Aspects of Exotic branes

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1004.2521, 1107.2650, 1110.2781, 1209.6056, 1307.xxxx, 1308.xxxx

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

Known codim-2 object $\xrightarrow{\text{U-duality}}$ 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 $\mathcal{V} \in E_{8(8)}(\mathbb{Z})\backslash E_{8(8)}(\mathbb{R})/SO(16)$
- 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 $(\mathbf{7})$, F1 $(\mathbf{7})$, D0 $(\mathbf{1})$, D2 $(\mathbf{21})$, D4 $(\mathbf{35})$, D6 $(\mathbf{7})$, NS5 $(\mathbf{21})$, KKM $(\mathbf{42})$, 5^2_2 $(\mathbf{21})$, 0^7_3 $(\mathbf{1})$, 2^5_3 $(\mathbf{21})$, 4^2_3 $(\mathbf{35})$, 6^1_3 $(\mathbf{7})$, $0^{(1,6)}_4$ $(\mathbf{7})$, 1^6_4 $(\mathbf{7})$
Type IIB	P $(\mathbf{7})$, F1 $(\mathbf{7})$, D1 $(\mathbf{7})$, D3 $(\mathbf{35})$, D5 $(\mathbf{21})$, D7 $(\mathbf{1})$, NS5 $(\mathbf{21})$, KKM $(\mathbf{42})$, 5^2_2 $(\mathbf{21})$, 1^6_3 $(\mathbf{7})$, 3^4_3 $(\mathbf{35})$, 5^2_3 $(\mathbf{21})$, 7_3 $(\mathbf{1})$, $0^{(1,6)}_4$ $(\mathbf{7})$, 1^6_4 $(\mathbf{7})$
M-theory	P $(\mathbf{8})$, M2 $(\mathbf{28})$, M5 $(\mathbf{56})$, KKM $(\mathbf{56})$, 5^3 $(\mathbf{56})$, 2^6 $(\mathbf{28})$, $0^{(1,7)}$ $(\mathbf{8})$

- Notation for exotic states

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

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

Duality rules

- Duality rules can be read off from:

$$T_y: \quad R_y \to \frac{l_2^2}{R_y}, \quad g_s \to \frac{l_s}{R_y} g_s \qquad\qquad S: \quad g_s \to \frac{1}{g_s}, \quad l_s \to g_s^{1/2} l_s$$

- Example:

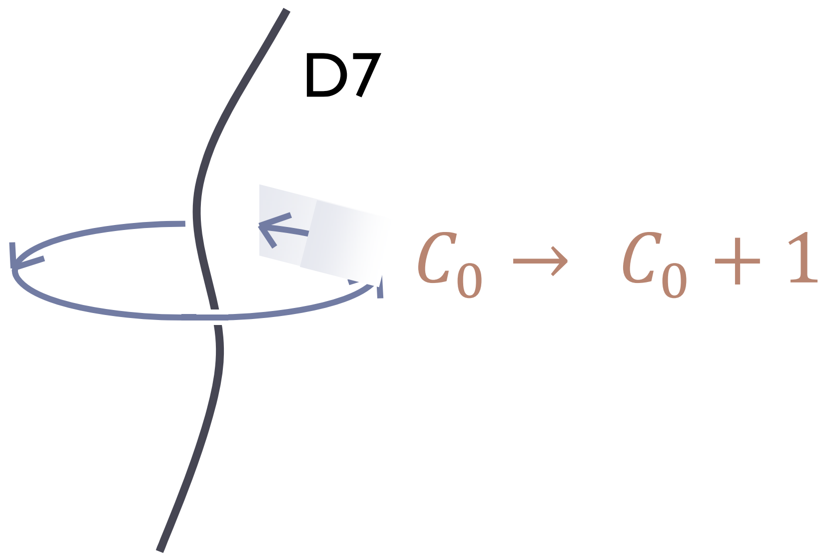
$$\mathrm{NS5}(34567) \xrightarrow{\mathrm{T}_8} \mathrm{KKM}(34567,8) \xrightarrow{\mathrm{T}_9} 5_2^2(34567,89)$$

$$M = \frac{R_3 \cdots R_7}{g_s^2 l_s^6} \xrightarrow{\mathrm{T}_8} \frac{R_3 \cdots R_7}{(l_s/R_8)^2 l_s^6} = \frac{R_3 \cdots R_7 R_8^2}{g_s^2 l_s^8} \quad : 5_2^1 = \mathrm{KKM}$$

$$\xrightarrow{\mathrm{T}_9} \frac{R_3 \cdots R_7 R_8^2}{(l_s/R_9)^2 l_s^8} = \frac{R_3 \cdots R_7 (R_8 R_9)^2}{g_s^2 l_s^{10}} \quad : 5_2^2$$

Exotic branes as U-folds

D7-brane

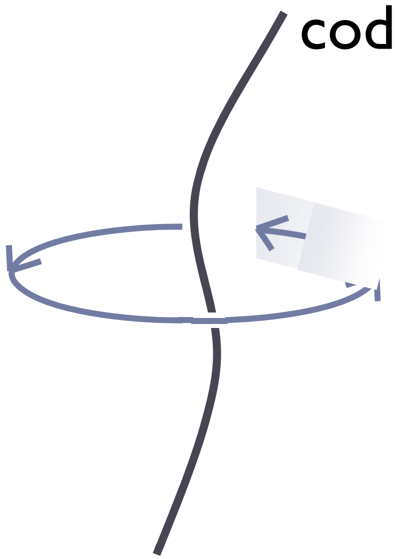


More generally…

- 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: $q \in G(\mathbb{Z})$



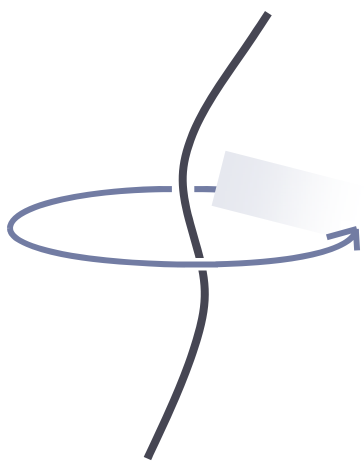
codim-2 exotic brane with charge q

$\mathcal{V} \to q\mathcal{V}$: $G(\mathbb{Z})$ monodromy

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”)**

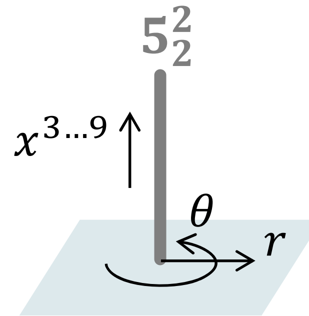
[Greene+Shapere+Vafa+Yau] [Vafa], [Kumar+Vafa] [Liu+Minasian] [Hellerman+McGreevy+Williams] …
[Hull] [Dabholkar+Hull] [Flournoy+Wecht+Williams] [Kachru+Schultz+Tripathy+Trivedi]
[McOrist+Morrison+Sethi] …

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

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

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

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



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

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

- T-fold structure:

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

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

→ 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

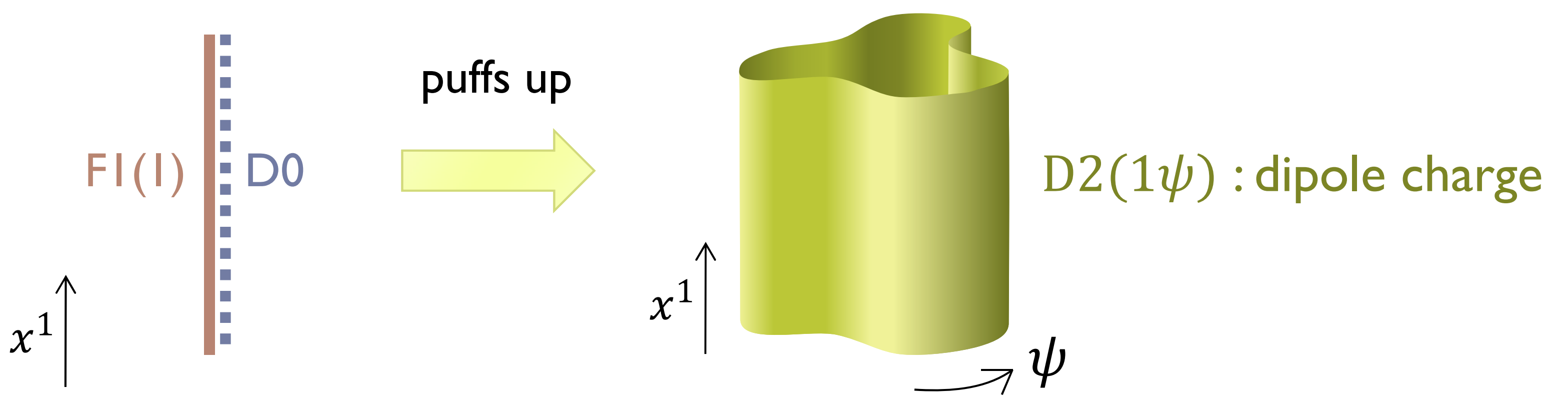
$$V \sim \frac{1}{r^{d-2}} \xrightarrow{d\,=\,2} V \sim \log\left(\frac{\mu}{r}\right)$$

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

Supertube effect

- Supertube effect
  = spontaneous polarization phenomenon

[Mateos+Townsend 2001]



Dualizing supertubes

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

$$\Big\Downarrow\; T_{234}$$

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

$$\Big\Downarrow\; S$$

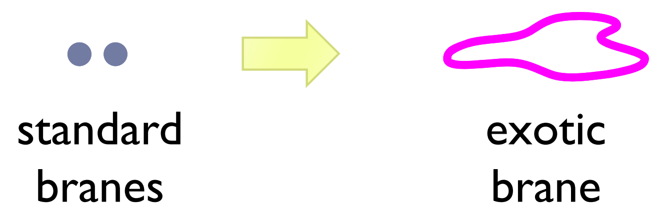
$$\mathrm{D3}(234) + \mathrm{D1}(1) \to \mathrm{NS5}(1234\psi)$$

$$\Big\Downarrow\; T_{256}$$

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

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

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

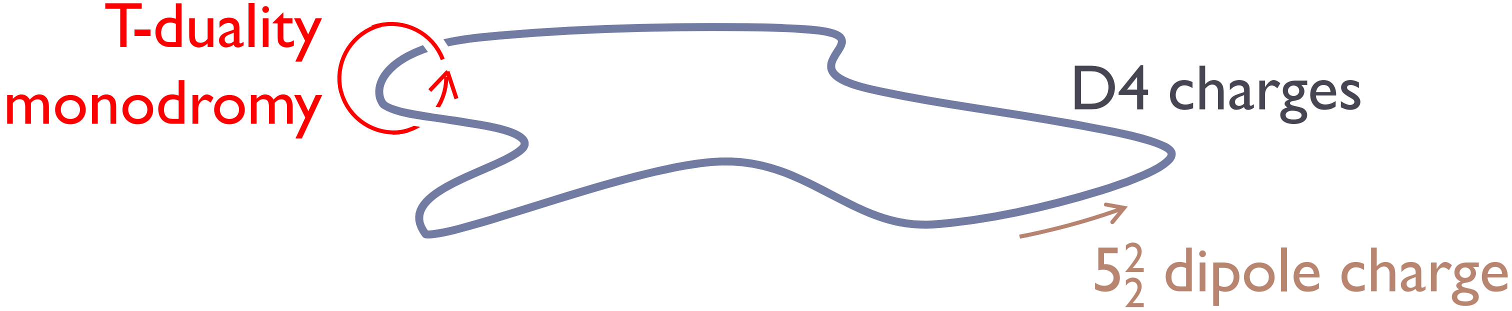


→ No log divergence (codim > 2 at large distance)

→ 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)

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

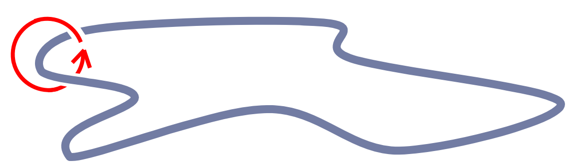
f_i , A : sourced along curve

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

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

- 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)→5^2_2 (4567ψ,89)

Other fields:

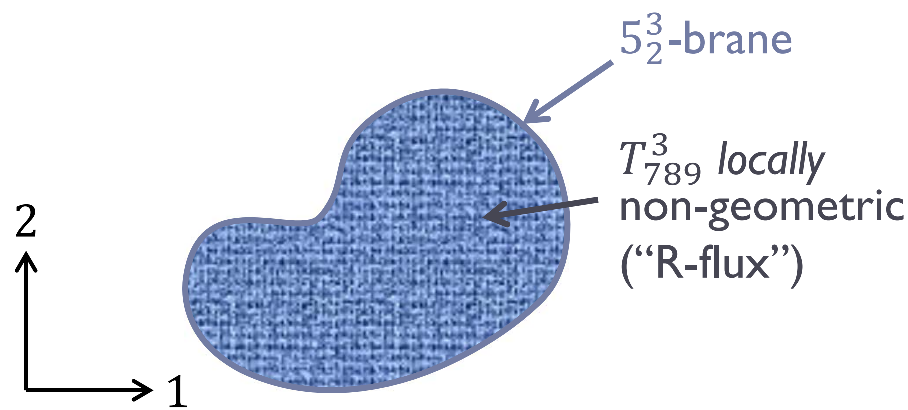
$$e^{2\Phi} = \frac{\sqrt{f_1 f_2}}{f_1 f_2 + \gamma^2}, \qquad B^{(2)}_{89} = \frac{\gamma}{f_1 f_2 + \gamma^2}, \qquad C^{(3)} = -\gamma\rho + \sigma$$

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

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

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

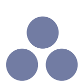
$$\mathrm{M2}(56),\ \mathrm{M2}(78),\ \mathrm{M2}(9\mathrm{A})$$

: Well studied for microstate geometry

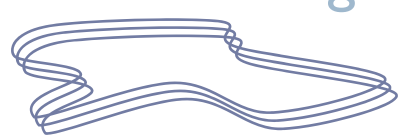
[Mathur] [Bena+Warner] [Berglund+Gimon+Levi]
[de Boer+El-Showk+Messamah+Van de Bleeken]

- Possible supertube transitions:

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



cf. black ring



non-geometric

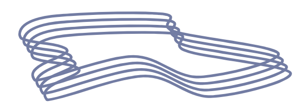
Double bubbling (2)

- Standard 4D BH system (MSW)

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

: Well studied for microstate counting

- Possible supertube transitions:



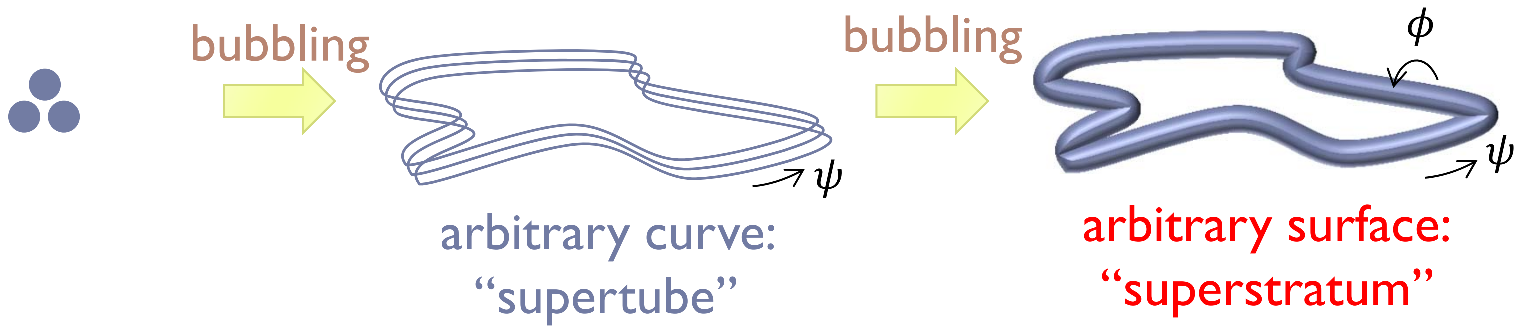
$$\begin{array}{cccc} & \mathrm{D4}(6789) & & \mathrm{NS5}(6789\psi) \quad 5^2_2(6789,45\psi) \\ \mathrm{D0} & \mathrm{D4}(4589) & \xrightarrow{\text{bubble}} & \mathrm{NS5}(4589\psi) \quad 5^2_2(4589,67\psi) \\ & \mathrm{D4}(4567) & & \mathrm{NS5}(4567\psi) \quad 5^2_2(4567,89\psi) \end{array}$$

non-geometric

$\xrightarrow{\text{bubble}}$ 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]



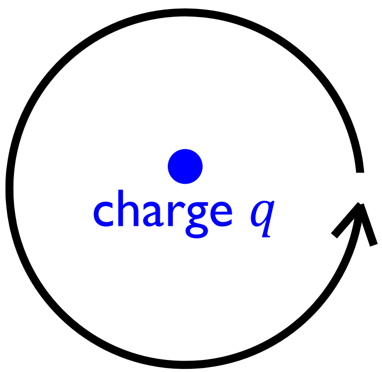
- Bubbling can in principle occur multiple times, producing all possible branes, including exotic ones
- *Generic BH microstates involve exotic branes*
- Still work in progress…

Charge as monodromy

[de Boer+MS 1209.6056]

Charge as monodromy (1)

- How do we define charge = monodromy?
  - Moduli:
    $$\mathcal{V} \in G(\mathbb{Z})\backslash G(\mathbb{R})/H$$
  - Monodromy:
    $$\mathcal{V} \to q\mathcal{V}, \quad q \in G(\mathbb{Z})$$

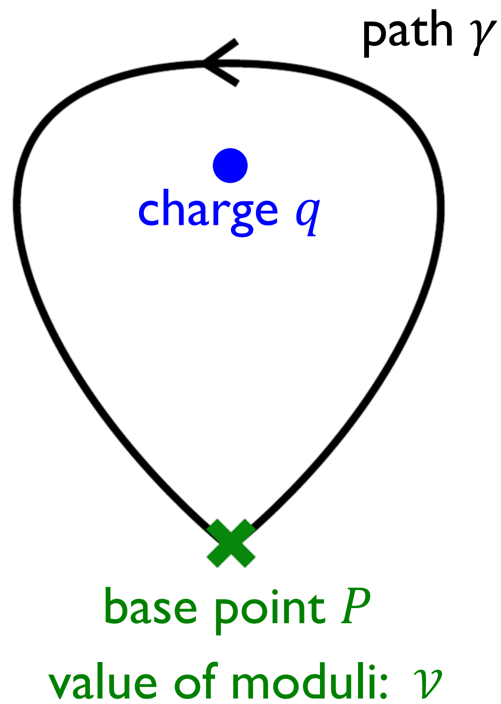


→ Need more precise data

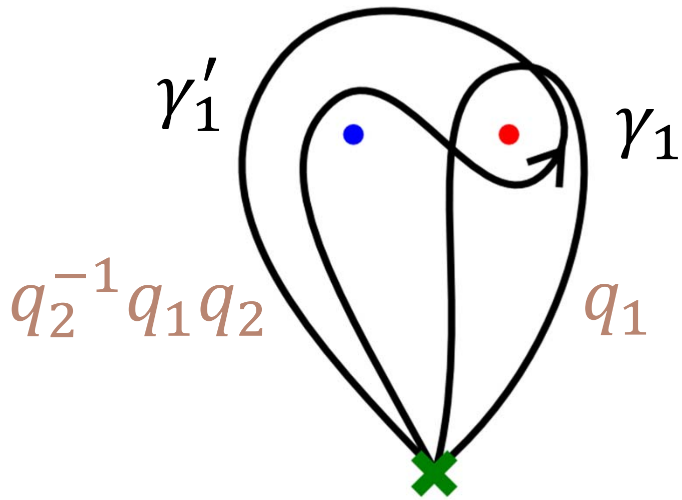
Charge as monodromy (2)

- 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 $\tilde{\mathcal{V}} = U\mathcal{V}$

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



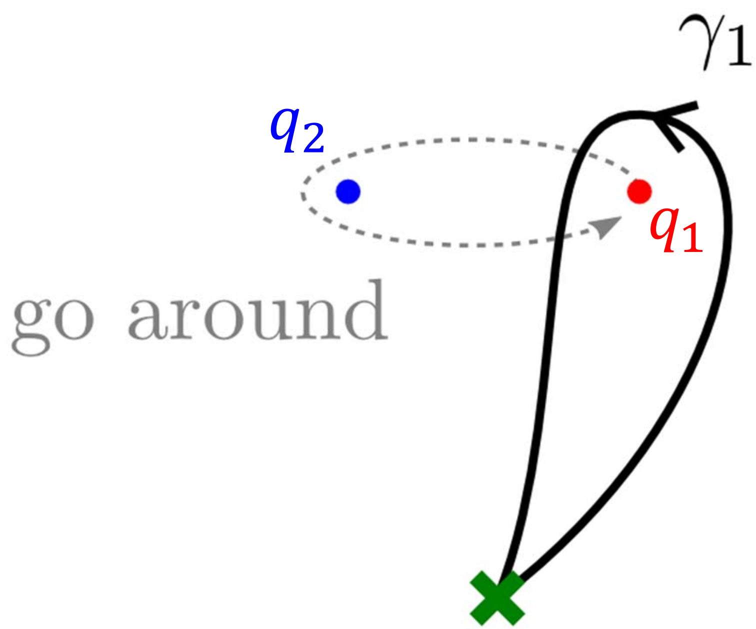
Charge and defining paths



Multiple ways to go around q_1

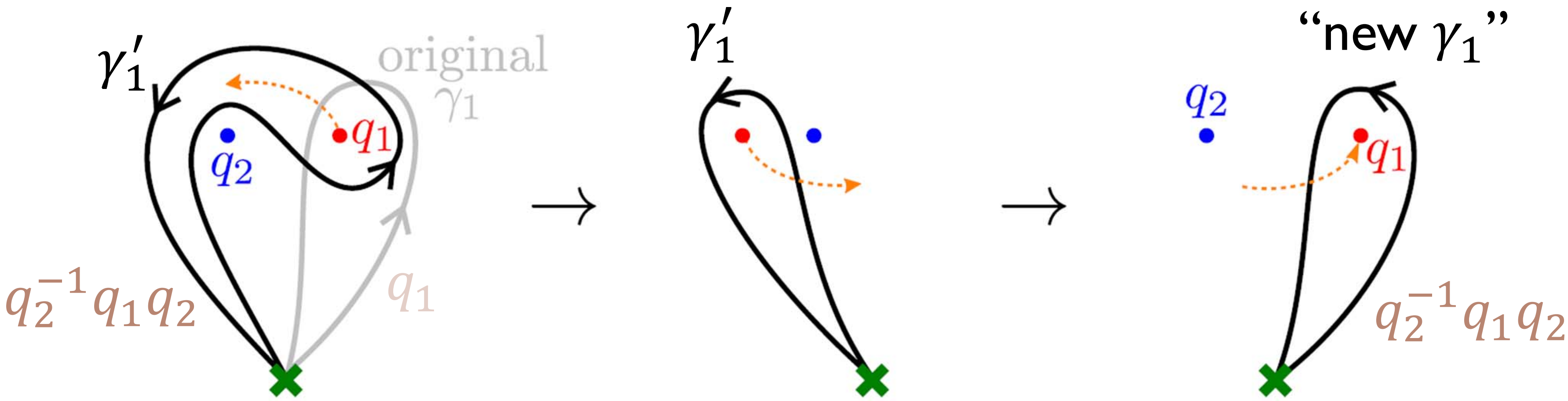
- Crucial to fix path to define charge
- Homotopically different paths define different charges related to each other by *U*-duality

Moving charge around another (1)



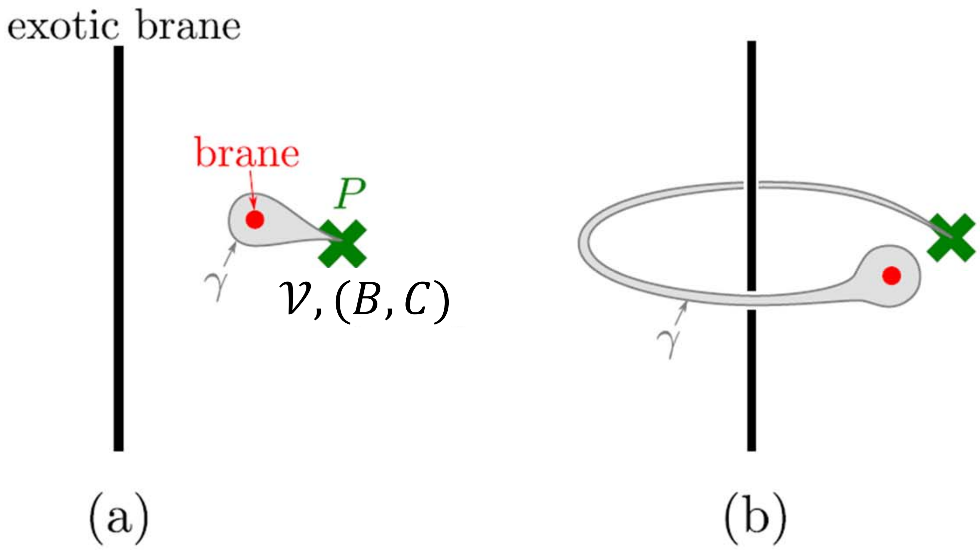
Q: What happens to monodromy,
if q_1 is moved around q_2?

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



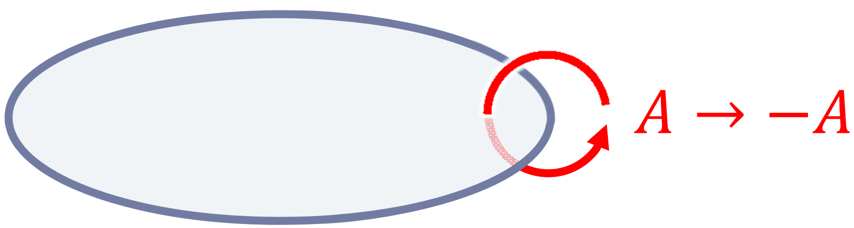
- Moduli $\mathcal{V}$ and forms (B, C) are multi-valued
- Charge defined in relation to base point P
- Different paths define different charges related by *U*-duality

Alice string

Alice string

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

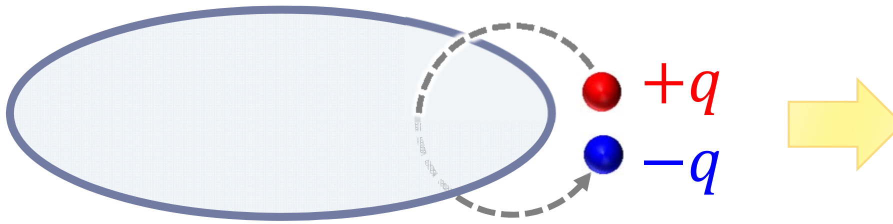
- Gauge theory with discrete gauge symmetry
  - E.g. $U(1)$ theory with $\mathbb{Z}_2$: $A_\mu = -A_\mu$
- Vortex solution with $\mathbb{Z}_2$ twist



"Alice string"

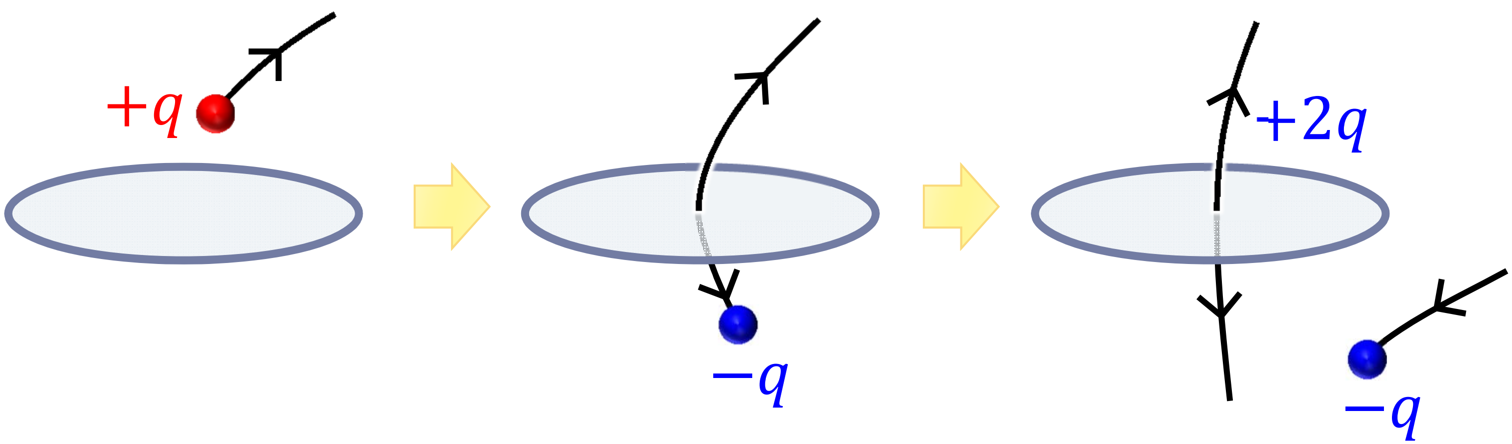
Alice string & charge conservation

- Move charge through Alice string loop

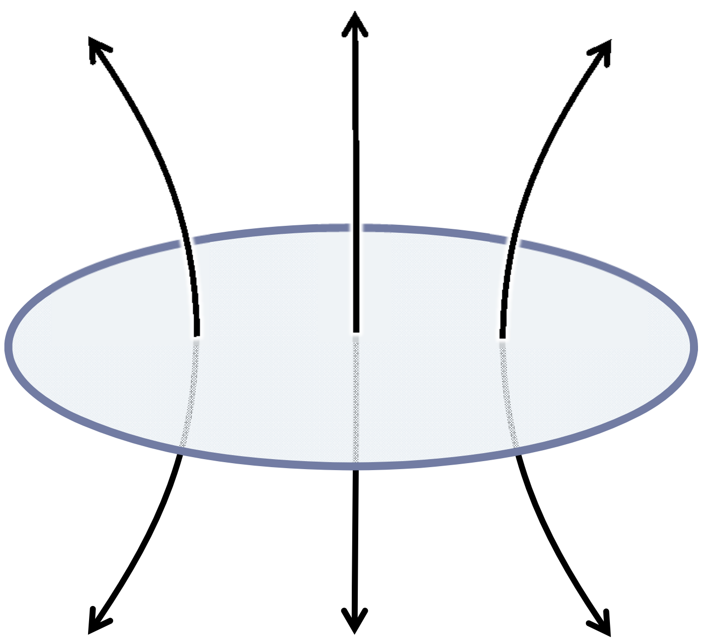


Charge not conserved?

- Charge left behind at the Alice string

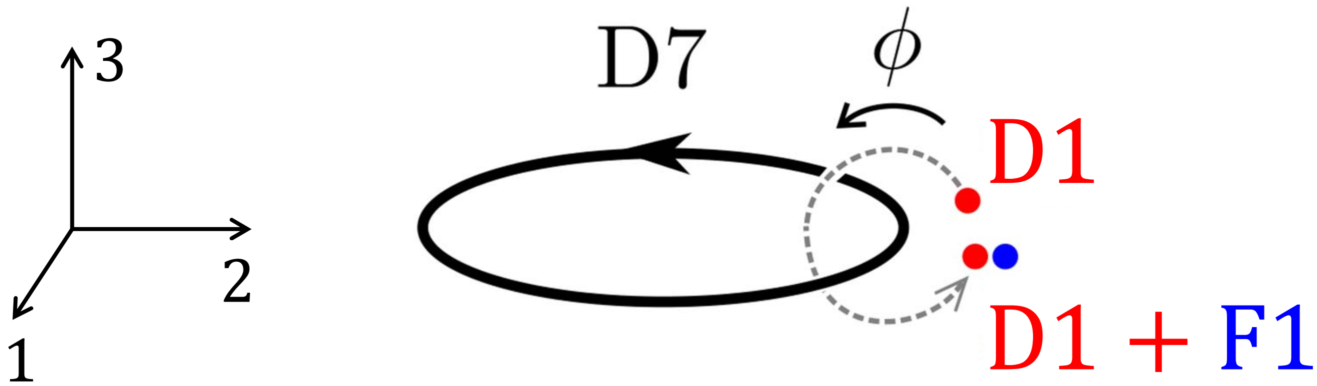


Cheshire charge



Charge without source

D7 as Alice string

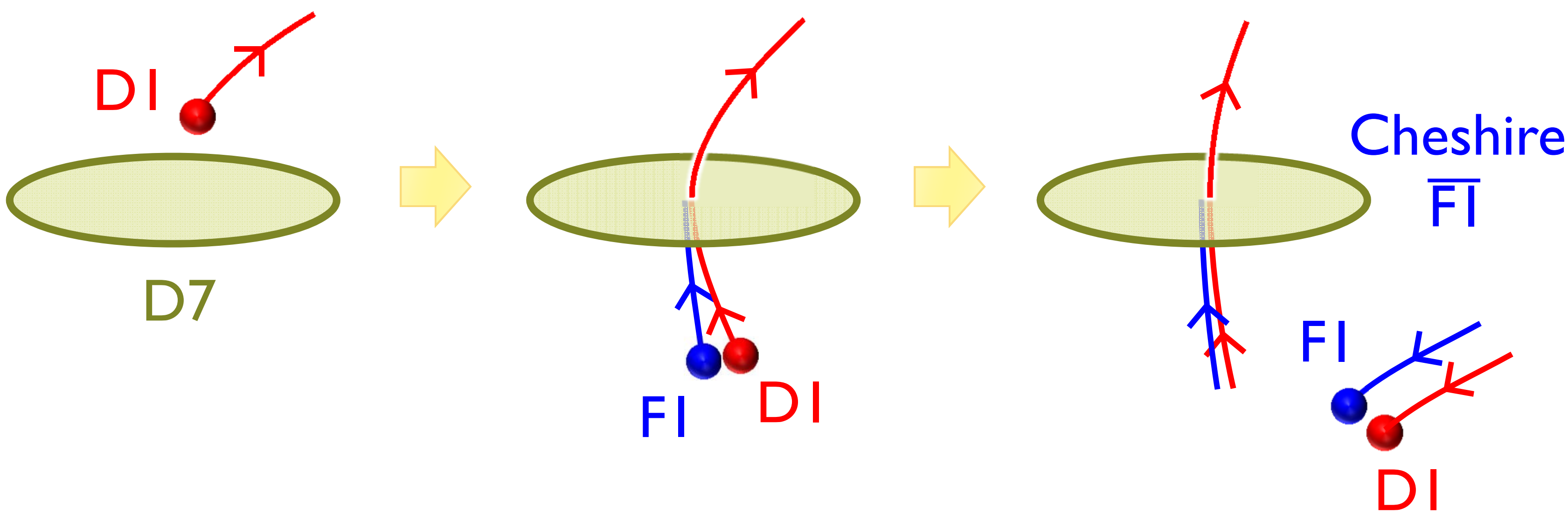


Going around $\mathrm{D7}(\psi 456789)$:

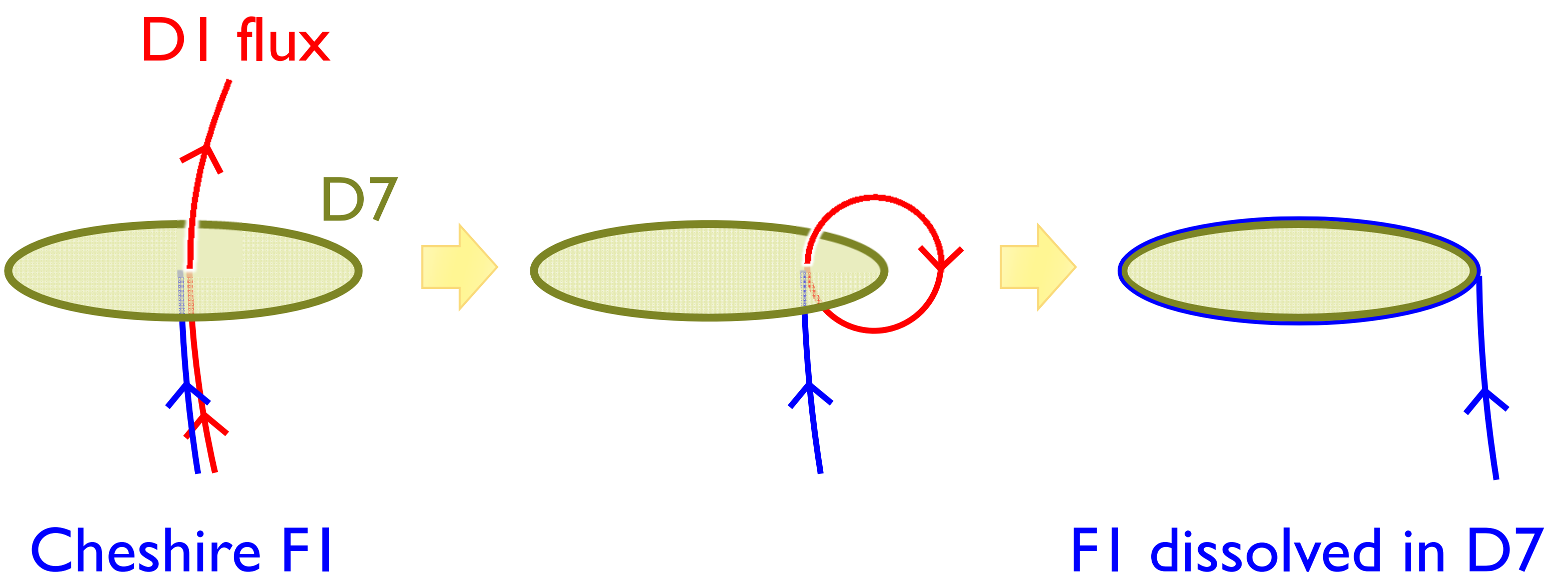
- Monodromy: $C_0 \to C_0 + 1$
- $\mathrm{D1}(4) \to \mathrm{D1}(4) + \mathrm{F1}(4)$

* Ring D7 stable as supertube $\mathrm{D5}(56789) + \mathrm{F1}(4)$

Stringy Cheshire charge



Cheshire charge & supertube



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

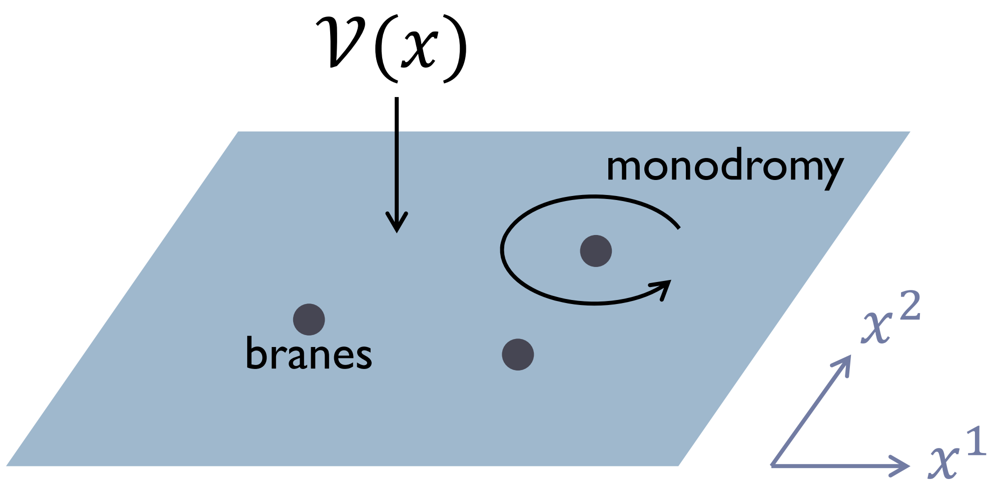
Classification

[de Boer+Mayerson+MS 1307.xxxx]

Classification

"How many" exotic branes are there?

- Classify configurations up to U-duality group G
- 3D: codim-2 branes are point-like
- All fields packaged in moduli matrix $\mathcal{V}(x) \in G/H$



An exercise

Simple example: $G = SL(2), H = SO(2)$

- 10D IIB sugra, ignore $x^{3\ldots9}$
- Moduli

$$\tau = \tau_1 + i\tau_2 = C_0 + ie^{-\Phi}$$

$$\mathcal{V} = \begin{pmatrix} \sqrt{\tau_2} & \tau_1/\sqrt{\tau_2} \\ 0 & 1/\sqrt{\tau_2} \end{pmatrix} \in SL(2)/SO(2)$$

Want to classify configurations of τ or $\mathcal{V}$

Know the answer: 7-branes of F-theory

Susy solutions

[Greene+Shapere+Vafa+Yau 1990]
[Bergshoeff+Hartong+Ortin+Roest 2006]

- Susy transformation

$$\mathcal{V}^{-1}d\mathcal{V} = \underbrace{P}_{sl(2)\ominus so(2)} + \underbrace{Q}_{so(2)} \in sl(2)$$

non-compact, physical   compact, gauge

$$\delta\chi \sim P_\mu \Gamma^\mu \epsilon, \qquad \delta\psi_\mu \sim (D_\mu + P_\mu)\epsilon$$

- Susy solution

$$ds^2 = -dt^2 + \tau_2|f|^2 dz d\bar{z} + dx_{3\ldots9}^2\,, \quad \tau = \tau(z), \quad f = f(z)$$

$$P_z = \frac{\tau'(z)}{2\tau_2}\underbrace{\tilde{Y}}_{\text{nilpotent}}, \quad P_{\bar{z}} = \frac{\bar{\tau}'(\bar{z})}{2\tau_2}\underbrace{\tilde{X}}_{\text{nilpotent}}, \quad Q = \frac{d\tau_1}{2\tau_2}\widetilde{H}$$

$$X = \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}, \quad Y = \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}, \quad H = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}, \quad [X,Y] = H, \quad [H,X] = 2X, \quad [H,Y] = -2Y$$

$$\tilde{X} = \frac{1}{2}(X + Y + iH), \quad \tilde{Y} = \frac{1}{2}(X + Y - iH), \quad \widetilde{H} = i(X - Y)$$

The real thing: $E_{8,8}/SO(16)$

Type II on T^7 / M on T^8

- $d = 3, \mathcal{N} = 16$ sugra [Marcus-Schwarz 1983]
- U-duality group: $G = E_{8,8},\ H = SO(16)$
- Moduli matrix: $\mathcal{V} \in E_{8,8}/SO(16)$

Susy solution:

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

$$\delta\chi \sim \gamma^\mu \epsilon^I \Gamma^I_{\dot{A}A} P^A_\mu = 0$$

$$\mathcal{V}^{-1} d\mathcal{V} = P + Q$$

$$\delta\psi^I_\mu \sim (D_\mu + P_\mu)\epsilon^I = 0$$

Strategy

$\delta\chi \sim \gamma^\mu \epsilon^I \Gamma^I_{\dot{A}A} P^A_\mu = 0$: difficult to solve in general

Embed $SL(2)$ into $E_{8,8}$:

$$P_z \sim X, \quad P_{\bar{z}} \sim Y, \quad Q \sim H$$

$$[X,Y] = H, \quad [H,X] = 2X, \quad [H,Y] = -2Y$$

Classify nilpotent elements of $g = e_{8,8}$
up to conjugation by *U*-duality $E_{8,8}$

Namely, classify *nilpotent orbits* of $E_{8,8}$

(* *For single-center case, can almost show nilpotency without susy*)

Nilpotent orbits of $E_{8,8}$

- 115 nilpotent orbits
- Representatives X, Y, H explicitly known [Djokovic 2000]
- Can compute #susy preserved

$\mathbb{C}$#	$\mathbb{C}$ BC lbl	wtd diag	dim	$\mathbb{R}$#	$\mathbb{R}$ label	inv	odr	susy	representative for X
1	A_1	00000001	58	1	A_1	64	3	16	E_{120}
2	$2A_1$	10000000	92	2	$2A_1$	44	3	8	$E_{97} + E_{120}$
3	$3A_1$	00000010	112	3	$3A_1$	40	4	4	$E_{74} + E_{104} + E_{118}$
4	A_2	00000002	114	4	$(4A_1)''$	70	5	4	$E_8 + E_{74} + E_{104} + E_{118}$
				5	$(4A_1)''$	64	5	0	$E_8 + E_{74} + E_{104} - E_{118}$
					A_2		5	0	$\sqrt{2}(E_8 + E_{119})$
5	$4A_1$	01000000	128	6	A_2	32	4	2	$E_{69} + E_{91} + E_{106} + E_{114}$
6	$A_2 + A_1$	10000001	136	7	$5A_1$	38	5	2	$E_{47} + E_{81} + E_{97} + E_{100} + E_{110}$
				8	$5A_1$	32	5	0	$E_{47} - E_{81} + E_{97} + E_{100} + E_{110}$
					$A_2 + A_1$		5	0	$\sqrt{2}(E_{47} + E_{112}) + E_{97}$
7	$A_2 + 2A_1$	00000100	146	9	$6A_1$	38	5	2	$E_{61} - E_{73} - E_{84} + E_{97} + E_{98} + E_{99}$
				10	$6A_1$	26	5	0	$E_{61} + E_{73} - E_{84} + E_{97} + E_{98} + E_{99}$
					$A_2 + 2A_1$		5	0	$\sqrt{2}(E_{73} + E_{102}) + E_{61} + E_{97}$
8	A_3	10000002	148	11	A_3	32	7	0	$\sqrt{3}(E_8 + E_{74}) + 2E_{97}$
9	$A_2 + 3A_1$	00100000	154	12	$7A_1$	50	5	2	$E_{44} + E_{71} - E_{83} + E_{89} + E_{90} + E_{91} - E_{92}$
				13	$7A_1$	26	5	0	$E_{44} + E_{71} + E_{83} + E_{89} + E_{90} + E_{91} - E_{92}$
					$A_2 + 3A_1$		5	0	$\sqrt{2}(E_{83} + E_{95}) + E_{44} + E_{71} + E_{89}$
10	$2A_2$	20000000	156	14	$8A_1$	92	5	2	$E_1 + E_{44} + E_{71} - E_{83} + E_{89} + E_{90} + E_{91} - E_{92}$
				15	$8A_1$	50	5	0	$E_1 + E_{44} + E_{71} + E_{83} + E_{89} + E_{90} + E_{91} - E_{92}$
					$A_2 + 4A_1$		5	0	$\sqrt{2}(E_{83} + E_{95}) + E_1 + E_{44} + E_{71} + E_{89}$
				16	$8A_1$	44	5	0	$E_1 - E_{44} + E_{71} + E_{83} + E_{89} + E_{90} + E_{91} - E_{92}$
					$A_2 + 4A_1$		5	0	$\sqrt{2}(E_{83} + E_{95}) + E_1 - E_{44} + E_{71} + E_{89}$
					$2A_2$		5	0	$\sqrt{2}(E_1 + E_{112}) + \sqrt{2}(E_{44} + E_{96})$

Susy configs (1)

- Find representatives in higher dims.
- Are there configs that can*not* be represented by standard branes?

1/2 BPS

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

1/4 BPS

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

Susy configs (2)

1/8 BPS

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

Susy configs (3)

1/16 BPS

	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 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

………