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HIERARCHY OF SUPERSYMMETRIES AND THE LIGHT GRAVITINO MASS

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ABSTRACT

We propose a scheme of hierarchical supersymmetry breaking in the framework of $N = 8$ supergravity with dynamical $SU(8)$ gauge symmetry. This scheme naturally explains the existence of a light gravitino with mass $O(m^2/M_P)$, where m is the spontaneous breaking scale of both $SU(2) \times U(1)$ and supersymmetry. This mass for the gravitino is consistent with the absence of the present cosmological constant. The residual low-energy local supersymmetry may also provide a solution for the standard gauge hierarchy problem.

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There are reasons to believe that supersymmetry is perhaps the unique consistent framework which describes physics below the Planck scale. Grand unified theories based on renormalizable interactions are in fact faced with the so-called gauge hierarchy problem¹⁾. This problem may be solved if the relevant scalar particles are supersymmetric partners of fermions whose mass term is prevented by a suitable chirality²⁾. On the other hand, an ultimate unifying framework of fundamental interactions should include gravity. Then, if supersymmetry is taken seriously, one has to go to supergravity³⁾. Extended supergravity theories tend to be better behaved⁴⁾ in the ultra-violet with increasing N and the highest value of N for which such theories exist is $N = 8$. Therefore, the best candidate for the final unification appears to be $N = 8$ supergravity⁵⁾.

In this context an important question must be answered. Why is the cosmological constant of the universe so small despite the fact that supersymmetry is certainly broken^{*)} at present energies? A potential answer to this question is found if the relation⁷⁾

$$m_{3/2} = \frac{1}{\sqrt{6}} \frac{m^2}{M_P} \quad (1)$$

occurs between the gravitino mass and the supersymmetry breaking parameter m (M_P is the Planck mass). In such a case a cancellation takes place between two cosmological terms of different sign. This phenomenon is only possible in local supersymmetry due to the fact that the scalar potential, unlike the case of global supersymmetry, is not positive⁸⁾.

In this paper we propose a scheme of hierarchical supersymmetry breaking in the context of $N = 8$ extended supergravity with dynamically realized $SU(8)$ gauge symmetry. This scenario will naturally give a superlight gravitino with mass as predicted by (1)^{**)} . This will require having part of the original local supersymmetry as well as part of the $SU(8)$ gauge symmetry broken at the Planck scale, whereas the residual local supersymmetry will survive up to the 1 TeV low energy scale. Remarkably this hierarchy of supersymmetries can only occur within extended supergravity theories, unlike the case of global extended supersymmetry²⁾. Indeed, examples exist in supergravity where it is possible to spontaneously break some supersymmetries without breaking all of them⁹⁾.

*) Unbroken global supersymmetry forbids a cosmological constant⁶⁾, but its spontaneous breakdown re-introduces it.

**) within the present computational ability only as an order of magnitude relation.

With supersymmetry unbroken up to the 1 TeV low energy scale, it is natural to identify the supersymmetry breaking parameter m with the $SU(2) \times U(1)$ breaking parameter $\langle \phi \rangle$ ¹⁰⁾. In this case, the gravitino mass (1)

$$m_{3/2} \sim \frac{\langle \phi \rangle^2}{M_P} \quad (2)$$

bears a striking similarity to the analogous formula

$$m_{\nu_L} \sim \frac{\langle \phi \rangle^2}{M} \quad (3)$$

suggested¹¹⁾ for an induced Majorana mass of the left-handed neutrino, where M is a model-dependent superlarge mass scale. Equation (3) can be understood as resulting from an effective interaction

$$\frac{1}{M} \bar{\nu}_L \not{\partial}^2 \nu_L \quad (4)$$

obtained for example by the exchange of a superheavy right-handed neutrino. Analogous interactions for the gravitino of the form⁸⁾

$$\bar{\psi}_{\mu L} \sigma^{\mu\nu} f(z) \psi_{\nu L} \quad (5)$$

indeed exist in $N = 1$ supergravity theories, where $f(z)$ is a function of some complex scalar field z . No natural explanation exists however for f taking, at the minimum, the value given by (1).

The situation may improve in the context of $N = 8$ supergravity, with the dynamical $SU(8)$ gauge symmetry containing the group $SU(3) \times SU(2) \times U(1)$ of the established interactions and eventually the standard $SU(5)$. The fundamental spin $3/2$ left-handed fields $\psi_{\mu L}^A$ ($A=1, \dots, 8$) behave as an octet under $SU(8)$. To give rise to the local supersymmetry breaking, one can envisage different ways of giving mass to these gravitini, in any case requiring rather speculative dynamical mechanisms. One possibility is to pair the multiplet $\psi_{\mu L}^A$ by dynamically generated right-handed counterparts, $\psi_{\mu R}^A$, so allowing for an $SU(8)$ invariant mass term

$$\bar{\psi}_{\mu L}^A \sigma^{\mu\nu} (\psi_{\nu R}^A)^c \quad (6)$$

perhaps at the Planck scale^{*)}. This would correspond to the picture where all supersymmetries are broken at the Planck scale¹²⁾⁻¹⁴⁾, thus leaving us with the gauge hierarchy problem unsolved. As an alternative, one may consider a situation where the $\psi_{\mu R}^A$ composite is not formed, but for instance a composite scalar field, ϕ_{AB} , exists transforming as a 36 dimensional representation of $SU(8)$, coupled to the octet of gravitino fields as follows

$$\psi_{\mu L}^A \sigma^{\mu\nu} \psi_{\nu L}^B \phi_{AB} \quad (7)$$

In both cases the dynamical fields $\psi_{\mu R}^A$ or ϕ_{AB} will have to be accompanied by the corresponding $N = 8$ supersymmetric partners^{**)}. Unlike (6), the interaction (7) may give rise to hierarchy of supersymmetries corresponding to a hierarchy of gauge symmetries. Under the observed $SU(3) \times SU(2) \times U(1) \subset SU(5) \subset SU(8)$, the octet of gravitini transforms as

$$(3, 1, 1/3) + (1, 2, -1/2) + 3(1, 1, 0)$$

Considering the mass matrix in the sector of the four neutral gravitinos and assuming $SU(8)$ to be spontaneously broken at the Planck scale to a subgroup whose larger simple factor is $SU(5)$, one normally expects the three singlet gravitini $\psi_{\mu S}$ to acquire a mass $\sim M_P$, whereas the fourth one $\psi_{\mu D}$ remains massless [being a doublet under $SU(2)$]. When $SU(2)$ gets spontaneously broken at m together with the residual supersymmetry, off-diagonal mass terms of the form

$$m \psi_{\mu D} \sigma^{\mu\nu} \psi_{\nu S} \quad (8)$$

occur, giving rise, after complete diagonalization, to the last eigenvalue $\sim m^2/M_P$ ^{***)}. The size of this mass term for the gravitino is precisely the one needed

^{*)} Observe that a mass term for the spin 3/2 gravitino corresponds to broken supersymmetry unless a positive cosmological term Λ with $\Lambda = 3 m_{3/2}^2 M_{Pl}^2$ is present. In this last case one has an unbroken local supersymmetry de Sitter space⁷⁾.

^{**)} The scalar field ϕ_{AB} could generically represent a product of fields with the appropriate quantum numbers or a state of an independent composite supermultiplet. The simplest $N = 8$ massless supermultiplet which contains the scalar field $\phi_{AB} = \phi_{BA}$ is the one with $\lambda_{MAX} = 7/2$ transforming as an octet under $SU(8)$. We take here the attitude that the states of the graviton multiplet are not confined but rather they have effective interactions with the other composite multiplets. Preliminary dynamical calculations seem to support this picture¹⁵⁾.

^{***)} We are tacitly assuming here that the $SU(2)$ triplet component in ϕ_{AB} does not acquire a significant vacuum expectation value. An analogous hypothesis is often made in the context of grand unified theories when discussing the neutrino mass problem¹⁶⁾.

to offer an explanation for the smallness of the cosmological term⁷⁾. Notice that a first breaking of $SU(8)$ occurring at the Planck scale to a sub-group containing a larger simple factor than $SU(5)$ [e.g., $SU(6)$ or $SU(7)$], with an intermediate breaking to $SU(3) \times SU(2) \times U(1)$ at $M_X < M_P$, would most likely lead to a gravitino mass of order m^2/M_X which is not what is required by (1). This is because one would have a heavy intermediate gravitino of mass M_X dominating the induced contribution to the light gravitino mass^{*)}.

The remaining charged gravitinos cannot receive a mass from (7). In order for the breaking of the corresponding residual supersymmetry to be consistent with unbroken $SU(3) \times U(1)$, they will have to be paired by dynamical right-handed parts. Quite independently of the actual mechanism, the mass of the colourless charge one gravitino cannot exceed as an order of magnitude the $SU(2)$ breaking scale m .

Needless to say, the option for dynamical supersymmetry breaking considered in this paper is highly speculative. If accepted, its implications are rather strong. First of all it requires a hierarchy of local supersymmetries, thus excluding $N = 1$ supergravity as a fundamental starting theory. Moreover, the realization of this scenario in the context of $N = 8$ supergravity with dynamical $SU(8)$ gauge symmetry ties the hierarchical breaking of supersymmetry with that of the gauge symmetry, which is desirable in order to explain the standard gauge hierarchy problem. More specifically, the first stage of breaking of $SU(8)$ is required to occur, at the Planck mass, to a subgroup whose maximal simple factor is $SU(5)$, if the correct size for the mass of the light $SU(3) \times U(1)$ singlet gravitino is to be obtained. It has not escaped our attention that such a superlight gravitino may have striking phenomenological consequences¹⁰⁾.

In conclusion, the considerations presented here in the absence of definite computational schemes, indicate a way of exploring the content of $N = 8$ supergravity where some of the presently debated problems may find a solution. We hope to be able to come back to discuss them concretely in the near future.

*) An intermediate step of breaking, e.g., $SU(5) \rightarrow SU(3) \times SU(2) \times U(1)$, is obviously harmless if $SU(5)$ is obtained at M_P at the first stage of breaking.

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