The SSM with Suppressed SUSY Charge

John Dixon

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Suppressed SUSY Charge is a new idea about how to split SUSY masses, without using Explicit or Spontaneous SUSY breaking.

OUTLINE:

- INTRODUCE Suppressed SUSY Charge for the Chiral Scalar Multiplet.
  - Need master equation
  - Need BRST cohomology
- USE Suppressed SUSY Charge in a very simple version of the SSM:
  - Suppress Squarks and Sleptons.
  - Partially Suppress the Higgs multiplets.
  - Keep UNBROKEN SUSY as a symmetry.
- DESCRIBE the resulting model
- DISCUSS GOOD FEATURES
- DISCUSS BAD FEATURES
- SPECULATE about unfinished issues

INTRODUCE Suppressed SUSY Charge.

The Chiral Multiplet has the Action:

$$\mathcal{A}_{\rm Total} = \mathcal{A}_{\rm Kinetic} + \mathcal{A}_{\rm Int} + \mathcal{A}_{\rm Zinn} \tag{1}$$

$$\mathcal{A}_{\rm Kinetic} = \int d^4x \, \left\{ F\overline{F} - \psi_\alpha \partial^{\alpha\dot\beta} \overline{\psi}_{\dot\beta} + \frac{1}{2} \partial_{\alpha\dot\beta} A \partial^{\alpha\dot\beta} \overline{A} \right\} \tag{2}$$

The mass and interactions look like:

$$\mathcal{A}_{\rm Int} = \int d^4x \, \left\{ m_1 AF - \frac{1}{2} m_1 \psi^\alpha \psi_\alpha + g_1 A^2 F - g_1 A \psi^\alpha \psi_\alpha + * \right\} \tag{3}$$

To formulate the Master Equation we need the SUSY variations coupled to Zinn Sources:

$$\mathcal{A}_{\rm Zinn} = \int d^4x \, \left\{ \Gamma \left(C^\alpha \psi_\alpha + \xi \cdot \partial A \right) + Y^\alpha \left(\overline{C}^{\dot\delta} \partial_{\alpha\dot\delta} A + C_\alpha F + \xi \cdot \partial \psi_\alpha \right) \right. \tag{4}$$

$$\left. + \Lambda \left(\overline{C}^{\dot\beta} \partial_{\alpha\dot\beta} \psi^\alpha + \xi \cdot \partial F \right) + * \right\} - C^\alpha \overline{C}^{\dot\alpha} h_{\alpha\dot\alpha} \tag{5}$$

Remove the F

Replace the Auxiliary Field F according to the equations of motion, or equivalently, integrate it in the Feynman path integral formulation. This yields:

$$\mathcal{A}_{\text{F Int}} = \int d^4x \left\{ -\psi_\alpha \partial^{\alpha\dot\beta} \overline{\psi}_{\dot\beta} + \frac{1}{2} \partial_{\alpha\dot\beta} A \partial^{\alpha\dot\beta} \overline{A} + \Gamma \left(C^\alpha \psi_\alpha + \xi \cdot \partial A \right) \right. \quad (6)$$

$$+ Y^\alpha \left(\overline{C}^{\dot\alpha} \partial_{\alpha\dot\alpha} A + \xi \cdot \partial \psi_\alpha \right) + \overline{\Gamma} \left(\overline{C}^{\dot\alpha} \overline{\psi}_{\dot\alpha} + \xi \cdot \partial \overline{A} \right) - \frac{1}{2} m_1 \psi^\alpha \psi_\alpha \quad (7)$$

$$+ \overline{Y}^{\dot\alpha} \left(C^\alpha \partial_{\alpha\dot\alpha} \overline{A} + \xi \cdot \partial \overline{\psi}_{\dot\alpha} \right) - g_1 A \psi^\alpha \psi_\alpha - \frac{1}{2} \overline{m}_1 \overline{\psi}^{\dot\alpha} \overline{\psi}_{\dot\alpha} - \overline{g}_1 \overline{A} \overline{\psi}^{\dot\alpha} \overline{\psi}_{\dot\alpha} \quad (8)$$

$$\left. - \left(\overline{m}_1 \overline{A} + \overline{g}_1 \overline{A}^2 + \overline{Y}^{\dot\alpha} \overline{C}_{\dot\alpha} \right) \left(m_1 A + g_1 A^2 + Y^\alpha C_\alpha \right) \right\} - C^\alpha \overline{C}^{\dot\alpha} h_{\alpha\dot\alpha} \quad (9)$$

The Master Equation has the form of a Poisson Bracket:

The Action $\mathcal{A}_{\rm F\ Int}$ yields zero when put into the Master Equation:

$$\mathcal{M}[\mathcal{A}] = \int d^4x \left\{ \frac{\delta \mathcal{A}}{\delta \overline{A}} \frac{\delta \mathcal{A}}{\delta \overline{\Gamma}} + \frac{\delta \mathcal{A}}{\delta \overline{\psi}_{\dot\alpha}} \frac{\delta \mathcal{A}}{\delta \overline{Y}^{\dot\alpha}} + \frac{\delta \mathcal{A}}{\delta A} \frac{\delta \mathcal{A}}{\delta \Gamma} + \frac{\delta \mathcal{A}}{\delta \psi_\alpha} \frac{\delta \mathcal{A}}{\delta Y^\alpha} \right\} + \frac{\partial \mathcal{A}}{\partial h_{\alpha\dot\alpha}} \frac{\partial \mathcal{A}}{\partial \xi^{\alpha\dot\alpha}} \tag{10}$$

The Master Equation generates BRST cohomology with a nilpotent δ. This δ is the 'Square Root' of the Master Equation:

$$\delta = \int d^4x \left\{ \frac{\delta \mathcal{A}}{\delta \overline{A}} \frac{\delta}{\delta \overline{\Gamma}} + \frac{\delta \mathcal{A}}{\delta \overline{\Gamma}} \frac{\delta}{\delta \overline{A}} + \cdots \right\}; \quad \delta^2 = 0 \tag{11}$$

Essentially the renormalized action and the bare action are related by

$$\mathcal{A}_{\rm Renormalized} = \delta \mathcal{B}_{\rm Bare} + \mathcal{I}_{\rm Bare} \tag{12}$$

where $\mathcal{I}_{\rm Bare}$ are local invariants of δ and $\mathcal{B}_{\rm Bare}$ is LOCAL

The Cheap Trick

The Extremely Cheap Trick with Very Serious Consequences

- The Master Equation has the form of a Poisson Bracket. That means it is invariant under 'Canonical Transformations'.
- Consider the following 'Exchange Transformation'. It is a special 'Canonical Transformation'.

$$c$$

- Here we decide to treat J as a Zinn Source, and η as a Field.
- This is just a renaming of letters, so the 'form' of the action is not changed at all.
- However it changes the physics drastically, because scalars propagate and sources do not.
- The result still satisfies the 'changed' Master Equation, as shown on the next slide:

The Un-Chiral Action, after $A \to J$ and $\Gamma \to \eta$:

$$\mathcal{A}_{\rm Un-Chiral} = \int d^4x \left\{ -\psi_\alpha \partial^{\alpha\dot\beta} \overline{\psi}_{\dot\beta} + \frac{1}{2} \partial_{\alpha\dot\beta} J \partial^{\alpha\dot\beta} \overline{J} + \eta \left(C^\alpha \psi_\alpha + \xi \cdot \partial J \right) \right. \tag{13}$$

$$+ Y^\alpha \left(\overline{C}^{\dot\alpha} \partial_{\alpha\dot\alpha} J + \xi \cdot \partial \psi_\alpha \right) + \overline{\eta} \left(\overline{C}^{\dot\alpha} \overline{\psi}_{\dot\alpha} + \xi \cdot \partial \overline{J} \right) - \frac{1}{2} m_1 \psi^\alpha \psi_\alpha \tag{14}$$

$$+ \overline{Y}^{\dot\alpha} \left(C^\alpha \partial_{\alpha\dot\alpha} \overline{J} + \xi \cdot \partial \overline{\psi}_{\dot\alpha} \right) - g_1 J \psi^\alpha \psi_\alpha - \frac{1}{2} \overline{m}_1 \overline{\psi}^{\dot\alpha} \overline{\psi}_{\dot\alpha} - \overline{g}_1 \overline{J} \overline{\psi}^{\dot\alpha} \overline{\psi}_{\dot\alpha} \tag{15}$$

$$\left. - \left(\overline{m}_1 \overline{J} + \overline{g}_1 \overline{J}^2 + \overline{Y}^{\dot\alpha} \overline{C}_{\dot\alpha} \right) \left(m_1 J + g_1 J^2 + Y^\alpha C_\alpha \right) \right\} - C^\alpha \overline{C}^{\dot\alpha} h_{\alpha\dot\alpha} \tag{16}$$

Master Equation after $A \to J$ and $\Gamma \to \eta$:

The above Action yields zero for new Master Equation $\mathcal{M}[\mathcal{A}]_{\rm Un-Chiral} =$

$$\int d^4x \left\{ \frac{\delta \mathcal{A}}{\delta \overline{J}} \frac{\delta \mathcal{A}}{\delta \overline{\eta}} + \frac{\delta \mathcal{A}}{\delta \overline{\psi}_{\dot\alpha}} \frac{\delta \mathcal{A}}{\delta \overline{Y}^{\dot\alpha}} + \frac{\delta \mathcal{A}}{\delta J} \frac{\delta \mathcal{A}}{\delta \eta} + \frac{\delta \mathcal{A}}{\delta \psi_\alpha} \frac{\delta \mathcal{A}}{\delta Y^\alpha} \right\} + \frac{\partial \mathcal{A}}{\partial h_{\alpha\dot\alpha}} \frac{\partial \mathcal{A}}{\partial \xi^{\alpha\dot\alpha}} \tag{17}$$

The Model Used here is very close to the usual SSM, without any trimmings–no hidden sector etc.

Does Suppressed SUSY Charge yield a New Kind of SUSY Breaking?

- No. It is more accurate is to say that Suppressed SUSY Charge is an alternative to spontaneous or explicit SUSY breaking
- The Model presented in this paper starts with the following:
  - Start with the SSM with the usual Quark and Lepton chiral multiplets
  - Add the usual two Higgs multiplets of type $(\frac{1}{2}, \frac{1}{2})$ and $(\frac{1}{2}, \frac{-1}{2})$
  - Add one extra Higgs chiral multiplet of type $(1, 0)$
  - Couple this in the usual way to the usual SUSY gauge theories $SU(3) \times SU(2) \times U1)$
  - It turns out that we also need to couple the above to Supergravity, because the algebra needs to close, and the ghost $\xi_{\alpha\dot{\beta}}$ must depend on space-time, so that we can integrate it and derive the Master Equation.
  - But this brings in all the fields and ghosts for Supergravity.

We then get a new action and a new Master Equation.

- For the Matter Sector we take the usual CKM matrices and quark and lepton masses. The model looks like the old SM in its matter sector.
- This of course is consistent with Experiment.
- The Squarks and Sleptons start off degenerate with the Quarks and Leptons, but we transform them into Sources.
- We remove half of the scalars from the Higgs multiplets by converting them to Sources, and we implement Gauge Symmetry Breaking from $SU(3) \times SU(2) \times U(1)$ to $SU(3) \times U(1)$ for this theory in the usual way using the Superpotential of the Higgs multiplets.
- This does not break SUSY spontaneously, because there is no auxiliary field here which develops a VEV.
- We do not need 124 parameters, because we have removed the Squarks and Sleptons
- There is no spontaneous breaking of SUSY, no hidden sector, and only six parameters in the Gauge/Higgs sector, namely $g_1, g_2, g_3, M_W, M_Z, M_H$.

At this point the model is completely determined using the usual CKM matrices, masses of the Quarks and Leptons, neutrino data, and six more real parameters

The six real parameters are the masses M_W, M_Z, M_H and the couplings g_3, g_2, g_1 for $SU(3) \times SU(2) \times U(1)$.

The model then makes predictions, since it has additional fields, and all parameters are now determined:

- There are two new Higgs predicted, one charged and one neutral.
- Their masses are very heavy and close to each other: 13.4 TeV.
- The theory also predicts that there are also Gauginos and Higgsinos degenerate with each of the Gauge and Higgs particles. But these are not coupled to the Quarks and Leptons, so they are not as easy to see as one might think, since they also have to be produced in pairs because of G-parity.

The point is that we can generate a new action with a new Master Equation, and a new δ, which are very similar to the original ones that we got from the Chiral Action

But the new system has very different physics, because some of the Scalar Fields are treated as Zinn Sources rather than as Fields.

And the new system is very restricted by the new Master Equation and the new δ, and in particular the Supercharge is suppressed in some parts of the new action (but not all)

What goes wrong?

What goes wrong is that we end up with some mass degeneracy

Standard Model For Fermionic Quarks and Leptons plus						
Degenerate Higagino Masses for Gauge and Higgs Sector (GeV)						
Bosons	γ	W^+	Z^0	Higgs H^0	$\mathrm{H}^0_{\mathrm{Heavy}}$	$\mathrm{H}^+_{\mathrm{Heavy}}$
Deg. Free.	2	6	3	1	1	2
Fermions	$\widetilde{\gamma}$	Wino $\widetilde{\mathrm{W}^+}$	Zino $\widetilde{\mathrm{Z}}^0$	$\widetilde{\mathrm{H}}^0$	$\widetilde{\mathrm{H}}^0_{\mathrm{Heavy}}$	$\widetilde{\mathrm{H}}^+_{\mathrm{Heavy}}$
Deg. Free.	2	8	4	2	2	4
Mass	0	80.385	91.1876	125.7	$\approx 13,400$	$\approx 13,400$

(18)

- The most obvious problem is that we will see is an excess of W^+, W^- bosons

This model is not consistent with experiment, but it is not terribly far off either, maybe.

Experimental Comparison and Issues

- The two new very heavy Higgs, and their Higgsinos, are not a problem, because they would be very hard to see, being so heavy.
- The Zino and the Light Higgsino and the massless Photino may be problems, but that depends on what happens with the Wino.
- The Wino $\widetilde{W}^+$ is certainly a problem. It can decay (off shell) via

$$\widetilde{W}^+ \to W^+ + \widetilde{\gamma} \tag{19}$$

  and this yields too many W^+, W^- to be consistent with experiment.
- What the model needs is a mechanism to make the $\widetilde{W}^+$ much heavier, so that the Zino and Higgsino could be stable and constitute missing mass candidates, and so that there is not an excess of production of W^+, W^- .

Work to do

Can the problem of the Wino, Zino, Higgsinos and Photino be solved in this context?

- from coupling this kind of model to Supergravity? This is necessary anyway.
- from extending this model to SUSY GUT theories like SU(5) and SO(10)?
- The diagonalization to the Mass and Charge Eigenstates need study.

The Excess W^+, W^- Problem and some Vague Ideas to Solve it?

- Maybe we can get a reasonable spectrum for the Higgs and Gauge sector, and also get candidates for the missing matter,
- BUT WE NEED TO GET THE WINO VERY HEAVY SOMEHOW!!!!
- Could this arise from a GUT SUSY theory at one loop maybe like pseudogoldstone bosons do in Weinberg's old paper?
- What about Hierarchy and non-renormalization theorems?

What does Suppressed SUSY Charge do?

- **It generates profoundly new predictions from SUSY**
- **Issues**
  - **Squarks and Sleptons, are not needed.**
  - **Spontaneous SUSY breaking is not needed.**
  - **The cosmological constant problem is not really there.**
  - **These models are terrifically constrained.**
  - **Gaugino and Higgsino masses consistent with Experiment?**
  - **Is there a model that is not obviously wrong?**
  - **Can it then be tested by experiment?**

Conclusion

Summary

- We can cut the Squarks and Sleptons out of the theory, while maintaining SUSY in the Master Equation sense, which is tight because of BRST cohomology.
- Does this explain why the Standard Model, without SUSY, has such good experimental results, even if SUSY is experimentally correct?
- We do not need the invisible sector, the messenger sector or the 100 extra parameters for the explicit breaking of SUSY.
- We can cut Spontaneous Breaking of Supersymmetry out of the theory since we do not need it once the Smatter is gone.
- The cosmological constant problem is no longer a problem and we can see why the cosmo constant could be naturally very tiny, as it is.
- By cutting half of the Higgs Scalars out, we can get a good spectrum for the Gauge and Higgs Bosons, but there is trouble with Winos and the other Higgsinos and Gauginos.