Compositeness and Supersymmetry Breaking

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Abstract

We introduce a supersymmetric preon model in which the symmetry is broken by a mechanism internal to the model itself. Scalar superpartner masses are in principle calculable.

Keywords: Composite particles; Gauge Symmetry; Supersymmetry; Supersymmetry breaking

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1 Introduction

Preon scenarios, despite their speculative nature, are a possible extension of the Standard Model (SM) to smaller length scales. The phenomenological preon model [1] has been shown to be an eligible candidate paradigm for unifying particles, gravity and cosmology [2].

The purpose of this note is to clarify the preon gauge symmetries and to introduce a novel mechanism for supersymmetry breaking. We omit here the details of preon binding dynamics, whether of the Chern-Simons type [3] or hyper color [4, 5]. The term *confining* is used below.

In section 2 we define the preon supermultiplets. Section 3 presents the preon gauge symmetry $U(1) \times SU(3)$. Model-specific, novel supersymmetry breaking is introduced in section 4. Conclusions follow in section 5.

2 Preon Model

Preon Supermultiplets. At low energies, fundamental particles—preons—are grouped into vector and chiral supermultiplets [1]. The preons are free particles above the critical scale $\Lambda_{\rm cr} \sim 10^{12} - 10^{16}$ GeV, close to the reheating scale $T_{\rm R}$ and the grand unified theory (GUT) scale. Below $\Lambda_{\rm cr}$, preons form composite states by a confining interaction.

Table 1 summarizes the superparticle content of the model.[1] The m's are fermions, with the superscript indicating their charge in units of one-third electron charge, and the subscript indicating color (R, G, B). The s and σ are scalars. The γ and g_i are the familiar gauge bosons of the SM.

Table 1: Superscripts = $U(1)$ charge (in units $e/3$), subscripts = SU(3) color index.

Chiral	m^-, s^-	;	m_i^0, σ_i^0	;	n, a
Vector	γ, m^0	;	g_i, m_i^0		

The Standard Model particles and dark matter are formed by preon composites in the very early universe, at temperature of approximately the reheating value T_R.

Numerically, inflation begins at about 10^{-36} s and ends at 10^{-32} s, corresponding to energies 10^{13} to 10^{16} GeV, depending on the model. Towards the end of inflation, all fermionic preons are arranged by the confining force into composite states (table 3), which are now broken-SUSY particles, much like in the minimal supersymmetric SM (MSSM). After 10^{-32} s, reheating begins in the standard way with the inflaton producing MSSM particles (with some model-dependent differences). For reference, the electroweak phase transition (EWPT) occurs about 10^{-11} s after inflation ends.

3 Preon Gauge Symmetries

Finite-dimensional three-particle representations. The central property of the model is the product group

$$G = U(1) \times SU(3). \tag{1}$$

The fundamental representation of $SU(3)$ is denoted $\mathbf{3}$ with basis vectors labeled by color (R, G, B). The abelian group $U(1)$ acts via complex phases $e^{i\theta q}$, where q is the electric charge.

Each preon transforms under one of two representations:

$$\psi_0 \sim (0, \mathbf{3}) \qquad \text{neutral, color triplet preon,} \tag{2}$$

$$\psi_1 \sim \left(\tfrac{1}{3}, \mathbf{1}\right) \qquad \text{charged, color singlet preon.} \tag{3}$$

[1] The indices of particles in tables 1 and 3 are corrected from those in [1, 2].

Three body composites are built as follows: U(1) charges are additive and SU(3) tensor product composition is $\mathbf{1} \otimes \mathbf{3} = \mathbf{3}$, $\mathbf{3} \otimes \mathbf{3} = \mathbf{6} \oplus \bar{\mathbf{3}}$, $\mathbf{3} \otimes, \mathbf{3} \otimes \mathbf{3} \otimes = \mathbf{1} \oplus \mathbf{8} \oplus \mathbf{8} \oplus \mathbf{10}$. Each composite state is of the form (charge, color).

Physical picture. The correspondence between the representations and SM particles is shown in table 2.

Table 2: Physical Picture

Representation	Charge	Color	Analogy
(0, **1**)	0	singlet	neutrino
(-1, **1**)	-1	singlet	electron
($\frac{2}{3}$, **3**)	$\frac{2}{3}$	R/G/B	up quark
($\frac{-1}{3}$, **3**)	$\frac{-1}{3}$	R/G/B	down quark

The state (0, **3**) is an uncharged, color triplet quark, a good candidate to dark matter. The fractionally charged color-singlet states ($\frac{1,2}{3}, \mathbf{1}$) have not been observed. They would either be forbidden by integer charge quantization or indicate lepto-quark properties [6]. Composites containing SU(3) **6/8/10** irreps are non-observed exotic.

The SM fermions as composites of preons and their superpartners are shown in table 3.

Table 3: First-generation composite particles.

SM fermion	preon composition	sfermion / spreon composition
ν_e	$m^0_R\, m^0_G\, m^0_B$	$\tilde{\nu}_e$: $\sigma^0_R\, \sigma^0_G\, \sigma^0_B$
$u_{R/B/B}$	$m^+\, m^+\, m^0_{R/B/B}$	$\tilde{u}_{R/B/B}$: $s^+\, s^+\, \sigma^0_{R/B/B}$
$d_{R/B/B}$	$m^-\, m^0_{G/B/R}\, m^0_{B/R/G}$	$\tilde{d}_{R/B/B}$: $s^-\, \sigma^0_{G/B/R}\, \sigma^0_{B/R/G}$
e^-	$m^-\, m^-\, m^-$	$\tilde{e}^-$: $s^-\, s^-\, s^-$

4 Supersymmetry Breaking

The quadratic sensitivity to M_{UV} - the scale at which new physics modifies the loop integrations - is absent in SUSY theories with the following SUSY-breaking terms added in (for a review see [7]):

$$\begin{aligned} \mathcal{L}_{soft} = &-\frac{1}{2}\big(M_a \lambda^a \lambda^a + c.c.\big) - (m^2)^i_j \phi^{*j} \phi_i \\ &-\big(\frac{1}{2} b^{ij} \phi_i \phi_j + \frac{1}{6} a^{ijk} \phi_i \phi_j \phi_k + c.c.\big) \end{aligned} \quad (4)$$

where M_a is the gaugino, or m^0_i, mass and $m^{2\,i}_{\;j}$, are scalar mass and couplings, respectively.

In this framework, squarks (sleptons) are $SU(3)$ triplet (singlet) composite states of charge $\pm\frac{1}{3}$ or $\pm\frac{2}{3}$ (0, ± 1), as seen in table 3. Composite states made of three spin $\frac{1}{2}$ preons have different masses from composites of three spin 0 spreons, which causes supersymmetry being broken below $\Lambda_{\rm cr} \sim 10^{12} - 10^{16}$ GeV.

All non-gauge masses and interactions are determined by the superpotential W

$$W = \frac{1}{2} M^{ij} \phi_i \phi_j + \frac{1}{6} y^{ijk} \phi_i \phi_j \phi_k \quad (5)$$

From table 3, we see two scalars, $\tilde{\nu}_e$ and $\tilde{e}^-$. In fact, across three generations there are six scalars. The masses and couplings of the gauginos and sleptons are, in principle, calculable in the present composite model, where supersymmetry is broken autogenously. Therefore, a separate

SUSY-breaking sector may not be needed (though it remains possible). Concrete calculations are beyond the scope of this short note.

Other Bosonic States. In general, bosonic states include laboratory-observable particles, boson stars [8] and Bose-Einstein condensate fluids [9]. Bosonic systems may also constitute dark galaxies, galactic halo objects and hot "spots". They may grow under gravity and form heavy boson stars [8]. The hadronic-scale particle states would be bound by the chromodynamic force, but hey have not been detected at the LHC [10, 11]. Ultra-light particles are being intensively searched for, with possible masses down to 10^{-33} eV [12].

5 Conclusions

The main result of this note is that compositeness of SM particles alone causes supersymmetry breaking. The parameters of SUSY beaking are calculable in principle. For simplicity, the effects of the Higgs particle have not been considered here as we have limited this study to very early universe.

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