# Anti-brane induced inflation

Marco Scalisi

based on

E. McDonough and MS - JCAP 1611, n.11, 028 (2016) [arXiv:1609.00364]

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*FWO*
*European Union's Horizon 2020 Marie Skłodowska-Curie grant agreement N. 665501*

September $27^{th}$, 2017 - DESY Theory Workshop "Fundamental Physics in the Cosmos"- Hamburg

*M17 Nebula in Sagittarius - Gianni Benintende (Sicily - Italy)*

# Two Observations

String Theory

Anti-D3 Brane

1

de Sitter

$$V > 0$$

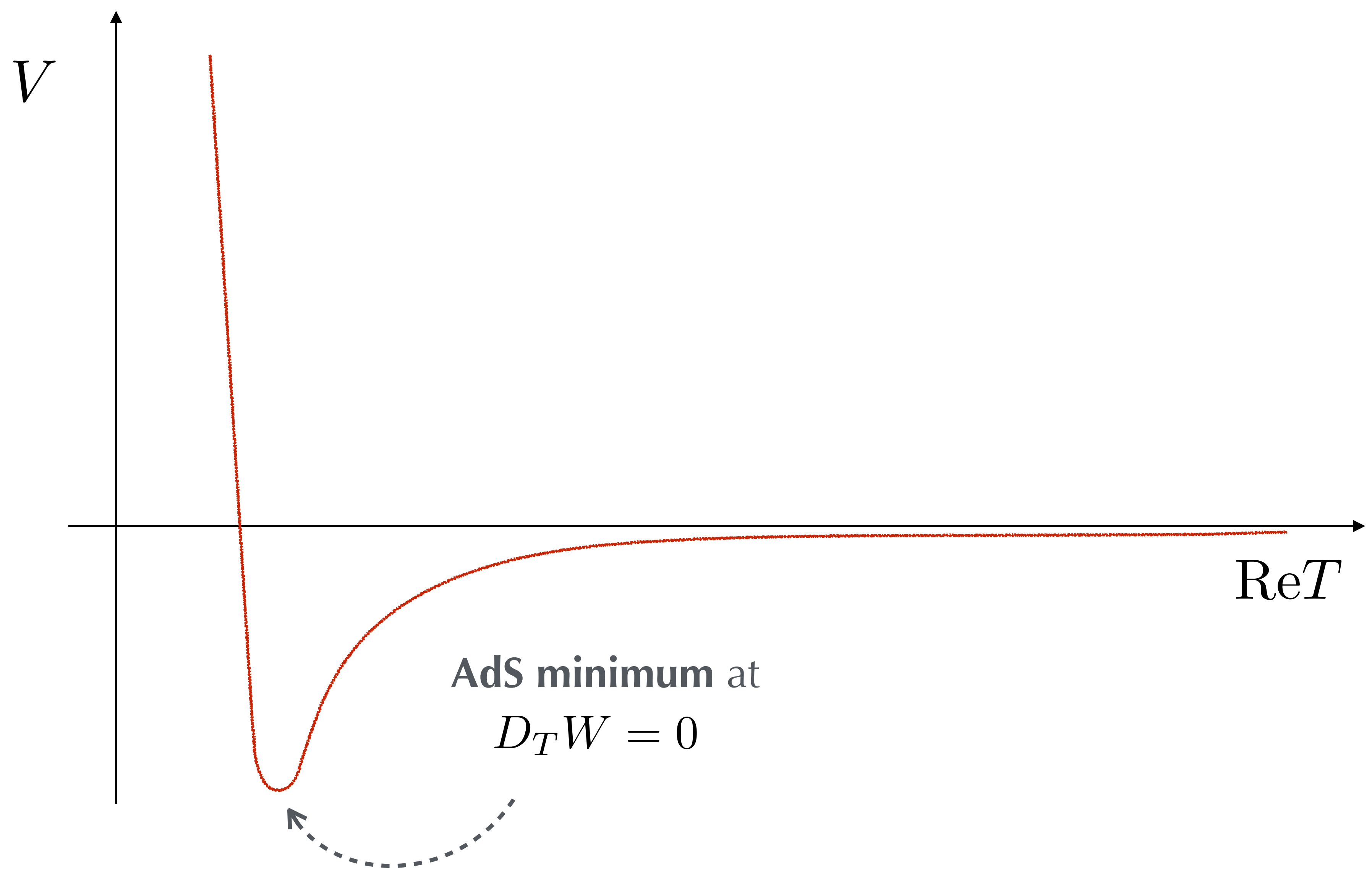
# KKLT

*Kachru, Kallosh, Linde, Trivedi 2003*

$$K = -3\log(T + \bar{T})$$

$$W = W_0 + A\exp(-aT)$$

$$V = V_T$$




**AdS minimum** at

$D_T W = 0$

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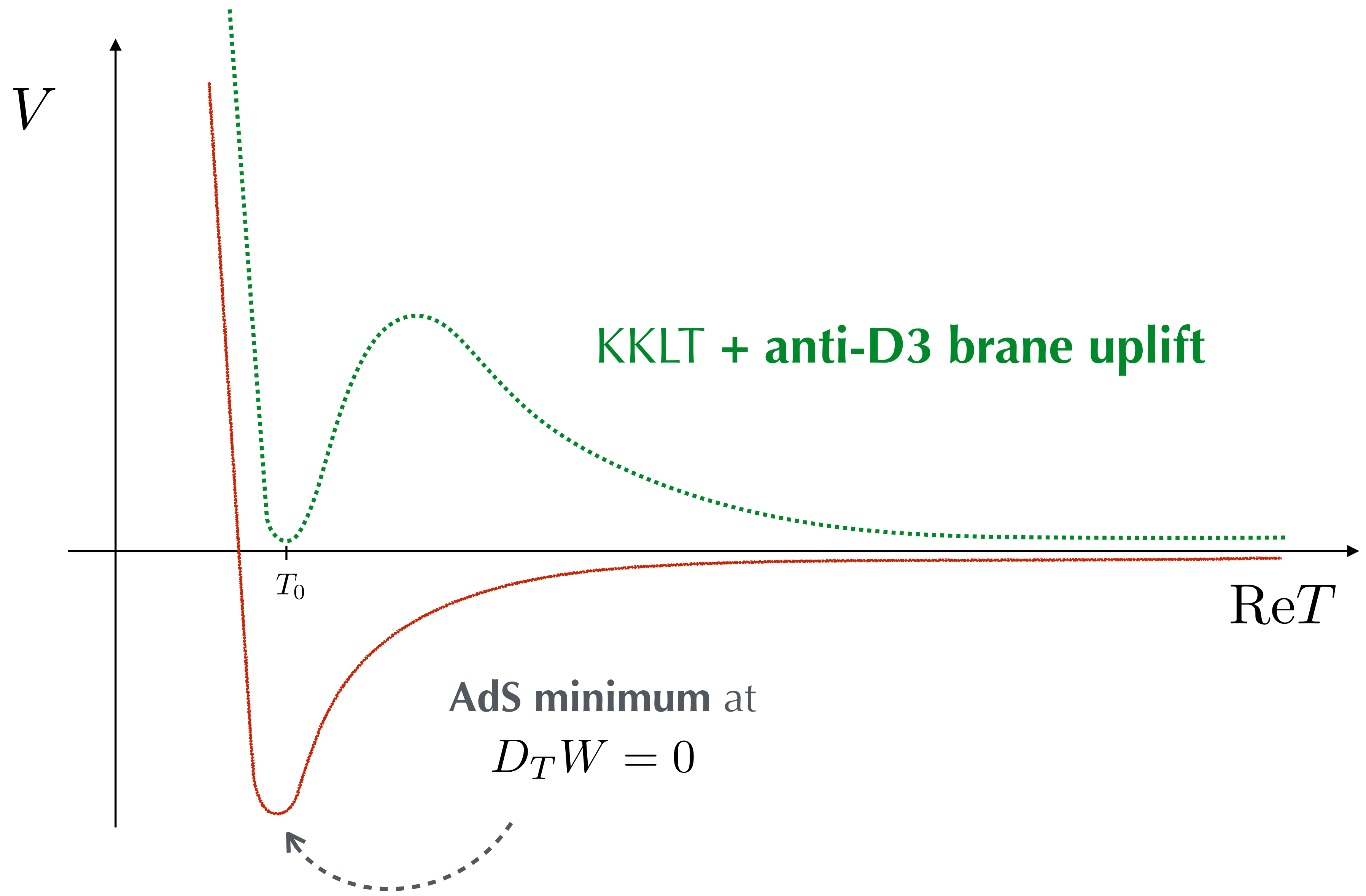

String Theory

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String Theory

Anti-D3 Brane

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# de Sitter

$$V > 0$$

2

Supergravity

Nilpotent Superfield


*see Wrase's talk*

# The nilpotent superfield

$$S(x,\theta) = s(x) + \sqrt{2}\lambda(x)\theta + F(x)\theta^2$$

$$S^2(x,\theta) = 0$$

$$\Downarrow$$

$$S(x,\theta) = \frac{\lambda\lambda}{2F} + \sqrt{2}\lambda\theta + F\theta^2$$

**no scalar!** **just fermions!**

*Volkov, Akulov 1972,1973*

*Rocek; Ivanov, Kapustnikov 1978*

*Lindstrom, Rocek 1979*

*Casalbuoni, De Curtis, Dominici, Feruglio, Gatto 1989*

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when coupled to SUGRA

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!

*Farakos, Kehagias 2013*
"Decoupling Limits of sGoldstino Modes in Global and Local Supersymmetry"
***Appendix*** *of arXiv:1302.0866**v1***

# de Sitter supergravity

$$K = S\bar{S}$$

$$W = W_0 + MS$$ most general $W$ as $S^2 = 0$

at $S = 0$

$$V = M^2 - 3W_0^2$$

SUSY breaking of *S*

Gravitino mass

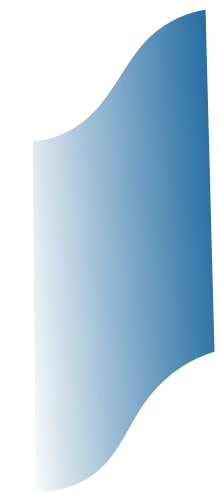
no scalar degrees of freedom!

**'de Sitter supergravity'**

*Antoniadis, Dudas, Ferrara, Sagnotti 2014*
*Bergshoeff, Freedman, Kallosh, Van Proyen 2015*
*Hasegawa, Yamada 2015*

String Theory

**Anti-D3 Brane**



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**de Sitter**

$$V > 0$$

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Supergravity

**Nilpotent Superfield**

de Sitter

$V > 0$

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String Theory

Anti-D3 Brane

2

Supergravity

Nilpotent Superfield

QUESTION **#1**

**Does the Anti-D3 brane break SUSY spontaneously?**

*McGuirk, Shiu, Ye 2012*

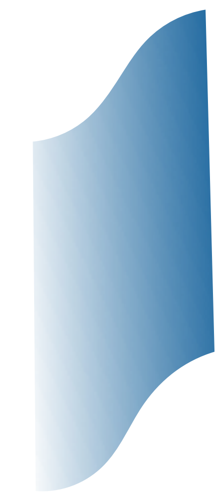
QUESTION **#2**

**Can we package the uplifting term into *K* and *W*?**

*Ferrara, Kallosh, Linde 2014*

String Theory

Anti-D3 Brane



Supergravity

Nilpotent Superfield

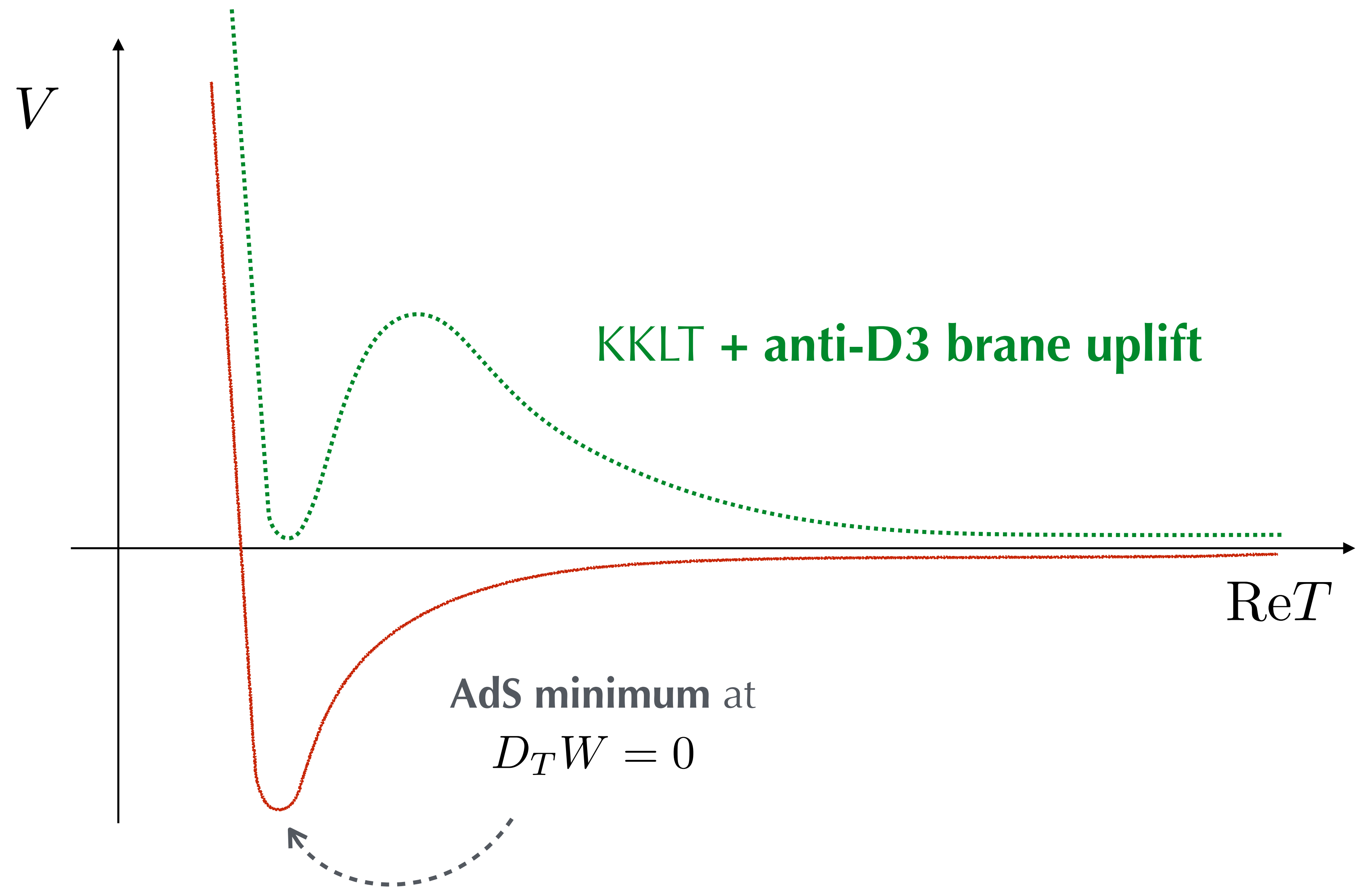
# KKLT + Nilpotent Superfield

*Ferrara, Kallosh, Linde 2014*

$$K = -3\log(T + \bar{T} - S\bar{S})$$

$$W = W_0 + A\exp(-aT) + \mu^2 S$$

$$V = V_T + \frac{\mu^4}{3(T+\bar{T})^2}$$



## NILPOTENT SUPERFIELD <—-> D-BRANES

The **four dimensional** description of an **anti-D3 brane** in an $N = 1$ flux background is a supergravity theory of a **nilpotent superfield**.

*Kallosh & Wrase 2014*

## NILPOTENT SUPERFIELD <—-> D-BRANES

The **fermions** arising when one or more **anti-branes**, placed in certain geometries, break supersymmetry spontaneously can often be packaged into **constrained superfields**.

*McGuirk, Shiu, Ye 2012*
*Kallosh & Wrase 2014*
*Bergshoeff, Dasgupta, Kallosh, Van Proeyen & Wrase 2014*
*Kallosh, Quevedo & Uranga 2015*
*Bertolini, Musso, Papadimitriou & Raj 2015*
*Aparicio, Quevedo & Valandro 2015*
*Garca-Etxebarria, Quevedo & Valandro 2015*
*Dasgupta, Emelin and McDonough 2016*
*Vercnocke & Wrase 2016*
*Kallosh, Vercnocke & Wrase 2016*
*Bandos, Heller, Kuzenko, Martucci and Sorokin 2016*
*Aalsma,van der Schaar, Vercnocke 2017*
*Garcia del Moral, Parameswaran, Quiroz, Zavala 2017*

# Our Work

*McDonough & MS 2016*

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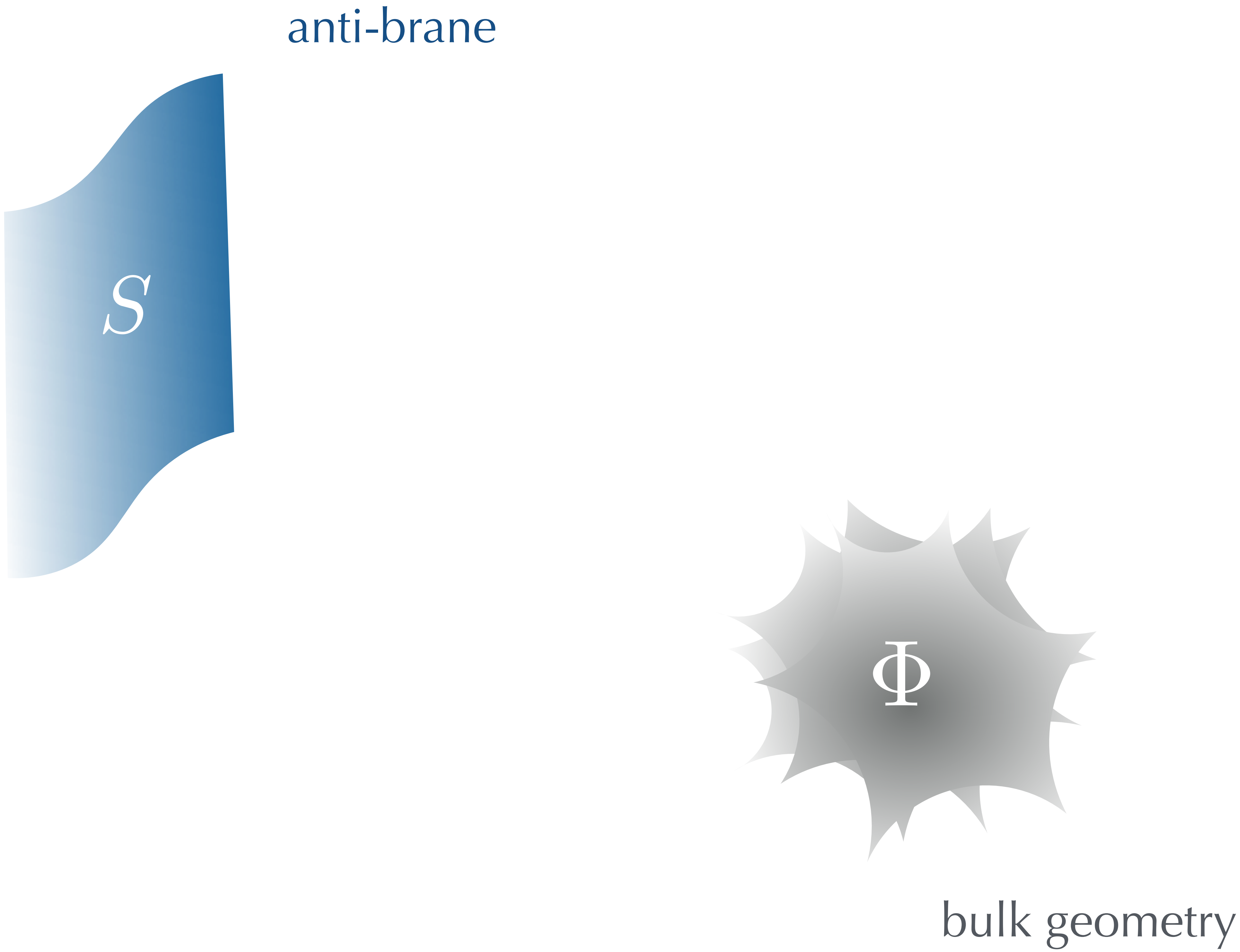
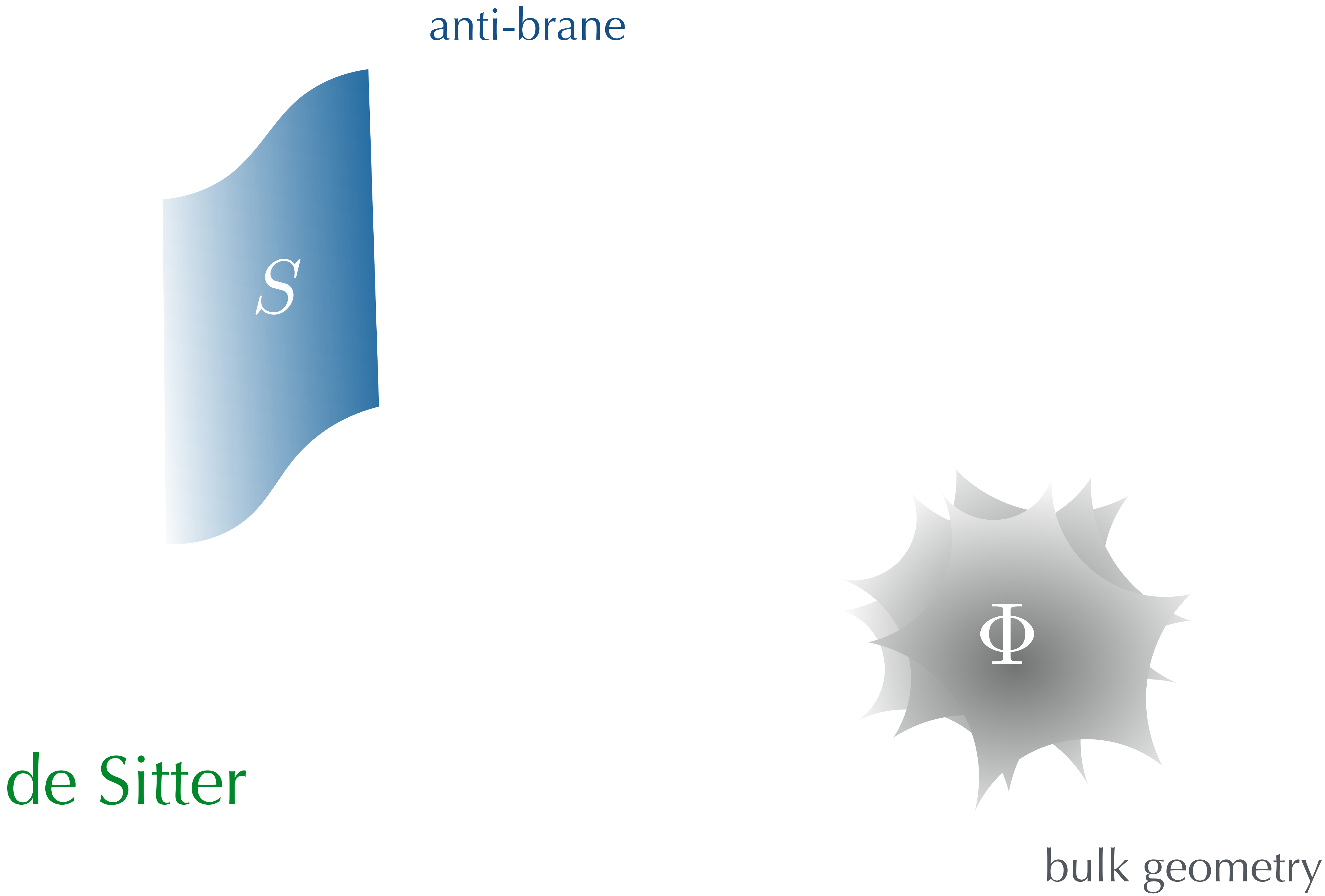


McDonough & MS 2016



*McDonough & MS 2016*

anti-brane


10D analysis of the backreaction

!

*Moritz, Retolaza, Westphal 2017*

*see Moritz's talk*

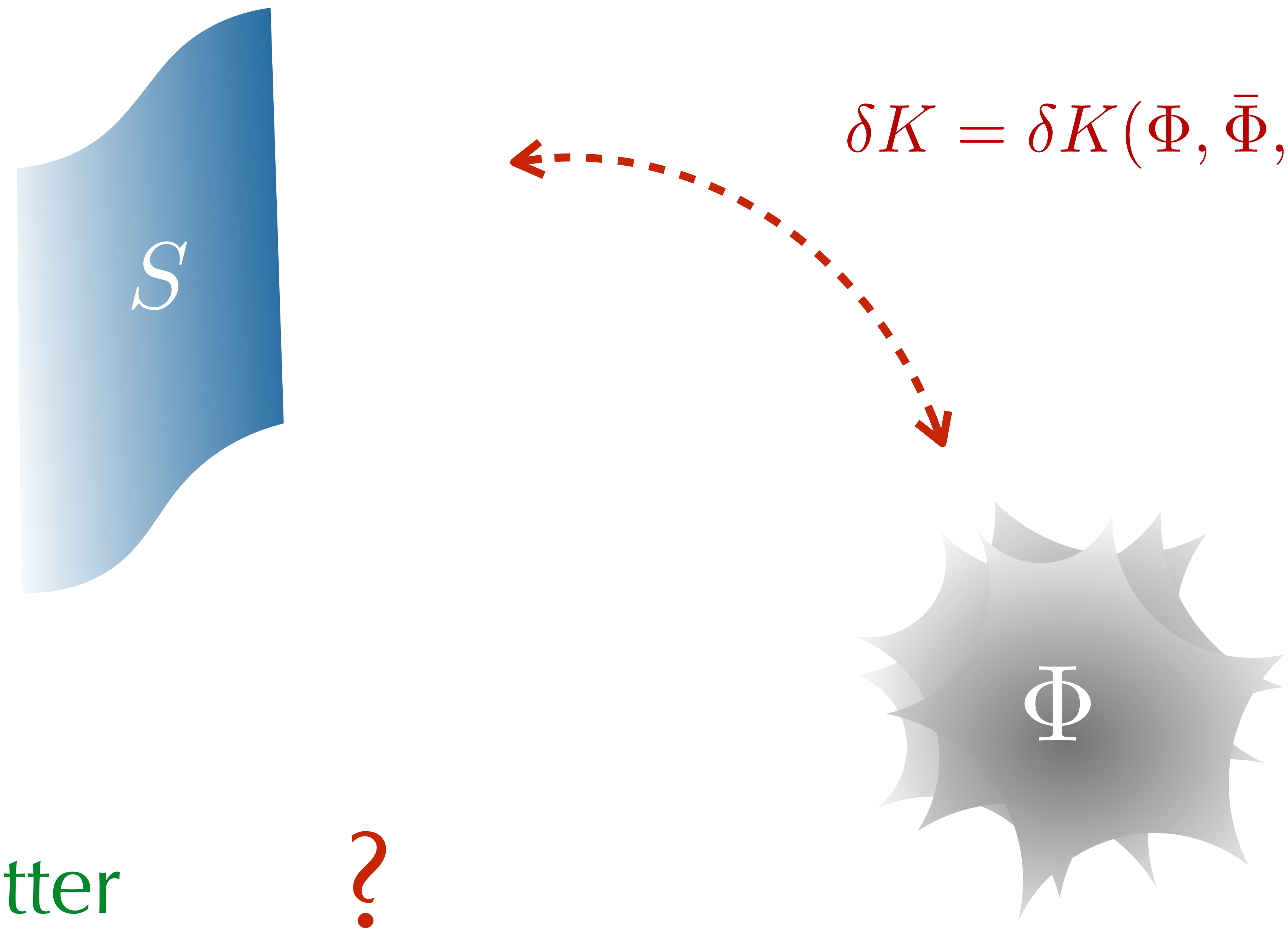

de Sitter

bulk geometry

*McDonough & MS 2016*

anti-brane

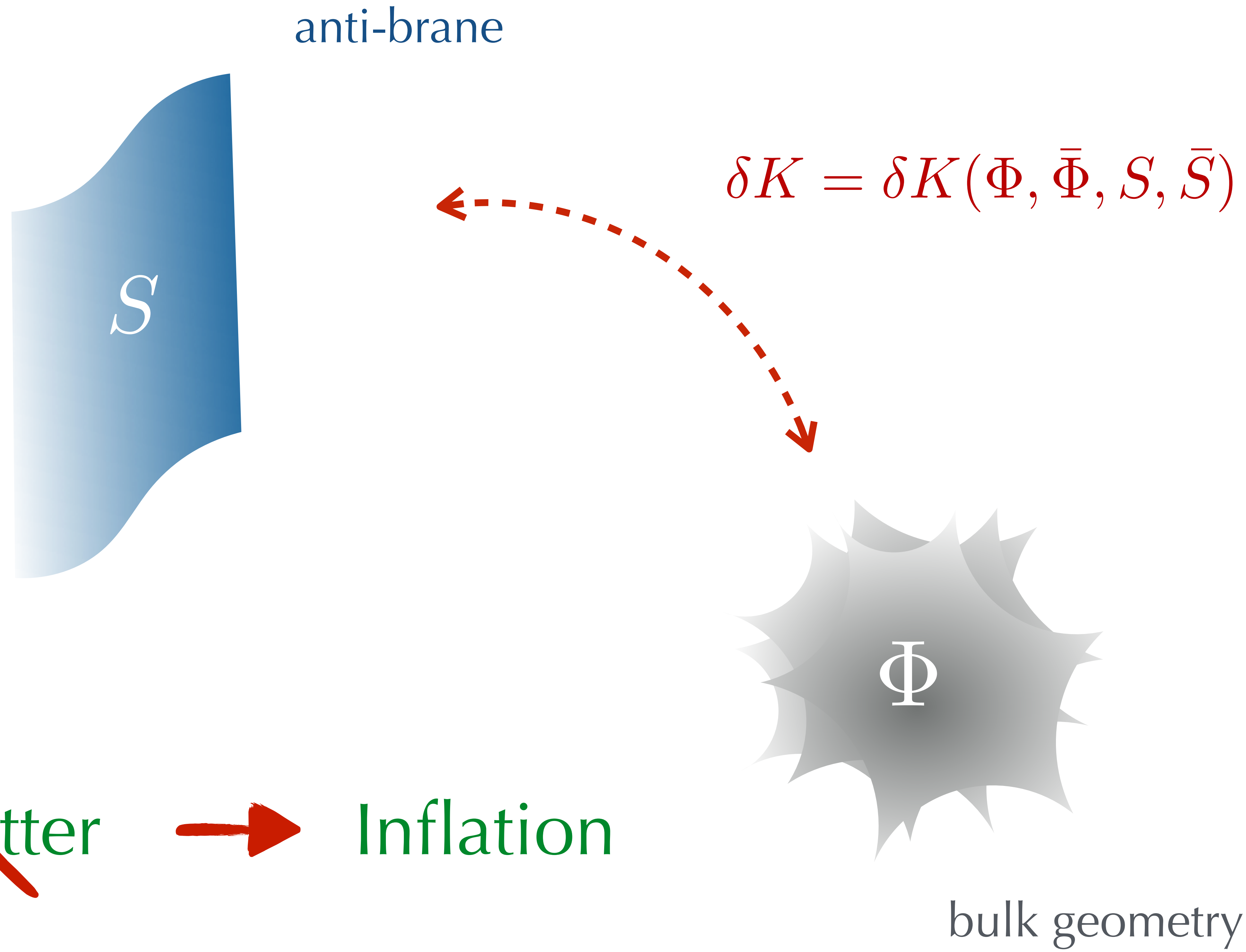
$$\delta K = \delta K(\Phi, \bar{\Phi}, S, \bar{S})$$




de Sitter ?

bulk geometry

McDonough & MS 2016




~~de Sitter~~ → Inflation

*McDonough & MS 2016*

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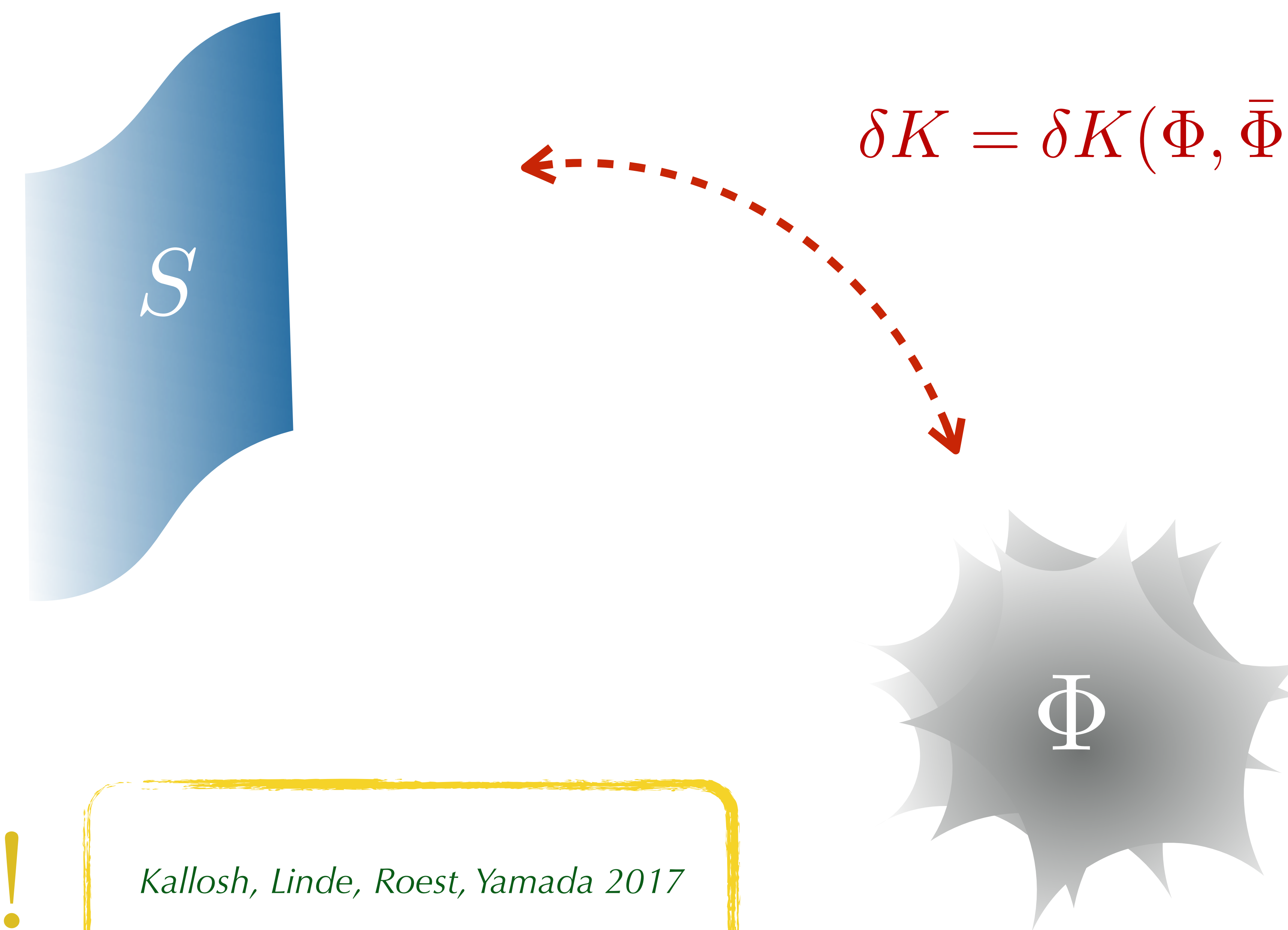


bulk geometry

!

*Kallosh, Linde, Roest, Yamada 2017*

“anti-D3 brane induced inflation”

McDonough & MS 2016

$$K = S\bar{S}$$

$$W = W_0 + MS$$

$$\Big\downarrow \text{ at } S = 0$$

$$V = M^2 - 3W_0^2$$

**SUSY breaking of *S***

**Gravitino mass**

# Flat Kähler geometry

*McDonough & MS 2016*

$$K = S\bar{S} - \frac{1}{2}\left(\Phi - \Phi\right)^2$$

$$W = W_0 + MS$$

$$\text{at } S = 0 \ \text{ and at } Im\Phi = 0$$

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**no inflation!** (shift symmetry not broken!)

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$$K = S\bar{S} - \frac{1}{2}\left(\Phi - \Phi\right)^2$$

**inflation!**

$$W = W_0 + MS \qquad\qquad W = g(\Phi) + f(\Phi)S$$

*Kallosh, Linde, MS 2014*

at $S = 0$ and at $Im\Phi = 0$

*Kallosh, Linde 2014*

*Dall'Agata,Zwirner 2014*

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$$K = S\bar{S} - \tfrac{1}{2}\left(\Phi - \Phi\right)^2 + \underbrace{f(\Phi,\bar{\Phi})S\bar{S} + g(\Phi,\bar{\Phi})S + \bar{g}(\Phi,\bar{\Phi})\bar{S}}_{\delta K}$$

$$W = W_0 + MS$$

# Flat Kähler geometry

McDonough & MS 2016

$$K = -\frac{1}{2}\left(\Phi - \bar{\Phi}\right)^2 + \left[1 + f\left(\Phi, \bar{\Phi}\right)\right] S\bar{S}$$

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$$\boxed{V = M^2 F(\Phi) - 3W_0^2}$$

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***<u>Phenomenological Flexibility</u>***

- Arbitrary **Inflationary Potential**
- Controllable level of **SUSY breaking**
- Tunable level of the **CC**

***<u>SUSY broken just in the S direction</u>***

$$D_\Phi W = 0 \qquad D_S W = M$$

McDonough & MS 2016

**SUSY breaking of S**

$$K^{S\bar{S}}|D_S W|^2$$

**Gravitino mass**

$$\boxed{V = \overline{\underline{M}^2 \underline{F(\Phi)}} - 3W_0^2}$$

**Effects of Kähler corrections**

**"Original" SUSY breaking of *S***

! ***SUSY broken just in the S direction***

$$D_\Phi W = 0 \quad D_S W = M$$

# Ex. Quadratic Inflation

*McDonough & MS 2016*

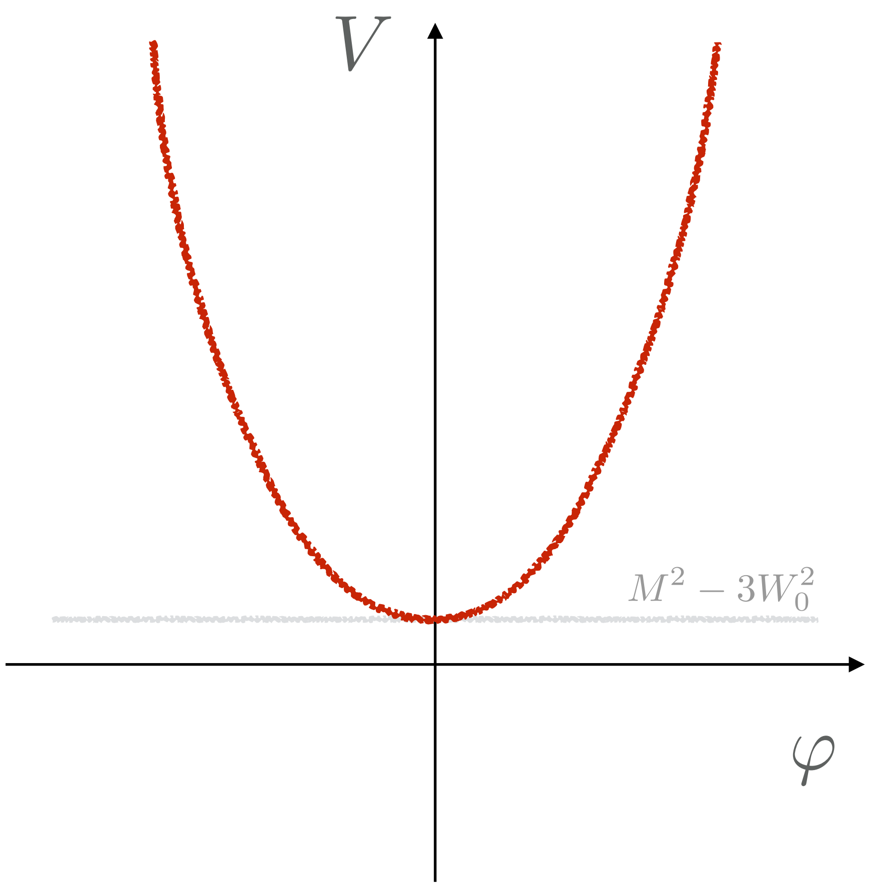
$$K = -\tfrac{1}{2}\left(\Phi - \bar{\Phi}\right)^2 + S\bar{S} - \frac{m^2}{2M^2}\Phi\bar{\Phi}\cdot S\bar{S}$$

$$W = W_0 + MS$$

at $S = 0$ and at $Im\Phi = 0$

$$\boxed{V = \left(M^2 - 3W_0^2\right) + \frac{1}{2}m^2\varphi^2}$$

with $\varphi = \sqrt{2}\mathrm{Re}\Phi$



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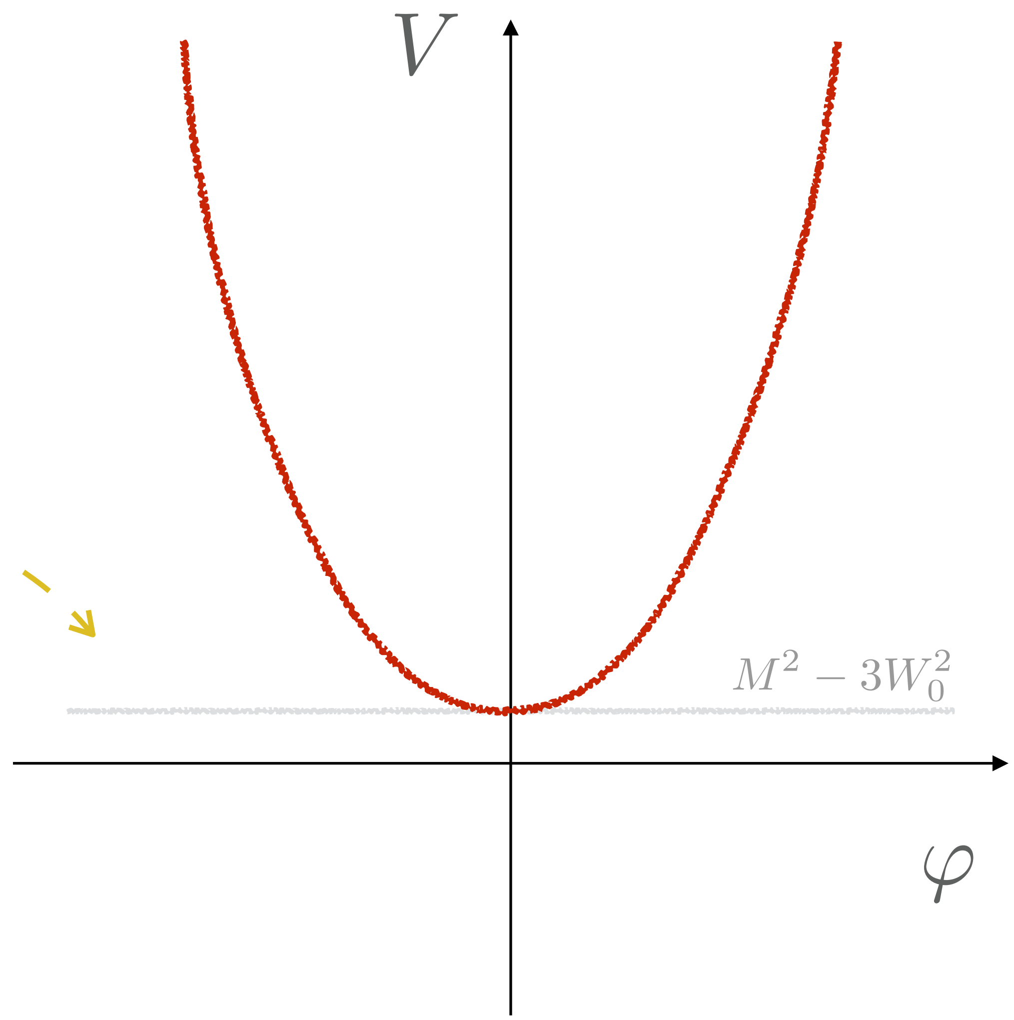


The anti-D3 brane provides the **small cosmological constant**

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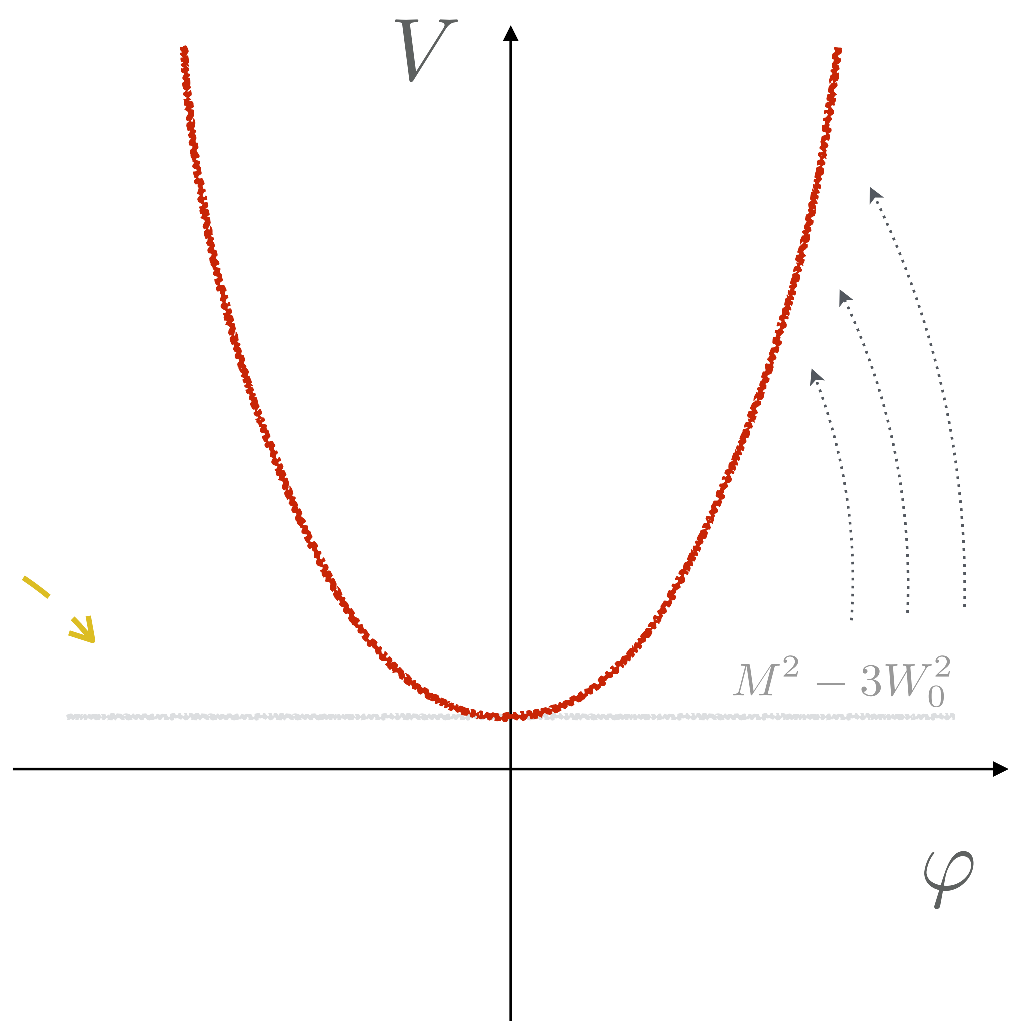


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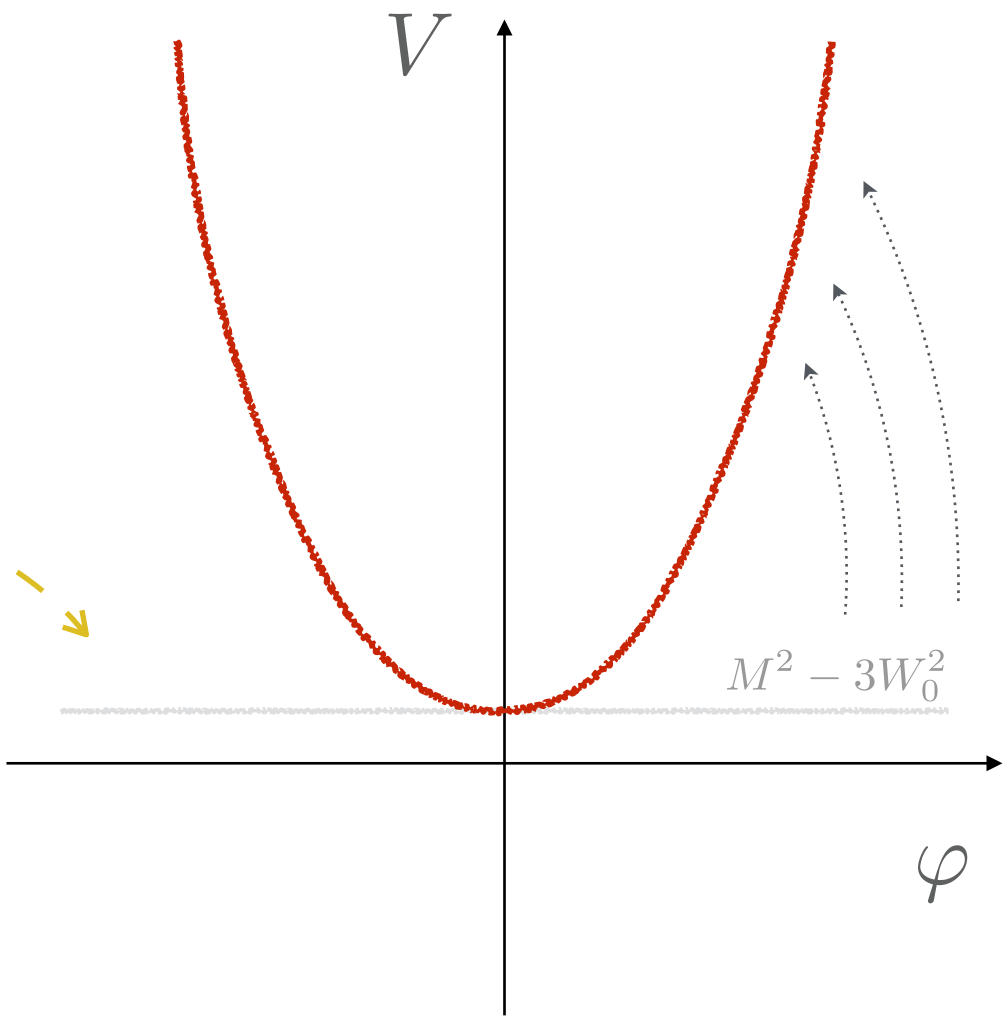


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Inflation happens at **large Kähler corrections**

# Hyperbolic Kähler geometry

*McDonough & MS 2016*

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$$K = S\bar{S} - 3\alpha \log\left(\frac{\Phi + \bar{\Phi}}{2|\Phi|}\right)$$

$$W = W_0 + MS$$

related to

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by means of a
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at $S = 0$ and at $Im\Phi = 0$

$$V = M^2 - 3W_0^2$$

**no inflation!** (shift symmetry not broken!)

# Hyperbolic Kähler geometry

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$$K = S\bar{S} - 3\alpha \log\left(\frac{\Phi + \bar{\Phi}}{2|\Phi|}\right) \underbrace{+ f(\Phi, \bar{\Phi}) S\bar{S} + g(\Phi, \bar{\Phi})(S + \bar{S})}_{\delta K}$$

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at $S = 0$ and at $Im\Phi = 0$

**the same story as before!**

$$\boxed{V = M^2 F(\Phi) - 3W_0^2}$$

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at $S = 0$ and at $Im\Phi = 0$

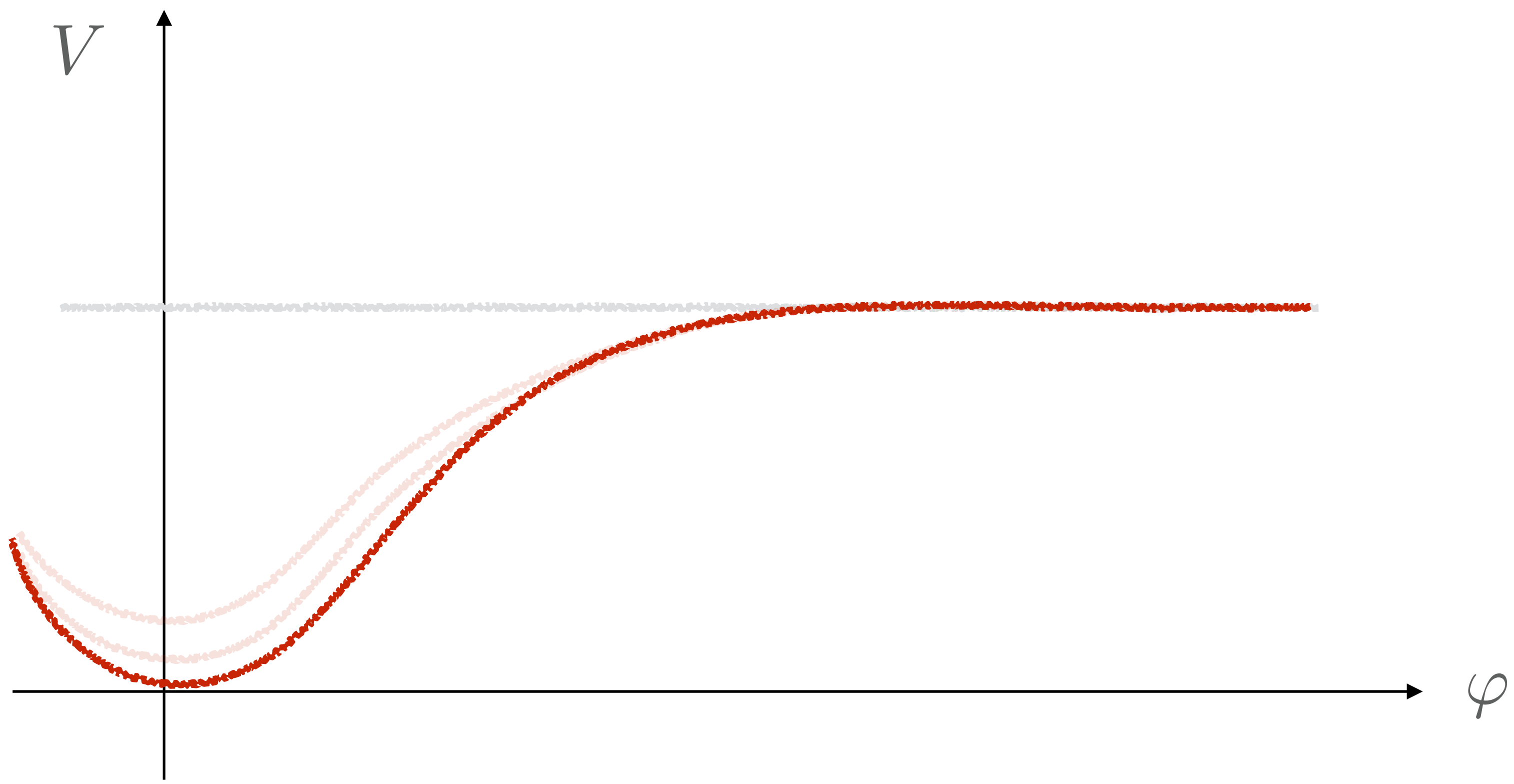
$f = \sum_{n=1}^{\infty} f_n |\Phi|^n \quad g = \sum_{n=1}^{\infty} g_n |\Phi|^n$ **small** perturbative corrections!

$$V = V_0 + V_1 \exp\left(-\sqrt{2/3\alpha}\,\varphi\right) + \ldots$$

$$V_0 = M^2 - 3W_0^2$$

# Hyperbolic Kähler geometry

*McDonough & MS 2016*

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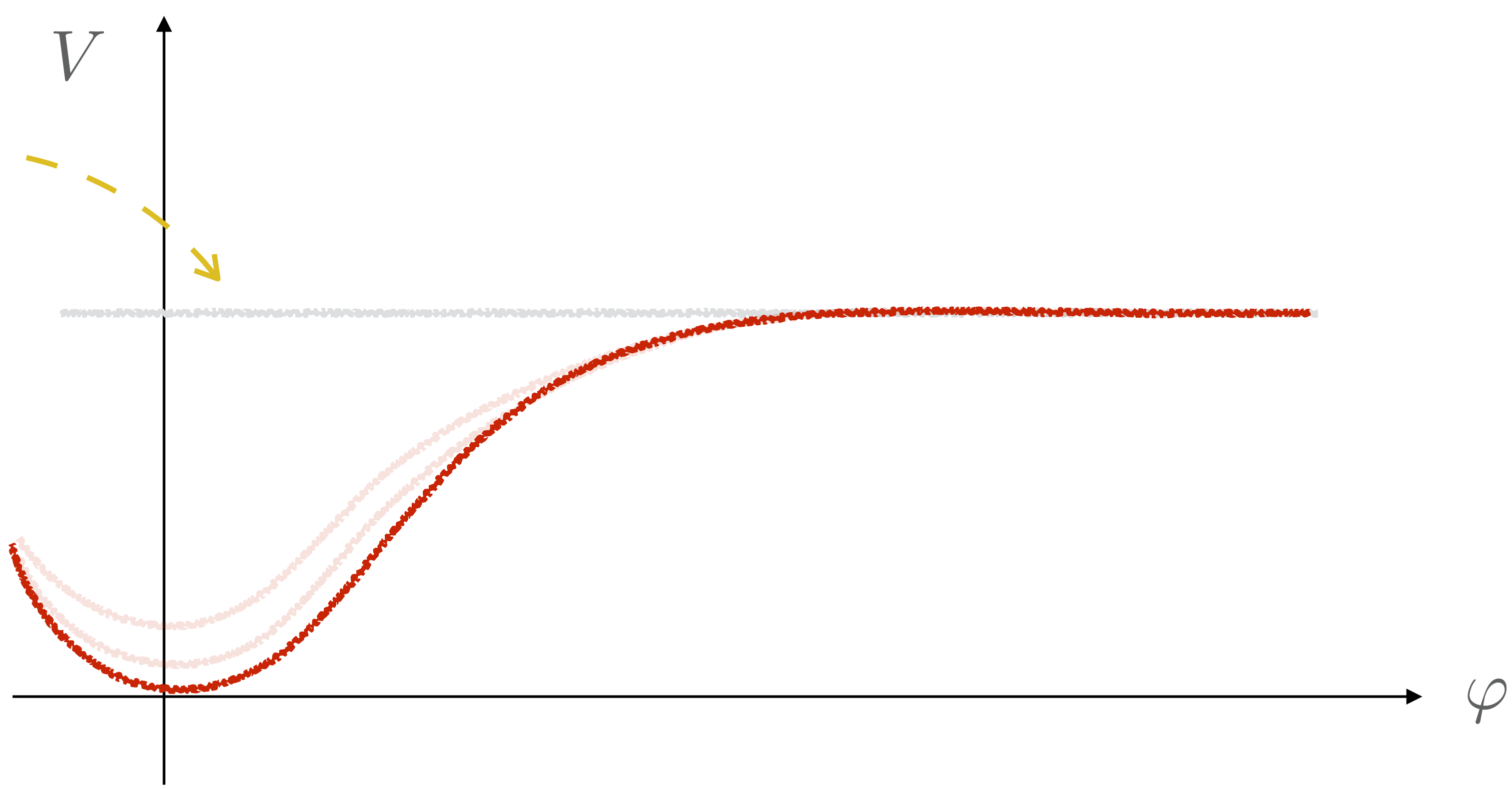


The anti-D3 brane provides the **Hubble inflationary energy**

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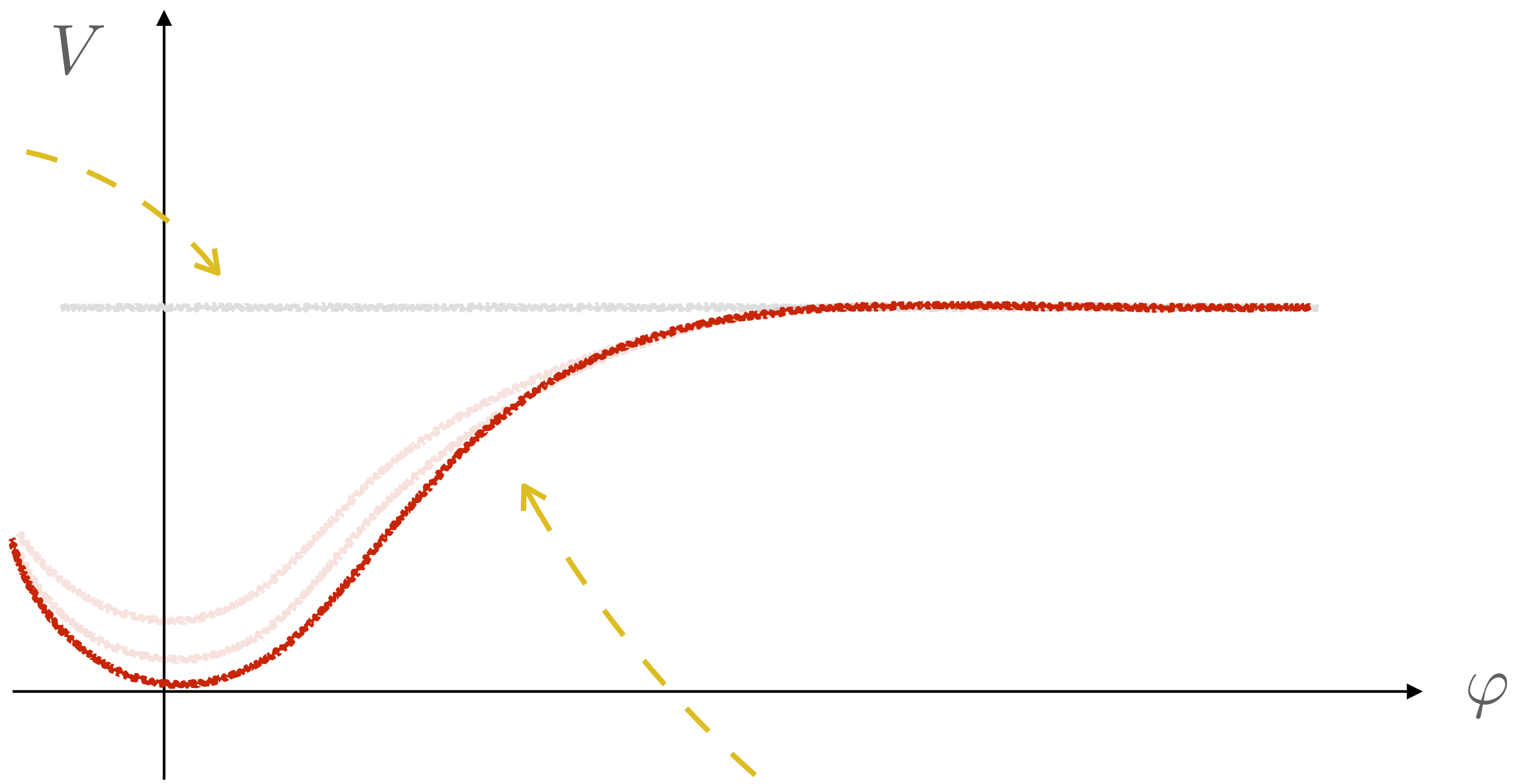



The anti-D3 brane provides the **Hubble inflationary energy**

The **Kähler corrections** provide the **exponential fall-off** from dS

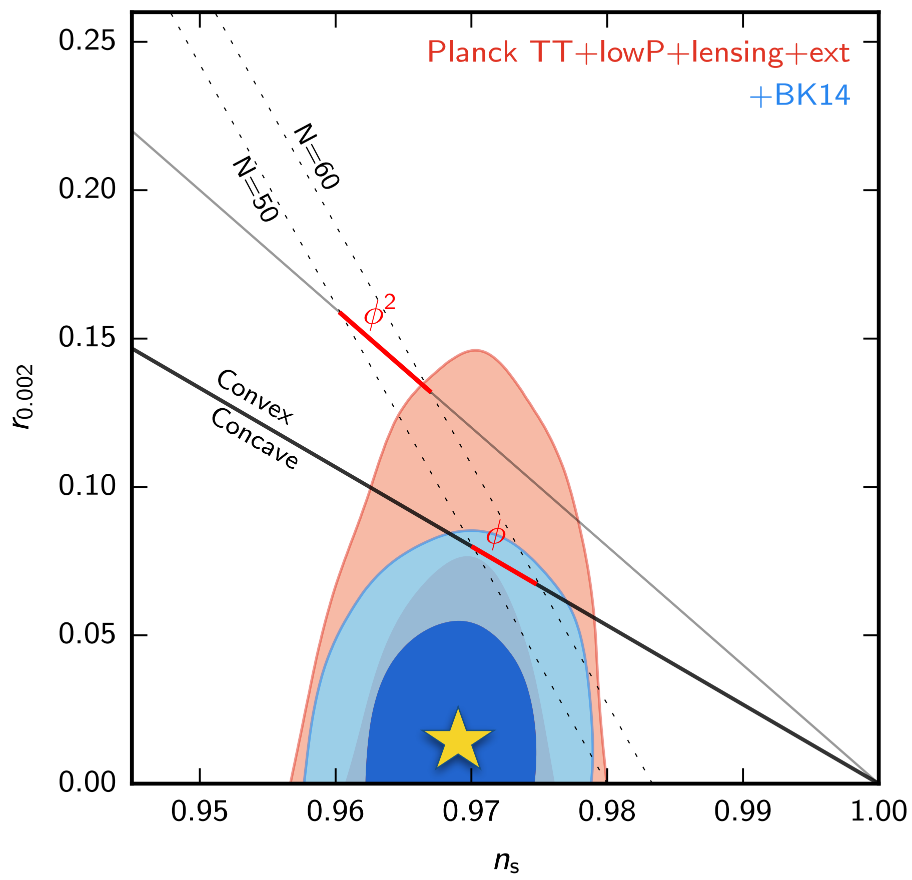
$$V = V_0 + V_1 \exp\left(-\sqrt{2/3\alpha}\;\varphi\right) + \ldots$$

$$V_0 = M^2 - 3W_0^2$$

Inflation happens at **small Kähler corrections**

# Hyperbolic Kähler geometry

*McDonough & MS 2016*




## α-attractors

$$n_s = 1 - \frac{2}{N} \qquad r = \frac{12\alpha}{N^2}$$

$$V = V_0 + V_1 \exp\left(-\sqrt{2/3\alpha}\ \varphi\right) + \dots$$

$$V_0 = M^2 - 3W_0^2$$

# Supersymmetry breaking scale

*McDonough & MS 2016*

$$V = M^2 F(\Phi) - 3W_0^2$$

$$m_{3/2} = W_0$$

$$F(\Phi) \equiv \frac{1}{1 + f(\Phi, \Phi)}$$

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***at the minimum***

$$\Lambda = M^2 F(0) - 3W_0^2$$

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**large** Kähler corrections

$$|f| \gg 1 \qquad |F| \ll 1$$

**small Gravitino mass**

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**large** Kähler corrections

$$|f| \gg 1 \qquad |F| \ll 1$$

**small Gravitino mass**

**small** Kähler corrections

$$|f| \ll 1 \qquad |F| \sim 1$$

$$M \geq H$$

**large Gravitino mass**

# Stability

McDonough & MS 2016

$$m^2_{\mathrm{Im}\Phi} = -4W_0^2 + 4M^2F(\Phi)$$

during inflation

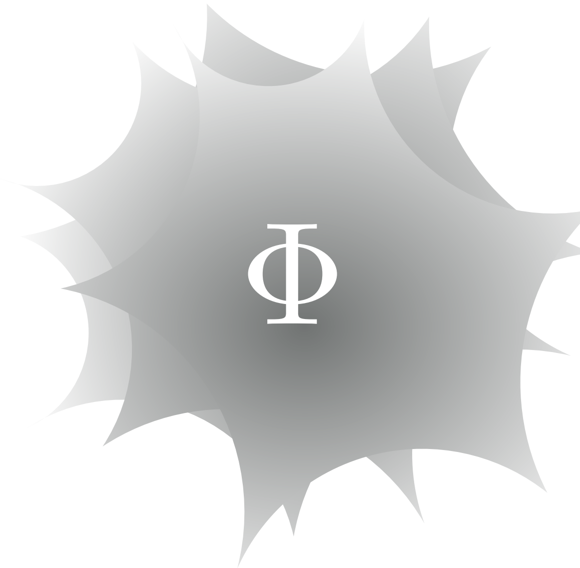
$$\frac{m^2_{\mathrm{Im}\Phi}}{H^2} = 12 + \frac{24W_0^2}{M^2F(\Phi) - 3W_0^2}$$

at the minimum

$$m^2_{\mathrm{Im}\Phi} = 8W_0^2 + 4\Lambda$$

## Recap-Cartoon

anti-brane

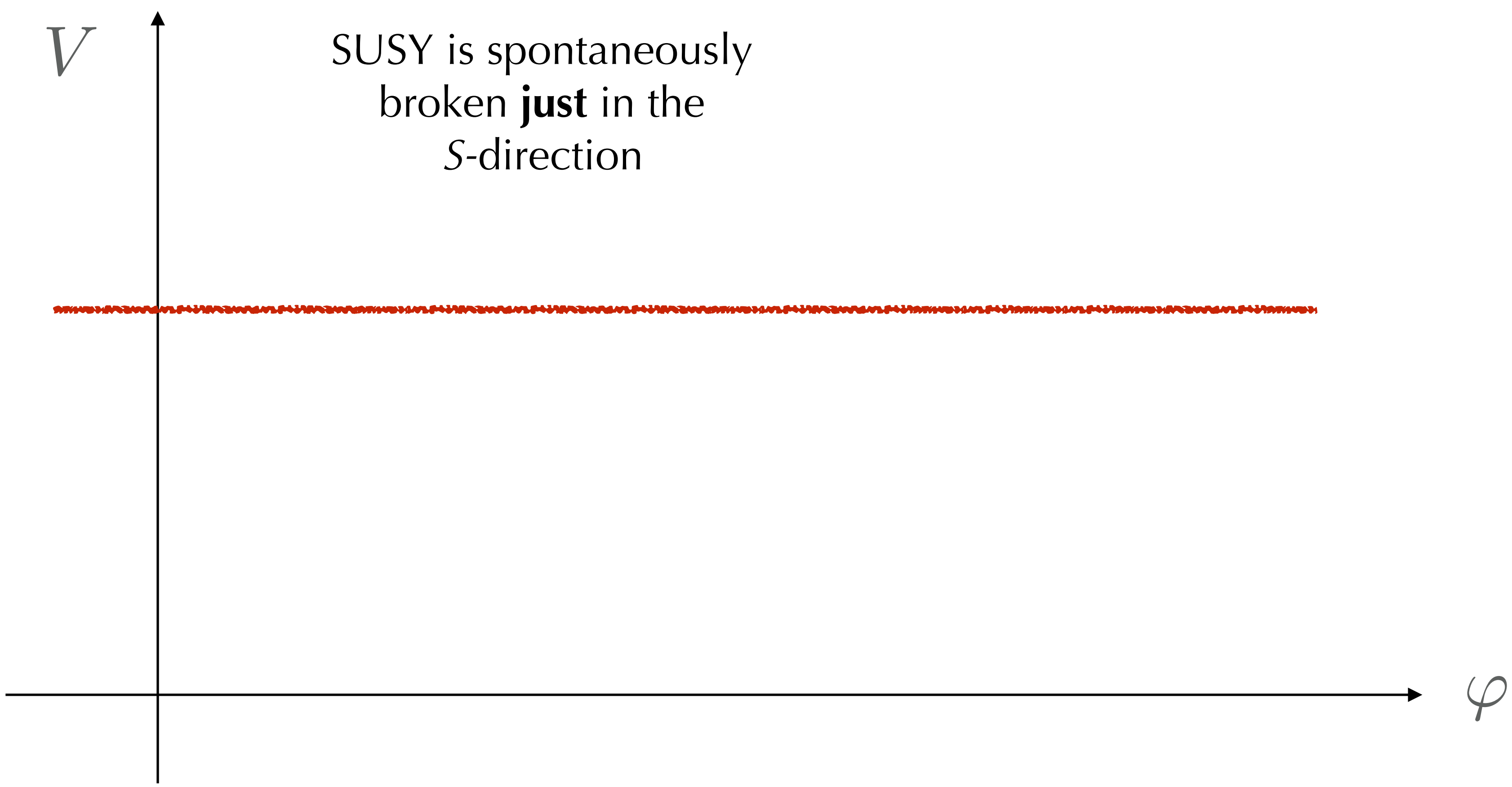

bulk geometry

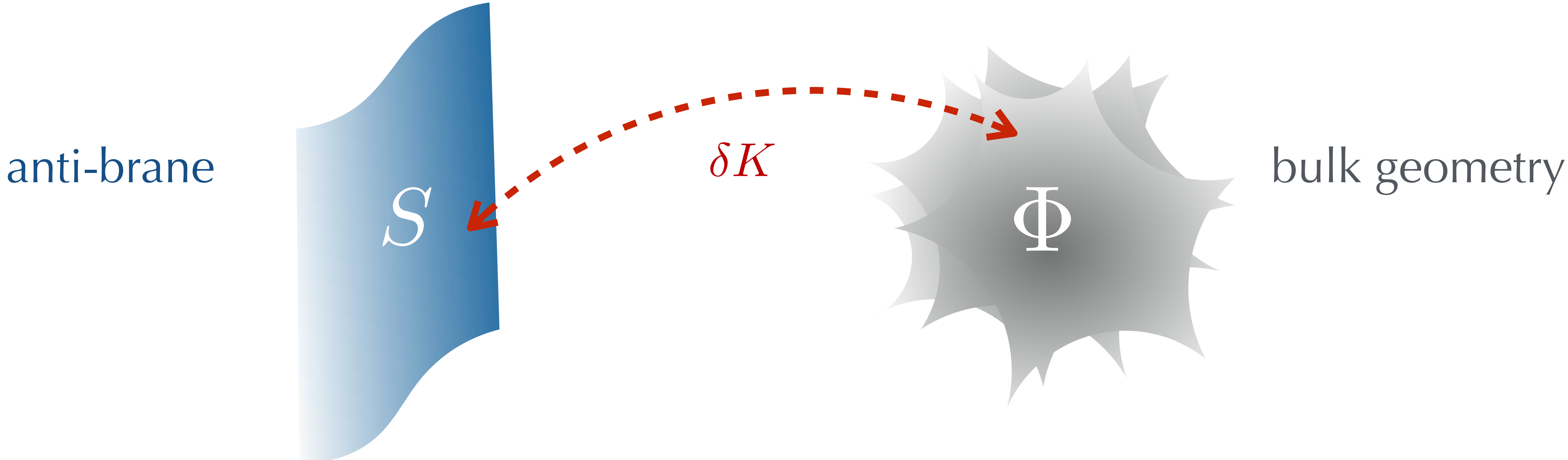
$$D_S W \neq 0$$

$$D_\Phi W = 0$$

pure de Sitter

SUSY is spontaneously broken **just** in the *S*-direction

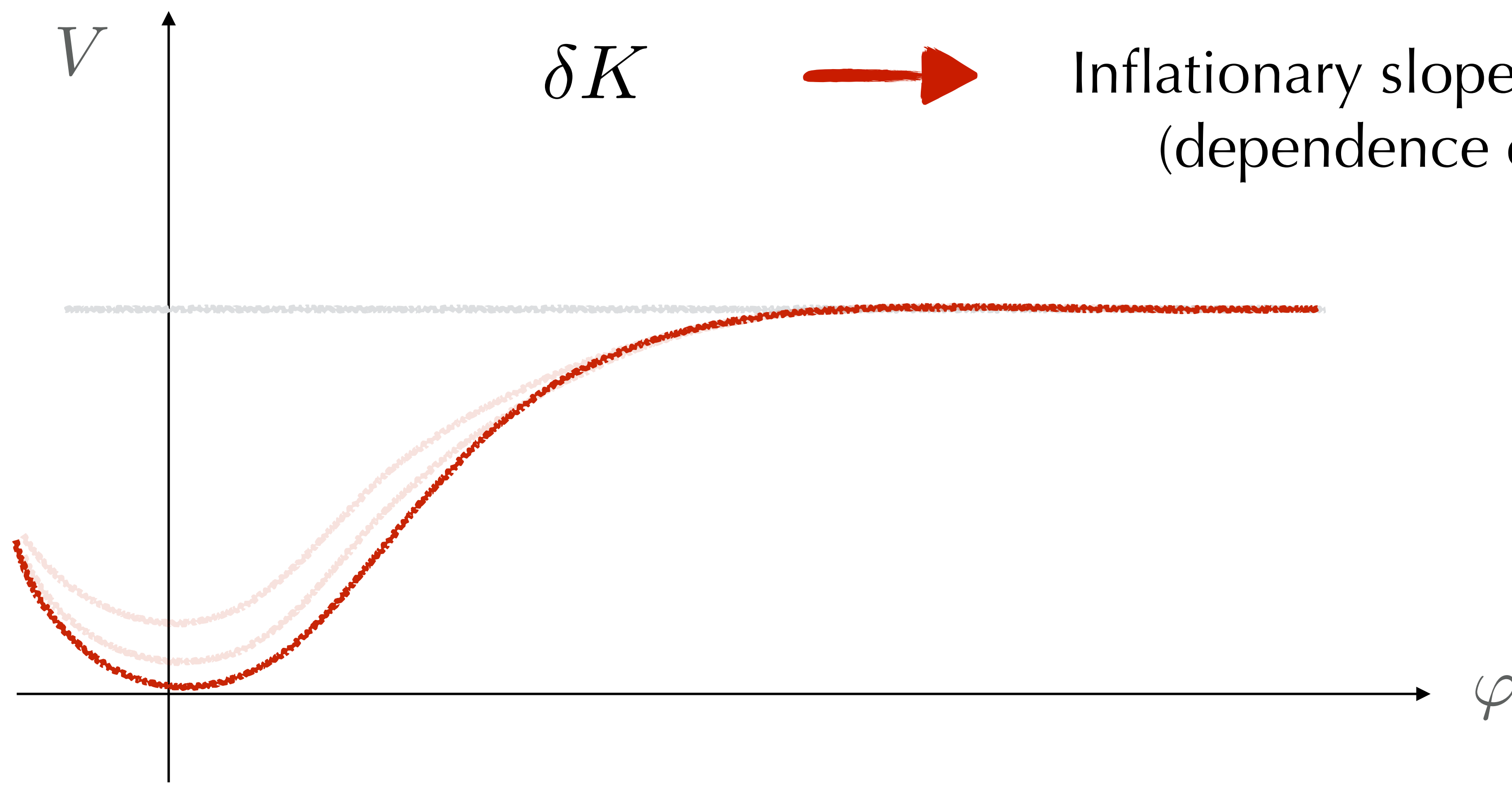




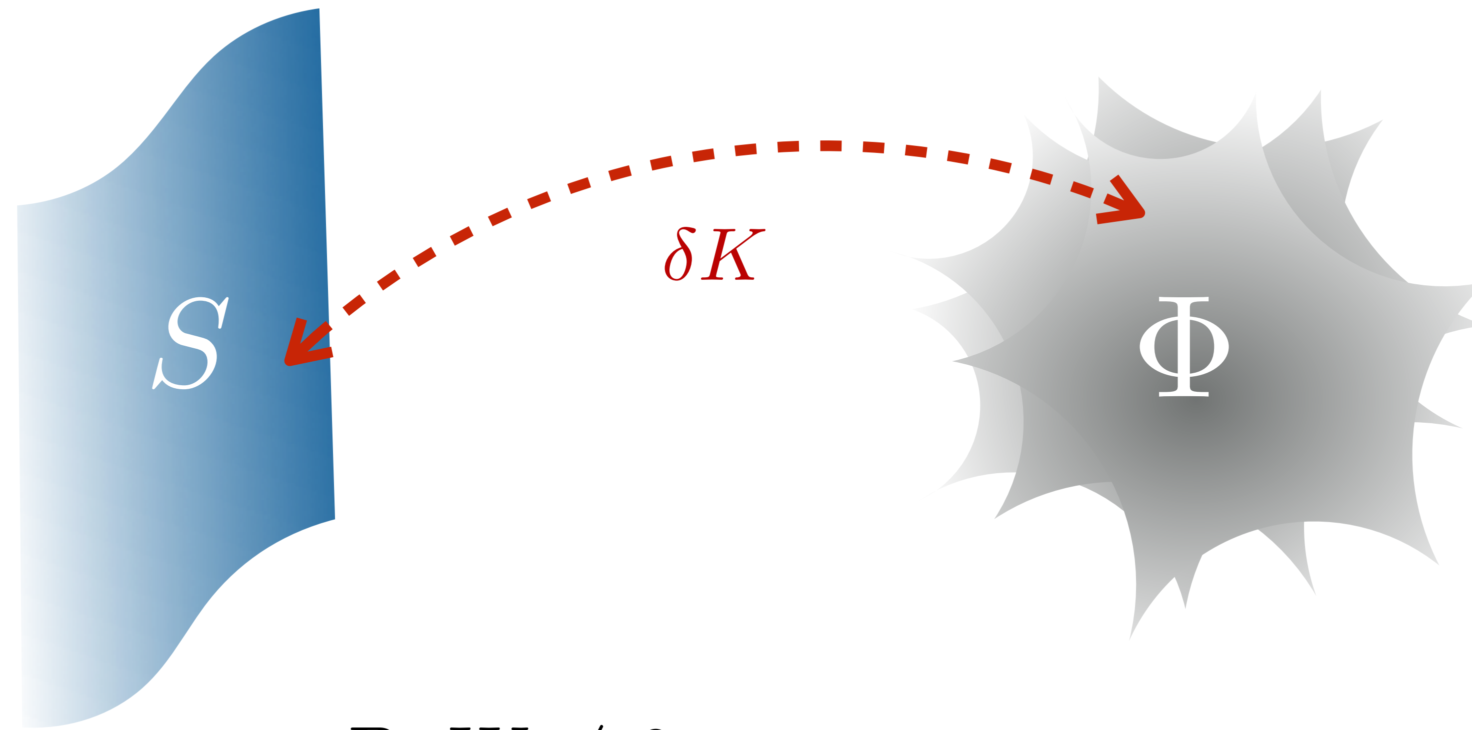

$D_S W \neq 0$ → Hubble inflationary energy

$D_\Phi W = 0$

$\delta K$ → Inflationary slope/dynamics (dependence on $\Phi$ )



anti-brane

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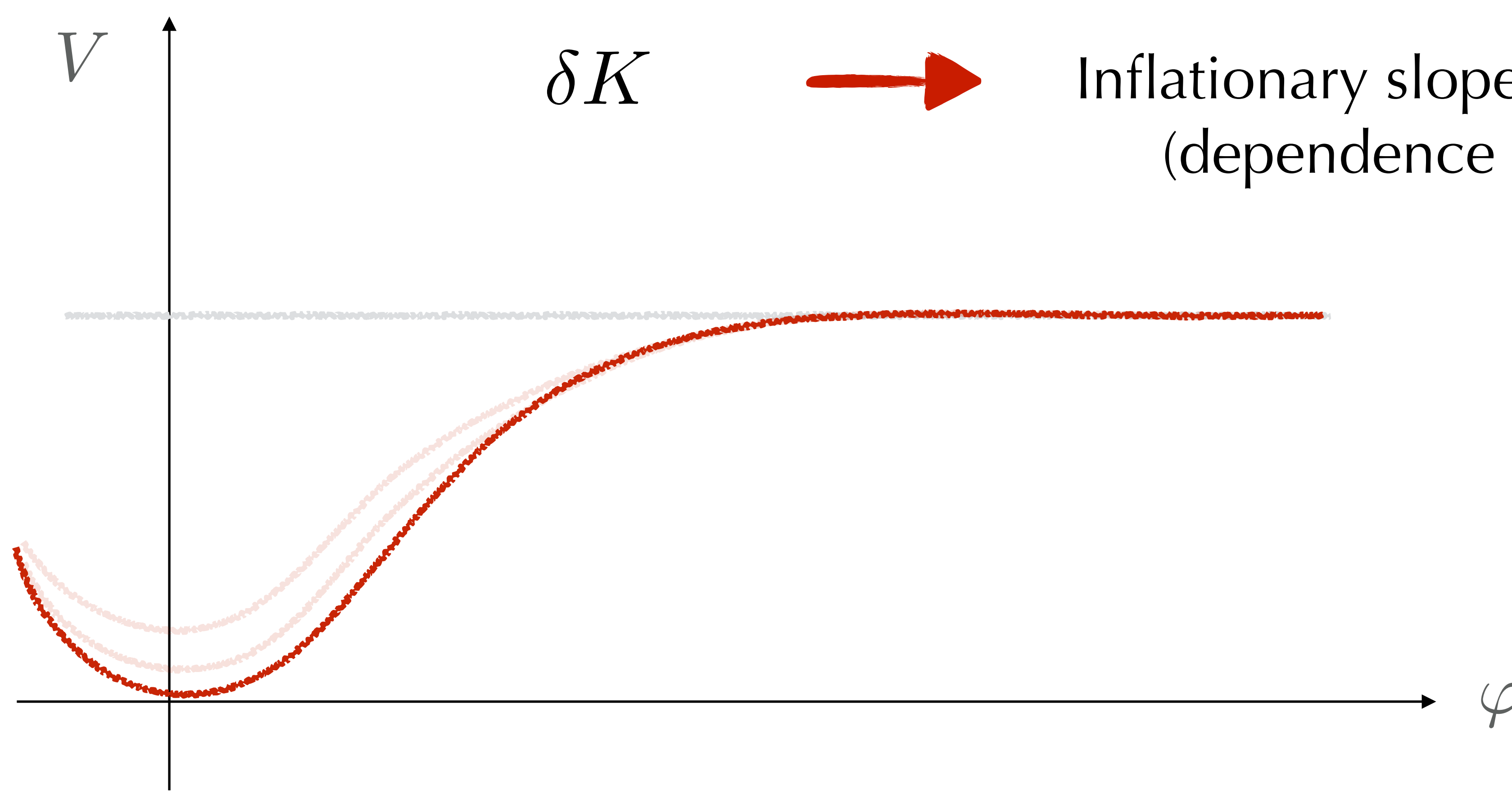
→ Hubble inflationary energy

$\delta K$ → Inflationary slope/dynamics (dependence on $\Phi$ )




thanks!