

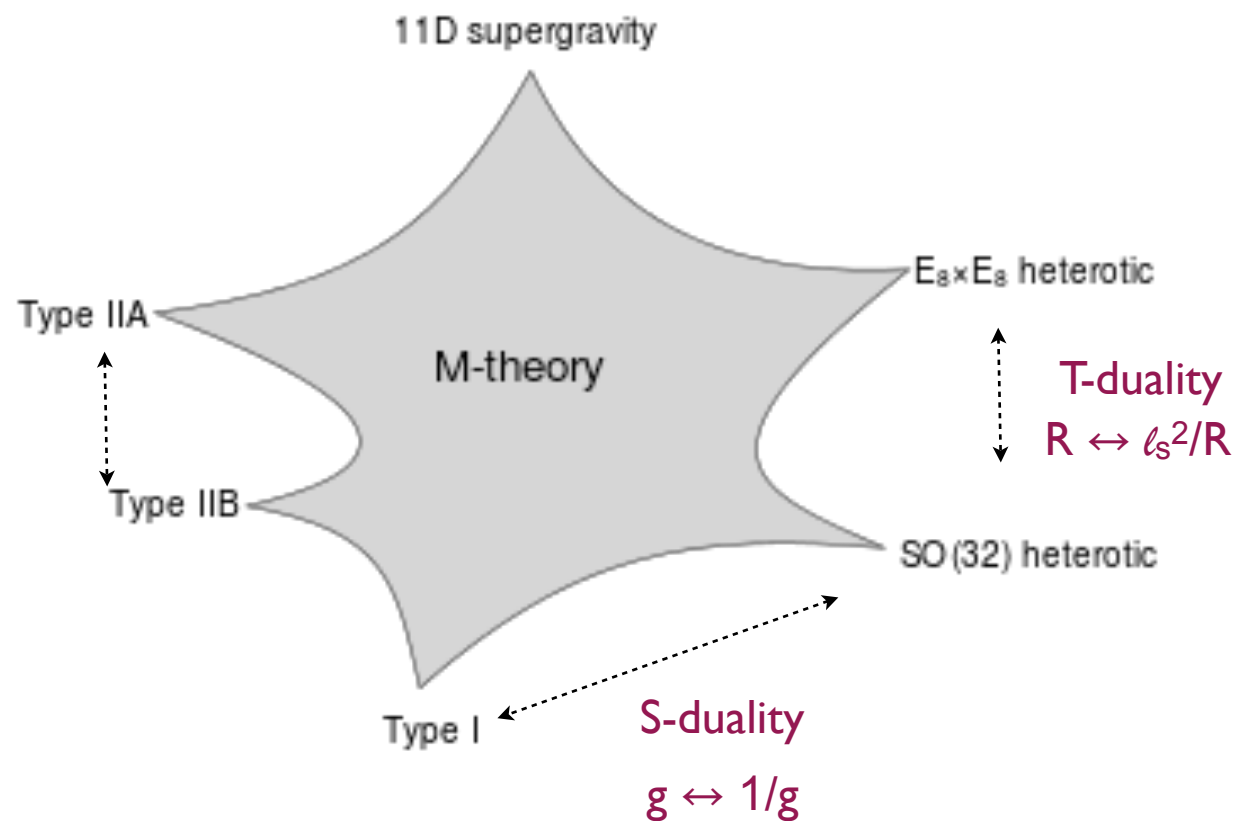
String theory, from the landscape to the swampland

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Institut de Physique Théorique
CEA / Université Paris-Saclay
France

TUG, Paris, October 2023

String theory

- A remarkable theory of **quantum gravity**, calculable
- Second superstring revolution ('95): **unique theory!**

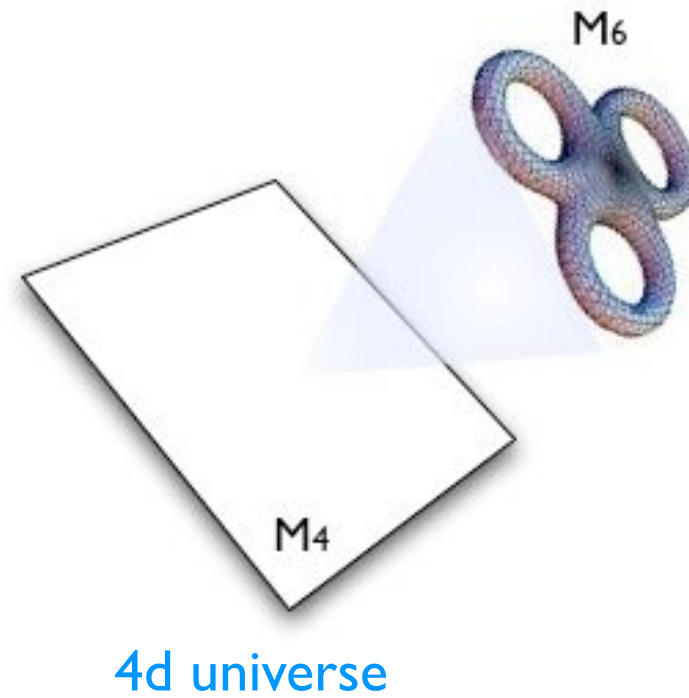


But

Unique theory 10d

6d compact space

$$M_{10} = M_4 \times M_6$$



Geometry of M_6
determines physics
in 4d

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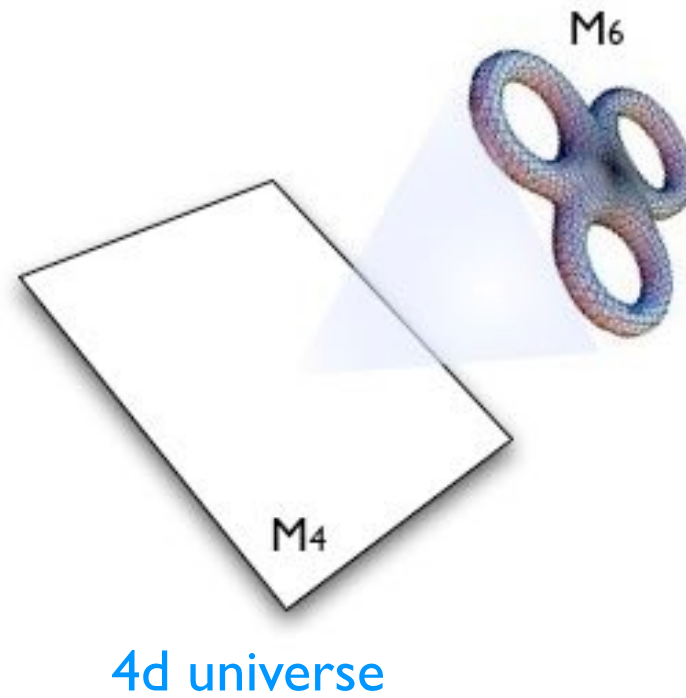
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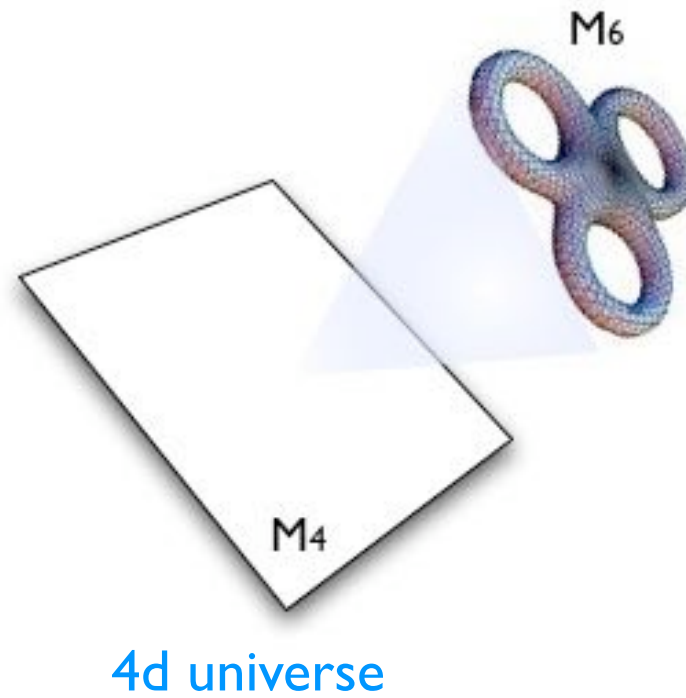
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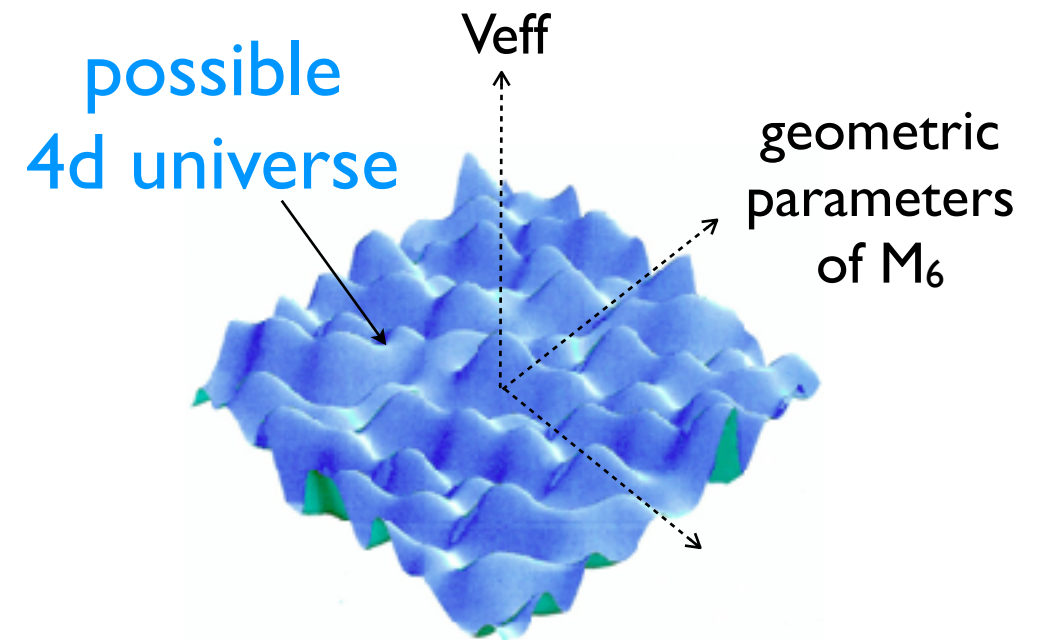
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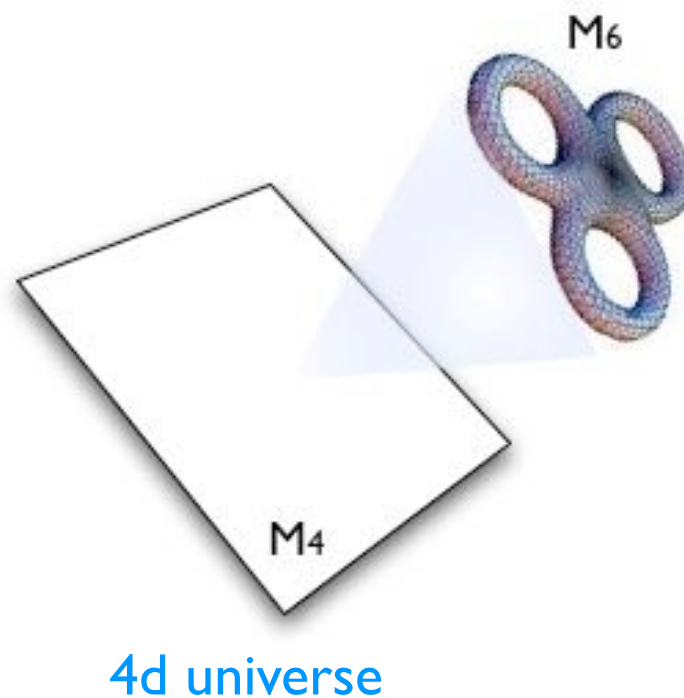
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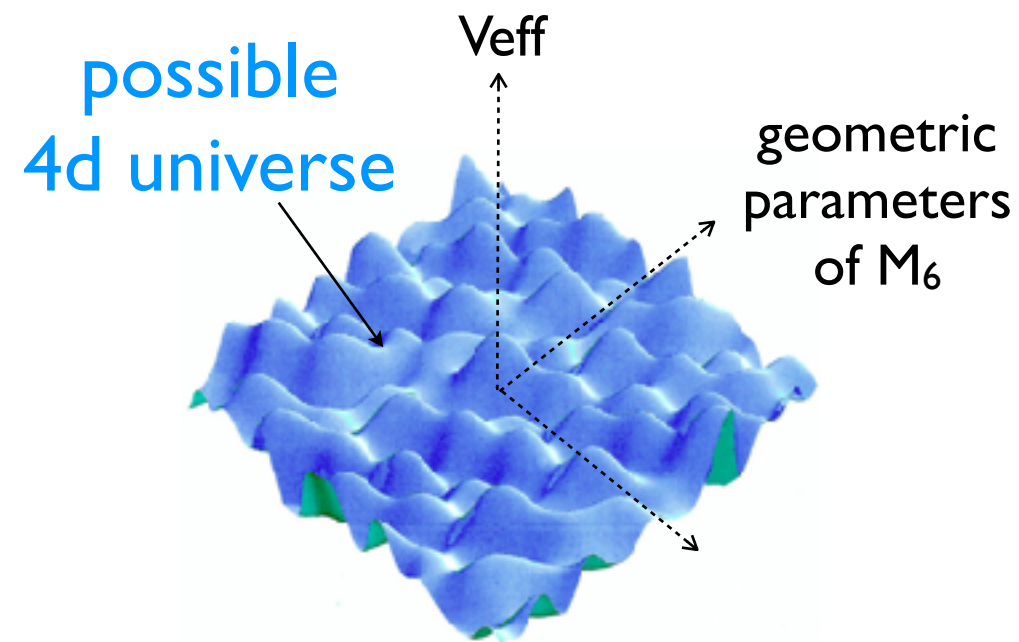
Multiple solutions : 10^{500}

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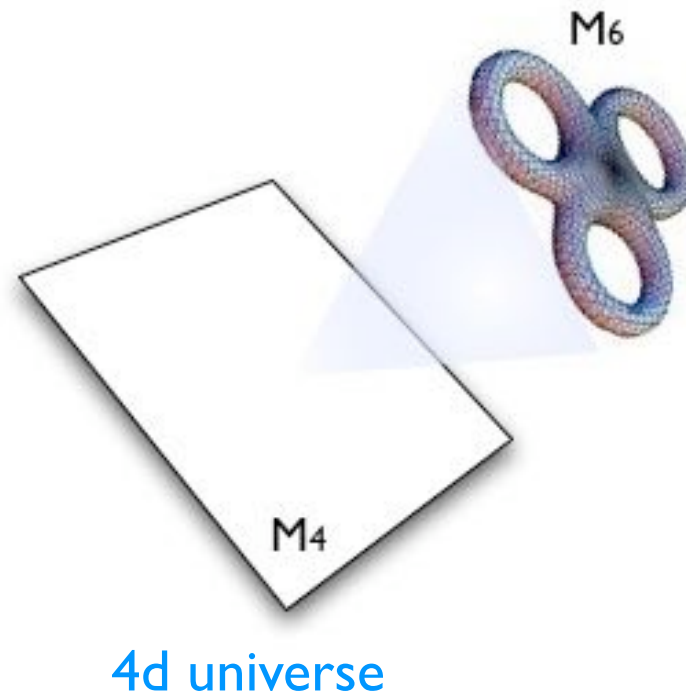
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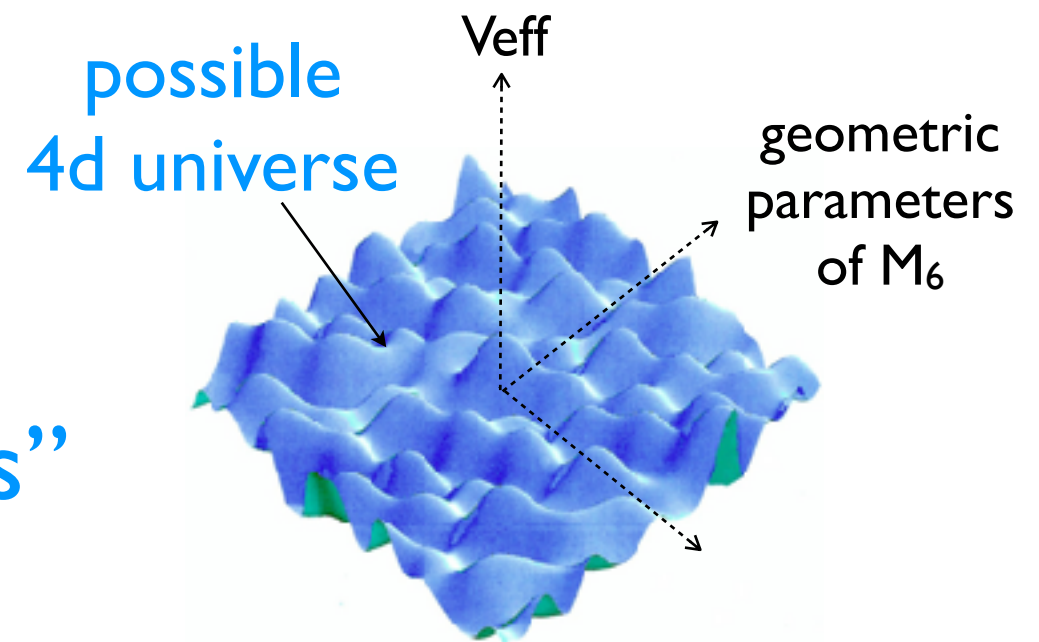
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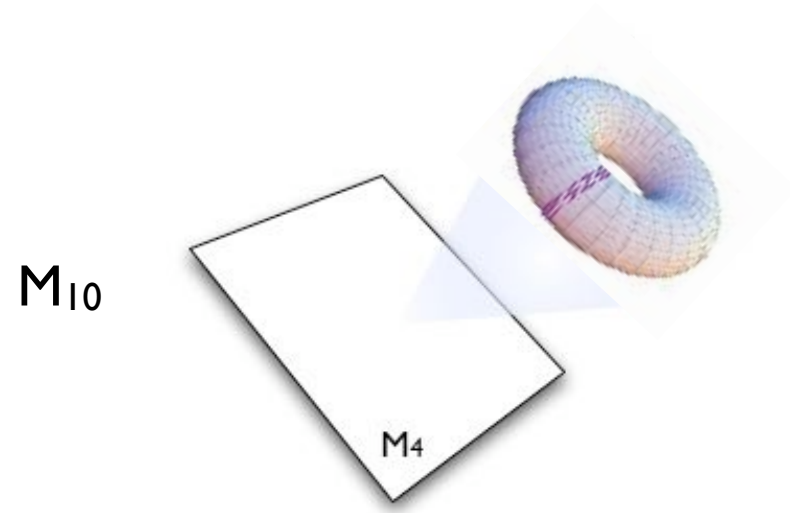
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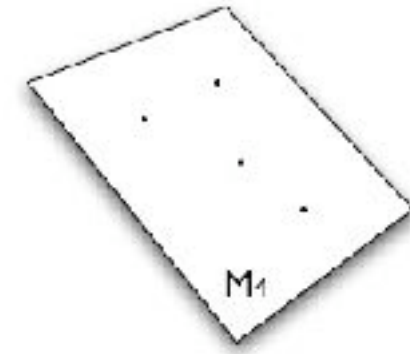
Landscape of possible 4d “universes”



Simplest exemple

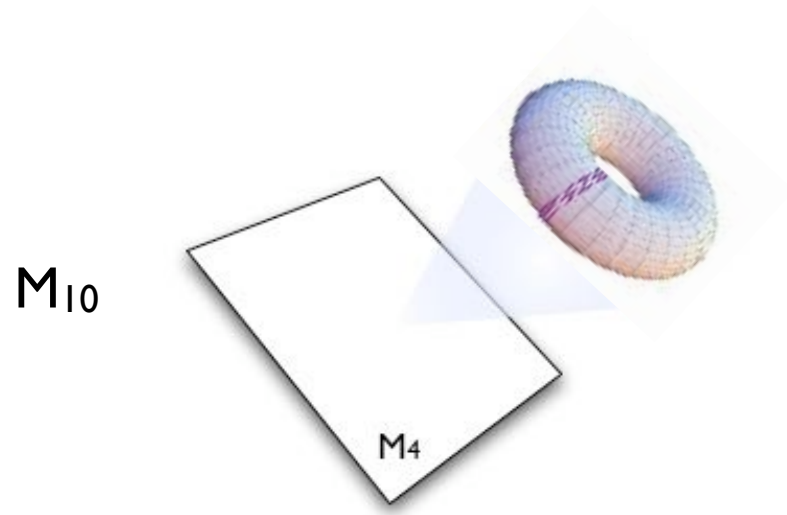


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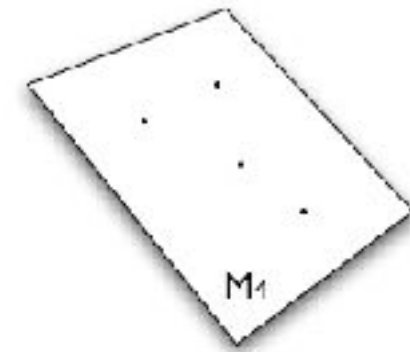


Observable world

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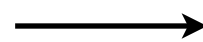


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Observable world

Supersymmetric



supersymmetric spectrum

BUT

4D space = Minkowski



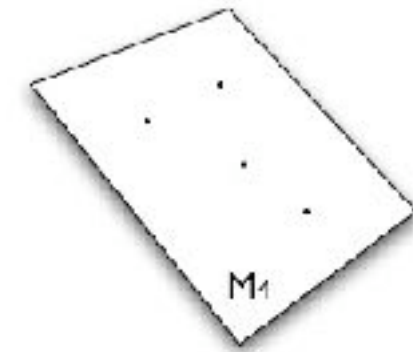
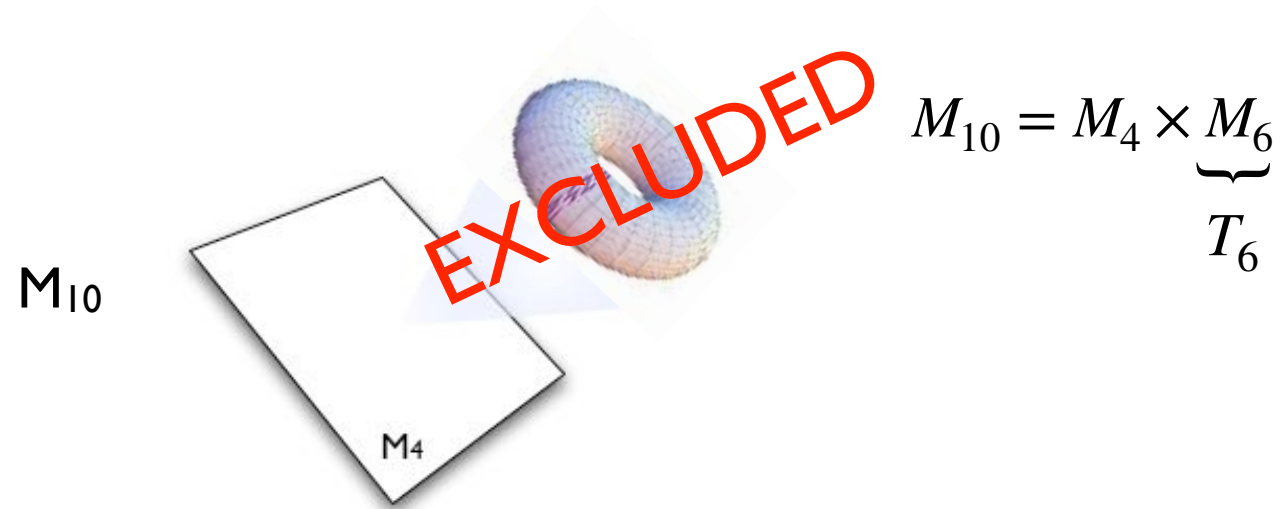
no cosmological constant

Radii of circles not fixed



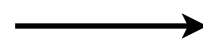
Massless scalars (moduli)

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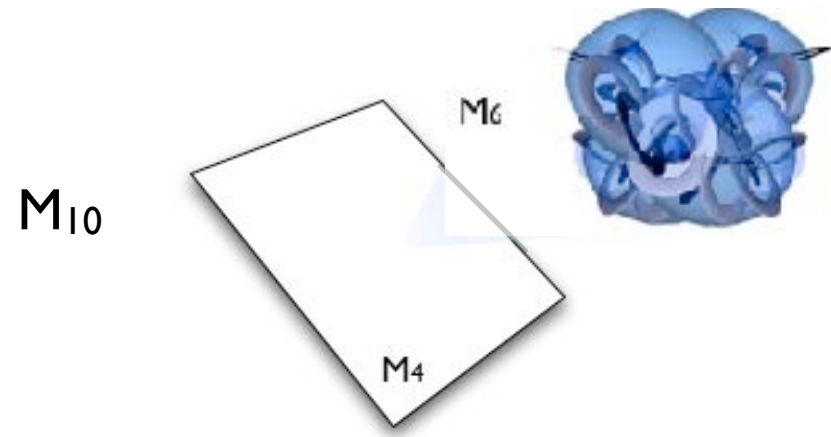
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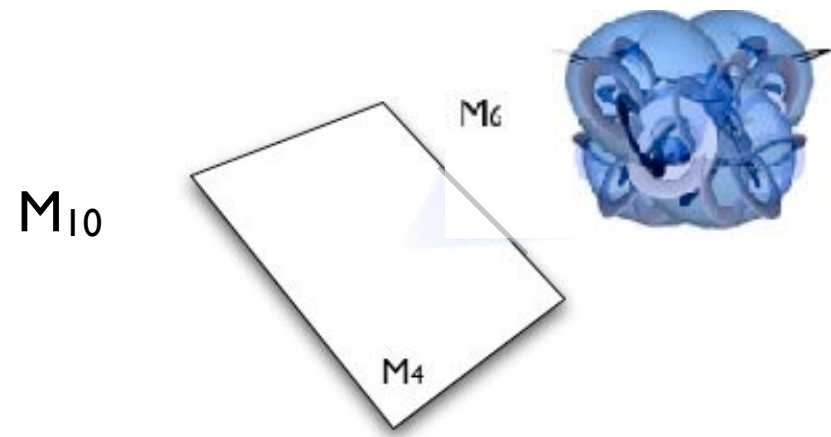
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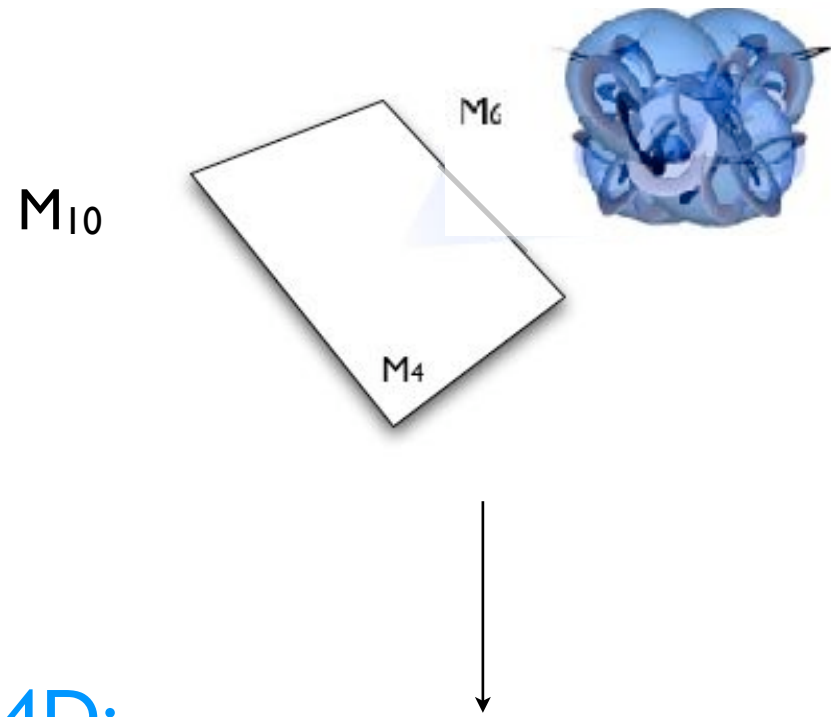
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Eq. of motion:
 $E \ll M_s \lesssim M_P$

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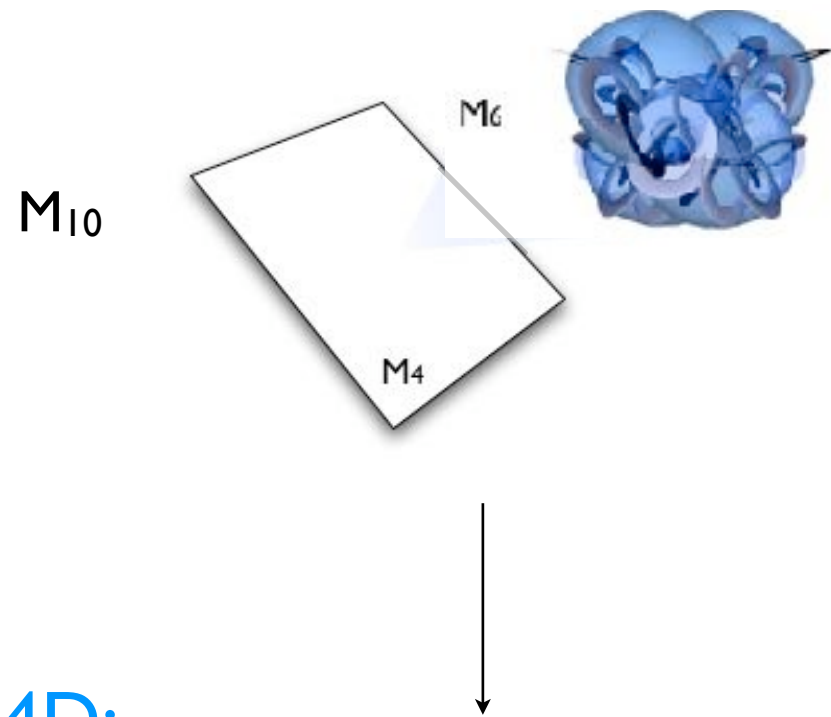
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Still supersymmetric (less than for tori, $\mathcal{N} = 1$)

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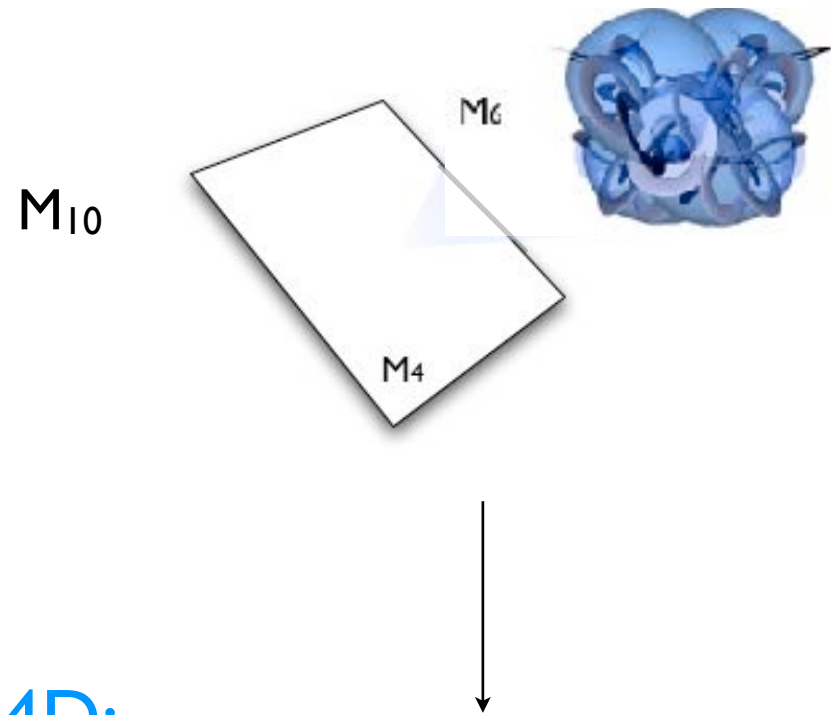
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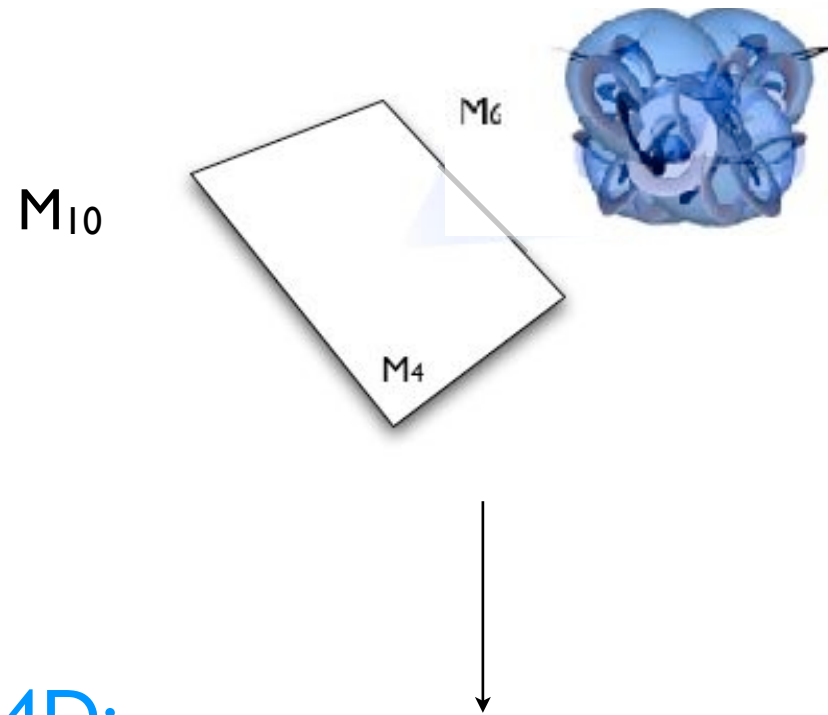
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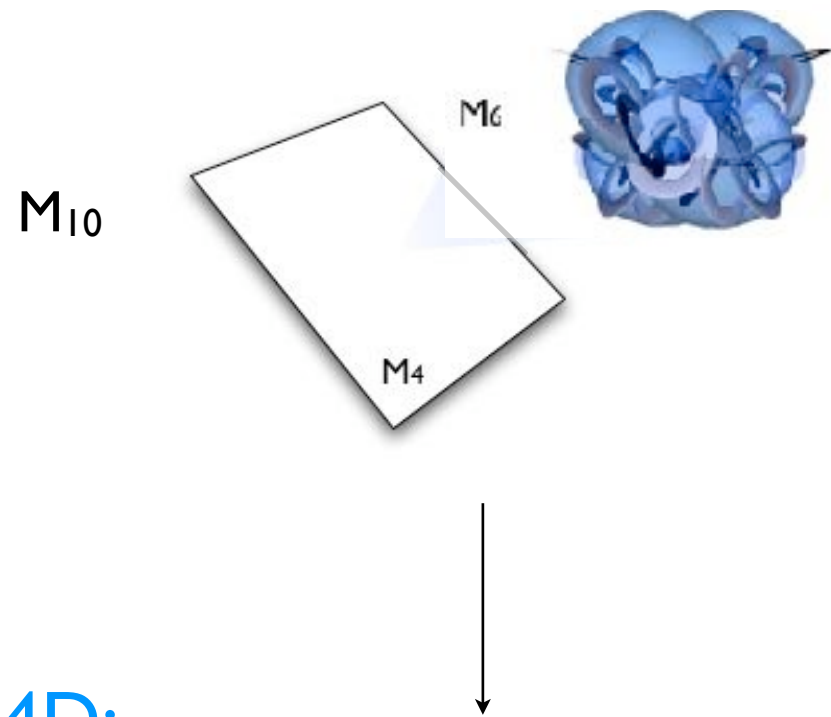
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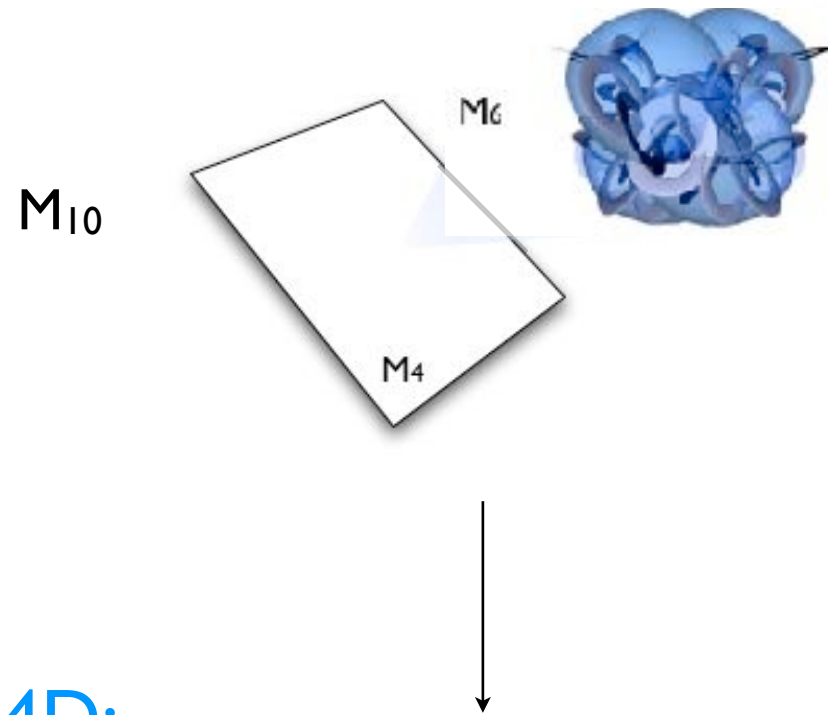
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Landscape of possible 4d universes

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Obtained using Calabi-Yau spaces, and the rest **bottom-up**,
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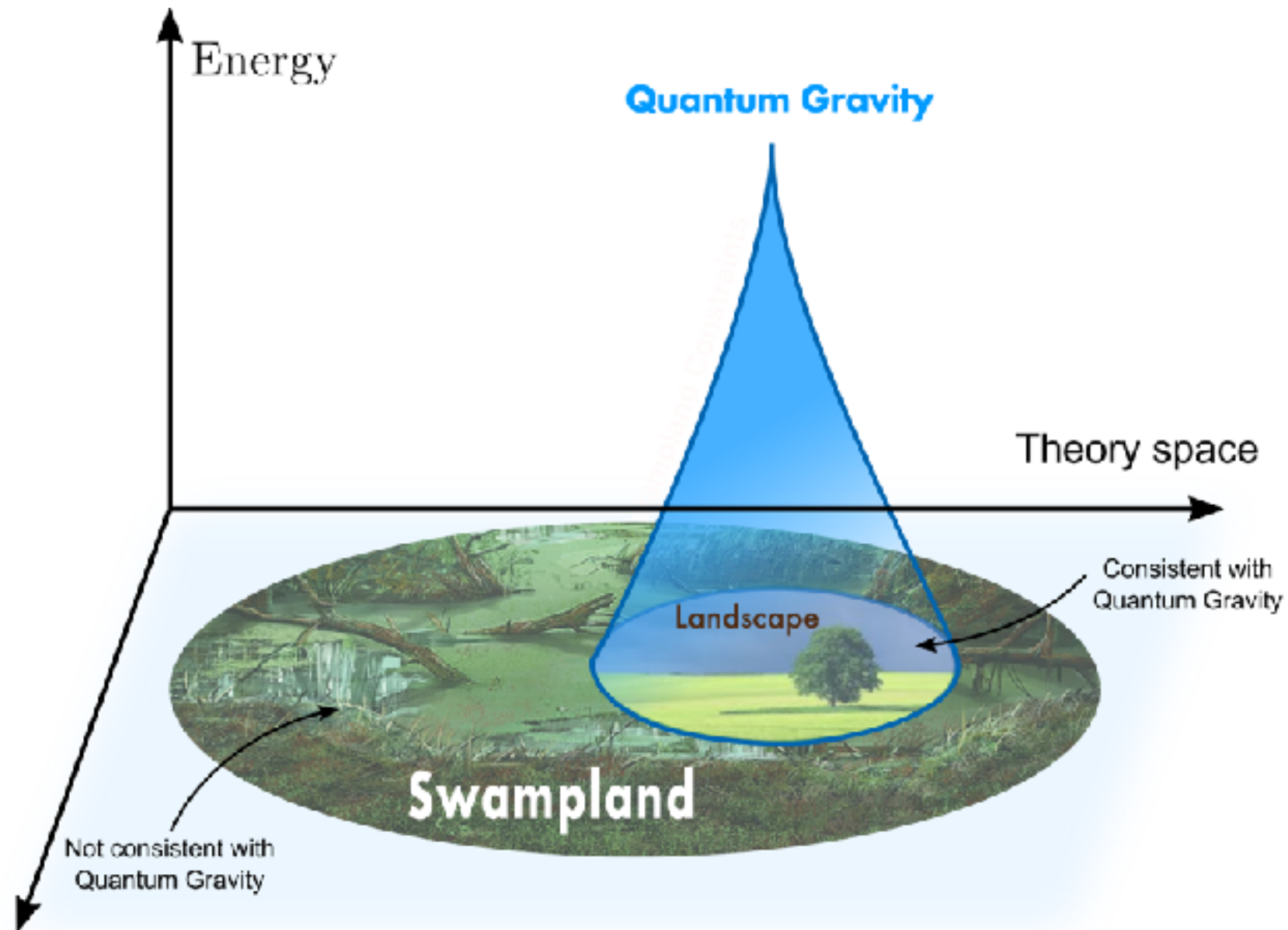
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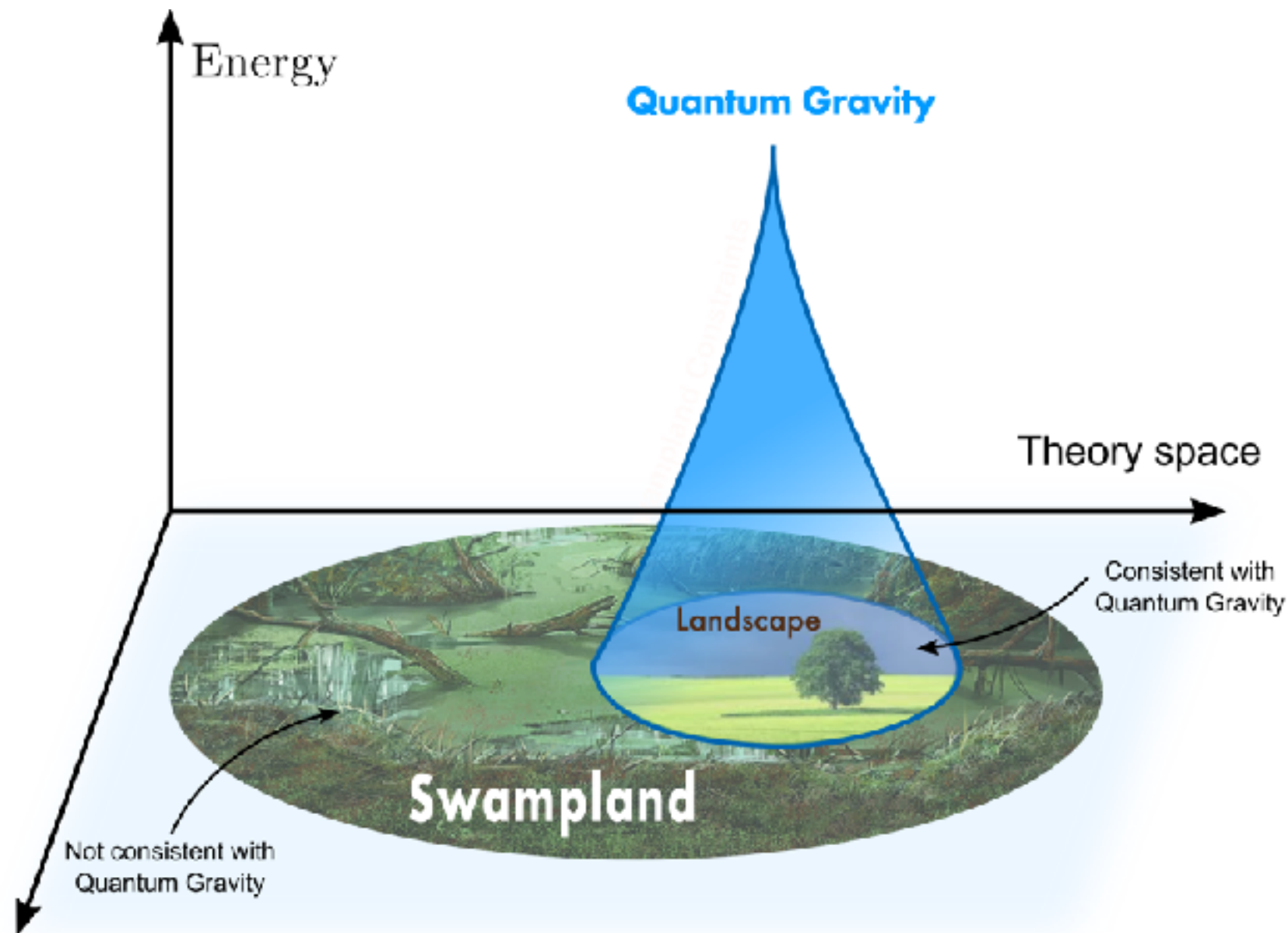
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Or did we fall into the swampland ?

The landscape and the swampland

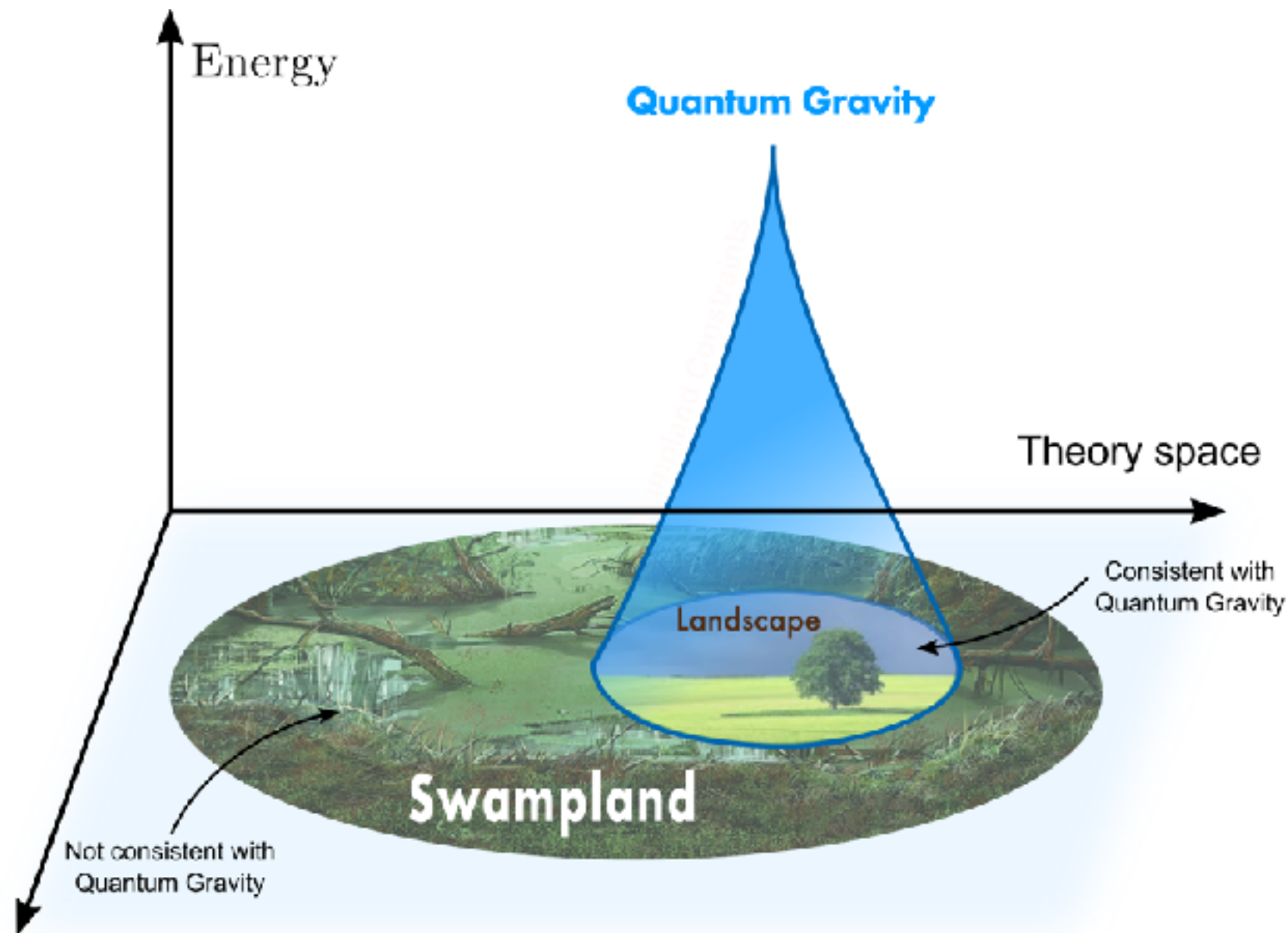


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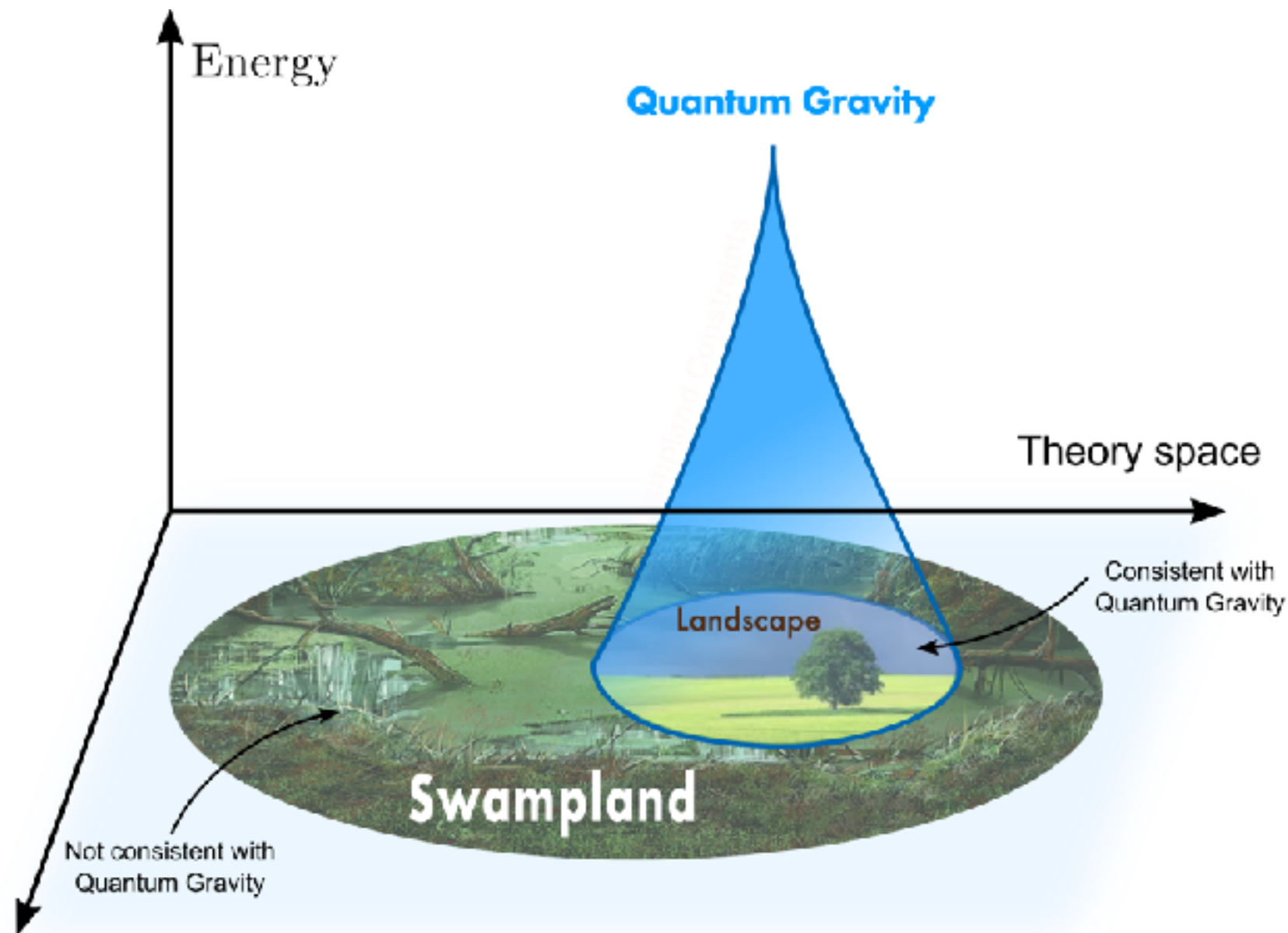
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Conjectures based on physics of black holes and/or inspired by string theory

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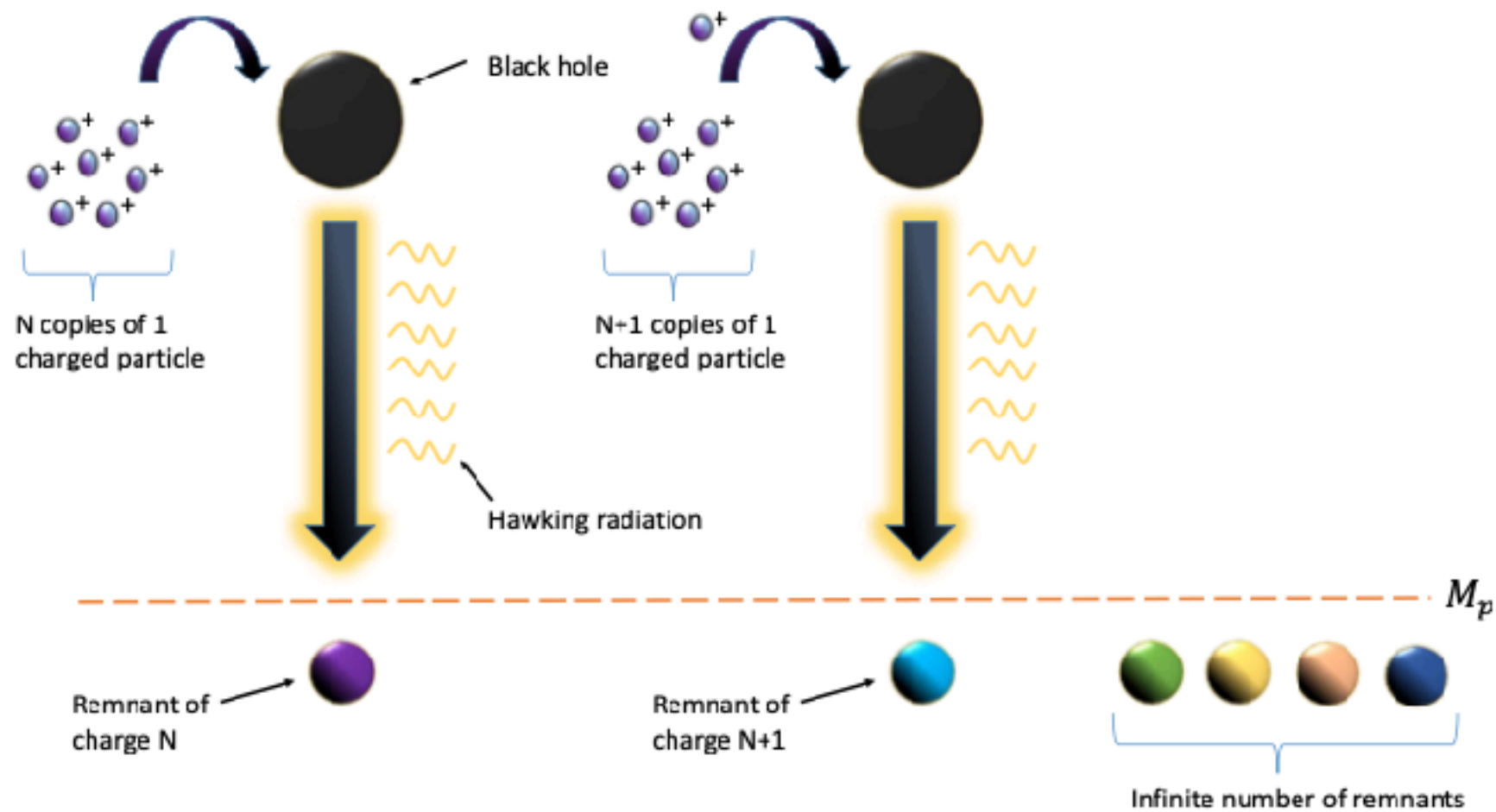
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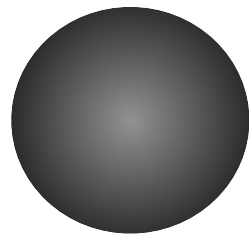
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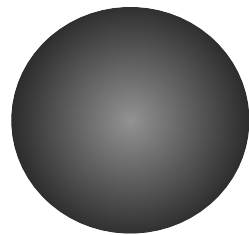
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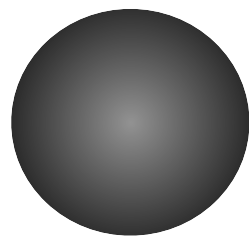
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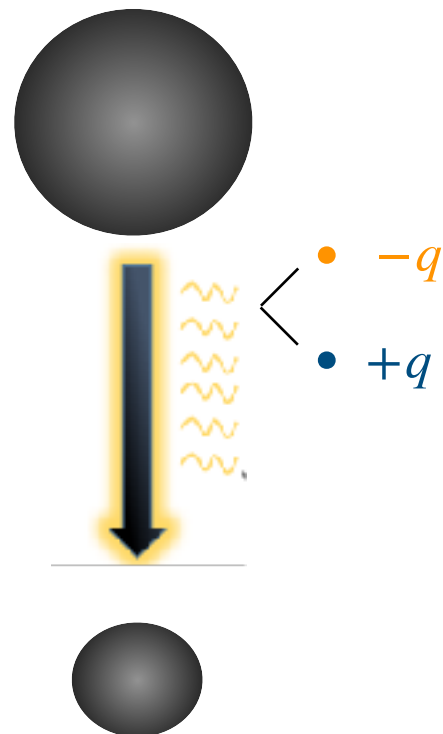
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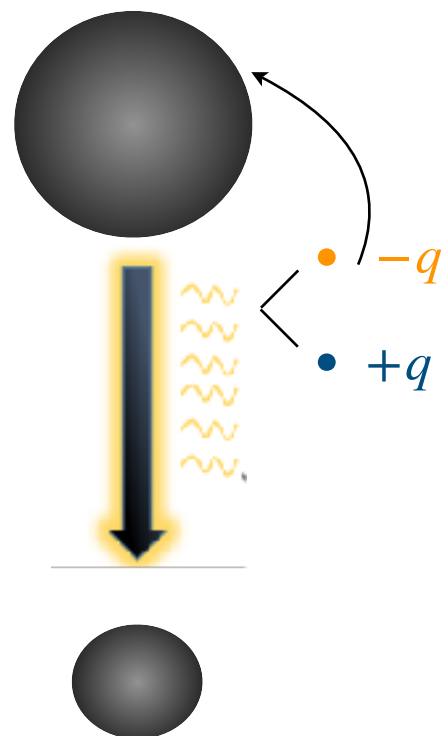
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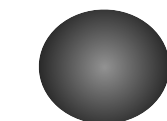
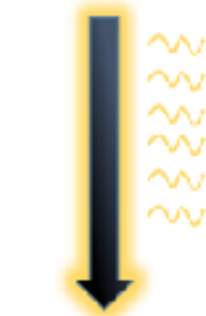
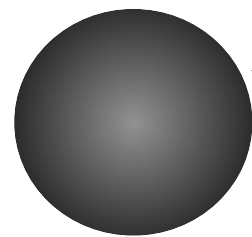
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$-q$
 $+q$

If all particles $m > q$

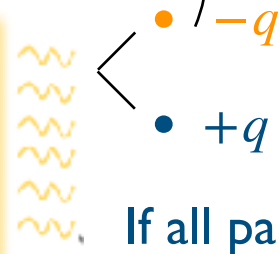
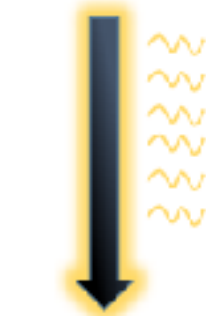
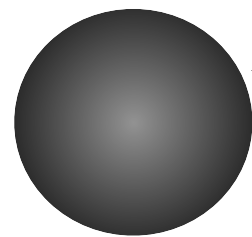
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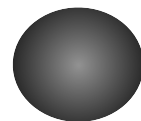
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If all particles $m > q$



$$M_2 < Q_2$$

superextremal black hole:
naked singularity

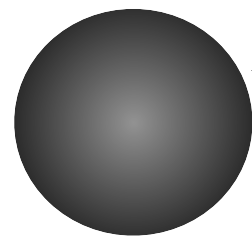
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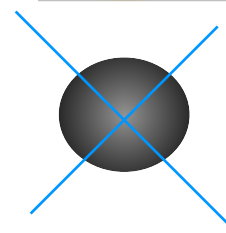
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\Rightarrow extremal black holes
cannot decay: remnants

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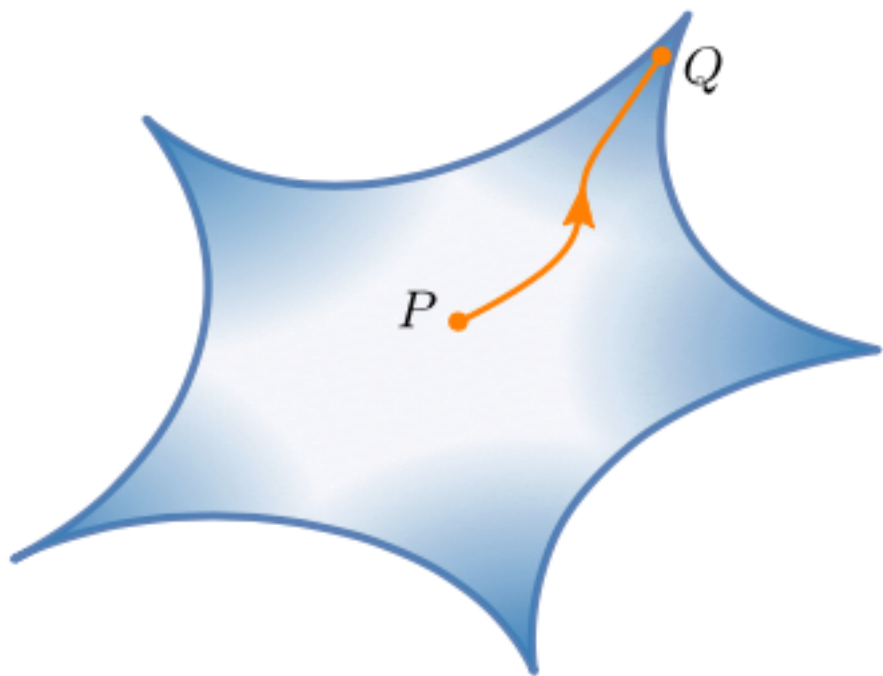
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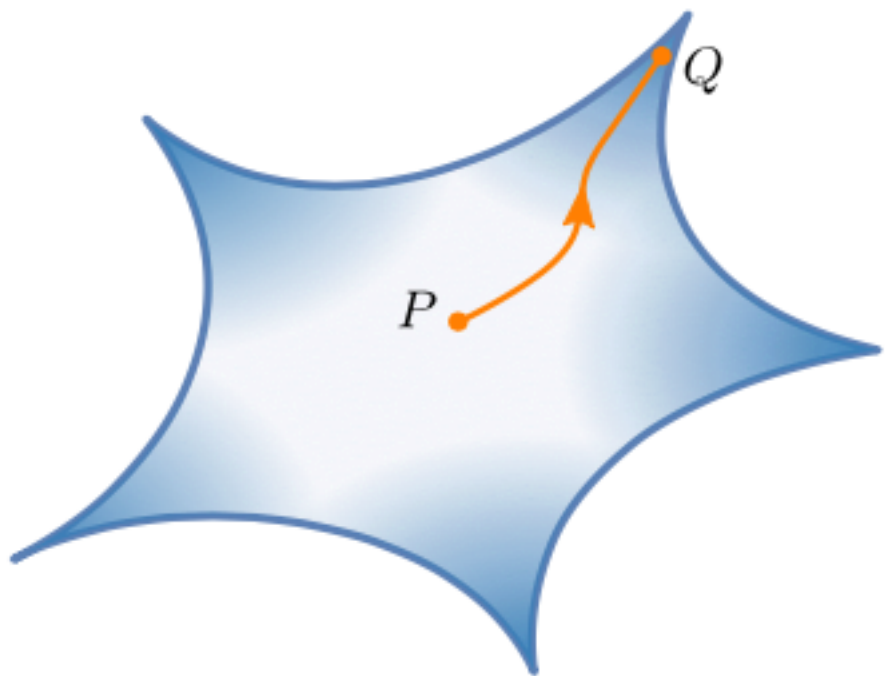


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ex: compactification on circle
Modulus $\phi = R$ (radius)

$$\begin{aligned} \mathcal{L}_{10} &= \mathcal{R}_{10} \\ &\downarrow \\ \mathcal{L}_9 &= \mathcal{R}_9 + \frac{1}{R^2} \partial_\mu R \partial^\mu R \end{aligned}$$

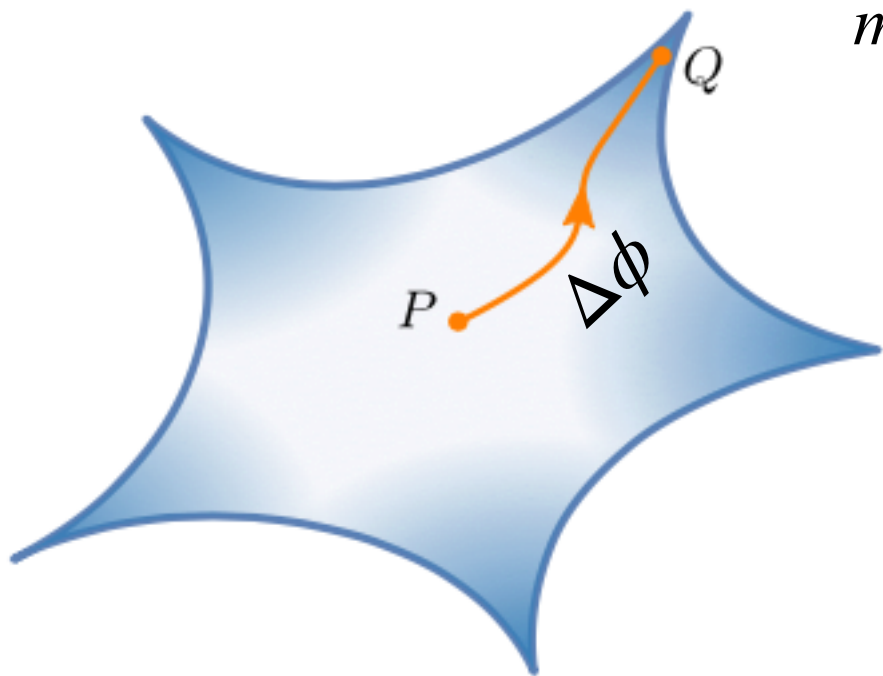
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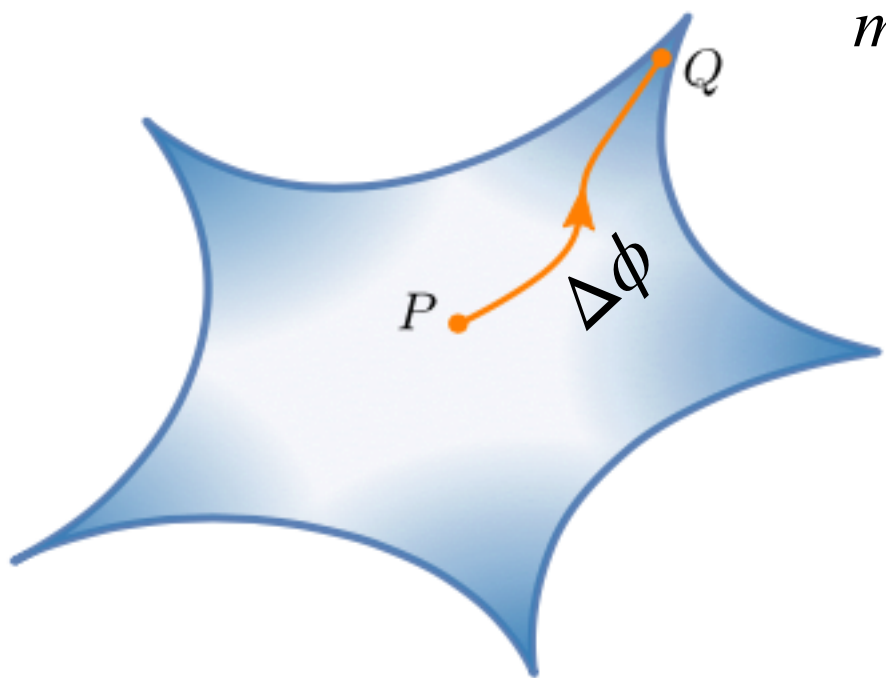
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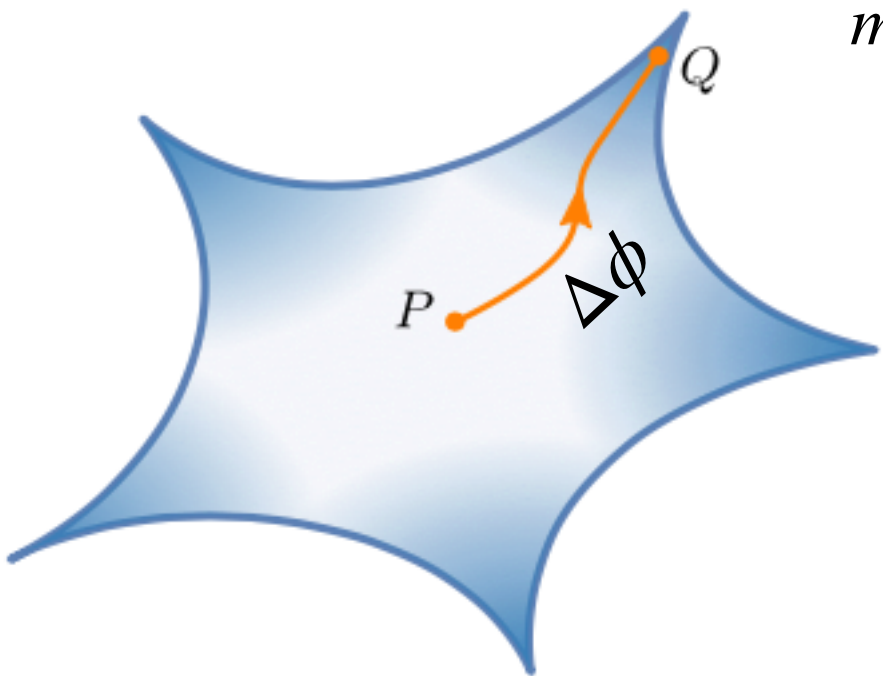
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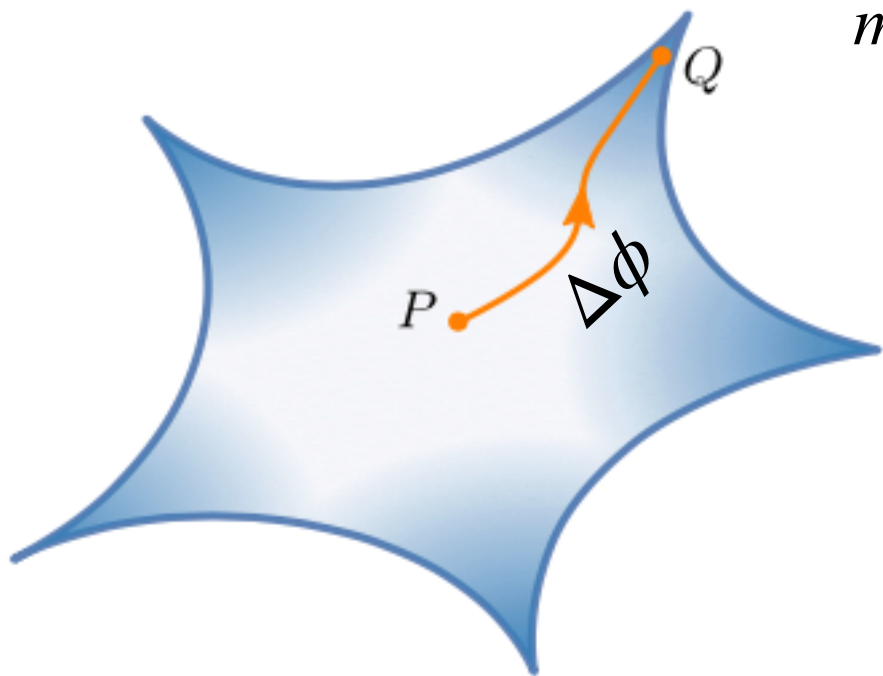
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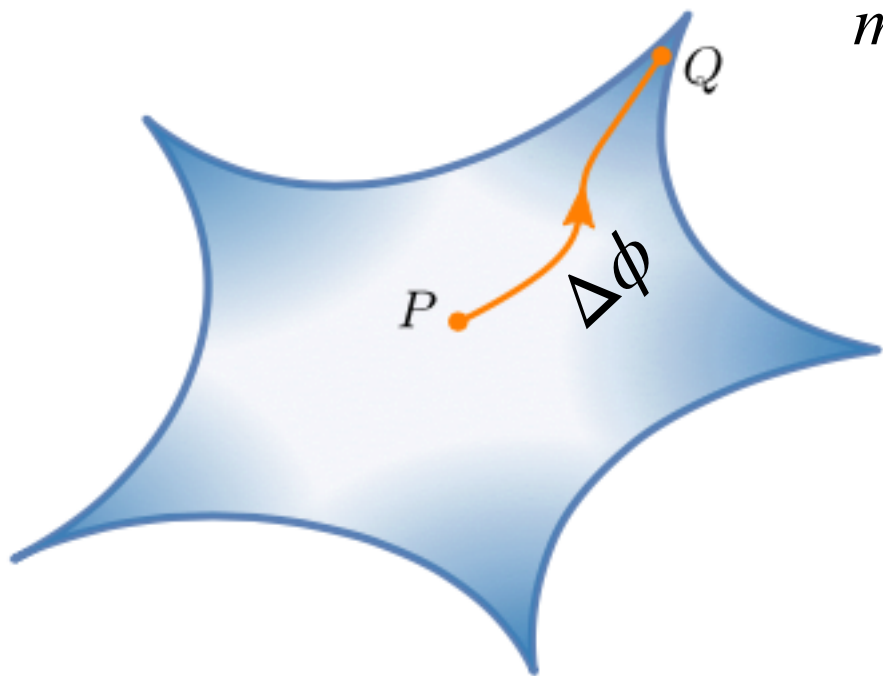
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EFT breaks down when $\Delta\phi \rightarrow \infty$

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de Sitter space is in the swampland!!

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In a theory on the landscape

The potential satisfies $|\nabla V| \geq cV$ with $c > 0$ ($\mathcal{O}(1)$ in Planck units)

or

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Obied, Ooguri, Spodyneiko, Vafa 18
(OOSV)

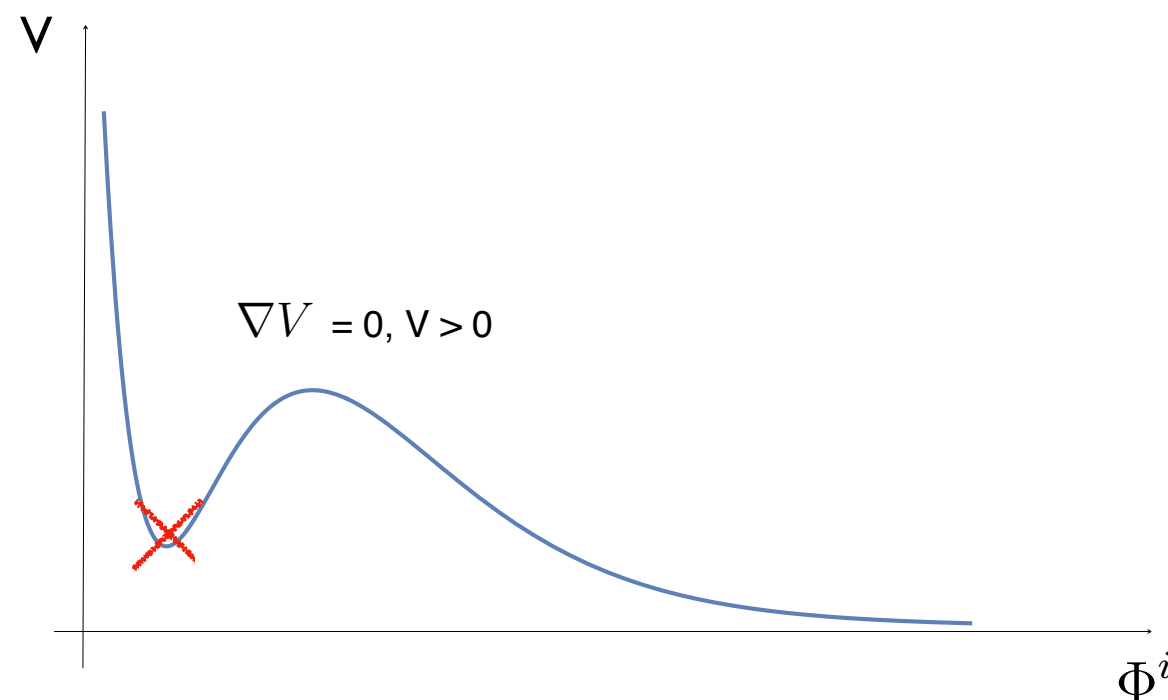
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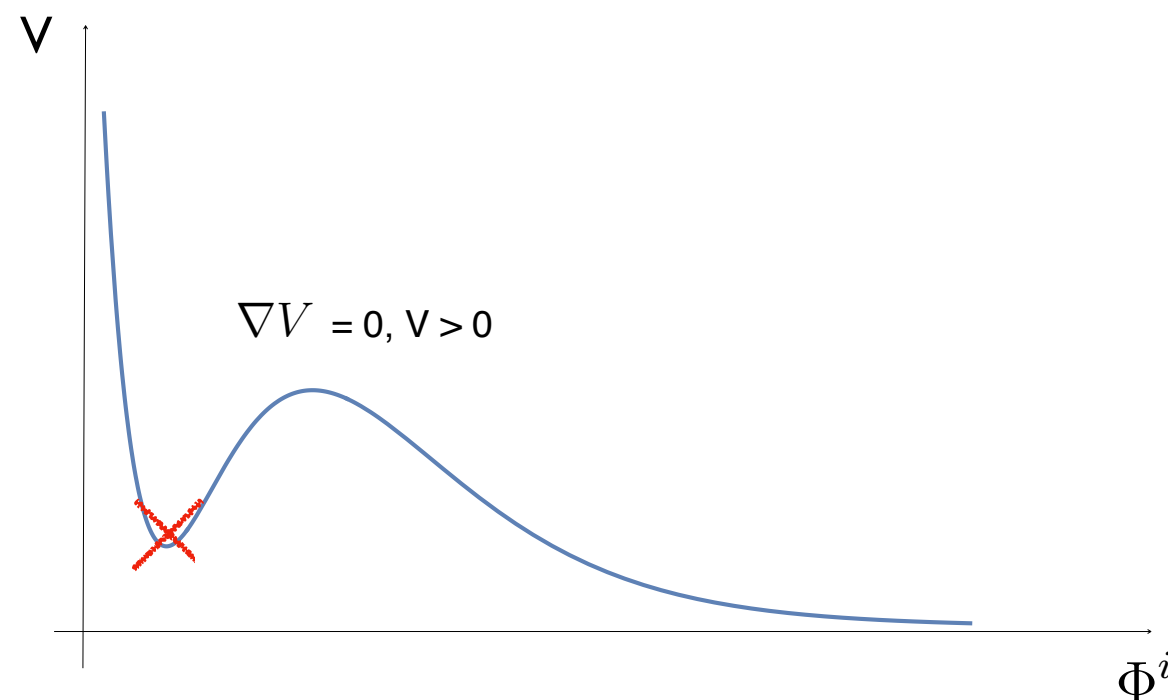
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If so, dark energy comes from quintessence field(s)

Back to the landscape: de Sitter vacua in string theory where do we stand?

KKLT 03

10^{500}
dS vacua

OOSV 18

No dS vacua

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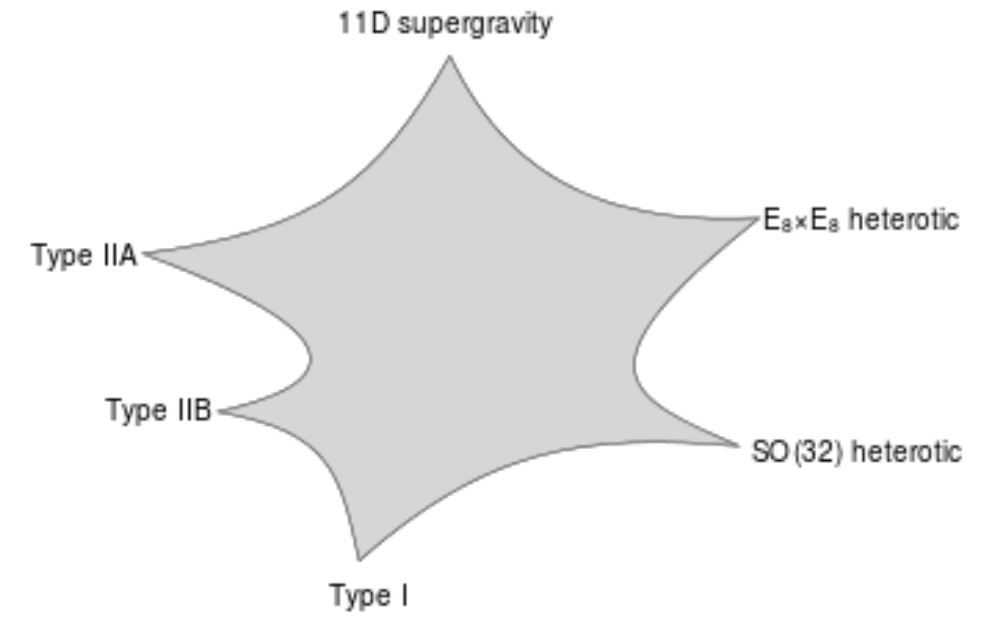
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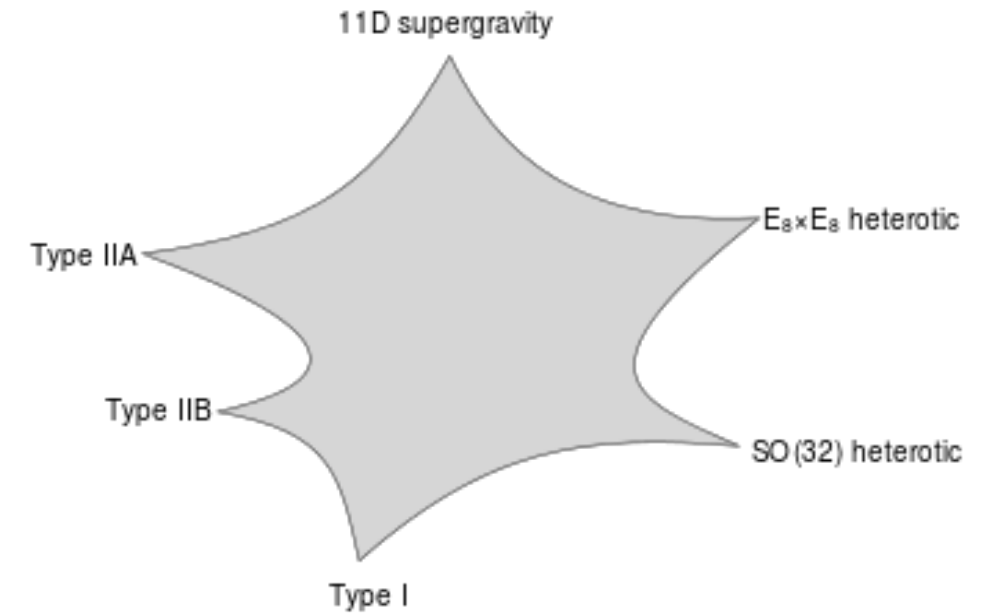
String theory is a remarkable and unique theory of quantum gravity



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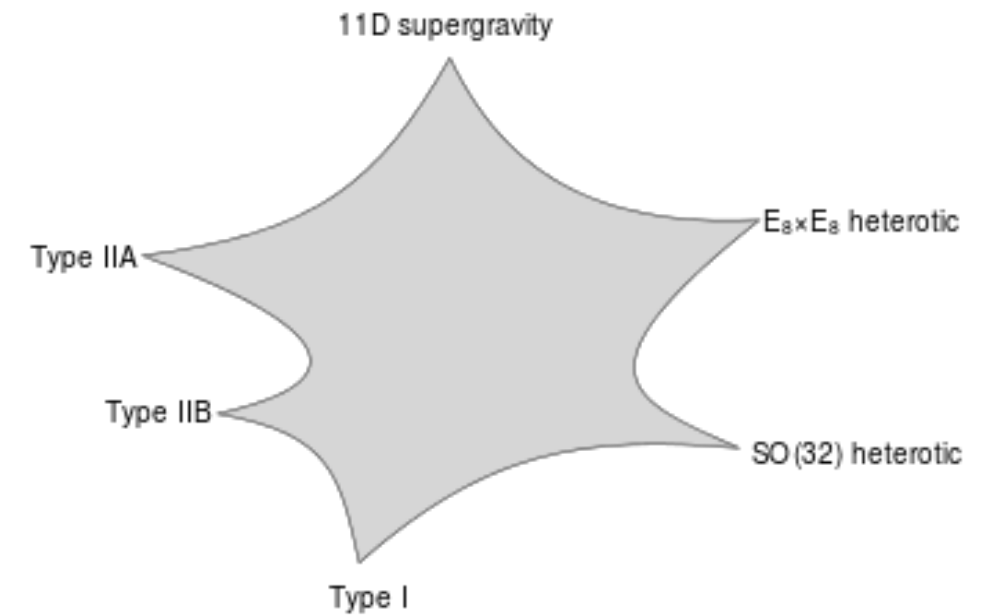
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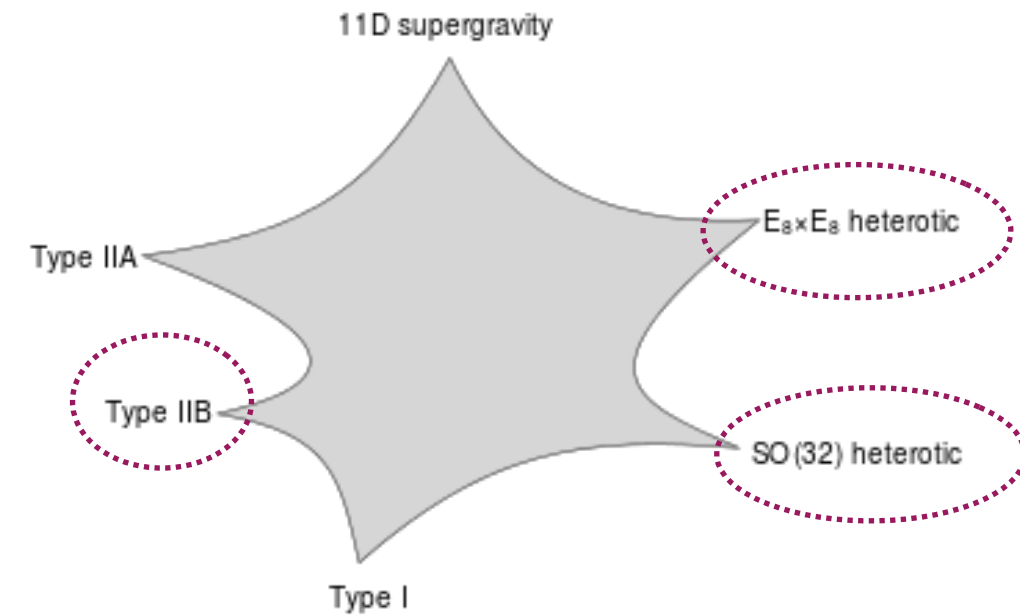
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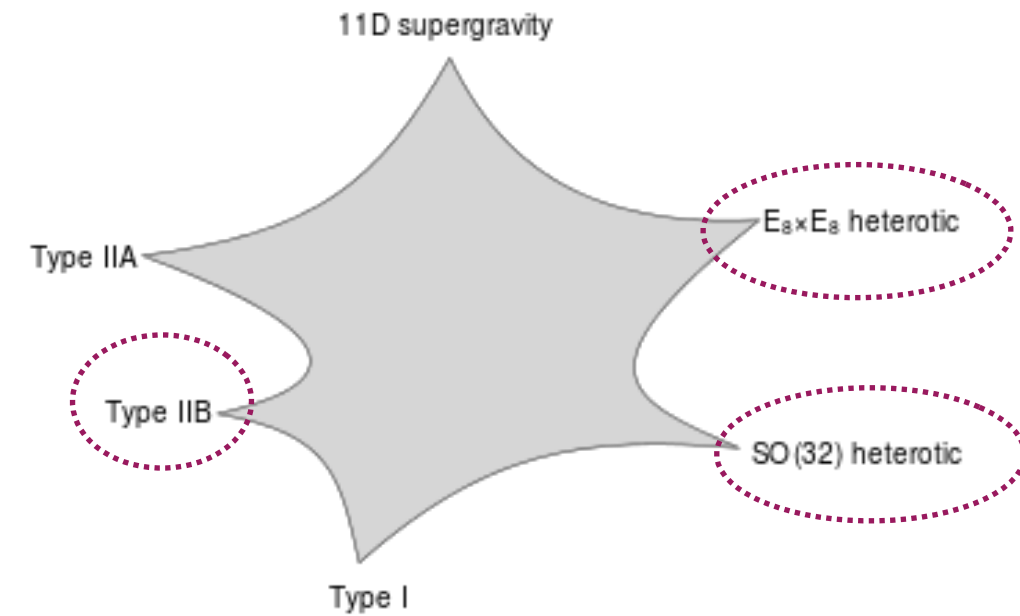
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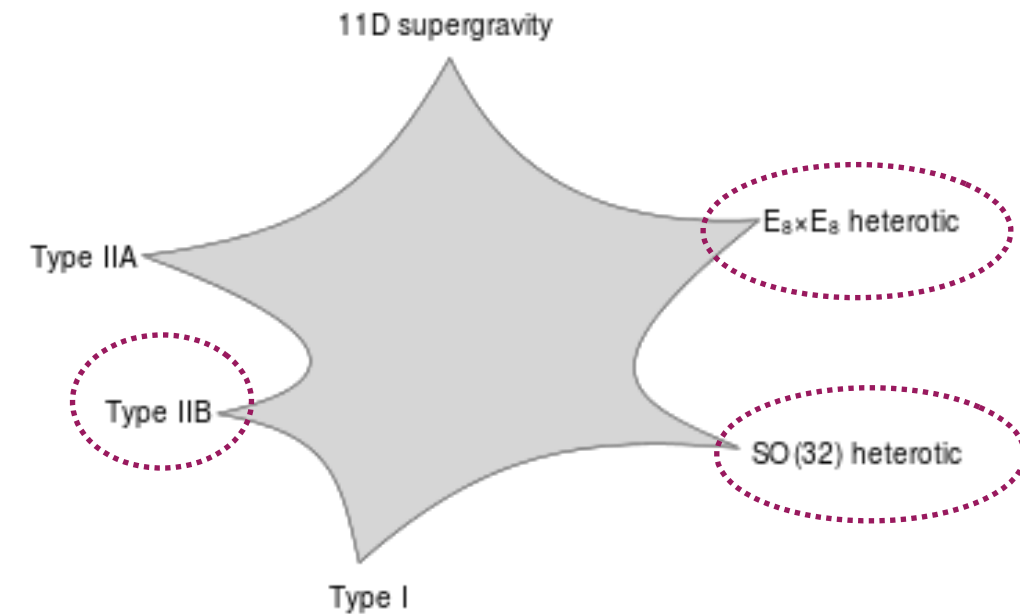
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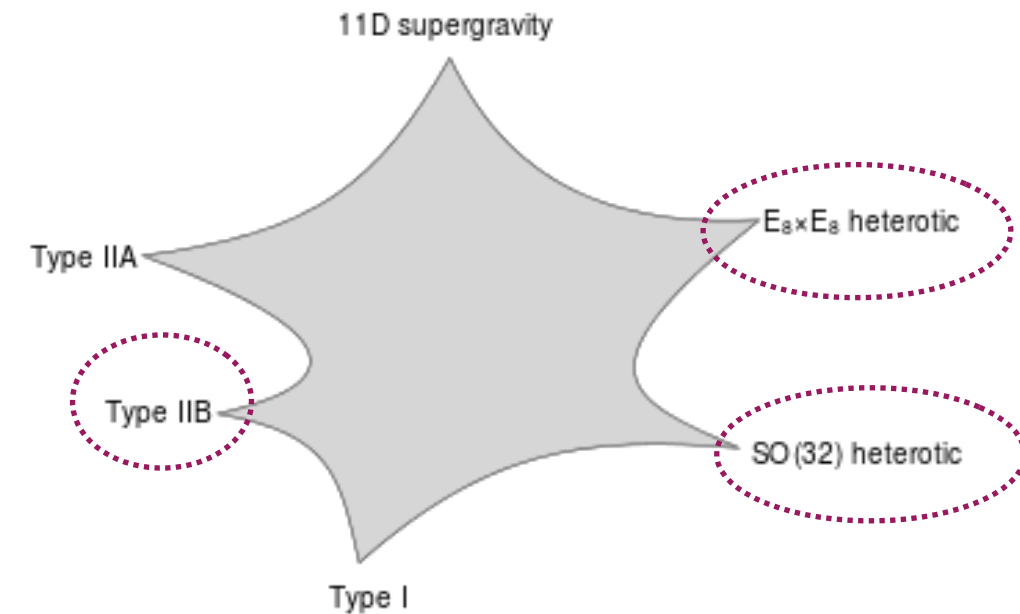
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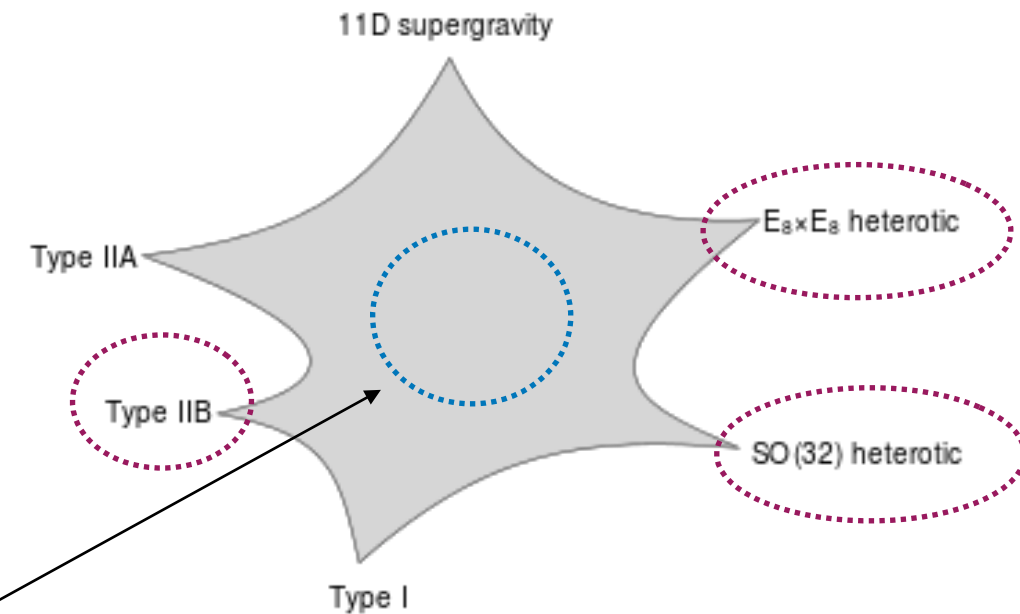


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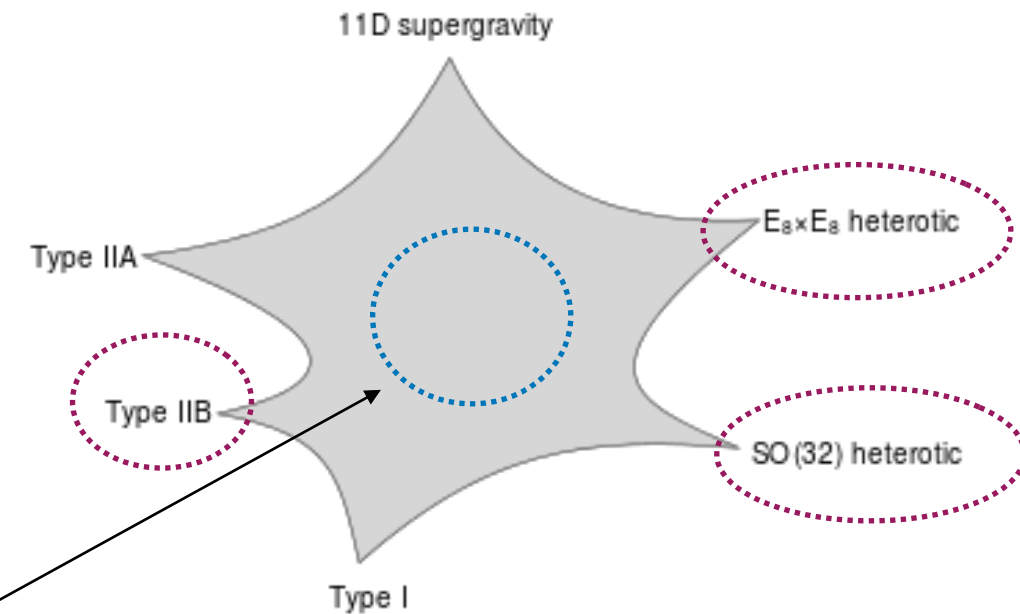
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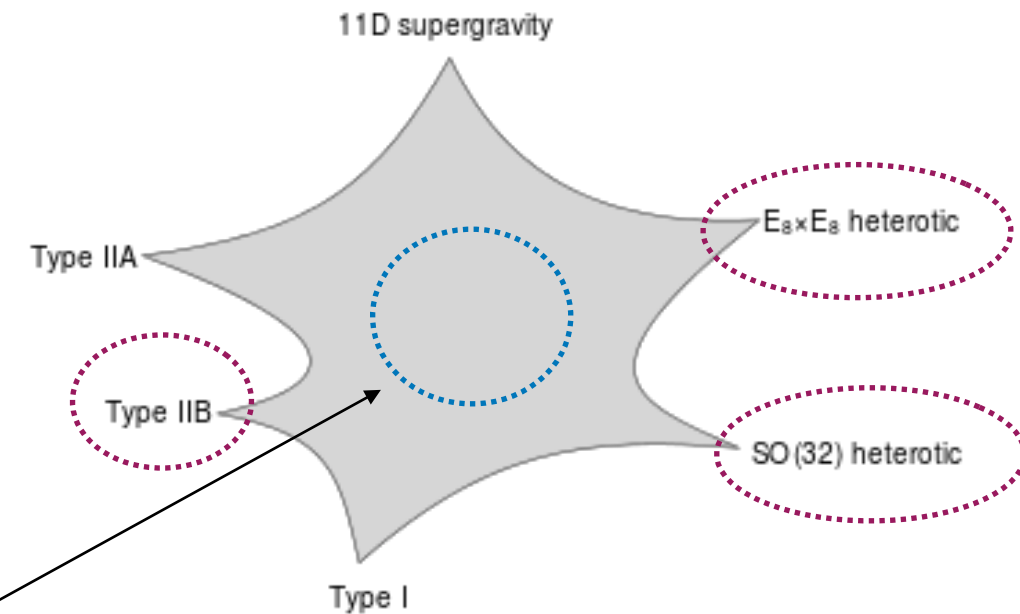
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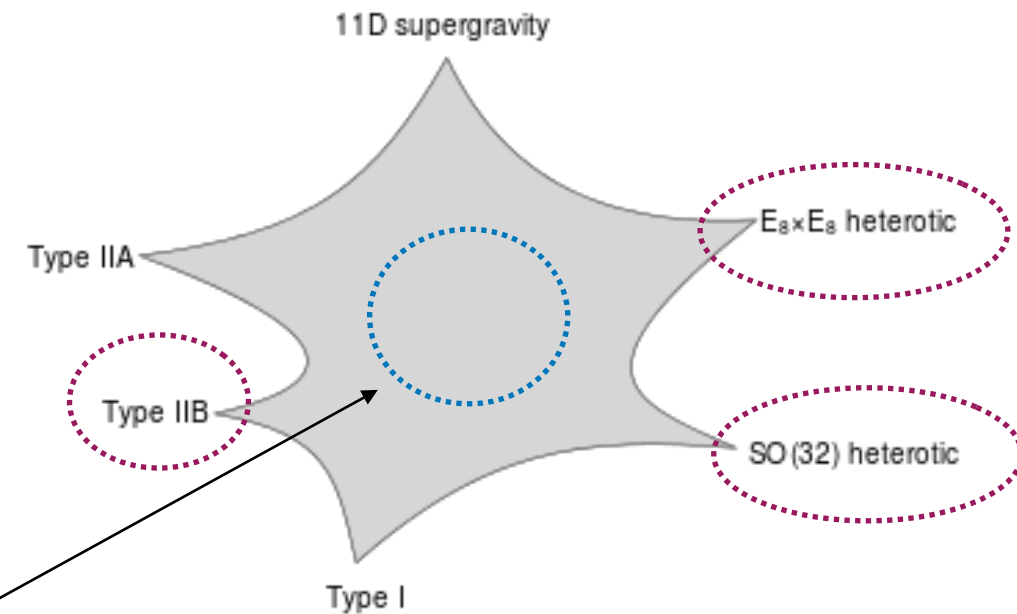
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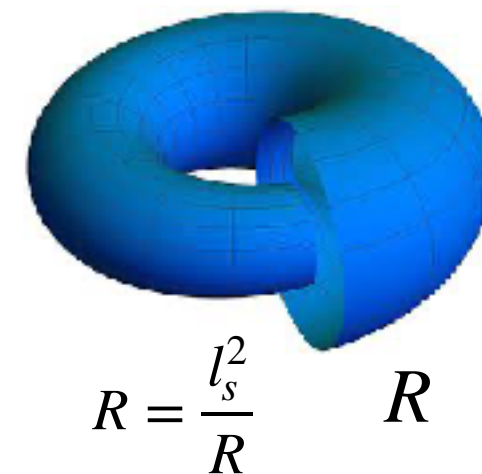
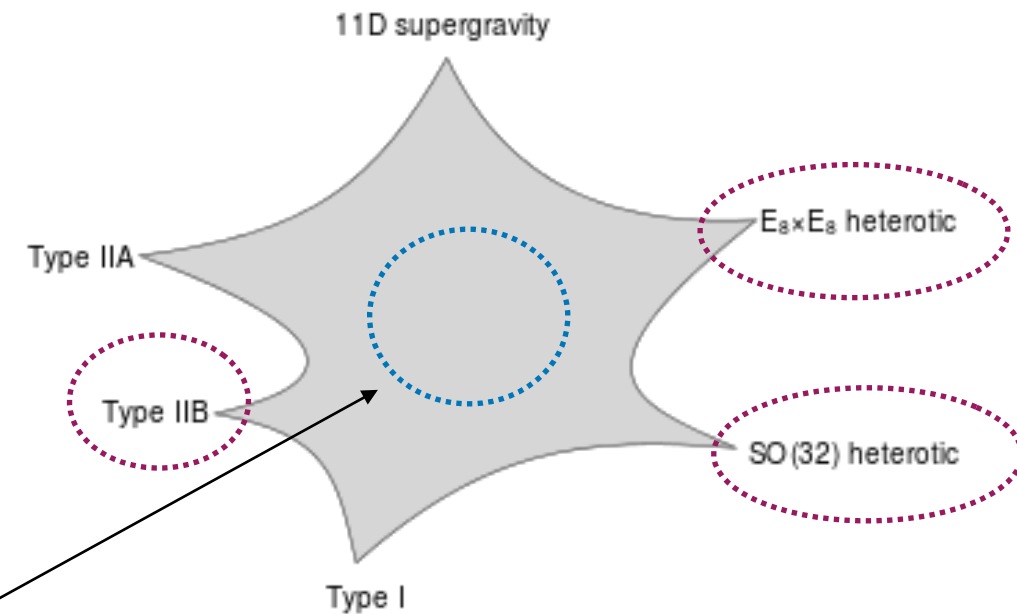
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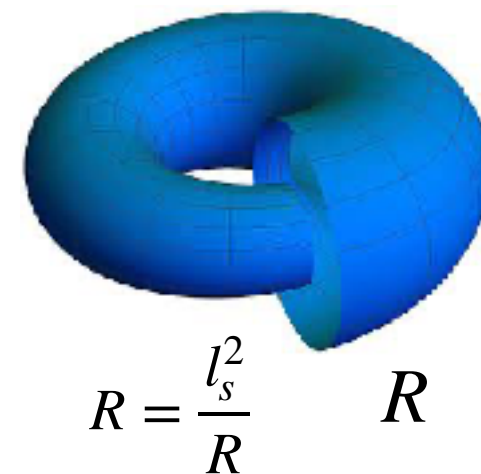
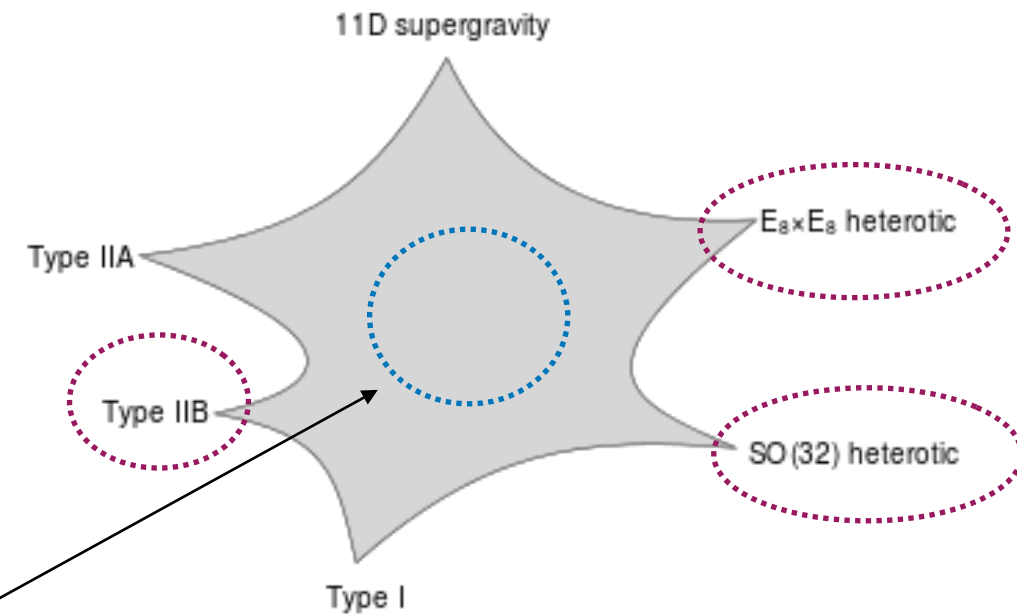
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T-folds

Beautiful and still largely unexplored landscape

Transplanckian Censorship Conjecture

- The expansion of the universe must slow down before all Planckian modes are stretched beyond the Hubble size

Two implications:

- no dS close to boundaries of moduli space, where

$$\frac{|\nabla V|}{V} \geq \frac{2}{\sqrt{(d-1)(d-2)}}$$

- dS can exist inside the bulk, if short lived

$$\tau \leq \frac{1}{H} \log \frac{M_P}{H}$$