Meta-Stable Dynamical Supersymmetry Breaking Near Points of Enhanced Symmetry

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SUSY 07

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Motivation

- If SUSY relevant for hierarchy problem, then $M_{\not{SUSY}} << M_{Planck}$
- Dynamical Sypersymmetry Breaking (DSB) (Witten)

$\longrightarrow$ can dynamically generate a scale related to ~~SUSY~~ scale that is hierarchically smaller than any fundamental scale: $\Lambda = M\, e^{-c/g(M)^2} \ll M$

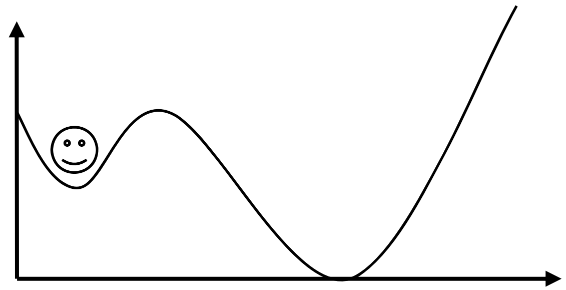
- Non-trivial "requirements" for (stable) ~~SUSY~~:
  - chiral matter

    (some exceptions, e.g. with massless vector-like matter Intriligator, Thomas; Izawa, Yanagida)
  - lifting of all non-compact flat directions & a spontaneously broken global symmetry are sufficient for DSB (Affleck, Dine, Seiberg)
  - $U(1)_R$ – symmetry or non-generic superpotential (Nelson, Seiberg)

$\longrightarrow$ DSB seems non-generic

Motivation

- No such requirements for DSB in *meta-stable* vacua!



- Model Building Goals:
    - Singlets coupled to DSB fields
    - Renormalisable model (calculability)
    - Large Global Symmetry (direct gauge mediated ~~SUSY~~)
    - $U(1)_R$ spontaneously broken (nonzero gaugino masses) + small explicit breaking (non-zero R-axion mass)
    - No relevant parameters, all scales dynamically generated

- Also: when building models look for features that may be important for the landscape of all possible SUSY gauge theories, and in the landscape of string vacua

Models with Moduli Dependent Masses

Consider two SUSY QCD sectors with (N_c, N_f, Λ) & (N_c', N_f', Λ')

coupled by a singlet Φ

	$SU(N_c)$	$SU(N_c')$	
Q_i	$\square$	1	$i = 1, \ldots, N_f$
$\overline{Q}_i$	$\overline{\square}$	1	
$P_{i'}$	1	$\square$	$i' = 1, \ldots, N_f'$
$\overline{P}_{i'}$	1	$\overline{\square}$	
Φ	1	1	

with tree-level superpotential

$$W = (\lambda_{ij}\Phi + \xi_{ij})Q_i\overline{Q}_j + (\lambda'_{i'j'}\Phi + \xi'_{i'j'})P_{i'}\overline{P}_{j'}$$

- Take global $SU(N_f)_V \times SU(N_f')_V$ limit

$\longrightarrow$ Superpotential reduces to

$$W = (\lambda\Phi + \xi)\mathrm{tr}(Q\overline{Q}) + (\lambda'\Phi + \xi')\mathrm{tr}(P\overline{P})$$

Models with Moduli Dependent Masses (ctd)

For $\xi = \xi'$, can absorb masses into Φ

$$W = \lambda\Phi \ \mathrm{tr}(Q\overline{Q}) + \lambda'\Phi \ \mathrm{tr}(P\overline{P})$$

(can add $\kappa\Phi^3$ to W and stabilise Φ supersymmetrically; (Brümmer 0705.2153)

we'll find metastable vacua without this additional term)

Note:

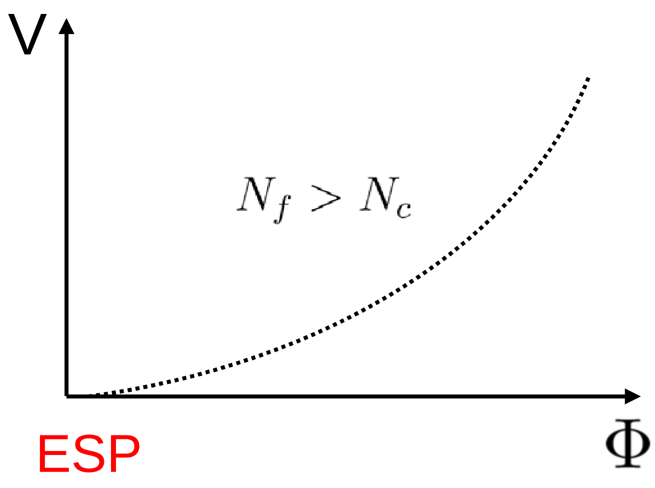
- Enhanced Symmetry Point (ESP) at which extra matter becomes massless coincides for both gauge groups (Φ = 0)
- There is a non-anomalous discrete symmetry that can be gauged to make it technically natural for ESPs of both gauge groups to coincide
- W contains no relevant parameters, only marginal couplings

Thus consider: $W = \lambda\Phi \,\mathrm{tr}(Q\overline{Q}) + \lambda'\Phi \,\mathrm{tr}(P\overline{P})$

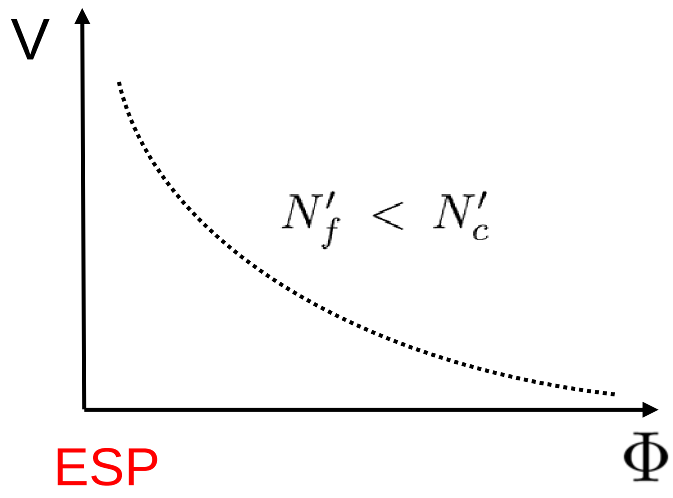
Far from ESP get gaugino condensation in both sectors

$$W = N_c \left[(\lambda\Phi)^{N_f}\Lambda^{3N_c-N_f}\right]^{1/N_c} + N_c' \left[(\lambda'\Phi)^{N_f'}\Lambda'^{3N_c'-N_f'}\right]^{1/N_c'}$$

Unprimed sector: pushes towards ESP for $N_f > N_c$



Primed sector: pushes away from ESP for $N_f' < N_c'$



SUSY vacua satisfy $W_\Phi = \partial W/\partial\Phi = 0$

Consider scales and energies $\Lambda' \ll E \ll \Lambda$

(i) $SU(N_c')$ weakly coupled ($N_f' < N_c'$)

(ii) $SU(N_c)$ strongly coupled

$\longrightarrow$ choose $N_c + 1 \leq N_f < \frac{3}{2}N_c$ (free magnetic range); go to

IR free Seiberg dual, with gauge group $SU(\tilde{N}_c)$, $\tilde{N}_c = N_f - N_c$

Full superpotential is then:

$$W = m\Phi \text{ tr } M + h \text{ tr } qM\tilde{q} + \lambda'\Phi \text{ tr } P\bar{P} + (N_c' - N_f')\left(\frac{\Lambda'^{3N_c'-N_f'}}{\det P\bar{P}}\right)^{1/(N_c'-N_f')}$$

$$+ (N_f - N_c)\left(\frac{\det M}{\tilde{\Lambda}^{3N_c-2N_f}}\right)^{1/(N_f-N_c)}$$

$$M_{ij} = Q_i\bar{Q}_j/\Lambda$$
$$m = \lambda\Lambda$$
$$\tilde{\Lambda} = \Lambda$$

ESP at $M = 0$

Landau pole in IR free Seiberg dual

Consider limit $\tilde{\Lambda} \to \infty$: neglect (only important for SUSY vacua)

- If take $\Lambda' \to 0$:

$$W_{cl} = m\Phi \;\mathrm{tr}\; M + h \;\mathrm{tr}\; qM\tilde{q} + \lambda'\Phi \,\mathrm{tr}\; P\bar{P}$$

as in ISS if Φ = constant (ISS = Intriligator, Seiberg, Shih)

Find moduli space of supersymmetric vacua, given by $W_\Phi = 0$

- Now take Λ' finite, but $\lambda'\Phi \gg \Lambda'$ ($\longrightarrow$near, not at, ESP)

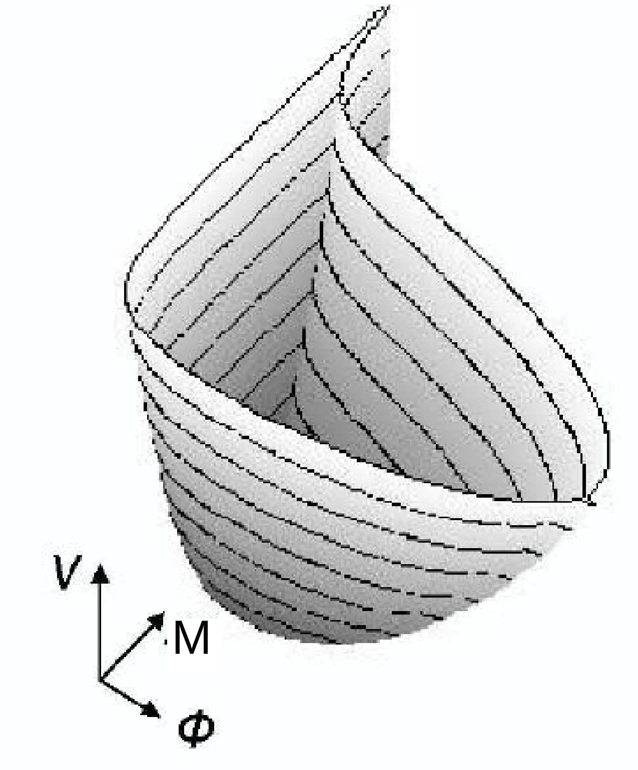
- $(P, \bar{P})$ are massive, and may be integrated out; again get gaugino condensation; W reduces to

$$W = m\Phi \,\mathrm{tr}\, M + h \,\mathrm{tr}\, qM\tilde{q} + N_c' \left[\lambda'^{N_f'} \Lambda'^{3N_c' - N_f'} \Phi^{N_f'}\right]^{1/N_c'}$$

- Find no stable vacuum!

- Runaway towards $M \to \infty, \; \Phi \to 0$

Global view of potential:



Plot made with the help of K. van den Broek's
"Vscape V1.1.0: An interactive tool for metastable vacua"
0705.2019 [hep-ph]

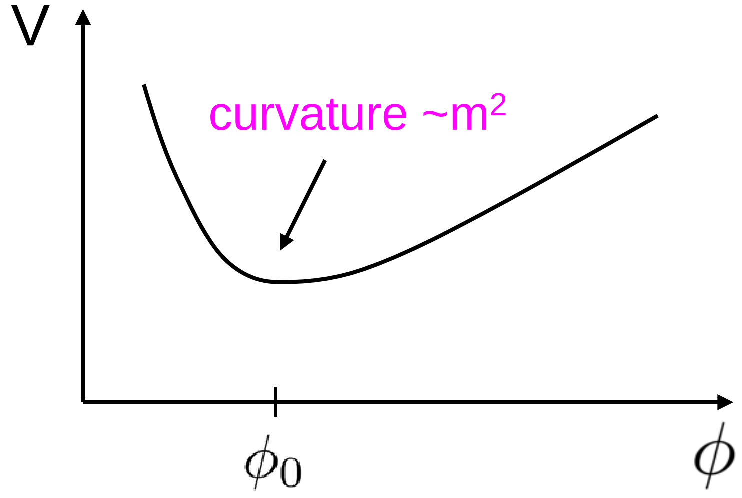
- Expand around ESP $M = 0$ and let $\phi = \langle \Phi \rangle$

$$q = \begin{pmatrix} q_0 & 0 \end{pmatrix} \ , \ \tilde{q} = \begin{pmatrix} \tilde{q}_0 \\ 0 \end{pmatrix} \ , \ M = \begin{pmatrix} 0 & 0 \\ 0 & 0 + X \cdot I_{N_c \times N_c} \end{pmatrix} \qquad (*)$$

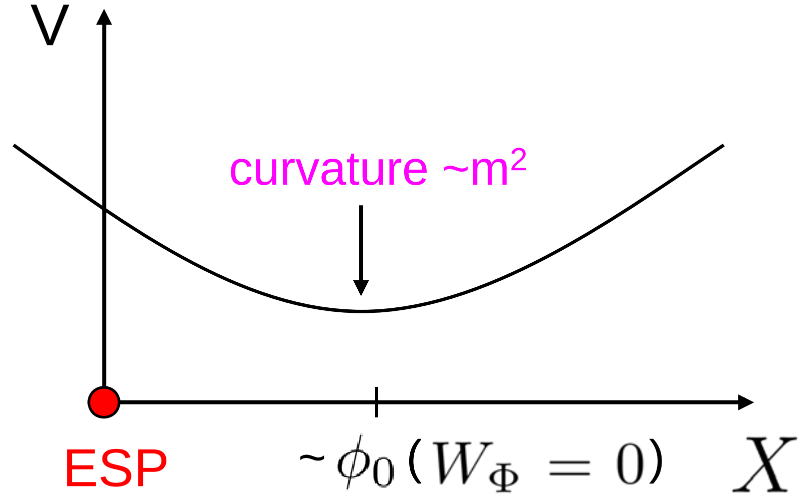
- q_0 and $\tilde{q}_0$ are $\tilde{N}_c \times \tilde{N}_c$ matrices, satisfying

$$h q_{0i} \tilde{q}_{0j} = -m\phi \, \delta_{ij} \ , \ i, j = \tilde{N}_c + 1, \ldots N_f$$

- at $X = 0$



- at $\phi = \phi_0$



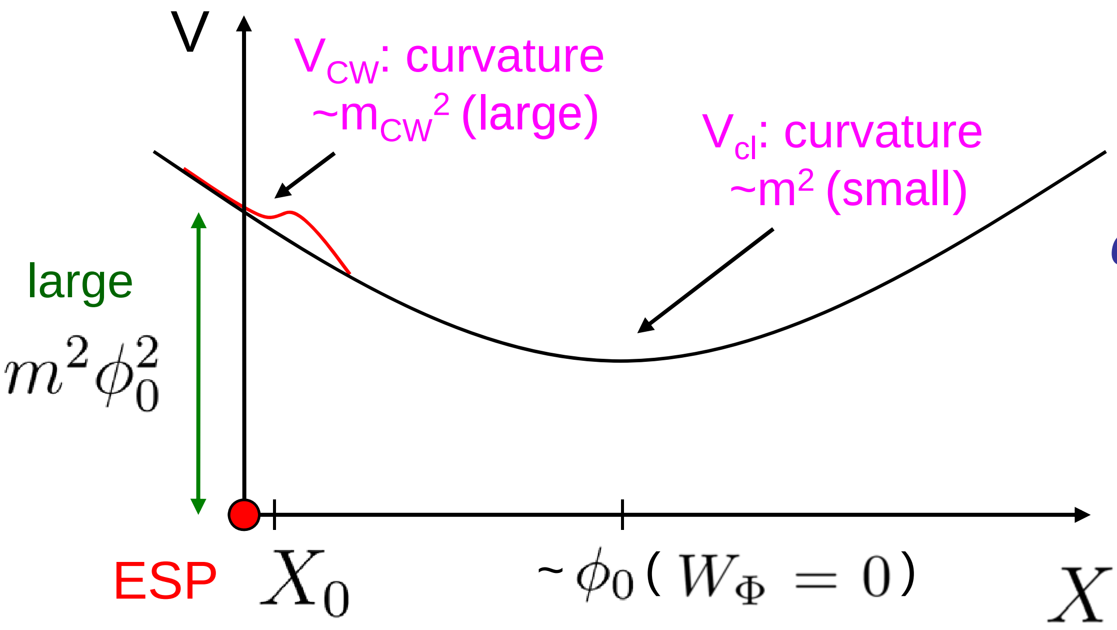
- Perturbative quantum corrections (Coleman-Weinberg potential) at 1-loop, from integrating out dominant massive fluctuations around (*):

$$V_{CW} = \underbrace{N_c b h^3 m|\phi|}_{m_{CW}^2}|X|^2 + \dots \qquad b = (\log 4 - 1)/8\pi^2 \tilde{N}_c$$

(cf. ISS)

quadratic near ESP at $X = 0$
(logarithmic far from ESP)

- To create metastable vacuum, enough to take marginal coupling λ small enough such that $\epsilon \equiv \frac{m^2}{m_{CW}^2} = \frac{m}{N_c b h^3 \phi} \ll 1$

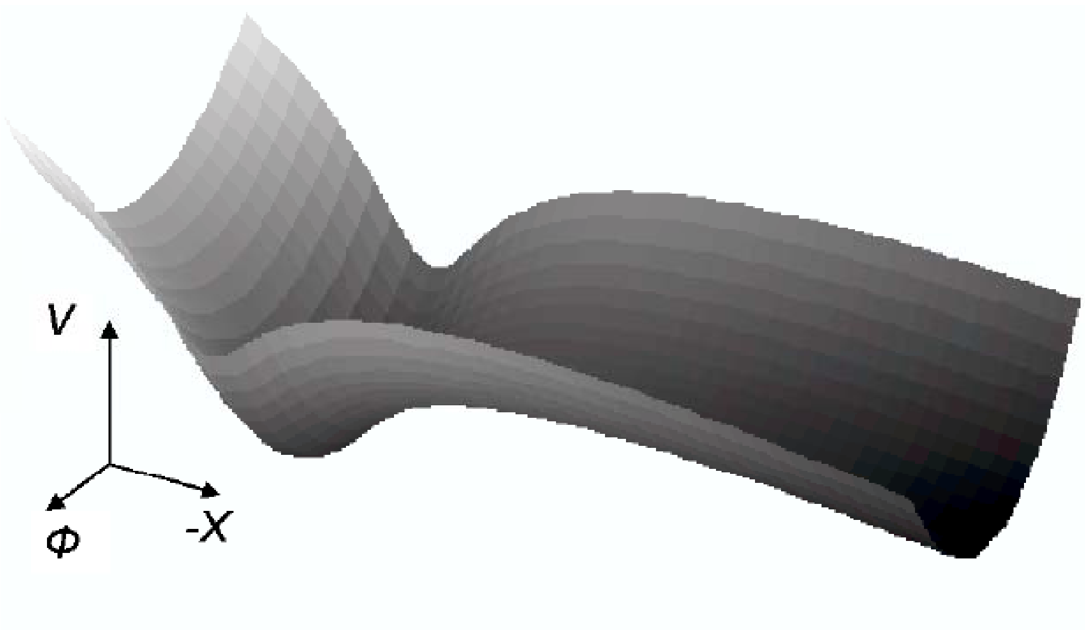


CW potential overwhelms curvature (but not height) of the classical potential near ESP

metastable vacuum at

$$|X_0| \sim \frac{m}{bh^3}$$

Potential near metastable vacuum:



Plot made with the help of "Vscape", 0705.2019 [hep-ph]

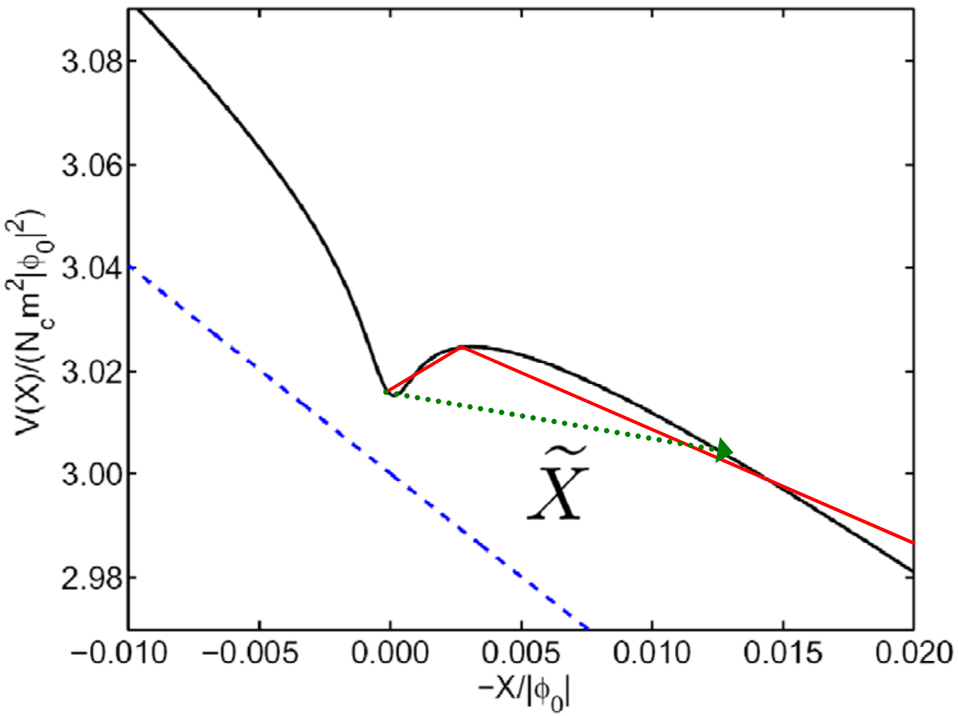
Pseudo-Runaway: runaways lifted by *perturbative* quantum corrections

Lifetime of meta-stable vacua

Field tunnels in X-direction, with fixed $|\phi| = |\phi_0|$

Model potential in X-direction by a triangular barrier (Duncan & Jensen 1992)

Plot made with the help of “Vscape”, 0705.2019



$$B \sim \frac{\widetilde{X}^4}{V(X_{peak}) - V(X_0)}$$

$$\sim b\,h^3\,\frac{1}{\epsilon^2}$$

$$\to \infty \text{ as } \epsilon \to 0$$

Meta-stable vacua are parametrically long-lived for

$$\epsilon \equiv \frac{m^2}{m_{CW}^2} = \frac{m}{N_c b h^3 \phi} \ll 1$$

- Higher order quantum corrections from CW, and perturbative corrections from g` may be argued to be small

- $U(1)_R$ - symmetry is spontaneously broken $\Longrightarrow$ R-axion exists

- For finite Λ, $U(1)_R$ is also explicitly broken $\Longrightarrow$ R-axion massive

- Can embed SM gauge group inside global symmetry group of model to obtain renormalisable models of direct gauge mediated ~~SUSY~~

- For non-coincident ESPs can show that existence of metastable vacuum requires fine-tuning of relevant parameter

- In general, metastable vacua of above type come from

$$W = f(\Phi) + \lambda\,\Phi \mathrm{tr}(Q\bar{Q}) \;\Longrightarrow\; W = f(\Phi) + m\Phi\,\mathrm{tr}\;M + h\,\mathrm{tr}\;qM\widetilde{q}$$

(near ESP, Seiberg dual for $N_c + 1 \leq N_f < \frac{3}{2}N_c$)

- Can find conditions on $f(\Phi)$ to obtain metastable vacua
- no fine-tuning in the case of coincident ESPs
- metastable ~~SUSY~~ seems rather generic near ESPs

Conclusions

Our ~~SUSY~~ model has the following desirable features:

- Renormalisability
- Large Global Symmetry
- No relevant parameters, all scales are dynamically generated
- spontaneous and explicit breaking of $U(1)_R$ – symmetry
- parametrically long-lived metastable vacua

Interesting feature: "pseudo-runaway" directions, i.e. runaway directions lifted by *perturbative* quantum corrections

Metastable ~~SUSY~~ seems rather generic near certain Enhanced Symmetry Points on Moduli Spaces

$\longrightarrow$ May have important implications for the landscape