Discrete gauge symmetries in flux compactifications

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Based on:
M.B-G., P. G. Cámara, F. Marchesano, Á. M. Uranga; arXiv: 1211.5317

Discrete symmetries in SM/BSM

- Discrete symmetries are a key ingredient in SM and BSM
  - Symmetries preventing dimension 4 proton decay in the MSSM: R-parity, baryon triality...
  - Flavor symmetries to explain/reproduce quarks and lepton masses and mixings,...

- Quantum gravity does not like global symmetries.

Banks, Seiberg 2011

  - Microscopic arguments in string theory. Banks, Dixon '88
  - General arguments in black hole evaporation.

- Exact symmetries should be gauge.

Discrete gauge symmetries in 4d

Banks, Seiberg 2011

- The basic Lagrangian for a Z_p gauge symmetry is

$$(d\phi - pA) \wedge *(d\phi - pA) + \frac{1}{2} F \wedge *F \qquad \phi \sim \phi + 1$$

Axion

The gauge transformation is

$$A \to A + d\lambda \quad , \quad \phi \to \phi + p\,\lambda$$

Discrete gauge symmetries in 4d

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- The Lagrangian in the dual description is

$$\frac{1}{2}H \wedge *H + pB \wedge F + \frac{1}{2}F \wedge *F$$

$$\begin{aligned} H &= dB &= *d\phi \\ dV &= *dA \end{aligned}$$

The gauge transformation is

$$B \to B + d\Lambda \quad , \quad V \to V + p\,\Lambda$$

- Thus, the Z_p discrete symmetry can be read from the B∧F coupling.

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- Thus, the Z_p discrete symmetry can be read from the B∧F coupling.

- The objects charged under this symmetry are:
  - Z_p-charged particles, which can be annihilated by instantons in sets of p.
  - Z_p-charged strings, which can be annihilated by string junctions in sets of p.

Discrete gauge symmetries from flux compactifications

- In type II theory, B∧F arises from KK reduction of the 10d CS couplings

$$\int_{10d} H_3 \wedge F_p \wedge C_{7-p} \quad , \qquad \int_{10d} B_2 \wedge F_p \wedge F_{8-p}$$

- Charged strings and particles are given by branes wrapped on homologically non-trivial Z-valued cycles.

- They can decay in sets of p, due to processes allowed by the presence of fluxes (flux catalysis).

A simple example

- Consider type IIB compactified on X_6 with NSNS 3-form flux and only two 3-cycles α, β.

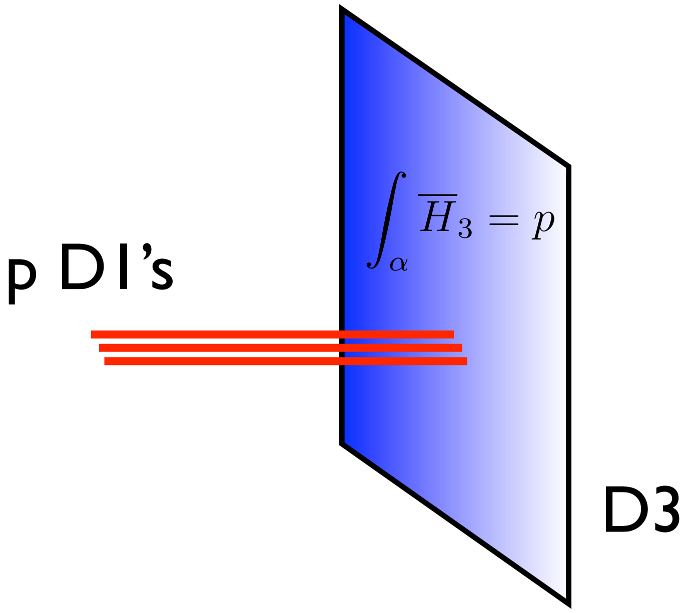
$$\int_\alpha \overline{H}_3 = p \quad , \quad \int_\beta F_5 = \hat{F}_2$$

- The B∧F coupling arises from

$$\int_{10d} \overline{H}_3 \wedge C_2 \wedge F_5 \rightarrow \int_{4d} p\, C_2 \wedge \hat{F}_2$$

- We get a Z_p discrete gauge symmetry.

- The charged objects under the Z_p are:
  - Particle: D3 on β.
  - Instanton: D5 on X6.
  - Strings: D1 branes.
  - Junction: D3 on α.



Freed, Witten 1999
Maldacena, Moore, Seiberg 2001

Non-Abelian discrete gauge symmetry from fluxes (generalities)

- In some configurations there can be several Z_P which may be non-commuting.

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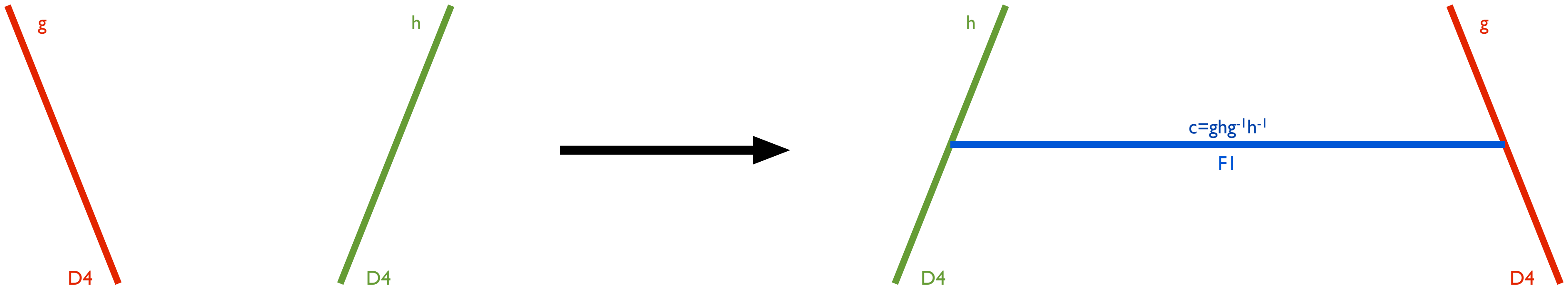
- This implies that strings associated to non-commuting elements g and h, when crossing each other, produce a new string stretching between them, associated to the commutator $c=ghg^{-1}h^{-1}$.

Alford, Benson, Coleman, Lee, March-Russell, Preskill, Wilczek '90s



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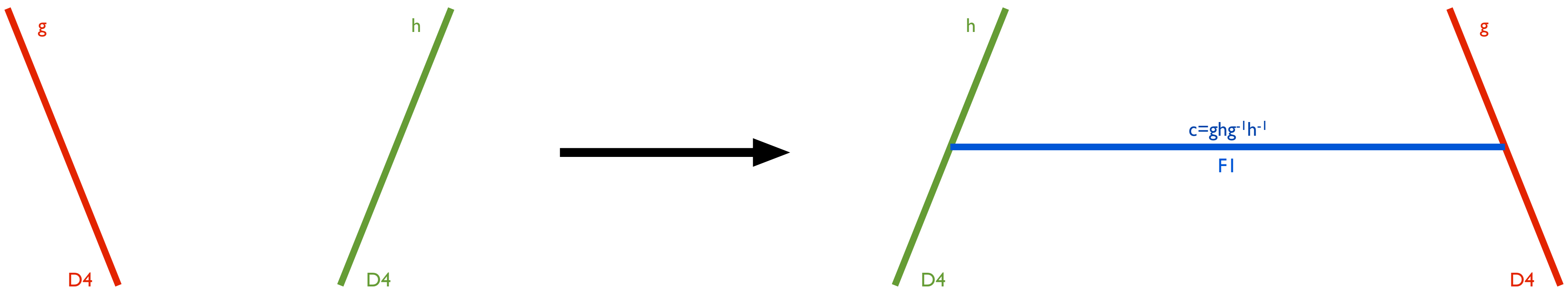

- Microscopically, these new strings appear by the Hanany-Witten brane creation effect.
- The strings created in the crossing are finite in extent, but the theory must also contain stable infinite strings associated to c.

Non-Abelian discrete gauge symmetry from fluxes (example)

- Consider type IIA with 2-form fluxes compactified on $X_6=B_4\times T^2$, and introduce the T^2 1-cycles a and b, and two dual basis of 2-cycles $\{\Pi_k\}$ and $\{\Pi_k'\}$ in B_4. Define

$$\int_{\Pi_k} \overline{F}_2 = p_k \quad , \qquad \int_a H_3 = \hat{F}_2^a \quad , \qquad \int_b H_3 = \hat{F}_2^b$$

$$\int_{\Pi_k'\times b} C_5 = \hat{B}_k \quad , \qquad \int_{\Pi_k'\times a} C_5 = \hat{B}_k'$$

- The BF couplings arise from

$$\int_{10d} \overline{F}_2 \wedge H_3 \wedge C_5 \quad \to \quad \int_{4d} \left(\sum_k p_k\, \hat{B}_k \wedge \hat{F}_2^a - \sum_k p_k\, \hat{B}_k' \wedge \hat{F}_2^b \right)$$

- Each of the two U(1) gauge factors is broken to a Z_P gauge symmetry with $p = \mathrm{gcd}(p_k)$.

- The charged objects under each Z_P are:

‣ Particle: F1 on a.	‣ Particle: F1 on b.
‣ Instanton: D2 on a l. c. of $\Pi_k' \times b$.	‣ Instanton: D2 on a l. c. of $\Pi_k' \times a$.
‣ String: D4 on $\Delta = \sum_k (p_k/p)\Pi_k' \times b$.	‣ String: D4 on $\Delta' = \sum_k (p_k'/p')\Pi_k' \times a$.
‣ Junction: NS5 on $b \times \mathbf{B}_4$.	‣ Junction: NS5 on $a \times \mathbf{B}_4$.

- Crossing two 4d strings minimally charged under the two Z_p produces r F1s with

$$r = \Delta \cdot \Delta' = \sum_k \frac{p_k p_l}{p^2} \, \Pi'_k \cdot \Pi'_l$$

- The symmetry is a discrete Heisenberg group generated by T, T´ and C, with relations

$$T^p = T'^p = 1 \quad , \qquad TT' = C^r \, T'T$$

- The BF couplings associated to C are

$$\int_{10d} B_2 \wedge \overline{F}_2 \wedge F_6 \quad \rightarrow \quad \int_{4d} B_2 \sum_k p_k \hat{F}_2^k \qquad\qquad \textstyle\int_{\Pi'_k \times a \times b} F_6 = \hat{F}_2^k$$

- This leads to a Z_q symmetry with $q = \frac{\sum_k (p_k)^2}{p}$, which implies

$$C^q = 1$$

Combining fluxes

- When several kinds of fluxes are simultaneously present in a compactification, inconsistent configurations of Z_p-valued wrapped branes may naively arise.

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- Consider type IIB with NSNS and RR 3-form fluxes, and only two 3-cycles α, β.

Dasgupta, Rajesh, Sethi 1999
Giddings, Kachru, Polchinski 2002

$$\int_\beta F_5 = \hat{F}_2 \qquad \int_\alpha \overline{F}_3 = p \; , \qquad \int_\beta \overline{H}_3 = p' \qquad \int_\alpha F_5 = \hat{F}'_2$$

$$\int_{4d} \left(p\, B_2 \wedge \hat{F}_2 \; - \; p'\, C_2 \wedge \hat{F}'_2 \right)$$

- Particle: D3 on β.
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- Strings ending in junctions ending in instantons?

Combining fluxes

- When several kinds of fluxes are simultaneously present in a compactification, inconsistent configurations of Z_p-valued wrapped branes may naively arise.

- Consider type IIB with NSNS and RR 3-form fluxes, and only two 3-cycles α, β.
- In this configuration there is a tadpole of D3-brane charge given by

Dasgupta, Rajesh, Sethi 1999
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$$N_{\rm flux} = \int_{\mathbf{X}_6} \overline{F}_3 \wedge \overline{H}_3 \, = \, pp' \qquad \int_\alpha \overline{F}_3 = p \ , \qquad \int_\beta \overline{H}_3 = p'$$

- The extra ingredients needed to cancel the tadpole also solve the above inconsistencies. We have several possibilities: anti-branes, orientifold planes...

- In the case of O3-planes, all flux-induced BF couplings are projected out, and therefore also strings ending on string junctions.

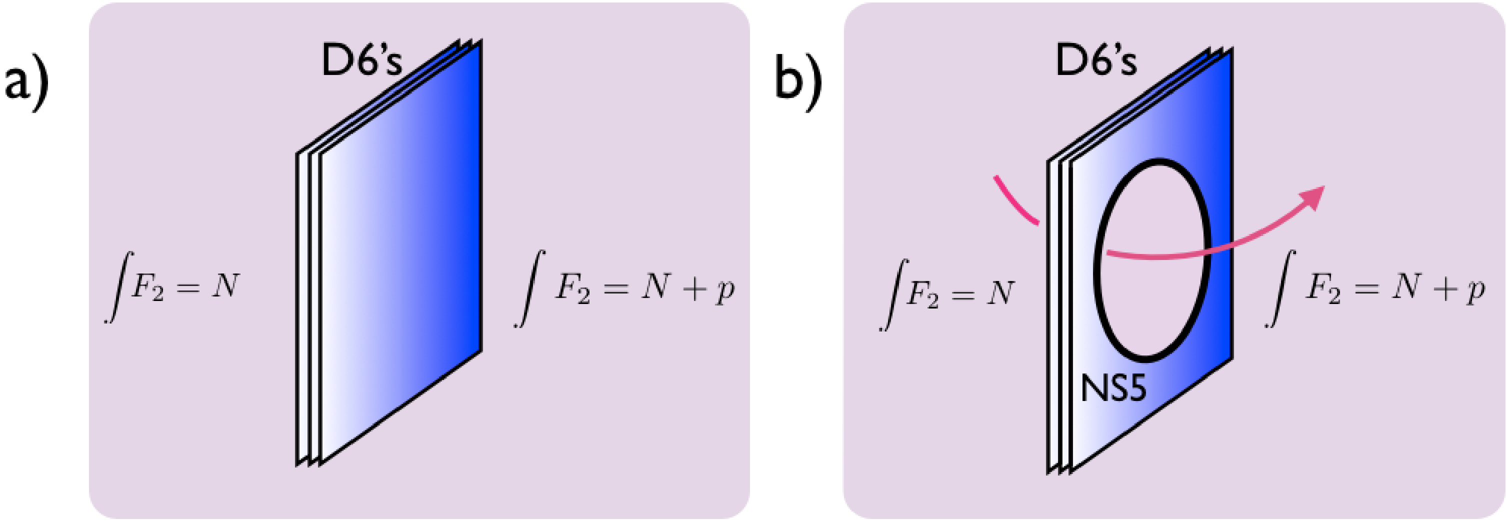
- However there is another set of discrete Z_p-valued brane wrappings that survive the orientifold projection: 4d strings with domain walls attached.

Unstable domain walls

- In addition to the charged strings, we can have 4d strings with p domain walls attached.

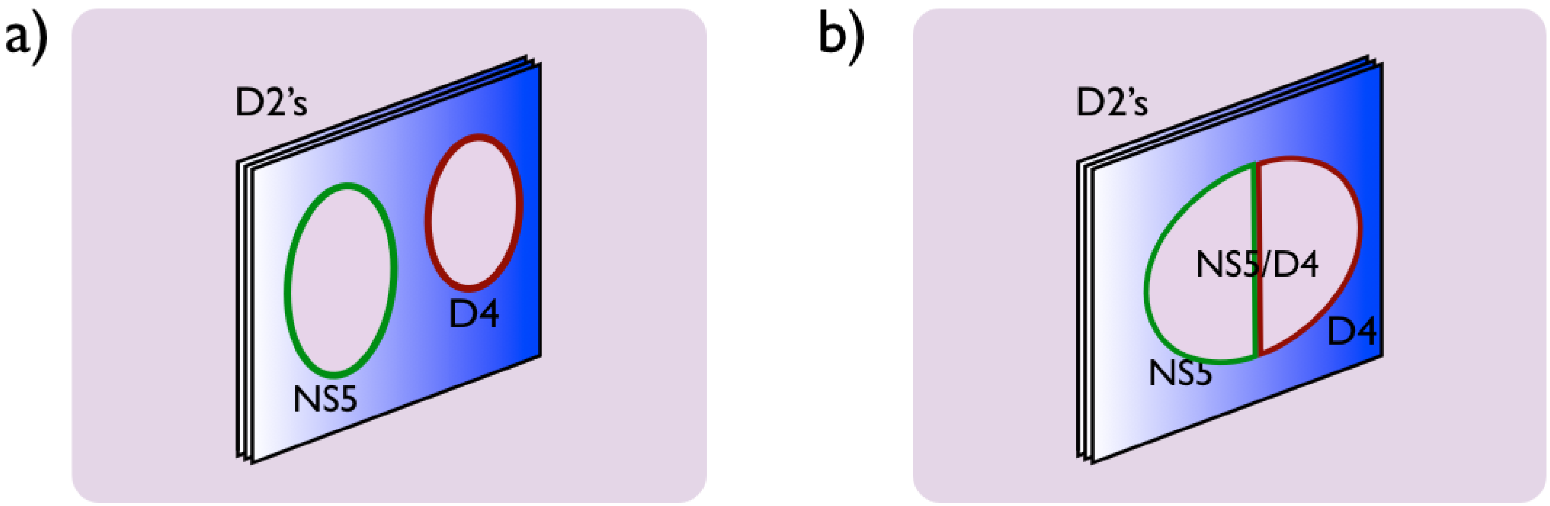
- Therefore, p domain walls are unstable against nucleation of a string loop, and the vacua separated by them must be equivalent.

- **Flux quantization:** Two vacua separated by a domain wall wrapping a k-cycle differ in one unit of RR (6-k)-form flux along the (6-k)-cycle dual to the wrapped k-cycle. Because of nucleation of holes bounded by strings both vacua must be equivalent, so the flux is Z_p-valued.



D6-brane domain walls with F_0 flux.

- **Hole collisions**: If a domain wall can decay via nucleation of different strings, holes can collide and lead to a single hole, crossed by a new 4d string.



D2-brane domain walls with F_4 and H_3 fluxes.

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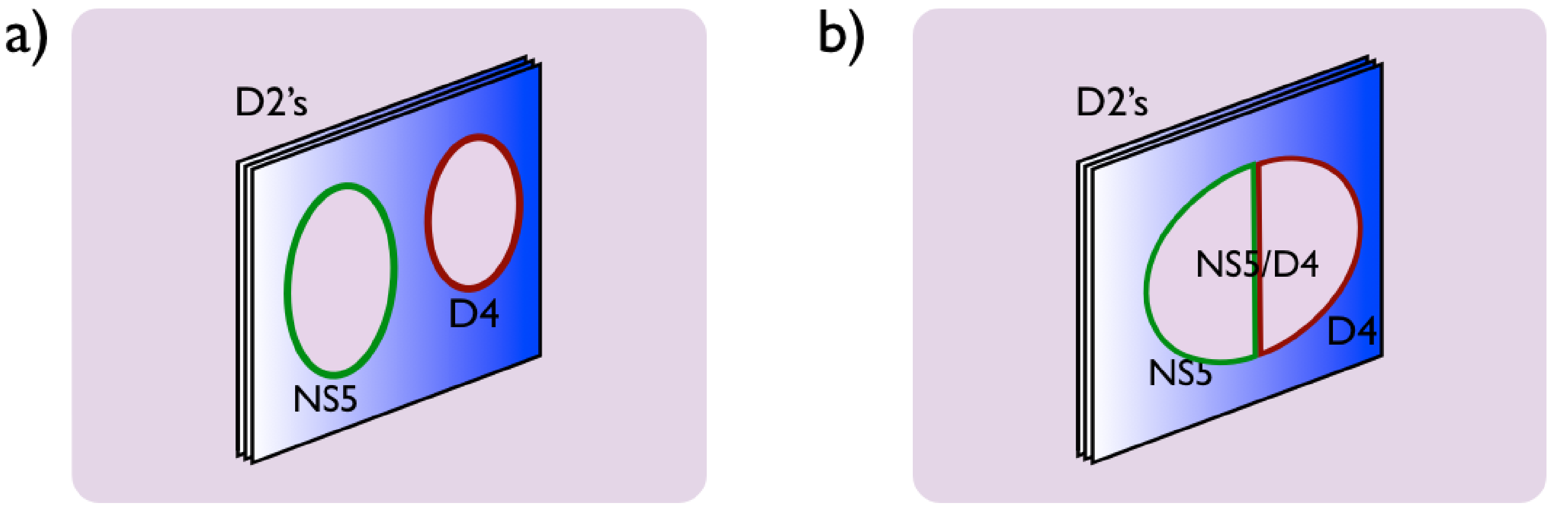
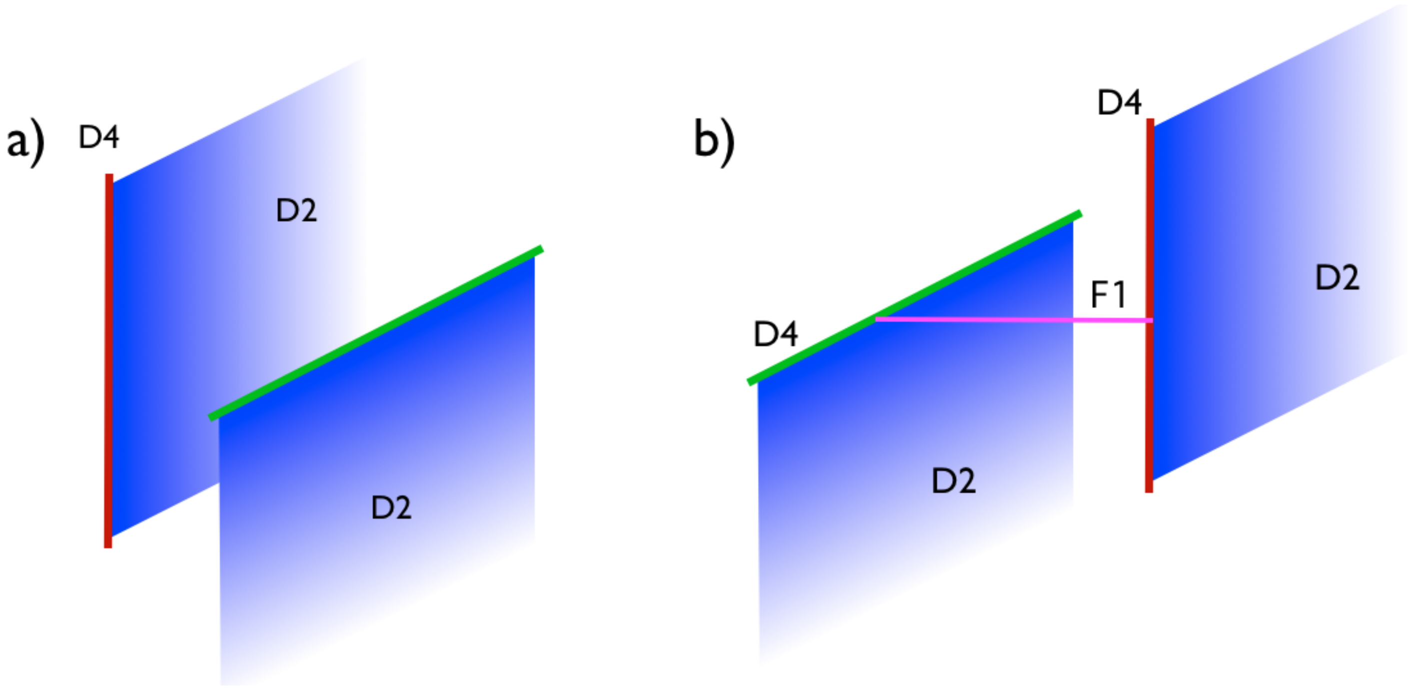


D2-brane domain walls with F_4 and H_3 fluxes.

- **Hanany-Witten effect**: The crossing of two strings with non-commuting monodromies associated to broken generators of G and commutator in H leads to the creation of a new 4d string with no domain wall attached.



D2-brane domain walls with H_3 fluxes

Summary

- We have seen that type II flux compactifications give rise to Abelian and non-Abelian discrete gauge symmetries.
- We have also studied the problems that may arise when several kinds of fluxes are simultaneously present in a compactification and how string theory avoids those inconsistent configurations.

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Thank you