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. Superpartners have wide mass spectrum up to astrophysical objects. Only some of them may be detectable at the LHC.

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

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1 Introduction

Supersymmetry's missing partners were expected by many to be discovered at CERN's LHC. The dream was not realized. *"Has the LHC ruled out supersymmetry? The answer is no!"* [1]. We present arguments that "no" is the correct answer. Our claim is based on a new, autogenous method for supersymmetry breaking in the supersymmetric preon model [2]. Although preons are still speculative, we believe they are a natural extension of the Standard Model to smaller length scales. Namely, we have proposed that below the quark-lepton level length scale, $\sim 10^{-18}$ m, there is a topological level of supersymmetric (SUSY) preons. The binding force between preons is a 3D Abelian Chern-Simons (CS) interaction, which is engineered stronger than Coulomb repulsion between like-charge preons. The key idea in the symmetry breaking is that squarks and sleptons are formed of scalar constituents and their bosonic composite states form a broad, semi-continuous spectrum rather than the particle system expected from SUSY. Such states should be looked for among astrophysical systems.

This article is organized as follows. Our preon model for visible matter and the dark sector is summarized in section 2. Autogenous supersymmetry breaking is presented 3. Questions of spacetime dimensions are touched in section 4. Concluding remarks are presented in section 5. Main details of preon binding based on Chern-Simons theory are given in appendix A.

This note is intended as a brief introduction to phenomenology of preons. Readers interested in the technical details are encouraged to consult the references.

2 Particle Model

The low energy fundamental particles—preons—are organized into vector and chiral supermultiplets [2]. Preons are free particles above the energy scale Λ_{cr},

Multiplet	Particle, Sparticle
chiral multiplets spins 1/2, 0	$m^-,\ s^-;\ m_i^0,\ \sigma_i^0\ ;\ n, a$
vector multiplets spins 1, 1/2	$\gamma, m^0;\ g_i, m_i^0$

Table 1: The particles m^-, m^0 are charged and neutral, respectively, Dirac spinors. The particle s^- is a charged scalar particle. The a is axion and n axino [3, 4, 5]. m^0 is color singlet particle and γ is the photon. m_i and g_i, σ_i^0 (i = R, G, B) are zero charge color triplet fermions and bosons, respectively. The s^- and σ_i^0 bound states are sleptons.

numerically about $\sim 10^{10}-10^{16}$ GeV. It is close to the reheating scale T_R and the grand unified theory (GUT) scale. A binding mechanism for the preon bound states has been constructed using the spontaneously broken 3D Chern-Simons theory [6] described in appendix A. From this scale Λ_{cr} down preons form composite states by a Yukawa-type attractive Chern-Simons model interaction into of Standard Model quarks and leptons, with the usual SM gauge interactions.

We now define a sample model for preons by the supermultiplets shown in table 1.[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 (if the axion(s) are found).

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.

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.

After quarks are formed by the process described in [7] 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):

$$\text{Gluons}: \mathrm{R\bar{G}, R\bar{B}, G\bar{R}, G\bar{B}, B\bar{R}, B\bar{G}}, \frac{1}{\sqrt{2}}(\mathrm{R\bar{R}-G\bar{G}}), \frac{1}{\sqrt{6}}(\mathrm{R\bar{R}+G\bar{G}-2B\bar{B}})\ . \quad (2.1)$$

[1] The indices of particles in tables 1 and 2 are corrected from those in [2, 7].
[2] It is possible to consider γ and g_i as emergent fields [8, 9]

SM Matter 1st gen.	Preon state
ν_e	$m^0_R m^0_G m^0_B$
u_R	$m^+ m^+ m^0_R$
u_G	$m^+ m^+ m^0_G$
u_B	$m^+ m^+ m^0_B$
d_R	$m^- m^0_G m^0_B$
d_G	$m^- m^0_B m^0_R$
d_B	$m^- m^0_R m^0_G$
e^-	$m^- m^- m^-$
Sfermions	Preon state
$\tilde{\nu}$	$\sigma^0_R \sigma^0_G \sigma^0_B$
$\tilde{u}_R$	$s^+ s^+ \sigma^0_R$
$\tilde{u}_G$	$s^+ s^+ \sigma^0_G$
$\tilde{u}_B$	$s^+ s^+ \sigma^0_B$
$\tilde{d}_R$	$s^- \sigma^0_G \sigma^0_B$
$\tilde{d}_G$	$s^- \sigma^0_B \sigma^0_R$
$\tilde{d}_B$	$s^- \sigma^0_R \sigma^0_G$
$\tilde{e}^-$	$s^- s^- s^-$
W-Z Dark Matter	Particle
$\sigma^0_R \sigma^0_G \sigma^0_B$	dark scalar
boson (or BC)	s, axion(s)
e'	axino n
meson, baryon o	$n\bar{n}, 3n$
nuclei (atoms with γ')	multi n
celestial bodies	any dark stuff
black holes	anything (neutral)

Table 2: Low energy visible and Dark Matter with corresponding particles and preon composites. m^0_i $(i = R, G, B)$ is color triplet, $m^\pm$ are color singlets of charge $\pm 1/3$. s^- and σ^0_i (i = R, G, B) are scalars. Sfermions are indicated by $\tilde{S}$. e' and γ' refer to dark electron and dark photon, respectively. BC stands for Bose condensate.

Finally, 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 (2.1).

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 and a mechanism 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 [10], but they are beyond the scope of this article.

3 Autogenous Supersymmetry Breaking

The squarks in table 2 are $SU(3)$ colored composite states of charge $\pm\frac{1}{3}$ or $\pm\frac{2}{3}$. Their dynamics will form physical systems – like observable particles, boson stars [11] or Bose-Einstein condensate fluid [12] – without any extra supersymmetry breaking mechanism. It is seen that SUSY is strongly broken but in control of interactions, for a review see eg. [13].

Excluding SM quark–anti-quark states, observed scalars include the Higgs boson. A theoretical candidate is the axion. In the present model, consider any squark–anti-squark and any color neutral three squark composite state. These states are mesons and baryons, respectively, bound by the chromodynamic force (and the potential (A.6)) [14]. They can further form composite states of even more constituents, and the mesons be subject to Bose condensation.

Consider $\tilde{u}_R \sim s^+s^+\sigma^0_R$ and . By (A.6) and chromodynamic force it can form a composite "molecule" of nine preons with $\tilde{u}_G$ and $s^+s^+\sigma^0_G$. These are bosonic states and consequently the can further form composite states of even more composites due to Bose condensation.

Boson systems may grow by gravity and form heavy boson stars [11], which we recommend as a fascinating review on boson stars. Here we only mention that the maximum mass of a non-collapsed boson star is

$$M_{max} = \frac{M^2_{\mathrm{Pl}}}{2m} \tag{3.1}$$

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. Such a solution is a topological soliton. Boson stars may be stars, dark galaxies or galactic halo objects.

4 Dimensions of Spacetime

The action in (A.2) 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 (A.2).

How do we understand a three-dimensional model in four-dimensional spacetime? This question has been studied in [15, 16]. One starts with the Einstein-Hilbert action $S_{EH} = \frac{1}{2\kappa^2}\sqrt{-g}R$. Then add a Chern-Simons term

$$\begin{aligned} S_{CS} &= \tfrac{1}{4}\int d^4x\ \theta(x)\epsilon^{\mu\nu\sigma\rho}R_{\mu\nu\alpha\beta}R_{\rho\sigma}{}^{\alpha\beta} \\ &= \int d^4x\ \theta(x)\ {}^*RR \end{aligned} \tag{4.1}$$

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

$${}^*RR = \frac{1}{2}\epsilon^{\mu\nu\alpha\beta}R_{\alpha\beta\gamma\delta}R_{\mu\nu}{}^{\gamma\delta} \tag{4.2}$$

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

$$S_\theta = -\frac{1}{2}d^4x\sqrt{-g}\partial_\mu\theta\partial^\mu\theta. \tag{4.3}$$

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

$$K^a = \epsilon^{abcd}\Gamma^n_{bm}\Big(\partial_c\Gamma^m_{dn} + \frac{2}{3}\Gamma^m_{cl}\Gamma^l{}_{dn}\Big) \tag{4.4}$$

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

$$S = S_{EH} + S_{CS} + S_\theta + S_{matter} \tag{4.5}$$

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

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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

$$S_{CS}[A] = \frac{k}{4\pi} \int_M d^3x \epsilon^{\mu\nu\rho} A_\mu \partial_\nu A_\rho. \tag{A.1}$$

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 [6][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 [17, 18] 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 [19, 17] is

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

$$
\begin{aligned}
S_{\mathrm{QED_3-MCS}} = \int d^3x\{ & -\frac{1}{4}F^{\mu\nu}F_{\mu\nu} + i\overline{\psi}_+\gamma^\mu D_\mu\psi_+ + i\overline{\psi}_-\gamma^\mu D_\mu\psi_- + \\
& \theta\epsilon^{\mu v\alpha}A_\mu\partial_v A_\alpha - m_e(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-) + \\
& - y(\overline{\psi}_+\psi_+ - \overline{\psi}_-\psi_-)\varphi^*\varphi + D^\mu\varphi^* D_\mu\varphi - V(\varphi^*\varphi),
\end{aligned}
\tag{A.2}
$$

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

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

which is the most general one renormalizable in $1+2$ dimensions [20].

In $(1+2)$ dimensions, a fermionic field has its spin polarization fixed up by the mass sign [21]. In the action (A.2) 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

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

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

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

where the mass parameters,

$$
M_A^2 = 2v^2e_3^2, \quad m_{eff} = m_e + yv^2, \quad M_H^2 = 2v^2(\zeta + 2\lambda v^2), \quad M_\theta^2 = \xi M_A^2,
\tag{A.5}
$$

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 (A.4): 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 [22, 23]

$$V_{\mathrm{MCS}}(r) = \frac{e^2}{2\pi}\left[1-\frac{\theta}{m_e}\right]K_0(\theta r) + \frac{1}{m_e r^2}\left\{l - \frac{e^2}{2\pi\theta}[1-\theta r K_1(\theta r)]\right\}^2 . \quad \text{(A.6)}$$

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 (A.6) 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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