Autogenous Supersymmetry Breaking

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Abstract

We discuss a supersymmetric preon model in which the symmetry is broken by a mechanism of the model itself. Scalar superpartners have wide mass spectrum, extending up to the scale of astrophysical objects. Some superpartners may be detectable at the LHC.

Keywords: Composite particles; Supersymmetry breaking; Chern-Simons model

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1 Introduction

The search for supersymmetry's missing partners, particularly at CERN's LHC, has not yielded the anticipated results. "Has the LHC ruled out supersymmetry? The answer is no!" [1]. In this paper, we present arguments supporting this position, based on a new, autogenous mechanism for supersymmetry breaking within a supersymmetric preon model [2].

Although preons remain speculative, they are a natural extension of the Standard Model (SM) to smaller length scales. We propose that below the quark-lepton scale, around 10^{-18} m, there exists a topological level of supersymmetric (SUSY) preons. These preons are bound by a three-dimensional Abelian Chern-Simons (CS) interaction, designed to be stronger than the Coulomb repulsion between like-charged preons.

The key idea is that squarks and sleptons are formed of scalar constituents, spreons. Their bosonic composite states form a broad, semi-continuous spectrum, rather than discrete particles. Some of these states are likely astrophysical.

Section 2 outlines the preon model. Section 3 presents the autogenous SUSY breaking mechanism. Spacetime dimensionality is briefly discussed in section 4. Conclusions follow in section 5. Appendix A gives details of preon binding via CS theory.

This note is about phenomenology of preons. Readers interested in the technical details should consult the references.

2 Particle Model

At low energies, fundamental particles—preons—are grouped into vector and chiral supermultiplets [2]. These preons are free particles above the critical scale $\Lambda_{\rm cr} \sim 10^{10}$–$10^{16}$ GeV, close to the reheating scale $T_{\rm R}$ and the grand unified theory (GUT) scale. Below $\Lambda_{\rm cr}$ preons form composite states using a Yukawa-type interaction derived from spontaneously broken 3D CS theory [3].

Table 1 summarizes the particle content.[1] The m's are fermions 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.[2]

The superpartners of standard model particles are formed of s^- and σ_i^0 composites. They generate a rich spectroscopy with the lowest composite state masses in the usual lepton/hadron mass scale. Therefore they should be detectable with present accelerator experiments. The dark sector is obtained from the scalar $\sigma_R^0\sigma_G^0\sigma_B^0$ and the axion multiplet $\{a, n\}$ in table 1.

[1] The indices of particles in tables 1 and 2 are corrected from those in [2, 4].
[2] It is possible to consider γ and g_i as emergent fields [5, 6].

Denote baryon number by B, lepton number by L and spin by s, then R-parity $P_R = (-1)^{(3B-L)+2s}$ is a symmetry that forbids these couplings. All SM particles have R-parity of +1 while superpartners have R-parity of -1. In the preon model, $B = L = 0$. This leads to a situation where a group of preons and antipreons can form either hydrogen or antihydrogen atoms in the after preons have formed quarks and leptons. Statistical fluctuations cause $N_H \neq N_{\bar{H}}$. This creates the numerically small baryon asymmetry n_B/n_γ [4].

Table 1: Supermultiplet particles and their properties

Multiplet	**Particles (Spins)**
Chiral	m^-, s^- (fermion, scalar), m_i^0, σ_i^0 (neutral, color), n, a (axino, axion)
Vector	γ, m^0 (photon, singlet fermion), g_i, m_i^0 (color bosons and fermions)

The matter-preon correspondence for the first two flavors (r = 1, 2; i.e., the first generation) is indicated in table 2 for the left-handed particles.

Table 2: Visible and dark sector particles and preon states (first generation)

SM Particle	**Preon Composition**
ν_e	$m_R^0 m_G^0 m_B^0$
$u_{R,G,B}$	$m^+ m^+ m_{R,G,B}^0$
d_R	$m^- m_G^0 m_B^0$, similarly for d_G, d_B
e^-	$m^- m^- m^-$
Sfermion	**Preon Composition**
$\tilde{\nu}_e$	$\sigma_R^0 \sigma_G^0 \sigma_B^0$
$\tilde{u}_{R,G,B}$	$s^+ s^+ \sigma_{R,G,B}^0$
$\tilde{d}_{R,G,B}$	$s^- \sigma_{G,B,R}^0 \sigma_{B,R,G}^0$
$\tilde{e}^-$	$s^- s^- s^-$

After quarks are formed by the process described in [4] the SM octet of gluons emerges. To make observable color neutral, integer charge states (baryons and mesons) we proceed as follows. The local $SU(3)_{color}$ octet structure is formed by quark-antiquark composite pairs as follows (with only the color charge indicated):

$$\text{Gluons}: \mathrm{R\bar{G}, R\bar{B}, G\bar{R}, G\bar{B}, B\bar{R}, B\bar{G}}, \frac{1}{\sqrt{2}}(\mathrm{R\bar{R} - G\bar{G}}), \frac{1}{\sqrt{6}}(\mathrm{R\bar{R} + G\bar{G} - 2B\bar{B}}) \,. \tag{1}$$

We briefly and heuristically introduce the weak interaction - the scalar sector is rather complex. For simplicity, we append the Standard Model electroweak interaction in our model as an $SU(2)_Y$ Higgs extension with the weak bosons presented as composite pairs, such as gluons in (1).

The Standard Model and dark matter are formed by preon composites in the very early universe at temperature of approximately the reheating value T_R. Because of spontaneous symmetry breaking in three-dimensional QED$_3$ by a heavy Higgs-like particle the Chern-Simons action can provide by Möller scattering mediated by two particles (the Higgs scalar and the massive gauge field) a binding force stronger than Coulomb repulsion between equal charge preons. The details of preon binding (essential also for baryon asymmetry in the universe) are presented in appendix A.

Chern-Simons theory with larger groups such as $G = U(N_c)$ with fundamental matter and flavor symmetry group $SU(N_f) \times SU(N_f)$ have been studied, for example [7], but they are beyond the scope of this article.

3 Autogenous Supersymmetry Breaking

In this framework, squarks are $SU(3)$ colored composite states of charge $\pm\frac{1}{3}$ or $\pm\frac{2}{3}$. They naturally form physical systems without any extra supersymmetry breaking mechanism [8], including observable particles, boson stars [9] and Bose-Einstein condensate fluid [10]. Boson stars may also be dark galaxies or galactic halo objects. The particle states are bound by the chromodynamic force (and the potential (14)) and may be detectable at the LHC [11].

Boson systems may grow by gravity and form heavy boson stars [9]. Here we only mention that the maximum mass of a non-collapsed boson star is

$$M_{max} = \frac{M_{\rm Pl}^2}{2m} \tag{2}$$

where m is the star's constituent particle mass. The lightest scalar mass is expected to be the axion mass $m_a \geq 1$ μeV.

Scalar bosons obey Klein-Gordon and vector bosons the Proca equation. Wave equations tend to disperse fields and gravity keeps them together. The stability of boson composites is not fully known. There are, however, many soliton and soliton-like solutions in three dimensions like the field theory monopole of 't Hooft and Polyakov which is a localized solution of a triplet scalar field.

4 Dimensions of Spacetime

The action in (9) is three-dimensional. In a rapidly expanding universe four-dimensional general relativity begins to contribute at or before reheating. Therefore the the Einstein-Hilbert action must be added to (9). How do we understand a three-dimensional model in four-dimensional spacetime? This question has been studied in [12, 13]. One starts with the Einstein-Hilbert action $S_{EH} = \frac{1}{2\kappa^2}\sqrt{-g}R$. Then add a Chern-Simons term

$$\begin{aligned} S_{CS} &= \tfrac{1}{4}\int d^4x\ \theta(x)\epsilon^{\mu\nu\sigma\rho}R_{\mu\nu\alpha\beta}R_{\rho\sigma}{}^{\alpha\beta} \\ &= \int d^4x\ \theta(x)\ {}^*RR \end{aligned} \tag{3}$$

where the pseudo-scalar $\theta(x)$ is the CS coupling field and ${}^*RR$ is the gravitational Pontryaging density, defined as

$${}^*RR = \frac{1}{2}\epsilon^{\mu\nu\alpha\beta}R_{\alpha\beta\gamma\delta}R_{\mu\nu}{}^{\gamma\delta} \tag{4}$$

$\theta(x)$ is a field of dynamical Chern-Simons gravity with a kinetic term

$$S_\theta = -\frac{1}{2}d^4x\sqrt{-g}\partial_\mu\theta\partial^\mu\theta. \tag{5}$$

The Pontryaging density can be written as the divergence of Chern-Simons topological current K^a

$$K^a = \epsilon^{abcd}\Gamma^n_{bm}\Big(\partial_c\Gamma^m_{dn} + \frac{2}{3}\Gamma^m_{cl}\Gamma^l_{dn}\Big) \tag{6}$$

where Γ is the Christoffel connection, letters a,b,...,h correspond to spacetime indices, and i,j,...,z stand for spatial indices.

The term θ^*RR leads to the CS gravitational term that breaks parity symmetry. The total action is

$$S = S_{EH} + S_{CS} + S_\theta + S_{matter} \tag{7}$$

General relativity is obtained in the limit $\theta \to 0$.

5 Conclusions

Autogenous supersymmetry breaking enables:

1. Absence of hidden SUSY-breaking sectors.
2. Detectable sparticles in the 1 GeV–1 TeV range.
3. Existence of sparticles in astrophysical mass regimes.

The Chern-Simons framework offers a compelling mechanism for physics beyond the Standard Model. Future work will focus on particle interactions, mass predictions, and experimental constraints.

A Preon Binding

The standard form of three-dimensional Abelian CS action with connection A_μ is

$$S_{CS}[A] = \frac{k}{4\pi}\int_M d^3x \epsilon^{\mu\nu\rho} A_\mu \partial_\nu A_\rho. \tag{8}$$

The preon binding interaction is based on this action and spontaneous symmetry breaking.

An immediate question for table 2 particles is the Coulomb repulsion between like charge preons. This problem has been solved for polarized electrons in [3][3] where the authors derived an interaction potential electrons in the framework of a Maxwell-Chern-Simons QED_3 with spontaneous breaking of local U(1) symmetry. An attractive electron-electron interaction potential was found whenever the Higgs sector contribution is stronger than the repulsive contribution of the gauge sector, provided appropriate fitting of the free parameters is made.

We generalize the results for e^-e^- binding energy in [14, 15] for preons. One starts from a QED_3 Lagrangian built up by two Dirac spinor polarizations, ψ_+, ψ_-) with SSB. The authors evaluate the Möller scattering amplitudes in the nonrelativistic approximation. The Higgs and the massive photon are the mediators of the corresponding interaction in three different polarization expressions: $V_{\uparrow\uparrow}, V_{\uparrow\downarrow}, V_{\downarrow\downarrow}$.

The action for a QED_3 model is built up by the fermionic fields (ψ_+, ψ_-), a gauge (A_μ) and a complex scalar field (φ) with spontaneous breaking of the local U(1)-symmetry [16, 14] is

$$\begin{aligned} S_{\mathrm{QED_3-MCS}} = \int d^3x \{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + i\overline{\psi}_+\gamma^\mu D_\mu \psi_+ + i\overline{\psi}_-\gamma^\mu D_\mu\psi_- + \\ & \theta\epsilon^{\mu v \alpha} A_\mu \partial_v A_\alpha - m_e(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-) + \\ & - y(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)\varphi^*\varphi + D^\mu\varphi^* D_\mu\varphi - V(\varphi^*\varphi), \end{aligned} \tag{9}$$

where $V(\varphi^*\varphi)$ is the sixth-power φ self-interaction potential

$$V(\varphi^*\varphi) = \mu^2\varphi^*\varphi + \frac{\zeta}{2}(\varphi^*\varphi)^2 + \frac{\lambda}{3}(\varphi^*\varphi)^3, \tag{10}$$

which is the most general one renormalizable in $1+2$ dimensions [17].

In $(1+2)$ dimensions, a fermionic field has its spin polarization fixed up by the mass sign [18]. In the action (10) there are two spinor fields of opposite polarization. In this sense, there are two positive-energy spinors, or families, each one with one polarization state according to the sign of the mass parameter.

Considering $\langle\varphi\rangle = v$, the vacuum expectation value for the scalar field squared is given by

$$\langle\varphi^*\varphi\rangle = v^2 = -\zeta/(2\lambda) + \left[(\zeta/(2\lambda))^2 - \mu^2/\lambda\right]^{1/2},$$

[3] We take their low energy result as a first approximation.

The condition for minimum is $\mu^2 + \frac{\zeta}{2}v^2 + \lambda v^4 = 0$. After the spontaneous symmetry breaking, the scalar complex field can be parametrized by $\varphi = v + H + i\theta$, where H represents the Higgs scalar field and θ the would-be Goldstone boson. To preserve renormalizability of the model, one adds the gauge fixing term $\left(S^{gt}_{R_\xi} = \int d^3x[-\frac{1}{2\xi}(\partial^\mu A_\mu - \sqrt{2}\xi M_A\theta)^2]\right)$ to the broken action. By keeping only the bilinear and the Yukawa interaction terms, one has finally

$$
\begin{aligned}
S^{\rm SSB}_{\rm CS-QED_3} = \int d^3x \Big\{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + \frac{1}{2}M_A^2 A^\mu A_\mu \\
& - \frac{1}{2\xi}(\partial^\mu A_\mu)^2 + \overline{\psi}_+(i\partial\!\!\!/ - m_{eff})\psi_+ \\
& + \overline{\psi}_-(i\partial\!\!\!/ + m_{eff})\psi_- + \frac{1}{2}\theta\epsilon^{\mu v\alpha}A_\mu\partial_v A_\alpha \\
& + \partial^\mu H\partial_\mu H - M_H^2 H^2 + \partial^\mu\theta\partial_\mu\theta - M_\theta^2\theta^2 \\
& - 2yv(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)H - e_3\left(\overline{\psi}_+ A\!\!\!/\psi_+ + \overline{\psi}_- A\!\!\!/\psi_-\right)\Big\}
\end{aligned}
\tag{11}
$$

where the mass parameters,

$$
M_A^2 = 2v^2e_3^2, \quad m_{eff} = m_e + yv^2, \quad M_H^2 = 2v^2(\zeta + 2\lambda v^2), \quad M_\theta^2 = \xi M_A^2, \tag{12}
$$

depend on the SSB mechanism. The Proca mass, M_A^2, represents the mass acquired by the photon through the Higgs mechanism. The Higgs mass, M_H^2, is associated with the real scalar field. The Higgs mechanism causes an effective mass, m_{eff}, to the electron. The would-be Goldstone mode, with mass (M_θ^2), does not represent a physical excitation. One sees the presence of two photon mass-terms in (12): the Proca and the topological one. The physical mass of the gauge field will emerge as a function of two mass parameters.

Electron-electron scattering, the potential must exhibit the combination $(l-\alpha^2)^2$ for the sake of gauge invariance. In order to ensure the gauge invariance one takes into account the two-photons diagrams, which amounts to adding up to the tree-level potential the quartic order term $\left\{\frac{e^2}{2\pi\theta}[1-\theta r K_1(\theta r)]\right\}^2$. Now one has the following gauge invariant effective potential [19, 20]

$$
V_{\rm MCS}(r) = \frac{e^2}{2\pi}\left[1 - \frac{\theta}{m_e}\right]K_0(\theta r) + \frac{1}{m_e r^2}\left\{l - \frac{e^2}{2\pi\theta}[1-\theta r K_1(\theta r)]\right\}^2 . \tag{13}
$$

In the expression above, the first term corresponds to the electromagnetic potential, whereas the last one incorporates the centrifugal barrier $\left(l/mr^2\right)$, the Aharonov-Bohm term and the two-photon exchange term. One observes that this procedure becomes necessary when the model is analyzed or defined out of the pertubative limit.

In search for applications to Condensed Matter Physics, one must require $\theta \ll m_e$. The scattering potential (14) is then positive. In our preon scenario we have rather $\theta \gg m_e$ and the potential is negative leading to an attractive force of Yukawa type.

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