String theory, from the landscape to the swampland

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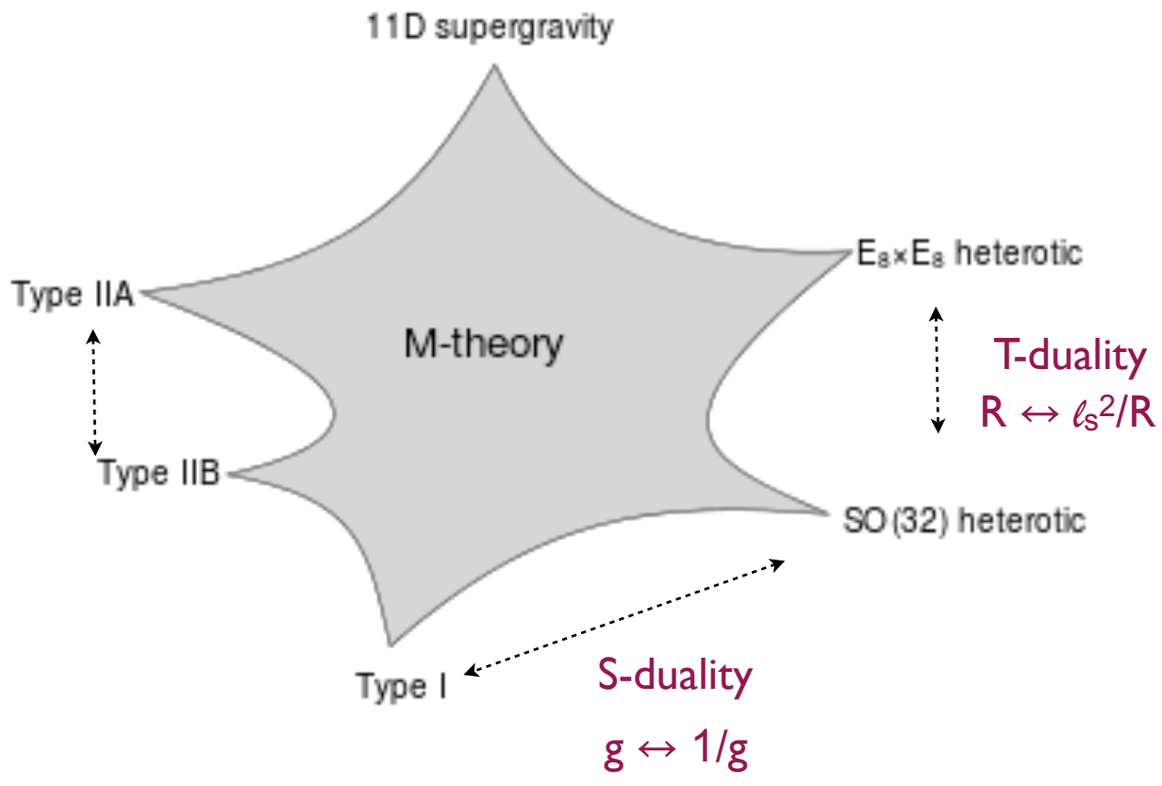
France

RPP, Jussieu, January 2024

String theory

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

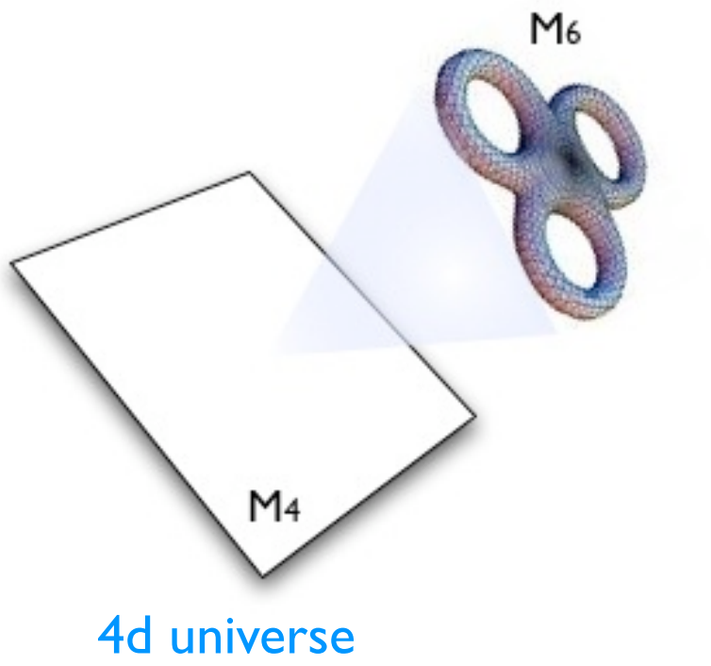


But

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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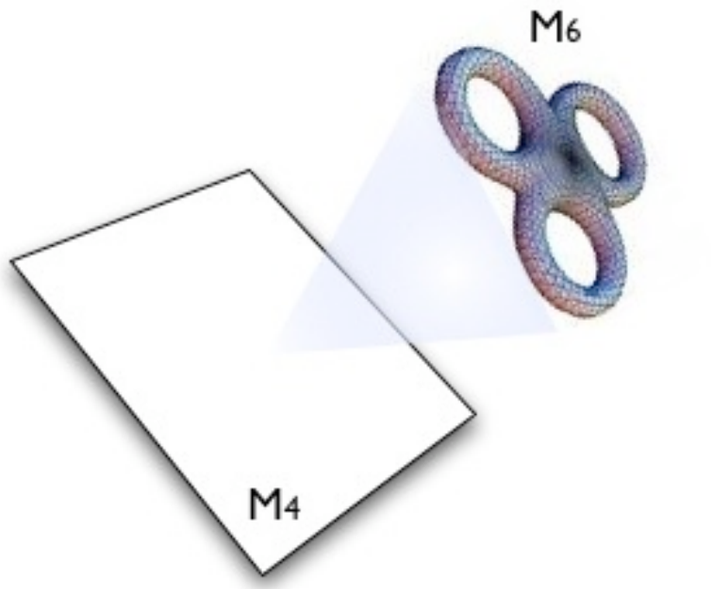

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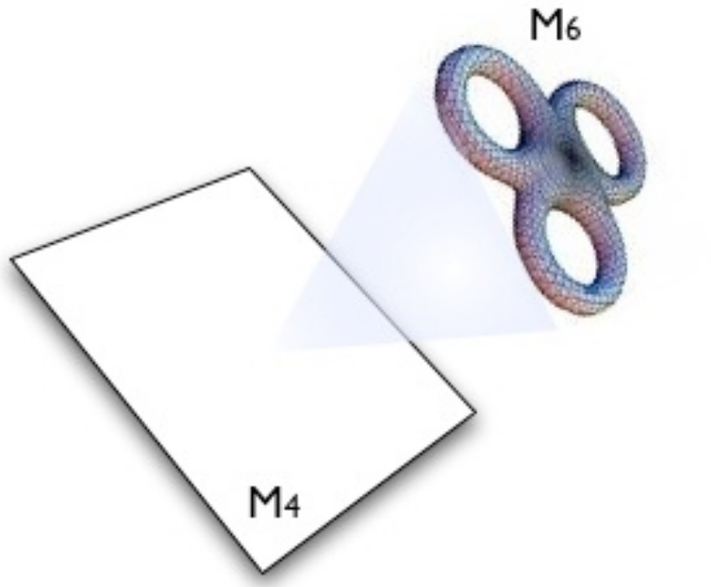

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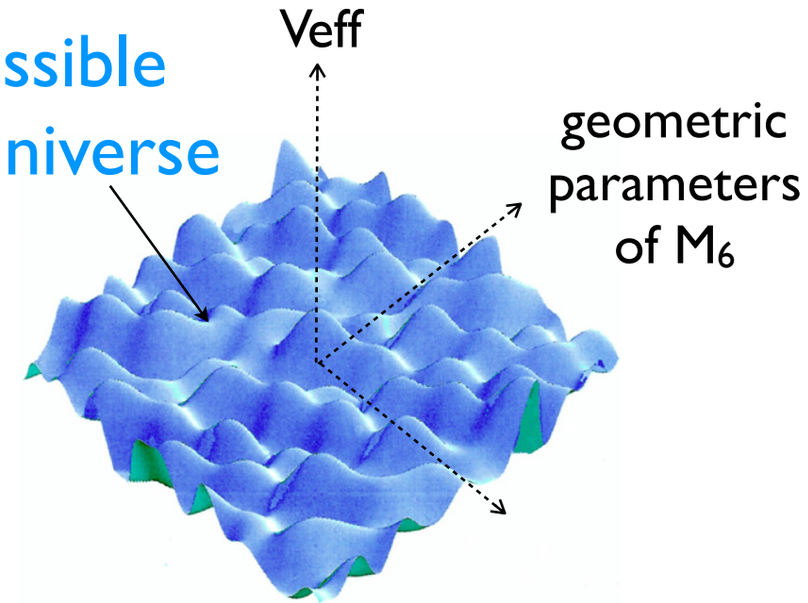

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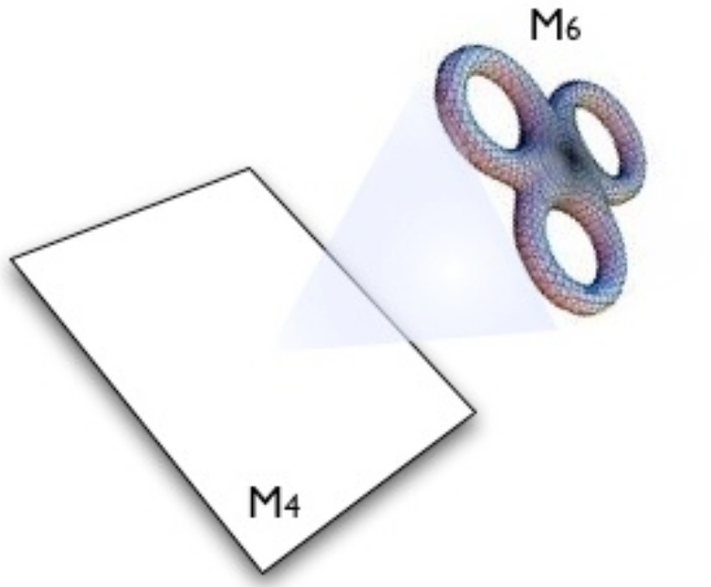

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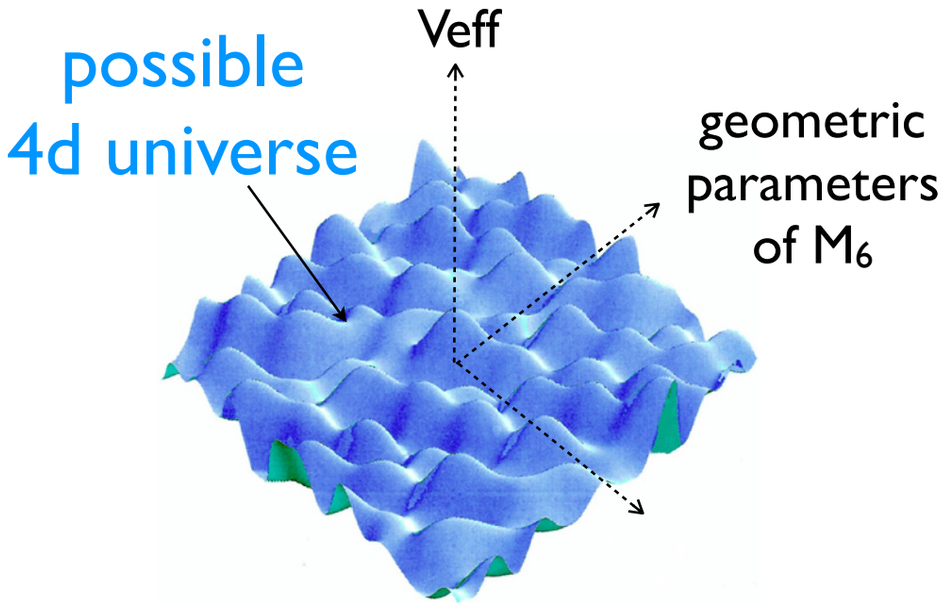

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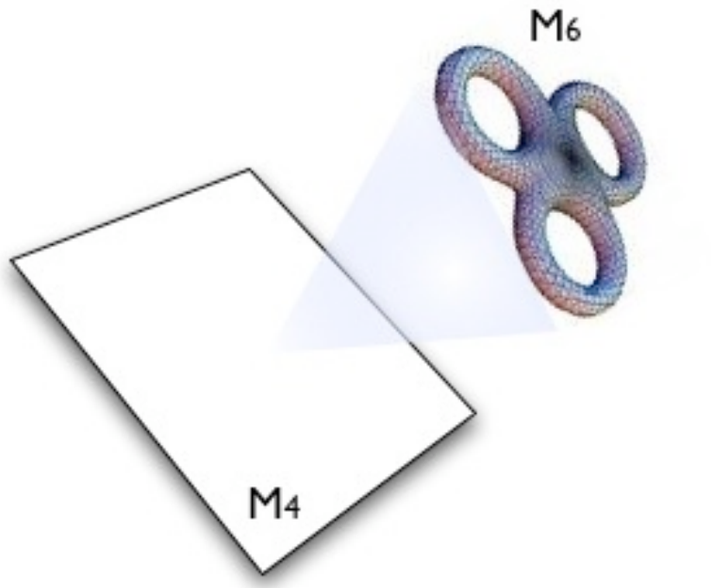

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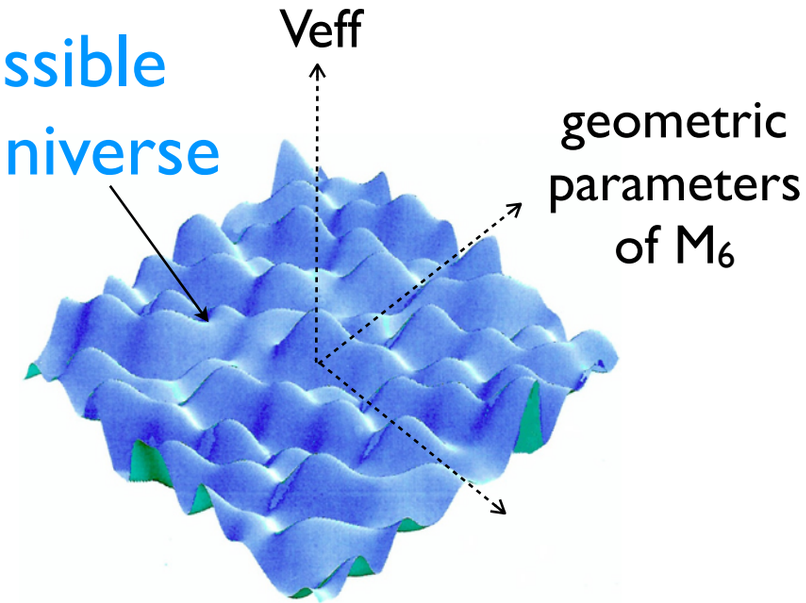
Landscape of possible 4d "universes"



Simplest exemple

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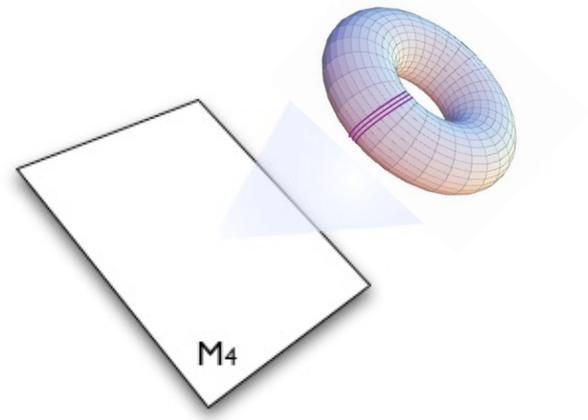

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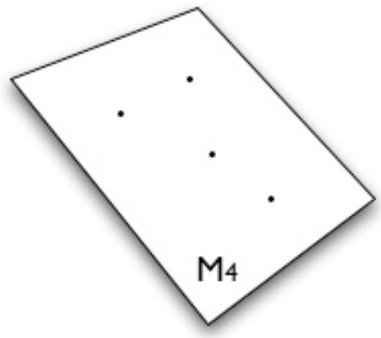

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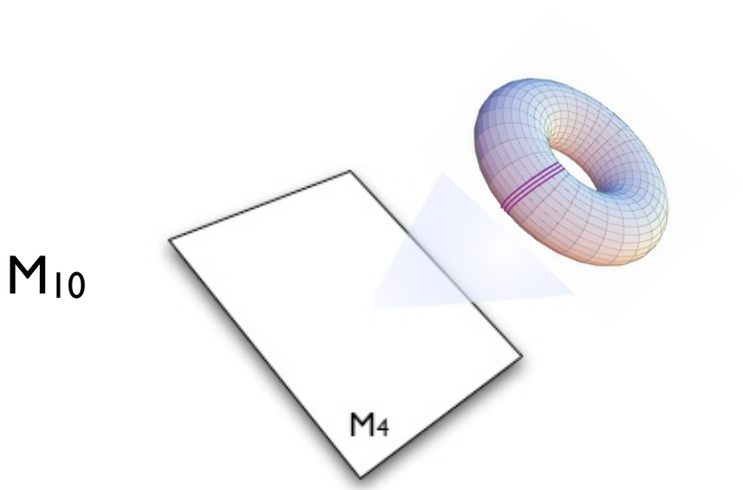

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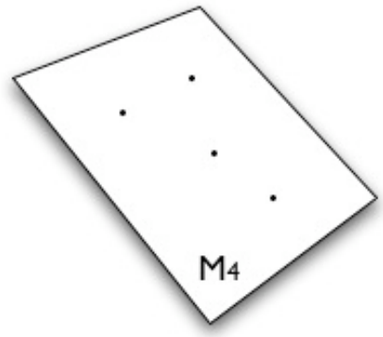

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Supersymmetric → supersymmetric spectrum

BUT 4D space = Minkowski → no cosmological constant

Radii of circles not fixed → Massless scalars (moduli)

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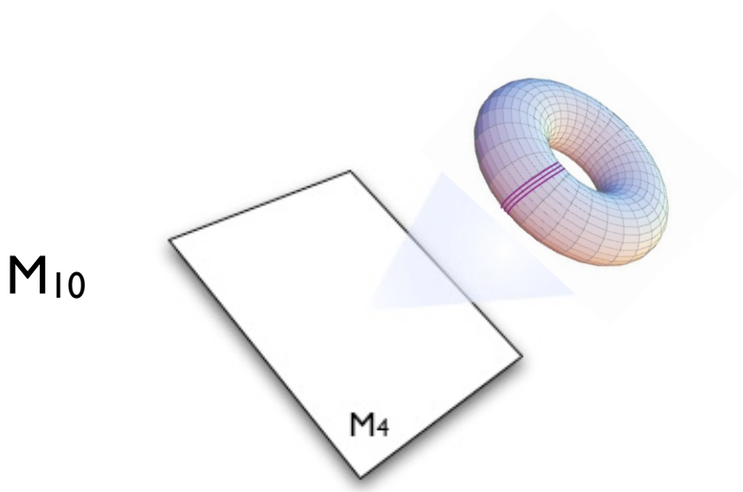

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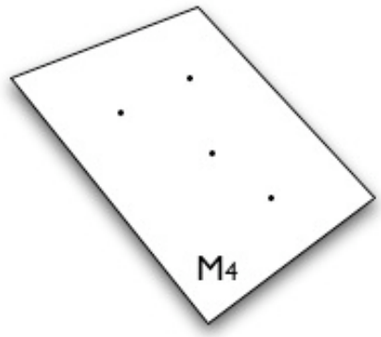

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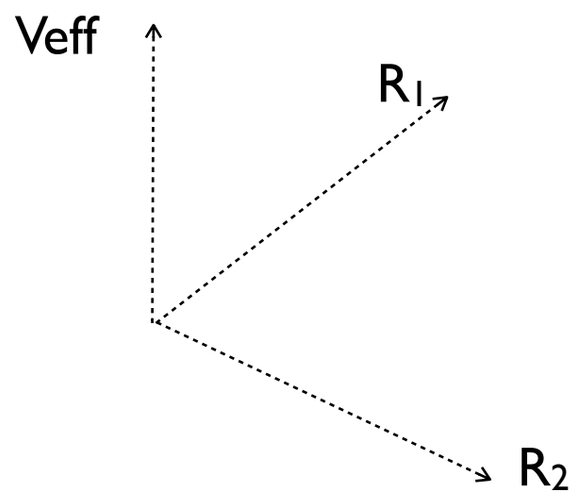

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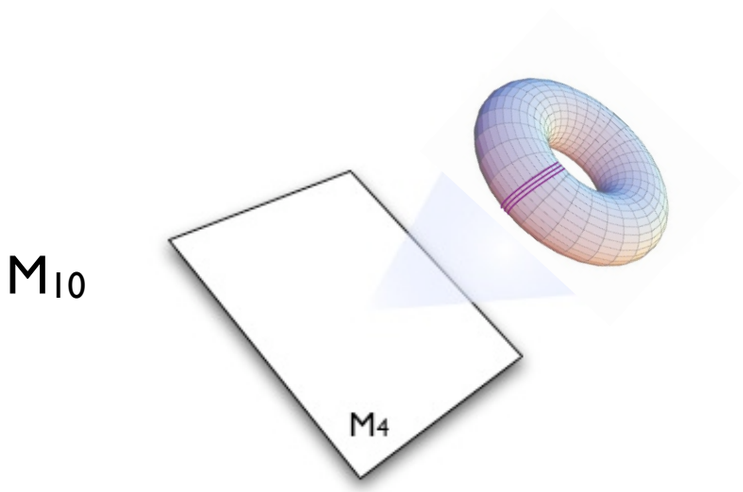

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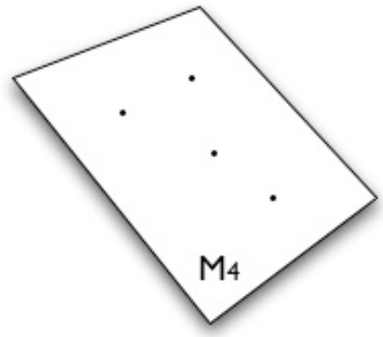

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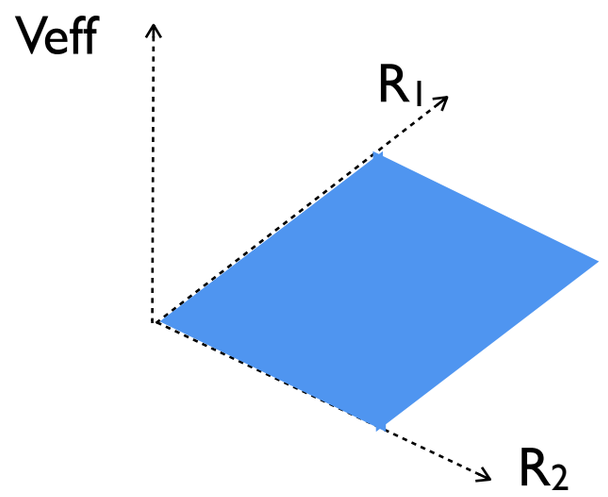

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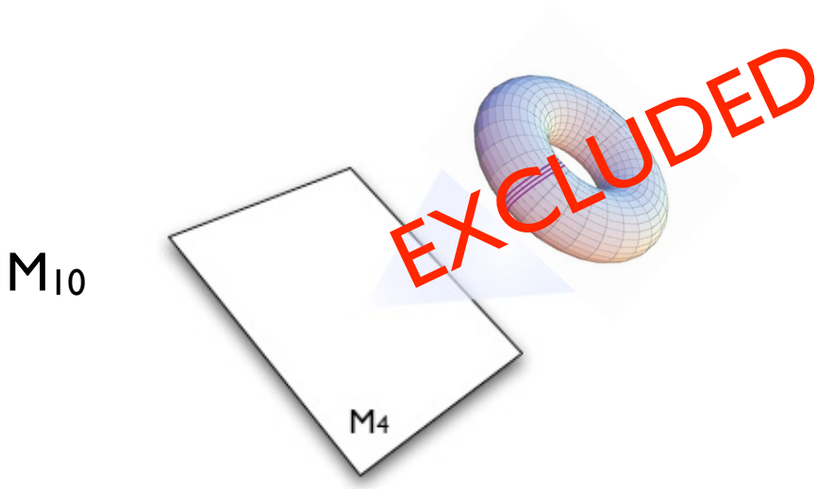

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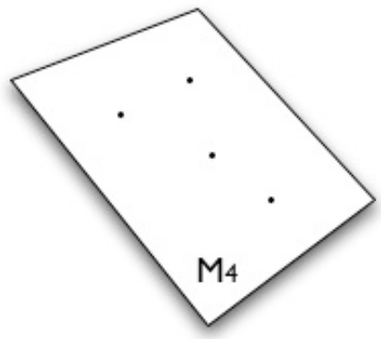

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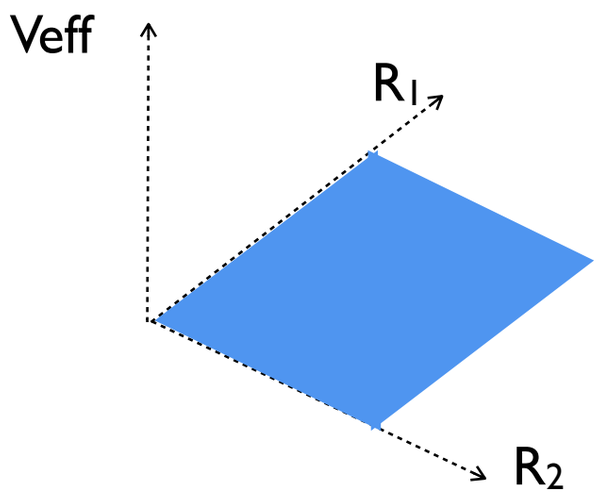

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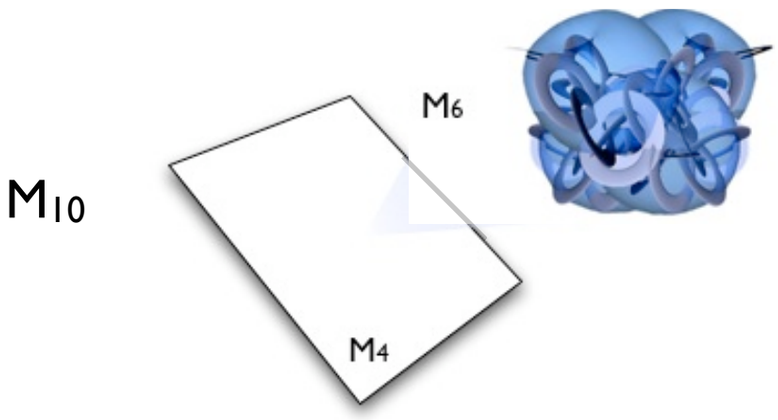

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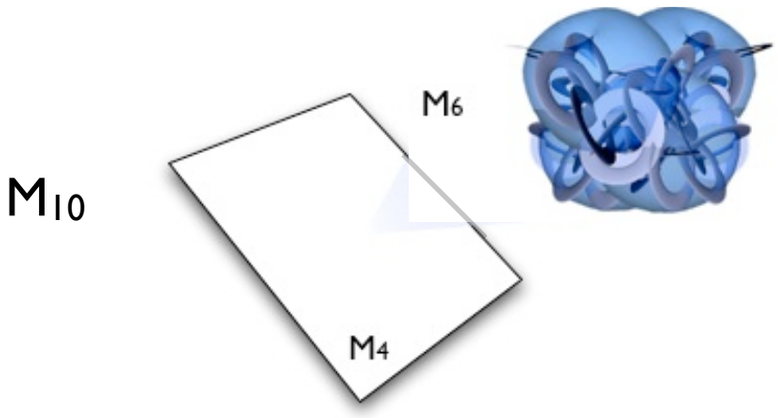

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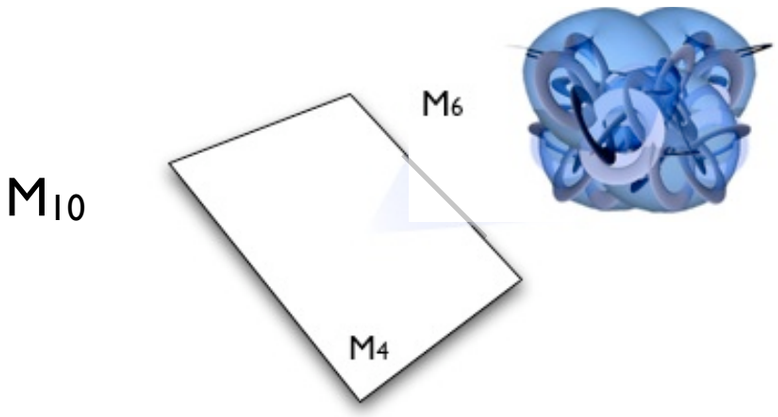

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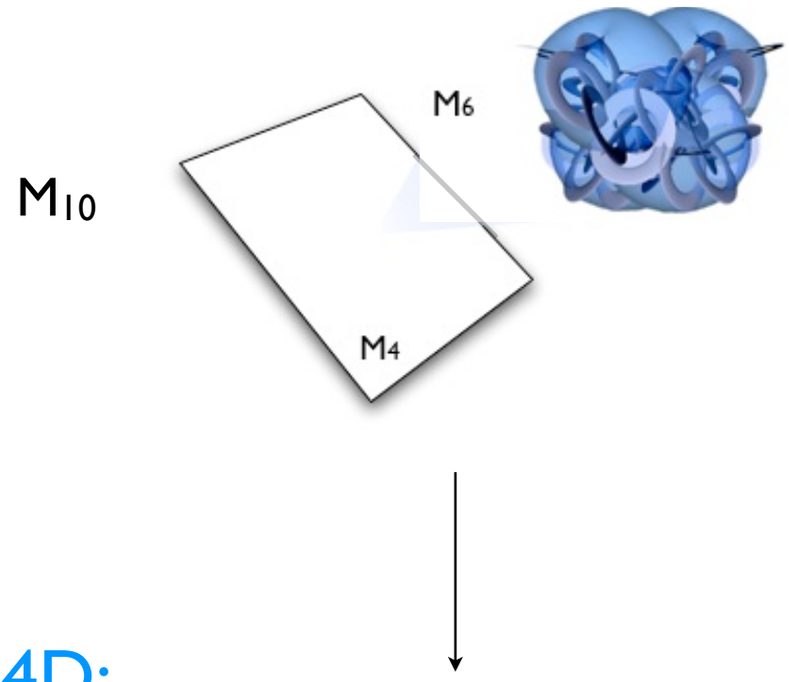

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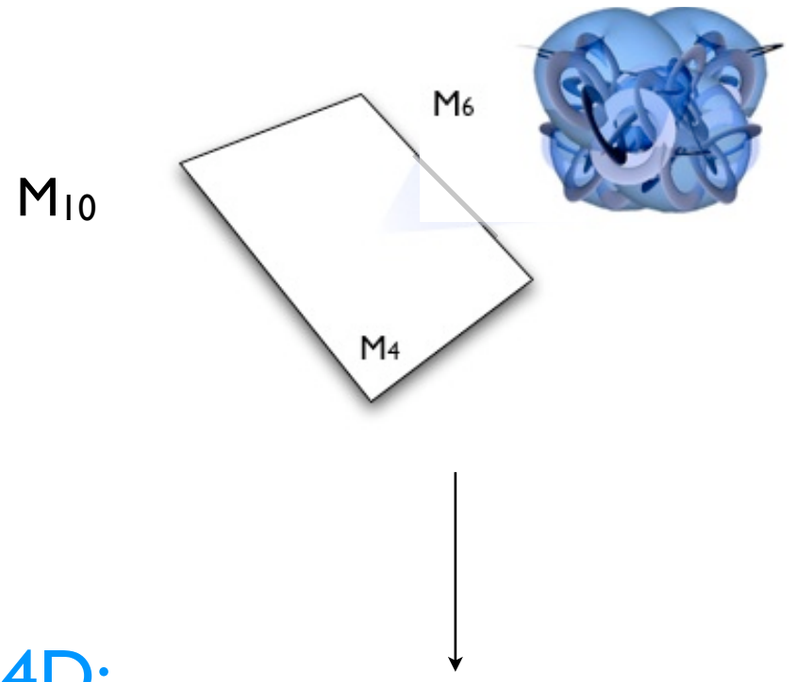

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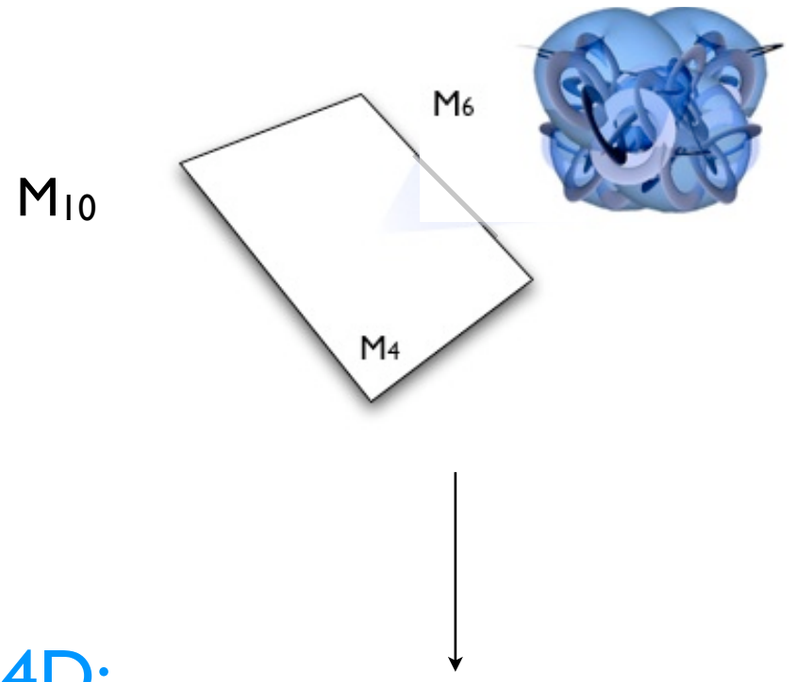

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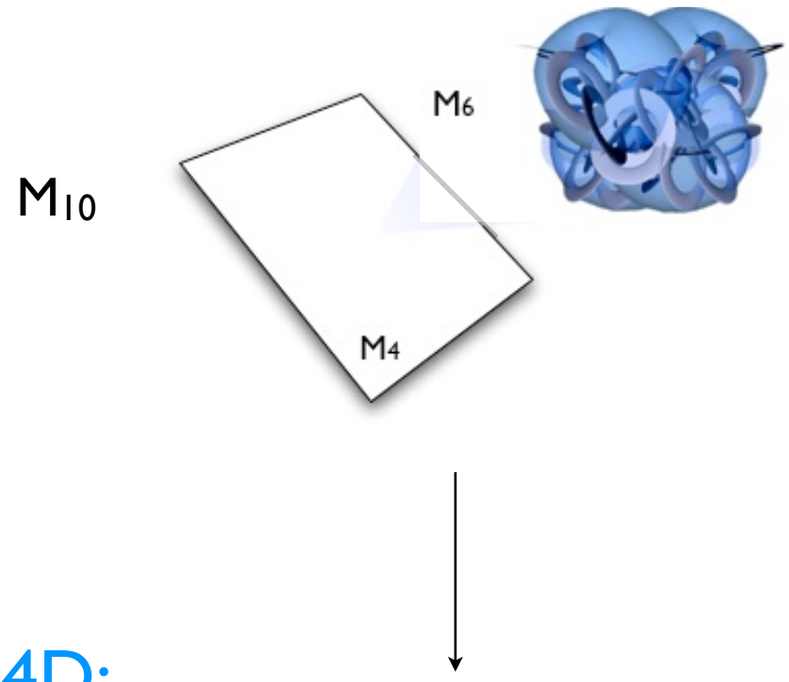

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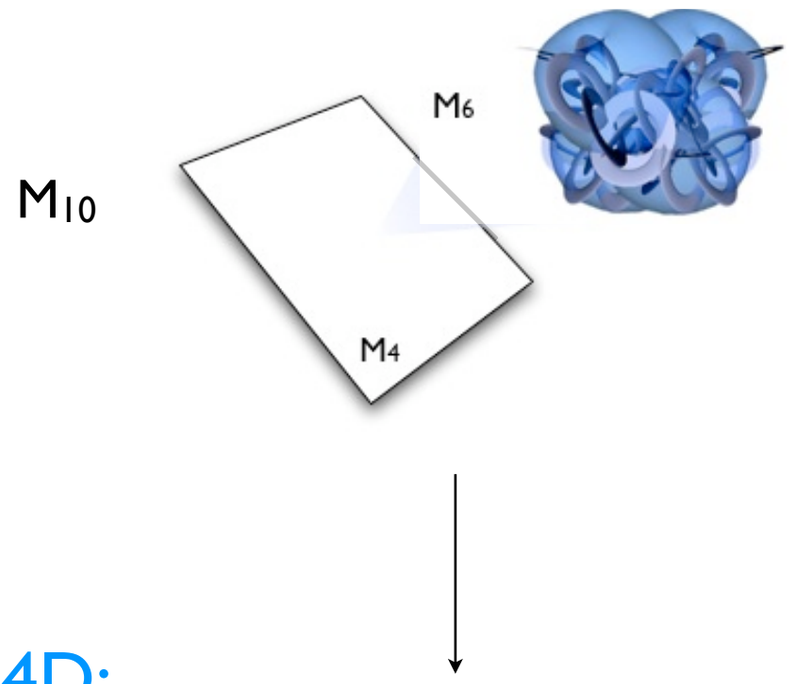

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Landscape of possibles 4d universes

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Obtained using Calabi-Yau spaces, and the rest bottom-up, requiring in 4D: 4D 10D

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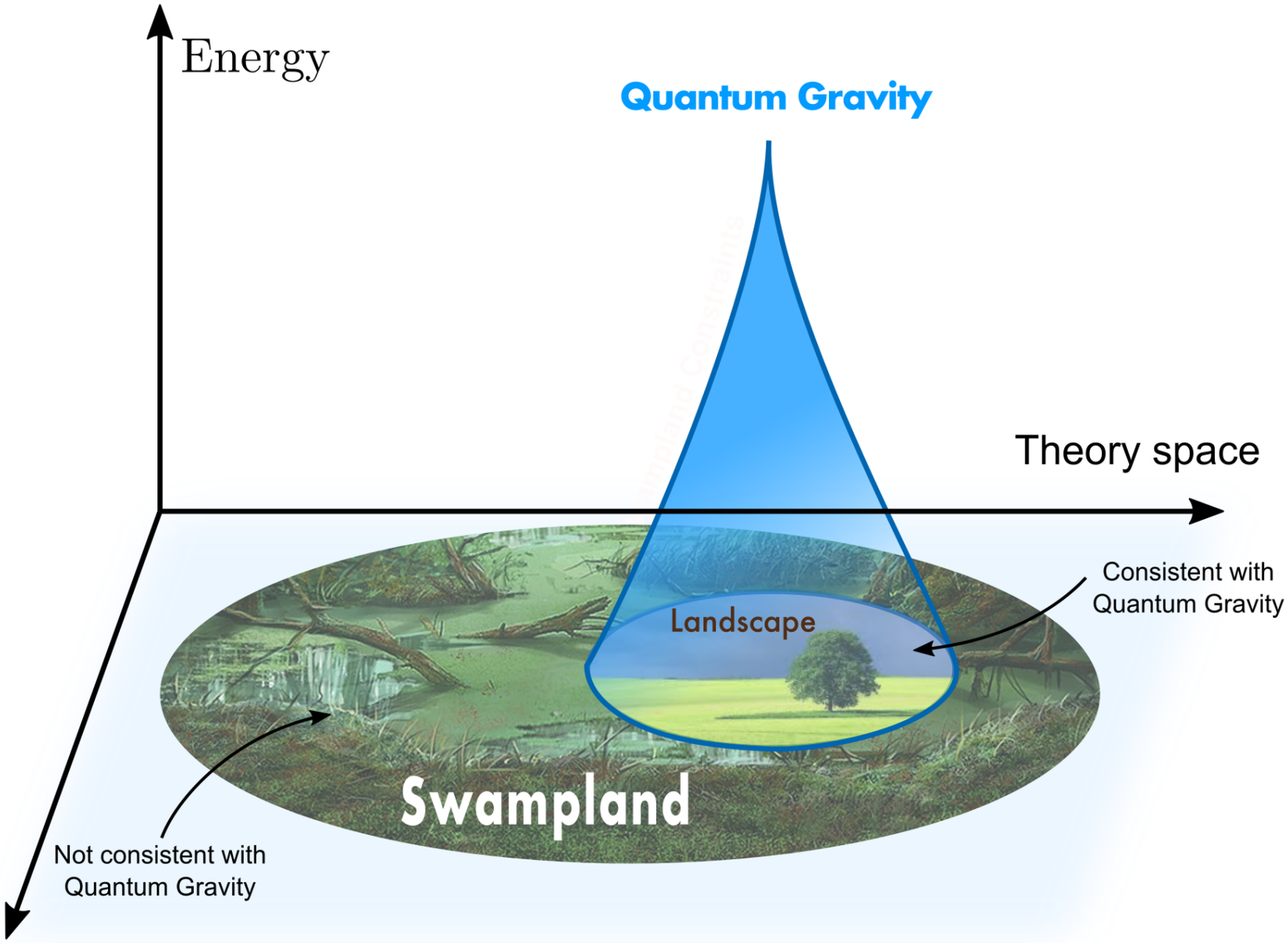
Or did we fall into the swampland ?

The landscape and the swampland



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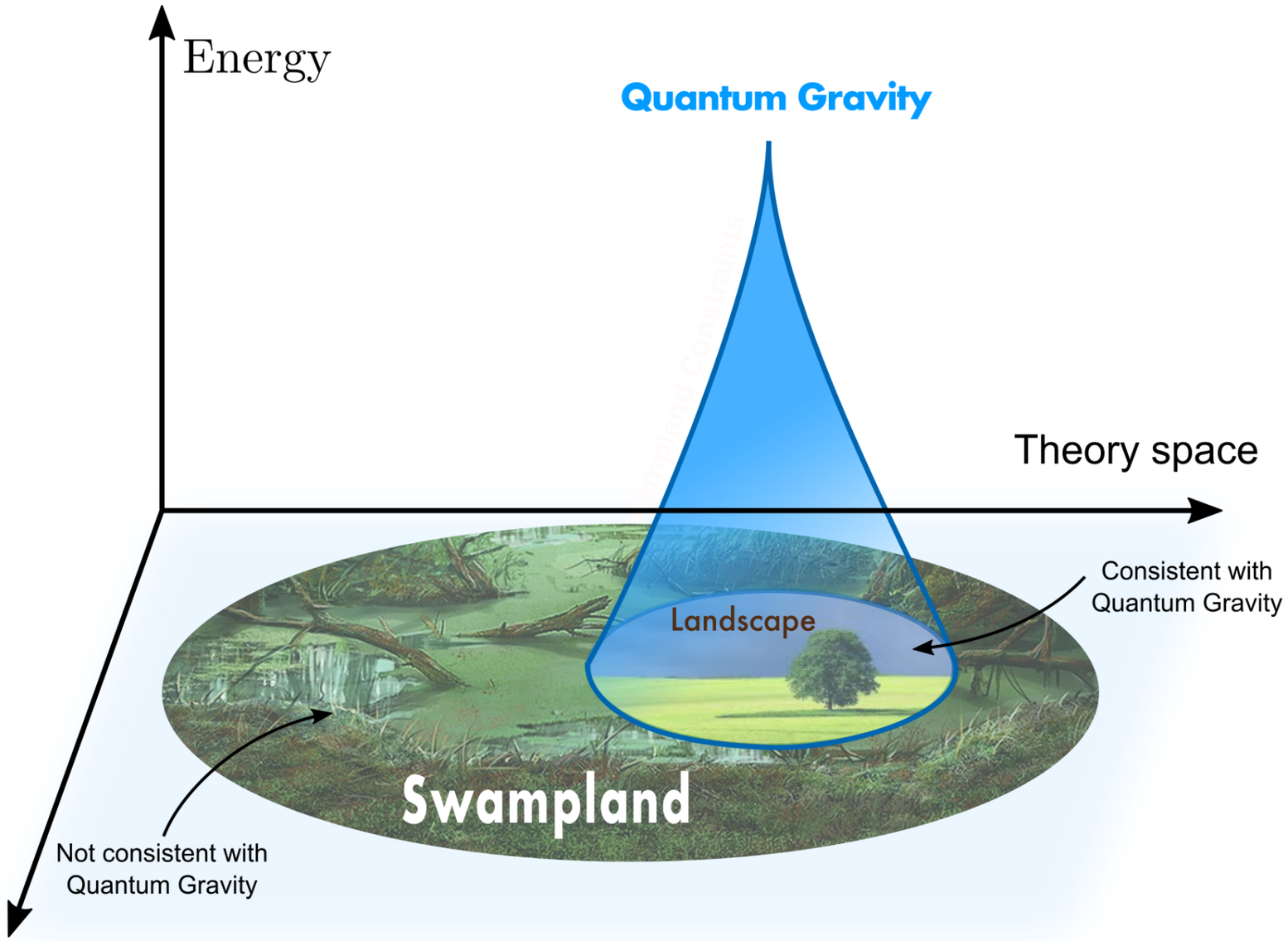

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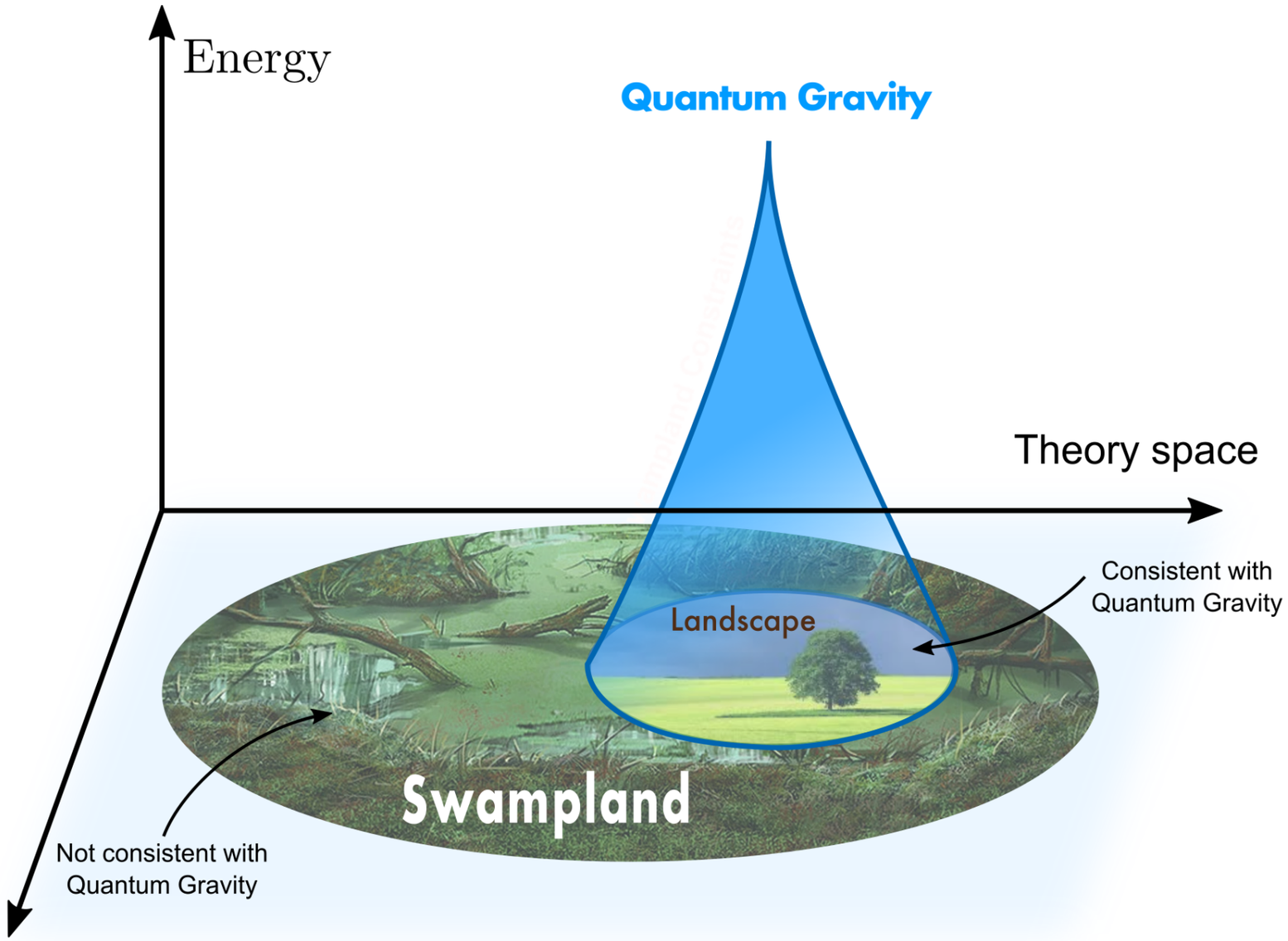

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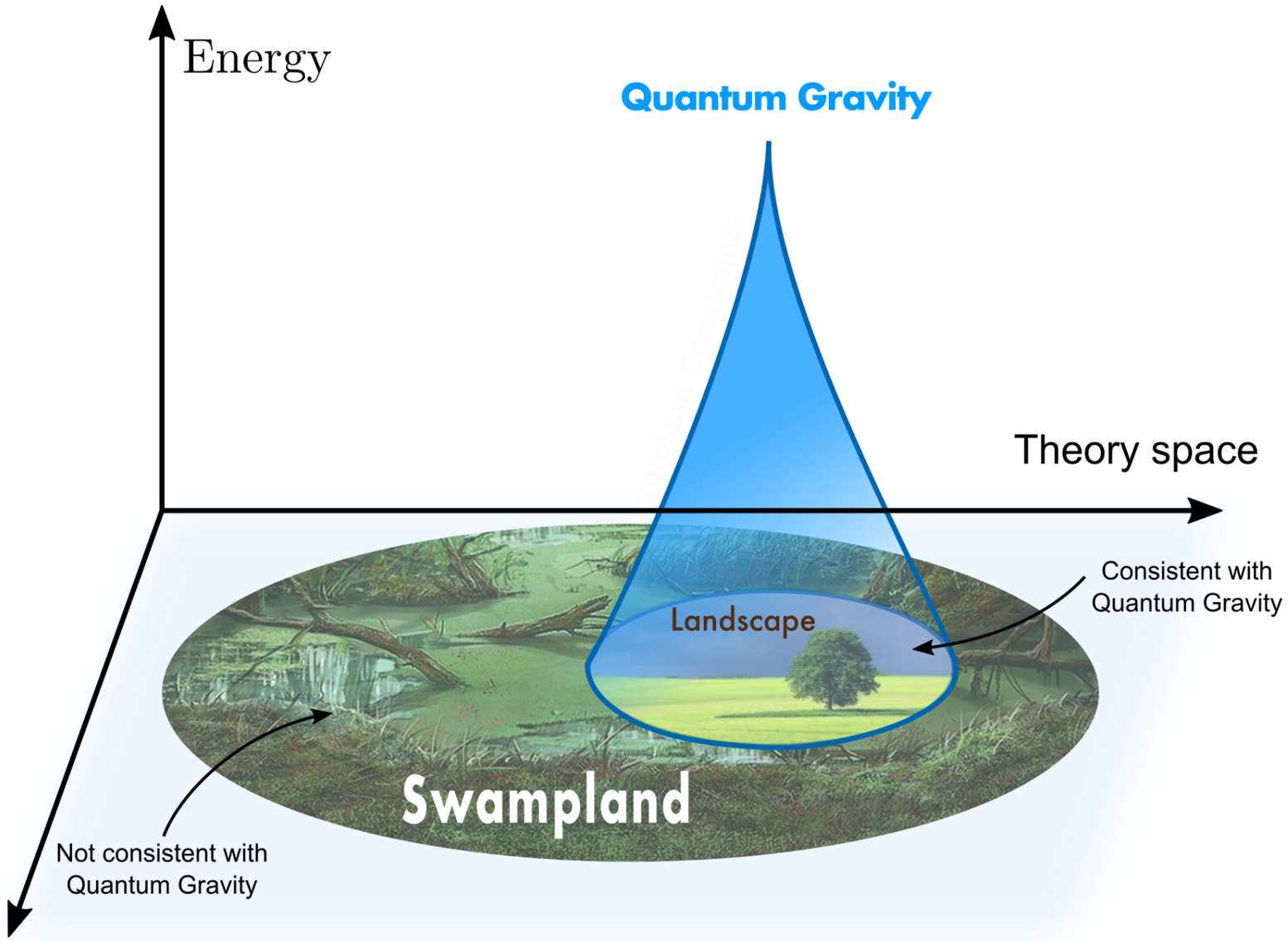

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Conjectures based on physics of black holes and/or inspired by string theory

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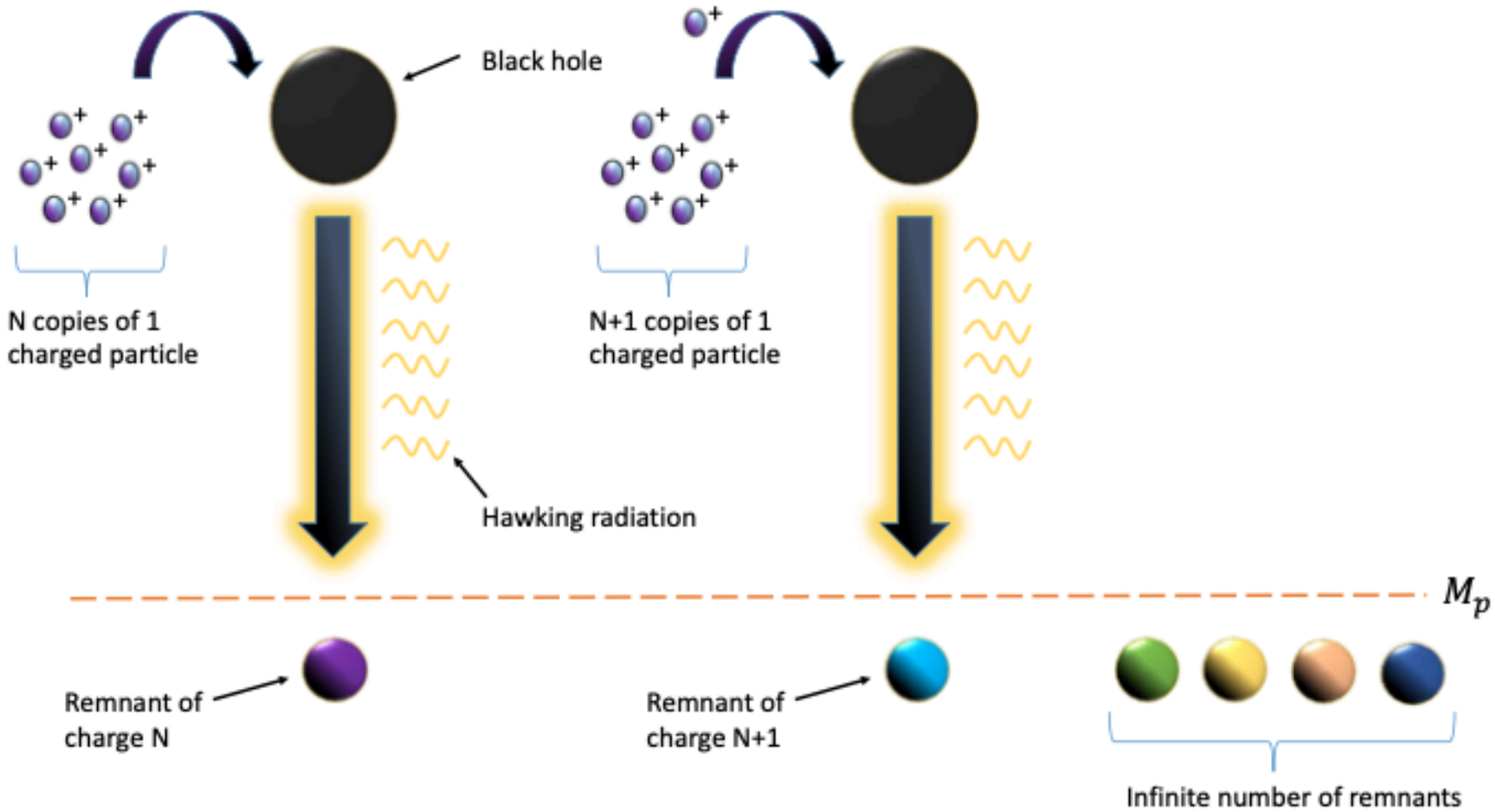

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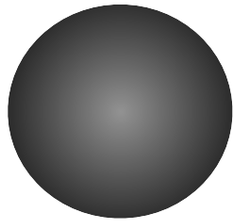

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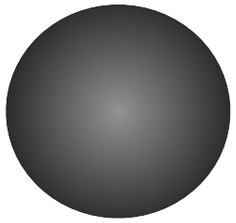

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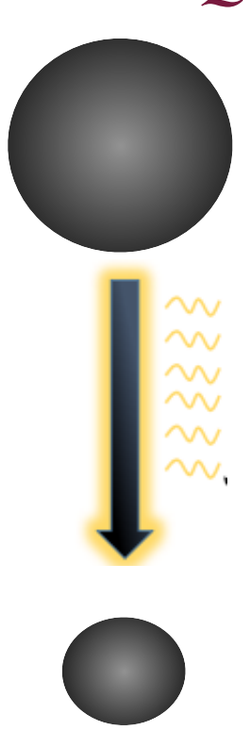

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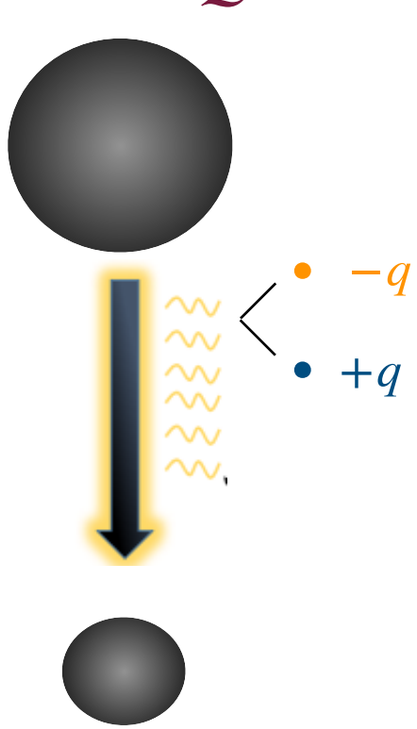

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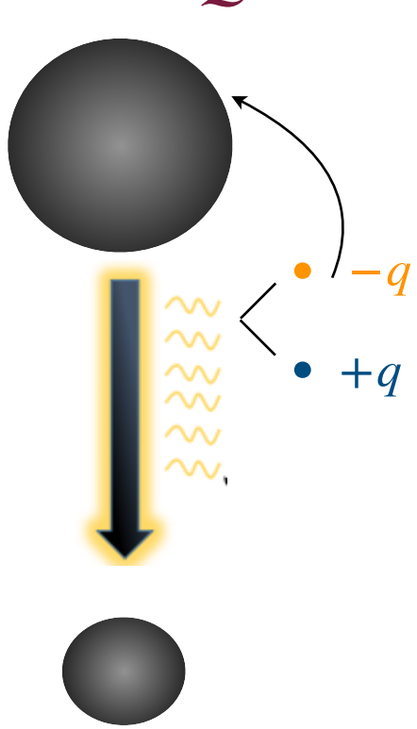

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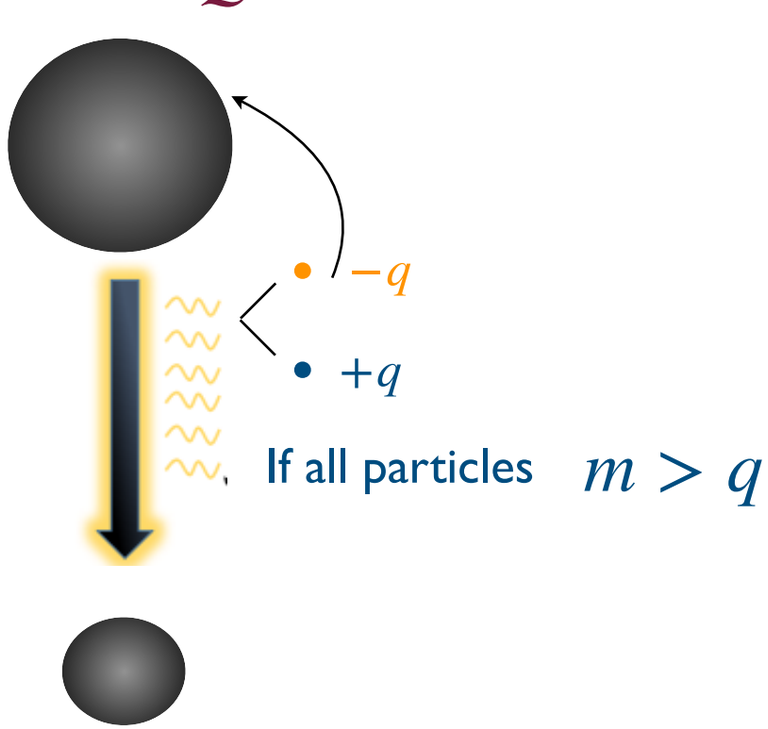

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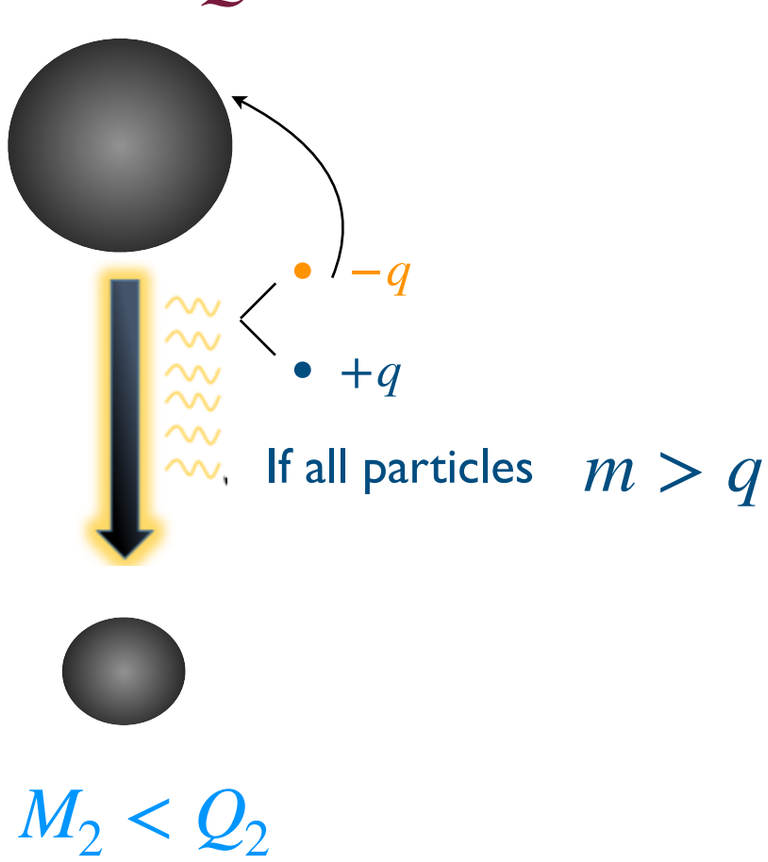

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superextremal black hole:
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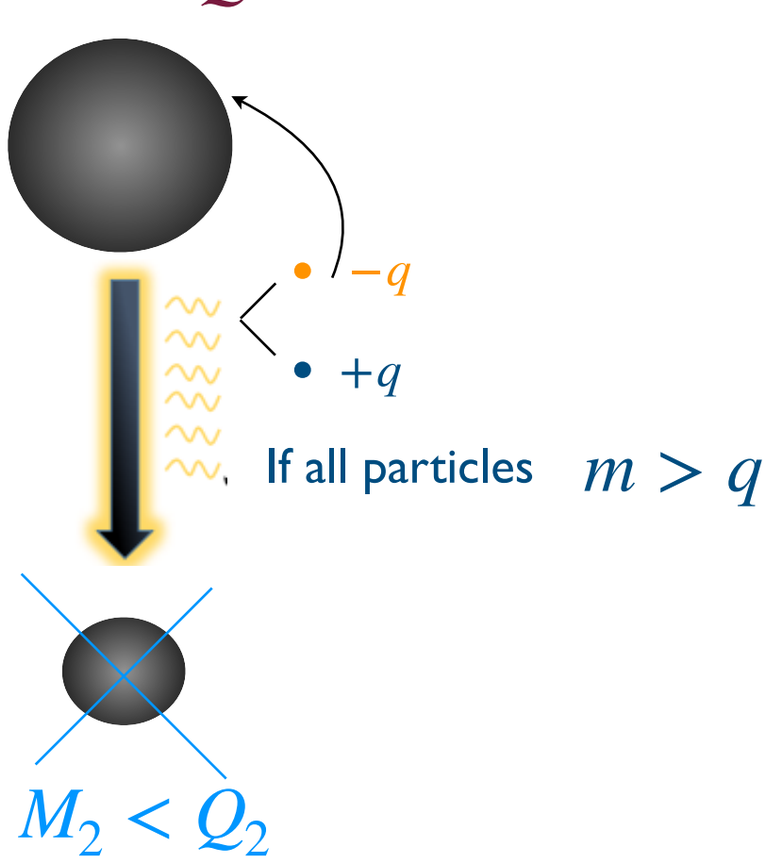

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⇒ extremal black holes cannot decay: remnants

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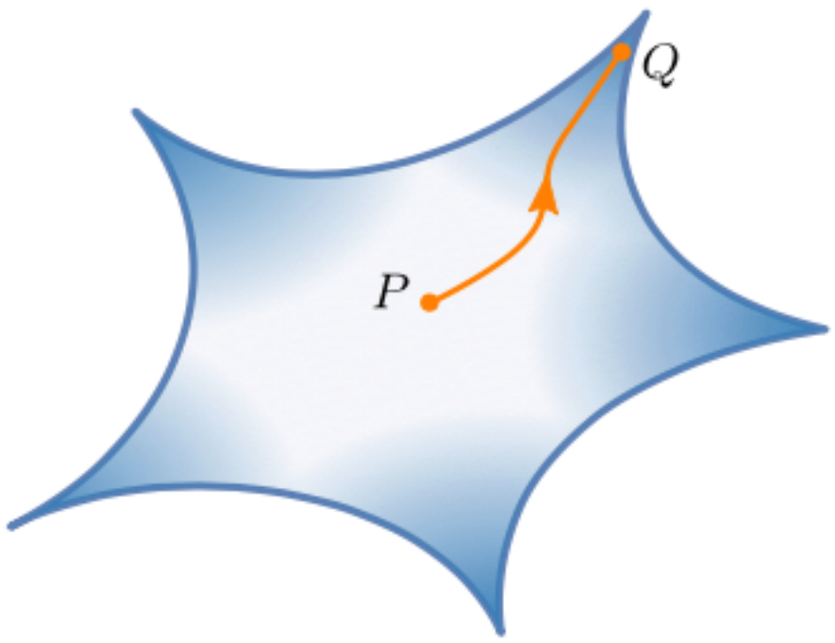
$$\mathscr{L} = g_{ij}(\phi)\, \partial_\mu \phi^i \partial^\mu \phi^j$$ scalar manifold (moduli space)



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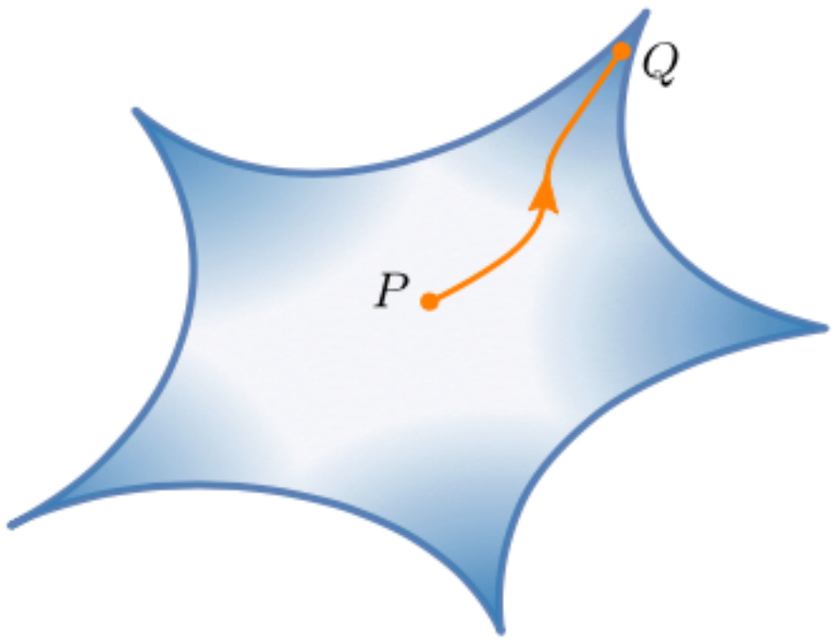

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Modulus ϕ = R (radius)

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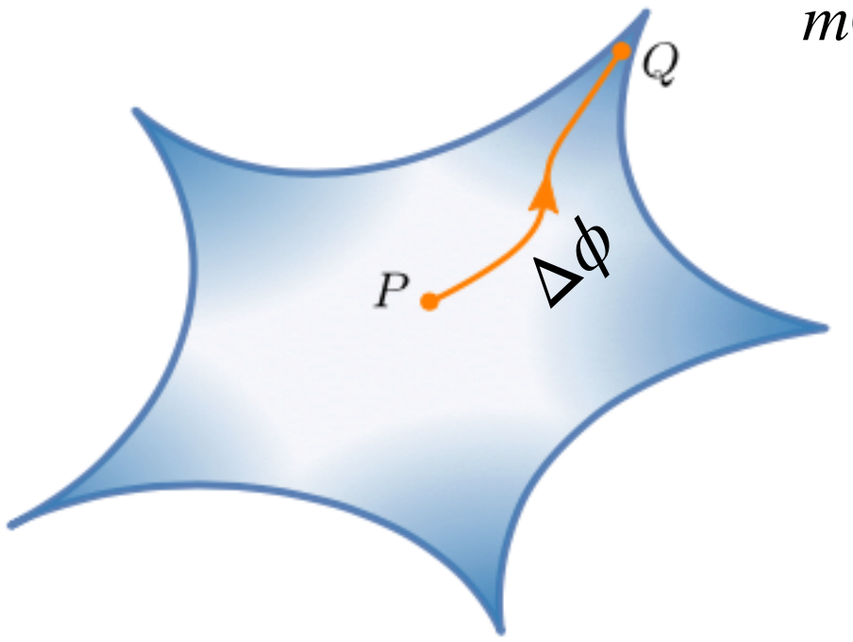

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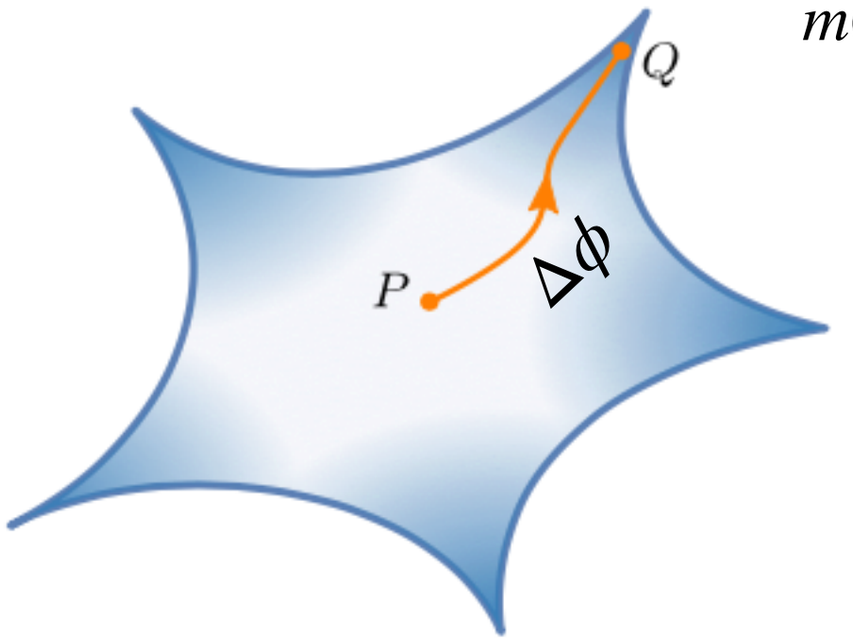

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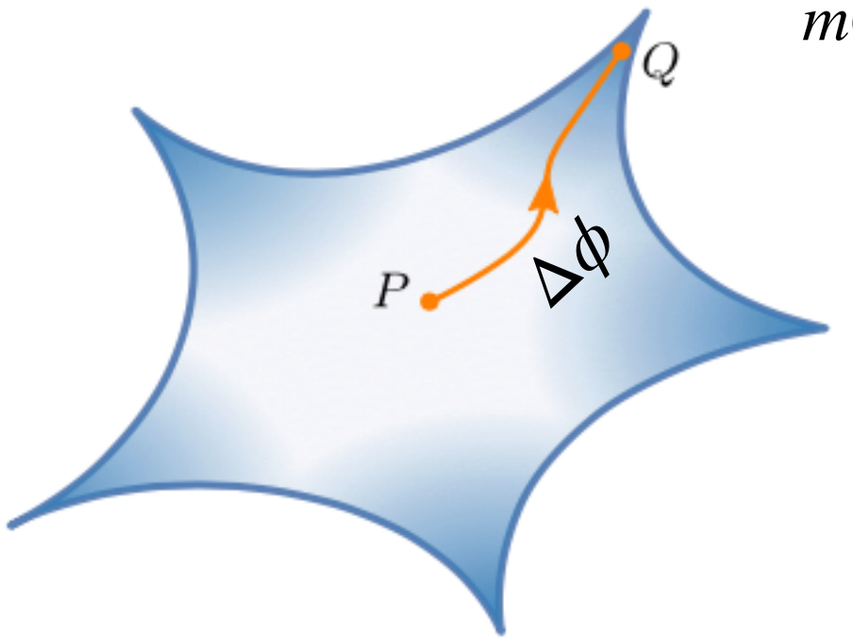

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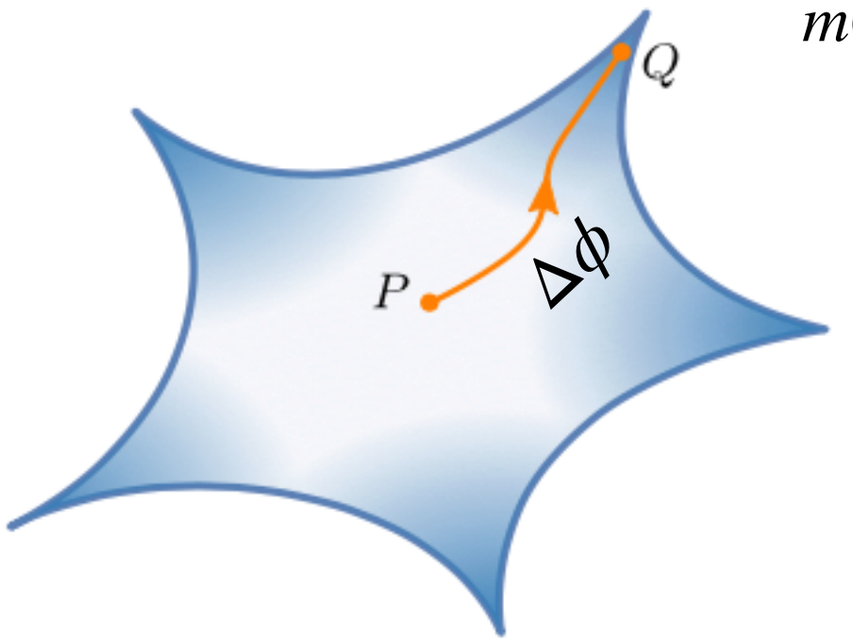

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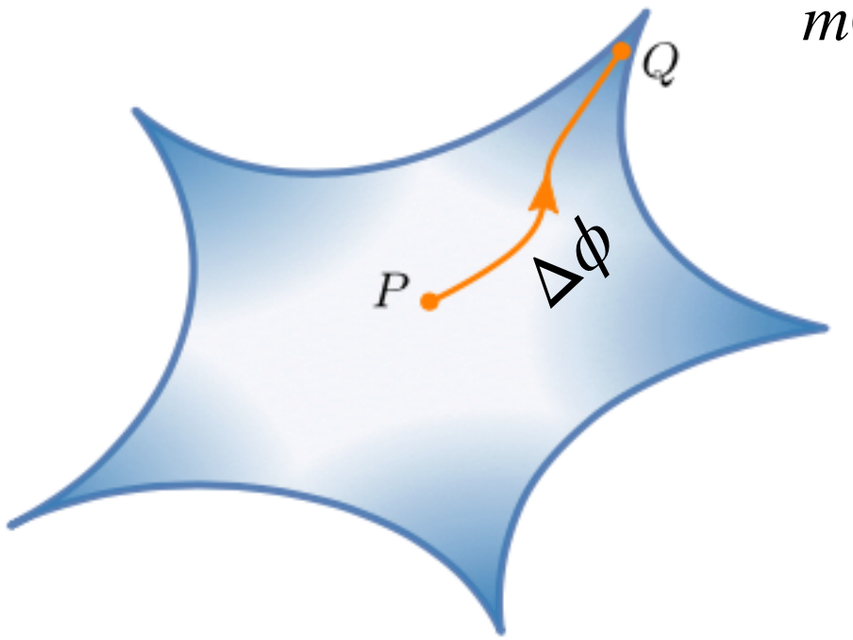

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EFT breaks down when $\Delta\phi \to \infty$

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- de Sitter swampland conjecture

Obied, Ooguri, Spodyneiko, Vafa 18
(OOSV)

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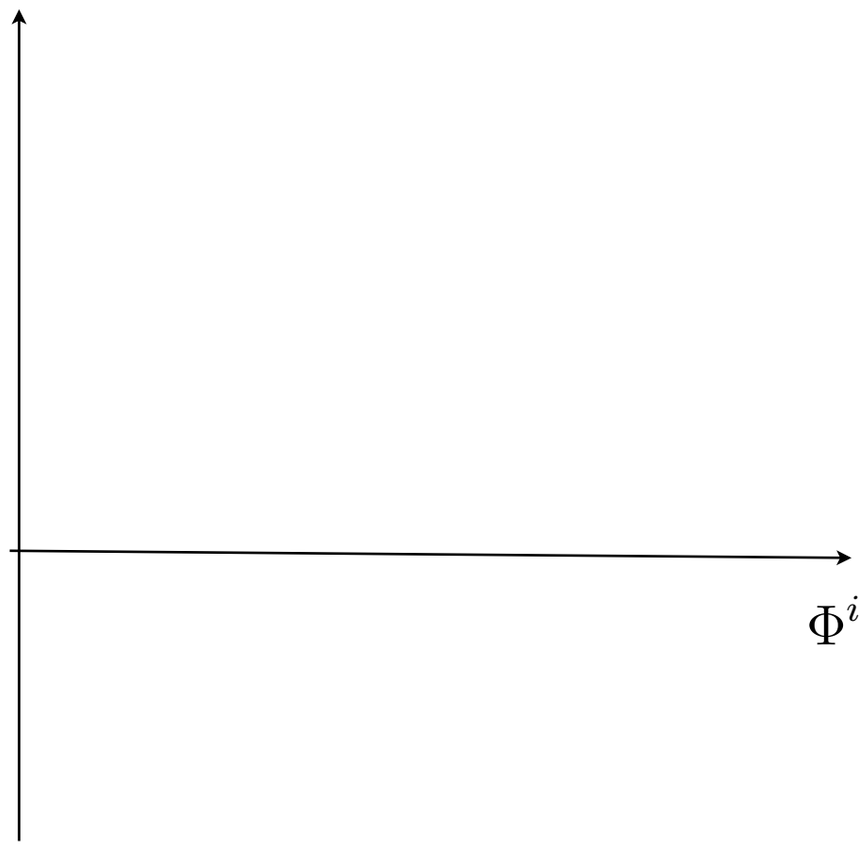

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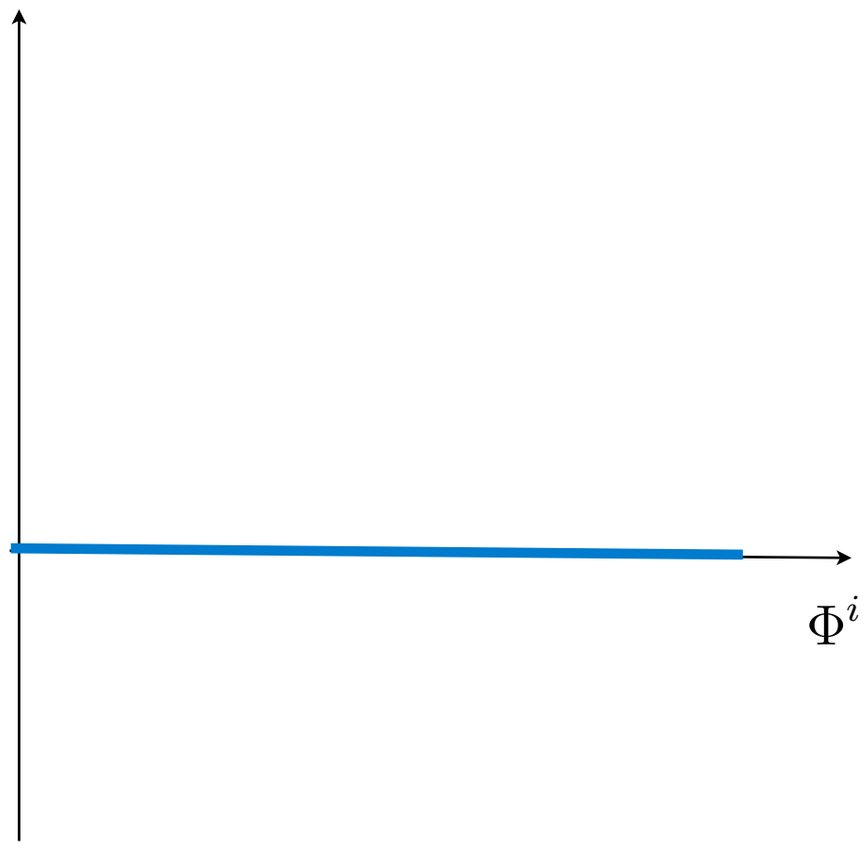

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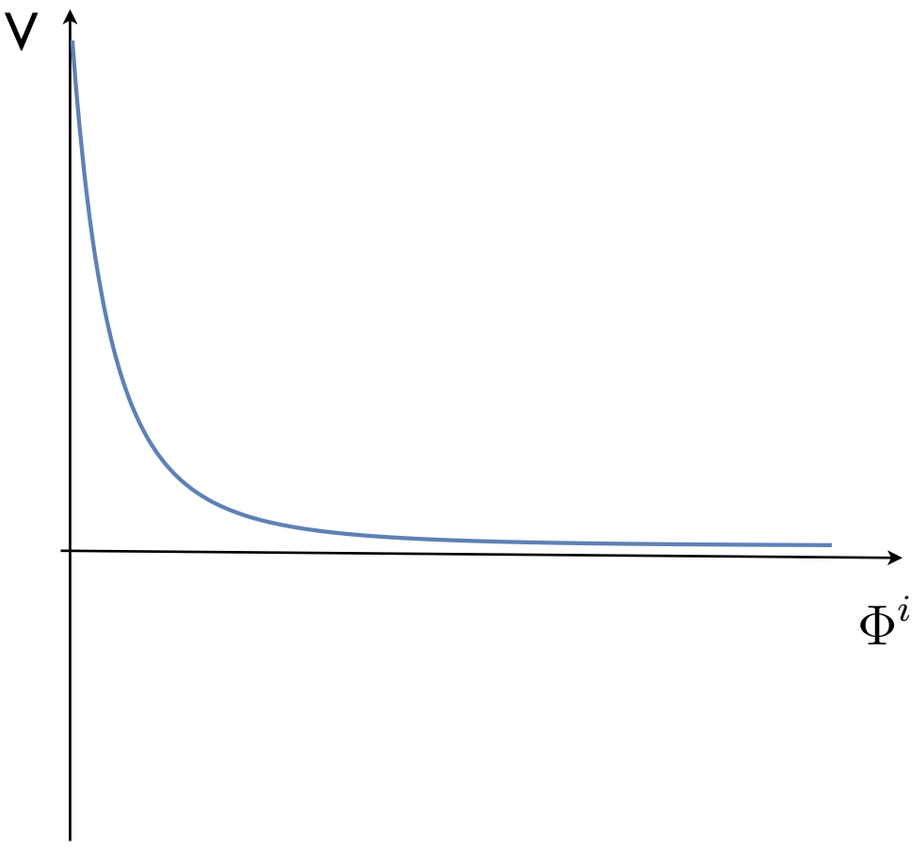

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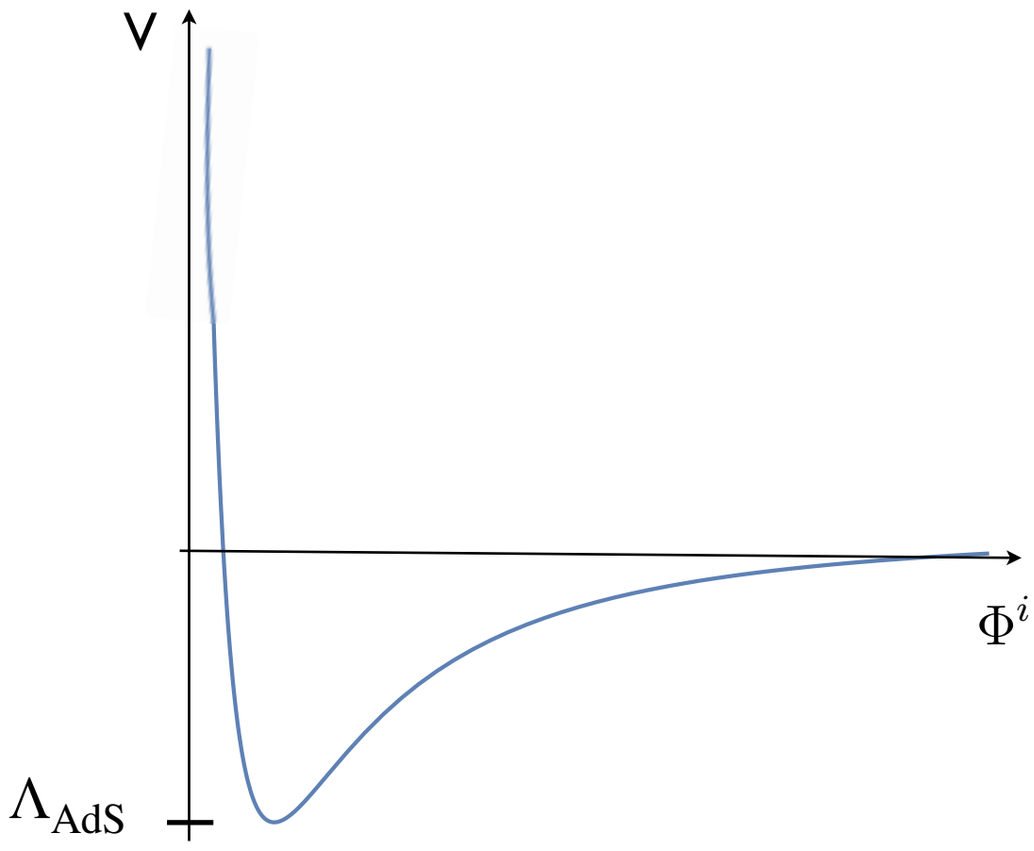

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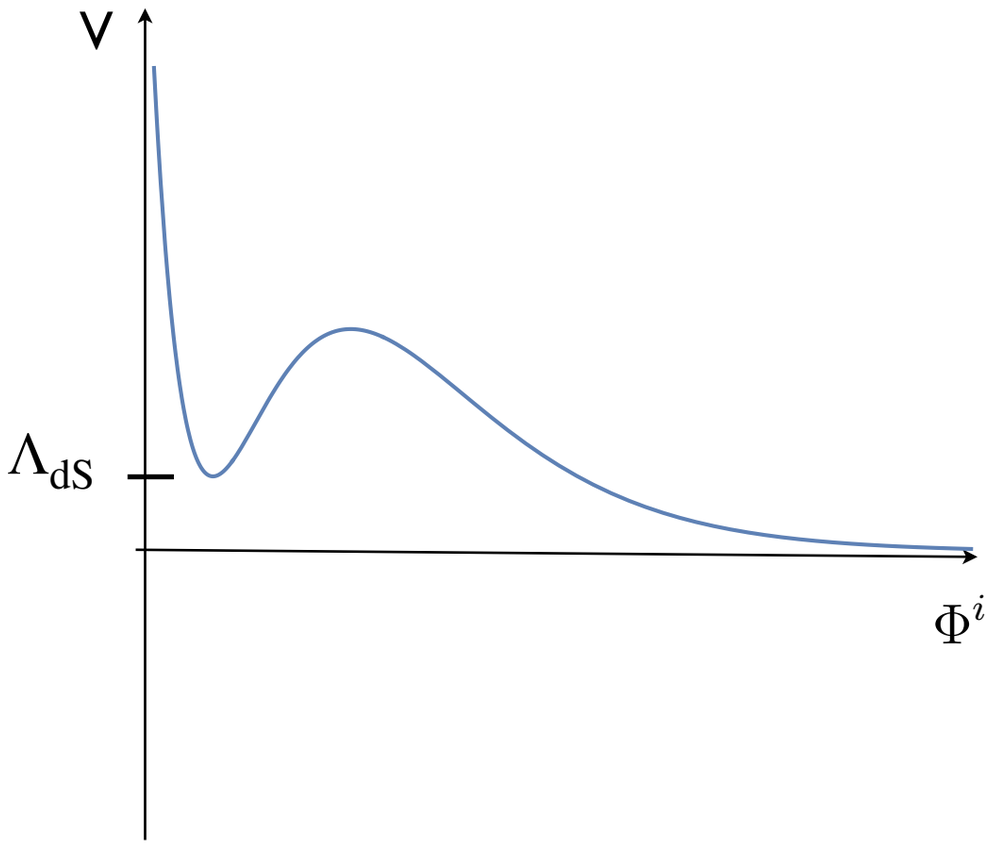

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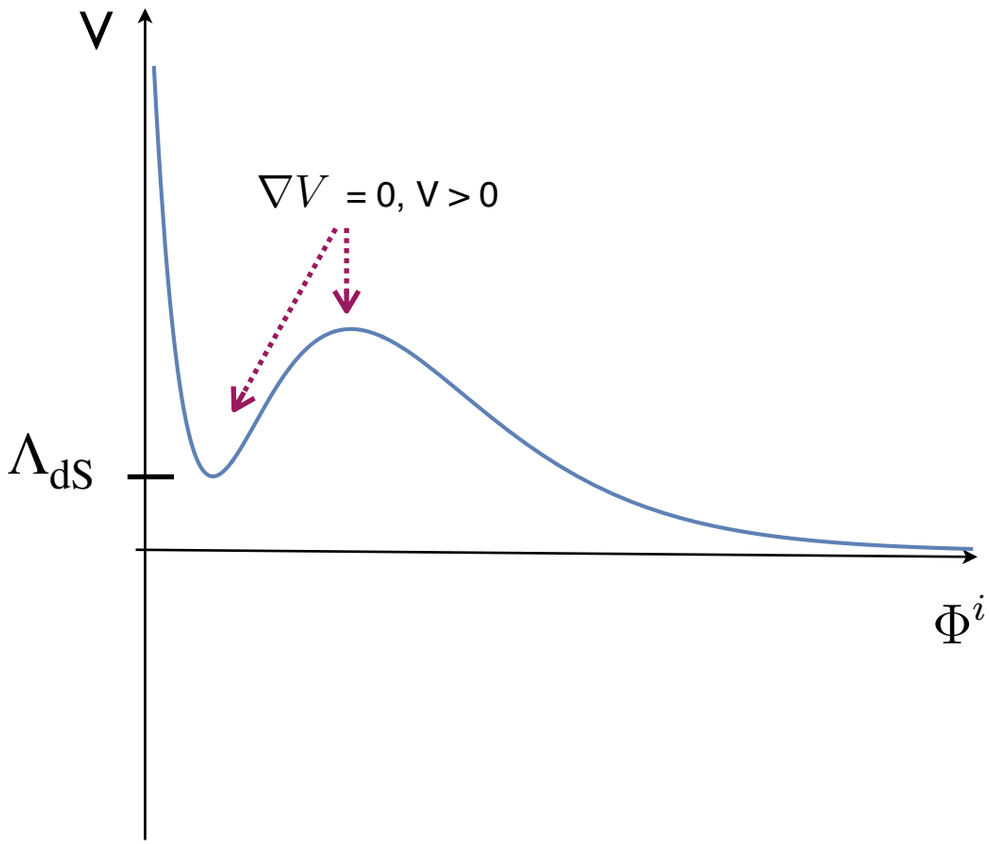

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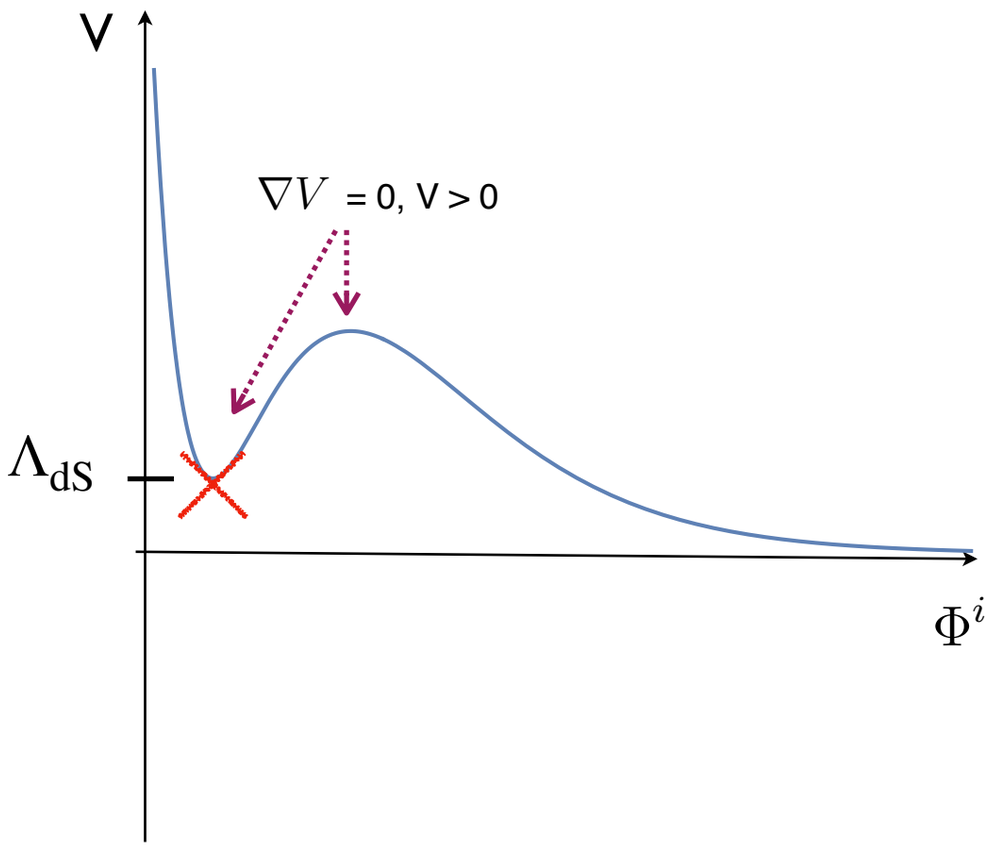

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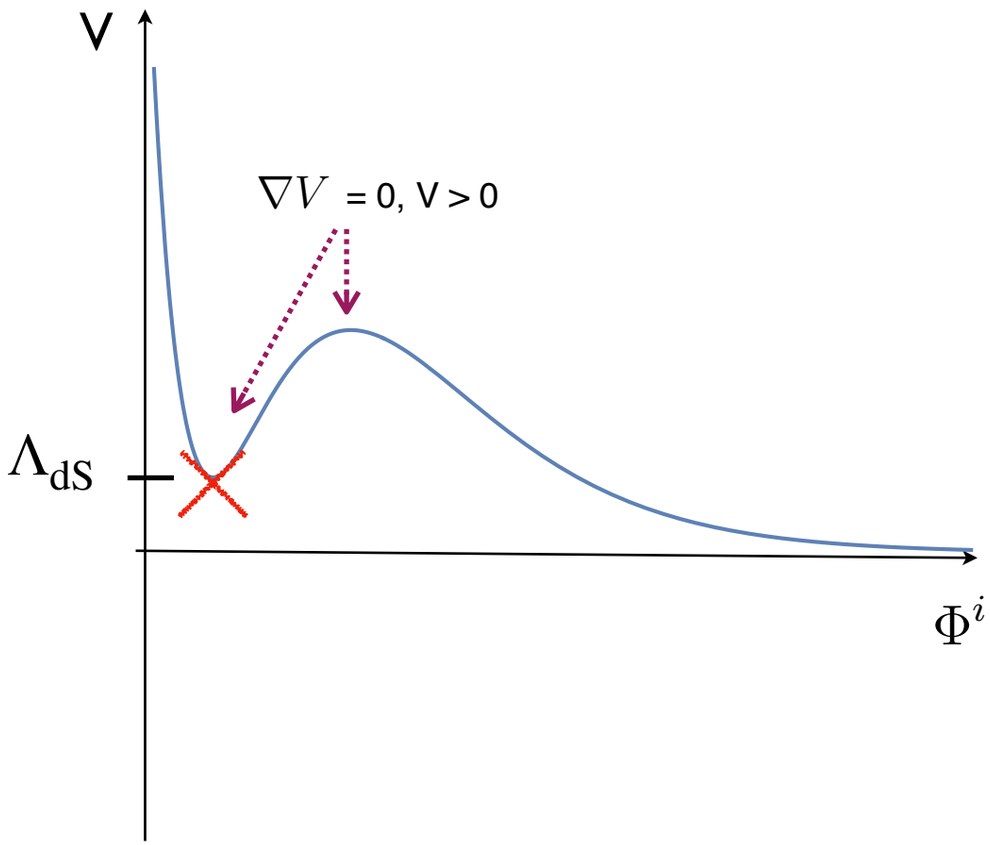

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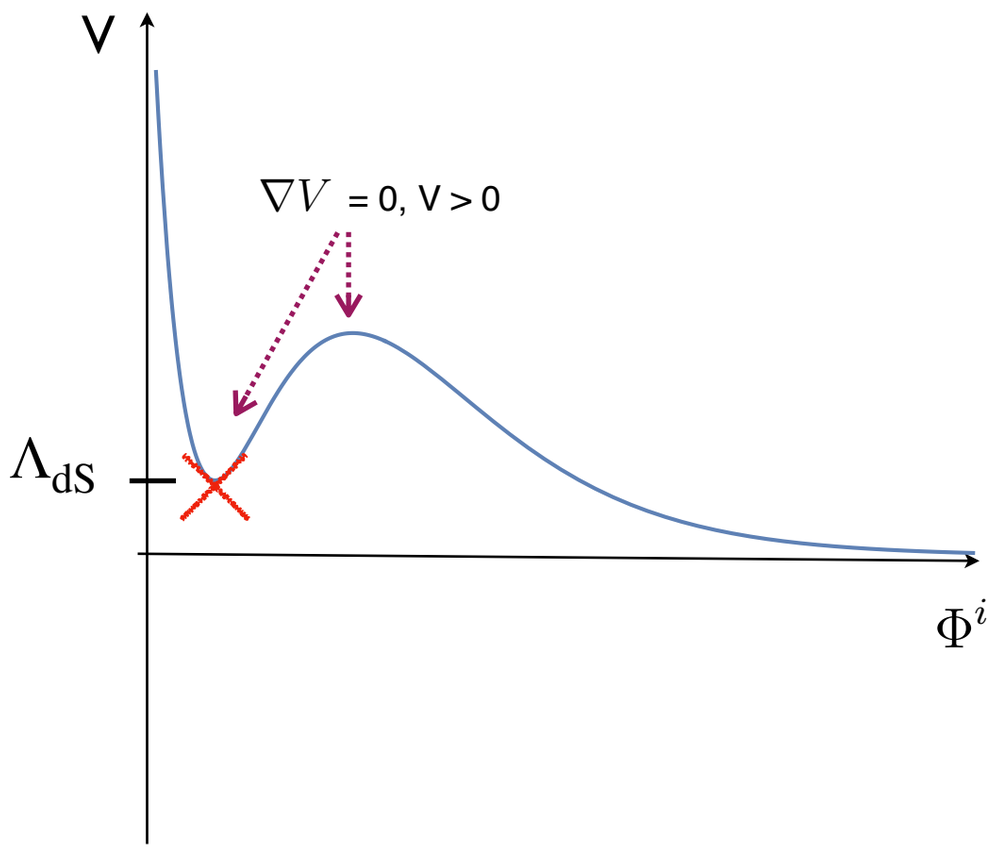

Metastable dS vacua
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If so, dark energy comes from quintessence field(s)

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

KKLT 03

10^{500}

dS vacua

OOSV 18

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Complicated construction

uses non-perturbative ingredients

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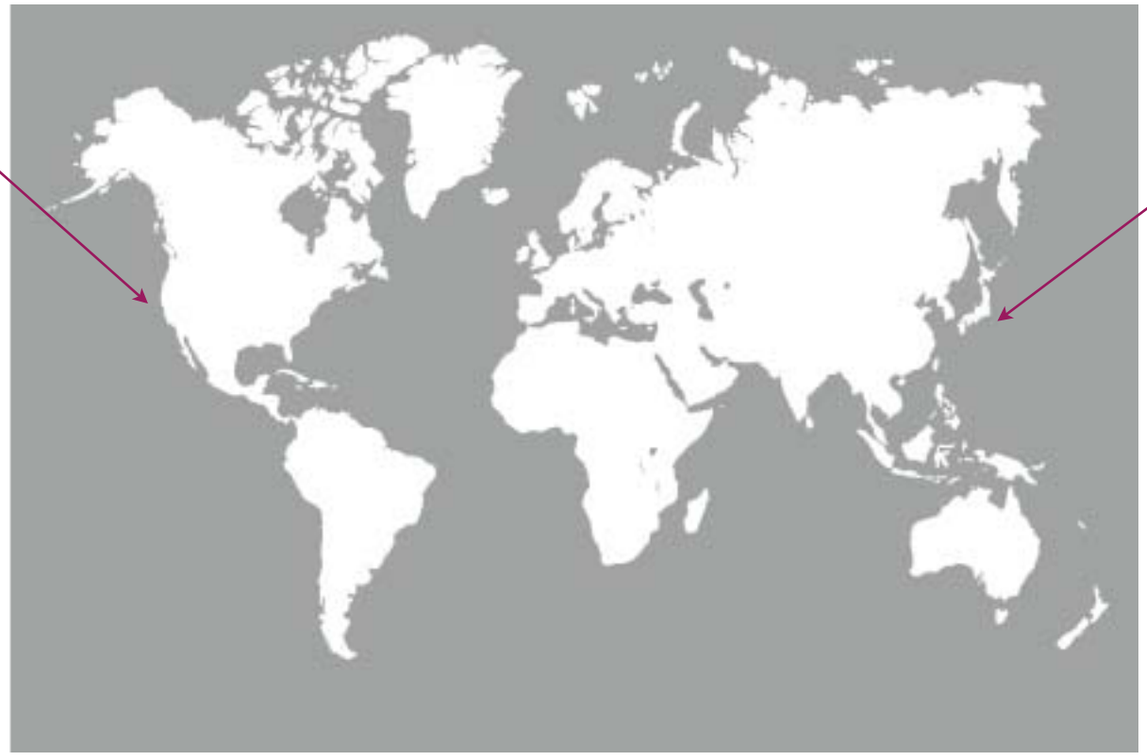

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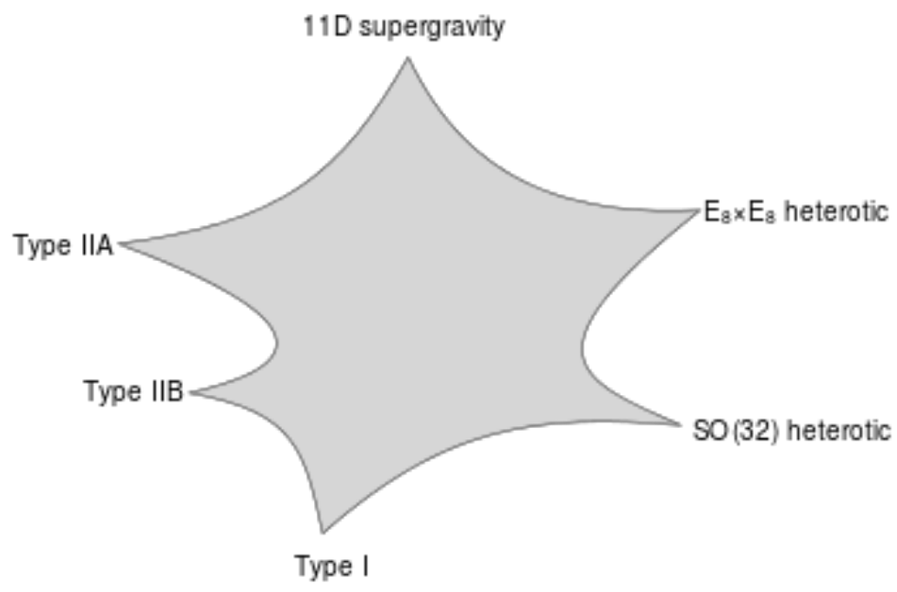

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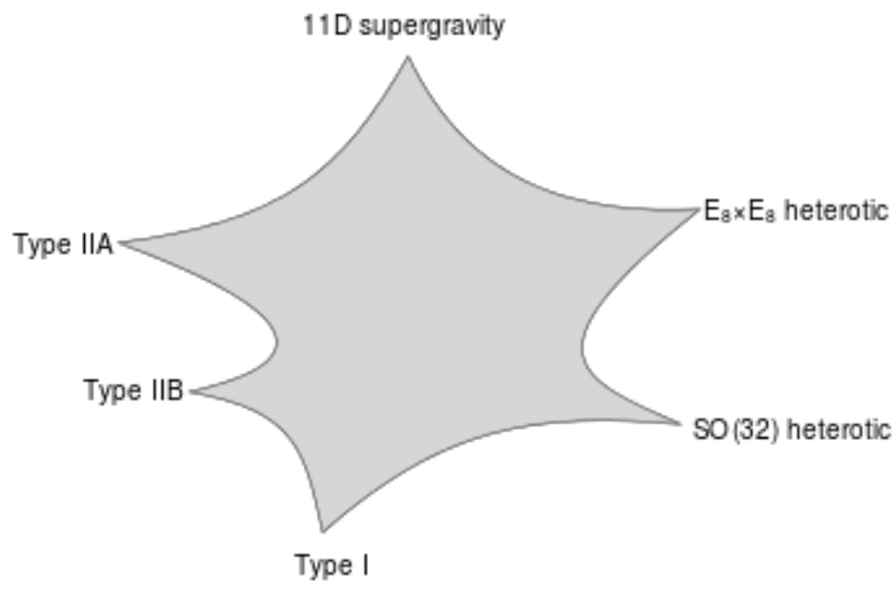

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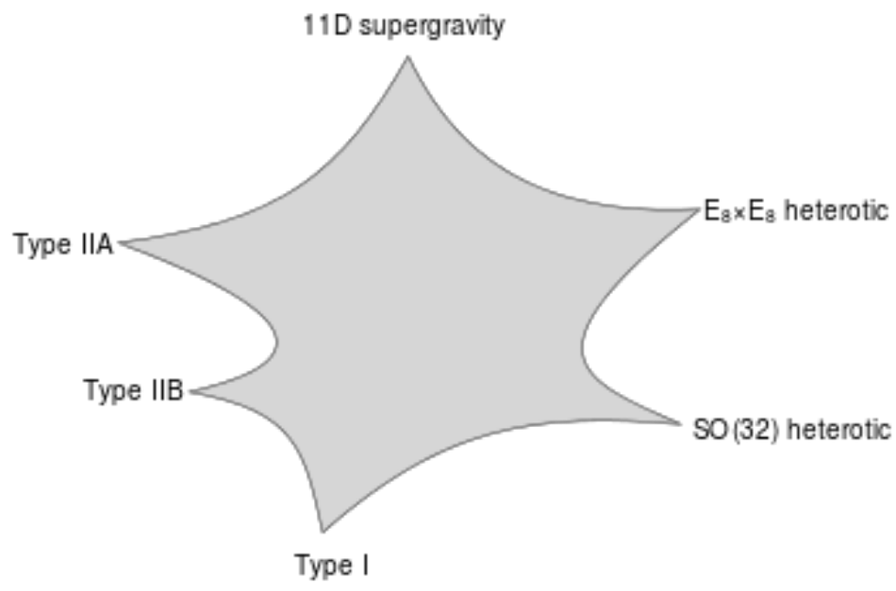

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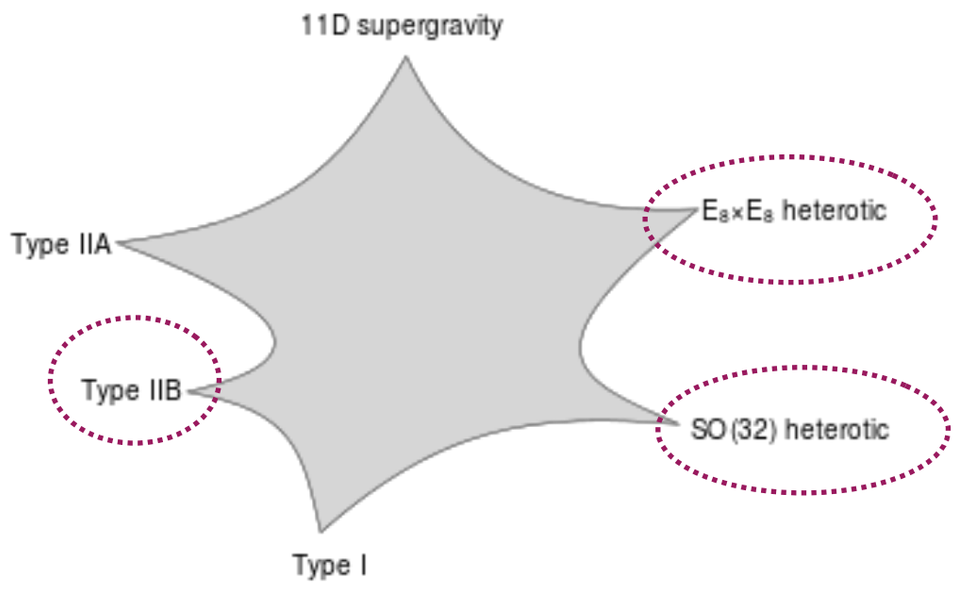

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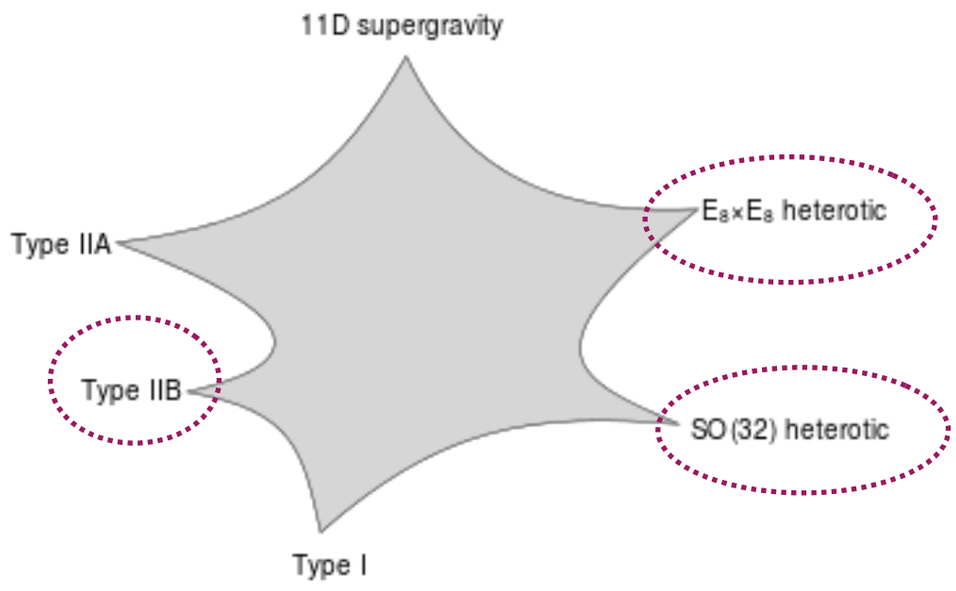

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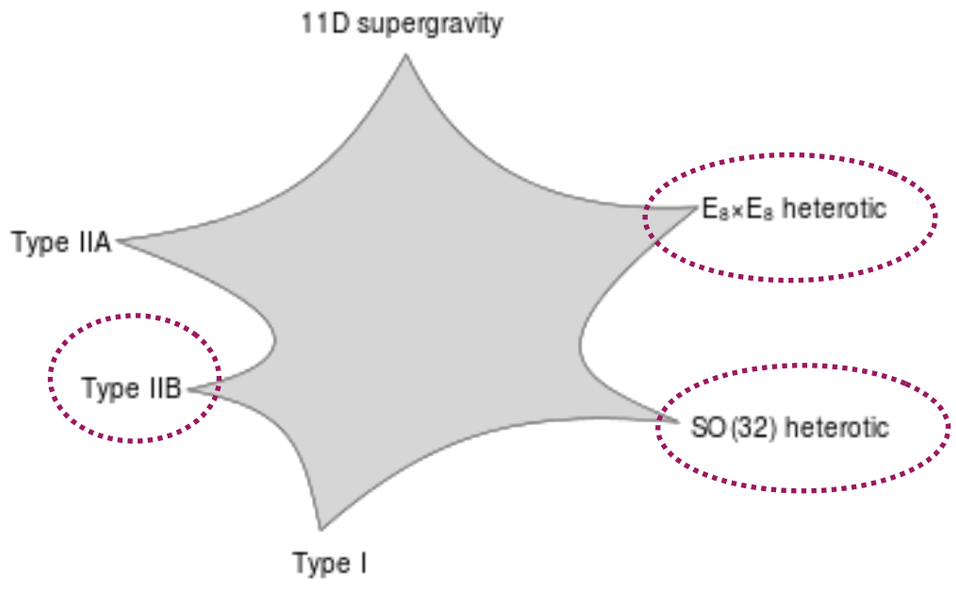

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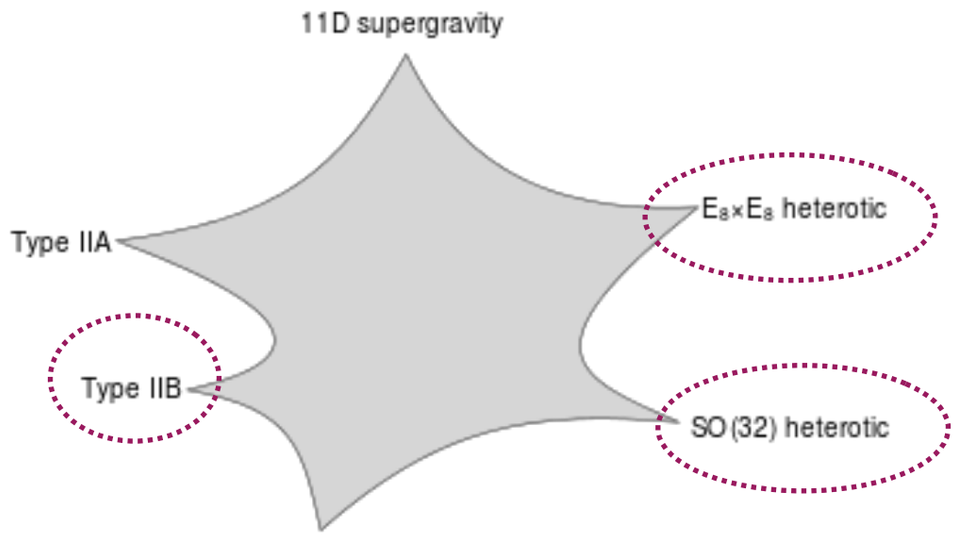

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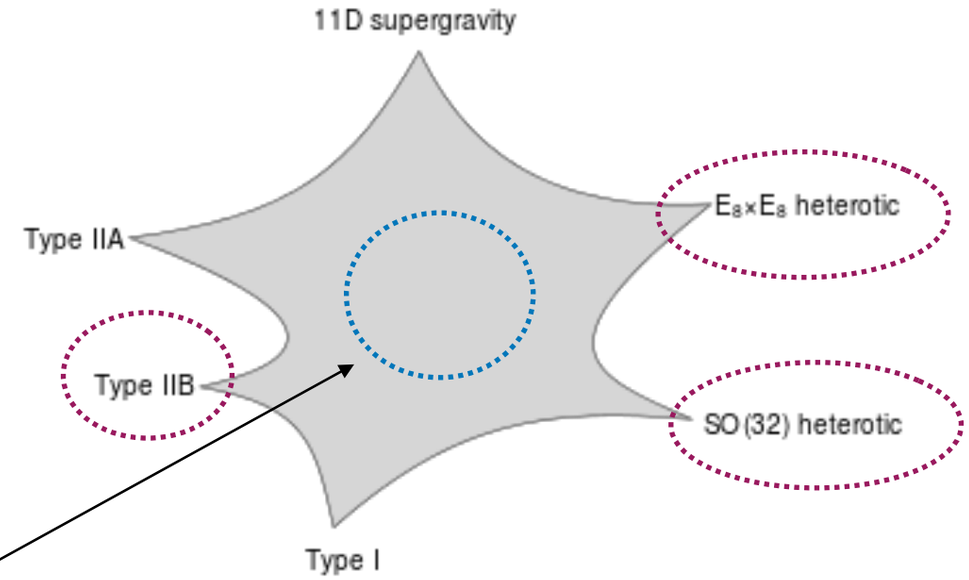

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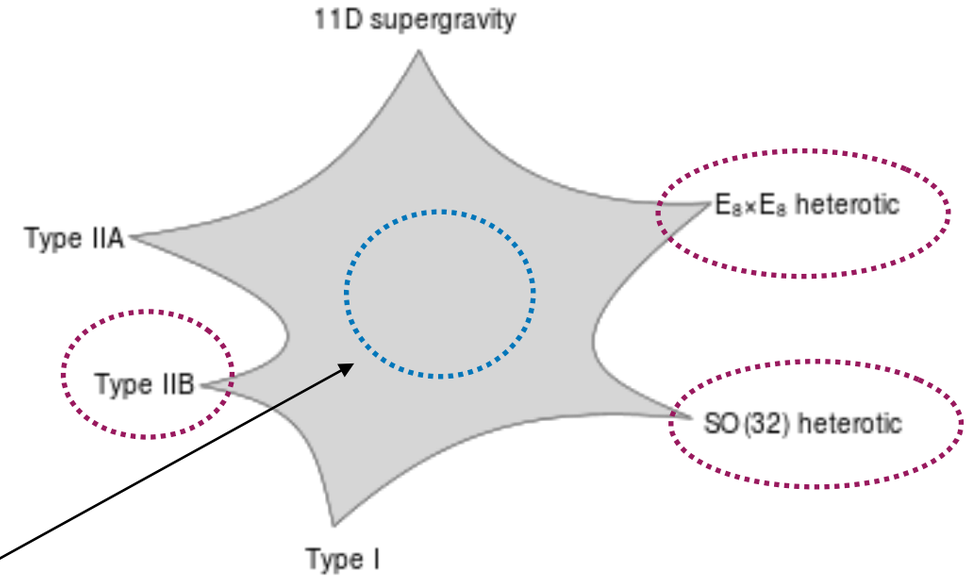

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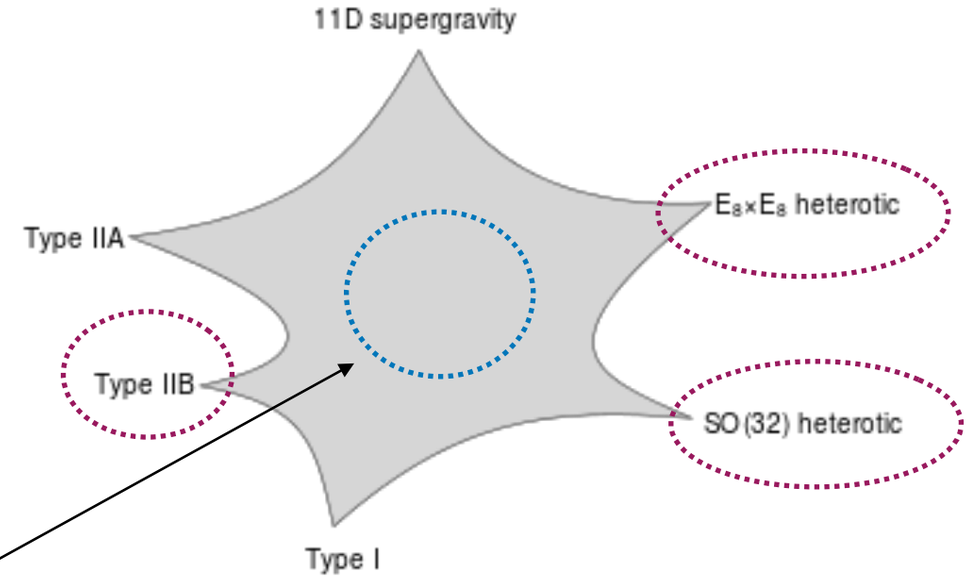

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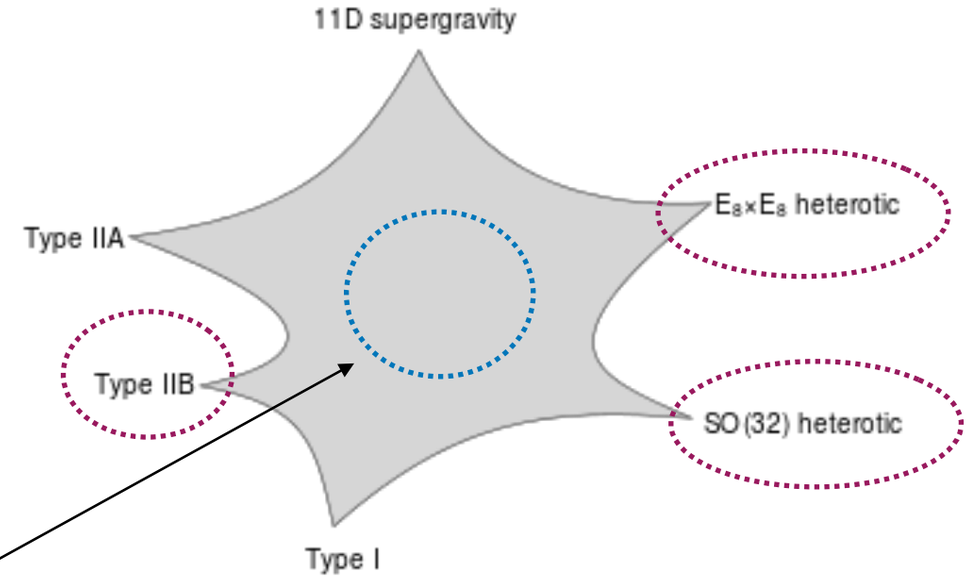

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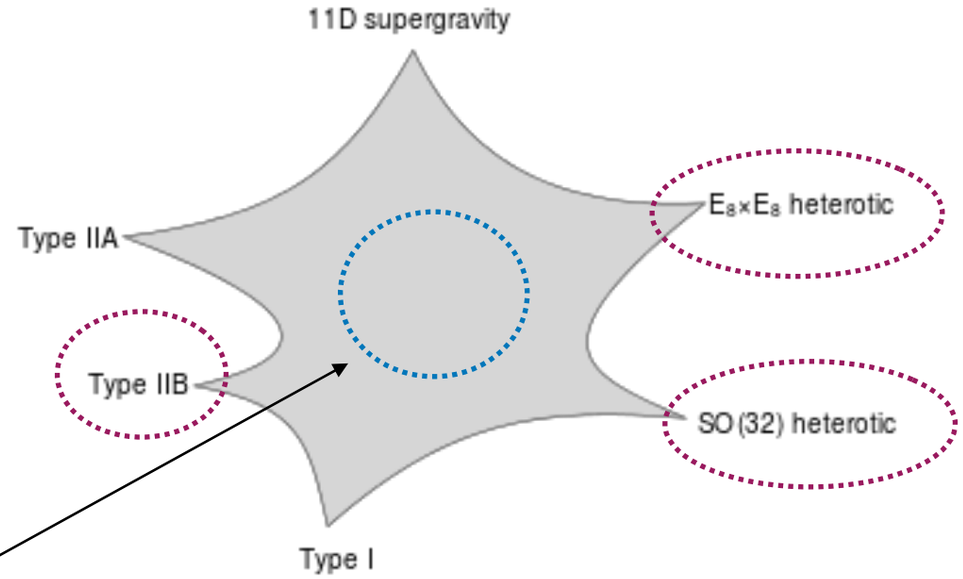

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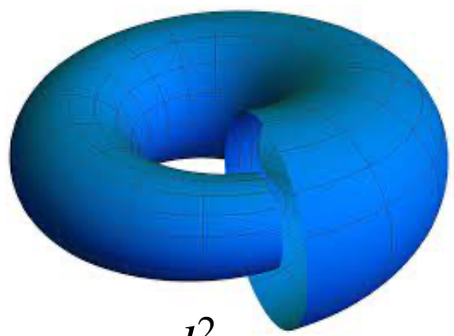

T-folds

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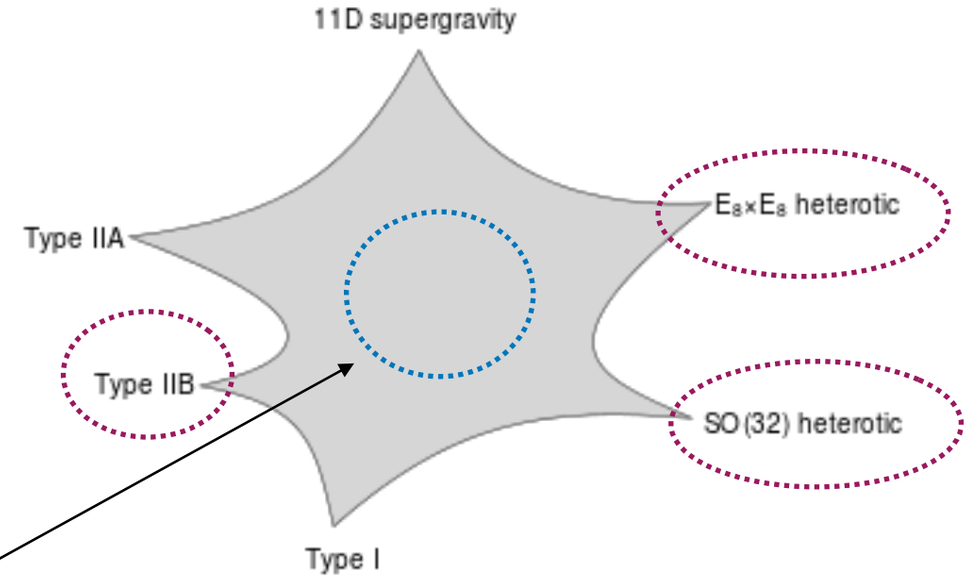

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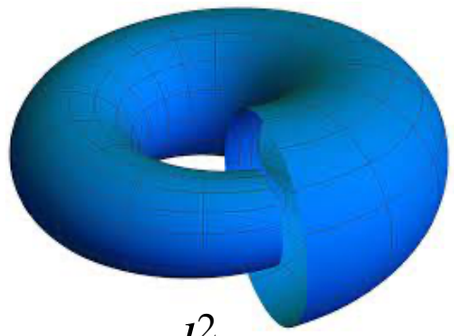

T-folds

$$R = \frac{l_s^2}{R} \qquad R$$

Beautiful and still largely unexplored landscape

Transplanckian Censorship Conjecture

Bedroya, Vafa 2019

- Sub-Planckian quantum fluctuations should remain quantum (cannot become larger than Hubble radius)

  Or equivalently: The expansion of the universe must slow down before all sub-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

$$\tau \leq \frac{1}{H} \log \frac{M_P}{H} \sim 60 \frac{1}{H}$$