COSMOLOGICAL & TOPOLOGICAL

ASPECTS OF

NON-SUPERSYMMETRIC STRINGS

Miguel Montero
IFT Madrid

String Phenomenology 2024

Padova, June 26 2024

CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

COSMOLOGICAL & TOPOLOGICAL

ASPECTS OF

NON-SUPERSYMMETRIC STRINGS

What does this mean?

Miguel Montero

IFT Madrid

String Phenomenology 2024

Padova, June 26 2024

I'm going to tell you about recent work on **bordism groups** on non-susy strings (**2310.06895**) + additional comments

Ivano Basile

Arun Debray

Matilda Delgado

I'm going to tell you about recent work on **bordism groups** on non-susy strings (**2310.06895**) + additional comments

Ivano Basile

Arun Debray

Matilda Delgado

(that's the topology part)

I’m going to tell you about recent work on **bordism groups** on non-susy strings (**2310.06895**) + additional comments

Ivano Basile

Arun Debray

Matilda Delgado

(that’s the topology part)

… as well as some **cosmology-ballpark ideas** both finished & unfinished…

… with a large group of **IFT collaborators**

Bruno Bento

Matilda Delgado

George
Alestas

Yashar
Akrami

Gonzalo
F. Casas

Ignacio
(Nacho) Ruiz

Savvas
Nesseris

… with a large group of **IFT collaborators**

Bruno Bento

(Ongoing) seach for dS

Matilda Delgado

George Alestas

Yashar Akrami

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

… with a large group of **IFT collaborators**

See his parallel talk **yesterday**

Bruno Bento

(Ongoing) seach for dS

Matilda Delgado

George Alestas

Yashar Akrami

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

… with a large group of **IFT collaborators**

See his parallel talk **yesterday**

Bruno Bento

Matilda Delgado

George Alestas

Yashar Akrami

(Ongoing) seach for dS

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

Cosmological Chameleons (2406.07614)

… with a large group of **IFT collaborators**

See his parallel talk **yesterday**

Bruno Bento

Matilda Delgado

George Alestas

Yashar Akrami

(Ongoing) seach for dS

See his parallel talk **yesterday**

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

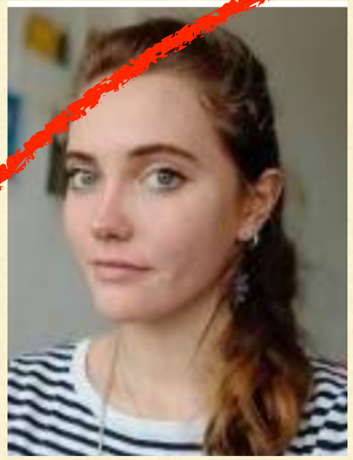
Cosmological Chameleons (2406.07614)

… with a large group of **IFT collaborators**

See his parallel talk yesterday

Bruno Bento

(Ongoing) seach for dS



Matilda Delgado

See his parallel talk yesterday

George Alestas

Yashar Akrami

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

Curvature-assisted acceleration (2406.09212)

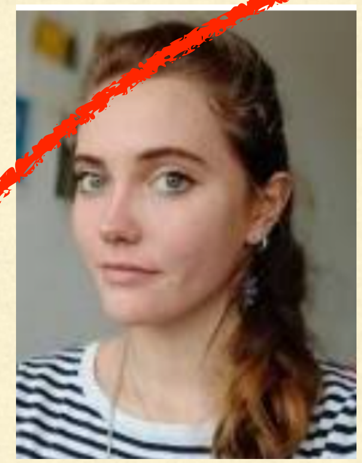
Cosmological Chameleons (2406.07614)

... with a large group of **IFT collaborators**

See his parallel talk **yesterday**

Bruno Bento

(Ongoing) seach for dS



Matilda Delgado

See his parallel talk **yesterday**

George Alestas

See Yashar's parallel talk **tomorrow**

Yashar Akrami

Gonzalo F. Casas

Ignacio (Nacho) Ruiz

Savvas Nesseris

Curvature-assisted acceleration (2406.09212)

Cosmological Chameleons (2406.07614)

If you are hiring this season:
You are **in luck**!

If you are hiring this season:
You are **in luck**!

Applying this fall

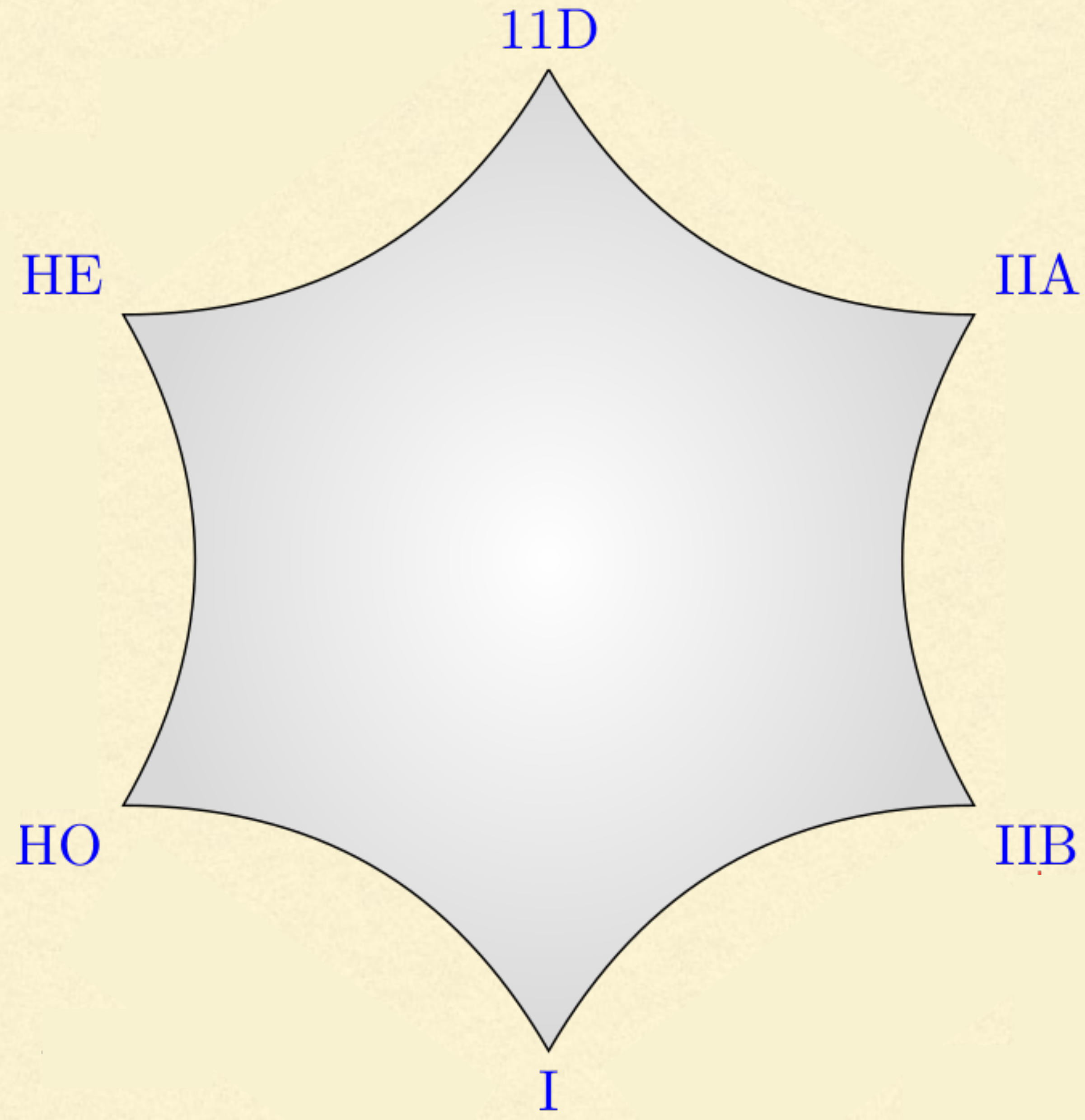
Let's **get going!**

Part I

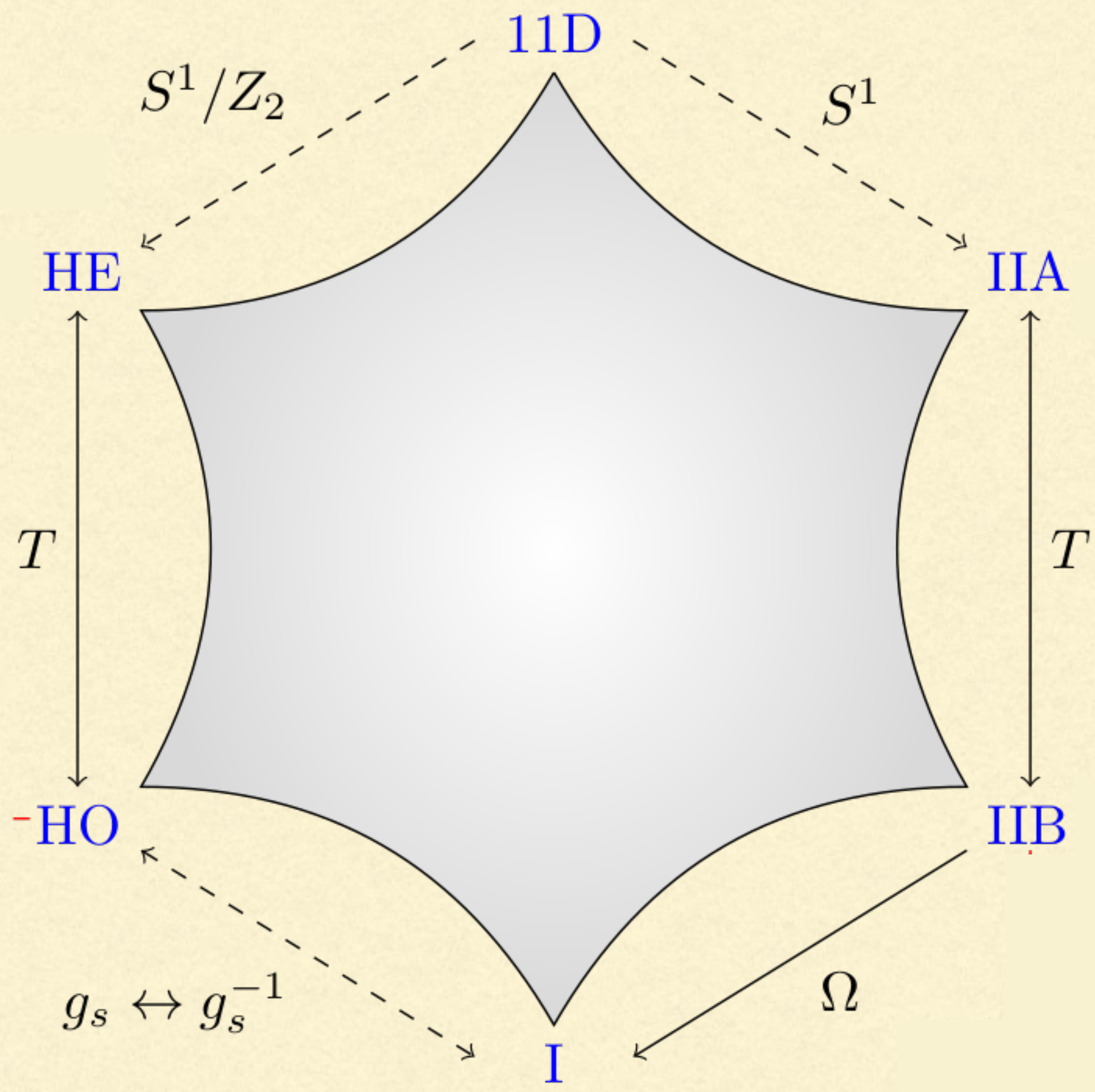
Non-supersymmetric string bordism

(see also A. Sagnotti's talk on Thursday)

We are familar with the usual duality web…

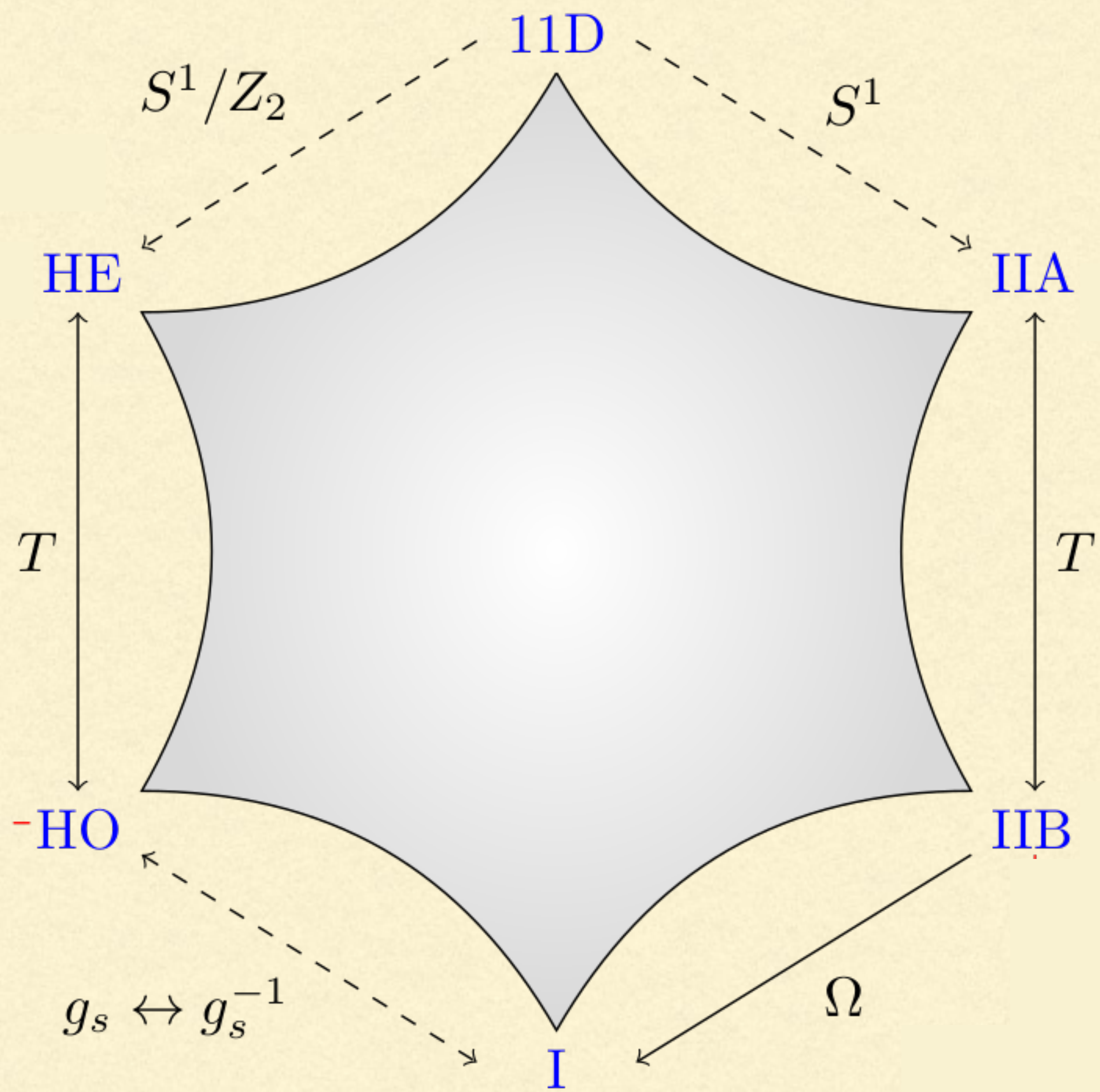


We are familar with the usual duality web…



…as well as the connections between the different SUSY theories.

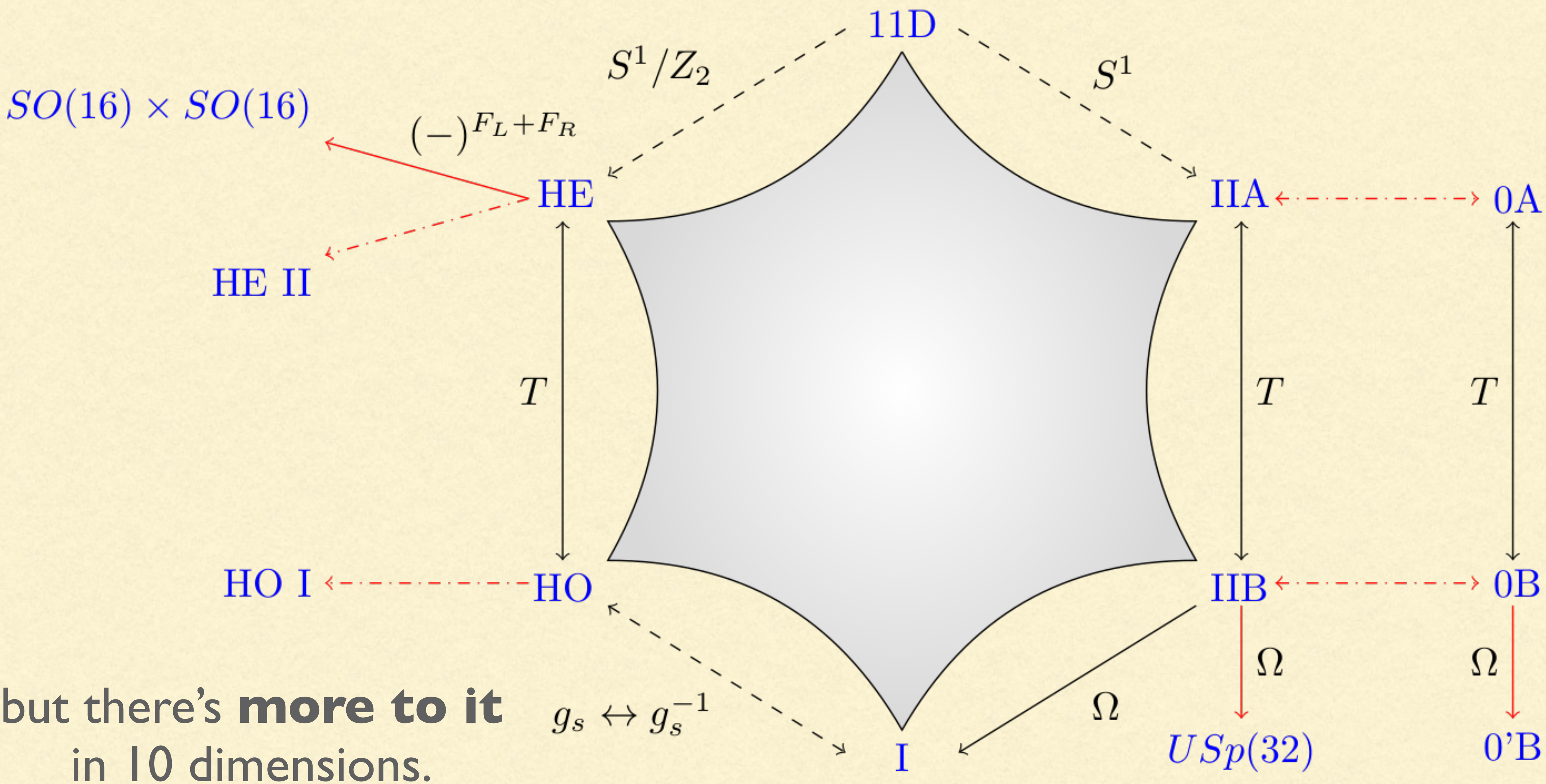
We are familar with the usual duality web…



but there's **more to it** in 10 dimensions.

…as well as the connections between the different SUSY theories.

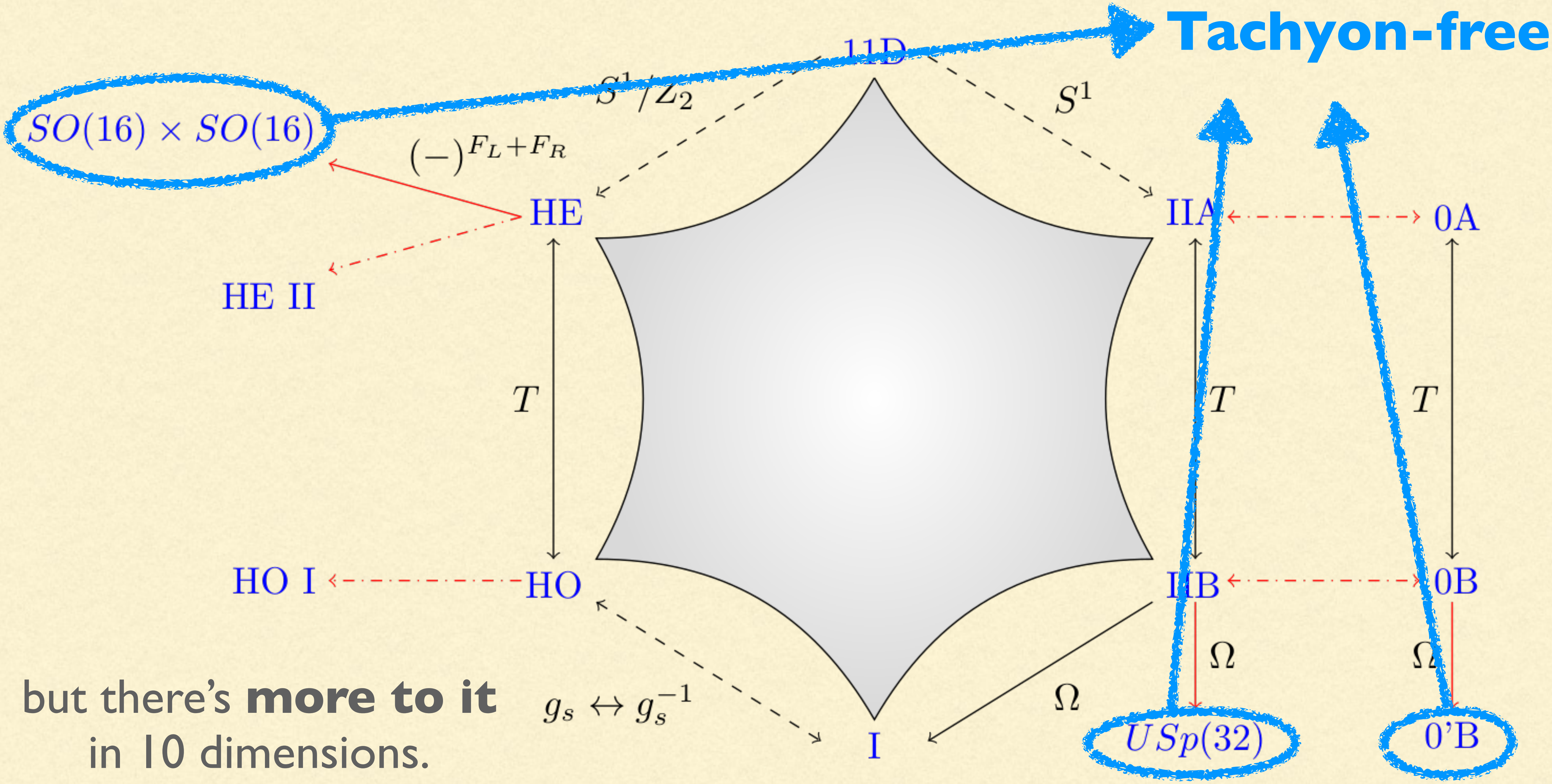
We are familar with the usual duality web…



but there's **more to it** in 10 dimensions.

…as well as the connections between the different SUSY theories.

We are familar with the usual duality web…



but there's **more to it** in 10 dimensions.

…as well as the connections between the different SUSY theories.

The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

that can be used for moduli stabilization,

The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

that can be used for moduli stabilization,

Casimir energies to stabilize geometric moduli, fluxes… as cool as the SUSY guys, if not more!

The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

that can be used for moduli stabilization,

Casimir energies to stabilize geometric moduli, fluxes… as cool as the SUSY guys, if not more!

What we did: computed their **bordism groups**

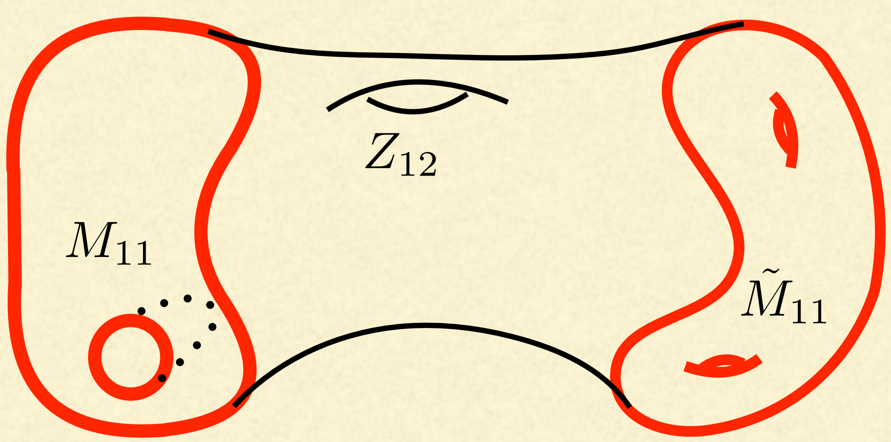
The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

that can be used for moduli stabilization,

Casimir energies to stabilize geometric moduli, fluxes… as cool as the SUSY guys, if not more!

What we did: computed their **bordism groups**



The equivalence relation

$$M_{11} \sim \tilde{M}_{11}$$

if

$$M_{11} \cup \tilde{M}_{11} = \partial Z_{12}$$

for some Z12 is called **bordism**

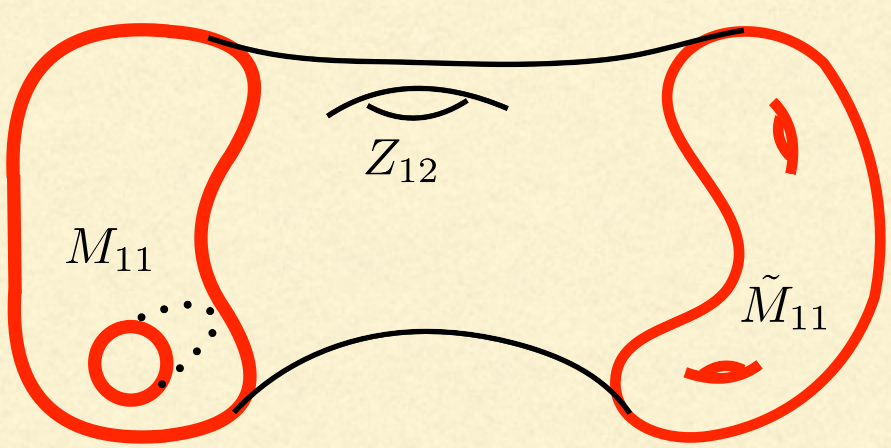
The existence of **tachyon-free** non-supersymmetric string theories opens up new corners for phenomenology.

E.g. there is a classical/quantum **dilaton potential**

that can be used for moduli stabilization,

Casimir energies to stabilize geometric moduli, fluxes… as cool as the SUSY guys, if not more!

What we did: computed their **bordism groups**



The equivalence relation

$$M_{11} \sim \tilde{M}_{11}$$

if

$$M_{11} \cup \tilde{M}_{11} = \partial Z_{12}$$

for some Z12 is called **bordism**

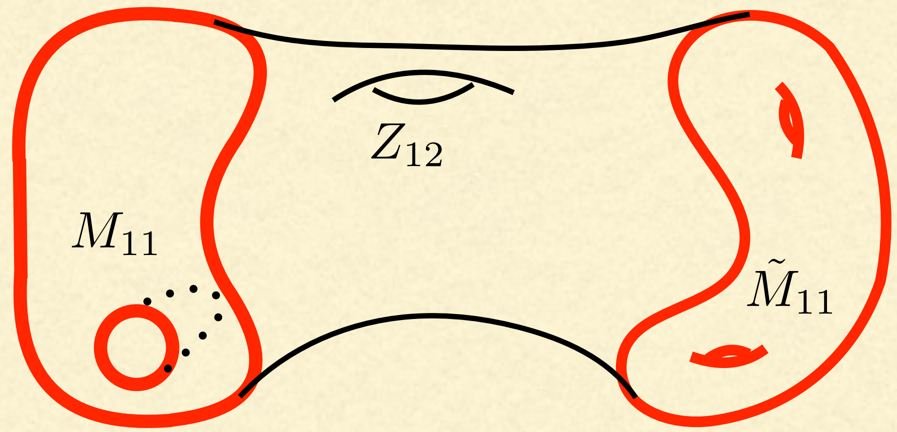
Set of **bordism classes** forms a group

$$\Omega_d^{\text{Theory}}$$

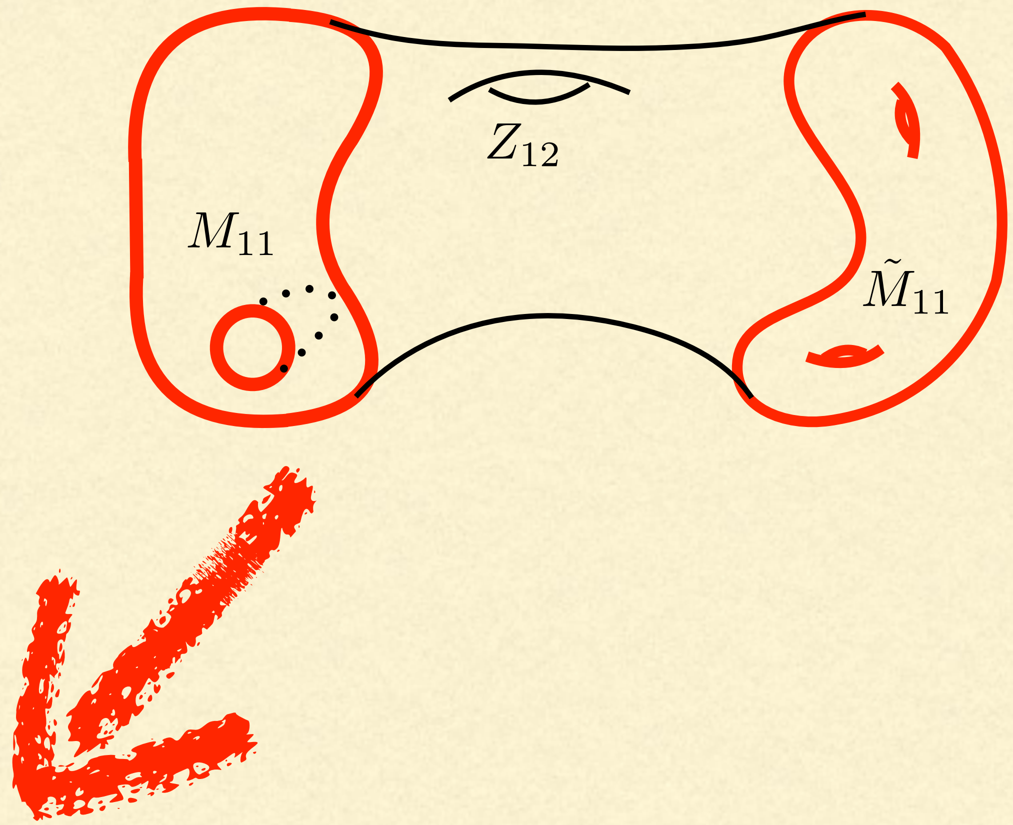
Why?

Why? Two reasons:

Why? Two reasons:



Why? Two reasons:

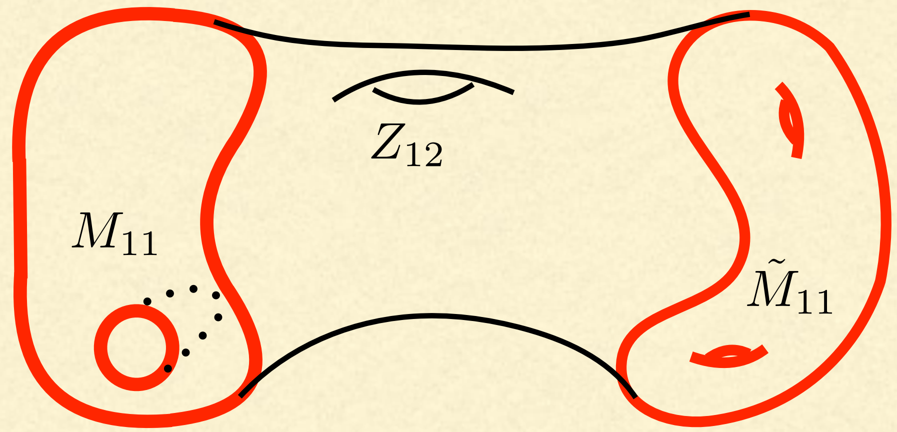


Computation of global anomalies

(was open problem!)

(e.g. type I checked only in '01 by Freed)

Why? Two reasons:



[Angius, Basile, Bedroya, Berglund, Blumenhagen, Buratti, Calderón Infante, Cribiori, Cvetič, De Biasio, Debray, Delgado, Dierigl, Gonzalo, Hamada, Hebecker, Heckman, Herráez, Hertog, Huertas, Hübner, Hübsch, Ibanez, Kaidi, Karch, Kneissl, Lanza, Lin, Lüst, Makridou, Marchesano, Martucci, McNamara, Milutin Minic, Montella, Montero, Mourad, Ohmori, Parra De Freitas, Parra-Martinez, Raucci, Reece, Rudelius, Sagnotti, Sati, Schreiber, Sterckx, Tachikawa, Tatitscheff, Torres, Trivedi, Uranga, Vafa, Valenzuela, Van Riet, Wan, Wang, Yonekura, You, Zhang]

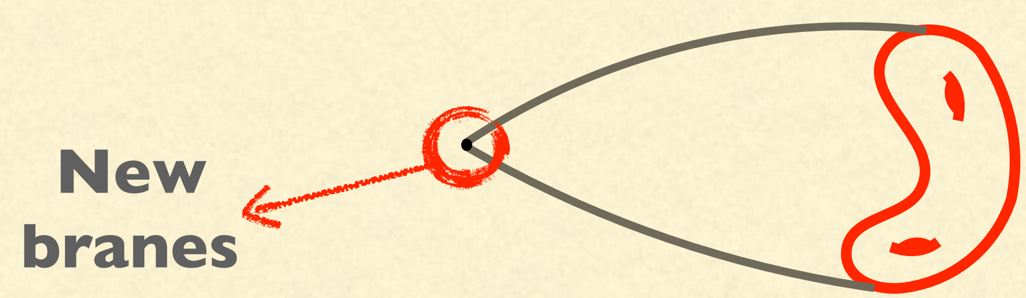
Computation of global anomalies

(was open problem!)

(e.g. type I checked only in '01 by Freed)

Discovery of **new branes** via cobordism conjecture

$\Omega^{\mathrm{QG}} = 0$ [McNamara Vafa '19]



Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D}9$$

$$q_{O9^{+}} + 32 q_{\overline{D}9} = 0$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D}9$$

$$q_{O9^{+}} + 32 q_{\overline{D}9} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D}9$$

$$q_{O9^{+}} + 32 q_{\overline{D}9} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

Sagnotti's 0'B string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D}9$$

$$q_{O9^{+}} + 32 q_{\overline{D}9} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

Sagnotti's 0'B string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0\text{'B}} = X_2\,X_{10} + X_4\,X_8 + X_6\,X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\ dF_3 = X_4,\ dF_5 = X_6$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

Sagnotti's 0'B string

SO(16)xSO(16) heterotic

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0'\mathrm{B}} = X_2\,X_{10} + X_4\,X_8 + X_6\,X_6\,.$$

$$\int C_0 X_{10} \quad \int C_2 X_8 \quad \int C_4 X_6$$

$$dF_1 = X_2,\; dF_3 = X_4,\; dF_5 = X_6$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\, \overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0'\mathrm{B}} = X_2\, X_{10} + X_4\, X_8 + X_6\, X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\ dF_3 = X_4,\ dF_5 = X_6$$

SO(16)xSO(16) heterotic

$$E_8 \times E_8 \xrightarrow{(-1)^F} SO(16)^2$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \overset{(-1)^F}{\rightarrow} 0B \overset{\Omega}{\rightarrow} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0\text{'B}} = X_2\, X_{10} + X_4\, X_8 + X_6\, X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\; dF_3 = X_4,\; dF_5 = X_6$$

SO(16)xSO(16) heterotic

$$E_8 \times E_8 \overset{(-1)^F}{\rightarrow} SO(16)^2$$

Spectrum: g, ϕ, B (it is a heterotic)

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0'\mathrm{B}} = X_2\, X_{10} + X_4\, X_8 + X_6\, X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\; dF_3 = X_4,\; dF_5 = X_6$$

SO(16)xSO(16) heterotic

$$E_8 \times E_8 \xrightarrow{(-1)^F} SO(16)^2$$

Spectrum: g, ϕ, B (it is a heterotic)

SO(16)xSO(16) gauge algebra

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \xrightarrow{(-1)^F} 0B \xrightarrow{\Omega} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0'\mathrm{B}} = X_2\,X_{10} + X_4\,X_8 + X_6\,X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\; dF_3 = X_4,\; dF_5 = X_6$$

SO(16)xSO(16) heterotic

$$E_8 \times E_8 \xrightarrow{(-1)^F} SO(16)^2$$

Spectrum: g, ϕ, B (it is a heterotic)

SO(16)xSO(16) gauge algebra

+ fermions in the

$$(\mathbf{128}, \mathbf{1}) + (\mathbf{1}, \mathbf{128}) - (\mathbf{16}, \mathbf{16})$$

Let us now **meet** the main characters: The 10d, tachyon free, non-SUSY string theories!

Sugimoto string

$$\mathrm{IIB} + O9^{+} + 32\,\overline{D9}$$

$$q_{O9^{+}} + 32 q_{\overline{D9}} = 0$$

Field content: Gravitino, dilatino, g, ϕ, B

USp(32) gauge fields + chiral fermions in the antisymmetric + singlet

Perturbative anomalies cancelled by GS

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

Sagnotti's 0'B string

$$\mathrm{IIB} \overset{(-1)^F}{\rightarrow} 0B \overset{\Omega}{\rightarrow} 0'B$$

Metric, dilaton, U(32) gauge group

Chiral 10d fermions in the $\mathbf{496}$

C_0, C_2, C_4 (self-dual)

GS **triple**

$$P_{12}^{0'\mathrm{B}} = X_2\,X_{10} + X_4\,X_8 + X_6\,X_6\,.$$

$$\int C_0 X_{10} \qquad \int C_2 X_8 \qquad \int C_4 X_6$$

$$dF_1 = X_2,\ dF_3 = X_4,\ dF_5 = X_6$$

SO(16)xSO(16) heterotic

$$E_8 \times E_8 \overset{(-1)^F}{\rightarrow} SO(16)^2$$

Spectrum: g, ϕ, B (it is a heterotic)

SO(16)xSO(16) gauge algebra

+ fermions in the

$$(\mathbf{128}, \mathbf{1}) + (\mathbf{1}, \mathbf{128}) - (\mathbf{16}, \mathbf{16})$$

GS term

$$\int B_2 \wedge X_8 \qquad dH_3 = X_4$$

How does one compute bordism groups?

How does one compute bordism groups?

Very **simple** algorithm.

How does one compute bordism groups?

Very **simple** algorithm.

Spin

$dH_3 = X_4$

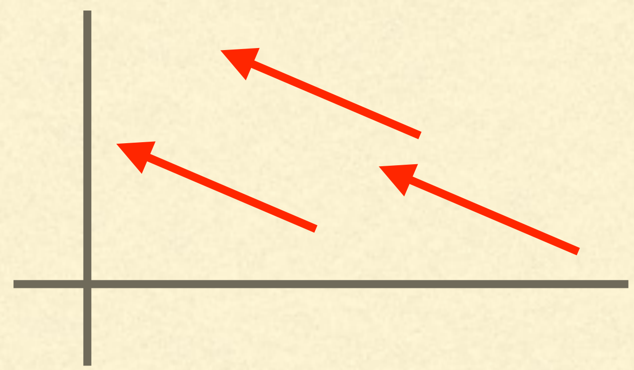
1. Write down structure

How does one compute bordism groups?

Very **simple** algorithm.

Spin

$dH_3 = X_4$



1. Write down structure

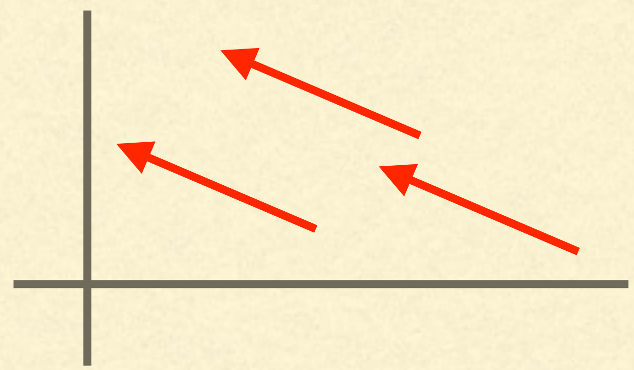
2. Write down the relevant Adams/Atiyah-Hirzebruch **spectral sequence**

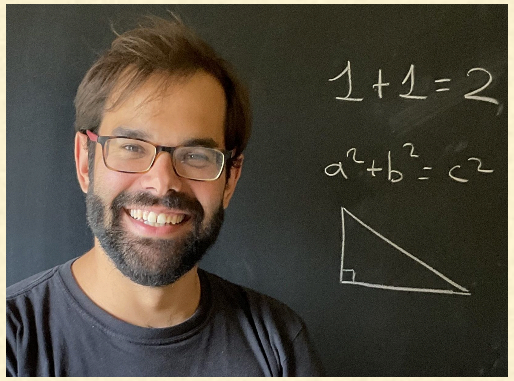
How does one compute bordism groups?

Very **simple** algorithm.

Spin

$dH_3 = X_4$





1. Write down structure

2. Write down the relevant Adams/Atiyah-Hirzebruch **spectral sequence**

3. Remember you don't actually know how to solve the Adams spectral sequence

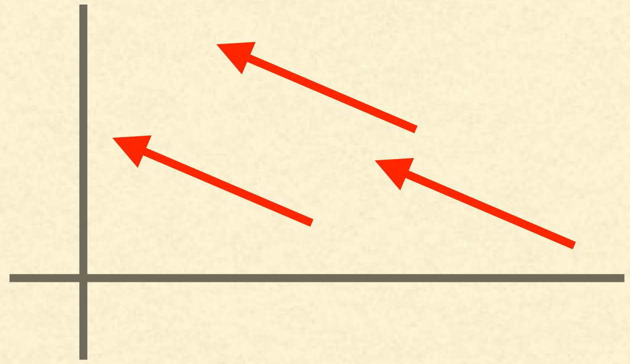
How does one compute bordism groups?

Very **simple** algorithm.

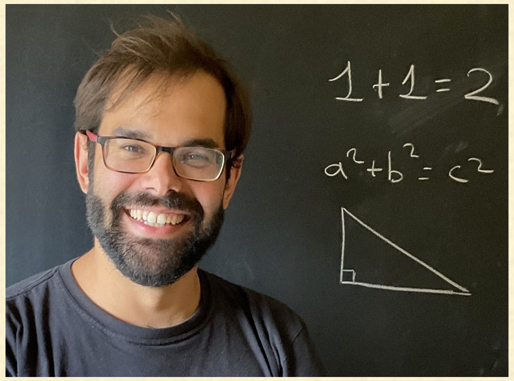
Spin

$dH_3 = X_4$

1. Write down structure



2. Write down the relevant Adams/Atiyah-Hirzebruch **spectral sequence**



3. Remember you don't actually know how to solve the Adams spectral sequence

4. Bring your Adams SS to **Arun, mathemagician extraordinaire**

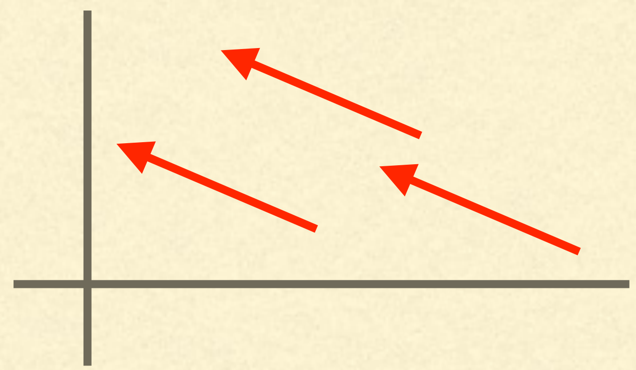
How does one compute bordism groups?

Very **simple** algorithm.

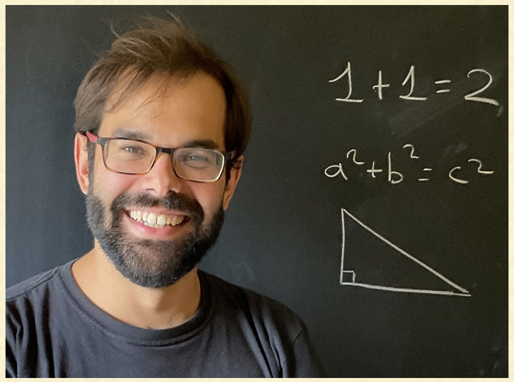
Spin

$dH_3 = X_4$

1. Write down structure



2. Write down the relevant Adams/Atiyah-Hirzebruch **spectral sequence**



3. Remember you don't actually know how to solve the Adams spectral sequence

4. Bring your Adams SS to **Arun, mathemagician extraordinaire**

$$\Omega_d^{\text{Theory}}$$

5. Fresh batch of **new bordism groups**

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Sugimoto and SO(16)
global anomalies vanish!

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Sugimoto and SO(16) global anomalies vanish!

Can't be sure about 0'B, but we have reduced it to a single bordism class

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Sugimoto and SO(16) global anomalies vanish!

Anomalies of SO(16)xSO(16) **including the Swap**

Can't be sure about 0'B, but we have reduced it to a single bordism class

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

It is an abelian group A of order 64 with at most two generators

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

It is an abelian group A of order 64 with at most two generators

We don’t know what A is.

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

It is an abelian group A of order 64 with at most two generators

We don’t know what A is.

But we don't care, because we know what the generators are:

$$\mathbb{RP}^3 \times Spin(7), \quad \frac{S^4 \times S^4 \times S^3}{\mathbb{Z}_2}$$

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

It is an abelian group A of order 64 with at most two generators

We don’t know what A is.

But we don't care, because we know what the generators are:

$$\mathbb{RP}^3 \times Spin(7), \quad \frac{S^4 \times S^4 \times S^3}{\mathbb{Z}_2}$$

and we could evaluate the anomaly theory explictly, showing that it vanishes.

For anomalies including the swap of the two SO(16) factors, we showed the bordism group in fact is **nonzero.**

It is an abelian group A of order 64 with at most two generators

We don't know what A is.

But we don't care, because we know what the generators are:

$$\mathbb{RP}^3 \times Spin(7), \qquad \frac{S^4 \times S^4 \times S^3}{\mathbb{Z}_2}$$

and we could evaluate the anomaly theory explictly, showing that it vanishes.

So the SO(16)xSO(16) is also anomaly-free when the swap is included in the gauge group.

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$``E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Imagine taking 1 copy of SO(32) heterotic, and restricting to an SO(16)^2 subgroup:

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$``E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Imagine taking 1 copy of SO(32) heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino, $\mathbf{496} \rightarrow (\mathbf{120}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{16}, \mathbf{16})$

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Imagine taking 1 copy of SO(32) heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino, $\mathbf{496} \rightarrow (\mathbf{120}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{16}, \mathbf{16})$

Then take 1 copy of E8xE8 heterotic, and restricting to an SO(16)^2 subgroup:

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$``E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Imagine taking 1 copy of SO(32) heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino, $\mathbf{496} \to (\mathbf{120}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{16}, \mathbf{16})$

Then take 1 copy of E8xE8 heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino,

$$(\mathbf{248}, \mathbf{1}) + (\mathbf{1}, \mathbf{248}) \to (\mathbf{120}, \mathbf{1}) + (\mathbf{128}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{1}, \mathbf{128})$$

Actually, here is **another way** to show, much more quickly, that global anomalies vanish in the SO(16)xSO(16) example:

[Schelleckens-Warner '87]

$$\text{``}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

Imagine taking 1 copy of SO(32) heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino, $\mathbf{496} \to (\mathbf{120}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{16}, \mathbf{16})$

Then take 1 copy of E8xE8 heterotic, and restricting to an SO(16)^2 subgroup:

Gravitino, dilatino,

$$(\mathbf{248}, \mathbf{1}) + (\mathbf{1}, \mathbf{248}) \to (\mathbf{120}, \mathbf{1}) + (\mathbf{128}, \mathbf{1}) + (\mathbf{1}, \mathbf{120}) + (\mathbf{1}, \mathbf{128})$$

Then **stack them** with opposite chirality!

Gravitino, dilatino, $(\mathbf{120},\mathbf{1})+(\mathbf{1},\mathbf{120})+(\mathbf{16},\mathbf{16})$

-(Gravitino, dilatino,

$\rightarrow(\mathbf{120},\mathbf{1})+(\mathbf{128},\mathbf{1})+(\mathbf{1},\mathbf{120})+(\mathbf{1},\mathbf{128})$)

~~Gravitino, dilatino,~~ $(\mathbf{120},\mathbf{1})+(\mathbf{1},\mathbf{120})+(\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$\rightarrow(\mathbf{120},\mathbf{1})+(\mathbf{128},\mathbf{1})+(\mathbf{1},\mathbf{120})+(\mathbf{1},\mathbf{128})$)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + (\mathbf{1},\mathbf{120}) + (\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + (\mathbf{128},\mathbf{1}) + (\mathbf{1},\mathbf{120}) + (\mathbf{1},\mathbf{128})$)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + (\mathbf{128},\mathbf{1}) + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{1},\mathbf{128})$$)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + (\mathbf{128},\mathbf{1}) + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{1},\mathbf{128})$)

We get the **spectrum** of the SO(16)xSO(16) string!

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})}+\cancel{(\mathbf{1},\mathbf{120})}+(\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$\to \cancel{(\mathbf{120},\mathbf{1})}+(\mathbf{128},\mathbf{1})+\cancel{(\mathbf{1},\mathbf{120})}+(\mathbf{1},\mathbf{128})$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$\text{``}E_8\times E_8 - SO(32) = SO(16)\times SO(16)''$$

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{16},\mathbf{16})}$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + \underline{(\mathbf{128},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{1},\mathbf{128})}$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$“E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

No global anomalies (Witten)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{16},\mathbf{16})}$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + \underline{(\mathbf{128},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{1},\mathbf{128})}$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)''$$

No global anomalies (Witten)

No global anomalies (Freed)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{16},\mathbf{16})$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + (\mathbf{128},\mathbf{1}) + \cancel{(\mathbf{1},\mathbf{120})} + (\mathbf{1},\mathbf{128})$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)\text{”}$$

No global anomalies (Witten) + No global anomalies (Freed)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{16},\mathbf{16})}$

-(~~Gravitino, dilatino,~~

$\rightarrow \cancel{(\mathbf{120},\mathbf{1})} + \underline{(\mathbf{128},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{1},\mathbf{128})}$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)\text{''}$$

No global anomalies (Witten) + No global anomalies (Freed) = No global anomalies in SO(16) x SO(16)

~~Gravitino, dilatino,~~ $\cancel{(\mathbf{120},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{16},\mathbf{16})}$

-(~~Gravitino, dilatino,~~

$\to \cancel{(\mathbf{120},\mathbf{1})} + \underline{(\mathbf{128},\mathbf{1})} + \cancel{(\mathbf{1},\mathbf{120})} + \underline{(\mathbf{1},\mathbf{128})}$)

We get the **spectrum** of the SO(16)xSO(16) string!

Thus, we can say that, formally,

$$\text{“}E_8 \times E_8 - SO(32) = SO(16) \times SO(16)\text{”}$$

No global anomalies (Witten) + No global anomalies (Freed) = No global anomalies in SO(16) x SO(16)

Physical interpretation?

k	$\Omega_k^{\mathrm{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\mathrm{String}-Sp(16)}$	$\Omega_k^{\mathrm{String}\text{-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Each nonvanishing entry with degree up to 9 predicts new **non-supersymmetric** branes, via the cobordism conjecture

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Swap of the two SO(16)'s

Each nonvanishing entry with degree up to 9 predicts new **non-supersymmetric** branes, via the cobordism conjecture

k	$\Omega_k^{\text{String}-Spin(16)^2}$	$\Omega_k^{\mathbb{G}_{16,16}}$	$\Omega_k^{\text{String}-Sp(16)}$	$\Omega_k^{\text{String-}SU(32)\langle c_3\rangle}$
0	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$	$\mathbb{Z}$
1	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
2	$\mathbb{Z}_2$	$\mathbb{Z}_2^2$	$\mathbb{Z}_2$	$\mathbb{Z}_2$
3	0	$\mathbb{Z}_8$	0	0
4	$\mathbb{Z}^2$	$\mathbb{Z} \oplus \mathbb{Z}_2$	$\mathbb{Z}$	$\mathbb{Z}$
5	0	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$
6	0	$\mathbb{Z}_2$	$\mathbb{Z}_2$	0 or $\mathbb{Z}_2$
7	0	$\mathbb{Z}_{16}$	$\mathbb{Z}_4$	$\mathbb{Z}_2$ or $\mathbb{Z}_4 \oplus \mathbb{Z}_2$
8	$\mathbb{Z}^6$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2^i$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$	$\mathbb{Z}^3 \oplus \mathbb{Z}_2$ or $\mathbb{Z}^3 \oplus \mathbb{Z}_2^2$
9	$\mathbb{Z}_2^5$	$\mathbb{Z}_2^j$	$\mathbb{Z}_2^3$	$\mathbb{Z}_2^3$
10	$\mathbb{Z}_2^7$	$\mathbb{Z}_2^k$	$\mathbb{Z}_2^3$	$\mathbb{Z} \oplus \mathbb{Z}_2^2$ or $\mathbb{Z} \oplus \mathbb{Z}_2^3$
11	0	A	0	0 or $\mathbb{Z}_2$

Swap of the two SO(16)'s

Nontrivial Sp(16) bundle on 5-sphere

Each nonvanishing entry with degree up to 9 predicts new **non-supersymmetric** branes, via the cobordism conjecture

We explored in some detail the simplest example.

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

Consider small instanton limit of SO(16)xSO(16)

(would be a nonsusy NS5-brane)

[Blaszczyka, Groot Nibbelink, Loukas, Ruehl ’16]

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

Consider small instanton limit of SO(16)xSO(16)
(would be a nonsusy NS5-brane)

[Blaszczyka, Groot Nibbelink, Loukas, Ruehl '16]

Its anomaly polynomial is (almost) the X8 in the GS term

$$X_8 = P_8 + X_4 Y_4$$

$$\int B_2 \wedge X_8$$

$$dH_3 = X_4$$

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

Consider small instanton limit of SO(16)xSO(16)
(would be a nonsusy NS5-brane)

[Blaszczyka, Groot Nibbelink, Loukas, Ruehl '16]

Its anomaly polynomial is (almost) the X8 in the GS term

$$X_8 = P_8 + X_4 Y_4$$

$$\int B_2 \wedge X_8$$

We showed such a splitting,

$$dH_3 = X_4$$

$$(X_8)_{SO(16)^2} = -\frac{1}{32}(c^{(1)}_{\mathbf{16},2} - c^{(2)}_{\mathbf{16},2})^2 - \mathcal{I}_{\rm SD} - 4\,\mathcal{I}_{\rm Dirac}$$
$$- \frac{1}{48}(X_4)_{SO(16)^2}(c^{(1)}_{\mathbf{16},2} + c^{(2)}_{\mathbf{16},2} + 3p_1) + \mathcal{I}^{\mathbf{16}_{(1)}}_{\rm Dirac} + \mathcal{I}^{\mathbf{16}_{(2)}}_{\rm Dirac}$$

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

Consider small instanton limit of SO(16)xSO(16)
(would be a nonsusy NS5-brane)

[Blaszczyka, Groot Nibbelink, Loukas, Ruehl '16]

Its anomaly polynomial is (almost) the X8 in the GS term

$$X_8 = P_8 + X_4 Y_4$$

$$\int B_2 \wedge X_8$$

We showed such a splitting,

$$dH_3 = X_4$$

$$(X_8)_{SO(16)^2} = -\frac{1}{32}(c^{(1)}_{\mathbf{16},2} - c^{(2)}_{\mathbf{16},2})^2 - \mathcal{I}_{\text{SD}} - 4\,\mathcal{I}_{\text{Dirac}} - \frac{1}{48}(X_4)_{SO(16)^2}(c^{(1)}_{\mathbf{16},2} + c^{(2)}_{\mathbf{16},2} + 3p_1) + \mathcal{I}^{\mathbf{16}_{(1)}}_{\text{Dirac}} + \mathcal{I}^{\mathbf{16}_{(2)}}_{\text{Dirac}}$$

which suggest that, if the small instanton limit exists,
there are self-dual tensors

We explored in some detail the simplest example.

These objects must have localized degrees of freedom.

Can lead to **interesting dynamics**

Consider small instanton limit of SO(16)xSO(16)
(would be a nonsusy NS5-brane)

[Blaszczyka, Groot Nibbelink, Loukas, Ruehl '16]

Its anomaly polynomial is (almost) the X8 in the GS term

$$X_8 = P_8 + X_4 Y_4 \qquad \int B_2 \wedge X_8$$

We showed such a splitting, $\quad dH_3 = X_4$

$$(X_8)_{SO(16)^2} = -\frac{1}{32}(c^{(1)}_{\mathbf{16},2} - c^{(2)}_{\mathbf{16},2})^2 - \mathcal{I}_{\text{SD}} - 4\mathcal{I}_{\text{Dirac}}$$
$$- \frac{1}{48}(X_4)_{SO(16)^2}(c^{(1)}_{\mathbf{16},2} + c^{(2)}_{\mathbf{16},2} + 3p_1) + \mathcal{I}^{\mathbf{16}_{(1)}}_{\text{Dirac}} + \mathcal{I}^{\mathbf{16}_{(2)}}_{\text{Dirac}}$$

which suggest that, if the small instanton limit exists,
there are self-dual tensors

However, it may "fatten out" to a gauge instanton

This is because the NS5 brane is trivial in string bordism.
More generally, all the examples I highlighted before

have the property that they have interesting **anomaly inflow** properties

This is because the NS5 brane is trivial in string bordism.
More generally, all the examples I highlighted before

have the property that they have interesting **anomaly inflow** properties

that cannot possibly be realized by free theories

Cobordism defect

This is because the NS5 brane is trivial in string bordism.
More generally, all the examples I highlighted before

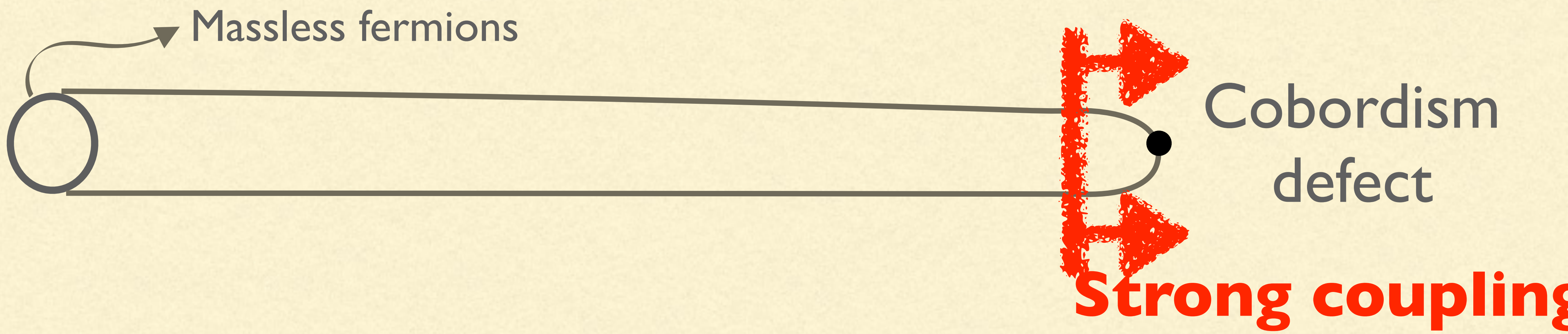
have the property that they have interesting **anomaly inflow** properties

that cannot possibly be realized by free theories

This is because the NS5 brane is trivial in string bordism. More generally, all the examples I highlighted before

have the property that they have interesting **anomaly inflow** properties

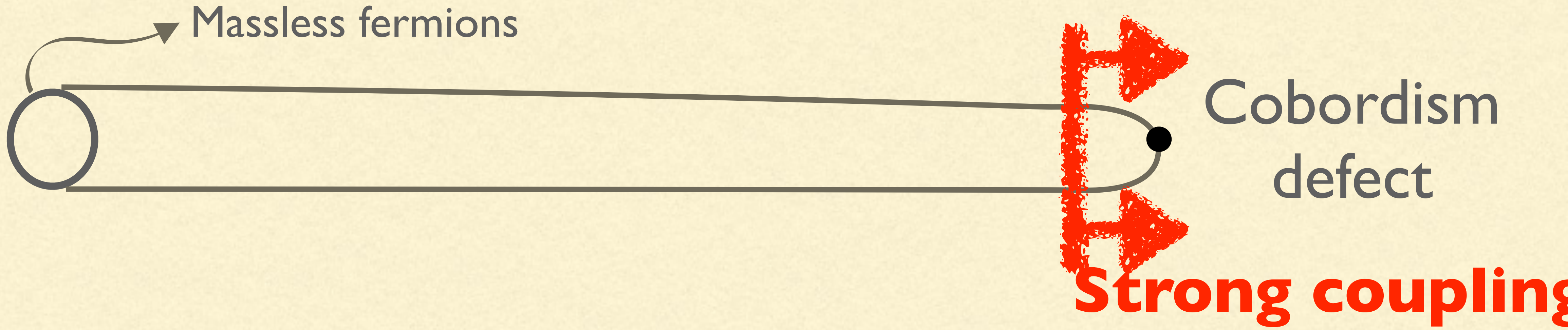
that cannot possibly be realized by free theories



This is because the NS5 brane is trivial in string bordism.
More generally, all the examples I highlighted before

have the property that they have interesting **anomaly inflow** properties

that cannot possibly be realized by free theories



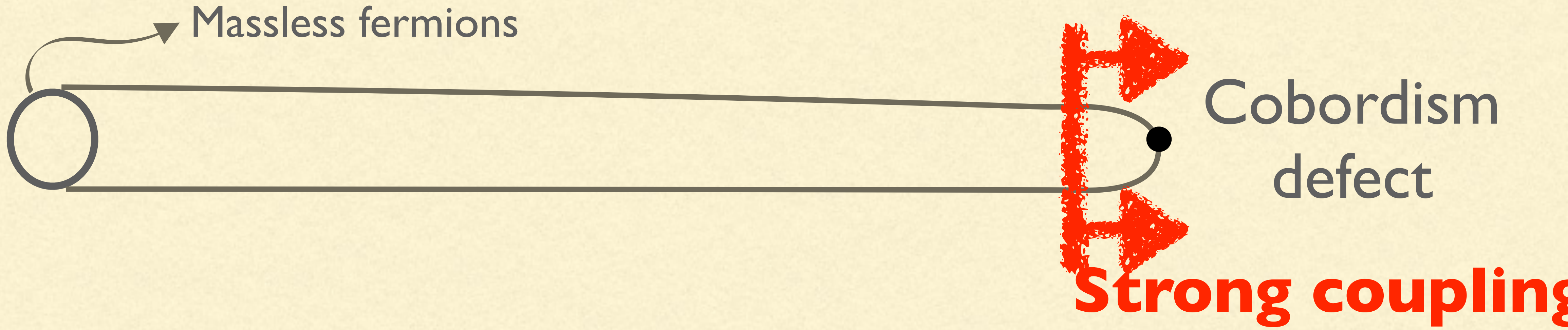
These are **stringy, interacting branes**

(like R7 brane [Dierigl-MM-Torres '22], or SUSY het. branes of Kaidi-Tachikawa-Yonekura [Dierigl-MM-Torres '23])

This is because the NS5 brane is trivial in string bordism. More generally, all the examples I highlighted before

have the property that they have interesting **anomaly inflow** properties

that cannot possibly be realized by free theories



These are **stringy, interacting branes**

(like R7 brane [Dierigl-MM-Torres '22], or SUSY het. branes of Kaidi-Tachikawa-Yonekura [Dierigl-MM-Torres '23])

If we can show they have to be **IR interacting**, we would have a first example of interacting **CFT in d>6**

Now we get to the (shorter)

Part II

Casimir de Sitter & Cosmological Chameleons

(recap of parallels by Bruno Bento & Nacho Ruiz, yesteday)

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein '21

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein ‘21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein ‘21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

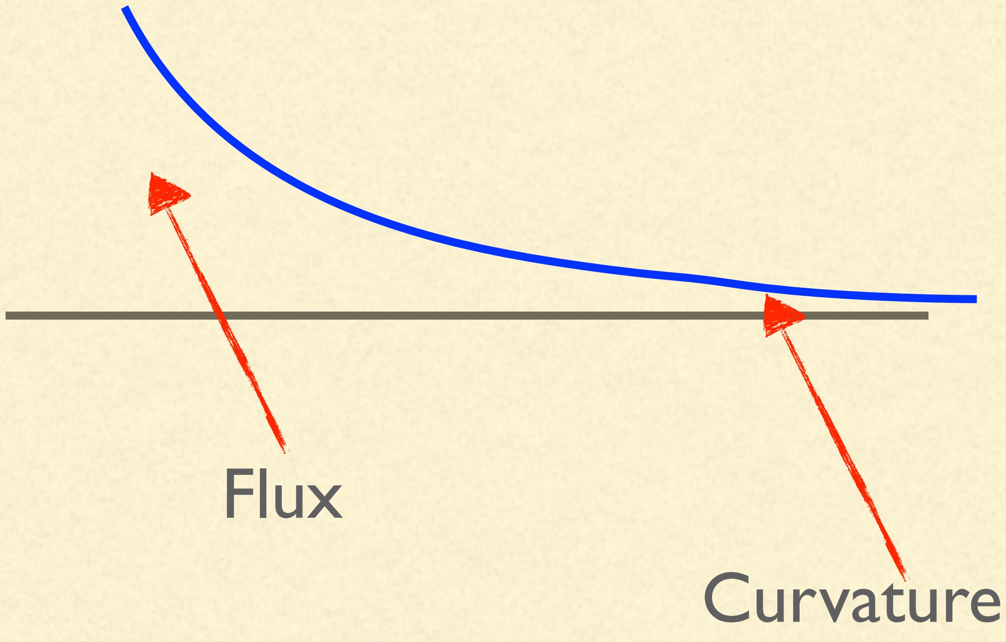
Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein '21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Hyperbolic

Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux



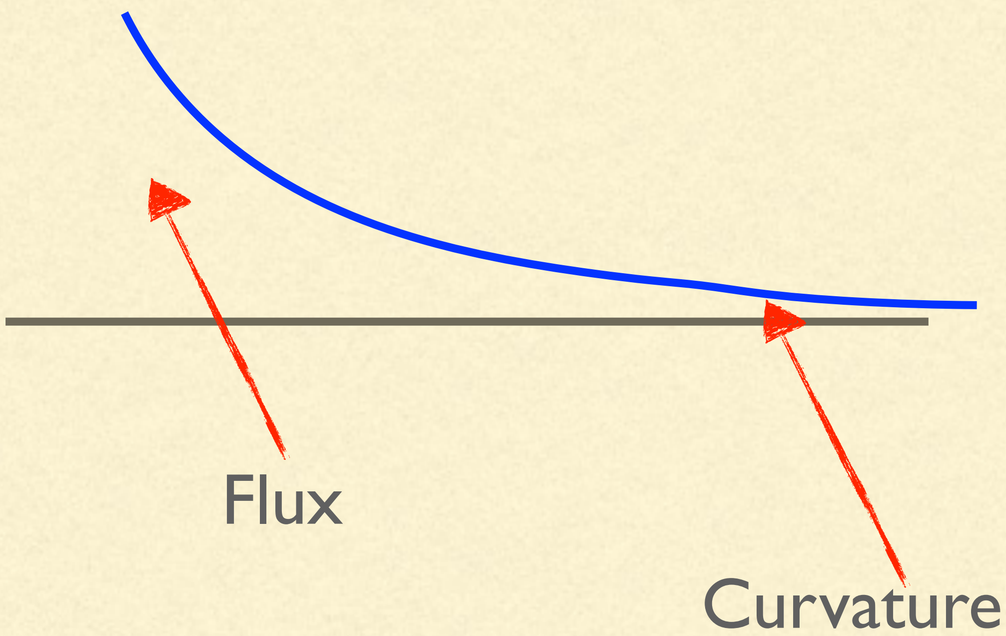
$$V = \frac{|G_7|^2}{R^{14}} \qquad + \frac{\kappa}{R^2}$$

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein ‘21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Hyperbolic

Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux



$$V = \frac{|G_7|^2}{R^{14}} \qquad + \frac{\kappa}{R^2}$$

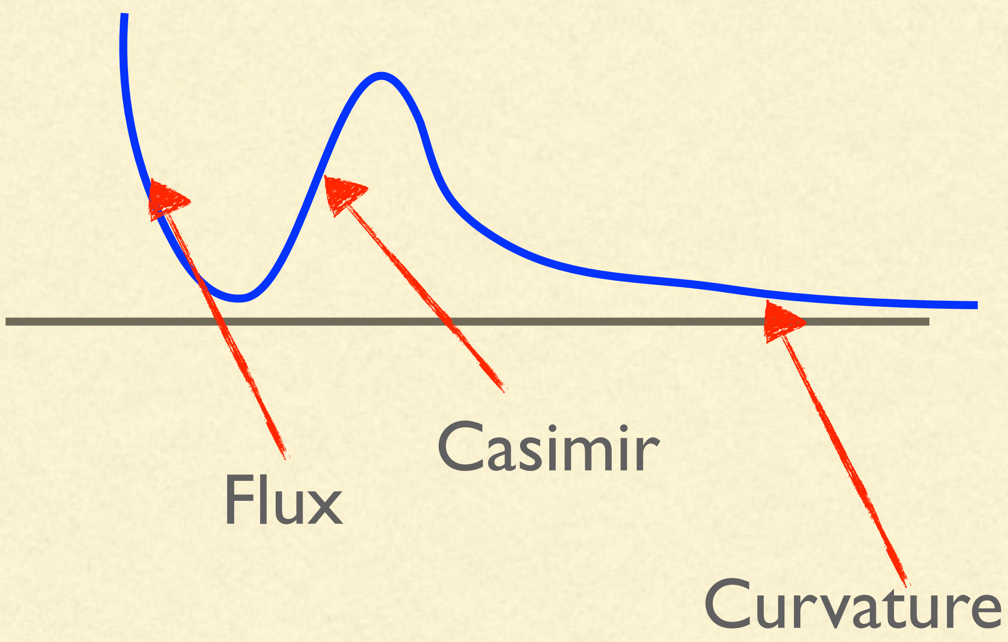
since all **SUSY** broken, there is a Casimir energy

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein '21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Hyperbolic

Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux



$$V = \frac{|G_7|^2}{R^{14}} \qquad\qquad + \frac{\kappa}{R^2}$$

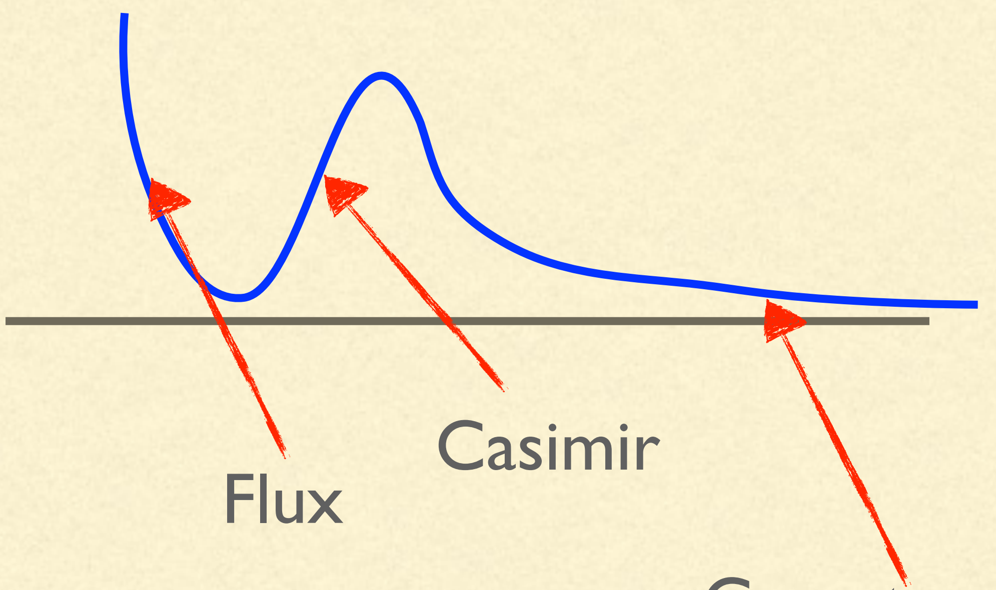
since all **SUSY** broken, there is a Casimir energy

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein '21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Hyperbolic

Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux



$$V = \frac{|G_7|^2}{R^{14}} \qquad + \frac{\kappa}{R^2}$$

since all **SUSY** broken, there is a Casimir energy

& there can be a minimum

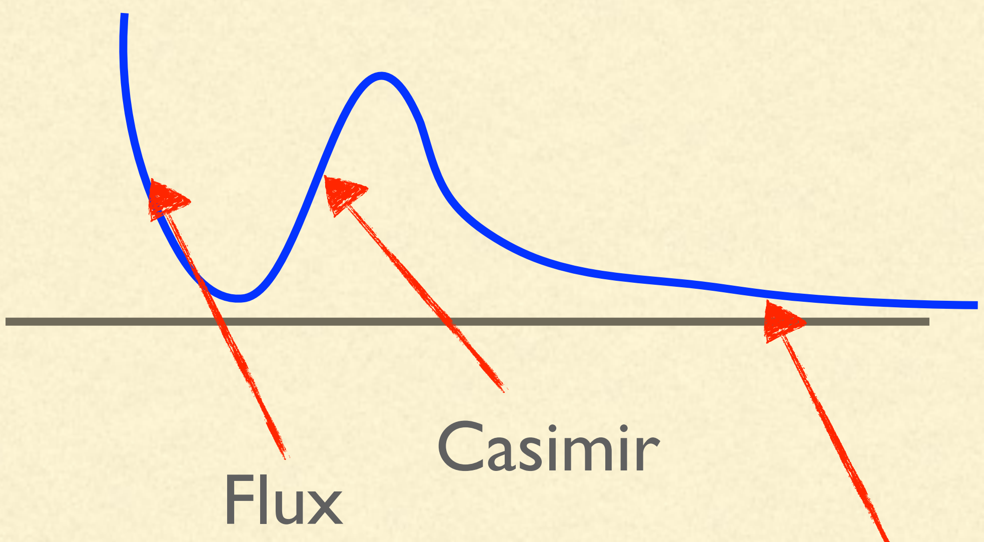
No moduli other than R!

Casimir de Sitter: Original idea in De Luca, Torroba, Silverstein '21

Use **calculable, 1-loop supergravity quantum effects** to evade Maldacena-Nuñez & find a de Sitter solution

Hyperbolic

Setup: M-theory on $AdS_4 \times \mathcal{H}_7$ with G7 flux



$$V = \frac{|G_7|^2}{R^{14}} \qquad + \frac{\kappa}{R^2}$$

since all **SUSY** broken, there is a Casimir energy

& there can be a minimum

No moduli other than R!

But no fully explicit example: Equations complicated

We are exploring this idea in the context of **Riemann-flat** manifolds

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are performing a **systematic search** for minima

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are performing a **systematic search** for minima

In many cases, we have no-go due to “conspiracies”

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are performing a **systematic search** for minima

In many cases, we have no-go due to “conspiracies”

(e.g. some duality freezes modulus, but also kills useful flux)

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are performing a **systematic search** for minima

In many cases, we have no-go due to "conspiracies"

(e.g. some duality freezes modulus, but also kills useful flux)

Large, but finite, nonsusy mini-Landscape

We are exploring this idea in the context of **Riemann-flat** manifolds

$$\frac{T^n}{\Gamma}$$

Acts freely (+ duality bundle)

Instead of curvature, we have **two fluxes**

All moduli can be frozen by Gamma, except **two**

Casimir energy can be computed **explicitly**

We are performing a **systematic search** for minima

In many cases, we have no-go due to "conspiracies"

(e.g. some duality freezes modulus, but also kills useful flux)

Large, but finite, nonsusy mini-Landscape

Work in Progress:

STAY TUNED


Finally: Brief mention of

Cosmological Chameleons

Finally: Brief mention of

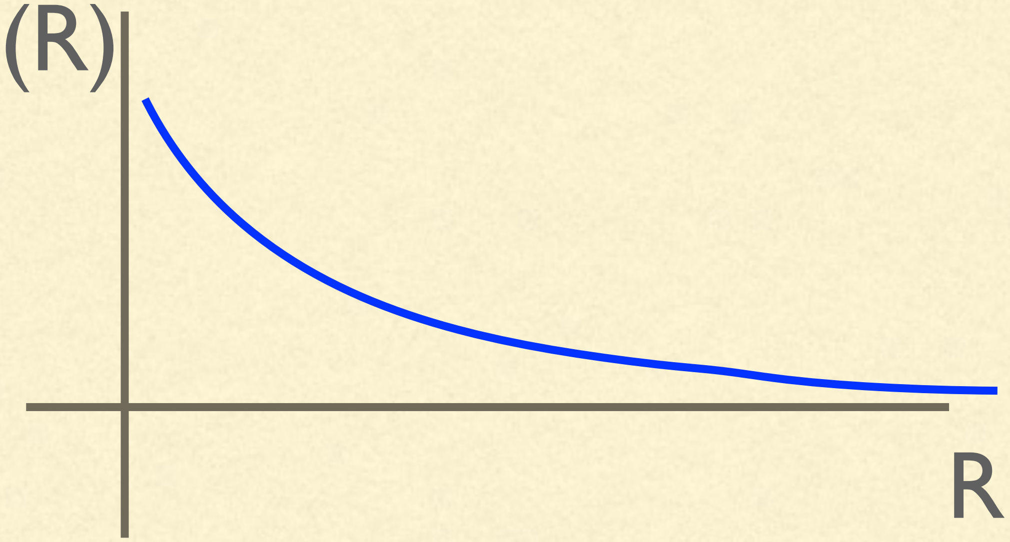
Cosmological Chameleons

The story for this starts with something very familiar to anybody who ever tried to get de Sitter in string theory:

Finally: Brief mention of

Cosmological Chameleons

The story for this starts with something very familiar to anybody who ever tried to get de Sitter in string theory:



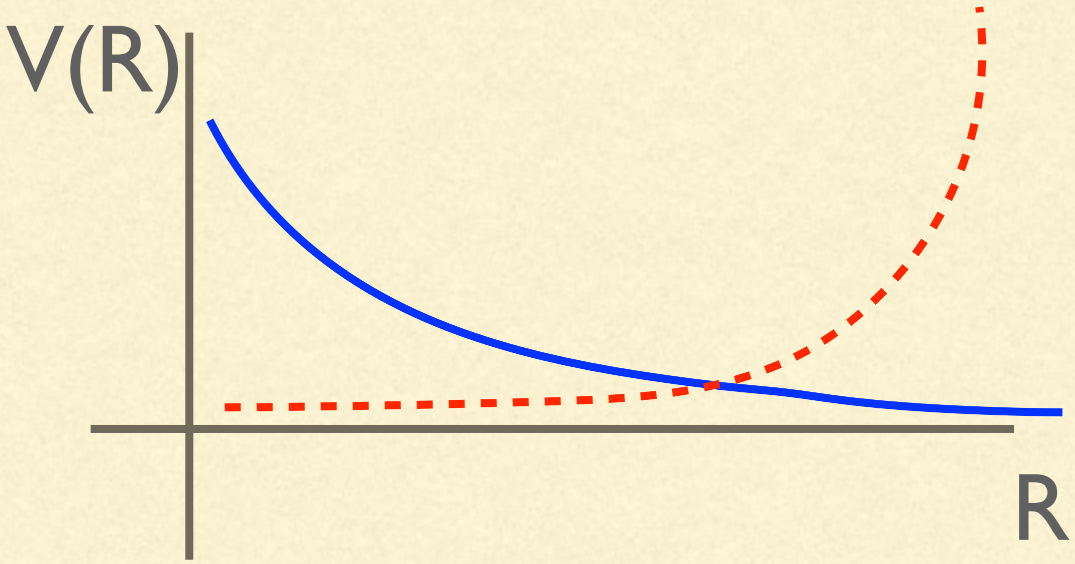
$$\frac{1}{R^k}$$

"In string theory I only get potentials that go to zero at large radius!! So I need to balance at least 3 terms to get dS"

Finally: Brief mention of

Cosmological Chameleons

The story for this starts with something very familiar to anybody who ever tried to get de Sitter in string theory:



$$\frac{1}{R^k}$$

"In string theory I only get potentials that go to zero at large radius!! So I need to balance at least 3 terms to get dS"

"Wouldn't it be **much easier** if there was a way to engineer something that doesnt go to zero, but that I can control?"


Well, we found a way to
do that.

Well, we found a way to
do that.

But it comes **at a price.**


Well, we found a way to
do that.

But it comes **at a price.**

String theory has towers of states whose mass **grows** with R.

(e.g. wrapped branes) $m \propto R^n$

Well, we found a way to
do that.

But it comes **at a price.**

String theory has towers of states whose mass **grows** with R.

(e.g. wrapped branes) $m \propto R^n$

If we introduce a non-zero **density** of these guys, "effectively" they behave as

$$\rho \sim n \cdot m \propto R^n$$


Well, we found a way to
do that.

But it comes **at a price.**

String theory has towers of states whose mass **grows** with R.

(e.g. wrapped branes) $m \propto R^n$

If we introduce a non-zero **density** of these guys, "effectively" they behave as

$$\rho \sim n \cdot m \propto R^n$$

so **matter** can stabilize a runaway potential


Well, we found a way to
do that.

But it comes **at a price.**

String theory has towers of states whose mass **grows** with R.

(e.g. wrapped branes) $m \propto R^n$

If we introduce a non-zero **density** of these guys, "effectively" they behave as

$$\rho \sim n \cdot m \propto R^n$$

so **matter** can stabilize a runaway potential

(similar to "Chameleon" mechanism for fifth-force screening)


However:


However:

Finite density **breaks de Sitter isometries**


However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

(at most O(1) e-folds)

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

(at most O(1) e-folds)

Many **control issues**

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

(at most O(1) e-folds)

Many **control issues**

Decays to the towers
Engineering the right dependence
Stabilize all moduli


However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

(at most O(1) e-folds)

Many **control issues**

Decays to the towers
Engineering the right dependence
Stabilize all moduli

We didn't find a fully controlled stringy embedding (yet)


However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

We checked so that you don't have to

(at most O(1) e-folds)

Many **control issues**

Decays to the towers
Engineering the right dependence
Stabilize all moduli

We didn’t find a fully controlled stringy embedding (yet)

However:

Finite density **breaks de Sitter isometries**

(so quintessence-like accelerated expansion)

Eventually, particles **dilute** and the accelerating phase **terminates**

(it is a model of **transient acceleration**, good for a while)

We checked so that you don't have to

(at most O(1) e-folds)

Decays to the towers

Many **control issues**

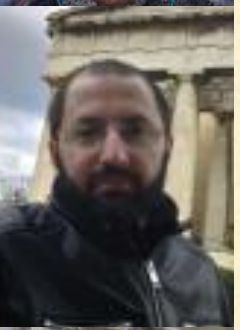
Engineering the right dependence

Stabilize all moduli

Or maybe you should/ can do better?

We didn't find a fully controlled stringy embedding (yet)




And finally (very, very quickly)





And finally (very, very quickly)

In **[Marconnet, Tsimpis '23, Andriot, Tsimpis, Wrase '23]**

And finally (very, very quickly)

In **[Marconnet, Tsimpis ’23, Andriot, Tsimpis, Wrase ’23]**

it was shown that accelerated expansion can be obtained even with **steep potentials** if **nonzero spatial curvature** is included.

And finally (very, very quickly)

In **[Marconnet, Tsimpis '23, Andriot, Tsimpis, Wrase '23]**

it was shown that accelerated expansion can be obtained even with **steep potentials** if **nonzero spatial curvature** is included.

We studied the **feasibility** of this scenario, both for inflation & today





And finally (very, very quickly)

In **[Marconnet, Tsimpis ’23, Andriot, Tsimpis, Wrase ’23]**

it was shown that accelerated expansion can be obtained even with **steep potentials** if **nonzero spatial curvature** is included.

We studied the **feasibility** of this scenario, both for inflation & today

…go to **Yashar's parallel talk** tomorrow to see the results! :-)

(See also Susha’s talk on Friday on very similar work)

CONCLUSIONS

- We showed that the three non-susy tachyon free string theories are anomaly-free
- Computed all relevant twisted string bordism groups
    - Many new branes, with nontrivial worldovlume dynamics
- Work in progress for Riemann-Flat Casimir-dS
- **Cosmological Chameleons:** When towers of states drive accelerated expansion
    - Control issues, but maybe they can be solved!

Grazie mille!

Thank you!