Where do we live in the string landscape?

Irene Valenzuela

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StringPheno, Liverpool, July 2022

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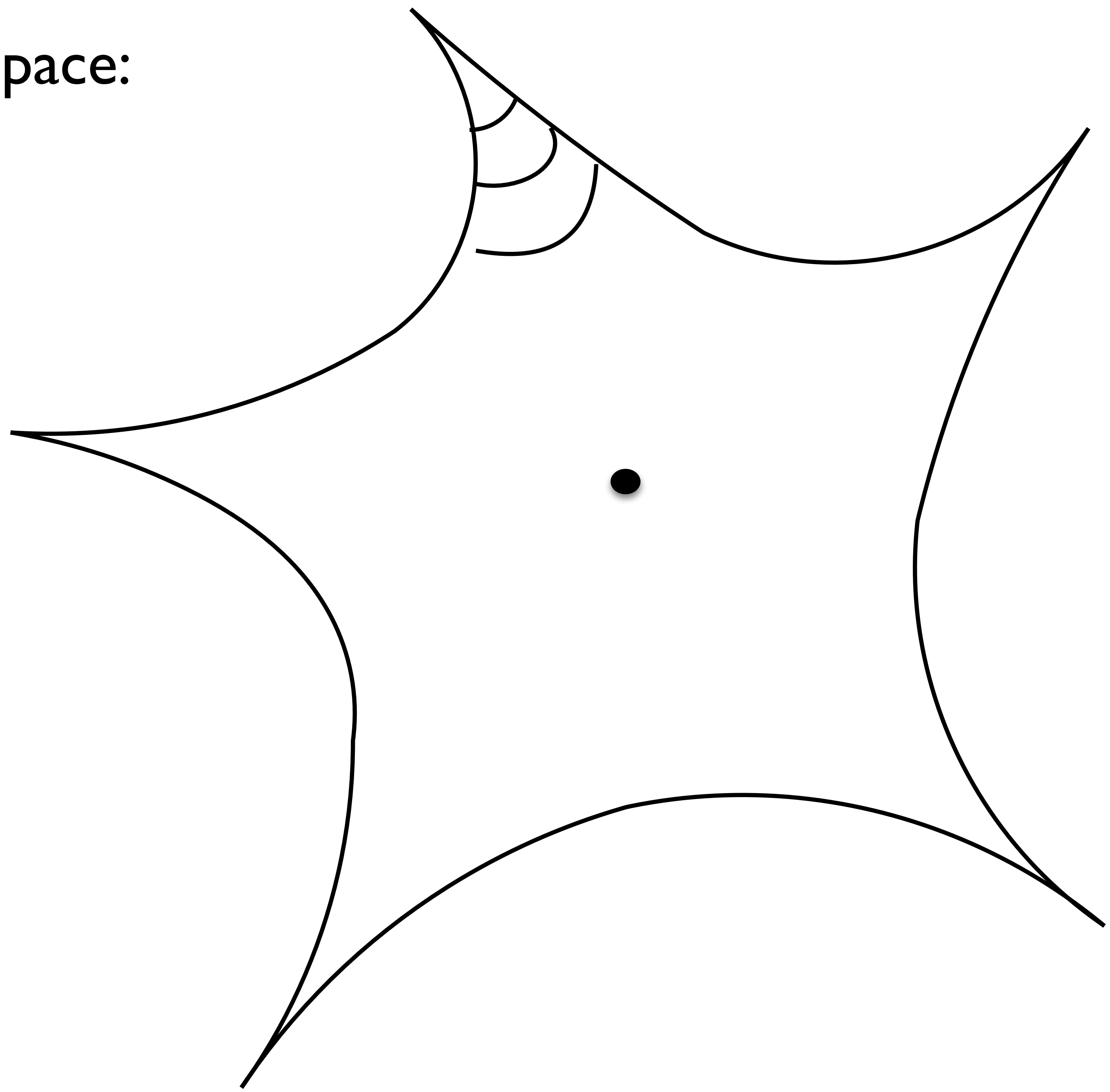
Scalar field space:



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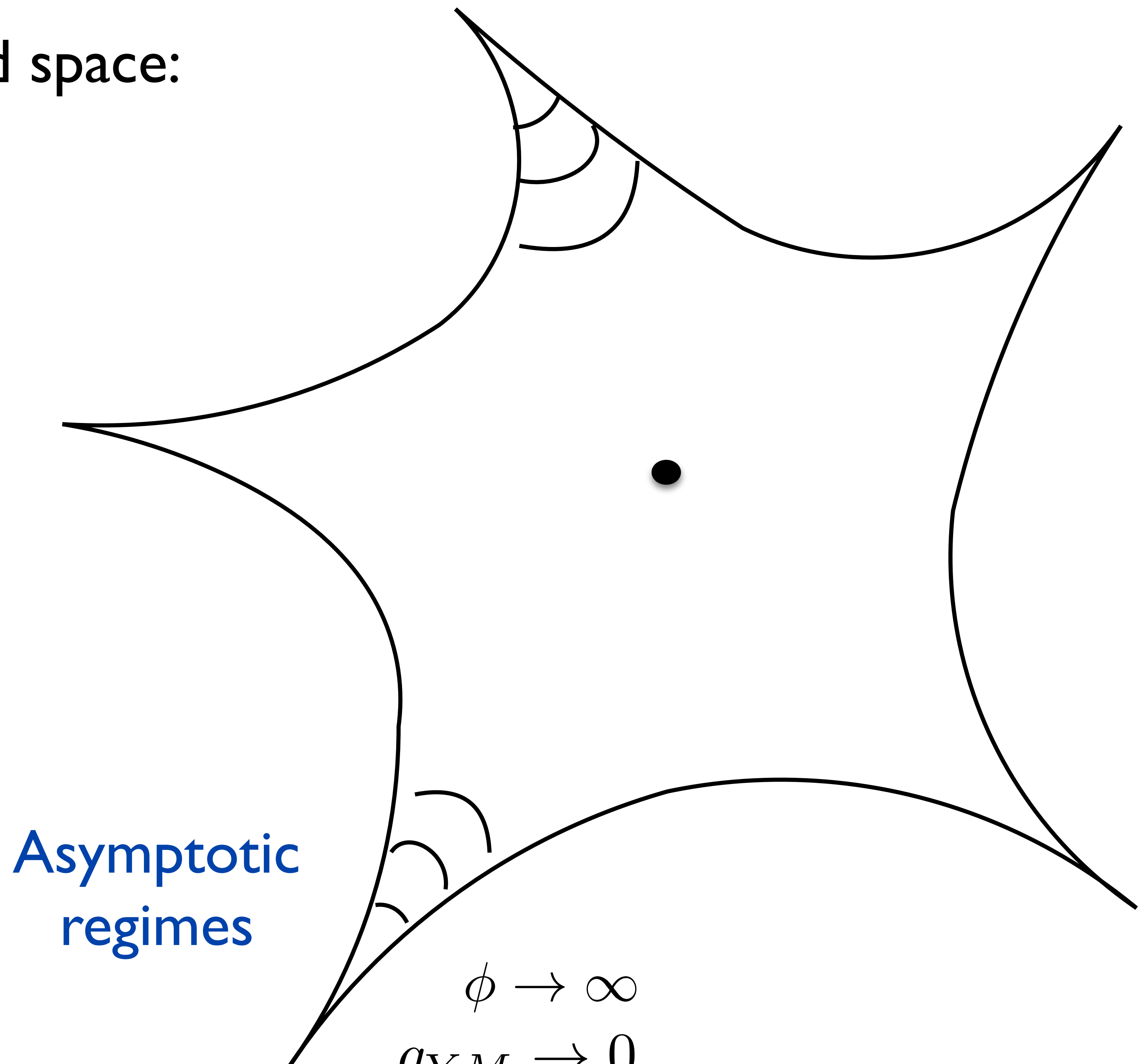

restores global symmetry

Could we live in an asymptotic limit?

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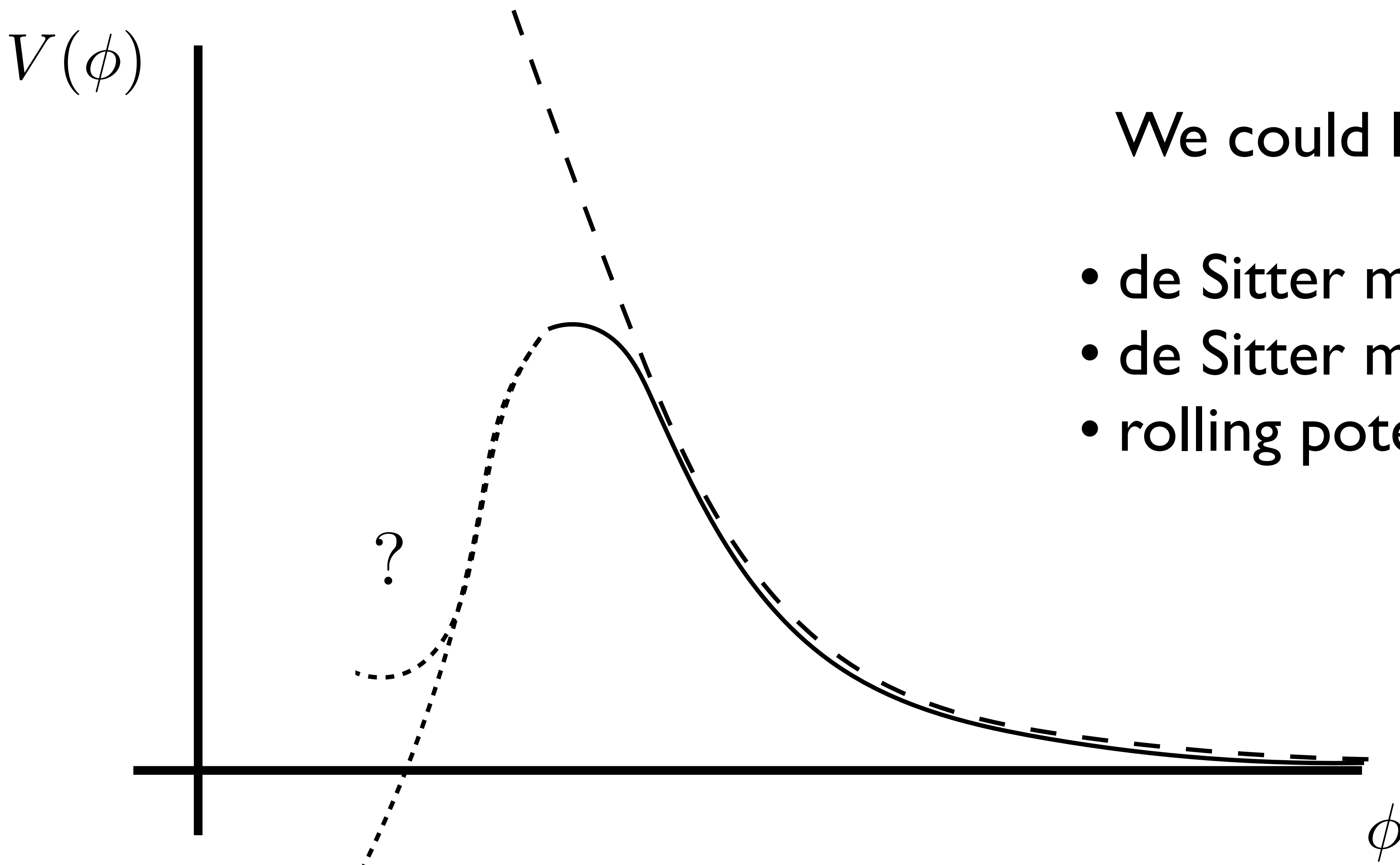
- Light states [Razamat,Tong'20] ✓
- Approximate global symmetries ✓
- Small cosmological constant: $V \to 0$ at infinite distance ✓
- Quantum gravity effects become important at scales much below Mp:

Opportunity to explain naturalness issues?

Could we live in an asymptotic limit?



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- de Sitter minima
- de Sitter maxima
- rolling potential (quintessence)

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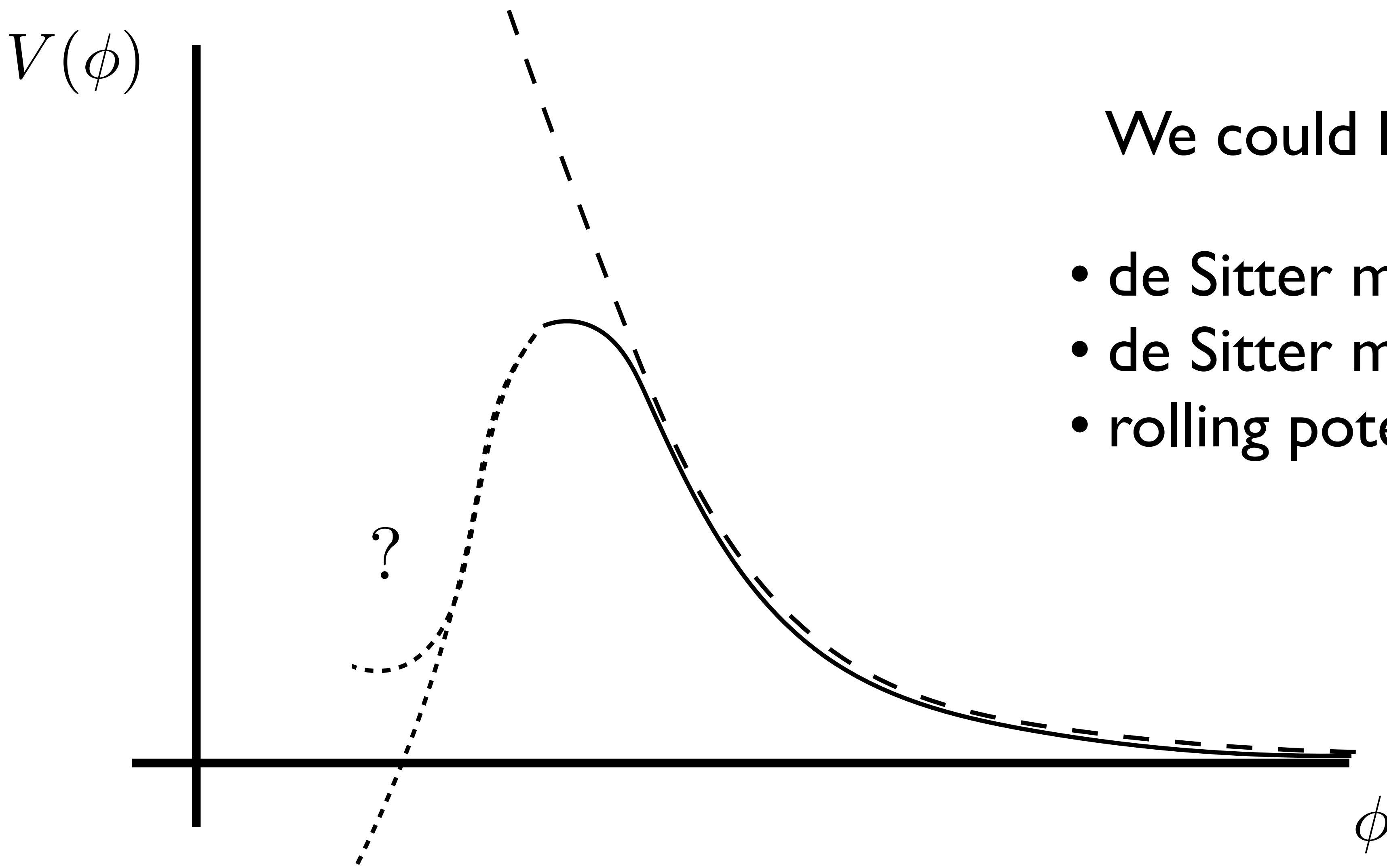

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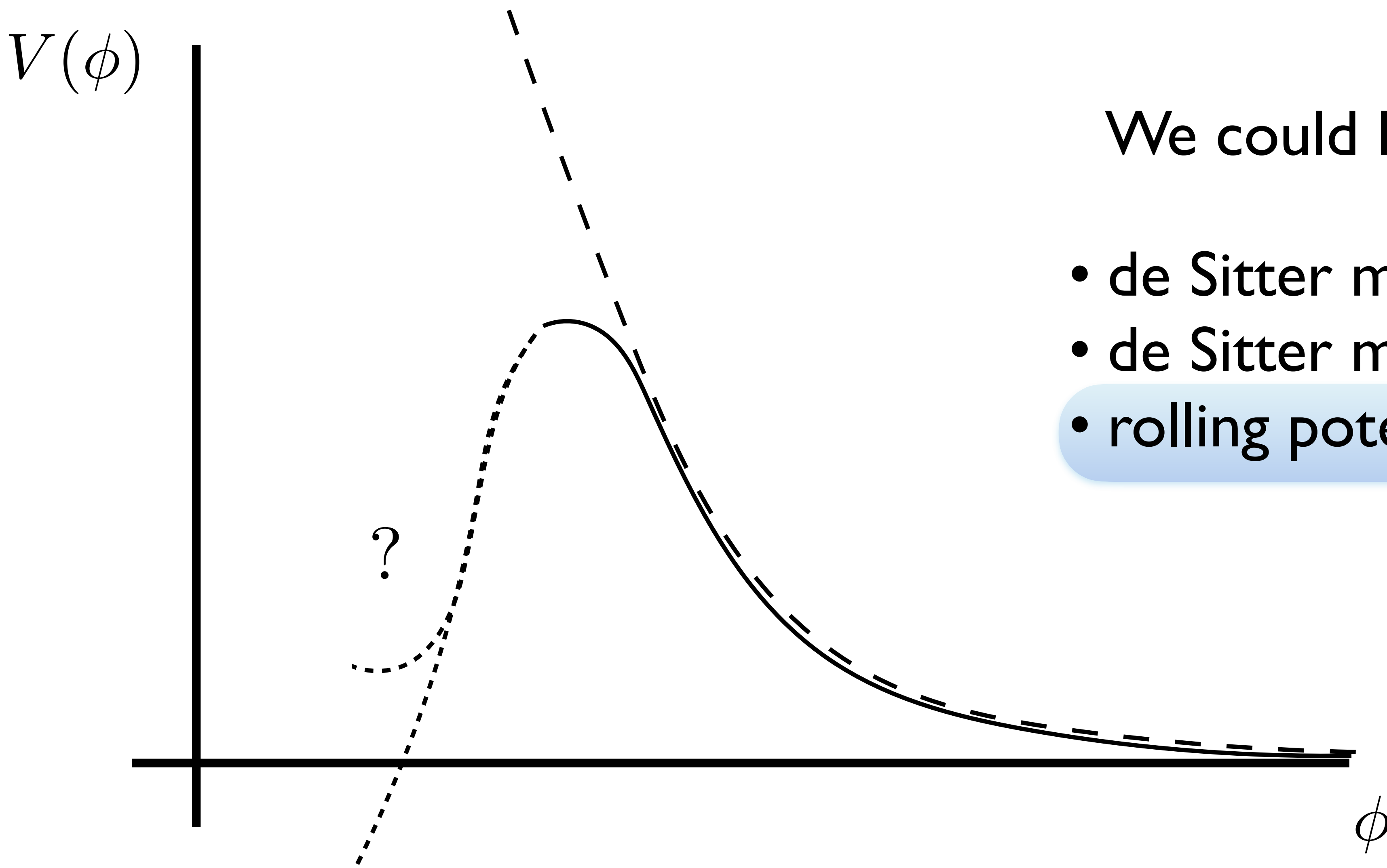

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First part of the talk

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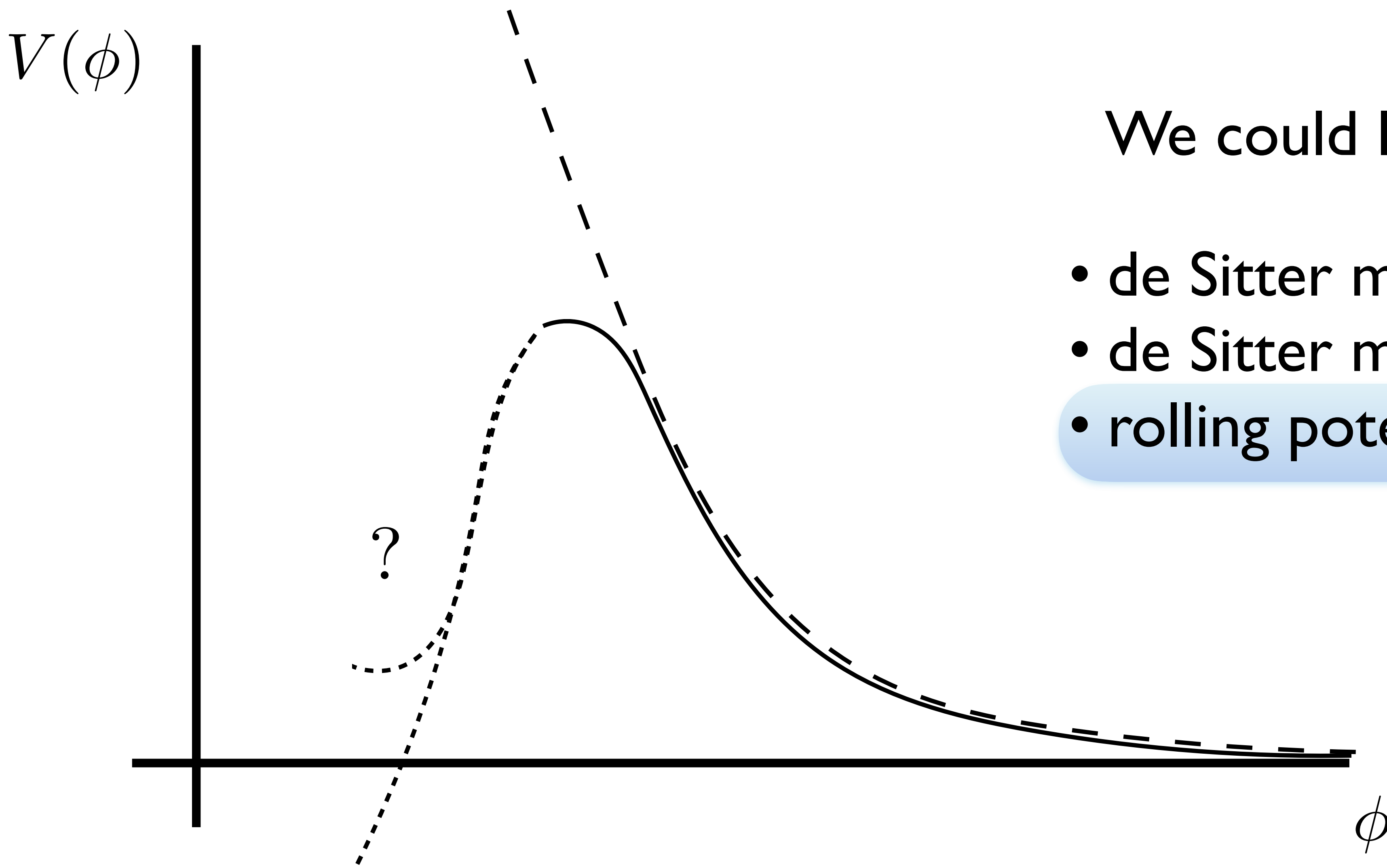

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Asymptotic Quintessence

$$S = \int d^d x \sqrt{-g} \left\{ \frac{R}{2} + \frac{1}{2} g^{\mu\nu} G_{ab} \partial_\mu \varphi^a \partial_\nu \varphi^b - V(\varphi) \right\}$$

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Universal asymptotic runaway behaviour of potential:

$$\frac{\|\nabla V(\varphi)\|}{V(\varphi)} \geq c_d \sim \mathcal{O}(1) \quad \text{as} \quad D(\varphi_0, \varphi(t)) = \int_{t_0}^{t} \sqrt{G_{ab} \varphi^{a\prime} \varphi^{b\prime}} dt \to \infty$$

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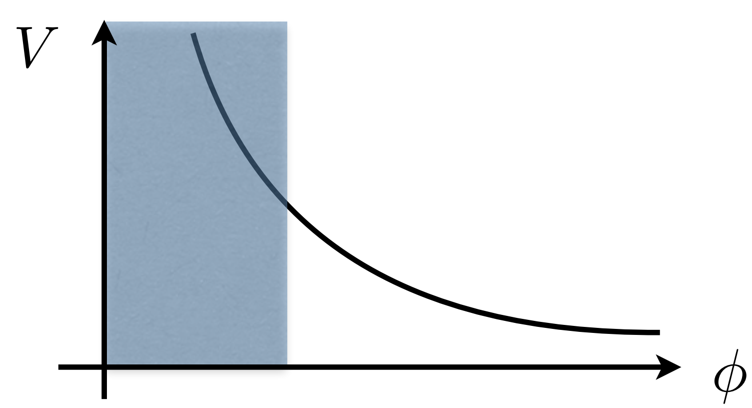

[Obied et al'18]

- Asymptotic dS conjecture [Ooguri et al'18]
- Generalization of Dine-Seiberg for any field space direction
- String theory evidence [Wrase,Junghans,Andriot… '18-19] [Grimm et al'19]

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Proposed Swampland bounds:

$$c_d^{\mathrm{TCC}} = \frac{2}{\sqrt{(d-1)(d-2)}}$$

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No accelerated expansion!

Can we have asymptotic accelerated expansion in string theory?

4d N=1 supergravities

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e.g. $V \propto \exp\left(-\gamma\phi\right)$ and $\mathcal{T} \propto \exp\left(-\gamma\phi/2\right)$

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A priori, no obstruction to get asymptotic accelerated expansion in SUGRA

Flux potentials in string theory

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This is just one corner of the landscape, many more types of asymptotic limits!

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Hodge Theory

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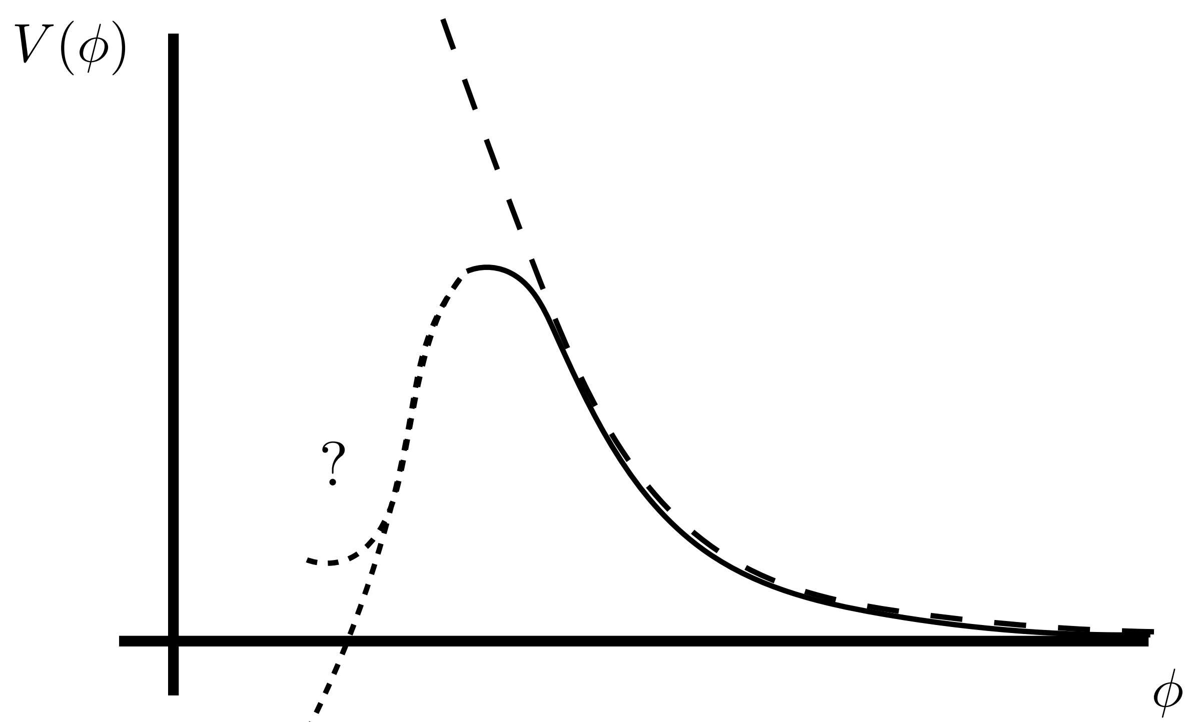
This is not enough to get accelerated expanison, since we are ignoring Kahler moduli stabilization

More work is needed!

Asymptotic limits

Still within asymptotic regime, it might be possible to get accelerated expansion during some time:



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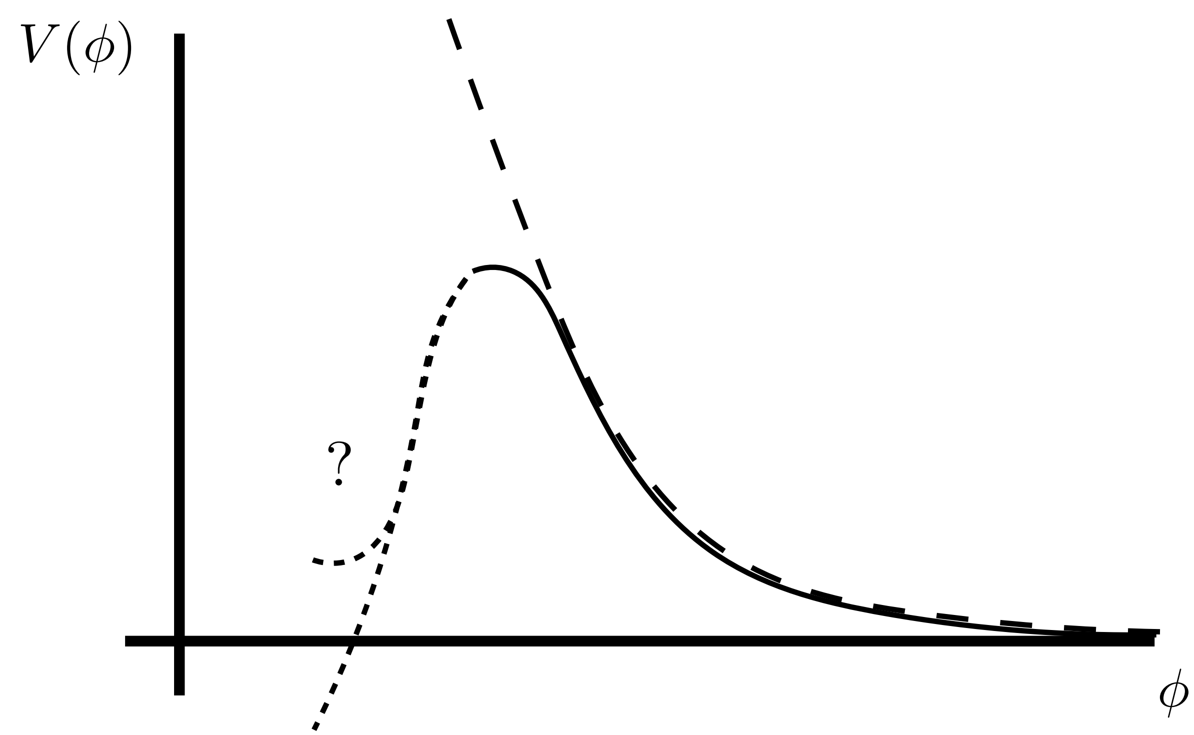

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Distance conjecture:

There is an infinite tower of states becoming light at every infinite distance limit:

$$m \sim m_0 e^{-\lambda \Delta\phi}$$

as $\Delta\phi \to \infty$

Evidence for Distance conjecture

Flat moduli spaces:

- String theory evidence [Grimm, Palti, IV'18] [Grimm,Palti,Li'18] [Lee,Lerche,Weigand'18-20] …

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$$S = \int d^4x\sqrt{-g}\left[R + 2|d\phi|^2 + \frac{1}{2g(\phi)^2}|F|^2\right] \quad \text{s.t.} \quad g(\phi)\to 0 \quad \text{as} \quad \phi\to\infty$$

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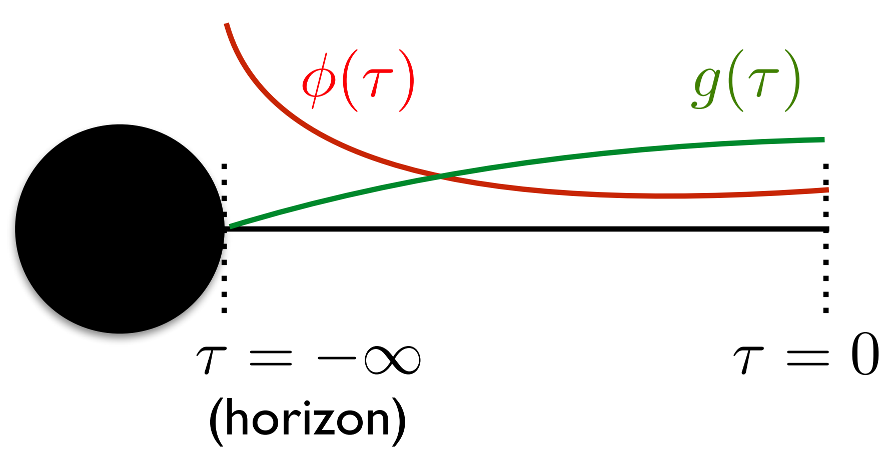
There are electrically charged BH solutions with classical zero area (small BHs):



$$A(-\infty)\to 0$$

large field range!
small gauge coupling!

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Small BHs lead to a violation of the entropy bound, unless the EFT cutoff $(|d\phi|^2 \sim \Lambda^2_{\text{cut-off}})$ decreases as dictated by the SDC / WGC

(so that they gain an effective area)

→ $\Lambda_{\text{cut-off}} \lesssim g M_p$ due to an infinite tower of states

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4d N=1 EFTS: [Lee et al'19] [Klaewer et al'20] **[Lanza,Marchesano,Martucci,IV'20-21]**

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Presence of a potential: strings attached to membranes

$$T_m \sim T_s^n \quad \rightarrow \quad V \sim m_{\text{tower}}^{\alpha} \qquad 2 \leq \alpha \leq 6$$

Relation between V and m

In all known string theory examples, it occurs that

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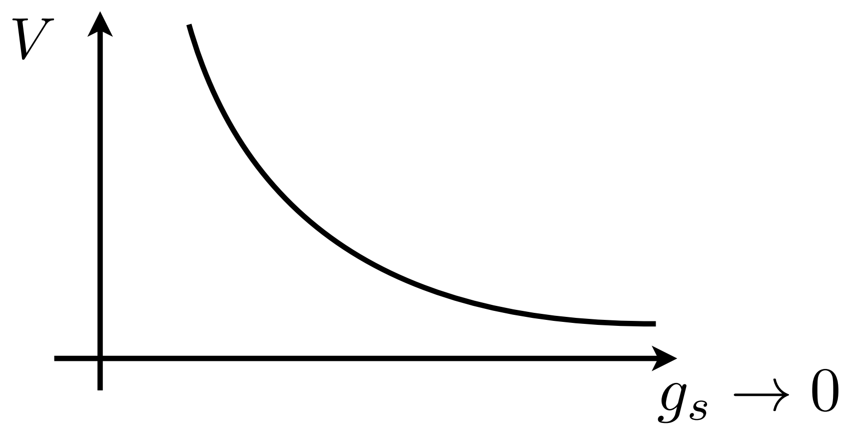
Supported by all families of AdS vacua when $V_0 \to 0$ (even DGKT)
[DeWolfe et al'05]

Non-SUSY example

SO(16)xSO(16) non-SUSY (tachyon-free) heterotic string theory:



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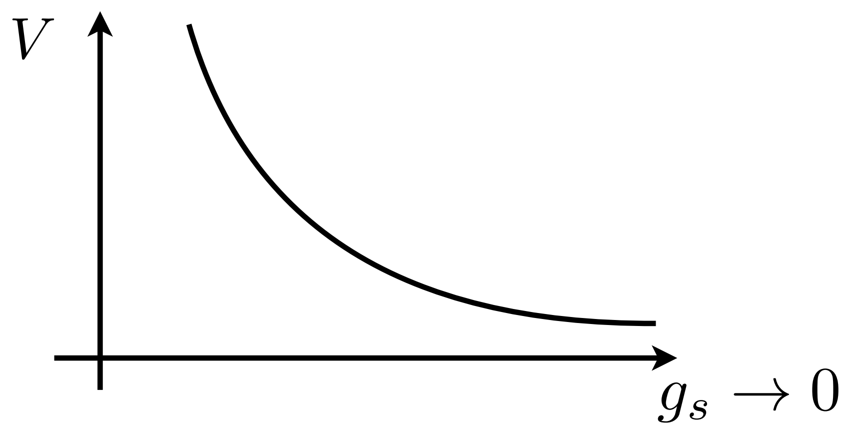

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Tower of string modes becoming light in the weak coupling limit

$$V_{\text{1-loop}} \sim -\sum_i (-1)^{F_i} \int_{\Lambda_{UV}^{-2}}^{\infty} \frac{ds}{s^6} \exp\left(-\frac{m_i^2 s}{2}\right)$$

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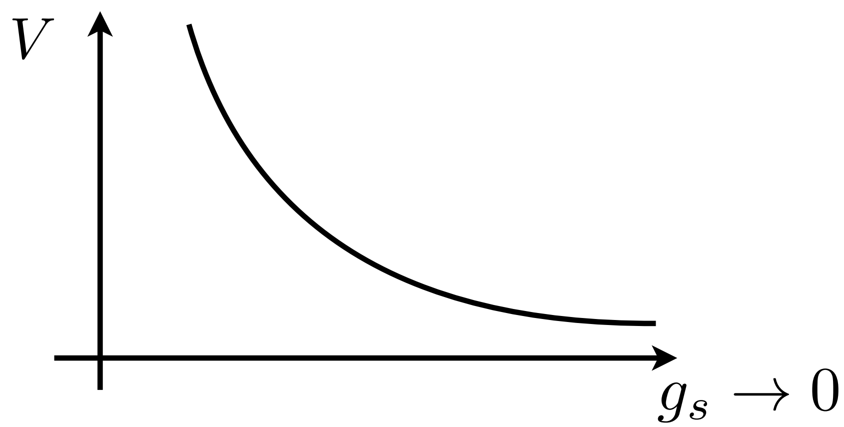

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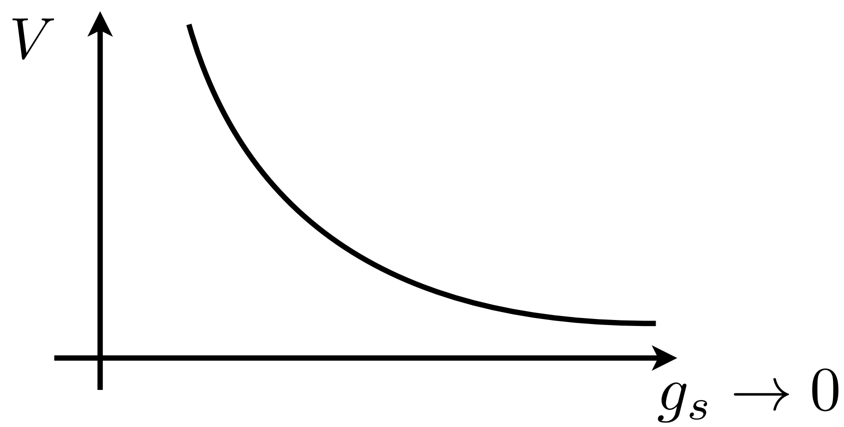

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Contribution of massive string excitations
is cut-off at Ms due to modular invariance

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Consistent with Light Fermion conjecture: [Gonzalo,Ibañez,IV'21]

If $V \geq 0$ there is a surplus of light fermions with $m \lesssim V^{1/d}$

(to avoid inconsistency of Casimir vacua with AdS swampland conjectures upon compactification of the theory)

Our universe

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implying one large extra dimension $l \sim 0.1 - 10\mu m$

The Dark Dimension [Montero,Vafa,IV'22]

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Thank you!

back-up slides

CFT Distance Conjecture

AdS_{d+1}/CFT_d with $d > 2$ [Perlmutter,Rastelli,Vafa,IV'20] (see also [Baume et al'20])

$\exists$ tower of HS with $\gamma_J \sim e^{-\alpha d(\tau,\tau')}$ as $d(\tau,\tau') \to \infty$ in the conformal manifold

Consequence: 3d conformal manifolds are compact

(measured by Zamolodchikov metric)

not proven (supported by all known examples)

[Maldacena,Zhiboedov'11]

Infinite distance ⇄ Free point ⇄ Higher Spin tower

proven in SCFTs $\quad g_{YM} \to 0 \quad$ proven in SCFTs

By perturbation theory:

Marginal operator: $\mathcal{O}_\tau = \mathrm{Tr}(F^2 + \ldots)$, $ds^2 = \beta^2 \dfrac{d\tau d\bar{\tau}}{(\mathrm{Im}\tau)^2}$ as $\mathrm{Im}\tau \to \infty$

$$\gamma_J \sim f(J) g_{YM}^2 \sim f(J) \exp\left(-\frac{d(\tau,\tau')}{\beta}\right)$$

$\tau = \frac{4\pi i}{g_{YM}^2} + \frac{\theta}{2\pi}$

It gives a lower bound for the exponential rate in Planck units!

$\beta^2 = 24\, \mathrm{dim}G$ → $\alpha = \sqrt{\dfrac{2c}{\mathrm{dim}G}}$

gauge group getting free

Status report of SDC

Asymptotically Minkowski compactifications:			Exponential behaviour of the tower mass	Tower populated by infinitely many states	Classification of limits
More than 8 supercharges: coset spaces					
8 supercharges	4d N=2 (Type II on CY3)	Vector multiplets			
		Hypermultiplets			
	5d/6d N=1 (M/F-theory on CY3)	Vector/tensor multiplets			
		Hypermultiplets			
4 supercharges: 4d N=1					
No supersymmetry					
Asymptotically AdS compactifications:					
Weak coupling points in d>3					
Other points					

Two moduli limits

Enhancements	Potential V_{M}
$\mathrm{I}_{0,\hat m-2},\ \mathrm{V}_{1,\hat m} \to \mathrm{V}_{1,\hat m-2}$	$\frac{c_1}{\tau}+\frac{c_2}{\rho^4}+\frac{c_3}{\rho^2}+c_4\rho^2+c_5\rho^4+c_6\tau-c_0$
$\mathrm{I}_{0,\hat m-2},\ \mathrm{V}_{1,\hat m-2} \to \mathrm{V}_{2,\hat m}$	$\frac{c_1}{\rho\tau}+\frac{c_2}{\rho^4}+\frac{c_3}{\rho^2}+\frac{c_4\rho}{\tau}+\frac{c_5\tau}{\rho}+c_6\rho^2+c_7\rho^4+c_8\rho\tau-c_0$
$\mathrm{I}_{1,\hat m},\ \mathrm{V}_{1,\hat m} \to \mathrm{V}_{2,\hat m}$	$\frac{c_1}{\tau^2}+\frac{c_2}{\rho^4}+\frac{c_3}{\rho^2}+c_4\rho^2+c_5\rho^4+c_6\tau^2-c_0$
$\mathrm{II}_{0,\hat m-2},\ \mathrm{IV}_{0,\hat m-2} \to \mathrm{V}_{2,\hat m}$	$\frac{c_1}{\rho^3\tau}+\frac{c_2}{\rho\tau}+\frac{c_3\rho}{\tau}+\frac{c_4\rho^3}{\tau}+\frac{c_5\tau}{\rho^3}+\frac{c_6\tau}{\rho}+c_7\rho\tau+c_8\rho^3\tau-c_0$
$\mathrm{I}_{0,\hat m-2},\ \mathrm{I}_{0,\hat m-4} \to \mathrm{I}_{1,\hat m-2}$ [a] $\mathrm{I}_{0,\hat m-2},\ \mathrm{II}_{0,\hat m-2} \to \mathrm{II}_{1,\hat m}$	$\frac{c_1}{\rho\tau}+\frac{c_2}{\rho}+\frac{c_3\rho}{\tau}+\frac{c_4\tau}{\rho}+c_5\rho+c_6\rho\tau-c_0$
$\mathrm{I}_{0,\hat m-2},\ \mathrm{I}_{1,\hat m} \to \mathrm{I}_{1,\hat m-2}$ [b] $\mathrm{I}_{0,\hat m-2},\ \mathrm{III}_{0,\hat m-2} \to \mathrm{III}_{0,\hat m-4}$ $\mathrm{I}_{1,\hat m},\ \mathrm{II}_{0,\hat m} \to \mathrm{II}_{1,\hat m}$	$\frac{c_1}{\tau}+\frac{c_2}{\rho^2}+c_3\rho^2+c_4\tau-c_0$
$\mathrm{I}_{0,\hat m-2},\ \mathrm{I}_{1,\hat m-2} \to \mathrm{I}_{2,\hat m}$ $\mathrm{I}_{0,\hat m-2},\ \mathrm{III}_{0,\hat m-4} \to \mathrm{III}_{1,\hat m-2}$	$\frac{c_1}{\rho\tau}+\frac{c_2}{\rho^2}+\frac{c_3\rho}{\tau}+\frac{c_4\tau}{\rho}+c_5\rho^2+c_6\rho\tau-c_0$
$\mathrm{I}_{0,\hat m-2} \Longrightarrow \mathrm{I}_{0,\hat m-4}$ $\mathrm{I}_{0,\hat m-2} \Longrightarrow \mathrm{II}_{0,\hat m-2}$ $\mathrm{II}_{0,\hat m} \Longrightarrow \mathrm{II}_{0,\hat m-2}$ $\mathrm{I}_{0,\hat m-2},\ \mathrm{II}_{0,\hat m} \to \mathrm{II}_{0,\hat m-2}$	$\frac{c_1}{\tau}+\frac{c_2}{\rho}+c_3\rho+c_4\tau-c_0$
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We compute leading behaviour of the flux induced scalar potential for the 46 possible asymptotic limits

$$\tau, \rho \to \infty$$

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$\mathrm{I}_{0,\hat{m}-2}$, $\mathrm{I}_{0,\hat{m}-4} \xrightarrow{a} \mathrm{I}_{1,\hat{m}-2}$	$\frac{c_1}{\rho\tau}+\frac{c_2}{\rho}+\frac{c_3\rho}{\tau}+\frac{c_4\tau}{\rho}+c_5\rho+c_6\rho\tau-c_0$
$\mathrm{I}_{0,\hat{m}-2}$, $\mathrm{II}_{0,\hat{m}-2} \rightarrow \mathrm{II}_{1,\hat{m}}$	
$\mathrm{I}_{0,\hat{m}-2}$, $\mathrm{I}_{1,\hat{m}} \xrightarrow{b} \mathrm{I}_{1,\hat{m}-2}$	$\frac{c_1}{\tau}+\frac{c_2}{\rho^2}+c_3\rho^2+c_4\tau-c_0$
$\mathrm{I}_{0,\hat{m}-2}$, $\mathrm{III}_{0,\hat{m}-2} \rightarrow \mathrm{III}_{0,\hat{m}-4}$	
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$\mathrm{I}_{0,\hat{m}-2} \Longrightarrow \mathrm{I}_{0,\hat{m}-4}$	$\frac{c_1}{\tau}+\frac{c_2}{\rho}+c_3\rho+c_4\tau-c_0$
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$\mathrm{I}_{0,\hat{m}-2} \Longrightarrow \mathrm{I}_{1,\hat{m}}$	$\frac{c_1}{\rho\tau}+\frac{c_2\rho}{\tau}+\frac{c_3\tau}{\rho}+c_4\rho\tau-c_0$
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$$\tau,\rho\to\infty$$

weak coupling + large volume limit in IIA

$$V_{\mathrm{M}}\sim\frac{1}{\mathcal{V}_4^3}\left(\sum_{p=0,2,4,6}\frac{A_{f_p}}{\rho^{p-3}\tau}+\sum_{q=0,1,2,3}\frac{A_{h_q}\tau}{\rho^{3-2q}}-A_{\mathrm{loc}}\right)$$

What is the value of the exponential rate?

- AdS_{d+1}/CFT_d with $d > 2$ [Perlmutter,Rastelli,Vafa,IV'20]

$$\alpha = \sqrt{\frac{2c}{\mathrm{dim}G}} \geq \frac{1}{\sqrt{3}} \quad \text{for 4d N=2}$$

$$\geq \frac{1}{2} \quad \text{for 4d N=1}$$

[Grimm, Palti, IV'18] [Gendler,IV'20]

- Lower bound for BPS states in CY compactifications: $\alpha \geq \frac{1}{\sqrt{2n}}$ for CY_n

$$K = -n \log \phi + \ldots$$

- 4D N=2 theories: $\alpha^2 \geq \left.\frac{Q^2_{\rm ext}}{T^2_{\rm ext}}\right|_{\rm BPS\,particles} - \frac{1}{2}$

- 4D N=1 theories: $\alpha \geq \frac{1}{2}\left.\frac{Q_{\rm ext}}{T_{\rm ext}}\right|_{\rm BPS\,string}$

→ bounded by scalar contribution to WGC/extremality bound!

[Lee,Lerche,Weigand'19] [Gendler,IV'20] [Bastian, Grimm,Van de Heisteeg'20]

- TCC $\alpha \geq \frac{1}{\sqrt{(d-2)(d-3)}}$ [Bedroya,Vafa'19] [Andriot et al'20]