Frozen SUSY with Susyons as the Dark Matter

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SUSY 2019 Corpus Christi

Figure 1: Frozen SUSY is a SUSY theory where all the unobserved superpartners with spin 0 and $\frac{1}{2}$ are 'frozen out' using 'canonical transformations' in the context of Suppressed SUSY [1, 2]. This avoids the need for the spontaneous breaking of SUSY. But the spin $\frac{3}{2}$ gravitino cannot be 'frozen out', because it is a gauge particle. The gravitino gets a huge mass, and we call it the Susyon.

Figure 2: The Susyon mass in the Frozen SUSY model follows from a see-saw argument. One assumes zero vacuum energy, and then uses the mass of the Higgs boson and the Planck mass. This means that the Susyon weighs roughly a Megatonne, even though it is just a tiny elementary gravitino. This is the mass of about 7 Cruiseships combined.

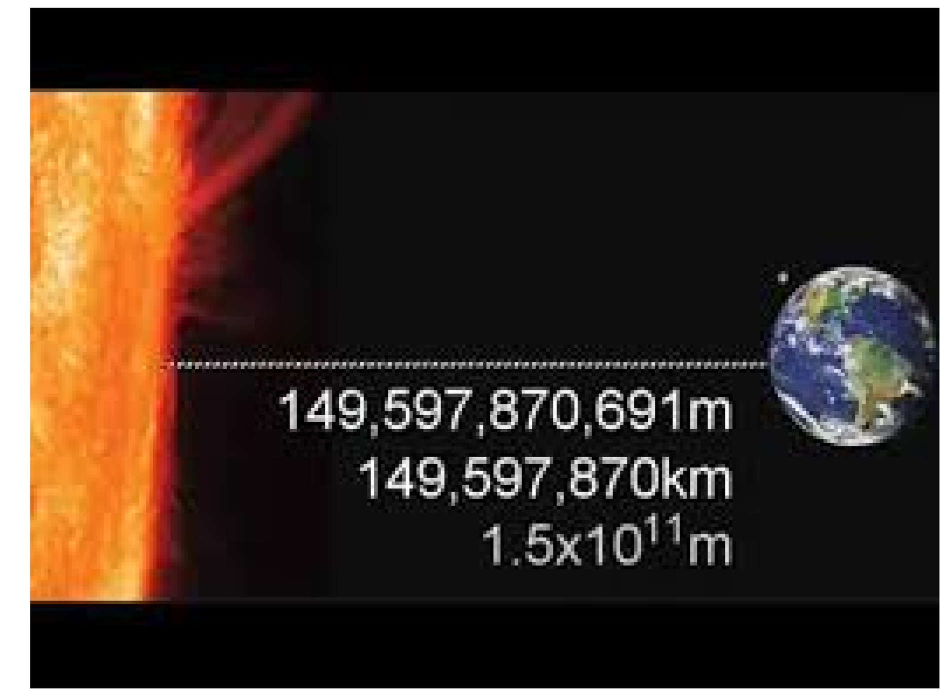

Figure 3: If Susyons are the dark matter, then there ought to be about 11 thousand Susyons in a volume with radius 1 A.U. This is a large volume. Susyons are so massive that they can afford to be very rare, while still accounting for the dark matter.

Figure 4: If Susyons are the dark matter, then the probability that there is a Susyon in the earth's volume is 1 out of a billion. This is a very large volume to search in for a particle, even if that particle is very weird. So, even if Susyons exist, it still appears to be very unlikely that we can observe an individual Susyon experimentally.

The cosmological constant problem and the failure to find superpartners are the motivation behind Frozen SUSY

Forty-five years ago, it looked like SUSY had something to say about the **cosmological constant problem**. But spontaneous breaking of SUSY destroys this. Frozen SUSY goes back to an old, but fascinating, result of rigid SUSY. This result was that the vacuum energy in a rigid SUSY theory is exactly zero when SUSY is not spontaneously broken, even if there is gauge symmetry breaking present. This result is fundamental to Frozen SUSY, as is the **failure to find any superpartners experimentally**.

Technical Implemention of Frozen SUSY

- Frozen SUSY starts from the SU(5) SUSY GUT coupled to Supergravity.
- We choose a special set of 'Exchange Transformations' which interchange the fields and the conjugate Zinn sources, for those fields which correspond to the superpartners to the known particles, as described in [1, 2].
- Then we revise the integration variables in the Feynman path integral to implement these transformations, while preserving the form of the Master Equation. The new variables are sterile non-propagating antighosts.
- We choose a superpotential to generate spontaneous gauge symmetry breaking $SU(5) \to SU(3) \times U(1)$. Half of the Higgs fields are also 'frozen out', and the cosmological constant is zero at tree level.
- The resulting theory still has the same Master Equation as the original theory, but it is implemented in a different way, as set out in [2]. So SUSY is still present, but with a very different result.

Important Results of the Frozen SUSY Model

Frozen SUSY generates a model from SUSY SU(5) GUT with Supergravity that has notable improvements [2]:

- It uses the power of unbroken SUSY to generate a **zero cosmological constant at tree level**.
- There are only **four** parameters in the Gauge/Higgs sector, and they generate **thirteen** reasonable masses:
- The **four parameters** are two masses M_1, M_2, the gauge coupling g_5, and the Planck length κ.
- The **thirteen masses** are: Photon, Graviton, Higgs, Z, W, X, Y, Susyon and five sets of super-Planck unstable scalars.
- The venerable doublet-triplet problem is resolved. All Higgs scalars except the observed one get huge masses.
- The X, Y vector boson masses are near the Planck mass, which implies an acceptable predicted nucleon lifetime.
- No unobserved superpartners are predicted by Frozen SUSY. Squarks, Sleptons, Higgsinos and Gauginos are all removed, as are half the Higgs scalars.
- The resulting theory is constrained by a Master Equation, which implies BRST cohomology.
- The invisible sector, the messenger sector, and the large number of unknown parameters in the MSSM are not needed.
- The Susyon and its mass are predicted as a unique candidate for dark matter.

Exercises for the Student

- Show that if Susyons are gravitationally bound in the Milky Way, then one Susyon hits the earth about every century.
- Add the line \$Assumptions = f > 0 to bring the computer code in [2] up to date, and then check the 13 masses.

Stability of the Susyon

Consider, for example, the following term in the Lagrangian, with one Gravitino ψ, and spin $\frac{1}{2}$ chiral multiplet fermions χ^α and chiral bosons z^β:

$$\frac{1}{\sqrt{2}} g_{\alpha\bar{\beta}} \overline{\psi}_\mu \hat{\partial} \overline{z}^{\bar{\beta}} \gamma^\mu \chi^\alpha + \text{h.c.} \qquad (1)$$

We choose Exchange Transformations so that all of the Squarks and Sleptons z^α and Higgsinos χ^α (and also the Gauginos λ^A and half of the Higgs scalars z^α), become Zinn sources. Then all terms like (1) change to source terms, so that the gravitino cannot use them as a decay mechanism. **The result is that if we take Squarks, Sleptons, Higgsinos and Gauginos to be Sources, the Gravitino becomes stable.**

Expected Density of Susyons From Dark Matter Density

Roughly speaking, the see-saw mechanism in Frozen SUSY yields the Susyon mass through a formula [2] which is close to:

$$M_{\text{Higgs}} M_{\text{Susyon}} \approx M^2_{\text{Planck}} \approx 10^{38} \text{GeV}^2 \qquad (2)$$

If Susyons are the dark matter, then in the volume enclosed within one astronomical unit, we could expect there are about $11,000$ Susyons. The probability that the earth contains one Susyon is about 1 out of a billion. It is not an enticing experiment to try to detect a Susyon, because they are so rare.

Questions about Frozen SUSY

- What does this say about the superstring?
- Can we forget about the MSSM and the Landscape?
- Is there something wrong with this huge Susyon mass?
- What happens when a Susyon collides with the earth?
- What about Quantum Gravity?
- Do galaxy formation and cosmology work?
- What is the effect of the BRST cohomology at one loop?
- Can Frozen SUSY give us some insight into Dark Energy?
- If there is an experimental problem for Frozen SUSY, can it be repaired?
- Does the renormalization group work for $\sin \theta_W$?
- What can be said about the hierarchy problem?

References

[1] J. A. Dixon, "Genuine and effective actions, the Master Equation and Suppressed SUSY," Phys. Lett. B **777**, 31 (2018).

[2] J. A. Dixon, "Suppressed SUSY for the SU(5) Grand Unified Supergravity Theory," arXiv:1706.07796 [physics.gen-ph].

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