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# Gauging Flavour in Meta-Stable Susy Breaking Models

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**Abstract**

We modify the first ISS model [1] by gauging a diagonal flavour symmetry. We add additional multiplets transforming as fundamentals and anti-fundamentals under the gauged flavour group. Their number is chosen such that the microscopic theory is asymptotically free whereas in the Seiberg dual (w.r.t. the colour group) it changes to an infrared free theory. Non perturbative effects within the flavour group can correct the location of the supersymmetric vacuum. Statements about meta-stability of the susy breaking vacuum would require a two loop calculation. For general couplings, the question whether gauging flavour destabilises susy breaking remains open.

# 1 Introduction

The idea of meta-stable susy breaking [2] has recently been realised in appealingly simple models [1]. The underlying microscopic theory can be as simple as supersymmetric QCD with a quadratic superpotential. There is a point in the field space of the theory where a dual macroscopic description is in its perturbative regime and only susy breaking vacua exist. The susy breaking scale is a function of a dynamically generated scale and a tree level mass. At another point in moduli space the macroscopic theory is strongly coupled at the susy breaking scale. Due to non perturbative corrections a supersymmetric vacuum exists at that point. The tunnelling from the susy breaking to the susy preserving vacuum is, however, highly suppressed and the mechanism is stable enough for all practical purposes. The authors of [1] indicate that they would like to use their mechanism for direct mediation of susy breaking.

In principle, one could also try to use it for breaking susy in a hidden sector and mediate the breaking to the visible sector by one of the known mechanisms. Indeed, such constructions have been put forward in [3]. In the present note, we investigate as a toy model for this possibility a simple modification of [1], where the flavour group is gauged. In order to avoid strong gauge couplings at the susy breaking point in field space we have to add some colour singlets transforming non trivially under flavour. In the non super symmetric vacuum there are fields which remain massless after one loop corrections.

The moduli space of supersymmetric vacua within this theory is not completely understood. With a certain amount of fine tuning on the flavour coupling we can keep non perturbative corrections due to gauged flavour small at the susy breaking scale and compute first order corrections of such effects to the location of the supersymmetric vacuum. The first order correction can move the supersymmetric vacuum towards the non supersymmetric one. Our calculation is only valid if these corrections are small. This is indeed the case and hence the calculation is self consistent.

In the next section we review the model [1]. In section three we gauge the flavour symmetry and add colour singlets transforming as fundamentals and anti-fundamentals under the flavour group. We complete the electric-magnetic dictionary for this case. In section four we discuss meta-stable susy breaking for the modified model. There are mass squareds which could become negative at a two loop level. We compute corrections to the location of the supersymmetric vacuum due to non perturbative effects in the gauged flavour sector, in an approximation where these corrections are necessarily small. Finally, we provide some concluding remarks. In spirit, the discussed model is similar to [4] where gauged flavour has been considered in the context of quiver theories.

# 2 The ISS model

Several models for meta-stable supersymmetry breaking have recently been presented in [1], and subsequently in [3–11]. Here, the focus will be on the first model in [1] which we briefly review in the following. The model has two dual descriptions: One, the microscopic model, is appropriate for calculations in the ultraviolet region, since it is asymptotically free, and has no further non renormalisable couplings. The dual description, or the macroscopic model, is infrared free, and hence the adequate choice for investigating phenomena at lower energy. In the macroscopic model, supersymmetry breaking occurs at lower energies, where the perturbative description is reliable.

The microscopic model is an $SU(N_c)$ gauge theory with $N_f$ fundamentals, combined into an $N_f \times N_c$ matrix $Q$, and anti-fundamentals, written into an $N_c \times N_f$ matrix $\tilde{Q}$, with

$$N_c + 1 \le N_f < \frac{3}{2} N_c. \tag{1}$$

There is a tree level potential[1]

$$W = m \mathrm{Tr} \left( Q \tilde{Q} \right) \tag{2}$$

breaking the global $SU(N_f) \times SU(N_f)$ flavour symmetry to its diagonal subgroup.

The Seiberg dual [12] (for reviews see e.g. [13–15]) of this theory has gauge group $SU(N)$ with

$$N = N_f - N_c, \tag{3}$$

$N_f$ quarks $\varphi$, $N_f$ anti-quarks $\tilde{\varphi}$ and singlets $\Phi$ transforming as an adjoint plus singlet under the diagonal flavour. The superpotential is

$$W = h \mathrm{Tr} \left( \tilde{\varphi} \Phi \varphi \right) - h \mu^2 \mathrm{Tr} \Phi. \tag{4}$$

The dictionary for the couplings and parameters reads [1]

$$\hat{\Lambda}^{N_f} = \Lambda_c^{3N_c - N_f} \tilde{\Lambda}_c^{3N - N_f} (-1)^N , \tag{5}$$

$$\varphi = q, \ \ \tilde{\varphi} = \tilde{q}, \qquad h = \frac{\sqrt{\alpha} \Lambda_c}{\hat{\Lambda}}, \ \ \mu^2 = - m \hat{\Lambda}, \tag{6}$$

$$\Phi = \frac{Q \tilde{Q}}{\sqrt{\alpha} \Lambda_c}, \tag{7}$$

where $\Lambda_c$ and $\tilde{\Lambda}_c$ are the scales at which the colour couplings of the microscopic and macroscopic theory diverge, respectively. The scale $\hat{\Lambda}$ is an additional scale appearing in the dual theory. $Q$, $\tilde{Q}$ are related to $q$, $\tilde{q}$ by Hodge duality on the baryons as in [13]. The factor in (7) appears due to a rescaling giving $\Phi$ mass dimension one and removing an order one factor $\alpha$ from the Kähler potential [1]. This will be of some importance in the next section.

The major observation of [1] is the existence of a meta-stable non supersymmetric vacuum in the perturbative regime of the macroscopic model,

$$\Phi = 0 \ , \ \ \varphi^T = \tilde{\varphi} = \left( \mathbb{1}_N , 0_{N_f - N} \right) . \tag{8}$$

[1] We do not introduce a general mass matrix breaking this symmetry completely, since later we want to consider a model where the unbroken diagonal subgroup is gauged.

In this vacuum, some fields have tree level masses of the order $|h\mu|$. In particular $\mathrm{Tr}_N\Phi$ is classically massive, where the index $N$ indicates that the trace is taken over the first $N$ diagonal entries. Other fields, the pseudo moduli, become massive at one loop of perturbation theory. The Goldstone bosons of broken global symmetries remain massless.

In the supersymmetric vacuum, all matter fields are massive and $\Phi$ has the expectation value

$$\Phi = \frac{\tilde{\Lambda}_c}{h}\left(\frac{\mu}{\tilde{\Lambda}_c}\right)^{\frac{2N}{N_f-N}} \mathbb{1}_{N_f}. \tag{9}$$

Translated to the microscopic theory, this corresponds to

$$Q\tilde{Q} = m^2\left(\frac{\Lambda_c}{m}\right)^{\frac{3N_c-N_f}{N_c}} \mathbb{1}_{N_f}. \tag{10}$$

At the supersymmetry breaking vacuum this VEV is zero. So, if the quark masses are well below the strong coupling scale of the microscopic theory, the susy breaking vacuum and the supersymmetric vacuum are well separated. This way, the tunnelling probability to the supersymmetric vacuum can be suppressed parametrically.

# 3 Dualising Colour with Gauged Flavour Watching

We modify the microscopic model of the previous section by gauging the diagonal flavour group $SU(N_f)$ and add colour singlets transforming under the fundamental and anti-fundamental representation of $SU(N_f)$. We add $k$ of such pairs, with

$$N_f + N_c < k < 3N_f - N_c. \tag{11}$$

(Note that $k > 3/2N_f$ is implied by (1).) So, altogether we have gauge group

$$SU\left(N_c\right) \times SU\left(N_f\right), \tag{12}$$

and

- one chiral multiplet, $Q$, in the $\left(N_c, \overline{N}_f\right)$,
- one chiral multiplet, $\tilde{Q}$, in the $\left(\overline{N}_c, N_f\right)$ ,
- $k$ chiral multiplets, $\rho$, in the $(1, N_f)$,
- $k$ chiral multiplets, $\tilde{\rho}$, in the $\left(1, \overline{N}_f\right)$ .

The one loop beta function coefficient of the flavour coupling is greater than zero, and hence the microscopic theory is well defined in the UV region. For the tree level potential we take

$$W = m\mathrm{Tr}\left(Q\tilde{Q}\right) + \sigma\mathrm{Tr}\left(\rho\tilde{\rho}\right), \tag{13}$$

where the mass sigma is taken to be far below the susy breaking scale, in order to ensure that these degrees of freedom contribute to the running coupling at and above the susy breaking scale. We assume[2]

$$\Lambda_f < \Lambda_c, \tag{14}$$

where $\Lambda_f$ is the scale at which the flavour coupling diverges. In the region where the flavour coupling is still small whereas the colour coupling becomes large, we replace the theory by an equivalent formulation. The dual theory is obtained by performing the same duality as in the previous section on the colour group. One obtains a theory with dual gauge group

$$SU(N = N_f - N_c) \times SU(N_f). \tag{15}$$

The dual spectrum consists of

- one chiral multiplet, $\varphi$, in the $\left(N, \overline{N}_f\right)$,
- one chiral multiplet, $\tilde{\varphi}$, in the $\left(\overline{N}, N_f\right)$ ,
- $k$ chiral multiplets, $\rho$, in the $(1, N_f)$,
- $k$ chiral multiplets, $\tilde{\rho}$, in the $\left(1, \overline{N}_f\right)$ ,
- one chiral multiplet $\Phi$ in the $(1,1) + \left(1, N_f^2 - 1\right)$.

As before, the one loop beta function coefficient of the colour group is negative. If $k$ satisfies (11), the one loop beta function coefficient of the flavour group is less than zero. Hence, the flavour group stays in its perturbative regime as long as none of the flavour charged matter becomes massive.

Next, we need to identify the scale $\tilde{\Lambda}_f$, at which the dual flavour coupling becomes large. We propose that the relation is

$$\Lambda_f^{3N_f - N_c - k} \tilde{\Lambda}_f^{-\left(3N_f - N_f - N - k\right)} = \hat{\Lambda}^{-N} \Lambda_c^{3\left(N_f - N_c\right)} \alpha^{N_f} 2^{-N_f}. \tag{16}$$

We have no strict derivation for (16). We can provide only some reasoning. The $\hat{\Lambda}$ dependence is fixed by imposing that $\hat{\Lambda}$ parameterises unknown factors in the Kähler potential for $\varphi$ and $\tilde{\varphi}$ [1]. In the theory with ungauged flavour, discussed in the previous section, there is a scaling symmetry of the superpotential and the matching relation (5) involving dual quantities

$$\varphi \to \gamma \varphi, \;\; \tilde{\varphi} \to \gamma \tilde{\varphi}, \;\; \hat{\Lambda} \to \gamma^2 \hat{\Lambda}, \;\; \Phi \to \gamma^0 \Phi. \tag{17}$$

Our proposal (16) respects that symmetry. Since $\Lambda_c$ is used throughout, in order to obtain canonical mass dimensions, we did so in (16) as well[3]. The $\alpha$ dependence is due to (7), and

[2] Here, and in the following, it should be understood that we compare real parts of dynamically generated scales.

[3] Taking a flavour scale instead would mean that the relation alters its form upon giving one of the pairs in the $(1, N_f)$ and $\left(1, \overline{N}_f\right)$ a large mass and integrating it out. Using $\tilde{\Lambda}_c$ would spoil the 'symmetry' (17) unless it comes together with $\hat{\Lambda}$ in an invariant combination. But such a combination is $\Lambda_c$.

the anomalous rescaling of the adjoint. The numerical coefficient $2^{-N_f}$ will be discussed in the end of the fourth section.

For the dual tree level potential[4] we obtain

$$W = h\mathrm{Tr}\left(\tilde{\varphi}\Phi\varphi\right) - h\mu^2\mathrm{Tr}\Phi + \sigma\mathrm{Tr}\left(\rho\tilde{\rho}\right). \tag{18}$$

In the dual theory we are interested in a situation where the dual flavour coupling diverges farther in the ultraviolet than the dual colour coupling

$$\tilde{\Lambda}_c < \tilde{\Lambda}_f. \tag{19}$$

This condition is not invariant under the previously discussed scaling symmetry. One has to supplement it with the requirement of canonical kinetic terms.

To see whether this involves some fine tuning we combine (5) and (16) into

$$\Lambda_f^{2\left(N_f-N_c\right)}\left(\frac{\tilde{\Lambda}_f}{\Lambda_f}\right)^{k+N_f+N-3N_f} = \left(\frac{\alpha}{2}\right)^{N_f}\left(\Lambda_c\right)^{2\left(N_f-N_c\right)}\left(\frac{\tilde{\Lambda}_c}{\Lambda_c}\right)^{\frac{N\left(N_f-3N\right)}{N_f}}. \tag{20}$$

The hierarchy imposed by $\Lambda_f < \Lambda_c$ and $\tilde{\Lambda}_f > \tilde{\Lambda}_c$ implies

$$\left(\frac{\alpha}{2}\right)^{N_f}\left(\frac{\Lambda_c}{\Lambda_f}\right)^{2\left(N_f-N_c\right)}\left(\frac{\tilde{\Lambda}_c}{\Lambda_c}\right)^{\tilde{b}_f-\frac{N}{N_f}\tilde{b}_c} > 1, \tag{21}$$

with

$$\tilde{b}_f = 3N_f - N - N_f - k, \qquad \tilde{b}_c = 3N - N_f, \tag{22}$$

being the (negative) one loop beta function coefficients of dual flavour and colour, respectively. We require further that there is a region where electric and magnetic gauge couplings are finite, i.e. $\tilde{\Lambda}_c/\Lambda_c > 1$. The inequality (21) holds naturally, if the dual colour coupling diverges fast enough, compared to the flavour coupling, for the exponent in (21) to be positive. Otherwise some fine tuning on $\Lambda_c/\Lambda_f$ is needed.

# 4 Meta-Stable Susy Breaking with Gauged Flavour?

As in [1] there is no supersymmetric vacuum in the perturbative regime. The potential is minimised by (8). The colour group is broken completely whereas the flavour group is broken to $SU\left(N_f - N = N_c\right)$. Some of the classical moduli provide the missing degrees of freedom for massive vector multiplets of broken flavour. Others acquire a D-term tree level mass due to the equations of motion of the flavour gauge degrees of freedom. Our condition that $\sigma$ is smaller than the susy breaking scale means that at the susy breaking

[4]Note that a term $\mathrm{Tr}\tilde{\rho}\Phi\rho$ would correspond to a non renormalisable coupling in the microscopic theory. We do not consider this case.

scale quantum corrections to the mass of $\rho$ and $\tilde{\rho}$ dominate over the tree level mass $\sigma$. Hence, $\rho$ and $\tilde{\rho}$ can effectively considered to be massless. One loop quantum corrections to their mass cancel since supersymmetry breaking is mediated only by gauge degrees of freedom whose mass spectrum is classically fermion-boson degenerate [1]. If they are not stabilised by higher order quantum corrections they can gain a vacuum expectation value up to $\sigma \mathrm{Tr} \langle \tilde{\rho}\rho \rangle$ being of the order of the susy breaking scale. The situation is similar to one of the examples in [5] where it was concluded that the given information is not sufficient for making statements about the stability of the vacuum. Instead of speculating about the nature of higher order quantum corrections to the susy breaking vacuum, we try to get insight into non perturbative flavour corrections to the supersymmetric vacuum.

To this end, we give a VEV to $\Phi$. Then the bifundamentals $\varphi$, $\tilde{\varphi}$ become massive. Below this mass both gauge groups become asymptotically free, if $k < 2N_f$. (As we will see shortly the adjoint becomes also massive and below that mass the flavour group is always asymptotically free.)

The supersymmetric moduli space of the colour sector is well understood [13, 16]. Due to the presence of the adjoint (traceless part of $\Phi$) the flavour sector is more complicated. There are some partial results in the literature [17–22]. It is, however, not obvious to us how to use these results in the given situation. Therefore, we will impose the simplifying assumption that the flavour group becomes strongly coupled at much lower energies than the colour group[5]. We assume further, that non perturbative effects within the flavour group can be neglected at the mass of the bifundamentals where the two theories decouple.

Due to instanton corrections within the colour group the superpotential (18) is supplemented by an additional contribution[6]

$$W_c^{np} = N \left( \tilde{\Lambda}_c^{-\left(N_f - 3N\right)} \det h\Phi \right)^{1/N} . \tag{23}$$

The traceless part of $\Phi$ acquires a mass

$$m_{N_f^2 - 1} = -\frac{h^2}{2N_f} \mathrm{Tr} h\Phi \left( \frac{\mathrm{Tr} h\Phi}{N_f \tilde{\Lambda}_c} \right)^{\frac{N_f - 3N}{N}} . \tag{24}$$

After integrating out the traceless part, we fix $\Phi$ to be of the form

$$\Phi = p \mathbb{1}_{N_f}, \tag{25}$$

and the masses of the bifundamentals become

$$m_\varphi = m_{\tilde{\varphi}} = hp. \tag{26}$$

[5]After decoupling the bifundamentals, the one loop beta function coefficients are: $3\left(N_f - N_c\right)$ for the magnetic colour group, and at most $N_f - N_c$ for the flavour group. So, the colour coupling will diverge at higher scales than the flavour one.

[6]For the case $N_f = N_c + 1$ see the discussion in [1].

Assuming that the decoupling of the flavour group at $hp$ occurs above the scale at which the coupling becomes strong, we can treat its non perturbative effects separately. After the adjoint and the bifundamentals decouple we obtain $SU(N_f)$ gauge theory with $k$ pairs of quarks and anti-quarks. Now, since $3N_f > k > 3/2N_f$, the Seiberg dual of the flavour theory is also asympotically free. However, we can still find a non trivial supersymmetric vacuum by giving a vacuum expectation value to the dual of $\mathrm{Tr}\rho\tilde{\rho}$. For this case, we can adapt the result for the supersymmetric vacuum from[7] (10)

$$\rho\tilde{\rho} = \sigma^2 \left(\frac{\tilde{\Lambda}_{f,L}}{\sigma}\right)^{\frac{3N_f-k}{N_f}} \mathbb{1}_k, \tag{27}$$

where

$$\tilde{\Lambda}_{L,f}^{3N_f-k} = \tilde{\Lambda}_f^{-\left(N+k-2N_f\right)} (hp)^N m_{N_f^2-1}^{N_f}. \tag{28}$$

Plugging this back into (27) we obtain

$$\sigma\rho\tilde{\rho} = -\frac{1}{2}\sigma^{\frac{k}{N_f}} \left(h^N \tilde{\Lambda}_f^{-\left(N+k-2N_f\right)}\right)^{\frac{1}{N_f}} \left(h^{N_f}\tilde{\Lambda}_c^{3N-N_f}\right)^{\frac{1}{N}} p^{\frac{N_f}{N}-\frac{N_f+N_c}{N_f}} \mathbb{1}_k. \tag{29}$$

In our approximation the superpotential becomes finally,

$$\begin{aligned} W &= N\left(h^{N_f}\tilde{\Lambda}_c^{-\left(N_f-3N\right)} p^{N_f}\right)^{1/N} - h\mu^2 N_f\, p \\ &\quad -\frac{N_f}{2}\sigma^{\frac{k}{N_f}} \left(h^N \tilde{\Lambda}_f^{-\left(N+k-2N_f\right)}\right)^{\frac{1}{N_f}} \left(h^{N_f}\tilde{\Lambda}_c^{3N-N_f}\right)^{\frac{1}{N}} p^{\frac{N_f}{N}-\frac{N_f+N_c}{N_f}}, \end{aligned} \tag{30}$$

where we have taken into account a contribution from gaugino condensation to the superpotential (for details see e.g. [13] section 5.5).

The contribution in the second line of (30) has to be small compared to the contribution in the first line, for our approximations to be consistent. Within this approximation the F-term condition for $\Phi$ can be solved to leading order in the correction, yielding

$$\Phi = \Phi_0\left\{1 - C\left(\sigma^k h^N \tilde{\Lambda}_f^{-\left(k+N-2N_f\right)}\right)^{\frac{1}{N_f}} \Phi_0^{-\frac{N_f+N_c}{N_f}}\right\}, \tag{31}$$

where $\Phi_0$ is the solution for the ungauged flavour case (9), and

$$C = \frac{N}{N_f}\left(\frac{N_f+N_c}{N_f} - \frac{N_f}{N}\right). \tag{32}$$

Note, that the correction term contains an $N_f$th root of unity.

[7] There could be also other supersymmetric vacua, we are interested in one giving an effect to our considerations.

In the microscopic language this corresponds to

$$Q\tilde{Q} = \left(Q\tilde{Q}\right)_0 \left\{1 - 2C\sigma^{\frac{k}{N_f}} \Lambda_f^{\frac{3N_f-k-N_c}{N_f}} \Lambda_c^{\frac{3N_c-N_f}{N_f}} \left(Q\tilde{Q}\right)_0^{-\frac{N_f+N_c}{N_f}}\right\}, \tag{33}$$

where $\left(Q\tilde{Q}\right)_0$ denotes the solution in the global flavour case (10).

With our choice of parameters there is indeed a small correction. If $\sigma$ is taken to zero the correction vanishes. Our treatment is valid if non perturbative effects in the flavour sector are negligible at the mass of the bifundamentals, where magnetic colour and flavour decouple.

Now, let us come back to the candidate for meta-stable susy breaking, discussed in the beginning of this section. If the two loop effective mass squared for $\rho$ and $\tilde{\rho}$ is negative these fields would condense breaking the residual flavour symmetry. Some of the degrees of freedom become part of a massive vector field. The 'mesons' $\rho\tilde{\rho}$ could condense further. These are singlets under the gauged colour and flavour groups. The backreaction of such a condensation would be suppressed. Therefore, it seems plausible that the $\rho\tilde{\rho}$ direction is along a valley where the position of $\Phi$ and the hight of the potential walls stays effectively constant. Flavour would return to a global symmetry which is spontaneously broken in the meta-stable vacuum. On the supersymmetric side we have seen that the width of the potential wall can be shortened by the condensation of $\rho\tilde{\rho}$. Since our approach is limited to a situation where this shortening of the width is only a small percentage we cannot say whether such effects could be significant for the life time of the meta-stable vacuum in the case that flavour and colour interactions are of comparable strength at the susy breaking scale.

Finally, let us come back to the relation (16) and reason for the numerical coefficient $2^{-N_f}$. Plugging our approximate solution (33) into (30) one obtains

$$W = N_c \left(\Lambda_c^{3N_c-N_f} m^{N_f}\right)^{\frac{1}{N_c}} + N_f \left(\Lambda_f^{3N_f-N_c-k} m^{N_c} \sigma^k\right)^{\frac{1}{N_f}} + \dots, \tag{34}$$

where dots stand for terms higher order in $\sigma$ which cannot be computed within our approximation. The superpotential (34) is the sum of contributions from gaugino condensation in the colour and flavour group with the correct numerical factors (see e.g. [13]). This explains our choice in (16).

# 5 Conclusions

Modifying the models of [1] by gauging flavour can serve as a toy model for gauge mediation of meta-stable susy breaking, where the hidden sector role is played by the colour gauge theory whereas the flavour gauge theory acts as the visible sector. We found that in the modified model it is much harder to derive exact results and make definite statements about meta-stability. However, we were able to compute corrections to the location of the supersymmetric vacuum due to non perturbative effects in the gauged flavour sector as long as these effects are small. These corrections shift the position of the supersymmetric vacuum towards the non supersymmetric one. Ensuring that non perturbative effects in the visible sector are highly suppressed at the susy breaking scale (as well in the supersymmetric vacuum as in the non supersymmetric one) would keep these corrections small. We do not know the first non trivial quantum corrections to some masses in the non supersymmetric vacuum. This would require a two loop calculation. Moreover, we lack an exact knowledge of the moduli space of supersymmetric vacua, for general couplings. In order to improve the situation one could e.g. try to modify the matter sector transforming under flavour. For instance, the models discussed in [4] have also product gauge groups and are under better control. (However, also the authors of [4] restrict to a decoupled situation when identifying the supersymmetric vacuum.) Also recent brane constructions [23, 24] may be helpful.

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