SUPERSYMMETRY BREAKING IN THE ANTHROPIC LANDSCAPE

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In this paper I attempt to address a serious criticism of the "Anthropic Landscape" and "Discretuum" approach to cosmology, leveled by Banks, Dine and Gorbatov. I argue that in this new and unfamiliar setting, the gauge Hierarchy may not favor low energy supersymmetry.

I don't believe I ever met Ian Kogan but in many ways I felt he was a friend. We shared both a struggle and a hobby. Ian's passion was to understand the universe and like many others he felt the key might be string theory [1]. The struggle to understand was a defining feature of Kogan's work.

The Hobby? We both made an occasional foray into condensed matter physics, again attempting to use lessons from string theory. His last contribution was [2].

1. The Landscape

Perhaps the struggle has entered a new phase. A new idea is beginning to influence the way string theorists view the universe and the laws that govern it. String theory it seems has a Landscape with a tremendous number of non-supersymmetric metastable vacuum states, each with nonvanishing cosmological constant. The spectrum of values of the cosmological constant will likely prove so dense that it is called a discretuum. The number may be as high as 10^{500}. Given this, the question for string theorists may not be–"What can be found in the universe?" but rather "What can not be found?"

How does nature make use of this diversity of possibilities? Here the ideas of Linde, Vilenkin and other cosmologists makes a spectacular entrance– Eternal inflation fills the universe with what Alan Guth calls pocket universes. Each pocket occupies a metastable valley in the Landscape, with its own distinct laws of particle physics and cosmological parameters. It is not surprising that the A-word, the Anthropic principle is also finding a place in this new framework.

If all of this is so, it is completely evident that the technical notions of naturalness, which have played such a large role in elementary particle physics have to be re-evaluated. For the problem of constant, this re-evaluation has already been done. But it is entirely possible that other issues of naturalness will also be affected. The obvious candidate is the gauge hierarchy.

2. The Banks Dine Gorbatov Argument

Let's begin by reviewing a successful use of the anthropic principle. In 1987 Steven Weinberg predicted that if the anthropic principle was correct, the cosmological constant should not be very much smaller than the bound provided by galaxy formation [4]. The argument is straightforward: a much smaller value would require fine tuning of the type which the anthropic principle was supposed to eliminate. Since the anthropic upper bound was only a couple of orders of magnitude above the empirical upper bound, Weinberg argued that the anthropic principle predicted that a cosmological constant would soon be discovered. And it was.

It is worth noting that there are also anthropic bounds on the weak scale that might be strong enough to require a gauge hierarchy like the one we actually observe. Increasing the Higgs expectation value keeping everything else fixed would among other things, increase the strength of gravity, making stars, galaxies and the universe evolve through their life cycle much too fast. Alternatively we could try to keep particle masses fixed by decreasing Yukawa couplings. This would decrease the strength of weak interactions and have many potentially disastrous effects on the creation of heavy elements in stars. There would also be effects on supernovaea, the primary agent for dispersing the elements.

Banks, Dine and Gorbatov (BDG) [3] have recently argued that similar logic can be applied to proton stability and that the exceptionally long life of the proton falsifies the Anthropic Principle. The context of the Banks Dine Gorbatov argument is the "Landscape" or "Discretuum" hypothesis [5–8]. They argue (correctly I think) that the anthropic bound on the proton lifetime is about 10^{17} years. Therefore the vast majority of *anthropically* *acceptable* landscape sites have proton lifetimes many orders of magnitude shorter than the experimental lower limit 10^{32} years.

One way out of the Banks Dine Gorbatov argument is to note that in the non-supersymmetric standard model, there is no mechanism for proton decay. If the scale signaling the breakdown of the standard model is high enough, there is no problem. Thus BDG begin by first arguing that the vast majority of anthropically acceptable vacua have a very low supersymmetry breaking scale. Their argument goes as follows:

Without supersymmetry both the cosmological constant and the Higgs mass scale, μ must be fine tuned. The combined fine tuning is about one part in 10^{150}. If the supersymmetry breaking scale is called M then the natural scale for radiative corrections to the cosmological constant is of order M^4. If the actual cosmological constant is λ then the likelihood of radiative corrections canceling and leaving the small value λ is of order λ/M^4. Thus making M as small as possible will yield the largest number of anthropically acceptable vacua. Similarly they argue that since the Higgs mass is quadratically sensitive to M the actual measure of fine tuning is

$$P(M, \mu, \lambda) = \lambda \mu^2 / M^6. \tag{2.1}$$

For M of order the Planck mass we get 10^{-150} but for M of order the weak scale, the fine tuning is only of order 10^{-60}. There is therefore a very strong statistical bias toward low energy supersymmetry breaking.

But low energy supersymmetry breaking is not without its problems. Many of the things which the standard model solved so neatly–proton stability, neutral strangeness changing currents and the like– are neither automatic nor especially natural in supersymmetric extensions. In particular, dimension 5 baryon violating operators are dangerous. Without some special non-generic symmetry, the proton lifetime in supersymmetric theories is several orders of magnitude too small. I might point out that dimension 4 operators can also occur in generic supersymmetry models. These lead to extremely short lifetimes unless R-parity forbids them. But unlike the dimension 5 operators, the dimension 4 operators are so bad that they can be ruled out anthropically.

The Banks Dine Gorbatov criticism is quite serious in my opinion, and needs to be addressed. In this note I will argue that Banks Dine Gorbatov overlooked one important statistical factor in their analysis which, when included, may change the conclusion. Here is the way I think the argument should go:

What we want to compute is the conditional probability that the supersymmetry breaking scale is M, given that the cosmological constant and weak scale are in the anthropic range. This is not the function P in 2.1. Rather the function P is the conditional probability that the cosmological constant and weak scale are in the allowed range, given that the supersymmetry breaking scale is M. The two distributions are related by Baye's theorem. Define the probability that the cosmological constant and weak scale are in the allowed range, given that the supersymmetry breaking scale is M to be

$$P(\lambda, \mu | M)$$

and the probability that the supersymmetry breaking scale is M, given that the cosmological constant and weak scale are in the anthropic range to be

$$P(M | \lambda, \mu)\,.$$

Also define the unconditional probabilities for given supersymmetry breaking scale and for the values λ, μ to be

$$P(M), \quad P(\lambda, \mu)\,.$$

Then Baye's theorem relates these probabilities

$$P(M|\lambda, \mu) = P(\lambda, \mu|M)P(M)/P(\lambda, \mu)\,. \tag{2.2}$$

Thus in comparing the likelihood of different values of M the factor $1/M^6$ should be multiplied by $P(M)$. The factor in the denominator of 2.2 can be ignored since it is independent of M. The question is, what is the value of the unconditional probability $P(M)$?

I believe it is likely that $P(M)$ tends to zero as a power of M as M tends to zero. The reason is that the conditions for supersymmetry generally pick out a subspace of the landscape whose dimensionality may be a good deal lower than the number of available dimensions including those that parameterize supersymmetry breaking. In this case $P(M)$ could overwhelm the factor $1/M^6$. To illustrate the point I will concoct an illustrative example within a framework similar to that of [6]. The supersymmetry breaking mechanism and the discrete fine tunings of the cosmological constant and Higgs scale take place in different sectors of the theory. In particular the supersymmetry breaking sector is located at the infrared end of a warped compactification while the tunings of the cosmological constant and μ are done through the choice of fluxes in the ultraviolet part of the compactification manifold. The only modification of [6] is to suppose that there are n throats instead of just one.

In [6] the mechanism for supersymmetry breaking is one or more antibranes placed at the end of the throat. The supersymmetry breaking scale is the combined mass of the branes. Thus

$$M = NM_D \,, \tag{2.3}$$

where M_D is the antibrane mass and N is the number of antibranes.

If there are n throats a given total number of antibranes can be distributed among the throats in many ways. For example n_1 antibranes can be placed in the first throat, n_2 in the second throat and so on. The number of ways of partitioning the mass M among n throats is of order M^{n-1}. Thus if the number of throats exceeds six, the distribution favors high energy supersymmetry breaking.

Which kind of throat structure–many or one– is favored by statistics of the landscape? This may be a delicate question. With no condition of supersymmetry breaking, one throat may dominate. But the statistics may be tilted toward many throats just because there are more ways to break supersymmetry if there are many throats.

If nothing else, I hope this note shows that the measure on the landscape is a very subtle issue that demands better quantitative methods of the kind being developed by Douglas and collaborators [8]. The whole idea of fine-tuning has to be re-evaluated and redefined in this new unfamiliar framework.

Acknowledgments

I would like to thank Tom Banks, Michael Dine, Ben Frievogel, Savas Dimopoulos Steve Shenker, Scott Thomas, Shamit Kachru and Michael Douglas for very useful discussions.

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