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SUPERGRAVITY, INTERMEDIATE SUPERSYMMETRY BREAKING

AND PARTICLES PHYSICS

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Since the discovery of supergravity^{1),2)} it has been realized that one of the most important issues to solve in order to make contact with the real world is to understand the relation between the gravitino mass and the other fundamental scales of Nature.

In fact, when supersymmetry is local, the gravitino mass is the order parameter of spontaneously broken supersymmetry in much the same way as the gauge vector boson masses are related to the symmetry breaking scales of spontaneously broken Yang-Mills theories.

The crucial difference is that for gauge vector boson masses one has a dimensionless coupling constant

$$m_v \propto g \langle \phi \rangle \quad (1)$$

while in supergravity the gauge coupling is dimensionfull, $k = M_P^{-1}$, and one gets

$$m_{3/2} \propto k \langle h \rangle \quad (2)$$

where $\langle h \rangle$ is the v.e.v. of some (auxiliary) non-propagating dimension two field which, in terms of the elementary scalar fields, has a model-dependent form.

From Eq. (2) it is fairly obvious that if $\langle h \rangle \sim \mu^2$ where μ is a low-energy scale, then $m_{3/2}$ is extremely small and, as pointed out by Fayet³⁾, the helicity $\pm 1/2$ components of the gravitino essentially behave as a Goldstino of a spontaneously broken globally supersymmetry theory.

It was later realized⁴⁾ that in globally supersymmetric models with spontaneously broken supersymmetry it is difficult to obtain a physically acceptable renormalizable theory with the correct pattern of gauge symmetry breaking unless the primordial supersymmetry breaking occurs at an intermediate scale

$$\langle h \rangle \sim \mu M_P \quad \text{with} \quad \mu \lesssim 1 \text{ TeV}$$

In this situation the gravitino mass becomes of order μ and supergravity may play an important role in particle physics at low energy⁵⁾.

I would like to report on some recent work on the general coupling of $n = 1$ supergravity to supersymmetric matter Yang-Mills systems which in particular indicates the possible relevance of supergravity to particle physics if the gravitino mass is of the order of the weak interaction scale. The supergravity Lagrangian which incorporates arbitrary matter and Yang-Mills interactions is obtained⁶⁾ by introducing vector multiplets in the adjoint representation of a generic Yang-Mills group G and chiral multiplets in arbitrary complex representations of G . The only restriction on the chiral multiplets is to form an anomaly-free set of representations of G . The final form of the Lagrangian is given by Cremmer et al. in Ref. 6) and all results which follow remain valid with the inclusion of $U(1)$ factors in G with or

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Without a Fayet-Iliopoulos term. The final Lagrangian depends on two arbitrary functions $G(z, z^*)$, $f_{\alpha\beta}(z)$ which have to fulfil the following properties: $G(z, z^*)$ is real and G invariant, i.e.,

$$\frac{\partial G}{\partial z_i} T_i^{\alpha j} z_j = \frac{\partial G}{\partial z^{*i}} T_j^{\alpha i} z^{*j} \quad (3)$$

$T_i^{\alpha j}$ are the generators of the gauge group G . $f_{\alpha\beta}(z)$ is an analytic function of the scalar components z_i of the chiral multiplets, which transforms as the symmetric product of the adjoint representation of G .

It has been pointed out by Cremmer et al.⁶⁾ that a non-trivial choice of $f_{\alpha\beta}(z) \neq \delta_{\alpha\beta}$ may introduce direct gaugino mass terms as well as CP violating terms:

Gaugino mass:
$$\left(\frac{1}{2}\right)^2 f_{\alpha\beta}^{\mu\nu} e^{-G/2} G_{\mu}^{\alpha} G_{\nu}^{\beta} \lambda_L^{\alpha} \lambda_L^{\beta} + h.c. \quad (4)$$

CP violating interaction:
$$\frac{i}{4} \text{Im} f_{\alpha\beta} F_{\mu\nu}^{\alpha} \tilde{F}_{\mu\nu}^{\beta}$$

These terms may be relevant for phenomenological applications.

We define as a "minimal" coupling the situation which corresponds to

$$\frac{\partial^2 G}{\partial z_i \partial z^{*j}} = \delta_j^i, \quad f_{\alpha\beta}(z) = \delta_{\alpha\beta} \quad (5)$$

In this case the interaction only depends on a superpotential function $g(z)$ since

$$G(z, z^*) = \sum_i |z_i|^2 + \log |g(z)|^2 \quad (6)$$

For these interactions, model-independent mass relations have been derived⁶⁾

$$\text{Trace } \mathcal{M}^2 = \sum_j (-1)^{2j+1} (2j+1) m_j^2 = (N-1)(2m_{3/2}^2 - \kappa^2 (D^\alpha)^2) + 2 \tilde{g}_\alpha T^\alpha D^\alpha \quad (7)$$

where N is the number of chiral multiplets, g_α the gauge coupling, and D^α the auxiliary component of the vector multiplet. In most cases $D^\alpha = 0$ at the minimum of the potential and one gets

$$\text{Trace } \mathcal{M}^2 = 2(N-1) m_{3/2}^2 \quad (8)$$

This mass formula proves⁶⁾ that when $m_{3/2} \approx 0(\mu)$, then supergravity effects are not negligible for particle physics. Interestingly enough, it automatically provides a physically acceptable mass splitting between quarks, leptons and their scalar superpartners without any need for extending the gauge group by at least an extra $\tilde{U}(1)$ factor as previously proposed³⁾. It should be stressed that for fields which get a vacuum expectation value, such as the normal Higgs doublets of weak interactions, the mass formula by no means implies that Higgs doublets have positive quadratic masses. In fact, in general the opposite is true since negative mass terms arise from the superpotential contribution to the mass matrix. The final supergravity scalar potential is:

$$V(z, z^*) = e^{\kappa^2 \sum_i |z_i|^2} \left(\sum_i |\tilde{g}_i|^2 - 3\kappa^2 |g|^2 \right) + \frac{1}{2} (D^\alpha)^2 \quad (9)$$

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with

$$\tilde{g}^i = \frac{\partial g}{\partial z_i} + k^2 z^{*i} g$$

A general formalism has been proposed⁷⁾ to study the low-energy limit of the supergravity Lagrangian and in particular of the potential given by Eq. (9). It is useful to separate the matter fields into a G-singlet z and fields y_i transforming under G.

The superpotential $g(z, y_i)$ can be taken to be of the form⁷⁾

$$g(z, y_i) = \bar{g}(z) + g(y_i) \quad (10)$$

so one can use the results of Cremmer et al.⁸⁾ to cancel the cosmological constant with

$$\bar{g}(z) = M^2(z + \beta) \quad \text{with} \quad \beta = (2 - \sqrt{3}) M_P, \quad z_0 = (\sqrt{3} - 1) M_P, \quad M^2 = \mu M_P \quad (11)$$

One can expand the Lagrangian around the v.e.v. of z and then neglect non-renormalizable interactions which are damped by inverse powers of M_P . The final result is:

$$V = V_{\text{SUSY}} + \Delta V \quad (12)$$

with

$$V_{\text{SUSY}} = \left| \frac{\partial g}{\partial y_i} \right|^2 + \frac{1}{2} (D^\alpha)^2 \quad (13)$$

$$\Delta V = m_{3/2}^2 \sum_i |y_i|^2 + m_{3/2} (\hat{h} + \hat{h}^*) \quad (14)$$

where $\hat{h}(y_i)$ is an analytic polynomial at most cubic in the fields y_i :

$$\hat{h}(y) = \frac{\partial g}{\partial y_i} y_i - \sqrt{3} g(y) \quad (15)$$

In the limit $k \rightarrow 0$ ($M_P \rightarrow \infty$) with $m_{3/2}$ fixed, the z -field completely decouples and it corresponds to two massive neutral free fields. Recently⁹⁾, it has been shown that a different parametrization of $g(z, y)$

$$g(z, y_i) = \bar{g}(z) g(y_i) \quad (16)$$

leads to a different choice of $\hat{h}$ such that the final low-energy potential can be written as

$$V = \sum_i \left| \frac{\partial g}{\partial y_i} + m_{3/2} y^{*i} \right|^2 \quad (17)$$

A possible advantage of (17) is that the study of the potential merely reduces to the solutions of the (quadratic) equations $\tilde{g}_i = 0 \forall i$. The potential danger is that many degenerate solutions may exist whose degeneracy is only removed by radiative corrections. In all cases, the soft breaking does not introduce new quadratic divergences since the mass formula is field independent. It is now easy to provide models¹⁰⁾ for QED, electroweak interactions and GUTs where, for instance, the weak interaction scale is induced by the gravitino mass and the GUT mass has to be put in the original superpotential $g(y_i)$. Irrespective of any particular model, the formalism developed in Ref. 7) seems to be a powerful tool for approximating in the low-energy regime spontaneously broken locally supersymmetry in terms of explicitly softly broken globally supersymmetric theories.

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