R-symmetry Matching in Supersymmetry Breaking Models

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Motivation

- SUSY is a leading candidate solution to the hierarchy problem
  - Provides a technically natural solution to stabilizing the weak scale
  - If SUSY is broken dynamically, the scale of SUSY breaking is exponentially suppressed relative to the Planck scale
- SUSY must be broken
  - Calculable, viable models of dynamical SUSY breaking are few
    - 3-2 (Affleck, Dine, Seiberg) and 4-1 (Dine, Nelson, Nir, Shirman + Poppitz, Trivedi) models
    - ITIY (Intriligator-Thomas-Izawa-Yanagida) model

Motivation

- Intriligator, Seiberg, Shih – models with metastable SUSY breaking vacua are generic
  - But R-symmetry is usually unbroken in these vacua
    - A remnant R-symmetry larger than Z_2 forbids Majorana gaugino masses
- Nelson, Seiberg – having an R-symmetry is a necessary condition to break SUSY given a **generic** superpotential
- How do we construct models with metastable, SUSY breaking vacua that also break R-symmetry?

Motivation

- Shih – generalized O'Raifeartaigh models that possess superfields with R-charge other than 0 or 2 will break SUSY and spontaneously break R-symmetry

$$W = \lambda X(\mu^2 - \phi_1\phi_2) + m_1\phi_1\phi_3 + \frac{m_2}{2}\phi_2^2$$

  - The Coleman-Weinberg potential generates a non-zero vev for the pseudomodulus, which is charged under the R-symmetry
  - Also introduces a supersymmetric vacuum at infinity, so finite vacuum is at best metastable

Motivation

- Shih $W = \lambda X(\mu^2 - \phi_1\phi_2) + m_1\phi_1\phi_3 + \frac{m_2}{2}\phi_2^2$
  - Generically need a superfield with negative R-charge
- Can we construct a UV completion that generates negative R-charges in the IR effective description?
  - Could in principle generate ϕ_1^{-2} non-perturbatively, consistent with R-symmetry
    - Such a term would destabilize any local vacuum near the origin, leading to runaway behavior

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- Yes! Will present 2 models with the desired behavior
  - Differ in whether UV R-symmetry is anomalous

Model A – Non-anomalous UV R-symm.

- Recall Shih's generalized O'Raifeartaigh model

$$W = \lambda X(\mu^2 - \phi_1\phi_2) + m_1\phi_1\phi_3 + \frac{m_2}{2}\phi_2^2$$

- UV completion based on a deformation of ITIY
  - SU(2) gauge theory with 2 flavors (4 doublets) and 6 singlets
    - Can check the deformation does not reintroduce a flat direction and W is generic
  - Here, $M_{12} = (Q_1 Q_2)$ and similarly for other M's
  - χ is a Lagrange multiplier to enforce the quantum constraint
  - Maximal global symmetry is $SU(2)^2 \times U(1)_R$

$$W = \chi(\text{ Pf } M - \Lambda^4) + \sum_{ij} \lambda_{ij} S_{ij} M_{ij} + \frac{M_{34}^2}{\Lambda_{UV}} + \frac{m_S}{2} S_{34}^2$$

Model A – R-symmetry Matching

- To match to Shih, we solve the q.c., integrate out heavy superfields (and adopt SU(4)≅SO(6) language)

$$W = \lambda_1 S_1 \left(\Lambda^2 - \frac{M_{12} M_{34}}{\Lambda^2} \right) + \lambda_{12} S_{12} M_{12} + \left(\frac{1}{\Lambda_{UV}} - \frac{\lambda_{34}^2}{2 m_S} \right) M_{34}^2$$

leading to the correspondence

$$X \sim S_1, \quad \phi_1 \sim M_{12}/\Lambda, \quad \phi_2 \sim M_{34}/\Lambda, \quad \phi_3 \sim S_{12}$$

- R-charges match exactly between UV and IR descriptions

$$R(Q_1) = R(Q_2) = -\frac{1}{2}\,, \quad R(Q_3) = R(Q_4) = \frac{1}{2}\,,$$

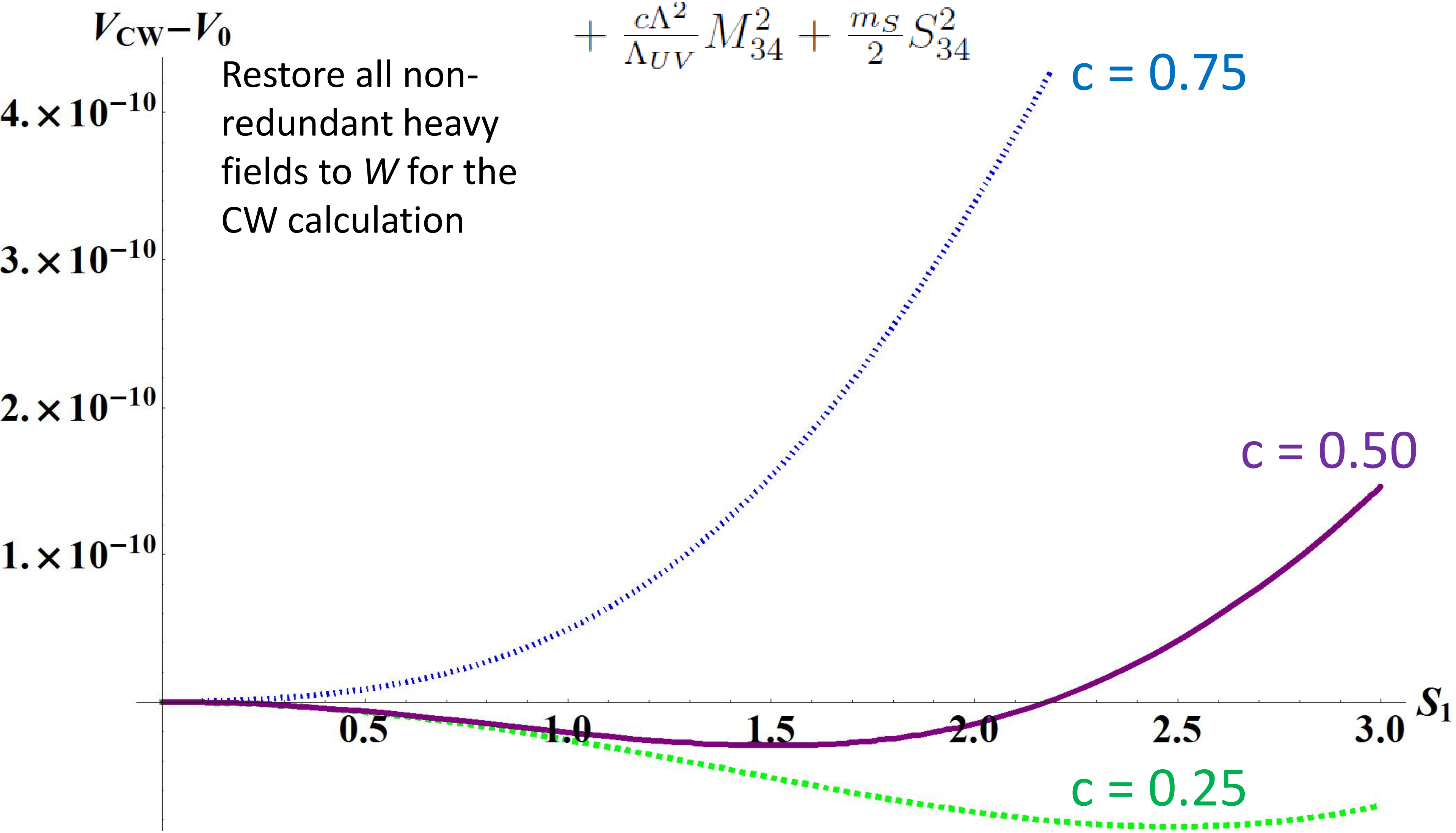
$$R(S_{12}) = 3\,, \quad R(S_{34}) = 1\,, \quad R(S_1) = R(S_2) = R(S_3) = R(S_4) = 2$$

- Do not generate $M_{12}^{-2}=(Q_1Q_2)^{-2}$ because the $U(1)_R$ symmetry (resulting from mixing $U(1)_F$ = diag (-1, -1, 1, 1) with the original ITIY $U(1)_R$) is **non-anomalous**

Model A
CW Potential

$$\begin{aligned} W &= \lambda_1 S_1 \left(\Lambda^2 - \tfrac{1}{2}M_2^2 - M_{12}M_{34}\right) \\ &+ \lambda_2 \Lambda S_2 M_2 + \lambda_{12}\Lambda S_{12} M_{12} + \lambda_{34}\Lambda S_{34} M_{34} \\ &+ \frac{c\Lambda^2}{\Lambda_{UV}} M_{34}^2 + \frac{m_S}{2} S_{34}^2 \end{aligned}$$

Restore all non-redundant heavy fields to *W* for the CW calculation



$$\Lambda = 1,\ \Lambda_{UV} = 10,\ \lambda_1 = 0.02,\ \lambda_2 = 1,\ \lambda_{12} = 0.03,\ \lambda_{34} = 0.03, m_S = 1$$

Model B – Anomalous UV R-symm.

- Extend Shih's generalized O'R model to *F* flavors

$$W = \lambda \phi_i X^{ij} \tilde{\phi}_j - \mu^2 \phi_1 + \frac{1}{2} m \ \mathrm{Tr}\ X^2 + n \tilde{\phi}_i S^i$$

- Based on a deformation of SQCD with *F = N+1*
- Note $\phi X \tilde{\phi} \sim B M \bar{B} / \Lambda^{2N-1}$ is dynamically generated
- Full UV superpotential is thus

$$W = \lambda \frac{B_i M^{ij} \bar{B}_j - \det M}{\Lambda^{2N-1}} + c_B \frac{B_1}{\Lambda_{UV}^{N-3}} + c_M \frac{\mathrm{Tr}\ M^2}{\Lambda_{UV}} + c_{\bar{B}} \frac{\bar{B}_i S^i}{\Lambda_{UV}^{N-2}}$$

with $B = Q^{F-1}$, $\overline{B} = \overline{Q}^{F-1}$, $M = Q\bar{Q}$

- Note the det *M* term is irrelevant in the IR

Model B – R-symmetry considerations

$$W = \lambda \frac{B_i M^{ij} \bar{B}_j - \det M}{\Lambda^{2N-1}} + c_B \frac{B_1}{\Lambda_{UV}^{N-3}} + c_M \frac{\mathrm{Tr}\ M^2}{\Lambda_{UV}} + c_{\bar{B}} \frac{\bar{B}_i S^i}{\Lambda_{UV}^{N-2}}$$

- Considering only the UV tree-level terms, there is an R-symmetry but it is **anomalous**
- In the IR description, we can formally restore the R-symmetry by allowing Λ to transform
  - Can fix B and M charges, leaving B̄ and S undetermined
  - The dynamical term constrains how to absorb the spurion Λ into B̄ and hence S as well

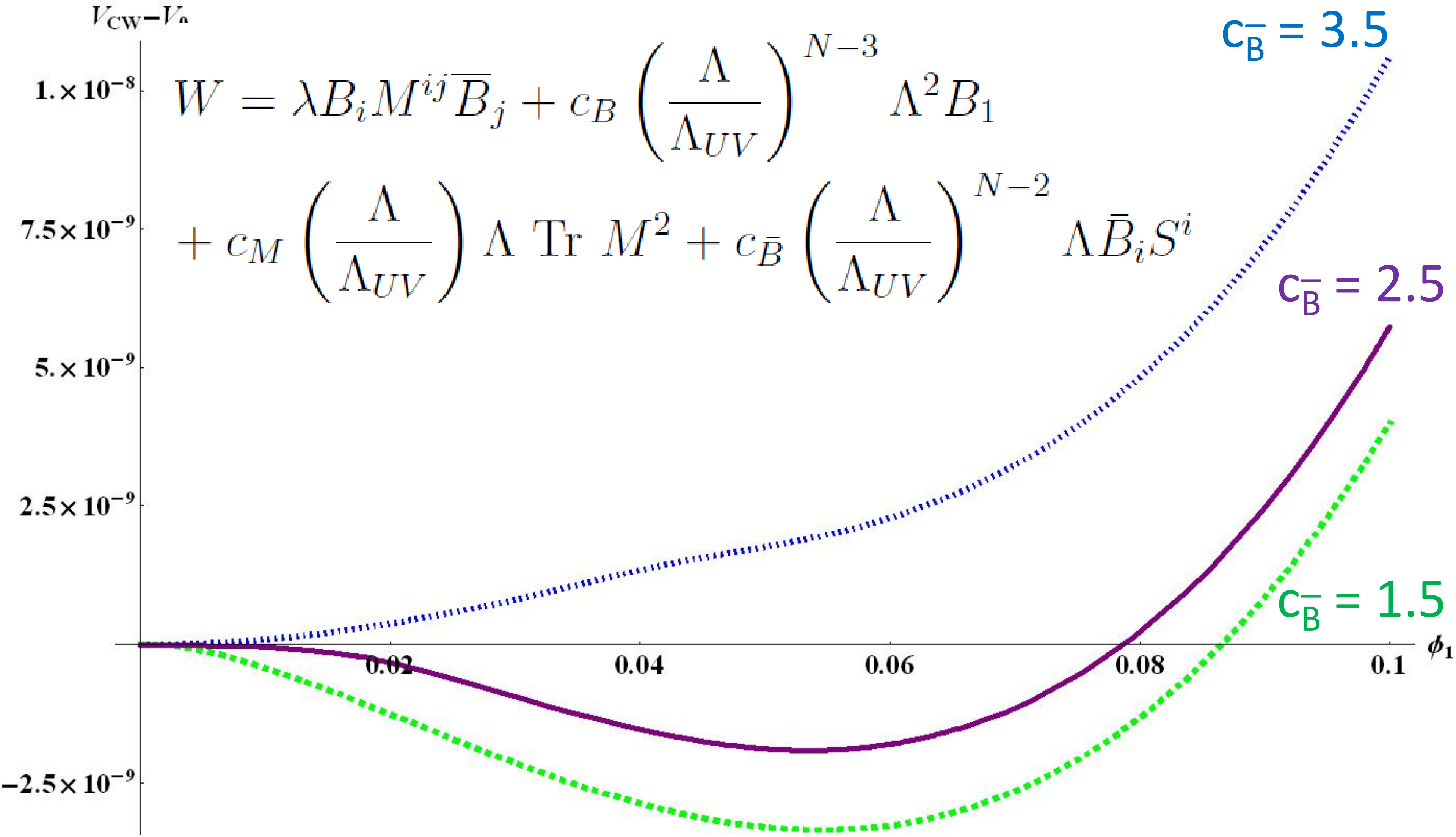
$$R_\phi = R_B \ , \quad R_X = R_M \ , R_{\tilde{\phi}} = R_{\bar{B}} - R_{\Lambda^{2N-1}} \ , \quad R_{S_{IR}} = R_{S_{UV}} + R_{\Lambda^{2N-1}}$$

- $(B_i)^{-2}$ is not generated, would violate $U(1)_B$ global symmetry

Model B – Coleman-Weinberg Potential

$$W = \lambda B_i M^{ij}\overline{B}_j + c_B\left(\frac{\Lambda}{\Lambda_{UV}}\right)^{N-3}\Lambda^2 B_1$$

$$+ c_M\left(\frac{\Lambda}{\Lambda_{UV}}\right)\Lambda\,\mathrm{Tr}\,M^2 + c_{\bar{B}}\left(\frac{\Lambda}{\Lambda_{UV}}\right)^{N-2}\Lambda\bar{B}_i S^i$$



$$\Lambda = 1,\ \Lambda_{UV} = 10,\ N = 4,\ \lambda = 1,\ c_B = 0.1,\ c_M = 4.0$$

Conclusions

- IR R-symmetry with superfields of negative R-charge can arise from non-anomalous R-symmetry of UV
- Or can arise from anomalous R-symmetry of UV
  - Mixing between $U(1)_R$ and non-anomalous U(1) symmetry prevented dynamical generation of dangerous operators
  - Cosmological history is changed since UV parameters have distinct regions of calculable validity
- Have presented a prescription for constructing UV completions of Shih-type generalized O'Raifeartaigh models
  - Future work will investigate the phenomenology of such models

Model B – Gauge and global symmetries

	$SU(F-1)_{\text{gauge}}$	$SU(F)_L$	$SU(F)_R$	$U(1)_B$	$U(1)_A$	$U(1)_R$
Q	$\square$	$\square$	1	$\frac{1}{F-1}$	$\frac{1}{F-1}$	0
$\bar{Q}$	$\overline{\square}$	1	$\overline{\square}$	$-\frac{1}{F-1}$	$\frac{1}{F-1}$	0
S	1	1	$\overline{\square}$	1	-1	2
Λ^{2F-3}					$\frac{2F}{F-1}$	-2
$B = Q^{F-1}$	1	$\overline{\square}$	1	1	1	0
$\overline{B} = \overline{Q}^{F-1}$	1	1	$\square$	-1	1	0
$X = Q\bar{Q}$	1	$\square$	$\overline{\square}$	0	$\frac{2}{F-1}$	0

$$U(1)_{R'} = U(1)_R + \frac{N}{2}U(1)_A + (2 - \frac{N}{2})U(1)_B$$