BRANE PROBES AND THE STRING LAMPPOST PRINCIPLE IN D>6

Based on 2110.10157 with Alek Bedroya, Yuta Hamada, and Cumrun Vafa, and on ideas from 2104.05724 by Hamada and Vafa

Miguel Montero
Harvard

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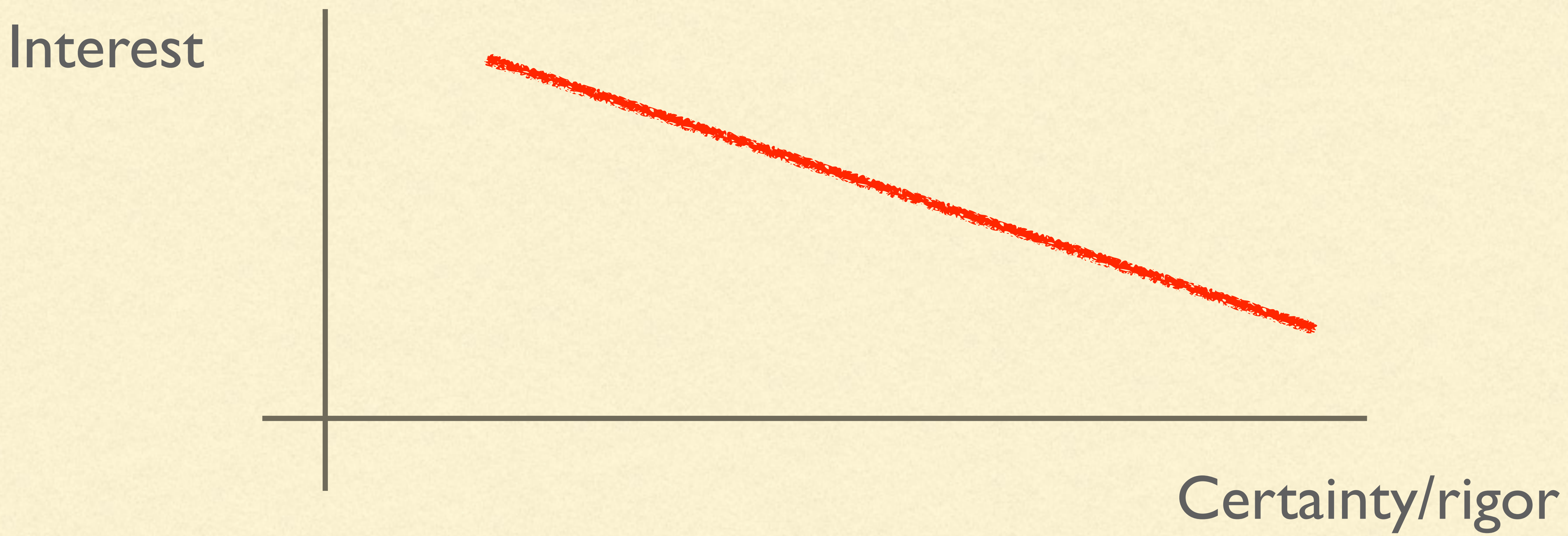

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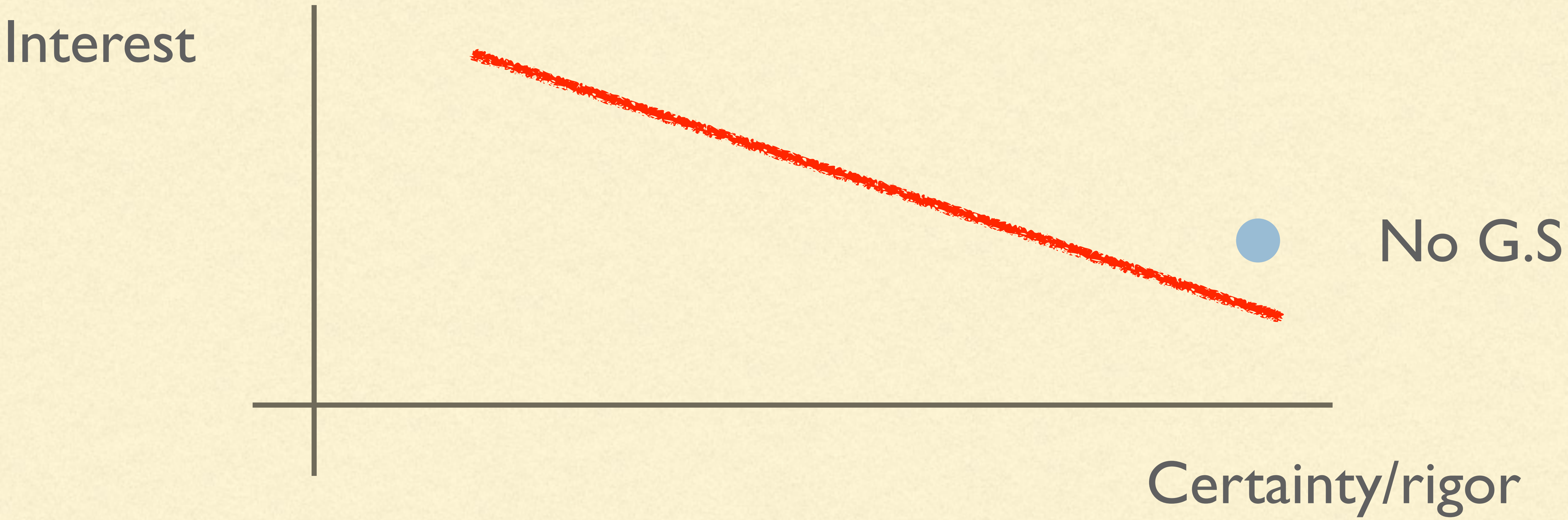

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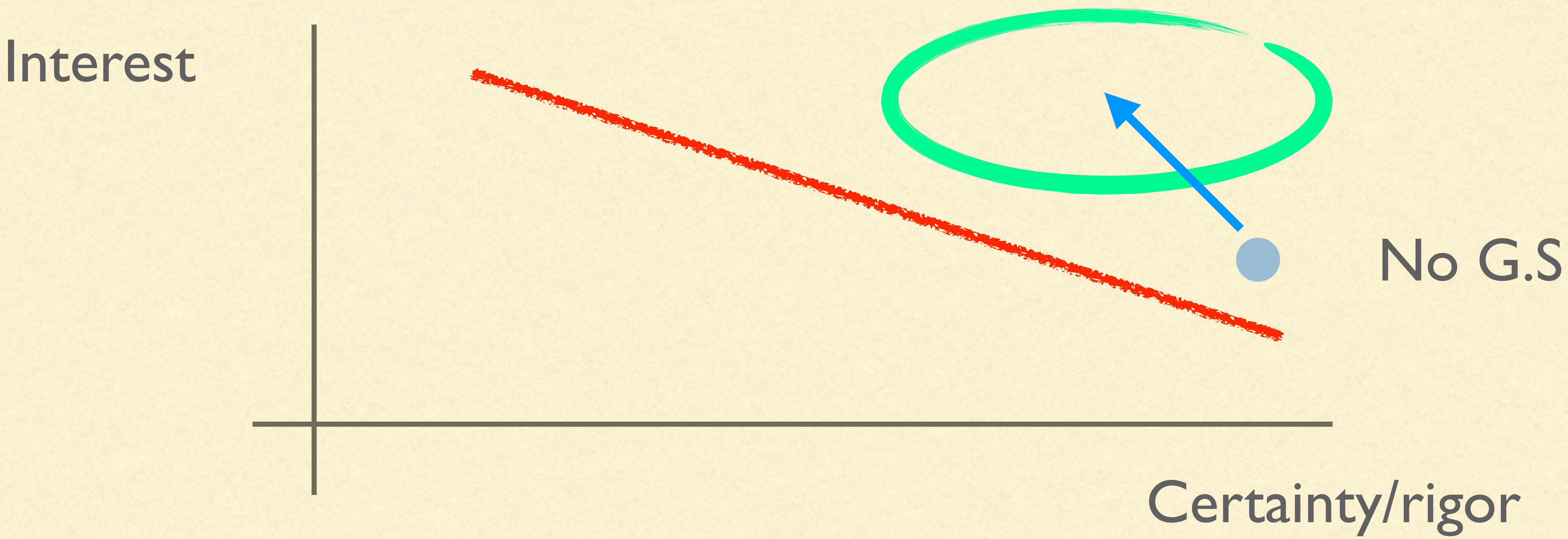

By using **supersymmetry**, even mild Swampland principles such as absence of global symmetries **become very powerful**

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i.e. with this # of supercharges, ST is the **unique** quantum theory of gravity. The basic physical ingredients are **Bekenstein's bound** and the Cobordism Conjecture

Plan of the talk

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Review of
N=1
SUGRA and
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Small instantons & their Coulomb branch

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Compactness & connectedness

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- There is a **Narain** moduli space parametrized by the scalars

$$\frac{SO(10-d,r)}{O(\Gamma)\text{``}\times\text{''}SO(10-d)\times SO(r)}$$

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$

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[Adams-De Wolfe- Taylor '10, Kim-Shiu-Vafa '19]

We get **string lamppost principle/string universality**

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…but no match of enhancements to ST predictions… and nobody knows why there is no Sp(n) in 9d

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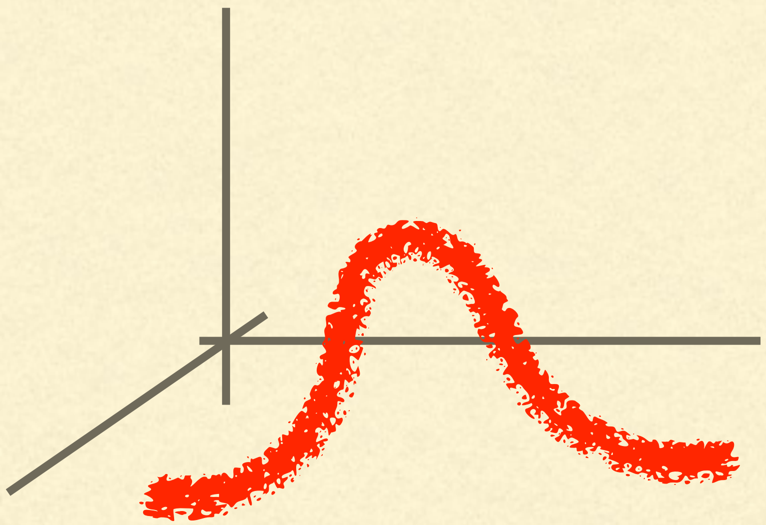
Due to the **Bianchi identity**

$$dH = \sum_i \kappa_i \mathrm{Tr}(F_i^2) - \kappa_g \mathrm{Tr}(R^2)$$

these can be identified with **instantons** of the gauge group.

(this is the only gauged Chern-Weil current)

There are BPS instantons, which preserve 8 supercharges.



They have (d-4) position moduli, and one size modulus.

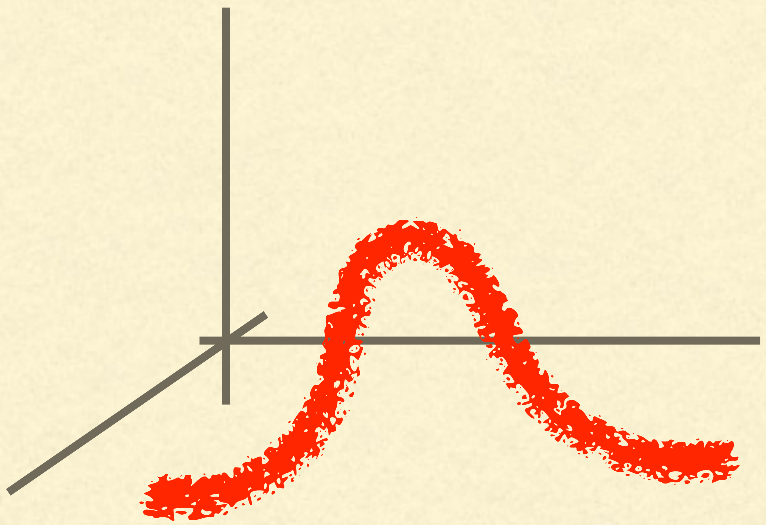
A “fat” instanton is completely characterized by SUGRA

Its worldvolume theory is a bunch of free fields.

The gauge group is broken by the instanton itself

$$G \to [\cdot, SU(2)]_G$$

When the size modulus becomes small (small instanton limit)



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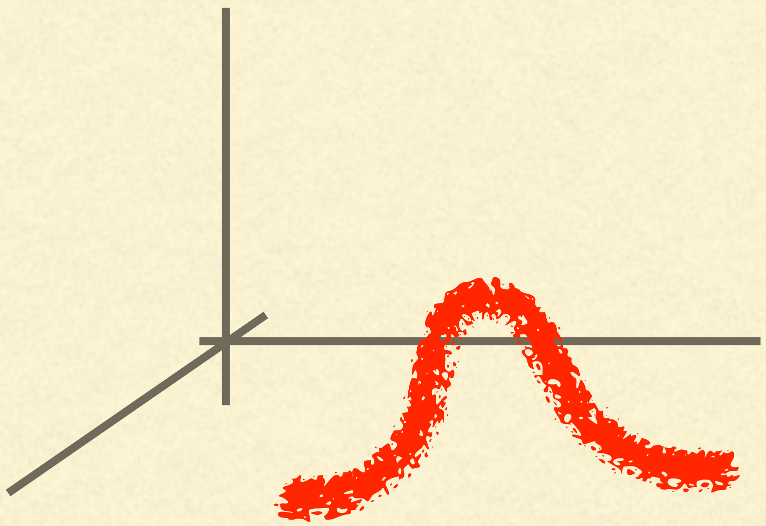

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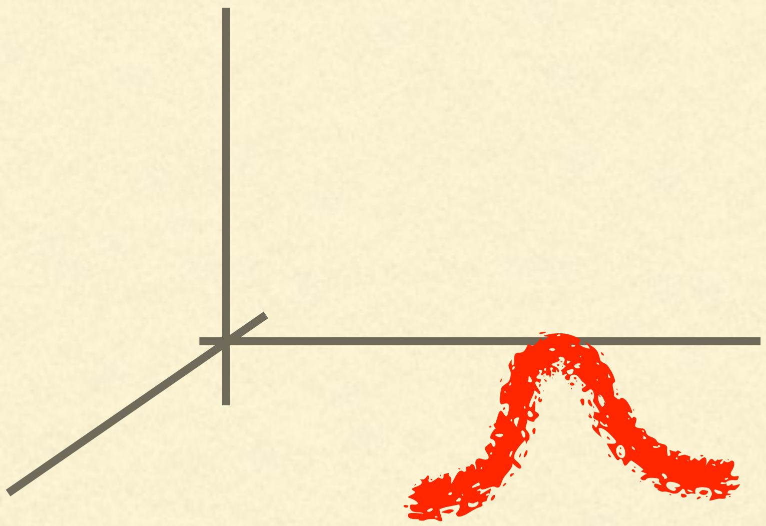

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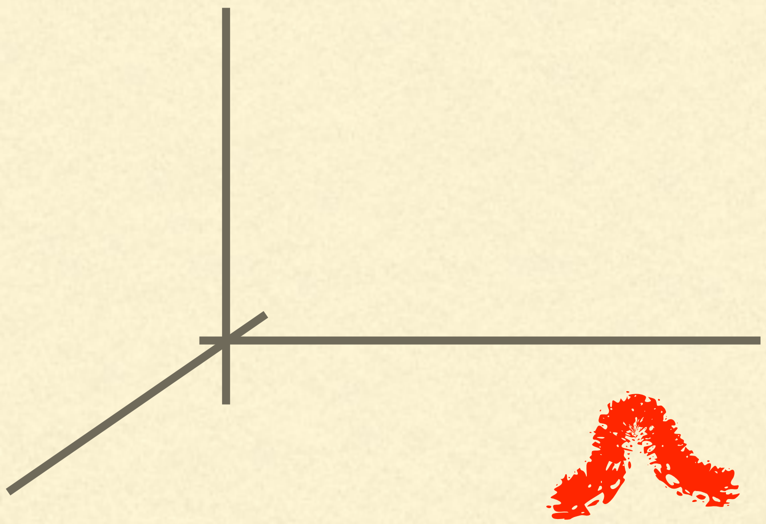

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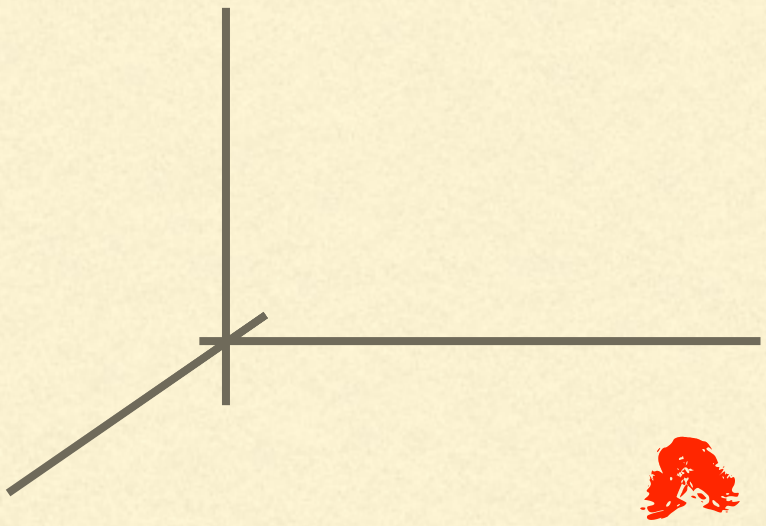

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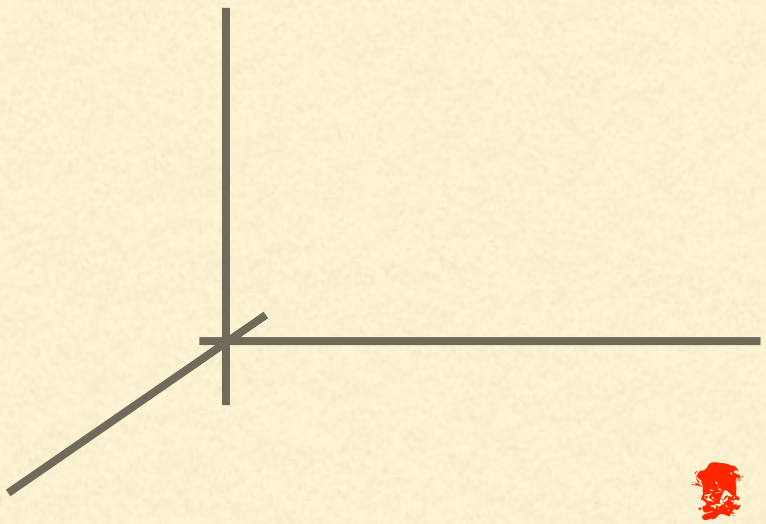

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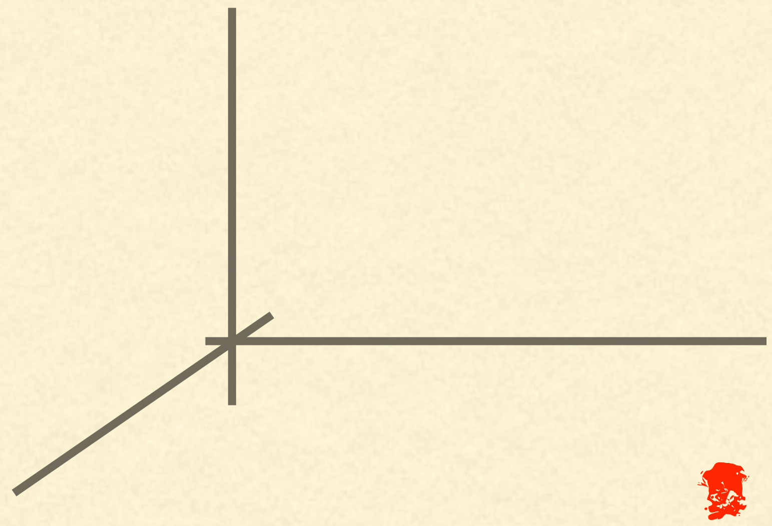

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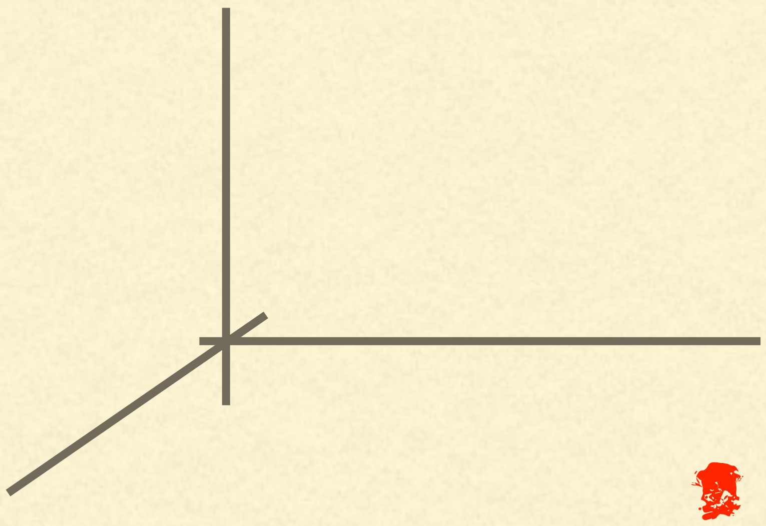

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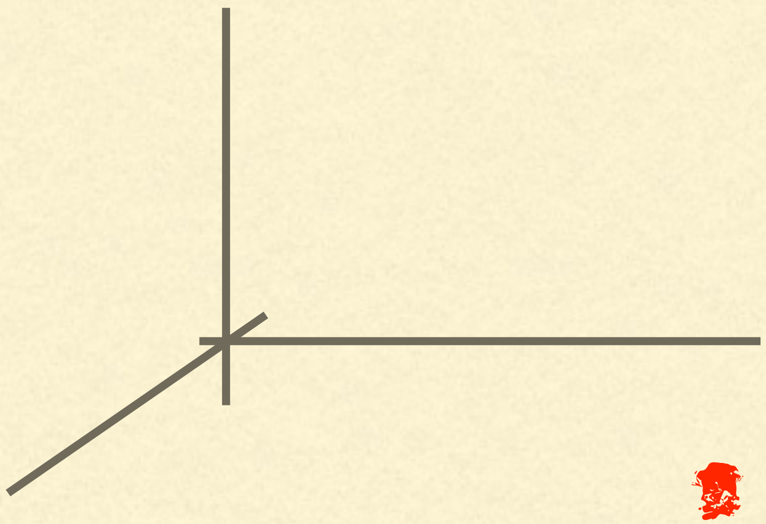

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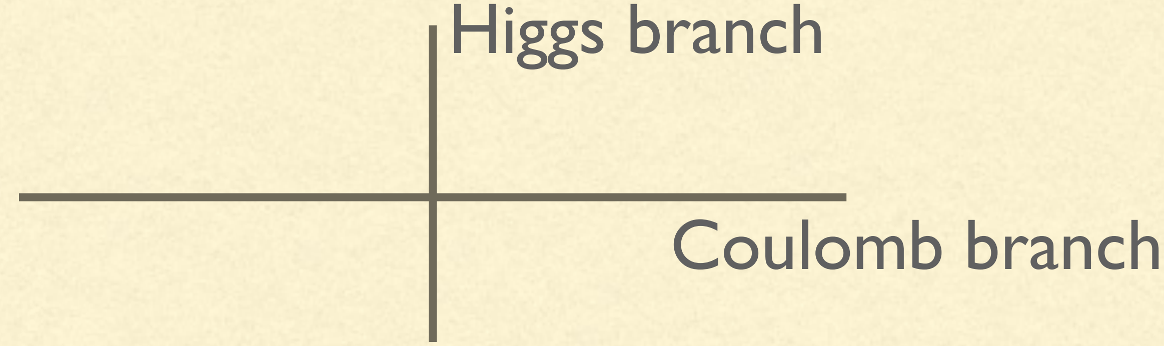

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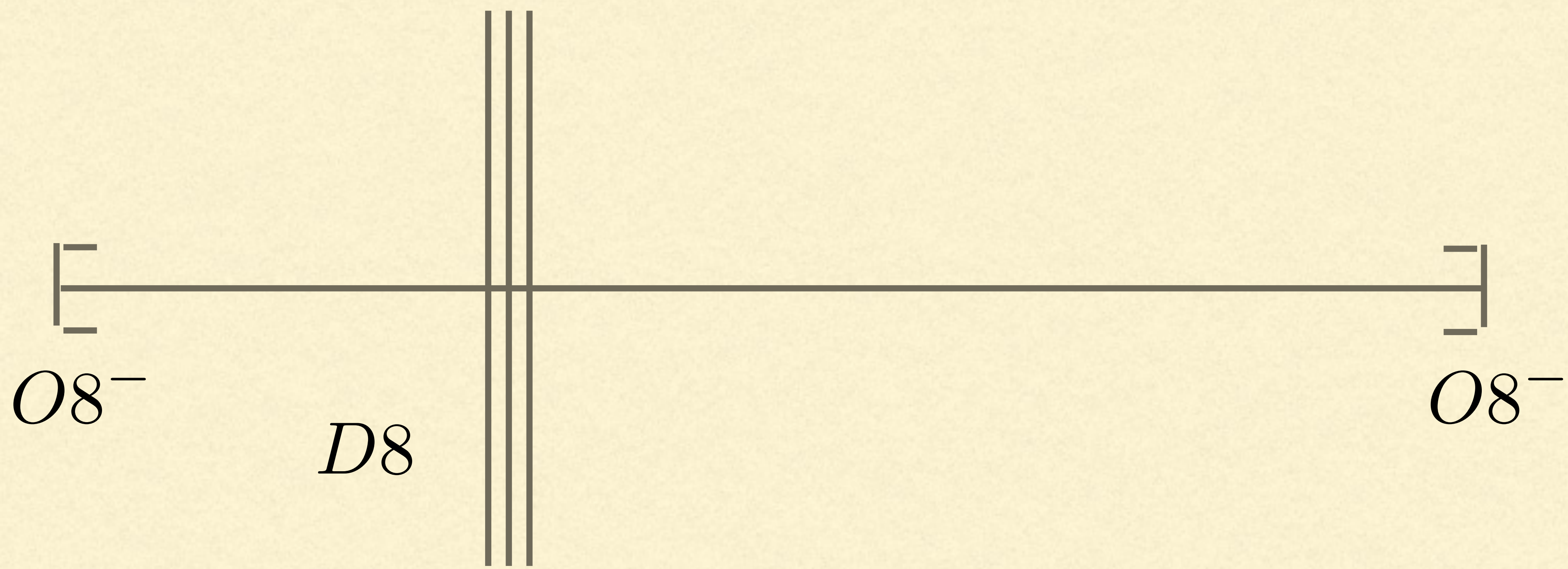

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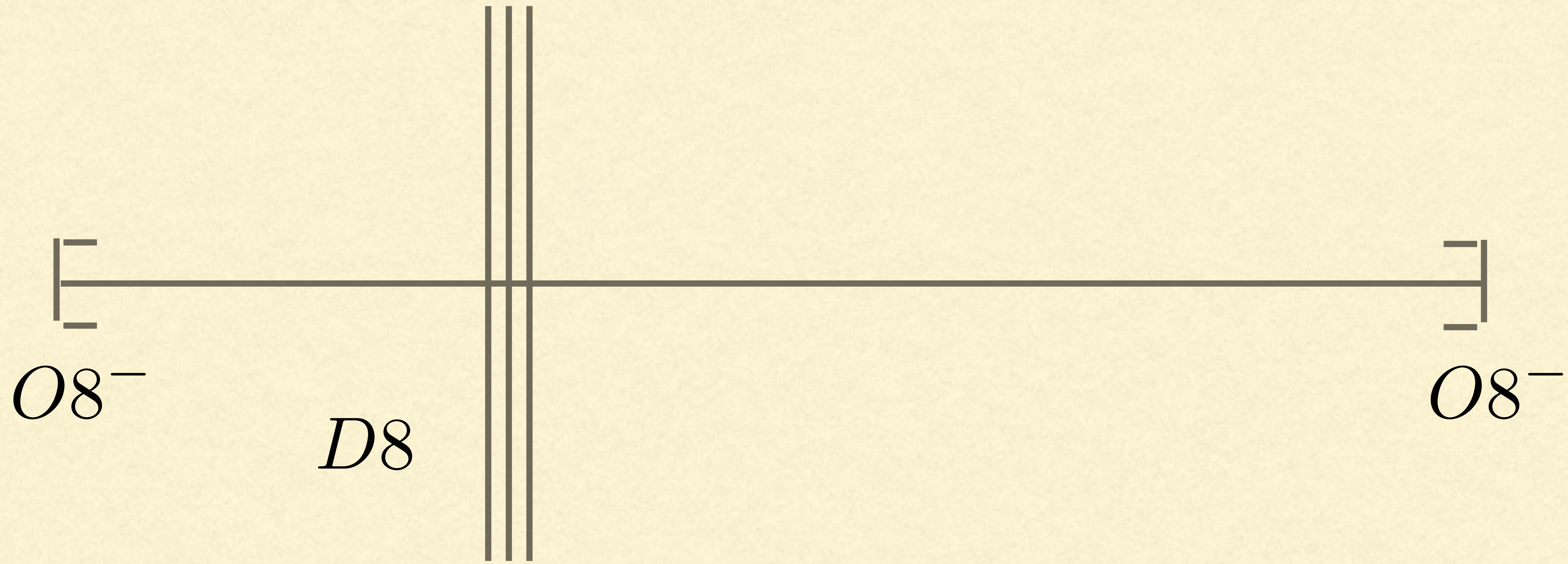

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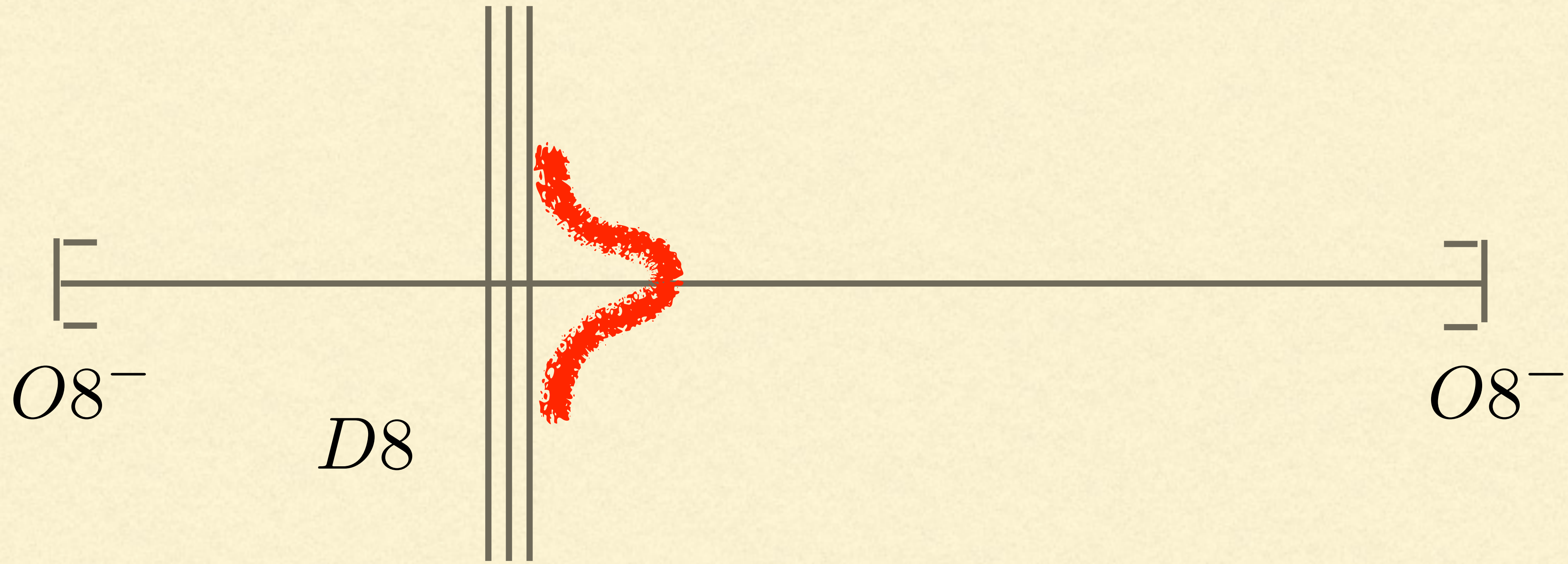

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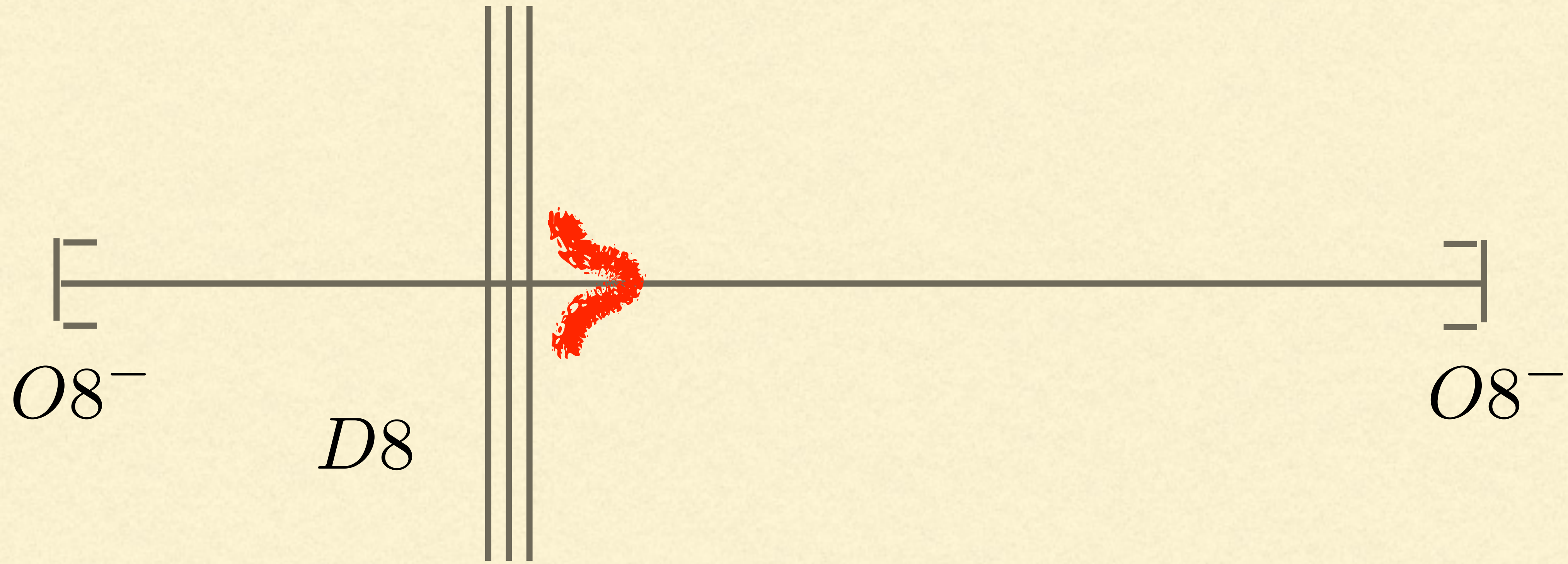

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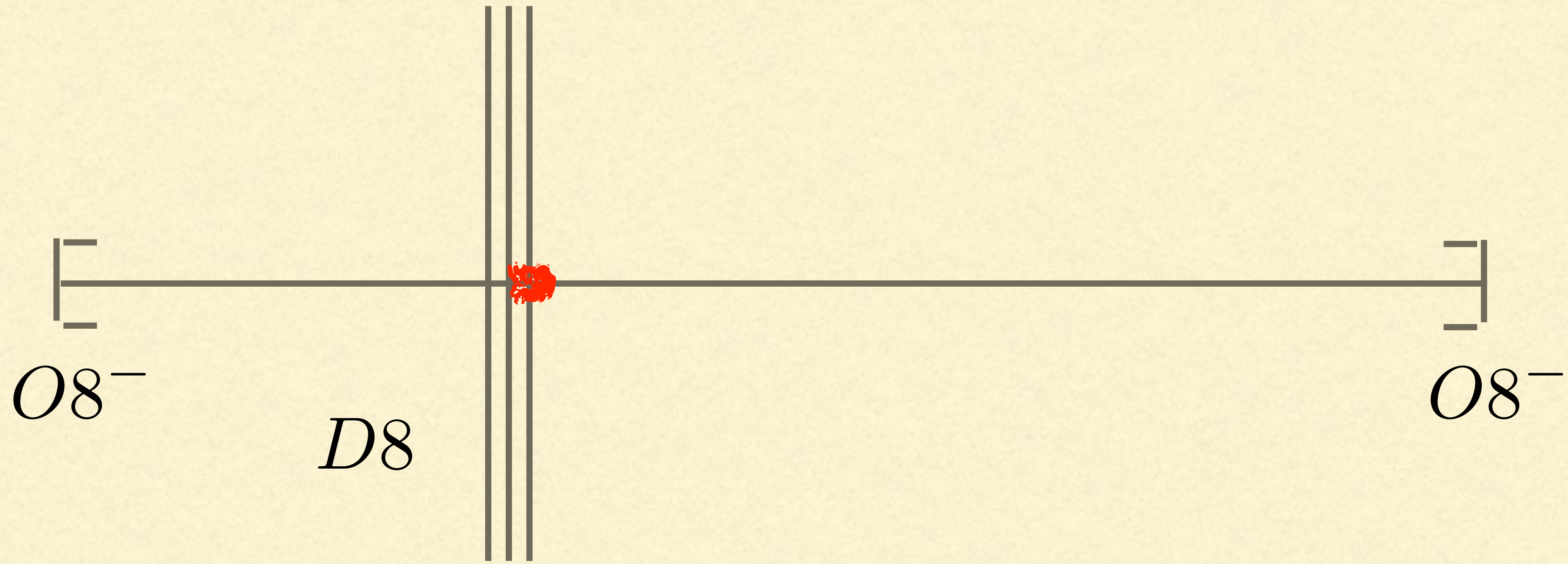

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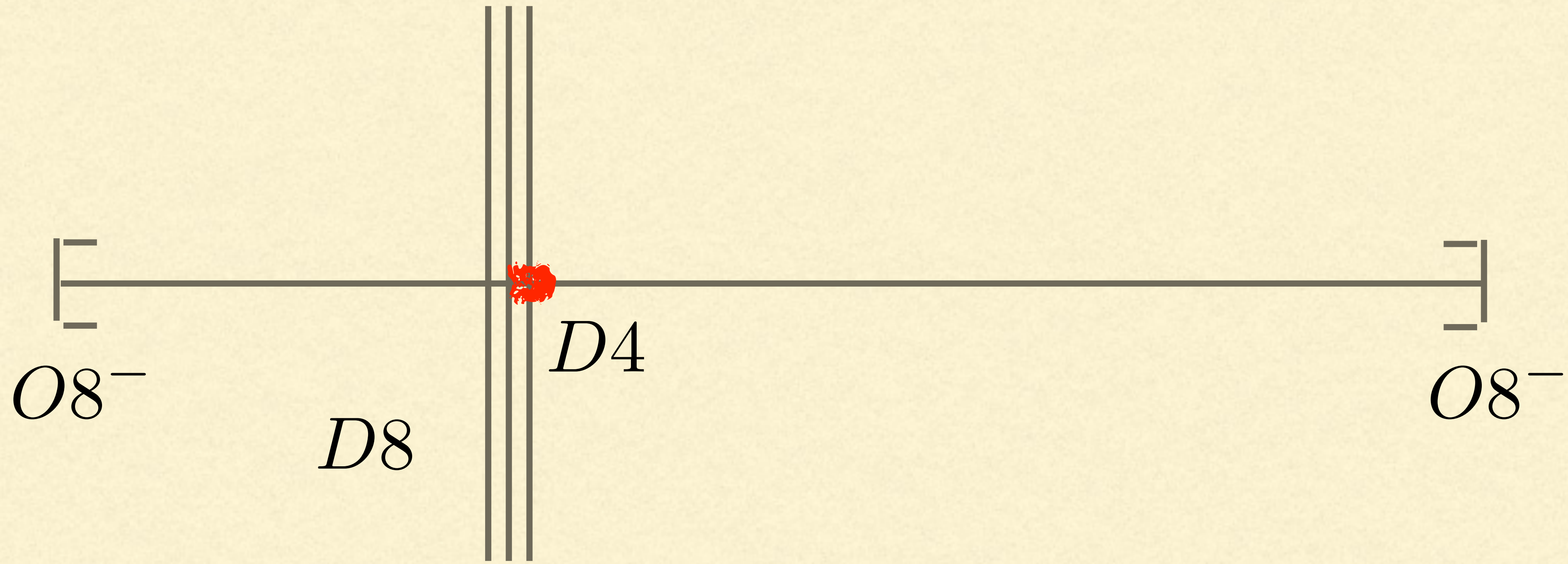

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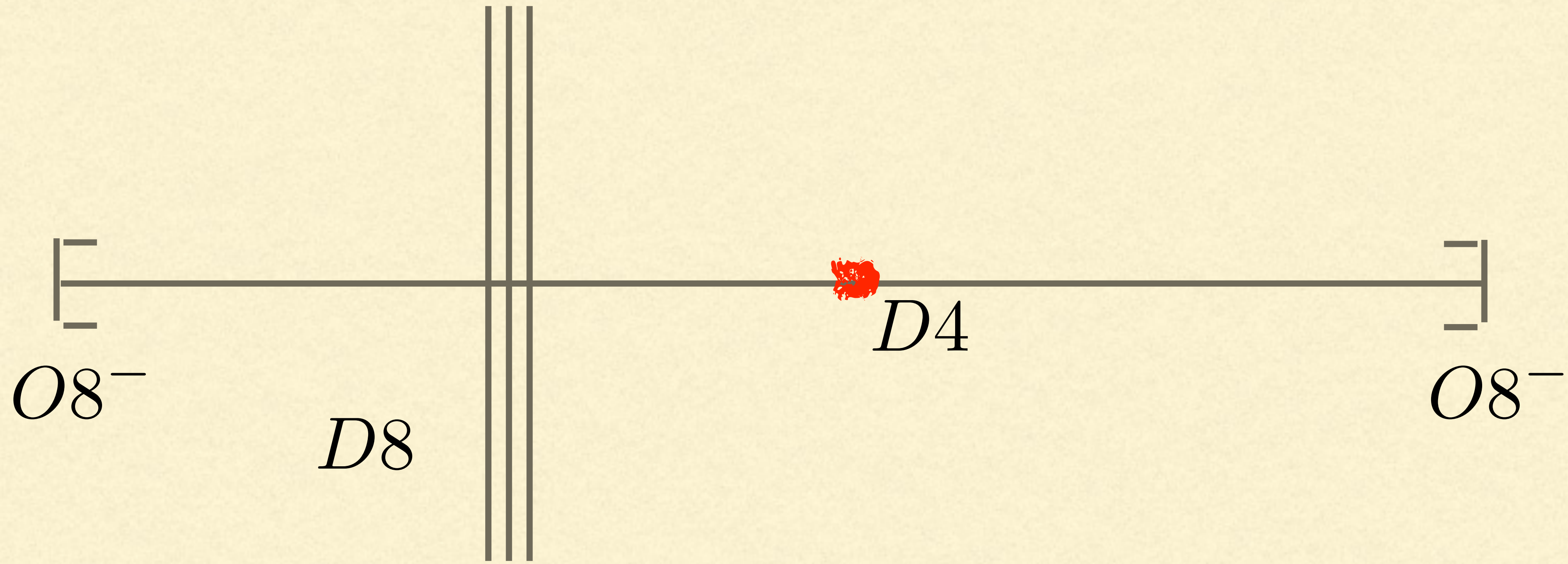

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SUSY/string theory predicts **Coulomb branch** of ranks 0,1

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A noncompact **internal degree of freedom** produces infinitely many states of arbitrarily low energy, e.g.

$$\Psi(\phi) = \exp(ik\phi), \quad E = \frac{k^2}{2}$$

This statement is general — any internal d.o.f of an object is compact in consistent QG.

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And the reason really is Bekenstein's bound, since it doesn't apply to scalars that take the brane out of the box:

Brane position moduli are noncompact

Higgs branch is noncompact

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And with this amount of SUSY, the only way a field can become massive is by coupling to hypermultiplets (so on a Higgs branch). So it cannot happen if we do not make the instanton fat.

For concreteness, I will focus on 9d during the rest of the talk.

(but we have similar results in 8d and 7d)

The CB is **compact, connected,** and (real) **1-dimensional.**

So its either S^1 or $S^1/\mathbb{Z}_2$ (interval)

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We can use the **known** classification of rank 1 5d SCFTs and their local Coulomb branches to glue together all possible compact Coulomb branches.

Name	free or CFT	Symmetry	Geometry	Brane	c/c_{A_0}
$A_n(n=0,\cdots)$	free	$\mathfrak{su}(n+1)$	$\mathbb{R}$	$(n+1)D8$	$-(n+1)$
$C_n(n=0,\cdots)$	free	$\mathfrak{sp}(n)$	$\mathbb{R}/\mathbb{Z}_2$	$O8^+ + nD8$	$-(8+n)$
$D_n(n=0,\cdots)$	free	$\mathfrak{spin}(2n)$	$\mathbb{R}/\mathbb{Z}_2$	$O8^- + nD8$	$8-n$
$E_n(n=1,\cdots,8)$	CFT	caption	$\mathbb{R}/\mathbb{Z}_2$	$O8^- + (n-1)D8$	$9-n$
$\tilde{E}_1$	CFT	$\mathfrak{u}(1)$	$\mathbb{R}/\mathbb{Z}_2$	$O8^-$	8
E_0	CFT	$\varnothing$	$\mathbb{R}/\mathbb{Z}_2$	$O8^{(-9)}$	9
$O8^{(-1)}$	CFT	$\varnothing$	$\mathbb{R}/\mathbb{Z}_2$	$O8^{(-1)}$	1

All probe branes **match** known string theory branes

There is a consistency condition that c (related to a worldvolume CS term) is single valued as we move around the Coulomb branch)

$$\sum_{\text{singus}} c_{\text{singu}} = 0$$

This is **essentially** the same info as a D8-brane tadpole!

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In particular, there is no way to cancel the tadpole supersymmetrically with Sp(n) group

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and something like the **D8 brane tadpole,**

We can argue that the **existing ST constructions are universal.**

In particular, there is no way to cancel the tadpole supersymmetrically with Sp(n) group

but one can do it either in a **noncompact** setup, or nonsupersymmetrically (Sugimoto string)

#	Placement of enhanced theories on the Coulomb branch	Gauge algebra	Root lattice
1	E_8——A_1——E_8	$\mathfrak{e}_8 + \mathfrak{e}_8 + \mathfrak{su}(2)$	$2E_8 + A_1$
2	E_8——A_2——E_7	$\mathfrak{e}_8 + \mathfrak{e}_7 + \mathfrak{su}(3)$	$E_8 + E_7 + A_2$
3	E_8——A_3——E_6	$\mathfrak{e}_8 + \mathfrak{e}_6 + \mathfrak{su}(4)$	$E_8 + E_6 + A_3$
4	E_8——A_4——E_5	$\mathfrak{e}_8 + \mathfrak{spin}(10) + \mathfrak{su}(5)$	$E_8 + D_5 + A_4$
5	E_8——A_5——E_4	$\mathfrak{e}_8 + \mathfrak{su}(6) + \mathfrak{su}(5)$	$E_8 + A_5 + A_4$
6	E_8——A_6——E_3	$\mathfrak{e}_8 + \mathfrak{su}(7) + \mathfrak{su}(3) + \mathfrak{su}(2)$	$E_8 + A_6 + A_2 + A_1$
7	E_8——A_8——E_1	$\mathfrak{e}_8 + \mathfrak{su}(9) + \mathfrak{su}(2)$	$E_8 + A_8 + A_1$
8	E_8——A_9——E_0	$\mathfrak{e}_8 + \mathfrak{su}(10)$	$E_8 + A_9$
9	E_7——A_3——E_7	$\mathfrak{e}_7 + \mathfrak{e}_7 + \mathfrak{su}(4)$	$2E_7 + A_3$
10	E_7——A_4——E_6	$\mathfrak{e}_7 + \mathfrak{e}_6 + \mathfrak{su}(5)$	$E_7 + E_6 + A_4$
11	E_7——A_5——E_5	$\mathfrak{e}_7 + \mathfrak{spin}(10) + \mathfrak{su}(6)$	$E_7 + D_5 + A_5$
12	E_7——A_6——E_4	$\mathfrak{e}_7 + \mathfrak{su}(7) + \mathfrak{su}(5)$	$E_7 + A_6 + A_4$
13	E_7——A_7——E_3	$\mathfrak{e}_7 + \mathfrak{su}(8) + \mathfrak{su}(3) + \mathfrak{su}(2)$	$E_7 + A_7 + A_2 + A_1$
14	E_7——A_9——E_1	$\mathfrak{e}_7 + \mathfrak{su}(10) + \mathfrak{su}(2)$	$E_7 + A_9 + A_1$
15	E_7——A_{10}——E_0	$\mathfrak{e}_7 + \mathfrak{su}(11)$	$E_7 + A_{10}$
16	E_6——A_5——E_6	$\mathfrak{e}_6 + \mathfrak{e}_6 + \mathfrak{su}(6)$	$2E_6 + A_5$

Reproduces results of **[Font et al' 20]**, see also Timo's talk

In 8d, we can argue the Coulomb branch is an **elliptically fibered K3**

In 7d, we can argue that the CB is a compact hyperkahler manifold, so T4 or K3

but we do not have a classification of 3d N=4 theories

(we do not have 7d string lamppost, but we are close!)

TO WRAP UP

In short we have seen how compactness and connection
allows Swampland to match the ST expectation.
The brane probe idea, correctly applied,
allows the SLP to be fully realized.

As a further direction, its natural to wonder
if low codimension probes
can take you any further

To find out the answer you won't have to work:
it is the main subject in Irene's next talk

My time's up now, thanks for your attention,
I will just stop and see if there's any questions.

Thank you!

Dankeschön!