# SUSY Gauge Singlets and Dualities

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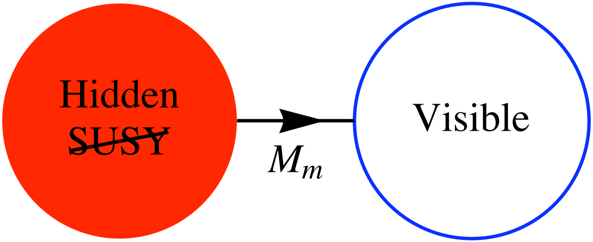
# Why bother?

- Seiberg duality[1] in $\mathcal{N} = 1$ SUSY gives us a different way of looking at supersymmetric gauge theories.
- We believe it will help in understanding many aspects of BSM physics such as gauge unification, proton decay and dynamical SUSY breaking.
- Problem: currently, dualities only exist for theories with highly constrained matter content and unrealistic superpotentials.
- Our goal is to find a dual theory to a more realistic GUT, like a supersymmetric $\mathrm{SU}(5)$ model.

[1] For a review: K. Intriligator, N. Seiberg - arXiv:hep-th/9509066

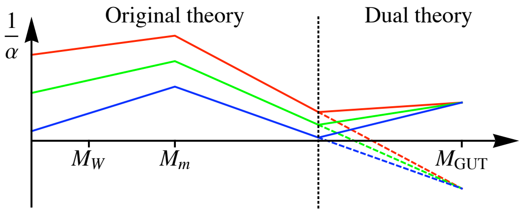
# Example: "Dualification"

- Consider a SUSY GUT which breaks SUSY via direct mediation.
- The messenger particles are charged under the visible sector gauge group.



# Example: “Dualification”

- Now look at the RG flows of coupling constants. The messengers deflect the gauge coupling unification.
- Extrapolating to higher scales it may appear as though unification occurs at a negative, unphysical value of the coupling constant $\frac{1}{\alpha}$.
- In the dual theory the unification is much more natural.[2]




[2] S. Abel, V.V. Khoze - arXiv:809.5262[hep-ph]

# Seiberg duality in a nutshell

## Original theory - SQCD with $N$ colours and $F_Q$ flavours

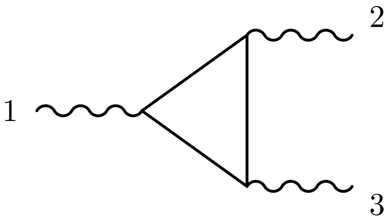
| | $\mathrm{SU}(N)$ | $\mathrm{SU}(F_Q)_L$ | $\mathrm{SU}(F_Q)_R$ |
|---|---|---|---|
| $Q$ | $\mathbf{N}$ | $\mathbf{F_Q}$ | $\mathbf{1}$ |
| $\tilde{Q}$ | $\overline{\mathbf{N}}$ | $\mathbf{1}$ | $\mathbf{F_Q}$ |

## Dual theory - SQCD+M with $n = F_Q - N$ colours and $F_Q$ flavours

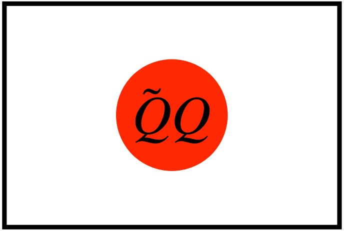
| | $\mathrm{SU}(n)$ | $\mathrm{SU}(F_Q)_L$ | $\mathrm{SU}(F_Q)_R$ |
|---|---|---|---|
| $q$ | $\mathbf{n}$ | $\overline{\mathbf{F_Q}}$ | $\mathbf{1}$ |
| $\tilde{q}$ | $\overline{\mathbf{n}}$ | $\mathbf{1}$ | $\overline{\mathbf{F_Q}}$ |
| $M$ | $\mathbf{1}$ | $\mathbf{F_Q}$ | $\mathbf{F_Q}$ |

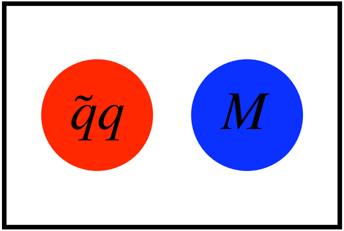
# Tests of the duality

- The global symmetries of both theories are the same.
- The classical moduli spaces of both theories are the same (i.e. the mesons and baryons match).
- The duality is preserved under deformations, e.g. quark mass terms.
- Highly non-trivial 't Hooft anomaly matching conditions are satisfied, especially those involving the $R$-symmetry.



# Mesons and superpotential



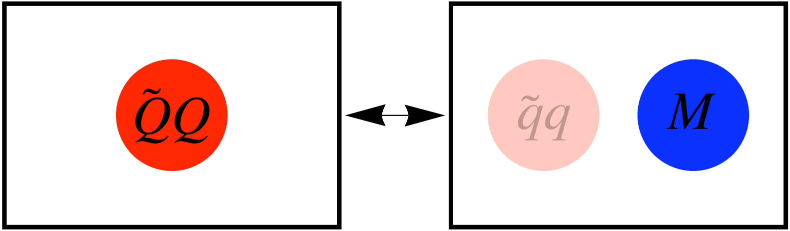

**Original theory - $\mathrm{SU}(N)$**

- ${F_Q}^2$ mesons $\tilde{Q}Q$

**Dual theory - $\mathrm{SU}(F_Q - N)$**

- ${F_Q}^2$ mesons $\tilde{q}q$
- ${F_Q}^2$ mesons $M$

# Mesons and superpotential




**Original theory - $\mathrm{SU}(N)$**

- ${F_Q}^2$ mesons $\tilde{Q}Q$

**Dual theory - $\mathrm{SU}(F_Q - N)$**

- $W_{\mathrm{dual}} = M\tilde{q}q$
- $F$-terms give $\tilde{q}q = 0$
- ${F_Q}^2$ mesons $M$

# Adding more matter

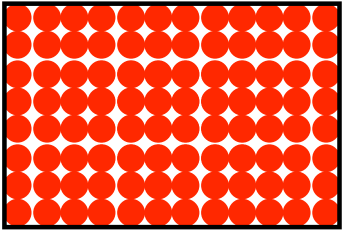
- To find a dual GUT, we need to be able to find dualities for theories with adjoint and/or antisymmetric representations of the gauge group.
- Consider adding an adjoint $X$ to the original theory[3]. The mesons are now

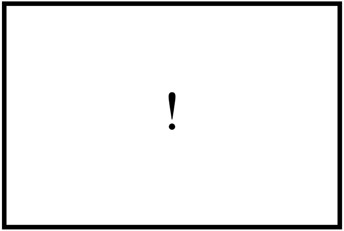
$$M_j = \tilde{Q} X^j Q$$

for **any** positive integer $j$.

[3] D. Kutasov, A. Schwimmer, N. Seiberg - arXiv:hep-th/9510222

# Adding more matter





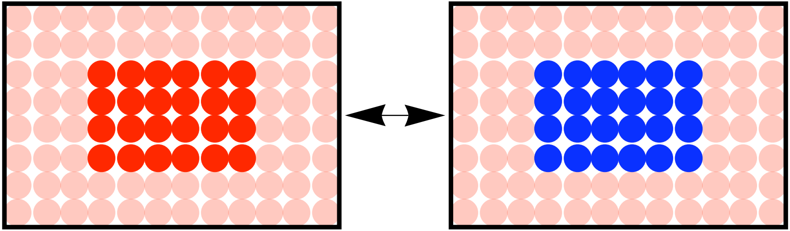

**Original theory - $\mathrm{SU}(N)$**

- $\infty$ mesons $\tilde{Q}X^jQ$

**Dual theory - $\mathrm{SU}(!)$**

- Argh!

# Adding more matter



## Original theory - $\mathrm{SU}(N)$

- $W_{\mathrm{orig}} = X^{k+1}$
- $F$-terms give $X^k = 0$
- $k{F_Q}^2$ mesons $M_j = \tilde{Q} X^j Q$
- $j = 0, \ldots, k-1$

## Dual theory - $\mathrm{SU}(kF_Q - N)$

- $W_{\mathrm{dual}} = x^{k+1} + \sum_j M_j \tilde{q} x^{k-1-j} q$
- $F$-terms give $x^k = \tilde{q} x^j q = 0$
- $k{F_Q}^2$ mesons $M_j$
- $j = 0, \ldots, k-1$

# Preserving $R$-symmetries

- Adding a superpotential to the original theory is often necessary, but reduces the number of global symmetries.
- If there are too few global symmetries we cannot test the duality properly.
- In particular, it seems very important for the theory to retain an $R$-symmetry to ensure non-trivial 't Hooft anomaly matching conditions.
- By adding gauge singlets to the superpotential we can generally retain an $R$-symmetry.
- This allows us to find **and test** new dualities with more general matter content.[4]

[4] S. Abel, J. Barnard - arXiv:0903.1313[hep-th]

# Example: three generations of antisymmetric tensor

- Consider SQCD with $N$ colours, $F_Q$ flavours of quark/antiquark, three antisymmetrics and a singlet $\phi$.
- Include a superpotential to fix the meson sector

$$W_{\rm orig} = \phi^{\rho_A}(A\tilde{A})^{k_A+1} + \phi^{\rho_B}(B\tilde{B})^{k_B+1} + \phi^{\rho_C}(C\tilde{C})^{k_C+1} + \phi^{\sigma}\left(A\tilde{B} + \tilde{A}B + B\tilde{C} + \tilde{B}C\right).$$

- The inclusion of $\phi$ restores an $R$-symmetry.
- A dual theory can now be shown to exist, with

$$n = (2k^* + 1)\, F_Q - 4k^* - N$$

colours, where

$$k^* = \frac{1}{2}\left[(2k_A + 1)\,(2k_B + 1)\,(2k_C + 1) - 1\right].$$

# Summary

- Seiberg duality has great potential to help in many areas of BSM phenomenology.
- If we want to fully exploit this potential, we **must** find dualities involving realistic models.
- This means relaxing the conditions on the superpotential and matter content required to permit a duality.
- Gauge singlets are a useful tool to help with this task.
- By including gauge singlets in our theories, we have already been able to construct dualities involving multiple generations of antisymmetric tensor.