SWAMPLAND CONSTRAINTS FROM COBORDISMS

Miguel Montero

IFT Madrid

Iberian Strings 2023

Universidad de Murcia, Jan 12 2023

Please interrupt me!!

with questions, comments, etc.

Swampland: Lightning review

At first sight, it seems that coupling any QFT to gravity is easy.

Swampland: Lightning review

At first sight, it seems that coupling any QFT to gravity is easy.

Pick a Lagrangian $\mathcal{L}_{EFT}$

Swampland: Lightning review

At first sight, it seems that coupling any QFT to gravity is easy.

Pick a Lagrangian $\mathcal{L}_{EFT}$ and write this:

$$\frac{1}{8\pi M_P^2}\int d^4x\sqrt{-g}\,R+\int\sqrt{-g}\mathcal{L}_{\rm EFT}$$

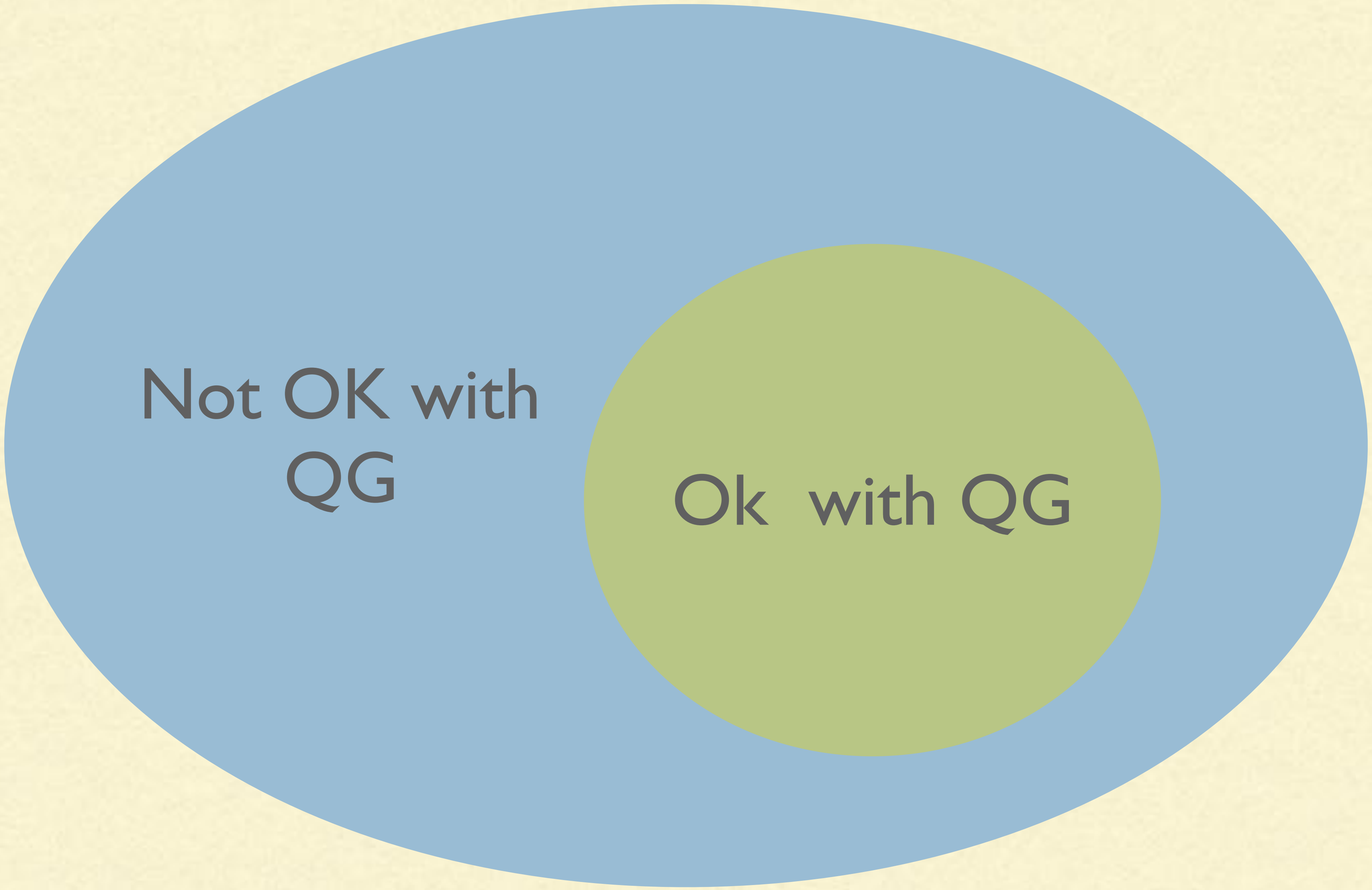
Swampland: Lightning review

At first sight, it seems that coupling any QFT to gravity is easy.

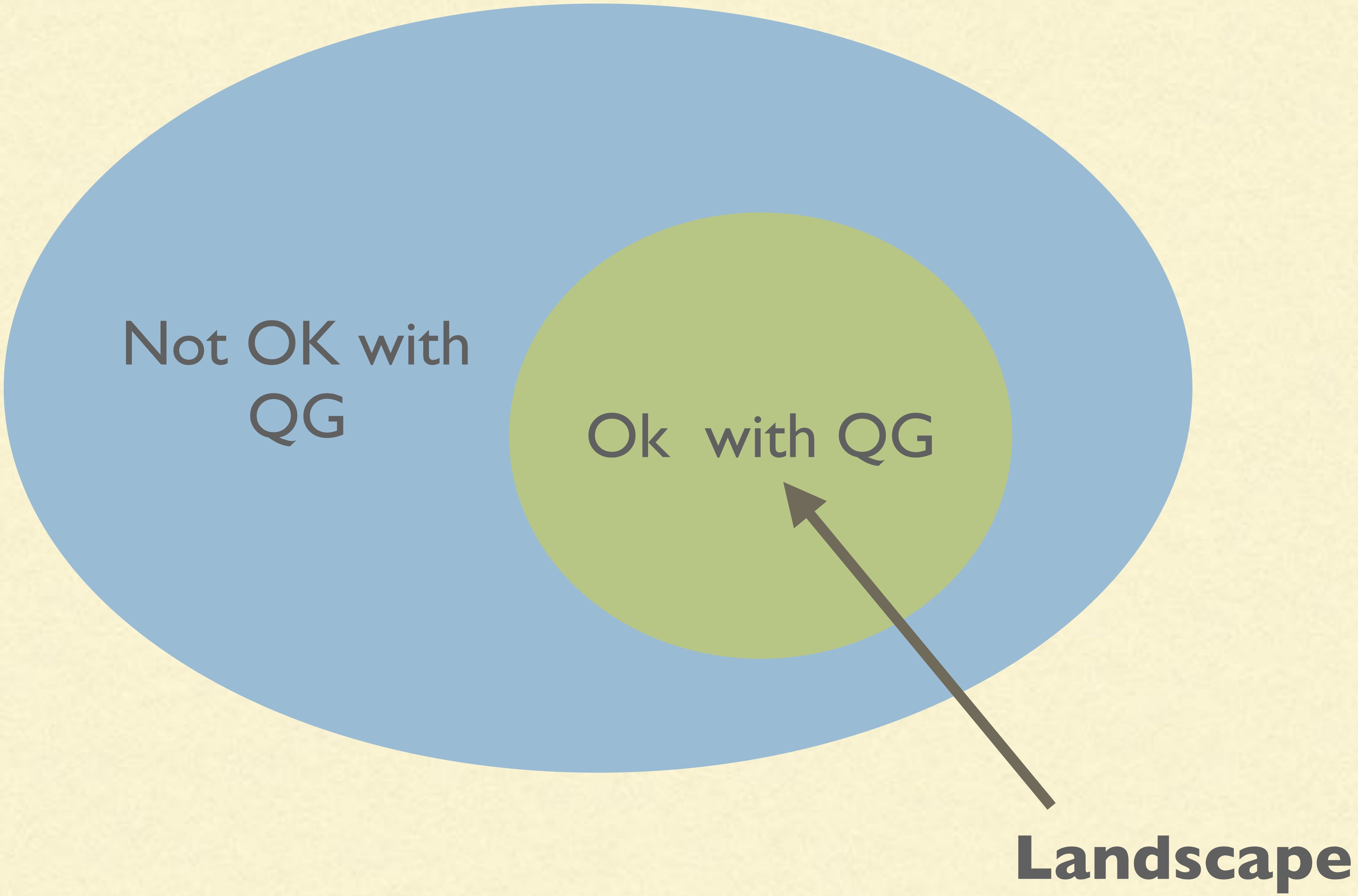
Pick a Lagrangian $\mathcal{L}_{EFT}$ and write this:

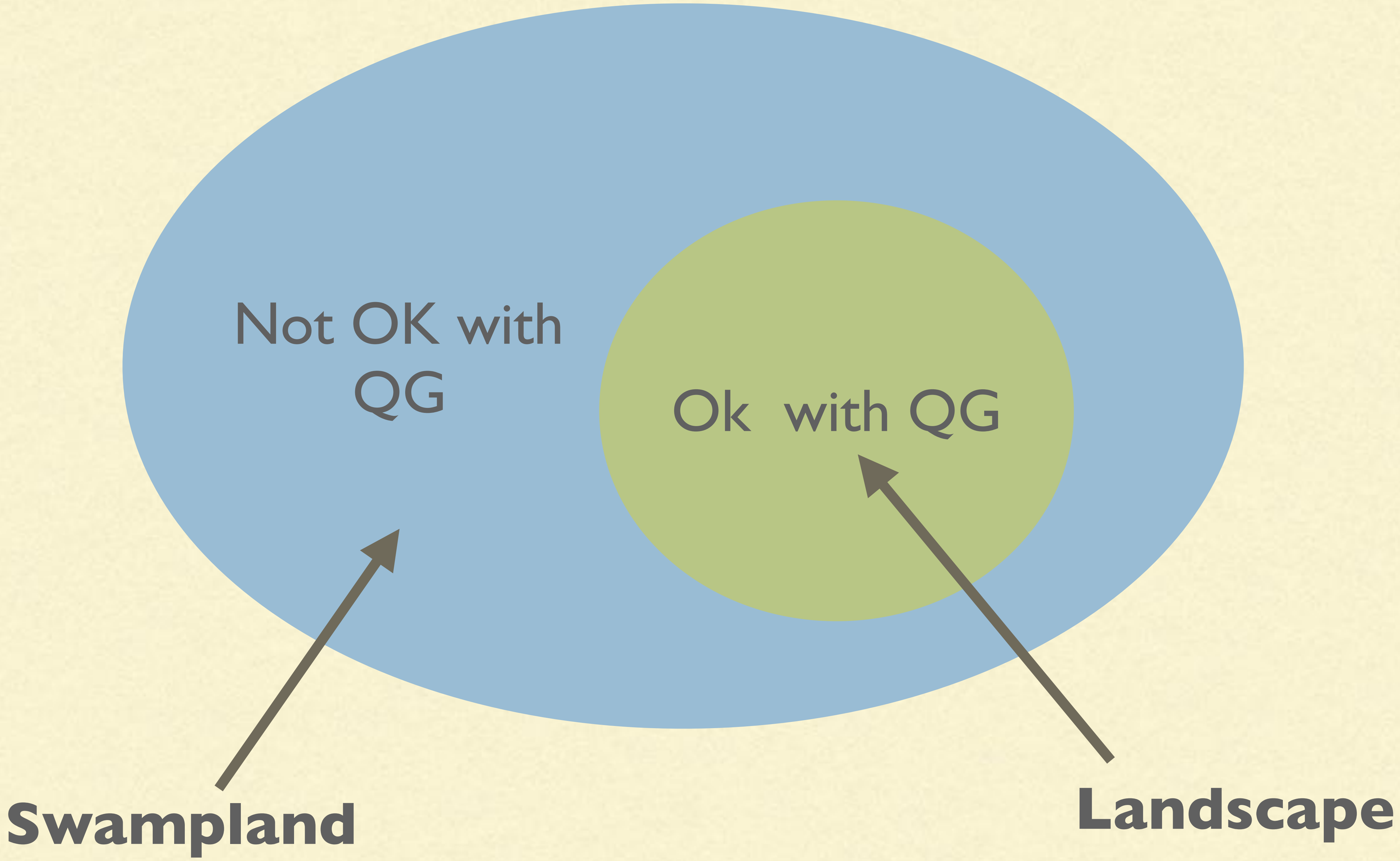
$$\frac{1}{8\pi M_P^2}\int d^4x\sqrt{-g}\,R+\int\sqrt{-g}\mathcal{L}_{\rm EFT}$$

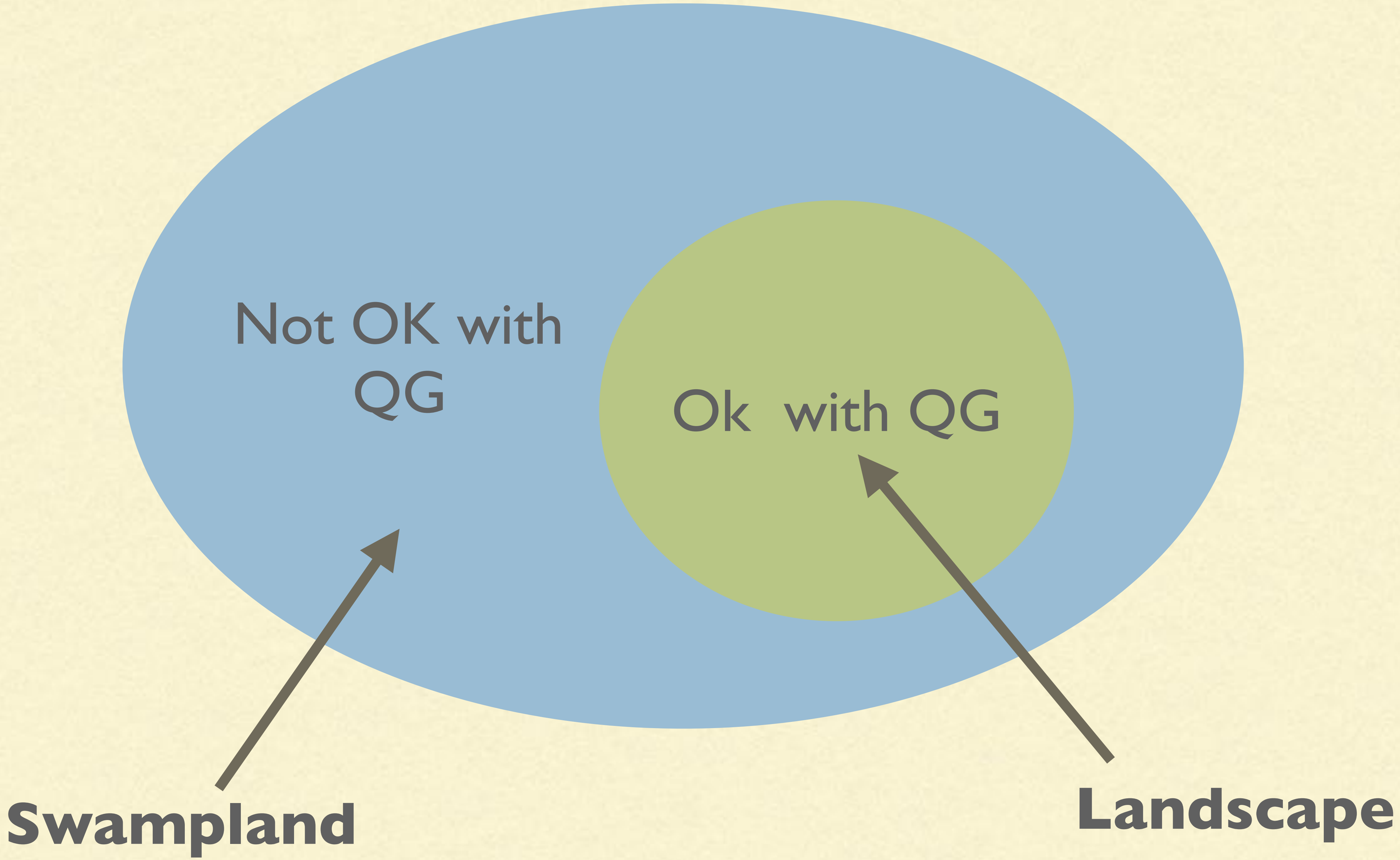
The above is OK perturbatively, but there is an increasing body of **evidence that** this procedure often fails at the non-perturbative level.



Not OK with QG
Ok with QG


Not OK with QG
Ok with QG
Landscape


Not OK with
QG
Ok with QG
Swampland
Landscape



Swampland Program: Determine the nontrivial **constraints** that QFT's in the landscape must satisfy.

Oldest Swampland constraint in the book:

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Arguments about black hole decay/absence of remnants

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Arguments about black hole decay/absence of remnants

Recent proofs using Euclidean QG for BH evap/amplitudes

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Arguments about black hole decay/absence of remnants

Recent proofs using Euclidean QG for BH evap/amplitudes

In AdS/CFT, for continuous global syms. equivalent to **Noether's theorem**

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Arguments about black hole decay/absence of remnants

Recent proofs using Euclidean QG for BH evap/amplitudes

In AdS/CFT, for continuous global syms. equivalent to **Noether's theorem**

Proof in perturbative ST

Oldest Swampland constraint in the book:

There are **no global symmetries in quantum gravity**

i.e.

if you have an exactly conserved charge, it can be measured via some long-range field (gauged).

Lots of **evidence**:

Arguments about black hole decay/absence of remnants

Recent proofs using Euclidean QG for BH evap/amplitudes

In AdS/CFT, for continuous global syms. equivalent to **Noether's theorem**

Proof in perturbative ST

Always true in every ST example

To sum up, there's good reason to believe that there are **no global symmetries in Quantum Gravity**.

To sum up, there's good reason to believe that there are **no global symmetries in Quantum Gravity**.

But this statement, by itself, seems a bit **toothless**

To sum up, there's good reason to believe that there are **no global symmetries in Quantum Gravity**.

But this statement, by itself, seems a bit **toothless**

e.g. (B-L) is a global symmetry of the SM.

To sum up, there's good reason to believe that there are **no global symmetries in Quantum Gravity**.

But this statement, by itself, seems a bit **toothless**

e.g. (B-L) is a global symmetry of the SM.

But if it is broken by operators suppressed by e.g

$$10^{-10000}$$

To sum up, there's good reason to believe that there are **no global symmetries in Quantum Gravity**.

But this statement, by itself, seems a bit **toothless**

e.g. (B-L) is a global symmetry of the SM.

But if it is broken by operators suppressed by e.g

$$10^{-10000}$$

for all intends and purposes, B-L is a global symmetry.

The **point of this talk** is

that sometimes

The **point of this talk** is

that sometimes

the mere absence of global symmetries

can be **very powerful**

and lead to **quantitative** Swampland constraints on QG

The **point of this talk** is

that sometimes

the mere absence of global symmetries

can be **very powerful**

and lead to **quantitative** Swampland constraints on QG

I will focus on a **particularly useful** version of the **no global symmetries** idea:

The **point of this talk** is

that sometimes

the mere absence of global symmetries

can be **very powerful**

and lead to **quantitative** Swampland constraints on QG

I will focus on a **particularly useful** version of the **no global symmetries** idea:

The Cobordism Conjecture

[McNamara, Vafa '19]

Basic idea of the cobordism conjecture:

1) Nontrivial topology can lead to **global charges**

Basic idea of the cobordism conjecture:

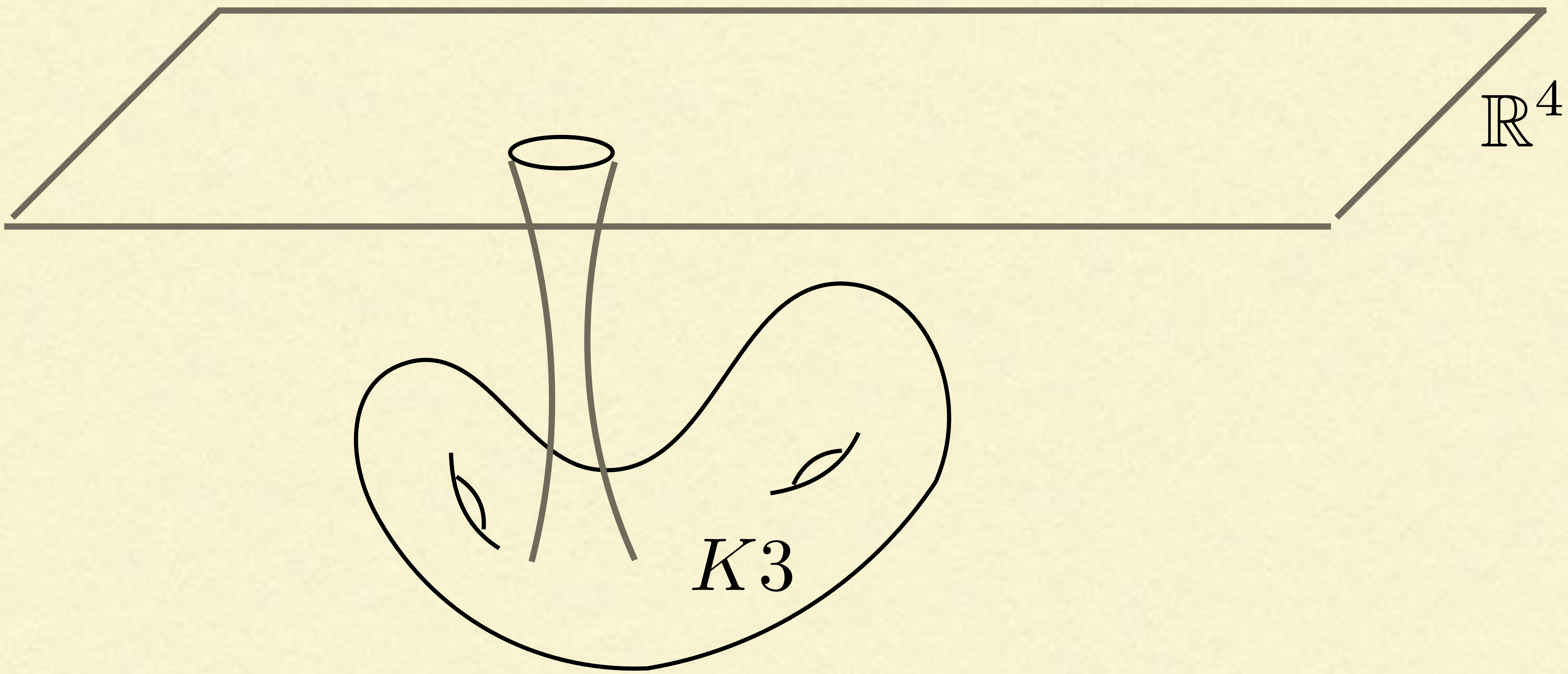
1) Nontrivial topology can lead to **global charges**

For instance, take 5d gravity and on a t=0 slice

Basic idea of the cobordism conjecture:

1) Nontrivial topology can lead to **global charges**

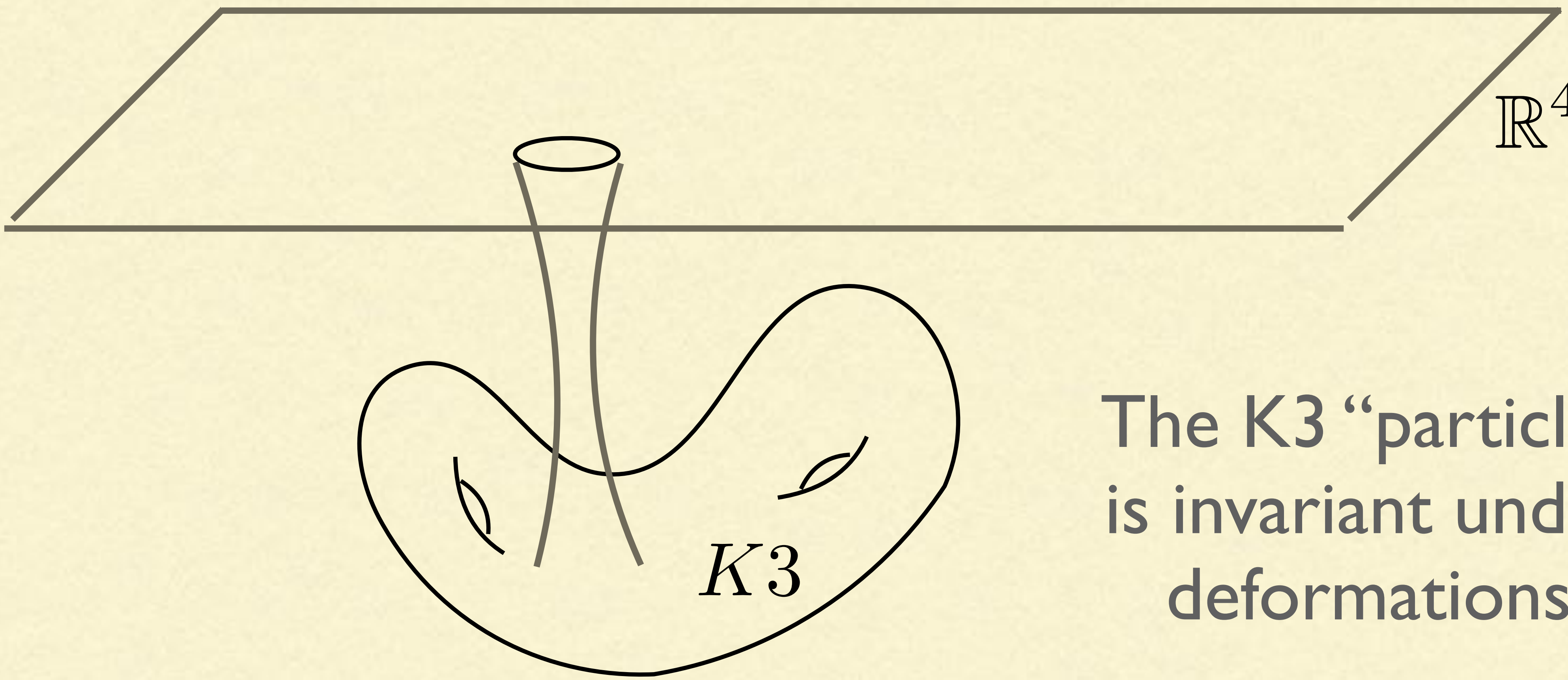
For instance, take 5d gravity and on a t=0 slice



Basic idea of the cobordism conjecture:

1) Nontrivial topology can lead to **global charges**

For instance, take 5d gravity and on a t=0 slice

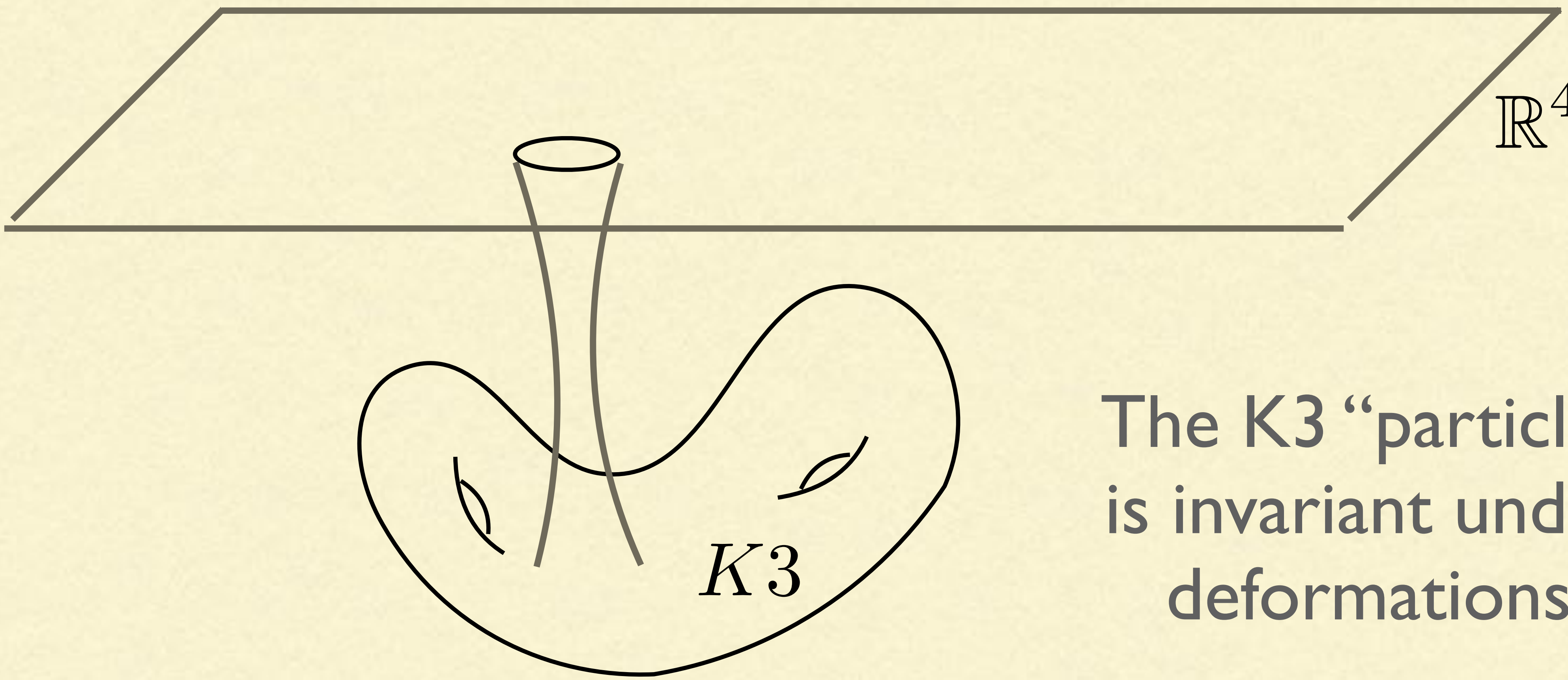


The K3 "particle" is invariant under deformations

Basic idea of the cobordism conjecture:

1) Nontrivial topology can lead to **global charges**

For instance, take 5d gravity and on a t=0 slice

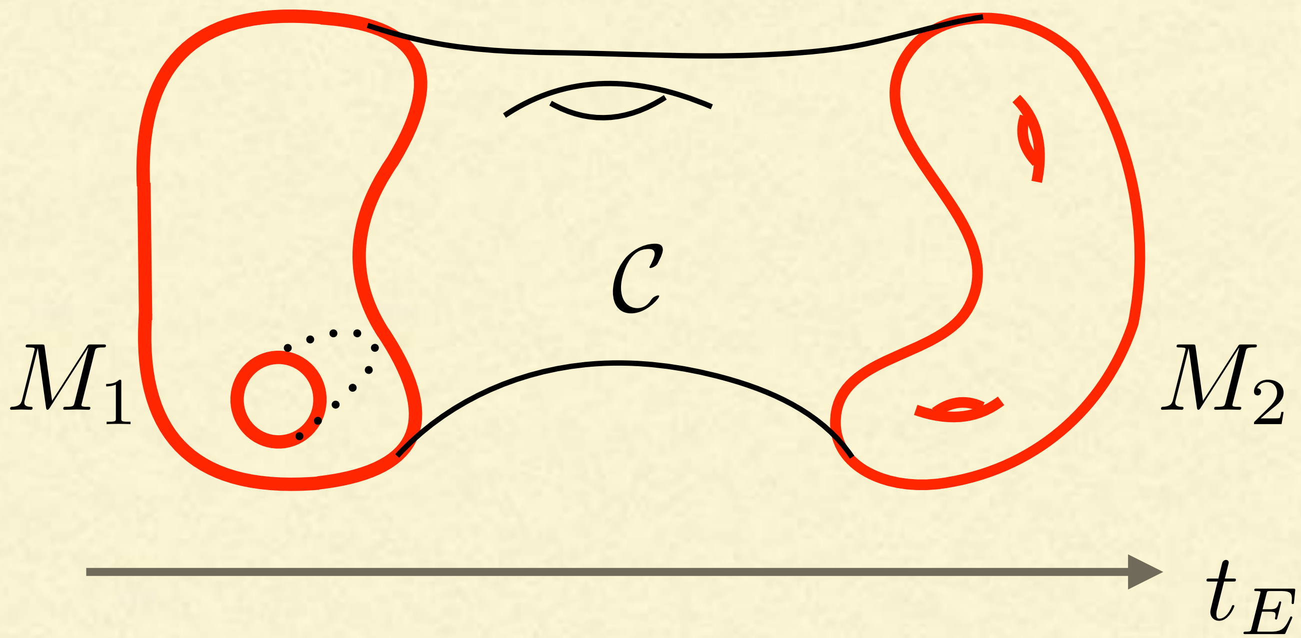


The K3 “particle” is invariant under deformations

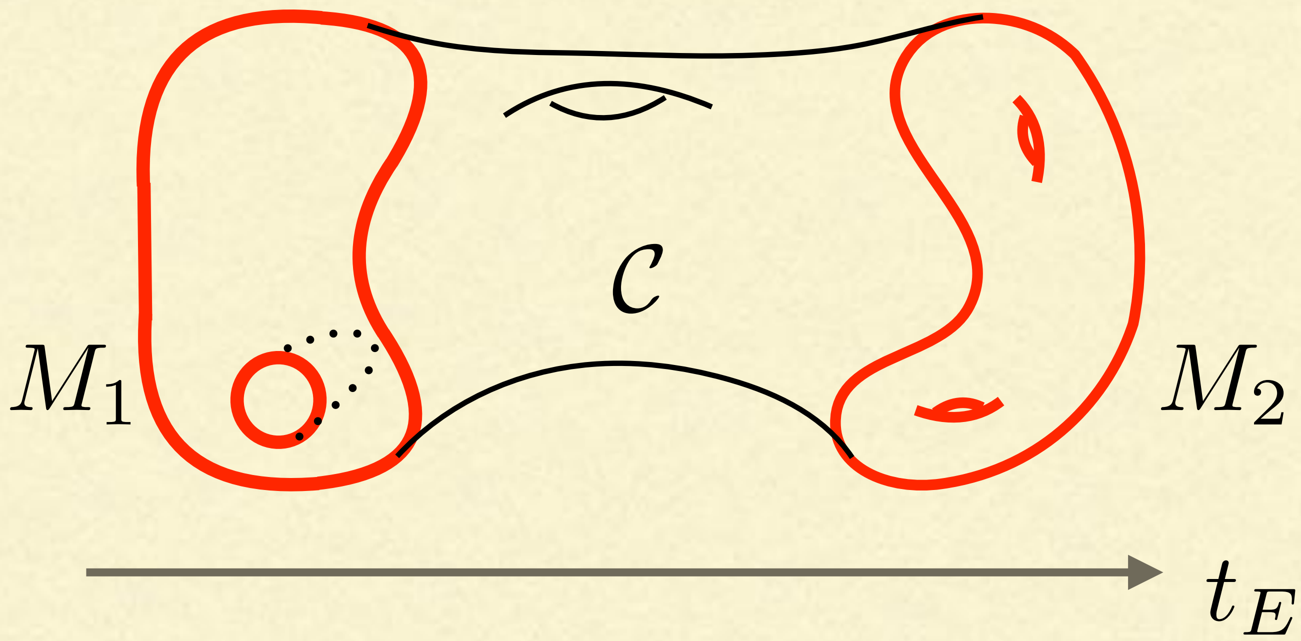
But in QG, topology is **dynamical…**

2) One kind of global charge is **preserved** under smooth topology fluctuations: the **cobordism class**

2) One kind of global charge is **preserved** under smooth topology fluctuations: the **cobordism class**

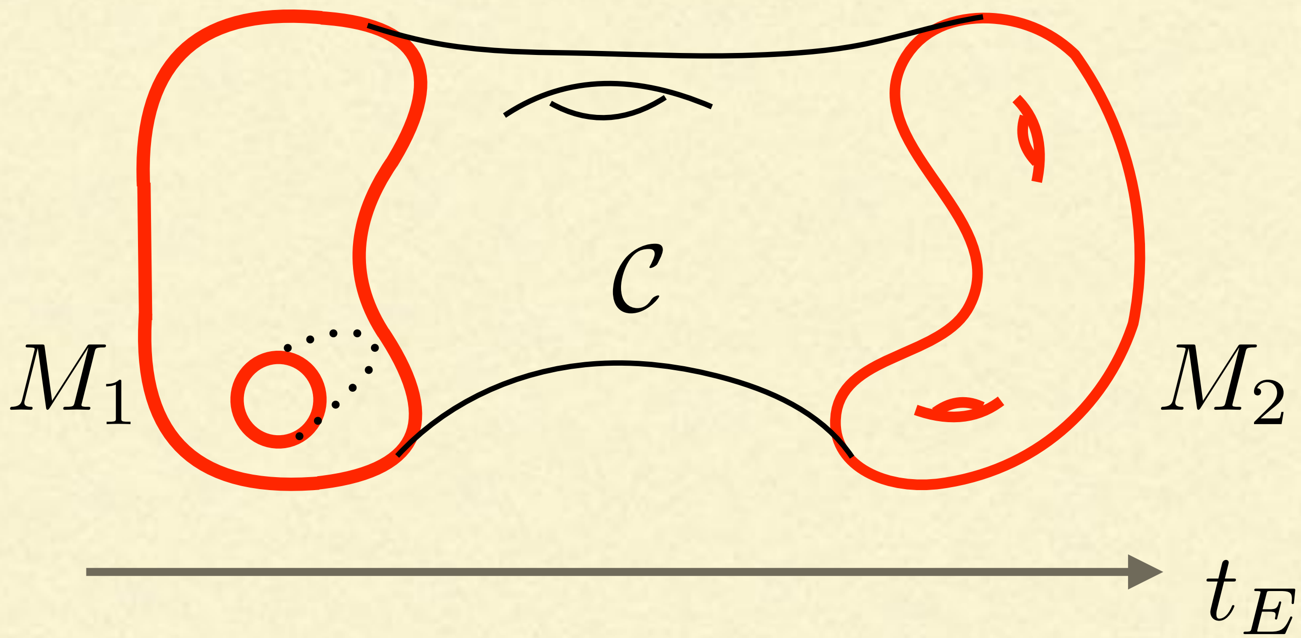


2) One kind of global charge is **preserved** under smooth topology fluctuations: the **cobordism class**



C is a **cobordism** between M1 and M2

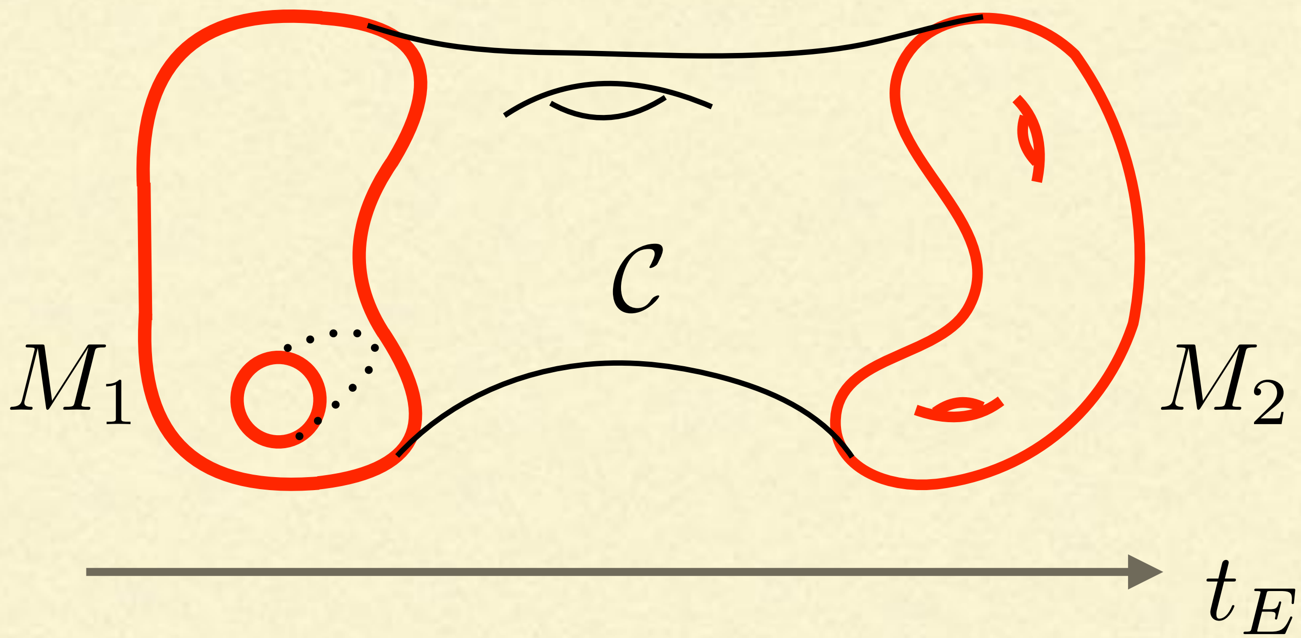
2) One kind of global charge is **preserved** under smooth topology fluctuations: the **cobordism class**



C is a **cobordism** between M1 and M2

The set of cobordism classes forms a group, the **cobordism group**

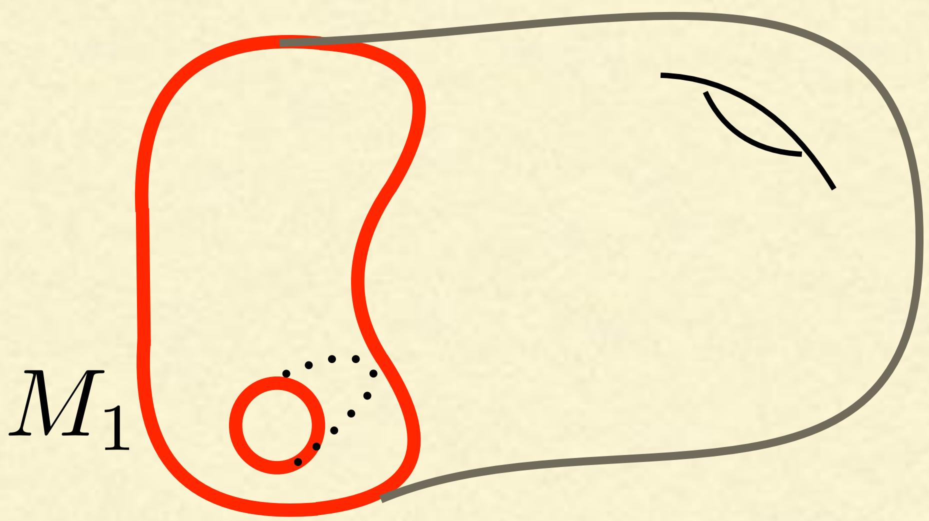
2) One kind of global charge is **preserved** under smooth topology fluctuations: the **cobordism class**



C is a **cobordism** between M1 and M2

The set of cobordism classes forms a group, the **cobordism group**

e.g. $\Omega_4^{\mathrm{Spin}} = \mathbb{Z}$ generated by [K3]



In particular, when M1 is a
boundary
([M1]=0)

the corresponding "global symmetry" is badly broken already at the EFT level.

The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

(the transitions you can describe with the low-energy EFT)

The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

(the transitions you can describe with the low-energy EFT)

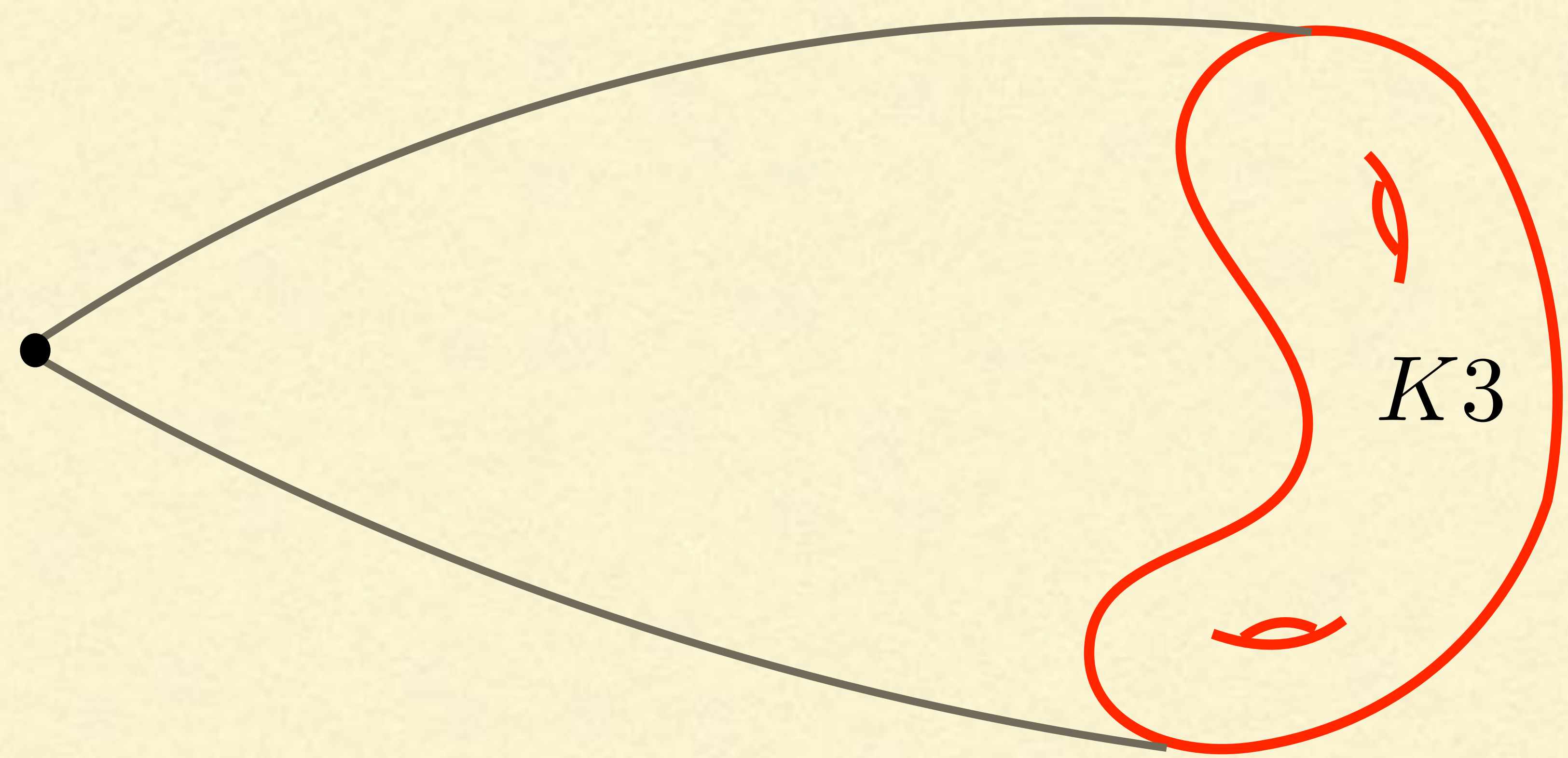
But there are no global symmetries in QG…

The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

(the transitions you can describe with the low-energy EFT)

But there are no global symmetries in QG…

…so it must be possible to kill these global charges somehow!



The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

(the transitions you can describe with the low-energy EFT)

But there are no global symmetries in QG…

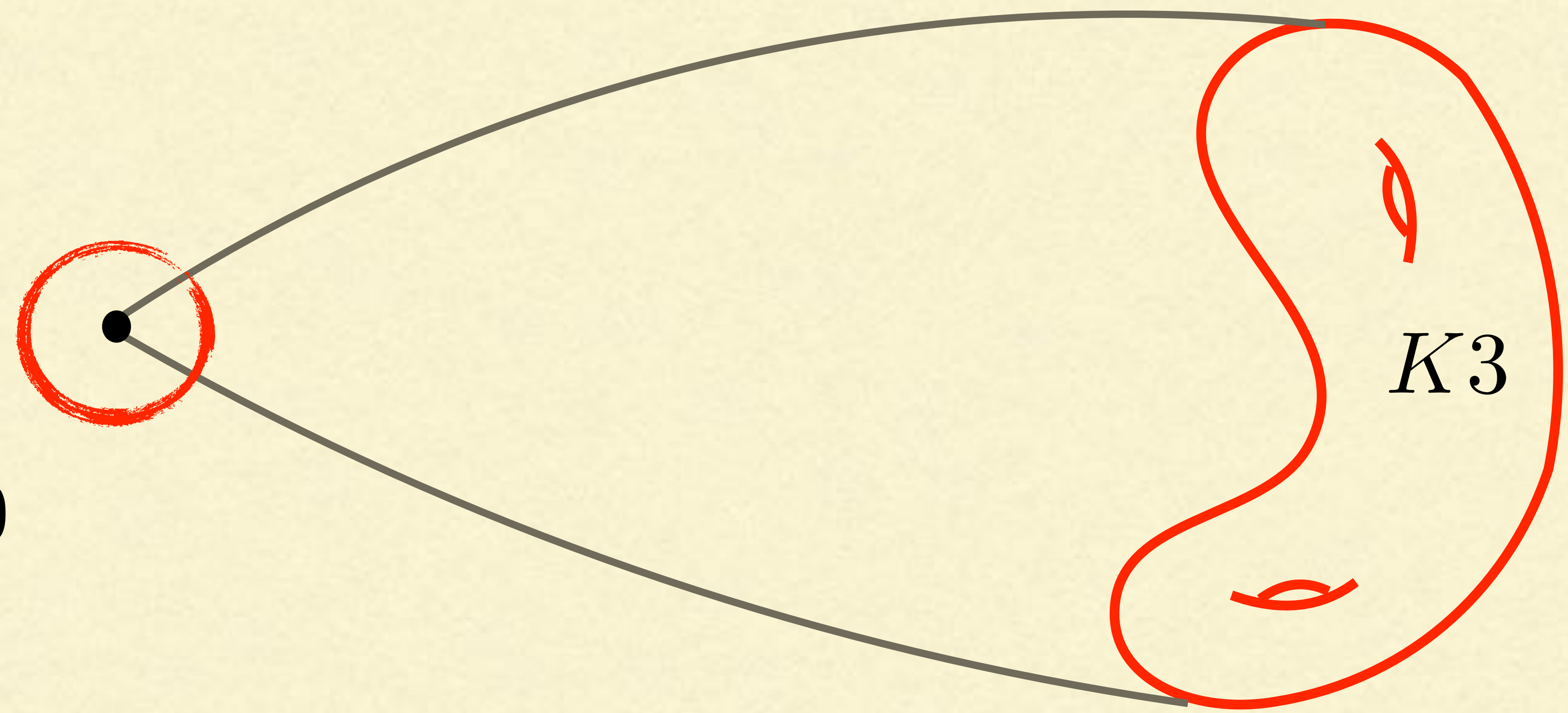
…so it must be possible to kill these global charges somehow!

The **cobordism groups** capture (generalized) topological global symmetries that cannot be killed via **smooth** topological transitions

(the transitions you can describe with the low-energy EFT)

But there are no global symmetries in QG…

…so it must be possible to kill these global charges somehow!



$$\Omega_{\mathrm{QG}} = 0$$

Killing the global symmetry forces the introduction of **defects**

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa ’20]

- Minimal SUSY in d>6 = 16 supercharges

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

- Minimal SUSY in d>6 = 16 supercharges

- Life is simple: There are just **two multiplets**

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

- Minimal SUSY in d>6 = 16 supercharges
- Life is simple: There are just **two multiplets**
    - Gravity: $g, A_i, B \;\; \phi$

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

- Minimal SUSY in d>6 = 16 supercharges
- Life is simple: There are just **two multiplets**
  - Gravity: $g, A_i, B \;\; \phi$
  - Gauge: A, ϕ_i

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

- Minimal SUSY in d>6 = 16 supercharges

- Life is simple: There are just **two multiplets**
  - Gravity: $g, A_i, B \;\; \phi$
  - Gauge: A, ϕ_i

Lagrangian fully fixed by SUSY

Example: Theories with minimal SUSY in d=7,8,9

[MM, Vafa '20]

- Minimal SUSY in d>6 = 16 supercharges
- Life is simple: There are just **two multiplets**
  - Gravity: $g, A_i, B \;\; \phi$
  - Gauge: A, ϕ_i

Lagrangian fully fixed by SUSY

- There is a **Narain** moduli space parametrized by the scalars in vector and gravity multiplets

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

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.
- So a sugra is **fully specified** by the **rank** of the gauge group…

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.
- So a sugra is **fully specified** by the **rank** of the gauge group…

…and a choice of **Lie algebra** (at special points in moduli space)

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.
- So a sugra is **fully specified** by the **rank** of the gauge group…

…and a choice of **Lie algebra** (at special points in moduli space)

- The **Swampland** is just figuring out which combinations have a consistent UV embedding!

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.

- So a sugra is **fully specified** by the **rank** of the gauge group…

…and a choice of **Lie algebra** (at special points in moduli space)

- The **Swampland** is just figuring out which combinations have a consistent UV embedding!

At a generic point in moduli space, only one question makes sense…

- On a **generic point** in moduli space, the group is $U(1)^{r+d}$
- At some points in moduli space, **symmetry enhancement** can occur.
- So a sugra is **fully specified** by the **rank** of the gauge group…

…and a choice of **Lie algebra** (at special points in moduli space)

- The **Swampland** is just figuring out which combinations have a consistent UV embedding!

At a generic point in moduli space, only one question makes sense…

How many vector multiplets?

How many vector multiplets?

How many vector multiplets?

d=9

d=8

d=7

How many vector multiplets?

From low-energy EFT:

d=9 Any **odd** number of vectors

d=8 Any **even** number of vectors

d=7 Any number of vectors

How many vector multiplets?

	From low-energy EFT:	From ST
d=9	Any **odd** number of vectors	1 mod 8
d=8	Any **even** number of vectors	2 mod 8
d=7	Any number of vectors	1,3,5,9,11,13

How many vector multiplets?

	From low-energy EFT:	From ST
d=9	Any **odd** number of vectors	1 mod 8
d=8	Any **even** number of vectors	2 mod 8
d=7	Any number of vectors	1,3,5,9,11,13

1) Maybe the pattern is a “lamppost effect”, and there are more string compactifications to be discovered

How many vector multiplets?

	From low-energy EFT:	From ST
d=9	Any **odd** number of vectors	1 mod 8
d=8	Any **even** number of vectors	2 mod 8
d=7	Any number of vectors	1,3,5,9,11,13

1) Maybe the pattern is a "lamppost effect", and there are more string compactifications to be discovered

2) Maybe ST is not the unique quantum theory of gravity. Other theories realize more values of # of vectors

How many vector multiplets?

	From low-energy EFT:	From ST
d=9	Any **odd** number of vectors	1 mod 8
d=8	Any **even** number of vectors	2 mod 8
d=7	Any number of vectors	1,3,5,9,11,13

1)Maybe the pattern is a “lamppost effect”, and there are more string compactifications to be discovered

2) Maybe ST is not the unique quantum theory of gravity. Other theories realize more values of # of vectors

3) Maybe the pattern is universal, and can be argued independently of ST.

How many vector multiplets?

	From low-energy EFT:	From ST
d=9	Any **odd** number of vectors	1 mod 8
d=8	Any **even** number of vectors	2 mod 8
d=7	Any number of vectors	1,3,5,9,11,13

1) Maybe the pattern is a "lamppost effect", and there are more string compactifications to be discovered

2) Maybe ST is not the unique quantum theory of gravity. Other theories realize more values of # of vectors

3) Maybe the pattern is universal, and can be argued independently of ST.

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

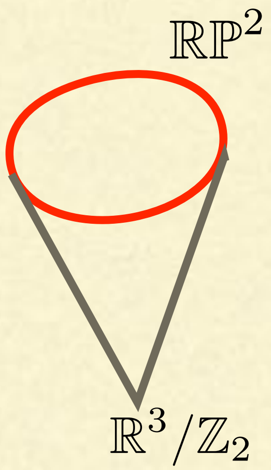
$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

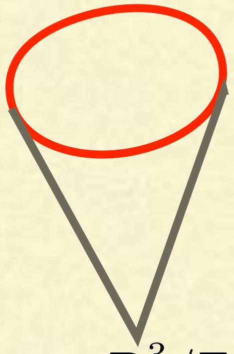
$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

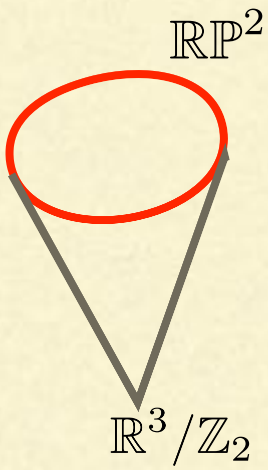
So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

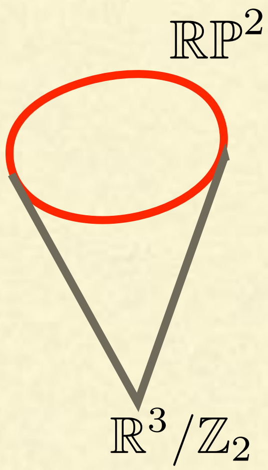
but this background has a **gravitational anomaly**

Let's do d=9 in detail:

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

Let's do d=9 in detail:

Sugra

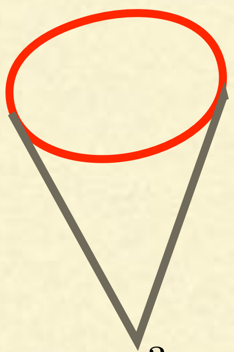
$T^3/\mathbb{Z}_2$

Grav,
1 tensor,
(3+(#of 9d vectors))hypers

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

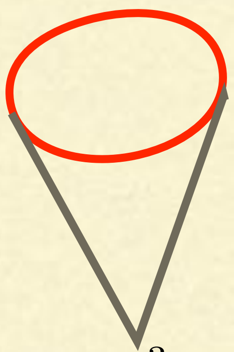
Let's do d=9 in detail:

	Sugra	**Singularities**
$T^3/\mathbb{Z}_2$	Grav, 1 tensor, (3+(#of 9d vectors))hypers	??? x 8

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

Let's do d=9 in detail:

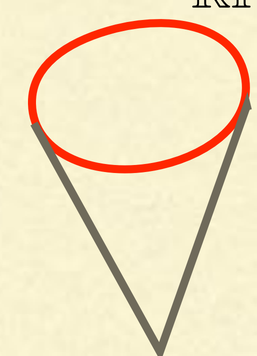
$$273 = 29\, n_T + n_H - n_V$$

	Sugra	**Singularities**
$T^3/\mathbb{Z}_2$	Grav, 1 tensor, (3+(#of 9d vectors))hypers	??? x 8

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

Let's do d=9 in detail:

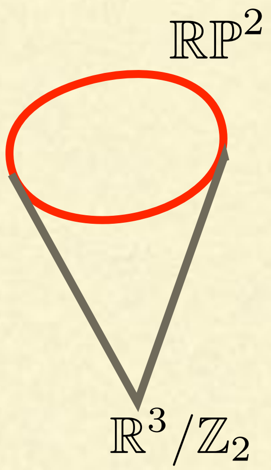
$$273 = 29\, n_T + n_H - n_V$$

	Sugra	**Singularities**	
$T^3/\mathbb{Z}_2$	Grav, 1 tensor, (3+(#of 9d vectors))hypers	??? x 8	$241 = 8 \cdot (???) + \#_{\text{9d vectors}}$

All these theories have a **parity** symmetry & can be put on non-orientable manifolds. There is a

$$\Omega_2^{\mathrm{Pin}^-} = \mathbb{Z}_8$$

global symmetry, generated by the class of $\mathbb{RP}^2$



To kill it, we introduce a defect that looks like

$$\mathbb{R}^3/\mathbb{Z}_2$$

So we can compactify also on $T^3/\mathbb{Z}_2$

but this background has a **gravitational anomaly**

Let's do d=9 in detail:

$$273 = 29\, n_T + n_H - n_V$$

	Sugra	**Singularities**	
$T^3/\mathbb{Z}_2$	Grav, 1 tensor, (3+(#of 9d vectors))hypers	??? x 8	$241 = 8 \cdot (???) + \#_{\text{9d vectors}}$

$$\#_{\text{9d vectors}} \equiv 1 \bmod 8$$

More generally, anomaly cancellation places constraints on # of vectors:

More generally, anomaly cancellation places constraints on # of vectors:

d=9 1 mod 8

More generally, anomaly cancellation places constraints on # of vectors:

d=9	1 mod 8
d=8	2 mod 8

More generally, anomaly cancellation places constraints on # of vectors:

d=9	1 mod 8	d=7	odd #
d=8	2 mod 8		

More generally, anomaly cancellation places constraints on # of vectors:

d=9	1 mod 8	d=7	odd #
d=8	2 mod 8		

Exactly matches ST constructions!

More generally, anomaly cancellation places constraints on # of vectors:

d=9	1 mod 8	d=7	odd #
d=8	2 mod 8		

Exactly matches ST constructions!

(in [Montero-Parra '22] we discovered a new string compactification with 16 charges in 9d. Has rank 1!)

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

E.g. in 8d with 10 vector multiplets, we made a **prediction** that the group

$$\mathrm{Sp}(k)/\mathbb{Z}_2$$

can only appear for **k a multiple of 8.**

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

E.g. in 8d with 10 vector multiplets, we made a **prediction** that the group

$$\mathrm{Sp}(k)/\mathbb{Z}_2$$

can only appear for **k a multiple of 8.**

This prompted the Saclay group to check, and they found

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

E.g. in 8d with 10 vector multiplets, we made a **prediction** that the group

$$\mathrm{Sp}(k)/\mathbb{Z}_2$$

can only appear for **k a multiple of 8.**

This prompted the Saclay group to check, and they found

$$\mathrm{Sp}(1), \mathrm{Sp}(2), \mathrm{Sp}(4), \mathrm{Sp}(6)$$

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

E.g. in 8d with 10 vector multiplets, we made a **prediction** that the group

$$\mathrm{Sp}(k)/\mathbb{Z}_2$$

can only appear for **k a multiple of 8.**

This prompted the Saclay group to check, and they found

$$\mathrm{Sp}(1), \mathrm{Sp}(2), \mathrm{Sp}(4), \mathrm{Sp}(6) \quad \text{and} \quad \mathrm{Sp}(8)/\mathbb{Z}_2$$

In the 8d and 9d theories, sometimes gauge symmetry can become non-abelian.

It is also possible to make predictions about the **non-abelian enhancements.**

E.g. in 8d with 10 vector multiplets, we made a **prediction** that the group

$$\mathrm{Sp}(k)/\mathbb{Z}_2$$

can only appear for **k a multiple of 8.**

This prompted the Saclay group to check, and they found

$$\mathrm{Sp}(1), \mathrm{Sp}(2), \mathrm{Sp}(4), \mathrm{Sp}(6) \quad \text{and} \quad \mathrm{Sp}(8)/\mathbb{Z}_2$$

They verified the **Swampland prediction**

More generally, the predictions we have

Algebra	$\dim(\mathfrak{g}) + \mathrm{rank}(\mathfrak{g})$	$\neq 0 \bmod 8$?	Group	Real reps?
A_k	$k^2 + 3k$	$k \neq 0, 5 \bmod 8$	$SU(k+1)$	✗
			$PSU(k+1)$	✓
B_k	$2k(2k+1)$	$k \equiv 1, 2 \bmod 4$	$Spin(2k+1)$	✗
			$SO(2k+1)$	✓
C_k	$2k(2k+1)$	$k \equiv 1, 2 \bmod 4$	$Sp(k)$	✗
			$Sp(k)/\mathbb{Z}_2$	✓
D_k	$2k^2$	k odd	$Spin(2k)$	✗
			$SO(2k)$	✓
			$Spin(2k)/\mathbb{Z}_4$	✓
E_6	84	✓	E_6	✗
			$E_6/\mathbb{Z}_3$	✓
E_7	140	✓	E_7	✗
			$E_7/\mathbb{Z}_2$	✓
E_8	256	✗	E_8	✓
F_4	56	✗	F_4	✓
G_2	16	✗	G_2	✓

are in agreement with all existing enhancements (roughly 400!)

Take-home message:

If you are interested in any EFT,

Take-home message:

If you are interested in any EFT,

compute its cobordism groups,

Take-home message:

If you are interested in any EFT,

compute its cobordism groups,

fish for global symmetries leading to inconsistencies,

Take-home message:

If you are interested in any EFT,

compute its cobordism groups,

fish for global symmetries leading to inconsistencies,

you get **Swampland constraints** (can rule EFT's out!)

Take-home message:

If you are interested in any EFT,

compute its cobordism groups,

fish for global symmetries leading to inconsistencies,

you get **Swampland constraints** (can rule EFT's out!)

Alternatively, you can predict **new objects** in a theory

Take-home message:

If you are interested in any EFT,

compute its cobordism groups,

fish for global symmetries leading to inconsistencies,

you get **Swampland constraints** (can rule EFT's out!)

Alternatively, you can predict **new objects** in a theory

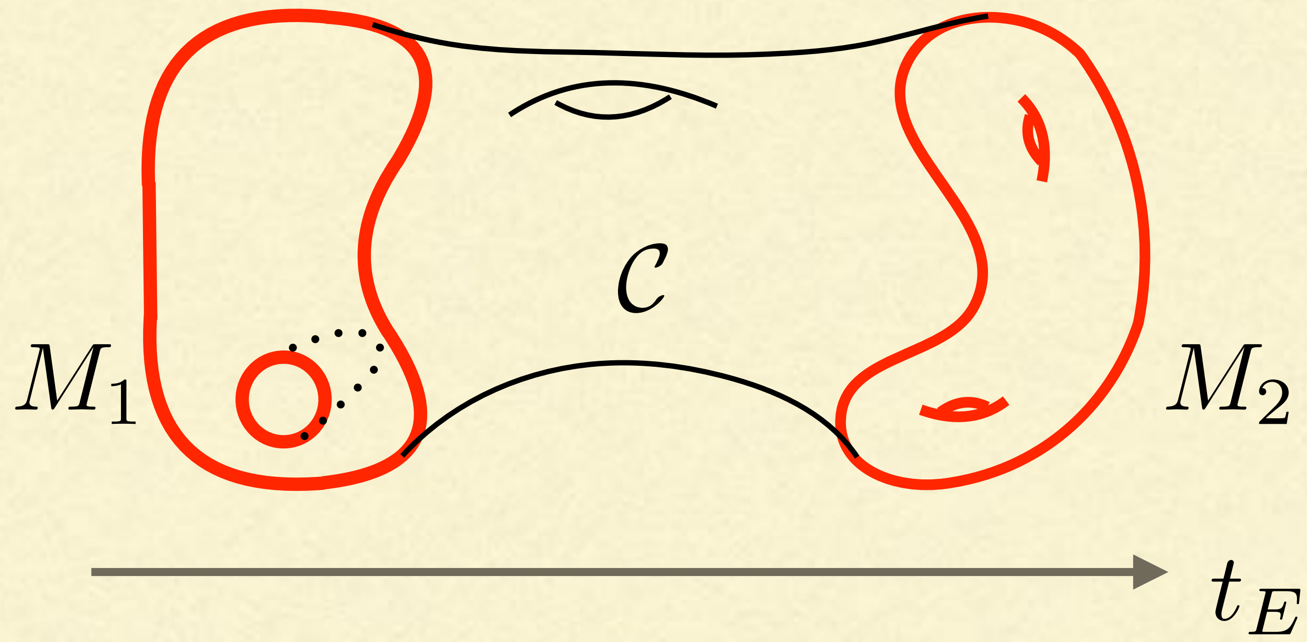
Example: Cobordism groups of **IIB supergravity**

taking into account its **duality symmetry**

In general, cobordism groups can be “dressed” or decorated with additional structures.

In general, cobordism groups can be “dressed” or decorated with additional structures.

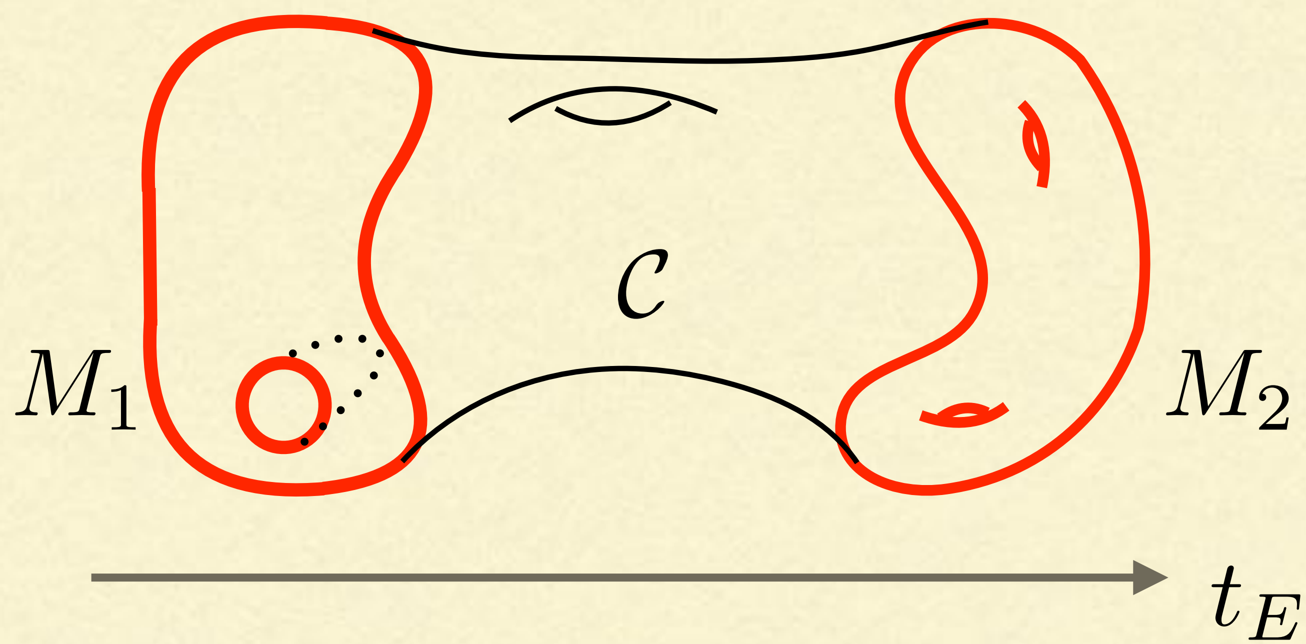
For instance,



In general, cobordism groups can be "dressed" or decorated with additional structures.

For instance,

$$\Omega_*^{\mathrm{Spin}}$$

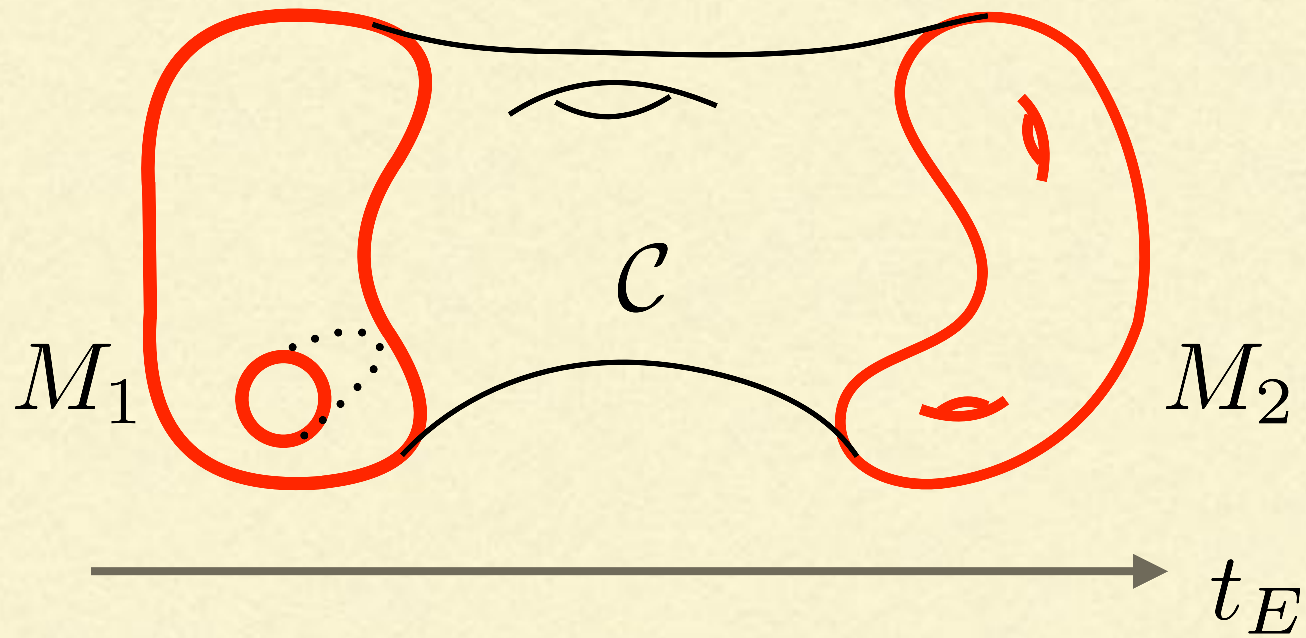


In general, cobordism groups can be "dressed" or decorated with additional structures.

For instance,

$$\Omega_*^{\text{Spin}}$$

$$\Omega_*^{\text{Spin}}(BU(1))$$



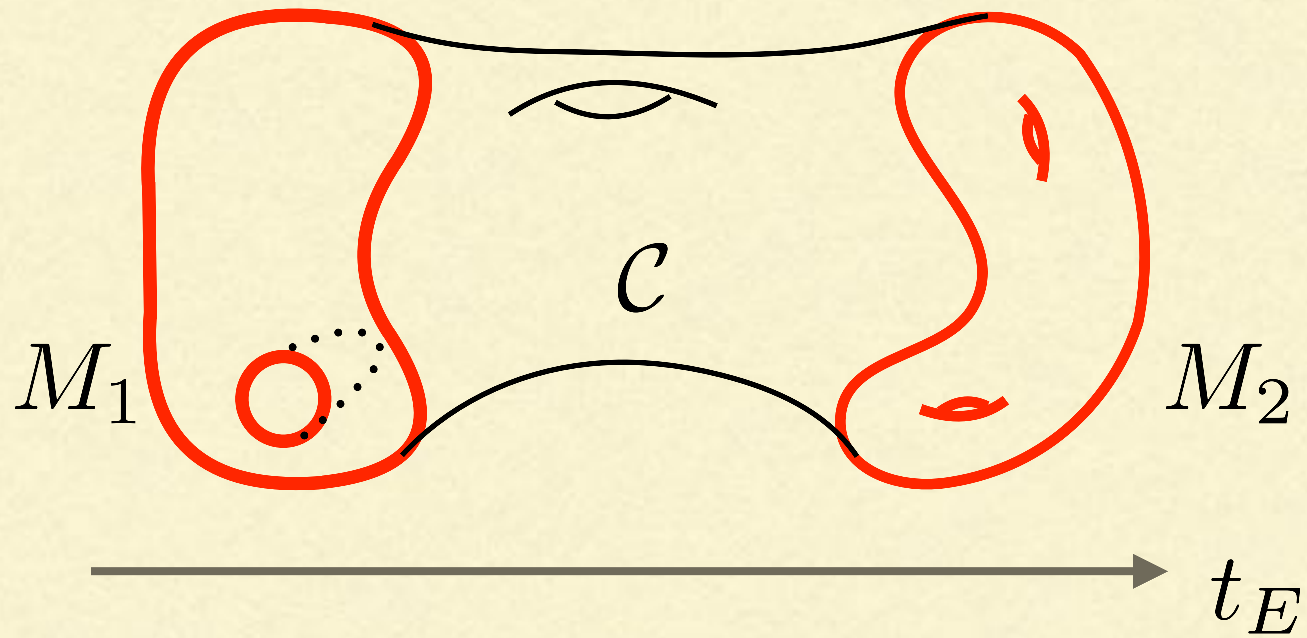
In general, cobordism groups can be "dressed" or decorated with additional structures.

For instance,

$$\Omega_*^{\mathrm{Spin}}$$

$$\Omega_*^{\mathrm{Spin}}(BU(1))$$

$$\Omega_*^{\mathrm{Structure}}$$



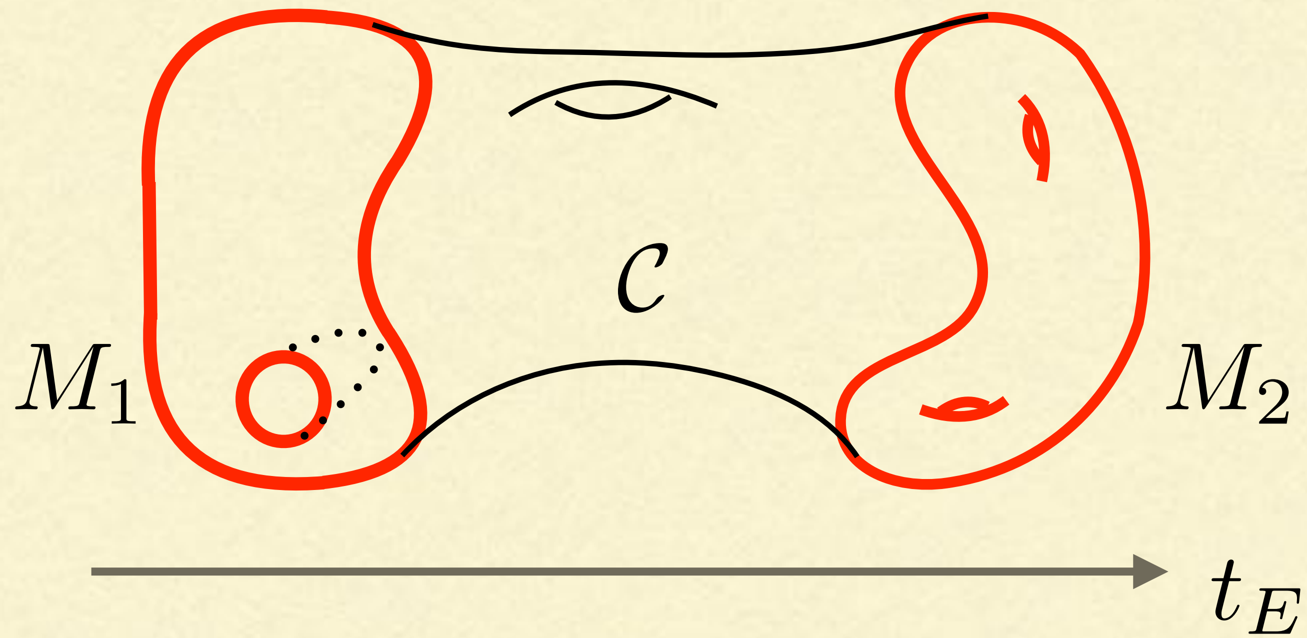
In general, cobordism groups can be "dressed" or decorated with additional structures.

For instance,

$$\Omega_*^{\mathrm{Spin}}$$

$$\Omega_*^{\mathrm{Spin}}(BU(1))$$

$$\Omega_*^{\mathrm{Structure}}$$



One just demands that M1, M2 have the required structure, and that this extends smoothly to C.

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

F-theory: mapp. class group of torus

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ ⟶ IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

M theory: torus diffeomorphisms ⟵ F-theory: mapp. class group of torus

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$
(broken by quantum effects)

M theory: torus diffeomorphisms ← F-theory: mapp. class group of torus

$SL(2,\mathbb{Z})$

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

M theory: torus diffeomorphisms ← F-theory: mapp. class group of torus

$SL(2,\mathbb{Z})$ —Because fermions→ $\mathrm{Mp}(2,\mathbb{Z})$

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

M theory: torus diffeomorphisms ← F-theory: mapp. class group of torus

$SL(2,\mathbb{Z})$ → (Because fermions) $\mathrm{Mp}(2,\mathbb{Z})$

Because M-theory includes reflections

↓

$GL(2,\mathbb{Z})$

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$ (broken by quantum effects)

M theory: torus diffeomorphisms ← F-theory: mapp. class group of torus

$SL(2,\mathbb{Z})$ → (Because fermions) → $\mathrm{Mp}(2,\mathbb{Z})$

$SL(2,\mathbb{Z})$ ↓ (Because M-theory includes reflections) $GL(2,\mathbb{Z})$

$\mathrm{Mp}(2,\mathbb{Z})$ ↓ $\mathrm{Pin}^+(GL(2,\mathbb{Z}))$

$GL(2,\mathbb{Z})$ → $\mathrm{Pin}^+(GL(2,\mathbb{Z}))$

What is the duality symmetry of IIB string theory?

[Tachikawa-Yonekura '18]

IIB supergravity: $SL(2,\mathbb{R})$ → IIB string: $SL(2,\mathbb{Z})$

(broken by quantum effects)

M theory: torus diffeomorphisms ← F-theory: mapp. class group of torus

$SL(2,\mathbb{Z})$ → (Because fermions) → $\mathrm{Mp}(2,\mathbb{Z})$

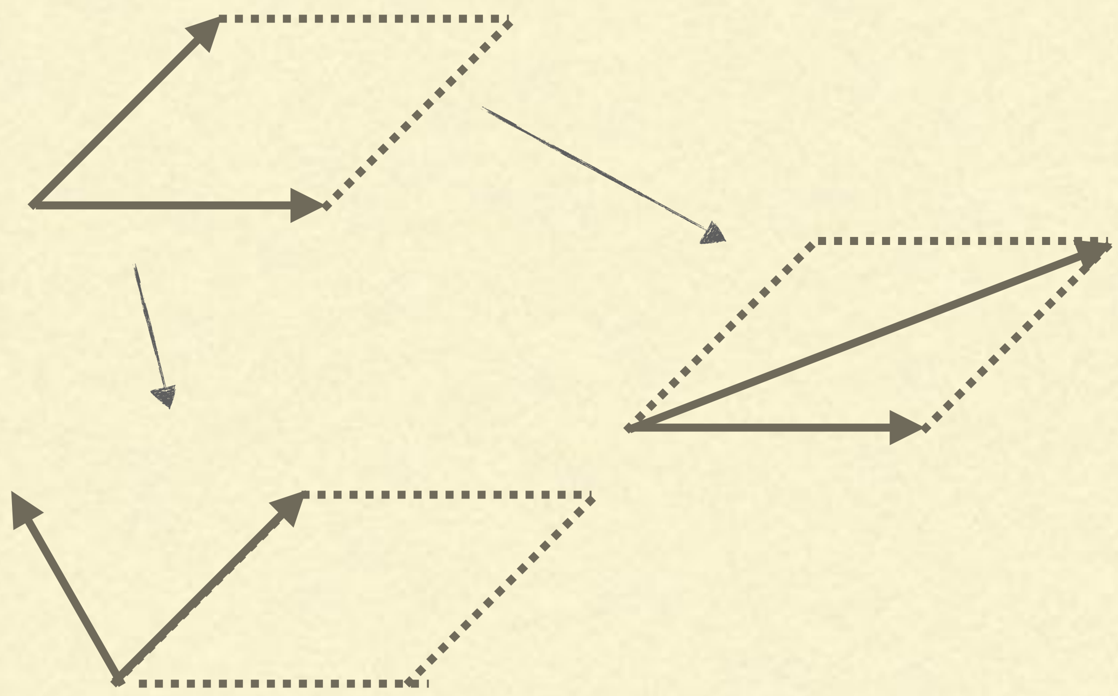
$SL(2,\mathbb{Z})$ ↓ (Because M-theory includes reflections) ↓ $GL(2,\mathbb{Z})$

$\mathrm{Mp}(2,\mathbb{Z})$ ↓ $\mathrm{Pin}^+(GL(2,\mathbb{Z}))$

$GL(2,\mathbb{Z})$ → $\mathrm{Pin}^+(GL(2,\mathbb{Z}))$

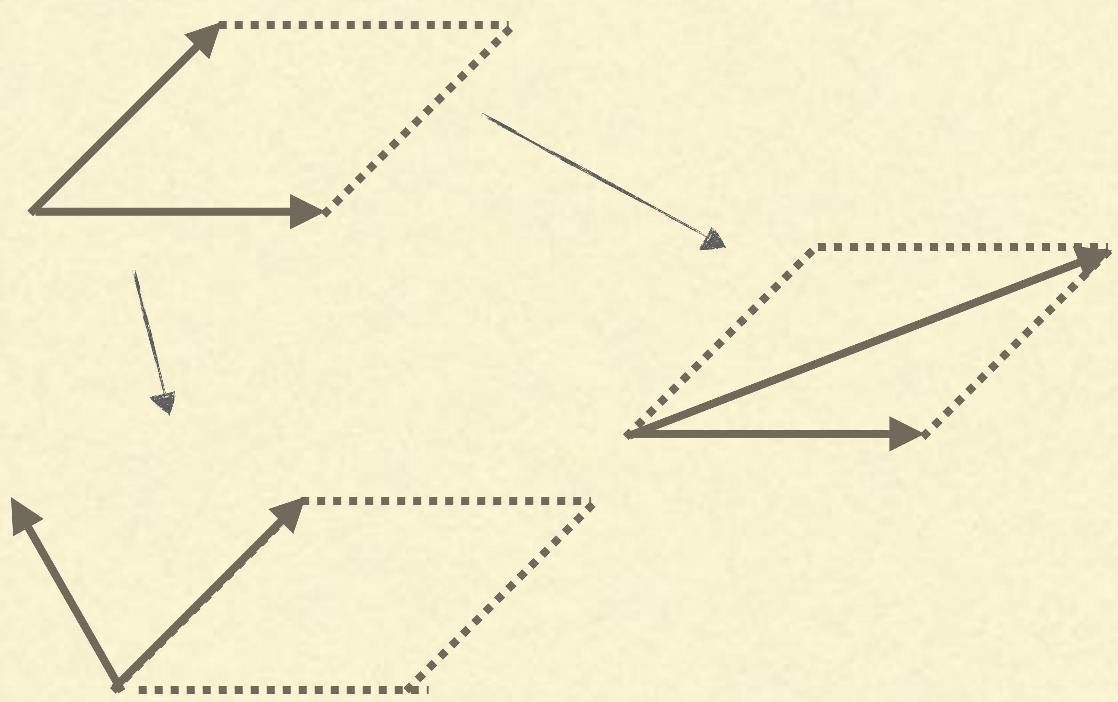
In other words, there are **three** approximations to F-theory cobordism groups:

In other words, there are **three** approximations to F-theory cobordism groups:



$SL(2,\mathbb{Z})$ $\Omega_d(BSL(2,\mathbb{Z}))$

In other words, there are **three** approximations to F-theory cobordism groups:



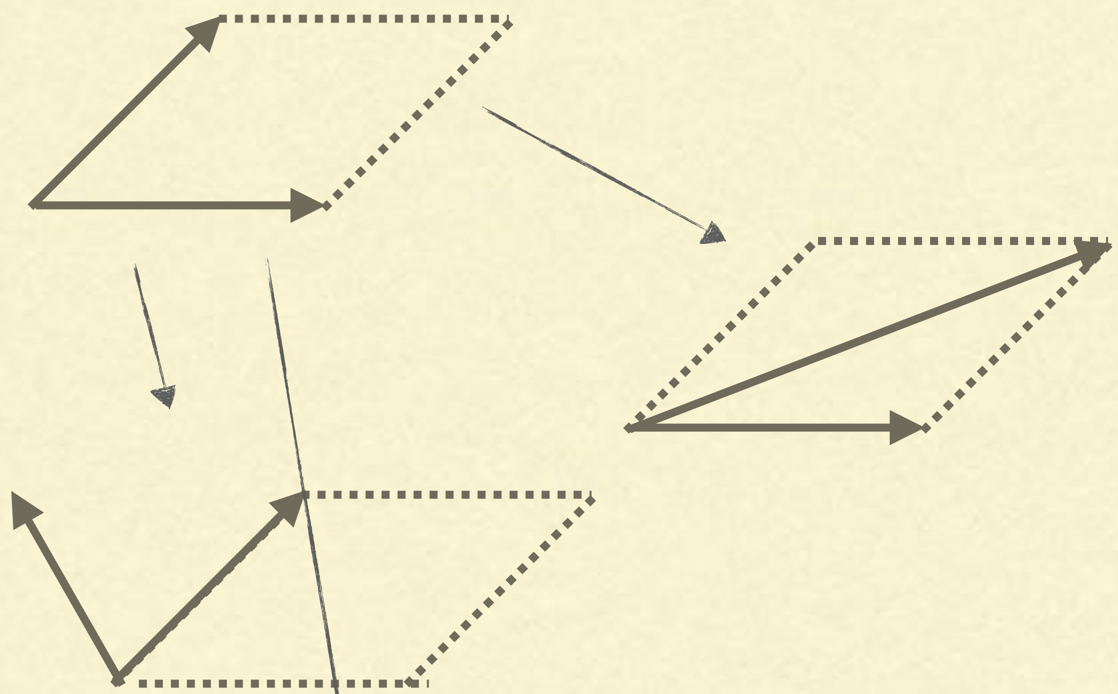
$$SL(2,\mathbb{Z}) \qquad \Omega_d(BSL(2,\mathbb{Z}))$$

Taking into account fermions:

$$\frac{\mathrm{Spin}\times \mathrm{Mp}(2,\mathbb{Z})}{\mathbb{Z}_2}$$

$$\Omega_d^{\mathrm{Spin-Mp}}$$

In other words, there are **three** approximations to F-theory cobordism groups:



$$SL(2,\mathbb{Z}) \qquad \Omega_d(BSL(2,\mathbb{Z}))$$

Taking into account fermions:

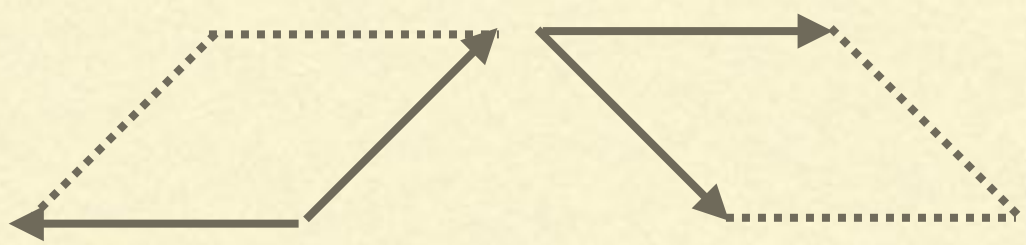
$$\frac{\mathrm{Spin}\times \mathrm{Mp}(2,\mathbb{Z})}{\mathbb{Z}_2}$$

$$\Omega_d^{\mathrm{Spin-Mp}}$$

Taking into account **reflections**:

$$\frac{\mathrm{Spin}\times \mathrm{GL}^+(2,\mathbb{Z})}{\mathbb{Z}_2}$$

$$\Omega_d^{\mathrm{Spin-GL}^+}$$



$(-1)^{F_L}$ and Ω symmetries of perturbative IIB

We computed **all three** approximations!

(Debray, Dierigl, Heckman, MM, work in progress)

d	$\Omega_d^{\text{Spin}}\big(BSL(2,\mathbb{Z})\big)$	$\Omega_d^{\text{Spin-Mp}(2,\mathbb{Z})}$	$\Omega_d^{\text{Spin-GL}^+(2,\mathbb{Z})}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2 \oplus \mathbb{Z}_{12}$	$\mathbb{Z}_3 \oplus \mathbb{Z}_8$	$2\mathbb{Z}_2$
2	$\mathbb{Z}_2 \oplus \mathbb{Z}_2$	0	$\mathbb{Z}_2$
3	$\mathbb{Z}_2 \oplus \mathbb{Z}_{24}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_3$	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3$
4	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
5	$\mathbb{Z}_{36}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$2\mathbb{Z}_2$
6	0	0	0
7	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$\mathbb{Z}_4 \oplus \mathbb{Z}_9$	$\mathbb{Z}_4 \oplus 3\mathbb{Z}_2 \oplus \mathbb{Z}_9$
8	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z} \oplus \mathbb{Z}_2$
9	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_{128} \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$8\mathbb{Z}_2$
10	$4\mathbb{Z}_2$	$\mathbb{Z}_2$	$4\mathbb{Z}_2$
11	$2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus 2\mathbb{Z}_8 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_{128}$	$\mathbb{Z}_8 \oplus 2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_8 \oplus 9\mathbb{Z}_2 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_3$

We computed **all three** approximations!

(Debray, Dierigl, Heckman, MM, work in progress)

d	$\Omega_d^{\text{Spin}}\big(BSL(2,\mathbb{Z})\big)$	$\Omega_d^{\text{Spin-Mp}(2,\mathbb{Z})}$	$\Omega_d^{\text{Spin-GL}^+(2,\mathbb{Z})}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2 \oplus \mathbb{Z}_{12}$	$\mathbb{Z}_3 \oplus \mathbb{Z}_8$	$2\mathbb{Z}_2$
2	$\mathbb{Z}_2 \oplus \mathbb{Z}_2$	0	$\mathbb{Z}_2$
3	$\mathbb{Z}_2 \oplus \mathbb{Z}_{24}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_3$	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3$
4	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
5	$\mathbb{Z}_{36}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$2\mathbb{Z}_2$
6	0	0	0
7	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$\mathbb{Z}_4 \oplus \mathbb{Z}_9$	$\mathbb{Z}_4 \oplus 3\mathbb{Z}_2 \oplus \mathbb{Z}_9$
8	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z} \oplus \mathbb{Z}_2$
9	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_{128} \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$8\mathbb{Z}_2$
10	$4\mathbb{Z}_2$	$\mathbb{Z}_2$	$4\mathbb{Z}_2$
11	$2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus 2\mathbb{Z}_8 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_{128}$	$\mathbb{Z}_8 \oplus 2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_8 \oplus 9\mathbb{Z}_2 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_3$

Let us now talk about the **first entry**

We computed **all three** approximations!

(Debray, Dierigl, Heckman, MM, work in progress)

d	$\Omega_d^{\mathrm{Spin}}(BSL(2,\mathbb{Z}))$	$\Omega_d^{\mathrm{Spin\text{-}Mp}(2,\mathbb{Z})}$	$\Omega_d^{\mathrm{Spin\text{-}GL}^+(2,\mathbb{Z})}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2 \oplus \mathbb{Z}_{12}$	$\mathbb{Z}_3 \oplus \mathbb{Z}_8$	$2\mathbb{Z}_2$
2	$\mathbb{Z}_2 \oplus \mathbb{Z}_2$	0	$\mathbb{Z}_2$
3	$\mathbb{Z}_2 \oplus \mathbb{Z}_{24}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_3$	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3$
4	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
5	$\mathbb{Z}_{36}$	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$2\mathbb{Z}_2$
6	0	0	0
7	$\mathbb{Z}_2 \oplus \mathbb{Z}_9 \oplus \mathbb{Z}_{32}$	$\mathbb{Z}_4 \oplus \mathbb{Z}_9$	$\mathbb{Z}_4 \oplus 3\mathbb{Z}_2 \oplus \mathbb{Z}_9$
8	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z}$	$\mathbb{Z} \oplus \mathbb{Z} \oplus \mathbb{Z}_2$
9	$3\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_{128} \oplus \mathbb{Z}_4 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_8 \oplus \mathbb{Z}_{27}$	$8\mathbb{Z}_2$
10	$4\mathbb{Z}_2$	$\mathbb{Z}_2$	$4\mathbb{Z}_2$
11	$2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus 2\mathbb{Z}_8 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_{128}$	$\mathbb{Z}_8 \oplus 2\mathbb{Z}_2 \oplus \mathbb{Z}_3 \oplus \mathbb{Z}_{27}$	$\mathbb{Z}_8 \oplus 9\mathbb{Z}_2 \oplus \mathbb{Z}_{27} \oplus \mathbb{Z}_3$

Let us now talk about the **first entry**

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

These are all **one-dimensional** cobordism groups

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

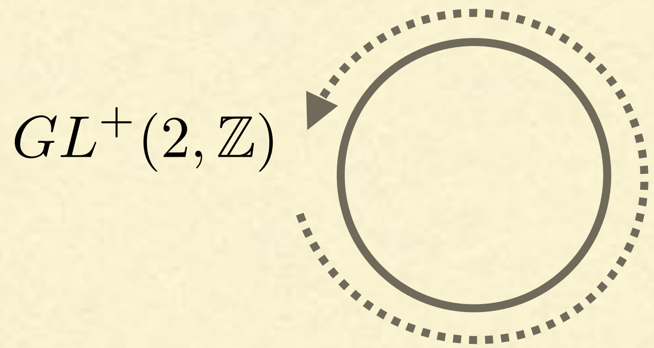
$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

These are all **one-dimensional** cobordism groups

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

Only 1-d manifold is **circle**, so all these classes are circles with duality holonomy

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$



$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

These are all **one-dimensional** cobordism groups

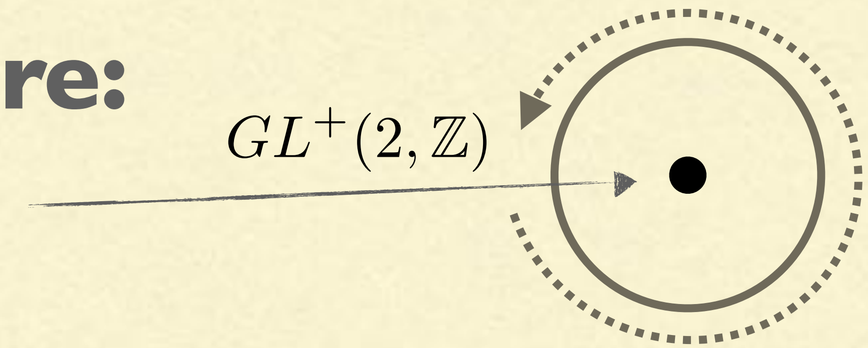
$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

Only 1-d manifold is **circle**, so all these classes are circles with duality holonomy

Cobordism conjecture:

Must have 7-branes



$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

Capture ordinary 7-branes

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

Capture ordinary 7-branes

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

↓

Class of a circle with U holonomy

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

Capture ordinary 7-branes

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

↓

Class of a circle with U holonomy

Killed by E6 singu, Kodaira type IV*

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

Capture ordinary 7-branes

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

Class of a circle with U holonomy

Killed by E6 singu, Kodaira type IV*

Class of a circle with S holonomy

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

Capture ordinary 7-branes

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

Class of a circle with U holonomy

Killed by E6 singu, Kodaira type IV*

Class of a circle with S holonomy

Killed by D4 singu, Kodaira type I0*

$$\Omega_1(BSL(2,\mathbb{Z}) = \mathbb{Z}_2 \oplus \mathbb{Z}_{12}$$

Capture ordinary 7-branes

$$\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$$

Class of a circle with U holonomy

Killed by E6 singu, Kodaira type IV*

Since S,U generate SL(2,Z), we have **all ordinary F-theory 7-branes**

Class of a circle with S holonomy

Killed by D4 singu, Kodaira type I0*

But … $\Omega_1^{\mathrm{Spin\text{-}Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$ is not the **true** duality cob group group of IIB sugra.

But … $\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$ is not the **true** duality cob group group of IIB sugra.

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$ **is.**

But … $\Omega_1^{\text{Spin-Mp}(2,\mathbb{Z})} = \mathbb{Z}_3 \oplus \mathbb{Z}_8$ is not the **true** duality cob group group of IIB sugra.

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$ **is.**

What is going on?

Where did the F-theory 7-branes go?

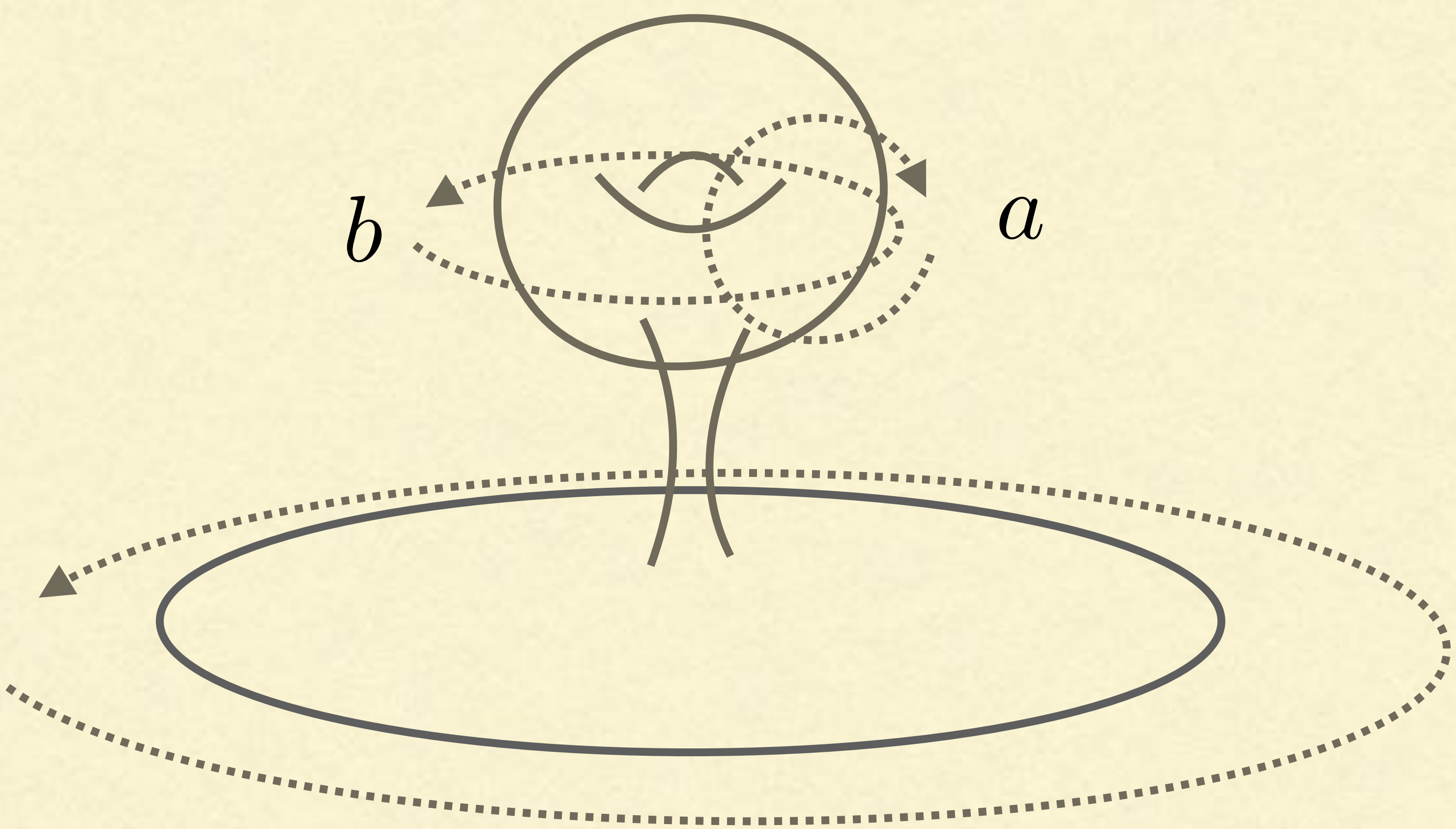
Answer: F-theory branes are **not** fundamental objects in IIB supergravity!

Answer: F-theory branes are **not** fundamental objects in IIB supergravity!

Objects with the same holonomy can be constructed **without any singularity** in the elliptic fiber.

Answer: F-theory branes are **not** fundamental objects in IIB supergravity!

Objects with the same holonomy can be constructed **without any singularity** in the elliptic fiber.



$aba^{-1}b^{-1}$

Basic construction in McNamara '21: Torus with holonomies allows one to construct **commutators**

Ok fine. But what are the Z2's in

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

?

Ok fine. But what are the Z2's in

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

?

They are classes of circles with **torus reflections** around them.

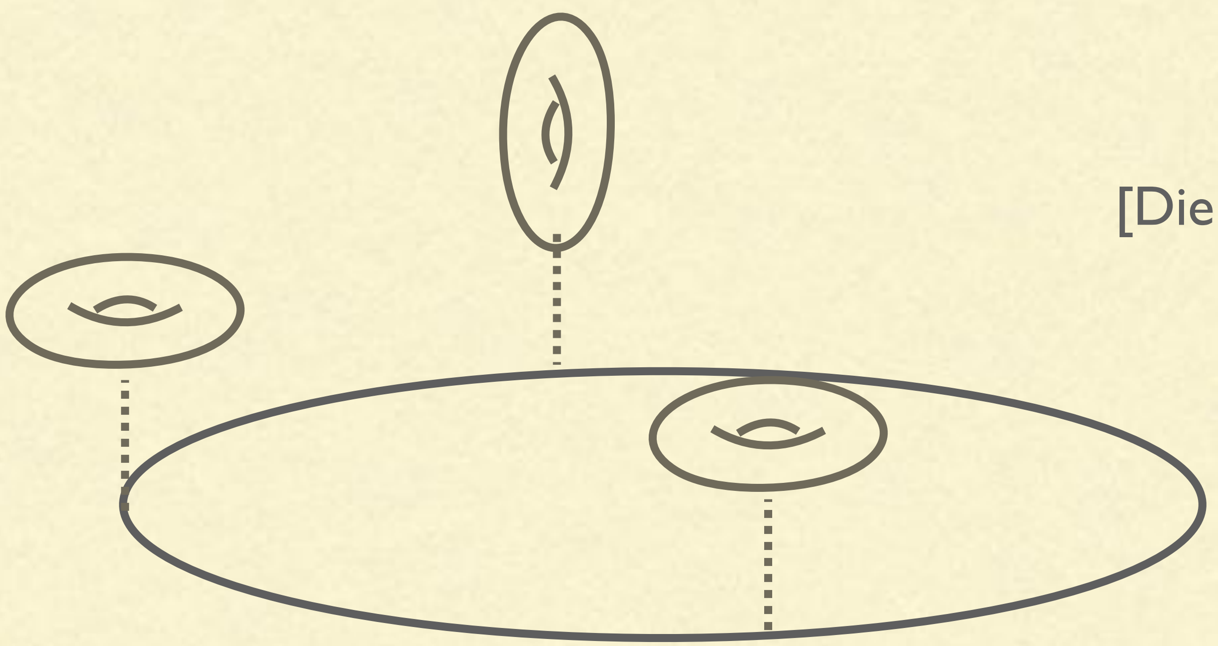
Ok fine. But what are the Z2's in

$$\Omega_1^{\text{Spin-GL}^+(2,\mathbb{Z})} = 2\mathbb{Z}_2$$

?

They are classes of circles with **torus reflections** around them.

[Dierigl-Heckman-MM-Torres, 2212.05077]



One **needs** introduce new fundamental 7-branes to kill these classes. We call them **reflection 7-branes**

New entry in F-theory dictionary.

There are two reflection 7-branes:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad (-1)^{F_L} \quad \text{brane}$$

There are two reflection 7-branes:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad (-1)^{F_L} \quad \text{brane}$$

$$\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \qquad \Omega \quad \text{brane}$$

There are two reflection 7-branes:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad (-1)^{F_L} \quad \text{brane}$$

$$\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \qquad \Omega \quad \text{brane}$$

They are S-dual: $\Omega = S(-1)^{F_L} S^{-1}$

There are two reflection 7-branes:

$$\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix} \qquad (-1)^{F_L} \quad \text{brane}$$

$$\begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \qquad \Omega \quad \text{brane}$$

They are S-dual: $\Omega = S(-1)^{F_L} S^{-1}$

And allow us to "fractionalize" an I0* singu:

$$\begin{pmatrix} -1 & 0 \\ 0 & -1 \end{pmatrix} = \begin{pmatrix} -1 & 0 \\ 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

The R7 is **strongly coupled** at its core.

Cannot be described in the worldsheet (e.g. as orbifold)

The R7 is **strongly coupled** at its core.

Cannot be described in the worldsheet (e.g. as orbifold)

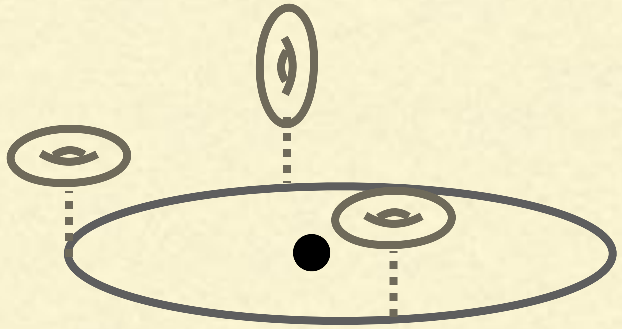
But we can learn a lot about the worldvolume degrees of freedom of the R7 via **anomaly inflow**

The R7 is **strongly coupled** at its core.

Cannot be described in the worldsheet (e.g. as orbifold)

But we can learn a lot about the worldvolume degrees of freedom of the R7 via **anomaly inflow**

Depict the R7 brane as the boundary of a long cigar:

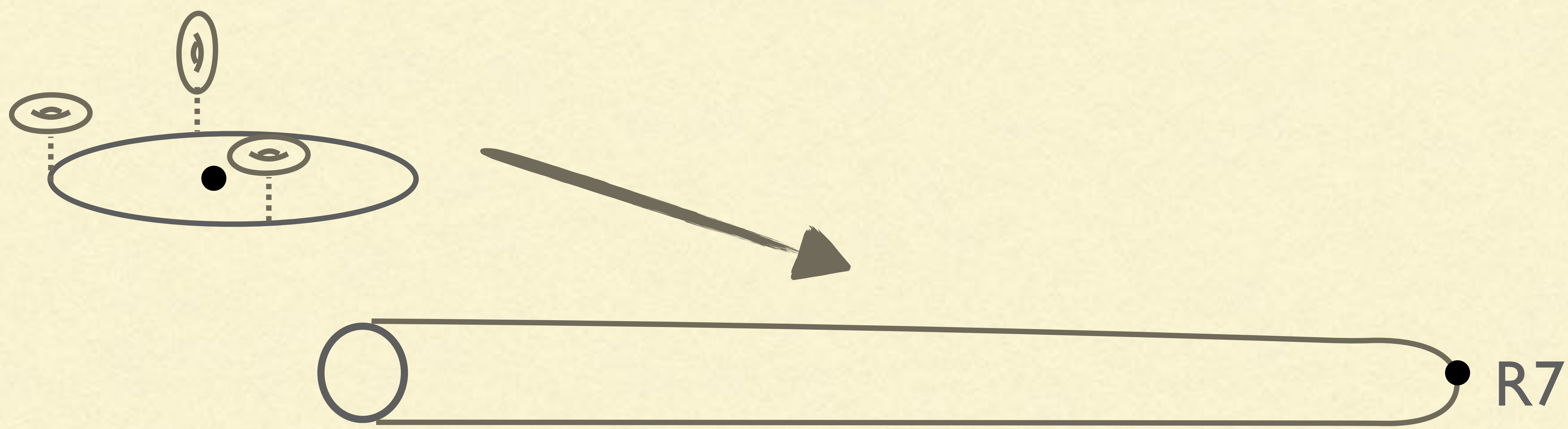


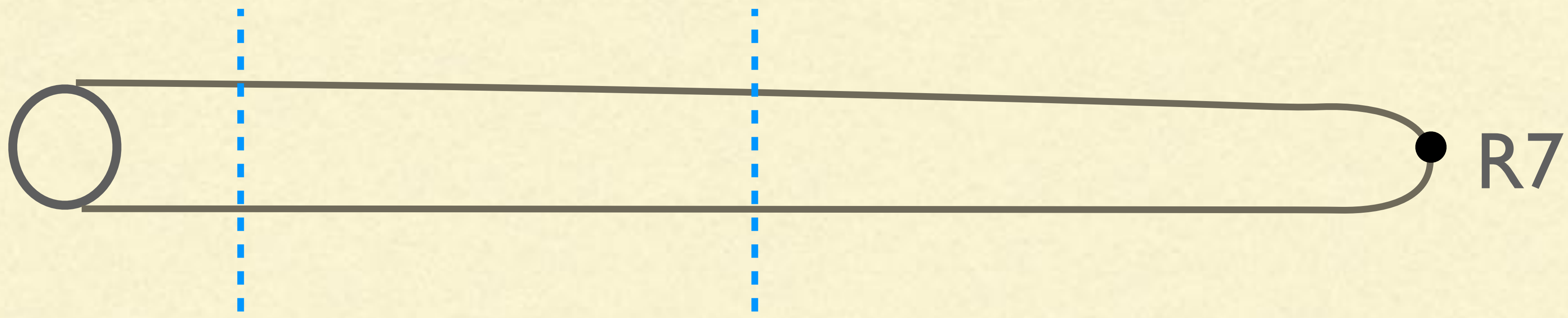
The R7 is **strongly coupled** at its core.

Cannot be described in the worldsheet (e.g. as orbifold)

But we can learn a lot about the worldvolume degrees of freedom of the R7 via **anomaly inflow**

Depict the R7 brane as the boundary of a long cigar:





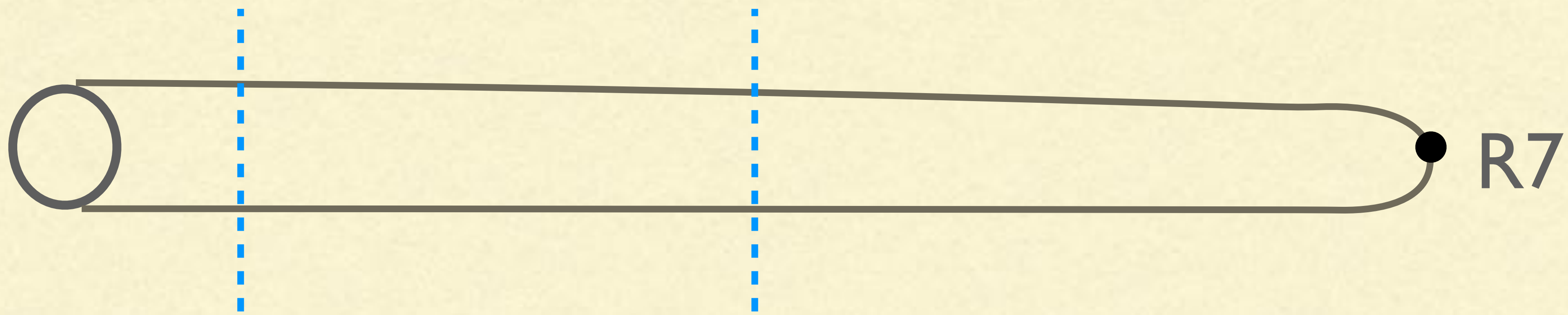
Far away from the R7 (e.g. between the blue lines), the configuration is just like IIB on a circle with holonomy

Far away from the R7 (e.g. between the blue lines), the configuration is just like IIB on a circle with holonomy

There is a **one-loop** Chern-Simons term

$$\frac{A_R \wedge \left(7p_1^2 - 4p_2\right)}{11520}$$

$$p_1 = -\frac{1}{8\pi^2}\mathrm{tr}(R^2), \ldots$$



Far away from the R7 (e.g. between the blue lines), the configuration is just like IIB on a circle with holonomy

There is a **one-loop** Chern-Simons term

$$\frac{A_R \wedge \left(7p_1^2 - 4p_2\right)}{11520} \qquad p_1 = -\frac{1}{8\pi^2}\mathrm{tr}(R^2), \ldots$$

By **anomaly inflow**, this is the anomaly of the worldvolume theory of the R7-brane

In other words, the anomaly polynomial of the R7 brane is

$$\frac{F_R \wedge \left(7p_1^2 - 4p_2\right)}{11520} + \ldots$$

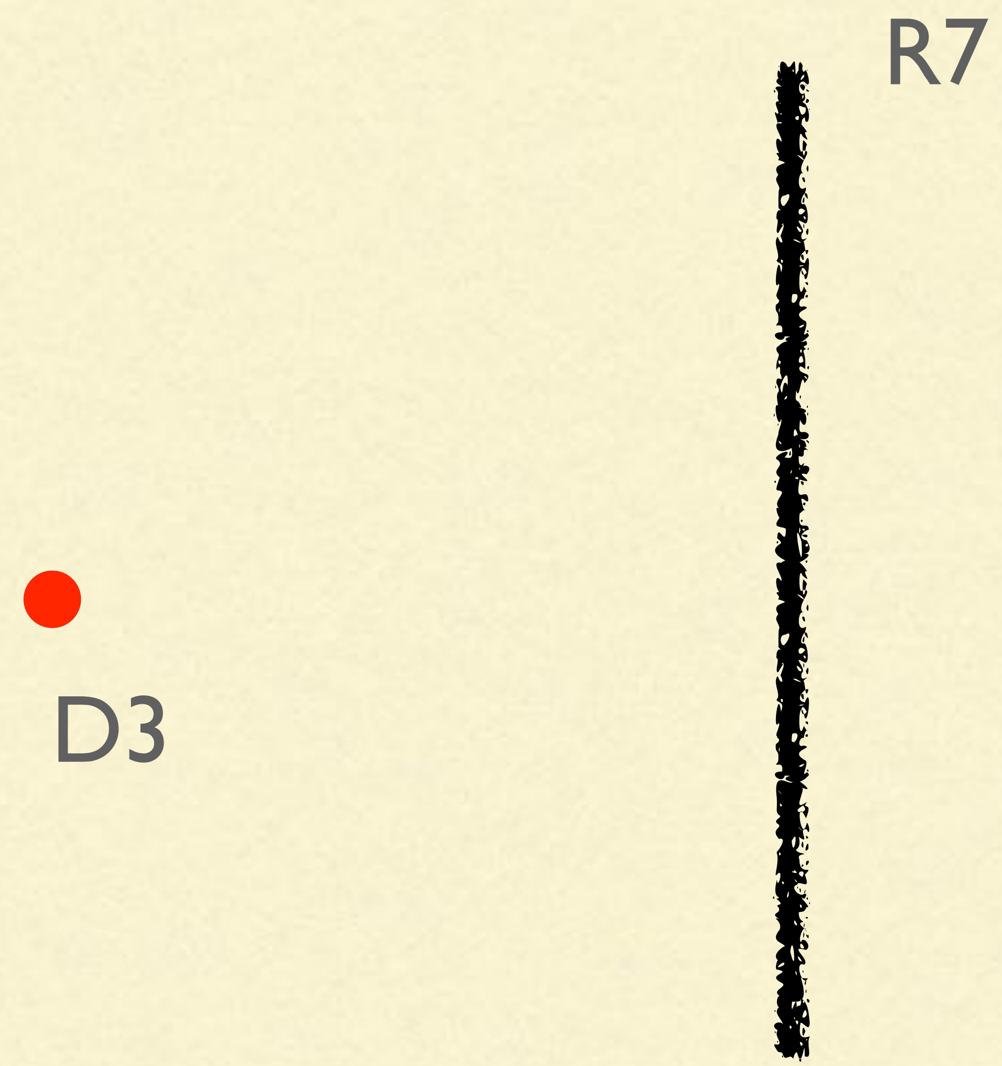
This is the anomaly polynomial of **one** Dirac fermion of R-charge 1/2.

That the coefficients **come out correctly quantized** is nontrivial. For instance,

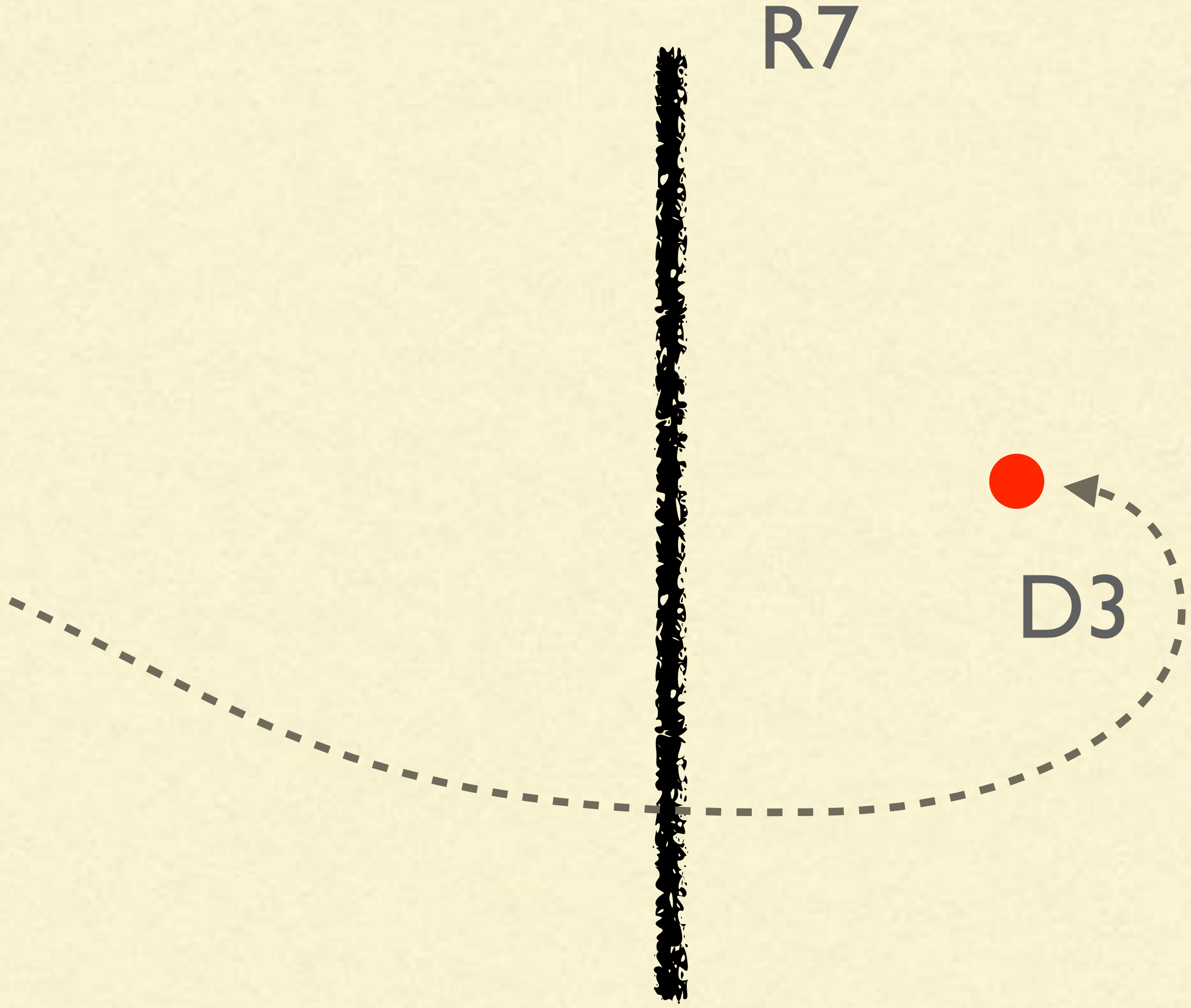
$$\frac{F_R \wedge \left(7p_1^2 - 4p_2\right)}{35000}$$

would not hoave corresponded to any sensible worldvolume theory.

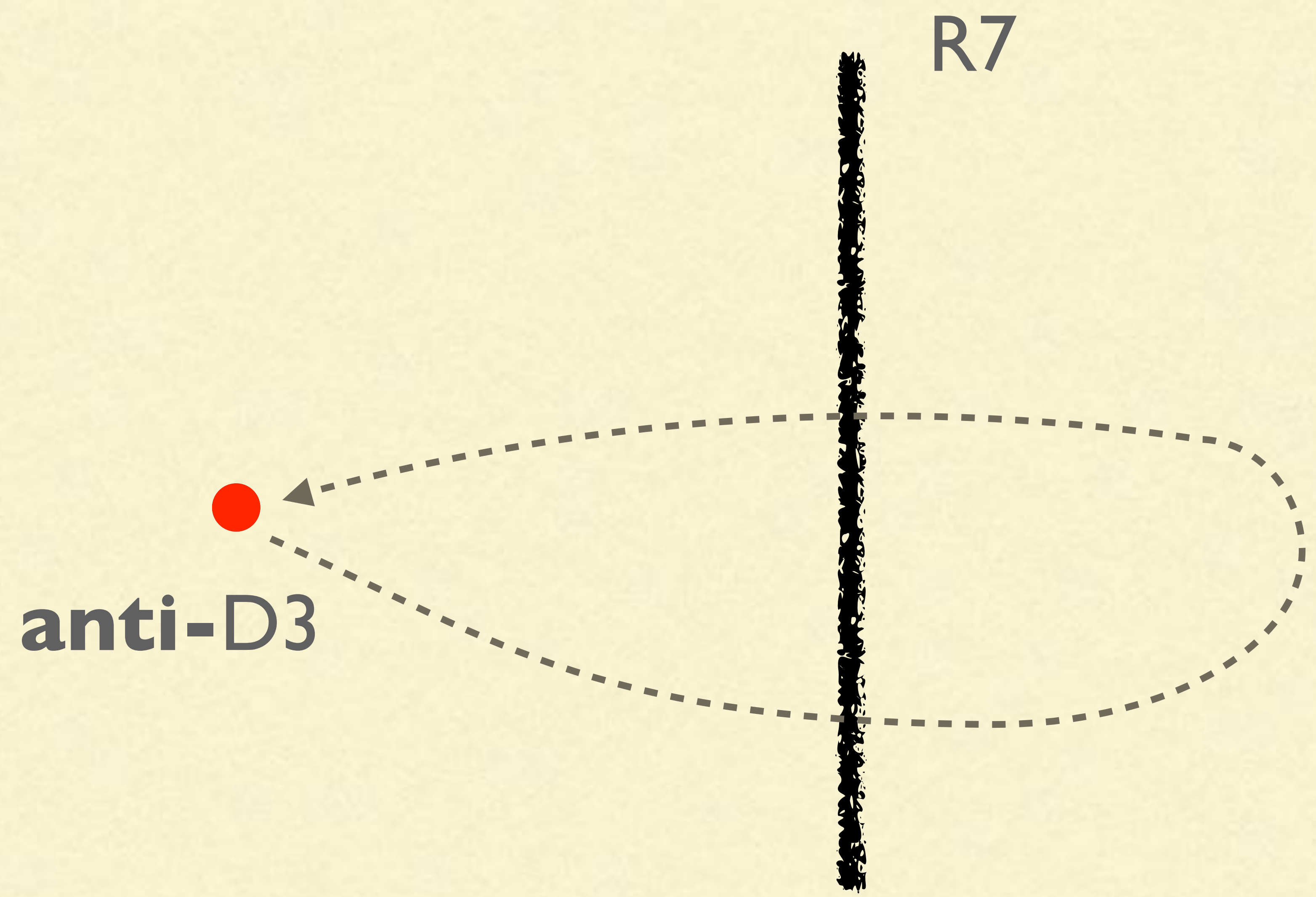
It also acts as an **Alice string** for e.g. D3 branes:



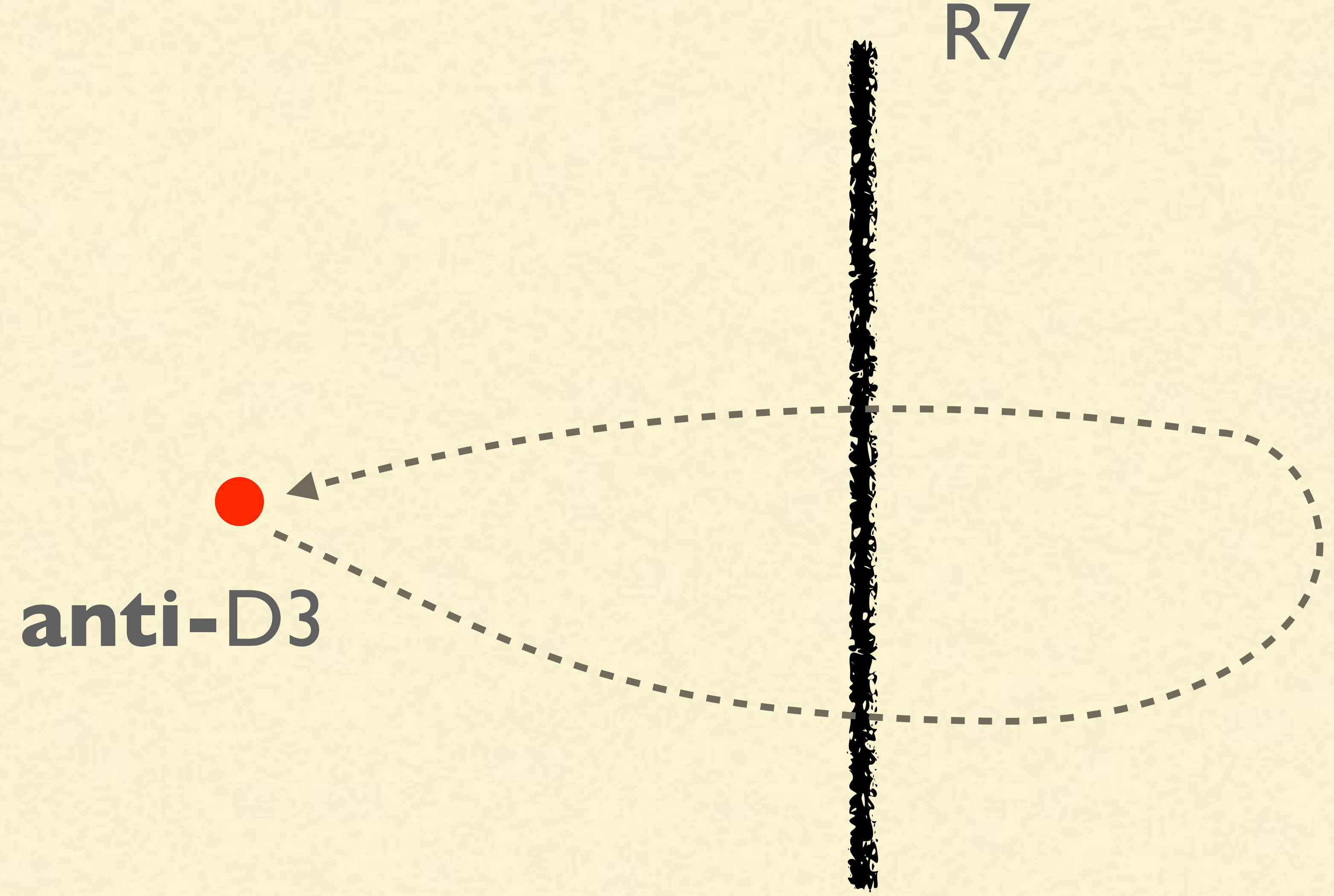
It also acts as an **Alice string** for e.g. D3 branes:



It also acts as an **Alice string** for e.g. D3 branes:



It also acts as an **Alice string** for e.g. D3 branes:

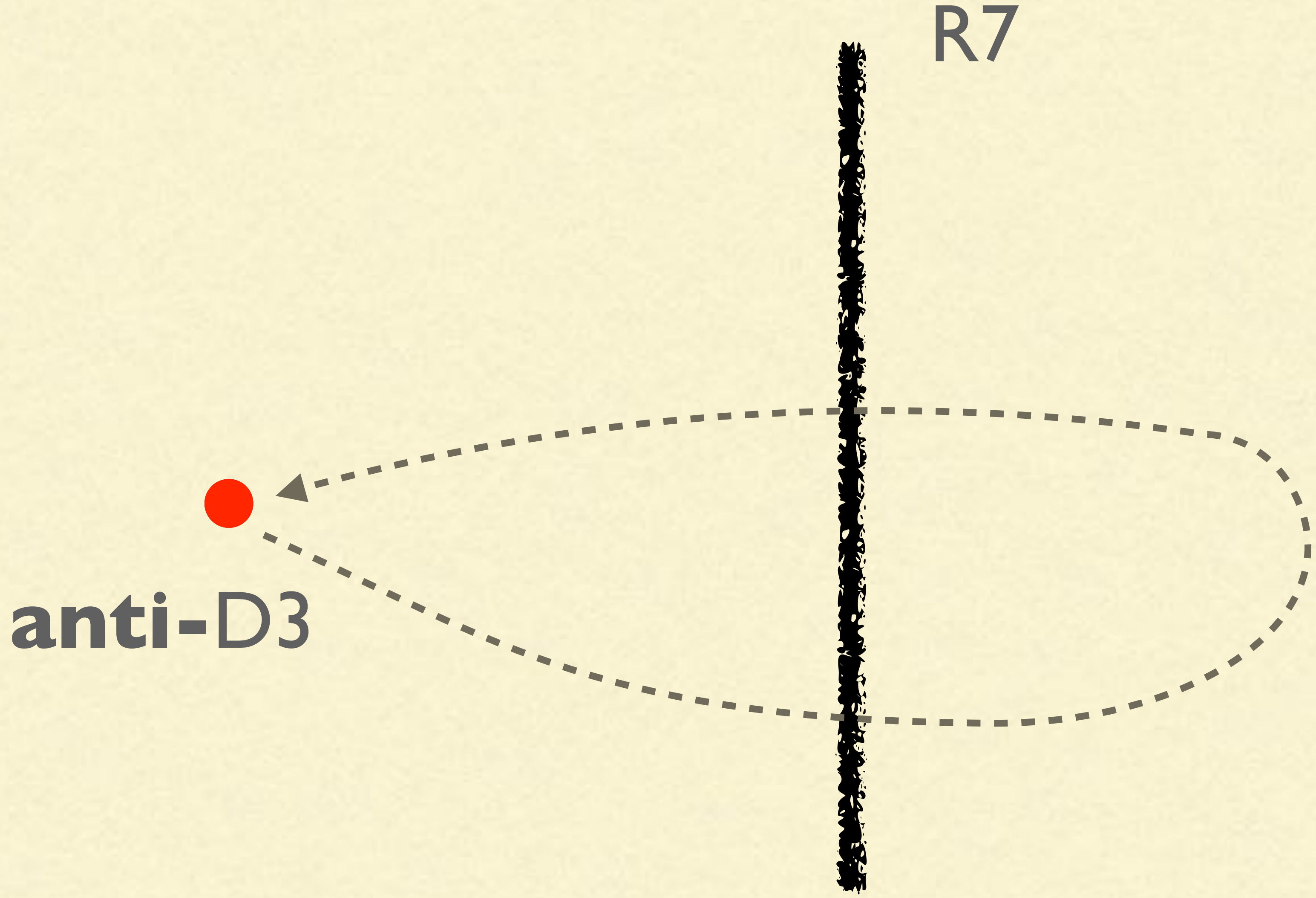


This means that there is a **massless 3-form field** on the R7 that couples to D3-brane charge.

(first example of a worldvolume theory with a massless 3-form)

It also acts as an **Alice string** for e.g. D3 branes:

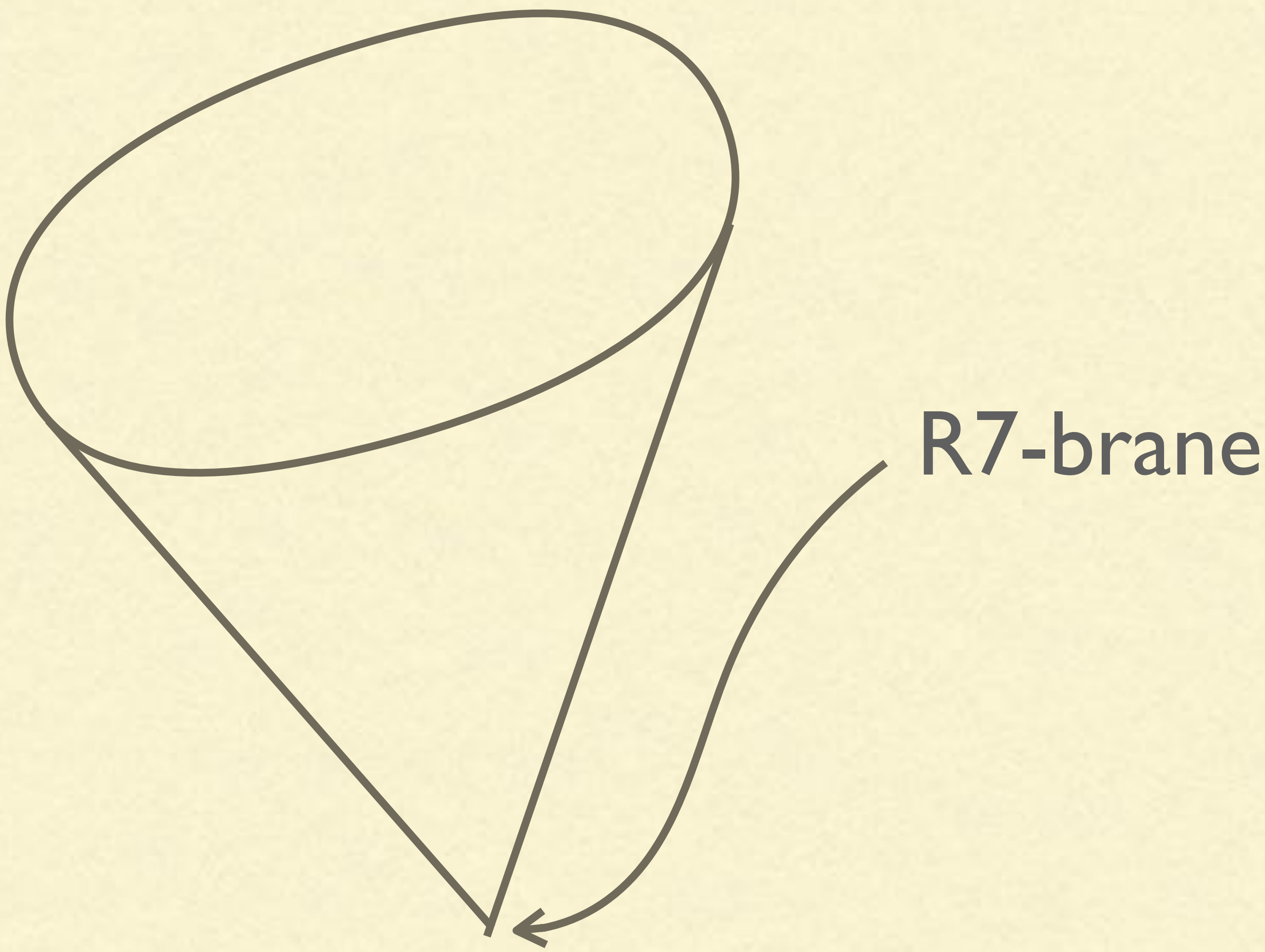
$$\int_{R7} dA_3 \wedge C_4$$



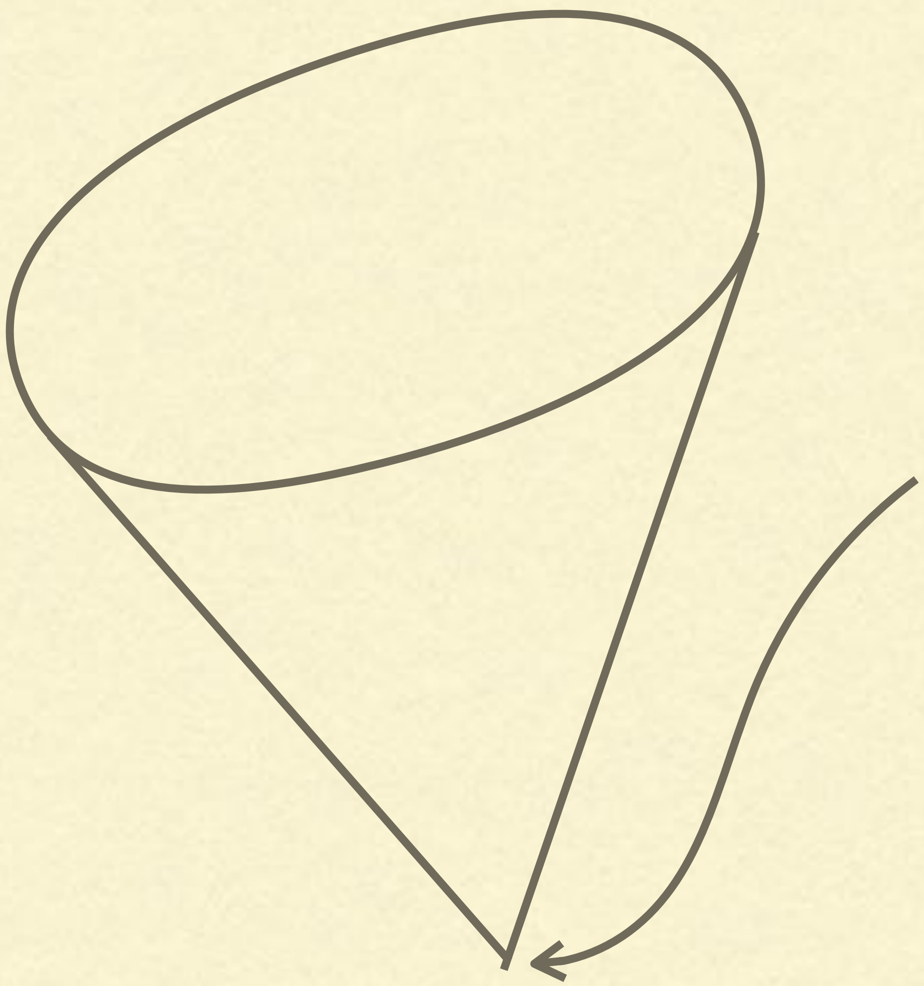
This means that there is a **massless 3-form field** on the R7 that couples to D3-brane charge.

(first example of a worldvolume theory with a massless 3-form)

One **very interesting** thing one can do is consider compactifications of the R7-brane e.g. on singularities



One **very interesting** thing one can do is consider compactifications of the R7-brane e.g. on singularities



R7-brane

Their worldvolume theories are examples of non-susy CFT's.

They kill several cobordism classes in higher degree.

CONCLUSIONS

- **Sometimes mere absence of global symmetries is powerful enough to kill an EFT**
- **Used this to make Swampland predictions in d>6, later verified**
- **Breaking symmetries also leads to new objects, such as a new 7-brane in IIB string theory**
- Currently exploring these ideas in 4d EFT's of interest

Thank you! **¡Gracias!**