On Scale Separation
&
a Membrane/Potential Correspondence

Alvaro Herraez

IPhT CEA/Saclay

Based on:
A. Font, AH, Luis E. Ibáñez [arXiv:1912.03317]
AH [arXiv: 2006.01160]

Seminar Series on String Phenomenology

October 20, 2020

Outline

1. Scale separation in a class of Type II orientifolds
   - (i) The Swampland, Scale separation and the ADC
   - (ii) A Type IIA toroidal example
   - (iii) A Type IIB toroidal example
2. Membranes and the Flux Potential
   - (i) 4-forms and the Flux potential
   - (ii) Interactions between membranes
3. Conclusions

Scale Separation in a class of Type IIA orientifolds

The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG

  [Vafa '05]

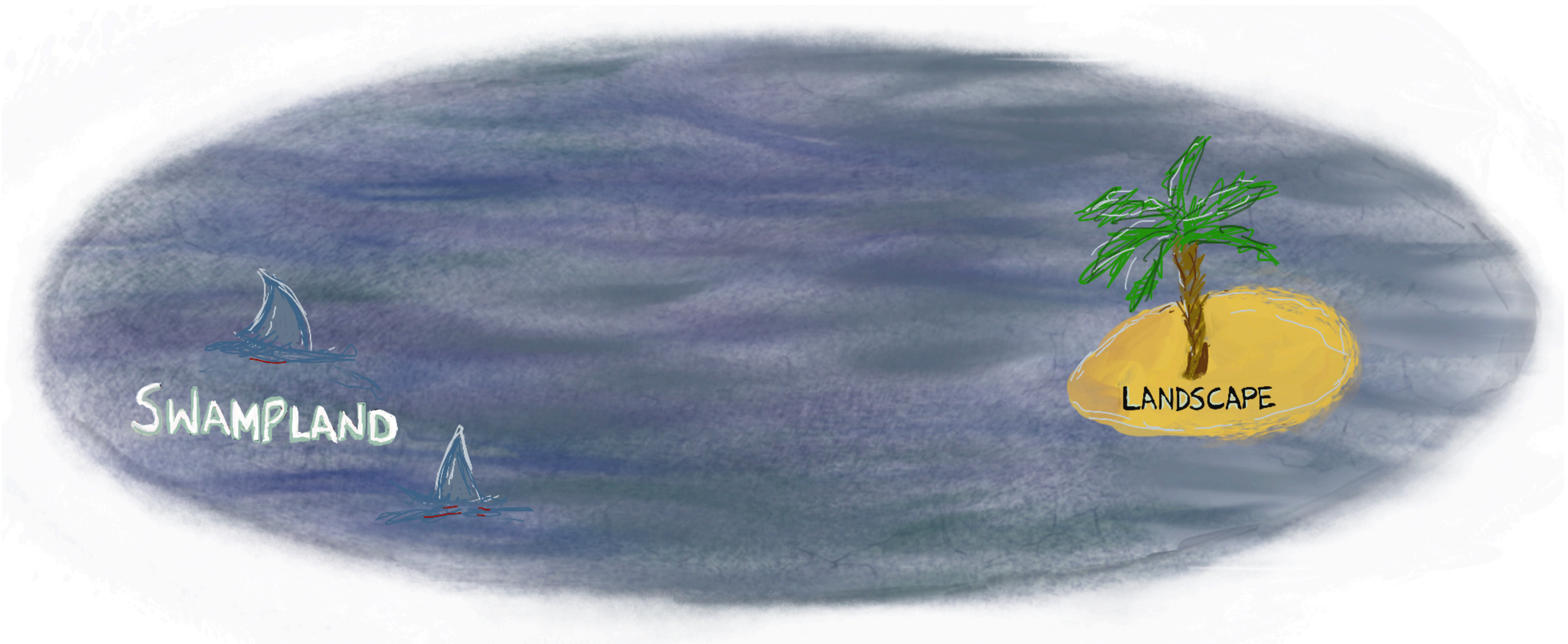
Reviews: [Brennan, Carta, Vafa '17] [Palti '19]

The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG
  [Vafa '05]

Reviews: [Brennan, Carta, Vafa '17] [Palti '19]



QUESTION:

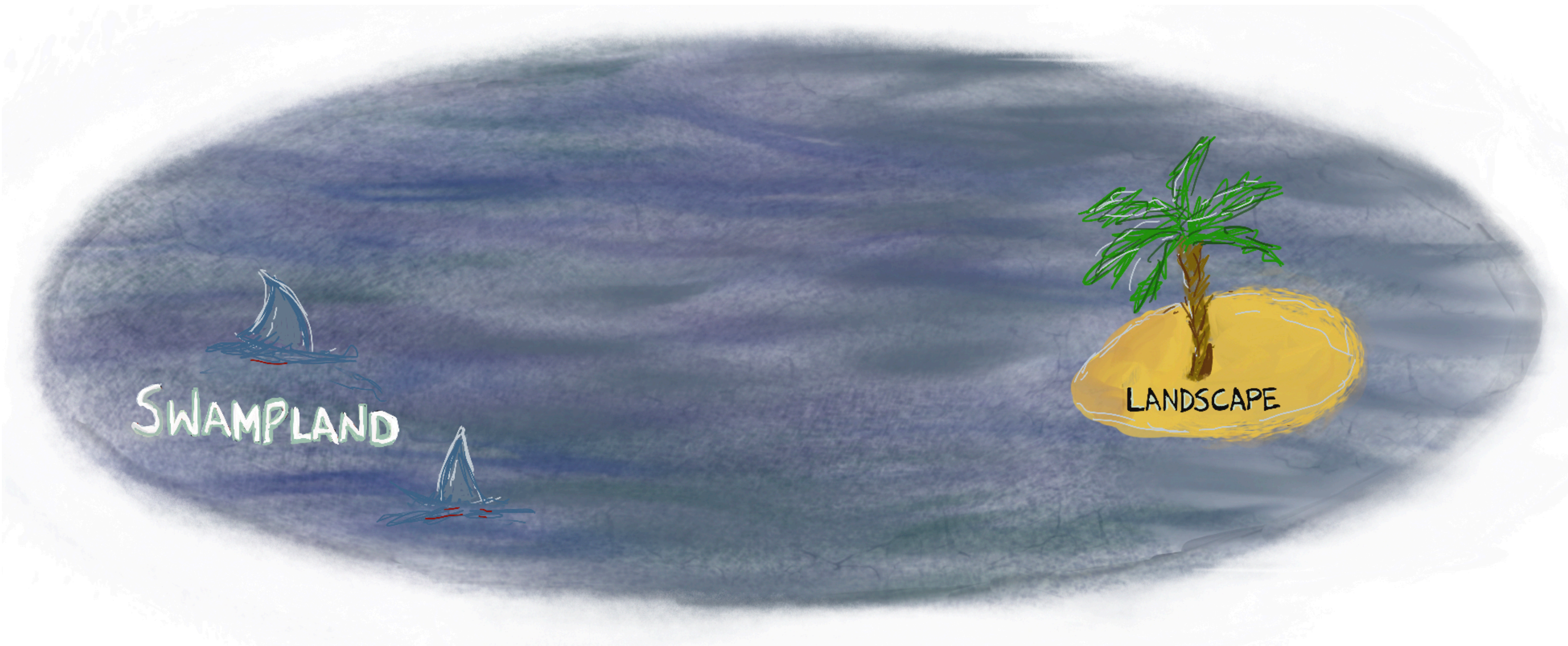
What are the general features of all QG EFT?

The Landscape vs the Swampland

- String Landscape ⟶ Naive expectation: Every EFT can be obtained from ST

- Swampland ⟶ Set of EFT that look consistent BUT cannot be consistently coupled to QG
  [Vafa '05]

Reviews: [Brennan, Carta, Vafa '17] [Palti '19]

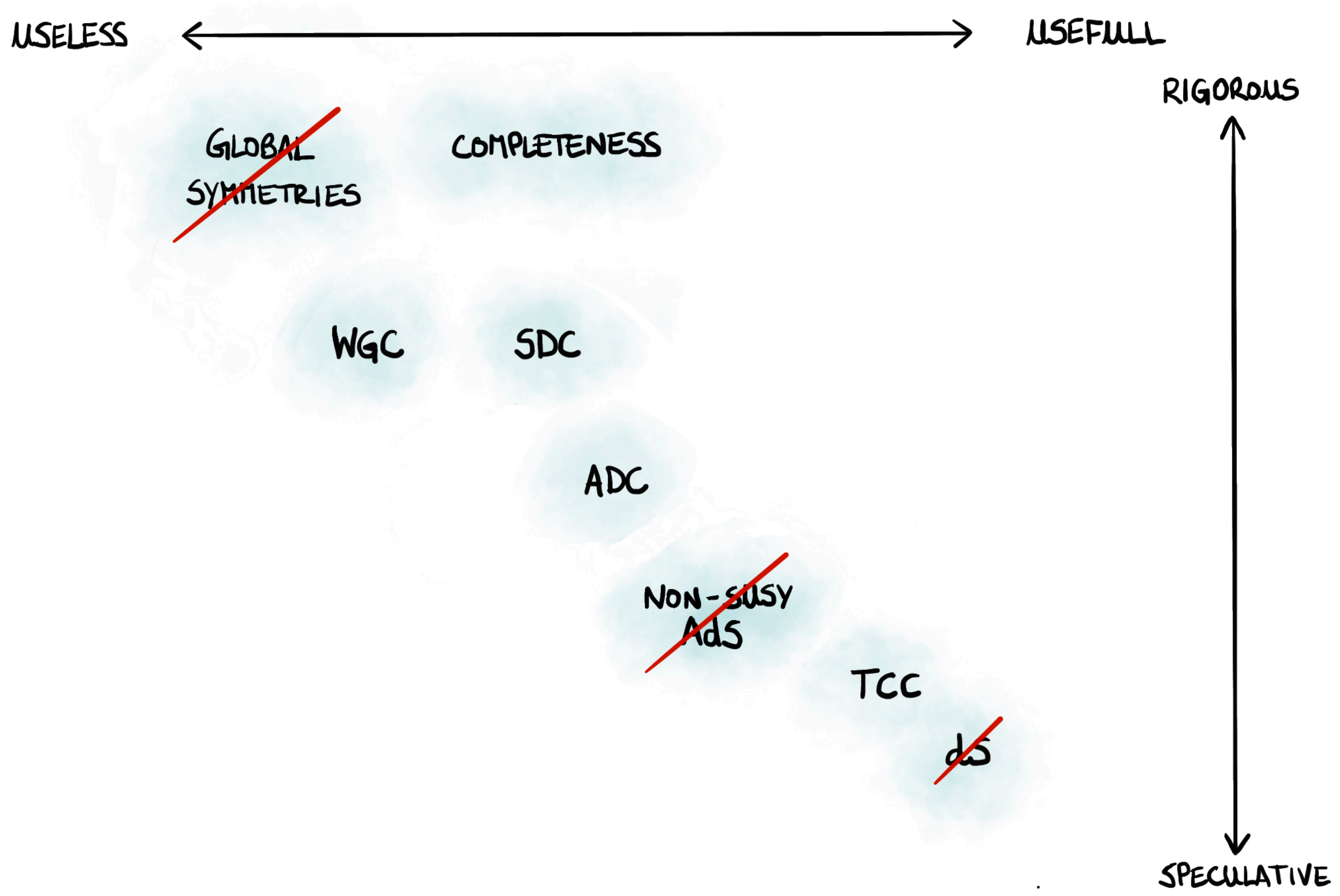


QUESTION:
What are the general features of all QG EFT?

↕

Quantum Gravity Conjectures

The Swampland Conjectures



Scale Separation and the ADC

[Duff, Nilsson, Pope '86] [Douglas, Kachru '07] [Tsimpis '12] [Gautason, Schillo, Van Riet, Williams '16]

<u>Anti de-Sitter Distance Conjecture:</u> In a theory of quantum gravity with cosmological constant Λ there exist a tower of states that becomes light in the limit $\Lambda \to 0$, whose masses behave as

$$m \sim M_p \left| \frac{\Lambda}{M_p^2} \right|^{\gamma} \qquad \gamma = \frac{1}{2} \ \text{(SUSY case)}$$

[Lüst, Palti, Vafa '19]

Scale Separation and the ADC

[Duff, Nilsson, Pope '86] [Douglas, Kachru '07] [Tsimpis '12] [Gautason, Schillo, Van Riet, Williams '16]

Anti de-Sitter Distance Conjecture: In a theory of quantum gravity with cosmological constant Λ there exist a tower of states that becomes light in the limit $\Lambda \to 0$, whose masses behave as

$$m \sim M_p \left| \frac{\Lambda}{M_p^2} \right|^{\gamma} \qquad \gamma = \frac{1}{2} \quad \text{(SUSY case)}$$

[Lüst, Palti, Vafa '19]

If this tower is the KK-tower and $\gamma = \frac{1}{2}$ $\longrightarrow$ $\boxed{R_{\text{int}} \sim R_{\text{ext}}}$

Scale Separation and the ADC

[Duff, Nilsson, Pope '86] [Douglas, Kachru '07] [Tsimpis '12] [Gautason, Schillo, Van Riet, Williams '16]

Anti de-Sitter Distance Conjecture: In a theory of quantum gravity with cosmological constant Λ there exist a tower of states that becomes light in the limit $\Lambda \to 0$, whose masses behave as

$$m \sim M_p \left| \frac{\Lambda}{M_p^2} \right|^{\gamma} \qquad \gamma = \frac{1}{2} \quad \text{(SUSY case)}$$

[Lüst, Palti, Vafa '19]

If this tower is the KK-tower and $\gamma = \frac{1}{2}$ $\longrightarrow$ $\boxed{R_{\text{int}} \sim R_{\text{ext}}}$

NO Scale Separation

Scale Separation and the ADC

[Duff, Nilsson, Pope '86] [Douglas, Kachru '07] [Tsimpis '12] [Gautason, Schillo, Van Riet, Williams '16]

<u>Anti de-Sitter Distance Conjecture:</u> In a theory of quantum gravity with cosmological constant Λ there exist a tower of states that becomes light in the limit $\Lambda \to 0$, whose masses behave as

$$m \sim M_p \left| \frac{\Lambda}{M_p^2} \right|^{\gamma} \qquad \gamma = \frac{1}{2} \quad \text{(SUSY case)}$$

[Lüst, Palti, Vafa '19]

If this tower is the KK-tower and $\gamma = \frac{1}{2}$ $\longrightarrow$ $\boxed{R_{\text{int}} \sim R_{\text{ext}}}$

Crucial for uplifting mechanisms

<u>NO</u> Scale Separation

Scale Separation on a Type IIA orientifold

- **<u>Playground:</u>** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes
$\downarrow$	$\downarrow$	$\downarrow$
$\underbrace{S,\ U}_{\text{Complex Structure}},\ \underbrace{T}_{\text{Kähler}}$	$F_0,\ F_2,\ F_4,\ F_6$	H_3
	$(M,\ c,\ e,\ e_0)$	$h_0,\ h$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes
$\downarrow$	$\downarrow$	$\downarrow$
$\underbrace{S,\ U}_{\text{Complex Structure}},\ \underbrace{T}_{\text{Kähler}}$	$F_0,\ F_2,\ F_4,\ F_6$	H_3
	$(M,\ c,\ e,\ e_0)$	$h_0,\ h$

- Superpotential: $W = e_0 + 3ieT + 3cT^2 + iMT^3 + ih_0S - 3ihU$

- Tadpole Cancelation condition: $\sum_\alpha \left([\Pi_\alpha] + [\mathscr{R}\Pi_\alpha] \right) - m\,[\Pi_H] - 4\,[\Pi_{O6}] = 0$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes
$\underbrace{S,\ U}_{\text{Complex Structure}},\ \underbrace{T}_{\text{Kähler}}$	$F_0,\ F_2,\ F_4,\ F_6$	H_3
	$(M,\ c,\ e,\ e_0)$	$h_0,\ h$

- Superpotential: $W = e_0 + 3ieT + 3cT^2 + iMT^3 + ih_0 S - 3ihU$

- Tadpole Cancelation condition: $\sum_\alpha \left([\Pi_\alpha] + [\mathscr{R}\Pi_\alpha] \right) - m\,[\Pi_H] - 4\,[\Pi_{O6}] = 0$

- There are vacua with scale separation $\longrightarrow$ OK in the 4d picture BUT 10d uplift?

[DeWolfe, Giryavets, Kachru, Taylor '05]
[Cámara, Font, Ibáñez '05]

[Blumenhagen, Brinkmann, Makridou '19]
[Junghans '20]
[Buratti, Calderon, Mininno, Uranga '20]
[Marchesano, Palti, Quirant, Tomasiello '20]

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes	Metric fluxes
$\underbrace{S,\ U}_{\text{Complex Structure}},\ \underbrace{T}_{\text{Kähler}}$	$F_0,\ F_2,\ F_4,\ F_6$	H_3	$d\eta^m = \omega^m_{np}\,\eta^n \wedge \eta^p$
	$(M,\ c,\ e,\ e_0)$	$h_0,\ h$	$a,\ f$

- Superpotential: $W = e_0 + 3ieT + 3cT^2 + iMT^3 + ih_0S - 3ihU - 3aST - 3bTU$

- Tadpole Cancelation condition: $Mh + fc = 0 \qquad h_0 M + 3ac = 0$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes	Metric fluxes
$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$\underbrace{S,\, U}_{\text{Complex Structure}},\, \underbrace{T}_{\text{Kähler}}$	$F_0,\, F_2,\, F_4,\, F_6$	H_3	$d\eta^m = \omega^m_{np}\,\eta^n \wedge \eta^p$
	$(M,\, c,\, e,\, e_0)$	$h_0,\, h$	$a,\, f$

- **Superpotential:** $W = e_0 + 3ieT + 3cT^2 + iMT^3 + ih_0S - 3ihU - 3aST - 3bTU$

- **Tadpole Cancelation** condition: $M\,h + fc = 0 \qquad h_0\,M + 3ac = 0$

[Cámara, Font, Ibáñez '05]

- SUSY AdS vacua with

$$\Lambda \simeq \frac{\left(af^3\right)\, M^3}{c^5}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2}\, M^3}{c^5}$$

$$\boxed{\frac{M_{KK}}{|\,\Lambda\,|^{1/2}} \simeq \frac{1}{\left(af^3\right)^{1/4}}}$$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

Moduli	RR-fluxes	NSNS-fluxes	Metric fluxes
$\downarrow$	$\downarrow$	$\downarrow$	$\downarrow$
$\underbrace{S,\ U,}_{\text{Complex Structure}}\ \underbrace{T}_{\text{Kähler}}$	$F_0,\ F_2,\ F_4,\ F_6$	H_3	$d\eta^m = \omega^m_{np}\,\eta^n \wedge \eta^p$
	$(M,\ c,\ e,\ e_0)$	$h_0,\ h$	$a,\ f$

- Superpotential: $W = e_0 + 3ieT + 3cT^2 + iMT^3 + ih_0 S - 3ihU - 3aST - 3bTU$

- Tadpole Cancelation condition: $\quad Mh + fc = 0 \qquad h_0 M + 3ac = 0$

- SUSY AdS vacua with

[Cámara, Font, Ibáñez '05]

$$\Lambda \simeq \frac{\left(af^3\right) M^3}{c^5}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2} M^3}{c^5}$$

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{1}{\left(af^3\right)^{1/4}}} \xrightarrow{a,\, f \to \infty} 0$$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

10d uplift: $AdS_3 \times S^3 \times S^3$

[Lüst, Tsimpis '05]
[Graña, Minasian, Petrini, Tomasiello '05 '07]
[Aldazábal, Font '07]

- Warped Metric $\longrightarrow ds^2 = e^{2A(y)}\hat{g}_{\mu\nu}dx^\mu dx^\nu + g_{mn}dy^m dy^n$

- Correction to the internal volume

$$\mathrm{Vol}\left(S^3 \times S^3\right) = \mathcal{C} t^3 \qquad \mathcal{C} \simeq \frac{1}{(af^3)^{3/2}}$$

- Tadpole Cancelation condition: $Mh + fc = 0 \qquad h_0 M + 3ac = 0$

- SUSY AdS vacua with

[Cámara, Font, Ibáñez '05]

$$\Lambda \simeq \frac{\left(af^3\right) M^3}{c^5}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2} M^3}{c^5}$$

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{1}{\left(af^3\right)^{1/4}}}$$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

10d uplift: $AdS_3 \times S^3 \times S^3$

[Lüst, Tsimpis '05]

[Graña, Minasian, Petrini, Tomasiello '05 '07]

[Aldazábal, Font '07]

- Warped Metric $\longrightarrow ds^2 = e^{2A(y)}\hat{g}_{\mu\nu}dx^\mu dx^\nu + g_{mn}dy^m dy^n$

- Correction to the internal volume

$$\mathrm{Vol}\left(S^3 \times S^3\right) = \mathcal{C} t^3 \qquad \mathcal{C} \simeq \frac{1}{(af^3)^{3/2}}$$

- Tadpole Cancelation condition: $\quad M h + fc = 0 \qquad h_0 M + 3ac = 0$

- SUSY AdS vacua with

[Cámara, Font, Ibáñez '05]

$$\Lambda \simeq \frac{\left(af^3\right) M^3}{c^5 \ \mathcal{C}}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2} M^3}{c^5 \ \mathcal{C}^{4/3}}$$

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{1}{\left(af^3\right)^{1/4}} \frac{1}{\mathcal{C}^{1/6}}}$$

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

10d uplift: $AdS_3 \times S^3 \times S^3$

[Lüst, Tsimpis '05]

[Graña, Minasian, Petrini, Tomasiello '05 '07]

[Aldazábal, Font '07]

- Warped Metric $\longrightarrow$ $ds^2 = e^{2A(y)}\hat{g}_{\mu\nu}dx^\mu dx^\nu + g_{mn}dy^m dy^n$

- Correction to the internal volume

$$\mathrm{Vol}\left(S^3 \times S^3\right) = \mathcal{C} t^3 \qquad\qquad \mathcal{C} \simeq \frac{1}{(af^3)^{3/2}}$$

- Tadpole Cancelation condition: $\quad Mh + fc = 0 \qquad h_0 M + 3ac = 0$

- SUSY AdS vacua with

[Cámara, Font, Ibáñez '05]

$$\Lambda \simeq \frac{\left(af^3\right) M^3}{c^5 \; \mathcal{C}}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2} M^3}{c^5 \; \mathcal{C}^{4/3}}$$

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \cancel{\frac{1}{\left(af^3\right)^{1/4}} \frac{1}{\mathcal{C}^{1/6}}} \rightarrow 1}$$

Flux Independent!

Scale Separation on a Type IIA orientifold

- **Playground:** Isotropic type IIA toroidal orientifold with fluxes

10d uplift: $AdS_3 \times S^3 \times S^3$

[Lüst, Tsimpis '05]

[Graña, Minasian, Petrini, Tomasiello '05 '07]

[Aldazábal, Font '07]

- Warped Metric $\longrightarrow$ $ds^2 = e^{2A(y)}\hat{g}_{\mu\nu}dx^\mu dx^\nu + g_{mn}dy^m dy^n$

- Correction to the internal volume

$$\mathrm{Vol}\left(S^3 \times S^3\right) = \mathcal{C}\, t^3 \qquad\qquad \mathcal{C} \simeq \frac{1}{(af^3)^{3/2}}$$

- Tadpole Cancelation condition: $\quad M\,h + fc = 0 \qquad h_0\,M + 3ac = 0$

- SUSY AdS vacua with

[Cámara, Font, Ibáñez '05]

$$\Lambda \simeq \frac{\left(af^3\right)\,M^3}{c^5\ \mathcal{C}}$$

$$M_{KK}^2 \simeq \frac{\left(af^3\right)^{1/2}\,M^3}{c^5\ \mathcal{C}^{4/3}}$$

ADC fulfilled

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \cancel{\frac{1}{\left(af^3\right)^{1/4}}\,\frac{1}{\mathcal{C}^{1/6}}}} \longrightarrow 1$$

Flux Independent!

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0S - 3ihT - 3aSU - 3bTU$

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0 S - 3ihT - 3aSU - 3bTU$

- SUSY AdS vacua with

[Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

$$\Lambda \simeq \frac{\left(af^3\right)\, c^{1/2}}{e_0^{3/2}}$$

$$M_{KK}^2 \simeq \frac{f}{(ce_0)^{1/2}}$$

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{e_0^{1/4}}{c^{1/4}\,(af)^{1/2}}}$$

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0 S - 3ihT - 3aSU - 3bTU$

- SUSY AdS vacua with

$$\Lambda \simeq \frac{(af^3)\ c^{1/2}}{e_0^{3/2}}$$

$$M_{KK}^2 \simeq \frac{f}{(ce_0)^{1/2}}$$

Scale Separation!

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{e_0^{1/4}}{c^{1/4}(af)^{1/2}}} \xrightarrow{e_0 \to \infty} \infty$$

[Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0 S - 3ihT - 3aSU - 3bTU$

- SUSY AdS vacua with

[Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

$$\Lambda \simeq \frac{\left(af^3\right)\, c^{1/2}}{e_0^{3/2}}$$

$$M_{KK}^2 \simeq \frac{f}{(ce_0)^{1/2}}$$

Scale Separation!

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{e_0^{1/4}}{c^{1/4}\,(af)^{1/2}}} \xrightarrow{e_0 \to \infty} \infty$$

- **BUT**… Recall that to go from IIA to IIB one performs three T-dualities along the three "x-directions" of the torus $\longrightarrow$ The scale asociated to M_{KK}^y is untouched $\longrightarrow$ Calculate it in the fully backreacted 10d solution in IIA

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0S - 3ihT - 3aSU - 3bTU$

- SUSY AdS vacua with

$$\Lambda \simeq \frac{(af^3)\; c^{1/2}}{e_0^{3/2}} \qquad M_{KK}^2 \simeq \frac{f}{(ce_0)^{1/2}}$$

NO Scale Separation!

[Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

$$\cancel{\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{e_0^{1/4}}{c^{1/4}(af)^{1/2}}}} \xrightarrow{e_0 \to \infty} \infty$$

- **BUT**… Recall that to go from IIA to IIB one performs three T-dualities along the three "x-directions" of the torus $\longrightarrow$ The scale asociated to M_{KK}^y is untouched $\longrightarrow$ Calculate it in the fully backreacted 10d solution in IIA

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq 1}$$

Scale Separation on a Type IIB orientifold

- **Playground:** Isotropic type IIB toroidal orientifold with non-geometric fluxes

  T-dual of type IIA with geometric fluxes: $S \longleftrightarrow S \qquad U \longleftrightarrow T$

- Superpotential: $W = e_0 + 3ieU + 3cU^2 + iMU^3 + ih_0 S - 3ihT - 3aSU - 3bTU$

- SUSY AdS vacua with

$$\Lambda \simeq \frac{(af^3)\ c^{1/2}}{e_0^{3/2}}$$

$$M_{KK}^2 \simeq \frac{f}{(ce_0)^{1/2}}$$

[Blumenhagen, Font, Fuchs, Herschmann, Plauschinn, Sekiguchi, Wolf '15]

NO Scale Separation!

$$\boxed{\cancel{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq \frac{e_0^{1/4}}{c^{1/4}(af)^{1/2}}}} \xrightarrow{e_0 \to \infty} \infty$$

- **BUT**… Recall that to go from IIA to IIB one performs three T-dualities along the three "x-directions" of the torus $\longrightarrow$ The scale asociated to M_{KK}^y is untouched $\longrightarrow$ Calculate it in the fully backreacted 10d solution in IIA

$$\boxed{\frac{M_{KK}}{|\Lambda|^{1/2}} \simeq 1}$$

ADC ✓

Membranes & the Flux Potential

3-forms and Membranes

- Consider the action for a 3-form in 4d

[Brown, Teitelboim, Bousso, Polchinski, Dvali...]

$$S = \underbrace{-\int d^4x \frac{1}{2}|F_4|^2}_{\text{Kinetic terms}} + \underbrace{q\int_{D_3} C_3}_{\text{Coupling to membranes}} + S_{bound}$$

- Equation of motion (away from the membranes)

$$F_{\mu\nu\rho\sigma} = f_0 \epsilon_{\mu\nu\rho\sigma}$$

3-forms and Membranes

- Consider the action for a 3-form in 4d

[Brown, Teitelboim, Bousso, Polchinski, Dvali...]

$$S = \underbrace{- \int d^4x \frac{1}{2} |F_4|^2}_{\text{Kinetic terms}} + \underbrace{q \int_{D_3} C_3}_{\text{Coupling to membranes}} + S_{bound}$$

- Equation of motion (away from the membranes)

$$F_{\mu\nu\rho\sigma} = f_0 \epsilon_{\mu\nu\rho\sigma} \longrightarrow \text{No propagating dof in 4d}$$

3-forms and Membranes

- Consider the action for a 3-form in 4d

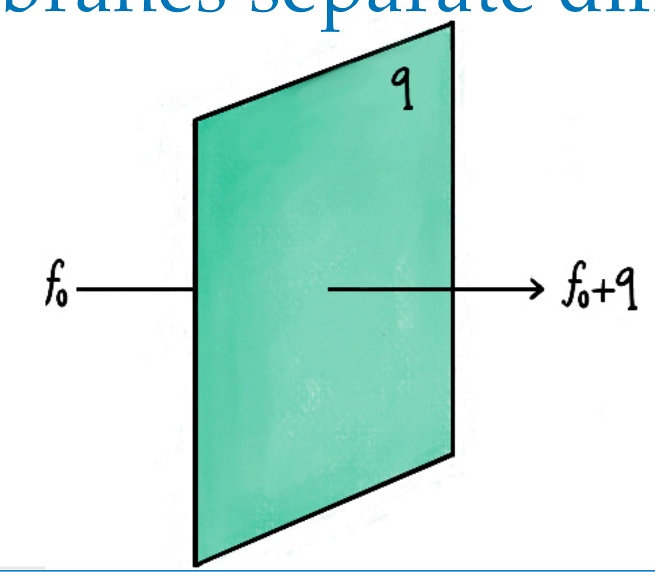
[Brown, Teitelboim, Bousso, Polchinski, Dvali...]

$$S = \underbrace{-\int d^4x \frac{1}{2}|F_4|^2}_{\text{Kinetic terms}} + \underbrace{q\int_{D_3} C_3}_{\text{Coupling to membranes}} + S_{bound}$$

- Equation of motion (away from the membranes)

$$F_{\mu\nu\rho\sigma} = f_0 \epsilon_{\mu\nu\rho\sigma} \longrightarrow$$ No propagating dof in 4d

- Membranes separate different vacua labelled by the value of f_0



At this level q is undetermined

Membranes and the Flux Potential

- The scalar potential in N=1 flux compactifications can be expressed as:

$$S = -\frac{1}{8}\int Z_{AB} F_4^A \wedge *_4 F_4^B + \frac{1}{4}\int F_4^A q_A \longrightarrow V = \frac{Z^{AB}}{2} q_A q_B$$

[Bandos, Bielleman, Carta, Dudas, Farakos, AH, Ibáñez, Lanza, Marchesano, Martucci, Staessens, Valenzuela, Zoccarato '15-20]

$$V = e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3\,|W|^2 \right)$$

[Cremmer et al.]

Membranes and the Flux Potential

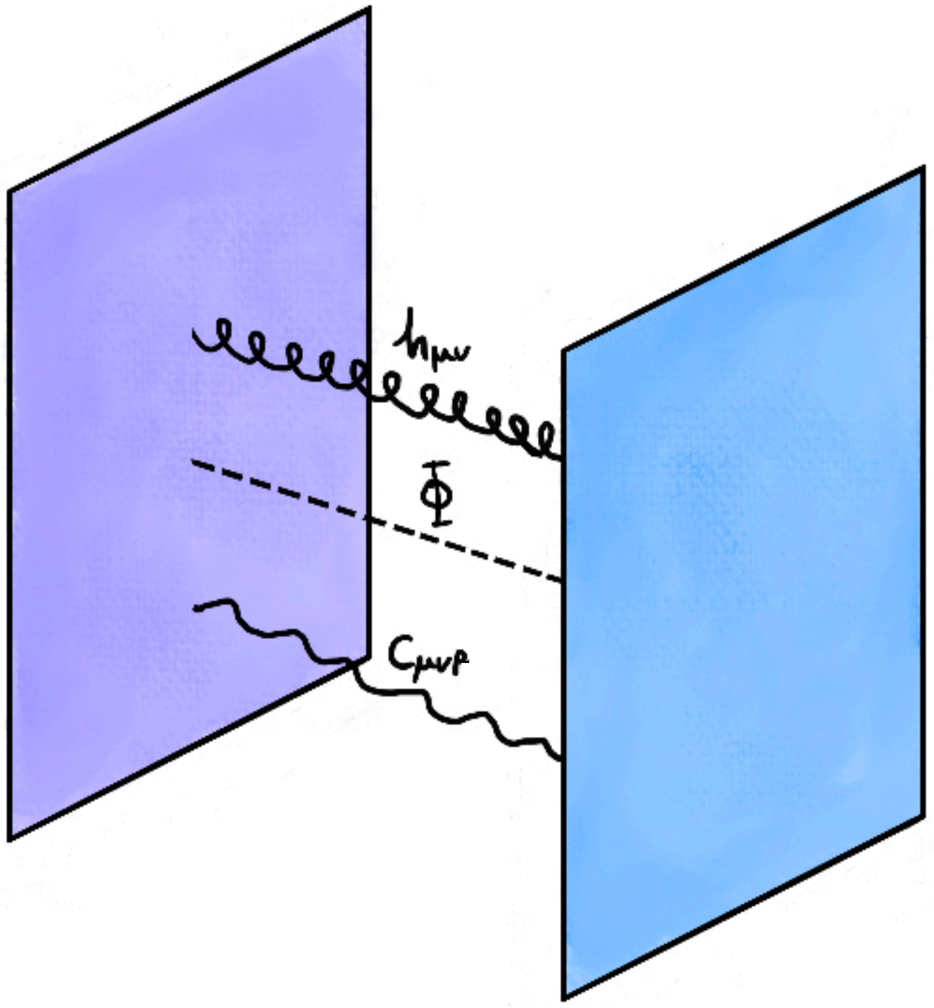
- The scalar potential in N=1 flux compactifications can be expressed as:

$$S = -\frac{1}{8}\int Z_{AB} F_4^A \wedge *_4 F_4^B + \frac{1}{4}\int F_4^A q_A \longrightarrow V = \frac{Z^{AB}}{2} q_A q_B$$

[Bandos, Bielleman, Carta, Dudas, Farakos, AH, Ibáñez, Lanza, Marchesano, Martucci, Staessens, Valenzuela, Zoccarato '15-20]

$$V = e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3|W|^2 \right)$$

[Cremmer et al.]



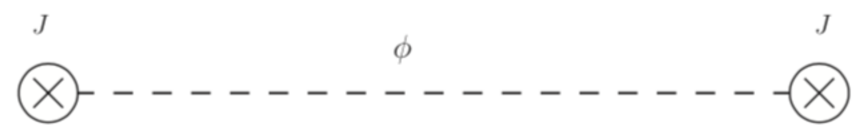
- Consider two parallel BPS membranes

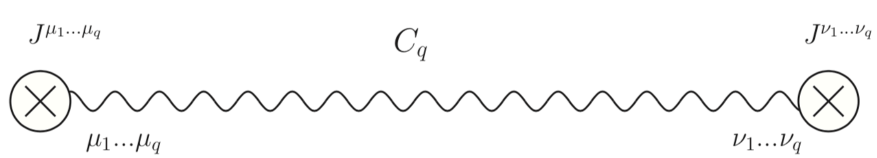
$$T = 2e^{K/2}|W|$$

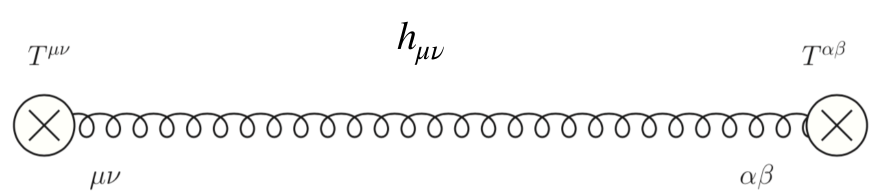
- **QUESTION:** Can we interpret the different contributions to the scalar potential in terms of interactions between the membranes which source the corresponding fluxes?

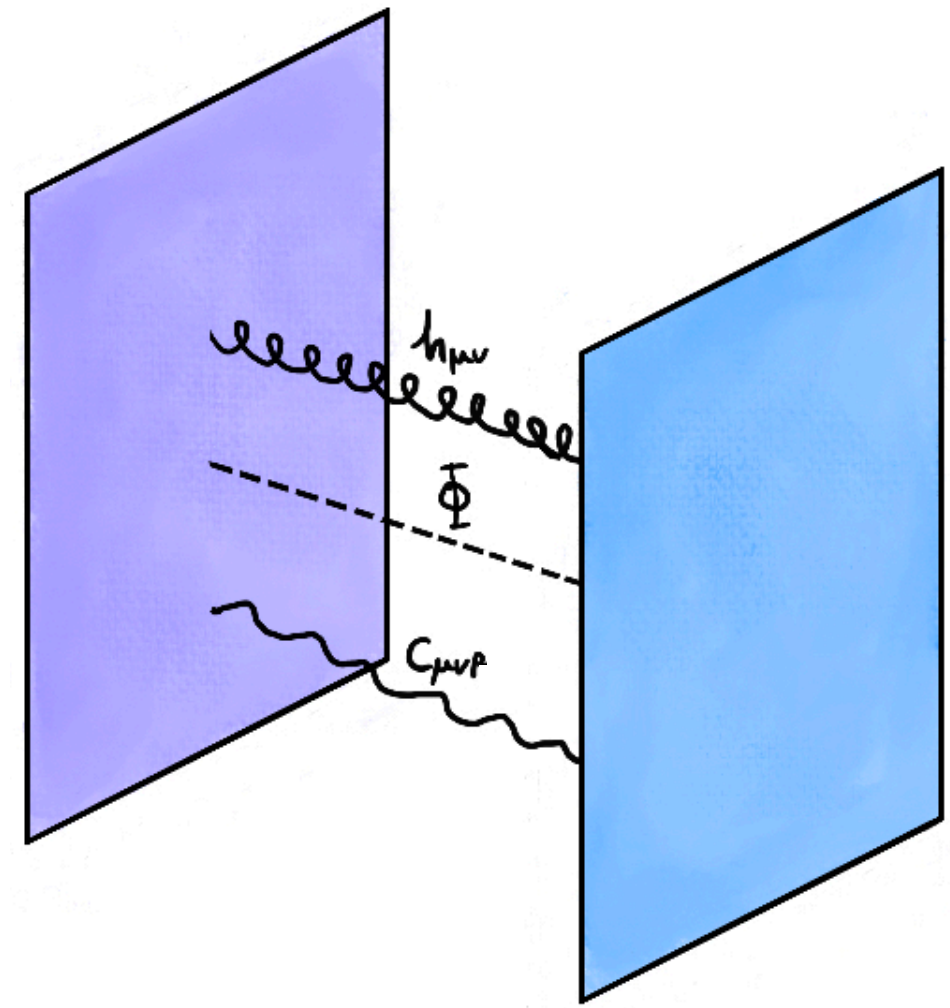
Membranes and the Flux Potential

Calculate the following interactions







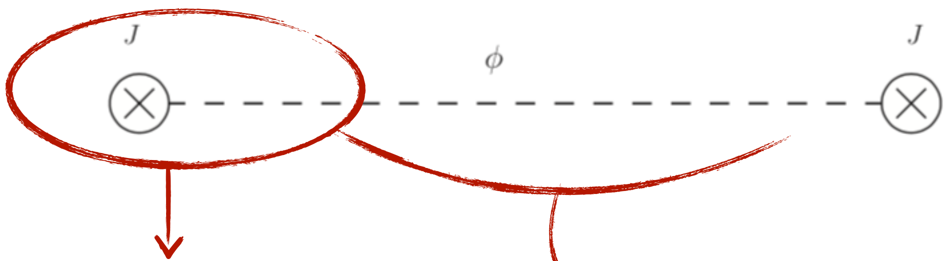


$$V = \frac{Z^{AB}}{2} q_A q_B$$

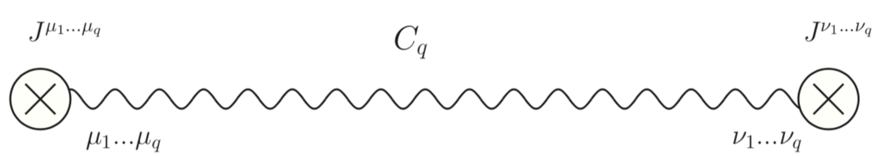
$$V = e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3\,|\,W\,|^2 \right)$$

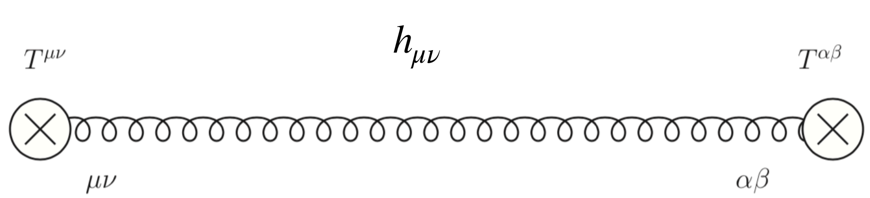
Membranes and the Flux Potential

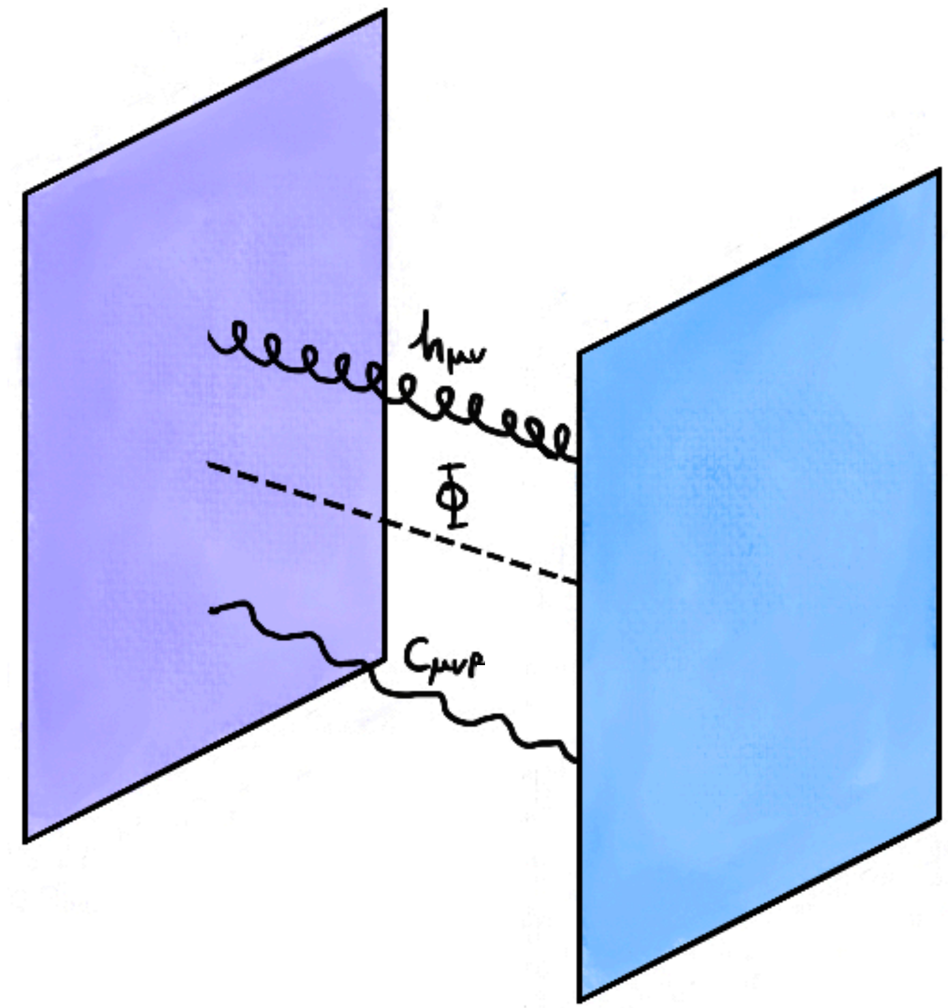
Calculate the following interactions



$$S_{\text{mem}} = -\int_{WV} d^3\xi \sqrt{|g_{ab}|}\, T\left(\Phi^I, \bar{\Phi}^{\bar{J}}\right) \qquad S_{\Phi,\text{kin}} = \frac{1}{\kappa_4^2}\int \sqrt{-g}\; d^4x\; K_{I\bar{J}}\partial_\mu \Phi^I \partial^\mu \bar{\Phi}^{\bar{J}}$$





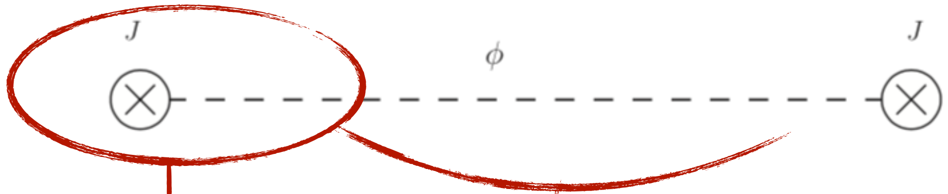


$$V = \frac{Z^{AB}}{2} q_A q_B$$

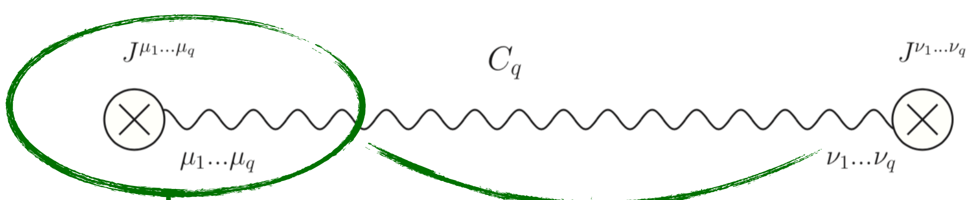
$$V = e^K\left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3\,|W|^2\right)$$

Membranes and the Flux Potential

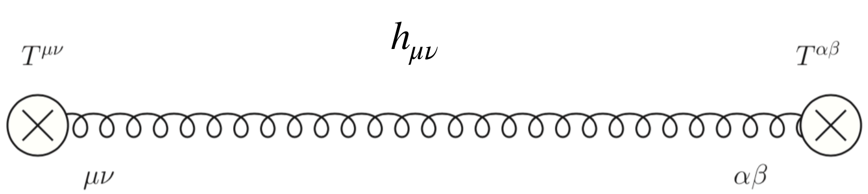
Calculate the following interactions

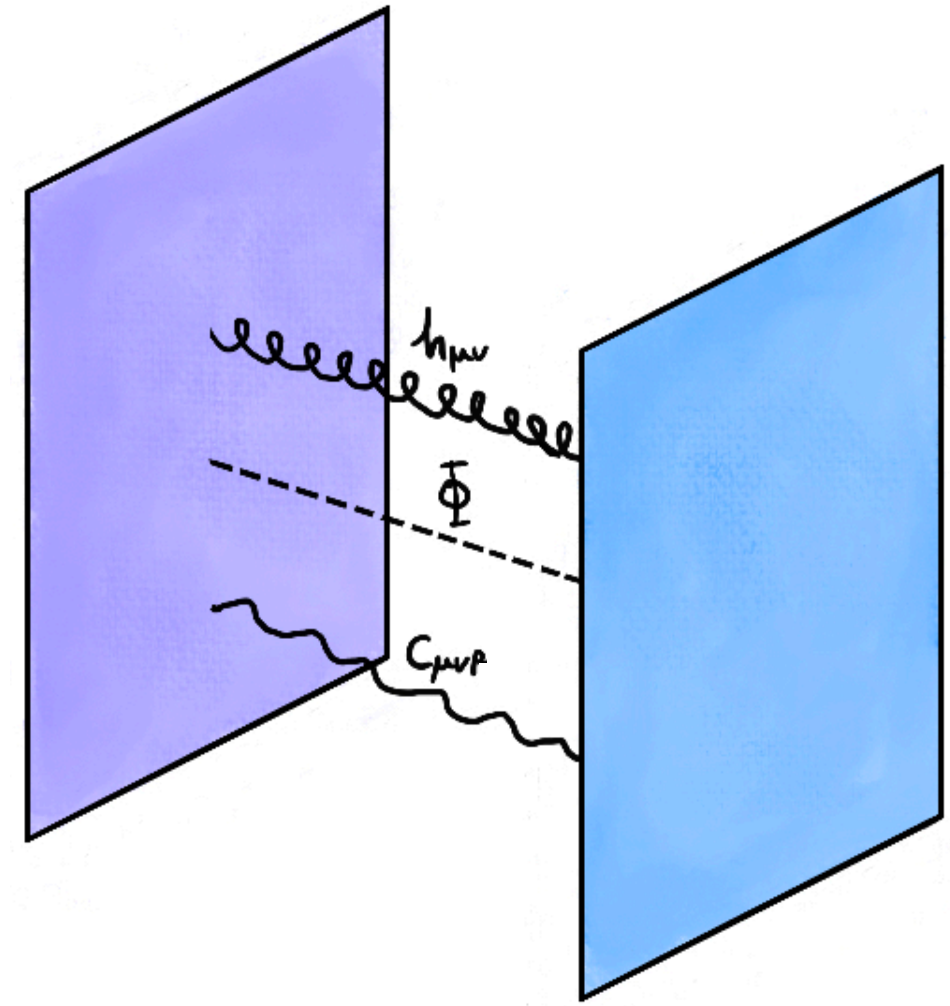


$$S_{\text{mem}} = -\int_{WV} d^3\xi \sqrt{|g_{ab}|}\, T\left(\Phi^I, \bar{\Phi}^{\bar{J}}\right) \qquad S_{\Phi,\text{kin}} = \frac{1}{\kappa_4^2}\int \sqrt{-g}\; d^4x\; K_{I\bar{J}}\partial_\mu \Phi^I \partial^\mu \bar{\Phi}^{\bar{J}}$$



$$S_{CS} = Q\int_{WV} C_3 \qquad S_{3,\text{kin}} = \frac{1}{2\kappa^2}\int Z_{AB}F^A \wedge * F^B$$



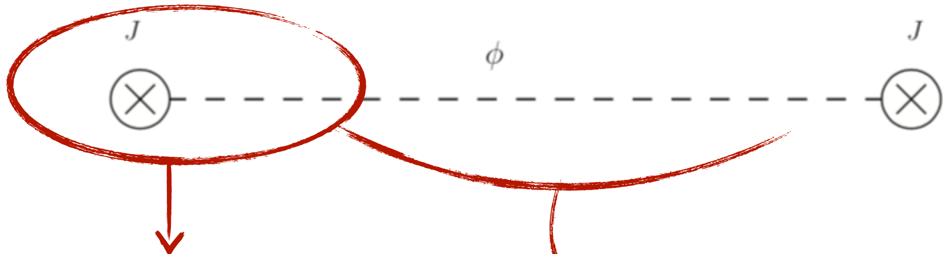


$$V = \frac{Z^{AB}}{2} q_A q_B$$

$$V = e^K\left(K^{I\bar{J}} D_I W D_{\bar{J}}\bar{W} - 3\,|W|^2\right)$$

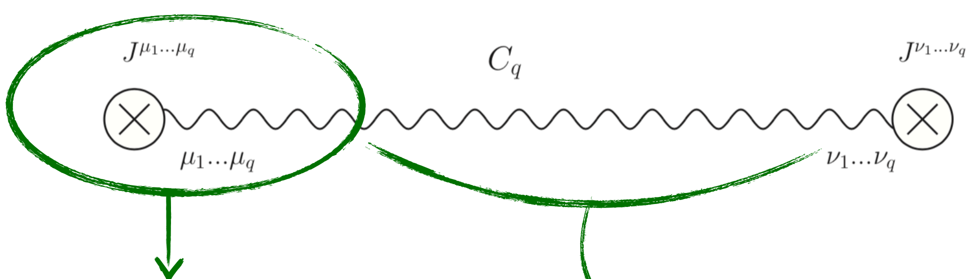
Membranes and the Flux Potential

Calculate the following interactions



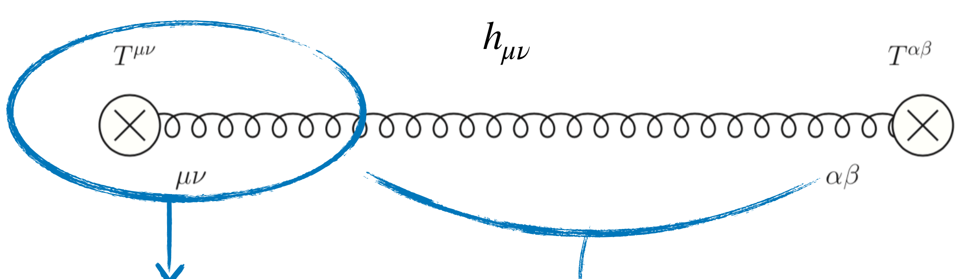
$$S_{\text{mem}} = -\int_{WV} d^3\xi \sqrt{\left|g_{ab}\right|}\, T\left(\Phi^I, \bar{\Phi}^{\bar{J}}\right)$$

$$S_{\Phi,\text{kin}} = \frac{1}{\kappa_4^2}\int \sqrt{-g}\; d^4x\; K_{I\bar{J}}\partial_\mu \Phi^I \partial^\mu \bar{\Phi}^{\bar{J}}$$



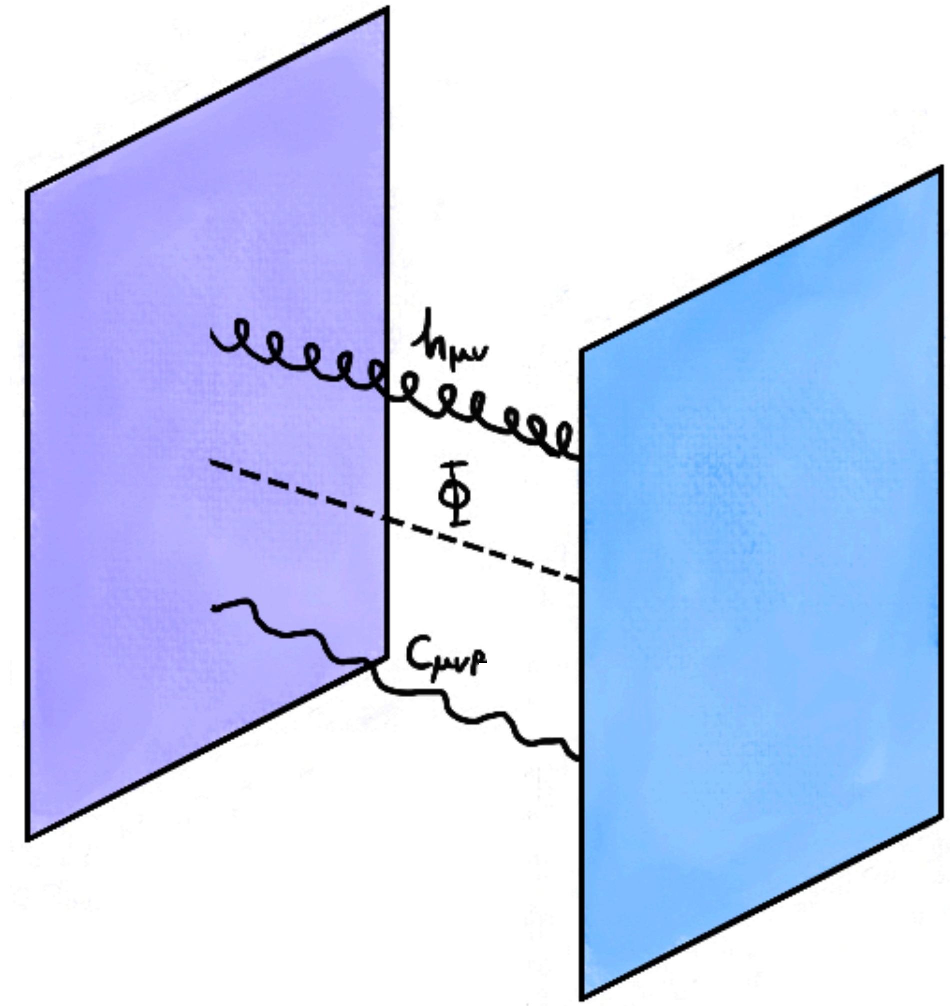
$$S_{CS} = Q\int_{WV} C_3$$

$$S_{3,\text{kin}} = \frac{1}{2\kappa^2}\int Z_{AB}F^A \wedge *F^B$$



$$S_{\text{mem}} = -\int_{WV} d^3\xi \sqrt{\left|g_{ab}\right|}\, T\left(\Phi^I, \bar{\Phi}^{\bar{J}}\right)$$

$$S_{\text{EH}} = \frac{1}{2\kappa^2}\int d^Dx \sqrt{-g}\; R$$

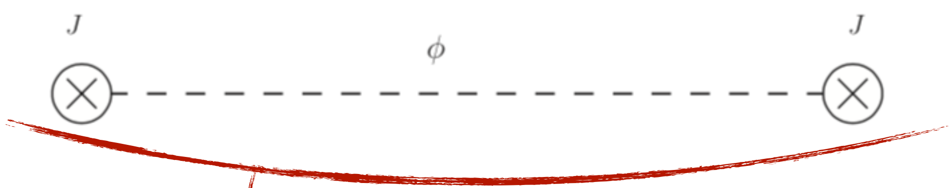


$$V = \frac{Z^{AB}}{2} q_A q_B$$

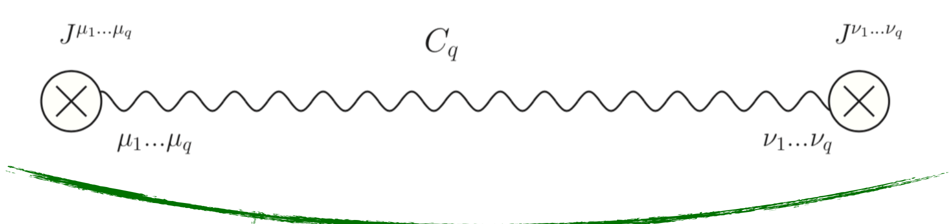
$$V = e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3\left|W\right|^2 \right)$$

Membranes and the Flux Potential

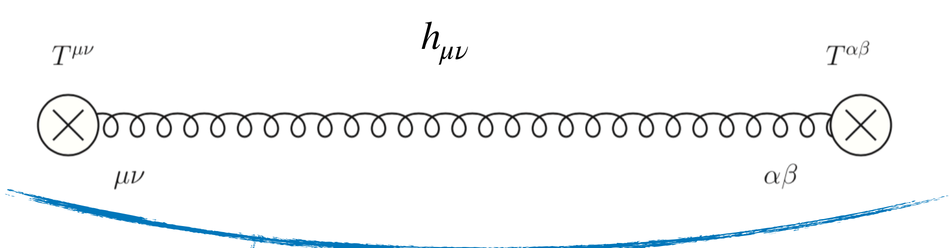
Calculate the following interactions



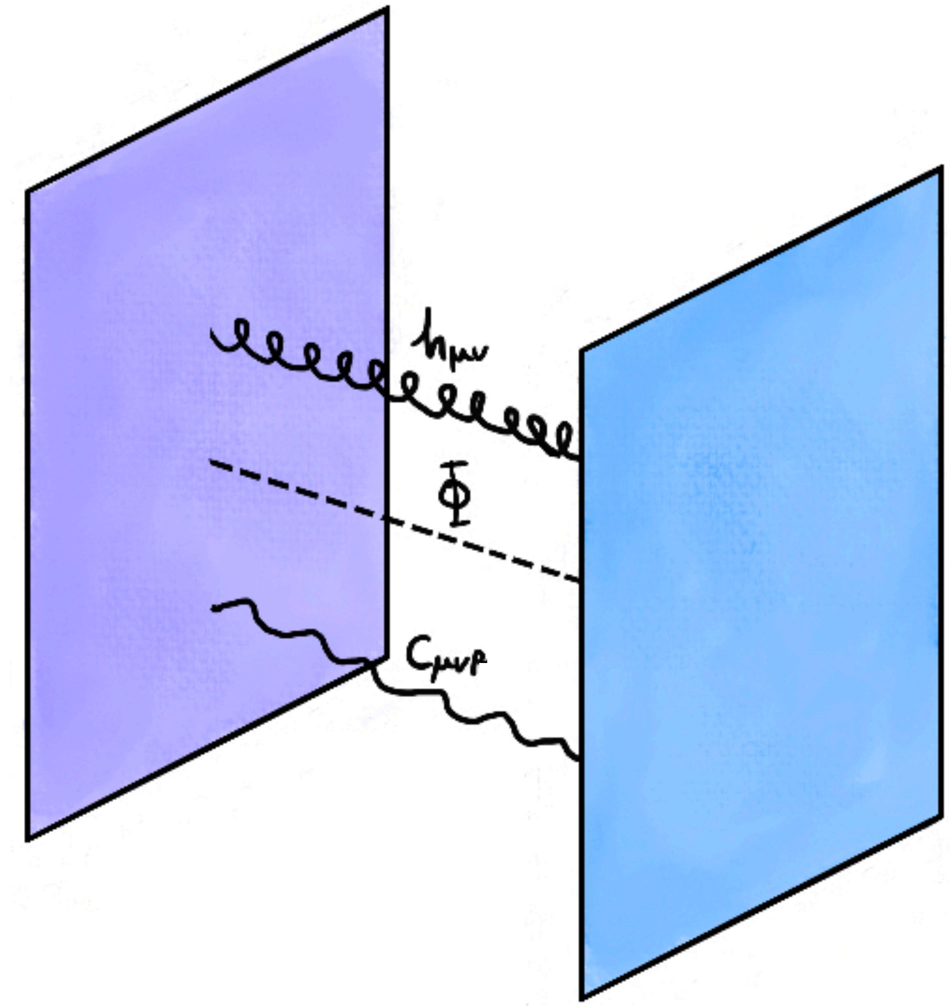
$\to -e^K K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W}$



$\to \sim \frac{1}{2} Z^{AB} Q_A Q_B$



$\to \sim 3e^K |W|^2$

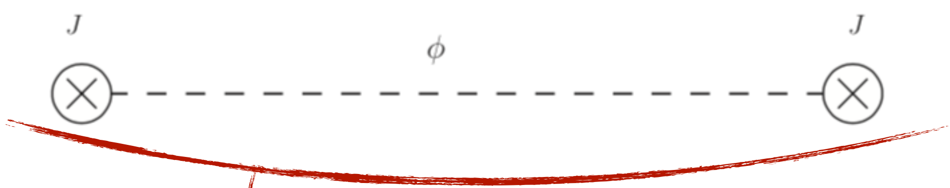


$$V = \frac{Z^{AB}}{2} q_A q_B$$

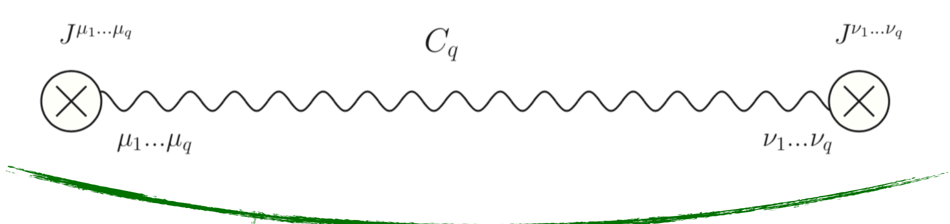
$$V = e^K \left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - 3 |W|^2 \right)$$

Membranes and the Flux Potential

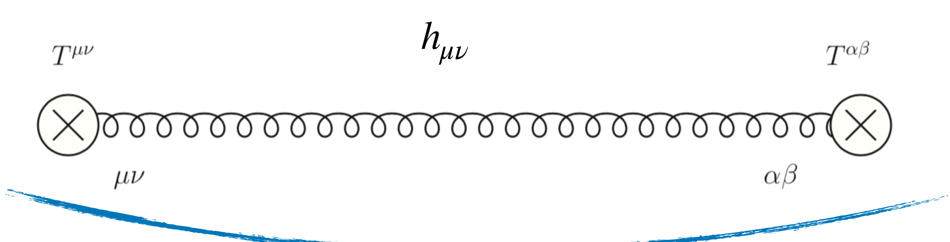
Calculate the following interactions



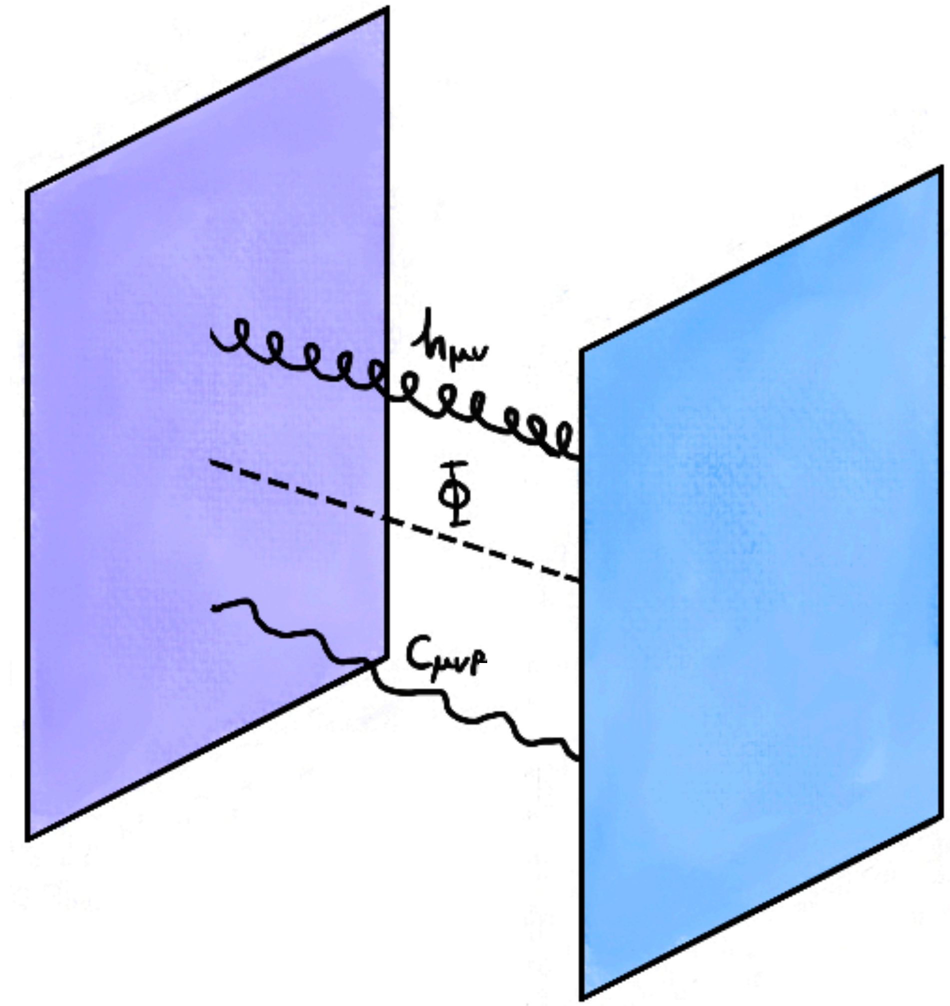
$-e^K K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W}$



$\sim \frac{1}{2} Z^{AB} Q_A Q_B$



$\sim 3 e^K |W|^2$



Scalar Potential = Membrane interaction

↓

Relations between Conjectures

[See Lanza, Marchesano, Martucci, Valenzuela '20]

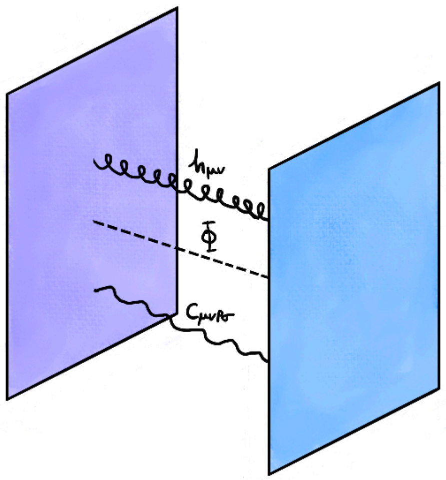
Conclusions

1. Corrections from internal backreaction (in this class of models) → Scale Separation disappears / ADC is fulfilled

2. Equivalence between N=1 flux induced scalar potential and BPS membrane interactions

   ↓

   Potential relations between Conjectures



thank you
شكراً جزيلاً
рахмат
danke
謝謝
ngiyabonga
teşekkür ederim
Баярлалаа
mersi
kia ora
barka
welalin
tack
spas
спасибо
faafetai lava
vinaka
blagodaram
dank je
misaotra
matondo
paldies
grazzi
mahalo
tapadh leat
gracias
хвала
kiitos
dankie
nanni
nandri
dhanyavad
спасибі
asante
manana
bedankt
hvala
maururu
köszönöm
bayarlalaa
gràcie
dankon
aciu
akun
obrigada
murakoze
tenki
enkosi
djiere dieuf
tau
mochchakkeram
дякую
mamnun
dziękuję
chnorakaloutioun
gratias ago
gràcies
sulpáy
taiku
go raibh maith agat
chokrane
sobodi
dēkuji
obrigado
sagolun
sukriya
kop khun krap
arigatô
takk
dakujem
trugarez
mèsi
didi madloba
ありがとう
tanemirt
grazie
najis tuke
terima kasih
rahmet
shukriya
mercè
мерси
kam sah hamnida
rahmat
ευχαριστώ
diolch
dhanyavadagalu
তোমাকে ধন্যবাদ
감사합니다
xièxie
merci