Non-supersymmetric duality and EWSB

SAA, Matt Buican, Zohar Komargodski, PRD84 (2011) 045005, ArXiV:1105.2885

Outline

- Lightning review of supersymmetric dualities
- Conserved currents and soft-terms
- Mapping anomalous currents
- Application: radiative EWSB in models of composite/fat higgs

Lightning review of SUSY dualities

Simplest $SU(N_c)\ \mathcal{N}=1$ SQCD form introduced by Seiberg: the electric model consists of

	$SU(N_c)$	$SU(N_f)\times SU(N_f)$	$U(1)_R$	$U(1)_B$
Q	$\mathbf{N_c}$	$\mathbf{N_f}\times\mathbf{1}$	$1-\frac{N_c}{N_f}$	1
$\widetilde{Q}$	$\overline{\mathbf{N}}_\mathbf{c}$	$\mathbf{1}\times\overline{\mathbf{N}}_\mathbf{f}$	$1-\frac{N_c}{N_f}$	-1

Lightning review of SUSY dualities

The magnetic description, found by matching moduli spaces, global anomalies ...

	$SU(N_f - N_c)$	$SU(N_f) \times SU(N_f)$	$U(1)_R$	$U(1)_B$
q	$\mathbf{N_f - N_c}$	$\overline{\mathbf{N}}_\mathbf{f} \times \mathbf{1}$	$\frac{N_c}{N_f}$	$\frac{N_c}{N_f - N_c}$
$\widetilde{q}$	$\overline{\mathbf{N}}_\mathbf{f} - \overline{\mathbf{N}}_\mathbf{c}$	$\mathbf{1} \times \mathbf{N_f}$	$\frac{N_c}{N_f}$	$-\frac{N_c}{N_f - N_c}$
M	$\mathbf{1}$	$\mathbf{N_f} \times \mathbf{N_f}$	$2 - 2\frac{N_c}{N_f}$	0

Lightning review of SUSY dualities

Under this duality we can map operators in the chiral-ring e.g. mesons and baryons

$$Q\tilde{Q} \quad \rightarrow \quad M$$
$$Q^{N_c} \quad \rightarrow \quad q^{N_f - N_c}$$

Lightning review of SUSY dualities

Can also compute magnetic superpotential, $W_{mag} \quad = \quad h\Phi q.\tilde{q}$

where $h \quad \sim \quad 1$ and ...

$$\boxed{\Phi \quad = \quad M/\Lambda}$$

Luty,
Cohen Kaplan Nelson,
Kitazawa

Various sorts of behaviour possible ...

Free-electric phase: $N_f \quad \geq \quad 3N_c$

Interacting - IR fixed point: $\frac{3N_c}{2} < \quad N_f \quad < 3N_c$

Free-magnetic phase: $N_c + 1 < \quad N_f \quad < \frac{3}{2}N_c$

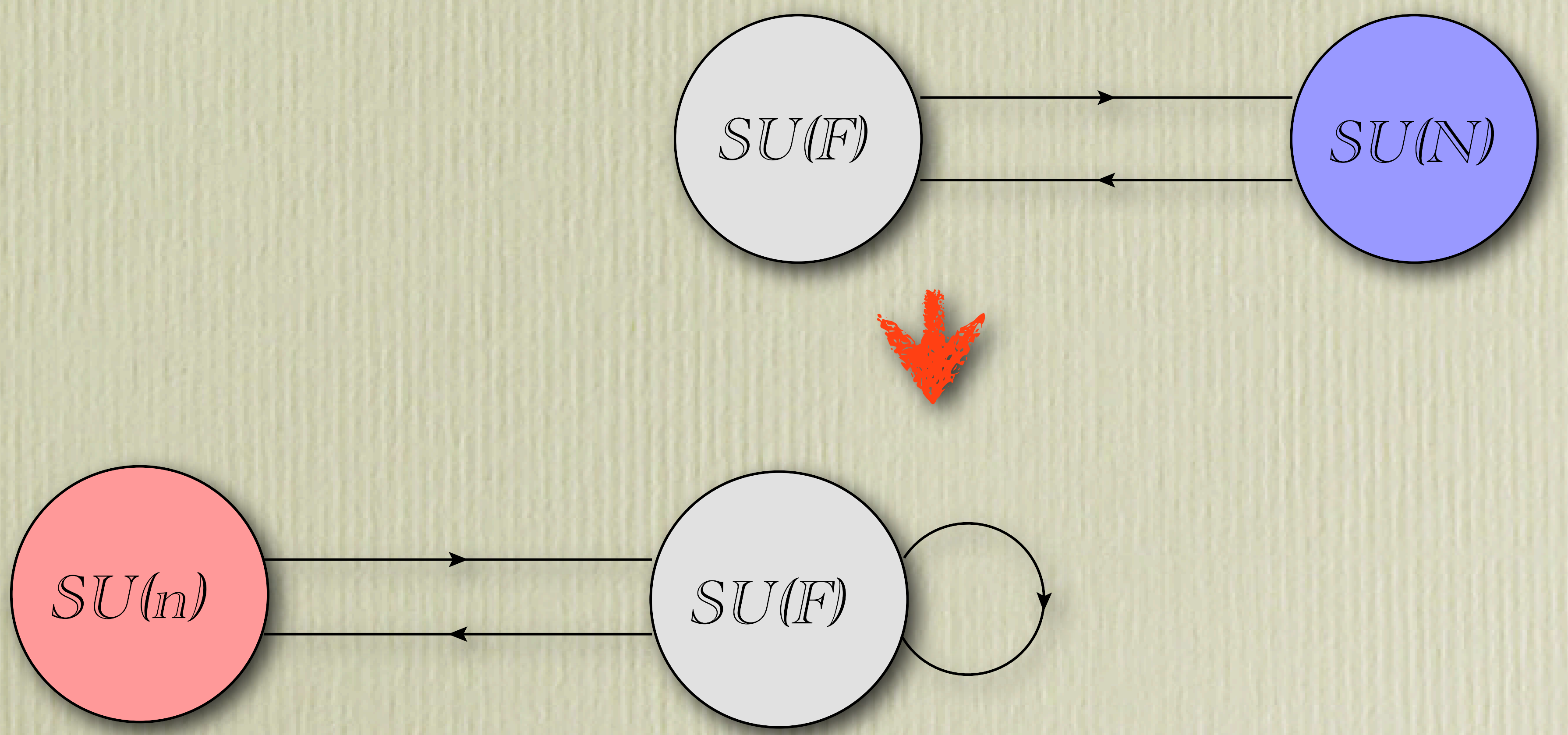
s-confining: $N_f \quad = \quad N_c + 1$

Chiral symmetry breaking: $N_f \quad = \quad N_c$

No vacuum: $N_f \quad < \quad N_c$

Lightning review of SUSY dualities

The same duality in terms of quiver diagrams ...



Soft-terms and Conserved Currents

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Soft-terms and Conserved Currents

In the past people tried many ideas for working out how softly broken theories map:

- Evans, Hsu, Schwetz, Selipsky
- Aharony, Sonnenschein, Peskin, Yankielowicz
- Cheng, Shadmi
- Arkani-Hamed, Rattazzi
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Nelson, Strassler ...

Our method is related to Luty and Rattazzi's idea of gauging R-symmetry to follow the flow, but is based on conserved global currents, making it very simple and general.

Soft-terms and Conserved Currents

- Consider the following (strange looking) mass-squared term in the electric theory (in the free-magnetic window)

$$\delta\mathcal{L}_{\rm el} = -m^2\left(Q^i Q_i^\dagger - \widetilde{Q}^i \widetilde{Q}_i^\dagger\right)$$

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$$\delta\mathcal{L}_{\text{el}} = -m^2\left(Q^i Q_i^\dagger - \widetilde{Q}^i \widetilde{Q}_i^\dagger\right)$$

- This term can be related to the conserved U(1)-baryon current
- Indeed, generally one can build a real linear current superfield,obeying

$$\overline{D}^2 \mathcal{J} = D^2 \mathcal{J} = 0$$

- In components ...

$$\mathcal{J} = J + i\theta j - i\overline{\theta}\overline{j} - \theta\sigma^\mu\overline{\theta} j_\mu + \frac{1}{2}\theta\theta\overline{\theta}\overline{\sigma}^\mu\partial_\mu j - \frac{1}{2}\overline{\theta}\overline{\theta}\theta\sigma^\mu\partial_\mu\overline{j} - \frac{1}{4}\theta\theta\overline{\theta}\overline{\theta}\Box J$$

Soft-terms and Conserved Currents

- Our soft-terms can be identified with the bottom component of the Baryon current, which obeys

$$\overline{D}^2 \left(Q^i Q_i^\dagger - \widetilde{Q}^i \widetilde{Q}_i^\dagger \right) = 0$$

- Since B is conserved, they map directly to the baryon current in the magnetic theory which can be read off the table...

$$QQ^\dagger - \widetilde{Q}\widetilde{Q} \longrightarrow \frac{N_c}{N_f - N_c} \left(|q|^2 - |\widetilde{q}|^2 \right)$$

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- Note that this is completely general: wherever there is a weakly coupled description along the flow we can write the soft-terms (as long as we can identify the charges there).

Soft-terms and Conserved Currents

What about more general soft-terms? Would like to be able to map

$$c_i^j Q^i Q_j^\dagger + \widetilde{c}_i^j \widetilde{Q}^i \widetilde{Q}_j^\dagger$$

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Clearly soft-terms proportional to flavour currents can be mapped in a similarly trivial manner: i.e. linear combinations of

$$Q T^a Q^\dagger \text{ and } \widetilde{Q} T^a \widetilde{Q}^\dagger$$

(Note that the mapping of conserved flavour currents can be used in normal QCD to map correlation functions corresponding to flavour currents into pion correlation functions)

Soft-terms and Conserved Currents

However there is one operator (the trace part) that is not trivial to map:

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So knowing how to map the soft-terms is equivalent to knowing how to map both conserved and anomalous currents

Mapping anomalous currents

A theory with an R-symmetry has an R-supermultiplet (does the same job as J)

$$\mathcal{R}_\mu = R_\mu + \theta S_\mu + c.c. + \theta\sigma^\nu\bar{\theta}(T_{\mu\nu} + \ldots$$

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When there are many abelian symmetries, there can be many different R-current supermultiplets on the LHS of this equation. However there is one special one $\mathcal{R}^{CFT}_{\alpha\dot{\alpha}}$.

As we approach a conformal fixed point in the IR (even a Gaussian free field one), we have

$$\overline{D}^{\dot{\alpha}}\mathcal{R}^{CFT}_{\alpha\dot{\alpha}} = 0$$

Mapping anomalous currents

Any R-current can be related to the CFT one by (an improvement transformation)

$$\mathcal{R}^{CFT}_{\alpha\dot{\alpha}} = \mathcal{R}^{IR}_{\alpha\dot{\alpha}} - [D_\alpha, \overline{D}_{\dot{\alpha}}]J \ , \qquad U^{CFT} = U^{IR} - \frac{3}{2}J = 0$$

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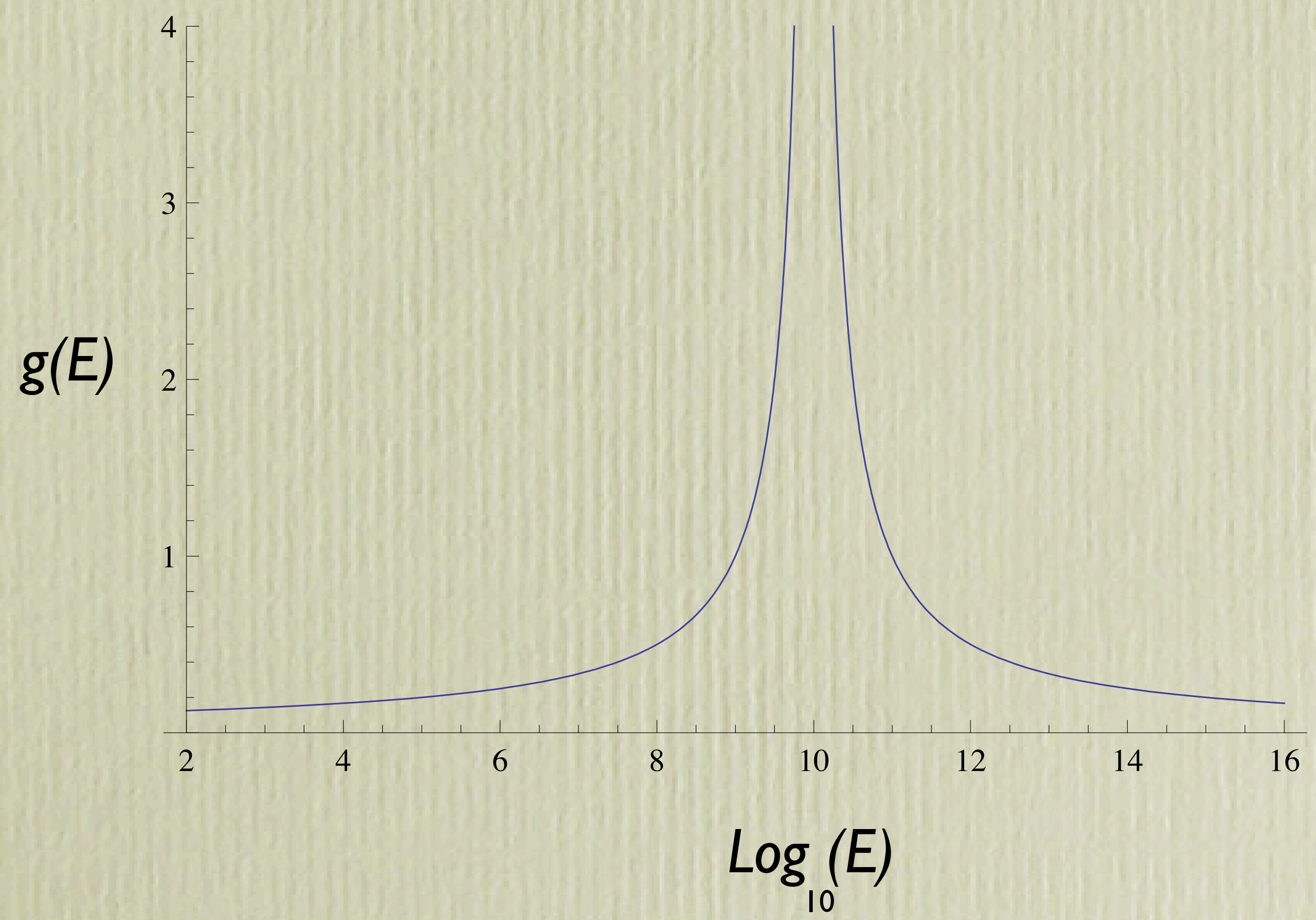
The point: U can include the anomalous currents we are interested in. If we can find the corresponding R-current, then we can use that to follow U along the flow. (Note that U is NOT just the difference in R-currents, but the superfield in the "improvement term".)

Mapping anomalous currents

Example 1: SQCD in the free magnetic range $N_c + 1 < \quad N_f \quad < \frac{3}{2} N_c$



Mapping anomalous currents

For free theories, $\overline{D}^{\dot{\alpha}}\mathcal{R}_{\alpha\dot{\alpha}} = \overline{D}^2 D_\alpha U$ can be solved to give

$$\mathcal{R}_{\alpha\dot{\alpha}} = \sum_i \left(2D_\alpha\Phi_i\overline{D}_{\dot{\alpha}}\overline{\Phi}^i - r_i[D_\alpha, \overline{D}_{\dot{\alpha}}]\Phi_i\overline{\Phi}^i\right) \ ,$$

$$U = \sum_i \left(1 - \frac{3r_i}{2}\right)\overline{\Phi}^i\Phi_i \ .$$

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Notice that if the corresponding R-symmetry is the CFT one, then r=2/3 at the Gaussian fixed point, so (as expected) U vanishes there.

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Hence find $U^{UV} = \left(-\frac{1}{2} + \frac{3N_c}{2N_f}\right)\left(QQ^\dagger + \widetilde{Q}\widetilde{Q}^\dagger\right)$

maps to $U^{IR} = \left(1 - \frac{3N_c}{2N_f}\right)(qq^\dagger + \widetilde{q}\widetilde{q}^\dagger) - \left(2 - \frac{3N_c}{N_f}\right)MM^\dagger.$

Mapping anomalous currents

Back to soft-terms

$$\delta\mathcal{L}_{\rm el} = -m^2 J_A| - m_\lambda(W^2_{\alpha,\rm el} + {\rm hc})| = -m^2\left(QQ^\dagger + \widetilde{Q}\widetilde{Q}^\dagger\right) + m_\lambda(\lambda^2_{\rm el} + c.c.)$$

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$$\Downarrow$$

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Apply ABJ equations to J to get this

Agrees with previous results but follows much more simply (IMHO) from the R-supermultiplet relation.

Mapping anomalous currents

Example 2: SQCD with an adjoint in the conformal window.

	$SU(N_c)$	$SU(N_f)\times SU(N_f)$	$U(1)_R$	$U(1)'$	$U(1)_B$
Q	$\mathbf{N_c}$	$\mathbf{N_f}\times\mathbf{1}$	$1-\frac{2N_c}{3N_f}$	1	1
$\widetilde{Q}$	$\overline{\mathbf{N}}_\mathbf{c}$	$\mathbf{1}\times\overline{\mathbf{N}}_\mathbf{f}$	$1-\frac{2N_c}{3N_f}$	1	-1
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Depending on the choice of colours and flavours, some mesons decouple and become free-fields: $M_i = QX^i\widetilde{Q}$. Use a-maximization to find out when. (Kutasov, Parnachev, Sahakyan).

Mapping anomalous currents

The same techniques tell us how UV soft-terms generate soft-terms for those fields that become free in the IR ...

$$\left(-\frac{1}{2}+\frac{N_c}{N_f}\right)\left(QQ^\dagger+\widetilde{Q}\widetilde{Q}^\dagger\right)\longrightarrow\sum_{j=0}^{P(N_f/N_c)}\left(1-\frac{3R(M_j)}{2}\right)M_jM_j^\dagger+\cdots$$

$$=-\sum_{i=0}^{P(N_f/N_c)}\left(j+2-2\frac{N_c}{N_f}\right)M_jM_j^\dagger+\cdots$$

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$$=-\sum_{i=0}^{P(N_f/N_c)}\left(j+2-2\frac{N_c}{N_f}\right)M_jM_j^\dagger+\cdots$$

This result is much less obvious. In particular it is exact even though the rest of the theory might be strongly coupled and we don't have a description for it!

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Kutasov duality - add a superpotential term to the previous theory

$$W = s_0 \mathrm{Tr}(X^{k+1})$$

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This term dominates the flow (it is dangerously irrelevant) and it breaks the anomaly free symmetry

$$J_X = \frac{N_c}{N_f}\left(QQ^\dagger + \widetilde{Q}\widetilde{Q}^\dagger\right) - XX^\dagger$$

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The RHS is trivial in the chiral ring (i.e. equivalent to zero), so we cannot say anything about the coefficient of J_X in U.

Mapping anomalous currents

So we can not follow this operator but we can still follow the orthogonal one:

$$U^{UV} = \left(-\frac{1}{2} + \frac{3}{k+1}\frac{N_c}{N_f}\right)\left(QQ^\dagger + \widetilde{Q}\widetilde{Q}^\dagger\right) + \left(1 - \frac{3}{k+1}\right)XX^\dagger$$

Generally, the more symmetries you can preserve the better, although if the term that breaks it is non-trivial in the chiral ring it should still be possible to follow the current (in principle).

Application: radiative EWSB with composite Higgs

Recall the general result ...

$$\delta\mathcal{L}_{\rm mag} = -m^2 \cdot \frac{2N_f - 3N_c}{3N_c - N_f}\left(qq^\dagger + \widetilde{q}\widetilde{q}^\dagger - 2MM^\dagger\right) + m_\lambda \cdot \frac{2N_f - 3N_c}{3N_c - N_f}(\lambda^2_{\rm mag} + c.c.)$$

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This is the same effect as radiative EWSB in the MSSM being driven by the large top-Yukawa. In this case the large coupling is the one of magnetic QCD, which leads to mass-squared sum-rules (noticed in e.g. Cheng, Shadmi).

Application: radiative EWSB with composite Higgs

Moreover if we gauge baryon-number there is a stable minimum which is calculable provided g_B is much bigger than m/Λ

If g_B is small then minimum at $q \sim \frac{m}{g_B}\mathbb{1},\ \tilde{q} = 0,\ M = 0$

If g_B is large then minimum at $q \sim \tilde{q} \sim m$

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$\widetilde{H}$	$\overline{\mathbf{N}}_\mathbf{c}$	$\mathbf{2}$	$-\frac{1}{2}$
$\Phi_{i=1\ldots N_c-1}$	$\mathbf{N_c}$	$\mathbf{1}$	$\frac{1}{2}$
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$N_f = N_c + 1$ so the confined degrees of freedom are baryons and mesons

$$B, \widetilde{B} \equiv (h, \widetilde{h}, \phi_{i=1\ldots N_c-1}, \widetilde{\phi}_{i=1\ldots N_c-1})$$

$$M \equiv \begin{cases} h_{i=1\ldots N_c-1} = & (H\widetilde{\Phi}_i) \\ \widetilde{h}_{i=1\ldots N_c-1} = & (\widetilde{H}\Phi_i) \\ \mathcal{T} + \eta = & (H\widetilde{H}) \\ \eta_{ij} = & (\Phi\widetilde{\Phi}) \end{cases}$$

Application: radiative EWSB with composite Higgs

As we have seen, the higgses have a vev in the vacuum. The correct way to think about it is that the magnetic theory of the SQCD with soft-terms, **is** the theory broken down to $SU(2)_L \times U(1)_Y \hookrightarrow U(1)_{QED}$

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As we have seen, the higgses have a vev in the vacuum. The correct way to think about it is that the magnetic theory of the SQCD with soft-terms, **is** the theory broken down to $SU(2)_L \times U(1)_Y \hookrightarrow U(1)_{QED}$

Note that the Yukawa couplings include the familiar NMSSM ones and also SU(2) triplet (TMSSM) couplings: this is a fat higgs model.

Possible alternative model-building tool: models with chiral symmetry breaking (same number of colours and flavours) have a stable minimum without gauging baryon number.

Concussion

- Progress in the mapping of anomalous currents (and hence soft-terms)
- Towards non-SUSY dualities - although decoupling remains a remote goal
- Seiberg duality is an interesting framework in which to consider radiatively induced EWSB in strongly coupled theories.
- Many other ideas can be looked at in this framework: e.g. emergent supersymmetry, SU(2) as a magnetic gauge theory, brane engineering of the softy deformed dualities, concrete model building ... and so on