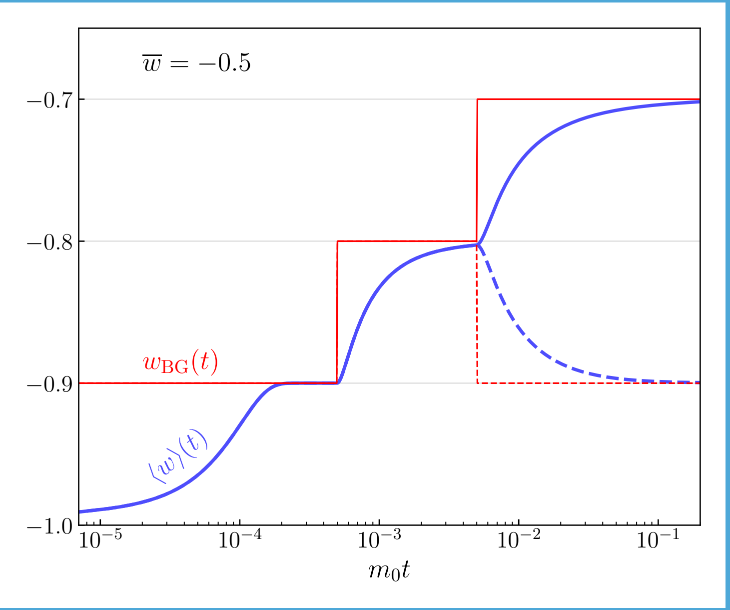
Cosmological Stasis from Dynamical Scalars



Brooks Thomas

LAFAYETTE COLLEGE

Work supported in part by NSF

Based on work done in collaboration with:

Keith R. Dienes, Fei Huang, Lucien Heurtier, and Timothy M. P. Tait [arXiv:2405.xxxxx]

Mitchell Conference, Texas A&M University, May 24th, 2024

Cosmological Stasis

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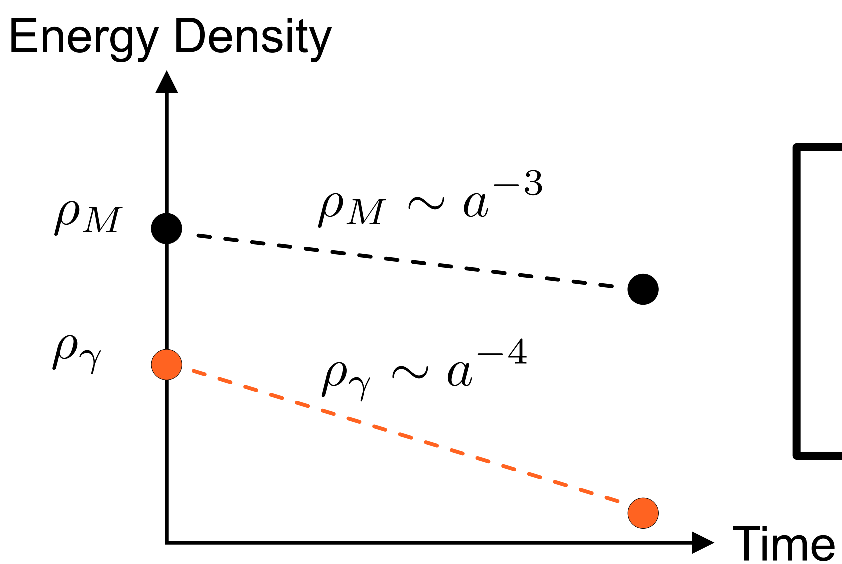

Boltzmann Equations

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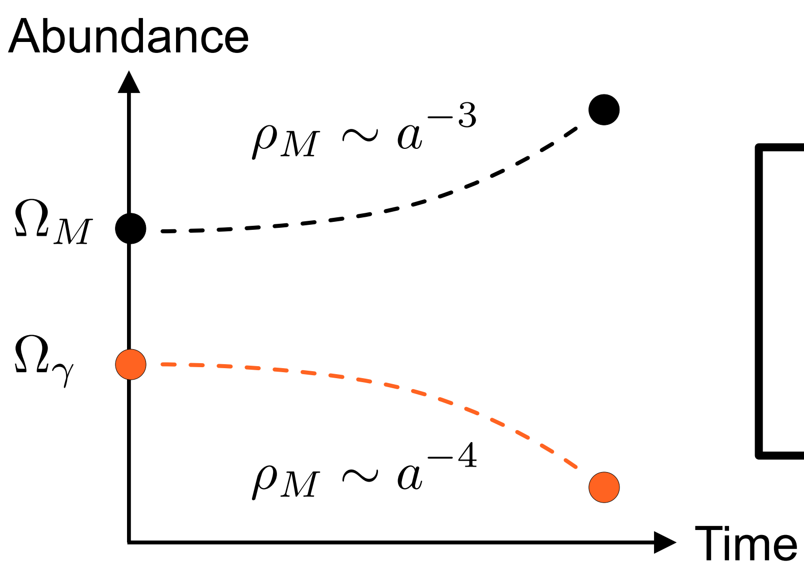

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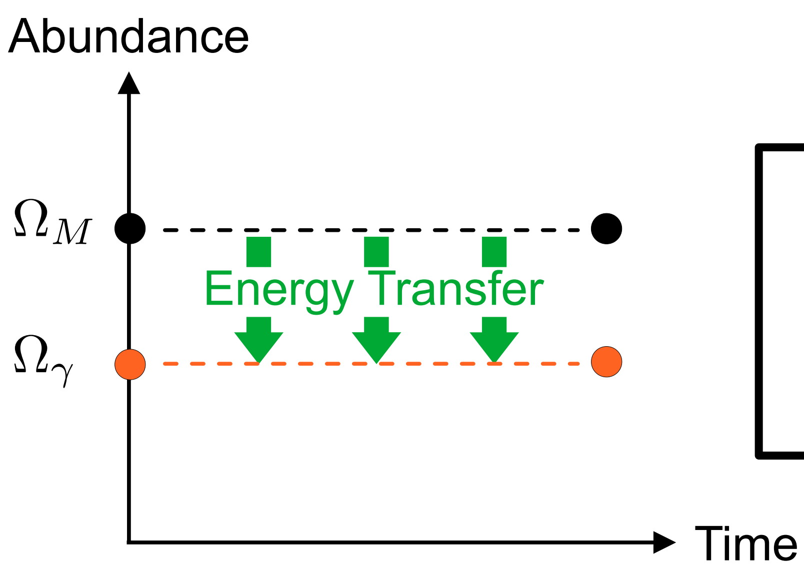

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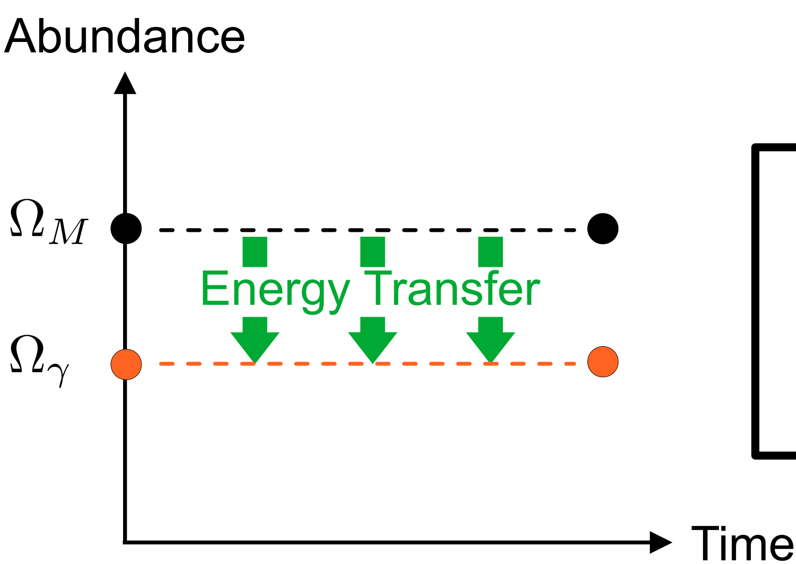

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$H\Omega_M\Omega_\gamma \propto t^{-1}$, so $P(t)$ should be as well.

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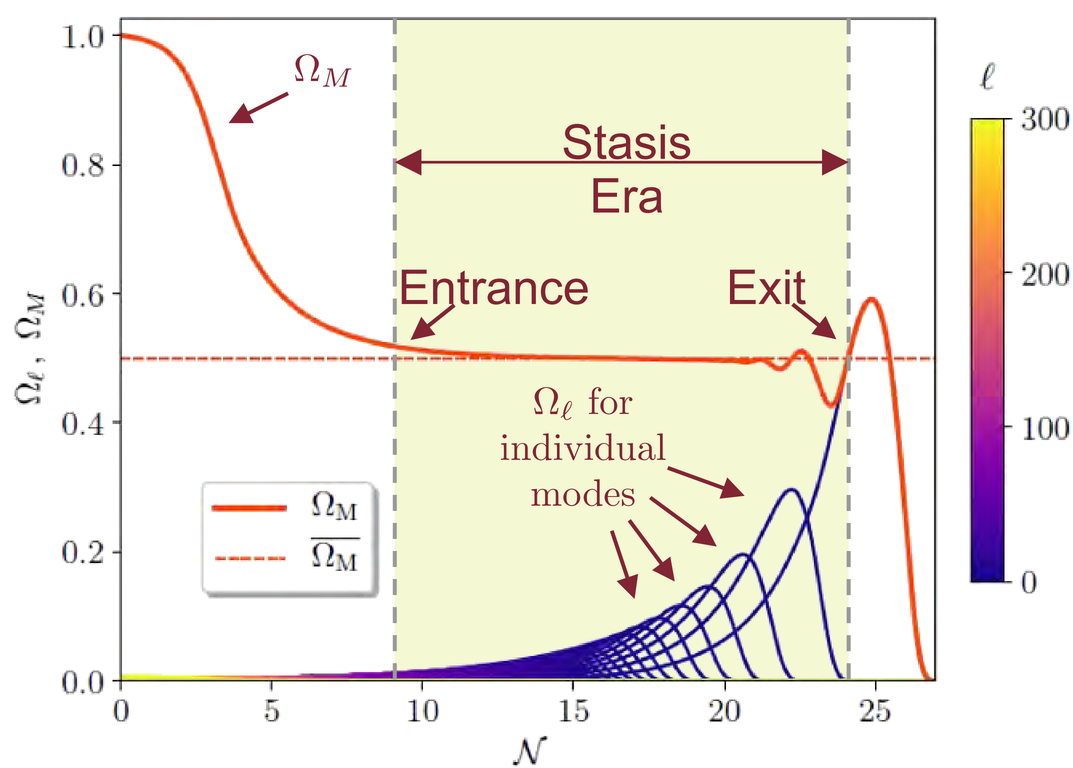

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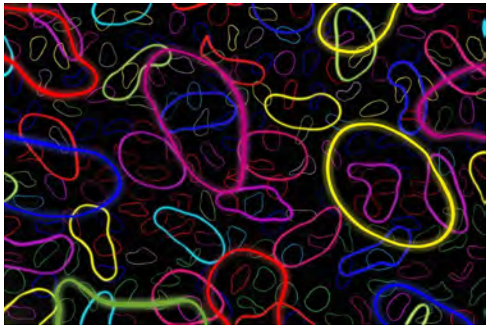

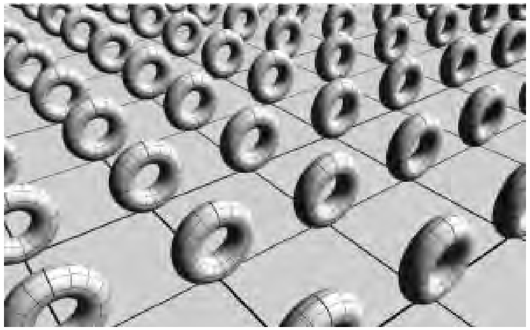

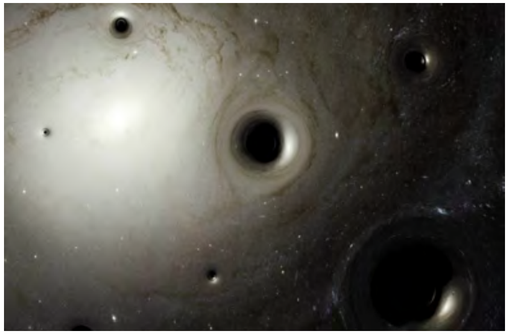

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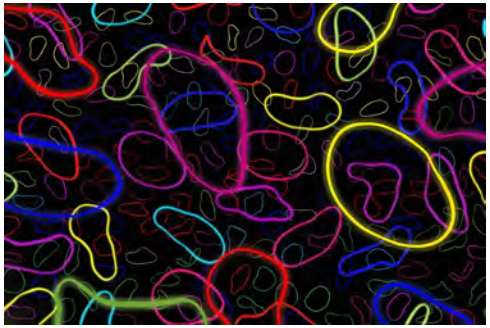

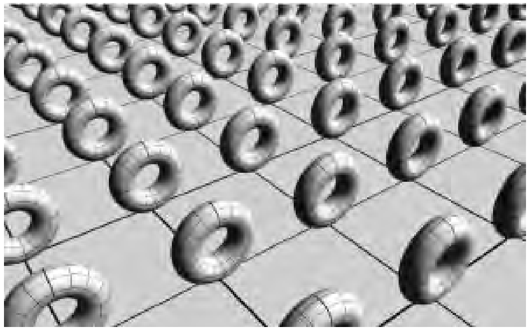

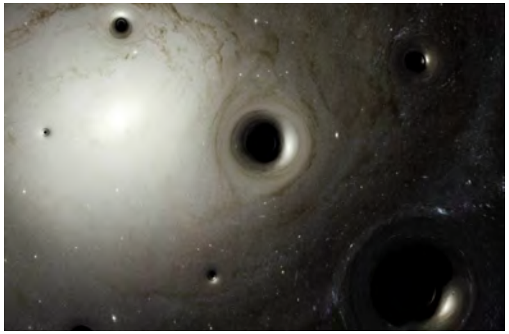

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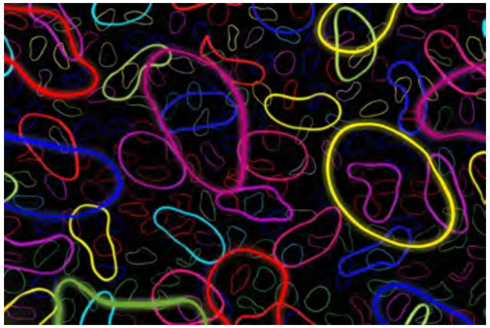
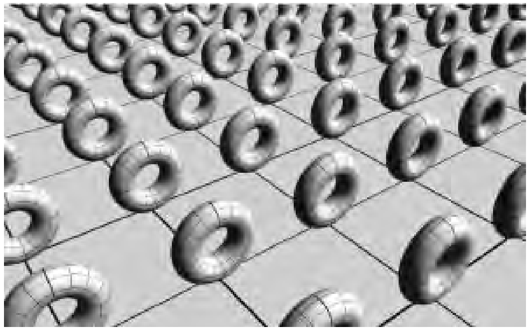
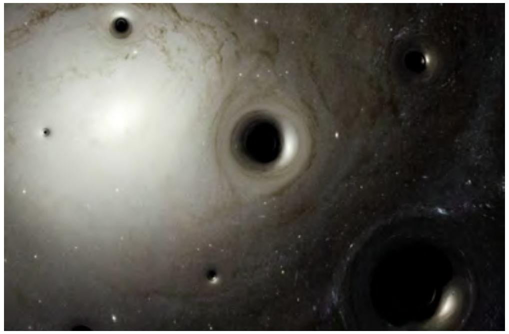
- The modified cosmological histories associated with stasis can affect the evolution of **scalar and tensor perturbations**.

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- Such a stasis, as we'll see, would be characterized by an effective equation-of-state parameter **between that of vacuum energy** ($w_\Lambda = -1$) **and matter** ($w_M = 0$).
- Moreover, stases involving dynamical scalars give rise to some **phenomena not seen in other realizations of stasis** which could potentially useful for addressing fundamenal questions in cosmology.

Warm-Up: A Single Scalar

- To set the stage, let's recall how the homogeneous zero-mode of a **single scalar field** ϕ of mass m with a quadratic potential $V(\phi)$ evolves in a flat FRW universe.

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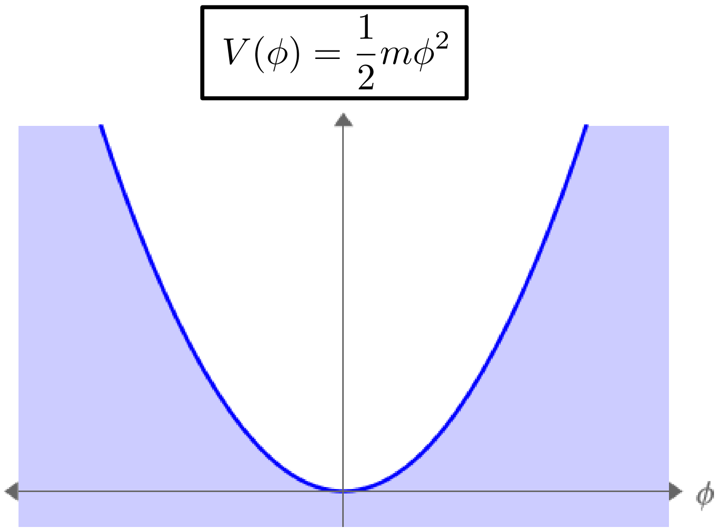

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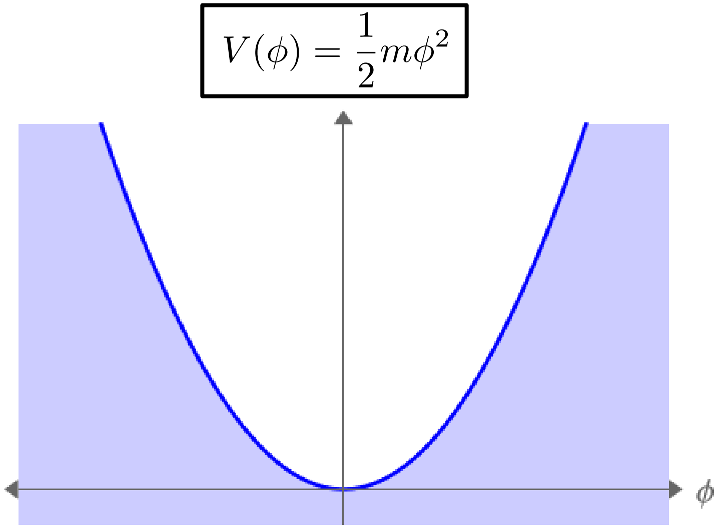

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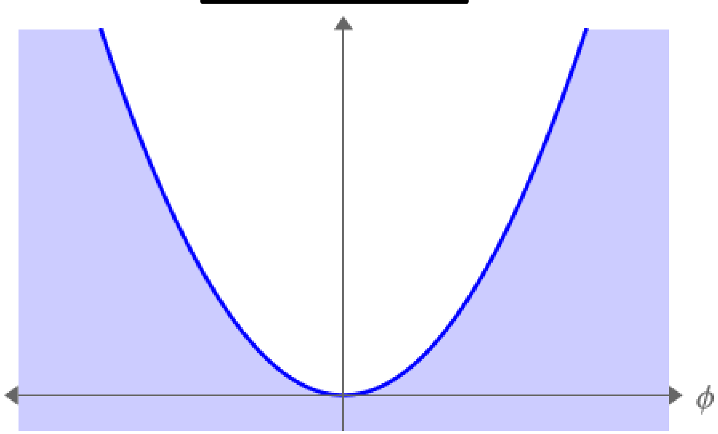

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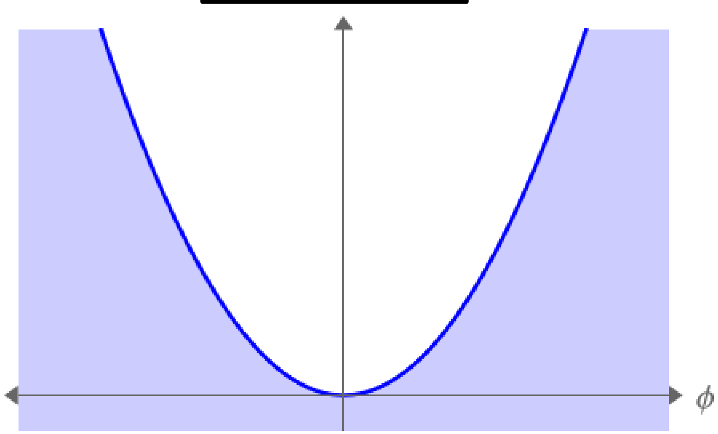

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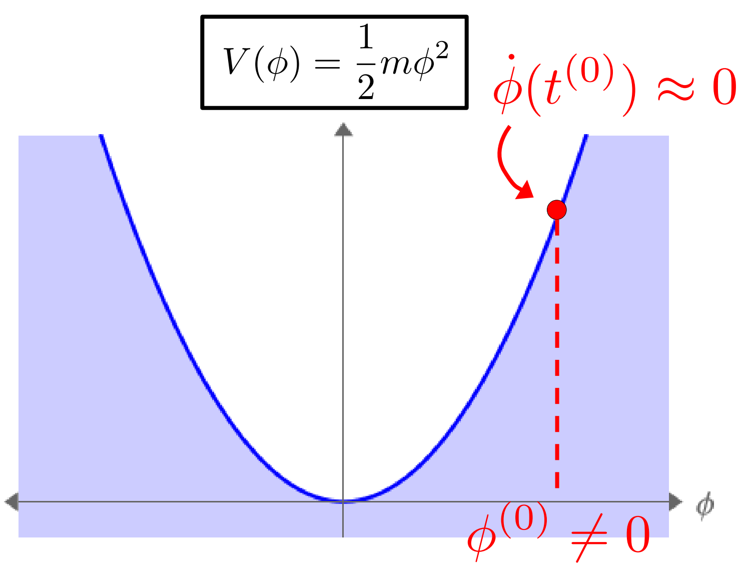

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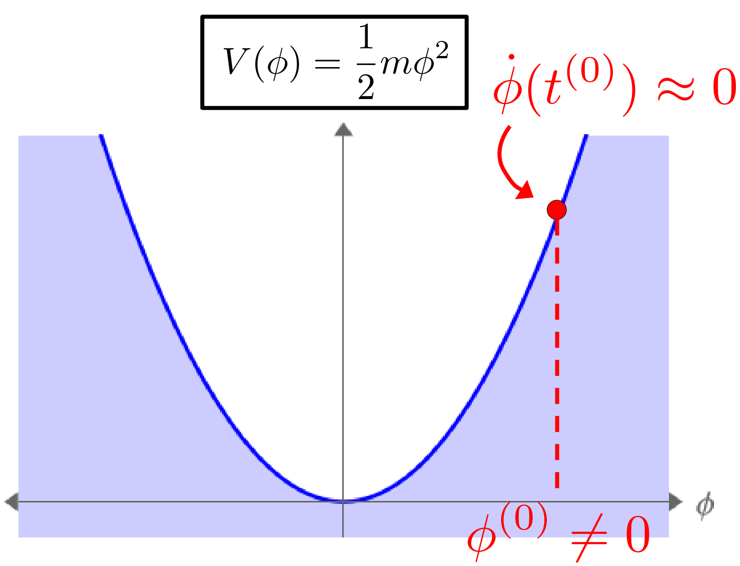

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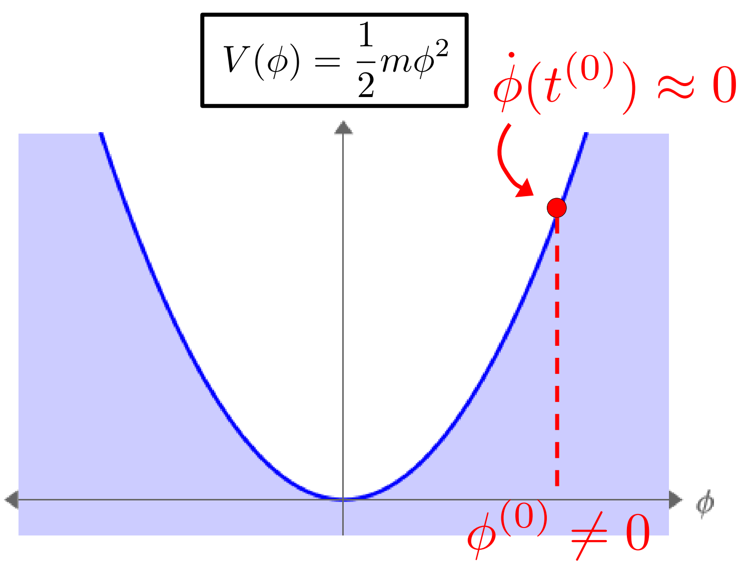

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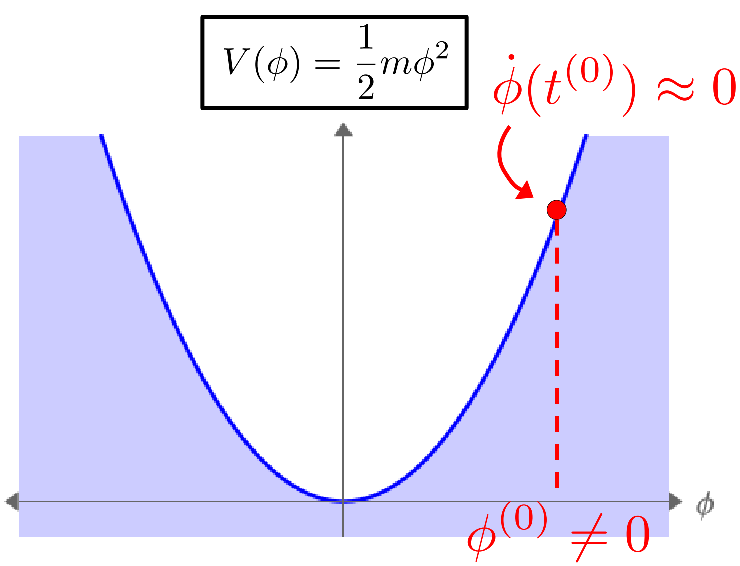
$$H \approx \frac{\kappa}{3t} \, , \quad \text{where} \quad \kappa \equiv \frac{2}{1+w}$$



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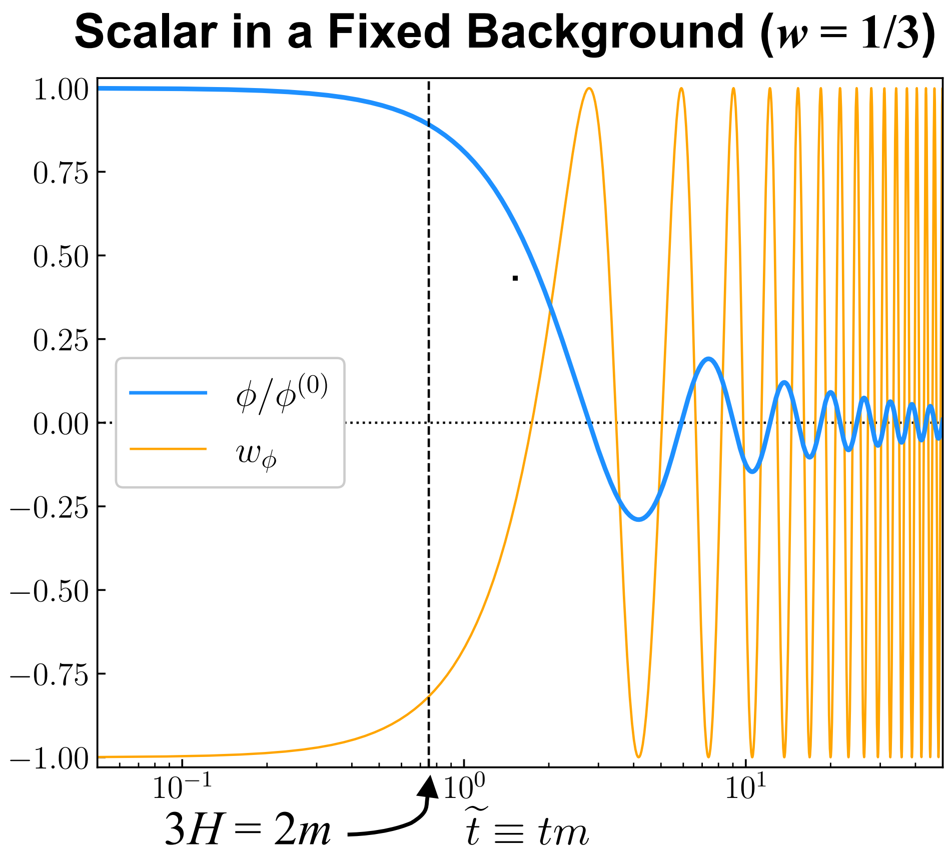

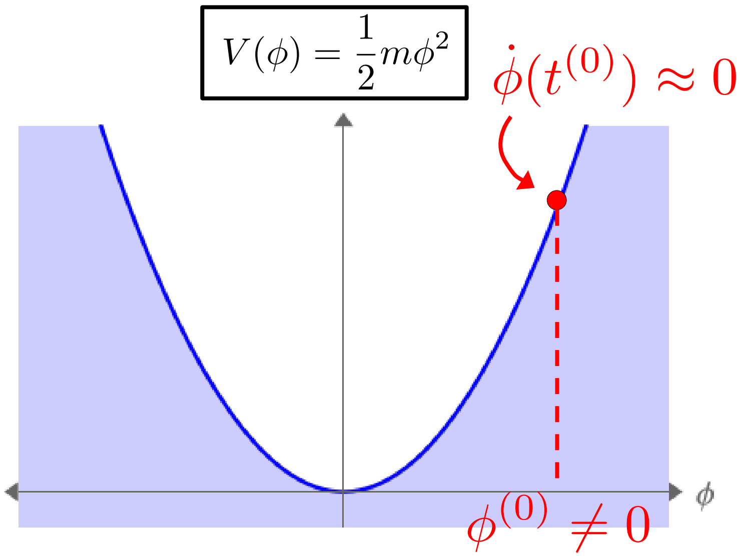

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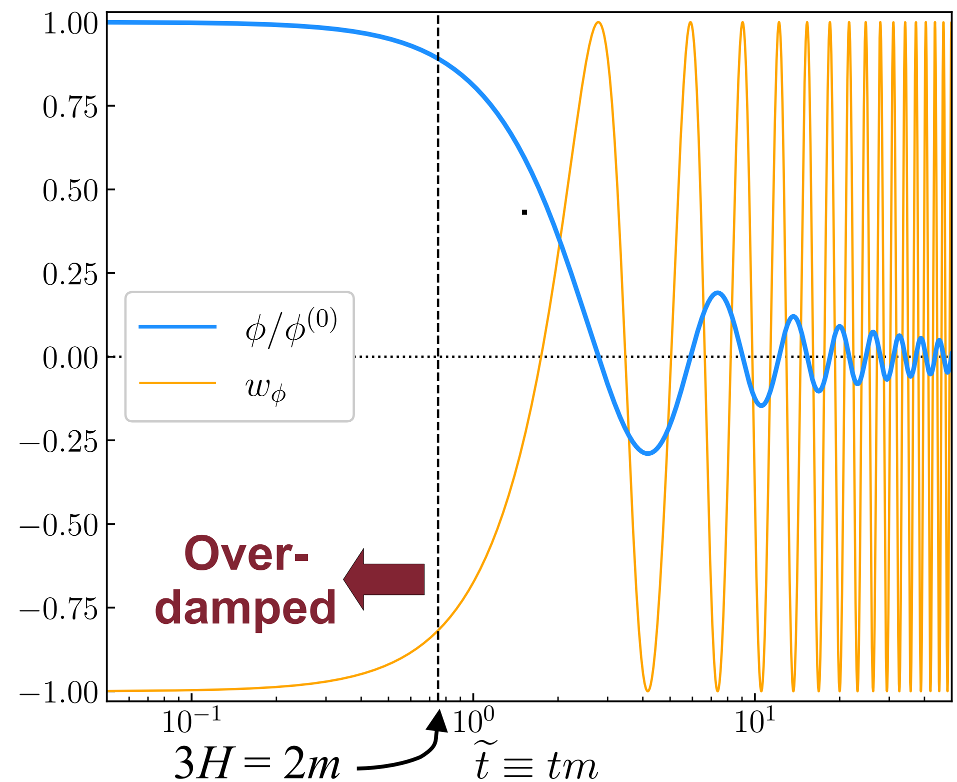

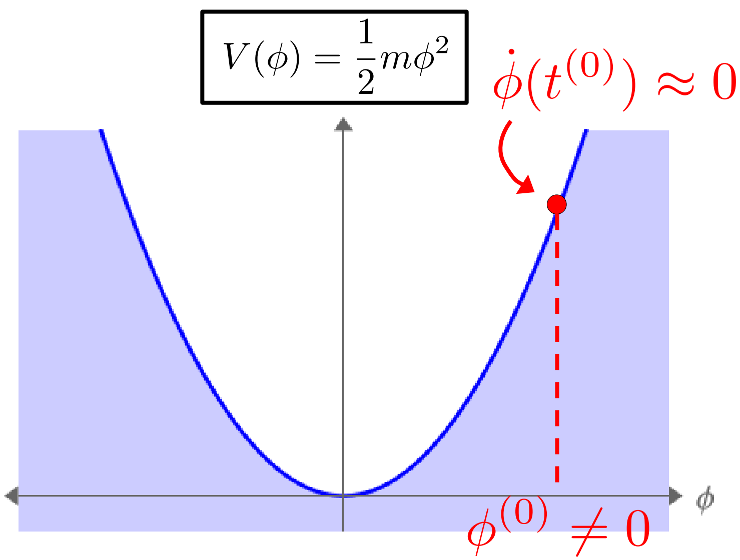

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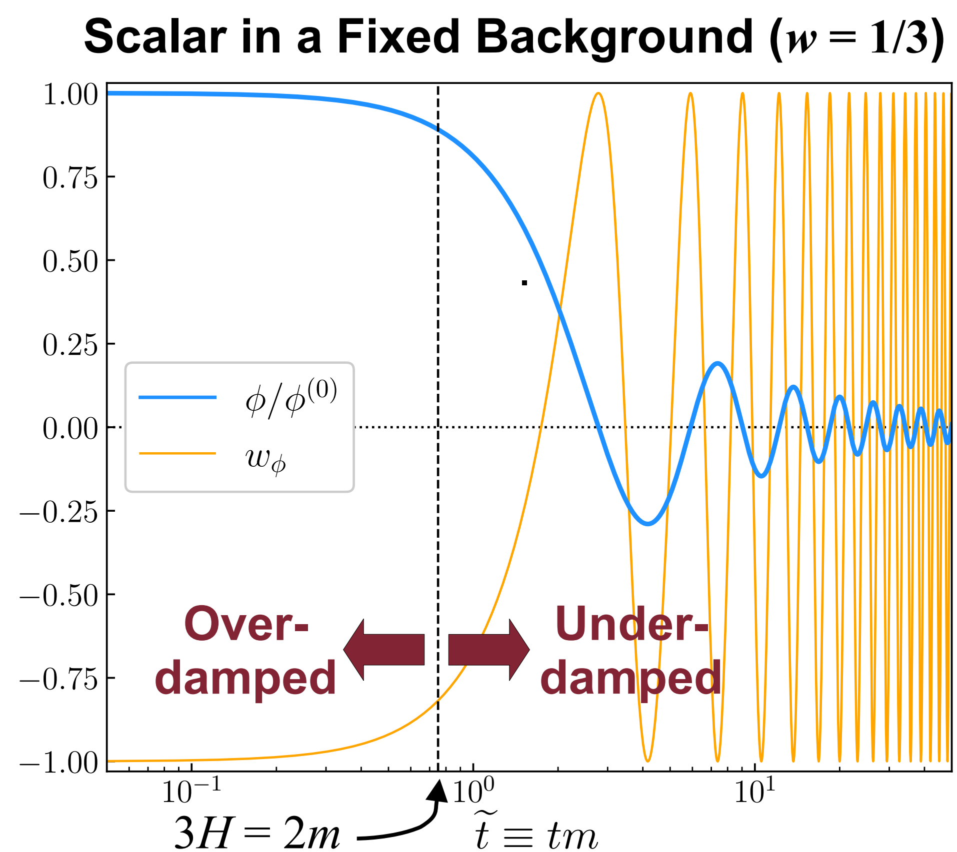

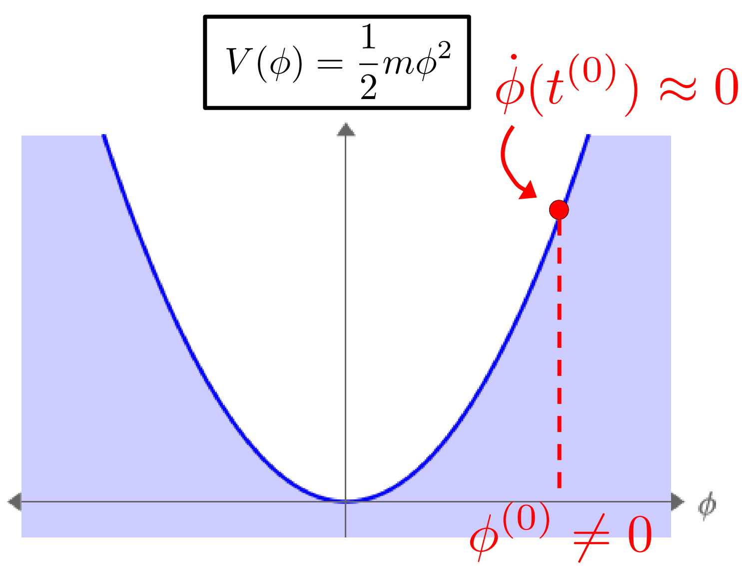

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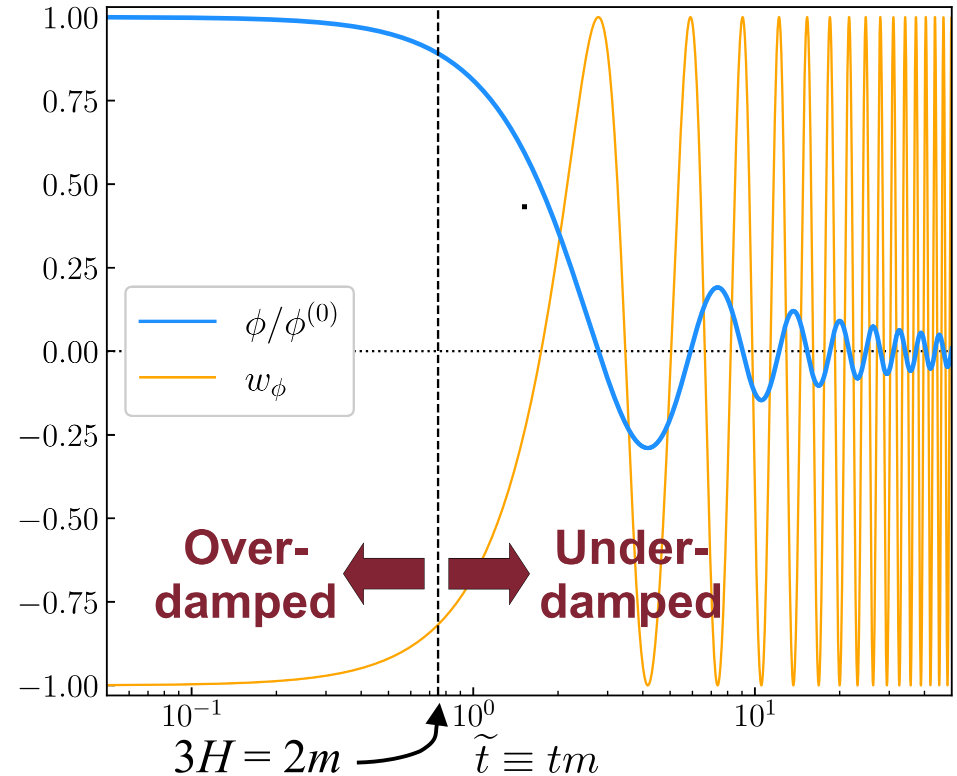

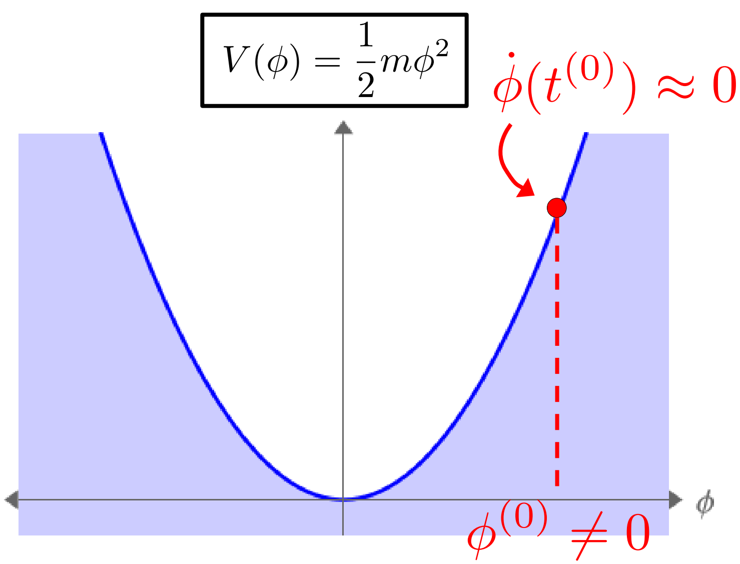

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➡ **Behaves like massive matter**

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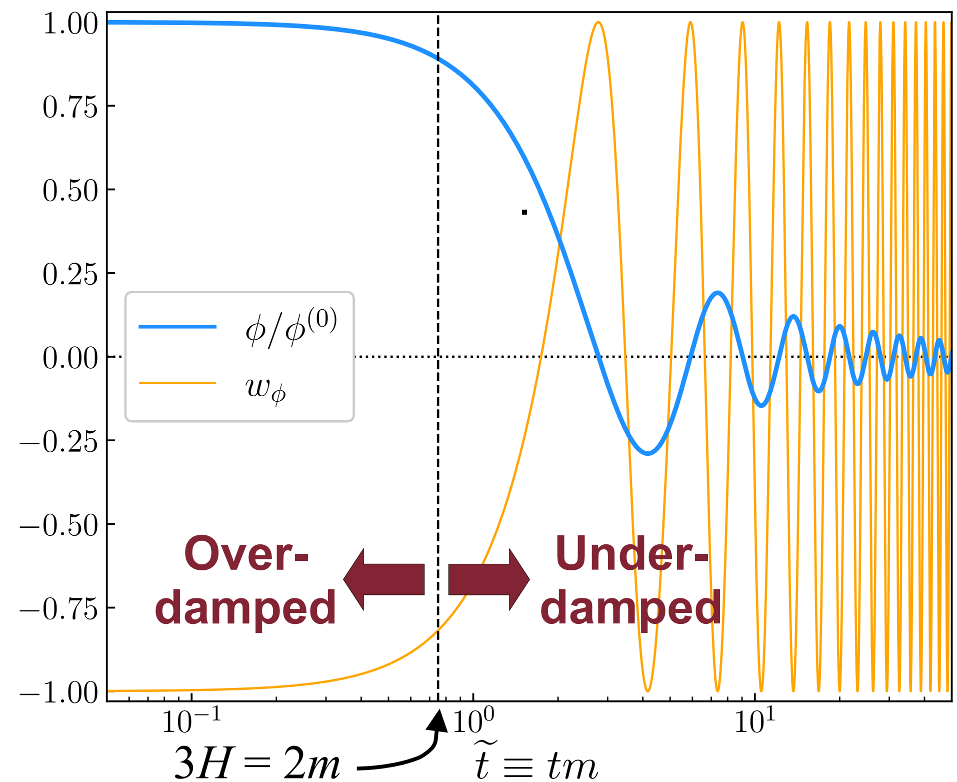

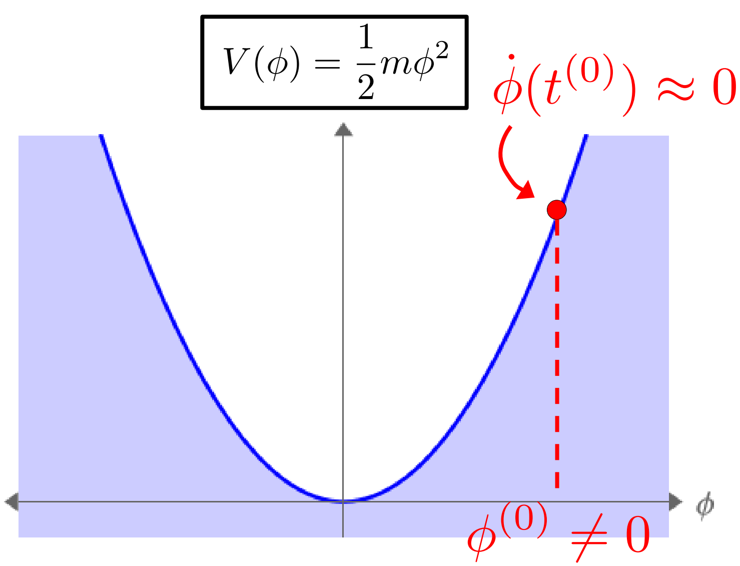

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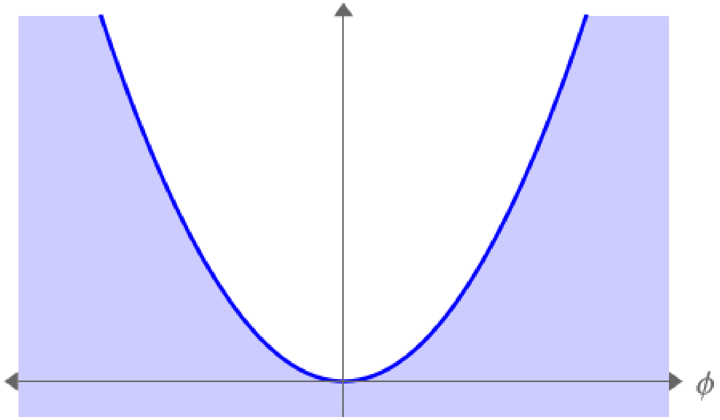

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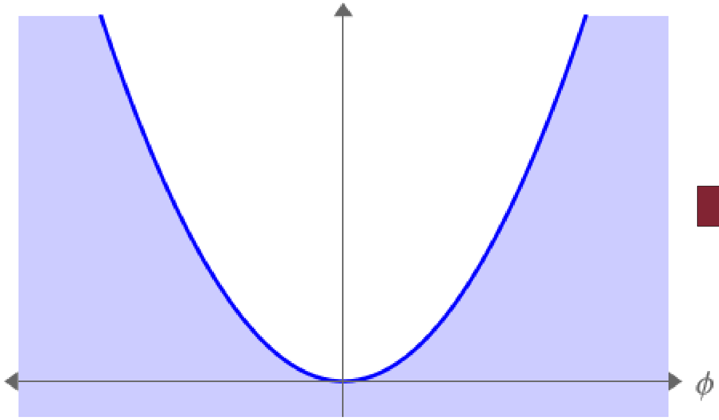

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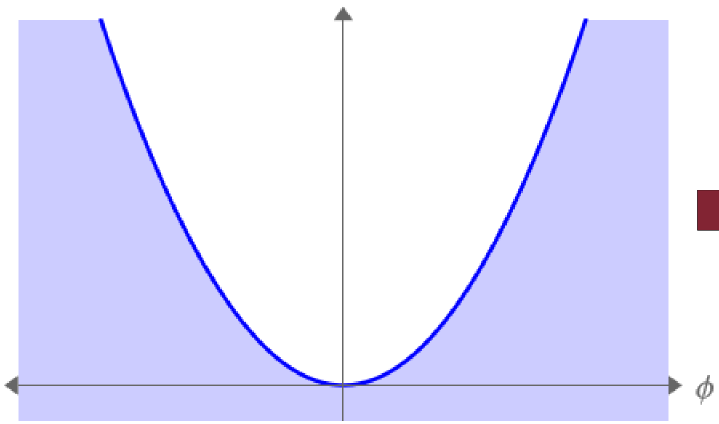

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- We'll also assume (for the moment) that there's **no background energy component**: the collective energy density of the ϕ_ℓ dominates the universe.

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Let's see what the cosmology of such a tower of scalar-field zero modes looks like!

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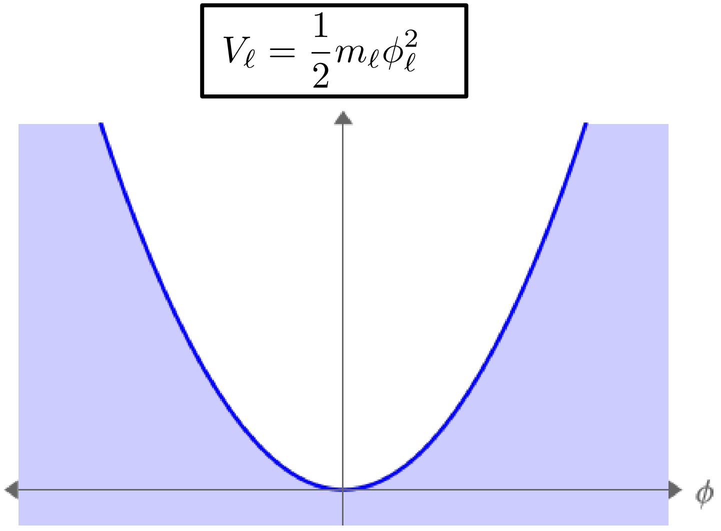

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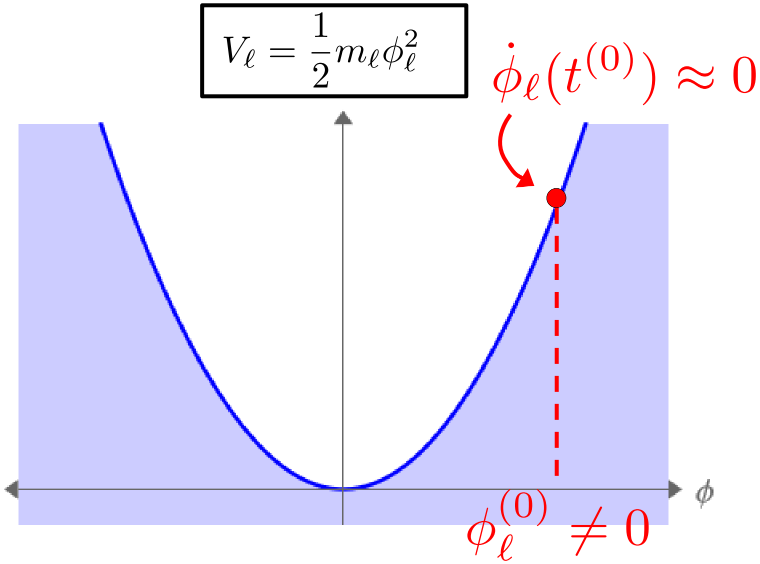

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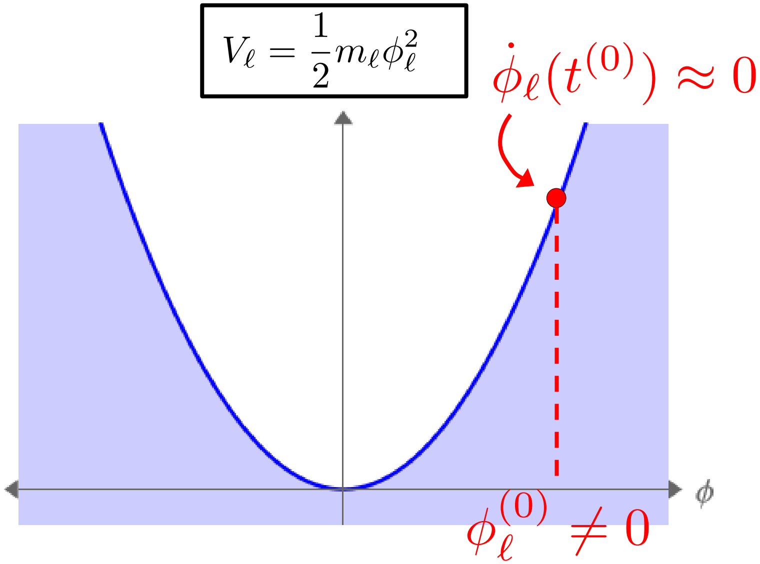

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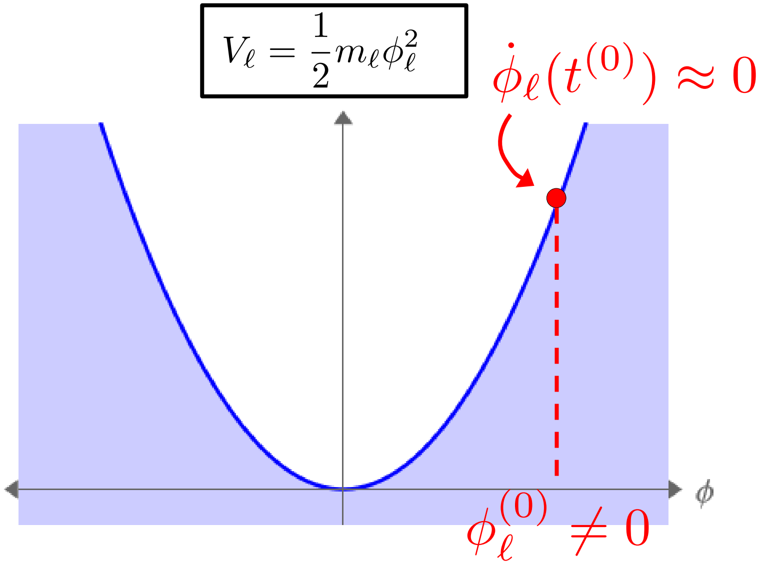

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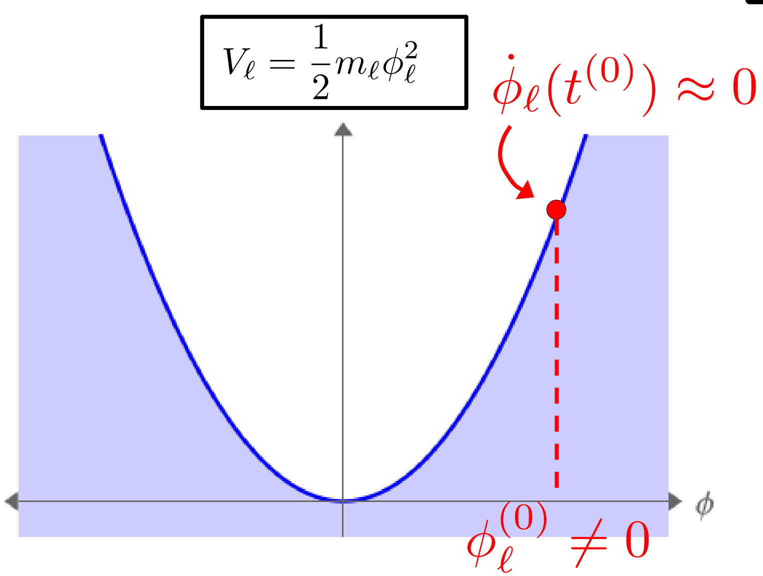

- For a given mass spectrum, the overall scale of the abundances can be parameterized by the ratio $\phi_0^{(0)}/M_P$, or, equivalently, by the ratio $H^{(0)}/m_{N\text{-}1}$.

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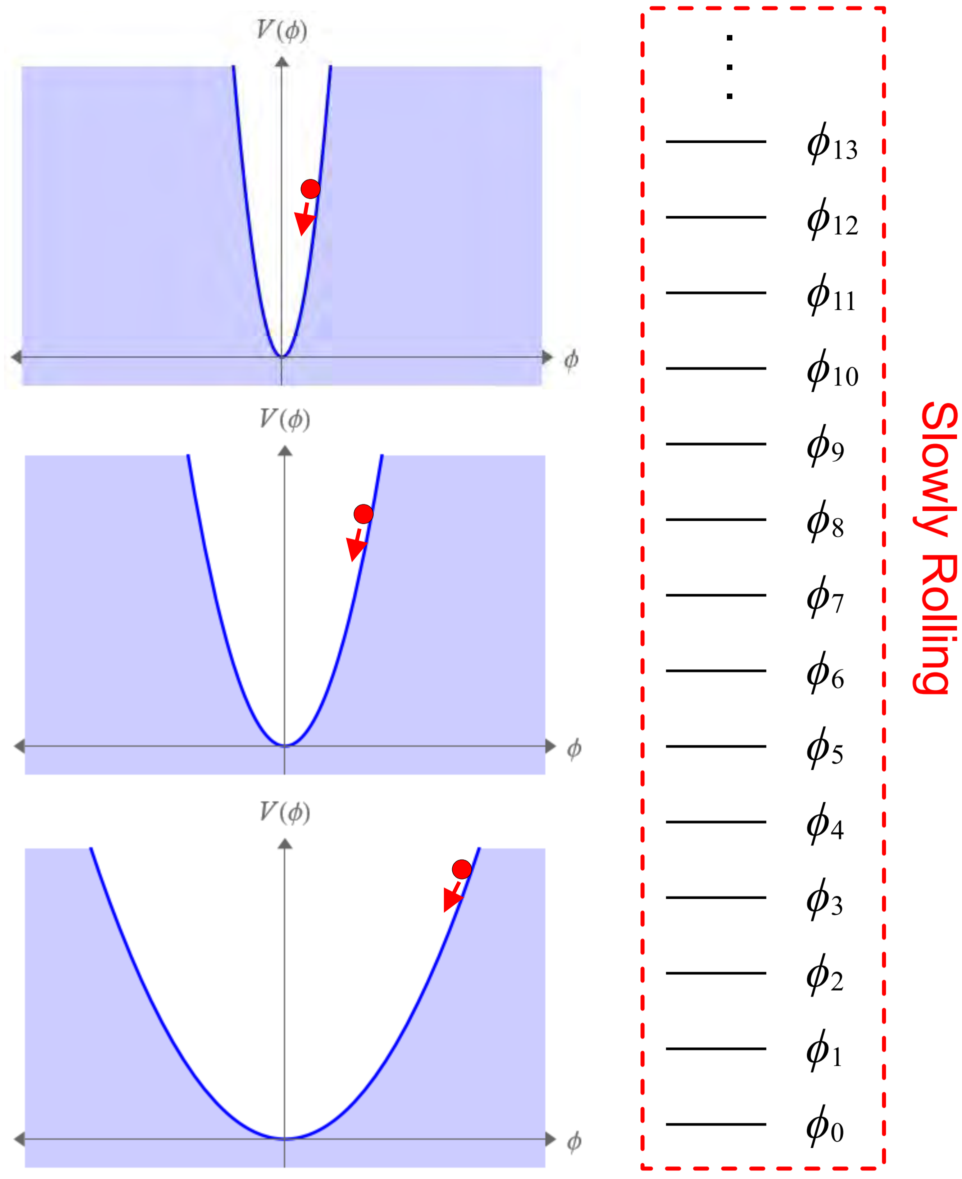

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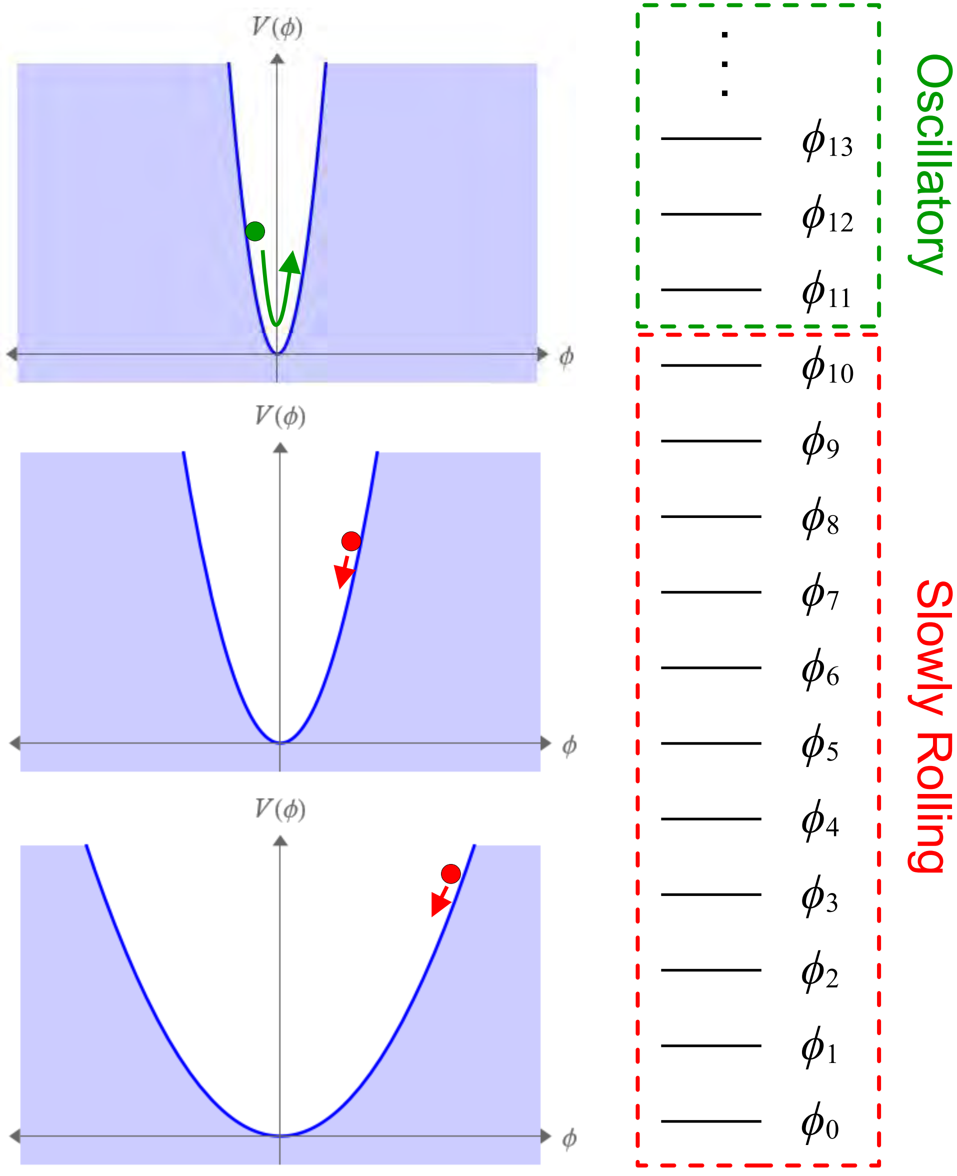

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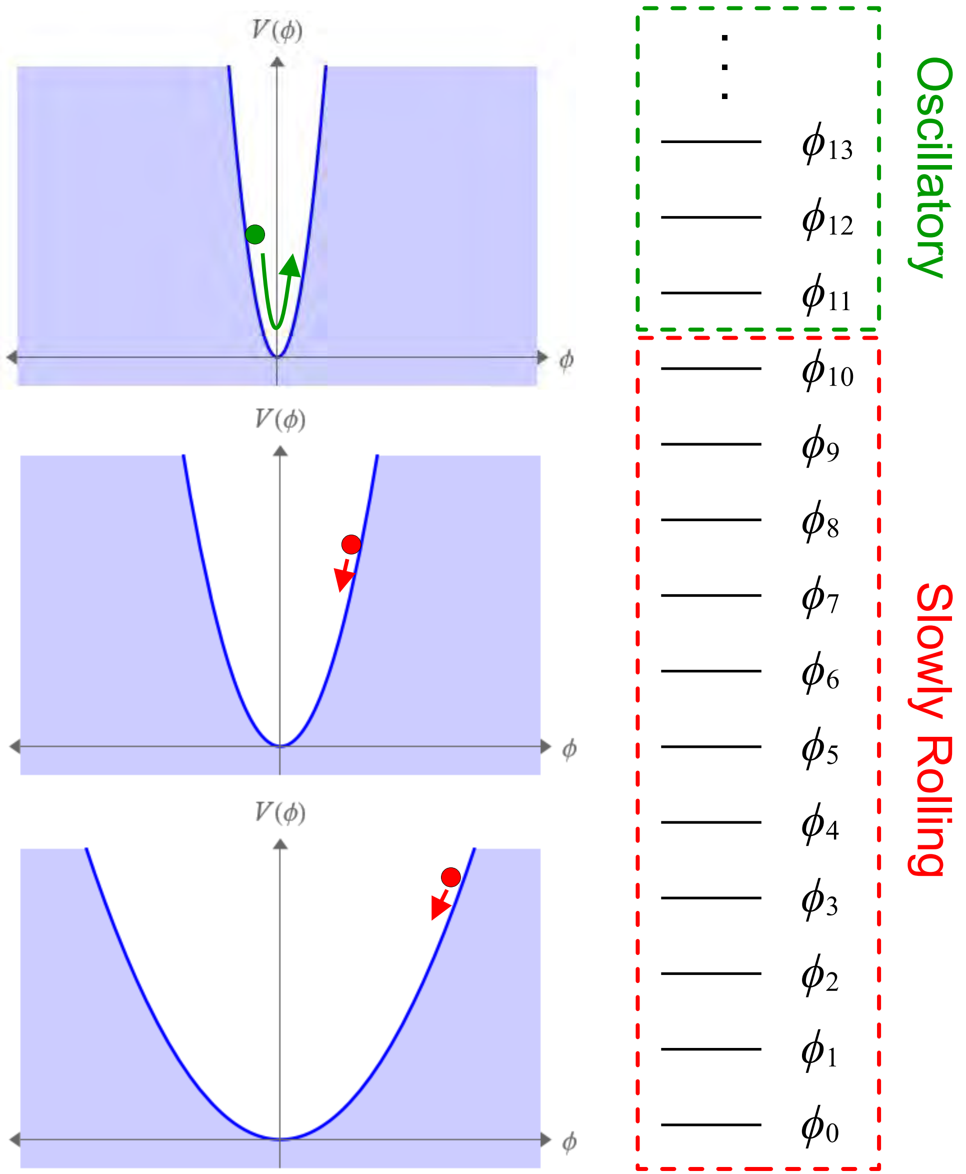

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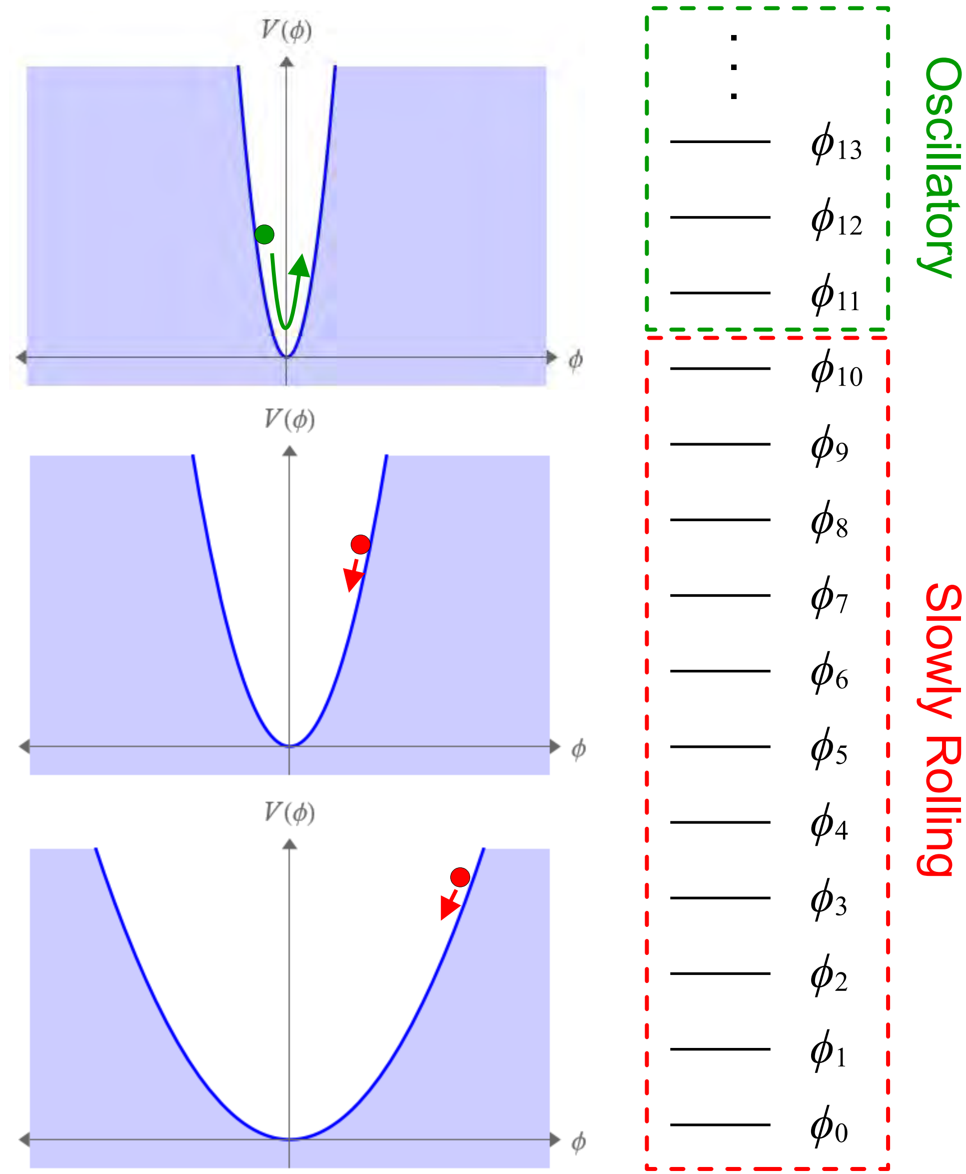

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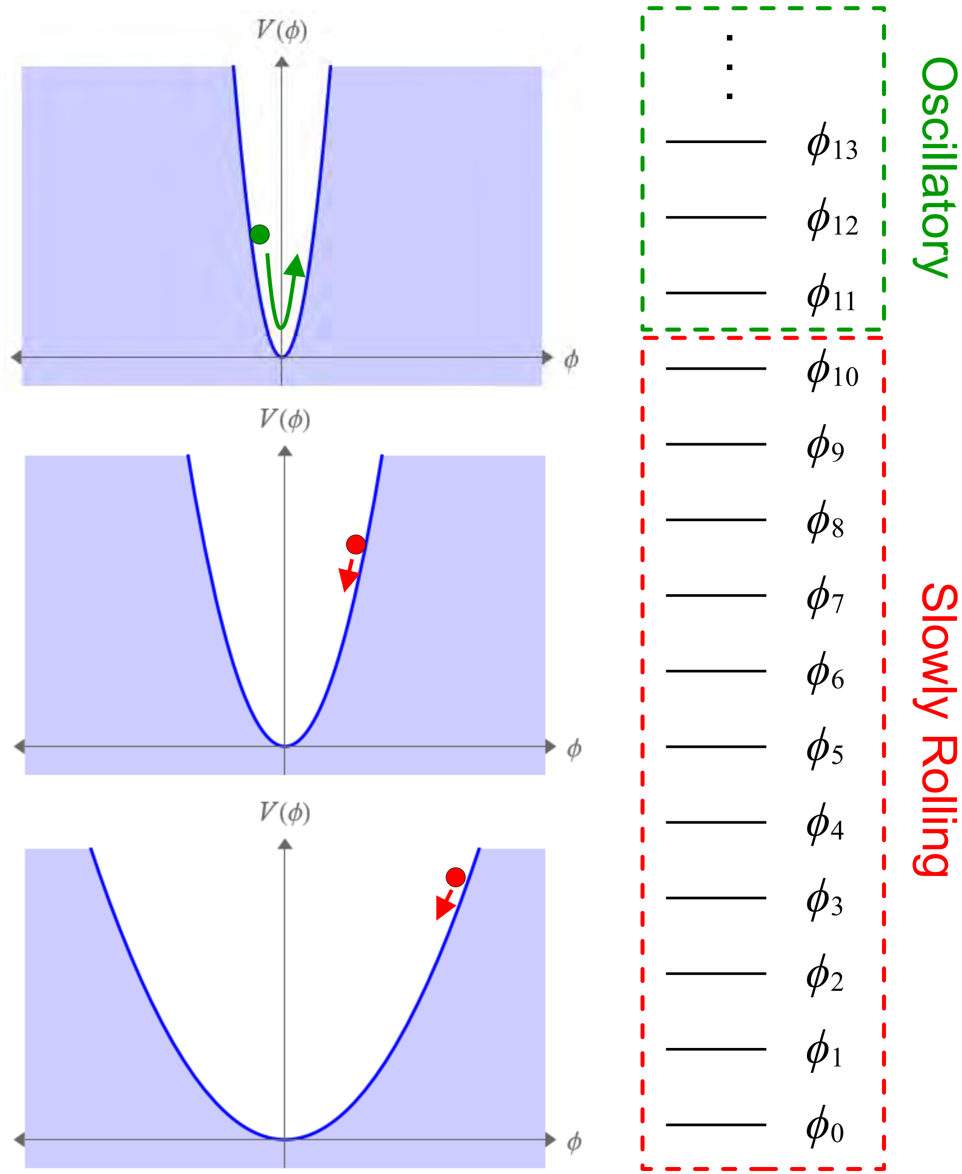

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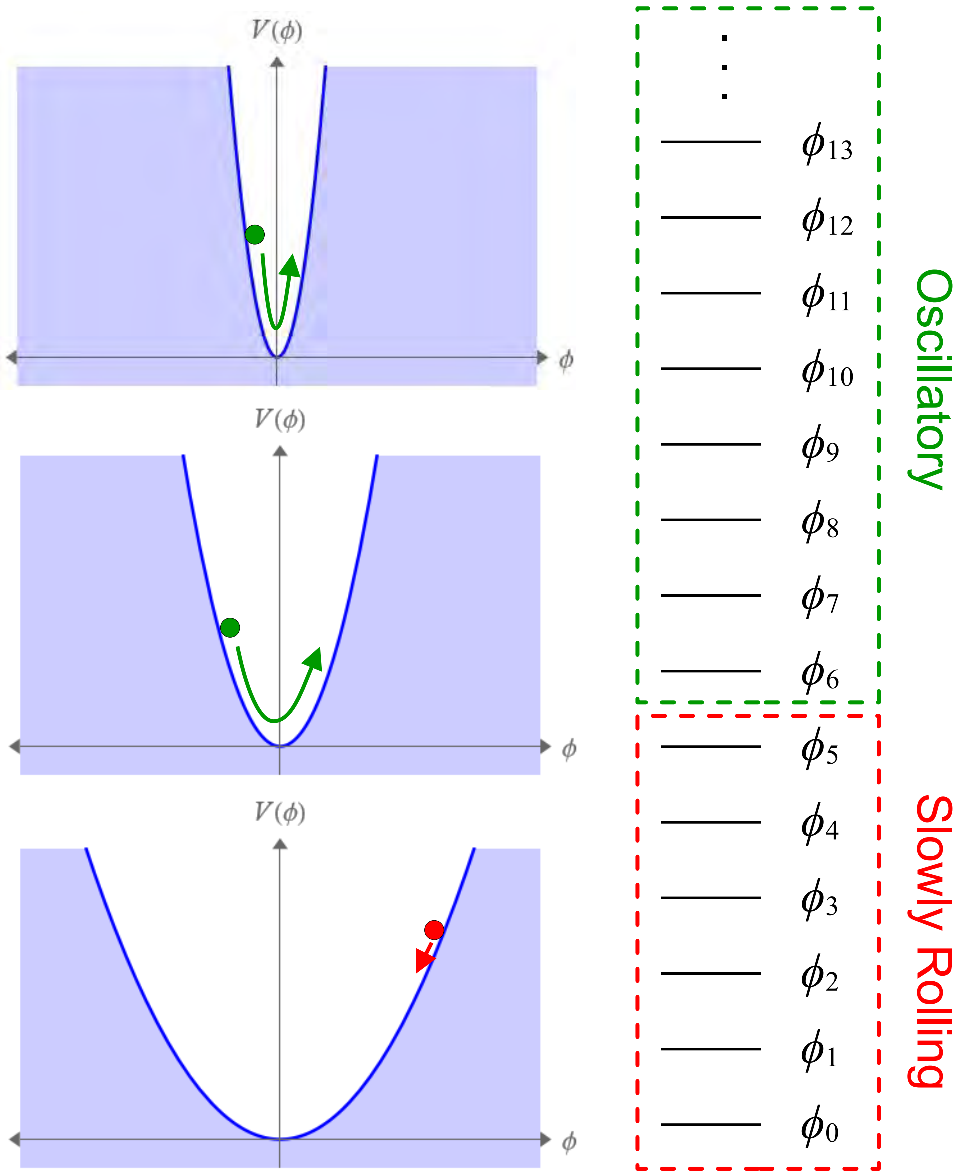

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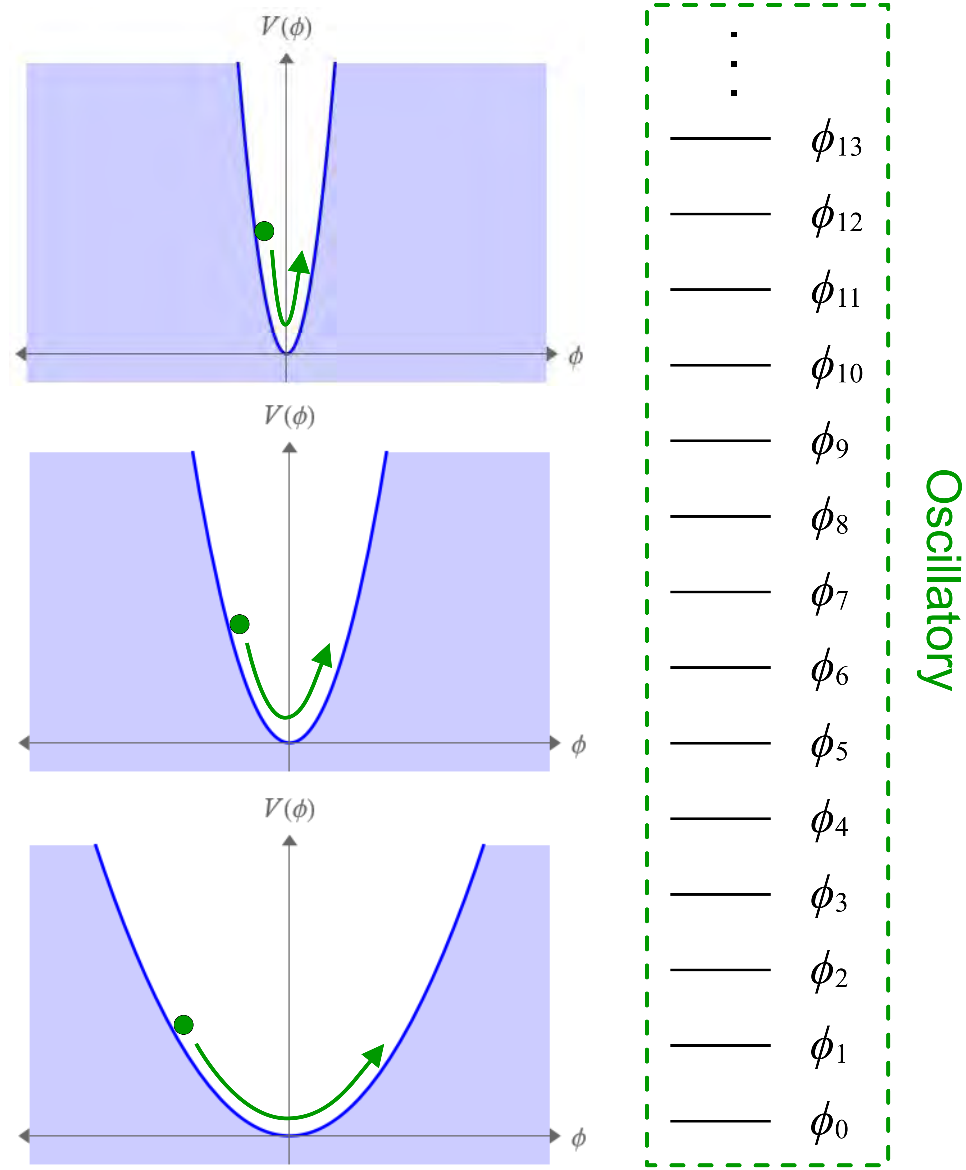

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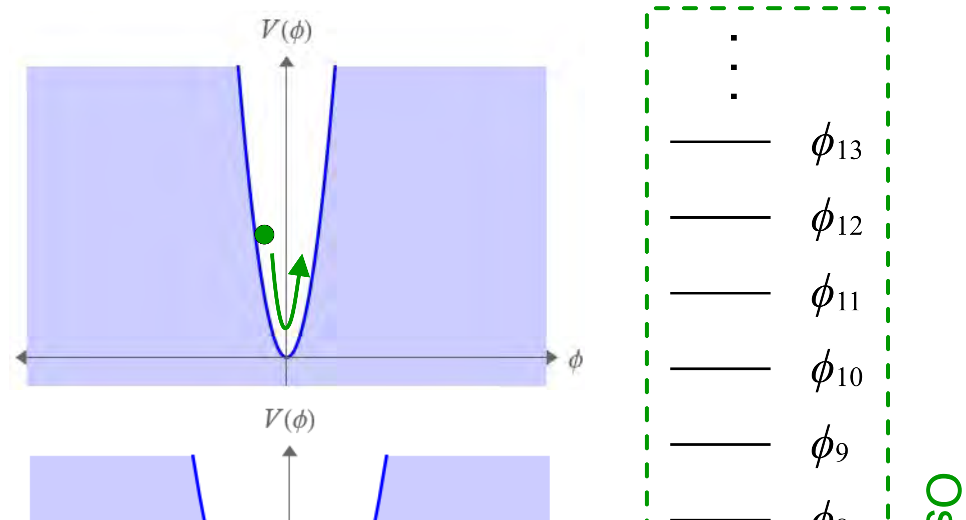

The Question:

Can we achieve a stasis between these slow-roll and oscillatory cosmological energy components, which act like vacuum energy and matter, respectively?

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Towers which satisfy this relation give rise to stasis. For $\delta = 1$, this corresponds to $\phi_\ell^{(0)} \sim \ell^{-1/2}$

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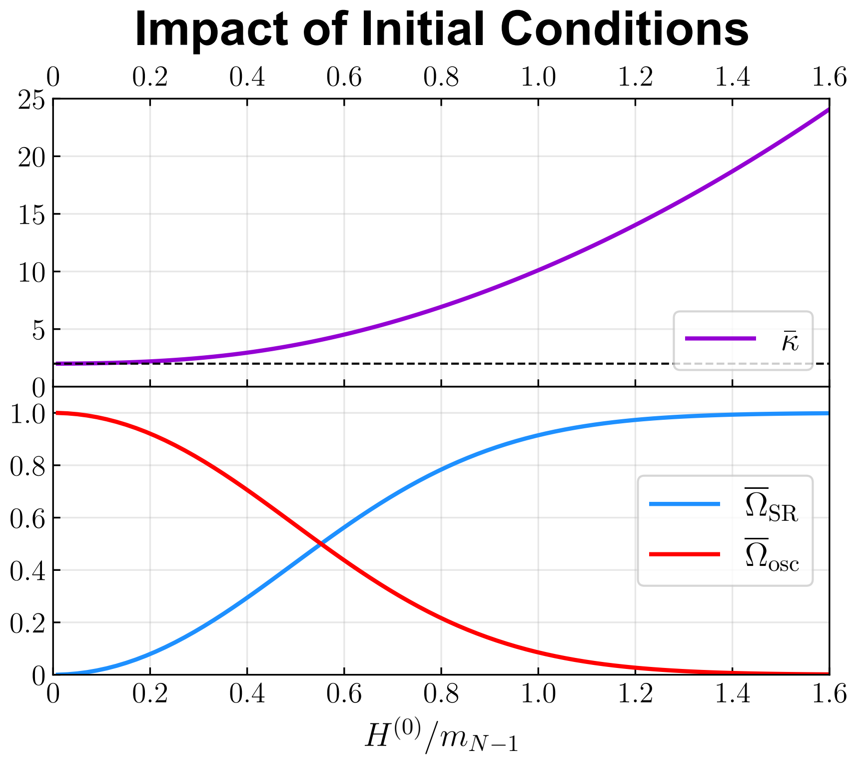

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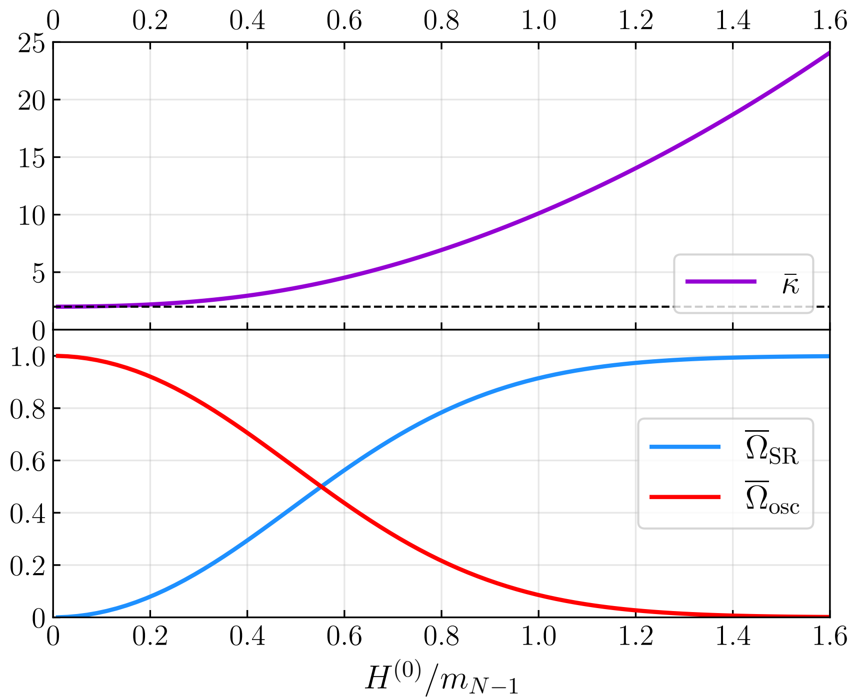

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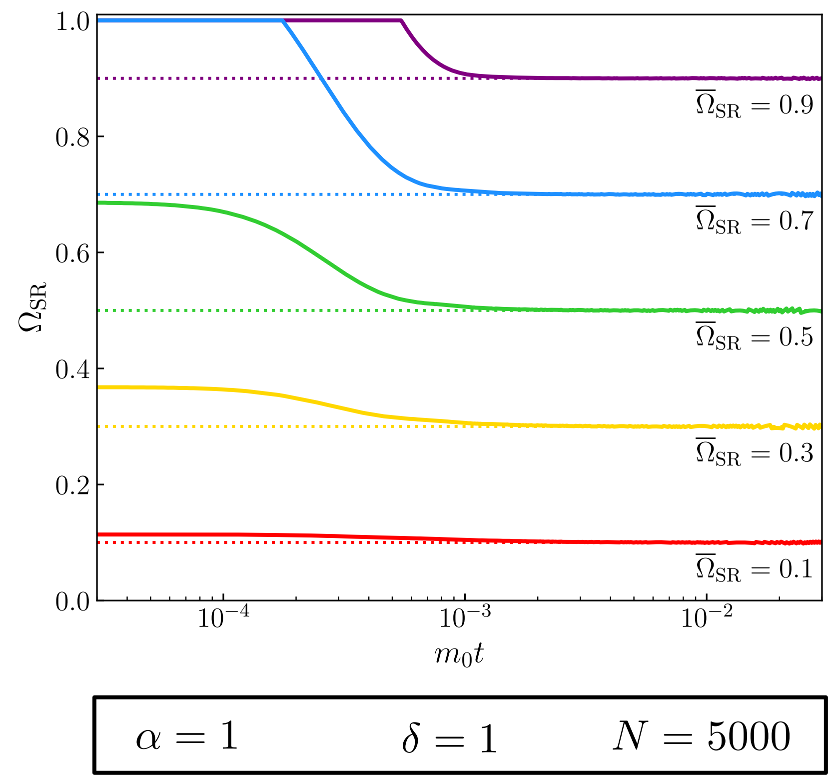

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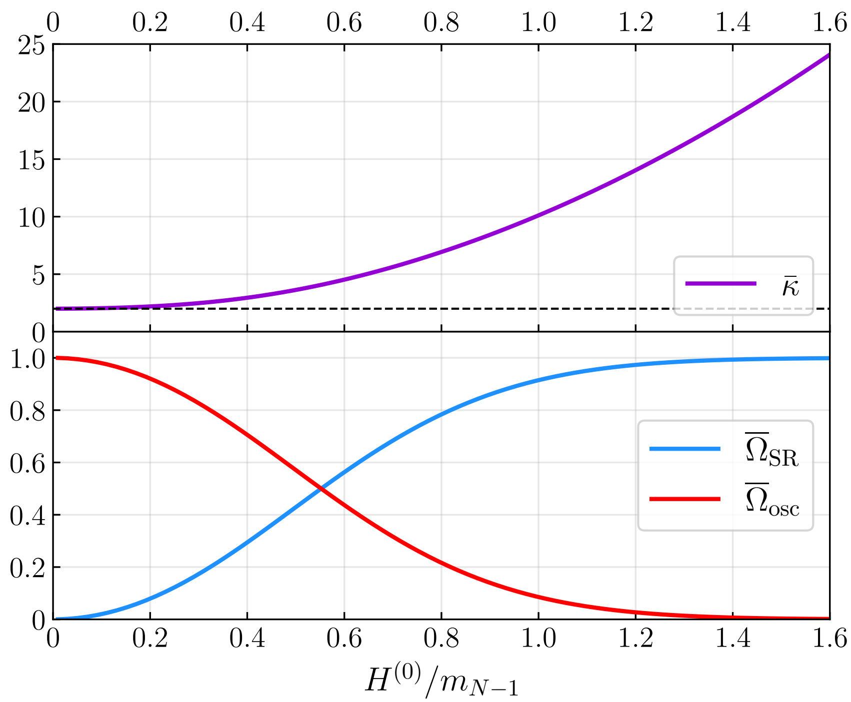

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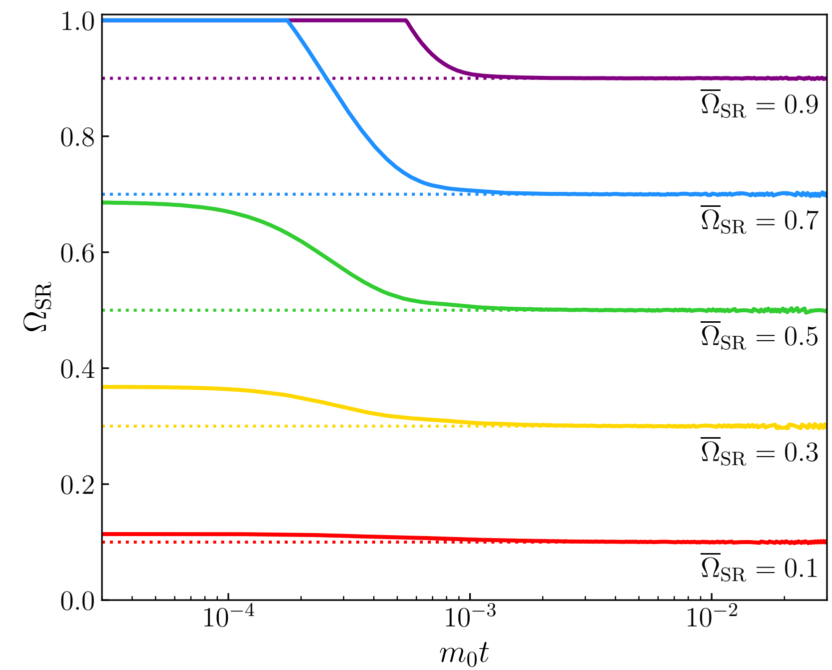

$\alpha = 1 \qquad \delta = 1 \qquad N = 5000$

Duration of Stasis

$$\mathcal{N}_s \approx \frac{\overline{\kappa}}{3}\left[\delta \log N + \log\left(\frac{\Delta m}{m_0}\right) + \log\left(\frac{3H^{(0)}}{2m_{N-1}}\right)\right]$$

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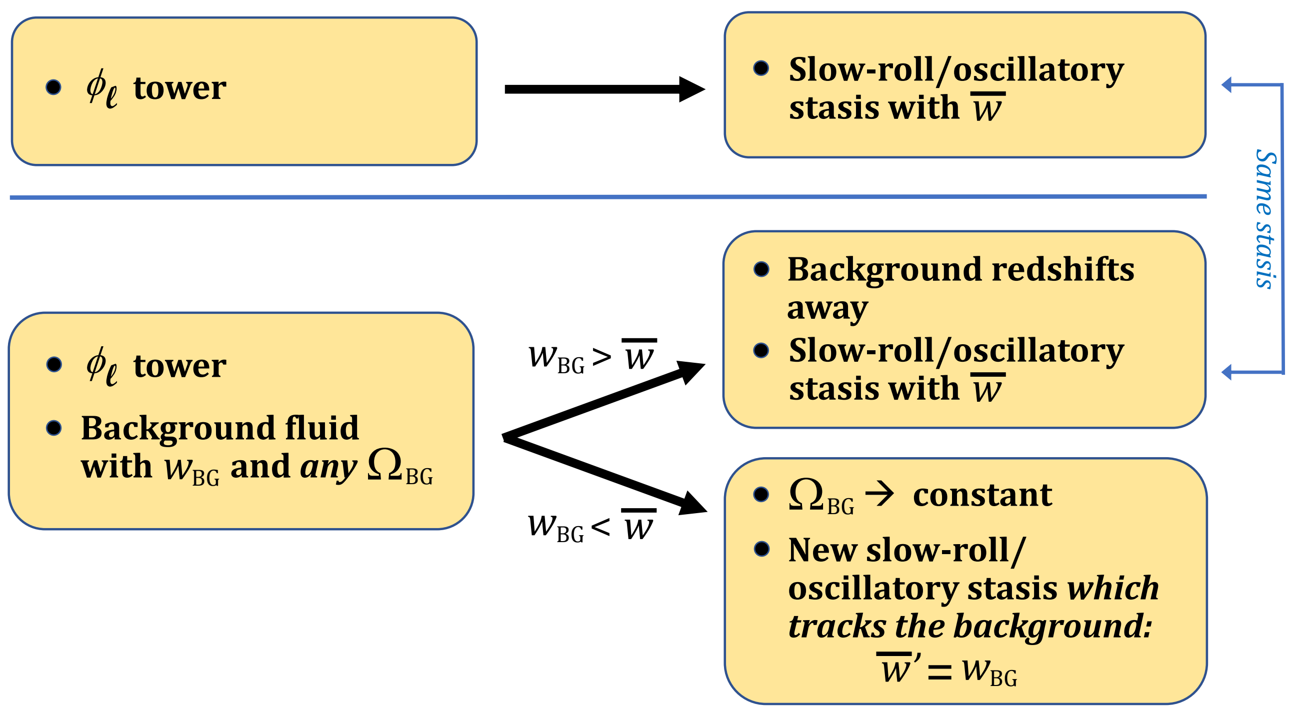
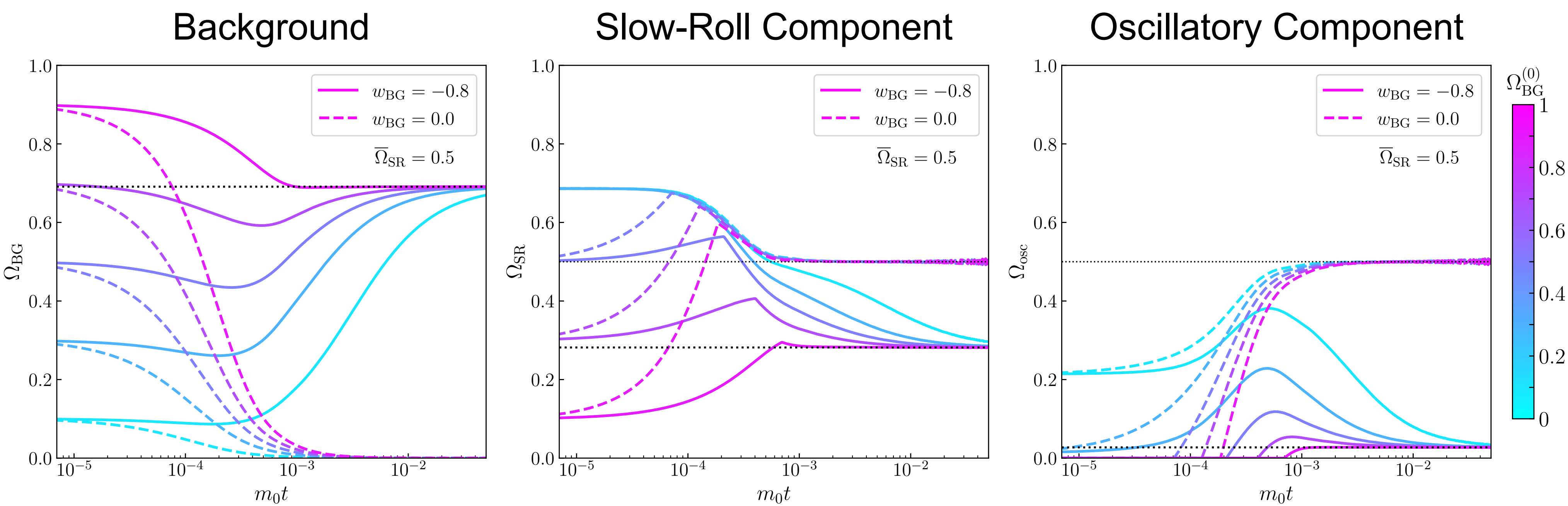
- It turns out that in the presence of such an energy component, the universe still evolves toward stasis (or something like it).
- However, the outcome depends on the relationship between $w_{\rm BG}$ and the equation-of-state parameter $\overline{w}$ the tower *would* have had during stasis if the background component weren't present.



Background Components and Tracking

- The **tracking phenomenon** which arises in wBG < w has not been observed in other realizations of stasis.



- These results provide insight about how the universe might **enter into** – or exit from – an stasis epoch involving dynamical scalars.

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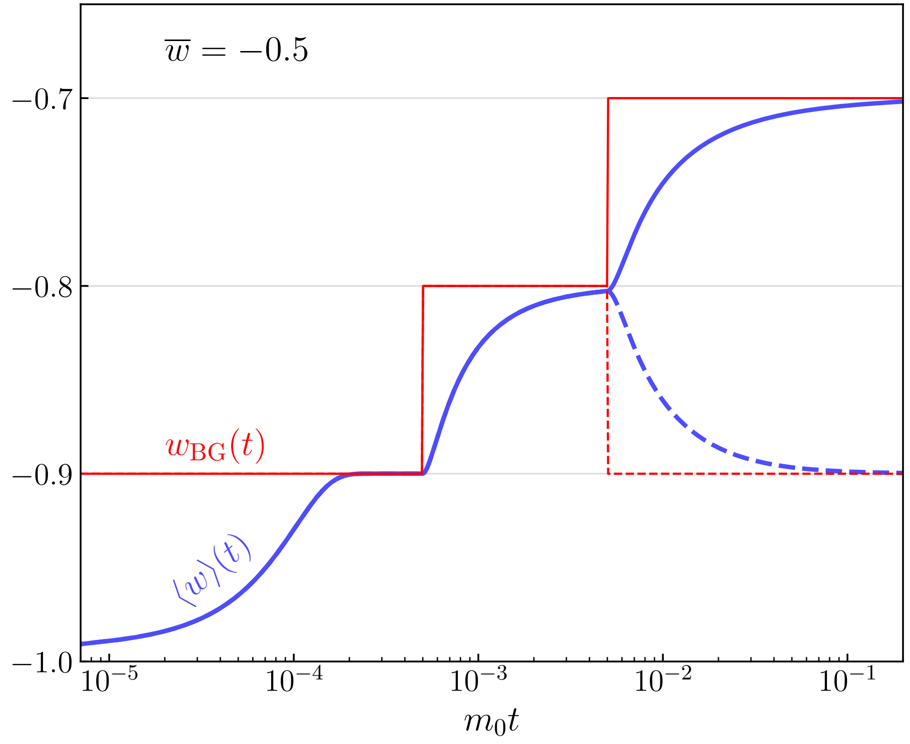
- It's also noteworthy that this tracking behavior is quite robust and persists even when w_{BG} **experiences an abrupt shift** (as might occur, for example, as the result of a phase transition).



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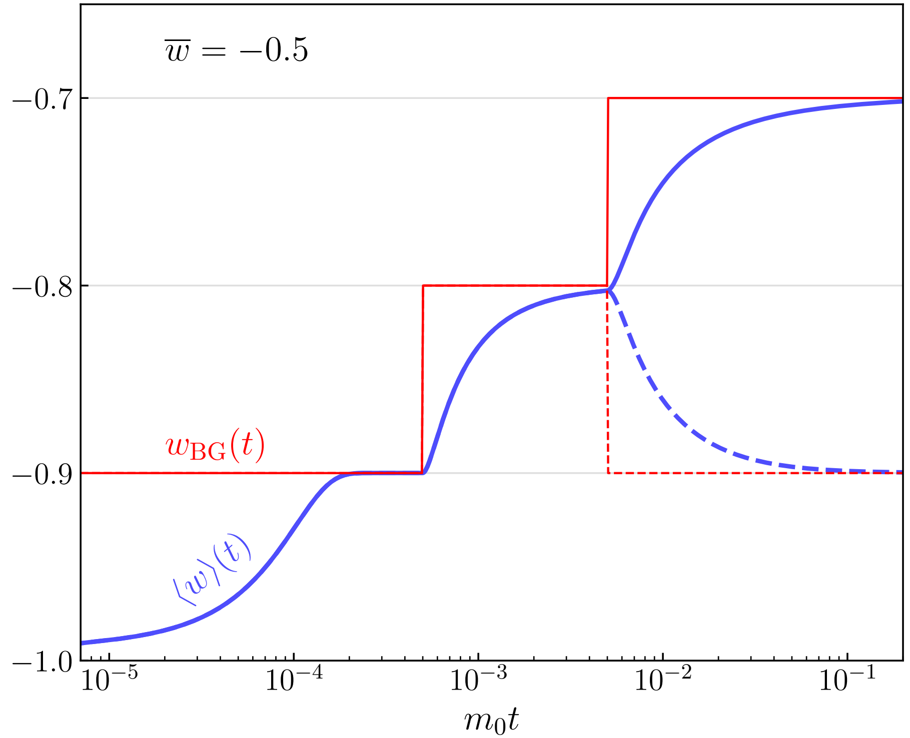
- It's also noteworthy that this tracking behavior is quite robust and persists even when $w_{\rm BG}$ **experiences an abrupt shift** (as might occur, for example, as the result of a phase transition).
- Indeed, as long as $w_{\rm BG}$ remains below $\overline{w}$, the tower's equation-of-state parameter $\langle w \rangle$ continues to evolve toward the new value of $w_{\rm BG}$ after the shift, regardless of whether this shift is positive or negative.



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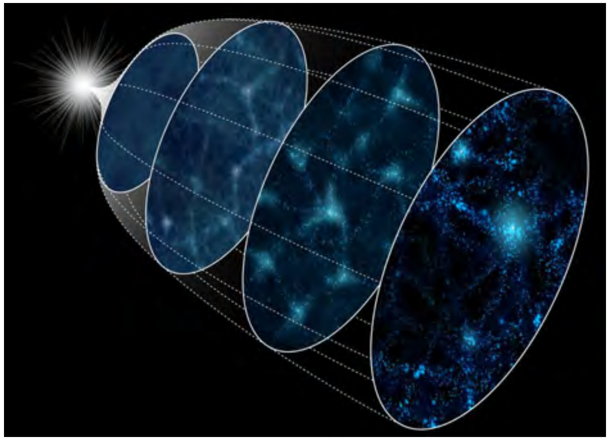

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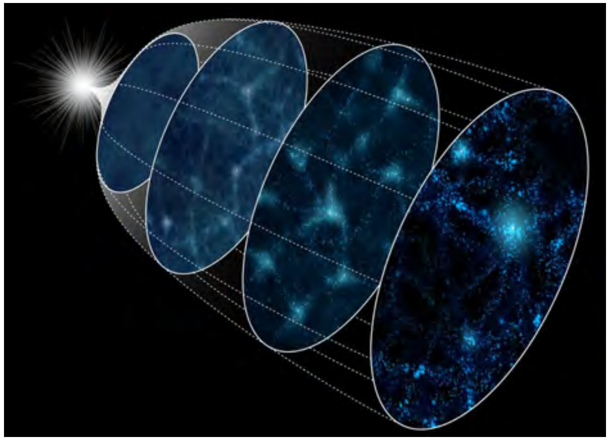

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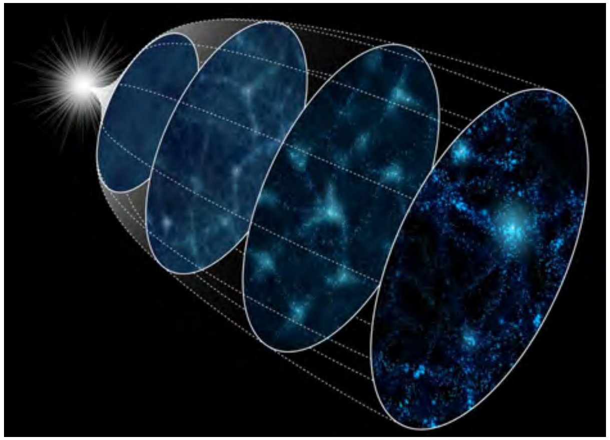

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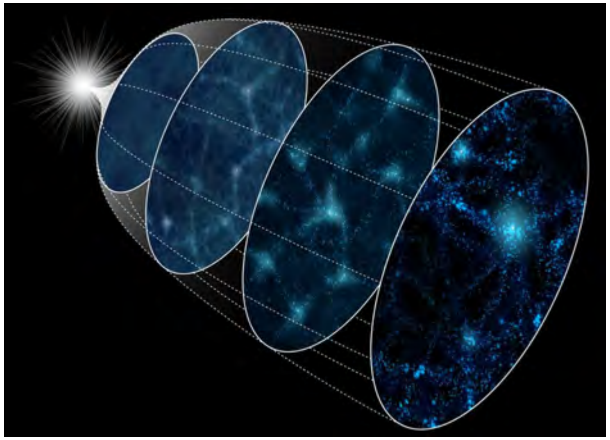

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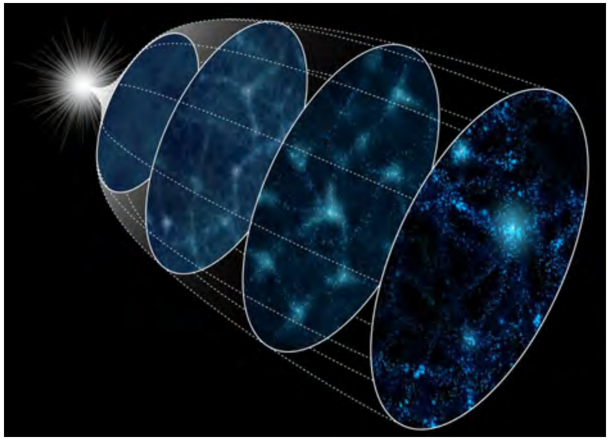

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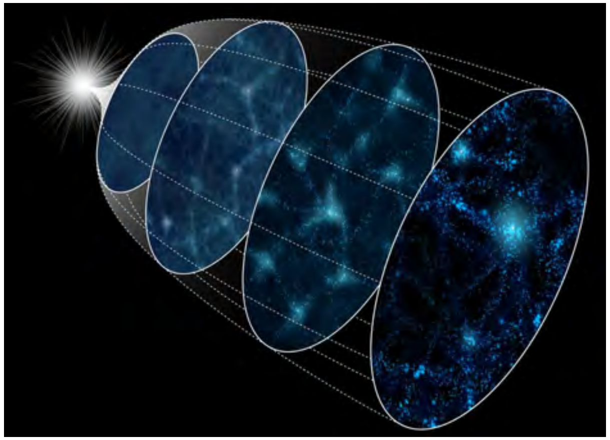

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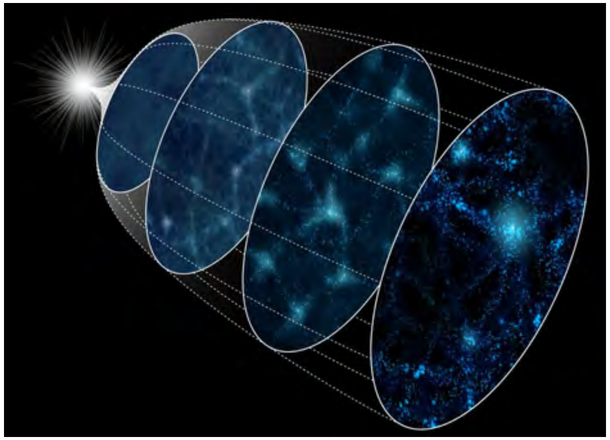

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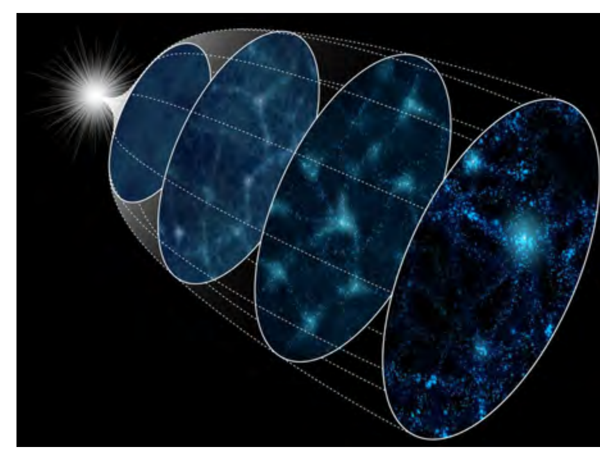

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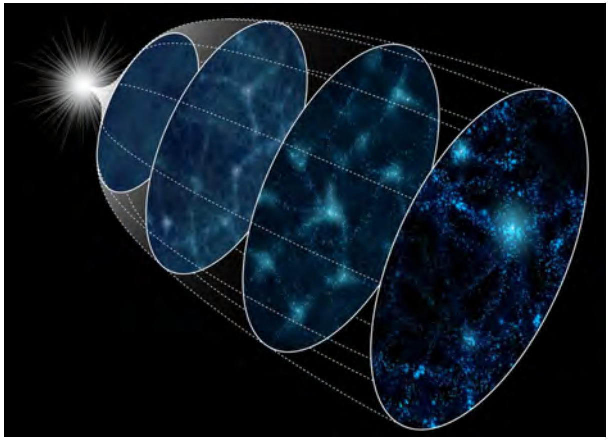

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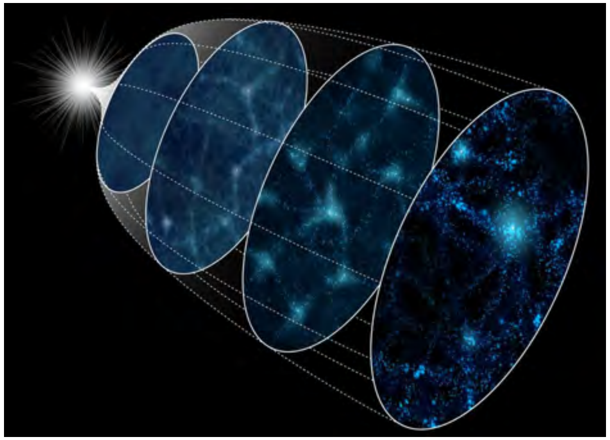

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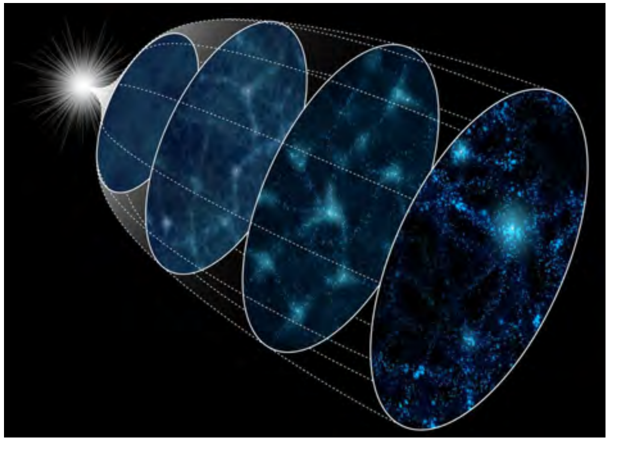

This is an intriguing possibility – and one that warrants further exploration!

Summary

- ***Stable, mixed-component cosmological eras*** – *i.e.* ***stasis eras*** – are indeed a viable cosmological possibility – and one that can arise naturally in many extensions of the Standard Model.
- A **tower of scalar fields** which undergo a transition from overdamped to underdamped evolution can give rise to stasis.
- Stasis itself is an **attractor** in these systems, but several fundamental characteristics of the stasis epoch toward which the universe evolves depend on the initial conditions.
- In the presence of an additional background component with equation-of-state parameter $w_{\rm BG}$, the tower exhibits a **tracking behavior** in which its own equation-of-state parameter evolves toward $w_{\rm BG}$.