Brane world supersymmetry breaking

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In brane world models of nature, supersymmetry breaking is often isolated on a distant brane in a higher dimensional space. The form of the Kähler potential in generic string and M-theory brane world backgrounds is shown to give rise to tree-level nonuniversal squark and slepton masses. This results from the exchange of bulk supergravity fields and warping of the internal geometry. This is contrary to the notion that bulk locality gives rise to a sequestered no-scale form of the Kähler potential with vanishing tree-level masses and solves the supersymmetric flavor problem. As a result, a radiatively generated anomaly mediated superpartner spectrum is not a generic outcome of these theories.

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I. INTRODUCTION

In many pictures of the origin of supersymmetry breaking, gravity and nonrenormalizable operators play a crucial role. In some, higher dimensional space-times play an important role. The only framework in which such questions can at present be consistently addressed is string or M theory. To actually show that string or M theory predicts low energy supersymmetry, much less a particular form for the pattern of soft breaking, is beyond present capabilities. However, given the assumption of an approximate low energy supersymmetry, one can survey supersymmetric states of string or M theory and look for generic features.

Among the proposed mediation mechanisms, one that can be studied along these lines is brane world supersymmetry breaking (BWSB). The defining feature of this picture is that visible sector fields are localized on a brane while supersymmetry breaking is isolated in hidden sector matter field auxiliary components on a physically separated hidden sector brane, all within a compact higher dimensional space. Such a structure is a plausible outcome of string or M theory. One might expect that bulk locality would have striking consequences for such ground states, and indeed it has been argued that the Kähler potential takes a particular no-scale or sequestered form which would lead to vanishing tree-level scalar masses. Under this assumption, the leading contributions to scalar masses have been argued to be due to anomaly mediation, yielding a solution to the supersymmetric flavor problem [1,2].

In this paper we determine the four-dimensional Kähler potential that couples the visible and hidden sector branes in a number of BWSB backgrounds. In all the cases we can analyze, the Kähler potential is not of the sequestered no-scale form. With supersymmetry breaking isolated in hidden sector matter field auxilliary components on the hidden sector brane, these Kähler potentials generally give rise to tree-level soft scalar masses for visible sector squark and slepton fields. The masses are of the order of the four-dimensional gravitino mass and are generally not universal. The leading brane-brane couplings contained within the Kähler potential that give rise to the tree-level masses can be understood in these examples as arising from exchange of bulk supergravity fields. Additional corrections to the tree-level masses arise from warping of the higher dimensional compact space. Without additional assumptions about flavor, the nonuniversal scalar mass matrices are not necessarily aligned with the quark and lepton mass matrices, and dangerous sflavor violation can occur. So physically separating the visible and hidden sector branes within a higher dimensional space alone is not enough to give a predictive (anomaly mediated) spectrum and solve the supersymmetric flavor problem.

The rest of this paper is organized as follows. After reviewing BWSB in Sec. II, general macroscopic considerations based on extended supersymmetry are employed in Sec. III to determine the leading form of the Kähler potential in a number of BWSB backgrounds, including type I′ theory, type IIB theory, and heterotic M theory. With hidden sector matter field auxiliary component supersymmetry breaking these Kähler potentials give rise to nonuniversal tree-level scalar masses which are of the same order as the four-dimensional gravitino mass. We then determine the microscopic origin of these apparently nonlocal brane-brane interactions; they arise from the exchange of bulk fields. We note in Sec. IV that there are further corrections to the lowest order form of the Kähler potential and therefore soft scalar masses in both types of theory. These can be thought of as arising from warping of the internal bulk geometry by the brane. In the Horava-Witten theory these are not likely to be particularly small. We also speculate on special circumstances under which the no-scale form of the Kähler potential and vanishing tree-level scalar masses may arise, but argue that these are not likely to be generic. More examples of BWSB backgrounds (including microscopic descriptions and leading corrections in various limits), the inclusion of gaugino masses, and a discussion of the closely related mechanism of gaugino mediation [3,4], are presented elsewhere [5].

II. THE BRANE WORLD PICTURE

In order to illustrate the coupling between visible and hidden sector branes it is convenient to work in the conformal or supergravity frame. The bosonic part of the four-dimensional supergravity action in this frame is [9]

$$\mathcal{L}=\frac{f}{6}\mathcal{R}_4-f_{i\bar{j}}\partial_\mu\varphi_i\partial_\mu\varphi_j^*-\frac{1}{4f}(f_i\partial_\mu\varphi_i-\text{H.c.})^2 +\cdots+f_{i\bar{j}}F_iF_j^*+|F_\Phi|^2 f +(W_iF_i+f_iF_\Phi^*F_i+3F_\Phi W+\text{H.c.}) \quad (1)$$

where f is the field dependent supergravity function that multiplies the four-dimensional Einstein term, F_i are chiral multiplet auxilliary components, and W is the superpotential. Expanding the supergravity f function in a power series in the fields, the Lagragian (1) contains the nonderivative couplings

$$\mathcal{L}\supset f_{i\bar{j}k\bar{l}}F_iF_j^*\varphi_k\varphi_l^*. \quad (2)$$

With these couplings, nonvanishing auxilliary components, $F_i\neq 0$, give rise to soft scalar masses. So in the supergravity frame the couplings that determine the soft masses reside in the supergravity f function. The supergravity f function and Einstein frame Kähler potential are related by

$$K=-3\ln(-f/3). \quad (3)$$

So in the four-dimensional Einstein frame the couplings that determine the soft masses reside in the Kähler potential.

In most phenomenological discussions of string- and M-theory brane world backgrounds it is assumed that supersymmetry is broken only in the locally supersymmetric limit by gaugino condensation in the hidden sector [6]. This can induce nonvanishing auxiliary expectation values for moduli and/or dilaton fields, $F_{T_i}\neq 0$ and/or $F_S\neq 0$. Since the moduli and dilaton fields T_i and S generally reside throughout the bulk of the compact internal space in brane world models, direct couplings (2) to visible sector brane matter fields Q_i of the form $f_{Q_i\bar{Q}_j T_k\bar{T}_l}$ and/or $f_{Q_i\bar{Q}_j S\bar{S}}$ can then give rise to visible sector soft masses [7,8]. Here, we are interested in the situation in which supersymmetry is broken in the globally supersymmetric limit by hidden sector matter field auxiliary expectation values $F_{\Sigma_i}\neq 0$ isolated on the hidden sector brane. The underlying origin of these hidden sector supersymmetry breaking auxiliary expectation values is not important to the discussion of the form of the visible sector soft masses given below, but they may be assumed to arise from, for example, hidden sector gauge theory nonperturbative dynamics. Unlike the case of moduli or dilaton supersymmetry breaking, in BWSB from hidden sector matter fields, Σ_i, the nonvanishing auxiliary expectation values are not in direct physical contact with the visible sector fields Q_i. The microscopic origin of the four-dimensional couplings $f_{Q_i\bar{Q}_j\Sigma_k\bar{\Sigma}_l}$ that give rise to soft masses is then more subtle as described below [10].

A special class of supergravity f functions is the separable form

$$f(T_i,Q_i,\Sigma_i)=f_{\text{vis}}(Q_i)+f_{\text{hid}}(\Sigma_i)-f_{\text{mod}}(T_i+T_i^\dagger) \quad (4)$$

where Q_i and Σ_i are visible and hidden sector fields, respectively, and T_i are moduli. In this case nonderivative couplings between fields on the different branes vanish since $f_{Q_i\bar{Q}_j\Sigma_k\bar{\Sigma}_l}=0$. The separable form (4) has been referred to as sequestered and argued to arise in BWSB backgrounds [1]. This may seem plausible given that bulk locality might lead one to expect some sort of decoupling of fields on the physically separated visible and hidden sector branes. The Kähler potential associated with the separable form (4) is of the no-scale type. With canonical tree-level kinetic terms for the visible and hidden sector fields, $f_{\text{vis}}=3\,\text{tr}\,Q_i^\dagger Q_i$ and $f_{\text{hid}}=3\text{tr}\Sigma_i^\dagger\Sigma_i$, and only a single modulus T, the no-scale Kähler potential [11] is

$$K=-3\ln[f_{\text{mod}}(T+T^\dagger)-\text{tr}\,Q_i^\dagger Q_i-\text{tr}\Sigma_i^\dagger\Sigma_i]. \quad (5)$$

A nonvanishing auxiliary component for either a hidden sector field F_{Σ_i} or modulus F_T does not give rise to visible sector scalar masses. In the Einstein frame, this seems to be the result of a miraculous cancellation, depending on the logarithmic form and the prefactor 3. In the supergravity frame, however, it is a result of the separable form of the f function. Since a separable sequestered form (4) for the supergravity f function is equivalent to the no-scale Kähler potential (5), it has been referred to as a no-scale sequestered Kähler potential in the context of brane world models.

With a no-scale sequestered Kähler potential (5) the leading contributions to scalar and gaugino masses arise from anomalous effects (nonanomalous one- and two-loop contributions with bulk scalar exchanges have been argued to be highly suppressed [1]). The one-loop gaugino and two-loop scalar anomaly mediated contributions to masses are given by

$$m_g=-b_0\frac{g^2}{16\pi^2}m_{3/2},$$

$$\tilde{m}_q^2=\frac{1}{2}c_0b_0\left(\frac{g^2}{16\pi^2}\right)^2|m_{3/2}|^2 \quad (6)$$

where b_0 and c_0 are the leading beta function and anomalous dimension coefficients, respectively (for vanishing Yukawa couplings), and $m_{3/2}$ is the gravitino mass. These contributions were first noticed in [12], but were fully appreciated in the work of [1,2]. Further theoretical insight into the anomaly has been provided by the work of [13,14]. These authors provided a thorough understanding of the nature of the anomaly, and also gave certain conditions under which the one- and two-loop formulas (6) are applicable.

There are, however, several questions which one might raise about the sequestered argument about the separability of the supergravity f function applied to BWSB. Even with the separable form (4) the fields on the visible and hidden sector branes are coupled through current-current interactions coming from the third term in the Lagrangian (1). So bulk locality cannot forbid brane-brane interactions in the low energy four-dimensional theory which appear nonlocal from the microscopic point of view. This is not surprising since there is no sense in which the branes are far apart in the low energy four-dimensional theory. From the microscopic point of view these brane-brane couplings must arise from exchange of bulk fields between the branes.

To explore these questions both the bulk fields and the couplings of these fields to brane fields need to be specified. The only available framework in which to address this is string or M theory. We will see that the specific form of the brane-brane couplings depend on what fields are present in the bulk and how these couple to brane fields. In addition, with a codimension 1 bulk as in heterotic Horava-Witten theory, the brane-brane couplings induced by exchange of bulk fields might be expected to grow, or at least remain constant with brane separation. With higher codimension, brane-brane couplings would be expected to be suppressed by the internal geometric volume. Indeed, we will show in the next section that this is the case. However, the four-dimensional gravitino mass is also suppressed by the same power of the internal volume. Soft masses arising from such brane-brane interactions are then not necessarily suppressed with respect to the gravitino mass.

III. LOWEST ORDER STRUCTURE OF THE KÄHLER POTENTIAL

A natural arena for realizing BWSB in a string theory is with D-branes. Another is with end of the world branes such as arise in Horava-Witten theory obtained by an orbifold projection of M theory. In this section we consider BWSB backgrounds with 16 supersymmetries. While obviously not as realistic as phenomenological models, these examples are instructive as they illustrate that the sequestered intuition for the separability of the supergravity f function breaks down even in highly supersymmetric situations, and thus cannot be robust. In addition, in more realistic models with only four supersymmetries which are obtained by projections of these models, the form of the lowest order tree-level Kähler potential for the states that survive the projection is inherited from the Kähler potential of the underlying theory with extended supersymmetry. Additional corrections that arise in backgrounds with fewer than 16 supersymmetries are discussed in the next section.

Consider, first, the Horava-Witten compactification of M theory on an S^1/Z_2 interval [15]. This theory has two E_8 gauge multiplets which reside on end of the world branes that bound the interval. These end of the world branes may be identified with the visible and hidden sectors. Compactification of this theory on T^6 gives a four-dimensional theory with 16 supersymmetries which completely fixes the form of the Kähler potential. Since the form is independent of the coupling it is identical to the weakly coupled heterotic string theory result. In four-dimensional $N=1$ notation the complex moduli include chiral fields $T_{i\bar{j}}$ and T_{ij} where $i,j=1,2,3$ are the T^6 complex coordinates, the dilaton S, and the visible and hidden sector brane chiral matter arising from compactification of the gauge multiplets denoted by Q_i and Σ_i, respectively. In terms of these [16],

$$K=-\ln\det(T_{i\bar{j}}+T^{\dagger}_{i\bar{j}}-\mathrm{tr}Q_iQ^{\dagger}_{\bar{j}}-\mathrm{tr}\Sigma_i\Sigma^{\dagger}_{\bar{j}}) -\ln(S+S^{\dagger}), \tag{7}$$

where the two traces are over E_8 and E_8' gauge groups, respectively, and the dependence on the T_{ij} moduli is suppressed. Note that this result is explicitly invariant under the $SU(3)\times U(1)_R$ subgroup of the SU(4) R-symmetry as expected for the low energy action at the level of two derivatives. The supergravity f function associated with the Kähler potential (7) is

$$f=-3[(S+S^{\dagger})\det(T_{i\bar{j}}+T^{\dagger}_{i\bar{j}} -\mathrm{tr}\,Q_iQ^{\dagger}_{\bar{j}}-\mathrm{tr}\,\Sigma_i\Sigma^{\dagger}_{\bar{j}})]^{1/3}. \tag{8}$$

The Kähler potential (7) is not of the no-scale sequestered form and the f function (8) is clearly not separable. This is true even ignoring the dilaton. So we see that in this highly symmetric brane world model the sequestered intuition breaks down even without the inclusion of corrections which would generically be present in more realistic models.

The breakdown of the sequestered intuition for the separability of the supergravity f function can be seen directly in this example by first considering the ten-dimensional effective action which results at length scales long compared with the S^1/Z_2 interval. This limit is relevant if the T^6 is much larger than the S^1/Z_2 interval. The ten-dimensional action at the level of two derivative terms involves terms that are quadratic and quartic in the fields. Most of these terms do not couple fields on the different branes. But there are Chern-Simons squared terms that do couple gauge fields in the two E_8 gauge groups. In the underlying theory these gauge fields reside on different branes and give rise to visible and hidden sector fields in the toroidally compactified theory. The existence of these terms is in fact crucial in the derivation of the four-dimensional Kähler potential, as explained in [17]. From an 11-dimensional perspective, these brane-brane interactions arise because the brane Chern-Simons terms act as a source for the bulk three-form potential [18]. The resulting constant bulk four-form field strength generates the Chern-Simons squared couplings between the branes. So even though the branes are physically separated, the visible and hidden sector fields are coupled through the exchange of a bulk field. This coupling and its flavor dependence may also be understood as arising from the exchange of bulk gauge bosons in a five-dimensional limit which is appropriate if the T^6 is smaller than the S^1/Z_2 interval [5].

In the presence of hidden sector supersymmetry breaking by hidden sector matter field auxilliary expectation values, the Kähler potential (7) gives visible sector tree-level mass squared eigenvalues of

$$m^2_{Q_i}=m^2_{3/2}(1,1,-2). \tag{9}$$

These masses are of order of the gravitino mass and are nonuniversal [19]. Without additional assumptions about flavor, the squark and slepton mass eigenstates associated with these eigenvalues need not be aligned with quark and lepton eigenstates. This would generally lead to dangerous supersymmetric contributions to low energy flavor violating processes. The breakdown of the sequestered intuition implies that BWSB does not in itself provide a solution to the supersymmetric flavor problem. The soft masses which arise in S^1/Z_2 M-theory backgrounds have also been considered previously in the context of moduli and dilaton supersymmetry breaking [7,20].

A D-brane realization of BWSB which does not have a codimension 1 bulk may be illustrated by considering first type I string theory with gauge group SO(32) compactified on T^6. This theory preserves 16 supersymmetries and therefore also has a Kähler potential of the form (7). Consider a T-duality transformation on all the T^6 directions. The resulting type IIB theory has (including images) 32 D3-branes and 16 O3-orientifold planes. Separating the D3-branes into two groups provides a model of the visible and hidden sector branes. In the type I description this corresponds to turning on Wilson lines. The Kähler potential (7) is invariant under this T duality since it is a symmetry of the four-dimensional theory; it is unaffected by Wilson lines and is not of the no-scale sequestered form.

The origin of the brane-brane interactions in this example may be understood by considering the simpler case of type I theory on S^1. In this theory, there are, as in the heterotic case, Chern-Simons squared terms. These terms remain as Wilson lines are turned on. Now consider the T-dual type I′ description. In this theory there are (including images) 32 D8-branes and two O8 orientifold planes. A Wilson line in the type I description corresponds to motions of the D8-branes in the type I′ description. In the low energy four-dimensional theory resulting from further compactification on T^5, fields that reside on separated groups of D8-branes therefore have brane-brane interactions corresponding to the Chern-Simons squared couplings of the type I description. Microscopically, these can be understood in the type I′ description as arising from the exchange of the bulk Ramond two-form potential in a manner analogous to the bulk exchange in the Horava-Witten model [5]. The type IIB model above is obtained from the type I′ model on S^1 by T duality on the remaining T^5 directions. The original type I theory is also dual to the Horava-Witten theory by type I–heterotic duality in the strongly coupled limit. So all the BWSB backgrounds of this section are related by dualities. The Kähler potentials for somewhat similar type I backgrounds with only four supersymmetries have been considered previously in the context of dilaton and moduli supersymmetry breaking [7].

In the type IIB model the brane-brane interaction terms are suppressed by the internal volume [5]. Since the four-dimensional gravitino mass is also suppressed by the internal volume, hidden sector supersymmetry breaking then translates into squark and slepton masses of order of the gravitino mass. It is not surprising that such volume-suppressed terms are present, and that they violate naive notions of locality. At the level of the brane-brane interaction amplitude, these interactions arise in the open-string channel from the quantum one-loop amplitude of massive strings which stretch between the branes. The volume dependence may be understood as arising from the sum over open-string winding modes [21].

In sum, already at the leading level, the no-scale sequestered form of the Kähler potential does not hold in BWSB backgrounds where one can calculate. At the microscopic level the brane-brane interactions which lead to the tree-level scalar masses may be understood, at least in some descriptions, as arising from exchange of bulk fields. One might imagine that the arguments leading to the sequestered no-scale form of the Kähler potential might then hold in a theory with a very minimal set of bulk fields. With a flat interior it has been suggested that this occurs for a pure five-dimensional supergravity with end of the world branes [22]. Because of inheritance from the underlying theory, this in fact may be the case at lowest order for a hypothetical M-theory background which had a pure five-dimensional limit with end of world branes [5]. However, as discussed in the next section, a finite brane tension leads to warping of the internal geometry which gives additional contributions to tree-level scalar masses. Given that in the would-be five-dimensional model there is no modulus on which the brane tension could depend, and therefore be parametrically small, it would be surprising, again, to find a sequestered no-scale Kähler potential in the full theory unless the brane tensions happened to vanish for some reason.

IV. BEYOND THE LEADING ORDER

The BWSB backgrounds of the previous section preserve 16 supersymmetries for which the form of the Kähler potential is determined completely by supersymmetry. In theories with less supersymmetry, the leading form of the tree-level Kähler potential is often inherited from the form dictated by the extended supersymmetry of some underlying theory. However, with less supersymmetry the Kähler potential is not protected, and corrections to the leading tree-level results should be expected. There are at least two situations where such corrections have been analyzed: configurations of branes in type II theory with eight supersymmetries [23], and Horava-Witten theory compactified on Calabi-Yau spaces with four supersymmetries [24]. We review these and discuss their implications here. The corrections may be understood as due to the distortion (warping) of bulk background fields and geometry by brane sources. This warping leads to modifications of the Kähler potential, which need not be universal, much less of the no-scale sequestered form.

Consider, first, a type II D-brane configuration with a source hidden sector Dp'-brane and a probe visible sector Dp-brane [23]. The metric line element and dilaton backgrounds of the source Dp'-brane at distances large compared to the string scale are

$$ds^2 = f(r)^{-1/2} dx_\parallel^2 + f(r)^{1/2} dx_\perp^2 ,$$

$$e^{-2\phi} = f(r)^{(p'-3)/2}, \tag{10}$$

with

$$f(r) = 1 + g_s \left(\frac{\sqrt{\alpha'}}{r} \right)^{7-p'} . \tag{11}$$

On the visible sector probe Dp-brane world volume, these background bulk fields yield possible corrections to the potential and visible sector kinetic terms. Evaluating the Dp-brane Dirac-Born-Infeld action in these background fields

$$S_p = -T_p \int d^{p+1}x e^{-\phi} \sqrt{\det(h_{\mu\nu} + F_{\mu\nu})}, \tag{12}$$

where $h_{\mu\nu}$ is the induced metric, yields

$$S_p = -T_p f(r)^{(p'-3)/4} f(r)^{-(p+1)/4} \times \left[1 + f(r) \left(\frac{1}{2} \partial_\mu X^i \partial^\mu X_i + \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \right) + \cdots \right] \tag{13}$$

with indices now raised and lowered using the Minkowksi metric. For $p = p'$, the D-branes preserve 16 supersymmetries. In this case from Eq. (13) it is apparent that the Dp-brane world volume kinetic terms receive no corrections. The Kähler metric is flat and the Kähler potential is exact as required with 16 supersymmetries. (The correction to the potential term in Eq. (13) is canceled by the exchange of the Ramond-Ramond p-form antisymmetric tensor field for $p = p'$.) For $p = p' - 4$, the configuration preserves eight supersymmetries. In this case, the dilaton contribution cancels the gravitational contribution to the potential, but there is a correction to the Dp-brane world volume kinetic terms. The flat inherited Kähler metric for an isolated Dp-brane, which alone would preserve 16 supersymmetries, is modified by the background fields generated by the Dp'-brane. The inherited Kähler potential is therefore modified by brane-brane interactions in the configuration with only eight supersymmetries. This modification is due to the distortion of space caused by the source brane at the position of the probe. This effect appears to be general.

Additional corrections to the Kähler potential could arise in backgrounds which preserve only four supersymmetries, such as the Horava-Witten theory, compactified on a Calabi-Yau space [24]. Here we will content ourselves with a brief summary of the main results, leaving the details for [5]. In this theory, as explained in [25], classical solutions for the bulk fields may be obtained by systematically expanding in powers of $\epsilon = T/S$. To zeroth order, the solution is a direct product of the metric of the Calabi-Yau space, with gauge fields, say, equal to the spin connection on one of the walls, and a flat 11th dimension. At next order, the space is distorted by the presence of nonzero tension of the walls, and is a general fibration of a Calabi-Yau space over the M-theory interval. It is important that the shape of the Calabi-Yau space is modified along the interval in general. This distortion of the metric leads to modifications of the Kähler potential. In particular, the kinetic terms for fields localized on the walls receive corrections that depend on the distortion of the Calabi-Yau space. Because the zero mode wave functions on the Calabi-Yau manifold are not uniform, and in the absence of a flavor symmetry, the corrections to the zero mode kinetic terms are not in any sense universal. In the picture suggested by [25], the parameter ϵ is not terribly small (of order 1/3), and these corrections are likely to be substantial [26]. Thus, warping of space leads to large, nonuniversal corrections to the tree-level scalar masses.

It is worth noting that these remarks regarding nonuniversality are also relevant to another proposal for understanding degeneracy of squarks and sleptons: dilaton dominated supersymmetry breaking. In the heterotic string at weak coupling, it has long been known that if the dilaton F term is the principal source of supersymmetry breaking, squark and slepton masses are universal at tree level [27]. Indeed, this is the only proposal that realizes, in a fundamental theory, what has traditionally been called gravity mediation. The scenario, if realized, is quite predictive. The question has always been: Given that one does not expect the string coupling to be weak, how large are the corrections to this picture likely to be? An optimistic assumption based on the weakly coupled picture has been that these corrections would be of order $\alpha_{\rm GUT}/\pi$. This would provide just enough degeneracy to avoid dangerous sflavor violation [28]. The analysis above of the strongly coupled Horava-Witten limit suggests, however, that the corrections could, in practice, be much larger for the actual value of T/S.

V. CONCLUSIONS

There are many string- and M-theory backgrounds which can provide models for BWSB, and in which the Kähler potential can be calculated in a systematic fashion. None of the examples presented here, nor ones with similar properties, yield Kähler potentials of the no-scale sequestered form. Nonuniversal tree-level squark and slepton masses generally arise with BWSB from hidden sector matter field auxilliary components. In each case, it is possible to understand the microscopic origin of the brane-brane interactions which lead to these masses in the presence of hidden sector supersymmetry breaking. It is not surprising that the sequestered intuition generally breaks down since in the low energy four-dimensional theory there is no sense in which the visible and hidden sector branes are separated.

The effects discussed here can generally be understood as arising from exchange of bulk supergravity fields. This might lead one to speculate that perhaps the sequestered form would hold in a theory with a minimal number of bulk fields. In particular, one could conceive of a background which reduces to pure five-dimensional supergravity with eight supersymmetries in a five-dimensional bulk, broken to four dimensions by end of world branes. If the fifth dimension is flat and there is only a single overall volume modulus T, the no-scale sequestered form is in fact obtained at the classical level [22]. It is argued to occur also in a five-dimensional theory with a pure AdS bulk [29]. This form might also be obtained more generally in BWSB models with background fluxes which stabilize all moduli but a single overall volume modulus [30]. The discussion of the previous section, however, suggests that in any such situation the branes will generally warp the internal geometry. This in turn will induce T dependence in the kinetic terms and couplings of the fields on the brane and tree-level masses will result. It is difficult to test these ideas, at least in the case of pure five-dimensional supergravity since at present there are no known string- or M-theory backgrounds of this type, and certainly no realization within a controlled approximation [31].

Broad classes of string models have matter fields localized on separated branes, and thus BWSB seems a plausible outcome of string theory. However, the results presented here suggest that the model building and phenomenology of BWSB are similar to standard (super)gravity mediation scenarios rather than anomaly mediation. This suggests that we must look in other directions for the solution to the supersymmetric flavor problem.

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