# Superconformal Dynamics and SUSY Flavor Problem

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**Abstract**

We study the scenario leading to hierarchical Yukawa couplings and at the same time degenerate sfermion masses. Superconformal dynamics plays a role.

Understanding the origin of fermion masses and mixing angles is one of most important issues in particle physics. Yukawa couplings are free parameters within the framework of the standard model (SM). There are several types of flavor mechanisms to generate hierarchical Yukawa couplings. Within the framework of supersymmetric models, such flavor mechanism, in general, affects sfermion masses as well as supersymmetry (SUSY) breaking scalar trilinear couplings. That would lead to non-universal sfermion masses, but such non-universality is strongly constrained by experiments of flavor changing neutral currents (FCNCs). Thus, flavor-blind mediation mechanisms of SUSY breaking are usually assumed.

Here we would like to propose the flavor scenario that leads to hierarchical Yukawa couplings and degenerate sfermion masses. In our scenario superconformal dynamics plays an important role. We also consider possibility for string realization of our scenario.

We consider models including superconformal sector with non-trivial infrared fixed point. 4D N=1 SUSY theory with non-trivial infrared fixed point has been studied[1]. Renormalization group (RG) of soft SUSY breaking terms has been studied in generic theory with non-trivial infrared fixed point[2, 3]. (See also Ref. [4] for softly broken SQCD.) Those analyses have shown that the gaugino mass and a certain linear combination of soft scalar masses in pure superconformal sector are exponentially suppressed, that is, for sfermion masses we have the RG equation,

$$\frac{dm_i^2}{dt} = \Gamma_{ij} m_j^2, \tag{1}$$

where $\Gamma_{ij}$ are damping factors. These factors $\Gamma_{ij}$ are calculable in explicit models and are comparable with anomalous dimensions of the corresponding fields at the fixed point[2, 6].

Following Ref. [5], we consider the SUSY SM or its GUT extension coupled to superconformal (SC) sectors, which are strongly coupled and are assumed to have non-trivial infrared fixed point. Here we concentrate to the case that the SC sector has a product gauge group, $G_{\rm SC} = \prod_i G_{\rm SC}^{(i)}$, where gauge couplings are denoted by $g'_i$ $(i = 1, 2, 3)$. The SC sector has matter fields $\Phi_i$ and $\bar{\Phi}_i$, which are charged only under the $i$-th SC gauge group $G_{\rm SC}^{(i)}$. We denote three families of quarks and leptons

$\psi_i$ $(i = 1, 2, 3)$ collectively. Each family of quarks and leptons $\psi_i$ couples to SC matter fields $\Phi_i$ and $\bar{\Phi}_i$ through the following 'messenger' coupling in the superpotential,

$$\lambda_i \psi_i \Phi_i \bar{\Phi}_i \ . \tag{2}$$

Now the RG equation of sfermion masses in the SM sector has effects due to SM gaugino masses as well as the superconformal dynamics (1), and their RG equations are written as

$$\frac{dm_i^2}{dt} = \Gamma_{ij} m_j^2 - \sum_a 4C(R_\psi^{(a)}) \alpha_a(M_C) M_a^2(M_C) \ , \tag{3}$$

where $\alpha_a \equiv g_a^2/8\pi^2$ with the gauge couplings $g_a$ in the SM sector, $C(R_\psi^{(a)})$ is the quadratic Casimir coefficient and $M_a$ are the gaugino masses of the SM sector. Thus, sfermion masses converge into the following values [2, 3, 7],

$$m^2_{\tilde{\psi}_i}(M_C) \ \longrightarrow \ \frac{1}{\Gamma_{\psi_i}} \sum_a 4C(R_\psi^{(a)}) \alpha_a(M_C) M_a^2(M_C) \ , \tag{4}$$

for any initial condition of sfermion masses. As mentioned above, $\Gamma_{\psi_i}$ is comparable with the anomalous dimension. Thus, if the anomalous dimension is $O(1)$, $\Gamma_{\psi_i}$ is also $O(1)$ and the above convergence value is one-loop suppressed. We assume that the SC sector is decoupled universally at an energy scale $M_C$. Below $M_C$ sfermion masses receive radiative corrections due to the SM gaugino masses, which are flavor-blind for the first and second families, and these masses are almost degenerate at the weak scale. The difference of sfermion masses between the first and second families is written as

$$m^2_{\tilde{\psi}_1}(M_C) - m^2_{\tilde{\psi}_2}(M_C) = \left( \frac{1}{\Gamma_{\psi_1}} - \frac{1}{\Gamma_{\psi_2}} \right) \sum_a 4C(R_\psi^{(a)}) \alpha_a(M_C) M_a^2(M_C) \ . \tag{5}$$

Hence, the difference is one-loop suppressed, compared with radiative corrections due to gaugino masses between $M_C$ and $M_Z$. (See Ref. [2,7] for detail of the degeneracy of sfermion masses.)

Now let us study Yukawa couplings,

$$y_{ij} \psi_i \psi_j H \ , \tag{6}$$

where $H$ denotes the up and down sectors of the Higgs fields, again collectively. Their RG-flow is written as

$$y_{ij}(\mu) = Z_{\psi_i}(\mu, \Lambda) Z_{\psi_j}(\mu, \Lambda) Z_H(\mu, \Lambda) y_{ij}(\Lambda) \ , \tag{7}$$

where $Z_\varphi(\mu, \Lambda)$ stands for the chiral wave-function renormalization factor of a superfield $\varphi$ between $\Lambda$ and low-energy scale $\mu$. Thus, in the case that $Z_\varphi(\mu, \Lambda)$ is hierarchically suppressed, $y_{ij}(M_C)$ are hierarchical even if $y_{ij}(\Lambda) = O(1)$. Such drastic RG flow can be realized by superconformal dynamics, because superconformal dynamics induces large anomalous dimensions, e.g. $O(1)$. We use the RG-flow of messenger couplings,

$$\lambda_i(\mu) = Z_{\psi_i}(\mu, \Lambda) Z_{\Phi_i \bar{\Phi}_i}(\mu, \Lambda) \lambda_i(\Lambda) \ , \tag{8}$$

and the relation between the holomorphic and physical gauge couplings, $\widehat{\alpha}_i$ and $\alpha_i$, in the SC sector [9, 10],

$$\frac{1}{\widehat{\alpha}_i} + N_f^{(i)} \ln Z_{\Phi_i \bar{\Phi}_i} = F(\alpha_i) \equiv \frac{1}{\alpha_i} + N_c^{(i)} \ln \alpha_i + \cdots \ . \tag{9}$$

Then we obtain $Z_{\psi_i}(\mu, \Lambda)$

$$Z_{\psi_i}(\mu, \Lambda) = \left(\frac{\mu}{\Lambda}\right)^{\gamma_*^{(i)}} \times \left[\frac{\lambda_i(\mu)}{\lambda_i(\Lambda)}\right] \times \exp\left[\frac{F(\alpha_i(\Lambda)) - F(\alpha_i(\mu))}{N_f^{(i)}}\right] , \tag{10}$$

where $\gamma_*^{(i)} \equiv (3N_c^{(i)} - N_f^{(i)})/N_f^{(i)}$. Eq. (10) shows there are three possibilities for hierarchical Yukawa couplings. The first possibility is that $N_C^{(i)}$ and $N_f^{(i)}$ are different from those for the $j$-th sector $(i \neq j)$. Actually this is the scenario studied in Ref. [5]. The second possibility is that an initial value of $\lambda_i$ is different from $\lambda_j$ $(i \neq j)$. This scenario is studied in Ref. [6]. The third possibility is that an initial value of $\hat{\alpha}_i$ is different from $\hat{\alpha}_j$ $(i \neq j)$. This scenario is studied in Ref. [8], where we discuss the possibility for realization of the third scenario by string-inspired extra dimensional models. In the second and third cases, sfermion masses can be completely degenerate, because the same anomalous dimension can be realized and that implies $\Gamma_1 = \Gamma_2$.

To summarize, we have shown the superconformal dynamic is interesting, because the superconformal dynamics can wash out initial conditions of soft SUSY breaking terms and can lead to degenerate sfermion masses. At the same time, using the same dynamics we can generate realistically hierarchical Yukawa couplings.

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