Cybersusy Solves the
Cosmological Constant Problem

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Abstract

Cybersusy is a new mechanism for SUSY breaking. When the auxiliary fields are integrated in any theory like the SSM, certain special new composite superfields $\hat{\omega}_a$ arise. Spontaneous breaking of internal symmetry, like $SU(2) \times U(1) \Rightarrow U(1)$, gives rise to a new realization of SUSY for $\hat{\omega}_a$. This realization mixes elementary and composite states. In the resulting effective action, if $\hat{\omega}_a$ has mass, then there are SUSY anomalies. Since there are no massless supermultiplets, the SUSY anomalies must be present. They generate a spectrum for SUSY breaking that is consistent with the known particles. Supergravity does not couple to the anomalies because it does not couple to composite states. So unitarity is not violated. There is no cosmological constant generated, because SUSY is not spontaneously broken.

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1. Why Cybersusy?

One of the tantalizing features of unbroken supersymmetry (SUSY) is that it solves the 'Cosmological Constant Problem' [1,2,3]. This happens because the effective potential $P$ for unbroken SUSY has a zero Vacuum Expectation Value (VEV) [4,5]:

$$\langle P \rangle = 0 \quad (1)$$

A further tantalizing fact is that this remains true even when the scalar field $A^i$ develops a VEV $\langle A^i \rangle \neq 0$ which spontaneously breaks an internal symmetry, so long as SUSY itself is not spontaneously broken [6].

SUSY is spontaneously broken whenever an auxiliary field, such as $F^i$ (expressed as a function of $A^i$), develops a VEV $\langle F^i(A) \rangle \neq 0$. In that case, (1) becomes typically:

$$\langle P \rangle = \langle F^i \bar{F}_i \rangle \approx (100 \text{ GeV})^4. \quad (2)$$

This yields a huge cosmological constant $\Lambda$, because of the coupling of $P$ to supergravity:

$$\int d^4x \; P \sqrt{-g} \rightarrow \int d^4x \; \langle P \rangle \sqrt{-g} \Rightarrow \Lambda \int d^4x \; \sqrt{-g} \quad (3)$$

The Cosmological Constant Problem is that the maximum experimentally possible value [1,2,3] for $\Lambda$ is about $\rho_{\text{crit}} \approx 6 \times 10^{-47} \text{ GeV}^4$, whereas (2) yields a value that is $10^{54}$ times too large.

SUSY is certainly not observed, so it must be broken. The usual assumption is that SUSY is spontaneously broken. However, as discussed below, Cybersusy breaks SUSY in a way that is not spontaneous. As a result, the VEV of the potential remains zero as in (1), and the Cosmological Constant Problem does not arise for Cybersusy.

2. How does Cybersusy arise?

Cybersusy starts with the simplest interacting SUSY action in 3+1 dimensions. This is an action with a set of chiral scalar superfields, interacting with each other through trilinear interactions, with no mass terms. The first step is to integrate the auxiliary fields $F^i$. Although this integration is just a simple Gaussian integration in the path integral, after the completion of a square, it should be remembered that the result is exact and non-perturbative in nature.

Much of the information in the resulting non-linear SUSY theory is encapsulated in the BRST cohomology [7,8,9] of a local nilpotent functional derivative operator $\delta_{\text{BRST}}$. This cohomology can be analyzed using spectral sequences [10,11,12,16,17].
The analysis in [13] shows that there are certain composite fields \( \hat{\omega}_\alpha \), which behave like chiral dotted spinor superfields. A short way to express this is:

\[
\delta_{\text{BRST}} \hat{\omega}_\alpha = \delta_{\text{SS}} \hat{\omega}_\alpha
\]

(4)

where \( \delta_{\text{SS}} \) has the usual ‘SuperSpace’ form [4,5]:

\[
\delta_{\text{SS}} = C^\beta Q_\beta + \overline{C}^\beta \overline{Q}_\beta
\]

(5)

The next step is to reconsider the action with a mass term and an assumption that some scalar superfield develops a VEV which spontaneously breaks some internal symmetry, but without spontaneously breaking SUSY itself [6]. Then there is a new nilpotent realization [13] of SUSY of the form:

\[
\delta_{\text{BRST}} \hat{\omega}_\alpha = \delta_{\text{SS}} \hat{\omega}_\alpha + bm^2 \hat{A} \overline{C}_\alpha
\]

(6)

\[
\delta_{\text{BRST}} \hat{A} = \delta_{\text{SS}} \hat{A}
\]

(7)

where the constant \( b \) is proportional to the square of the VEV that breaks the internal symmetry, \( m \) is a mass parameter, and \( \hat{A} \) is one of the chiral superfields in the original theory.

### 3. Solutions and Mixing in the SSM

There are algebraic constraints that relate to the construction of the \( \hat{\omega}_\alpha \), and to the generation of the algebra (6). For example, in the Leptonic sector of the SSM, these constraints yield composite superfields \( \hat{\omega}_\alpha \) made of Lepton chiral superfields multiplied by Higgs/Goldstone superfields\(^2\). The equation (6) applies when \( SU(2) \times U(1) \) is spontaneously broken down to \( U(1) \), and the fields \( \hat{A} \) are the corresponding elementary Lepton chiral superfields. Quarks work the same way.

### 4. Effective Action and SUSY Anomalies

The hypothesis behind Cybersusy is that the composite superfields \( \hat{\omega}_\alpha \) correspond to bound states, and that they should be replaced by effective elementary superfields to explore the algebra (6). Effective \( \hat{\omega}_\alpha \) superfields have dimension \( m^{\frac{1}{4}} \), so the new Cybersusy algebra [13] for the effective theory is:

\[
\delta_{\text{CS}} = \delta_{\text{SS}} + \delta_{\text{MIX}}
\]

(8)

\(^2\)See the remarks at [13] for an example of \( \hat{\omega}_\alpha \).
where
\[ \delta_{\text{MIX}} \hat{\omega}_\dot{\alpha} = b \hat{A} \overline{C}_{\dot{\alpha}}. \] (9)

It is straightforward to write down a supersymmetric action for the \( \hat{\omega}_\dot{\alpha} \) for the case where \( b = 0 \) in equation (9). The action for the chiral scalar superfields \( \hat{A} \) is, of course, well known [4,5]. The action for the superfield \( \hat{\omega}_\dot{\alpha} \) represents a massive supermultiplet with mass \( m_\omega \) including spin \( \frac{1}{2} \), spin 1 and spin zero particles, mixed in an unusual way with an unusual propagator [13,15]. The mass term for \( \hat{\omega}_\dot{\alpha} \) is:
\[ A_{\text{Mass} \omega} = m_\omega^2 \int d^4x \ d^2\theta \ \hat{\omega}^\alpha \hat{\omega}_\dot{\alpha}. \] (10)

When the VEV arises, making \( b \neq 0 \), an attempt to make the effective action invariant under (8) meets an impasse. One needs to compensate for the variation of (10) under (9):
\[ \delta_{\text{MIX}} A_{\text{Mass} \omega} = -2bm_\omega^2 \int d^4x \ d^2\theta \ \hat{\omega}^\alpha \hat{A} \overline{C}_{\dot{\alpha}} \] (11)

But this term (11) has exactly the form of the anomalous terms found in the early SUSY cohomology papers [12,16,17]. This means that it is impossible to generate this term by the variation of any local term with (5).

The superspace invariant kinetic term for \( \hat{\omega}_\dot{\alpha} \) is of the form:
\[ A_{\text{Kinetic} \omega} = \int d^4x \ d^4\theta \ \hat{\omega}^\alpha \partial_{\alpha\dot{\alpha}} \hat{\omega}_\dot{\alpha}. \] (12)

Terms can be added to (12) so that the result is invariant under (8). This construction works because the relevant variations of (12) with (9) are not in the cohomology space of (5). A simple\(^3\) form for this is:
\[ A_{\text{CS Kinetic} \omega} = \int d^4x \ d^4\theta \left( \hat{\omega}^\alpha + b\hat{A}\overline{\theta}^\alpha \right) \partial_{\alpha\dot{\alpha}} \left( \hat{\omega}_\dot{\alpha} + b\hat{A}\overline{\theta}_\dot{\alpha} \right) \] (13)

So the SUSY breaking involves both \( b \) and \( m_\omega \):

1. If \( b = 0 \) and \( m_\omega \neq 0 \), then the action is the superspace invariant action and there are two supermultiplets, one from \( \hat{\omega}_\dot{\alpha} \) with mass \( m_\omega \), and one from \( \hat{A} \) with mass \( m_A \).

2. If \( b \neq 0 \) and \( m_\omega = 0 \), then SUSY is still unbroken. This is easy to see, because one can change (13) back to (12) by changing variables\(^4\)
\[ \hat{\omega}^\dot{\alpha} \Rightarrow \hat{\omega}^\dot{\alpha} - b\hat{A}\overline{\theta}^\dot{\alpha}. \] (14)

\(^3\)This ‘broken superspace’ form is new, but ‘equivalent’ to the expression in [13]. The invariance of (13) under (8) can be shown using integration by parts for \( \theta, \overline{\theta} \). This construction cannot work for (10), because (10) is a chiral integral.

\(^4\)This is a dubious transformation because it takes a chiral superfield into one that is not chiral. These results are best established using components as in [13]. But, as usual, superfield notation is easier to follow.
3. If $b \neq 0$ and $m_\omega \neq 0$, the change of variables (14) is not available because (10) is a chiral integral. This is equivalent to the existence of the SUSY anomaly of the form (11). So one gets a spectrum for broken SUSY.

If $m_\omega = 0$, there is a massless supermultiplet of charged Leptons, in sharp contradiction with experiment. The only choice that has a chance to be consistent with experiment is to keep $m_\omega \neq 0$ and $b \neq 0$.

In the above, we have oversimplified things a little. In the SSM there are actually Left and Right Superfields, which enables the theory to preserve Lepton number. When these details are added, it is easy to arrange for the Electron to be very light compared to the other members of its broken supermultiplet. The Neutrinos and Quarks work the same way.

5. Cosmological Constant, Unitarity and Double Counting

The presence of anomalies in a theory normally signals the breakdown of unitarity and consistency\[18\]. However it is easy to see that this does not happen for Supergravity with SUSY breaking from Cybersusy.

The SUSY anomalies relate to the $\tilde{\omega}^\alpha$ superfields. But since $\tilde{\omega}_\alpha$ are composite, we cannot validly couple them directly to supergravity. That would be double counting.

So the correct theory to couple to supergravity is simply the usual SSM with three Higgs superfields $\tilde{H}^i, \tilde{J}, \tilde{K}^i$. These spontaneously break $SU(2) \times U(1) \Rightarrow U(1)$, without spontaneous breaking of SUSY, as set out in \[13\].

At first glance, it seems preposterous to claim that SUSY is broken in this theory. However the situation is simply an extension of ideas that are common in QCD \[2\][19]. The hadrons (and the $\tilde{\omega}^\alpha$) are not explicit in the SSM action that is coupled to gravity. The hadrons are implicit bound states\[5\], and so are the $\tilde{\omega}^\alpha$.

It is clear that the Cosmological Constant Problem is not present for this action, because SUSY is not spontaneously broken.

6. Signature for Cybersusy

One clear signature of Cybersusy is that there should be a Vector Boson Electron at high mass. But this vector boson is not a gauge boson, because it arises from the $\tilde{\omega}_\alpha$ supermultiplet, which has nothing to do with a gauge multiplet. The same scenario carries through for the Neutrinos and Quarks.

\[5\]Cybersusy has hadronic supermultiplet towers which break SUSY, but the spectrum is not yet known \[14\].
7. Conclusion

Cybersusy is unavoidable for this $\hat{H}^i, \hat{J}, \hat{K}^i$ version of the SSM, and it does resolve some problems:

1. The effective $\hat{\omega}_\alpha$ superfields have actions which describe massive supermultiplets.
2. The SUSY breaking comes from SUSY anomalies of the $\hat{\omega}_\alpha$ superfields.
3. Cybersusy is well adapted to the SSM.
4. The Cybersusy breaking spectrum is consistent with experimental results so far, for Leptons and Quarks at least.
5. Even though the SUSY breaking is anomalous, no violation of unitarity arises because supergravity does not couple directly to the composite states.
6. Cybersusy breaking of SUSY happens when $SU(2) \times U(1)$ spontaneously breaks to $U(1)$, but no spontaneous breaking of SUSY is needed.
7. As a result of item 6 above, the Cosmological Constant Problem does not arise.

But Cybersusy also raises many new questions. Two important and difficult questions are:

1. Is there any way to constrain the magnitude of the breaking parameters $b$ and the mass parameters $m_\omega$, to get some phenomenological predictions?
2. How can one add interactions to the quadratic actions for Cybersusy?

Preliminary results indicate that the Hadron, Higgs and Gauge Supermultiplets also get SUSY breaking spectra that do not conflict with known experimental results. This requires detailed, but straightforward, analysis.
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[13] Ibid., arXiv:0908.0889 now published in SUSY 2009: AIP Conference Proceedings Volume 1200, Boston (Massachusetts), Eds: George Alverson, Pran Nath, Brent Nelson, at P 1085. This short article is a summary of the results in [14]. An unreported but important piece of progress since this paper is that the left handed Lepton dotspinor should be represented by $\tilde{\hat{\omega}}_{Li\dot{a}}^p = g^{-1}L_i\hat{\bar{\psi}}_{J\dot{a}} + (p^{-1})^{pq}(mk_i + \tilde{K}_i)\hat{\bar{\psi}}_{pq\dot{a}} - (r^{-1})^{pq}(mh_i + H_i)\hat{\bar{\psi}}_{Rq\dot{a}}$. With this change in equation (4) of [13], the spectrum described in section 8 of [13] can be derived from the SSM, without the problem mentioned in section 7 of [13]. The Quarks work similarly.
[14] Ibid., The first papers on Cybersusy are in arXiv: 0808-0811, 0808-2263, 0808-2276, 0808-2301, 0808.3749 [hep-th]. A summary of the most crucial material is in arXiv:0908.0889 [13]. These five papers need some revisions and clarifications, but they are largely still relevant. Related work is in [15].

[15] Ibid., 0911.0199 [hep-th]. This paper discusses various aspects of chiral dotted spinor superfields. Preliminary results indicate that the Baryons, Hadronic Mesons, Gauge and Higgs/Goldstone sectors get SUSY breaking too, but using multi-dotted spinor chiral superfields like $\hat{A}_{\dot{a}_1 \dot{a}_2}$ and $\hat{\omega}_{\dot{a}_1 \dot{a}_2 \dot{a}_3}$. The spectrum here is not yet known.

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