Meta-Stable Dynamical Supersymmetry Breaking Near Points of Enhanced Symmetry

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UC Davis, Seminar

Monday, December 17th, 2007

based on:

arxiv:0707.0007 [hep-th], JHEP 0709:032,2007

(see also arxiv:0710.4311 [hep-th])

RE, Kuver Sinha, Gonzalo Torroba

Motivation

- If SUSY relevant for hierarchy problem, then

$$M_{\not{SUSY}} << M_{Planck}$$

- How can we obtain this naturally?

$\Rightarrow$ Dynamical Sypersymmetry Breaking (DSB) Witten, 1981

- can dynamically generate a scale related to ~~SUSY~~ scale that is hierarchically smaller than any fundamental scale:

$$\Lambda = M\, e^{-c/g(M)^2} \ll M$$

Motivation (ctd.): DSB in *stable* vacua is hard

Many non-trivial "requirements" for (stable) ~~SUSY~~:

- chiral matter (some exceptions, e.g. with massless vector-like matter Intriligator, Thomas, 1996; Izawa, Yanagida, 1996)

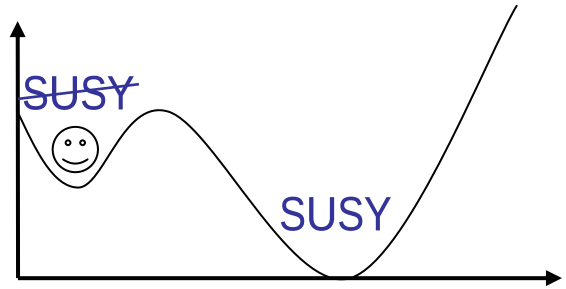
- lifting of all non-compact flat directions and a spontaneously broken global symmetry Affleck, Dine, Seiberg, 1984

- $U(1)_R$ – symmetry or non-generic superpotential

Nelson, Seiberg, 1993

$\Rightarrow$ DSB seems non-generic and hard to achieve

Motivation (ctd.): DSB in *metastable* vacua is generic



- No such requirements for DSB in *metastable* vacua!
- metastable DSB generic
- Intriligator, Seiberg, Shih 2006: metastable vacua in supersymmetric QCD (SQCD) with massive flavors
- many papers: Csaki, Shirman, Terning 2006; Murayama & Nomura; Dine, Feng & Silverstein; Franco & Kachru; Dine & Mason; Argurio, Bertolini; Kitano, Ooguri & Ookouchi; Brummer; Bai, Fan & Han; Dudas, Mourad & Nitti; Gomes-Reino & Scrucca; Amariti, Girardello & Mariotto; Ahn; Serone & Westphal; Cho & Park; Abel, Durnford, Jaeckel & Khoze; Tatar & Wetenhall; van den Broek; Ferretti; Pastras; Ooguri, Ookouchi & Park; Kawano, Ooguri & Ookouchi; Kachru, Kallosh, Linde & Trivedi; Choi, Falkowski, Nilles, Olechowski, Pokorski; Endo, Yamaguchi & Yoshioka; Choi, Jeong & Okumura; Falkowski, Lebedev & Mambrini; Kitano & Nomura; Lebedev, Nilles & Ratz; Lebedev, Loewen, Mambrini, Nilles & Ratz; Acharya, Bobkov, Kane, Kumar & Vaman (Shao); Randall & Sundrum; Giudice, Luty, Murayama & Rattazzi ………
- will discuss our model (RE, Sinha, Torroba) in this talk

Motivation (ctd.): Why is our model interesting?

- Model Building Goals for a realistic/aesthetically pleasing theory of ~~SUSY~~:
  - broken $U(1)_R$
    (here: spontaneous breaking gives non-zero gaugino masses
    + small explicit breaking gives non-zero R-axion mass)
  - No relevant parameters, all scales dynamically generated
  - Singlets coupled to DSB fields
  - Renormalizable model (calculability)
  - Large Global Symmetry (direct gauge mediated ~~SUSY~~)

- Also: look for features that could be generic in the landscape of all possible SUSY gauge theories (and in the landscape of string vacua)

The model presented in this talk has all these desirable features

Outline

A) Review of Intriligator, Seiberg & Shih (ISS) model:

~~SUSY~~ in SQCD with massive flavors

B) Our model:

~~SUSY~~ in two copies of SQCD which are coupled by a singlet

Key features:

- no relevant parameters (quark masses generated dynamically)
- ~~SUSY~~ near enhanced symmetry points along a “pseudo-runaway” direction: a runaway ($V \rightarrow 0$) lifted by *perturbative* quantum corrections

C) i) Show metastable vacua are long-lived

ii) Show R-symmetry is broken spontaneously and explicitly

iii) Brief comments on direct gauge mediation, cosmology etc.

D) Conclusions

A) Review of ISS model

ISS = Intriligator, Seiberg, Shih 2006

- ISS model: $SU(N_c)$ SQCD, with N_f flavors, with masses $m_{\rm ISS}$ much *smaller* than strong coupling scale Λ ($\beta_{el} = 3N_c - N_f$)
- "electric" theory (asymptotically free for $N_f < 3N_c$):

$$W_{\rm electric} = m_{\rm ISS}\,{\rm tr}\,Q\overline{Q}$$ (tree-level)

- when $m_{\rm ISS} \ll \Lambda$ have calculable quantum corrections for

$$N_c + 1 \leq N_f < \frac{3}{2}N_c$$

$\Rightarrow$ dual "magnetic" theory, which has same IR behavior as electric theory (Seiberg dual, 1994); dual theory is infrared free (theory is said to be in the "free magnetic range")

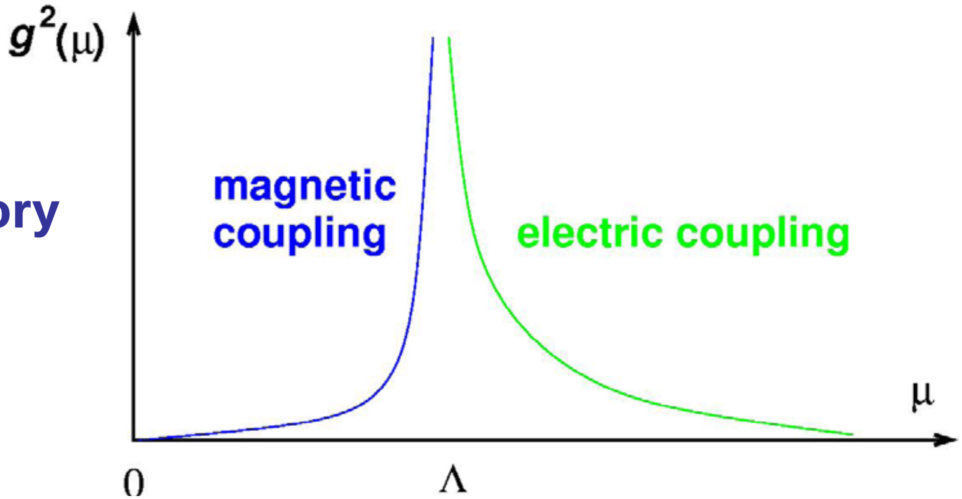
Review of ISS model (ctd.): the Seiberg dual

- Seiberg dual: $SU(\tilde{N}_c)$ SQCD, $\tilde{N}_c = N_f - N_c$,
  N_f^2 singlets $M_{ij} = Q_i \bar{Q}_j / \Lambda$,
  and N_f magnetic quarks $(q, \, \tilde{q})$ (all weakly coupled)
  with superpotential:

$$W_{\text{magnetic}} = m_{\text{ISS}} \, \Lambda \, \text{tr} \, M + h \, \text{tr} \, q M \tilde{q}$$ (tree-level)

magnetic theory is IR free

Landau pole at $\tilde{\Lambda} = \Lambda$



electric theory is UV free

Strong coupling scale at Λ

Review of ISS model (ctd.): ~~SUSY~~ at tree-level

- Can study ~~SUSY~~ in dual model without including gauge dynamics (these will only dynamically restore SUSY far away from ~~SUSY~~ vacuum, see later)
- dual theory breaks supersymmetry at tree-level:

$$\partial W/\partial M_{ij} \equiv W_{M_{ij}} = m_{\rm ISS}\,\Lambda\,\delta_{ij} + h\,q_i^c\,\tilde{q}_{jc} \neq 0$$

δ_{ij} has rank N_f

$q_i\,\tilde{q}_j$ has rank $\widetilde{N}_c = N_f - N_c$

~~SUSY~~ by "rank condition"

$c = 1, \ldots, N_f - N_c$
$i, j = 1, \ldots, N_f$

Review of ISS model (ctd.): vacua are metastable

- Classical moduli space of ~~SUSY~~ vacua:

$$q = (\, q_0 \quad 0\,)\ ,\ \widetilde{q} = \begin{pmatrix} \widetilde{q}_0 \\ 0 \end{pmatrix}\ ,\ M = \begin{pmatrix} 0 & 0 \\ 0 & 0 + X \cdot I_{N_c \times N_c} \end{pmatrix} \qquad h\, q_{0i}\, \tilde{q}_{0j} = -m_{\rm ISS}\, \Lambda\, \delta_{ij}$$

i, j = 1, …, N_f - N_c

- Many massless fields
- Pseudo-moduli: Arbitrary (N_f-N_c) x (N_f-N_c) and N_c x N_c fields
- these obtain a non-tachyonic mass from one-loop quantum corrections (Coleman-Weinberg potential):

$$V^{(1)}_{eff} = \frac{1}{64\pi^2} \mathrm{STr} \left(\mathcal{M}^4 \log \frac{\mathcal{M}^2}{M^2_{cutoff}} \right)$$

mass matrices are functions of pseudo-moduli

$\Rightarrow$ Vacua (meta)stable!

Vacua at X=0, i.e. M=0

Review of ISS model (ctd.): SUSY vacua far away

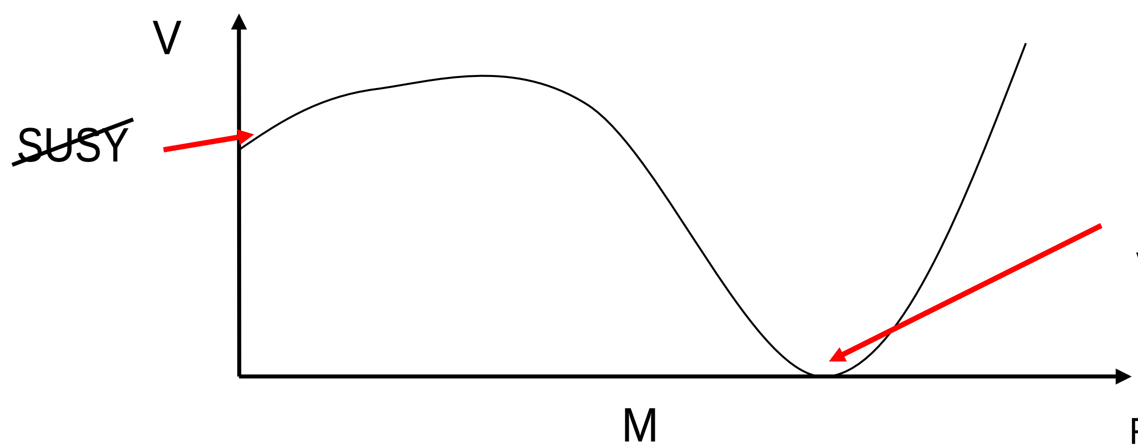
- Elsewhere in field space, SUSY is dynamically restored
- For $\langle M \rangle \neq 0$, magnetic quarks are massive; integrate them out; left with pure supersymmetric Yang-Mills $\Longrightarrow$ gaugino condensation generates nonperturbative superpotential

$$W_{dyn} \sim (\det M)^{1/(N_f - N_c)}$$

Davis, Dine, Seiberg 1983; Affleck, Dine, Seiberg 1984, 1985; Seiberg 1994; Finnell, Pouliot 1995

leads to N_c SUSY vacua: $$\langle M \rangle \sim \left(m_{\rm ISS}^{N_f - N_c} \Lambda^{2N_c - N_f} \right)^{1/N_c}$$

- Metastable vacua long-lived for $m_{\rm ISS} \ll \Lambda$



Going beyond ISS

- ISS contains explicit quark masses, i.e. a relevant parameter

  Can $m_{\rm ISS}$ be generated dynamically using only renormalizable operators? (not "retrofitting", which uses non-renormalizable operators Dine, Feng, Silverstein 2006; Aharony, Seiberg 2006;)

  Simply replacing $m_{\rm ISS}$ by $\lambda\Phi$, where Φ is a singlet, does not lead to ~~SUSY~~, and gives Φ = 0

  $\Longrightarrow$ need something more….

- Note: $$W_{\rm magnetic} = m_{\rm ISS}\,\Lambda\,{\rm tr}\,M + h\,{\rm tr}\,qM\tilde{q}$$

  has a $U(1)_R$ -symmetry with charges R[M]=2, R[q]=0, R[q̃]=0

  Since metastable state in ISS has M=0, the R-symmetry is not spontaneously broken

Going beyond ISS (ctd.)

- In ISS have small explicit R-symmetry breaking, coming from non-perturbative term (recall: R[M]=2)

$$W_{np} \sim (\det M)^{1/(N_f-N_c)} \sim M^{N_f/(N_f-N_c)}$$

- R-symmetry breaking mass terms contributing to gaugino masses are then given by

$$\frac{\partial^2 W_{np}}{\partial M^2} \sim M^{(2N_c-N_f)/(N_f-N_c)}$$

- But M=0 in ~~SUSY~~ minimum, so these contributions vanish (in free magnetic range) and thus the explicit R-symmetry breaking also does not give rise to non-zero gaugino masses

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Key features:

- no relevant parameters (quark masses generated dynamically)
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B) A Model with Moduli Dependent Masses

RE, Sinha, Torroba, 2007;

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

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

explicit quark mass

Note: large global symmetry $SU(N_f)_V \times SU(N'_f)_V$

A Model with Moduli Dependent Masses (ctd.)

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

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

Note:

- W contains no relevant parameters, only marginal couplings
- The point at which the quarks of both sectors become massless (Φ = 0) coincides for both gauge groups (we refer to this as an enhanced symmetry point, or ESP)
- Gauging a non-anomalous discrete symmetry can make it technically natural for the ESPs of both gauge groups to coincide
- Can add $\kappa\Phi^3$ to W and stabilise Φ supersymmetrically (Brümmer 2007); we'll find metastable vacua without this term

There are supersymmetric vacua

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

tree-level

For Φ very large, can integrate out Q's and P's to obtain two copies of pure SYM; get gaugino condensation in both sectors: Davis, Dine, Seiberg 1983; Affleck, Dine, Seiberg 1984, 1985; Finnell, Pouliot 1995

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

non-perturbative

Can solve $\partial W/\partial\Phi = 0$

for Φ to find SUSY vacua

Not important for rest of the discussion

How do we choose (N_c, N_f, Λ) and (N_c', N_f', Λ')?

Primed sector:

choose $N_f' < N_c'$ and consider energies $E \gg \Lambda'$

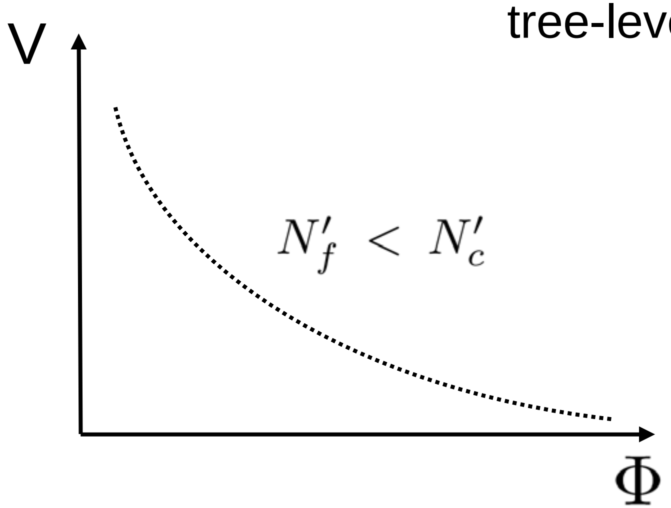
$SU(N_c')$ weakly coupled

Full superpotential for primed sector is

$$\lambda' \Phi \, \mathrm{tr}\, P\bar{P} + (N_c' - N_f') \left(\frac{\Lambda'^{3N_c' - N_f'}}{\det P\bar{P}} \right)^{1/(N_c' - N_f')}$$

tree-level

non-perturbative (gaugino condensation)
Affleck-Dine-Seiberg superpotential



after eliminating P's:

$$V \sim |\partial W/\partial \Phi|^2 \sim \Phi^{2(N_f' - N_c')/N_c'}$$

Key point: Φ pushed away from 0!

How do we choose (N_c, N_f, Λ) and (N_c', N_f', Λ')?

Unprimed sector:

choose $N_c + 1 \leq N_f < \frac{3}{2} N_c$ and consider energies $E \ll \Lambda$

$SU(N_c)$ strongly coupled; go to IR free weakly coupled

Seiberg dual, $SU(\tilde{N}_c)$, $\widetilde{N}_c = N_f - N_c$ (as in ISS)

Full superpotential for unprimed sector in magnetic dual is

$$m\Phi \ \mathrm{tr}\ M + h\ \mathrm{tr}\ qM\widetilde{q} + (N_f - N_c)\left(\frac{\det M}{\Lambda^{3N_c - 2N_f}}\right)^{1/(N_f - N_c)}$$

tree-level

non-perturbative
(gaugino condensation)

$$m = \lambda\Lambda$$

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

Λ= Landau pole in Seiberg dual

The full superpotential for $\Lambda' \ll E \ll \Lambda$:

Full superpotential in this range is then:

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

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

negligible for $\Lambda \to \infty$

Take limit $\Lambda \to \infty$: can neglect unprimed gauge dynamics (gives dynamical SUSY restoration)

Check: No ~~SUSY~~ if neglect gauge dynamics of primed sector

- Neglect gauge dynamics of primed sector by taking $\Lambda' \to 0$

- Superpotential reduces to

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

= ISS (if Φ = constant) + additional tree-level term

No ~~SUSY~~!

Instead find moduli space of SUSY vacua with $\Phi = 0$
and parametrised by $\partial W/\partial\Phi = m\ \mathrm{tr}M + \lambda'\ \mathrm{tr}P\overline{P} = 0$

Include gauge dynamics of primed sector:

- Take Λ' finite, but $\lambda'\Phi \gg \Lambda'$

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

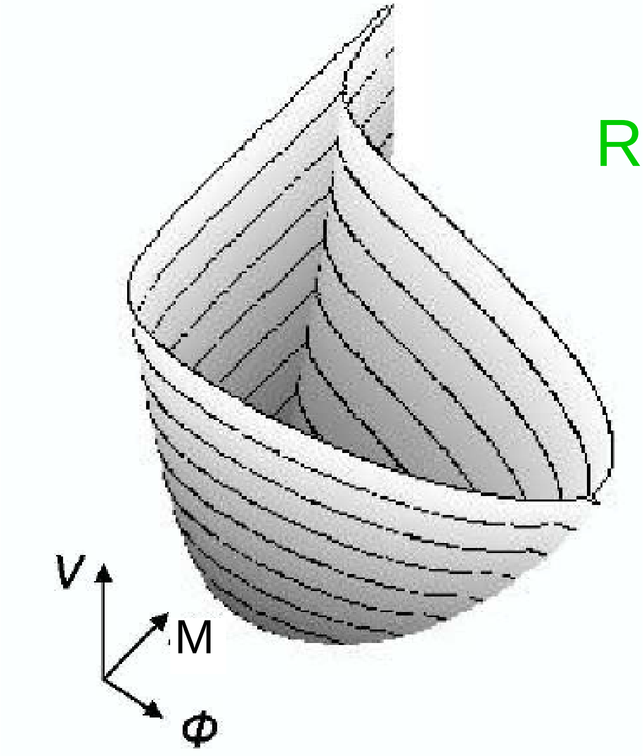
$$W = m\Phi \,\mathrm{tr}\, M + h \,\mathrm{tr}\, qM\tilde{q} + N_c' \left[\lambda'^{N_f'} \Lambda'^{3N_c' - N_f'} \Phi^{N_f'}\right]^{1/N_c'}$$

- Still find no stable vacuum and SUSY not broken!

- Instead have a runaway (V→0) towards $M \rightarrow \infty,\ \Phi \rightarrow 0$

But note: perturbative quantum corrections not yet included

Global view of potential:



Runaway (V→0) towards

$$M \rightarrow \infty, \ \Phi \rightarrow 0$$

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]

Now include perturbative quantum corrections

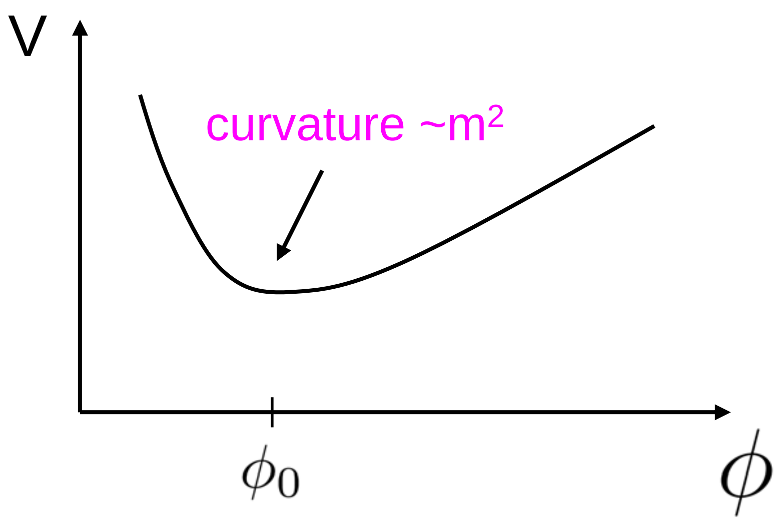
- First expand around $M = 0$ (ESP) and let $\phi = \langle \Phi \rangle$

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

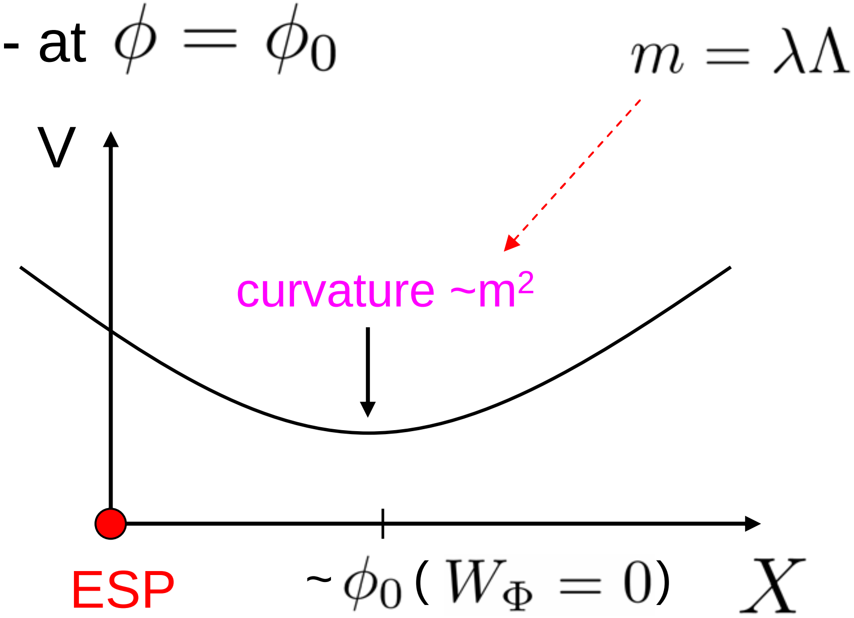
- q_0 and $\widetilde{q}_0$ are $\widetilde{N}_c \times \widetilde{N}_c$ matrices, satisfying

$$h q_{0i} \widetilde{q}_{0j} = -m\phi\, \delta_{ij} \ , \quad i, j = 1, \ldots, N_f - N_c$$

- at $X = 0$



- at $\phi = \phi_0$



Including perturbative quantum corrections (ctd.)

- Include perturbative quantum corrections (Coleman-Weinberg potential) at one-loop, from integrating out dominant massive fluctuations around (*):
  - corrections are logarithmic far from ESP and thus *too small* to stop the runaway
  - corrections are quadratic near ESP at $X = 0$ and can thus be *important* for potential:

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

(cf. ISS)

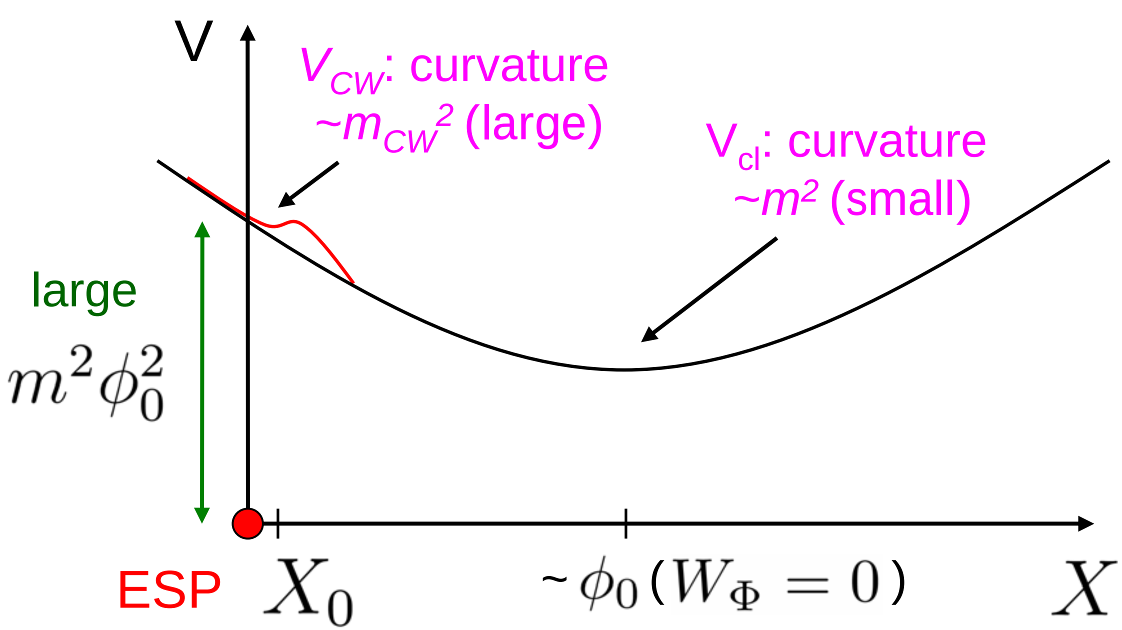
Other corrections not qualitatively important

Perturbative quantum corrections give metastable vacuum

- Find *metastable vacuum*!
- Need to choose $m = \lambda\Lambda$ much smaller than m_{CW} - i.e.

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

$\Longrightarrow$ choose coupling λ small enough

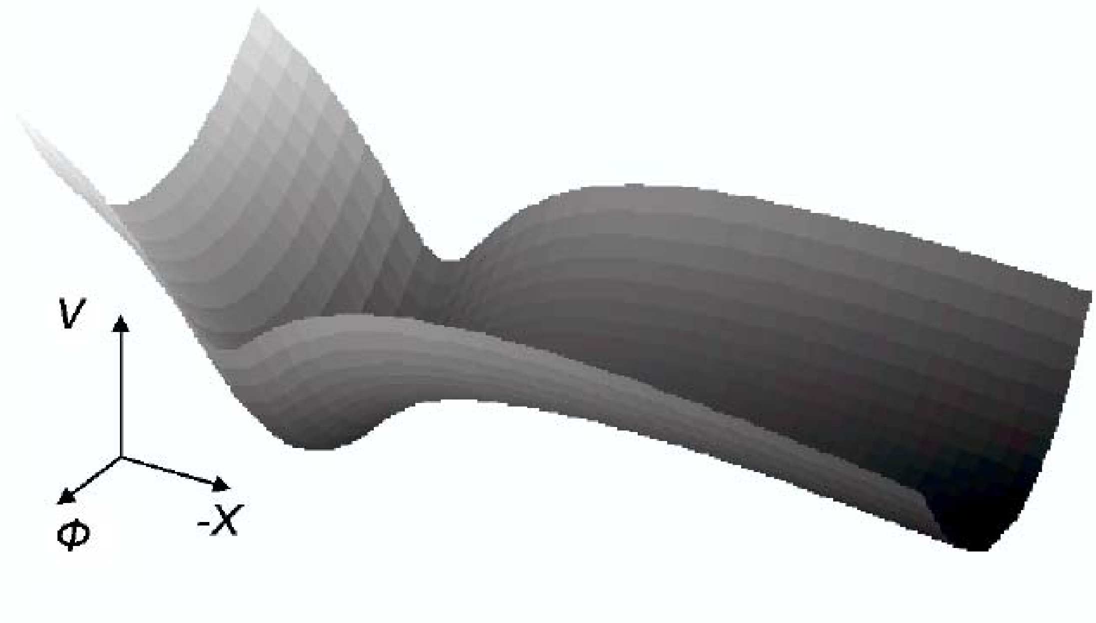


CW potential overwhelms curvature (but not height) of the classical potential

metastable vacuum at

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

Potential near metastable vacuum:



Plot made with the help of "Vscape" (van den Broek)

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

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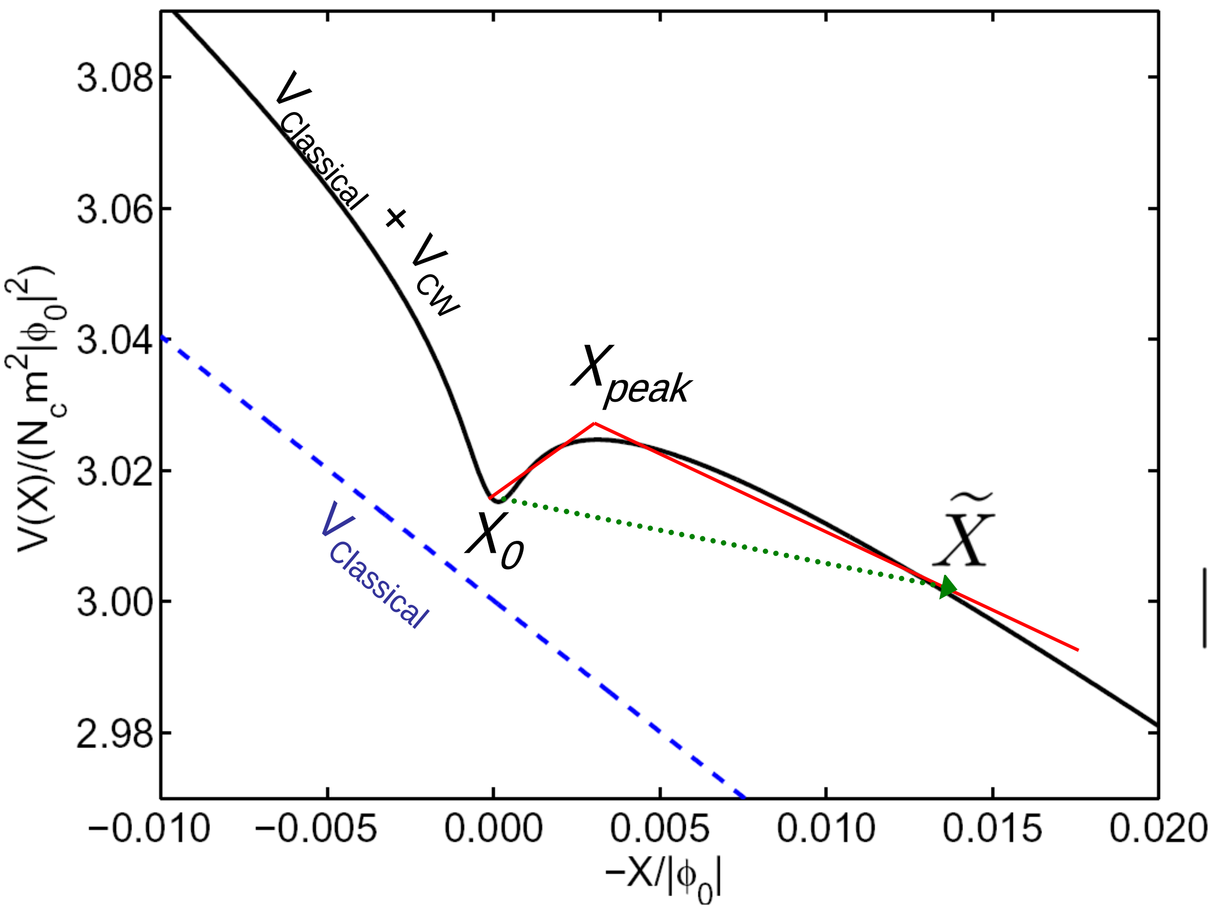
Metastable vacua are parametrically long-lived

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



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

$|X_{\rm peak}| \sim \sqrt{m|\phi_0|}$

$|\widetilde{X}| \sim b\, h^3\, |\phi_0|$

$|X_{W_\phi=0}| \sim |\phi_0|$

$|X_{W_\phi=0}| \simeq 1$

Metastable vacua are parametrically long-lived (ctd.)

Thus: $|X_0| \ll |X_{\text{peak}}| \ll |\widetilde{X}|$ as $\epsilon \longrightarrow 0$

Lifetime: $\sim e^B$

Coleman

Bounce Action: $B \sim \dfrac{\widetilde{X}^4}{V(X_{peak}) - V(X_0)} \sim b\, h^3 \, \dfrac{1}{\epsilon^2}$

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

Meta-stable vacua are parametrically long-lived for

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

Approximate R-symmetry implies long-lived metastable vacua

- Problem with stable DSB (i.e. no SUSY vacua):
  generically require superpotential with $U(1)_R$ - symmetry Nelson, Seiberg 1993
  BUT: to allow non-zero gaugino masses, R-symmetry
  should be broken explicitly and/or spontaneously

- Spontaneous breaking gives a massless R-axion

- Need explicit breaking to give R-axion a non-zero mass
  $\Longrightarrow$ *reintroduces* SUSY vacua (ignoring gravity) Bagger, Poppitz, Randall 1994
  $\Longrightarrow$ metastable DSB vacuum Intriligator, Seiberg, Shih 2007

- a *small* explicit breaking allows for an approximate
  R-symmetry, and a *long-lived* metastable state

How can one break R-symmetry?

- Can add gauge interactions — Witten 1981; Dine, Mason 2006; Csaki, Shirman, Terning 2006; Intriligator, Seiberg, Shih 2007

- Consider more exotic 'O Raifeartaigh models, containing a field with R-charge different from 0 or 2 — Shih 2007
  - such models usually have runaway directions and thus vacua are only metastable - Ferretti 2007

  (Note: effective theory for many metastable DSB models can be described by an O'Raifeartaigh-type model)

- Add operators which explicitly break R-symmetry by small amount — Nomura, Murayama 2006, 2007; Aharony, Seiberg 2006;

- Our model shows another way R-symmetry may be broken

Our model breaks R-symmetry *spontaneously*

For our model:

Recall: Low energy superpotential (for $\Lambda \to \infty$)

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

It has an exact R-symmetry:

$$R_\phi = 2\frac{N_c'}{N_f'}\ ,\ R_X = 2\frac{N_f'-N_c'}{N_f'}\ ,\ R_q = R_{\widetilde{q}} = \frac{N_c'}{N_f'}$$

BUT: these fields all have non-zero VEVs

$\Longrightarrow$ $U(1)_R$ - symmetry is spontaneously broken!

Pseudo-Runaways can break R-symmetry spontaneously

Our model also breaks R-symmetry *explicitly*

Including gauge dynamics of unprimed sector (finite Λ),

R-symmetry is anomalous and explicitly broken by small

amount (as in ISS)

$\Rightarrow$ R-axion obtains mass

Therefore: - Gauginos can obtain a mass
- R-axion has a mass

$\Rightarrow$ Good!

Another example with spontaneous R-symmetry breaking along a pseudo-runaway

- Another example with a pseudo-runaway direction was found afterwards by Abel, Durnford, Jaeckel, Khoze 2007

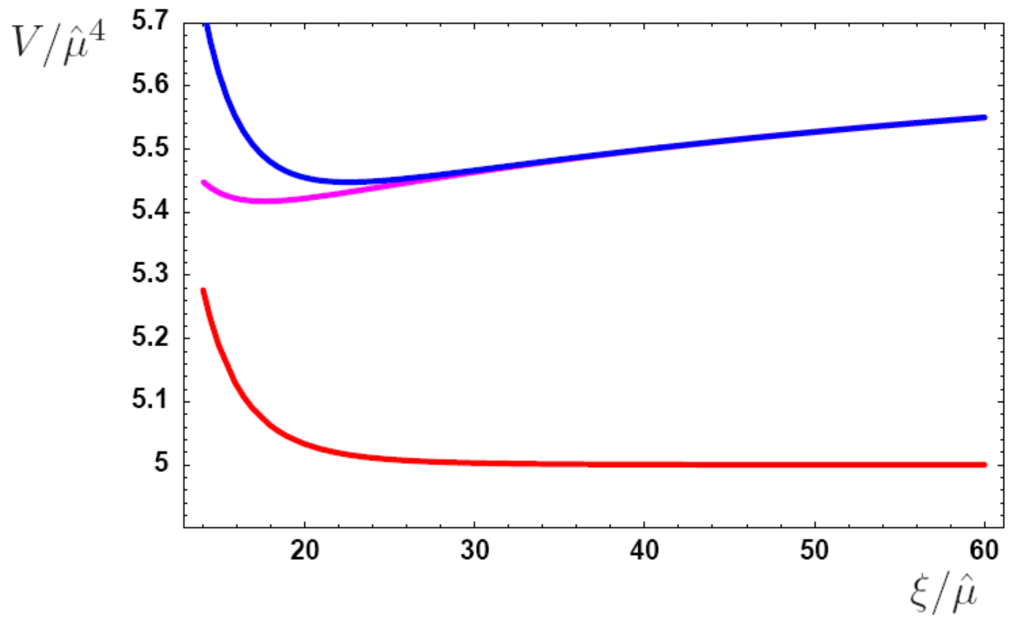
- They deformed the ISS model by adding a baryon term

$$W = \tilde{q}_{i\alpha} M_{ij} q_j^\alpha + \mu^2 M_{ii} + m\epsilon^{rs}\epsilon^{\alpha\beta} q_{r\alpha} q_{s\beta}$$

(has relevant couplings) (has field with R-charge $\neq$ 0,2):

- Pseudo-runaway to a non-supersymmetric metastable minimum of ISS type

- R-symmetry also broken spontaneously



Metastability for non-coincident ESPs is fine-tuned

Recall, general superpotential is

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

- now assume $\xi \neq \xi'$; can redefine Φ and absorb ξ;
- Have ESPs at: $\Phi = 0$ for unprimed sector

  $\Phi \sim -\xi'$ for primed sector

- Low-energy superpotential becomes:

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

- Generically ξ' is of order the UV cutoff, i.e. very large

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Metastability for non-coincident ESPs is fine-tuned (ctd.)

Again find metastable minimum, but condition

$$m \ll m_{CW}$$

leads to:

$$m^3 \ll \frac{b\, h^3 \left(N_c' \, \lambda'^{N_f'/N_c'} \, \Lambda'^{(3N_c'-N_f')/N_c'} \right)^2}{\xi'^{3-2N_f'/N_c'}}$$

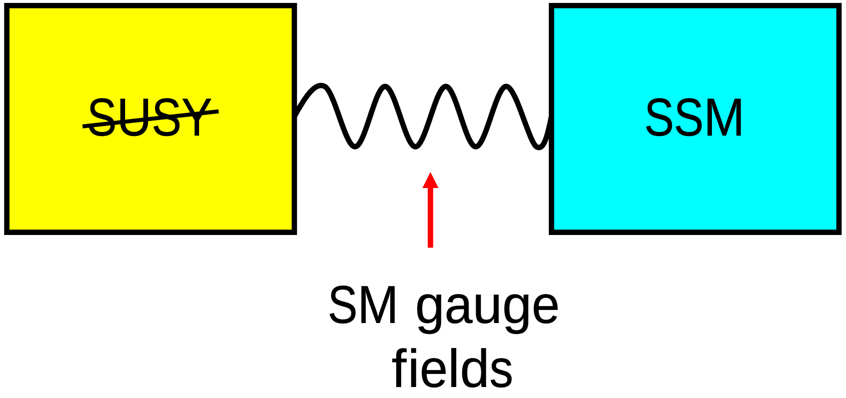
Large fine-tuning on m!

Thus, non-coincident ESPs lead to metastable vacua but these are not generic and require fine-tuning

No fine-tuning for coincident ESPs, so our setup is generic

Our model allows for Direct Gauge Mediation

- Subgroup of large global symmetry in SQCD can be identified with SM gauge group and weakly gauged



e.g. Csaki, Shirman, Terning 2006; Murayama, Nomura 2006; Dine, Mason 2006; Ibe, Kitano 2006; Ibe, Kitano 2007; Aharony, Seiberg 2006 ; Amariti, Girardello, Mariotti 2006, 2007; Kitano 2006; Kitano, Ooguri, Ookouchi 2006;

- Very large global symmetry in our model:

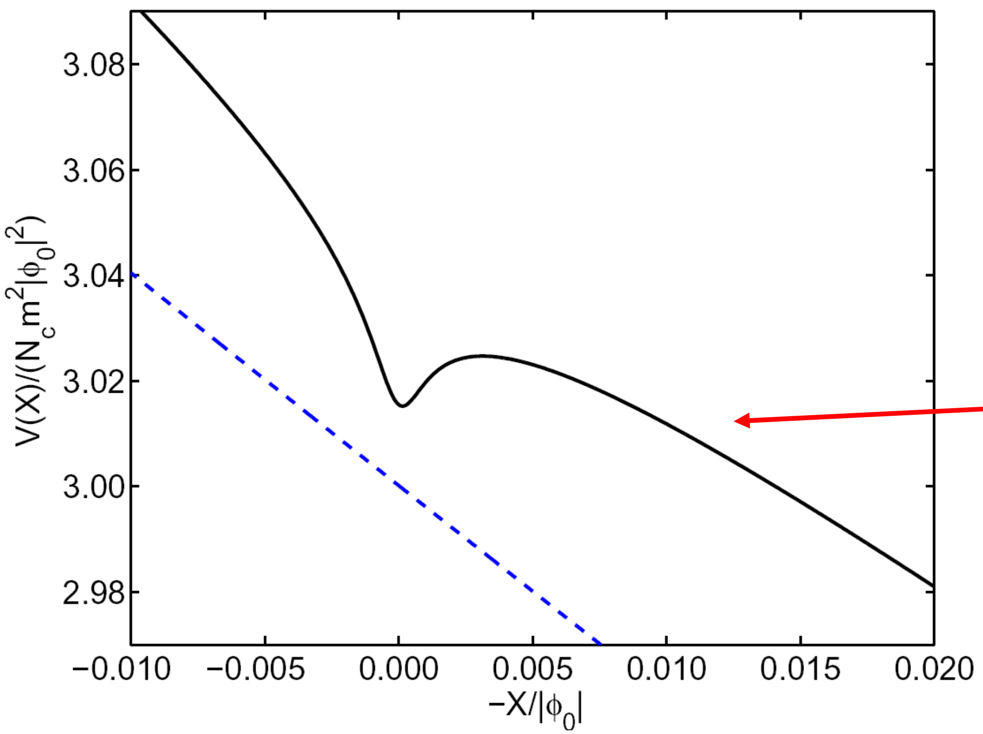
$$SU(N_f) \times SU(N'_f)$$

- Also: have singlet field in model

Cosmology favors DSB vacua

- Early universe favors DSB vacua over SUSY vacua:
  - continuous (moduli) space of DSB vacua versus small number of discrete SUSY vacua
  - thermal effective potential favors DSB vacua since they are closer to origin of moduli space and have more light fields

Craig, Fox, Wacker, 2006;
Fischler, Kaplunovsky, Krishnan, Mannelli, Torres, 2006;
Abel, Chu, Jaeckel, Khoze, 2006;
Abel, Jaeckel, Khoze, 2006;
L Anguelova, R Ricci, S Thomas, 2007;



Also:

Gentle slope of potential could be useful for inflation

Conclusions

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

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

Interesting feature: "pseudo-runaways"- 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