String theory compactifications with sources

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Introduction

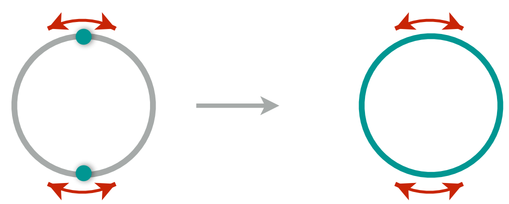
Internal space of string theory: often smooth, but sometimes sources are present

- in AdS/CFT they realize flavor symmetries
- necessary for de Sitter and for Minkowski beyond CY

However

- They are hard to localize [in curved spaces, or with intersections]

  so sometimes people resort to smearing



[Acharya, Benini, Valandro '05,
Graña, Minasian, Petrini, AT '06,
Caviezel, Koerber, Körs, Lüst, Wrase, Zagermann '08,
Andriot, Goi, Minasian, Petrini '10...]

- They create funny singularities where supergravity breaks down

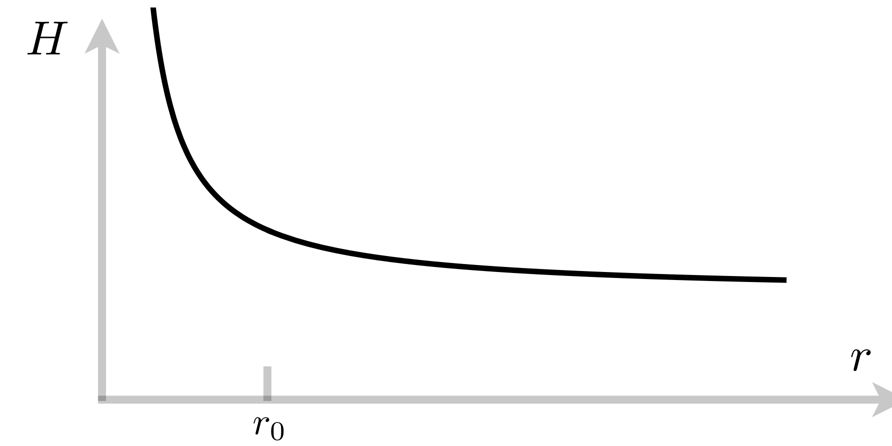
$$ds^2_{10} = \underbrace{H}_{\text{harmonic function in } \mathbb{R}^{9-p}_\perp}{}^{-1/2}\, \overset{0,\dots,p}{ds^2_\parallel} + H^{1/2}\, \overset{p+1,\dots,9}{ds^2_\perp}$$

$$e^\phi = g_s H^{(3-p)/4}$$

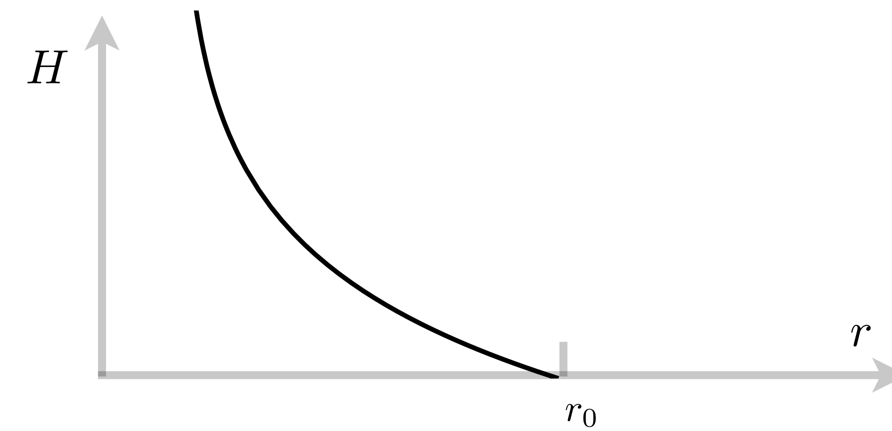
$$ds^2_\perp = dr^2 + r^2 ds^2_{S^{8-p}}$$

D-branes

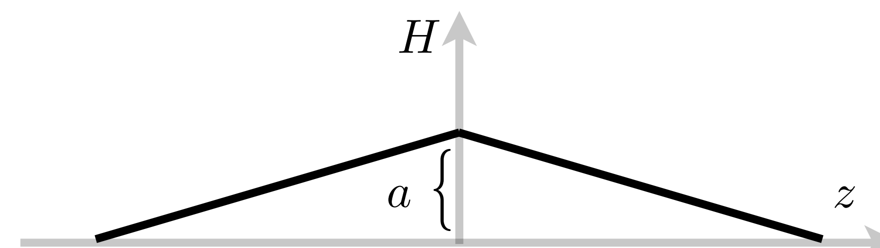
- $p < 7 : H = 1 + \left(\frac{r_0}{r}\right)^{7-p}$



- $p = 7 : H = -\log(r/r_0)$



- $p = 8 : H = a - |z/z_0|$

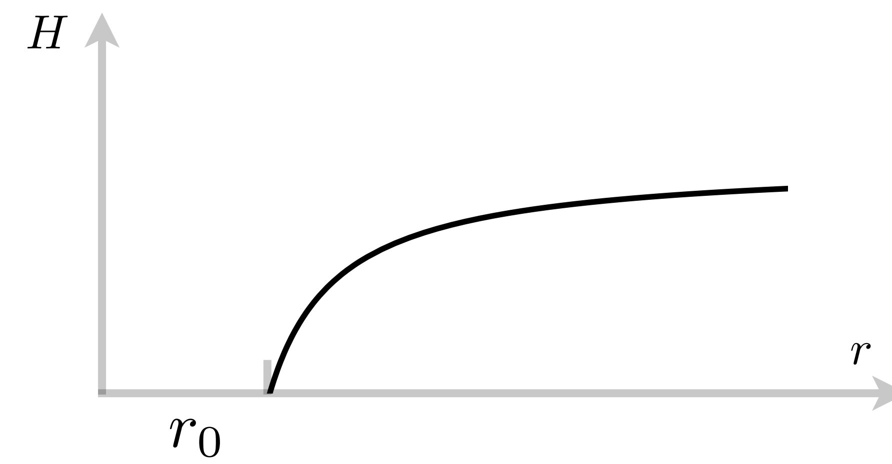


$p = 7, 8$: beyond a critical distance solution doesn't make sense

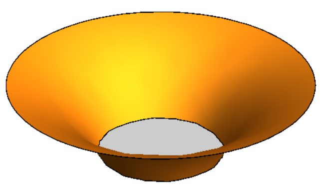
[not a problem for compact solutions]

O-planes

- $p < 7 : H = 1 - \left(\frac{r_0}{r}\right)^{7-p}$
- $p = 7 : H = \log(r/r_0)$

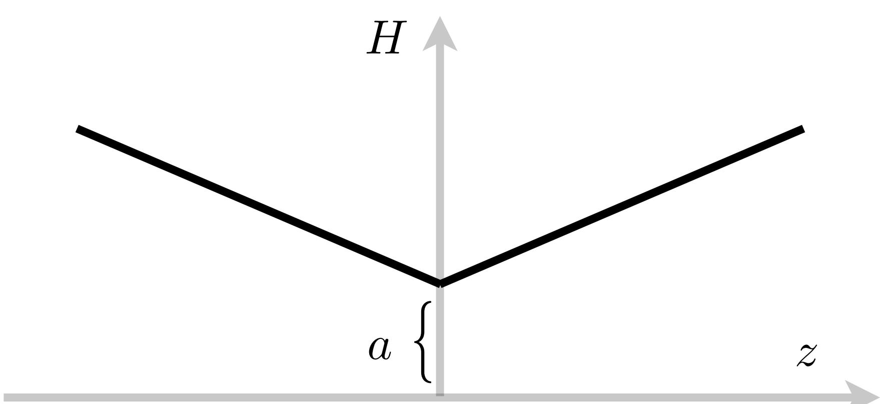


inside this 'hole' the solution doesn't make sense



curvature and string coupling become large earlier

- $p = 8 : H = a + |z/z_0|$



- the only case without a hole
- dilaton stays finite, unless $a = 0$

$$e^{\phi} = g_s H^{-5/4}$$

This talk: review on progress on solutions with sources

- AdS: many such solutions appear naturally

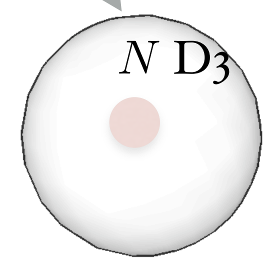
and can be checked using holography
especially in the supersymmetric case

- perhaps we can use this progress for dS as well?

AdS solutions

- near horizon limit around single source:

angular directions around brane



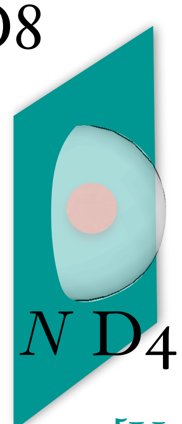
become internal sphere

D3 dissolve; no source remains after near-horizon $\longrightarrow$ $\mathrm{AdS}_5 \times S^5$

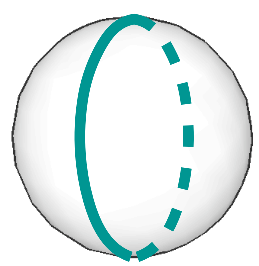
- but near intersections:

rare explicit example:

O8



$\longrightarrow$



[Youm '99]

	0	1	2	3	4	5	6	7	8	9
O8	×	×	×	×	×	×	×	×	×	
D4	×	×	×	×	×					

near-horizon: [Brandhuber, Oz '99]

$$ds^2_{10} = (\cos\alpha)^{-1/3}(ds^2_{\mathrm{AdS}_6} + \overbrace{\sin^2\alpha\, ds^2_{S^3} + d\alpha^2}^{S^4})$$

$$\Big\downarrow \quad \begin{array}{l} \alpha \to \pi/2 \\ x_9 \sim (\pi/2-\alpha)^{2/3} \end{array}$$

$$ds^2_{10} \sim x_9{}^{-1/2}(ds^2_{\mathrm{AdS}_6} + ds^2_{S^3}) + x_9{}^{1/2} dx_9^2$$

D4 have dissolved, but O8 at the equator remains

in several other cases, solutions are thought to arise from near-horizon

of unknown intersecting-brane solutions

- AdS7 in IIA

$$\frac{1}{\pi\sqrt{2}}ds^2 = 8\sqrt{-\frac{\alpha}{\ddot\alpha}}ds^2_{\mathrm{AdS}_7} + \sqrt{-\frac{\ddot\alpha}{\alpha}}\left(dz^2 + \frac{\alpha^2}{\dot\alpha^2 - 2\alpha\ddot\alpha}ds^2_{S^2}\right)$$

interval

$$e^\phi = 2^{5/4}\pi^{5/2}3^4\frac{(-\alpha/\ddot\alpha)^{3/4}}{\sqrt{\dot\alpha^2 - 2\alpha\ddot\alpha}}$$

$$B = \pi\left(-z + \frac{\alpha\dot\alpha}{\dot\alpha^2 - 2\alpha\ddot\alpha}\right)\mathrm{vol}_{S^2}$$

$$F_2 = \left(\frac{\ddot\alpha}{162\pi^2} + \frac{\pi F_0 \alpha\dot\alpha}{\dot\alpha^2 - 2\alpha\ddot\alpha}\right)\mathrm{vol}_{S^2}$$

$\dddot\alpha = F_0$ ⇨ α piecewise cubic

α, $\dot\alpha$, $\ddot\alpha$ continuous

[Apruzzi, Fazzi, Rosa, AT '13
Apruzzi, Fazzi, Passias, Rota, AT '15;
Cremonesi, AT '15]

- At endpoint, smoothness: S^2 should shrink, $\frac{\alpha}{\ddot\alpha}$ finite ⇨ $\alpha \to 0$, $\ddot\alpha \to 0$; $\alpha \sim z + F_0 z^3$

what happens with other boundary conditions?

$$\frac{1}{\pi\sqrt{2}}ds^2 = 8\sqrt{-\frac{\alpha}{\ddot\alpha}}ds^2_{\mathrm{AdS}_7} + \sqrt{-\frac{\ddot\alpha}{\alpha}}\left(dz^2 + \frac{\alpha^2}{\dot\alpha^2 - 2\alpha\ddot\alpha}ds^2_{S^2}\right)$$

- say only $\alpha \to 0$

  $\alpha \sim a_1 z + a_2 z^2 + F_0 z^3$

$$ds^2 \sim z^{1/2} ds^2_{\mathrm{AdS}_7} + z^{-1/2}\underbrace{(dz^2 + z^2 ds^2_{S^2})}_{\text{transverse } \mathbb{R}^3}$$

$H \sim 1/z \quad \Rightarrow \quad$ **D6**

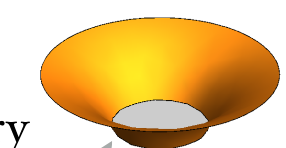
- or say only $\ddot\alpha \to 0$

  $\alpha \sim a_0 + a_1 z + F_0 z^3$

$$ds^2_{10} \sim z^{-1/2} ds^2_{\mathrm{AdS}_7} + z^{1/2}\underbrace{(dz^2 + ds^2_{S^2})}_{\text{transverse } \mathbb{R}^3}$$

$H \sim z \quad \Rightarrow \quad$ **O6**

near the boundary of its hole



- or $\alpha \to 0$, $\dot\alpha \to 0$

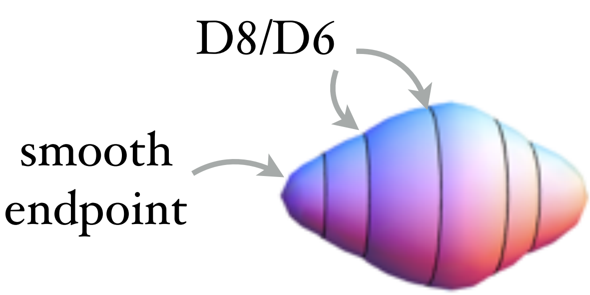
  $\alpha \sim a_2 z^2 + F_0 z^3$

$$ds^2_{10} \sim z^{-1/2}(ds^2_{\mathrm{AdS}_7} + ds^2_{S^2}) + z^{1/2} dz^2$$

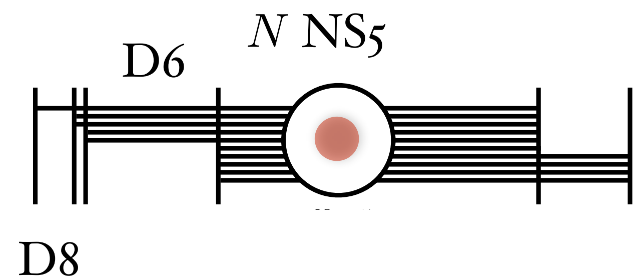
$H \sim z \quad \Rightarrow \quad$ **O8**

- finally inside interval, when F_0 jumps $\Rightarrow$ **D8** perhaps with D6 charge

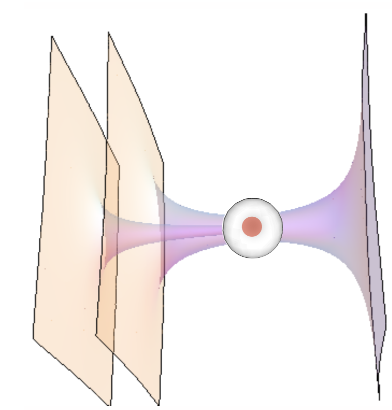
We can mix & match these singularities in many types of solutions



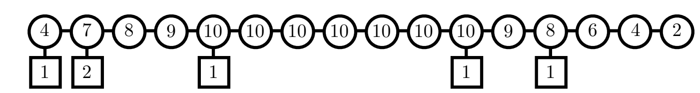
expected to come
from near-horizon of



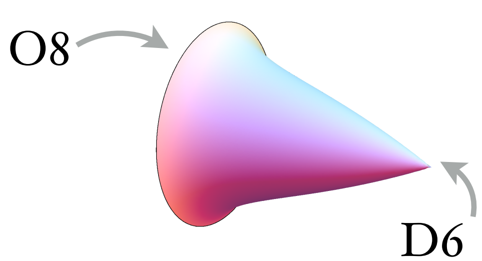
$\cong$



which again engineer
dual field theories



[Gaiotto, AT '14; Hanany, Zaffaroni '96]



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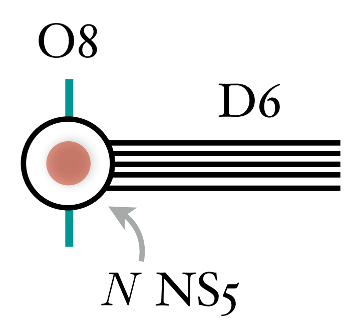
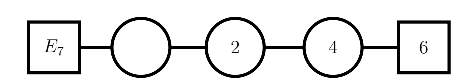




again exceptional flavor symmetry

... and many others

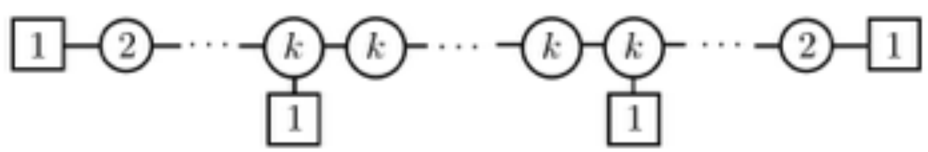
- **Holographic checks:**

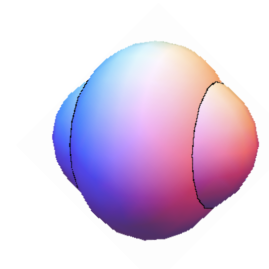
[Cremonesi, AT '15]
[Apruzzi, Fazzi '17]

Weyl anomaly a can be computed both from field theory and gravity

It agrees rather nontrivially.

for example:





using susy, grav. &
R-symmetry anomalies

[Ohmori, Shimizu,
Tachikawa, Yonekura '14]

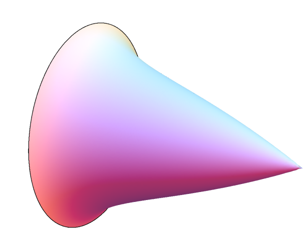
[Cordova, Dumitrescu, Intriligator '15]

an integral over
internal dimensions

[Henningson, Skenderis '98]

$$a = \frac{16}{7}k^2(N^3 - 4Nk^2 + \frac{16}{5}k^3)$$

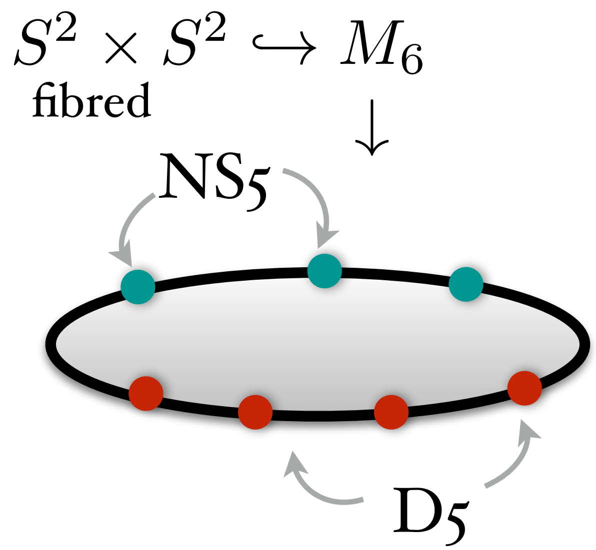
- **This works also when O-planes are present**



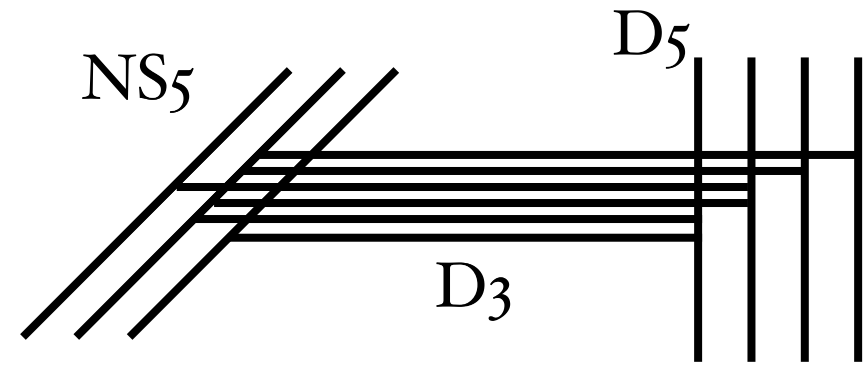
[Bah, Passias, AT '16]
[Apruzzi, Fazzi '17]

- $\mathrm{AdS}_4 \times M_6$ in IIB with $\mathcal{N} = 4$ supersymmetry

[Assel, Bachas, Estes, Gomis '11]
building on [d'Hoker, Estes, Gutperle '07]

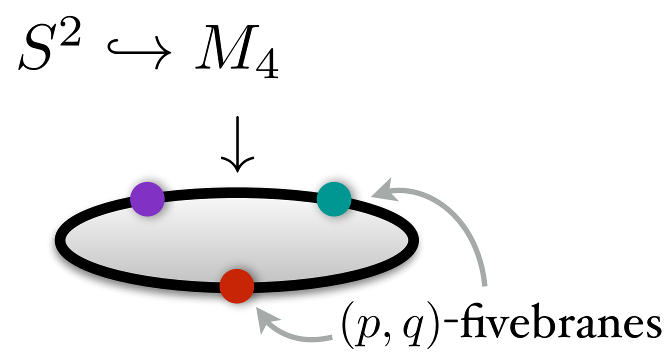


expected to come
from near-horizon of



- Similar $\mathrm{AdS}_6 \times M_4$

[d'Hoker, Gutperle, Karch, Uhlemann '16]



- AdS5, AdS4: many cases from 'compactifying' AdS7

[Apruzzi, Fazzi, Passias, Rota, AT '15]
[Rota, AT'15], [Bah, Passias, AT '16]

- AdS_3 with O8 and $\mathcal{N} = (0, 8)$ from O8-D2 near-horizon

[Dibitetto, Lo Monaco, Petri, Passias, AT '18]

dS

[Córdova, De Luca, AT '18]

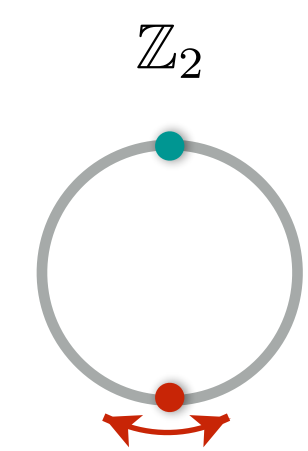
In examples seen so far: helped by

- Supersymmetry
- Conjectural near-horizon origin

Let's try to go further...

- A simple Ansatz

Bianchi: no D8s necessary



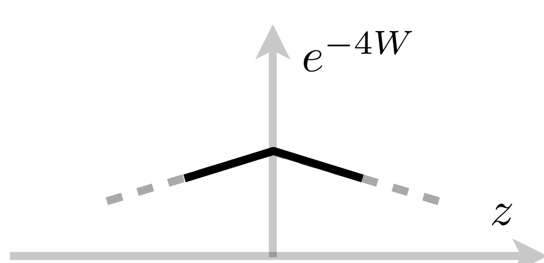
$$ds^2 = e^{2W} ds^2_{dS_4} + e^{-2W}(dz^2 + e^{2\lambda} ds^2_{M_5})$$

"cohomogeneity one": W, λ_i, ϕ only depend on z

- The functions won't be diff. at the O8+

[right side]

Jump in first derivatives can be determined: $W' = \frac{1}{5}\phi' = \frac{1}{2}\lambda' = -e^{\phi - W}$

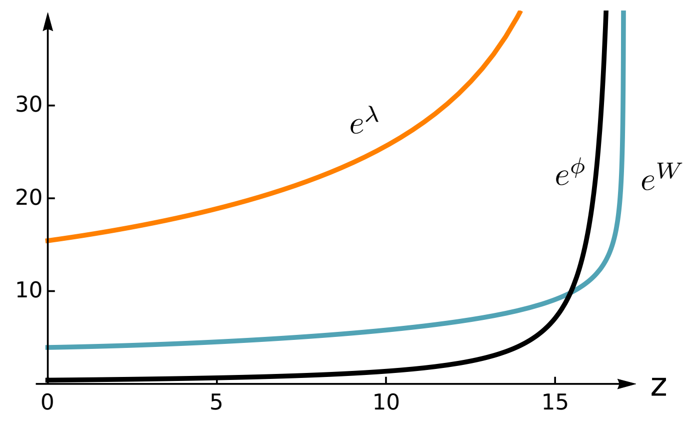


- by comparing with O8+ in flat space, or
- by paying attention again to δ terms in EoM

- For an open set of initial conditions, we then get attracted to the behavior

$$e^W \sim e^{\frac{1}{5}\phi} \sim e^{\frac{1}{2}\lambda_i/2} \sim |z - z_0|^{-1/4}$$ same as O8_

[even the coefficients work]



- Rescaling $$g_{MN} \to e^{2c} g_{MN}\ , \quad \phi \to \phi - c\ , \quad F_4 \to e^{4c} F_4$$

makes the solution weakly-coupled and weakly-curved... except at the O8_

- Presumably these moduli get lifted by stringy corrections.

Will a vacuum survive after this?

- Near the O8_ the supergravity action is completely irrelevant!

The singularity near the O8_ is similar to the O8_ in flat space,
which should exist in full string theory.

Are they similar enough?

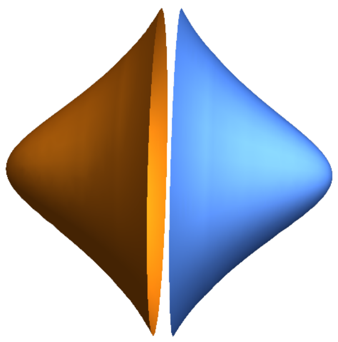
The O8_ in AdS solutions worked well [holography]

- Are there tachyons?

KK reduction: hard but doable.

- in a similar way we also found an AdS8 solution in IIA

if a corresponding CFT is found [eg with conformal bootstrap]
our methods would be vindicated.



Conclusions

- Localized sources are by now commonplace in AdS solutions
- Often they have origin in near-horizon limits of brane intersections
- They seem to work fine with holography, in spite of singularities
- Maybe time to look for de Sitter?

Using numerics, we find dS solutions with O8-planes
in relatively simple setup