How to connect String Theory with Reality

Florian Wolf

Young Scientists Workshop at Ringberg Castle
on June 7, 2016

Outline

From String Theory to Particle Physics

1. What is String Phenomenology?
2. D-Branes and Gauge Fields
3. Intersecting Branes and Matter
4. Family Replication
5. Example

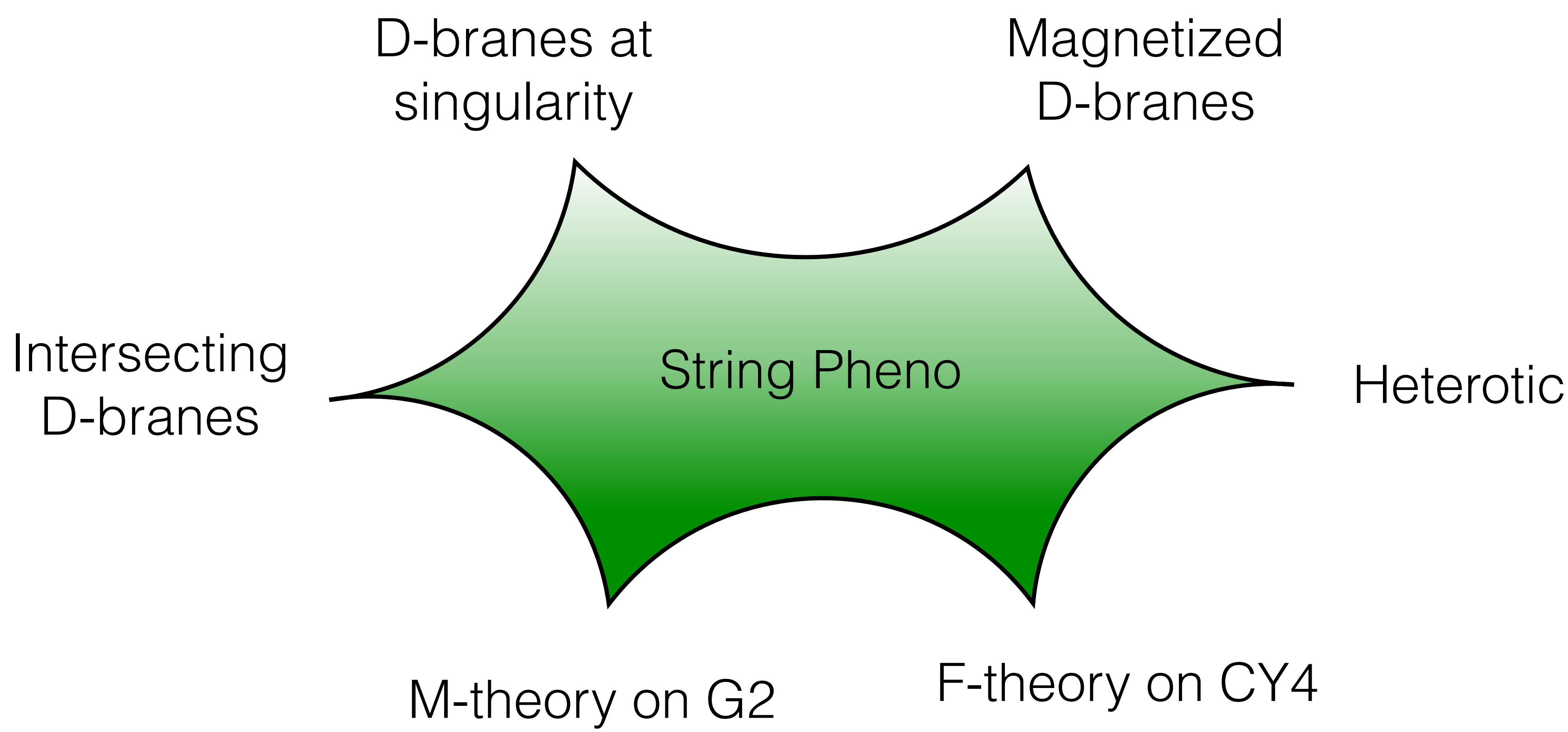
From String Theory to Cosmology

6. Axion Inflation and String Theory
7. Natural and Aligned Inflation
8. Our Recent Work

From String Theory to Particle Physics

String Phenomenology

String Theory offers different possibilities to engineer the Standard Model:



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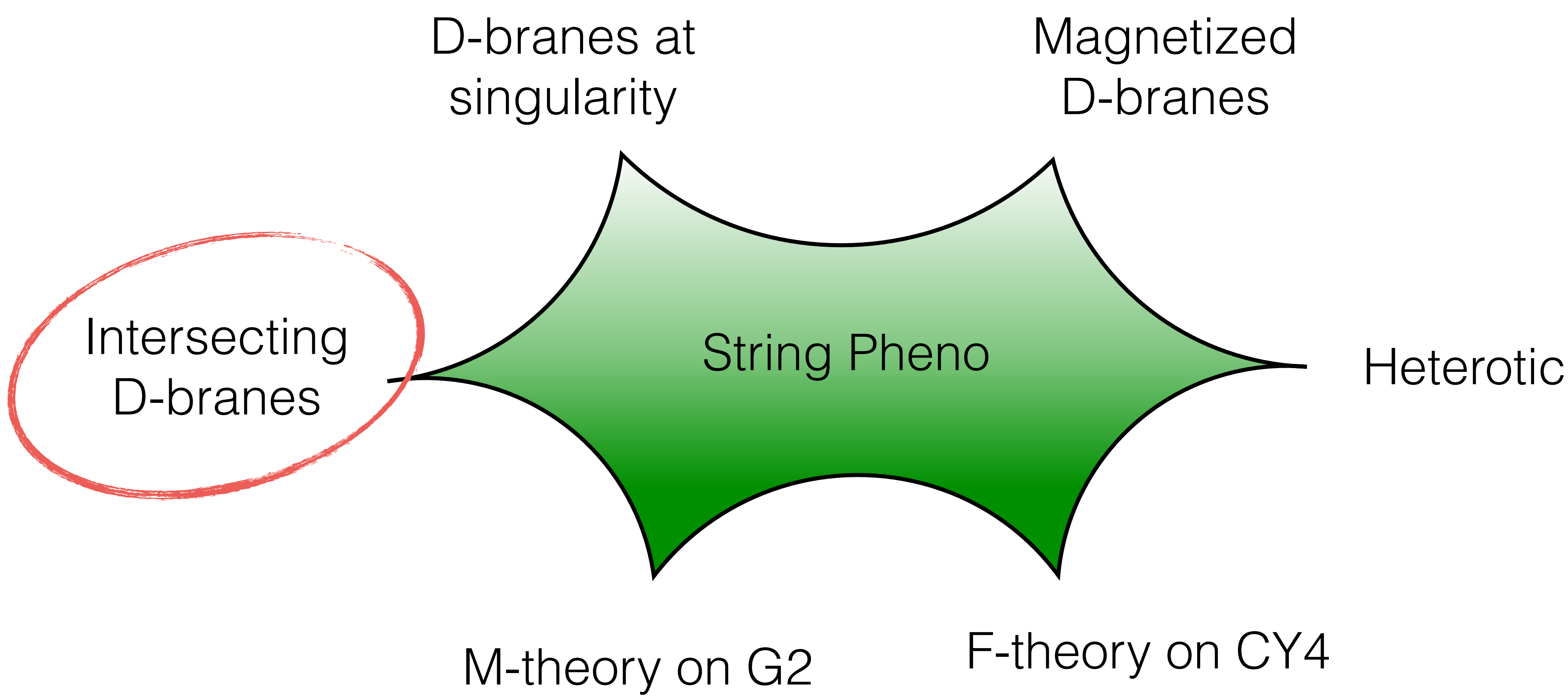
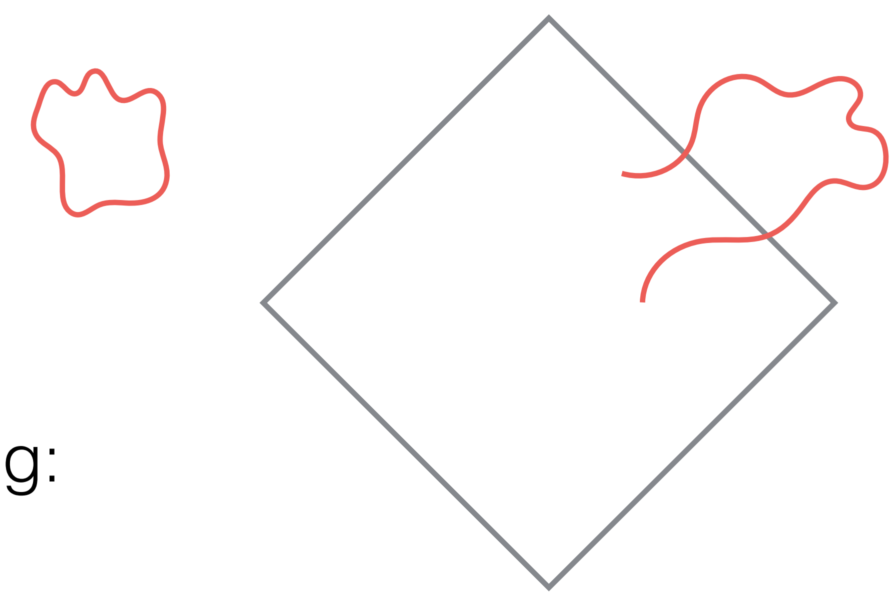


D-Branes

Definition: D-Branes are higher dimensional planes on which open strings end



open string:
gauge fields and matter on the brane

closed string:
gravity

D-brane

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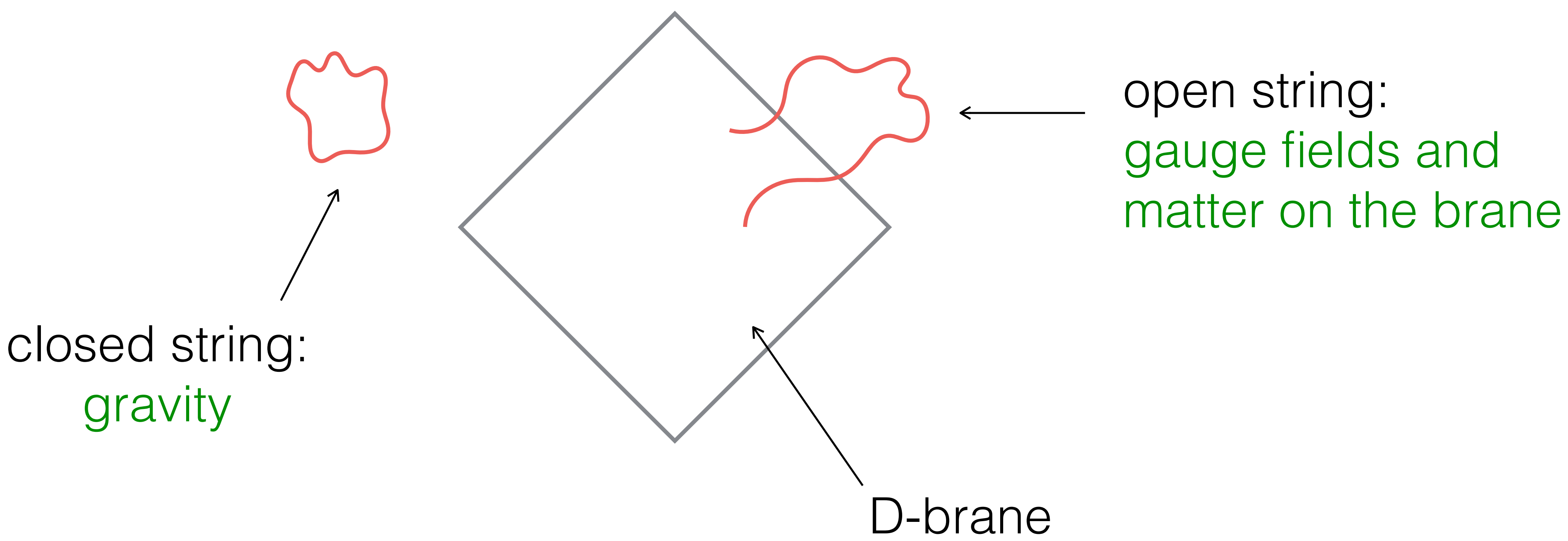

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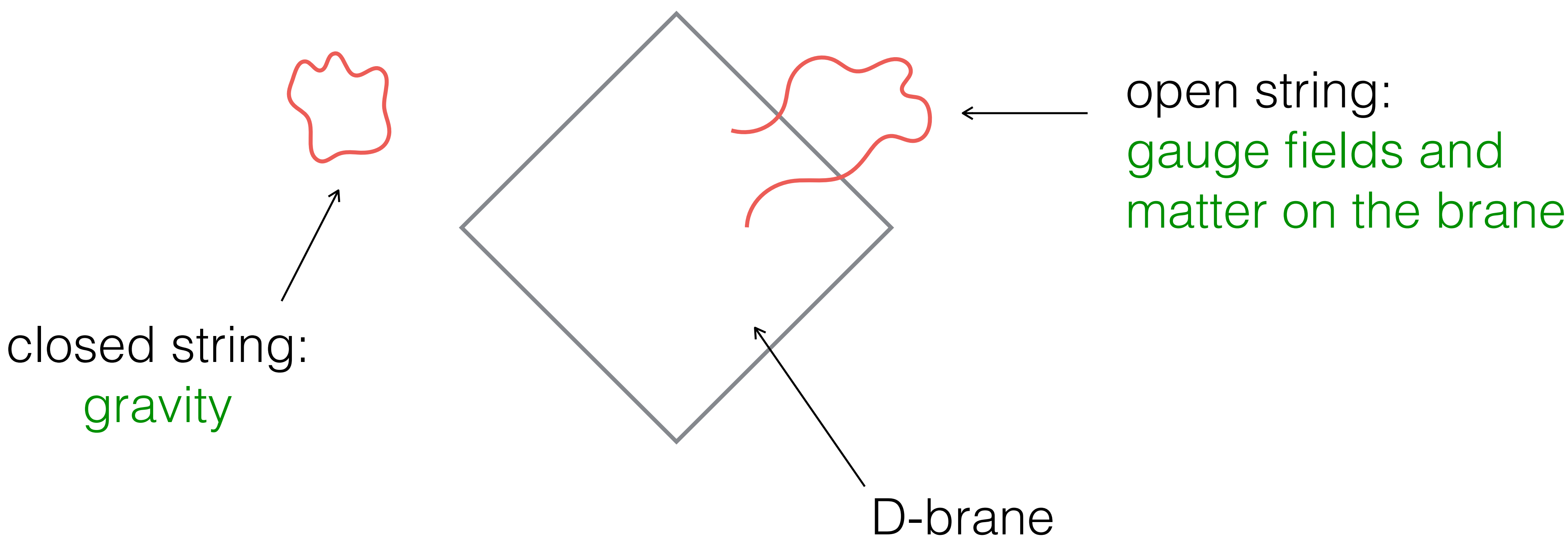
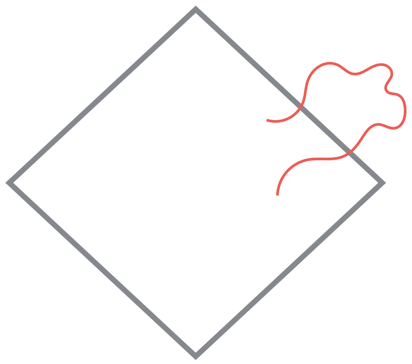


- it is convenient to consider D6-branes in type IIA string theory or D7-branes in type IIB including orientifold planes

Gauge Fields

1 D-brane



$U(1)$

vector multiplet

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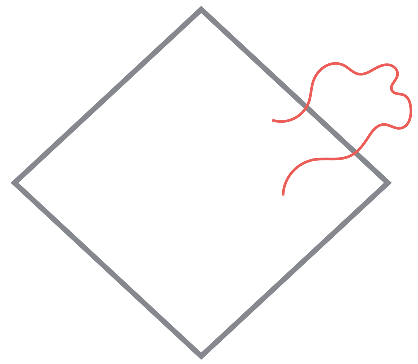

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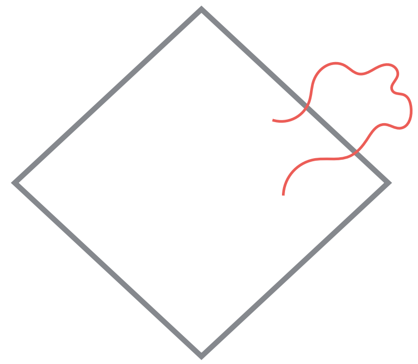

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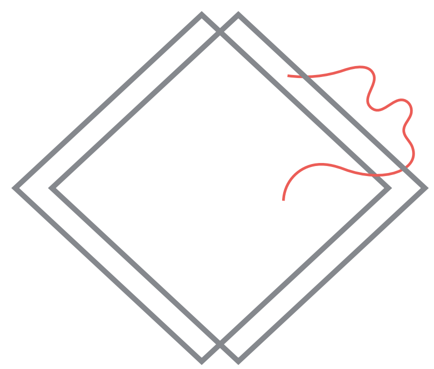

$$U(2) = SU(2) \times U(1)$$

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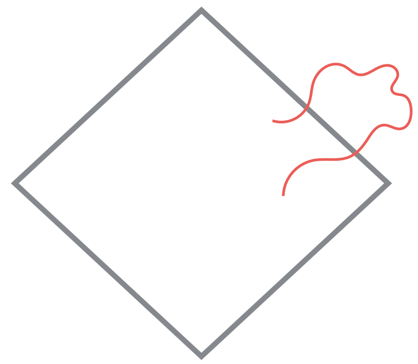

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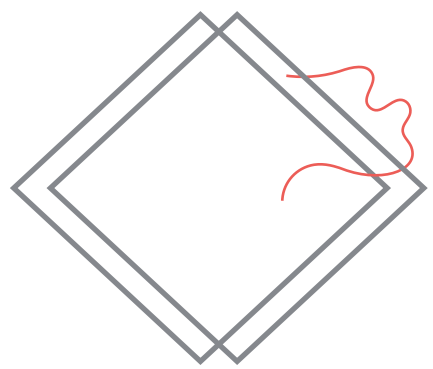

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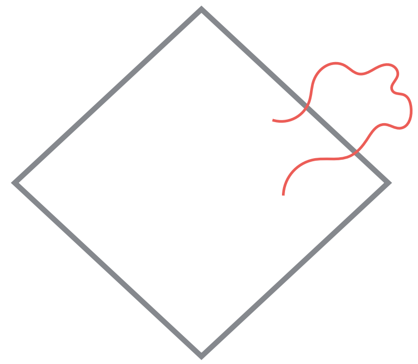

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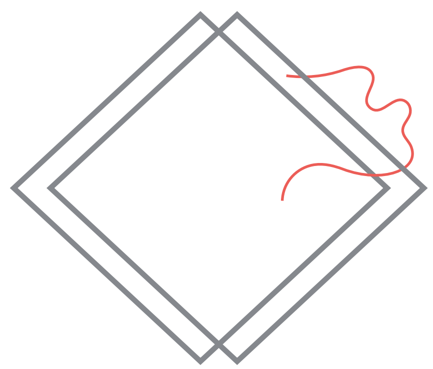

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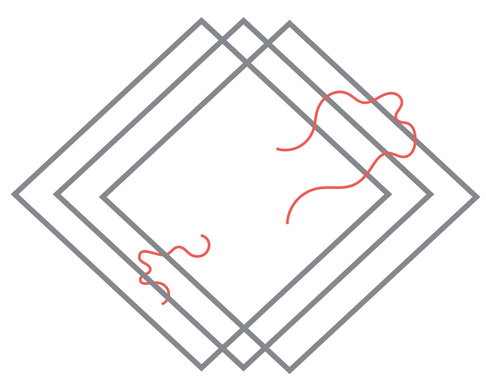

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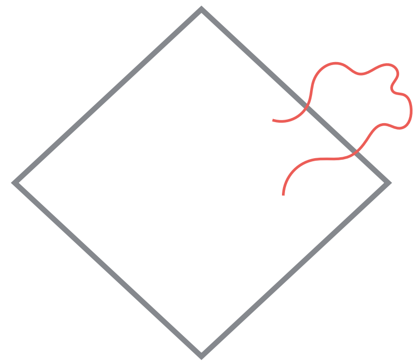

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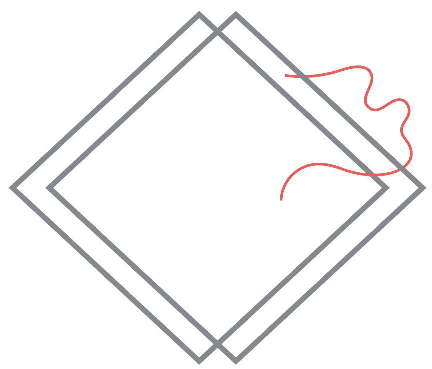

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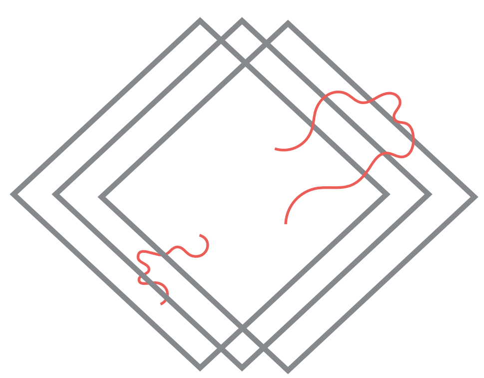

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strong interaction

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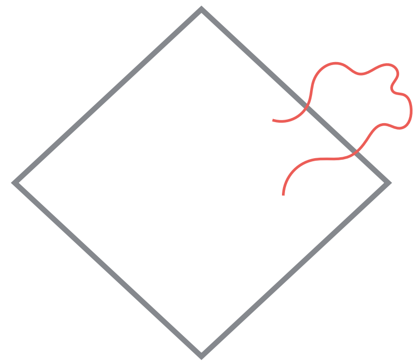

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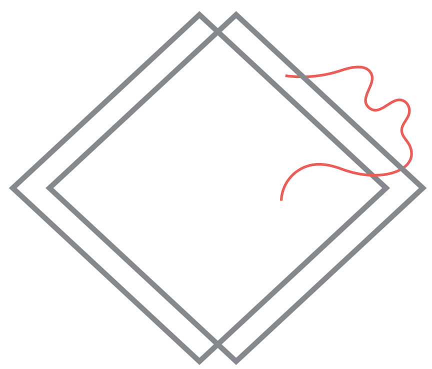

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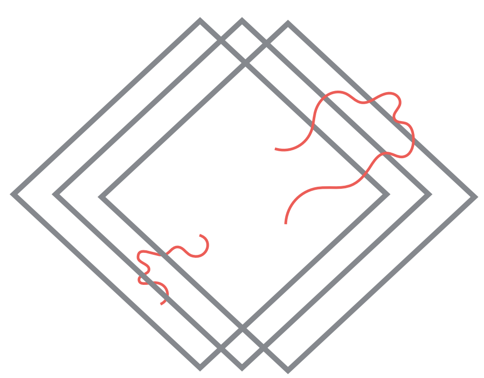

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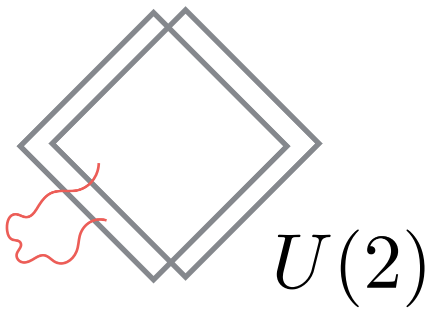
- D-branes can realise SM gauge group $SU(3) \times SU(2) \times U(1)$

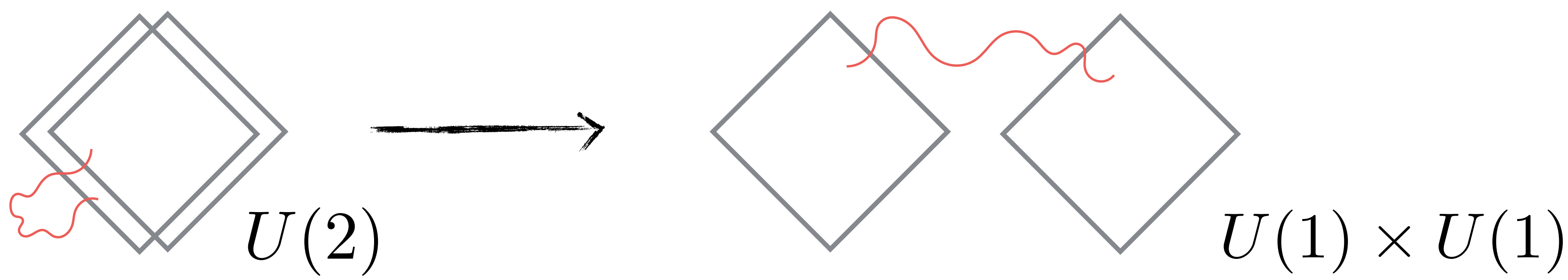
Chiral Matter via Intersecting Branes

Separating branes:



Chiral Matter via Intersecting Branes

Separating branes: Stringy Higgs effect



String states between 2 D-branes: became massive, but no chiral matter

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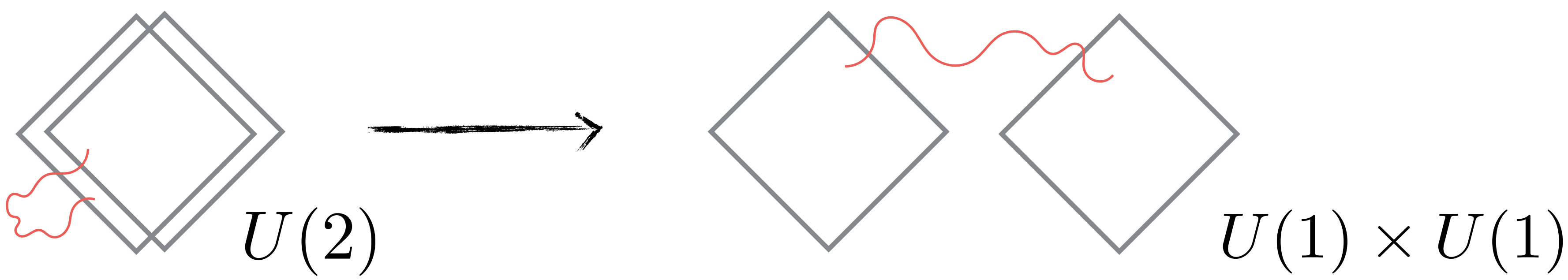

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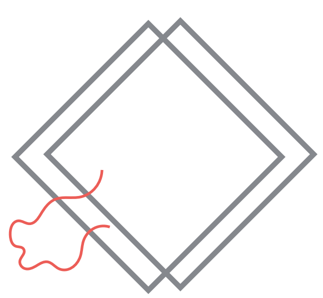

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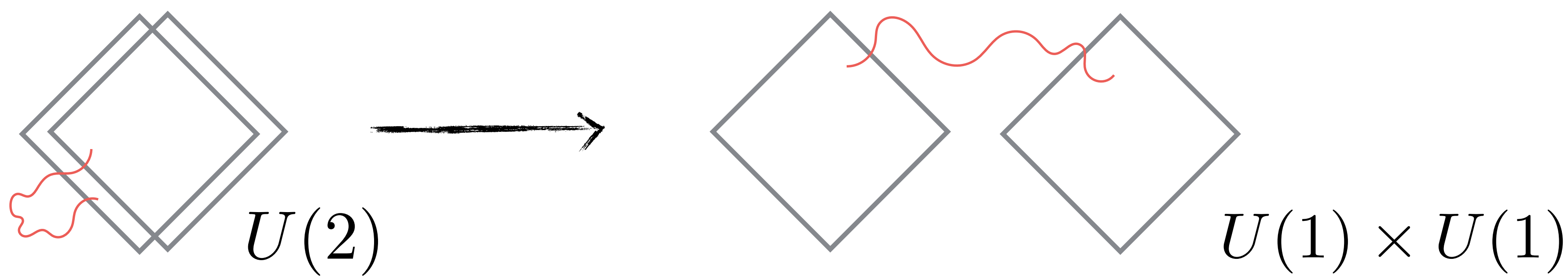

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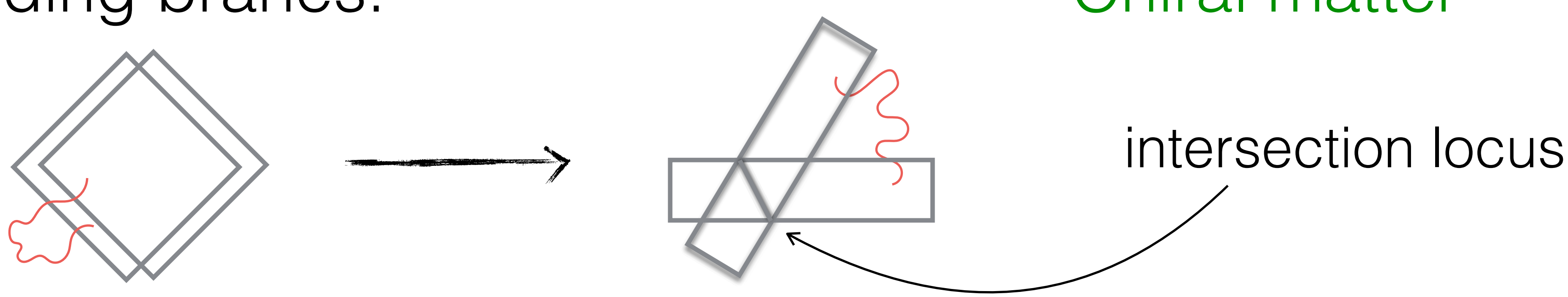

String states at intersection: chiral (massless) fermions

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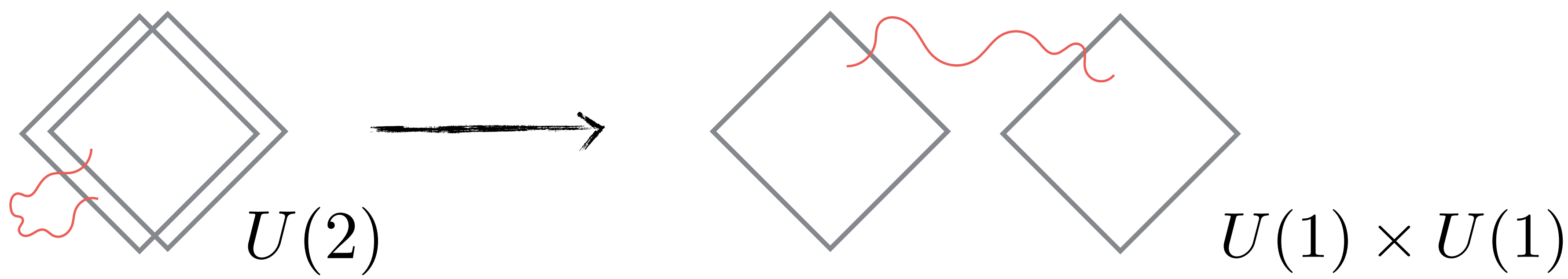

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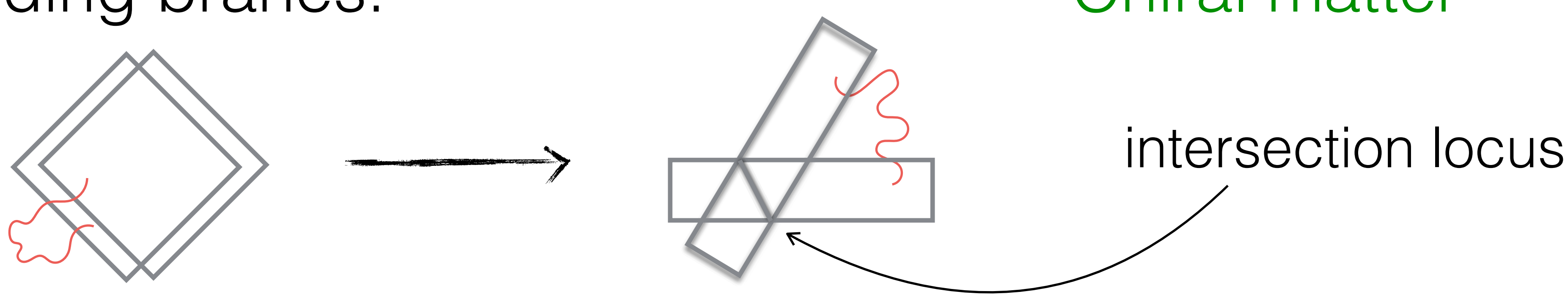


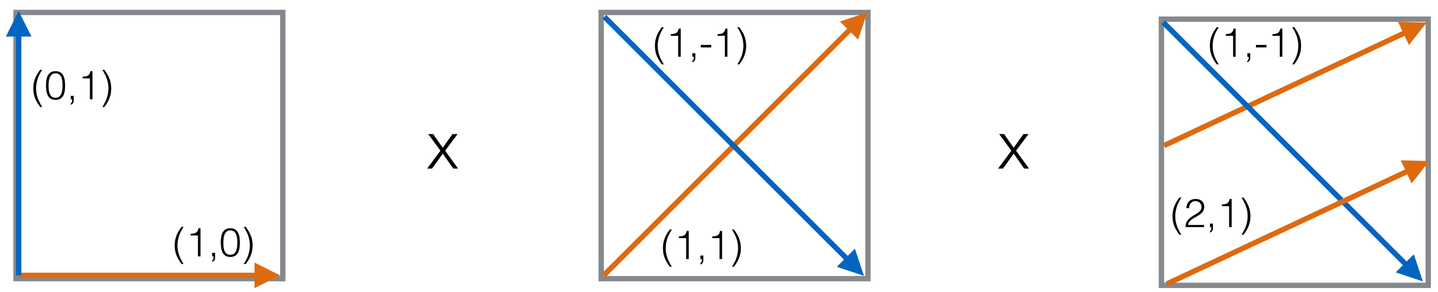
String states at intersection: chiral (massless) fermions

- intersecting D-branes give rise to SM quarks and leptons

Family Replication via Compactification

Simplest example: $T^6 = T^2 \times T^2 \times T^2$

2 intersecting D-branes on 6d torus



Intersection number = *number of families:*

$$I_{ab} = \prod_{i=1}^{3} (n_a^i m_b^i - m_a^i n_b^i)$$

wrapping numbers: (n^i, m^i)

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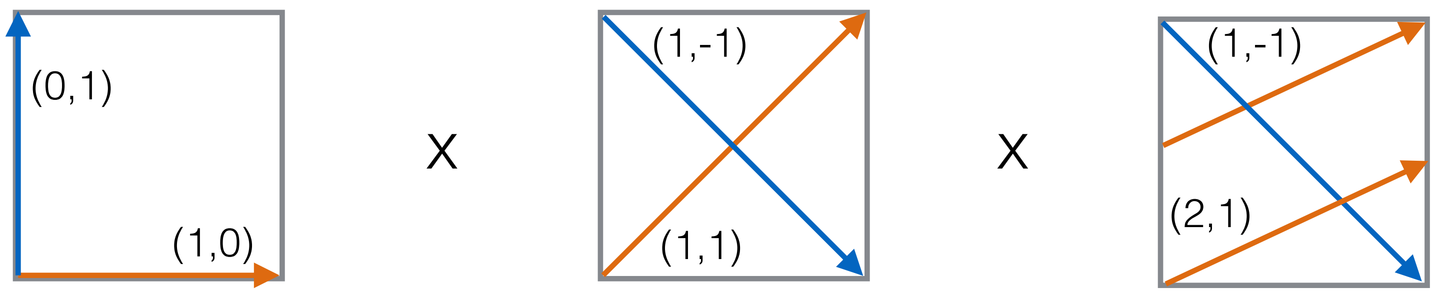

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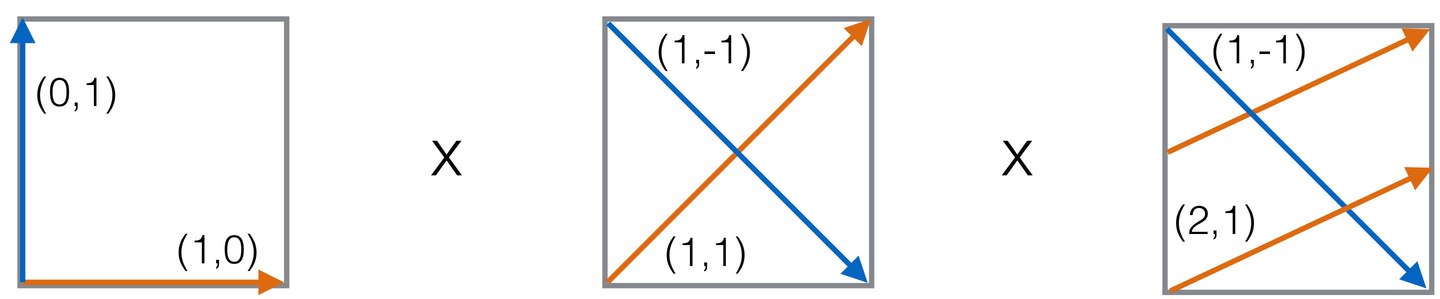

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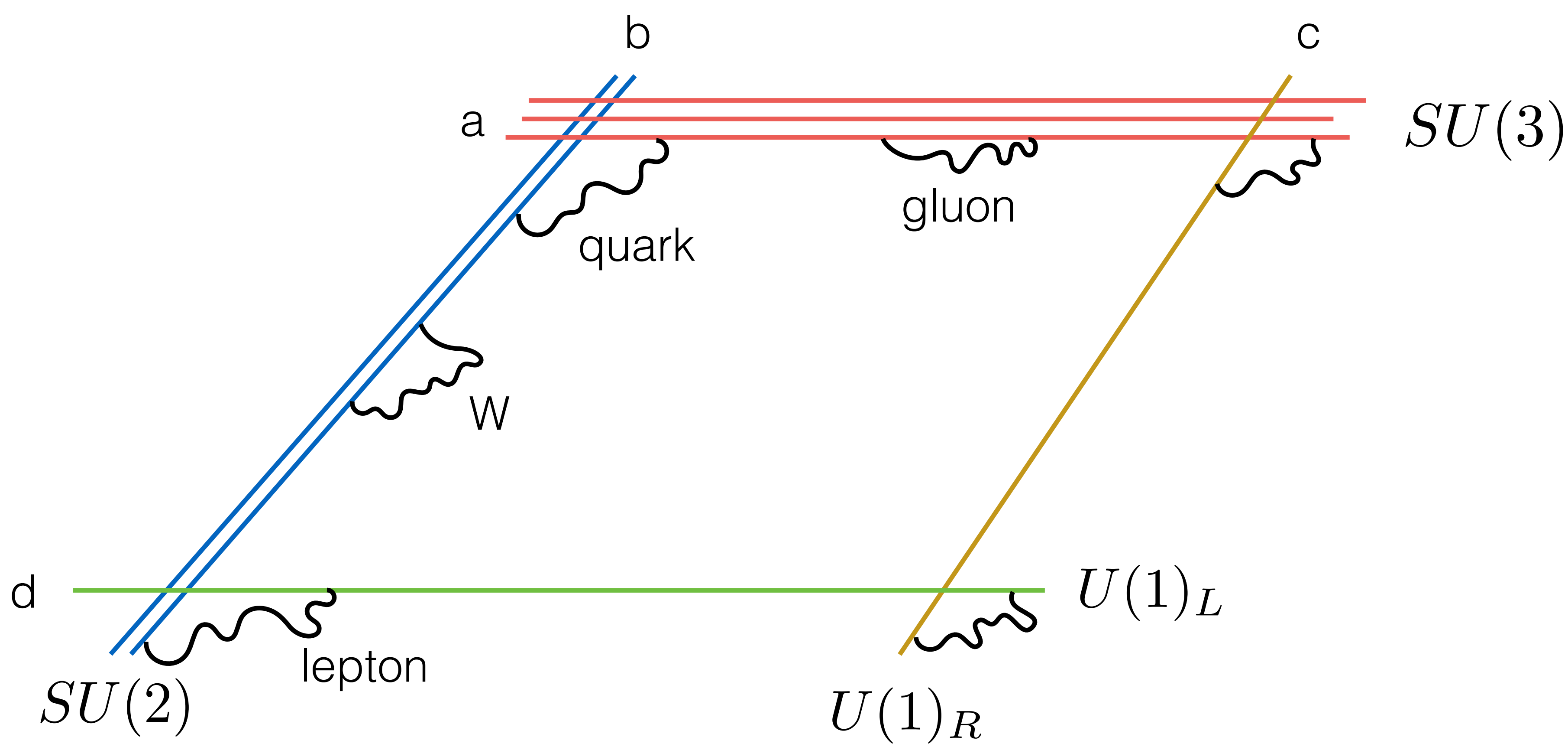
Comments:

- Calabi-Yau: homological 3-cycle and topological intersection number
- orientifolds: cycle involution invariant: $SO(N)$ or $SP(N)$
  cycle not involution invariant: $U(N)$

Example

Introduce 4 stacks of D6-branes a,b,c,d and orientifold plane



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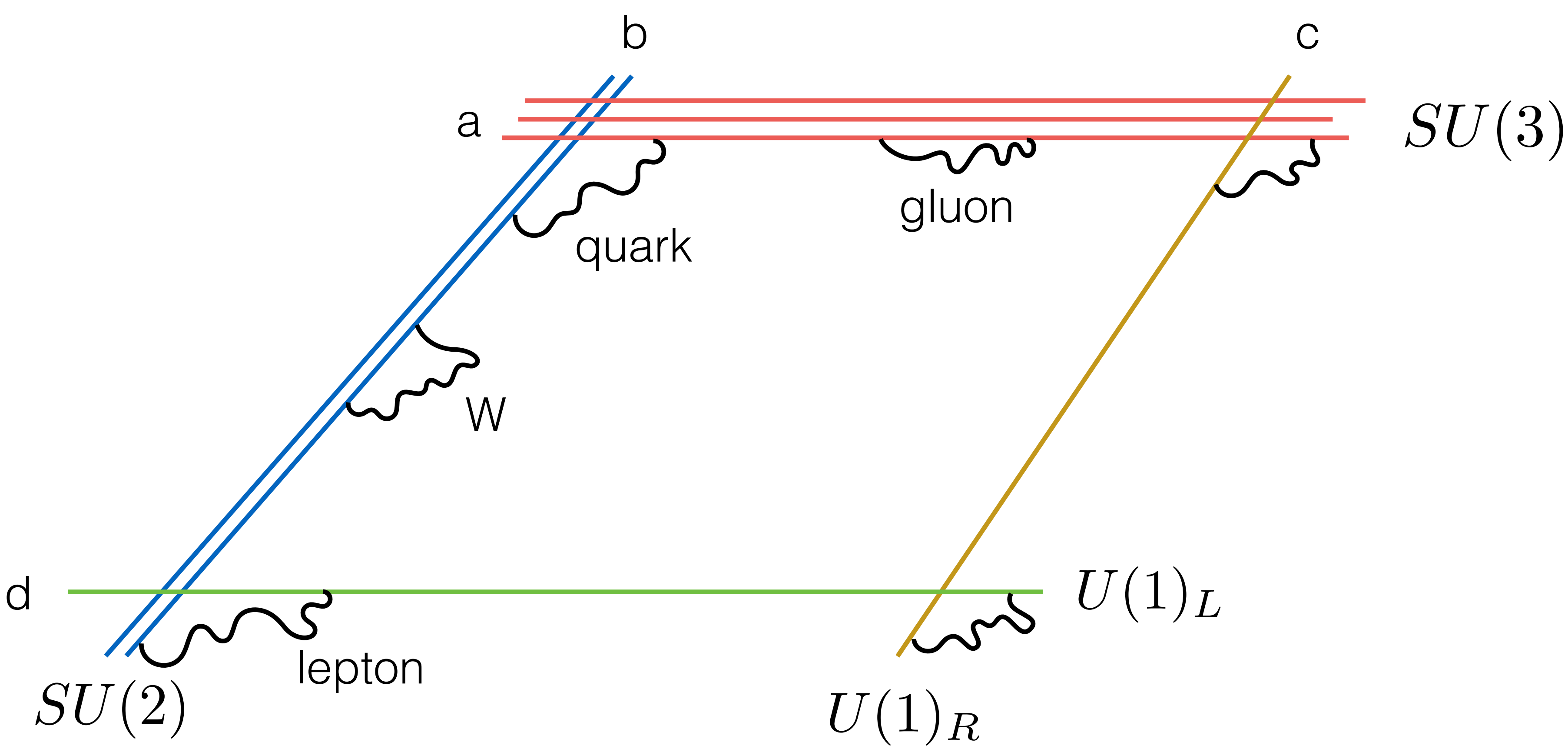


⟶ Gauge group: $U(3)_a \times U(2)_b \times U(1)_c \times U(1)_d$

⟶ need to ensure correct intersection numbers to get 3 families

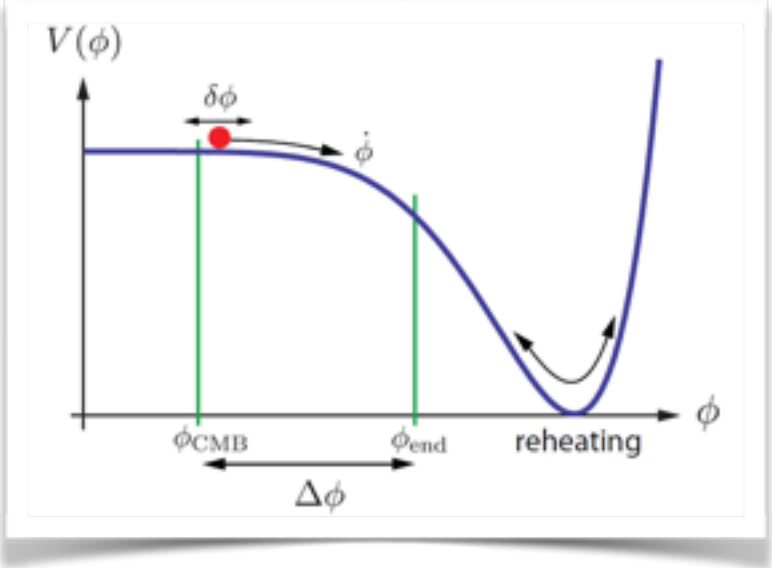
⟶ realises Standard Model + additional matter

From String Theory
to Cosmology

Axion Inflation

Inflation:

- exponential expansion during very early time period of the universe
- driven by scalar inflaton field ϕ with potential $V(\phi)$



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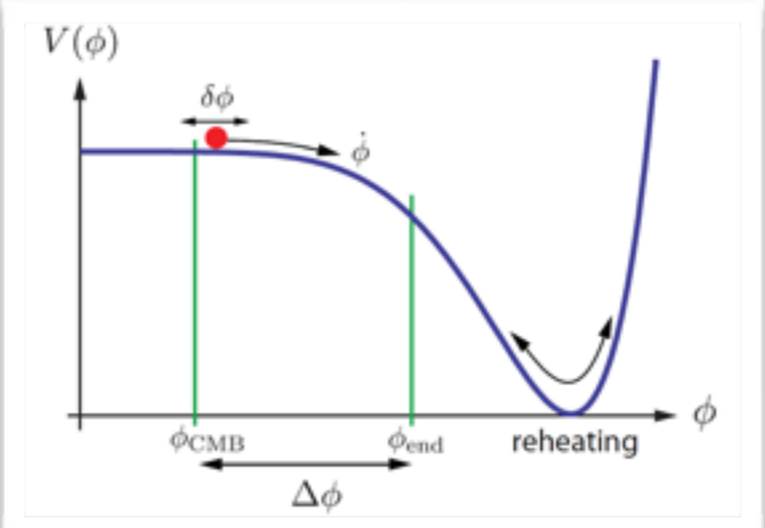

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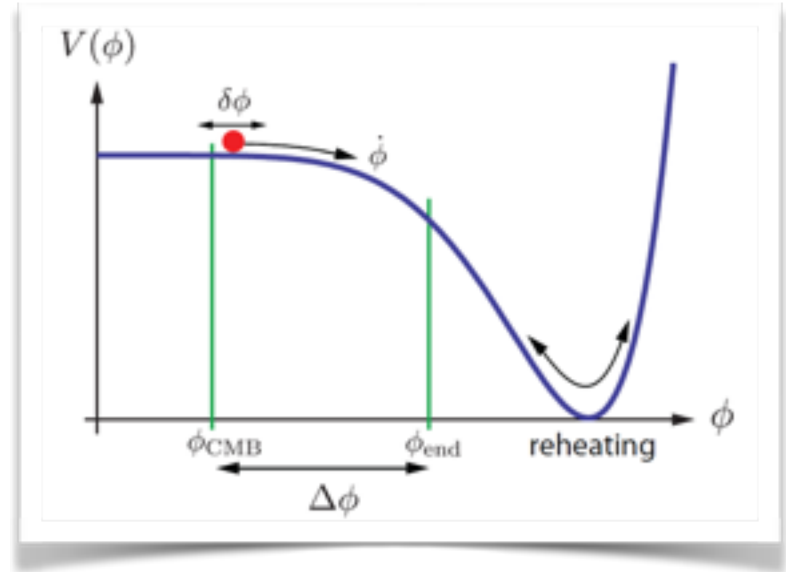
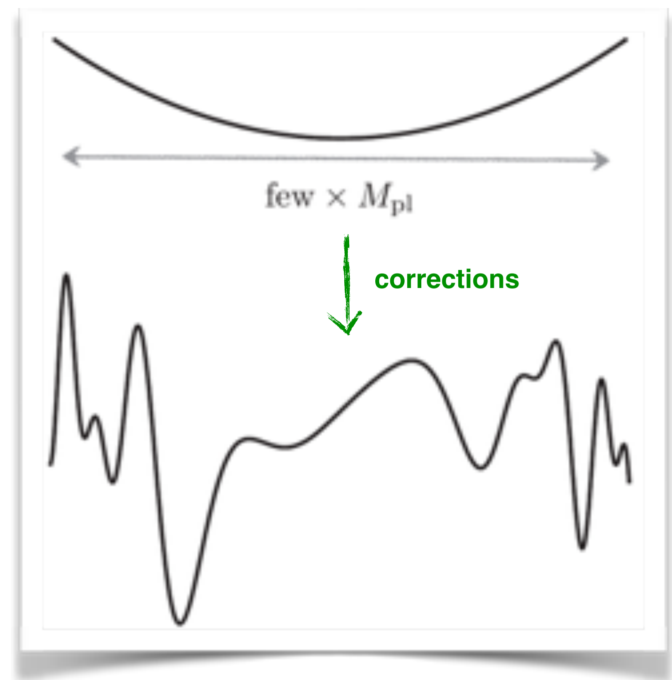


Experiments [BICEP2 '14, Planck '15] motivated to study large-field inflation ($\Delta\phi > M_{\rm Pl}$)

- highly sensitive to UV corrections
- axions with shift symmetry $\phi \to \phi + 2\pi$ prevent corrections to the inflaton potential

$\longrightarrow$ axions arise naturally in string theory as moduli



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Natural Inflation: axion shift symmetry implies periodic potential:

$$V(\phi) = V_0 \left[1 - \cos\left(\frac{\phi}{f} \right) \right]$$

approx. energy scale of inflation (V_0)

axion decay constant (f)

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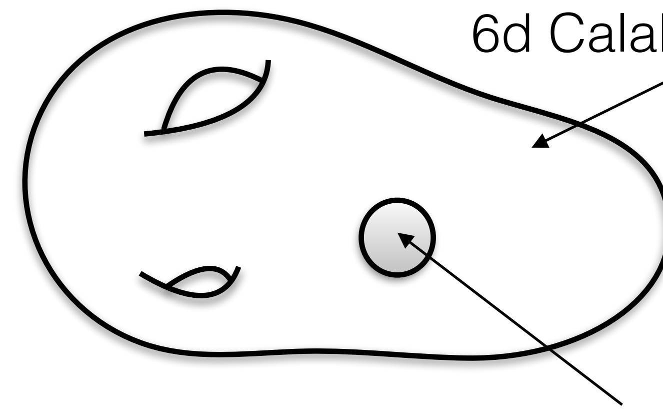
Solution: Aligned Inflation

- employ two axions with decay constants $f_1, f_2 < M_{\rm Pl}$
- "align" axions appropriately to achieve effective decay constant $f_{\rm eff} > M_{\rm Pl}$

Our recent work

arXiv: 1605.06299 by Blumenhagen, Herschmann, FW

Moduli Stabilisation at a conifold



- condition for effective supergravity description (exclude warping effects):

$$\mathcal{V}|Z| > 1$$

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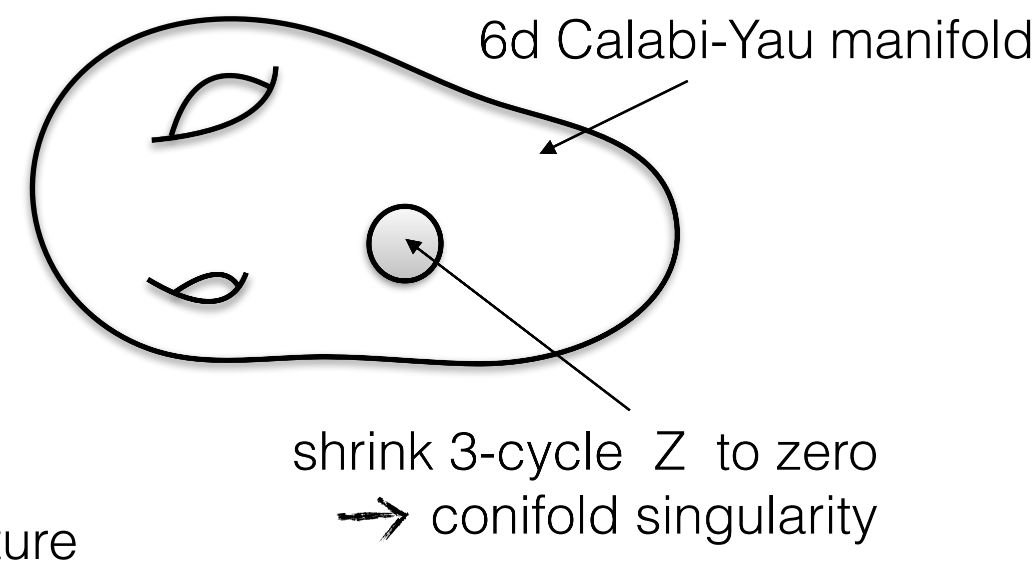

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CY volume ($\mathcal{V}$), complex structure modulus (Z)

- moduli stabilisation a la LARGE volume scenario possible

- vanishing F-term condition stabilises $Z \sim e^{-\mathrm{flux}\times S}$

  → integrating out Z mimics instanton terms in the superpotential

- neglecting Kähler moduli can lead to aligned inflation

  → exponential suppression gives great control over ALL effective theories

Summary

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- realises particle spectrum of the Standard Model
- capable of beyond to SM effects
- But …. always appearance of extra matter

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- realises particle spectrum of the Standard Model
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String Theory and Cosmology:

- axion inflation possible
- But … in general difficult to control effective theories

  ⟶ *moduli stabilisation at conifold might work!*
- ST can also explain dark matter and dark energy