SWAMPLAND CONJECTURES FOR STRINGS AND MEMBRANES

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based on arXiv: ***2006.15154***

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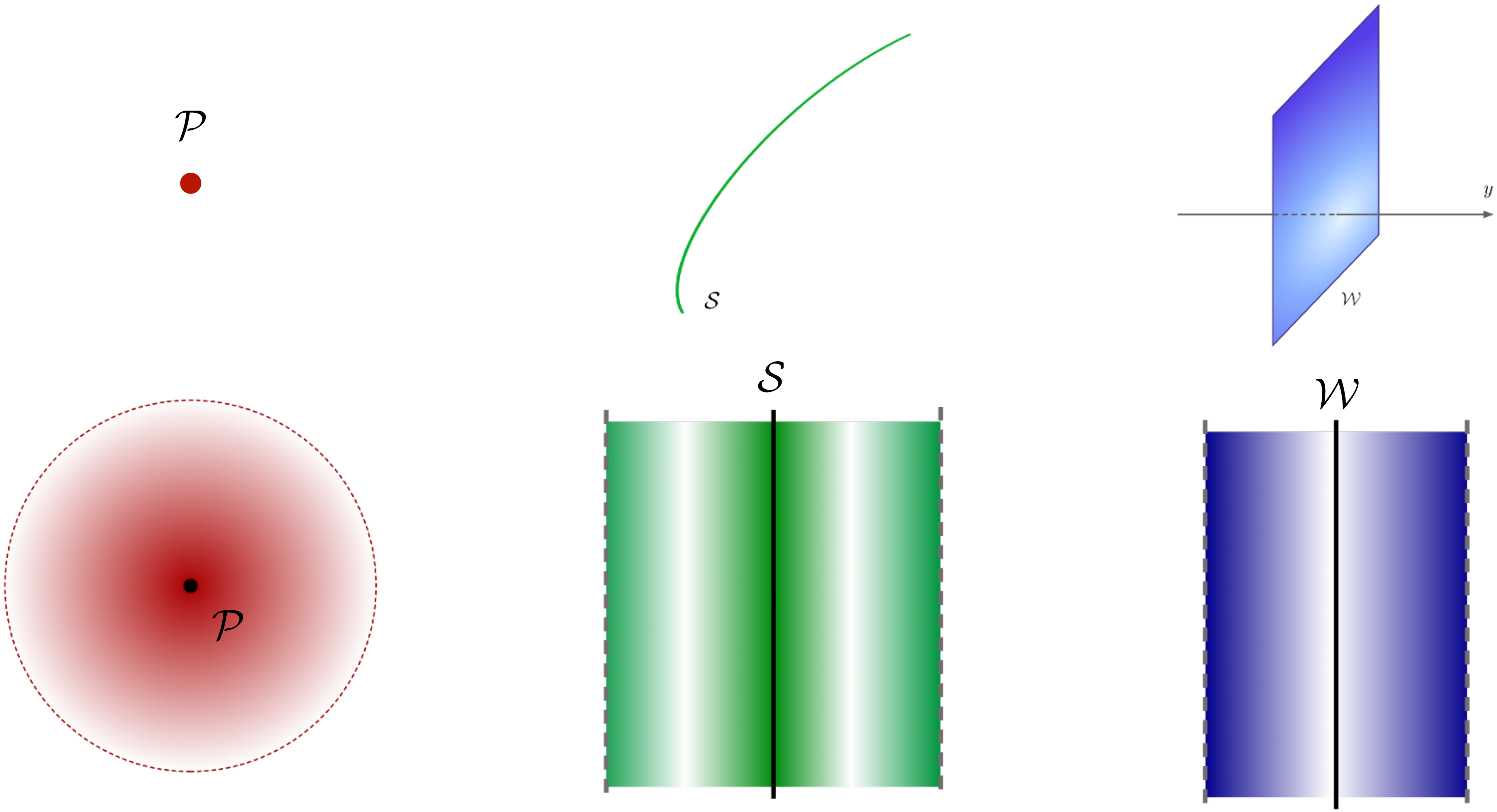
Summer Series on String Phenomenology ~ September 1, 2020

Low Codimension Objects and Backreactions

Extended objects with low codimension strongly backreact on the geometry; in 4D

Particle | String | Membrane



Backreaction negligible as $r \to \infty$

Strong backreaction as the distance from the source increases, with the metric breaking down at a finite distance from the object

Strong Backreactions and EFTs

Does the inclusion of strings or membranes break the EFT?

How can we understand the backreaction of the objects at EFT level?

Backreaction of the extended objects
onto the spacetime metric and the fields of the EFT

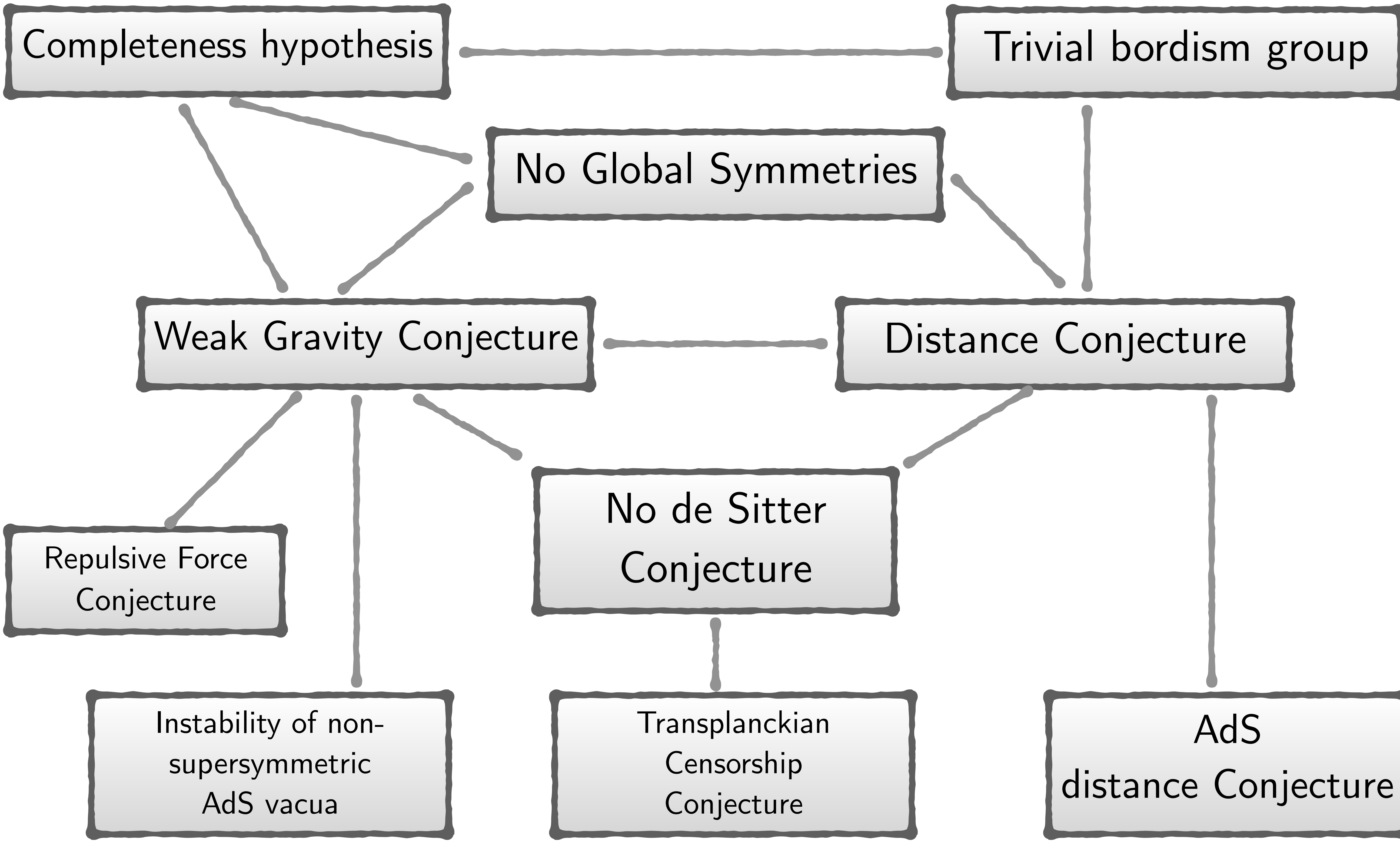
$\Updownarrow$

RG flow of the EFT couplings

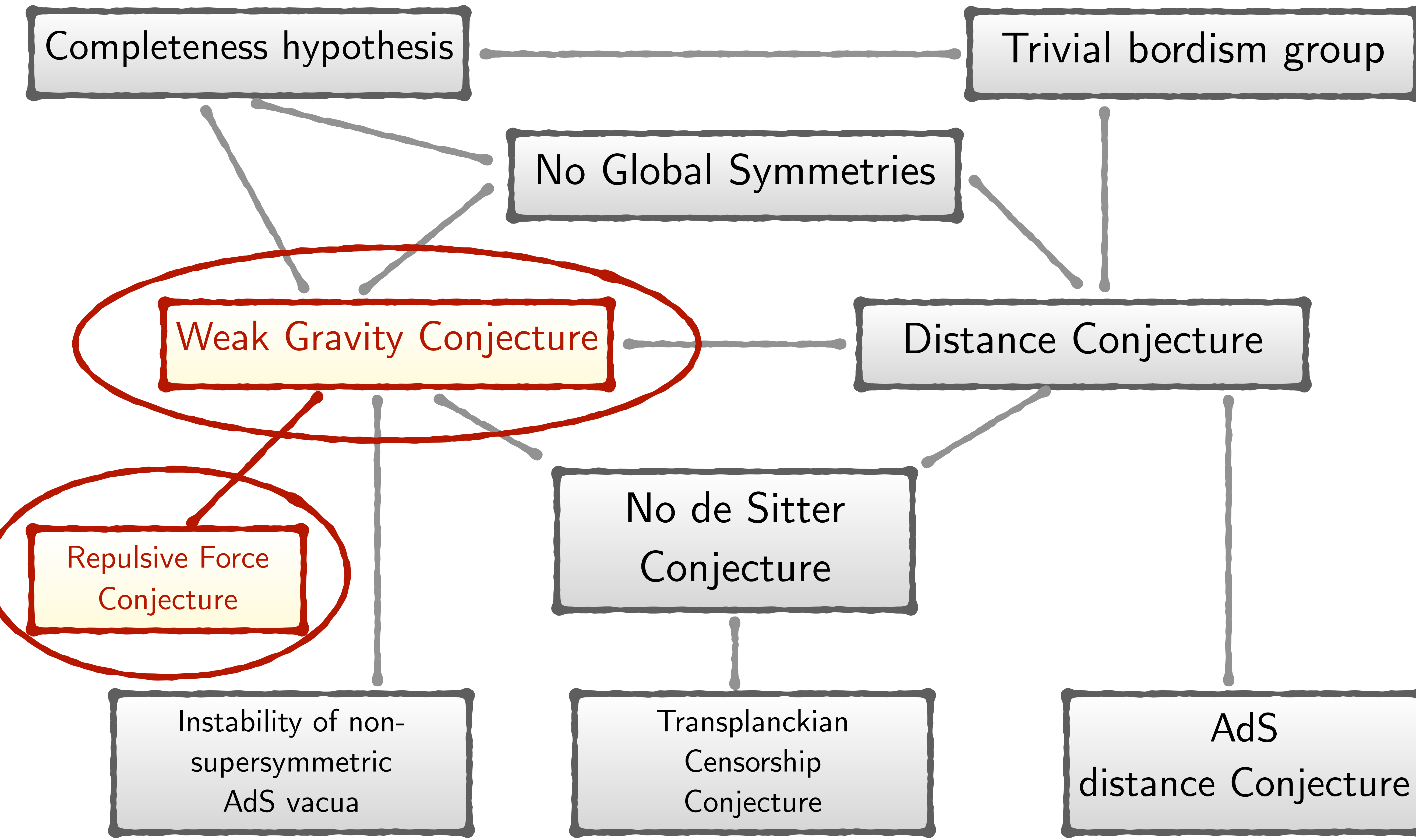
[Goldberger, Wise 2001; Polchinski et al. 2014]

We will show this correspondence in *N=1* Supergravity EFTs.

EXTENDED OBJECTS AND SWAMPLAND CONJECTURES



Extended Objects and Swampland Conjectures



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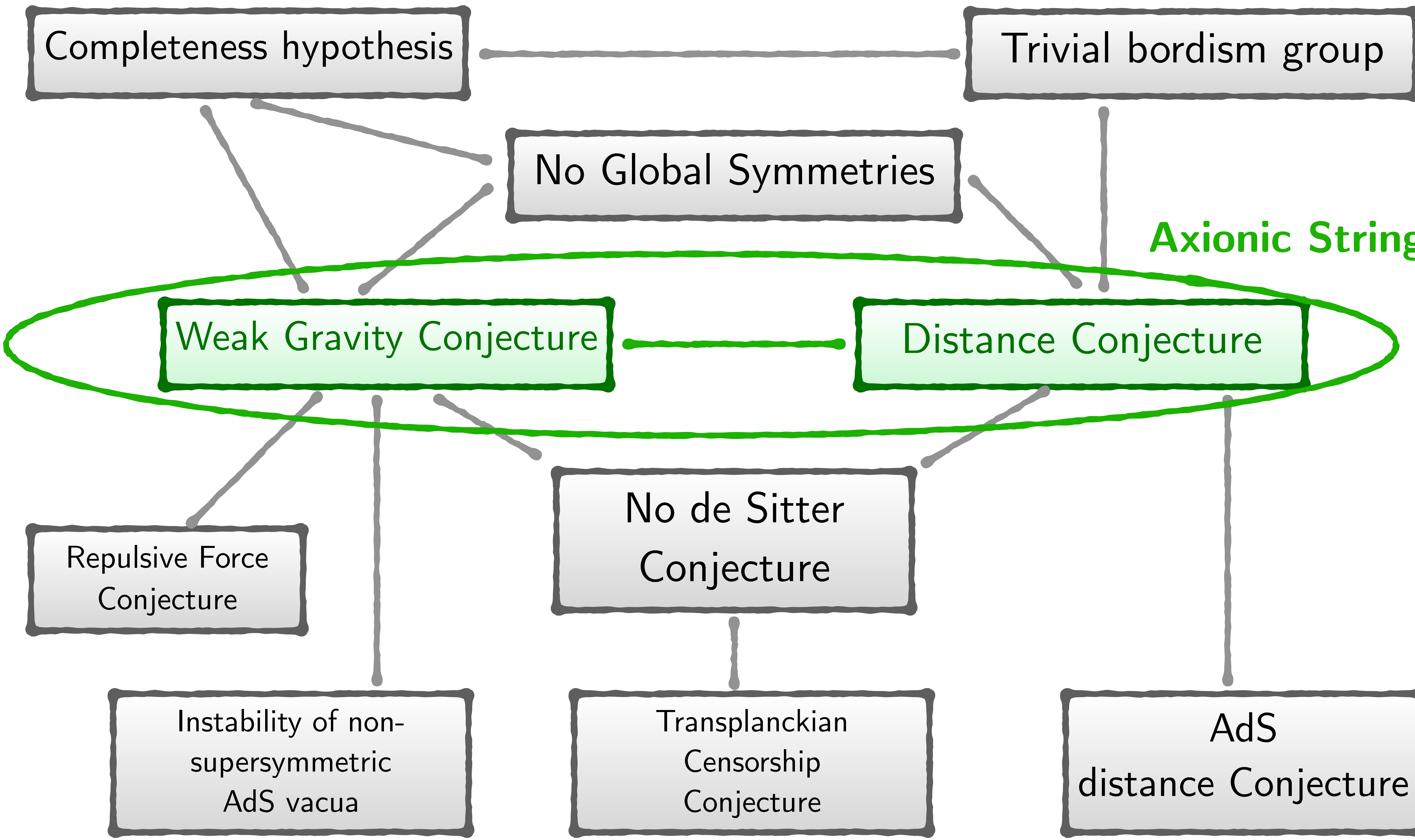
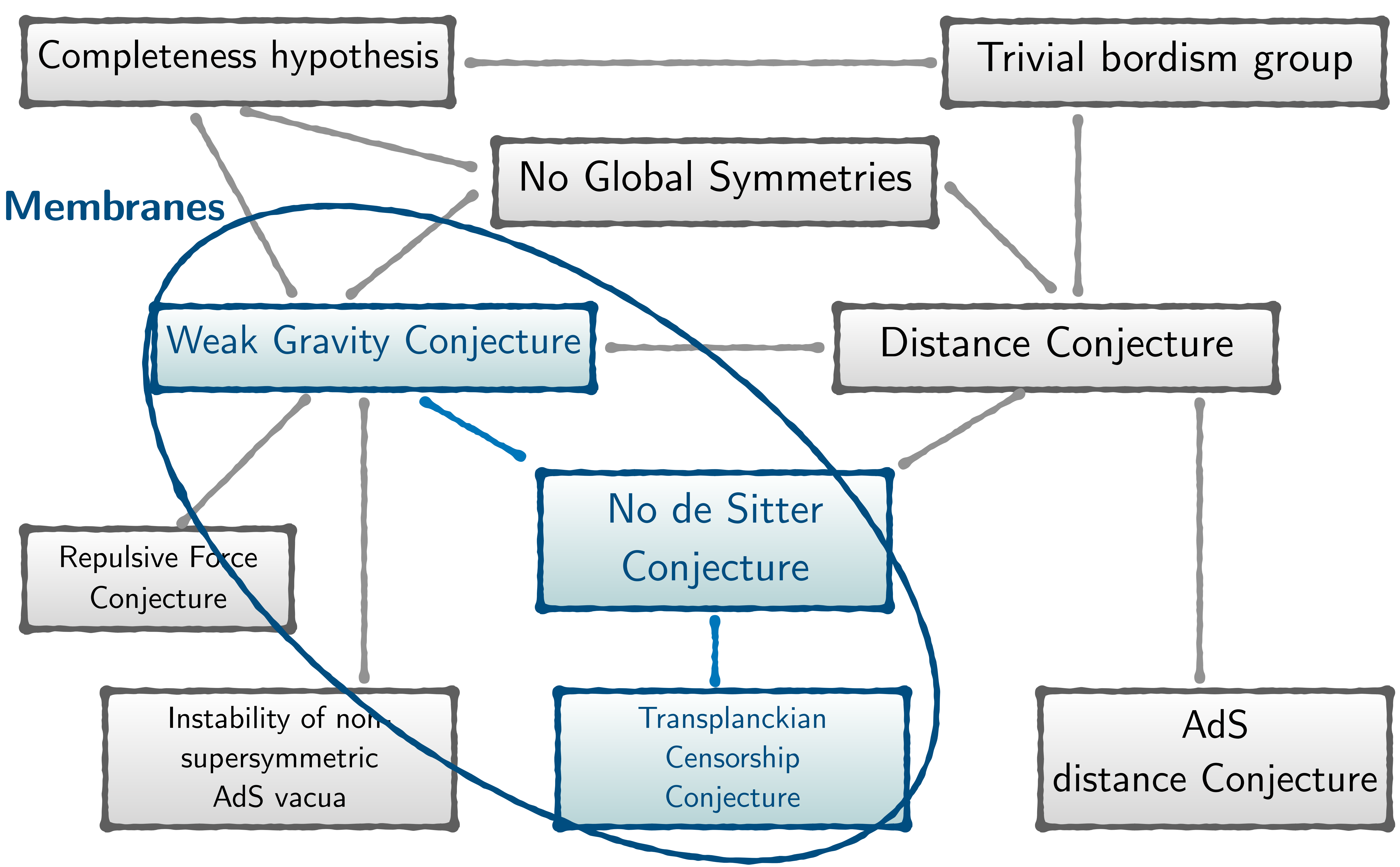


Extended Objects and Swampland Conjectures



Axionic Strings and Infinite Field Distance

Axionic Strings in $N=1$ Supergravity

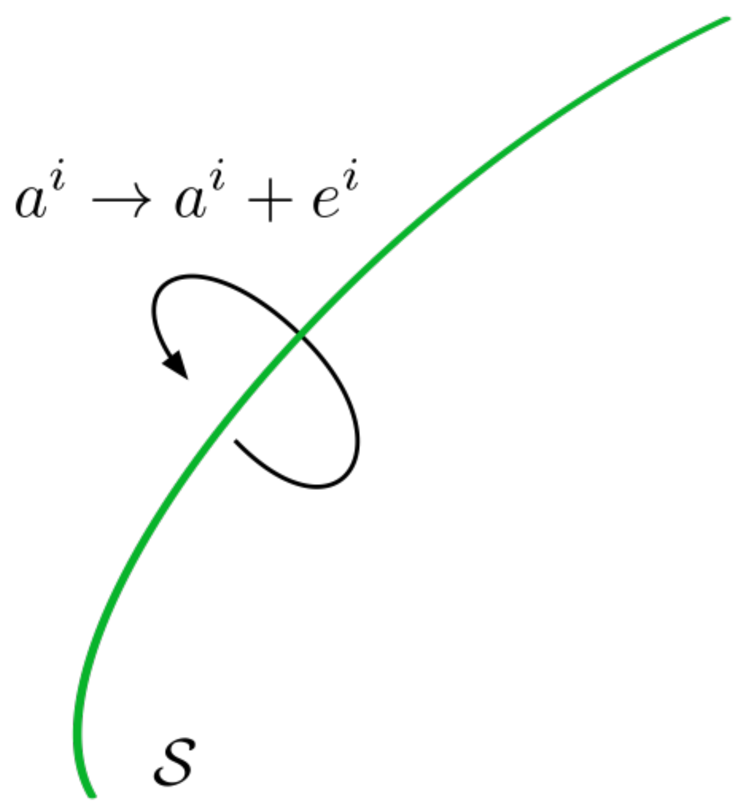
We will consider **fundamental axionic strings**:

- they are included directly within the EFT as fundamental objects, with *strict* codimension two;
- electrically coupled to gauge two-forms via:

$$e^i \int_{\mathcal{S}} \mathcal{B}_{2\,i}$$

- magnetically coupled to the dual axions:

$$a^i \to a^i + e^i$$



In order to consider strings semiclassically within an EFT with cutoff Λ, their tension needs to satisfy

$$\mathcal{T}_{\rm str} \gtrsim \Lambda^2$$

In order to embed fundamental strings in Supergravity, we need a proper formulation which supersymmetrically includes gauge 2-forms.

Axionic Strings in $N=1$ Supergravity

- The bosonic components of an *N=1* supersymmetric action of a set of chiral multiplets Φ^i is

$$S=\int\left(\frac{1}{2}M_{\rm P}^2\,R*1-M_{\rm P}^2\,K_{i\bar{j}}\mathrm{d}\phi^i\wedge*\mathrm{d}\bar{\phi}^{\bar{j}}\right)\qquad \phi^i=a^i+\mathrm{i}s^i$$

axions

saxions

Assume that the Kähler potential is invariant under axionic shifts: $K(\phi,\bar{\phi})\equiv K(s)$

Dualize the chiral multiplets Φ^i to linear multiplets L_i.

At the bosonic level:

saxions s^i $\longleftrightarrow$ dual saxions $\quad \ell_i=-\frac{1}{2}\frac{\partial K}{\partial s^i}$

axions (gauge 0-forms) a^i $\longleftrightarrow$ gauge 2-forms $\quad \mathcal{H}_{3i}=\mathrm{d}\mathcal{B}_{2i}=\frac{1}{2}\frac{\partial^2 K}{\partial s^i\,\partial s^j}*\mathrm{d}a^j$

- The dual action expressed in terms of a set of linear multiplets is

$$S=\frac{1}{2}\int\left(M_{\rm P}^2\,R*1-M_{\rm P}^2\,\mathcal{G}^{ij}\mathrm{d}\ell_i\wedge*\mathrm{d}\ell_j-\frac{1}{M_{\rm P}^2}G^{ij}_{B_2}\mathcal{H}_{3\,i}\wedge*\mathcal{H}_{3\,j}\right)$$

and *N=1* supersymmetry fixes the scalar metric and gauge kinetic function to be equal:

$$\mathcal{G}_{ij}=G^{B_2}_{ij}\equiv\frac{1}{2}\frac{\partial^2K}{\partial s^i\partial s^j}$$

[SL, Marchesano, Martucci, Sorokin, 2019]

Axionic Strings in $N=1$ Supergravity

- We can now couple a fundamental string:

$$S = -\frac{1}{2}\int \left(M_{\rm P}^2\, \mathcal{G}^{ij} \mathrm{d}\ell_i \wedge * \mathrm{d}\ell_j + \frac{1}{M_{\rm P}^2} \mathcal{G}^{ij} \mathcal{H}_{3\,i} \wedge * \mathcal{H}_{3\,j} \right) + S_{\rm str}$$

with

$$S_{\rm str} = -\int_{\mathcal{S}} \sqrt{-h}\, \mathcal{T}_{\rm str} + e^i \int_{\mathcal{S}} \mathcal{B}_{2\,i}$$

- The string tension is fixed by supersymmetry:

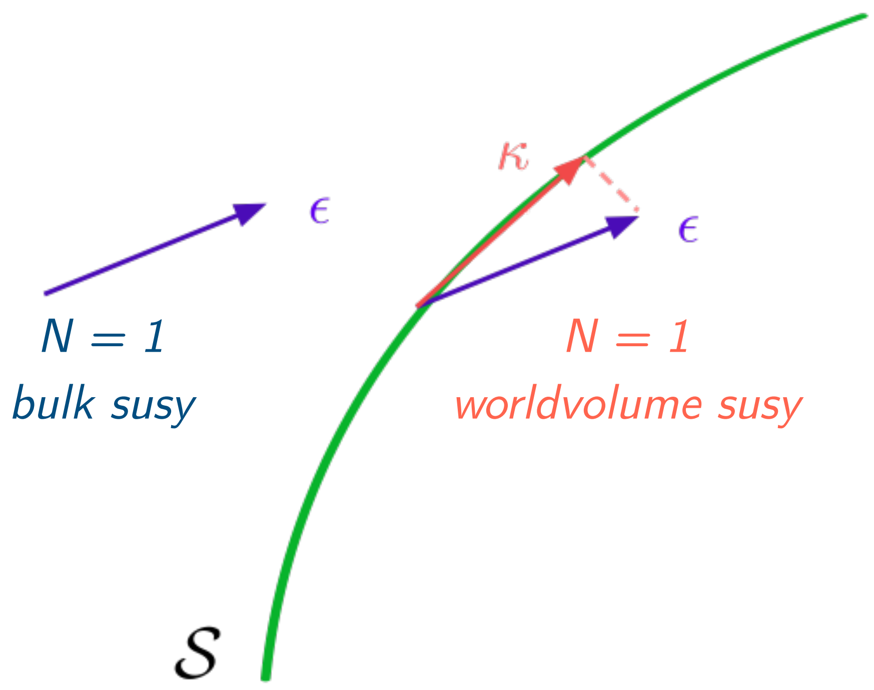
$$\mathcal{T}_{\rm str} = M_{\rm P}^2 |e^i \ell_i|$$

- The physical string charge is defined by

$$\mathcal{Q}_{\mathbf{e}}^2 = M_{\rm P}^2 \mathcal{G}_{ij} e^i e^j$$

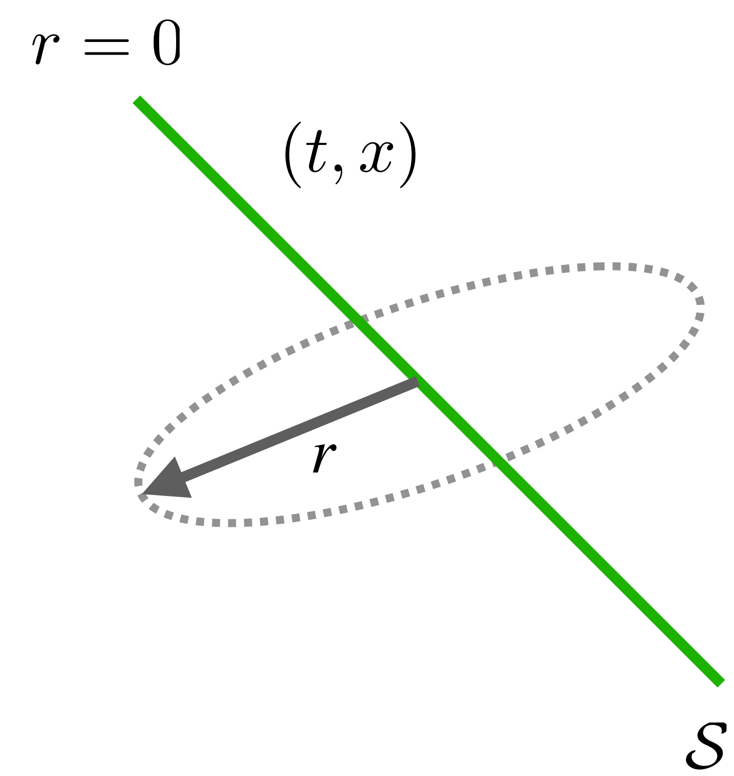
- The string tension obeys the tautological identity

$$\|\partial \mathcal{T}_{\rm str}\|^2 = M_{\rm P}^2 \mathcal{Q}_{\mathbf{e}}^2 \qquad \text{with} \qquad \|\partial \mathcal{T}_{\rm str}\|^2 \equiv \mathcal{G}_{ij} \partial_{\ell_i} \mathcal{T}_{\rm str} \partial_{\ell_j} \mathcal{T}_{\rm str}$$



Over its worldsheet, the string preserves at most 1/2 of the bulk supersymmetry, the other half being nonlinearly realized.

The String Backreaction



- Consider a single string located at radial coordinate $r = 0$ and whose worldvolume is described by the coordinates t, x .

  Metric ansatz

  $$\mathrm{d}s^2 = -\mathrm{d}t^2 + \mathrm{d}x^2 + e^{2D}\mathrm{d}z\mathrm{d}\bar{z}$$

  with z, $\bar{z}$ coordinates transverse to the string and $r = |z|$.

Consider a single saxion s, entering the Kähler potential as

$$K = -n \log s$$

Solving the equations of motions gives the backreacted solution:

- for the saxion s and axion a

$$s(r) = s_0 - \frac{e}{2\pi} \log \frac{r}{r_0} \,, \qquad a = \frac{\theta}{2\pi} e + \mathrm{const}$$

- for the warp factor

$$D \sim \frac{n}{2} \log s(r)$$

The solution breaks down at a finite distance

$$r_{\mathrm{IR}} = r_0 \exp\left[\frac{n\pi \, M_P^2}{\mathcal{T}_{\mathrm{str}}(r_0)}\right]$$

THE STRING BACKREACTION AS RG FLOW

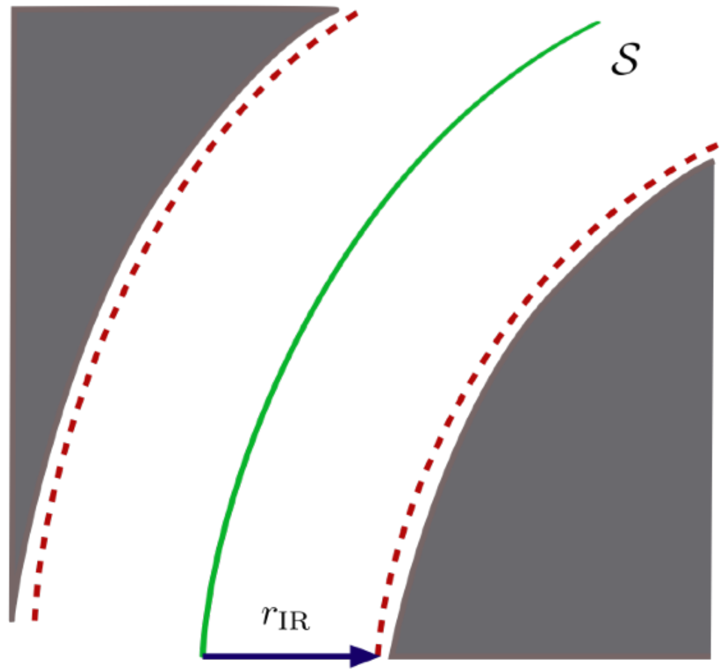
- The flow of the tension is

$$\mathcal{T}_{\rm str} = M_{\rm P}^2 e\,\ell(r) = \frac{e\,n\,M_{\rm P}^2}{2s_0 - \frac{e}{\pi}\log\frac{r}{r_0}}$$

which breaks down at a distance

$$r_{\rm IR} = r_0 \exp\left[\frac{n\pi\,M_P^2}{\mathcal{T}_{\rm str}(r_0)}\right]$$

In the limit $r \to 0$: $\quad \mathcal{T}_{\rm str} \to 0$



Define the energy scale $\Lambda = r^{-1}$

Consider the string tension as EFT coupling

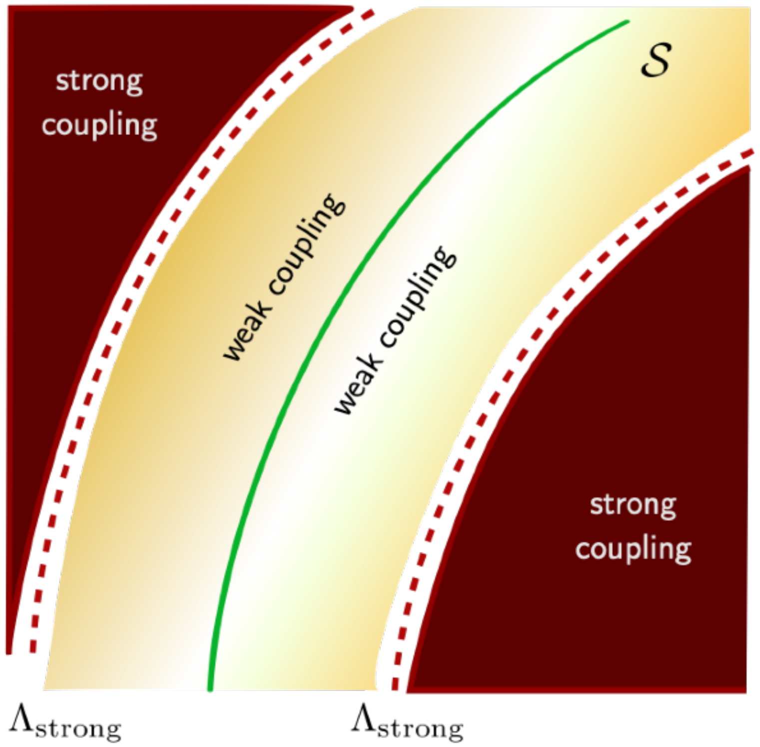
- We regard the profile of the tension as RG-flow of the tension

$$\mathcal{T}_{\rm str}^{\rm eff}(\Lambda) = \frac{\mathcal{T}_{\rm str}^0}{1 + \frac{\mathcal{T}_{\rm str}^0}{2\pi M_{\rm P}^2}\log(\Lambda r_0)}$$

and the EFT breaks at the strong coupling scale

$$\Lambda_{\rm strong} = \Lambda_0 \exp\left[-\frac{n\pi\,M_P^2}{\mathcal{T}_{\rm str}(\Lambda_0)}\right]$$

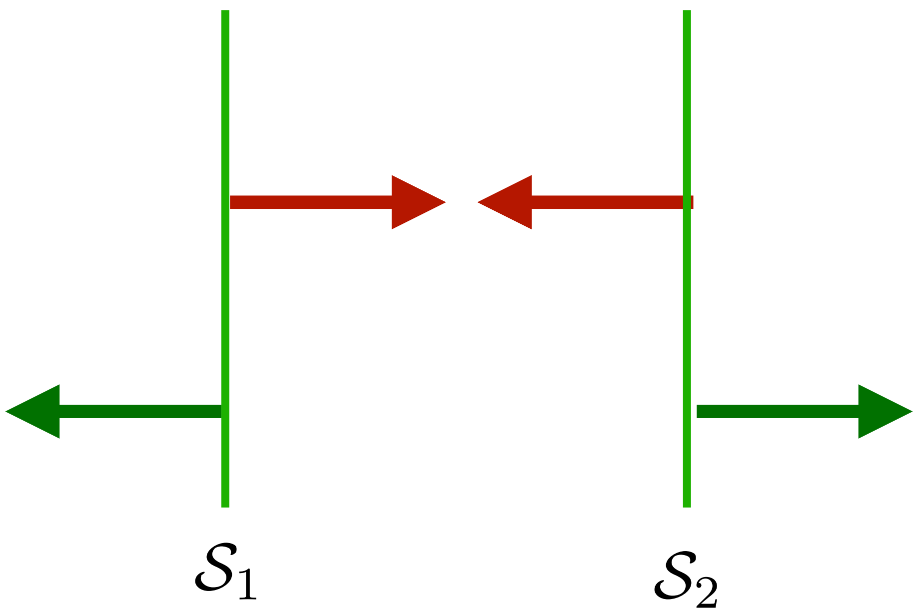
On the other hand, the limit $r \to 0$ corresponds to weak coupling.



RFC for Axionic Strings

[Palti, 2017; Heidenreich, Reece, Rudelius, 2019]

- Two identical strings interact with the following forces



No gravitational forces

Scalar forces $$\frac{1}{r}\mathcal{G}_{ij}\partial_{\ell_i}\mathcal{T}_{\rm str}\partial_{\ell_j}\mathcal{T}_{\rm str} = \frac{\|\partial\mathcal{T}_{\rm str}\|^2}{r}$$

Electric forces $$M_{\rm P}^4\frac{G^{B_2}_{ij}e^i e^j}{r} = M_{\rm P}^2\frac{\mathcal{Q}_{\mathbf{e}}^2}{r}$$

- The Repulsive Force Conjecture requires the existence of self-repulsive elementary axionic strings satisfying:

$$M_{\rm P}^4 G^B_{ij}e^i e^j = M_{\rm P}^2\mathcal{Q}_{\mathbf{e}}^2 > \|\partial\mathcal{T}_{\rm str}\|^2$$

which has to hold scale-wise along the RG-flow.

- Supersymmetric strings trivially satisfy the no-force condition

$$\|\partial\mathcal{T}_{\rm str}\|^2 = M_{\rm P}^2\mathcal{Q}_{\mathbf{e}}^2$$

WGC for Axionic Strings

Weak Gravity Conjecture for strings:

∃ a super-extremal string satisfying

$$\gamma \mathcal{T}_{\rm str} < M_{\rm P} \mathcal{Q}_{\mathbf{e}}$$

with γ being the extremality factor.

[Arkani-Hamed et al. 2006; Heidenreich, Reece, Rudelius, 2015; Reece, 2018; Craig et al. 2018, ...]

How to determine the extremality factor?

- Recall that a BPS-string satisfies the no-force condition

$$\|\partial \mathcal{T}_{\rm str}\| = M_{\rm P} \mathcal{Q}_{\mathbf{e}}$$

- For single scalar field, with Kähler potential $K = -n \log s$ the extremality factor is specified by the no-scale factor

$$\|\partial \mathcal{T}_{\rm str}\| = \sqrt{\frac{2}{n}} \mathcal{T}_{\rm str} \qquad M_{\rm P} \mathcal{Q}_{\mathbf{e}} = \gamma \mathcal{T}_{\rm str} \qquad \gamma = \sqrt{\frac{2}{n}}$$

- For multiple scalar fields, asymptotically in field space, we can use the sl(2) orbit theorem to approximate

$$K \simeq -\log P(s) + \ldots = -\log s_1^{n_1} s_2^{n_2 - n_1} \cdots s_n^{n_I - n_{I-1}} + \ldots$$

  using which it can be shown

$$M_{\rm P} \mathcal{Q}_{\mathbf{e}} > \gamma_{\rm min} \mathcal{T}_{\rm str} \qquad \text{with} \qquad \gamma_{\rm min} = \sqrt{\frac{2}{n_I}}$$

Axionic Strings and Infinite Field Distances

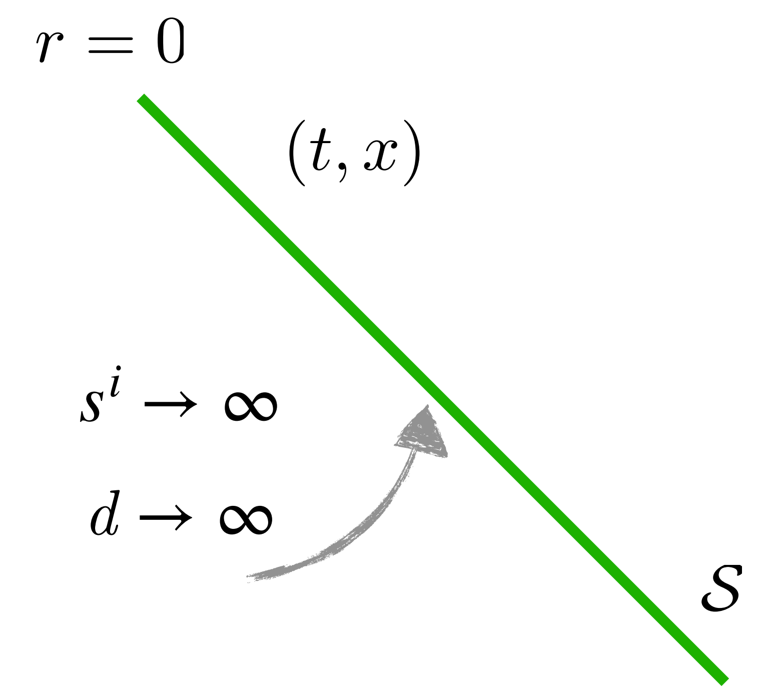
- The limit $r \to 0$, with

$$s^i \to \infty$$

corresponds to infinite field distance

$$s^i = s^i_0 + e^i \sigma \quad , \quad \sigma \equiv \frac{1}{2\pi} \log \frac{r_0}{r}$$

$$\mathrm{d}_* = \int_{\text{flow}} \sqrt{\mathcal{G}_{ij} \mathrm{d}s^i \mathrm{d}s^j} = \frac{1}{M_\mathrm{P}} \int_0^{\sigma_*} \mathcal{Q}_\mathbf{e}(\sigma)\, \mathrm{d}\sigma$$



or:

$$\mathrm{d}_{\max} = \frac{1}{M_\mathrm{P}} \int_{\mathcal{T}_\mathbf{e}^{\max}}^{\mathcal{T}_\mathbf{e}^0} \frac{1}{\mathcal{Q}_\mathbf{e}} \mathrm{d}\mathcal{T}_\mathbf{e} \xrightarrow[\gamma \mathcal{T}_{\text{str}} < M_\mathrm{P} \mathcal{Q}_\mathbf{e}]{\text{string WGC}} \boxed{\mathrm{d}_{\max} \leq \frac{1}{\gamma} \int_{\mathcal{T}_\mathbf{e}^{\max}}^{\mathcal{T}_\mathbf{e}^0} \frac{1}{\mathcal{T}_\mathbf{e}} \mathrm{d}\mathcal{T}_\mathbf{e} = \frac{1}{\gamma} \log \frac{\mathcal{T}_\mathbf{e}^0}{\mathcal{T}_\mathbf{e}^{\max}}}$$

1. As $d_{max} \to \infty$, the EFT cutoff exponentially decreases:

$$\Lambda^2_{\max} = \mathcal{T}_\mathbf{e}(\Lambda_{\max}) < \mathcal{T}_\mathbf{e}^0 \exp\left(-\gamma\, \mathrm{d}_{\max}\right)$$

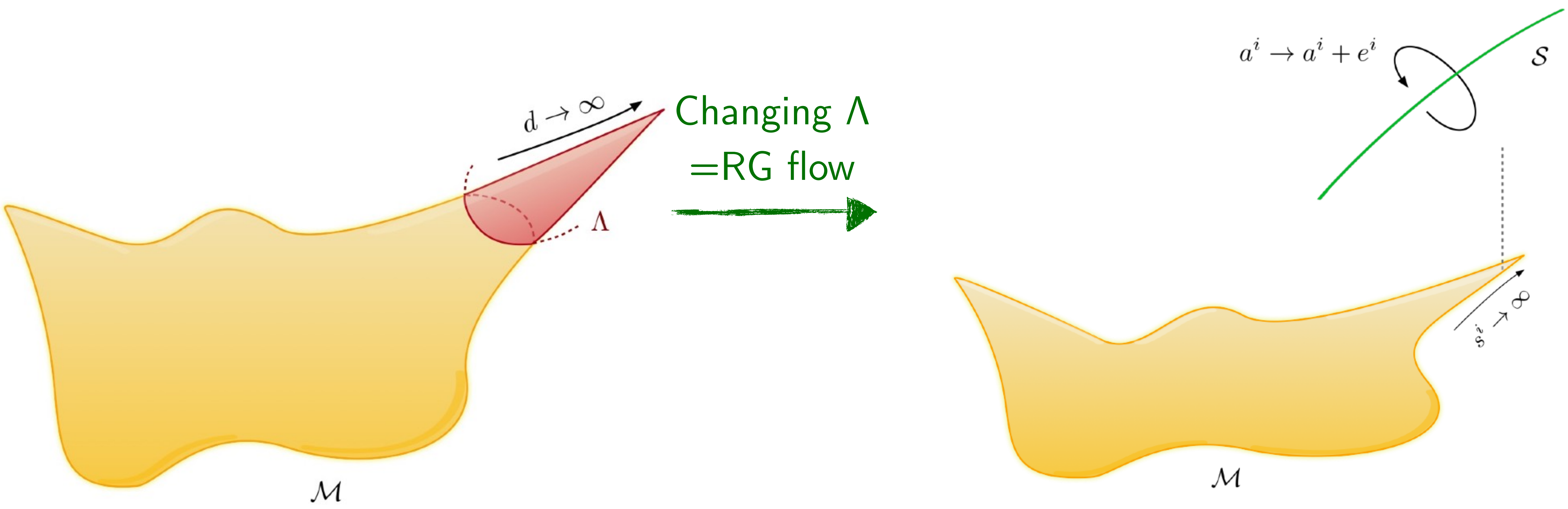
2. Close to the string, infinite oscillatory modes become massless, with fall off of the masses

$$m \sim m_0 \exp(-\lambda \Delta\phi) \qquad m \sim \Lambda \sim \mathcal{T}_\mathbf{e}^{\frac{1}{2}} \sim (\mathcal{T}_\mathbf{e}^0)^{\frac{1}{2}} \exp(-\frac{\gamma}{2} \mathrm{d}_{\max}) \longrightarrow \lambda \equiv \frac{\gamma}{2}$$

$\Rightarrow$ The string extremality factor fixes the rate at which the masses become massless
[see also Gendler, Valenzuela, '20]

THE DISTANT AXIONIC STRING CONJECTURE

Distant Axionic String Conjecture (DASC):
All infinite distance limits of a 4d EFT can be realised as an RG flow endpoint of a fundamental axionic string.



For finite cutoff Λ, the moduli space is only partially explorable.

Infinite field distances are ideally explorable when $\Lambda \to 0$, corresponding to the endpoint of the string RG flow.

THE DISTANT AXIONIC STRING CONJECTURE

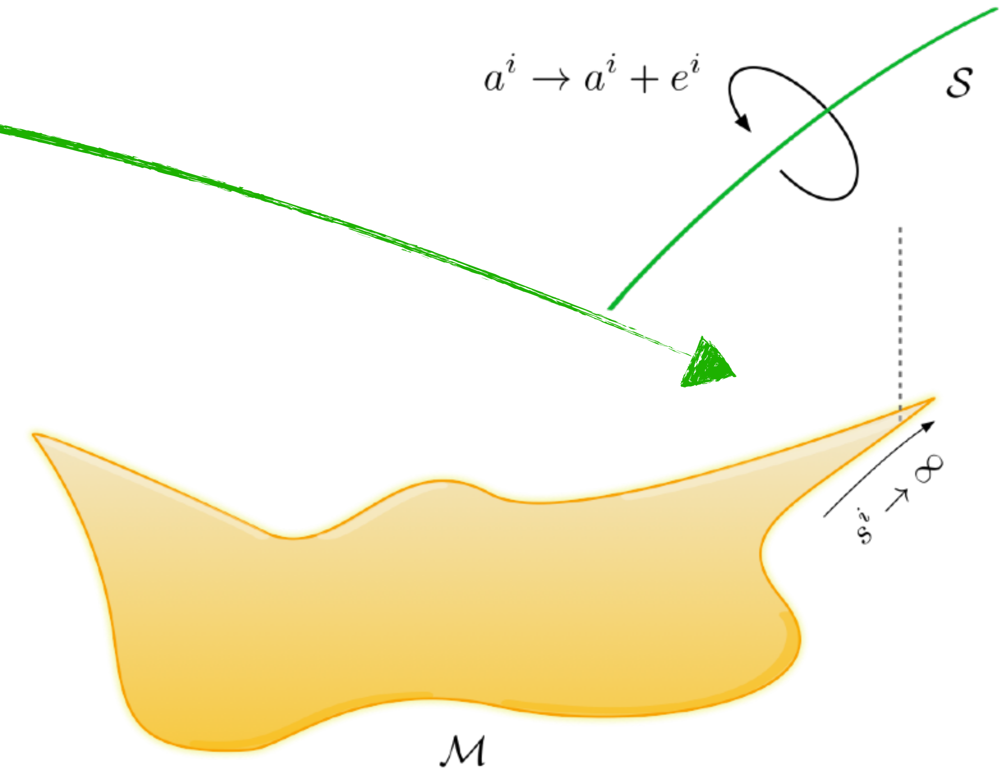
Distant Axionic String Conjecture (DASC):
All infinite distance limits of a 4d EFT can be realised as an RG flow endpoint of a fundamental axionic string.

Infinite tower of states become massless

KK modes, D0 branes, ...

$$\frac{m^2}{M_{\rm P}^2} \sim \left(\frac{\mathcal{T}_{\rm str}}{M_{\rm P}^2}\right)^r \to 0$$

with $r \geq 1$



[SL, Marchesano, Martucci, Valenzuela, *to appear*]

Infinite field distances are ideally explorable when $\Lambda \to 0$, corresponding to the endpoint of the string RG flow.

Membranes and Scalar Potential

Membranes in $N=1$ Supergravity

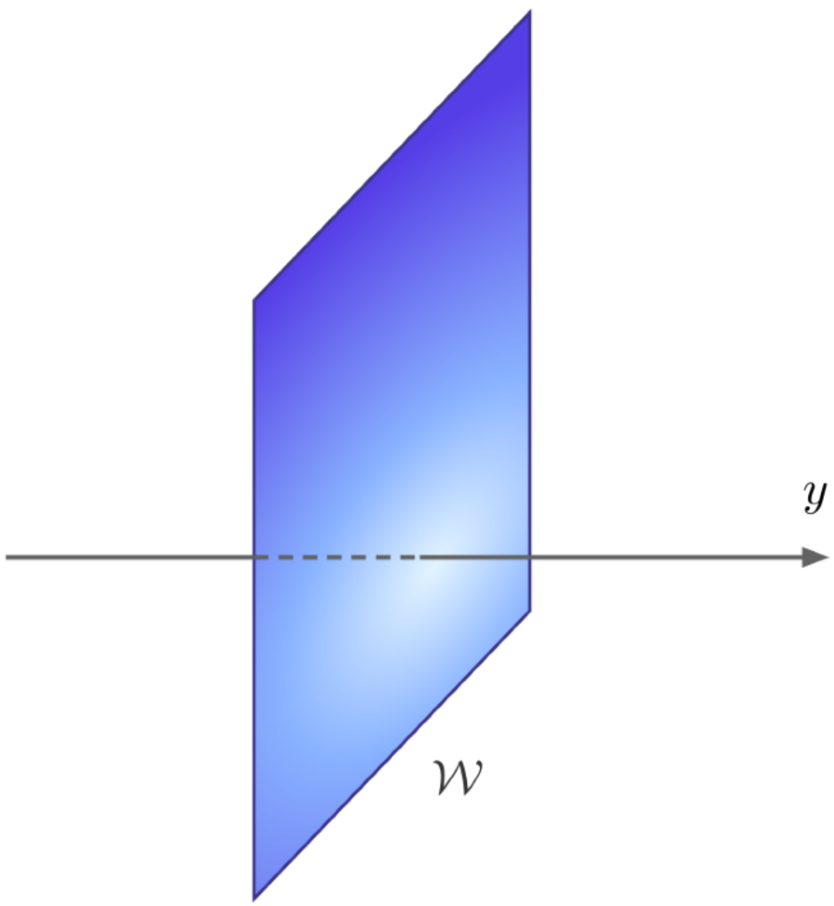
We will consider fundamental membranes:

- objects with *strict* codimension one;
- electrically coupled to a set of gauge three-forms:

$$q_a \int_{\mathcal{W}} A_3^a$$

In order for the membranes to be treated semiclassically within an EFT with cutoff Λ, their tension needs to satisfy

$$\mathcal{T}_{\text{mem}} \gtrsim \Lambda^3$$



Embedding membranes in Supergravity requires a formulation that supersymmetrically includes gauge three-forms.

MEMBRANES IN *N=1* SUPERGRAVITY

- **First step:** including gauge three-forms in *N=1* supergravity

Introduce the modified chiral multiplets

$$\Phi^\alpha = \{\phi^\alpha, A_3^a\} \qquad \text{with} \qquad \alpha = 1, \dots, n \quad a = 1, \dots, N \leq 2n+2$$

and construct the *N=1* supersymmetric action

$$S = \int \left(\frac{M_\mathrm{P}^2}{2} R * 1 - M_\mathrm{P}^2 K_{\alpha\bar\beta}\, \mathrm{d}\phi^\alpha \wedge * \mathrm{d}\bar\phi^{\bar\beta} - \frac{1}{2} T_{ab}\, F_4^a * F_4^b \right) + S_\mathrm{bd}$$

where T_{ab} is the inverse of

$$T^{ab} \equiv 2 M_\mathrm{P}^4\, e^K \mathrm{Re} \left(K^{\alpha\bar\beta} D_\alpha \Pi^a \bar D_{\bar\beta} \bar\Pi^b - 3 \Pi^a \bar\Pi^b \right)$$

$\Pi^a(\phi)$: holomorphic periods

Integrating out the gauge three-forms via

$$\boxed{T_{ab} * F_4^b = -f_a}$$

Gauge three-forms dual of fluxes

one gets

$$S = \int \left(\frac{M_\mathrm{P}^2}{2} R * 1 - M_\mathrm{P}^2 K_{\alpha\bar\beta}\, \mathrm{d}\phi^\alpha \wedge * \mathrm{d}\bar\phi^{\bar\beta} - V * 1 \right)$$

with the scalar potential

$$V = M_\mathrm{P}^{-2} e^K \left(\|DW\|^2 - 3|W|^2 \right) = \frac{1}{2} T^{ab} f_a f_b \qquad \text{and} \qquad W = M_\mathrm{P}^3 f_a \Pi^a(\phi)$$

Membranes in $N{=}1$ Supergravity

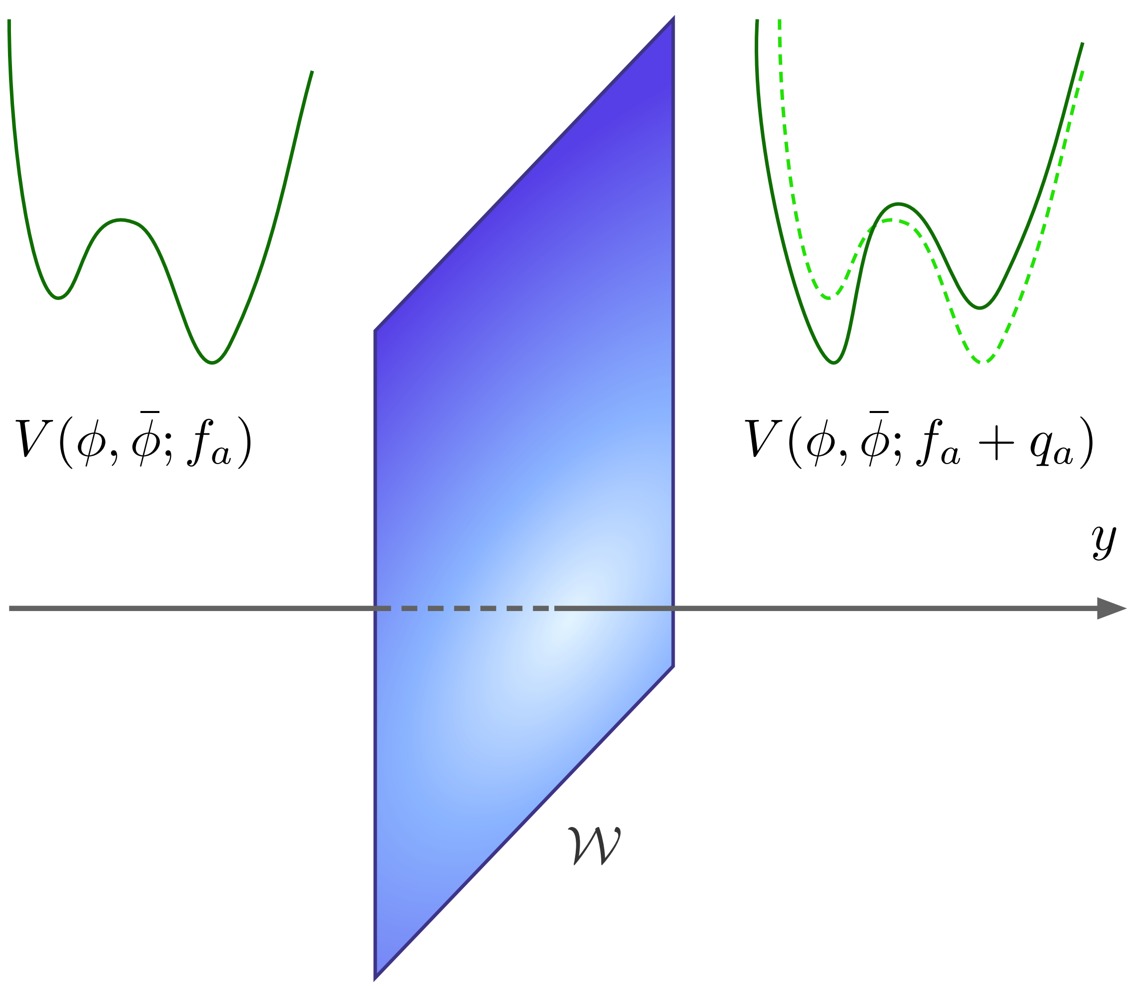
- **Second step:** including supersymmetric membranes

Fundamental membranes can be included as

$$S=\int\left(\frac{M_{\rm P}^2}{2}R*1-M_{\rm P}^2K_{\alpha\bar\beta}\,{\rm d}\phi^\alpha\wedge*{\rm d}\bar\phi^{\bar\beta}-\frac{1}{2}T_{ab}\,F_4^a*F_4^b\right)+S_{\rm bd}+S_{\rm mem}$$

with

$$S_{\rm mem}=-\int_{\mathcal{W}}\sqrt{-h}\,\mathcal{T}_{\rm mem}+q_a\int_{\mathcal{S}}A_3^a$$



The membrane modifies the 3-form eoms.

The potential 'jumps' as the membrane is crossed

$$V=V(\phi,\bar\phi;f_a)\Theta(-y)+V(\phi,\bar\phi;f_a+q_a)\Theta(y)$$

$$\frac{1}{2}T^{ab}f_af_b \qquad\qquad \frac{1}{2}T^{ab}(f_a+q_a)(f_b+q_b)$$

Membranes in N=1 Supergravity

- **Second step:** including supersymmetric membranes

  Fundamental membranes can be included as

$$S = \int \left(\frac{M_{\rm P}^2}{2} R * 1 - M_{\rm P}^2 K_{\alpha\bar\beta}\, {\rm d}\phi^\alpha \wedge * {\rm d}\bar\phi^{\bar\beta} - \frac{1}{2} T_{ab}\, F_4^a * F_4^b \right) + S_{\rm bd} + S_{\rm mem}$$

  with

$$S_{\rm mem} = - \int_{\mathcal{W}} \sqrt{-h}\, \mathcal{T}_{\rm mem} + q_a \int_{\mathcal{S}} A_3^a$$

- The membrane tension is fixed by supersymmetry

$$\mathcal{T}_{\mathbf{q}} = 2 M_{\rm P}^3 e^{\frac{1}{2}K} \left| q_a \Pi^a(\phi) \right|$$

- The physical charge is defined as

$$\mathcal{Q}_{\mathbf{q}}^2 = T^{ab} q_a q_b$$

Generating Membranes

BPS membranes tautologically satisfy

$$\|\partial\mathcal{T}_{\rm mem}\|^2 - \frac{3}{2}\mathcal{T}_{\rm mem}^2 = M_{\rm P}^2\mathcal{Q}_{\mathbf{q}}^2 \qquad \text{with } \|\partial\mathcal{T}_{\rm mem}\|^2 \equiv 2K^{\alpha\bar\beta}\partial_\alpha\mathcal{T}_{\rm mem}\bar\partial_{\bar\beta}\mathcal{T}_{\rm mem}$$

$$\mathcal{Q}_{\mathbf{q}}^2 = T^{ab}q_aq_b$$

$$V = M_{\rm P}^{-2}e^K(\|DW\|^2 - 3|W|^2) = \frac{1}{2}T^{ab}f_af_b$$

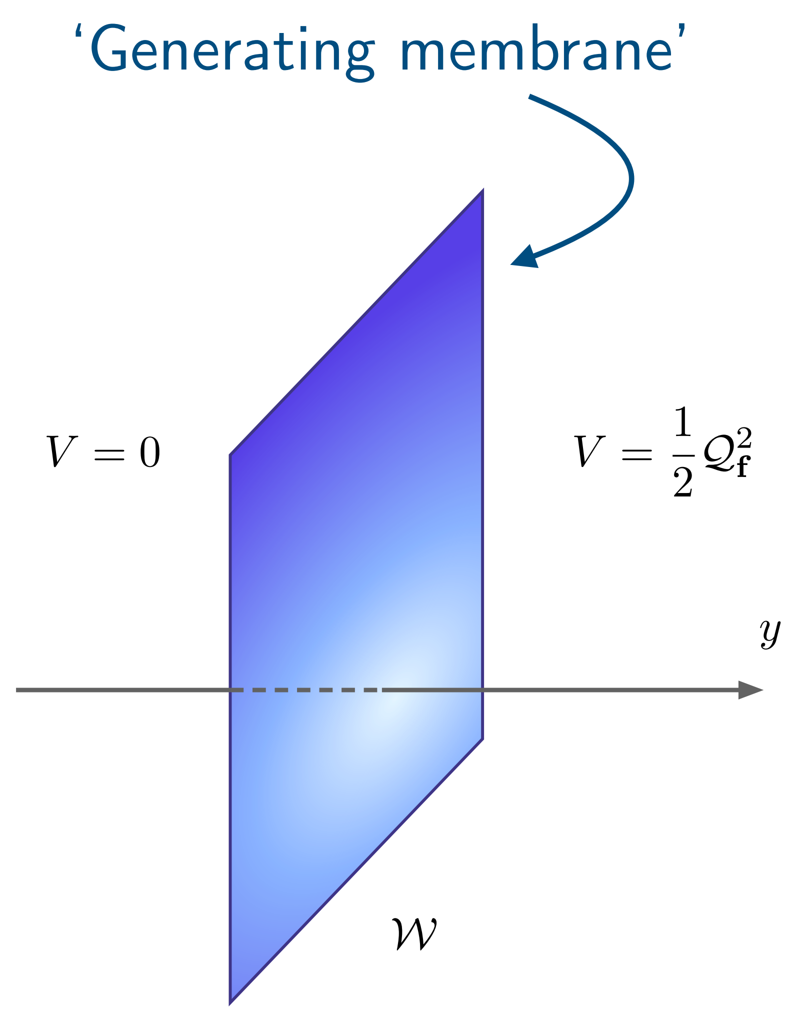
Compare with the scalar potential

They coincide for generating membranes.
They interpolate between a fluxless region and one with a nontrivial flux:

$$f_a = 0 \to f_a = q_a$$

which implies

$$V = \frac{1}{2}T^{ab}f_af_b = \frac{1}{2}T^{ab}q_aq_b = \frac{1}{2}\mathcal{Q}_{\mathbf{f}}^2$$



The Membrane Backreaction

- Asymptotically in field space, we can use the sl(2) orbit theorem to approximate

$$K \simeq -\log s_1^{n_1} s_2^{n_2-n_1} \cdots s_n^{n_I-n_{I-1}} + \dots$$

$$\mathcal{T}_{\mathrm{mem}} \simeq M_{\mathrm{P}}^3 \sum_{\mathbf{r}} \rho_{\mathbf{r}}(q, a^i) s_1^{\frac{\hat{r}_1}{2}} s_2^{\frac{\hat{r}_2-\hat{r}_1}{2}} \dots s_n^{\frac{\hat{r}_n-\hat{r}_{n-1}}{2}}$$

with $n_\alpha, \hat{r}_i$ discrete data that specify the asymptotic limit

and assume we can single out a monomial with the maximal growth so that

$$\partial_i \mathcal{T}_{\mathrm{mem}} = K_i \sigma_i \mathcal{T}_{\mathrm{mem}} \qquad \text{with} \qquad \sigma_i = -\frac{1}{2}\frac{\hat{r}_i - \hat{r}_{i-1}}{n_i - n_{i-1}}$$

[Grimm, Li, Palti, Valenzuela, ... '18-'20]

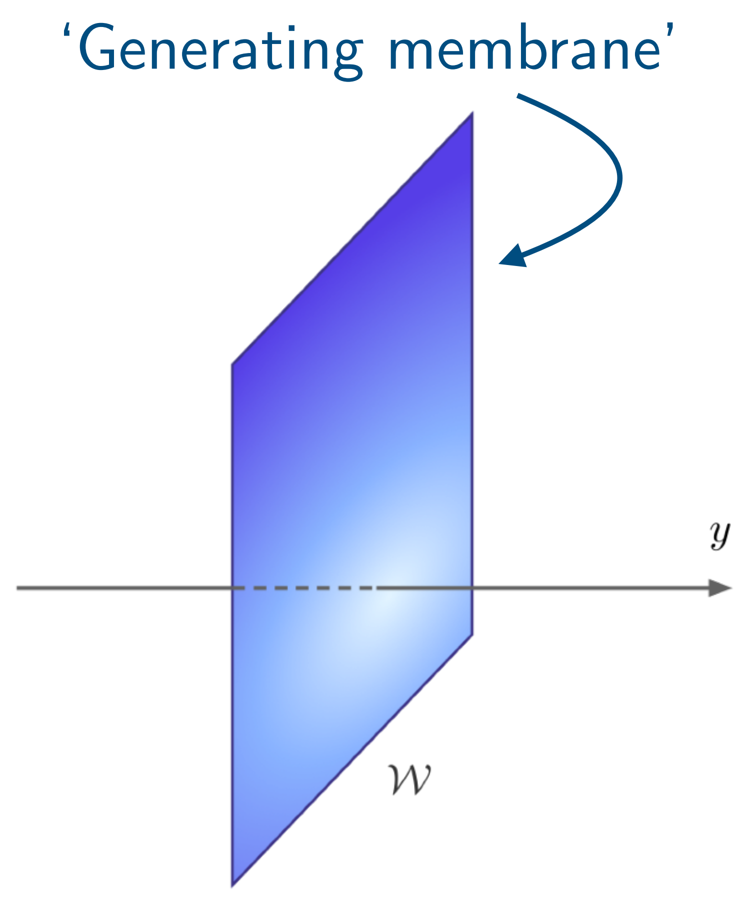
- For a supersymmetric domain wall with metric ansatz

$$\mathrm{d}s^2 = e^{2D(y)}\mathrm{d}x^\mu \mathrm{d}x_\mu + \mathrm{d}y^2 \qquad \mu = 0,1,2$$

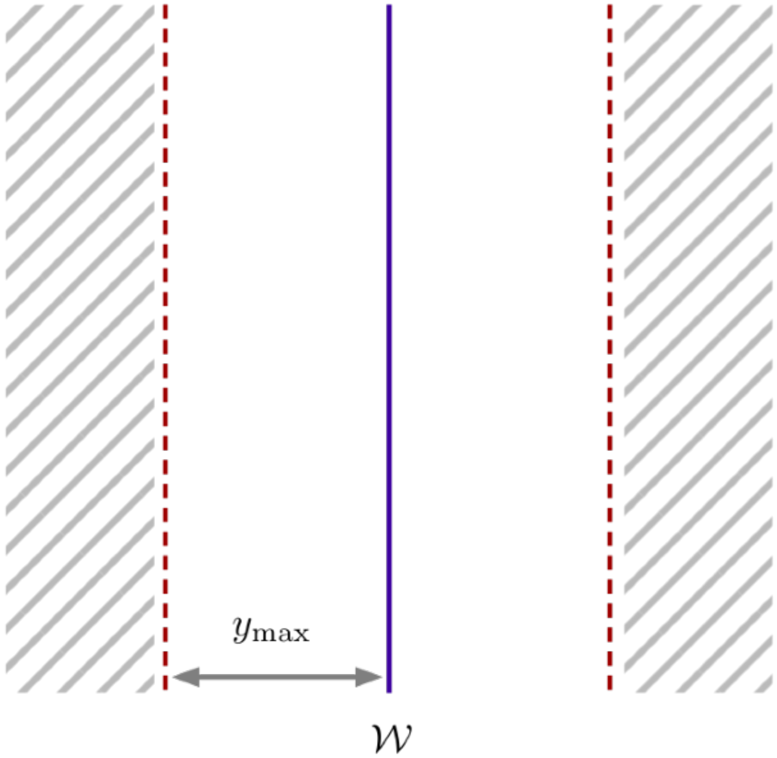
the warp factor and the membrane tension backreactions are

$$e^D = \left(1 - \alpha^2 \frac{\mathcal{T}^*_{\mathrm{mem}}}{4M_{\mathrm{P}}^2} y\right)^{\frac{1}{\alpha^2}} \qquad \alpha^2 \equiv 2\sum_i^I \frac{(\hat{r}_i - \hat{r}_{i-1})^2}{n_i - n_{i-1}}$$

$$\mathcal{T}_{\mathrm{mem}}(y) \simeq \frac{\mathcal{T}^*_{\mathrm{mem}}}{1 - \alpha^2 \frac{\mathcal{T}^*_{\mathrm{mem}}}{4M_{\mathrm{P}}^2} y}$$



THE MEMBRANE BACKREACTION AS RG-FLOW



- The backreaction onto the tension is

$$\mathcal{T}_{\rm mem}(y) \simeq \frac{\mathcal{T}^*_{\rm mem}}{1 - \alpha^2 \frac{\mathcal{T}^*_{\rm mem}}{4M_{\rm P}^2} y}$$

which breaks at the distance $y_{\rm max} = \frac{4M_{\rm P}^2}{\alpha^2 \mathcal{T}^*_{\rm mem}}$ from the membrane.

It is regular in the limit $y \to 0$

Define the energy scale $\Lambda = y^{-1}$
Consider the membrane tension as EFT coupling

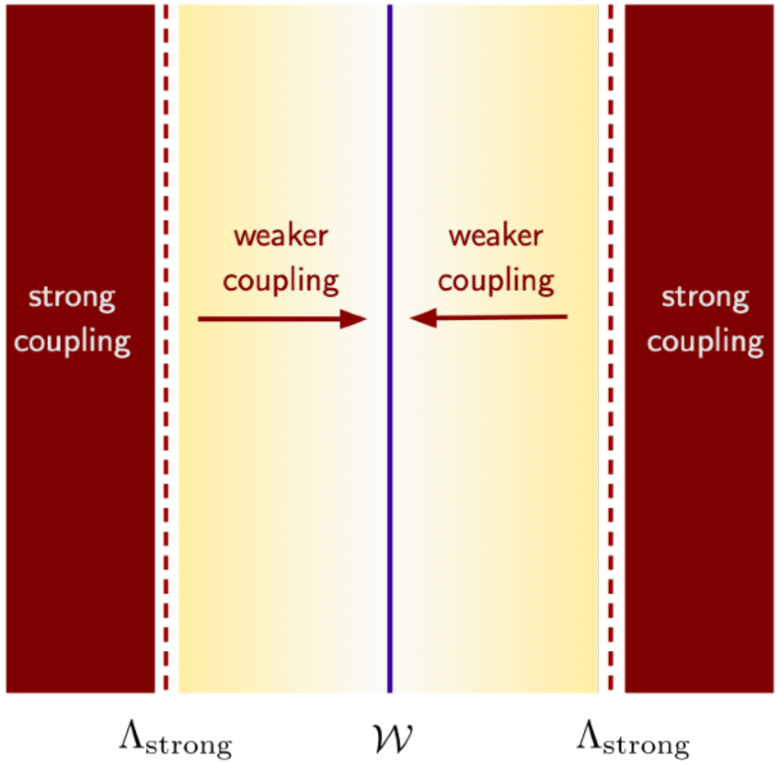
- We regard the profile of the tension as RG-flow of the tension

$$\mathcal{T}_{\rm mem}(\Lambda) \simeq \frac{\mathcal{T}^*_{\rm mem}}{1 - \alpha^2 \frac{\mathcal{T}^*_{\rm mem}}{4M_{\rm P}^2 \Lambda}}$$

and the EFT breaks at the strong coupling scale

$$\Lambda_{\rm strong} = \frac{\alpha^2 \mathcal{T}^*_{\rm mem}}{4M_{\rm P}^2}$$

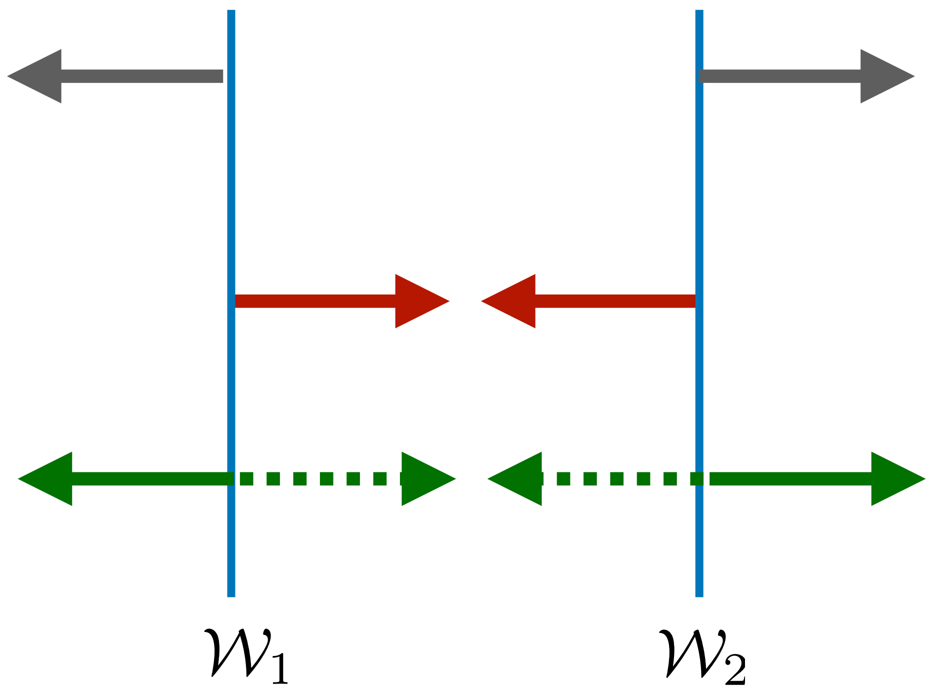
The membrane tension increases as $\Lambda \to \Lambda_{\rm strong}$.



The RFC for Membranes

[Palti, 2017; Heidenreich, Reece, Rudelius, 2019]

- Two identical membranes interact with the following constant forces



Gravitational forces $\frac{3}{2}\mathcal{T}_{\rm mem}^2$

[Vilenkin 1981]

Scalar forces $-2K^{\alpha\bar{\beta}}\partial_\alpha \mathcal{T}_{\rm mem}\bar{\partial}_{\bar{\beta}}\mathcal{T}_{\rm mem}$

Electric forces $T^{ab}q_a q_b = \mathcal{Q}_{\mathbf{q}}^2$

[see also Garriga, Megevand 2003; Herráez 2020]

- The Repulsive Force Conjecture requires the existence of self-repulsive elementary membranes, satisfying:

$$M_{\rm P}^2\mathcal{Q}_{\mathbf{q}}^2 + \frac{3}{2}\mathcal{T}_{\rm mem}^2 > \|\partial\mathcal{T}_{\rm mem}\|^2$$

which has to hold scale-wise along the RG-flow.

- Supersymmetric membranes trivially satisfy the no-force condition

$$M_{\rm P}^2\mathcal{Q}_{\mathbf{q}}^2 + \frac{3}{2}\mathcal{T}_{\rm mem}^2 = \|\partial\mathcal{T}_{\rm mem}\|^2$$

THE WGC FOR MEMBRANES

Weak Gravity Conjecture for membranes:

∃ a super-extremal membrane satisfying

$$\gamma \mathcal{T}_{\rm mem} < M_{\rm P} \mathcal{Q}_{\mathbf{q}}$$

with γ being the extremality factor.

[Arkani-Hamed et al. 2006; Heidenreich, Reece, Rudelius, 2015; Font, Ibanez, Herraez 2018 ...]

How to determine the extremality factor?

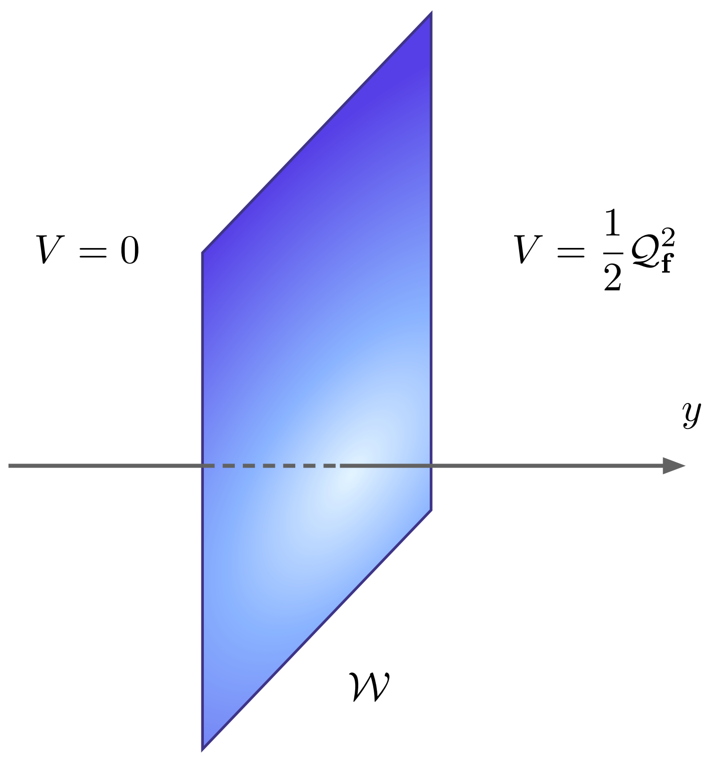
- A BPS-membrane satisfies
$$\frac{M_{\rm P}^2 \mathcal{Q}_{\mathbf{q}}^2}{\mathcal{T}_{\rm mem}^2} = \frac{\|\partial \mathcal{T}_{\rm mem}\|^2}{\mathcal{T}_{\rm mem}^2} - \frac{3}{2}$$
which is not in a "WGC-like form".

- Asymptotically in field space, for a saxionic membrane satisfying
$$\partial_i \mathcal{T}_{\rm mem} = K_i \sigma_i \mathcal{T}_{\rm mem} \qquad \text{with} \qquad \sigma_i = -\frac{1}{2} \frac{\hat{r}_i - \hat{r}_{i-1}}{n_i - n_{i-1}}$$
the physical charge becomes proportional to the membrane tension
$$M_{\rm P} \mathcal{Q}_{\mathbf{q}} = \gamma \mathcal{T}_{\rm mem} \ \text{ with the extremality factor } \quad \gamma = \sqrt{\sum_{i=1}^{I} 2(n_i - n_{i-1})\sigma_i^2 - \frac{3}{2}}$$

EXTREMAL MEMBRANES AND THE DE SITTER CONJECTURE

Consider an extremal membrane, obeying

$$M_{\mathrm{P}}\mathcal{Q}_{\mathbf{q}} = \gamma\mathcal{T}_{\mathrm{mem}} \qquad \text{with} \qquad \gamma = \sqrt{\sum_{i=1}^{I} 2(n_i - n_{i-1})\sigma_i^2 - \frac{3}{2}}$$



and assume that this membrane fully generates a potential with the physical charge:

$$V_0 = \frac{1}{2}\mathcal{Q}_{\mathbf{f}}^2$$

Asymptotically in field space, for elementary membranes

$$\partial_i\mathcal{T}_{\mathrm{mem}} = K_i\sigma_i\mathcal{T}_{\mathrm{mem}}$$

$$\Updownarrow$$

$$||\partial\mathcal{Q}_{\mathbf{f}}^2|| = 2\sqrt{2}\sqrt{\sum_{i=1}^{I}(n_i - n_{i-1})\sigma_i^2}\ \mathcal{Q}_{\mathbf{f}}^2$$

$$\Updownarrow$$

$$||\partial V_0|| = 2\sqrt{2}\sqrt{\sum_{i=1}^{I}(n_i - n_{i-1})\sigma_i^2}\ V_0$$

$$\Longrightarrow$$

The potential so generated obeys the **de Sitter conjecture** [Vafa et al. 2018]

$$\frac{||\partial V_0||}{V_0} \geq c \quad \text{with} \quad c = 2\sqrt{2}\sqrt{\sum_{i=1}^{I}(n_i - n_{i-1})\sigma_i^2}$$

The minimal value of c is

$$c_{\min} \geq \sqrt{\sum_{i=1}^{I}\frac{2}{n_i - n_{i-1}}}$$

Conclusions

Conclusions and Future Outlook

- The strong backreaction of low-codimension objects can be understood as RG flow of the EFT couplings;
- Physical quantities, such as tensions and charges, are scale dependent, changing along the flow;

$$\Downarrow$$

- RFC and WGC for low-codimension objects;
- WGC strings $\Rightarrow$ Distance Conjecture
- WGC saturating membranes $\Rightarrow$ de Sitter Conjecture

- These conclusions are expected to hold also for different spacetime dimensions, provided that the codimension of the objects is kept fixed;
- Possible relation RG-flow and vacua decay?
- Extension to non-supersymmetric cases?

Thank you!