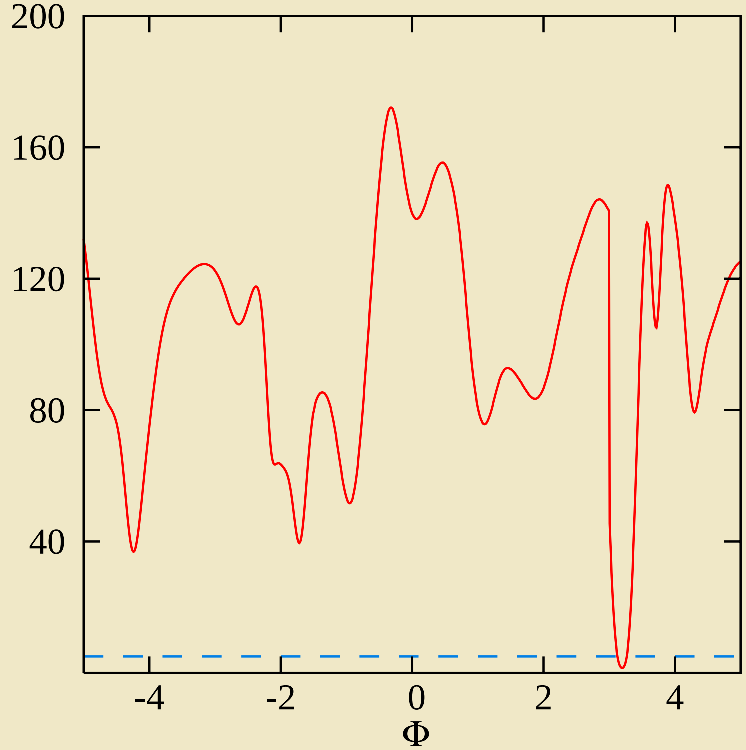
Phase Transition to Exact Susy

(a neighboring valley in the string landscape)

L. Clavelli

Susy06, June 14, 2006



Freivogel,Kleban,Martinez,Susskind (hep-th/0505232v2)
see also M. Douglas, (hep-th/0303194, 0409207)

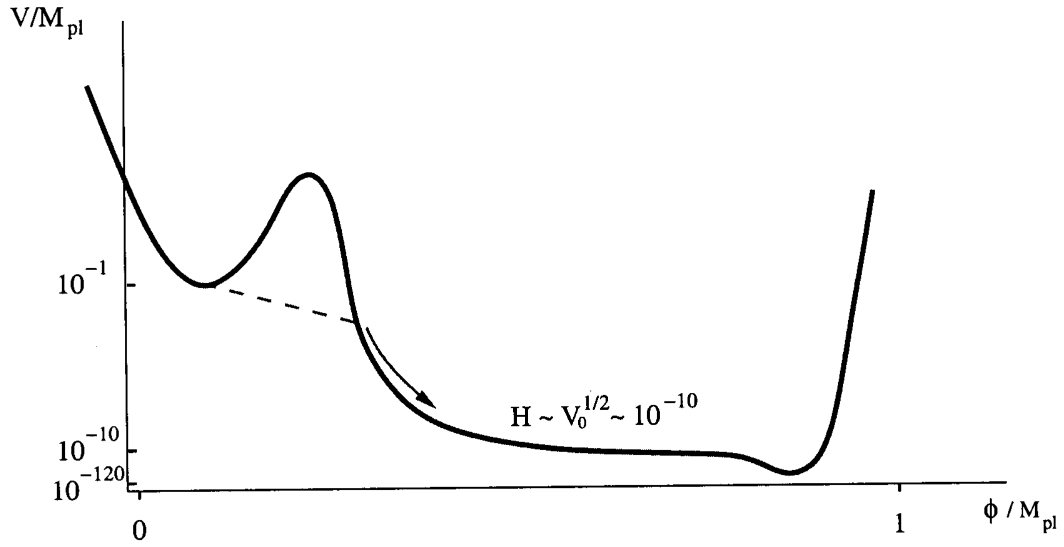
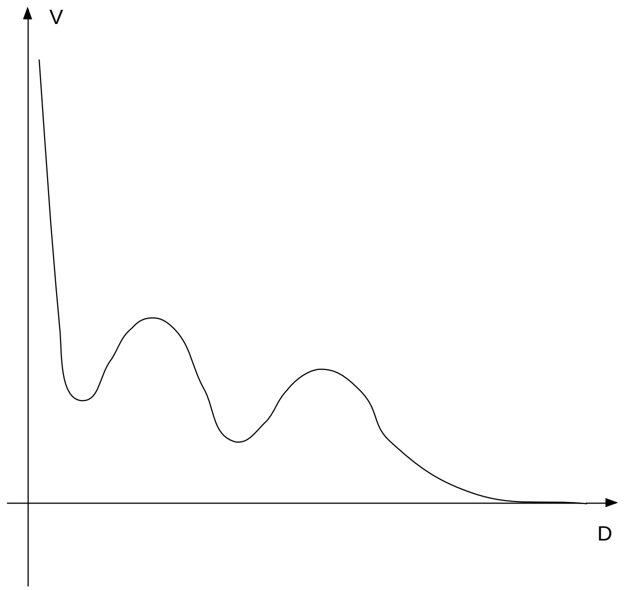
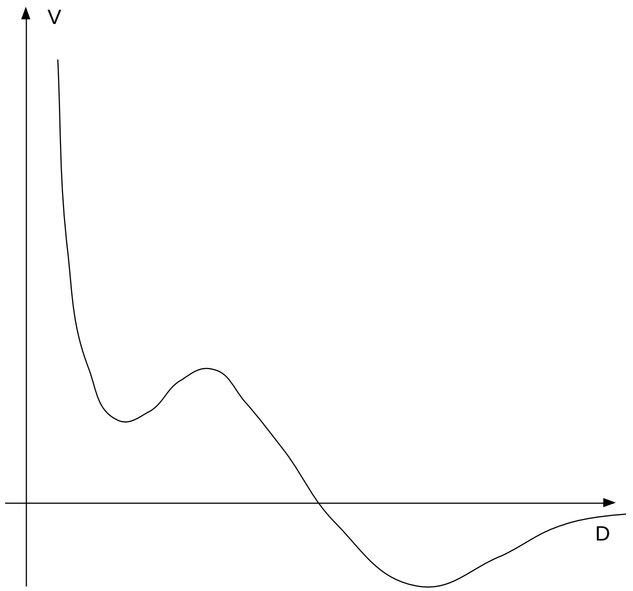


Figure 1: A highly unusual potential which is a typical example of the ones we will consider.

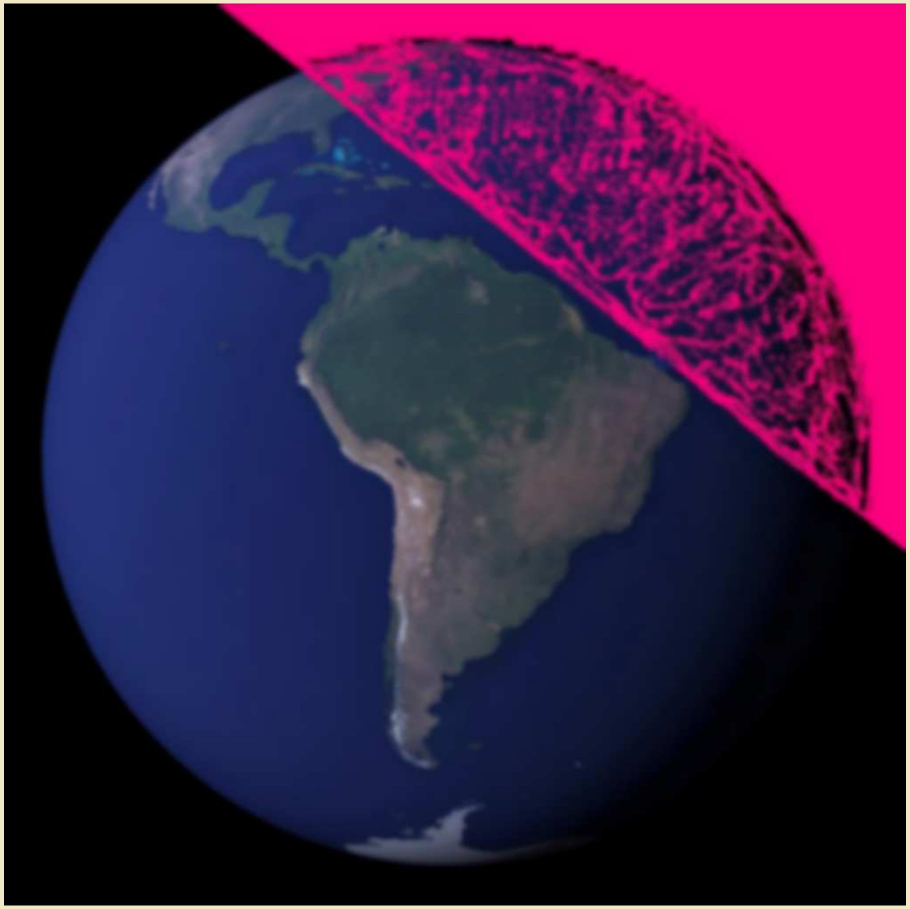
Transition to our current mildly accelerating universe from a rapidly inflating universe

Giddings
(hep-th/0303031)

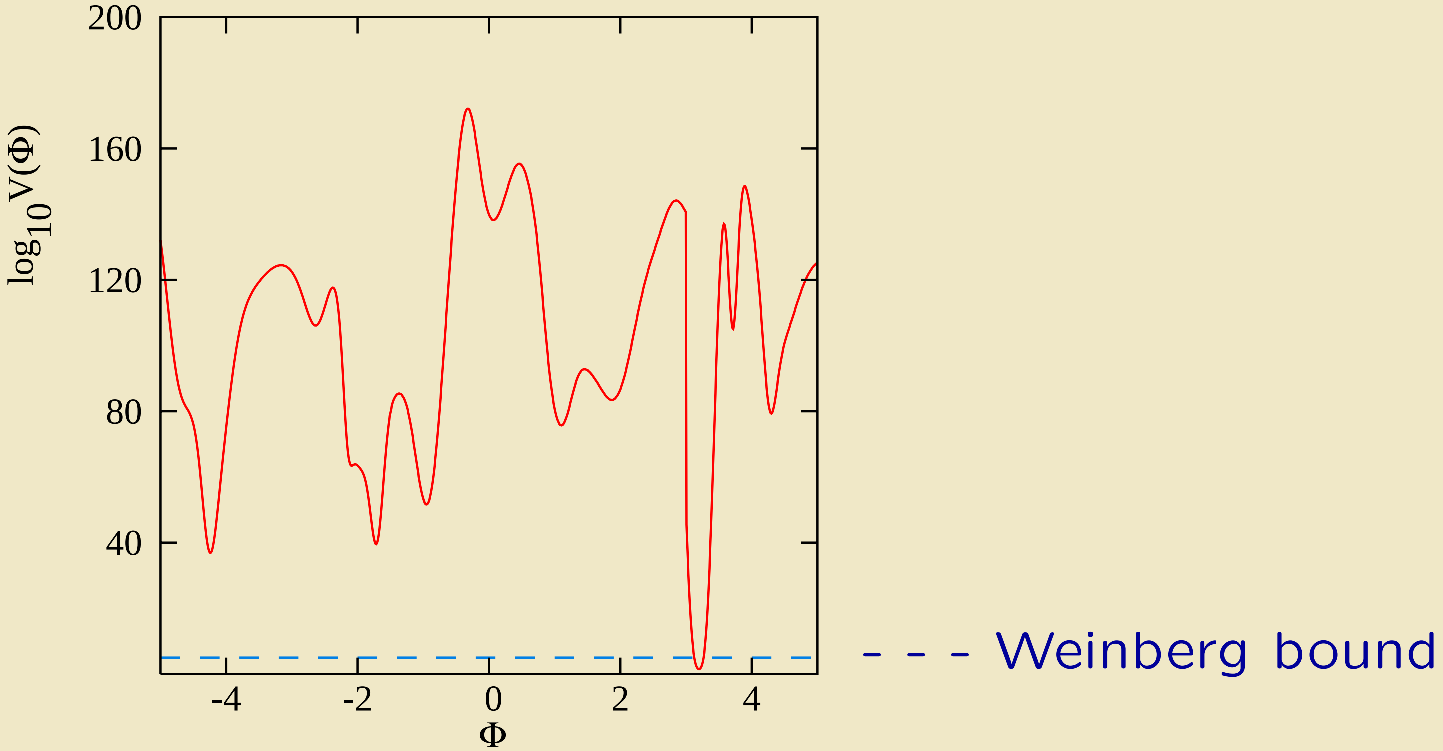




..the existence of a positive vacuum energy generically implies catastrophic instability of our four-dimensional world.

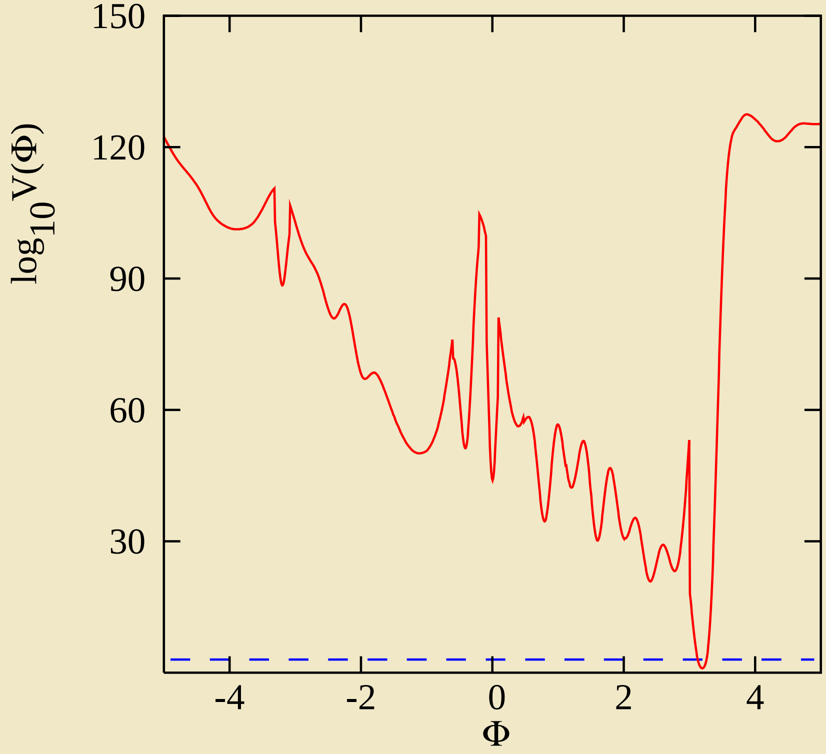


String Landscape



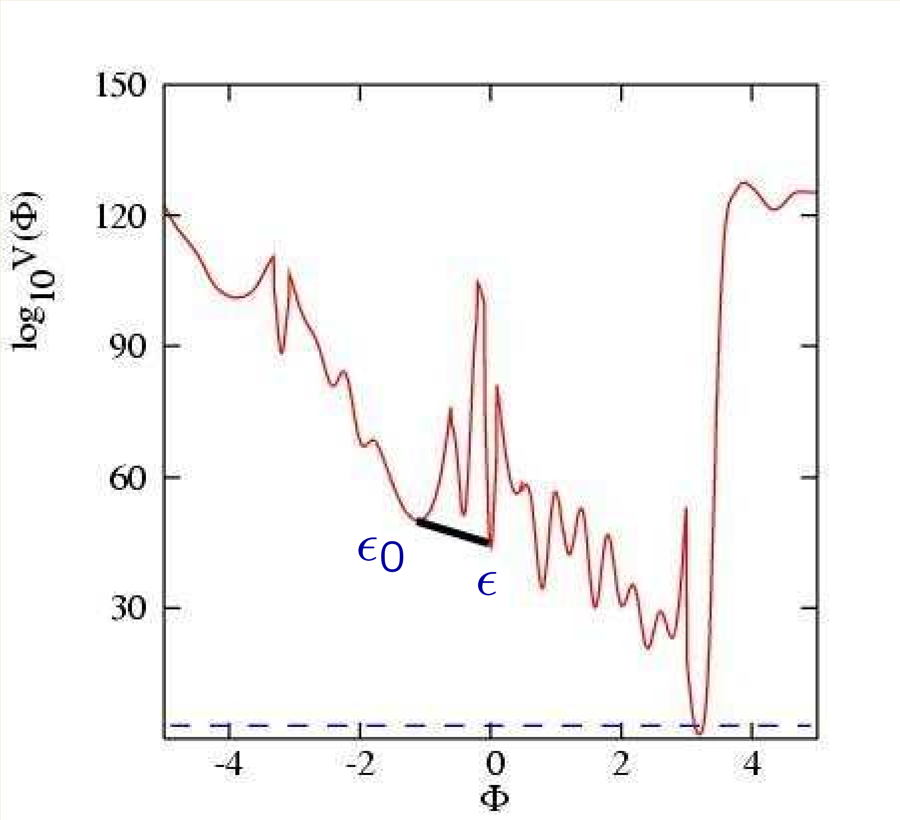
Every minimum in the effective potential of string theory corresponds to a potential universe with widely varying properties. There are perhaps 10^{100} such minima so that one or more would be expected to have low vacuum energy.

slow roll



$\frac{d^2P}{dVdt} = N(\epsilon)Ae^{-13.5\pi S^4/(\epsilon_0-\epsilon)^3}$ (Coleman, De Luccia)

$N(\epsilon) \approx e^{-k(\epsilon/M_P{}^4-1)^2}$ (Most string minima are at high vacuum energy)

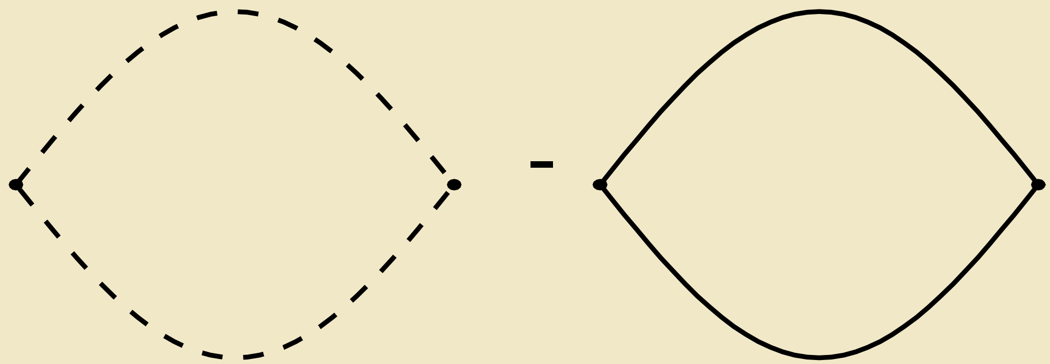


For $\epsilon_0 \approx M_P^4$, most probable transition is from ϵ_0 to $\epsilon_0 - \left(81 S^4 M_P^4 \pi/4k\right)^{1/5}$.

Escape from inflation might occur in many small steps. (slow roll)

Vacuum energy in superstring theory:

bosons - fermions

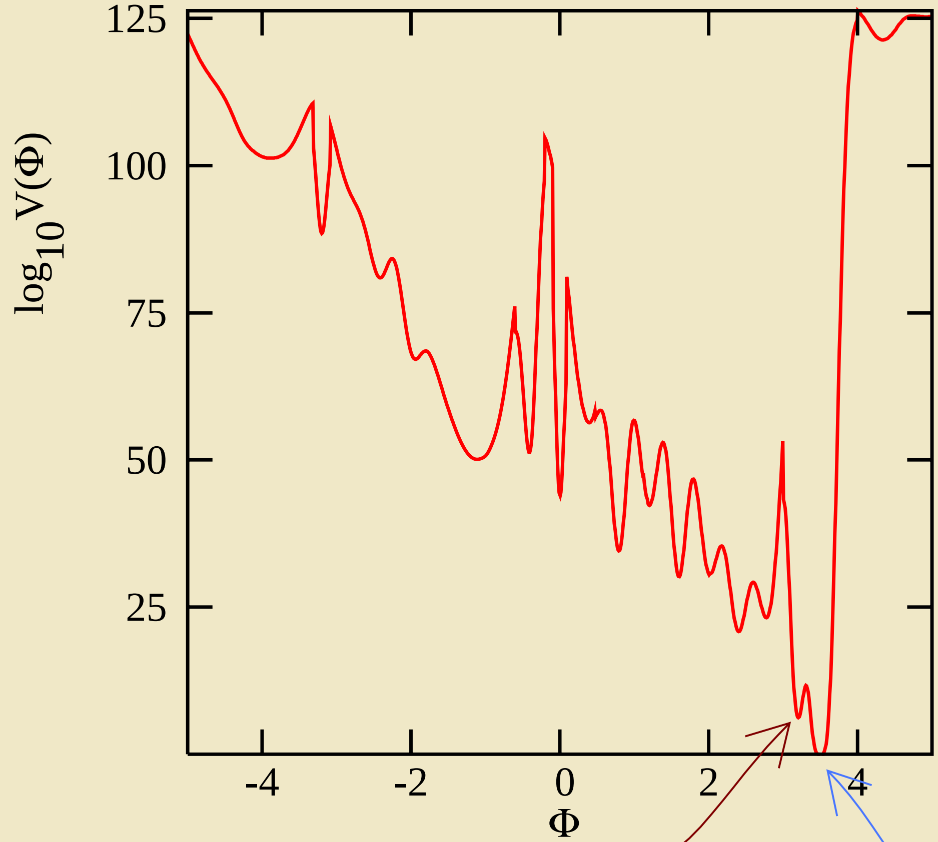


$$\theta_3^4 - \theta_4^4 \qquad - \qquad \theta_2^4 \qquad = 0 \qquad \text{(Jacoby)}$$

$$\theta_3 = \prod_{n=1}^{\infty} (1 + q^{2n-1})^2 (1 - q^{2n})$$

$$\theta_4 = \prod_{n=1}^{\infty} (1 - q^{2n-1})^2 (1 - q^{2n})$$

$$\theta_2 = 2q^{1/4} \prod_{n=1}^{\infty} (1 + q^{2n})^2 (1 - q^{2n})$$



“Susonia”

Susyria
(masses?)

Is Susonia the only minimum that will support life?

”le meilleur des mondes possibles?” (Leibniz 1710)

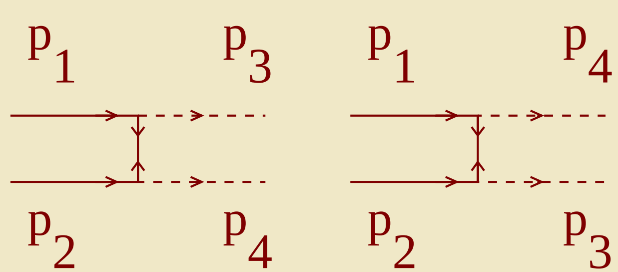
The broken susy world is dominated by the Pauli principle.

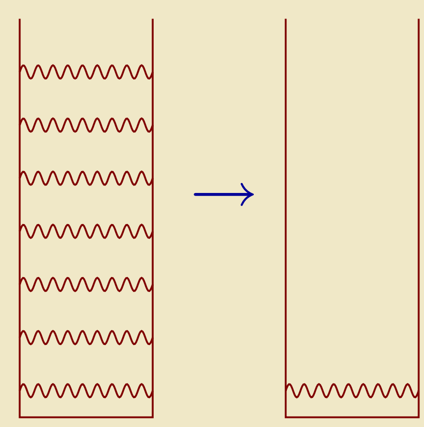
Every atom above Helium is characterized by energy permanently stored in a Pauli tower of electrons and in a separate tower of nucleons in the atomic nucleus.

In exact susy, conversion of fermion pairs to degenerate scalar pairs not governed by the Pauli principle allows the release of this energy.

LC, Irina Perevalova PRD 05

$$ff \rightarrow \tilde{f}\tilde{f}$$





Open Questions:

1. Could life have arisen if there had been a phase transition directly from the inflationary era to the exact susy minimum?

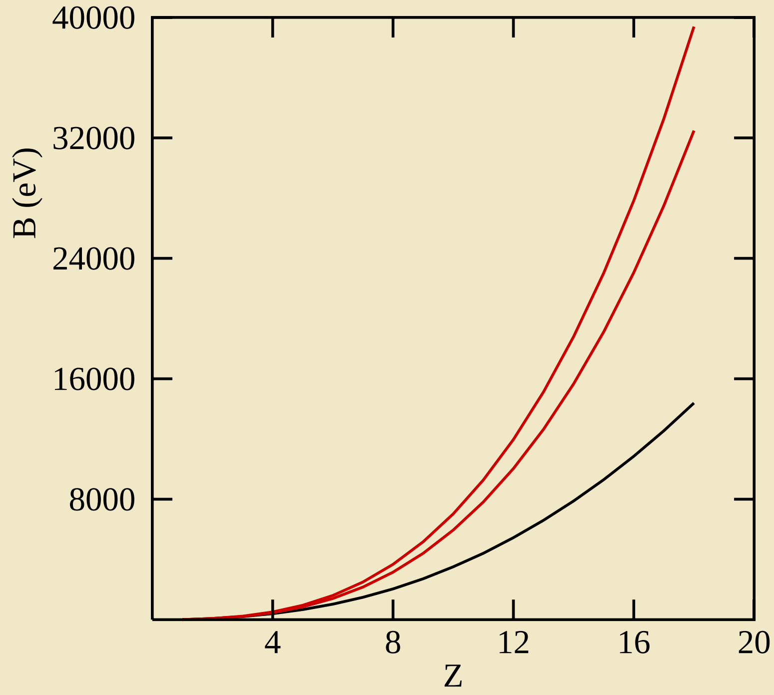
2. Could life survive, or re-establish itself, following a transition from our broken susy world to the exact susy world?

3. What would be the primary characteristics of the physics (and biology, if any,) of the exactly supersymmetric phase?

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

(LC hep-th/0508207, Properties of a Future Susy Universe)

What are the properties of bulk susy matter?



Tim Lovorn,
UA

Total electronic binding energy of atoms as a function of Z (experimental)

Two variational principle estimates of total electronic binding energy in a susy background

Difference between red and black curves gives estimate of electronic energy release in a susy transition.

The Semi-empirical nuclear mass formula

In Susonia, the broken susy world, the masses of nuclei are given, generally to better than 0.1%, by the semi-empirical formula

$$M(Z,A) = AM_n - Z(M_n - M_p) - a_v A + a_s A^{2/3} + a_c \frac{Z^2}{A^{1/3}} + a_a \frac{(Z-N)^2}{A^{2/3}} + \frac{\delta}{A^{1/2}}$$

where

$$\begin{aligned} a_v &= 15.67 MeV \\ a_s &= 17.23 MeV \\ a_c &= 0.714 MeV \\ a_a &= 93.15 MeV \\ \delta &= -11.5 MeV \ (even - even) \\ &= 0 \ (even - odd) \\ &= 11.5 MeV \ (odd - odd) \end{aligned}$$

In the susy phase, the Pauli principle can be evaded by pair conversion from fermions to bosons allowing all particles to drop into ground state energy levels.

The added energy required to store fermions would then be eliminated. We would therefore expect nuclear masses in the susy phase to be governed by a formula of the form

$$M_s(Z,A) = AM_n - Z(M_n - M_p) - a_v A + a_s A^{2/3} + a_c \frac{Z^2}{A^{1/3}} - \frac{11.5 MeV}{A^{1/2}}$$

A susy nucleus (snucleus) would undergo β_- decay if

$$M_s(Z,A) - M_s(Z+1,A) - m_e > 0$$

or β_+ decay if

$$M_s(Z,A) - M_s(Z-1,A) - m_e > 0$$

$$A_{min}(Z) < A < A_{max}(Z)$$

$$A_{min}(Z) = \left(\frac{2a_c(Z - 1/2)}{M_n - M_p + m_e} \right)^3$$

$$A_{max}(Z) = \left(\frac{2a_c(Z + 1/2)}{M_n - M_p - m_e} \right)^3 .$$

Coulomb repulsion disfavors a large number of protons or sprotons, the Pauli principle disfavors a large number of neutrons, but there is no principle disfavoring large numbers of sneutrons.

Hydrogen	$Z = 1$	$1 < A < 19$
Helium	$Z = 2$	$3 < A < 88$
Lithium	$Z = 3$	$8 < A < 243$
Berylium	$Z = 4$	$21 < A < 518$
Boron	$Z = 5$	$45 < A < 946$
Carbon	$Z = 6$	$82 < A < 1562$
Nitrogen	$Z = 7$	$136 < A < 2400$
Oxygen	$Z = 8$	$209 < A < 3494$
Fluorine	$Z = 9$	$304 < A < 4878$

Atomic weights of the stable isotopes of low-lying elements in the exact susy limit of the MSSM. Elements up to He^4 would have the same masses as in the standard model.

Susy Biology?

Adenine	$C_5H_5N_6$
Thymine	$C_5H_6N_2O_2$
Cytosine	$C_4H_5N_3O$
Guanine	$C_5H_5N_5O$

The elements up to Oxygen are sufficient to define the structure of DNA and, therefore, the genetic code of every life form.

Since these elements also exist in a susy world, each individual of every species has a potential supersymmetric counterpart.

When will it happen?

The probability per unit time per unit volume to nucleate a critically sized bubble and therefore affect a phase transition was given by Coleman in the form

$$\frac{dP}{dtdV} = Ae^{-B}$$

where in a vacuum with non-zero energy density ϵ, B takes the form

$$B(vac) = \frac{27\pi^2 S^4}{2\epsilon^3} \quad .$$

Here S is the surface tension of the susy bubble of true vacuum surrounded by the broken susy false vacuum . At any time, t, at which the universe has volume, V(t), the probability per unit time to nucleate a critical bubble which will grow to engulf the universe is

$$\frac{dP}{dt} = AV(t)e^{-B}.$$

In the presence of a vacuum energy density, ϵ, the scale factor will satisfy

$$\frac{\ddot{a}}{a} = -\frac{4\pi G_N}{3}(\rho_{vac} + 3p_{vac}).$$

Putting $p_{vac} = -\rho_{vac} = -\epsilon$, this has the solution

$$a(t) = e^{\gamma t/3} a(0) \left(1 + (\frac{3\dot{a}(0)}{\gamma a(0)} - 1)\frac{1 - e^{-2\gamma t/3}}{2}\right)$$

where, in terms of Newton's constant, G_N,

$$\gamma = \sqrt{24\pi G_N \epsilon}.$$

Neglecting sub-leading terms, we may write the volume of the universe at time t in terms of its present volume $V(0)$ as

$$V(t) = V(0)e^{\gamma t}.$$

The natural time scale for the growth in volume of the universe is

$$\gamma^{-1} = 5.61 \cdot 10^9 yr.$$

Take Earth in 2006 as the space-time origin. The probability per unit time for a susy bubble to arrive at time t is the probability per unit time for a critically sized bubble to be nucleated at any position r' at the retarded time $t' = t - r'/c$

$$\frac{dP(0,t)}{dt} = \int d^3r' e^{\gamma t'} \frac{dP(r',t')}{dV'dt'} dt' \delta(t' - t + r') = e^{\gamma t} A e^{-B} \int d^3 r' e^{-\gamma r'}.$$

$$\frac{dP(0,t)}{\gamma dt} = e^{(\gamma t - B + \ln(8\pi A/\gamma^4))}.$$

Requiring that the integrated probability from the big bang to now ($t = 0$) be less than unity suggests

$$B > ln(8\pi A/\gamma^4), \qquad \gamma^{-1} = 5.6 \cdot 10^9 yr$$

If the lower limit on B is saturated, 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 $1/\gamma$.

$$P(T) = (e^{\gamma T} - 1) e^{(-B + \ln(8\pi A/\gamma^4))}.$$