Non-Perturbative Corrections to the OSV Conjecture

Hirosi Ooguri (Caltech)

The Joint DPF/JPS Meeting
Honolulu, Hawaii (Oct 30 - Nov 3, 2006)

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Comments on the String Landscape

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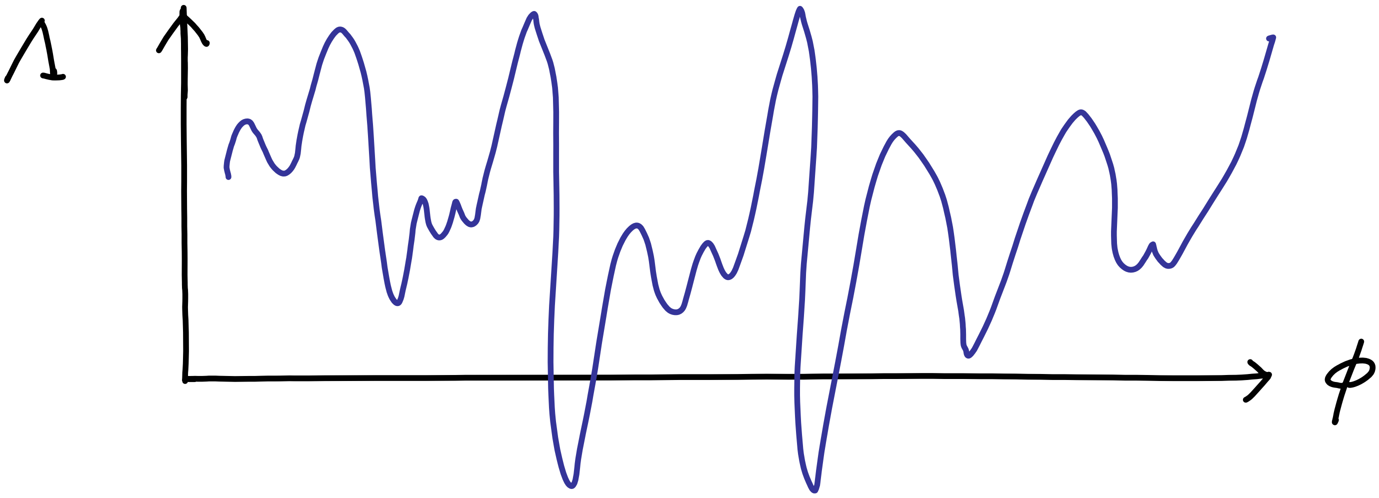
There is a growing body of evidence for the conjecture that there is a large landscape of meta-stable vacua with broken supersymmetry in string theory.



(1) Does this exist, really?

(2) If so, what kind of science can one do with it?

Does the landscape exist?

Some historical perspective:

In the early study of heterotic string compactification, it has already been suggested that there is a large number of ground states in string theory.

The non-uniqueness was noted, for example, by Lerche, Luest and Schellekens in 1987:

> *It seemed to me that it was wishful thinking to assume that all these problems [unbroken supersymmetry, unfixed moduli] would be solvable for just one ground state, the one corresponding to the standard model.*
>
> *(Schellekens; see hep-th/0604134 for more historical notes.)*

"These problems" could change the story drastically.

For example, Dine and Seiberg argued in 1985 that, if the moduli are fixed, a stable non-trivial vacuum cannot be found by perturbative computation since the weak coupling limit is a runaway direction.

What is it that we know now that we did not know then?

The work by Kachru-Kallosh-Linde-Trivedi (following the observations by Weinberg and Bousso-Polchinski) opened a new ground to study meta-stable vacua in string theory.

Most of the landscape analysis has relied on the supergravity approximation + instantons.

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Recently Intriligator-Shih-Seiberg demonstrated that simple gauge theories can have meta-stable vacua.

This story has been embedded in string theory:

brane configurations: Ookouchi + H.O./0607183; Franco, et al/0607218; Bena, et al/0608157

large *N*: Argurio, et al/0610212;
Aganagic, et al/0610249

This development may lead to a new insight -- a new language to describe the string landscape.

Suppose the large landscape exists.

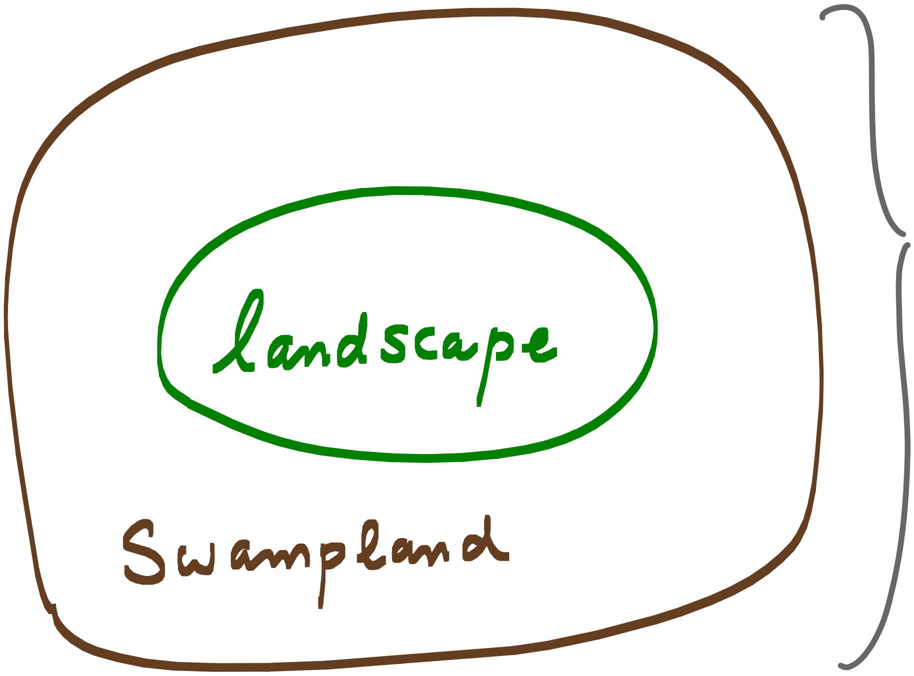
Does it mean that anything goes?

Can all possible low energy effective theory be realized?

Landscape and Swampland

Define the landscape as a set of low energy effective theories that have UV completions in consistent quantum gravity theories.

How can we characterize it ?



All low energy theories that one can write down.

Vafa

Early Observations

from general principles :

- anomaly cancellation
- no global symmetry

from string theory constructions :

- limit on gauge groups

e.g. cannot have $U(N)$ with arbitrarily large N.

(This is possible if $M_{Planck} = \infty$.

e.g. type II on $\mathbb{C}^2/\mathbb{Z}_N \times T^2 \times \mathbb{R}^4$

$\Rightarrow$ $U(N)$ gauge symmetry)

Constraints on gauge coupling

(Arkani-Hamed, Motl, Nicolis, and Vafa,
hep-th/0601001)

Consider a low energy theory with a U(1) gauge field with coupling e.

For a general effective theory

- e and Newton's constant G are independent.
- If $e \ll 1$ and without other scale, the low energy theory would be valid upto m_{Planck}.

However, ...

AMNV claims

- There have to be a charged particle of mass $m < e \cdot m_{\text{Planck}}$.
- The effective theory breaks down prematurely at $\Lambda < e \cdot m_{\text{Planck}}$.

These generalize the statement that there is no global symmetry in a consistent quantum gravity theory since they imply that we cannot take the limit $e \to 0$.

Note:

- The constraints disappear in the limit $M_{Planck} \to \infty$.

- The inequality $\Lambda < e \cdot M_{Planck}$ means that the LHC would not find extra $U(1)$ interactions with very weak coupling constants.

Constraints on light scalar fields

$$\mathcal{L}_{eff} = g(\phi)_{ij}\, \partial_\mu \phi^i \partial^\mu \phi^j + \dots$$

The fields ϕ live in a manifold $\mathcal{M}$ with metric $g(\phi)_{ij}$.

The following properties hold for all known effective theories derived from string theory.

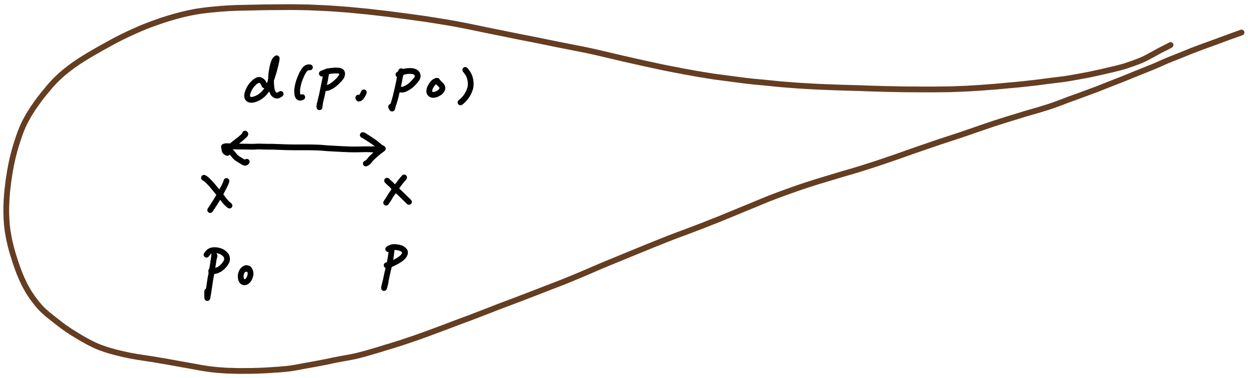
(Vafa + H.O., hep-th/0605264)

They should also hold when a small potential is turned on.

0. All the coupling constants of the theory come from expectation values of ϕ. In particular, they can be varied locally at a finite cost of energy.

1. $\mathcal{M}$ has infinite diameter.

Namely, the possible distances between pairs of points in $\mathcal{M}$ are unbounded.



This does not have to hold when $M_{\text{Planck}} = \infty$.

e.g.

non-compact Calabi-Yau $\supset S^2$

N D_6 branes on S^2

$\Rightarrow$ moduli space $\sim (S^2)^{\otimes N}$

Compact

2. Fix $p_0 \in \mathcal{M}$.

The property 1 means we can find p so that $d(p, p_0)$ is arbitrarily large. As $d(p, p_0) \gg 1$, there appear extra light particles with masses $\sim e^{-c \cdot d(p, p_0)}$

for some $c > 0$.

The low energy effective theory at p_0 breaks down as $d(p, p_0) \to \infty$.

e.g.

Kaluza-Klein modes

Wrapped branes and strings

Typically, infinitely many

- M theory on S^1, R : radius

metric : $\frac{dR^2}{R^2}$

$$\Rightarrow \quad d(R, R_0) = \left| \log\left(\frac{R}{R_0}\right) \right|$$

- $R \to \infty$: light Kaluza-Klein modes

In 10d scale $m \sim R^{-1/8} R^{-1}$

$$\sim \exp\left(-\frac{9}{8} d(R, R_0)\right)$$

- $R \to 0$: light stringy excitations

In 10d scale $m \sim R^{-1/8} R^{1/2}$

$$\sim \exp\left(-\frac{3}{8} d(R, R_0)\right)$$

- It has been noted by

  Banks, Dine, Fox, and Gorbatov (hep-th/0303252)

  Arkani-Hamed, Motl, Nicolis and Vafa (hep-th/0601001)

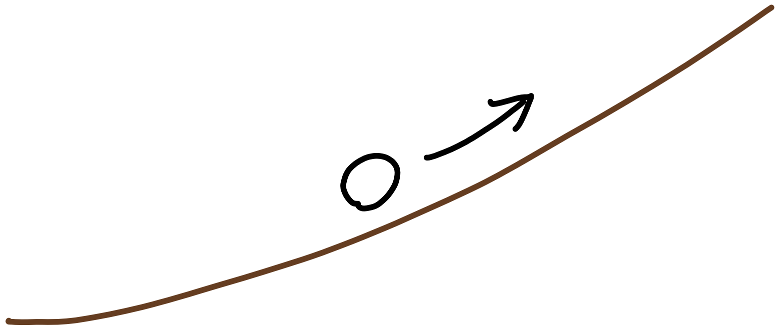
  Svrcek (hep-th/0607086)

  that, in all examples of compactifications to 4d that they studied, the axion decay constant F cannot be made parametrically larger than M_{Planck}.

$$\mathcal{L} \sim F^2 (\partial\theta)^2 + \cdots$$

$$F \sim \text{radius}$$

This may have implications on models of inflationary cosmology.



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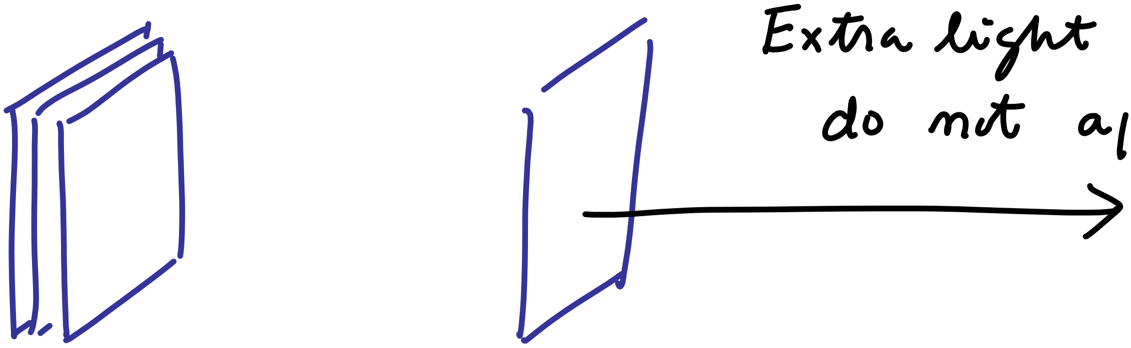
e.g.

Dp branes in $\mathbb{R}^{10}$.



Extra light particles do not appear.

3. $\pi_1(\mathcal{M}) = 0$.

More precisely, there is no non-trivial 1-cycle with minimum length within a given homotopy class.

(Typically, $\mathcal{M} \sim T/\Gamma$

with T : contractible

Γ : duality group

Γ is generated by enhanced symmetries at different points of $\mathcal{M}$.

$$\Downarrow$$

$\forall h \in \Gamma$, $h = g_1 \cdots g_n$

s.t. a closed path for g_i is contractible at its fixed point.)

This does not have to hold when $M_{\text{Planck}} = \infty$.

- D5 brane on $T^2 \times \mathbb{R}^4$

  $\Rightarrow$ moduli space is $\underset{\substack{\uparrow \\ \text{U(1) holonomy}}}{T^2} \times \underset{\substack{\uparrow \\ \text{transverse} \\ \text{directions}}}{\mathbb{R}^4}$

- Axions in QCD $\quad (\mathcal{M} \sim S^1)$

  $\Rightarrow$ For finite M_{Planck},
  it should have a radial direction
  where the S^1 can shrink.

It appears that theories coupled to gravity are more limited than generic field theories in non-trivial ways.

This is similar to the mathematical distinction between

non-compact ⋯ easy

compact ⋯ difficult