\dagger}F_X^\dagger - \frac{1}{4}\gamma_S(|\hat{S}|)F_\Phi^\dagger\right)\left\langle\frac{\hat{S}^\dagger}{\hat{S}}\right\rangle$$

(γ_S : anomalous dimension of S)



Axino mass arises at two-loop.

cf. other soft masses at one-loop

⇒ **The axino becomes LSP**

Generation of μ and B in Axionic Mirage Mediation

similar to
Pomarol,Rattazzi 99
Abe,Moroi,MY 01

Introduction of two other singlets S_2, T

$$W = y_1 T H_1 H_2 + y_2 S_1 S_2 T$$

$$\Omega = |S_1|^2 + |S_2|^2 + |T|^2 + \kappa S_1^\dagger S_2 + \text{h.c.}$$

$$\left[\Omega = -3e^{-K/3}\right]$$

When S_1 gets VEV, we can integrate out S_2 and T

$$\mathcal{L} = -\kappa \frac{y_1}{y_2} \int d^4\theta \frac{\hat{S}_1^\dagger}{\hat{S}_1} H_1 H_2 + \text{h.c.}$$

➡ **μ and B generated at correct order of magnitude**
(a variant of Giudice-Masiero mechanism)

Note: $F_S/S \approx -F_\Phi$ plays an essential role.

3. Cosmology Highlights

Nakamura,Okumura, MY 08

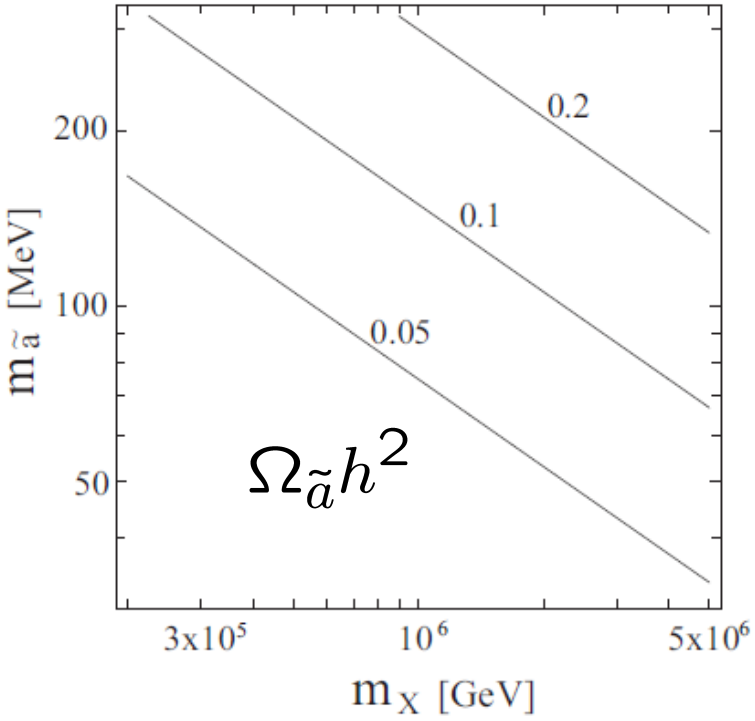
- **Moduli Decay:** entropy production (before BBN)
  gravitino (sparticle) production

- **Gravitino Decay:** life time shorter than 1 sec

- **Axino LSP abundance**
  dominant production mode:
  moduli→ gravitino → (sparticles) →NLSP → axino LSP

$$Y_{\tilde{a}} \sim 4 \times 10^{-9} \left(\frac{\mathrm{Br}(X \to \psi_{3/2}\psi_{3/2})}{0.01} \right) \times \left(\frac{m_X}{10^6 \mathrm{GeV}} \right)^{1/2}$$

axino dark matter



axino abundance for typical NLSP

Axino can be dark matter when mass ~0.1 GeV.

Axinos are produced energitically.

→ **Free-streaming length O(0.1) MPc.**

Maybe some implication to (small) scale structure

4. Phenomenology Highlights

- **Neutralino NLSP decay (to Axino)**

  Nakamura,Okumura,MY 08, and work in progress

  decay length

  bino-like NLSP: very long

  higgsino-like NLSP $c\tau \sim 1\mathrm{m}$

  for $m_\chi = 150$ GeV, $\langle S \rangle = 10^{10}$ GeV

  → displaced vertex to *h/Z:*

  specutacular signals at LHC!

- **Sparticle Mass Spectrum**

  Everret et al '08
  MY et al, in preparation

  general mixture of Moduli/Gauge/Anomaly mediation

  Mirage unification still holds for gaugino masses.
  This is not the case for scalar masses.

5. Summary

- New Proposal: Axionic Mirage Mediation
  - solution to Moduli-induced Gravitino problem.
  - solution to mu/Bmu problem

- Cosmological and Phenomenological implications: very interesting
  - axino dark matter
  - displaced vertex etc