Dark energy and string theory: an update

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Introduction

Our universe is currently expanding + expansion is **accelerating**

→ What is the energy responsible for this acceleration? → **Dark energy**

Nature is unknown / not understood

(early universe: possible phase of accelerated expansion: inflation → similar question)

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Cosmological model to describe dark energy: with a scalar potential $V > 0$

⟶ 4d theory of scalar fields φ^i minimally coupled to gravity:

$$\int \mathrm{d}^4x \sqrt{|g_4|} \left(\frac{M_p^2}{2} \mathcal{R}_4 - \frac{1}{2} g_{ij} \partial_\mu \varphi^i \partial^\mu \varphi^j - V \right)$$

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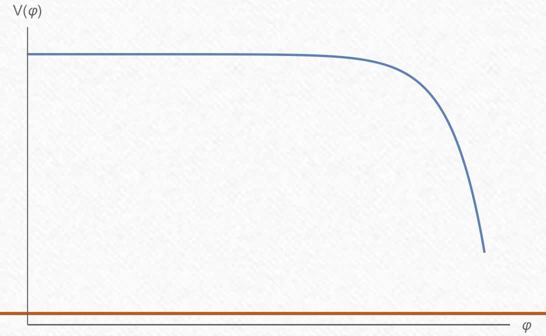
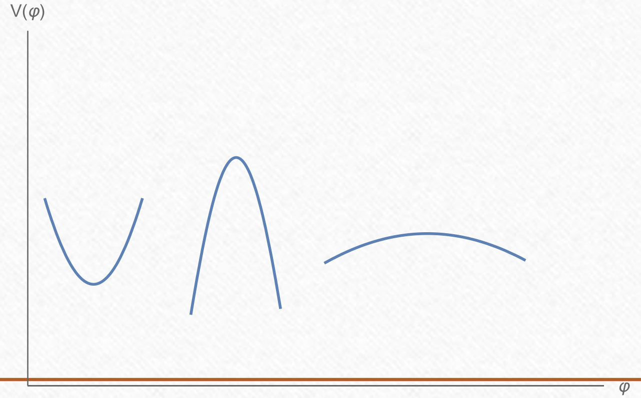
Prime example: cosmological constant $\Lambda = \frac{V}{M_p^2} =$ constant, $\checkmark$ in agreement with current observations

$\longrightarrow$ several ways to have an (almost) constant V

almost flat,
plateau V



critical point,
de Sitter solution
$V' \equiv \partial_\varphi V = 0$



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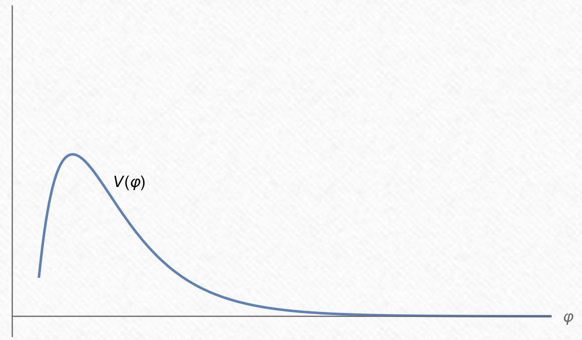

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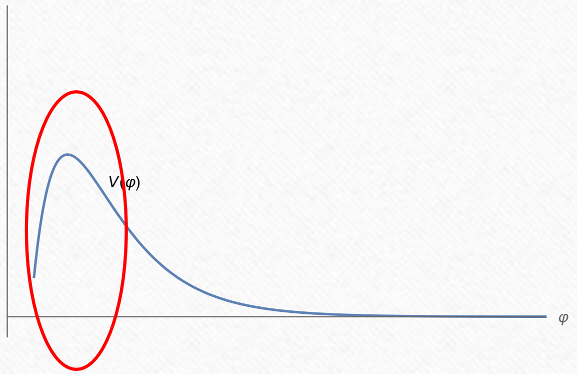
  ⟶ **Difficult** to get positive **cosmo. constant**!



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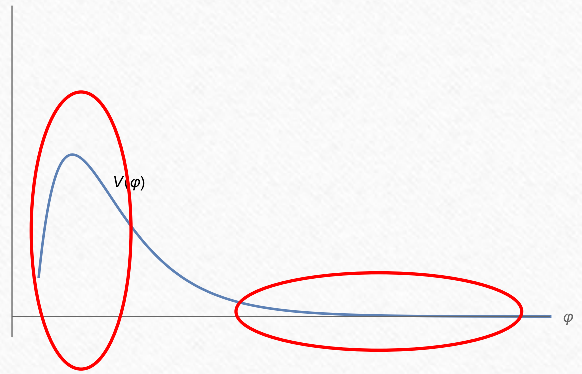

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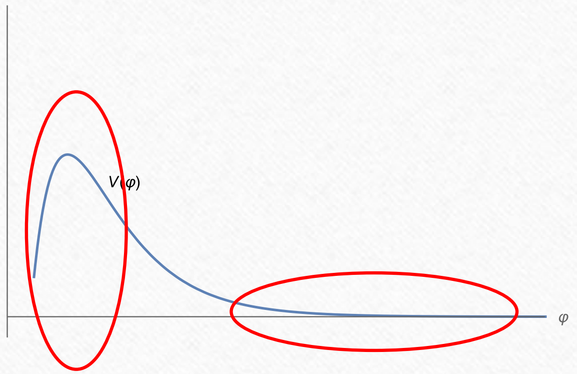
  ⟶ study **transient** scenarios?



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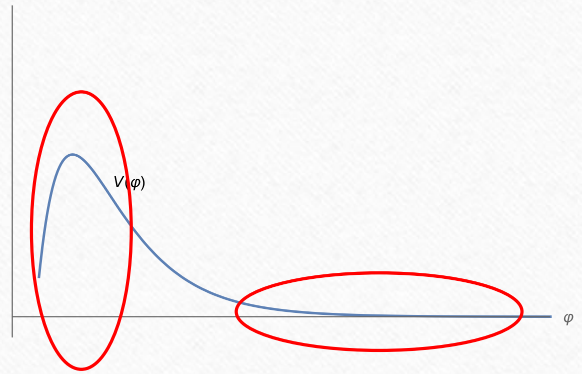

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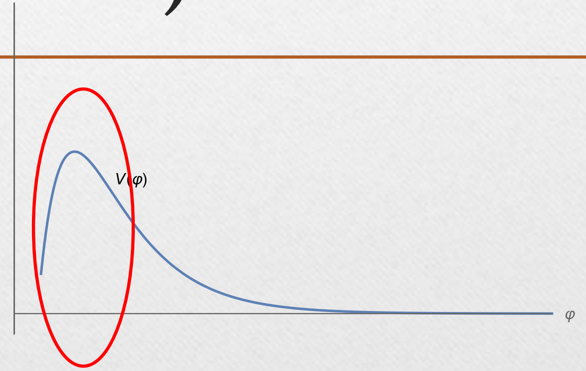
- Acceleration and high $\frac{|V'|}{V}$ in asymptotics $\checkmark$ with space curvature (**open universe** $k = -1$)

I. (Classical) de Sitter solutions



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1. Low energy, perturbative approx. of string theory ⟶ use 10d supergravity (and 4d effective theory)

find solution in 10d supergravity: candidate solution

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⟶ **No known good (classical) de Sitter solution!**

From 10d supergravity solution (database IIA/B) $dS_4 \times$ 6d group manifold

$\longrightarrow$ dimensional reduction / consistent truncation to 4d theory with V

Automatized into code `MSSV.nb` : 10d solutions $\longrightarrow$ $g_{ij}(\varphi^k),\ V(\varphi^k)$

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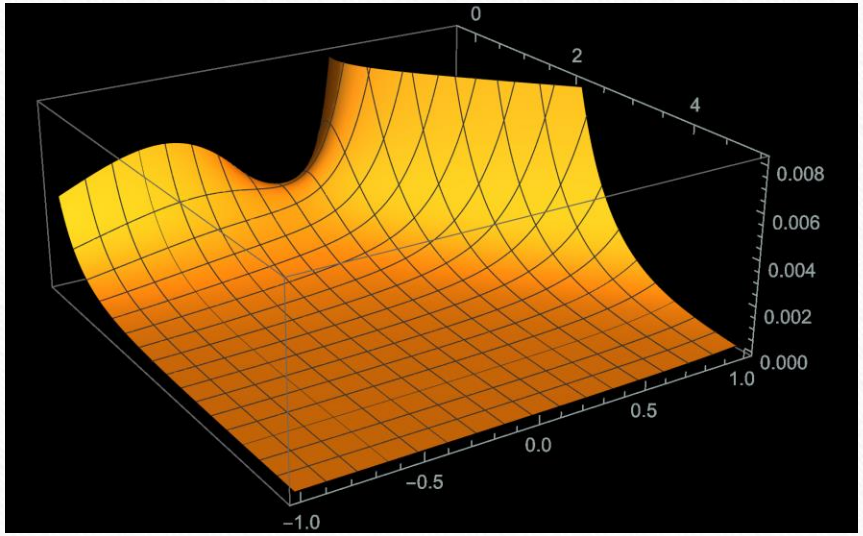

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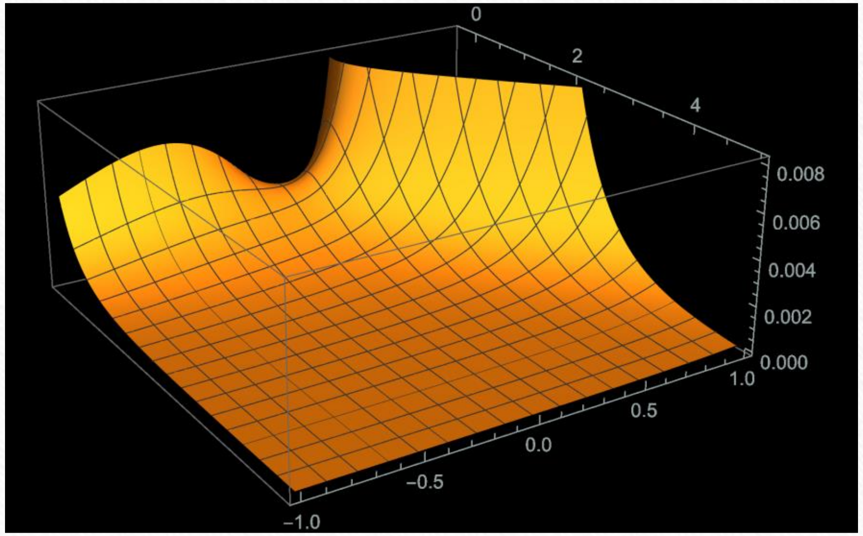
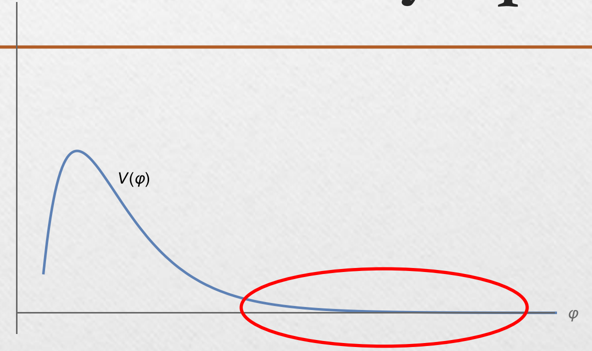


A whole region (towards asymptotics) where classical regime / **trustable** V

$\longrightarrow$ of interest to further applications

II. Rolling fields and asymptotic slopes



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If no de Sitter critical point: $V > 0,\ V' \neq 0,\ \frac{|V'|}{V} > 0$

Cosmology with potential slopes and rolling fields: inflation, quintessence

Can we get $\frac{|V'|}{V} \ll 1$: quasi de Sitter / almost flat V ? ⟶ Very unlikely!

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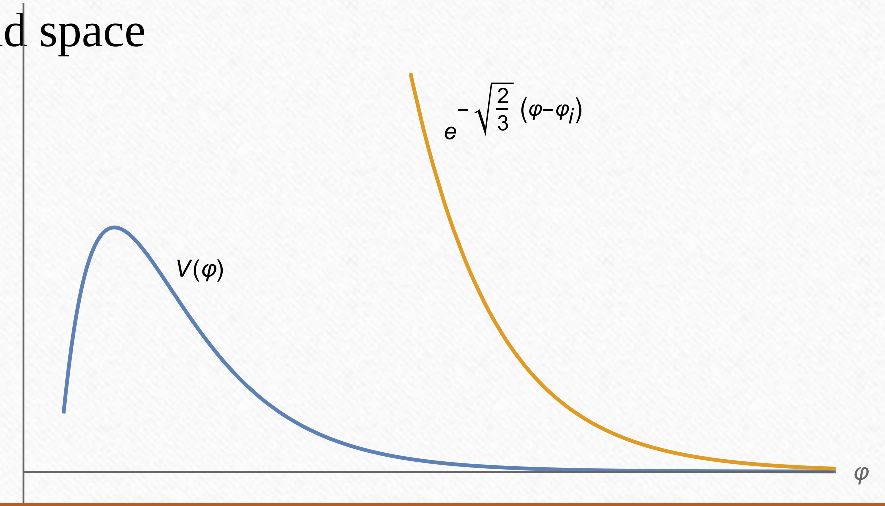
$V \sim V_0\, e^{-\gamma\varphi}\,, \quad |V'|/V = \gamma$



4d multifield: **Strong de Sitter conjecture** (asymptotics in field and time): $\frac{\nabla V}{V} \geq \sqrt{2}$ Rudelius '21, '22

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More dramatic: theoretical bound on **asymptotic accelerated expansion**: $\gamma \leq \sqrt{2}$

Halliwell '86, Copeland, Liddle, Wands '97
Shiu, Tonioni, Tran '23

$\longrightarrow$ explain and extend this

Andriot, Tsimpis, Wrase, '23

Take a single (canonically normalized) field and $V = V_0\, e^{-\gamma\,\varphi}$

Take FLRW metric with arbitrary space curvature, $k = 0, \pm 1$

(observations: very small Ω_k , compatible with $k = 0$ or diluted (expansion) $k \neq 0$)

Write down 3 equations of motion

$\longrightarrow$ can be rewritten as a dynamical system $\longrightarrow$ **study the fixed points**

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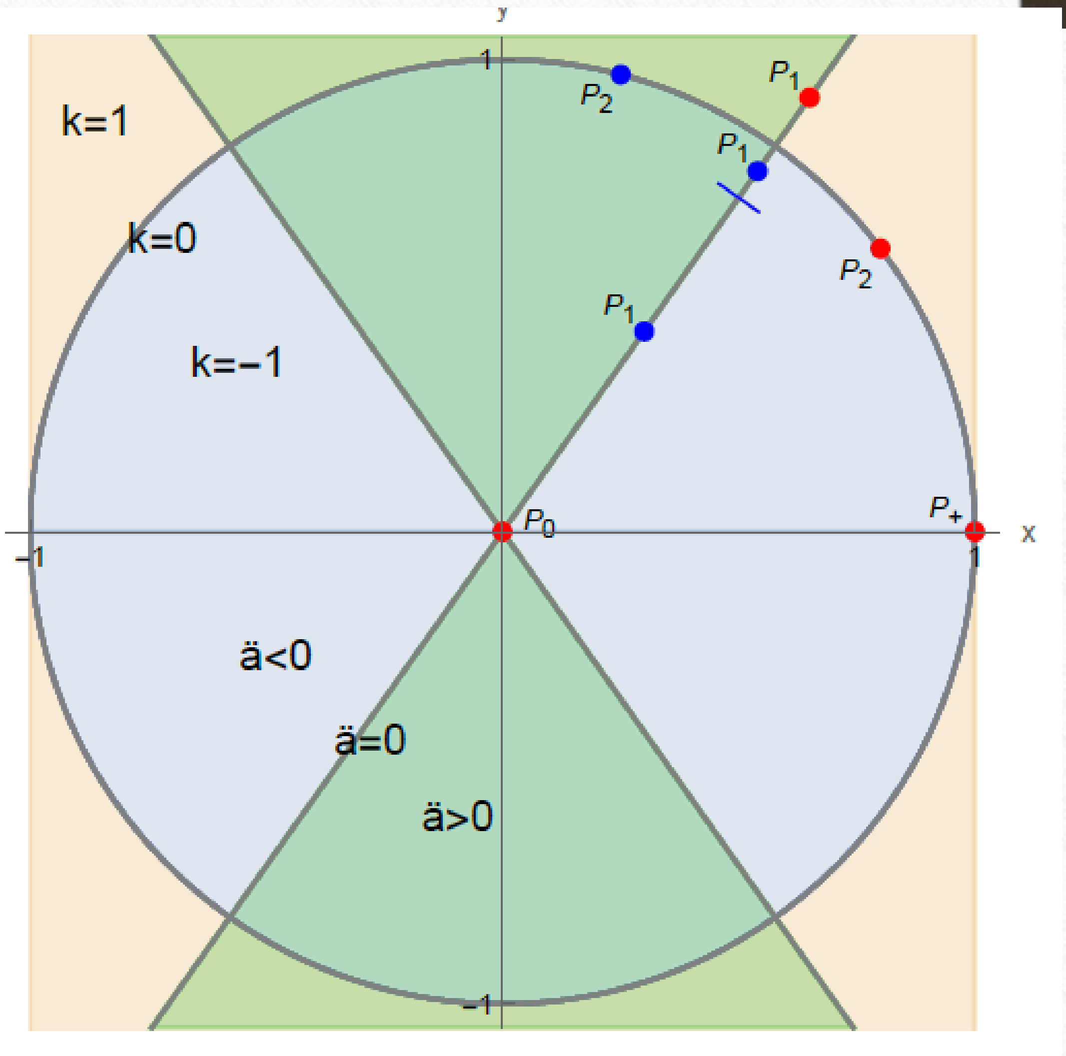
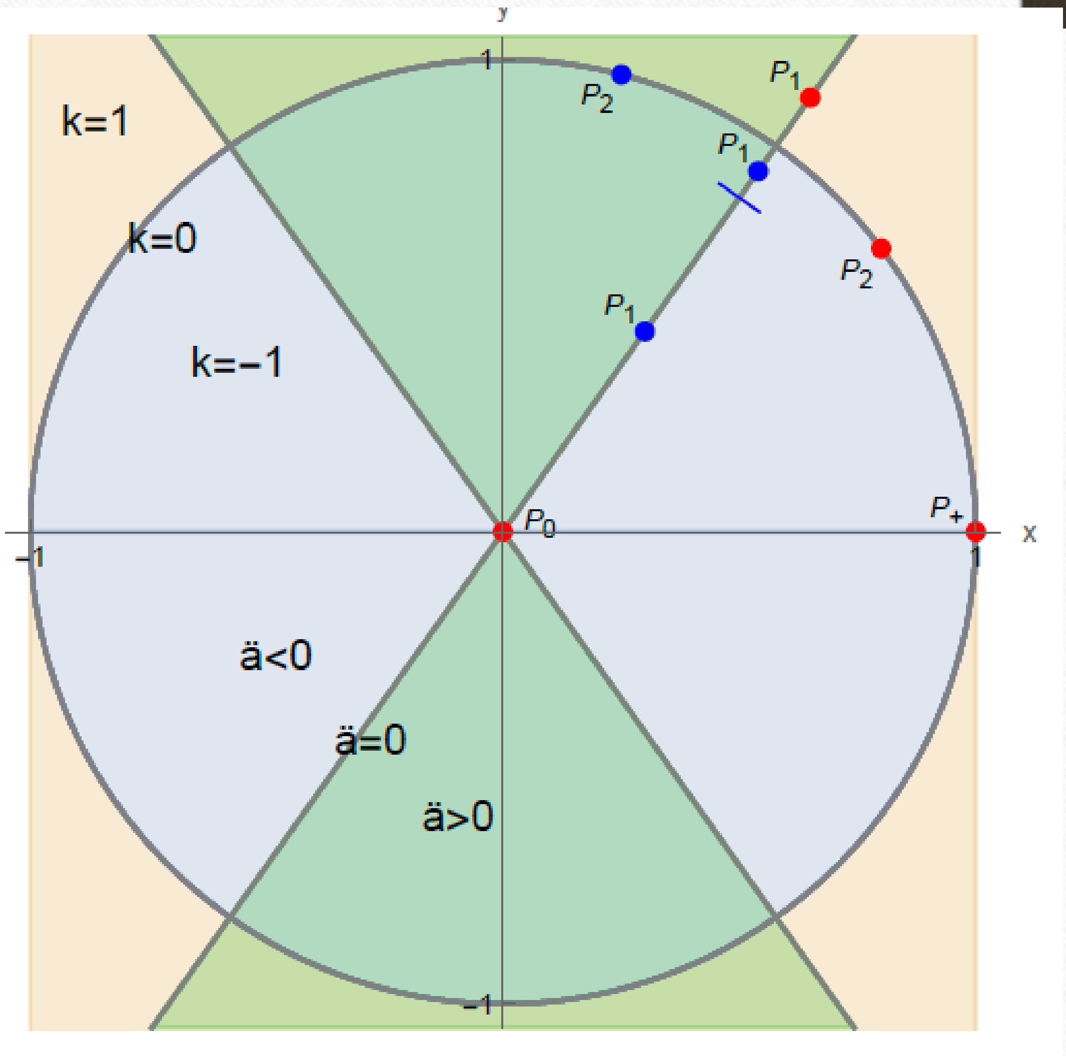
Acceleration at P_1 : no! $\ddot{a} = 0$

But solutions in its **vicinity** exhibit (eternal) acceleration!

$\longrightarrow$ « **asymptotic acceleration** »!



Phase space $(x, y) = \left(\frac{\dot{\varphi}}{H\sqrt{6}}, \frac{\sqrt{V}}{H\sqrt{3}}\right)$



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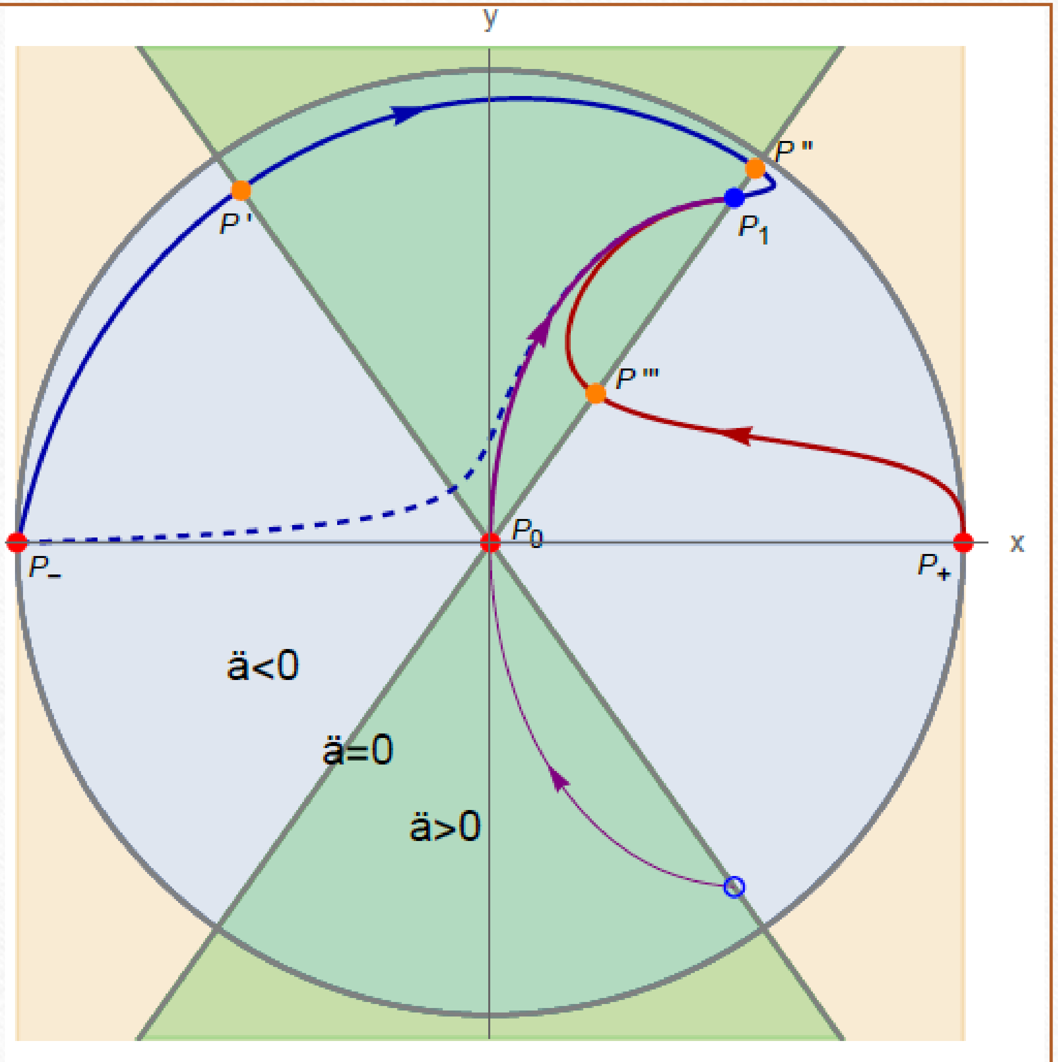
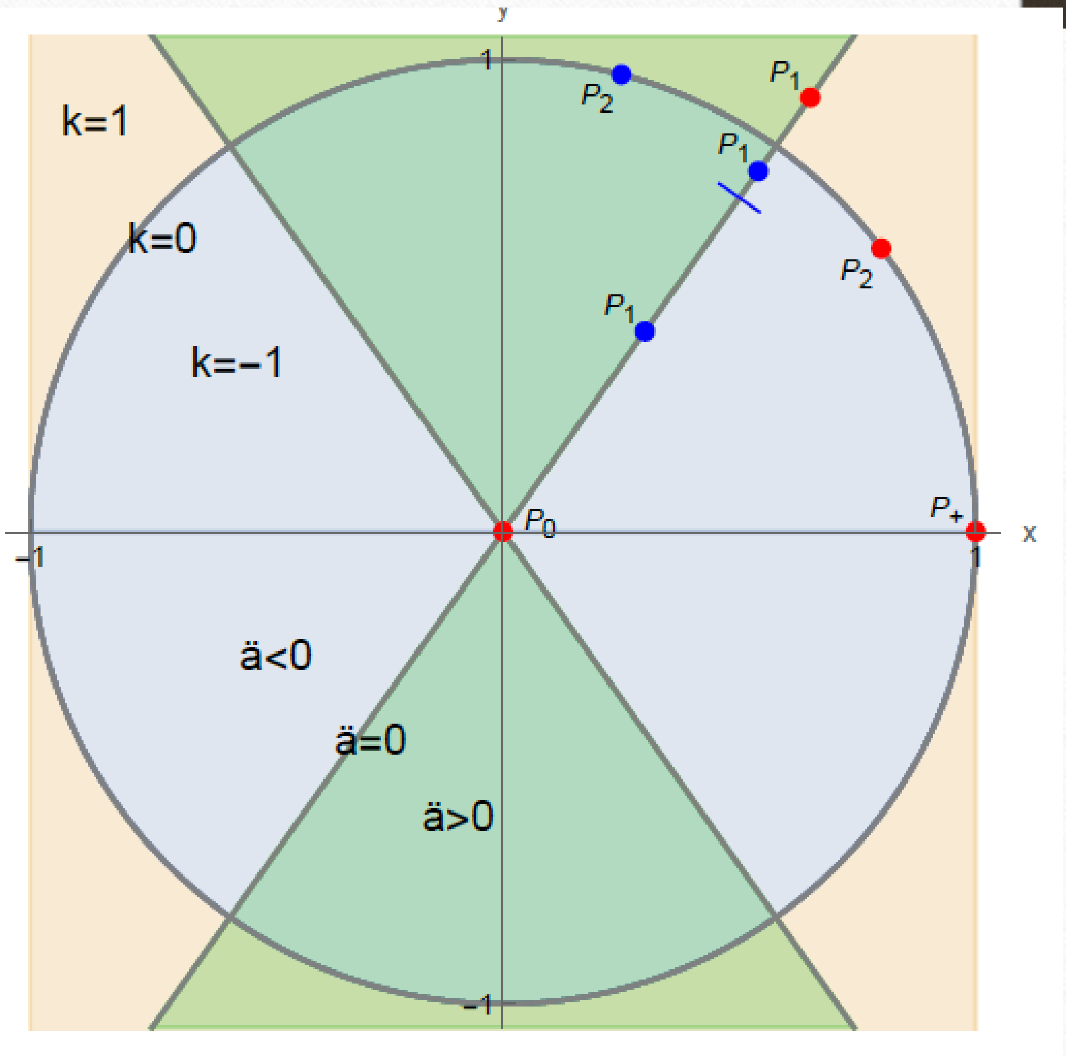


Cosmological solutions asymptoting to P_1



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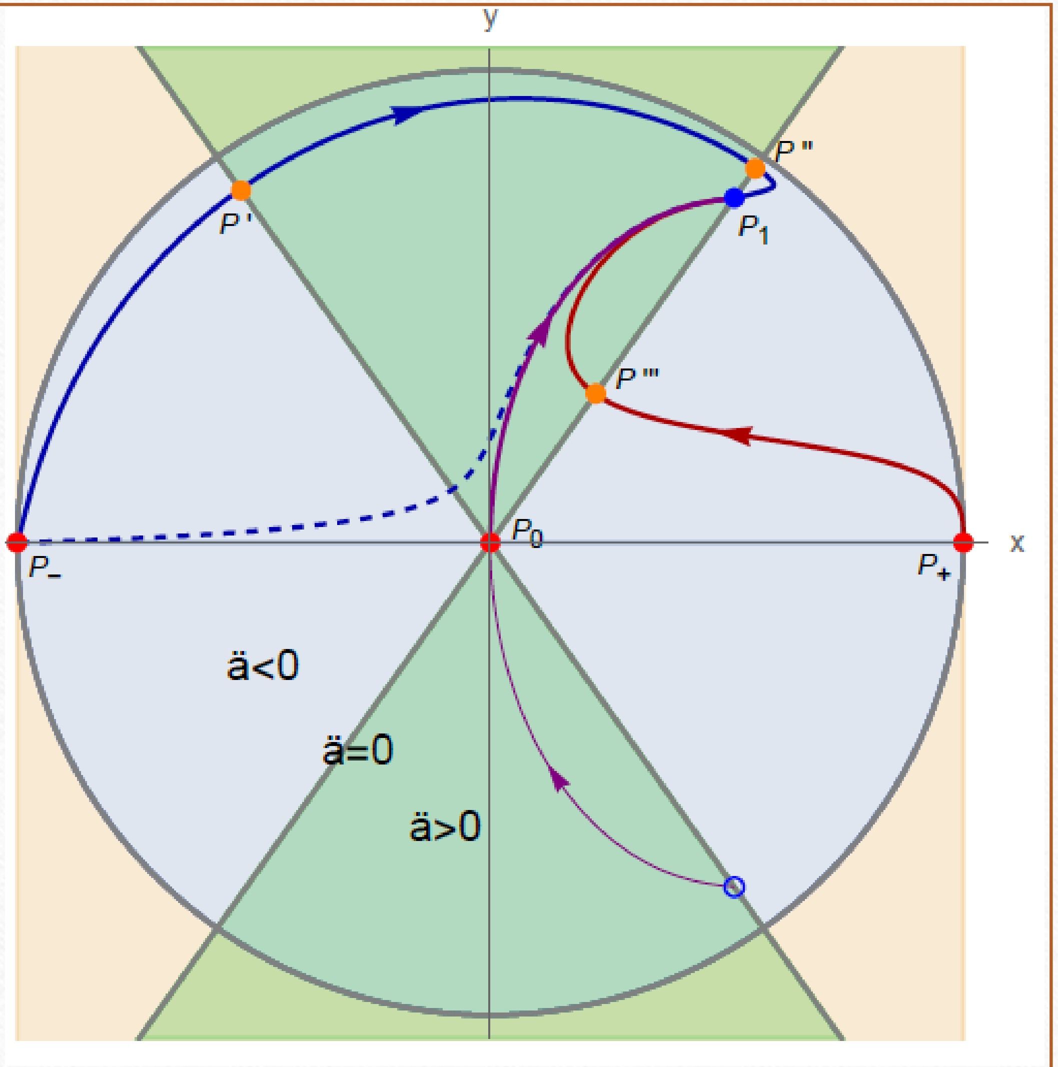
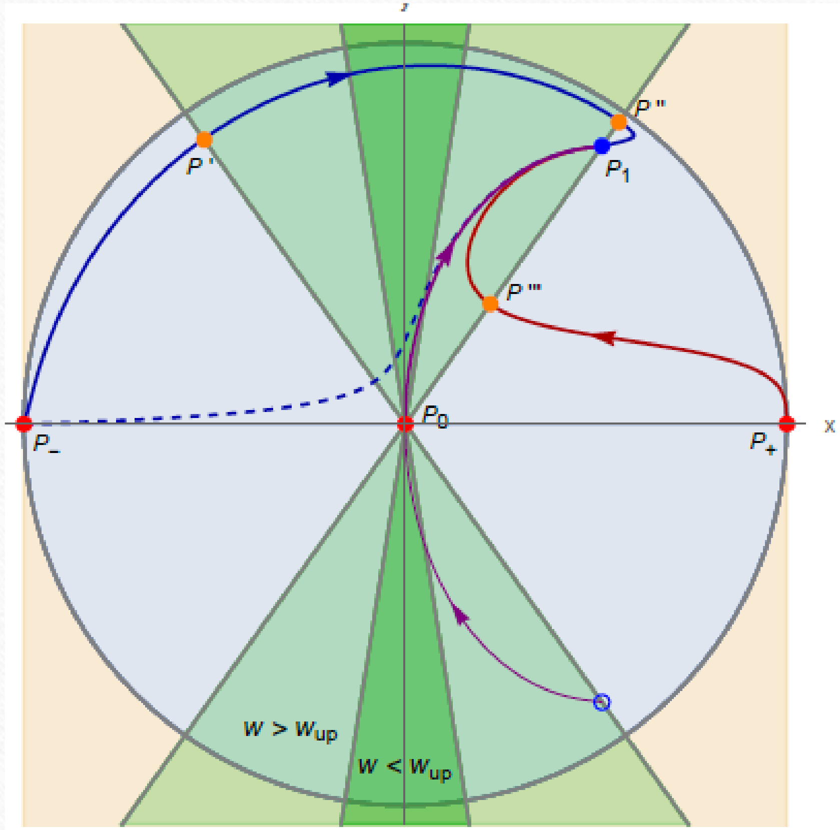
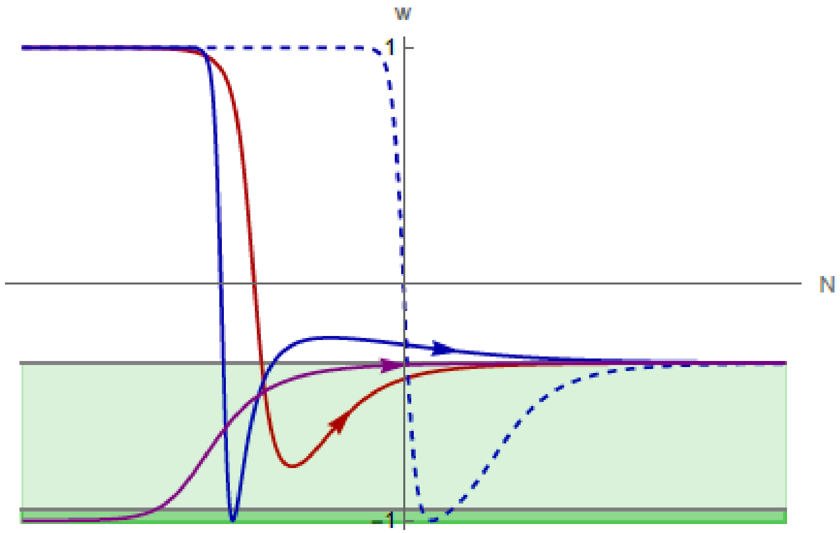


Cosmological solutions asymptoting to P_1

Acceleration: eternal, semi-eternal, transient

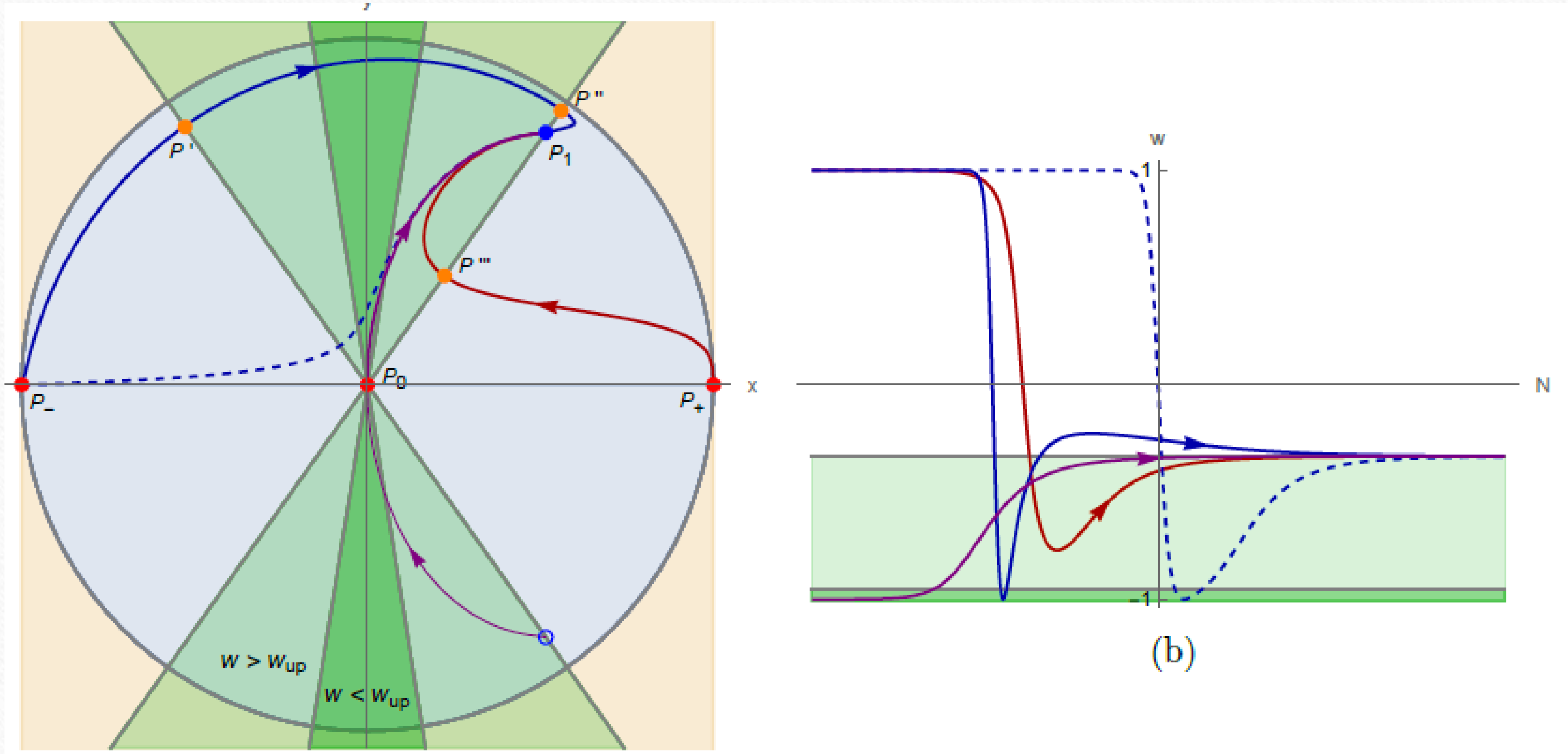


(a)



(b)

How **realistic**? $w < -0.95 = w_{\rm up}$



(a) (b)

How **realistic**? $w < -0.95 = w_{\rm up}$

Transient acceleration solution: tunable **number of e-folds** $\longrightarrow$ Possible solutions for dark energy and inflation….

String theory realisations? $\gamma > \sqrt{2}$ makes it much easier

Consistent truncation from 10d to 4d, giving a single field with exponential potential

Marconnet, Tsimpis ’22

Field: volume, or volume and dilaton $\longrightarrow$ dynamical compactifications

Advantage: no O-plane, no smearing discussion, and classical regime easily reached

Deserves more investigation (other fields?)

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Event horizon, of size $d_e = a(t_i) \int_{t_i}^{\infty} \frac{\mathrm{d}t}{a(t)}$ for solutions asymptoting to P_1

Determined by fixed point $P_1 : a(t) \sim t$ $\longrightarrow$ $d_e = \infty$, **no horizon**

Instead of ``no asymptotic acceleration'' claim (for string theory/quantum gravity),
rather ``**no cosmological/event horizon**''…?!

(in particular no pure de Sitter solution)

Conclusion

- De Sitter solutions: difficult to obtain from string theory; no fully controlled example (for now)
- Accelerated expansion via rolling fields: in the asymptotics? Not with $k=0$
- Possible / string realized with $k=-1$; how realistic are the solutions?
- General claim on the absence of cosmological event horizon from string theory?
- Transient scenarios: a lot to explore

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Thank you for your attention!