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Suppression of Supergravity Anomalies in Conformal Sequestering

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Abstract

We show that the anomaly-mediated supersymmetry breaking via the Kähler and sigma-model anomalies is suppressed by conformal dynamics in the supersymmetry breaking sector.

I. INTRODUCTION

Low-energy supersymmetry (SUSY) is one of the most plausible extensions of the standard model (SM). So far, low-energy experiments such as measurements of flavor-changing neutral currents (FCNCs) have imposed constraints on its breaking mechanism and mediation. We often assume to put our world be secluded from the SUSY breaking sector. Then, the SUSY breaking is mediated only via the gravitational effects [1, 2, 3], and the dangerous FCNCs are suppressed naturally.

It was proposed that the separation is achieved by geometrical configuration in higher dimensions [1]. This mechanism is simple and easy to imagine. However, it has been noted that moduli fields in the bulk may induce the dangerous couplings. The contributions depend on the background, and the warped one, namely the AdS space, is successful, because they are warped away [4].

On the other hand, the separation is realized in the four dimensional setup by assuming a conformal dynamics in the SUSY breaking sector. This scenario is called as the conformal sequestering [5]. The renormalization group (RG) evolution of the conformal dynamics suppresses the contact couplings between the SM and SUSY breaking sectors.

These two mechanisms are suggested to be dual to each other according to the AdS/conformal field theory (CFT) correspondence [6]. This implies an equivalence of the mass spectrum of the superparticles. It has been studied that the tree-level mediation of the SUSY breaking is suppressed in both cases [1, 5]. Then the soft parameters arise at the quantum level. There are three anomalies in supergravity (SUGRA), which are known to mediate the SUSY breaking [1, 2, 3]. In the AdS setup, the mediation is given by the Super-Weyl (SW) anomaly, while the other two anomalies in SUGRA, called the Kähler and sigma-model anomalies, are known to cancel to each other [3]. In contrast, any cancellation or suppression has not been discussed in CFT. In this letter, we will show that the conformal dynamics suppresses the Kähler and sigma-model anomalies are suppressed.

II. ANOMALY MEDIATION

The anomaly-mediated SUSY breaking (AMSB) with respect to the SW, Kähler and sigma-model transformations is represented by the non-local operators in SUGRA [3]. How-

ever, the result is not easy to discuss the conformal dynamics. They are easily obtained from the superconformal formula of SUGRA [7]. Only the leading terms with respect to $1/M_P$ are phenomenologically significant. Then the Lagrangian is expanded as

$$\mathcal{L} \;=\; [\phi^\dagger \phi\, Q^\dagger Q]_D + [\Delta K]_D - \frac{1}{6}[K^2]_D + [\phi^3\, W]_F + \cdots, \tag{1}$$

where K and W denotes the Kähler and superpotential in the Einstein frame. The chiral superfield field Q denote the visible and hidden mattes. It is noted that ϕ is the chiral compensator field to fix the gauge degrees of freedom of the superconformal symmetry. Namely, the frame is not fixed before giving a VEV for ϕ. The notation $[\cdots]_{D,F}$ means to take D- and F-components in the global SUSY, respectively. Further, we simply assume a canonical normalization for the matters. The second term in the right-handed side represents the higher dimensional terms, potentially including direct couplings between the visible and hidden sectors. The third one is obtained after expanding $-3e^{-K/3}$. The neglected terms are phenomenologically irrelevant, since they correspond to higher order terms of $1/M_P^n$ in the Einstein frame.

The chiral compensator field, ϕ is a source to mediate the SUSY breaking via the SW anomaly. It is easy to introduce the Pauli-Villas (PV) fields Q' to see AMSB. Essentially, the superpotential involves the mass term,

$$W \;=\; M' Q' \bar{Q}' \tag{2}$$

with the regularization scale M'. After canonically rescaling Q', the SUSY breaking B term is evaluated as $B = M' F_\phi$ in addition to the mass term $M = M'\phi$. Thus similarly to the evaluation of the gaugino mass in the gauge-mediated SUSY breaking, the loop diagram mediating Q' gives

$$M_\lambda \;=\; \frac{\alpha}{4\pi}\frac{F_\phi}{\phi}. \tag{3}$$

This has a sign opposite to that of the gauge-mediation because Q' is the PV field. We notice that the result is independent of M' and finite even for $M' \to \infty$. The Einstein frame is realized by taking [a]

$$\phi \;=\; e^{K/6}\left[1 + \theta^2\left(e^{K/2}W^* + \frac{1}{3}K_i F^i\right)\right]. \tag{4}$$

[a] See [3] for the terms involving spinors.

Then we reproduce the AMSB result from the SW anomaly.

The sigma-model contribution originates in the second term of the right-handed side in (1). The B term is from the higher dimensional operator in the Kähler potential. In fact, for a hidden matter Z, $\delta K = cZQ'Q'^{\dagger} + \text{h.c.}$ gives $\delta F_{Q'} = -cF_Z Q'$, leading to $B = -M'cF_Z$ by combining to the mass term (2) (e.g. see below). Note that ϕ does not contribute to the sigma-model anomaly. Thus the gaugino mass becomes

$$M_\lambda \;=\; -\frac{\alpha}{4\pi} cF_Z . \tag{5}$$

This result is generalized to the result in [3] straight-forwardly. Then the anomaly is only from the $U(1)$ subgroup of the connection, $\Gamma^j_{ij} \equiv K^{j\ell^*} K_{i\ell^* j}$. It is also commented that this result depends on the higher dimensional operator in K and can appear in global SUSY models [8].

Let us discuss the Kähler anomaly. The third term of the right-handed side plays a role to mediate the SUSY breaking in (1). It looks like a higher dimensional operator in the D-term, $[\cdots]_D$, and the B term becomes $B = 2/3 M' K_Z F_Z$ for both Q and $\bar{Q}$, similarly to the sigma-model anomaly. So the gaugino mass is

$$M_\lambda \;=\; \frac{\alpha}{4\pi}\frac{2}{3} K_Z F_Z . \tag{6}$$

It is stressed that although the result depends on the linear term of K, it substantially comes from the higher dimensional operator in (1).

From (3), (5) and (6), we obtain the complete AMSB for the gaugino mass which is coincide with the result in [3]. In the literature, the operator is denoted by the superfields, involving the gravity superfield, R. We can see that the superfield representation of the non-local terms is derived from the second and third terms in (1) for the Kähler and sigma-model anomalies. However, only a part is obtained for that of the SW anomaly, because we focus on a source of AMSB and introduced only ϕ in this letter.

The B terms are essential to derive AMSB in the above. For the Kähler and sigma-model anomalies, they come from the higher dimensional operators. The Kähler potential is generally written as (here and in the following, we omit a prime of fields for simplicity)

$$K \;=\; |Z|^2 + |Q|^2 + |\bar{Q}|^2 + \Big[d\, Z + c_Q Z|Q|^2 + c_{\bar{Q}} Z|\bar{Q}|^2 + \text{h.c.} \Big] + \cdots , \tag{7}$$

and the mass term is $W = MQ\bar{Q}$. Here the coefficients $c_{Q,\bar{Q}}$, d may depend on the (hidden)

matters as a background. Expanding $e^{K/3}$, we obtain the higher dimensional operators;

$$-3e^{-K/3} \supset (c_Q - d/3)\, Z|Q|^2 + (c_{\bar{Q}} - d/3)\, Z|\bar{Q}|^2 + \text{h.c.}. \tag{8}$$

These terms are a source of mediating the SUSY breaking in the Kähler and sigma-model AMSB. The B term is easily obtained by solving the equation of motion of F_Q and $F_{\bar{Q}}$. Another approach is to erase them by rescaling, $Q \to Q[1-(c_Q - d/3)Z]$. Then the mass term is modified as

$$MQ\bar{Q} \longrightarrow M\left[1 - \left(c_Q - c_{\bar{Q}} - \frac{2d}{3}\right) Z\right] Q\bar{Q}. \tag{9}$$

This involves the B term, and provides the gaugino masses. It is noted that the tadpole terms of Z are irrelevant after the expansion.

The contributions from the Kähler and sigma-model anomalies, (5) and (6), exactly cancel to each other, if the Kähler potential is the sequestered form [3],

$$K = -3\ln\left[1 - \frac{1}{3}(|Q|^2 + |Z|^2)\right]. \tag{10}$$

This cancellation is easily seen in (1). The second and third terms in the right-handed side are a source of the SUSY breaking for the sigma-model and Kähler anomalies. If we substitute (10) for the Kähler potential in (1), they cancel to each other. From another point of view, they correspond to the higher dimensional operators of $-3e^{K/3}$. Namely, the higher dimensional operators in the Einstein frame are practically equivalent to those in the conformal frame [9]. In the conformal frame, since (10) does not have the contact terms between the visible and the SUSY breaking sectors, the Kähler and sigma-model anomalies are absent, and only the SW anomaly remains.

III. CONFORMAL SEQUESTERING

Let us discuss the Kähler and sigma-model anomalies under the conformal dynamics. In the previous section, we saw that they are related to the higher dimensional operators in (1). Thus we focus on the evolution of them in the conformal dynamics.

At the cutoff scale, the Lagrangian is assumed to be general, involving the (flavor-violating) higher dimensional operators. Let us first discuss the case when the operators in the D-term linearly depend on the matters in the SUSY breaking sector, S. This means

that $c_{Q,\bar{Q}}$ and d in (7) are independent of the SUSY breaking fields. To see a suppression of them, we rescale the visible matters as $Q \to Q[1-(c_Q - d/3)S]$. Then the AM contributions is derived from a coupling of S in front of the mass term in the superpotential, giving the B term. Its evolution is represented by the anomalous dimension of S. Near the fixed point, the B term behaves as (see e.g. [10, 11])

$$W \sim \left(\frac{\mu}{M_*}\right)^{\gamma_S^*} MSQ\bar{Q}, \tag{11}$$

where γ_S^* is the anomalous dimension at the fixed point. Since S should be gauge-singlet, γ_S^* is positive. Thus the B term becomes suppressed in the infrared limit.

The bilinear terms with respect to the SUSY breaking fields in the D-term can also be a source of mediating the SUSY breaking if the field has a finite vacuum expectation value. Regarding the visible fields as a background, their evolutions are represented by the anomalous dimensions [5];

$$(\Delta \ln Z) = e^{Lt}(\Delta \ln Z)_0. \tag{12}$$

Here the scale is $t = \ln(\mu/M_*)$ and $(\Delta \ln Z)$ is defined as $(\Delta \ln Z) \equiv \ln Z + \gamma^* t$. Since the SUSY breaking sector usually consists of multiple fields, L forms a matrix. If it is positive, i.e. all eigenvalues are positive, $(\Delta \ln Z)$ approaches to zero for the infrared limit $t \to -\infty$. Then the contact terms are absent from the low-energy effective Lagrangian, because they arise as $(\Delta \ln Z)_0 \supset cQQ^\dagger$. Therefore the conformal sequestering is realized for $L > 0$ [5, 10, 12]. At the same time, the sources of the SUSY breaking mediation become small as well, because they are denoted by the higher dimensional operators. Thus the Kähler and sigma-model anomalies are suppressed by the conformal dynamics. Although the coefficients c and d in (9) may depends on the hidden matters more complexly, they can be treated similarly, or are practically irrelevant for phenomenology.

Consequently, the B terms relevant for the Kähler and sigma-model anomalies are suppressed, and so they are absent in the conformal sequestering. In contrast, the SW anomaly still remains after the dynamics, since ϕ arises as an overall factor in front of the D-term [b].

Let us comment on a choice of the regularization scheme. So far, we used the PV regularization. If we apply the other scheme (see e.g. [3, 8, 13]), the discussions in the

[b] The conformal dynamics may affect $K_i F^i/3$ in (4). The evolution, however, depends on details of SUGRA, and we retain the discussion for a future work.

above are not so trivial. In order to see the suppression of AMSB, we focus on the UV insensitivity. When a matter field decouples by a heavy mass, the threshold corrections give the gaugino mass, $M_\lambda^{(\mathrm{dec.})}$. The UV insensitivity tells us that it exactly cancels with that from the regularization, that is, the AMSB mass, $M_\lambda^{(\mathrm{AM})}$. Thus if we evaluate the gaugino mass from the matter threshold by postulating a hypothetical mass term, we obtain the AMSB mass as $M_\lambda^{(\mathrm{AM})} = -M_\lambda^{(\mathrm{dec.})}$. Repeating the same discussions in this letter, we obtain the same result.

So far, we focused on the gaugino mass. The soft SUSY breaking effects also contain scalar masses, scalar trilinear couplings, and holomorphic scalar mass terms. The SUGRA anomalies mediate the SUSY breaking to the parameters. Nevertheless, the complete result has not been known for the Kähler and sigma-model anomalies (see also [14]). On the other hand, the SUSY breaking is mediated by the higher dimensional operators in (1). The soft parameters other than the gaugino mass are also considered to originate in the terms. We saw that they are suppressed in the geometrical and conformal sequestering. Thus, if the sequestering is realized in nature, the Kähler and sigma-model anomalies do not contribute to the soft parameters.

IV. DISCUSSION AND CONCLUSIONS

In this letter, we discuss the suppression of the Kähler and sigma-model anomalies in the conformal sequestering. The contributions are obtained from the higher dimensional operators in the D-term, namely after expanding $-3e^{-K/3}$. Since the conformal dynamics suppresses them, the anomalies are found to vanish.

A dynamics of the gauge term $\int d^2\theta ZWW$ is treated by using the anomalous dimensions [11]. However, the operators we focus on now are represented by the non-local operators at the Planck scale [3], so its evolution is non-trivial. Instead, the counter term may exist at the cutoff, and can affect the gaugino mass [3]. If it has a form of $\int d^2\theta f(Z)WW$, where $f(Z) = \alpha Z + \cdots$ is a function of Z, its contribution tends to be suppressed by the conformal dynamics.

The method in this letter can also be applied to discuss the anomaly-induced inflaton decay [9, 15]. The decay into the SUSY breaking sector is obtained by the higher dimensional operators of Z in the D-term for the Kähler and sigma-model anomalies. Thus they are

naturally suppressed by the conformal dynamics, even when the SUSY breaking fields do not always appear explicitly in the operators [16].

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