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A Note on New Sources of Gaugino Masses

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ABSTRACT

In IIB orientifold models, the singlet twisted moduli appear in the tree-level gauge kinetic function. They might be responsible for generating gaugino masses if they acquire non–vanishing F-terms. We discuss some aspects of this new possibility, such as the size of gaugino masses and their non-universalities. A possible brane setting is presented to illustrate the usefulness of these new sources.

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Supersymmetry breaking is a major issue in superstring and M-theory. It is for instance necessary to lift the degeneracy of vacua. For phenomenological applications, supersymmetry breaking will provide mass splitting between supersymmetric partners, explaining why these have not been observed in nature yet. The precise dynamics involved in the generation of such masses is still unknown, but one can use a phenomenological parametrization which turns out to be useful for many purposes dealing with low-energy predictions.

For weakly coupled heterotic strings, such a line of ideas was advocated in [1], where non–vanishing F-terms were assumed for the moduli fields S (dilaton) and T_i (associated to the Kahler structure of the compact internal space). The gauge groups originating from reduction of the ten-dimensional gauge symmetry have a universal tree-level coupling. Non-universalities of couplings and gaugino masses arise at one-loop through a T_i dependence of threshold corrections.

Another convenient framework to pursue these investigations is provided by type IIB orientifolds. Soft terms for such compactifications have been discussed in [2]. It was noticed that non-universal gaugino masses could be generated if for instance different parts of the standard model gauge group originated from different sets of branes [2, 3]. To allow unification of gauge couplings one would then need to construct models where the moduli, controlling the gauge couplings on different branes, get potentials with minima at the same value. Here we will address another origin for soft terms: twisted moduli related to blowing-up modes.

The IIB orientifolds are obtained as compactifications on three tori T^1, T^2, T^3 on which different points are identified under a discrete symmetry Z_N, which leads to a set of fixed points. Requiring $\mathcal{N} = 1$ supersymmetry and Poincaré invariance in four dimensions allows the presence of 9- and 5-branes (equivalently under T-dualities 3- and 7-branes).

The space group action of the orbifold is defined by some twist eigenvector $v = (v_1, v_2, v_3)$. In the sector twisted by θ^k the orbifold group acts as $X_i \to \theta^k X_i$, $\theta = \exp 2\pi i v \cdot J$, where $J = (J_1, J_2, J_3)$, with X_i and J_i the coordinate and generator of rotation in the i-th torus respectively. For a given twist θ^k one finds $\prod_{i=1}^{3} 4\sin^2 \pi k v_i$ fixed points that we label by an index f. In a similar way, the orbifold acts also on the Chan-Paton factors through some twist parametrized by a vector V_a with model-dependent fractional entries l/N. In the case of even N, some sets of $D5_i$-branes are present, sitting at the origin $X_j = X_k = 0$ in the $j \neq i$ and $k \neq i$ complex planes. We label by an index p_i the $4\sin^2 \pi k v_i$ fixed points located in the world-volume of the $D5_i$-branes.

In addition to the dilaton S and to the three moduli T_i, $i = 1, 2, 3$, parametrizing the Kahler structure (volume) of the tori, there are the twisted moduli Y_f^k associated to blowing-up the orbifold singularities f due to a twist θ^k [2]. The new feature in IIB orientifolds is that these moduli couple at tree-level to gauge kinetic terms. The gauge kinetic functions for gauge fields on the D9- and D5-branes are given by [4, 5, 6]

$$
\begin{aligned}
f_b^9 &= S + \frac{1}{N} \sum_{k=1}^{[N-1/2]} \frac{\cos 2\pi k V_b^9}{\prod_{i=1}^3 2 \sin \pi k v_i} \sum_f Y_f^k \\
f_{ia}^5 &= T_i + \frac{1}{N} \sum_{k=1}^{[N-1/2]} \frac{cos 2\pi k V_{ia}^5}{2 \sin \pi k v_i} \sum_{p_i} Y_{p_i}^k .
\end{aligned} \tag{1}
$$

In general (1) results in different independent linear combinations of Y_{ai} of the Y_i^k for each of the gauge kinetic function corresponding to gauge groups G_a. So F-terms for the twisted moduli Y_i^k will be a new source of tree-level gaugino masses:

$$
M_a = \sum_i c_a^i M_{Y_{ai}}, \tag{2}
$$

where $M_{Y_{ai}}$ are the contributions of different Y_{ai} and the coefficients c_a^i are model-dependent. We see that the gaugino masses and the associated complex phases could be non-universal in these models.

The cases of odd N lead to a drastic simplification. Only one linear combination, which we denote as Y, of the twisted moduli appears in the gauge kinetic function. The coefficient of the dependence for the group G_a is given by the beta-functions b_a of the running of the corresponding gauge coupling [7]:

$$
f_a^9 = S + \frac{b_a}{2} Y. \tag{3}
$$

In the absence of an F-term for S but for Y, a tree–level gaugino mass proportional to the one-loop beta-function coefficient will be generated (using the convention of [1]):

$$
M_a = \frac{\sqrt{3}}{2} \frac{b_a g_a^2}{16\pi^2} m_{3/2} \, e^{-\alpha_Y} \, (K_Y^Y)^{-1/2} = \sqrt{\frac{3}{8}} \frac{b_a g_a^2}{16\pi^2} m_{3/2} \, e^{-\alpha_Y} \tag{4}
$$

where we have used $\mathrm{Re} f_a^9 = 8\pi^2 / g_a^2$ with g_a the four-dimensional gauge coupling. In (4), α_Y is the complex phase, K is the Kahler potential which we assumed in the second equality

[2]We have changed notation from the usual M_f^k to avoid confusion with masses.

to be given by $(Y + \bar{Y} + \cdots)^2$. The fact that the form of the gaugino masses is similar to a one-loop form can be traced back to the fact that the dependence on Y is there to cure sigma-model anomalies [8]. One-loop contributions to gaugino masses could be important in this case[3].

The relation (4) means that the gauginos have non-universal masses but a unique phase. The beta-functions coefficients b_a take into account all the states that are massless at the string scale. If these are identified with the low-energy ones, one then has the low-energy prediction:

$$\frac{M_3}{b_3} = \frac{M_2}{b_2} = \frac{M_1}{b_1}, \tag{5}$$

where M_3, M_2 and M_1 are the gaugino masses associated with the $SU(3)$, $SU(2)$ and $U(1)$ factors of the standard model.

The presence of both F_S and F_Y will obviously lead to non-universal gaugino masses with two independent phases, one of which could be chosen to vanish. The F_S is expected to dominate because of the coupling constant suppression of the F_Y.

Does this non-universality also mean that gauge unification is lost? The crucial issue here is that although we have used non-vanishing $F_{Y_i^k}$, we have made no assumption on the vacuum expectation values of Y_i^k moduli themselves. In fact, to be more precise, the gauge kinetic function is given in the string basis by linear multiplets l and y_{as}:

$$f_a \quad = \quad \frac{1}{l} + \sum_s c_{as} y_{as}, \tag{6}$$

where c_{as} are model-dependent constants. Under linear-chiral duality, l is associated with the dilaton while y_{as} are associated with the Y_i^k moduli. It was argued in [6] that the latter modulus y_{as} should have a vanishing[4] vev to be in the orientifold limit, where our results are valid. This ensures automatic unification.

Let us turn to some brane setting to illustrate how this new possibility can be useful.

In general one might have 9-branes and three types of 5_i–branes corresponding to the different choices T^i of the torus on which the 5-branes are wrapping. There are three kind of charged states that originate from open strings stretched between 9-branes denoted as

[3] A nice discussion of such effects might be found for example in [9].

[4] Supersymmetry breaking could lead to vevs y_{as}, but these should remain very small to keep the orientifold picture valid.

(99) states, those stretched between 5-branes denoted as $(5_i 5_j)$ and those stretched between 5-branes and 9-branes denoted as $(5_i 9)$. The (99), $(5_i 5_i) \equiv (55)_i$ strings give rise to gauge vector multiplets of the corresponding gauge group G^9 and G^5_i, respectively. They also lead to chiral multiplets (99) and $(55)_i$ charged only under G^9 and G^5_i respectively. In contrast, the $(5_i 5_j)$ lead to chiral fields charged under both G^5_i and G^5_j, while $(5_i 9)$ open strings lead to chiral superfields charged under both G^5_i and G^9.

Suppose that the standard model gauge symmetry originates from 9-branes. We also assume that there are two (or three, but the the last one plays no role) sets of D5-branes: 5_1 located at $X_2 = X_3 = 0$ and 5_2 located at $X_1 = X_3 = 0$. The gauge coupling on the two sets are given by:

$$
\begin{aligned}
f^5_{1a} &= T_1 + \frac{1}{N} \sum_{k=1}^{[N-1/2]} \frac{cos 2\pi k V^5_{1a}}{2 \sin \pi k v_1} \sum_{p1} Y^k_{p1} \\
f^5_{2a} &= T_2 + \frac{1}{N} \sum_{k=1}^{[N-1/2]} \frac{cos 2\pi k V^5_{2a}}{2 \sin \pi k v_2} \sum_{p2} Y^k_{p2}
\end{aligned} \tag{7}
$$

Consider the 5_1-brane to be a hidden sector where non-perturbative effects break supersymmetry breaking and generate F–terms for some of the Y^k_{p1} moduli. This could arise from gaugino condensation (or string-scale breaking as the brane–antibrane models of [10] if the string scale is at an intermediate region [11]), which leads to a potential which goes as $e^{-c/g^2_{1a}}$, which depends on the Y^k_{p1} and could lead to F-terms for the latter. The 9-brane standard model gauge kinetic function involves all the twisted moduli and will thus have the corresponding gaugino masses generated at tree-level.

We identify the standard model matter fields as coming from $(5_2 9)$ open strings. These feel only the Y^k_{p2} moduli, which share with the Y^k_{p1} set only the modulus Y^k_0 associated to the blowing-up mode of the origin $X_1 = X_2 = X_3 = 0$. If $F_{Y^k_{p1}} \neq 0$ for $p_1 \neq 0$ and $F_{Y^k_0} = 0$, then the scalar soft masses will be generated at one-loop only, mediated by gaugino masses. This might provide a brane realization for the scenario[5] proposed in [12]. However, here the gaugino masses are generically non-universal. A μ-term of the same order as the gaugino masses will be generated through a Kahler potential [15] if there is a coupling $Y^k_{p2} H_1 H_2$. Such a term is expected for instance for the case of compactifications of the form $(K3 \times T^2)/\Gamma$ with a singular $K3$ and Γ a discrete symmetry as Z_N. Before compactification on T^2 and acting

[5] The nice phenomenological peculiarities of soft terms as suggested in [12] were also present in [13]. The low-energy predictions are also similar to [14]. I thank A. Pomarol for stressing these points to me.

with Γ, it is known from [4] that there are couplings $Y_q^k F^2$ with F^2 the six-dimensional gauge field strength from the (99) sector and Y_q^k are the twisted moduli associated with blowing up the $K3$ singularities. Now upon the reduction to some of the gauge-field components will lead to chiral fields in four dimensions that could be identified with the Higgs doublets. It is interesting to look for explicit string models with such properties.

In conclusion, we have seen that in addition to contributions from the dilaton S and the moduli fields T_i, there might be new contributions from twisted moduli Y_f^k corresponding to blowing-up modes for the singularities of IIB-orientifolds. These are generically present and allow an extension of new possiblities for soft-terms as generic non-universalities of masses and phases, as well as the possibility to naturally restrict the tree-level soft-terms to part of the spectrum while generating other masses at higher orders.

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