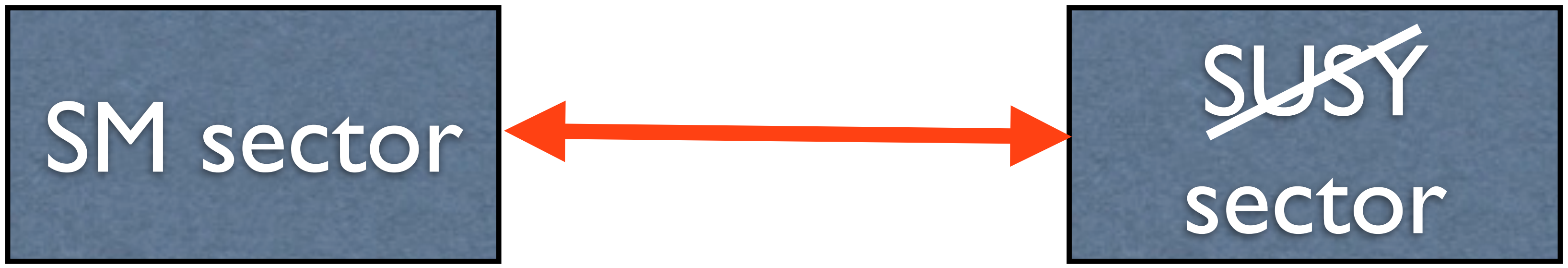
Deflected and Dual unification

SAA and Valya Khoze, JHEP**0811**:024,2008, ArXiV:0809.5262

Outline

- Landau poles in direct gauge mediation
- Solution 1: Deflected Unification
- Solution 2: Dual unification
- Dual unified SU(5)

Landau poles in direct gauge mediation:



Landau poles in direct gauge mediation:

Landau poles in direct gauge mediation: example

Based on Seiberg duality: the electric model consists of ...

$\mathcal{N}=1$ gauge	$SU(N)$	
mesons	$Q^j\tilde{Q}_j$	$;\, i,j = 1\ldots F_Q$
fundamental electric quarks	Q_i^a	$;\, a = 1\ldots N$
antifundamentals (Dirac mass m_Q)	$\tilde{Q}_a^i$	

The gauge coupling runs as $$e^{-8\pi^2/g^2(E)} = \left(\frac{E}{\Lambda}\right)^{-b_0}$$

If the beta-function is negative $b_0 = 3N - F_Q > 0$ then hit Landau pole

Landau poles in direct gauge mediation: example

The magnetic model found by matching baryons and global anomalies is

$\mathcal{N}=1$ gauge	$SU(n)$	$n = F_Q - N$
mesons	M_i^j	$;\, i,j = 1 \ldots F_Q$
fundamental magnetic quarks	q_i^a	$;\, a = 1 \ldots n$
antifundamentals	$\tilde{q}_a^i$	

Runs to weak coupling in IR if $\overline{b}_0 = 3n - F_Q < 0$ so strong->IR-free if

$$N + 1 \leq F_Q \leq \frac{3}{2} N$$

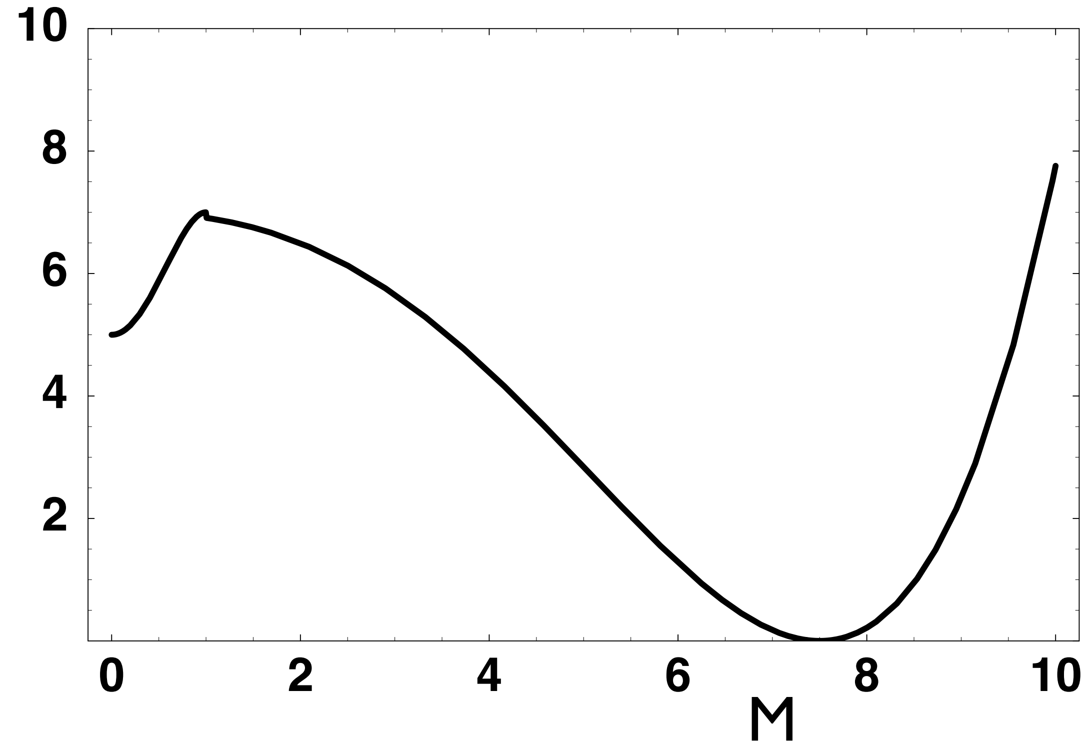
Landau poles in direct gauge mediation: example

The origin is metastable because of approximate R-symmetry

Nelson, Seiberg

Abe, Kobayashi, Omura

$$W = W_{cl} + W_{dyn}:$$



anomalously broken by W_{dyn}

Landau poles in direct gauge mediation: example

Complete example: "deform" ISS for direct gauge mediation (SAA, Durnford, Jaeckel, Khoze)

$$W = M_{ij} q_i . \tilde{q}_j - Tr(\mu^2_{ISS} M) + m \varepsilon_{ab} \varepsilon_{rs} q^a_r q^b_s$$

where $r, s = 1, 2$ are the 1st and 2nd flavour numbers. Take $n = 2,\ F_Q = 7$

$$(\mu^2_{ISS})_{ij} = diag\{\mu^2_2 \mathbf{I_2},\ \mu^2_5 \mathbf{I_5}\}$$

and gauge the remaining $SU(5)_f \supset G_{SM}$

Landau poles in direct gauge mediation: example

The mediators are $q^a_{i=1..5}$ and $\tilde{q}_a^{i=1..5}$ and the typical scalar mass is

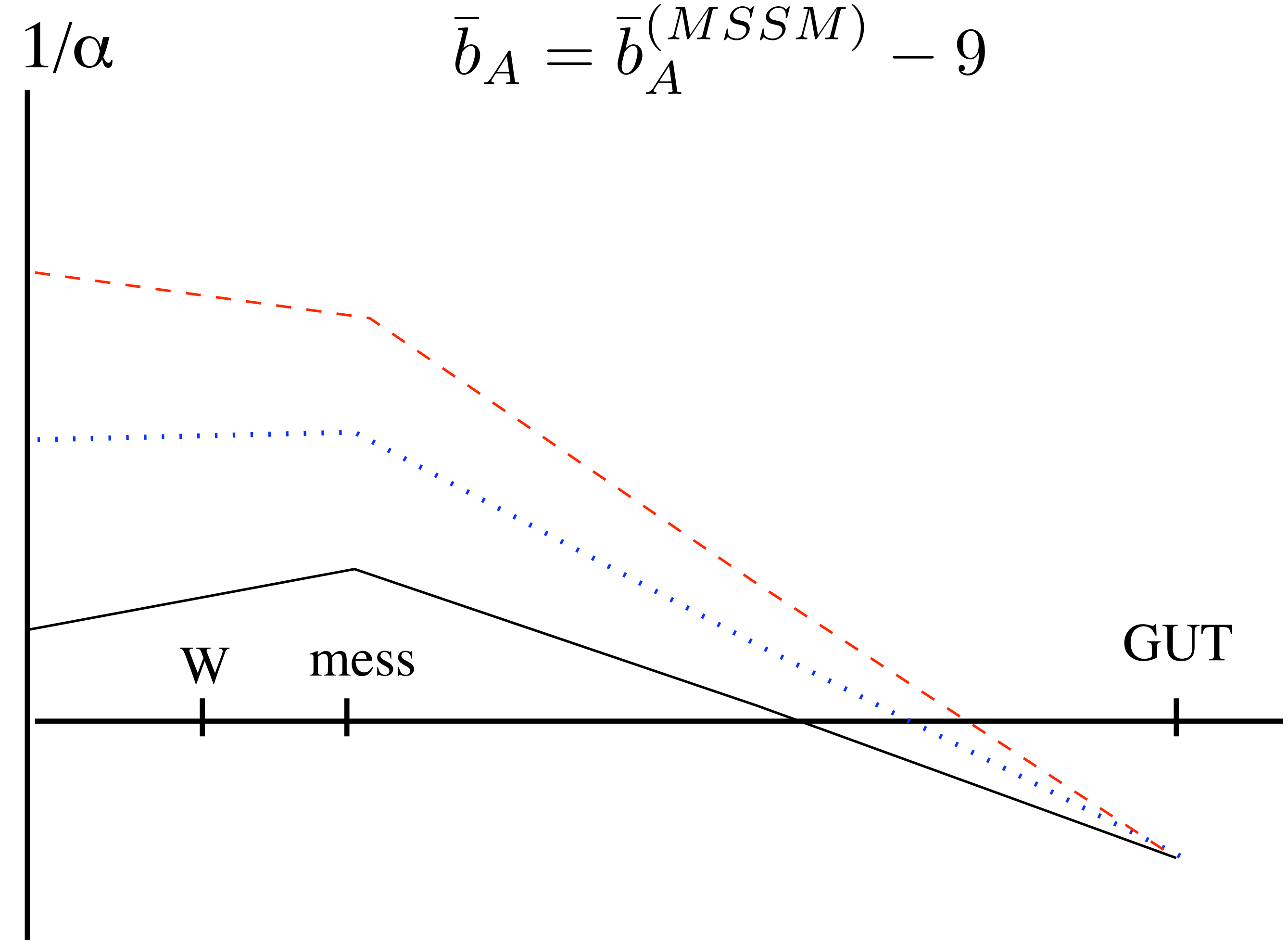
$$m_{scalar} \sim \frac{g_A^2}{16\pi^2}\mu_2$$

This is a model of 'slightly split SUSY'.

Landau poles in direct gauge mediation: example

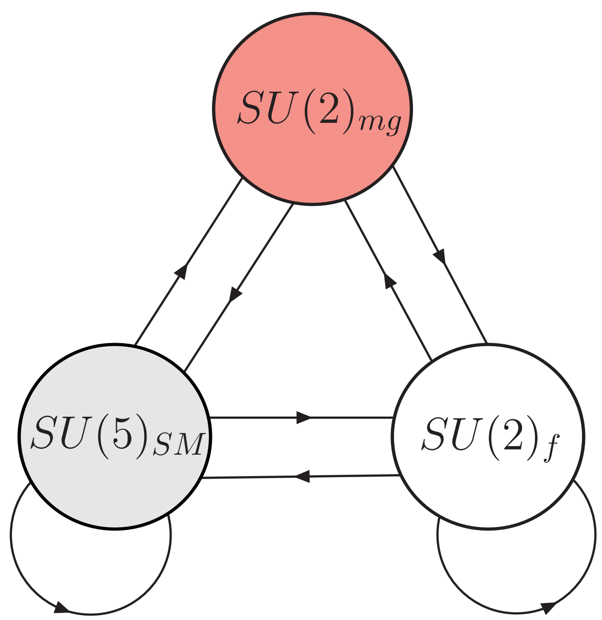
- Direct gauge mediation is attractive but typically a problem - a large contribution to the beta-functions...
- In this case (and typically) since the additional fields are in complete SU(5) multiplets there is a universal contribution above messenger scale

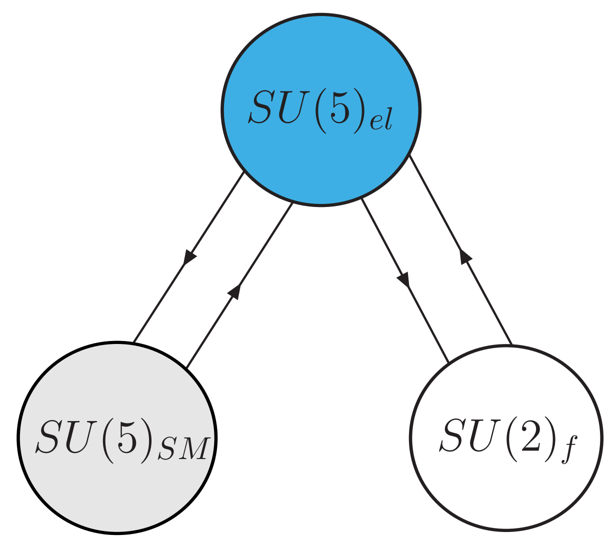
$$\bar{b}_A = \bar{b}_A^{(MSSM)} - 9$$



Solution 1: Deflected unification

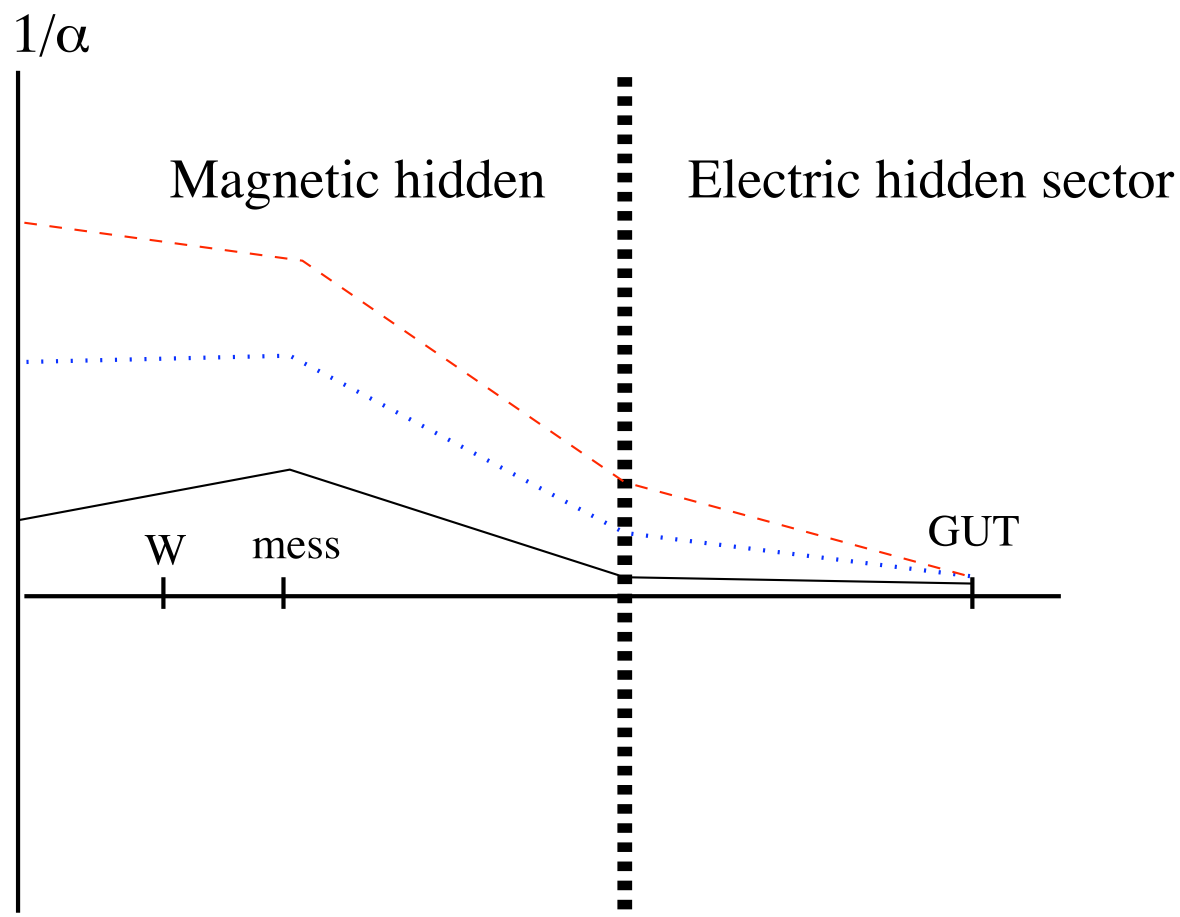
The physics of the ISS sector changes at the strong coupling scale (i.e. the Landau pole scale of the ISS part of the theory) ...





Solution 1: Deflected unification

So the effective number of degrees of freedom decreases above the Landau pole scale of the SUSY-breaking ISS sector ...



Solution 1: Deflected unification

A Landau pole is avoided if this happens at a low enough scale ... e.g. $\Lambda_{ISS} \sim 10^{1-3}\mu_2$

$$(\alpha_{GUT}^{-1})^{(MSSM)} \lesssim 4\log(\Lambda_{ISS}/\mu_2) + 5\log(M_{GUT}/\mu_2)$$

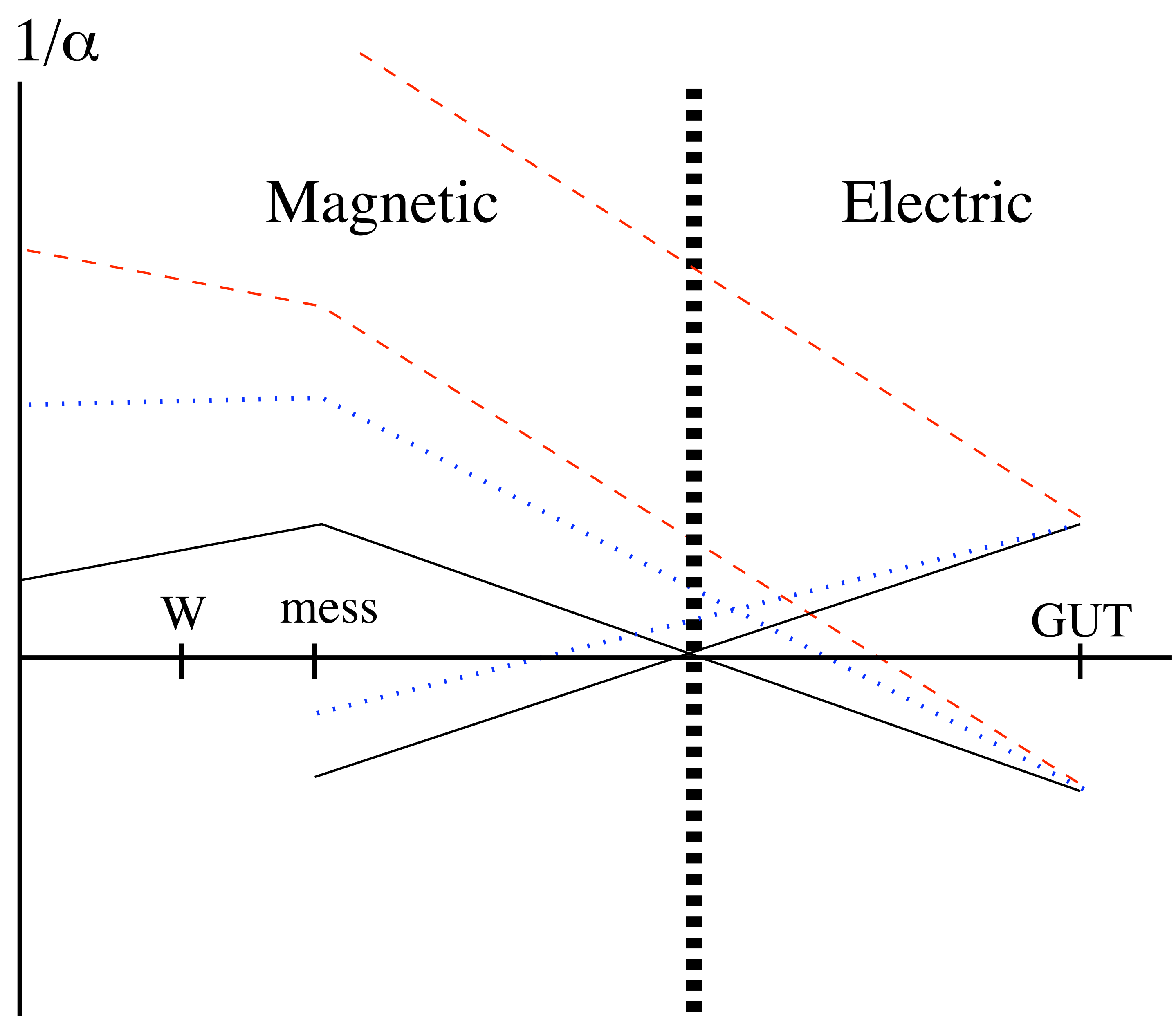
Landau pole avoided if ...

$$\mu_2 \geq 4 \times 10^5 \text{ GeV.}$$

Can be (just about) met by this model.

Solution 2: Dual unification

Could it be that the MSSM is itself a magnetic dual theory, with apparent GUTs in the magnetic theory mirroring unification in electric theory? (Klebanov Strassler)



Solution 2: Dual unification

This picture is correct in known (Kutasov, Schwimmer, Seiberg) elec/mag duals to GUTs with adjoint X that breaks the GUT symmetry!

Works as follows: first need a superpotential for X ...

$$W_{\rm el} = \sum_{i=0}^{k-1} \frac{t_i}{k+1-i} \,{\rm Tr}\left[X^{k+1-i}\right]$$

When GUT symmetry unbroken then $SU(n) = SU(kF_Q - N)$

Solution 2: Dual unification

Additional terms give the *same* GUT breaking in both theories:

$$SU(N) \to SU(r_1) \times SU(r_2) \ldots SU(r_k) \times U(1)^{k-1}$$

$$SU(n) = SU(kF_Q - N) \to SU(\bar{r}_1) \times SU(\bar{r}_2) \ldots SU(\bar{r}_k) \times U(1)^{k-1},$$

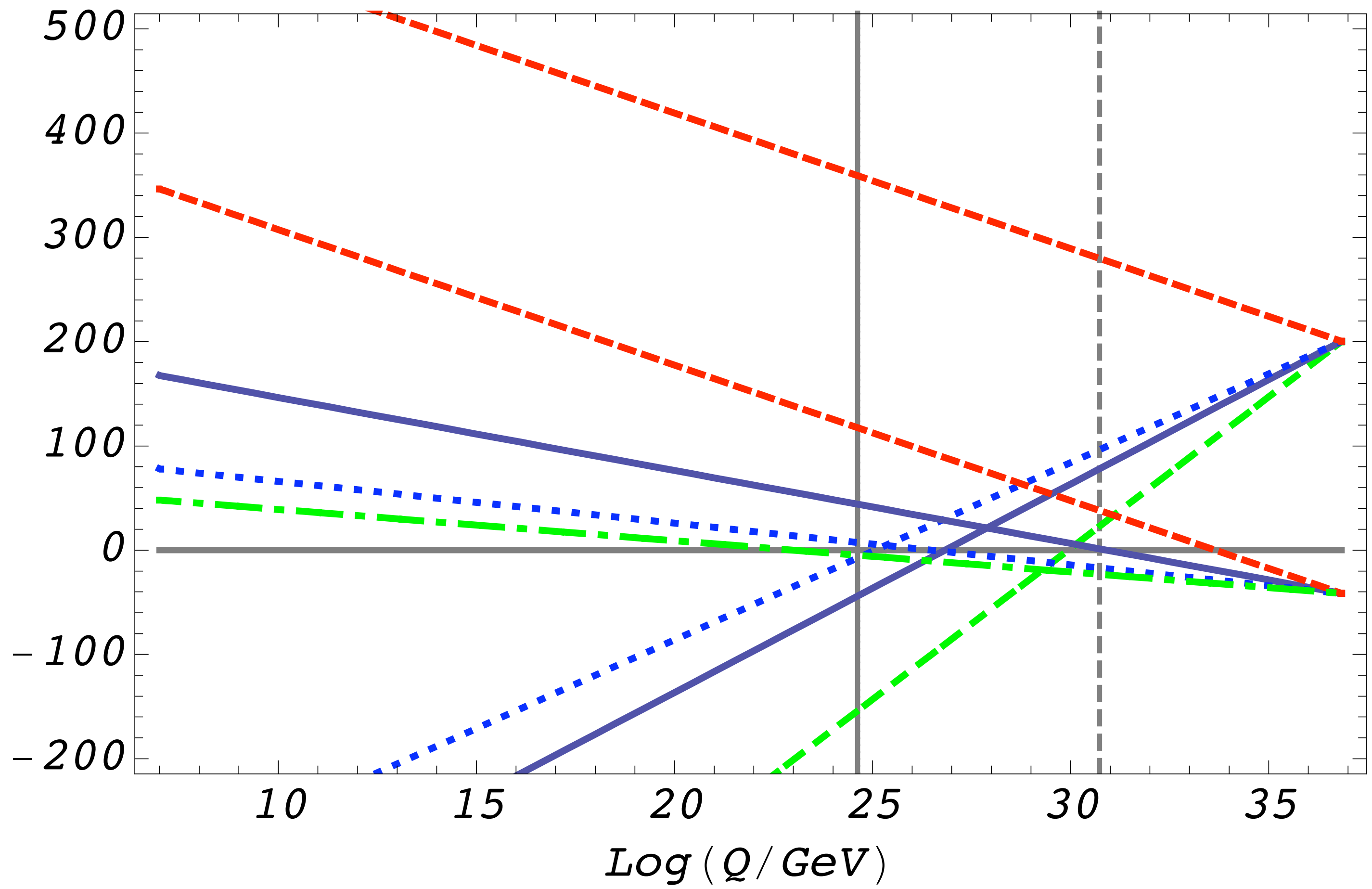
where $\bar{r}_i = F_Q - r_i$. Example ...

$$\boxed{\begin{array}{ll} \text{elec: } SU(21) & \to SU(11) \times SU(10) \times U(1), \\ \text{mag: } SU(5) & \to SU(2) \times SU(3) \times U(1), \end{array}}$$

Solution 2: Dual unification

Moreover *unification in electric theory implies unification in magnetic theory.* (SAA, Khoze)

$$\boxed{\begin{array}{ll} \text{elec: } SU(21) \to SU(11)\times SU(10)\times U(1), \\ \text{mag: } SU(5) \;\; \to SU(2)\times SU(3)\times U(1), \end{array}}$$



Dual unified SU(5)

Electric theory: $\mathrm{SU}(11) \times \mathrm{Sp}(1)^3$

	$\mathrm{SU}(11)$	$\mathrm{Sp}(1)_a$	R_p
$Y_{a=1\ldots3}$	$\square$	$\square$	i
$\tilde{Q}_{\bar{J}=1\ldots3}$	$\tilde{\square}$	1	1
$\tilde{H}_{\bar{J}=1\ldots3}$	$\tilde{\square}$	1	-1
$\tilde{F}_{\bar{J}=1,2}$	$\tilde{\square}$	1	$-i$
$F_{J=1,2}$	$\square$	1	i
X	Adj	1	1
Z_a	1	$\square$	i

$$W = \frac{m_X}{2}X^2 + \frac{s_0}{3}X^3 + \kappa_i ZYX^i\tilde{H}$$
$$+\lambda_{ij}\tilde{Q}X^iYYX^j\tilde{H} + \lambda'_{ij}\tilde{F}X^iYYX^j\tilde{F} + \lambda''_{ij}\tilde{H}X^iF\tilde{Q}X^jF + \lambda'''_{ij}\tilde{F}X^iF\tilde{F}X^jF$$

Dual unified SU(5)

Chain of well understood dualities ....

$SU(11) \times Sp(1)^3$

↓ KSS duality

$SU(5) \times Sp(1)^3$

↓ Sp(1) Confinement

$SU(5)$

Dual unified SU(5)

Magnetic theory: $\mathrm{SU}(5)$

	$\mathrm{SU}(5)$	R_p
$\tilde{h}_{J=1\ldots3}$	$\tilde{\Box}$	1
$\tilde{q}_{\bar{J}=1\ldots3}$	$\tilde{\Box}$	-1
$\tilde{f}_{\bar{J}=1,2}$	$\tilde{\Box}$	i
$f_{J=1,2}$	$\Box$	$-i$
x	Adj	1
a_a	$\begin{smallmatrix}\Box\\\Box\end{smallmatrix}$	-1
h_a	$\Box$	1

$$W = \frac{m_x}{2}x^2 - \frac{s_0}{3}x^3 + \tilde{\kappa}_i\, h x_s^i \tilde{h} + \tilde{\lambda}_{ij}\, \tilde{h} x_s^i a x_s^j \tilde{q} + \lambda_U a a h + \tilde{\lambda}'_{ij}\, \tilde{f} x_s^i a x_s^j \tilde{f} + \text{quartic}$$

Dual unified SU(5)

Magnetic theory: $\mathrm{SU}(5)$

	$\mathrm{SU}(5)$	R_p
$\tilde{h}_{J=1\ldots3}$	$\tilde{\square}$	1
$\tilde{q}_{\bar{J}=1\ldots3}$	$\tilde{\square}$	-1
$\tilde{f}_{\bar{J}=1,2}$	$\tilde{\square}$	i
$f_{J=1,2}$	$\square$	$-i$
x	Adj	1
a_a	$\begin{smallmatrix}\square\\\square\end{smallmatrix}$	-1
h_a	$\square$	1

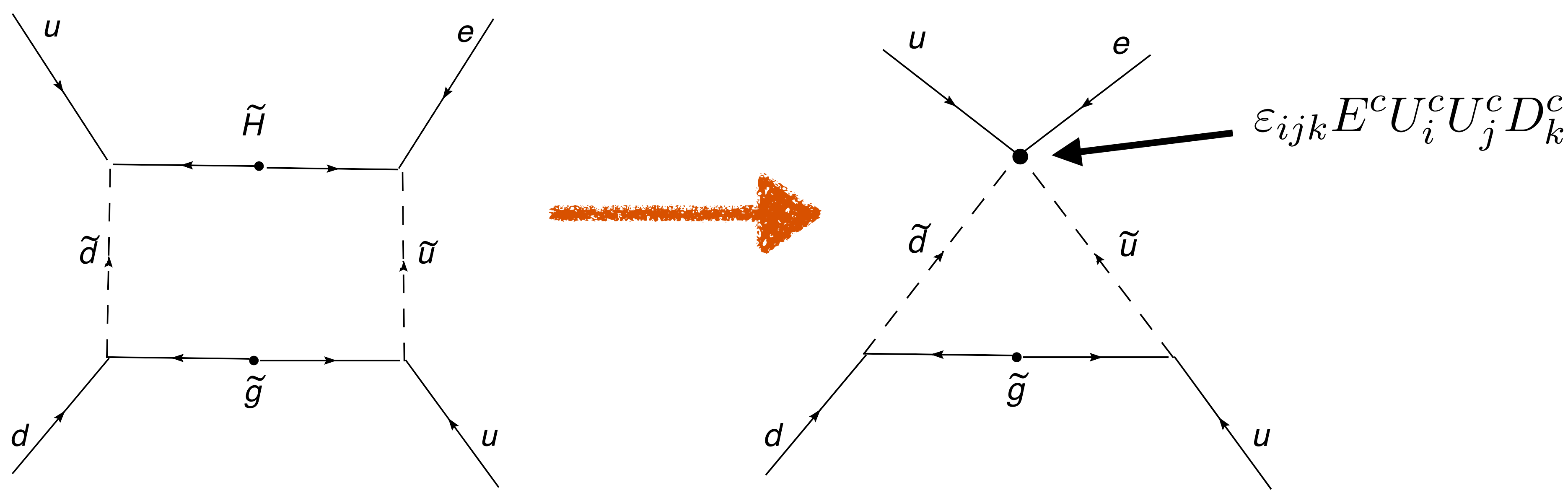
MSSM "mu-term"

$$W = \frac{m_x}{2}x^2 - \frac{s_0}{3}x^3 + \tilde{\kappa}_i\, h x_s^i \tilde{h} + \tilde{\lambda}_{ij}\, \tilde{h} x_s^i a x_s^j \tilde{q} + \lambda_U aah + \tilde{\lambda}'_{ij}\, \tilde{f} x_s^i a x_s^j \tilde{f} + \text{quartic}$$

Up quark Yukawas generated by instantons

Dual unified SU(5)

Application to proton decay - why does nature seem to unify but the proton not decay?



Note that the effective operator is a "baryon": $\varepsilon AA(A\tilde{Q}) \supset \varepsilon EUUD$

Dual unified SU(5)

The baryon number violation proportional to a baryon operator in the magnetic theory *but this is generated in the electric theory: on dimensional grounds expect*

$$W_{el} \sim \frac{Q^d}{M_{GUT}^{d-3}}$$

where Q represents generic electric fields and d is *at least* N.

But we know how to map to the operator in the magnetic theory

$$\varepsilon_{ijk} E^c U_i^c U_j^c D_k^c \leftrightarrow \Lambda^{4-d} Q^d$$

hence

$$\boxed{W_{eff} \supset \left(\frac{\Lambda}{M_{GUT}}\right)^{d-4} \frac{1}{M_{GUT}} \varepsilon_{ijk} E^c U_i^c U_j^c D_k^c}$$

Dual unified SU(5)

In this case (X is dimensionless)...

$$W = \frac{(\tilde{F}X)^2\tilde{F}^2(XY)^7(YX\tilde{H})}{M_{GUT}^{10}} \leftrightarrow \left(\frac{\Lambda}{M_{GUT}}\right)^9 \frac{\varepsilon AA(A\tilde{Q})}{M_{GUT}}$$

Dual unified SU(5)

Preserving unification prediction: need 2-loop accuracy (~5%), but have only 1-loop matching

No - Dual GUTs have the same predictive accuracy if

$$\frac{\Lambda}{M_{GUT}} > 10^{-6}$$

Summary

- Deflected unification can save direct gauge mediation from Landau poles
- Dual unification can happily accommodate them ...
- New methods for finding electric/magnetic duals