Challenging the Swampland Distance Conjecture

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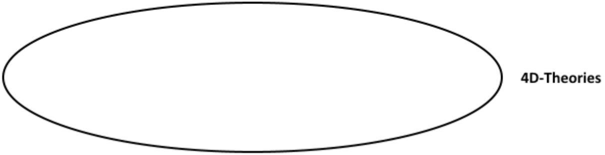
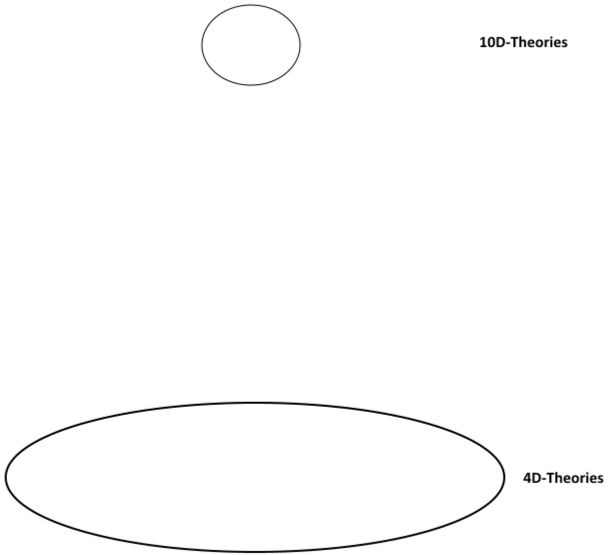
The Landscape and the Swampland



The Landscape and the Swampland



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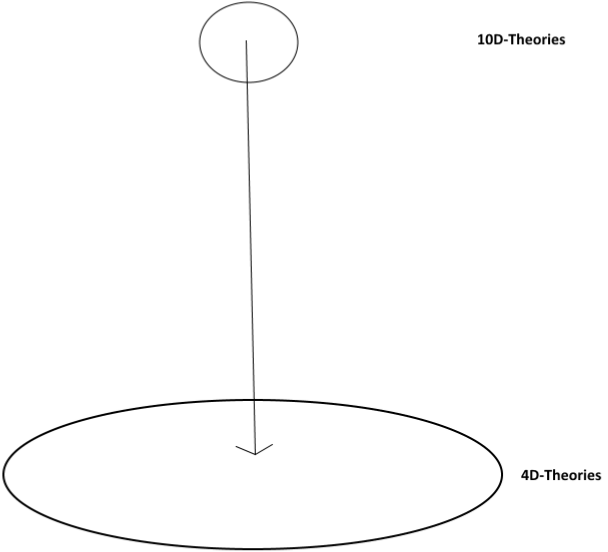

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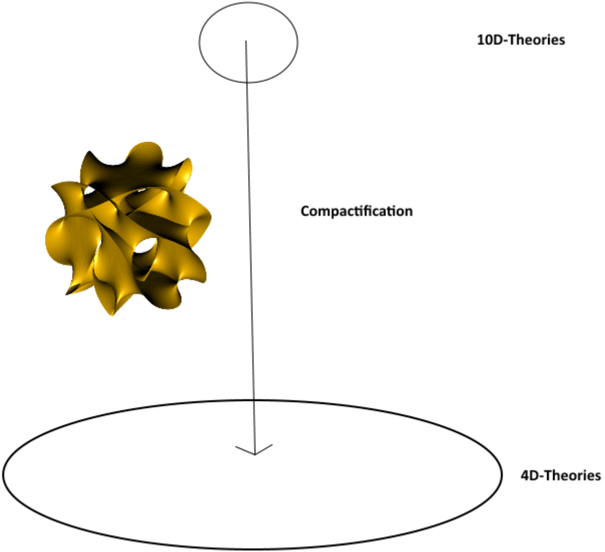

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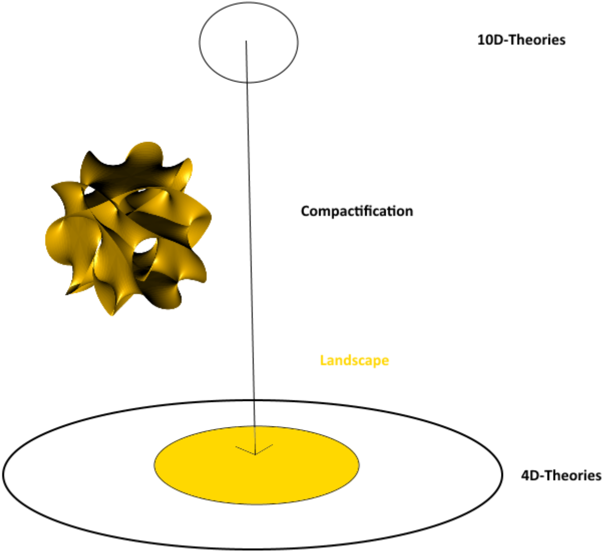

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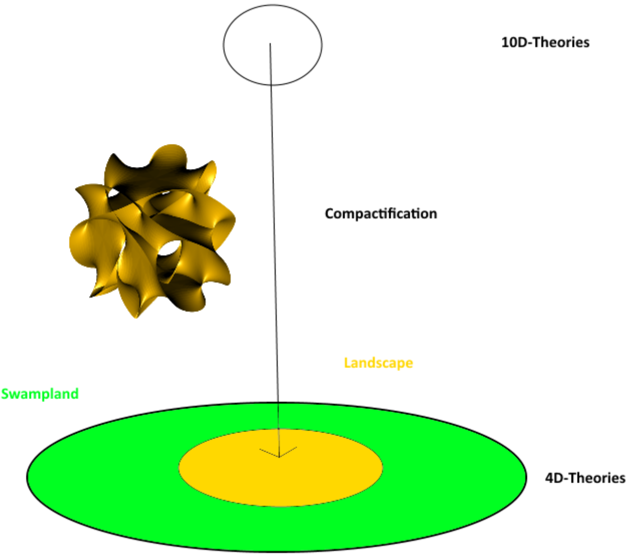


The Moduli Space

- The swampland conjecture is a statement about effective theories in the landscape.
- Assume type II string theory, then the phenomenological most attractive models are 3d Calabi Yau compactifications.
- The 4d effective theory is a $\mathcal{N} = 2$ supergravity theory.
- Deformations of the internal space($=$ moduli) appear as scalar fields in the effective theory.

The Moduli Space

- There are two different types of deformations, Kähler deformations and complex structure deformations
- Mirror symmetry relates the Kähler deformation of one Calabi Yau to the complex structure sector of its mirror

$\rightarrow$ only need to calculate one of the two!
Example: Torus

$$\tau = \frac{R_1}{R_2} \qquad t = R_1 R_2 \tag{1}$$

In this case, Mirror symmetry is $R_2 \rightarrow \frac{1}{R_2}, \tau \leftrightarrow t$

The Swampland Distance Conjecture

The original conjecture

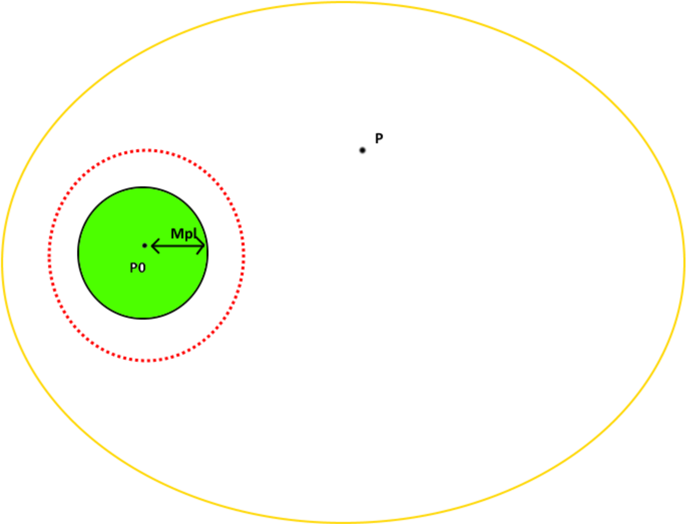
If two points P and P_0 are infinitely far away in the moduli space, there is an infinite tower of exponentially light states.

The refined conjecture

If two points P and P_0 are more than M_{Pl} away in the moduli space, there is an infinite tower of states which mass can be described by

$M_P \sim M_{P_0} \cdot e^{-\lambda \frac{\Theta(P,P_0)}{M_{Pl}}}$.

The Swampland Distance Conjecture



The Proper Distance

The proper distance Θ between two points in the moduli space is the length of the shortest geodesic $\gamma(\tau)$ connecting the two points.

$$\Theta = \int_{\gamma} d\tau \sqrt{G_{ij} \frac{\partial \Phi_i}{\partial \tau} \frac{\partial \Phi_j}{\partial \tau}} \tag{2}$$

Behavior of the proper Distance

$$M_P \sim M_{P_0} \cdot e^{-\lambda\Theta} \to \Theta \sim \frac{1}{\lambda}\log[\frac{M_{P_0}}{M_P}] \tag{3}$$

$$M_{KK} \sim \frac{1}{r} \to \Theta \sim \frac{1}{\lambda}\log[\frac{r}{r_0}] \tag{4}$$

Torus with fixed complex structure→ only 1 Kähler modulus t.

$$G_{tt} = \frac{3}{4t^2} \tag{5}$$

$$\Theta = \int_{t_0}^{t} dt\sqrt{\frac{3}{4}}\frac{1}{t} = \frac{1}{\lambda}\log(\frac{t}{t_0}) \qquad , \lambda = \frac{2}{\sqrt{3}} \tag{6}$$

The Proper Distance

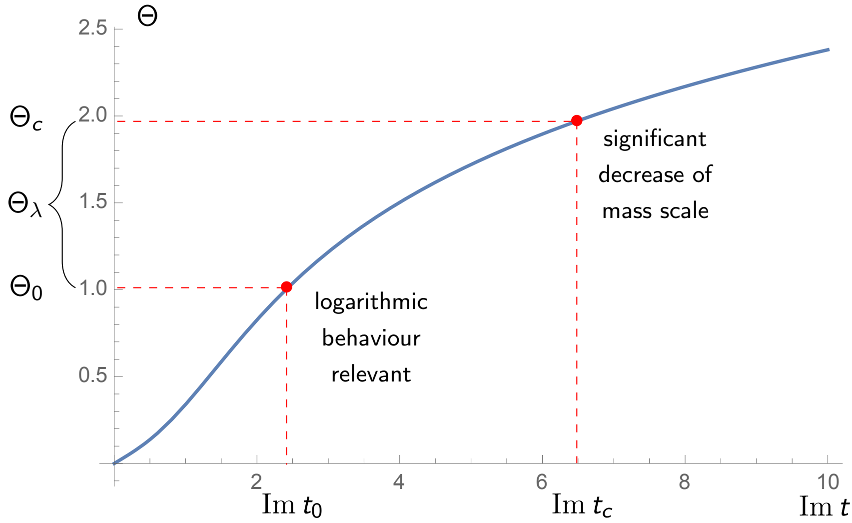


Figure: Expected relation between proper field distance Θ and $\mathrm{Im}\, t$.

The Programm

Goal: Check the conjecture ($\Theta_c = \Theta_0 + \Theta_\lambda = \mathcal{O}(M_{Pl})$) in explicit examples.

TODO:

- Calculate the metric on the moduli space.
- Find the shortest geodesic between two points.
- Calculate the proper distances.
- Check at which distance the logarithmic behavior appears.

The Kähler Potential

$$G_{ij} = \partial_i \partial_j K(\Phi) \tag{7}$$

The Kählerpotential K of the effective SUGRA theory can be calculated via different methods:

- Periods of the Calabi Yau
- Gauged Linear Sigma Models

Both methods work and have different advantages and disadvantages
$\rightarrow$ use both and crosscheck.

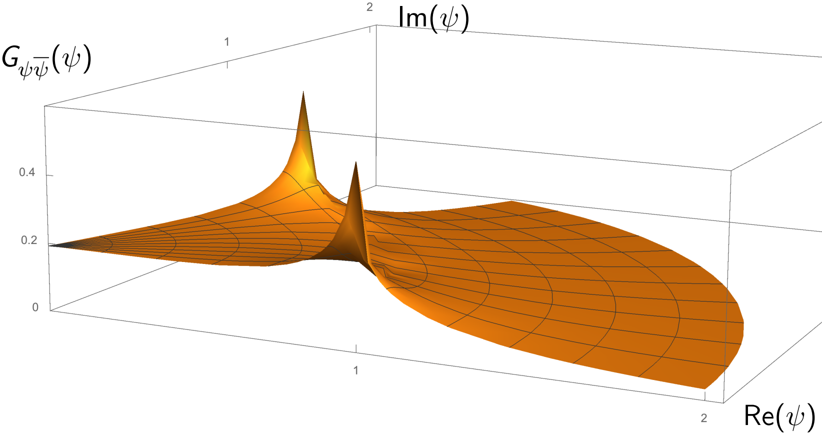


Figure: The metric on the moduli space of the mirror quintic.

The Programm

TODO:

- Calculate the metric on the moduli space. ✓
- Find the shortest geodesic between two points.
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Geodesics for the Quintic

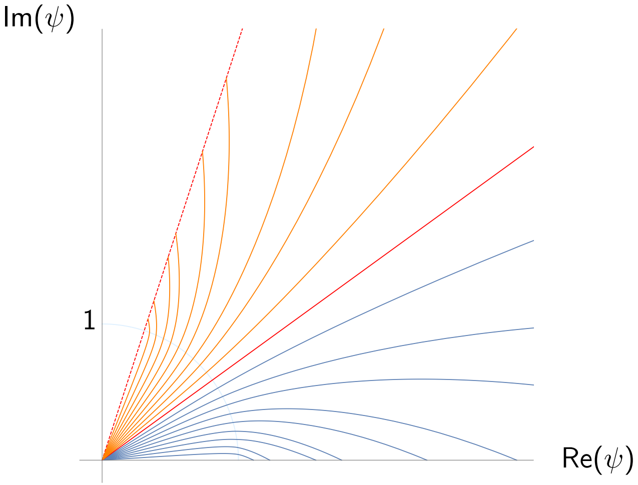


Figure: Geodesics for the initial data $(r, \dot{r}, \theta, \dot{\theta}) = (0, 1, i \cdot \pi/50, 0)$, for $i = 1, \ldots, 10$. The orange geodesics are the $\mathbb{Z}_2$ images.

The Programm

TODO:

- Calculate the metric on the moduli space. ✓
- Find the shortest geodesic between two points. ✓
- Calculate the proper distances. ✓
- Check at which distance the logarithmic behavior appears.

The logarithmic Behaviour

Asymptotic form of the proper distance Θ at the LCS point known.

$$\Theta = \alpha \log(t) + \frac{\beta}{t^3} + \mathcal{O}\left(\frac{1}{t^6}\right) \, . \tag{8}$$

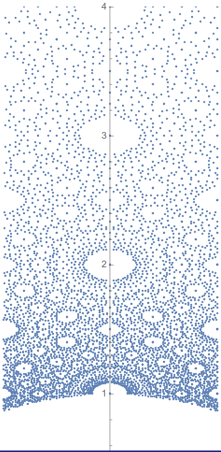
$\rightarrow$ Fit to determine α and β.
$\rightarrow$ Result: The logarithm is always the dominating term and the corrections are small in the LCS phase
$\rightarrow$ Define Θ_0 at the phase boundary.

Results

- The Conjecture holds in all models.
- $\Theta_0 + \Theta_\lambda = \mathcal{O}(M_{pl})$.
- $\Theta_0 < 0.5$
- Θ_0 per phase decreases with the number of moduli.

Outlook

- Periods are known for a large number of CY in all phases.
- Add fluxes to stabilize moduli
- Search for Swampland inside the flux Vacua Landscape



The End

Model Setup

- 1-parameter models

  $\mathbb{P}^4_{11111}[5]$, $\mathbb{P}^4_{11112}[6]$, $\mathbb{P}^4_{11114}[8]$, $\mathbb{P}^4_{11125}[10]$
  $\mathbb{P}^5_{111111}[3\ 3]$, $\mathbb{P}^7_{1111111}[2\ 2\ 2\ 2]$

- 2-parameter models

  $\mathbb{P}^4_{11222}[8]$, $\mathbb{P}^4_{11226}[12]$, $\mathbb{P}^4_{11169}[18]$

- 101-parameter models

  Mirror-Quintik

The Geodesic Equation

$$\frac{d^2 x^\mu}{d\tau^2} + \Gamma^\mu_{\alpha\beta} \frac{dx^\alpha}{d\tau} \frac{dx^\beta}{d\tau} = 0 \,, \tag{9}$$

- Can be solved numerically for given initial conditions.
- Problem: A priori one does not know where one will end up.

$\rightarrow$ Calculate a 'fan' of geodesics