Phase Transition to Exact Susy

L. Clavelli

Dept. of Physics and Astronomy
University of Alabama
Tuscaloosa AL 35487

Abstract. The anthropic principle is based on the observation that, within narrow bounds, the laws of physics are such as to have allowed the evolution of life. The string theoretic approach to understanding this observation is based on the expectation that the effective potential has an enormous number of local minima with different particle masses and perhaps totally different fundamental couplings and space time topology. The vast majority of these alternative universes are totally inhospitable to life, having, for example, vacuum energies near the natural (Planck) scale. The statistics, however, are assumed to be such that a few of these local minima (and not more) have a low enough vacuum energy and suitable other properties to support life. In the inflationary era, the "multiverse" made successive transitions between the available minima until arriving at our current state of low vacuum energy. String theory, however, also suggests that the absolute minimum of the effective potential is exactly supersymmetric. Questions then arise as to why the inflationary era did not end by a transition to one of these, when will the universe make the phase transition to the exactly supersymmetric ground state, and what will be the properties of this final state.

Keywords: <string landscape, anthropic principle, susy phase transition,dark energy>
PACS: <95.36.+x,98.80.-k,12.90.+b,12.60.Jv>

There is no doubt that the fact that we are here puts constraints on the laws of physics. The question is whether this provides a sort of explanation for the way things are. The string landscape scenario attempts to provide a statistical understanding for the anthropic principle. This understanding depends on the assumption that the effective potential contains at most a few alternative universes in which life could evolve. There is some debate as to whether or not such viable universes are truly rare [1].

The current universe with broken supersymmetry seems to be accelerating outwards due to a positive vacuum energy density

\[ \varepsilon = 3560 \text{MeV/m}^3 = (0.0023 \text{eV})^4 \]  

(1)

The natural value that might have been expected for this quantity is

\[ M_{\text{Planck}}^4 = 10^{127} \text{MeV/m}^3 \]  

(2)

some 124 orders of magnitude greater than observed.

String theory suggests that, in addition to our broken susy universe, there is a lower lying neighboring valley in the string landscape described by a perfect supersymmetry (susy) [2][3] and, most likely, a vanishing cosmological constant as pictured in figure [1]. Some of the prominent features of the exact susy phase are independent of the exact space-time topology as long as the cosmological constant is not much greater in absolute value than our current one. We expect that this susy minimum is the true vacuum and, therefore, the final phase of the universe. While our primary interest, at present, is in
the final transition from our broken susy world to the exact susy universe, it is thought that the inflationary phase in the very early universe corresponded to a sequence of similar phase transitions to progressively lower vacuum energies. Many such scenarios have been considered recently by Susskind and collaborators [4] as well as by others. It is crucial for the rise of life that the universe escaped from the inflationary phase to a phase of low vacuum energy [5] but also that this transition occurred slowly but soon enough that the universe had not been ripped apart beforehand by inflation.

We have proposed [3] that the primary distinguishing property of matter in the exact susy phase relative to our universe is an effective weakening of the Pauli Principle. This is due to the fact that, in the broken susy world, every atom above helium is characterized by energy permanently stored in a Pauli tower of electrons and in a separate tower of nucleons in the atomic nucleus. In exact susy, conversion of fermion pairs to degenerate scalar pairs not governed by the Pauli principle allows the release of this energy:

$$ff \rightarrow f^+ f^- .$$

This process [6] occurs in every susy model with or without $R$ parity violation. Thus, following a phase transition to exact susy, fermions in excited states will convert in pairs to bosons which can then drop into the ground state.

A phase transition in vacuum will begin with the nucleation of a bubble of true vacuum with radius greater than a critical radius depending on the surface tension $S$.

$$R_c = \frac{3S}{\varepsilon} .$$

Although a supersymmetric true vacuum was not specifically considered, it was generically predicted [7] that such a bubble will expand in the vacuum at the speed of light converting all matter in its path to the new phase. Although there can be no advance
warning of the arrival time of a susy bubble nucleated in the vacuum, the inevitability of such a phase change is implied if the effective potential of string theory is dynamically determined and the true vacuum is supersymmetric.

The four basic questions posed in ref. [3] are

1. **Could life have arisen if there had been a phase transition directly from the inflationary era to the exact susy minimum?**
   There are several tentative arguments that no such possibility exists [3]. For example, one could note that galactic evolution seems to rely on a large dark matter component to provide the gravitational well within which normal matter can condense into galaxies. In an exact susy world the lightest susyparticle would not serve this function. Other sources of dark matter are, of course, possible.

2. **Could life survive, or re-establish itself, following a transition from our broken susy world to the exact susy world?**
   If it is confirmed that the rise of life would have been impossible if there had been a direct transition from an inflationary era to an exact susy universe, one could still ask whether an exact susy universe could support life if there was an intermediate broken susy phase. Like the time critical property of the transition from the inflationary era to our calm broken susy universe, the transition to exact susy might also be time critical. If the current accelerating phase lasts too long, most stars will consist of white dwarfs out of causal contact with each other. At that point it is unlikely that life could be revived through a susy phase transition. On the other hand, if the transition takes place while there are still earth-like planets orbiting burning stars, it is conceivable that life could re-establish itself as discussed in point 3 below.

3. **What would be the primary characteristics of the physics (and biology, if any) of the exactly supersymmetric phase?**
   The primary distinguishing features of bulk susy matter relative to matter in the broken susy phase are the greater numbers of states due to supersymmetry and the weakening of the Pauli Principle due to the possibility of pair conversion from fermions to bosons according to eq.3. Whenever, in the broken susy phase, bound fermions are forced into elevated energy levels, in the susy phase it will be advantageous for them to convert in pairs into their degenerate susy partners which, being bosons, can drop into the ground state. Susy atoms will, therefore, consist of zero, one, or two fermionic electrons but possibly many selectrons. The entire ground state leptonic cloud will be in the 1S state. This has the effect of making susy atoms much smaller in general than their broken susy counterparts. Smaller atoms in a solution will be expected to have slower reaction rates due to the decreased probability of collisions but might bind more tightly into molecules because of the smaller intra-molecular distances.
   Assuming degenerate susy multiplets have the same masses as the standard model particles in the broken susy world, the atomic weight of snuclei increases rapidly with atomic number so that stable elements above susy oxygen must have atomic weights well above 238. Since in the broken susy world there are long-lived elements with atomic weights only up to this number, after a susy phase transition only elements up to susy oxygen would be expected to be abundant. The elements
with higher atomic number would beta decay down to oxygen and below due to Coulomb repulsion and the absence of an effective Pauli principle \([3]\). It is plausible that molecular binding qualitatively similar to that of our world would then occur. Since all the elements needed to form DNA and 96% by weight of animal species are no heavier than oxygen, evolution might be expected to recur leading to the re-emergence of species qualitatively similar to many of those in the broken susy world and defined by the same genetic codes.

4. **Can we estimate the probable time remaining before our universe converts to a susy world?**

The vacuum decay probability per unit time per unit volume depends on the vacuum energy of the current phase, eq. [1] Thus the transition rate is proportional to the volume in which a phase change is possible, proportional in turn to the cube of the scale factor in the Friedman-Robertson-Walker (FRW) metric which, for positive cosmological constant, is exponentially growing at large times.

The natural time scale for the growth in volume of the universe in a FRW metric with vacuum energy density \(\varepsilon\) is

\[
\gamma^{-1} = \frac{1}{\sqrt{24\pi G_N \varepsilon}} = 5.61 \cdot 10^9 \text{yr}.
\]  

Depending on the parameters, there is a non-negligible probability that the Earth will be swallowed by a susy bubble in a time \(T\) from today that is smaller than \(1/\gamma\).

\[
P(T) \approx e^{\gamma T} - 1.
\]

We have outlined a possible new end-phase scenario for the universe. A more detailed review of this scenario is also available \([8]\).

**ACKNOWLEDGMENTS**

This work was partially supported by the DOE under grant number DE-FG02-96ER-40967. We acknowledge stimulating discussions with Paul Cox, Irina Perevalova, Tim Lovorn, and Stephen Barr.

**REFERENCES**

1. R. Harnik, G. Kribs, and G. Perez, *Phys. Rev.* D74, 035006 (2006).
2. S. Giddings, *hep-th/0303031*, *Phys. Rev.* D68, 026006 (2003).
3. L. Clavelli, *hep-th/0508207*, *Int. J. of Mod. Phys.* E Vol 15 No. 6, 1–17 (2006).
4. B. Freivogel, M. Kleban, M.R. Martinez, and L. Susskind, *hep-th/0505233*, *JHEP* 0603:039 (2006).
5. S. Weinberg, *Phys. Rev. Lett.* 59, 2607 (1987).
6. W.-Y. Keung and L. Littenberg, *Phys. Rev.* D24, 1067 (1983).
7. L. Clavelli and I. Perevalova, *hep-ph/0409194*, *Phys. Rev.* D71, 055001 (2005).
8. L. Clavelli, *hep-ph/0607029*. 