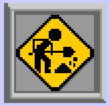
Construction and Statistics of M theory Vacua

Bobby Acharya
I.C.T.P.
String Vacuum Workshop
Munich, Nov. 2004


www.begann.de

Overview

Part 1: ***Vacuum Construction.***

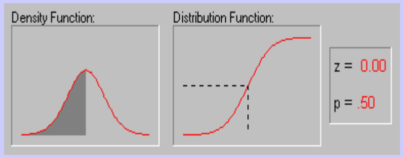


G2 Holonomy and Freund-Rubin Vacua

Brief Review of these M theory Vacua

Highlight the main outsdanding problems
(finding G2 manifolds with singularities)

Part 2: ***Vacuum Statistics***



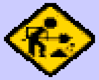
(w/ Frederik Denef and Roberto Valandro, to appear)

Distributions of susy and non-susy vacua.
Volumes and Cosmological constants.
Distributions of Yukawa couplings.

G2 holonomy Vacua

- D=4 N=1 Compactifications
- X must be endowed with particular singularities to obtain Yang-Mills fields and chiral fermions (BSA, Atiyah-Witten, BSA-Witten)

- Extremely interesting particle physics (Witten): supersymmetric grand unification, light higgses, heavy triplets, suppressed dim 4 and 5 proton decay. Quarks, Leptons localised in the extra dimensions: Natural hierarchies of Yukawa couplings.

- Main outsdanding problem: explicit construction of the G2 holonomy manifolds with singularities. 

  Existence: duality.   Local picture: established.

Stabilising G2 Moduli

- Classically $b_3(X)$ moduli
- BSA hepth/0212294: ***all*** get fixed by fluxes for bulk 4-form G and gauge fields localised on 3-cycle Q.
- Vacuum: supersymmetric AdS4 (and *unstable* dS4)

- Crucial ingredient: Q admits a complex flat connection with a ***non-real*** Chern-Simons invariant.

- Main problem again: construction of a compact example
- If Q is hyperbolic the mechanism works.

- ``Many'' vacua obtained by changing flux. How many?
- Non-susy vacua? Can vacuum energy be positive?
 ``Many'' hierarchies of Yukawa couplings.
- We will answer these later.

Freund-Rubin Vacua

- Flux Compactifications to AdS4 (intrinsic scale)
- Near Horizon (Large N) limit of M2 branes
- Existence of chiral fermions established recently (BSA, Denef, Hofman, Lambert, hepth/0308046)
- Supersymmetric and Non-supersymmetric

Main Outsdanding problems:

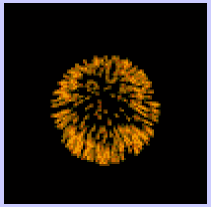
- Find examples with more realistic particle physics
- Classically these vacua are not realistic – the fundamental scale is too low. Need to understand large quantum corrections.


www.begann.de

Statistics: Freund-Rubin

Classically an infinite number of vacua labeled by N

At large N space decompactifies.



$$N_{vac}(V < \tilde{V}) = \tilde{V}^{6/7}$$

Similarly, $$N_{vac}(\Lambda > \tilde{\Lambda}) = \infty$$

$$N_{vac}(\Lambda < \tilde{\Lambda}) = \tilde{\Lambda}^{-2/3}$$

Can also allow X itself to vary:

Families of Einstein manifolds X(k) labeled by an integer k

Two parameters per vacuum (N, k)

This significantly changes the previous distributions:

$$N_{vac}(V < \tilde{V}) = \tilde{V}^{6}$$

$$N_{vac}(\Lambda < \tilde{\Lambda}) = \tilde{\Lambda}^{-2}$$

More vacua at large volume and small vacuum energy.

We also studied joint distributions.
The results depend upon the relative values of $\tilde{V}, \tilde{\Lambda}$

For example:

$$If \quad -\Lambda^{-1} < \tilde{V}^{9/7} \qquad\qquad If \quad \tilde{V}^{9/7} < -\Lambda^{-1} < \tilde{V}^{3}$$

$$N_{vac}(V > \tilde{V} ; \Lambda > \tilde{\Lambda}) = 0 \qquad N_{vac}(V > \tilde{V} ; \Lambda < \tilde{\Lambda}) = \tilde{\Lambda}^{-3} \tilde{V}^{-3}$$

This demonstrates strong correlations between observables on the landscape.

Eg the second region favours small volume and cosmological constant.

Susy? These results are ***independent of susy***. There are at least as many non-supersymmetric, stable Freund-Rubin vacua as there are supersymmetric.

What about analagous results for the case of G2 holonomy vacua?

Statistics of G2 Vacua

How to study without a concrete example?

The superpotential is simple. All the X dependence comes from the Kahler potential. We simply took a simple class of Kahler potentials, consistent with the constraints of G2 holonomy.

Even with this simple class, a lot of details.

I will just summarise the main results.

There are $n \equiv b_3(X)$ moduli fields s_i and fluxes N_i

The crucial Chern-Simons invariant is called c_2

We found that for a ***fixed choice of flux*** there are

2^n vacua.

Of these one is the supersymmetric vacuum described in hepth/0212294. One is unstable de Sitter, also described in hepth/0212294.

The rest are ***non-supersymmetric*** vacua with ***negative*** vacuum energies.

An exponentially large number are ***stable*** eg 2^{n-4}

These are also, roughly the ratios obtained by varying the fluxes.

In all of these vacua, the moduli decrease with flux:

$$s_i \sim \frac{c_2}{N_i}$$

This means that the volume decreases when the fluxes get large. Therefore:

Many more vacua at small volume (model dependent)

Finite number of vacua with bounded volume.

Similar remarks about cosmological constant:
many more vacua with large vacuum energy.

These results are very different to the Freund-Rubin case. However, there are some similarities when one considers joint distributions.

Yukawa Couplings

The Yukawa couplings are exponentially sensitive to changes in moduli, so small changes in flux can produce large changes in the couplings, leading to many possible hierarchies (BSA, hepth/0303234)

The number of vacua in a region of moduli space is

$$N_{vac} \sim c_2{}^{n} A_n$$

Where A is the volume of the region. (cf IIB case)

If each Yukawa coupling is dominated by a single membrane instanton, then fixing q couplings reduces this:

$$N_{vac}(q\,Yukawas) \sim c_2{}^{n-q} A_{n-q}$$

The renormalisable Yukawa couplings are presumably small in number compared to n, the number of moduli.

However, if there are also a large number of non-renormalisable couplings which play a significant role in the model then this could give a significant reduction in the number of vacua.

What Do We Learn?

- Different regions of the landscape ***can*** look different.

- Main result: evidence for exponentially more ***non-supersymmetric***, stable states on the landscape.

  Is this good or bad?

  In some sense its irrelevant because we dont yet have an example of a stable point on the landscape with small positive vacuum energy.

- Essentially: the Brown/Teitelboim(+Bousso/Polchinski) mechanism fails for these M theory vacua. All the fluxes get ***used*** up in stabilising the moduli.

- In KKLT it ***might*** work, but we still have to check this.

If our results also apply to regions of the landscape with more reasonable cosmology then these regions contain an overwhelming number of non-susy states suggesting that high scale susy breaking prevails.

However, because those vacua will necessarily contain large cancellations between contributions to the vacuum energy the distributions are likely to be different.

die Rinne

www.begann.de


www.begann.de