R-symmetry Matching in Supersymmetry Breaking Models

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Motivation

- The LHC has not discovered SUSY
- Nevertheless, 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

Motivation

- Until recently, collider searches have been dominated by the phenomenology of mSUGRA and mGMSB
  - Recent efforts towards “simplified models” helps reduce model dependence
- Yet we are still learning new results both about mediation scenarios (e.g. GGM) and SUSY breaking that motivate different SUSY phenomenology
  - Continued efforts may motivate a new LHC SUSY search

Motivation

- Focus on dynamical SUSY breaking models
  - 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
  - If mediated by gauge interactions, for example, entire model may be under complete theoretical control and phenomenology can be well understood

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
  - Maximal global symmetry is SO(4) x $U(1)_R$

$$W = \sum_{i,j=1,\ i<j}^{4} \lambda_{ij} S_{ij} Q_i Q_j + \frac{(Q_3 Q_4)^2}{\Lambda_{UV}} + \frac{m_S}{2} S_{34}^2$$

Model A – From UV to IR

- The full superpotential is

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

  - Here, $M_{12} = (Q_1 Q_2)$ and similarly for other M's
  - χ is a Lagrange multiplier to enforce the quantum constraint
- To match to Shih, we solve the quantum constraint for meson M_1

$$M_1 = \left(\Lambda^4 - \sum_{a=2}^{4} M_a^2 - 2M_{12}M_{34}\right)^{1/2} \simeq \Lambda^2 - \sum_{a=2}^{4} \frac{M_a^2}{2\Lambda^2} - \frac{M_{12}M_{34}}{\Lambda^2} + \ldots$$

Model A – From UV to IR

- The superpotential is then

$$\begin{aligned} W &= \lambda_1 S_1 \left(\Lambda^2 - \sum_a \frac{M_a^2}{2\Lambda^2} - \frac{M_{12} M_{34}}{\Lambda^2} \right) \\ &+ \sum_a \lambda_a S_a M_a + \lambda_{12} S_{12} M_{12} + \lambda_{34} S_{34} M_{34} + c \frac{M_{34}^2}{\Lambda_{UV}} + \frac{m_S}{2} S_{34}^2 \end{aligned}$$

- Once we integrate out the heavy fields M_a, S_a, and S_{34}, we find the desired correspondence

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

$$\mu \sim \Lambda, \quad \lambda \sim \lambda_1, \quad m_1 \sim \lambda_{12}\Lambda, \quad m_2 \sim \left(\frac{1}{\Lambda_{UV}} - \frac{\lambda_{34}^2}{2m_S} \right) \Lambda^2$$

with the IR Shih-type O'Raifeartaigh model

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

Model A – R-symmetry Matching

- R-charges match exactly between UV and IR descriptions
- In UV, we had $$W = \sum_{i,j=1,\ i<j}^{4} \lambda_{ij} S_{ij} Q_i Q_j + \frac{(Q_3 Q_4)^2}{\Lambda_{UV}} + \frac{m_S}{2} S_{34}^2$$

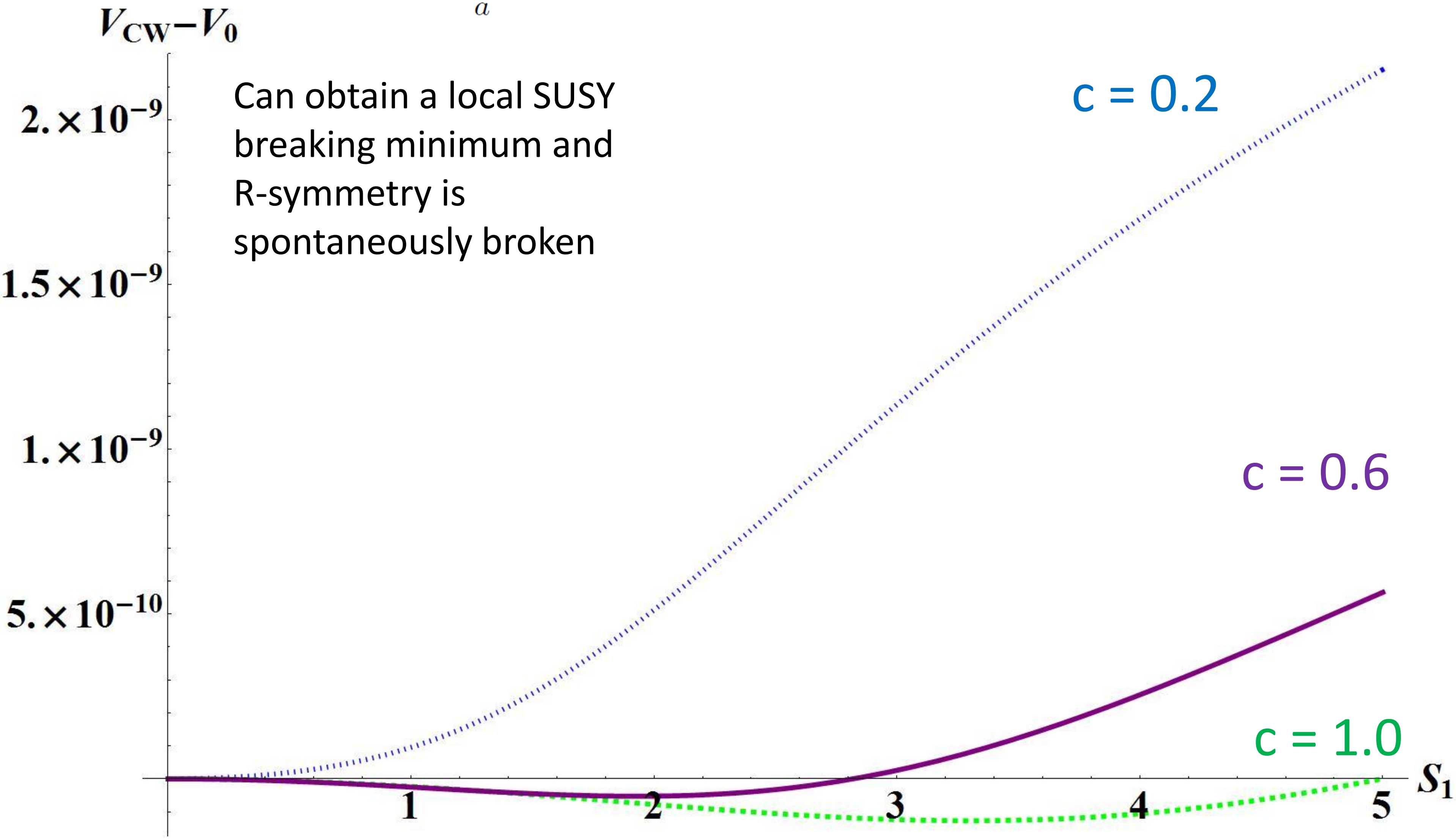
$$R(Q_1) = R(Q_2) = -\frac{1}{2}\,, \quad R(Q_3) = R(Q_4) = \frac{1}{2}\,,$$
$$R(S_{12}) = 3\,, \quad R(S_{34}) = 1\,, \quad R(S_1) = R(S_2) = R(S_3) = R(S_4) = 2$$

- In IR, we found the correspondence
$$X \sim S_1, \quad \phi_1 \sim M_{12}/\Lambda, \quad \phi_2 \sim M_{34}/\Lambda, \quad \phi_3 \sim S_{12}$$
- 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

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

CW



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

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*
  - Map $\phi_i \sim B_i \;, \quad \tilde{\phi}_i \sim \overline{B}_i \;, \quad X_{ij} \sim M_{ij}$ and keep S elementary
  - In the absence of the superpotential, the global symmetry is $SU(F)_L$ x $SU(F)_R$ x $U(1)_B$ x $U(1)_A$ x $U(1)_R$
- Need at least one term to be dynamically generated
  - $\phi X \tilde{\phi} \sim B M \bar{B} / \Lambda^{2N-1}$ is a well-known dynamical term

Model B – Gauge, global symmetries

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

- There is an anomalous R-symmetry in the UV superpotential

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

Model B – R-symmetry Matching

- Full dynamical UV superpotential is

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

  - Note the det *M* term is irrelevant in the IR
- $R'_B = 2$, $R'_{\bar{B}} = -2+N$, $R'_M = 1$, $R'_S = 4-N$, $R'_{\Lambda^{2N-1}} = -1+N$
- To match UV and IR R-charges, absorb spurion charge into $\bar{B}$ and correspondingly, S

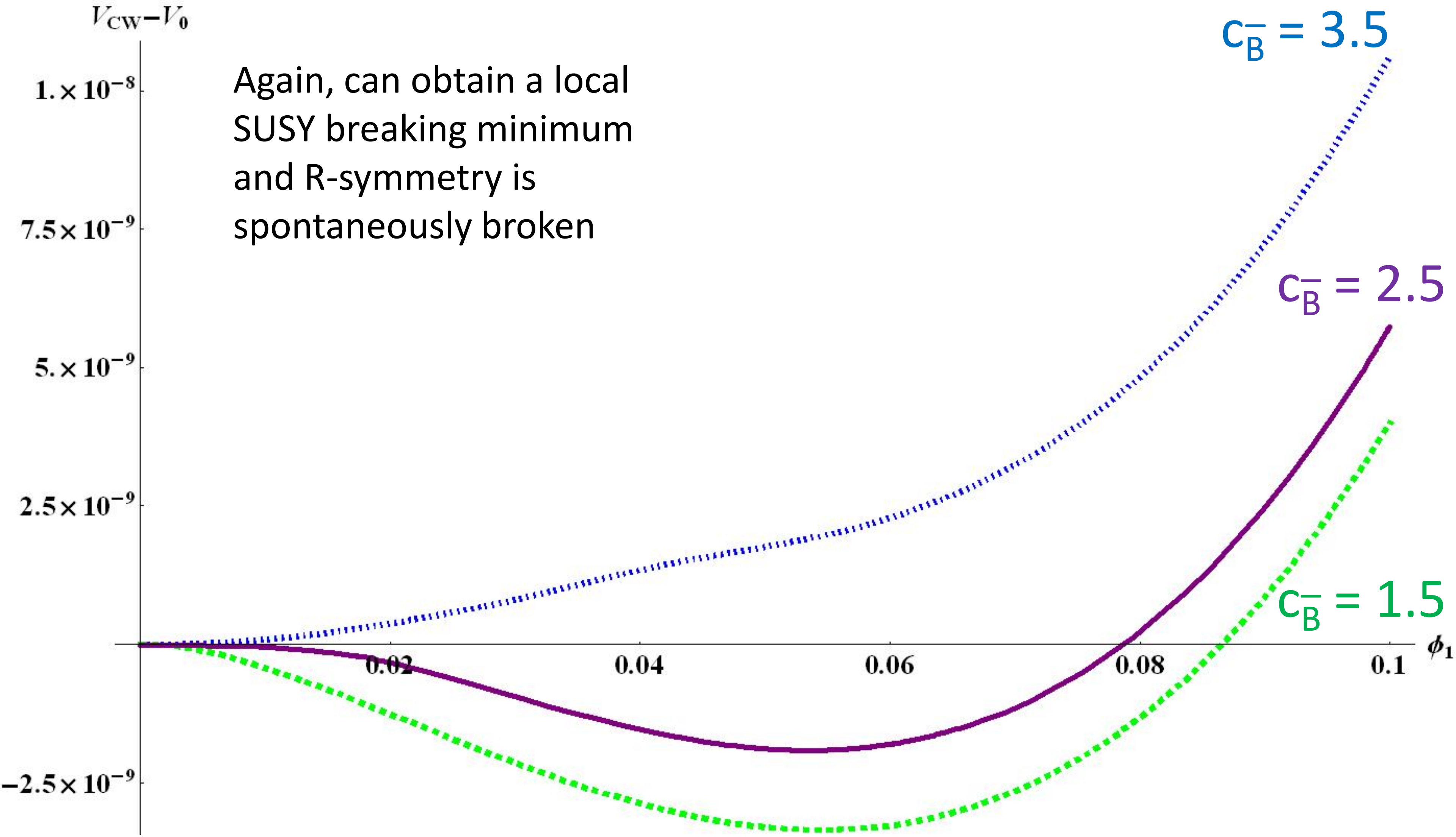
$$R_\phi = R_B \ , \quad R_X = R_M \ , R_{\tilde{\phi}} = R_{\bar{B}} - R_{\Lambda^{2N-1}} \ , \quad R_{S_{IR}} = R_{S_{UV}} + R_{\Lambda^{2N-1}}$$

  - All negative R-charges in IR arise from spurion contribution of Λ^{2N-1}
  - Thus dynamical NP terms are regular at the origin

Model B
CW

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

Again, can obtain a local SUSY breaking minimum and R-symmetry is spontaneously broken



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

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
  - Dangerous operators were avoided in either case
- Have presented a prescription for constructing UV completions of Shih-type generalized O'Raifeartaigh models
  - Future work will investigate the phenomenology of such models