Instituto de Física Teórica UAM-CSIC

Dynamical Cobordism and (Intersecting) End-of-the-World Branes

Based on 2312.16286 with R. Angius, A. Uranga,
and 2205.09782 with R. Blumenhagen, N. Cribiori, C. Kneissl

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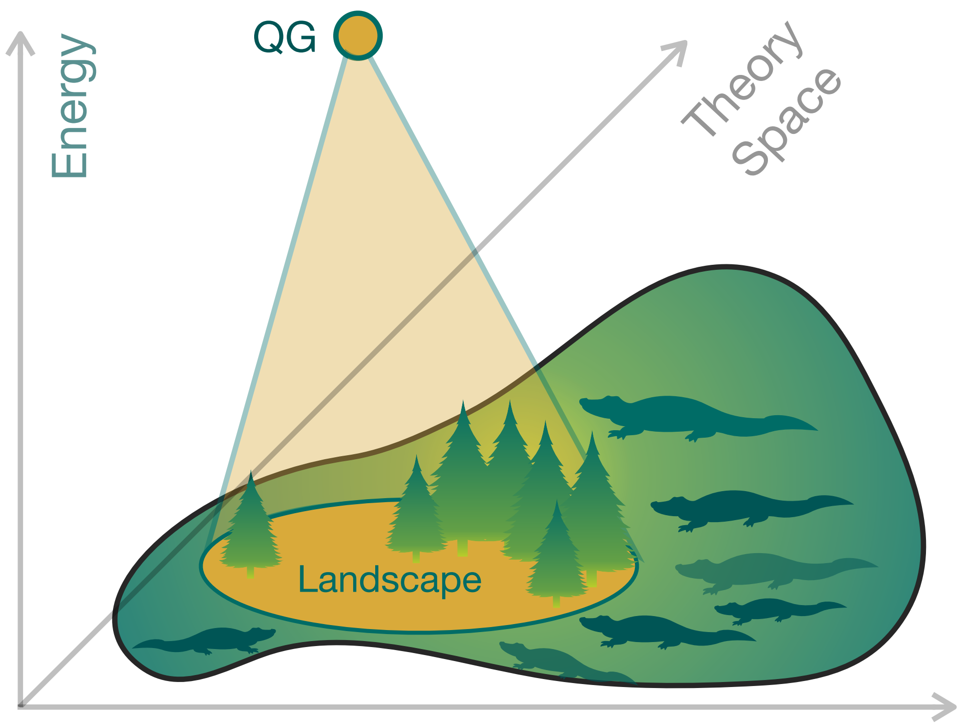
Swamplandia - in Bavaria -
Abbey Seeon, May 28th 2024

Background



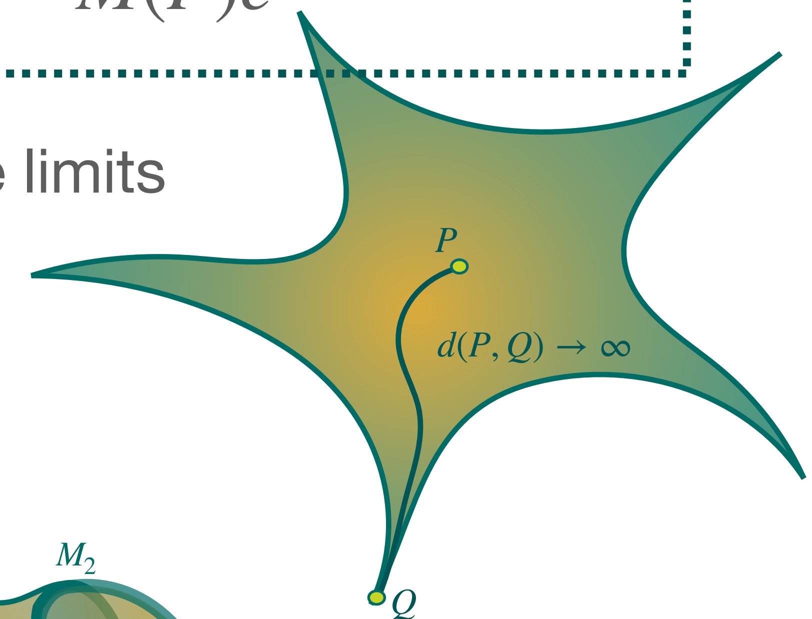
[Ooguri, Vafa '06]

Distance Conjecture:

There exists an infinite tower of states

with $m(Q) \sim M(P)e^{-cd(P,Q)}$

→ Infinite distance limits

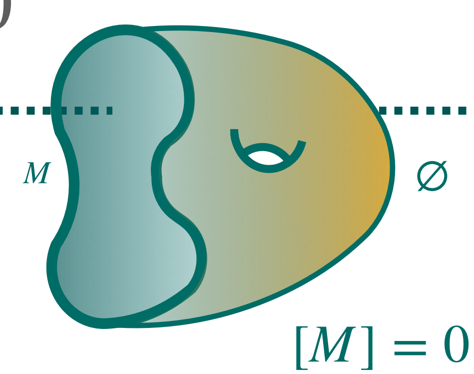


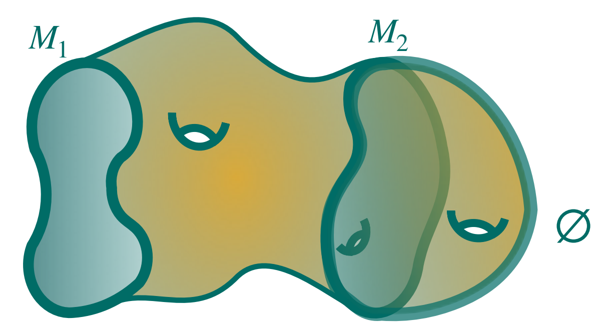
[McNamara, Vafa '19]

Cobordism Conjecture:

All Cobordism Classes should be trivial

$$\Omega_k^{QG} = 0$$

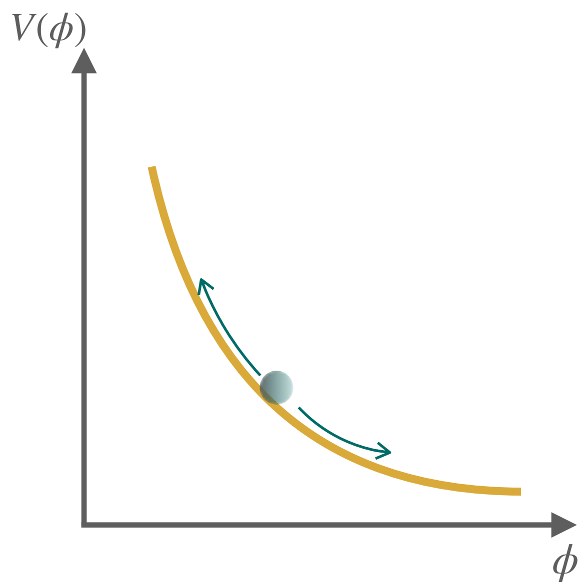




In D=d-k dimensions:

Motivation

[Sugimoto '99]
[Antoniadis, Dudas, Sagnotti '99]
[Angelantonj '99]
...
[Basile, Raucci, Thomée '22]
[Mourad, Sagnotti '23]
[Mininno, Uranga '20]
...



Dynamical tadpoles (vs RR tadpoles)

Naturally occurring in supersymmetry-breaking potentials

Indicate lack of maximally-symmetric vacuum

Example: Sugimoto Model (USp(32) Type I with N $\overline{D9}$ and N $O9^+$) [Sugimoto '99]

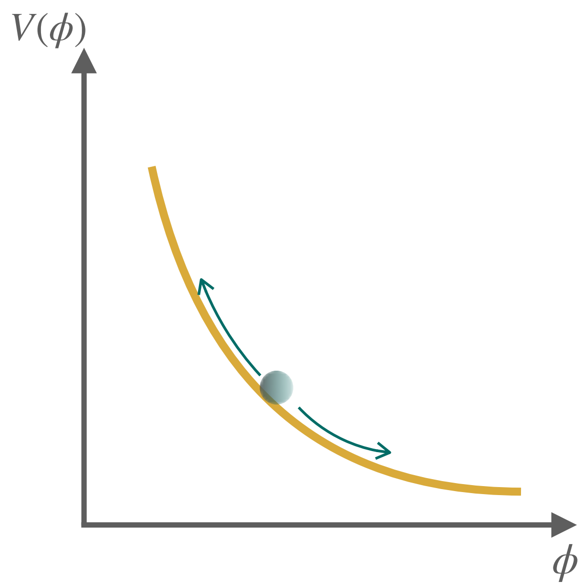
Dudas-Mourad solution - preserving 9d Poincaré invariance: [Dudas, Mourad '00]

$$ds_E^2 = |\sqrt{\alpha_E}|^{1/9} e^{-\frac{\alpha_E}{8}y^2} \eta_{\mu\nu} dx^\mu dx^\nu + |\sqrt{\alpha_E}y|^{-1} e^{-\frac{3\phi_0}{2}} e^{-\frac{9\alpha_E}{8}y^2} dy^2, \quad \alpha_E = 64k^2 T_9$$

→ singularities at finite spacetime distance, spontaneous compactification to 9d

See talks by Matilda, Hector, Houri!

Motivation



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Dynamical tadpoles (vs RR tadpoles)

Naturally occurring in supersymmetry-breaking potentials

Indicate lack of maximally-symmetric vacuum

Common features: → Solution extends over finite spacetime distance Δ

→ Ricci curvature singularity

→ Scalar diverges close to the singularity, i.e. field distance $D \to \infty$

Interpretation:

[Buratti, Delgado, Uranga '21]

Physical mechanism cutting off spacetime = cobordism defect of the initial theory

[Buratti, Calderon-Infante, Delgado, Uranga '21]

An infinite field distance limit is realized as running into a cobordism wall of nothing.

[Buratti, Calderon-Infante, Delgado, Uranga '21]

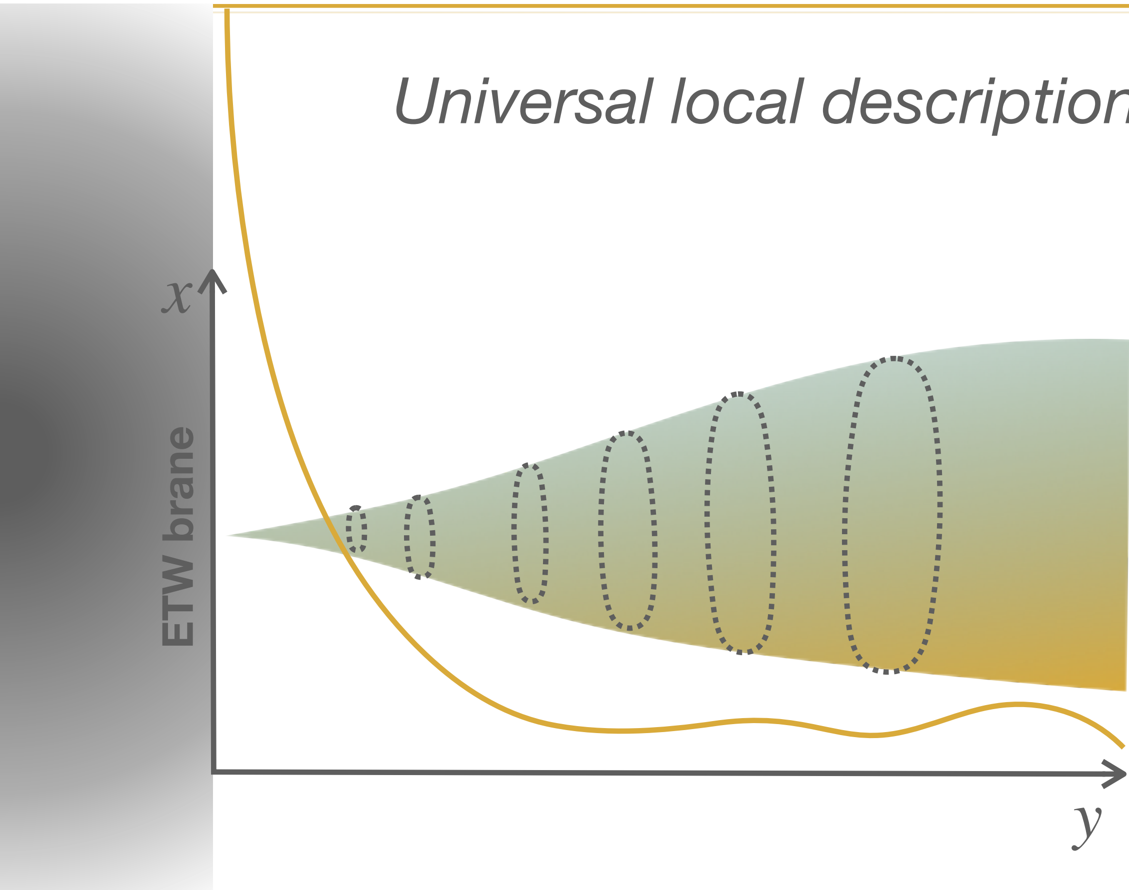
Dynamical cobordisms obey the scaling relations

$$\Delta \sim e^{-\frac{1}{2}\delta D}, \quad |\mathscr{R}| \sim e^{\delta D}, \qquad \delta > 0.$$

Universal description

[Angius, Calderon-Infante, Delgado, Huertas, Uranga '21]

Universal local description possible in terms of critical exponent δ



Action:

$$S = \int d^d x \sqrt{-g} \left(\frac{1}{2} R - \frac{1}{2} (\partial \phi)^2 - V(\phi) \right)$$

Metric ansatz:

$$ds_d^2 = e^{-2\sigma(y)} ds_{d-1}^2 + dy^2$$

Local description near ETW brane: $\phi(y) \sim -\frac{2}{\delta} \log y, \qquad \sigma(y) \sim -\frac{4}{(d-2)\delta^2} \log y + \frac{1}{2} \log c$

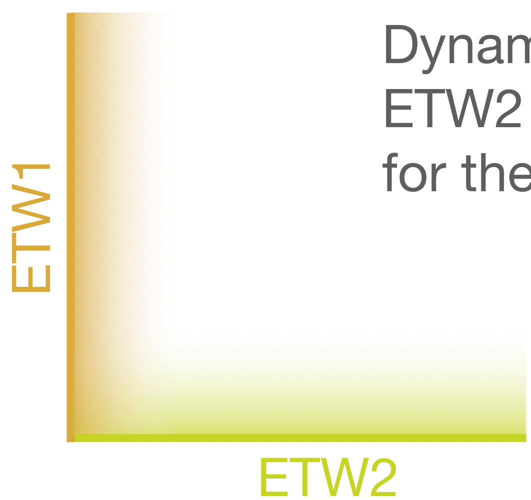
Leading behaviour of potential: $V(\phi) \sim -ace^{\delta\phi}, \qquad \delta = 2\sqrt{\frac{d-1}{d-2}(1-a)}$

	d	δ	α
[Witten '82] Bubble of Nothing	4	$\sqrt{6}$	0
D2-brane	4	$\sqrt{2/7}$	20/21
USp(32) string	10	$\sqrt{6}$	0

[Angius, Calderon-Infante, Delgado, Huertas, Uranga '21]

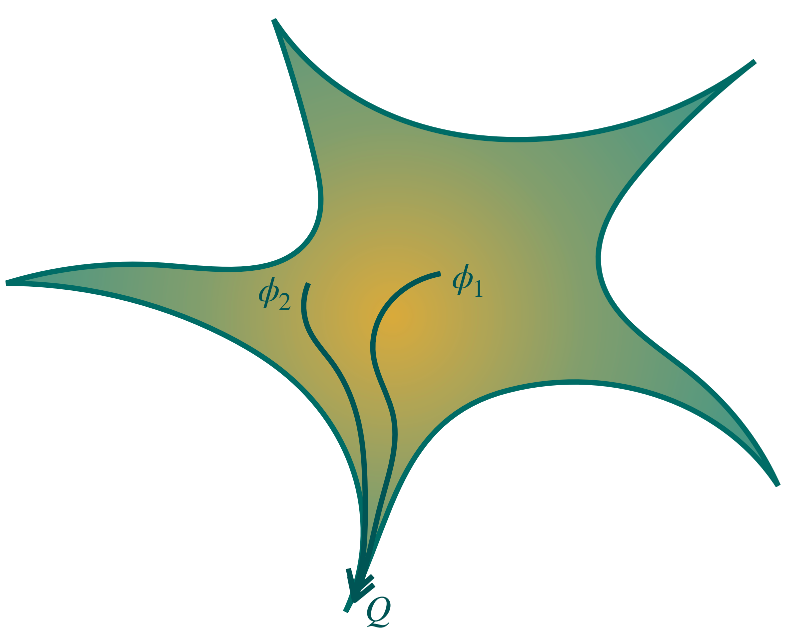
Why consider intersections?

We know higher-codimension ETWs exist: how do they relate to codimension-1 objects?



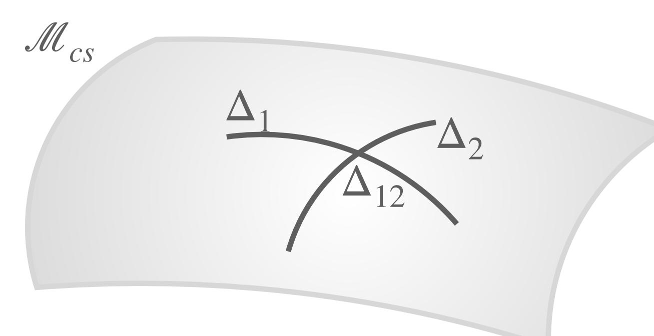
Dynamical cobordism with
ETW2 being the boundary
for the bulk theory ending on ETW1

Bulk theory ends on boundary which
switches from ETW1 to ETW2 and
vice versa



Exploration of network of infinite distance limits [Grimm, Li, Palti '18]

Intersecting divisors in Calabi Yau moduli space [Angius '24]



Possible cosmological applications? Collisions of cosmological bubbles?

See [Friedrich, Hebecker, Walcher '23] and *Bjorn's talk tomorrow!*

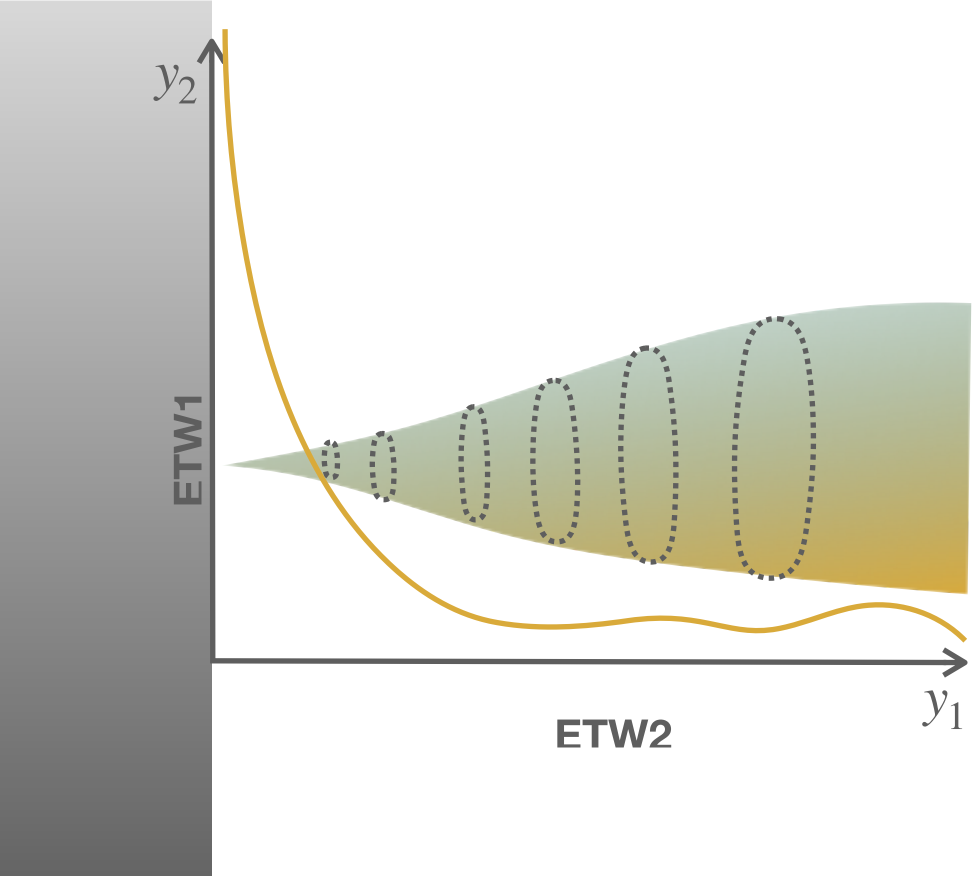
Codimension-2 case: Universal Description

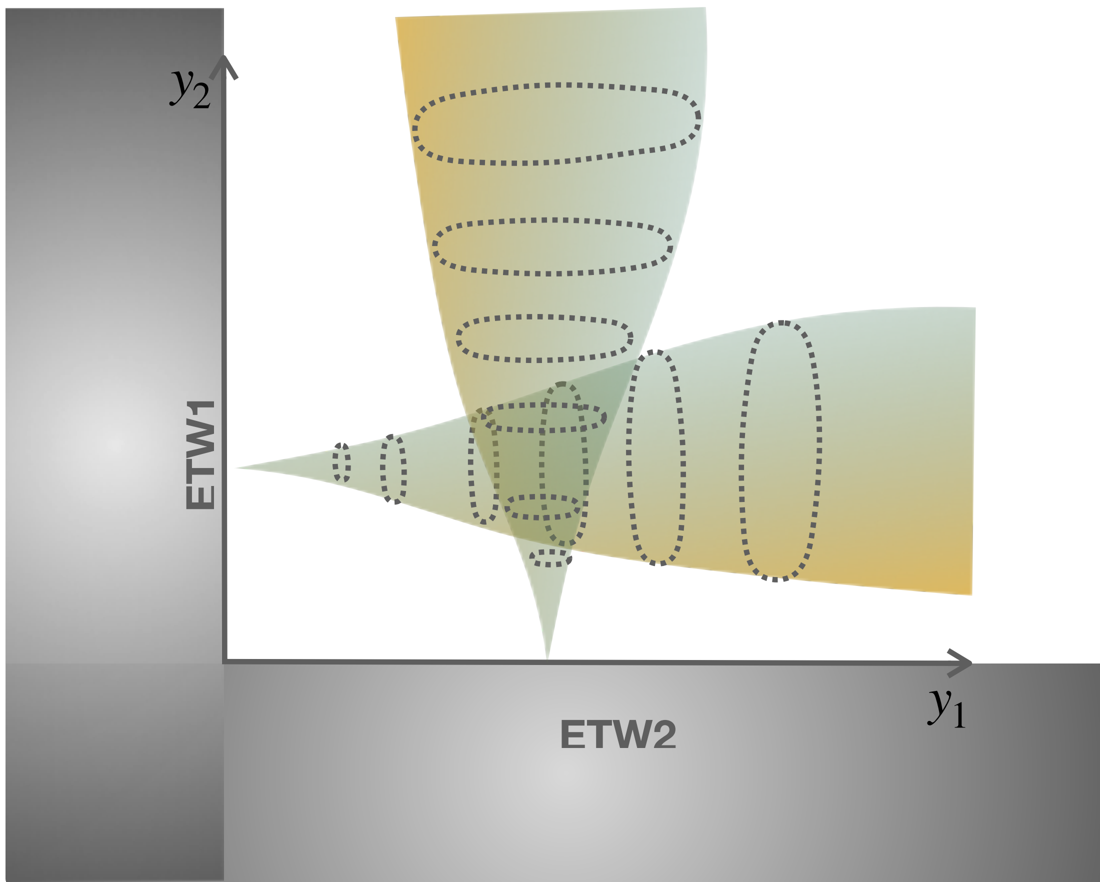
Starting Point: $S = \int d^{n+2}x\sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}(\partial\phi_1)^2 - \frac{1}{2}(\partial\phi_2)^2 - \frac{\alpha}{2}\partial_\mu\phi_1\partial^\mu\phi_2 - V(\phi_1,\phi_2)\right)$

Solution ansatz: $ds^2_{n+2} = e^{2A(y_1,y_2)}ds^2_n + e^{2B(y_1,y_2)}dy_1^2 + e^{2C(y_1,y_2)}dy_2^2$

$$\phi_1 = \phi_1(y_1), \quad \phi_2 = \phi_2(y_2)$$

We want to recover ETW-1 solutions for constant y_i and both scalars should explode around the origin





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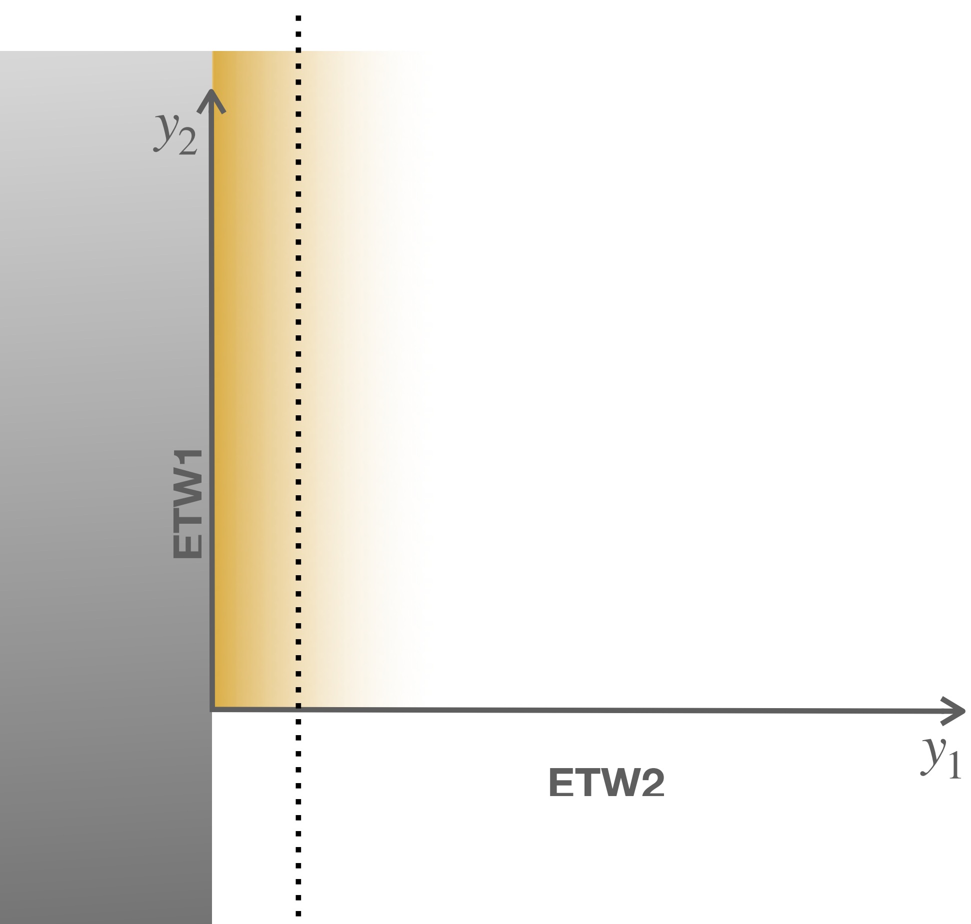

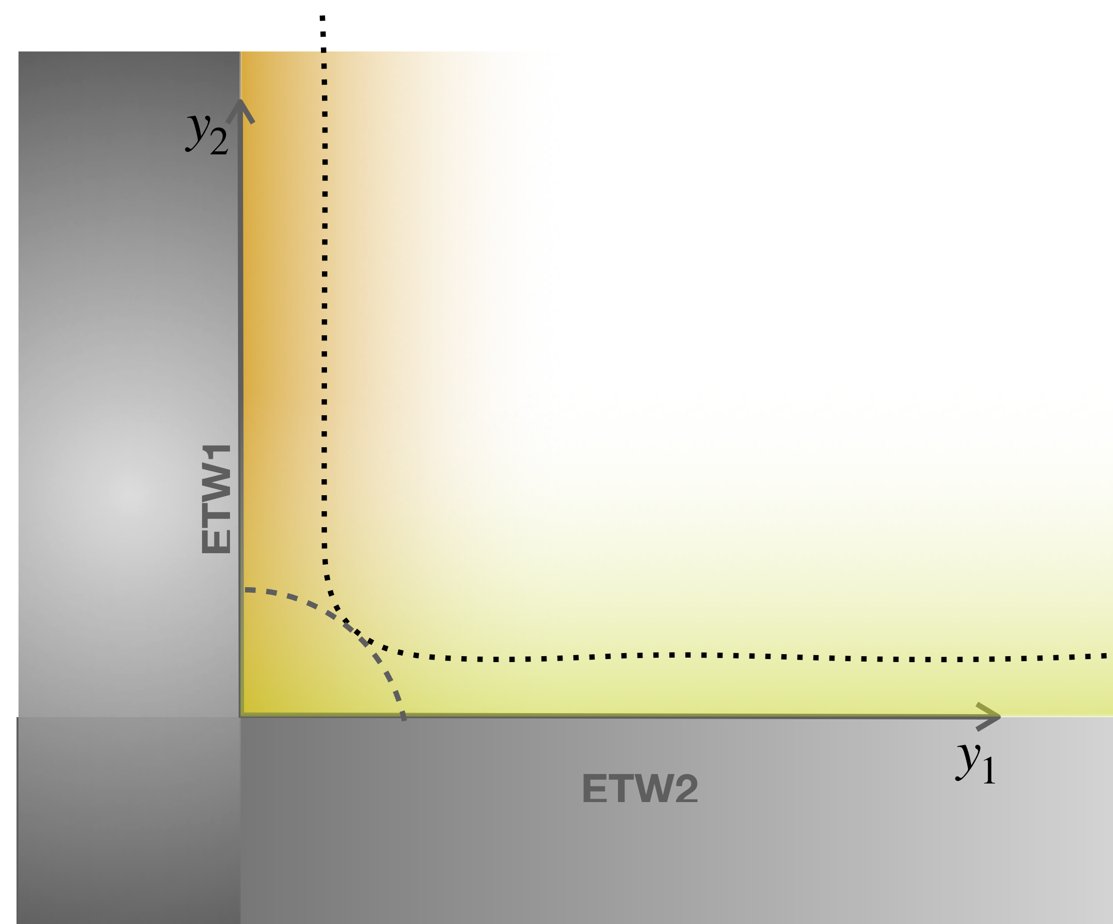

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$$\phi_1 = \phi_1(y_1), \quad \phi_2 = \phi_2(y_2)$$

We want to recover ETW-1 solutions for constant y_i
and both scalars should explode around the origin

$$A(y_1,y_2) = -\sigma_1(y_1) - \sigma_2(y_2) \qquad B(y_1,y_2) = -\sigma_2(y_2) \qquad C(y_1,y_2) = -\sigma_1(y_1)$$

$$dy_j = 0 \quad \leftrightarrow \quad ds^2_{n+1} = e^{-2\sigma_i(y)}ds^2_n + dy_i^2$$

Note: conformal flatness!

For $\quad dy_1 = e^{-\sigma_1}dx_1, \quad dy_2 = e^{-\sigma_2}dx_2 \quad$ we get :

$$ds^2_{n+2} = e^{-2\sigma_1-2\sigma_2}[ds^2_n + dx_1^2 + dx_2^2]$$

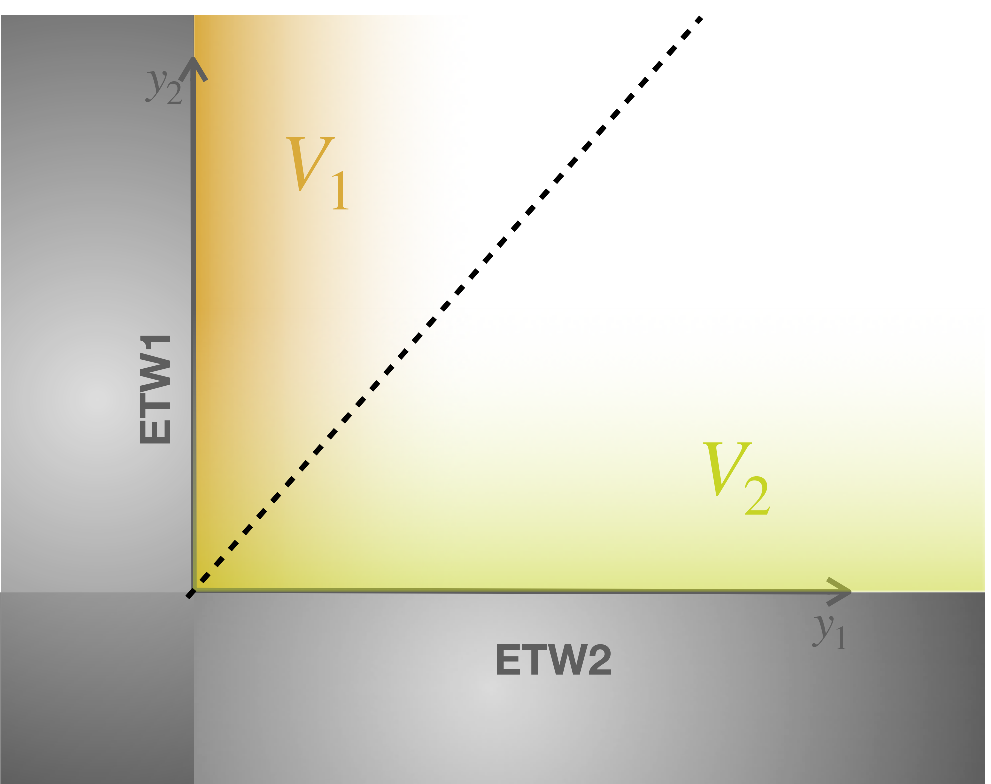
Codimension-2 case: Universal Description

Local description ansatz:

$$\sigma(y_1) = -a_1 \log y_1 + \frac{1}{2} \log c_1 \qquad \sigma(y_2) = -a_2 \log y_2 + \frac{1}{2} \log c_2$$

$$\phi_1(y_1) = -b_1 \log y_1 \qquad \phi_2(y_2) = -b_2 \log y_2$$

$$V = -c_1 v_1 y_1^{-2} y_2^{-2a_2} - c_2 v_2 y_1^{-2a_1} y_2^{-2} \equiv V_1 + V_2$$ (assuming $a_1, a_2 < 1$)



The asymptotic form of the potential fixes a_i

$$a_1 = \frac{1 \pm \sqrt{1 + 8v_1(1 + 1/n)}}{2(n+1)}$$

$$a_2 = \frac{1 \pm \sqrt{1 + 8v_2(1 + 1/n)}}{2(n+1)}$$

Codimension-2 case: Universal Description

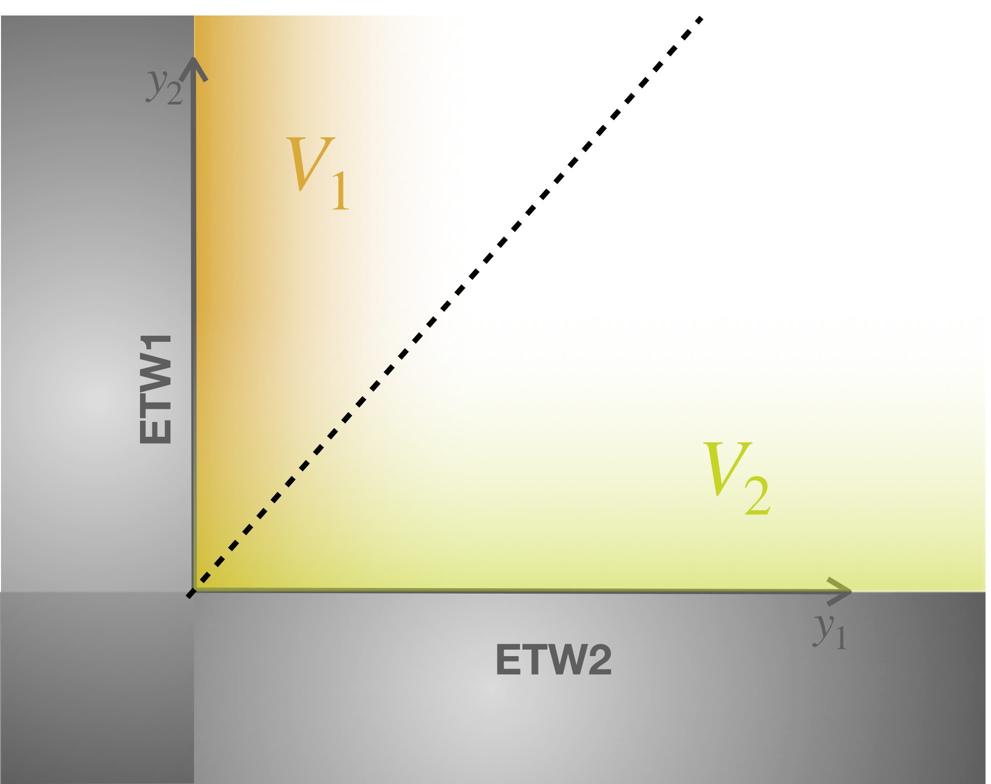
Local description ansatz II:

$$\sigma_1(y_1) = -\frac{4}{n\delta_1^2}\log y_1 \qquad \sigma_2(y_2) = -\frac{4}{n\delta_2^2}\log y_2$$

$$\phi_1(y_1) = -\frac{2}{\delta_1}\log y_1 \qquad \phi_2(y_2) = -\frac{2}{\delta_2}\log y_2$$

$$V = -c_1 v_1 y_1^{-2} y_2^{-2a_2} - c_2 v_2 y_1^{-2a_1} y_2^{-2} \equiv V_1 + V_2$$

$$V = -c_1 v_1 e^{\delta_1\phi_1} e^{a_2\delta_2\phi_2} + c_2 v_2 e^{a_1\delta_1\phi_1} e^{\delta_2\phi_2}$$



The full solution is given in terms of the two critical exponents δ_i

$$\delta_1^2 = \frac{8(n+1)}{n \pm \sqrt{n[n+8v_1(n+1)]}}$$

$$\delta_2^2 = \frac{8(n+1)}{n \pm \sqrt{n[n+8v_2(n+1)]}}$$

Codimension-2 case: Scaling relations

Goal: Extract the scaling relations $\mathscr{R} \sim e^{\delta_{int}\mathscr{D}}$, $\Delta \sim e^{-\frac{\delta_{int}}{2}\mathscr{D}}$ when approaching the intersection

Spacetime distance:

$$\Delta = \int [e^{-2\sigma_1}dy_1^2 + e^{-2\sigma_2}dy_2^2]^{1/2}$$

Field space distance:

$$\mathscr{D} = \int [d\phi_1^2 + d\phi_2^2 + \alpha d\phi_1 d\phi_2]^{1/2}$$

Pick a path $y_i(t)$

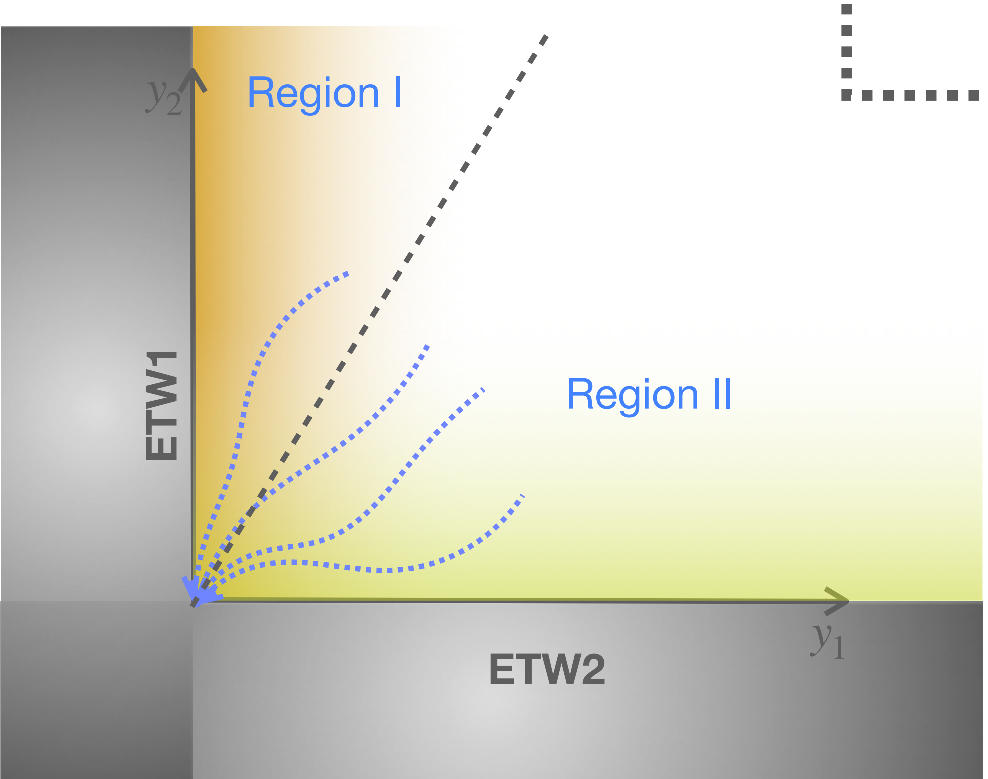
$$y_1(t) = t^{\gamma_1}$$
$$y_2(t) = t^{\gamma_2}$$

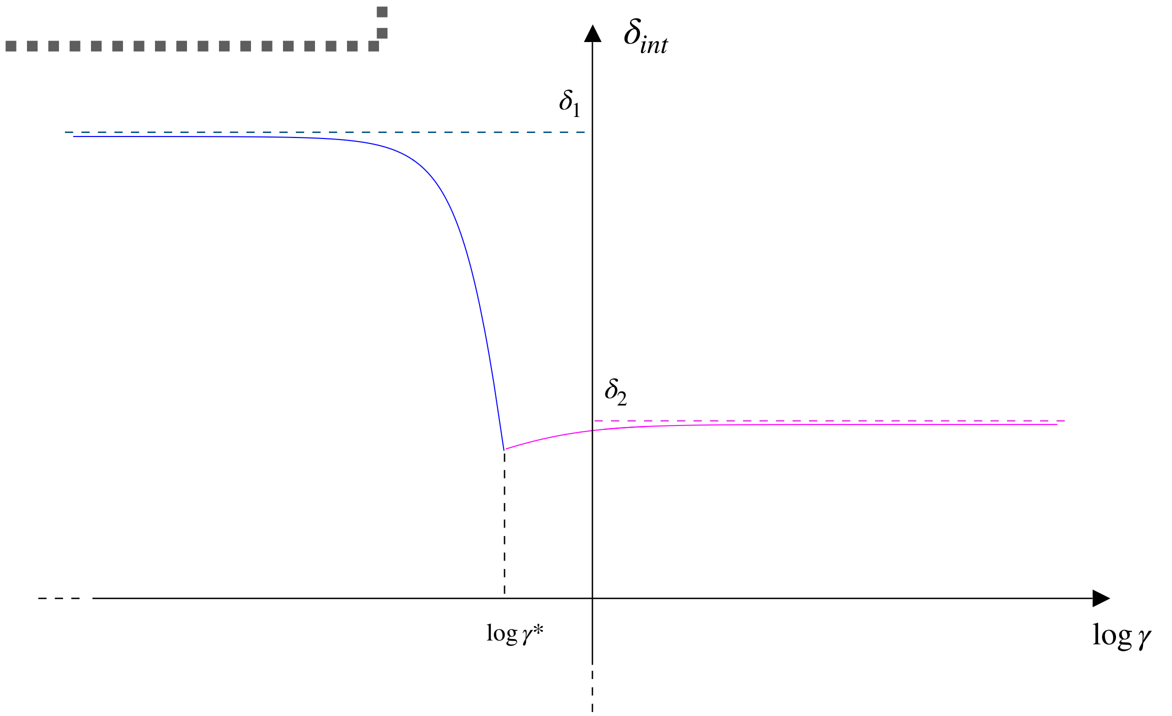
$$r_1 = \frac{4\gamma_2}{n\delta_2^2} + \gamma_1 - 1$$

$$\Delta = \int [\gamma_1^2 t^{2r_1} + \gamma_2^2 t^{2r_2}]^{1/2} dt$$

$$\mathscr{D} = -2\left(\frac{\gamma_1^2}{\delta_1^2} + \frac{\gamma_2^2}{\delta_2^2} + \frac{\alpha\gamma_1\gamma_2}{\delta_1\delta_2}\right)$$

$$\boxed{\delta_{int} = \left(\frac{\gamma_1^2}{\delta_1^2} + \frac{\gamma_2^2}{\delta_2^2} + \frac{\alpha\gamma_1\gamma_2}{\delta_1\delta_2}\right)^{-1/2}(r_i + 1)}$$





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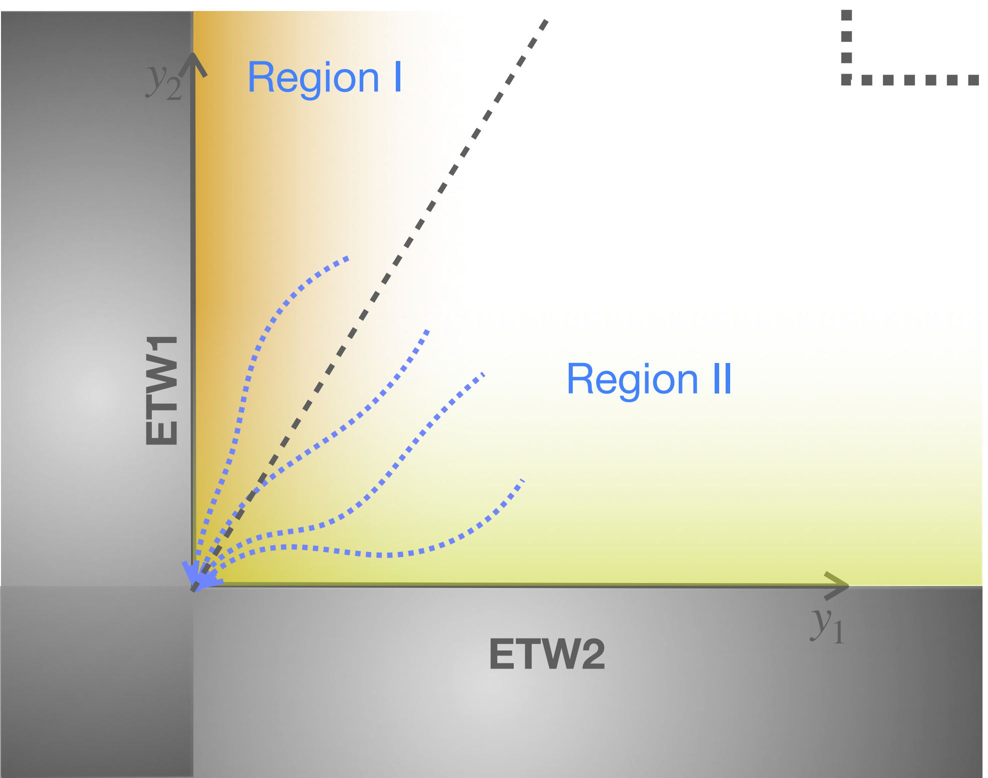
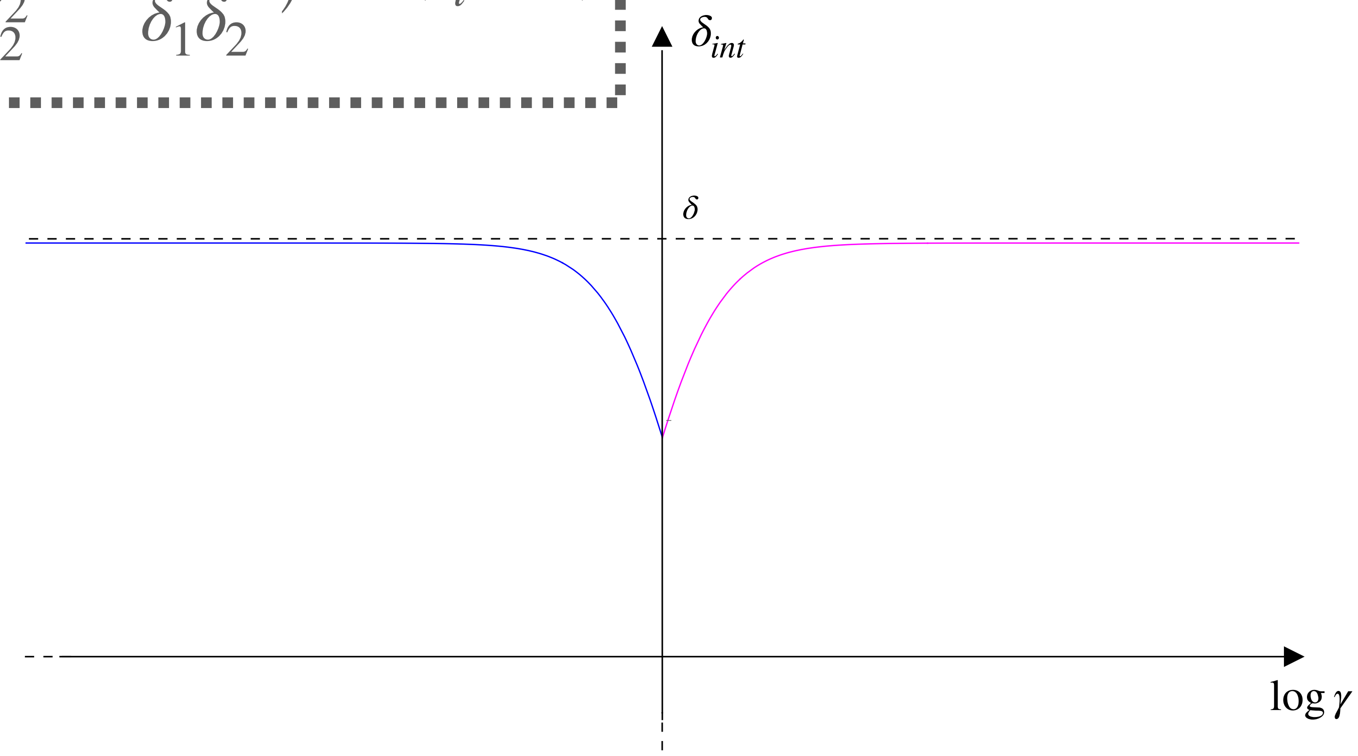




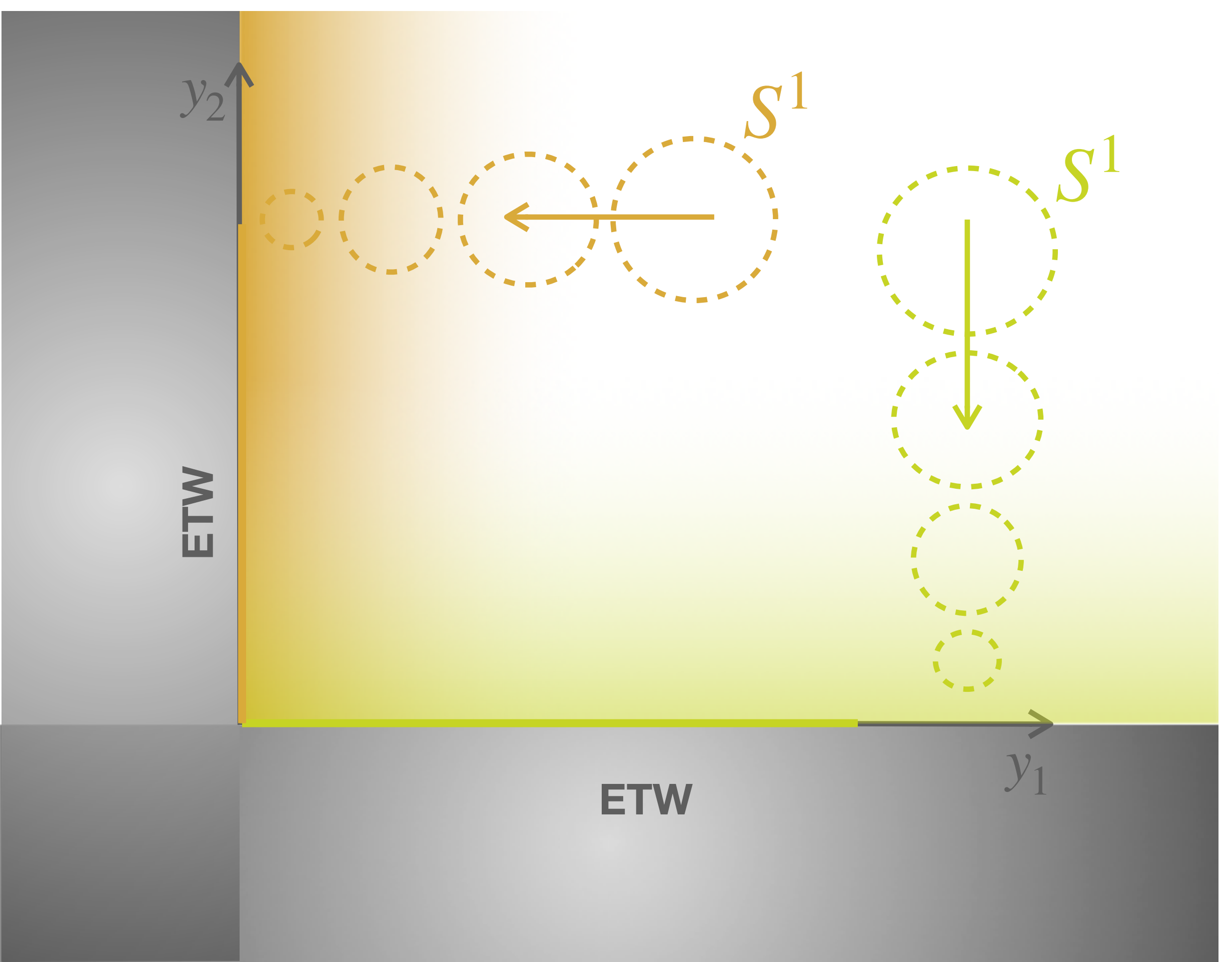
Example I: $S^1 \times S^1$ compactifications

Setup: Einstein gravity for (n+4)-dimensional space, reduced over $S^1 \times S^1$

Action: $$S_{n+2} = \frac{1}{2}\int d^{n+2}x\sqrt{-g_{n+2}}\left(R_{n+2} - |\partial\rho_1|^2 - |\partial\rho_2|^2 - \frac{2}{n+1}\partial_\mu\rho_1\partial^\mu\rho_2\right).$$

Solution: $$\begin{aligned} ds^2_{n+2} &= r_1^{2/n}r_2^{2/n}[ds_n^2 + dr_1^2 + dr_2^2] \\ &= y_1^{\frac{2}{n+1}}y_2^{\frac{2}{n+1}}ds_n^2 + y_2^{\frac{2}{n+1}}dy_1^2 + y_1^{\frac{2}{n+1}}dy_2^2 \end{aligned}$$

$$(y_i = \frac{n}{n+1}r_i^{\frac{n+1}{n}})$$



In this case, $\rho_i \equiv \phi_i$

$$\rho_i = -\sqrt{\frac{n}{n+1}}\log y_i, \quad i = 1, 2$$

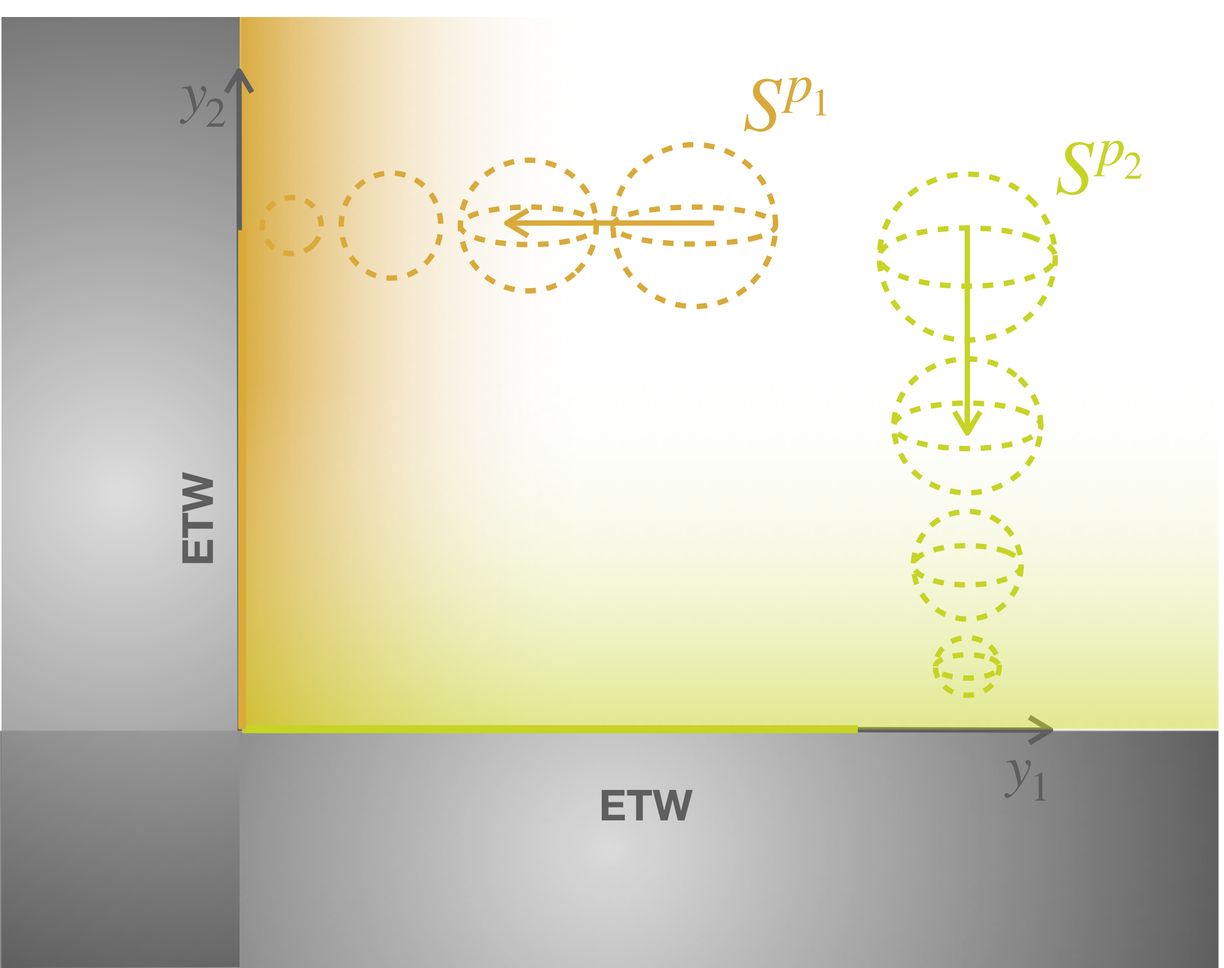
$$\delta_1 = \delta_2 = 2\sqrt{\frac{n+1}{n}}$$

Example I': $S^{p_1} \times S^{p_2}$ compactifications

Setup: Einstein gravity for (n+p+q+2)-dimensional space, reduced over $S^{p_1} \times S^{p_2}$

Action: $$S_{n+2} = \frac{1}{2}\int d^{n+2}x\sqrt{-g_{n+2}}\Big(R_{n+2} - |\partial\rho_1|^2 - |\partial\rho_2|^2 - \frac{2}{n+1}\partial_\mu\rho_1\partial^\mu\rho_2$$
$$+\frac{p_1(p_1-1)}{2}(\frac{n}{n+p_1})^2 e^{(\alpha_1+\beta_1)\rho_1+\alpha_2\rho_2} + \frac{p_2(p_2-1)}{2}(\frac{n}{n+p_2})^2 e^{(\alpha_2+\beta_2)\rho_2+\alpha_1\rho_1}\Big)$$

Solution: $$ds^2_{n+2} = y_1^{\frac{2p_1}{n+p_1}} y_2^{\frac{2p_2}{n+p+2}} ds_n^2 + y_2^{\frac{2p_2}{n+p_2}} dy_1^2 + y_1^{\frac{2p_1}{p_1+1}} dy_2^2$$

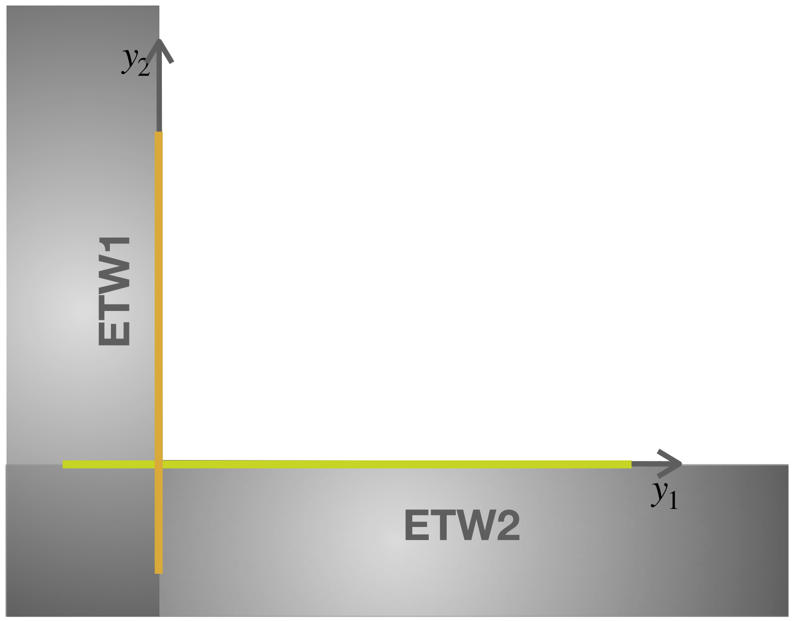


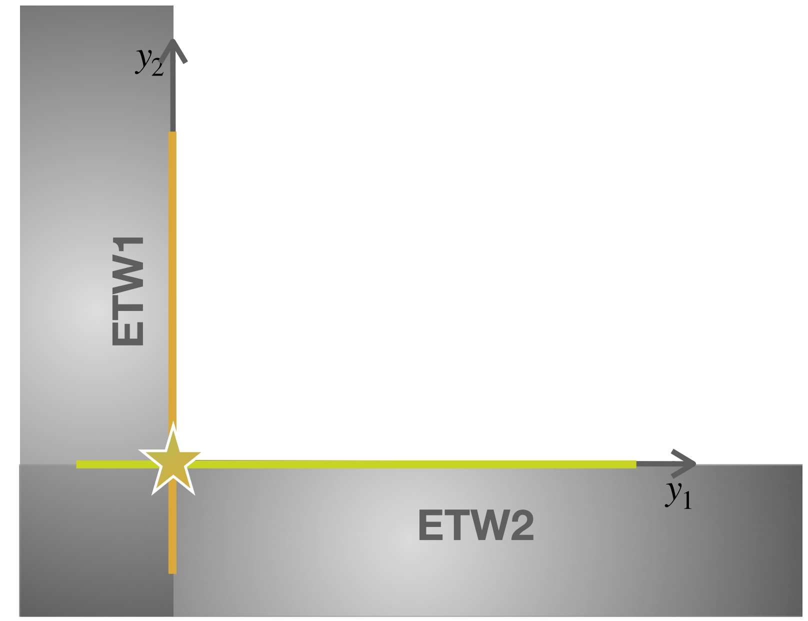
Once again, $\rho_i \equiv \phi_i$

$$\rho_i = -\sqrt{\frac{np_i}{n+p_i}}\log y_i,\, i = 1,\, 2$$

$$\delta_1 = \delta_2 = \sqrt{\frac{n+p_i}{np_i}}$$

What about the sources?





“Textbook” Dynamical Cobordism case:

$$S = \int d^d x \sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}(\partial\phi)^2\right) - \lambda \int d^{d-1}x\sqrt{-\tilde{g}}\, e^{\alpha\phi}\delta(y)$$

[Blumenhagen, Kneissl, Wang ’23,
Angius, AM, Uranga ’23]

Using the ansatz $\quad ds_d^2 = e^{-2\sigma(y)} ds_{d-1}^2 + dy^2$

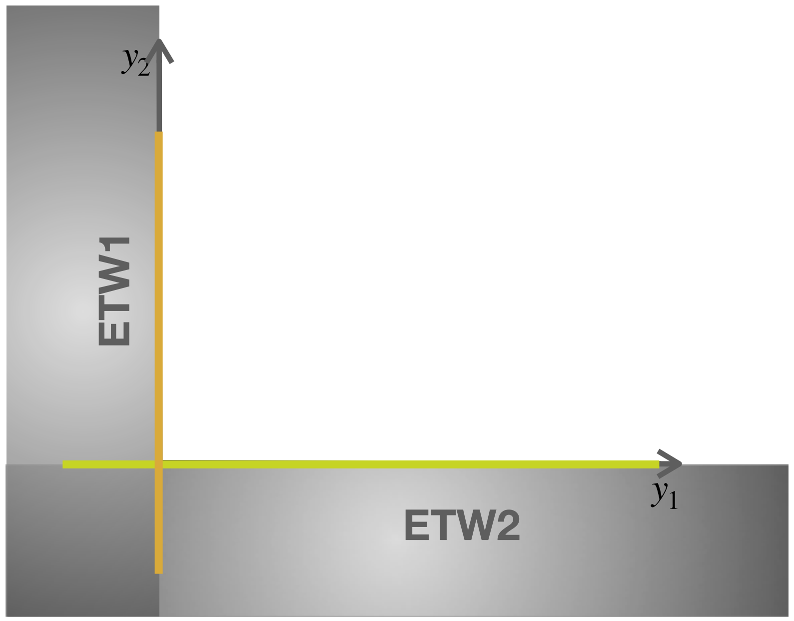
asking for solutions of the form $\quad \phi(y) \sim c_1 \log y, \quad \sigma(y) \sim c_2 \log y$

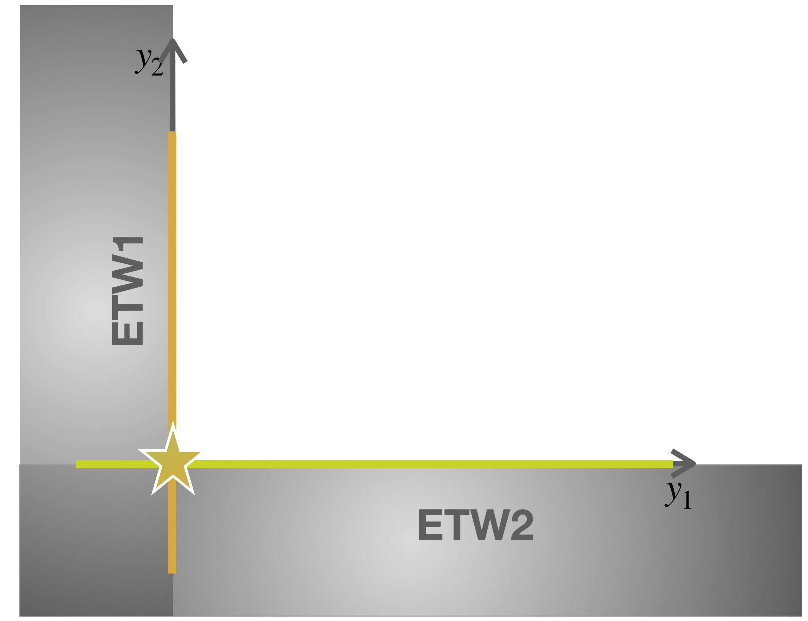
and imposing there is nothing for $y < 0$ fixes

Reminder: $\delta = 2a$ for V=0

$$a = \sqrt{\frac{d-1}{d-2}}, \qquad \lambda = -\frac{d-2}{d-1}$$

What about the sources?





Intersecting case:

$$S = \int d^{n+2}x\sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}(\partial\phi_1)^2 - \frac{1}{2}(\partial\phi_2)^2 - \frac{\alpha}{2}\partial\phi_1\partial\phi_2\right) - \lambda\int d^n x\sqrt{-\tilde{g}}\,e^{\alpha_1\phi_1+\alpha_2\phi_2}\delta(y_1, y_2)$$

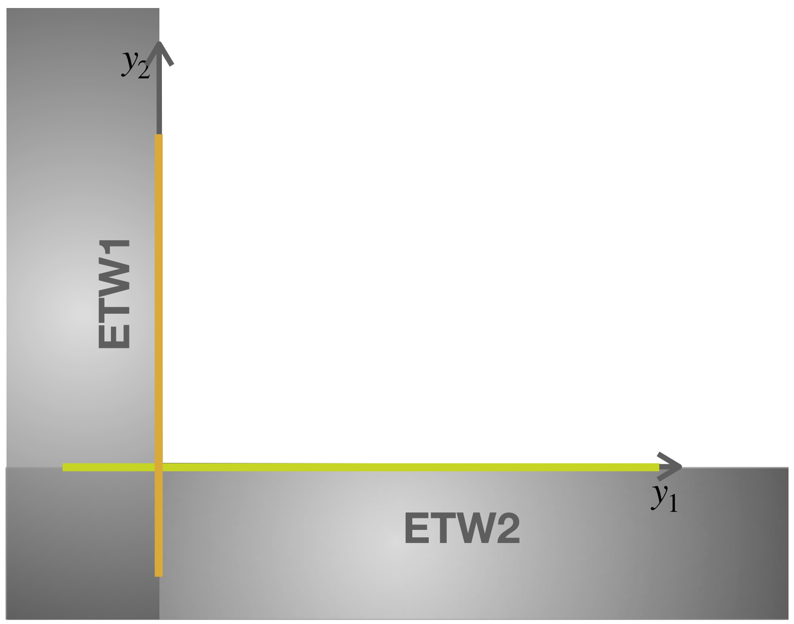
Using the ansatz $ds^2_{n+2} = e^{-2\sigma_1-2\sigma_2}ds^2_n + e^{-\sigma_2}dy_1^2 + e^{-2\sigma_1}dy_2^2$

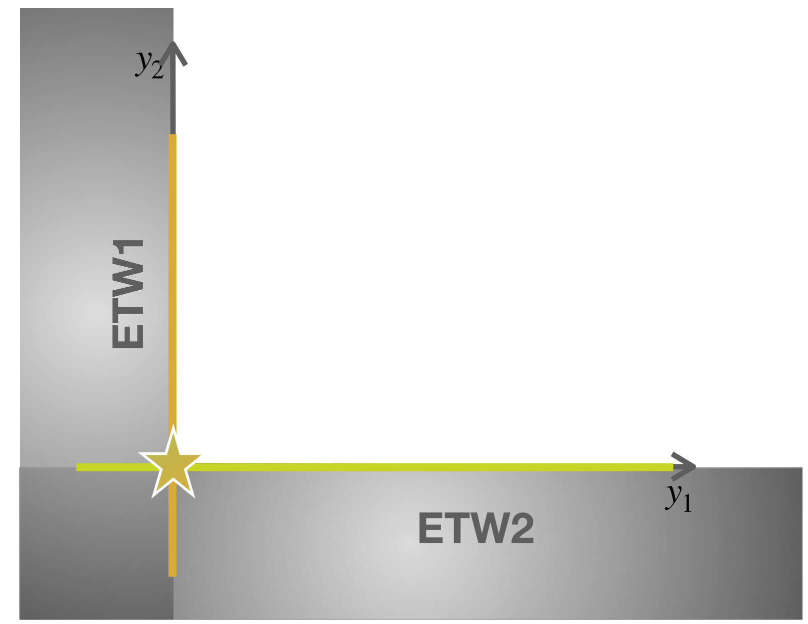
asking for solutions of the form $\phi_i(y_i) \sim c_{1i}\log y_i, \quad \sigma(y_i) \sim c_{2i}\log y_i$

and imposing there is nothing for $y < 0$

is inconsistent with the equations of motion!

What about the sources?





Intersecting case:

$$S = \int d^{n+2}x\sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}(\partial\phi_1)^2 - \frac{1}{2}(\partial\phi_2)^2 - \frac{\alpha}{2}\partial\phi_1\partial\phi_2\right) \; -\lambda_1\int d^{n+1}x\sqrt{-\tilde{g}_1}\,e^{\alpha_{11}\phi_1+\alpha_{21}\phi_2}\delta(y_1)$$
$$-\lambda_2\int d^{n+1}x\sqrt{-\tilde{g}_2}\,e^{\alpha_{21}\phi_1+\alpha_{22}\phi_2}\delta(y_2)$$

Now can go through the procedure self-consistently, getting

$$\alpha_{12} = \alpha_{21} = \frac{1}{\sqrt{n(n+1)}} \qquad \alpha = \frac{2}{n+1} \qquad \alpha_{11} = \alpha_{22} = \sqrt{\frac{n+1}{n}} = \sqrt{\frac{d-1}{d-2}}$$

$$\lambda_1 = \lambda_2 = -\frac{n-1}{n} = -\frac{d-2}{d-1}$$

ETWs: a different approach

[Blumenhagen, Cribiori, Kneissl, AM '22]

Setup: Gauge neutral, non-supersymmetric 9d object w/ brane-like dilaton coupling

Physical realisation: non-BPS $\widehat{D8}$ -brane, non-SUSY stack of $16 \times \bar{D}8 + O8^{++}$

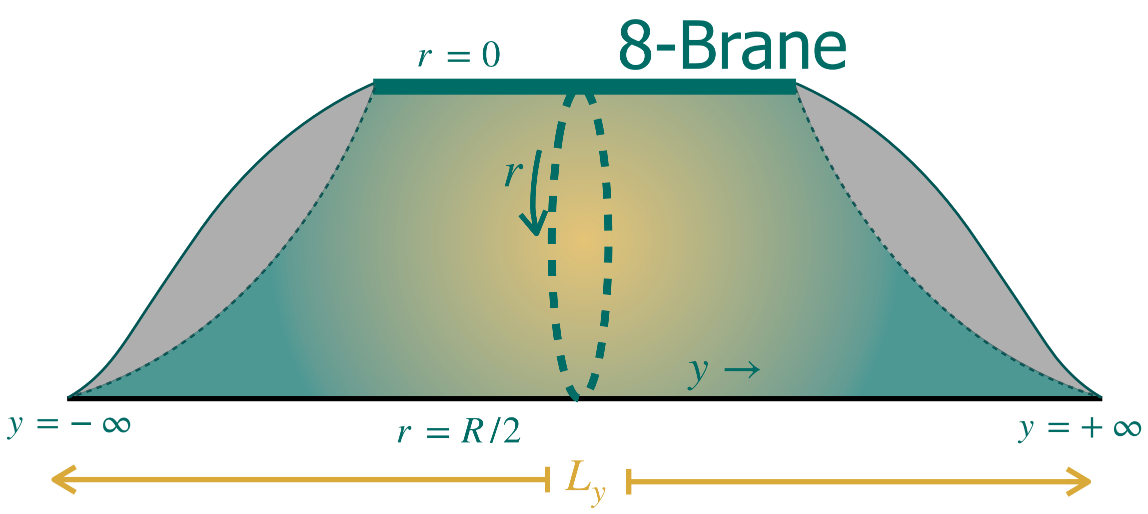
[Blumenhagen, Font '00]

Action: $$S = \frac{1}{2\kappa_{10}^2} \int d^{10}x \sqrt{-G} \left(\mathscr{R} - \frac{1}{2}(\partial\Phi)^2 \right) - T \int d^{10}x \sqrt{-g}\, e^{\frac{5}{4}\Phi} \delta(r)\,.$$

transverse direction

Solution Ansatz: $$ds^2 = e^{2\mathscr{A}(r,y)} ds_8^2 + e^{2\mathscr{B}(r,y)} (dr^2 + dy^2)\,.$$ [Blumenhagen, Font '00]

$$\mathscr{A} = A(r) + U(y) \qquad \mathscr{B} = B(r) + V(y) \qquad \Phi = \chi(r) + \psi(y)$$



$\longleftrightarrow$

r-direction spontaneously compactified

Logarithmic singularities at $r = \pm \dfrac{R}{2}$,

y-direction: finite interval

[Blumenhagen, Cribiori, Kneissl, AM '22]

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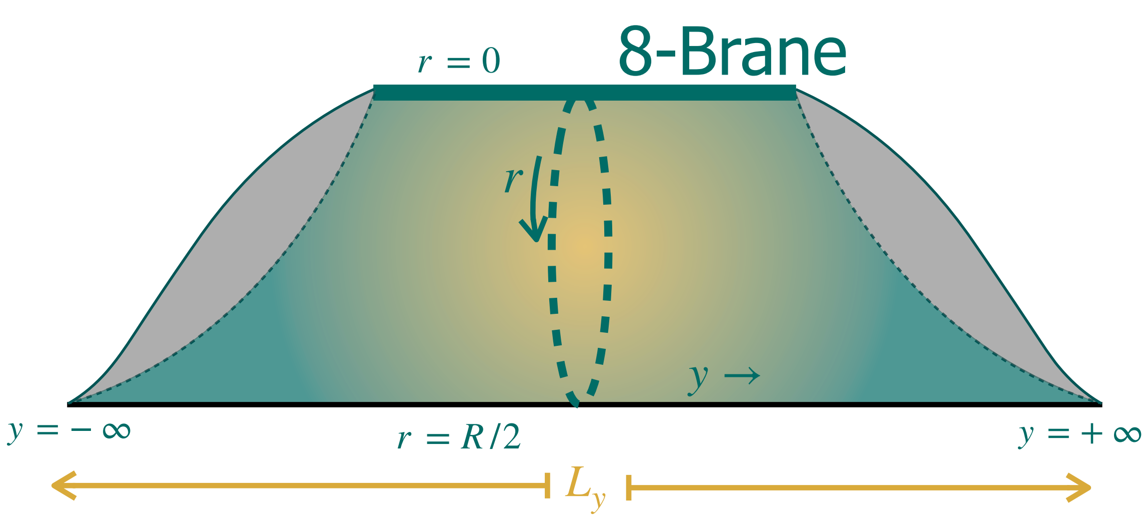

$\longleftrightarrow$

At $(r, y) = (R/2, \pm\infty)$:

$$\left. \begin{array}{l} \Delta \sim L_y \sim e^{-\frac{5}{4}\sqrt{2}D} \\ |\mathscr{R}| \sim e^{\frac{5}{2}\sqrt{2}D} \end{array} \right\} \delta = \frac{5\sqrt{2}}{2}$$

Codimension-2 ETW

[Blumenhagen, Cribiori, Kneissl, AM ’22] and generalised in [Blumenhagen, Kneissl, Wang ’23]

Input: 8-dimensional defect : log-singularity, S^1 direction capped off

Poincaré symmetry along the brane preserved

2d transversal rotational symmetry broken

Non-Isotropic Solution Ansatz: $$ds^2 = e^{2\hat{\mathscr{A}}(\rho,\varphi)}ds_8^2 + e^{2\hat{\mathscr{B}}(\rho,\varphi)}(d\rho^2 + \rho^2 d\varphi^2)\,.$$

Separation of variables

Logarithmic singularities at $\rho = 0$, string coupling diverges

Dynamical Cobordism scaling satisfied: $\Delta \sim e^{-\frac{5}{4}\sqrt{2}D},\ |\mathscr{R}| \sim e^{\frac{5}{2}\sqrt{2}D}$ $\quad \delta = \frac{5\sqrt{2}}{2}$

$$\boxed{S = -\,T_7^{\pm}\int d^{10}x\sqrt{-g}\,\delta^{(2)}(\vec{r})}$$

[Angius '24]

Codimension-2 ETW as an intersection?

Starting Point: $S = \int d^{n+2}x\sqrt{-g}\left(\frac{1}{2}R - \frac{1}{2}(\partial\phi_1)^2 - \frac{1}{2}(\partial\phi_2)^2 - \frac{\alpha}{2}\partial_\mu\phi_1\partial^\mu\phi_2 - V(\phi_1,\phi_2)\right)$

Solution ansatz: $ds^2_{n+2} = e^{2A(y_1,y_2)}ds^2_n + e^{2B(y_1,y_2)}dy_1^2 + e^{2C(y_1,y_2)}dy_2^2$

$$\phi_1 = \phi_1(y_1),\ \ \phi_2 = \phi_2(y_2)$$

$$A(y_1,y_2) = -\sigma_1(y_1) - \sigma_2(y_2) \qquad B(y_1,y_2) = -\sigma_2(y_2) \qquad C(y_1,y_2) = -\sigma_1(y_1)$$

Trade-offs:

I) $\phi_1 = \phi_1(y_1,y_2) = b_{11}\log y_1 + b_{12}\log y_2,$ $\quad \to \alpha = 0$

$$\phi_2 = \phi_2(y_2) = b_2\log y_2$$

II) $A(y_1,y_2) = -a_1\log y_1 + a_2\log y_2,$ $\quad \to V = -V_1\cdot V_2 \sim -e^{\lambda_1\phi_1}e^{\lambda_2\phi_2}$

$$B(y_2) = a_2\log y_2 - \frac{1}{2}\log c_2,$$

$$C(y_1) = (1-a_1 n)\log y_1 - \frac{1}{2}\log c_1$$

$\delta^{(2)}(y_1,y_2)$ compatible with equations of motion!

Summary and Outlook

- Dynamical Cobordism solutions can coexist
- The intersections can serve as “the end of the world for the-end-of-the-world objects”
- A universal local description exists in terms of the two critical exponents δ_1, δ_2
- In our “blueprint” framework, the solutions are a superposition of the ETW branes, with no true codimension-2 source.
- Giving up on conformal flatness, allows for genuine codimension-2 terms at intersection.
- Interplay with swampland conjectures, see also [Blumenhagen, Kneissl, Wang ’23] for such a proposal
  e.g. Convex Hull Distance Conjecture, Sharpened Distance Conjecture
  [Calderón-Infante, Uranga, Valenzuela ’20] [Etheredge, Heidenreich, Kaya, Kiu, Rudelius ’22]
- Systematic analysis of generalised case remains to be done - relation of critical exponent to physical characteristics
- Interplay with complementary ETW approaches?
  e.g. [Friedrich, Hebecker, Walcher ‘23]

Thank you!