

Frozen SUSY with Susyons as the Dark Matter

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Is SUSY dead? No. Here I will suggest that she is merely frozen.

Is the Minimal Supersymmetric Standard Model ('MSSM') the correct story for SUSY? I think NOT.

Some symptoms of illness for SUSY:

- 1 the experimental absence of superpartners,
- 2 spontaneous breaking of susy, with the invisible sector etc.
- 3 flavour conservation is easier in the SM

SU(5) GUT model with supergravity: Successes and Failures of Frozen SUSY

Successes of Frozen SUSY

- 1 Surprisingly, we can have SUSY algebra without superpartners
- 2 SUSY still is controlling and simplifying the theory.
- 3 The Higgs sector is far more controlled. Five very heavy Higgs multiplets predicted with masses and doublet triplet problem gone.
- 4 Frozen SUSY is near to the non-SUSY GUT model, However, the gravitino survives as the stable dark matter candidate, and its mass is predicted. It interacts only with gravity.
- 5 The XY vector bosons get heavier and their masses are predicted.

Failures of Frozen SUSY

- 1 Frozen SUSY is WRONG because it has no neutrino mass or mixing – need to redo the calculations with SO(10) at the very least
- 2 Otherwise Frozen SUSY would predict a DESERT

SU(5) GUT model with supergravity.

Choose superpotential:

$$W = e^{\frac{-1}{4}\kappa^2(2H_L^i H_{Ri} + \frac{1}{2}\text{Tr}S^2)} M_P^{\frac{3}{2}} \sqrt{g_1 \text{Tr}(SSS) - g_2 H_L^i S_i^j H_{Rj}} \quad (1)$$

The Higgs fields here are $5, \bar{5}, 24$. Scalar potential of supergravity.

$$V = e^{(\kappa^2 \sum_i z^i \bar{z}_i)} \left\{ \sum_j \left| \frac{\partial W}{\partial z^j} + \kappa^2 \bar{z}_j W \right|^2 - 3\kappa^2 |W|^2 \right\} + \frac{1}{2} \sum_\alpha |D_\alpha|^2 \quad (2)$$

The square root in W plays into the $-3\kappa^2 |W|^2$ in V :

$$2\frac{3}{2} - 3 = 0 \quad (3)$$

Results from this choice of superpotential:

This 'Square Root Superpotential' has several advantages:

- 1 It generates the correct breakdown of $SU(5) \rightarrow SU(3) \times U(1)$
- 2 It generates 14 good masses from 4 parameters, including heavier XY vector bosons
- 3 It leaves the cosmo constant zero after GSB
- 4 Need to go to $SO(10)$ to have neutrino sector with masses and mixing
- 5 That might also generate a measurable new Higgs

A number of interesting things happen after the Exchange Transformation:

The scalar potential looks a lot like a very special scalar potential of a non-susy theory, and gauge symmetry breaking is spontaneous as it is in theories like the SM, and at tree level the cosmo constant is zero, even after gauge symmetry breaking.

The residual SUSY symmetry makes the whole theory much more restricted than the MSSM or a non-SUSY GUT.

SUSY is guided by the Exchange Transformation. It is not broken at all, merely changed. This arises because the SUSY charge gets spread into the new Sources and Antighosts, through the Exchange Transformation. We call this the 'Suppression of SUSY'.

FREEZING USES THE MASTER EQUATION: It summarizes all the symmetry by $\mathcal{M}[\mathcal{A}] = 0 \Rightarrow \mathcal{M}[\mathcal{G}] = 0$

$$\mathcal{M}_{\text{Matter}}[\mathcal{A}] = 0 = \int d^4x \left\{ \cdots + \frac{\delta \mathcal{A}}{\delta H^i} \frac{\delta \mathcal{A}}{\delta \Gamma_i} + \frac{\delta \mathcal{A}}{\delta \psi^{i\alpha}} \frac{\delta \mathcal{A}}{\delta Y_{i\alpha}} + \cdots \right\} \quad (4)$$

- ① H^i is a Scalar field.
- ② Γ_i is a Zinn Source for the variation of the Scalar Field H^i

$$\mathcal{A}_{\text{Scalar Fields}} = \int d^4x \left\{ H^i \square \bar{H}_i + \Gamma_i (C^\alpha \psi_\alpha^i + T_j^{ai} H^j \omega^a) + \cdots \right\}$$

- ③ C^α is a Spin $\frac{1}{2}$ supersymmetry Ghost field
- ④ ω^a is a Spin 0 Faddeev-Popov Ghost field
- ⑤ T_j^{ai} are group representation matrices
- ⑥ ψ^α is a Spin $\frac{1}{2}$ field.
- ⑦ $Y_{i\alpha}$ is a Zinn Source for the variation of the Spin $\frac{1}{2}$ field.

Consider changing this part in the following way:

$$\mathcal{M}_{\text{Matter}}[\mathcal{A}] = \int d^4x \left\{ \frac{\delta \mathcal{A}}{\delta H^i} \frac{\delta \mathcal{A}}{\delta \Gamma_i} + \frac{\delta \mathcal{A}}{\delta \psi^{i\alpha}} \frac{\delta \mathcal{A}}{\delta Y_{i\alpha}} + \dots \right\}$$

$$\Rightarrow \mathcal{M}_{\text{New Matter}}[\mathcal{A}_{\text{New}}] = \int d^4x \left\{ \frac{\delta \mathcal{A}_{\text{New}}}{\delta J^i} \frac{\delta \mathcal{A}_{\text{New}}}{\delta \eta_i} + \frac{\delta \mathcal{A}_{\text{New}}}{\delta \psi^{i\alpha}} \frac{\delta \mathcal{A}_{\text{New}}}{\delta Y_{i\alpha}} + \dots \right\}$$

- 1 H^i was a Scalar field and J^i is a New Scalar Zinn Source.
- 2 Γ_i was a Zinn Source and η_i is a New Scalar Field
- 3 In the original path integral that defines the original theory, we did a Feynman path integral over the quantized fields H^i and ψ .
- 4 Of course, we did not integrate over the Zinn Sources Γ and Y , since they were just there to help us to formulate the Master Equation.
- 5 However to implement the Exchange Transformation, we change this:
- 6 In the new path integral that defines the new theory, instead of integrating over H^i , we integrate over η_i .

Here again are the above pieces of the scalar field action:

$$\mathcal{A}_{\text{Scalar Fields}} = \int d^4x \{ H^i \square \bar{H}_i + \Gamma_i (C^\alpha \psi_\alpha^i + T_j^{ai} H^j \omega^a) + \dots \} \quad (5)$$

Here is what this becomes after the above change of variables:

$$\mathcal{A}_{\text{New}}[J, \eta] = \mathcal{A}[H \rightarrow J, \Gamma \rightarrow \eta]$$

$$\mathcal{A}_{\text{New Theory From Scalars}} = \int d^4x \{ J^i \square \bar{J}_i + \eta_i (C^\alpha \psi_\alpha^i + T_j^{ai} J^j \omega^a) + \dots \}$$

- 1 Note that $J^i \square \bar{J}_i$ is not quantized because J is a Source.
- 2 The new field η_i is a quantized 'antighost field'
- 3 But η_i does not propagate, because it does not appear in any quadratic term in the action.
- 4 So in some sense we have '**frozen out**' the scalar H^i degree of freedom, while maintaining the SUSY algebra, and keeping the same old SUSY Master Equation

The Rest Follows like Ducks in a Row



It is possible to generate many completely new field theories this way. And the new theories still use Supersymmetry, but in a different way.

The physics of the New Theory is very different, **but it uses exactly the same SUSY and gauge algebra, at least at tree level, but the fields and Zinn Sources have got mixed up.**

- ① We have renamed the fields and Zinn Sources.
- ② But it is the same old action exactly. With the same old Master Equation identity. But with interchanged Fields and Zinn Sources.
- ③ So naturally the New Theory satisfies the New Master Equation, because it is really just the old Master Equation.
- ④ **However the new field η_i is a sterile antighost field. It does not propagate.**
- ⑤ **So we have frozen the H^i scalar field out of the theory, while keeping the Master Equation alive!**
- ⑥ The new theory diverges from the old one, severely, very quickly.
- ⑦ However BRST cohomology follows from the Master Equation.
- ⑧ So the new theory must obey the new master equation, loop by loop.

What about fermions and gauge fields?

- 1 Fermions work like Scalars, and we could go through the same argument for them. This is even true for Gauginos.
- 2 **But gauge fields V_μ^a cannot be suppressed this way**, because gauge fields have an inhomogeneous term in their variation:

$$\int d^4x \Sigma^{\mu a} \delta V_\mu^a = \int d^4x \Sigma^{\mu a} \partial_\mu \omega^a + \dots \Rightarrow \int d^4x \eta^{\mu a} \partial_\mu \omega^a + \dots \quad (6)$$

where we imagine taking a Zinn Source $\Sigma^{\mu a}$ and changing it to an antighost field $\eta^{\mu a}$, like we did above for the scalar example.

- 3 The problem is that this would wreak havoc with the theory after the Exchange Transformation, because this antighost $\eta^{\mu a}$ would propagate because of the quadratic term (6) above.
- 4 So Suppressed SUSY can only affect the scalars and spin $\frac{1}{2}$ fields, not the vector bosons, not the gravitino, nor the graviton.
- 5 This is why we end up with a massive gravitino here: the Susyon, and it looks like the dark matter.

The Bosonic Sector of SU(5) GUT with SUGRA and Supp SUSY: There are only four parameters g_1, g_2, M_P, g_5 here and one gets 9 non-zero boson masses plus the Susyon mass.

Define the following 'Hierarchy Parameters':

Tiny Parameters

$fg_5 = M_W/M_P$	$h = M_H/M_P$
$3.35 \times 10^{-17} g_5$	5.2×10^{-17}

Recall that superpotential has the form:

$$W = e^{\frac{-1}{4}\kappa^2(2H_L^i H_{Ri} + \frac{1}{2}\text{Tr}S^2)} M_P^{\frac{3}{2}} \sqrt{g_1 \text{Tr}(SSS) - g_2 H_L^i S_i^j H_{Rj}} \quad (7)$$

The Bosonic Sector of SU(5) GUST with Supp SUSY:

Masses of W,Z and H require these values for g_1, g_2 :

The Superpotential Parameters

g_1	$r = g_2/g_1$
$-5.81 \times 10^{34} g_5^4$	$-2 - 2f^2/9$

Define the Planck and SuperPlanck Masses:

Mass Names (GeV)	
M_P	M_{SP}
2.4×10^{18}	$1.22 \times 10^{36} g_5^2$

VeVs:

VEVs (GeV)		
M_{K9}	M_{K1}	M_{K2}
$-fM_P$	$-\frac{M_P f^2}{6\sqrt{10}}$	$-\sqrt{6}M_P$

The Bosonic Sector of SU(5) GUT with SUGRA and Supp SUSY: 13 masses arise from the four parameters

Electroweak Masses

Electroweak Masses Units of M_P		
$M_Z = \frac{8}{5}fg_5 M_P$	$M_W = fg_5 M_P$	$M_H = hM_P$

Heavy Vector Bosons

Heavy Vector Bosons : Units of M_P	
X	Y
$2\sqrt{10}g_5 M_P$	$2\sqrt{10}g_5 M_P$

Some Huge Scalar Masses and a Huge Gravitino Mass are predicted:

Super Planck Masses : Units of M_{SP}					
H_{Oct}	H_{Trip}	H^+	H_2	H_3	Gravitino = Susyon
2.05	0.68	2.05	.81	2.05	1.64

Frozen SUSY

- 1 Experiment seems to be indicating that there are no superpartners to be found.
- 2 Frozen SUSY predicts (or postdicts) this.
- 3 It also predicts (or postdicts) a zero cosmo constant at tree level.
- 4 If there were a superpartner of any kind, Suppressed SUSY would be in trouble,
 - 1 because it would require some mechanism to split superpartners,
 - 2 which would probably require something like the MSSM, with its invisible sector that breaks SUSY spontaneously somehow, etc.
- 5 However Frozen SUSY is based on the idea that we suppress every superpartner we can: Squarks, Sleptons, Higgsinos, Gauginos... all of them.
- 6 But the gravitino will not go away and it gets a huge mass.

Stability and Interactions of the Susyon

- 1 By the argument above, we cannot get rid of the gravitino: it gets a huge mass and a new name: the Susyon.
- 2 The Susyon cannot decay, because all the superpartners have been transformed into Zinn Sources
- 3 The Susyon interacts only with gravity, because all the superpartners have been transformed into Zinn Sources
- 4 This means that the Susyon interacts with ordinary matter (like us) only through gravity.
- 5 This means that it can be very hard to detect an individual susyon, since its mass makes it terribly rare while allowing it to dominate all matter through its gravitational effects.
- 6 On the other hand its simple properties might make it possible to deduce its effect and see whether that is consistent with galaxy formation, cosmology etc.
- 7 This is a new idea. Perhaps there are other effects of Frozen SUSY that are not yet apparent.

Horror: I am horrified to predict a desert and an unfindable heavy gravitino that weighs a megaton. However, $SO(10)$ or the superstring plus Frozen SUSY might predict something measurable.

References:

- “Genuine and effective actions, the Master Equation and Suppressed SUSY,” Phys. Lett. B **777**, 31 (2018): [This explains and illustrates the mechanism of suppressing a field using the Master Equation.](#)
- “Suppressed SUSY for the $SU(5)$ Grand Unified Supergravity Theory,” arXiv:1706.07796 [This uses mathematica to get the spectrum.](#)
- “Frozen SUSY with Susyons as the Dark Matter”, arXiv:1905.07232 [This recent paper tries to discuss the business in the simplest way possible.](#)

The Non-Renormalization Theorems are a Red Herring

We are accustomed to hear that somehow the non-renormalization theorems help to explain the hierarchy. But actually they never have done that. Some papers use strange language like 'advocated' to avoid explanation.

Are the non-renormalization theorems the RED HERRINGS OF SUSY?

Anyway Suppressed SUSY **throws them away without a worry**

The equality of degrees of freedom for bosons and fermions is gone. But the constraints of SUSY are still present, in a new form.