Aspects of Exotic Branes

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1004.2521, 1107.2650, 1110.2781, 1209.6056, 1307.3115, 13mm.xxxx

Take-home messages:

- Exotic branes exist
- They are ubiquitous

What are exotic branes?

Duality in string theory

- Maps various branes into one another

$$T:\ \ \mathrm{D}p \leftrightarrow \mathrm{D}(p+1),\ \ \mathrm{F1} \leftrightarrow \mathrm{P},\ \ \mathrm{NS5} \leftrightarrow \mathrm{KKM},\ \ \ldots$$

$$S:\ \ \mathrm{F1} \leftrightarrow \mathrm{D1},\ \ \mathrm{NS5} \leftrightarrow \mathrm{D5},\ \ \ldots$$

"U-duality"

- Enhances in lower dims.
  - Torus compactification to D dims

    → U-duality group:

$$E_{k(k)}(\mathbb{Z}),\quad k = 11 - D$$

[Cremmer+Julia, & others] [Hull+Townsend]

D	k	U-duality group G
10A	1	1
10B	1	$SL(2,\mathbb{Z})$
9	2	$SL(2,\mathbb{Z}) \times \mathbb{Z}_2$
8	3	$SL(3,\mathbb{Z}) \times SL(2,\mathbb{Z})$
7	4	$SL(5,\mathbb{Z})$
6	5	$O(5,5,\mathbb{Z})$
5	6	$E_{6(6)}(\mathbb{Z})$
4	7	$E_{7(7)}(\mathbb{Z})$
3	8	$E_{8(8)}(\mathbb{Z})$

Duality & codim-2 objects

- U-duality on codim-2 objects produces exotic branes

10D/11D branes wrapped on internal torus

10D/11D origin not obvious

can have tension $\sim g_s^{-3}, g_s^{-4}$

[Elitzur+Giveon+Kutasov+Rabinovici]
[Blau+O'Loughlin] [Hull]
[Obers+Pioline+Rabinovici], all 1997

Example: particles in 3D

- M on T^8 or Type II on T^7 → 3D theory
  - → U-duality group $E_{8(8)}(\mathbb{Z})$
  - → Scalars $\mathcal{V} \in E_{8(8)}(\mathbb{Z})¥E_{8(8)}(\mathbb{R})/SO(16)$
- Particle multiplet:
  - → Start from a point-like object

    e.g. D7(3456789) wrapped on T^7
  - → Take T- and S-dualities to get other states

Particle multiplet in 3D

Type IIA	P (**7**), F1 (**7**), D0 (**1**), D2 (**21**), D4 (**35**), D6 (**7**), NS5 (**21**), KKM (**42**), 5_2^2 (**21**), 0_3^7 (**1**), 2_3^5 (**21**), 4_3^2 (**35**), 6_3^1 (**7**), $0_4^{(1,6)}$ (**7**), 1_4^6 (**7**)
Type IIB	P (**7**), F1 (**7**), D1 (**7**), D3 (**35**), D5 (**21**), D7 (**1**), NS5 (**21**), KKM (**42**) , 5_2^2 (**21**), 1_3^6 (**7**), 3_3^4 (**35**), 5_3^2 (**21**), 7_3 (**1**), $0_4^{(1,6)}$ (**7**), 1_4^6 (**7**)
M-theory	P (**8**), M2 (**28**), M5 (**56**), KKM (**56**), 5^3 (**56**), 2^6 (**28**), $0^{(1,7)}$ (**8**)

- Notation for exotic states

$$b_n^c : M = \frac{R^b (R^c)^2}{g_s^n} \qquad b_n^{(d,c)} : M = \frac{R^b (R^c)^2 (R^d)^3}{g_s^n}$$

<u>Example:</u> $5_2^2(34567,89)$: $M = \frac{R_3 \cdots R_7 \, (R_8 R_9)^2}{g_s^2 l_s^8}$

Duality rules

- Duality rules can be read off from:

$$T_y: \quad R_y \to \frac{l_s^2}{R_y}, \quad g_s \to \frac{l_s}{R_y} g_s \qquad S: \quad g_s \to \frac{1}{g_s}, \quad l_s \to g_s^{1/2} l_s$$

- Example:

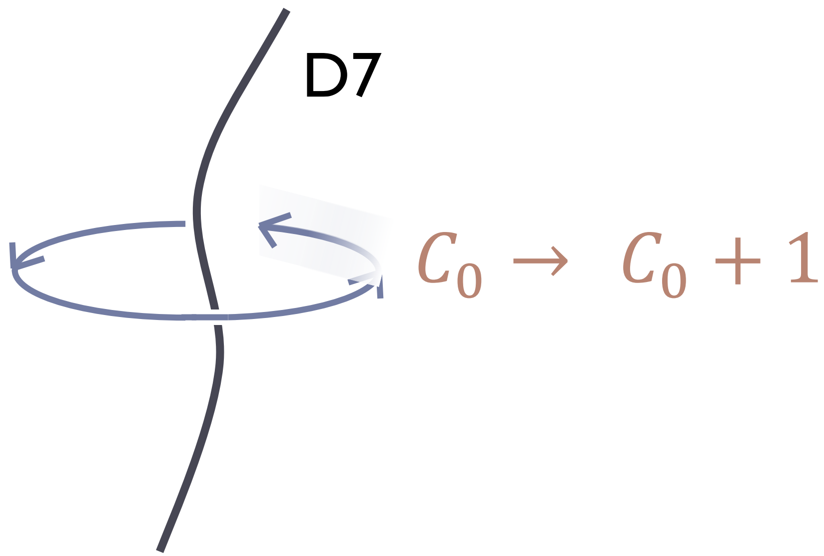
$$\mathrm{NS5}(34567) \xrightarrow{T_8} \mathrm{KKM}(34567,8) \xrightarrow{T_9} 5_2^2(34567,89)$$

$$M = \frac{R_3 \cdots R_7}{g_s^2 l_s^6} \xrightarrow{T_8} \frac{R_3 \cdots R_7}{(l_s/R_8)^2 l_s^6} = \frac{R_3 \cdots R_7 R_8^2}{g_s^2 l_s^8} \quad : 5_2^1 = \mathrm{KKM}$$

$$\xrightarrow{T_9} \frac{R_3 \cdots R_7 R_8^2}{(l_s/R_9)^2 l_s^8} = \frac{R_3 \cdots R_7 (R_8 R_9)^2}{g_s^2 l_s^{10}} \quad : 5_2^2$$

Exotic branes as non-geometric U-folds

D7-brane

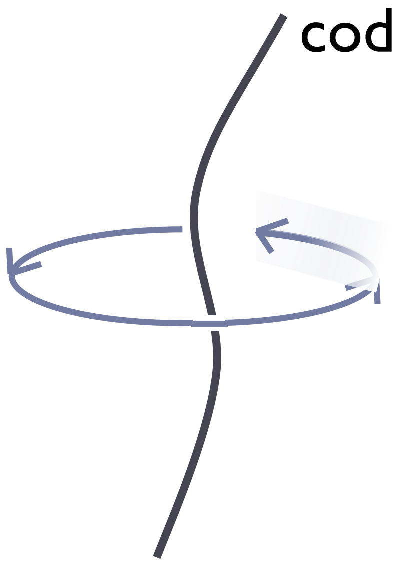


More generally…

- C_0: one of moduli scalars $\mathcal{V}$
- Shift sym: part of duality group $G(\mathbb{Z})$

Exotic brane = U-fold

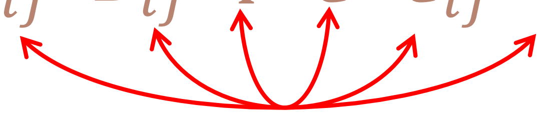
- *U*-duality group: $G(\mathbb{Z})$
- Moduli scalars: $\mathcal{V}$
- Charge: $q \in G(\mathbb{Z})$



Exotic brane as non-geom bg.

[de Boer+MS 2010, 2012]

- Moduli $\mathcal{V}$:
  internal components of metric and other fields
- U-duality mixes them $\quad \mathcal{V} \ni G_{ij} \;\; B_{ij} \;\; \Phi \;\; C \;\; C_{ij} \;\; C_{ijkl}$



$$\mathcal{V} \to q\mathcal{V}$$

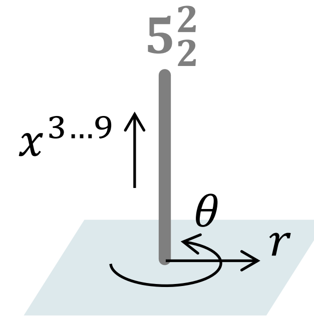
⇨ metric not single-valued;
It has monodromy

⇨ **non-geometric background ("*U*-fold")**

[Greene+Shapere+Vafa+Yau] [Vafa], [Kumar+Vafa] [Liu+Minasian] [Hellerman+McGreevy+Williams] …
[Hull] [Dabholkar+Hull] [Flournoy+Wecht+Williams] [Kachru+Schultz+Tripathy+Trivedi]
[McOrist+Morrison+Sethi] …

Sugra solution for 5_2^2 [de Boer+MS '10, '12]

$5_2^2(56789{,}34)$ metric:



$$ds^2 = -dt^2 + H\left(dr^2 + r^2 d\theta^2\right) + HK^{-1}dx_{34}^2 + dx_{56789}^2$$

$$B_{34} = -K^{-1}\theta\sigma, \qquad e^{2\Phi} = HK^{-1}, \qquad K \equiv H^2 + \sigma^2\theta^2$$

$$H(r) = h + \sigma \log\left(\frac{\mu}{r}\right) \qquad \sigma = \frac{R_3 R_4}{2\pi\alpha'}$$

Cf. [Blau+O'Loughlin 1997]: 6_3^1

- T-fold structure:

$$\theta = 0 \ : \quad G_{33} = G_{44} = H^{-1}$$

$$\theta = 2\pi : \quad G_{33} = G_{44} = \frac{H}{H^2 + (2\pi\sigma)^2}$$

→ x_3-x_4 torus size doesn't come back to itself

What are they good for?

Are they relevant?

- Codim-2: not well-defined as stand-alone object
  - Log behavior

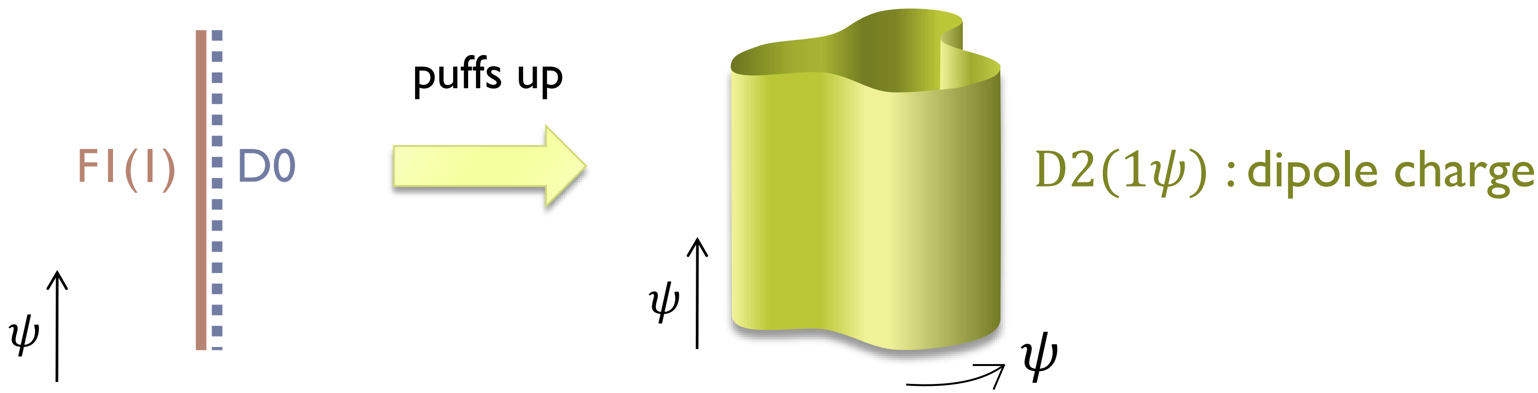
$$V \sim \frac{1}{r^{d-2}} \xrightarrow{d=2} V \sim \log\left(\frac{\mu}{r}\right)$$

  - Resolution:
    - Superpotision (cf. F-theory 7-branes)
    - Configs. with higher codims.

Supertube effect

- Supertube effect
  = spontaneous polarization phenomenon

[Mateos+Townsend 2001]



Dualizing supertubes

$$\mathrm{D0} + \mathrm{F1}(1) \to \mathrm{D2}(1\psi)$$

$$\Downarrow T_{234}$$

$$\mathrm{D3}(234) + \mathrm{F1}(1) \to \mathrm{D5}(1234\psi)$$

$$\Downarrow S$$

$$\mathrm{D3}(234) + \mathrm{D1}(1) \to \mathrm{NS5}(1234\psi)$$

$$\Downarrow T_{256}$$

$$\mathrm{D4}(3456) + \mathrm{D4}(1256) \to 5_2^2(1234\psi; 56)$$

Exotic supertubes [de Boer+MS '10, '12]

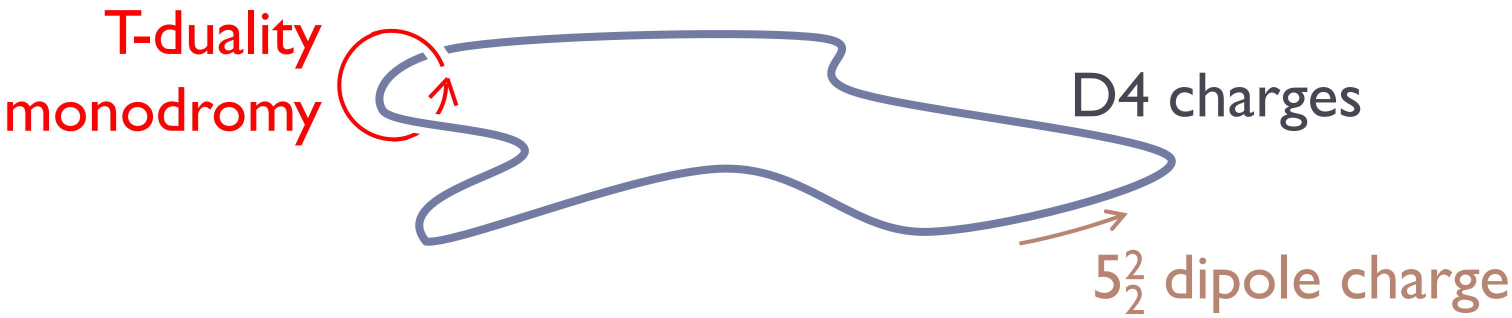
- Ordinary branes can puff up to produce exotic *dipole* charges

→ No log divergence (codim > 2 at large distance)

→ Exotic branes relevant to non-exotic physics;
More common than previously thought!

Sugra sol'n for exotic supertube

$$\mathrm{D4}(6789) + \mathrm{D4}(4589) \to 5^2_2(4567\psi, 89)$$



D4(6789)+D4(4589)→5^2_2 (4567ψ,89)

$$ds^2 = -\frac{1}{\sqrt{f_1 f_2}}(dt - A)^2 + \sqrt{f_1 f_5}\, dx_{123}^2 + \sqrt{\frac{f_1}{f_2}}\, dx_{45}^2 + \sqrt{\frac{f_2}{f_1}}\, dx_{67}^2 + \frac{\sqrt{f_1 f_2}}{f_1 f_2 + \gamma^2}\, dx_{89}^2,$$

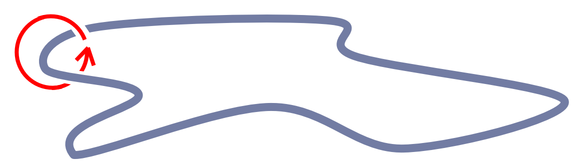
f_i , A : sourced along curve

$$f_1 = 1 + \frac{Q_1}{L}\int_0^L \frac{dv}{|\vec{x} - \vec{F}(v)|}, \quad f_2 = 1 + \frac{Q_1}{L}\int_0^L \frac{|\dot{\vec{F}}(v)|^2}{|\vec{x} - \vec{F}(v)|}dv, \quad A_i = -\frac{Q_1}{L}\int_0^L \frac{\dot{F}_i(v)}{|\vec{x} - \vec{F}(v)|}$$

$$d\beta_I = *_3\, df_I, \qquad d\gamma = *_3\, dA$$

- β_i, γ have monodromy around curve

$$\beta_I \to \beta_I - 2Q_I, \quad \gamma \to \gamma - 2q,$$



T-fold structure just as before

- Asymptotically flat 4D
- Non-geometric microstates (cf. [Sen])

D4(6789)+D4(4589)$\rightarrow 5_2^2$ (4567ψ,89)

Other fields:

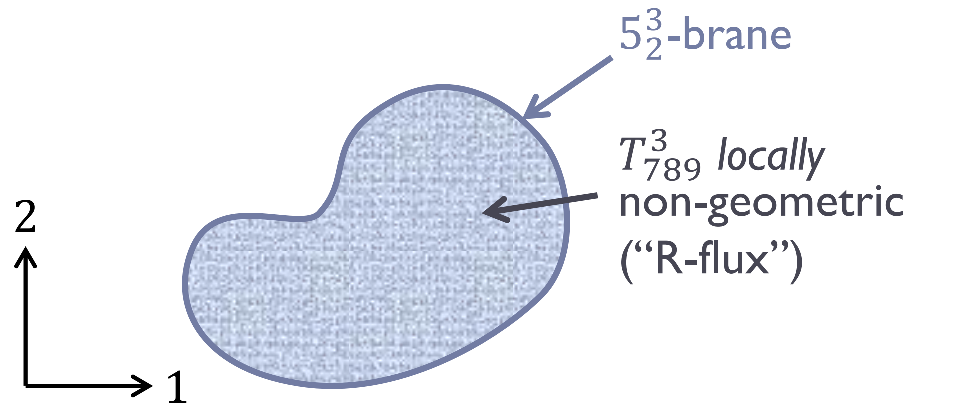
$$e^{2\Phi} = \frac{\sqrt{f_1 f_2}}{f_1 f_2 + \gamma^2}, \qquad B_{89}^{(2)} = \frac{\gamma}{f_1 f_2 + \gamma^2}, \qquad C^{(3)} = -\gamma\rho + \sigma$$

$$\rho = (f_2^{-1} + dt - A) \wedge dx^4 \wedge dx^5 + (f_1^{-1} + dt - A) \wedge dx^6 \wedge dx^7$$

$$\sigma = (\beta_1 - \gamma dt) \wedge dx^4 \wedge dx^5 + (\beta_2 - \gamma dt) \wedge dx^6 \wedge dx^7$$

Comments

- Other small-codim objects [Bergshoeff, Riccioni, …]
  - codim-2: exotic / defect branes
  - codim-1: domain walls E.g. [Haßler+Lüst 2013]
  - codim-0: space filling



$$\mathrm{D5}(34789) + \mathrm{D5}(56789) \to 5^3_2(3456\psi; 789)$$

Double bubbling
& black holes

Double bubbling (1)

- 5D BH system

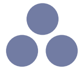
$$\mathrm{M2}(56),\ \mathrm{M2}(78),\ \mathrm{M2}(9A)$$

: Well studied for microstate geometry

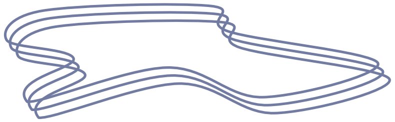
[Mathur] [Bena+Warner] [Berglund+Gimon+Levi]
[de Boer+El-Showk+Messamah+Van de Bleeken]

- Possible supertube transitions:

$\mathrm{M2}(56)$ $\mathrm{M2}(78)$ $\mathrm{M2}(9A)$	bubble →	$\mathrm{M5}(789A\psi)$ $\mathrm{M5}(568A\psi)$ $\mathrm{M5}(5678\psi)$	bubble →	$5^3(789A\phi, 56\psi)$ $5^3(569A\phi, 78\psi)$ $5^3(5678\phi, 9A\psi)$



cf. black ring



non-geometric

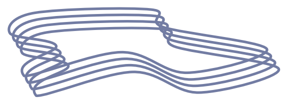
Double bubbling (2)

- Standard 4D BH system (MSW)

$$\mathrm{D0},\ \ \mathrm{D4}(6789),\ \ \mathrm{D4}(4589),\ \ \mathrm{D4}(4567)$$

: Well studied for microstate counting

- Possible supertube transitions:



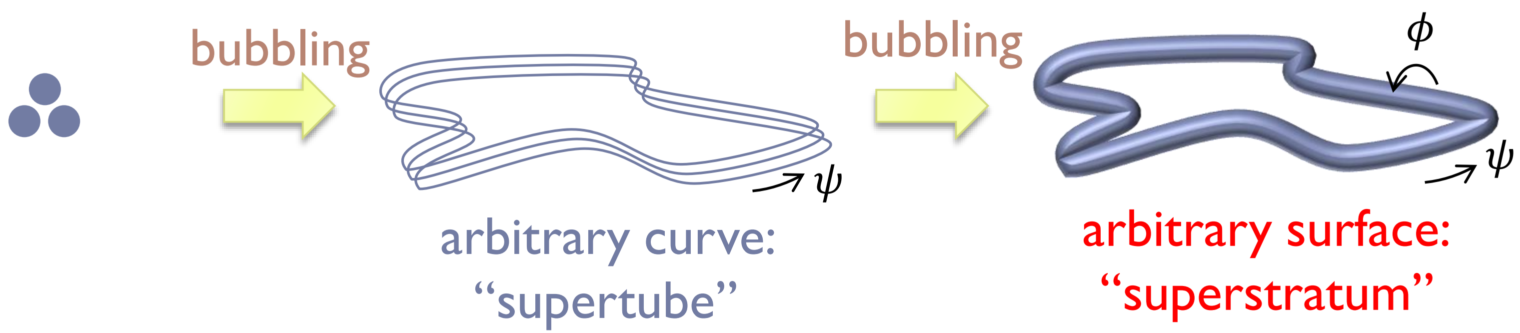
	$\mathrm{D4}(6789)$	bubble	$\mathrm{NS5}(6789\psi)$	$5^2_2(6789,45\psi)$
$\mathrm{D0}$	$\mathrm{D4}(4589)$	→	$\mathrm{NS5}(4589\psi)$	$5^2_2(4589,67\psi)$
	$\mathrm{D4}(4567)$		$\mathrm{NS5}(4567\psi)$	$5^2_2(4567,89\psi)$

non-geometric

bubble → More exotic charges?

Exotic branes & BH microstates

[de Boer+MS 1004.2521] [Bena+de Boer+MS+Warner 1107.2650]
[Bena+Giusto+MS+Warner 1110.2781] [MS 1307.3115]



- Bubbling can *in principle* occur multiple times, producing all possible branes, including exotic ones
- *Generic BH microstates involve exotic branes*
- Haven't yet constructed actual solutions.
  Still work in progress…

Charge as monodromy

[de Boer+MS 1209.6056]

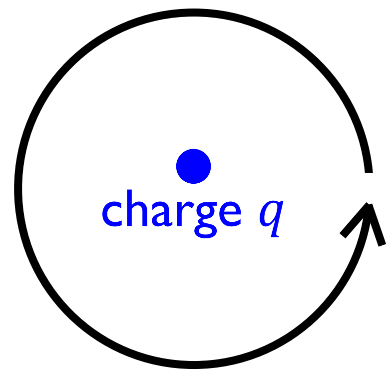
Charge as monodromy (1)

- How do we define charge = monodromy?
  - Moduli:

    $$\mathcal{V} \in G(\mathbb{Z})¥G(\mathbb{R})/H$$

  - Monodromy:

    $$\mathcal{V} \to q\mathcal{V}, \quad q \in G(\mathbb{Z})$$



→ Need more precise data

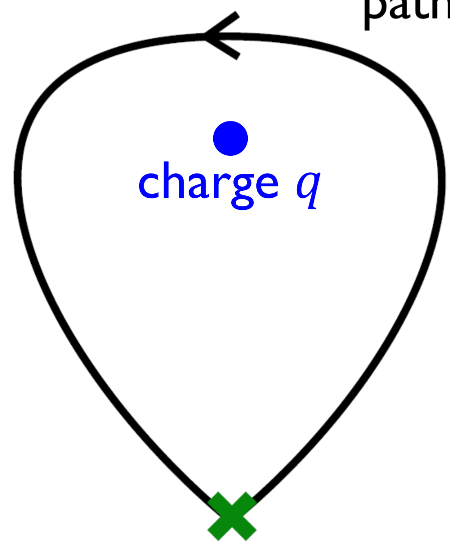
Charge as monodromy (2)

- Defining data
  - Base point P and value of moduli there, $\mathcal{V}(P)$
  - Path γ
  - Monodromy q:

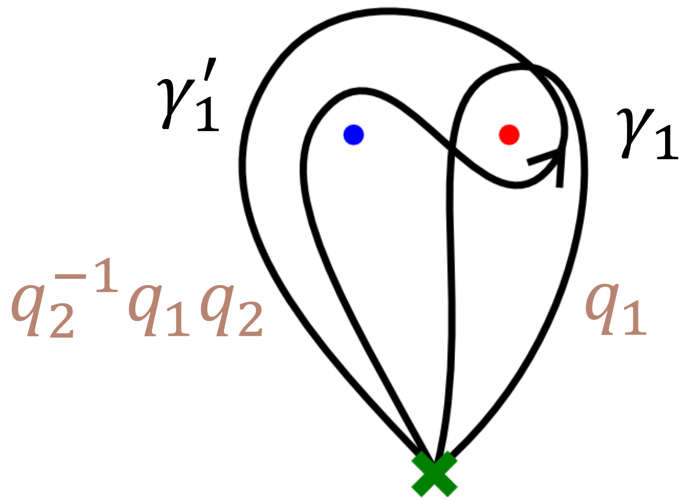
$$\mathcal{V} \to q\mathcal{V}$$

- Other moduli values
  - Moduli value $\tilde{\mathcal{V}} = U\mathcal{V}$

→ $\tilde{\mathcal{V}} \to \tilde{q}\tilde{\mathcal{V}}, \quad \tilde{q} \equiv UqU^{-1}$



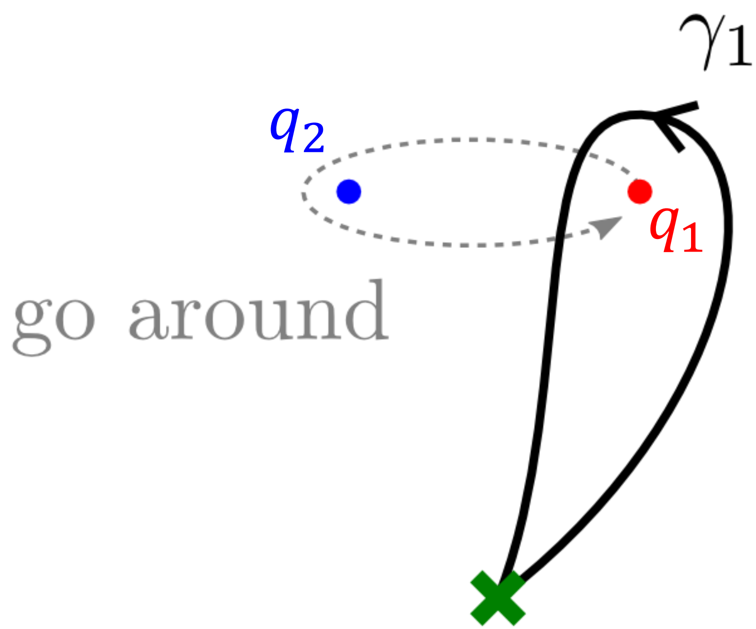
Charge and defining paths



Multiple ways to go around q_1

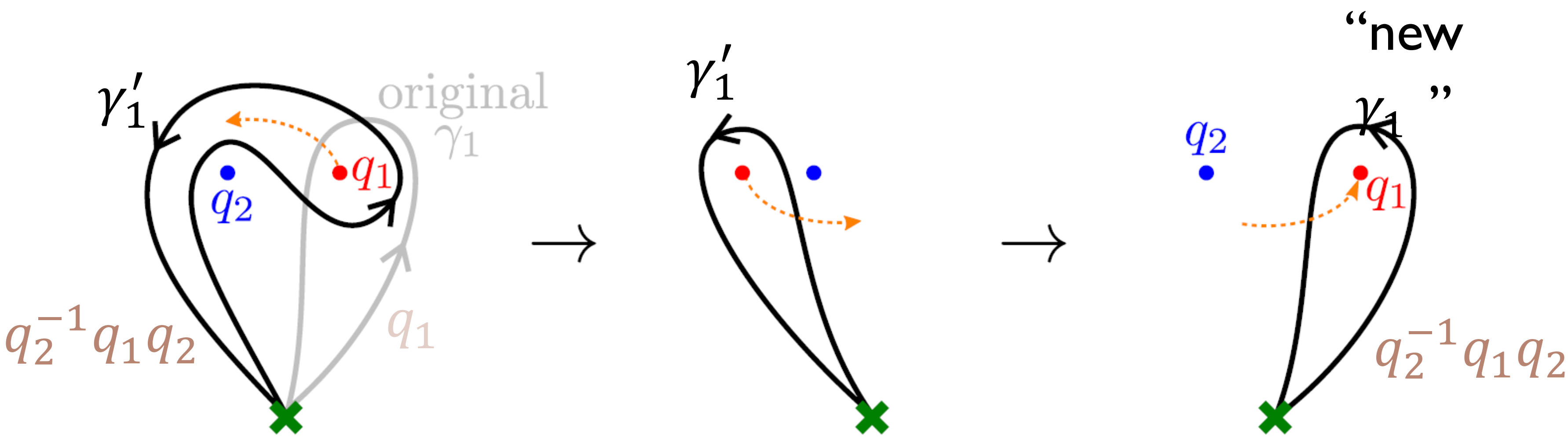
- Crucial to fix path to define charge
- Homotopically different paths define different charges related to each other by *U*-duality

Moving charge around another (1)



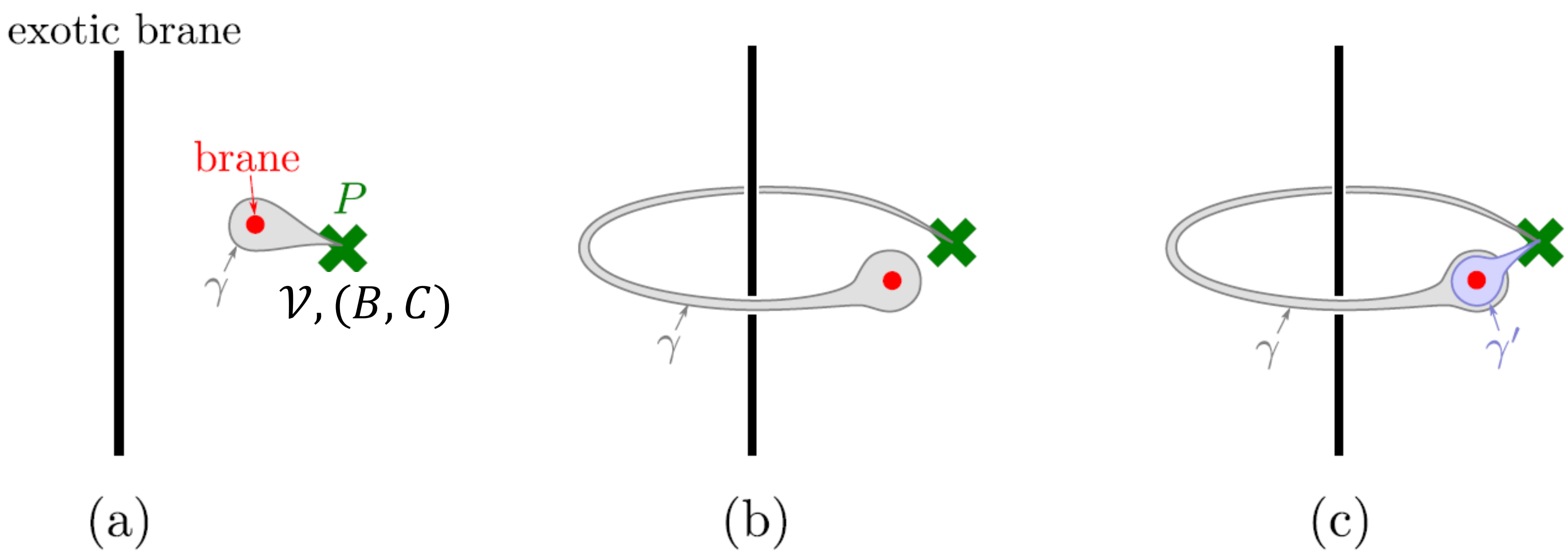
Q: What happens to monodromy, if q_1 is moved around q_2?

Moving charge around another (2)



- After moving q_1 around, γ_1' becomes “new γ_1”
- Looks as if charge jumps every time q_1 goes around
- No problem if we stick to one definition of charge

Lower charges



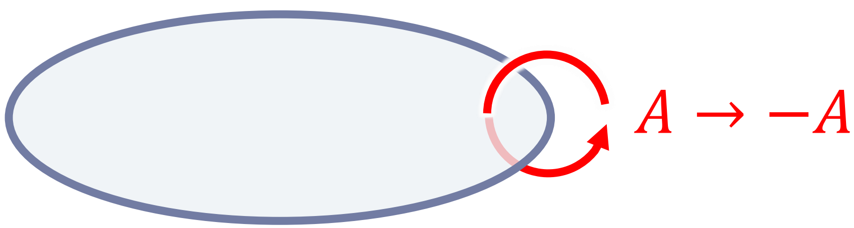
- Moduli $\mathcal{V}$ and forms (B, C) are multi-valued
- Charge defined relative to base point P
- Different paths define different charges related by *U*-duality

Alice string

Alice string

[A. Schwarz, 1982]
[Kikuchi+Okada+Sakatani 1205.5549]

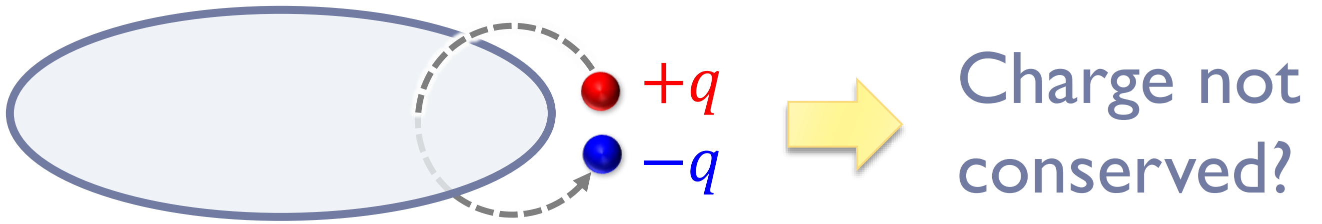
- Gauge theory with discrete gauge symmetry
  - E.g. $U(1)$ theory with $\mathbb{Z}_2$: $A_\mu = -A_\mu$
- Vortex solution with $\mathbb{Z}_2$ twist



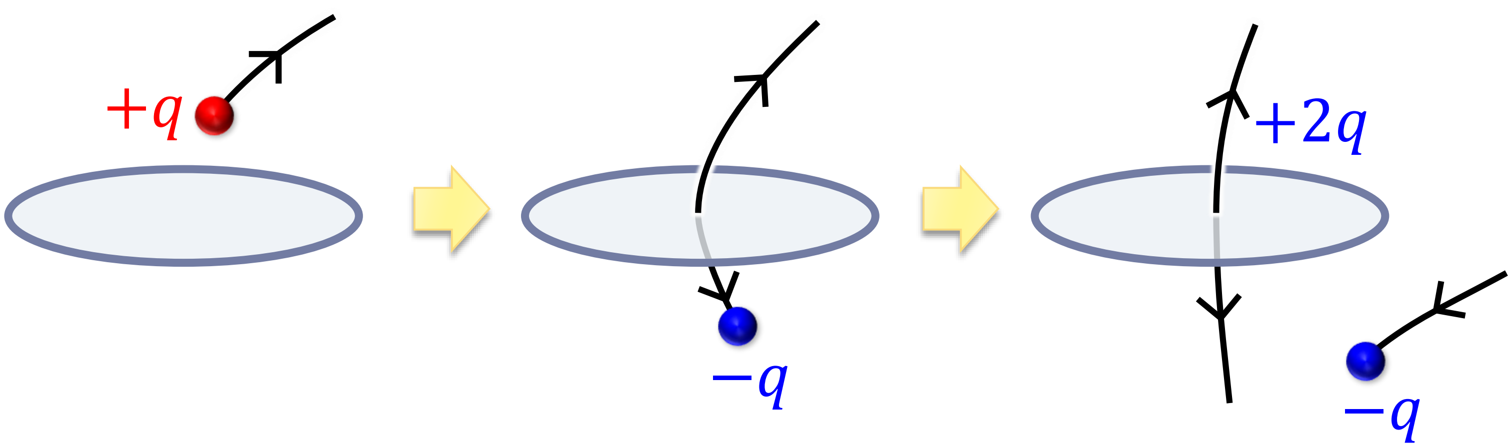
"Alice string"

Alice string & charge conservation

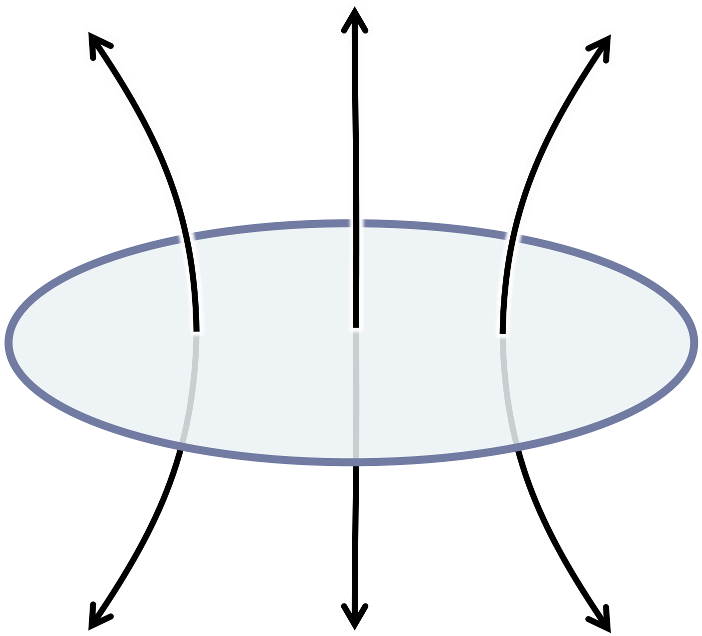
- Move charge through Alice string loop



- Charge left behind at the Alice string

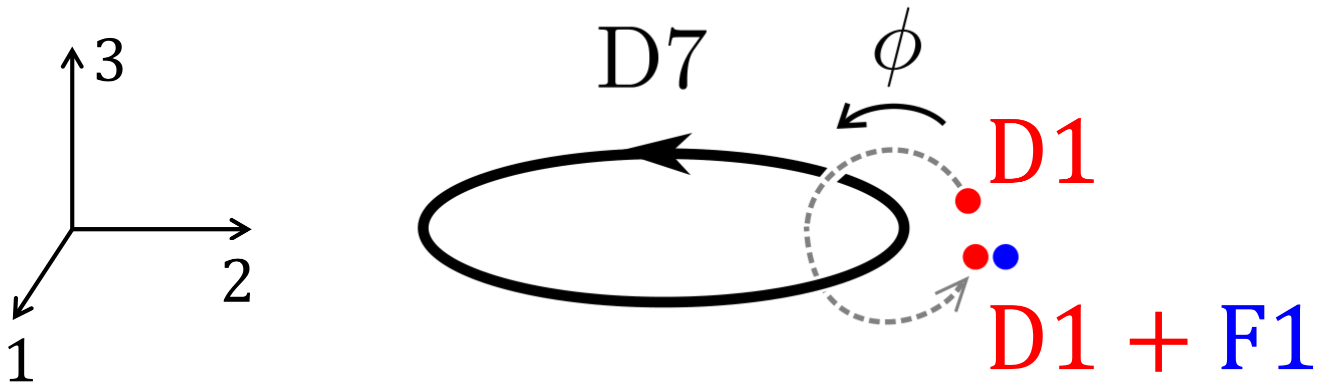


Cheshire charge



Charge without source

D7 as Alice string

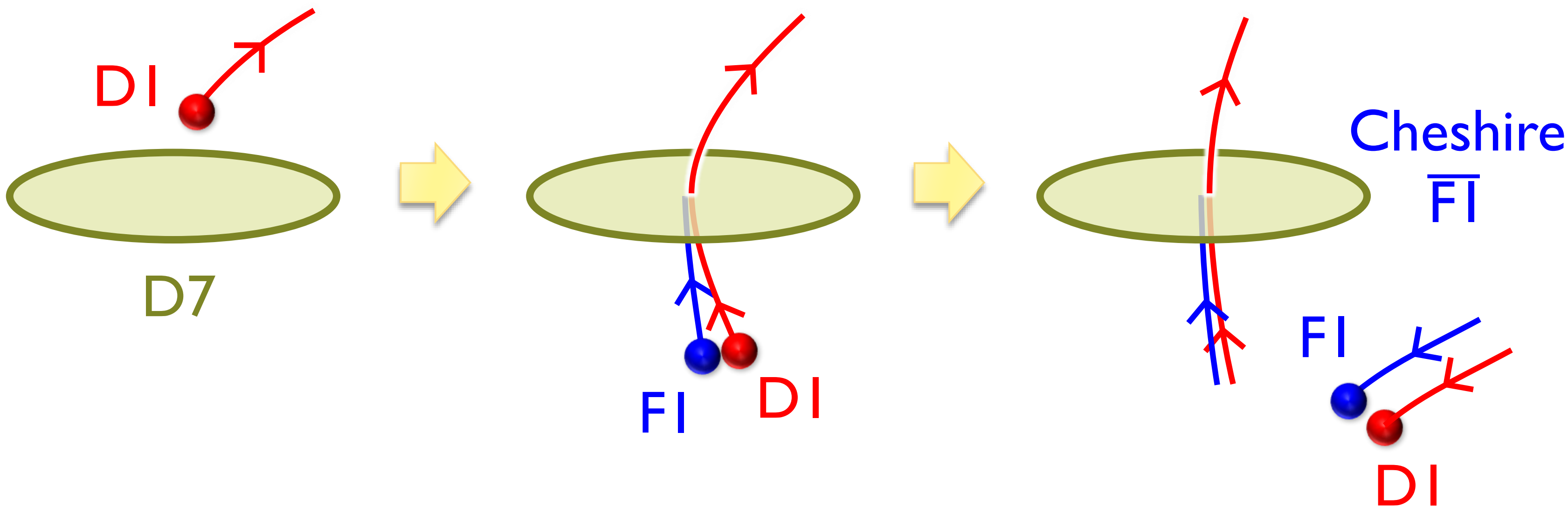


Going around D7(ψ456789) :

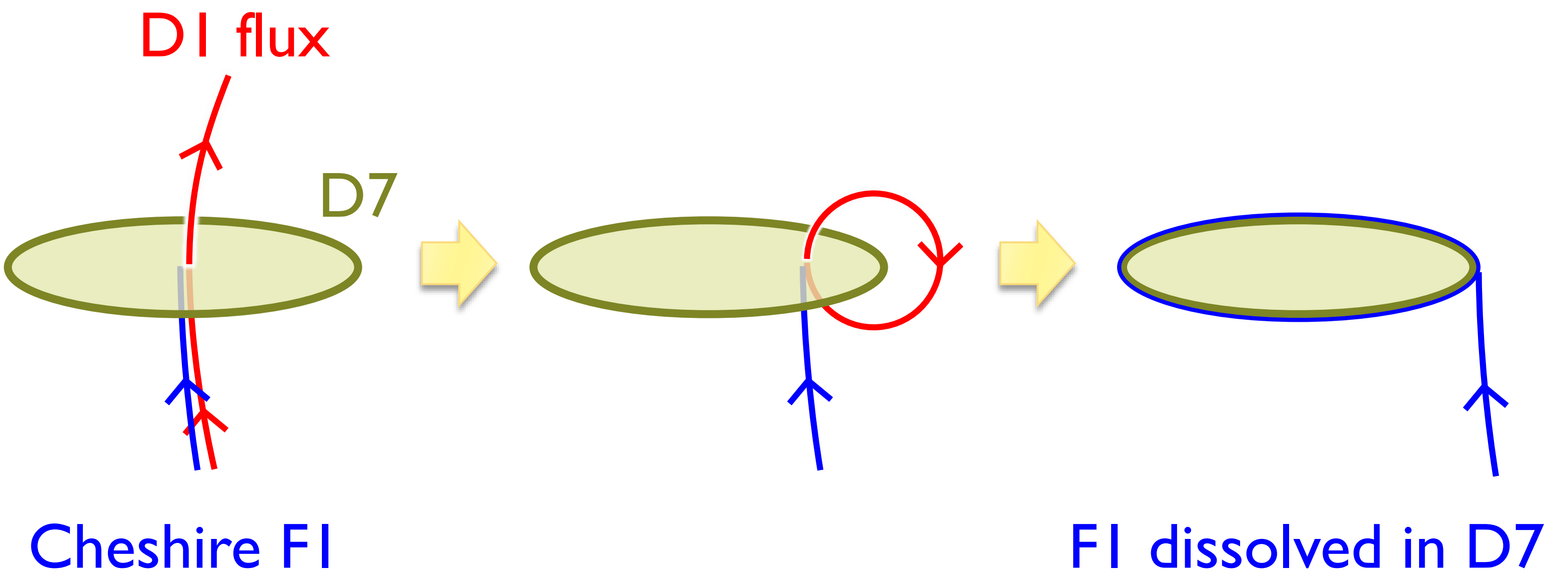
- Monodromy: $C_0 \to C_0 + 1$
- $\mathrm{D1}(4) \to \mathrm{D1}(4) + \mathrm{F1}(4)$

* Ring D7 stable as supertube D5(56789) + F1(4)

Stringy Cheshire charge



Cheshire charge & supertube



Can grow/reduce D5+F1→D7 supertube by moving D1 through it

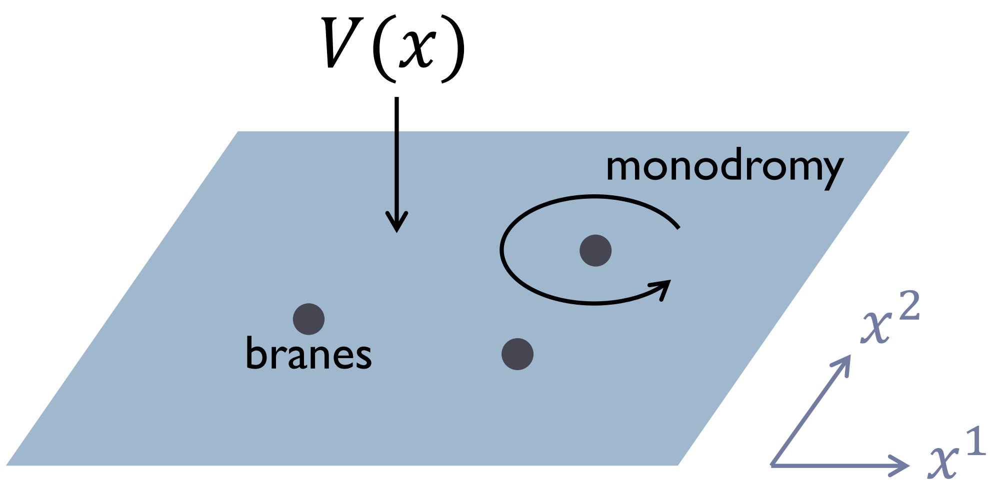
Classification

[de Boer+Mayerson+MS 13mm.xxxx]

Goal

“How many” exotic branes are there?

- Classify configs in sugra up to U-duality group G
- 3D: codim-2 branes are point-like
- All scalars packaged in matrix $V(x) \in G/K$



Coset scalars in sugra

- Scalars parametrize coset

$$V(x) \in G(\mathbb{R})/K(\mathbb{R})$$

G : duality group

K : maximal cpt. subgrp.

- Cartan decomposition:

$$\boldsymbol{g} = \boldsymbol{p} \oplus \boldsymbol{k}$$

$\boldsymbol{p}$: non-compact

$\boldsymbol{k}$: compact

- Fundamental form

$$V^{-1}dV = P + Q$$

$P \in \boldsymbol{g}$: physical

$Q \in \boldsymbol{k}$: "gauge"

- Action

$$S = \int d^3x\sqrt{-g}(R + g^{\mu\nu}\mathrm{tr}(P_\mu P_\nu)) + \cdots$$

3D maximal ($\mathcal{N} = 16$) sugra (1)

$$G = E_{8(8)}, \qquad K = SO(16)$$

$$\boldsymbol{g} = \boldsymbol{p} \oplus \boldsymbol{k}, \quad \boldsymbol{p} = \boldsymbol{e}_{8(8)} \ominus \boldsymbol{so}(16), \quad \boldsymbol{k} = \boldsymbol{so}(16)$$

$e_{8(8)}$ algebra:

- generators

  $\boldsymbol{k}$: X^{IJ} $(I, J = 1 \dots 16)$: so(16) generators

  $\boldsymbol{p}$: Q^A $(A = 1 \dots 128)$: so(16) spinors

- Commutation relations

$$[X^{IJ}, Q^A] = -\frac{1}{2}\Gamma^{IJ}_{AB} Q^B, \quad [Q^A, Q^B] = \frac{1}{2}\Gamma^{IJ}_{AB} X^{IJ}.$$

3D maximal ($\mathcal{N}=16$) sugra (2)

- Matter content

$$g_{\mu\nu}\,,\ \psi_\mu^I\,,\ \chi^{\dot{A}}\,,\ V$$

- Susy transformation

$$\delta\chi_{\dot{A}} \sim \gamma^\mu \epsilon^I \Gamma^I_{\dot{A}A} P^A_\mu$$

$$\delta\psi^I_\mu \sim \partial_\mu \epsilon^I + \frac{1}{4}\omega_\mu^{\hat{a}\hat{b}}\gamma_{\hat{a}\hat{b}}\epsilon^I + Q_\mu^{IJ}\epsilon^J$$

ϵ^I : susy transformation param

Supersymmetric solution

Require susy

$\Rightarrow$ $$ds^2 = -dt^2 + e^{U(z,\bar{z})} dz\, d\bar{z}$$ (timelike class)

— reduces to 2D problem

Susy condition:

$$\delta\chi_{\dot{A}} = 0 \Rightarrow P_z^A \Gamma^I_{\dot{A}A} \bar{\zeta}^I = 0$$ algebraic constraint cuts down ζ

$$\delta\psi^I_\mu = 0 \Rightarrow D(e^{-U}\zeta) = \bar{D}(e^U\zeta) = 0$$

differential constraint determing U

$$\zeta^I \equiv \epsilon^I_1 + i\epsilon^I_2$$

classification of susy solutions

⇕

classification of solutions of

$$P_z^{\ A}\Gamma^I_{\dot{A}A}\bar{\zeta}^I = 0$$

What is P_z that gives non-vanishing ζ?

Susy condition & orbits

$$P_z^A \Gamma^I_{\dot{A}A} \bar{\zeta}^I = 0$$

only rank of matrix $M^I_{\dot{A}} = P_z^A \Gamma^I_{\dot{A}A}$ matters

⇓

only conjugacy class (*orbit*) matters

$K_{\mathbb{C}}$ orbits in $\boldsymbol{p}_{\mathbb{C}}$

↕ "Kostant-Sekiguchi bijection"

$G_{\mathbb{R}}$ orbits in $\boldsymbol{g}_{\mathbb{R}}$

Types of orbit

Jordan decomposition:

Any $X \in \boldsymbol{g}$ can be decomposed as

$$X = X_S + X_N$$

semisimple (diagonalizable) → X_S

nilpotent ($X^n = 0, \exists n > 0$) → X_N

orbits:
- zero orbit
- semisimple orbits (infinite)
- nilpotent orbits (finite)
- other orbits

Lemma: statement

For two orbits $\mathcal{O}, \mathcal{O}'$

$$\bar{\mathcal{O}} \subseteq \bar{\mathcal{O}}' \quad \Rightarrow \quad x \geq x'$$

x : # susy preserved by $\mathcal{O}$

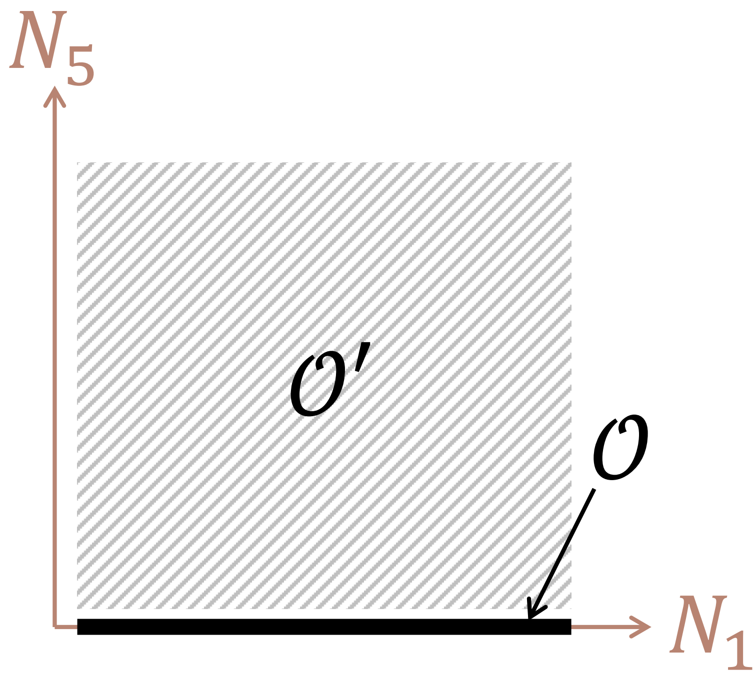
x': # susy preserved by $\mathcal{O}'$

"The smaller, the more supersymmetric"

Lemma: intuitive picture

$\mathcal{O}$: 1/2-BPS orbit (e.g. D1, $N_1 \neq 0$)

$\mathcal{O}'$: 1/4-BPS orbit (e.g. D1-D5, $N_1 \neq N_5 \neq 0$)



$$\bar{\mathcal{O}} \subseteq \bar{\mathcal{O}}'$$

Result 1: statement

P_Z *must be nilpotent to preserve susy*

Result 1: proof (1)

Assume $P_z \in \boldsymbol{p}_{\mathbb{C}}$ is *not* nilpotent.

Jordan decomposition:

$$P_z = P_S + P_N, \quad [P_S, P_N] = 0$$

Theorem [Kostant-Rallis]:

$$P_S \in \boldsymbol{p}_{\mathbb{C}}, \quad P_N \in \boldsymbol{p}_{\mathbb{C}}$$

Another theorem says

$$P_S \in \bar{\mathcal{O}}_P$$

Therefore

$$\mathcal{O}_{P_S} \subseteq \bar{\mathcal{O}}_P$$

Result 1: proof (2)

Theorem: every non-zero semi-simple orbit contains a nonzero element of Cartan subalgebra.

$$\Rightarrow \qquad c_i H_i \in \mathcal{O}_{P_S} \subseteq \bar{\mathcal{O}}_P$$

Using Mathematica, can check that $c_i H_i$ always breaks all susy. From Lemma,

$$\Rightarrow \quad \mathcal{O}_P \text{ breaks all susy}$$

So, P_Z must have been nilpotent to preserve susy.

□

Result 2: statement

Đoković classified all 115 nilpotent orbits of $E_{8(8)}(\mathbb{R})$.

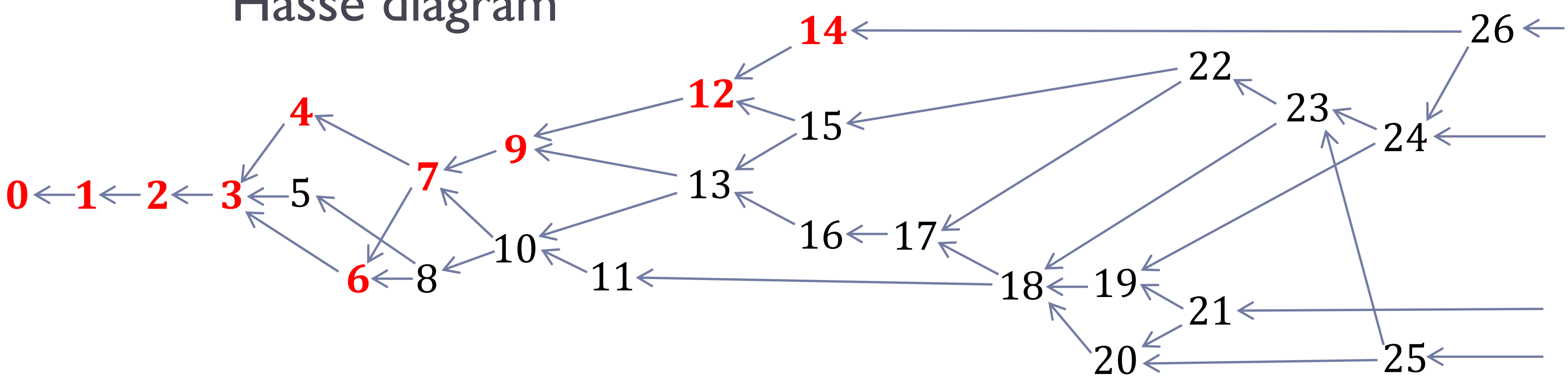
To preserve susy, P_Z must be an element of nilpotent orbits 1,2,3,4,6,7,9,12, or 14.

$$\begin{aligned} 1 &: 1/2 \text{ BPS} \\ 2 &: 1/4 \text{ BPS} \\ 3, 4 &: 1/8 \text{ BPS} \\ 6, 7, 9, 12, 14 &: 1/16 \text{ BPS} \end{aligned}$$

Result 2: proof

Closure relation [Đoković]: $\bar{\mathcal{O}}_i \subseteq \bar{\mathcal{O}}_j : i \leftarrow j$

"Hasse diagram"



- From explicit P_z given by Đoković, can show susy for orbits 1,2,3,4,6,7,9,12,14
- Orbit 5 breaks all susy. Lemma means all other orbits break all susy.

Brane realizations

- Focus on single-center configuration
- From P_z, read off what brane it corresponds to

Question:
Are there configs that can*not* be represented by standard branes, in any U-duality frame?

Susy configs (1)

1/2 BPS (orbit #1)

	3	4	5	6	7	8	9
D4	-	-	-	O	O	O	O

1/4 BPS (orbit #2)

	3	4	5	6	7	8	9
D4	-	-	-	O	O	O	O
D4	-	O	O	-	-	O	O

Susy configs (2)

1/8 BPS

(#3)

	3	4	5	6	7	8	9
D4	-	-	-	O	O	O	O
D4	-	O	O	-	-	O	O
D4	-	O	O	O	O	-	-
D0	-	-	-	-	-	-	-

(#4)

	3	4	5	6	7	8	9
D4	-	-	-	O	O	O	O
D4	-	O	O	-	-	O	O
D4	-	O	O	O	O	-	-
D4	O	O	-	O	-	O	-

Susy configs (3)

1/16 BPS (#12)

	3	4	5	6	7	8	9
D4	-	-	-	○	○	○	○
D4	-	○	○	-	-	○	○
D4	-	○	○	○	○	-	-
D0	-	-	-	-	-	-	-
F1	○	-	-	-	-	-	-
KKM	○	◎	-	○	○	○	○
KKM	○	○	○	◎	-	○	○
KKM	○	○	○	○	○	◎	-

Comments

- All *single-center susy* configs can be represented by standard branes
- New $\frac{1}{16}$-BPS config with standard branes??
- *Non-susy single-center* configs (such as orbit #115) involve exotic branes
- *Multi-center* configs involve exotic branes
- Work in progress toward more complete classification…

Conclusions

Summary

- Exotic branes are
  - Non-geometric *U*-folds
  - More common than previously thought
    — Relevant for BH physics?
- Codim-2 nature leads to non-trivial interplay between charges and monodromies
- Classification of codim-2 branes
  $\sim$ classification of nilpotent orbits

Future directions

- Non-Abelian vortices, Alice electrodynamics
- Spacetimes with exotic monodromies
  [Chiodaroli+D'Hoker+Guo+Gutperle] [Martucci+Morales+Pacifici]
- Doubled geometry, double (extended) field theory, non-geometric compactification
  [Hull]… [Hohm] [Zwiebach][Hillmann][Bermann+Perry]…
  [Aldazabal+][Grana+Marquess][Berman+][Andriot+]…
- Worldsheet description [Kimura+Sasaki]
- BH microstates

………

Thanks!