ARE THE SUPERSYMMETRIC HIGGS PARTICLES
PSEUDO-GOLDSTONE BOSONS?  
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A promising solution to the doublet-triplet splitting problem of SUSY GUT’s is the Higgs as pseudo-Goldstone boson mechanism. We present two models which naturally implement this idea and extend one of them to include fermion masses. We examine the phenomenological consequences of this mechanism and present the favored parameter region.

The perhaps most problematic aspect of SUSY GUT’s is the doublet-triplet splitting problem. The problem is to explain the large separation in mass scales between the Higgs doublet and triplet fields without introducing fine-tuning. The original motivation for considering SUSY theories was to eliminate the fine-tuning needed to keep the Higgs doublets light. Therefore it would be embarrassing to reintroduce such a fine-tuning into the theory.

The only solution based on a symmetry principle to the doublet-triplet splitting problem (and therefore, perhaps, the most natural one) is the Higgs as pseudo-Goldstone boson mechanism. In this picture the explanation for why the Higgs doublets are light is that they are pseudo-Goldstone bosons of a spontaneously broken global accidental symmetry of the Higgs sector. When Yukawa couplings (couplings of the Higgs sector to matter fields) are incorporated, the accidental global symmetry is explicitly broken. However, because of the non-renormalization theorems the Higgs mass can only be of the order of the SUSY-breaking, or weak scale.

The only known implementation of this mechanism that can be made natural is based on the $SU(6)$ gauge group. In this model the accidental symmetry of the superpotential arises because there are two sectors of the chiral superfields responsible for gauge symmetry breaking that do not mix and thus the global symmetry of that sector is $SU(6) \times SU(6)$. During spontaneous symmetry breaking one of the global $SU(6)$’s breaks to $SU(4) \times SU(2) \times U(1)$, while the other to $SU(5)$. The diagonal (gauged) $SU(6)$ thus breaks to $SU(3) \times SU(2) \times U(1)$. There are exactly two light doublets in this model, so after adding the matter fields the low-energy particle content is that of the MSSM. This accidental global $SU(6) \times SU(6)$ symmetry could be enforced by a discrete symmetry that forbids the mixing of the two sectors of the Higgs fields.

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\textsuperscript{a}Based on work done in collaboration with Lisa Randall and Zurab Berezhiani.
symmetry however has to be such, that even higher order mixing terms suppressed by the ratio $M_{\text{GUT}}/M_{\text{Pl}} \sim 10^{-3}$ are forbidden up to $(M_{\text{GUT}}/M_{\text{Pl}})^5$ not to give large masses to the Higgs doublets. It is very difficult to find explicit realizations for such a model. The reason is that usually the more one suppresses the terms breaking the accidental global symmetry the more fine tuning is needed to get the right values of VEV’s from the superpotential. Thus one would again need a small parameter in the Lagrangian. Two possible solutions to this problem have been presented in Ref.\textsuperscript{4}. Here we present the simpler of the two models. This model will make use of the small parameters that have to be present in the theory anyway: the soft breaking terms.

Consider an $SU(6) \times Z_n$ GUT theory where the Higgs sector consists of an adjoint field $\Sigma$ and a fundamental and antifundamental field $H + \bar{H}$. If we assume that $(\bar{H}H)$ has charge $n$ under $Z_n$ while $\Sigma$ is invariant, then the most general superpotential allowed by the gauge and discrete symmetries is given by

$$W(\Sigma, H, \bar{H}) = \frac{1}{2} M \text{Tr} \Sigma^2 + \frac{1}{3} \lambda \text{Tr} \Sigma^3 + \frac{\alpha}{M_{\text{Pl}}^{n-3}} (\bar{H}H)^n. \quad (1)$$

After the addition of the soft SUSY breaking terms to the scalar potential, the VEV’s are determined by $\langle \Sigma \rangle = \text{diag}(1, 1, 1, 1, -2, -2)$, $\langle H \rangle = \langle \bar{H} \rangle = a(M_{\text{weak}} M_{\text{Pl}}^{-1})^{n-2} M_{\text{Pl}}$, where the coefficient $a$ depends on the soft breaking terms. The first allowed term mixing the two sectors is $\frac{1}{M_{\text{Pl}}^{n-2}} (\bar{H}H)^{2n-2} (\bar{H} \Sigma H)$, whose contribution to the Higgs mass is acceptably small. One can modify this theory such that one of the sectors includes two adjoints $\Sigma_1$ and $\Sigma_2$ and the fields $\bar{H}, H$ in the other sector, and the superpotential $(n \geq 4)$

$$W(\Sigma_1, \Sigma_2, H, \bar{H}) = M \text{Tr} \Sigma_1 \Sigma_2 + \frac{1}{3} \lambda_1 \text{Tr} \Sigma_1^3 + \frac{1}{3} \lambda_2 \text{Tr} \Sigma_2^3 + \frac{\alpha}{M_{\text{Pl}}^{2n-3}} (\bar{H}H)^n, \quad (2)$$

and an additional discrete $Z_3$ symmetry under which $Q_{\Sigma_1} = -Q_{\Sigma_2} = \frac{1}{3}, Q_{\bar{H}H} = 0$. One can extend this model to include matter fields as well. We add the $SU(6)$ representations $\mathbf{15} + 6 + 6'$, $i = 1, 2, 3$. A discrete $Z_n \times Z_n \times Z_3$ symmetry can enforce a realistic Yukawa coupling structure. The light fields are in exact correspondence with the fields of the MSSM, and the top Yukawa coupling is of $O(1)$, because this is the only coupling of the light fields arising from a renormalizable term. The hierarchy in the fermion masses arises naturally due to the suppression of the nonrenormalizable terms by $(\bar{H}H)/M_{\text{Pl}} \sim 1/30$, $\langle \Sigma \rangle / M_{\text{Pl}} \sim 1/1000$. This is therefore a complete SUSY GUT model, which solves both the doublet-triplet splitting problem and the fermion hierarchy problem\textsuperscript{4}.\textsuperscript{2}
Figure 1: The favored parameter region for the presented model. The figure on the left displays the region of $M_{1/2} - A_0$ space where the equation for $\tan \beta$ of Ref. 4 has a solution for three different values of $m_0$, with $\lambda_t = 0.8$. The allowed region for $m_0 = 0$ is above the solid line, for $m_0 = 500$ GeV above the dashed line and for $m_0 = 1000$ GeV above the dotted line. The figure on the right displays the values of the possible solutions of the equation for $\tan \beta$, for varying $M_{1/2}$, $m_0 = 0$ and $\lambda_t = 0.8$ is fixed in this figure.

The phenomenology of this (and similar) models can be tested using the fact that in these models the $\mu$-term at the GUT-scale is fixed to be $m_0^2 + \mu^2 = -B\mu$, where $m_0$ is the common soft breaking scalar mass at the GUT scale, and $B$ is the soft breaking parameter corresponding to the $\mu$-term. This means that the number of independent MSSM parameters in this model is reduced by one. After taking the RGE running between the GUT and the weak scale and the requirement of radiative symmetry breaking into account, one obtains an equation for $\tan \beta$ in terms of the other input parameters ($m_0, M_{1/2}, A_0$) and the top Yukawa coupling $\lambda_t$. This equation does not have a solution for every values of the input parameters, thus restricting the parameter space of this model. It is interesting to note, that the equation for $\tan \beta$ is not symmetric under $\tan \beta \rightarrow -\tan \beta$, because the above mentioned boundary condition breaks this symmetry. A typical plot for the favored parameter region where the equation for $\tan \beta$ has a solution is given in Fig. 1, together with the values $\tan \beta$ can take on in this regime. Thus the assumptions on the GUT-scale Higgs sector physics result in testable predictions for weak-scale physics.

In summary, we have presented a complete SUSY GUT model which solves the doublet-triplet splitting problem, the $\mu$-problem and the fermion hierarchy problem and we have discussed the implications of this model for weak-scale physics.
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Note Added

After this talk has been presented at DPF’96 there has been an interesting new proposal by G. Dvali and S. Pokorski to use the anomalous $U(1)$ symmetry to enforce the accidental global $SU(6) \times SU(6)$ symmetry. 

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