Asymptotic limits in moduli space

Timm Wrase

LEHIGH UNIVERSITY

CTPU, IBS, Daejeon

July 3rd, 2023

Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

Outline

- Dark energy in asymptotic limits
- Type IIB compactification with $h^{1,1} = 0$
- Sharpened distance and strong asymp. dS conjecture

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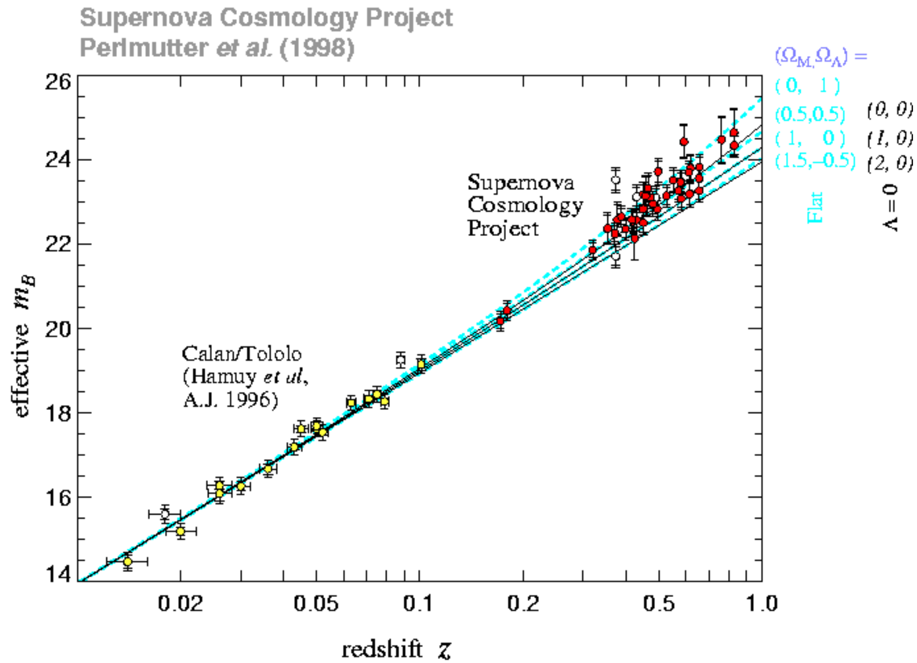
Accelerated expansion of our universe

In 1998 the *Supernova Cosmology Project* and the *High-Z Supernova Search Team* discovered accelerated expansion of our universe

Supernova Search Team collaboration astro-ph/9805201



Accelerated expansion of our universe

Discovery led to the 2011 Nobel Prize for

Saul Perlmutter, Adam Riess and Brian Schmidt

and lots of challenges for string theory…

The Acceleration of the Universe, a Challenge for String Theory

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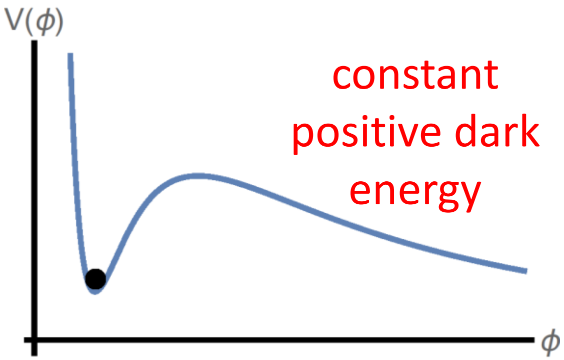
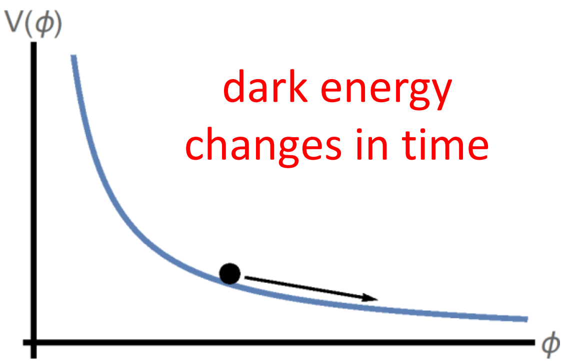
W. Fischler, A. Kashani-Poor, R. McNees, S. Paban,

String compactifications

Dark energy could be constant or time varying, e.g.,





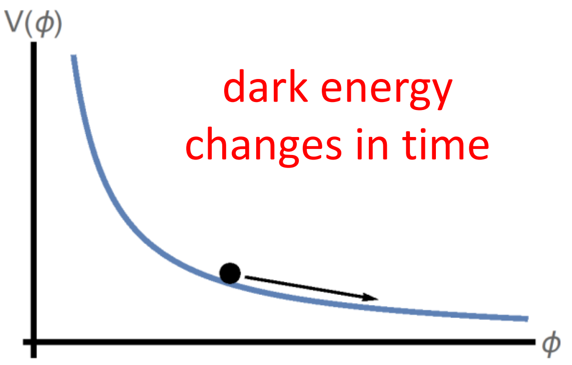
What about asymptotic limits $\phi \to \infty$?

String compactifications

Dine-Seiberg: Single scaling (term) dominates

Dine, Seiberg Phys. Lett. B 162 (1985) 299

No static solutions for $\phi \to \infty$?



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No static solutions for $\phi \to \infty$? Not necessarily correct!

Type IIA has fluxes that are unconstraint by tadpole, can send them to infinity, AdS vacua for $\phi \to \infty$!

DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160

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Not possible for dS vacua in type IIA

Junghans 1811.06990

Banlaki, Chowdhury, Roupec, TW 1811.07880

String compactifications

Quintessence was believed to be not really working

Recently reviewed

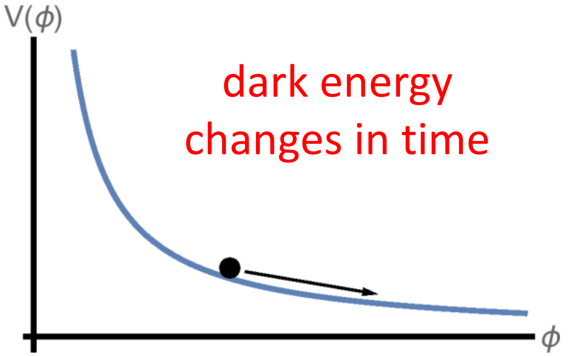
Cicoli, De Alwis, Maharana, Muia, Quevedo 1808.08967

Hebecker, Skrzypek, Wittner 1909.08625

Bento, Chakraborty, Parameswaran and Zavala 2005.10168

Brinkmann, Cicoli, Dibitetto, Pedro 2206.10649

Cicoli, Conlon, Maharana, Parameswaran, Quevedo, Zavala 2303.04819



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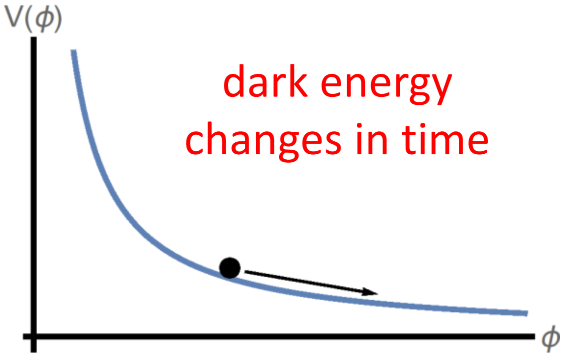
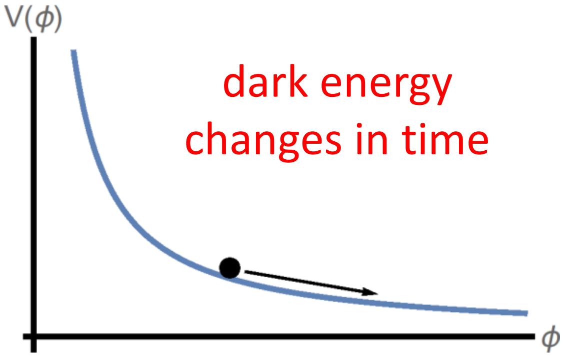
Unclear whether it is easier to get fully explicit models that are simpler than dS vacua



String compactifications

Asymptotically for any scalar field $\phi \to \infty$, we seem to generically find in string theory

$$V(\phi) \xrightarrow{\phi \to \infty} \Lambda\, e^{-\lambda\, \phi}$$



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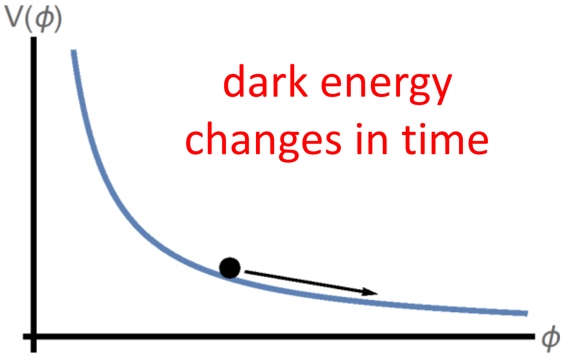
Can we get accelerated expasion in some asymptotic limits of string theory?



String compactifications

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$$V(\phi) \xrightarrow{\phi\to\infty} \Lambda\, e^{-\lambda\,\phi}$$

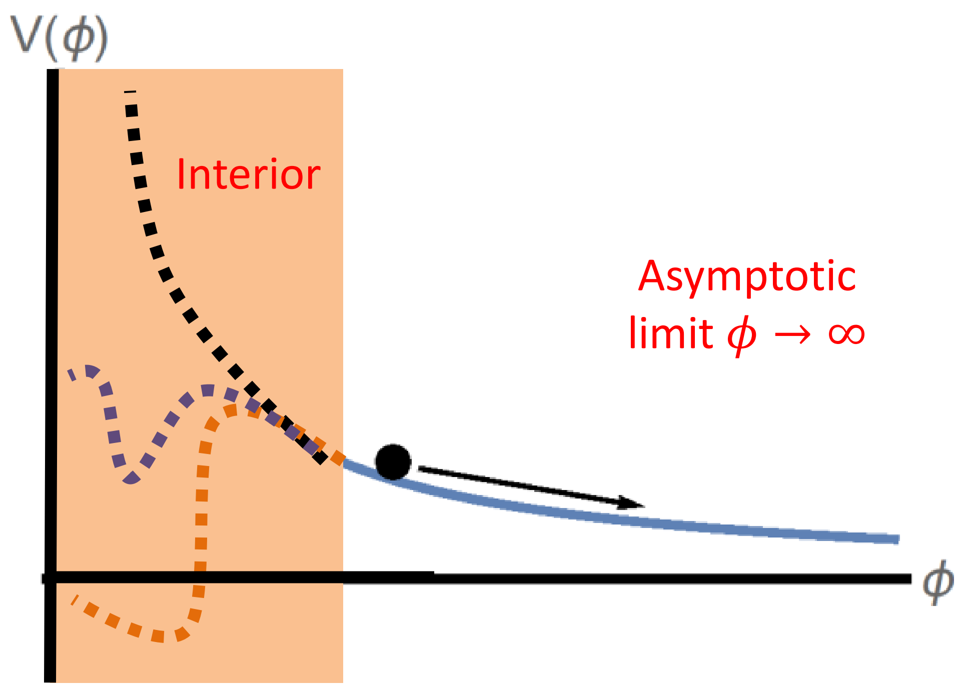
Note: We also have $\phi \to -\infty$

$$V(\phi) \xrightarrow{\phi\to-\infty} \Lambda\, e^{-\lambda\,\phi} \to \infty$$

EFT breaks down when $V \sim E_{cut-off}$

Asymptotic limits of field space

Asymptotic limits of moduli space (one scalar going to infinity) are easier to study



Asymptotic limits of field space

Asymptotic limits of moduli space have received a lot of attention recently:

Rudelius 2101.11617

Rudelius 2106.09026

Cicoli, Cunillera, Padilla, Pedro 2112.10779

Etheredge, Heidenreich, Kaya, Qiu, Rudelius 2206.04063

Rudelius 2208.08989

Calderon-Infante, Ruiz, Valenzuela 2209.11821

Marconnet, Tsimpis 2210.10813

Andriot, Horer, Tringas 2212.04517

Apers, Conlon, Mosny, Revello 2212.10293

Shiu, Tonioni, Tran 2303.03418

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Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

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Cremonini, Gonzalo, Rajaguru, Tang, TW	2306.15714

Asymptotic accelerated expansion with spatial curvature k=-1!

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Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

See Gary’s and Flavio’s talks

Asymptotic limits of field space

Best SUGRA limit cannot give rise to accelerated expansion in heterotic or type II on Calabi-Yau flux compactifications

Cicoli, Cunillera, Padilla, Pedro 2112.10779

parametric large volume $\Leftrightarrow$ no α'-corrections

parametric weak string coupling $\Leftrightarrow$ no loop correction

$$\Downarrow$$

No accelerated expansion in 4d

Asymptotic limits of field space

Asymptotic accelerated expansion for $V(\phi) \sim \ e^{-\lambda\, \phi}$ for

$$\lambda < \frac{2}{\sqrt{d-2}}$$

$$\epsilon = \epsilon_V = \frac{1}{2}\left|\frac{V'}{V}\right|^2 = \frac{\lambda^2}{2} = 1 \ \Leftrightarrow \ \ \lambda = \sqrt{2} \quad \text{in } \ d = 4$$

Asymptotic limits of field space

Asymptotic accelerated expansion for $V(\phi) \sim \ e^{-\lambda\,\phi}$ for

$$\lambda < \frac{2}{\sqrt{d-2}}$$

Generically in string theory examples

$$\lambda \geq \lambda_{min} = \frac{2}{\sqrt{d-2}}$$

Asymptotic limits of field space

The Strong Asymptotic dS Conjecture

Bedroya, Vafa 1909.11063
Rudelius 2208.08989

In any asymptotic limit of string theory:

$$\lambda \geq \lambda_{min} = \frac{2}{\sqrt{d-2}}$$

So, accelerated expansion would be forbidden in any asymptotic limit $\phi \to \infty$.

Asymptotic limits of field space

The Strong Asymptotic dS Conjecture

Bedroya, Vafa 1909.11063
Rudelius 2208.08989

For several scalar fields $\phi_1, \phi_2, \phi_3, \ldots$ we need to solve equations of motion and flow along the scalar potential gradient.

The Strong Asymptotic dS Conjecture states that there is no accelerated expansion along gradient flows.

Asymptotic limits of field space

Potential loopholes exist, if we send two scalar fields to infinity and have two competing terms

Calderon-Infante, Ruiz, Valenzuela 2209.11821

$$V(\phi_1, \phi_2) = \Lambda_1 e^{\lambda_{1,1}\phi_1 + \lambda_{1,2}\phi_2} + \Lambda_2 e^{\lambda_{2,1}\phi_1 + \lambda_{2,2}\phi_2}$$

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Choose a c such that

$$c\,\lambda_{1,1} + \lambda_{1,2} = c\,\lambda_{2,1} + \lambda_{2,2}$$

Then for $\phi_1 = c\,\sigma, \phi_2 = \sigma$ we have

$$V(\phi_1, \phi_2) = \Lambda_1 e^{(c\,\lambda_{1,1} + \lambda_{1,2})\,\sigma} + \Lambda_2 e^{(c\,\lambda_{2,1} + \lambda_{2,2})\,\sigma}$$

$$= (\Lambda_1 + \Lambda_2)\, e^{(c\,\lambda_{1,1} + \lambda_{1,2})\,\sigma}$$

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Then for $\phi_1 = c\,\sigma, \phi_2 = \sigma$ we have

$$V(\phi_1, \phi_2) = (\Lambda_1 + \Lambda_2)\, e^{(c\,\lambda_{1,1} + \lambda_{1,2})\sigma}$$

Gradient flow $\sigma \to \infty$ give in some cases

$$c\,\lambda_{1,1} + \lambda_{1,2} < \lambda_{min}$$

Asymptotic limits of field space

Potential loopholes exist, if we send two scalar fields to infinity and have two competing terms

Calderon-Infante, Ruiz, Valenzuela 2209.11821

Caveat: A third universal scalar!

$$V(\phi_1, \phi_2) = e^{-\sqrt{6}\,\phi_{vol}}(\Lambda_1 + \Lambda_2)\, e^{(c\,\lambda_{1,1}+\lambda_{1,2})\sigma}$$

Gradient flow also involves rolling along ϕ_{vol}! Too steep!

Can one remove or stabilize ϕ_{vol}?

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- Dark energy in asymptotic limits
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- Sharpened distance and strong asymp. dS conjecture

Asymptotic limits of field space

We study string compactifications without volume moduli

Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

Landau-Ginzburg $1^9/\mathbb{Z}_3$ model, $\mathbb{Z}_3$ is a quantum symmetry fixes/removes Kähler moduli: $h^{1,1} = 0$!

Becker, Becker, Vafa, Walcher hep-th/0611001

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See talk by
Muthusamy Rajaguru
on Thursday at 5pm!

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Restricting to the bulk moduli: τ, U_1, U_2, U_3

$$K = -4\log(\tau - \bar{\tau}) - \log[(-i)^3 (U_1 - \overline{U_1})(U_2 - \overline{U_2})(U_3 - \overline{U_3})]$$

$$\begin{aligned} W = &(f^0 - \tau h^0)U_1U_2U_3 - (f^1 - \tau h^1)U_2U_3 - (f^2 - \tau h^2)U_1U_3 \\ &-(f^3 - \tau h^3)U_1U_2 - (f_1 - \tau h_1)U_1 - (f_2 - \tau h_2)U_2 \\ &-(f_3 - \tau h_3)U_3 - (f_0 - \tau h_0) \end{aligned}$$

16 flux parameters

Asymptotic limits of field space

We study string compactifications without volume moduli

Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

Checked all possible gradient flows in this model with four scalar fields, 16 flux parameters

Asymptotic limits of field space

We study string compactifications without volume moduli

Cremonini, Gonzalo, Rajaguru, Tang, TW   2306.15714

Checked all possible gradient flows in this model with four scalar fields, 16 flux parameters

Could not reproduce loophole and never found accelerated expansion.

Strong Asymptotic dS Conjecture survives
in non-geometric string theory models

Asymptotic limits of field space

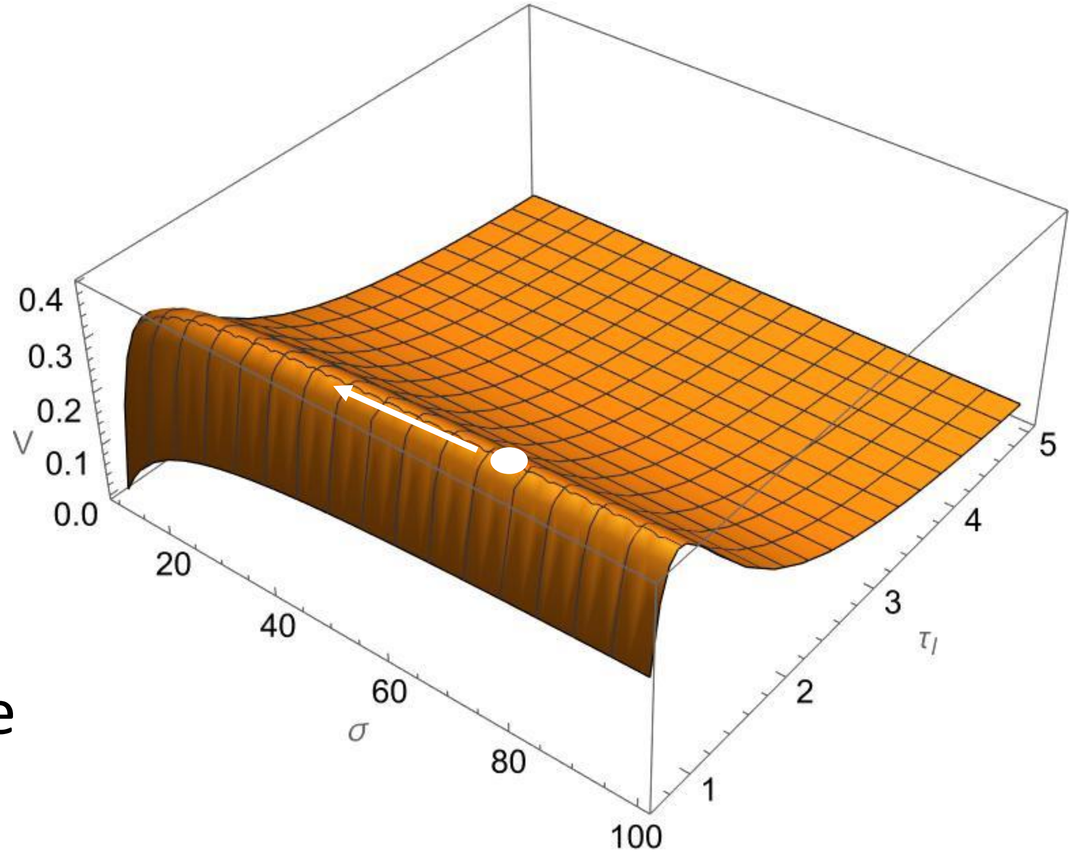
Interesting asymptotic limits

Cremonini, Gonzalo, Rajaguru, Tang, TW 2306.15714

Asymptotic ridges

$V \to const. > 0$

Unstable, gradient flow away from large σ to interior of moduli space



Asymptotic limits of field space

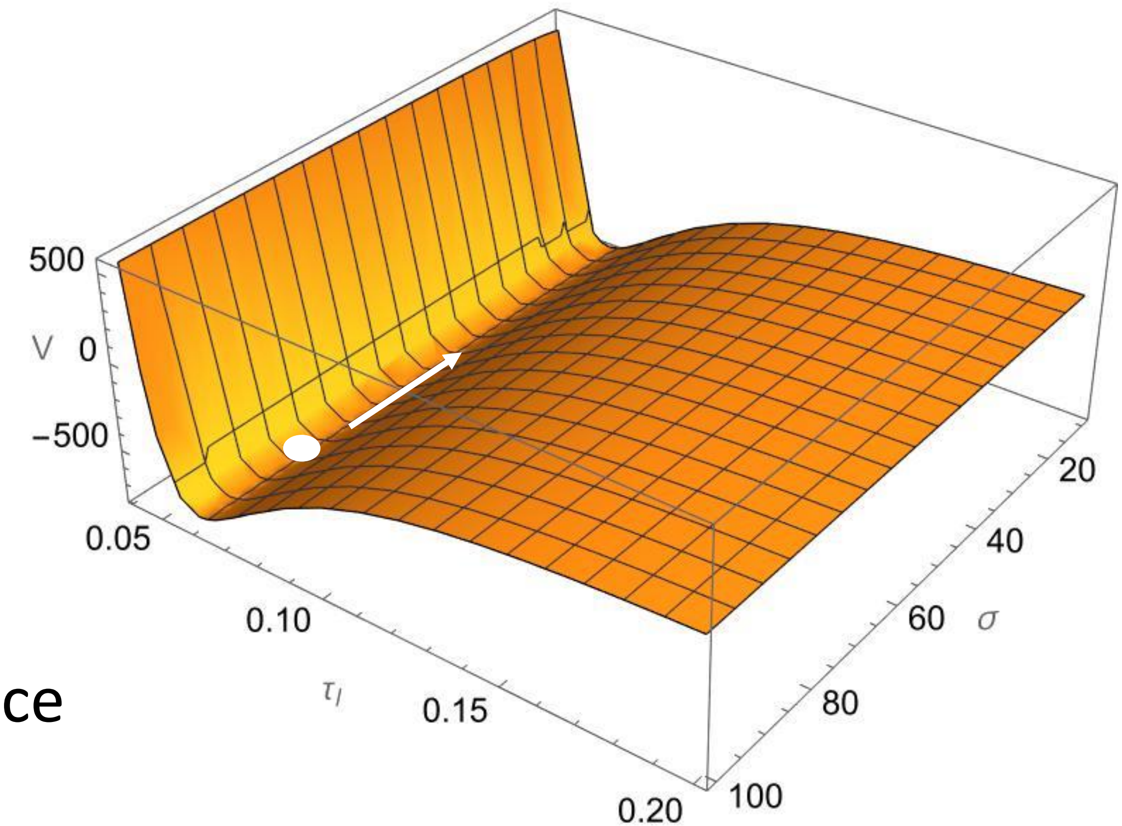
Interesting asymptotic limits

Cremonini, Gonzalo, Rajaguru, Tang, TW   2306.15714

Asymptotic valleys

$V \to const. < 0$

Stable, gradient flow away from large σ to interior of moduli space



Asymptotic limits of field space

Ridges and valleys interesting for swampland conjectures

The Trans-Planckian Censorship Conjecture

$V > 0$ *goes to zero exponentially in any asymptotic limit*

Bedroya, Vafa 1909.11063

The Anti-Trans-Planckian Censorship Conjecture

V< 0 *goes to zero exponentially in any asymptotic limit*

Andriot, Horer, Tringas 2212.04517

Asymptotic limits of field space

Distance Conjecture: Along any asymptotic limit in field space a tower of states becomes light $m_{tower} \sim e^{-\alpha\phi}$

Ooguri, Vafa hep-th/0605264

Klaewer, Palti 1610.00010

Etheredge, Heidenreich, Kaya, Qiu, Rudelius 2206.04063

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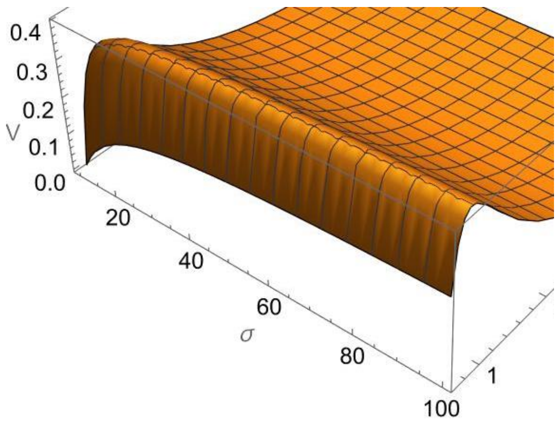
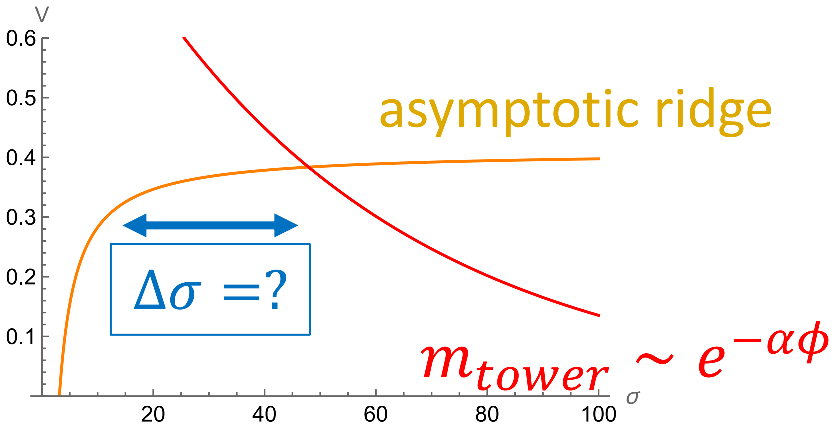
Low energy theory does not take tower into account
Cannot be trusted once $V \sim m_{tower}$





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New interconnections?

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This means that there a new states in the tower that have (at least) a mass term

$$V(\phi, \Phi_t) = m^2_{tower}(\phi)\ \Phi_t^2 = m_0^2 e^{-2\alpha\,\phi}\Phi_t^2$$

Again, exponential with $\lambda = 2\alpha$!

New interconnections?

Relationship $\lambda_{min} = 2\alpha_{min} = \frac{2}{\sqrt{d-2}}$ previously discussed

Hebecker, Wrase 1810.08182

Andriot, Cribiori, Erkinger 2004.00030

Bedroya 2010.09760

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Sharpened DC + Emergent String $\Rightarrow$ Strong Asymp. dS

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Maybe: Strong Asymp. dS $\Rightarrow$ Sharpened DC

$$V(\phi, \Phi_t) = m_{tower}^2(\phi)\ \Phi_t^2 = m_0^2 e^{-2\alpha\,\phi}\Phi_t^2$$

However, gradient flow will set $\Phi_t = 0$!

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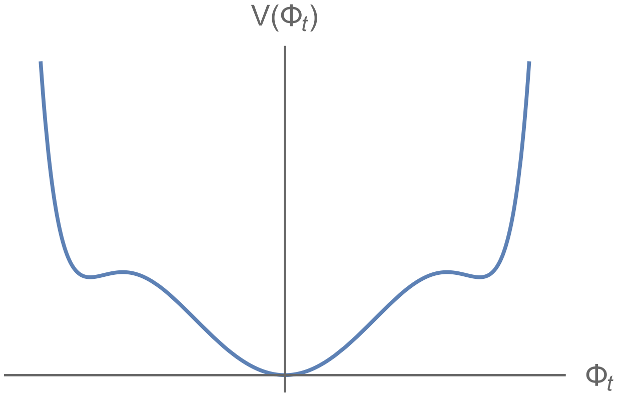
Interaction terms for Φ_t might fix this



$$V(\phi, \Phi_t) = e^{-2\alpha\,\phi}(m_0^2\Phi_t^2 + V_{int}(\Phi_t))$$

Interaction might allow for minima with $\Phi_t \neq 0$

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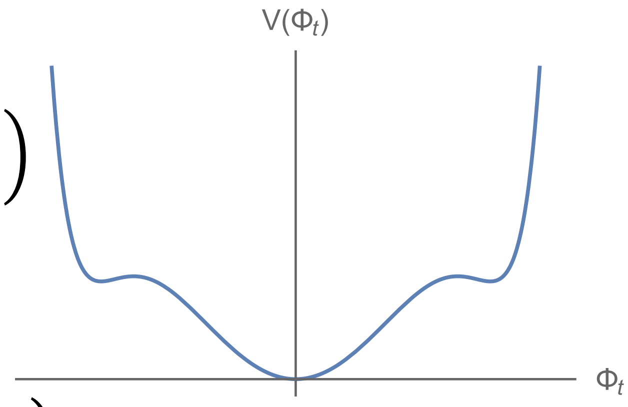
Toy example 5d scalar

$$S = \int d^4x dy \left(-\frac{1}{2}\partial\Phi^2 - \Lambda_1 e^{-\lambda_1\Phi} - \Lambda_2 e^{-\lambda_2\Phi}\right)$$

gives for $\Phi(x,y) = \Phi_0(x) + \Phi_t(x)\cos(2\pi y)$

$$V(\phi,\Phi_t) = e^{-2\alpha\,\phi}\left(m_0^2(\Phi_0)\,\Phi_t^2 + V_{int}(\Phi_0,\Phi_t)\right)$$

y-radius



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- Potential new connection

Strong dS $\Rightarrow$ Sharpened Distance ???

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THANK YOU!