

String Phenomenology 2019 @ CERN

# Swampland Variations on a Theme by KKLT

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# Outline

Swampland and the ~~de Sitter~~ conjecture



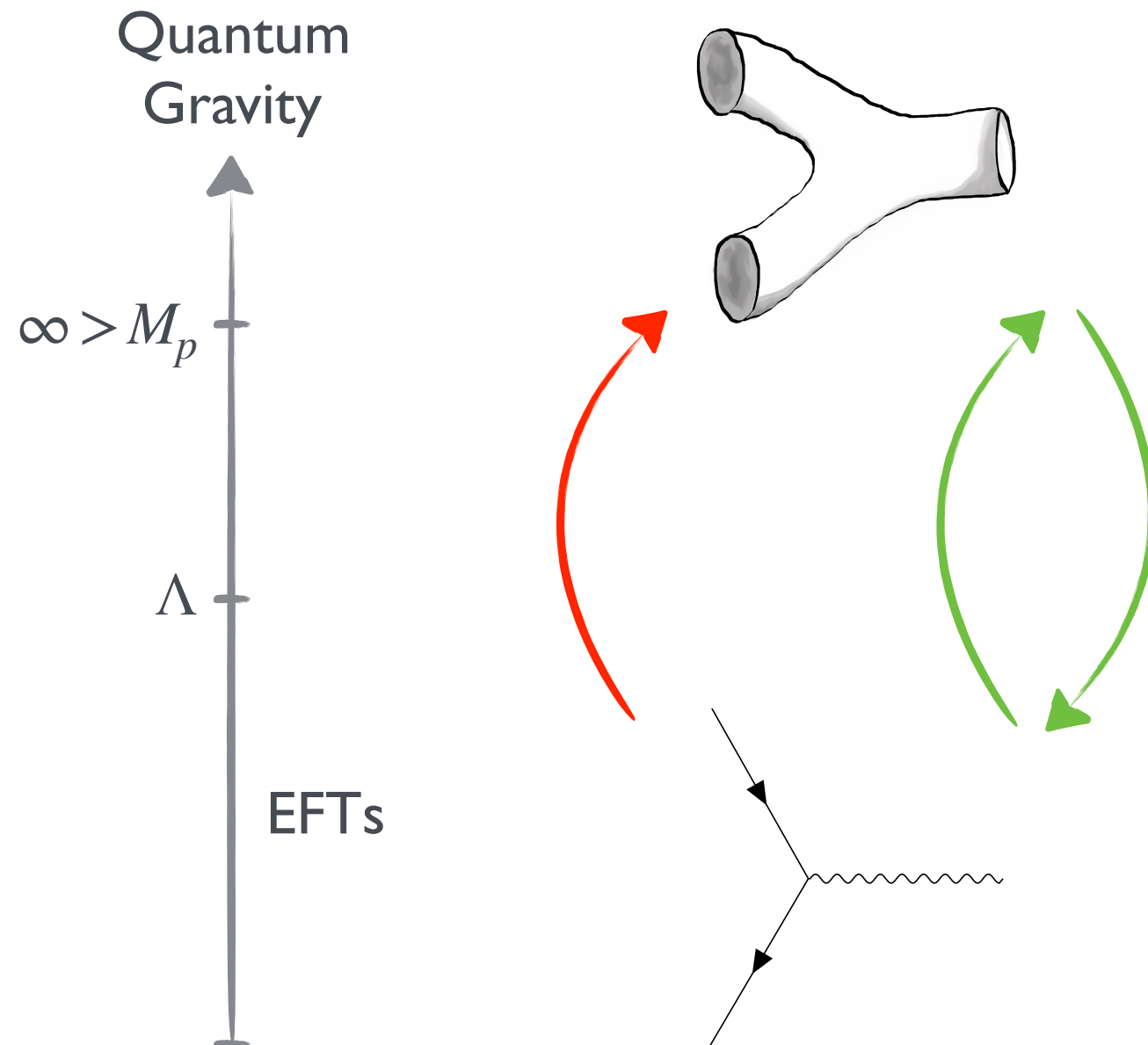
Warped KKLT EFT



Light modes, distance conjecture  
and emergence

# Landscape vs. Swampland

Vafa '05



## **Landscape:**

EFT consistent with quantum gravity

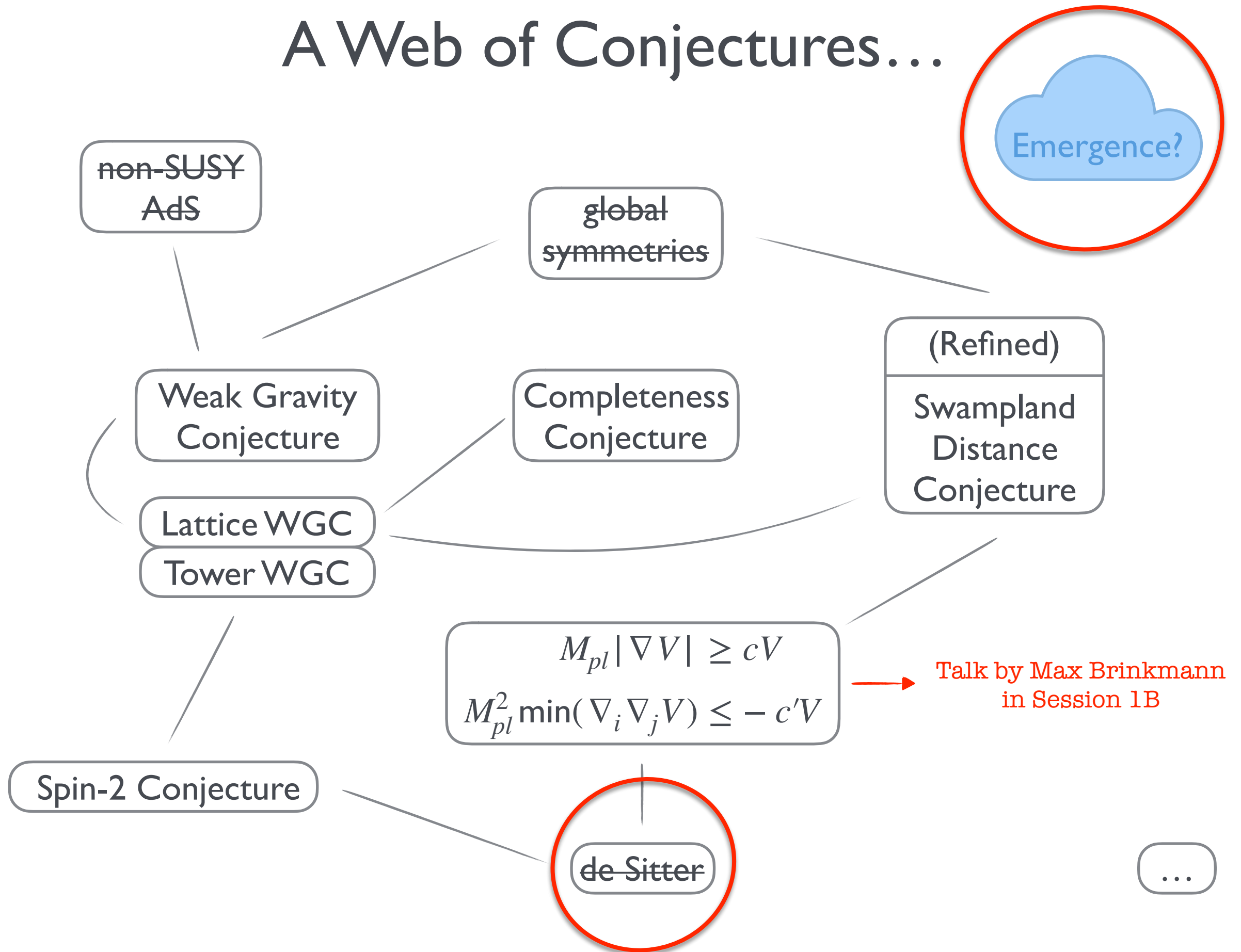
## **Swampland:**

EFT inconsistent with quantum gravity

## **Swampland conjectures:**

landscape vs. swampland

# A Web of Conjectures...



# The ~~de Sitter~~ Conjecture

Obied, Ooguri, Spodyneiko, Vafa '18

Ooguri, Palti, Shiu, Vafa '18

- Conventional wisdom of the last 20 years:

“String theory admits  $10^X$  vacua with  $\Lambda > 0$ , where  $X$  is a large number”

# The ~~de Sitter~~ Conjecture

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- Conventional wisdom of the last 20 years:

“String theory admits  $10^X$  vacua with  $\Lambda > 0$ , where  $X$  is a large number”

- Recently:

“what if  $X = -\infty$  ?”

$$M_{pl} |\nabla V| > cV \quad \text{with} \quad c = \mathcal{O}(1)$$

# The ~~de~~Sitter Conjecture

Obied, Ooguri, Spodyneiko, Vafa '18

Ooguri, Palti, Shiu, Vafa '18

- M-theory

$$2\kappa_{11}^2 S = \int d^{11}x \sqrt{-g} \left( R - \frac{1}{2} G_{\mu\nu\rho\sigma} G^{\mu\nu\rho\sigma} \right)$$

Maldacena,  
Nunez '01

- Smooth compactification  $\longrightarrow V = \underbrace{V_R e^{-\lambda_1 \rho}}_{\text{curvature}} + \underbrace{V_G e^{-\lambda_2 \rho}}_{\text{flux}}$

Obied, Ooguri,  
Spodyneiko,  
Vafa '18

- Can show:

$$M_{pl} \frac{|\nabla V|}{V} \geq \frac{6}{\sqrt{(d-2)(11-d)}}$$

# KKLT - a Counterexample?

Kachru, Kallosh, Linde, Trivedi '03 and 2500+ followups

$$K = \underbrace{-3 \log (T + \bar{T})}_{\text{Kähler}} \overbrace{-\log (-i \bar{\Pi} \Sigma \Pi) - \log (S + \bar{S})}^{\text{complex structure + dilaton}}$$

$$W = \int_{CY} G_3 \wedge \Omega$$

$\searrow$   
 $F_3 - SH_3$



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$$W = \int_{CY} G_3 \wedge \Omega \quad \begin{array}{c} \searrow \\ F_3 - SH_3 \end{array}$$

I) Stabilize CS moduli + dilaton using 3-form fluxes

$$\text{no-scale: } V = e^K \left| D_{\textcolor{red}{i}} W \right|^2 \quad \textcolor{red}{i} \in \text{CS moduli, } S \quad \Rightarrow D_i W = 0, \quad W = W_0$$

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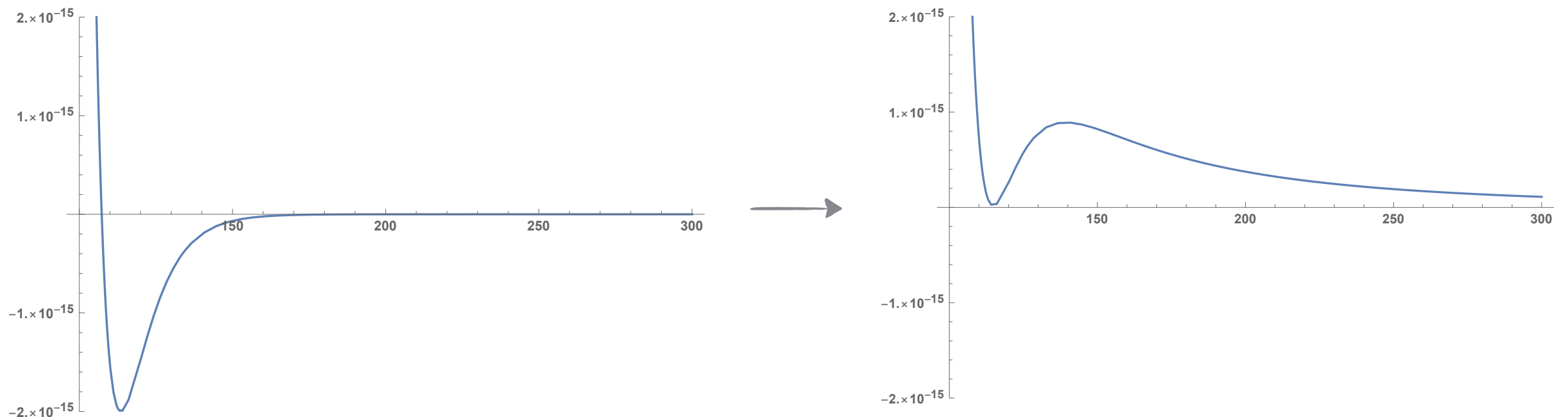
2) Argue for non-perturbative effects

$$W_{KKLT} = W_0 + A e^{-aT}$$

————→ SUSY AdS vacuum

# De Sitter Uplift

$$V_{AdS} \sim -e^{-2a\tau}/\tau$$



**warping!**

- Introduce  $\overline{D3}$ :

$$V_{\overline{D3}} \sim \frac{A}{\text{Im}(T)^3}$$

- Many criticisms of KKLT attack here...

Moritz, Retolaza, Westphal '17/'18

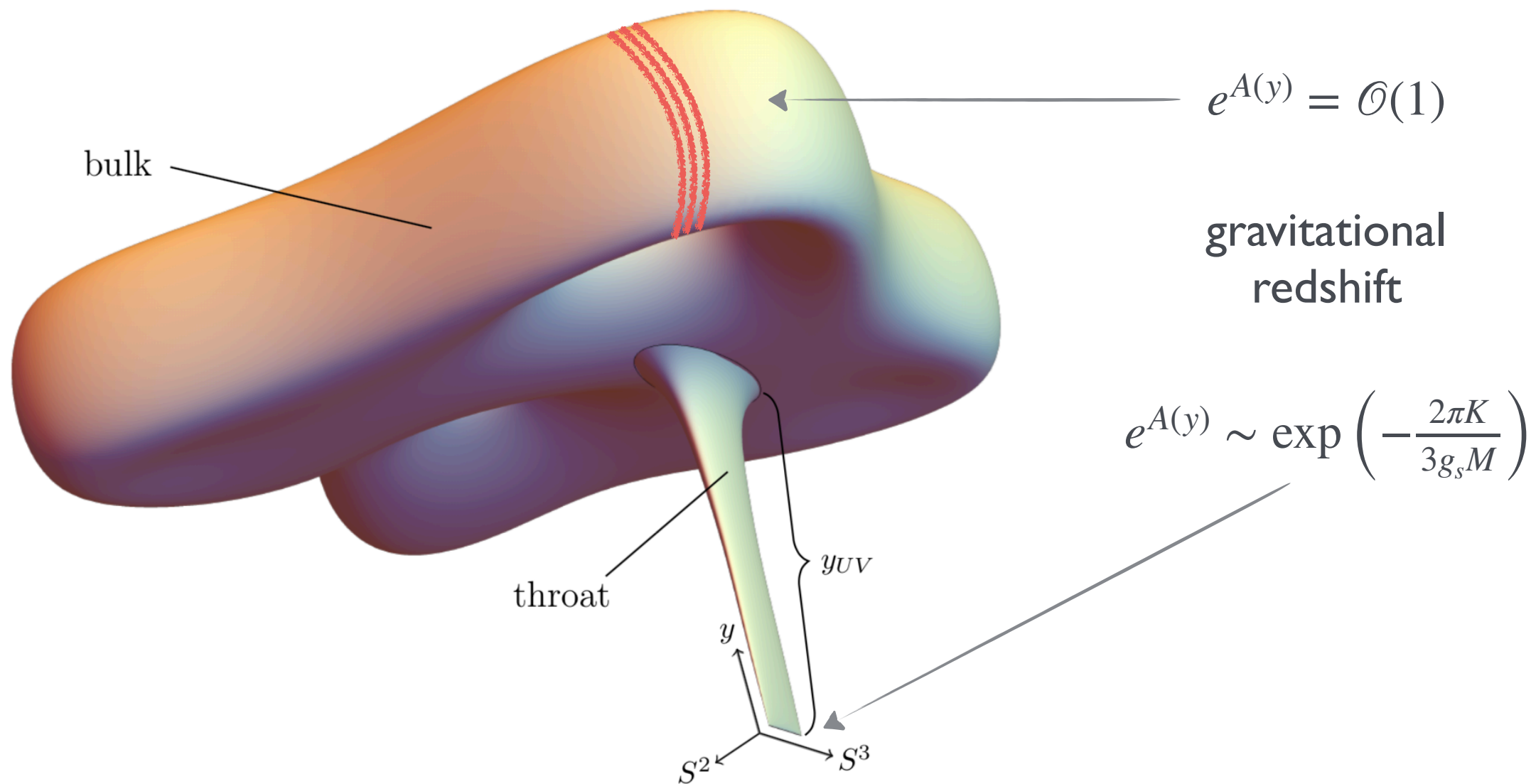
Hamada, Hebecker, Shiu, Soler '18/'19

Carta, Moritz, Westphal '19

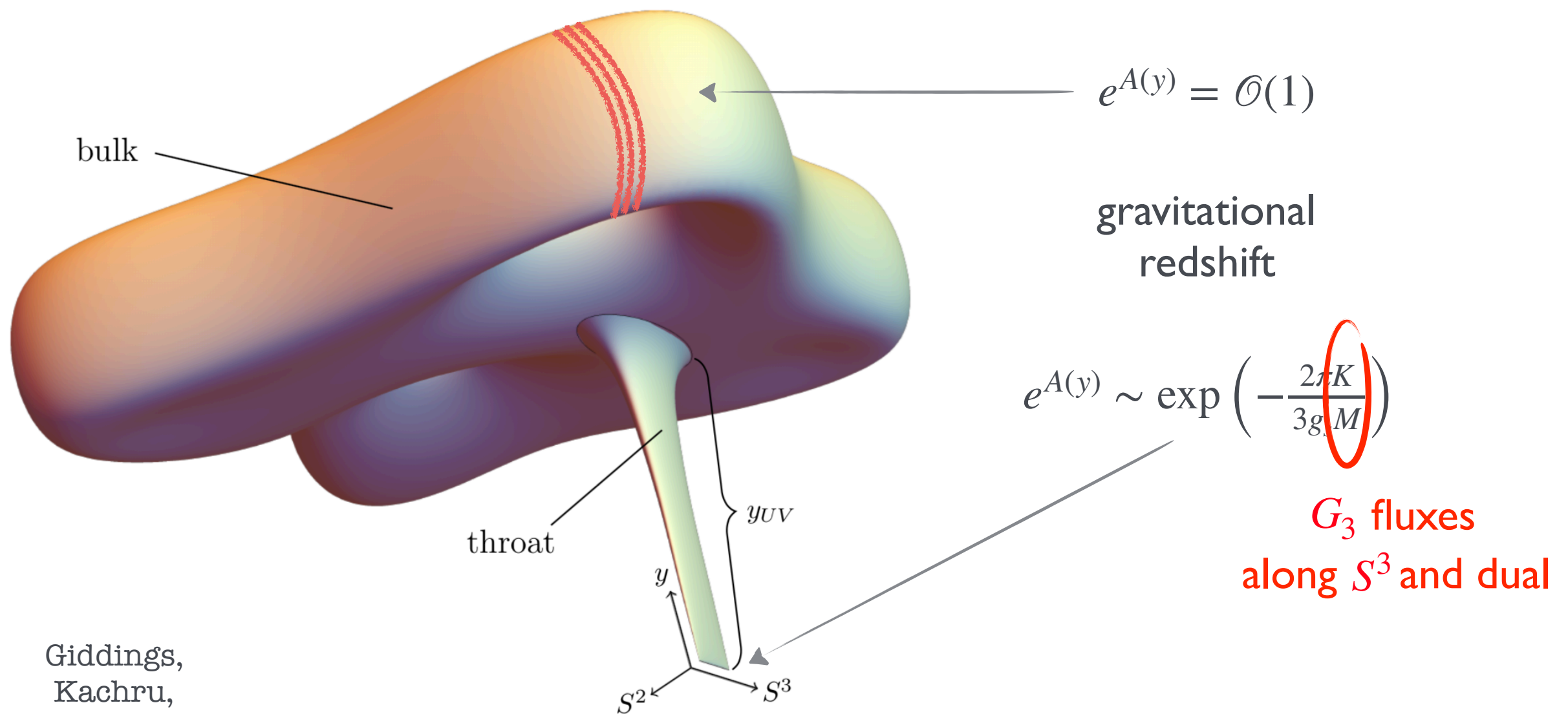
Gautason, Van Hemelryck, Van Riet, Venken '19

Bena, Dudas, Graña, Lüst '18

$$ds^2 = \underbrace{e^{2A(y)} \eta_{\mu\nu} dx^\mu dx^\nu}_{\text{Minkowski}} + \underbrace{e^{-2A(y)} \tilde{g}_{mn} dy^m dy^n}_{\text{Calabi-Yau}}$$



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Giddings,  
Kachru,  
Polchinski  
'02

# Warped EFT

- Warping modifies the 4D SUGRA
- EFT for volume and conifold moduli

$$K = -3 \log(T + \bar{T}) + \frac{\xi' |Z|^{2/3}}{T + \bar{T}} + \dots$$

$$Z = \int_{S^3} \Omega$$

$$\mathcal{V}_w = \frac{1}{g_s^{3/2} (\alpha')^3} \int d^6 y e^{-4A} \sqrt{\tilde{g}} \sim \text{Im}(T)^{\frac{3}{2}}$$

e.g. Giddings, Maharana '05  
Douglas, Shelton, Torroba '07  
Shiu, Torroba, Underwood, Douglas '08

- Assume all other CS moduli fixed

Bena, Dudas, Graña, Lüst '18

$$W = W_{cs} \ll 1$$

- Flux superpotential

$$W = W_{cs} - \frac{M}{2\pi i} Z (\log Z - 1) + \frac{i}{g_s} K Z + A e^{-aT}$$

- KKLT-like SUSY AdS minima - stabilization of  $Z$  generates

$$W_0 = W_{cs} - \frac{M}{2\pi i} \exp\left(-\frac{2\pi}{g_s} \frac{K}{M}\right)$$

# Warped EFT

Scale hierarchy:

$$M_{Kahler} < M_{CS} < M_{KK} < M_s < M_{pl}$$

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Scale hierarchy:

$$M_{Kahler} < M_{CS} < M_{KK} < M_s < M_{pl}$$

warping can destroy this!

Explicit calculation gives

$$m_Z^2 \sim \frac{(\mathcal{V}_w |Z|^2)^{1/3}}{g_s^{3/2} M^2} M_s^2$$

$$m_{KK,n}^2 \sim \frac{n^2 (\mathcal{V}_w |Z|^2)^{1/3}}{g_s^{3/2} M^2 y_{UV}^2} M_s^2$$

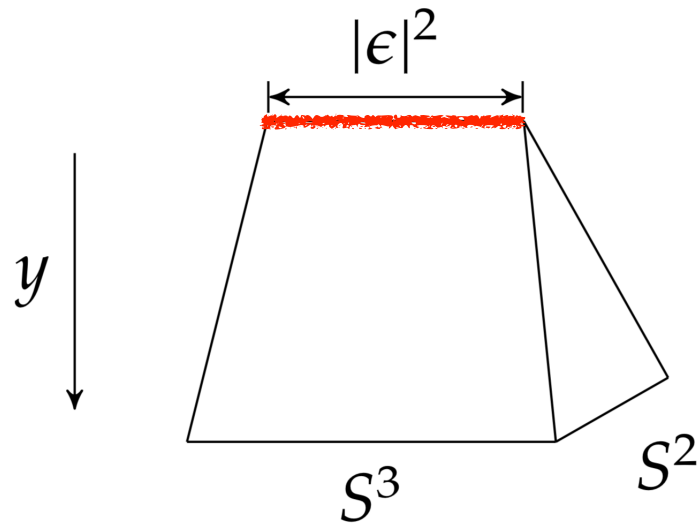
$$\frac{m_{KK}^2}{m_Z^2} \sim \frac{n^2}{y_{UV}^2}$$

for  $y_{UV} > 1$ , we should not ignore the KK modes in the EFT

# Emergence - Conifold

Strominger '95

Vafa '95



wrapped D3-brane = 4D hypermultiplet

$$S_{D3} = \frac{1}{g_s} M_s^4 \int_{\mathbb{R} \times S^3} \sqrt{-g} = \underbrace{g_s^{-1/4} M_s (\mathcal{V} |Z|^2)^{1/2}}_{m_{D3}} \int_{\mathbb{R}} d\tau$$

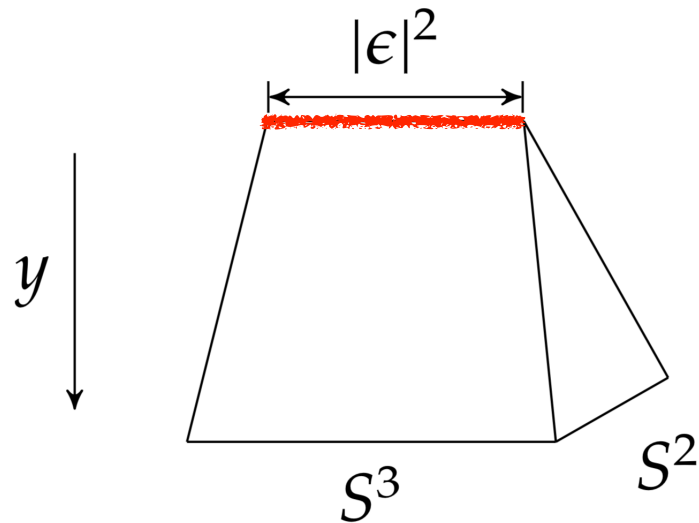
Classical moduli space metric singular

$$g_{Z\bar{Z}} \Big|_{tree} \sim -\log(|Z|^2)$$

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Singularity emergent from integrating out the D3-brane

$$\delta g_{Z\bar{Z}} \Big|_{1-loop} \sim \left| \partial_Z m_{D3} \right|^2 \log\left(\frac{\Lambda^2}{m_{D3}^2}\right) \sim -\log(|Z|^2) \quad \text{if } \Lambda = M_{pl}$$

# Emergence - Distance Conjecture

Harlow '15

Ooguri, Vafa '06

Heidenreich, Reece, Rudelius '18

Grimm, Palti, Valenzuela '18

...

$$S = \int \sqrt{-G} d^4x \left( M_{pl}^2 R(G) + \frac{1}{2} (\partial\phi)^2 + \sum_n \bar{\psi}_n \left( i\gamma^\mu \partial_\mu - \color{red}{m_n(\phi)} \right) \psi_n \right)$$

$$\color{red}{m_n(\phi)} = \color{red}{n\Delta m(\phi)} = \color{red}{n(\partial_\phi \Delta m)\phi} + \dots$$

Yukawa!

$$\Lambda_{sp} = \frac{M_{sp}}{N_{sp}^{1/2}} = \sqrt{\Delta m M_p^2} \qquad N_{sp} = \frac{\Lambda_{sp}}{\Delta m}$$

$$\delta g_{\phi\phi} \Big|_{1-loop} \sim \sum_n^{m_n < \Lambda_4} \left( \frac{\partial m_n}{\partial \phi} \right)^2 = (\partial_\phi \Delta m)^2 \sum_n^{m_n < \Lambda_4} n^2 \simeq (\partial_\phi \Delta m)^2 N_4^3 = M_{pl}^2 \left( \partial_\phi \log \Delta m \right)^2$$

If  $\Delta m$  vanishes polynomially for  $\phi \rightarrow 0 \quad \Rightarrow \quad \delta g_{\phi\phi} \Big|_{1-loop} \sim \frac{M_{pl}^2}{\phi^2}$

# Emergence - Klebanov-Strassler

Similar mechanism at play in the warped case?

$$g_{Z\bar{Z}} \Big|_{tree} \sim g_s M^2 \times \frac{1}{(\mathcal{V}_w |Z|^2)^{2/3}}$$

Integrate out tower of warped KK modes

$$\delta g_{Z\bar{Z}} \Big|_{1-loop} \sim N_{sp}^3 \frac{1}{g_s M^2 y_{UV}^2} \times \frac{1}{(\mathcal{V}_w |Z|)^{2/3}}$$

**Matching** requires  $N_{sp} \sim (g_s M^2 y_{UV})^{2/3} \gtrsim M^{2/3}$

$$\Rightarrow \tilde{\Lambda}_{sp} \sim N_{sp} \Delta m \sim \left( \frac{g_s M^2}{y_{UV}^2} \right)^{1/6} \left( \frac{|Z|}{\mathcal{V}_w} \right)^{1/3} M_{pl}$$

# Emergence - Klebanov-Strassler

$$\tilde{\Lambda}_{sp} \sim N_{sp} \Delta m \sim \left( \frac{g_s M^2}{y_{UV}^2} \right)^{1/6} \left( \frac{|Z|}{\mathcal{V}_w} \right)^{1/3} M_{pl}$$

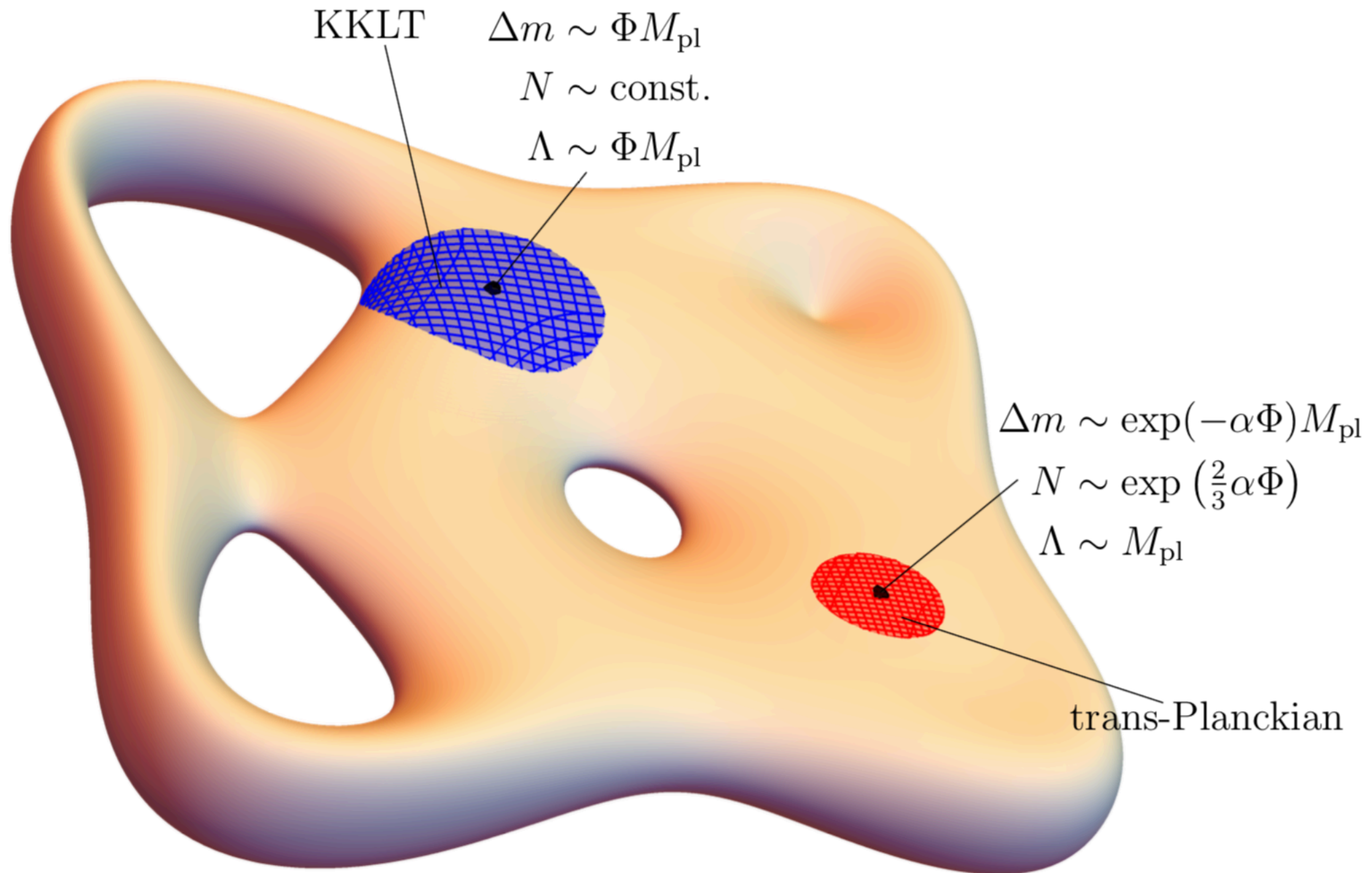
$$\tilde{\Lambda}_{sp} = \frac{\Lambda}{N_{sp}^{1/2}} \quad \Rightarrow \quad \Lambda \sim \sqrt{g_s M^2} \left( \frac{|Z|}{\mathcal{V}_w} \right)^{1/3} M_{pl} \sim m_{D3}$$

**Cutoff = Mass of D3 wrapped on A-cycle!**

$$S_{D3} \sim \frac{M_s^4}{g_s} \int d\tau \int_{S^3} d^3y \sqrt{-G} \sim \underbrace{\frac{M_s^4}{g_s} \int_{S^3} d^3y e^{-2A} \sqrt{\tilde{g}_{CY}}}_{m_{D3}} \int d\tau$$

$\tilde{\Lambda} \equiv$  scale at which 1-loop correction to  $M_{pl}$  is of order  $\Lambda$

# Light Modes, Emergence and SDC



# Conifold vs. Klebanov-Strassler

## Conifold

Kinetic term for  $Z$   
generated by  
integrating out  
wrapped **D3-brane**

Cutoff is Planck  
scale



## Klebanov-Strassler

Kinetic term for  $Z$   
generated by integrating  
out **redshifted KK modes**

Wrapped **D3-brane** sets  
cutoff



# Fate of KKLT AdS Minimum

In view of the results, we see **two options**:

A) The initial Wilsonian effective action  $S$  and the minima of the potential are not reliable because of the tower of extra modes that are not included in  $S$

B) The peculiar property

$$\delta g_{\phi\phi} \Big|_{1-loop} \sim g_{\phi\phi} \Big|_{tree}$$

signals that the effective action  $S$  is *not* completely out of control. Since the superpotential is not expected to be perturbatively corrected, also the effective potential in  $S$  is only slightly changed from the tree-level form  $V(\phi)$  in  $S$ .

# Conclusions

- Studied the warped EFT for the conifold and Kähler moduli
- Kinetic terms emergent from integrating out warped KK modes
- Finite distance  $\longleftrightarrow$  finite number of light modes
- Better understanding of control over EFT needed

**Thank You**

# Emergence - KK Modes?!

DK, Palti

Usually KK-modes seem to play different role

$$S_{5D} = \int \sqrt{-G} d^5x \left( M_5^3 R(G) + \frac{1}{2} (\partial\phi)^2 + \sum_n \bar{\psi}_n \left( i\gamma^\mu \partial_\mu - m_n(\phi) \right) \psi_n \right)$$

