Dark energy without fine tuning

arXiv:1807.04359

"Dark energy as a remnant of inflation and electroweak symmetry breaking"

arXiv:1905.00045

"Dark energy without fine tuning"

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COSMO-19

Aachen

Outline

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Outline

Problems with ρ_Λ

The Einstein equation

$$G_{\mu\nu} M_{\mathrm{P}}^2 = T_{\mu\nu} - g_{\mu\nu} \rho_\Lambda$$

$$\rho_\Lambda \equiv \Lambda_0 M_{\mathrm{P}}^2 + \text{'slow' fields} + \text{vacuum energy}$$

- Observations consistent with:

$$\rho_\Lambda^{\mathrm{obs}} \approx 2.6 \cdot 10^{-47} \mathrm{GeV}^4$$

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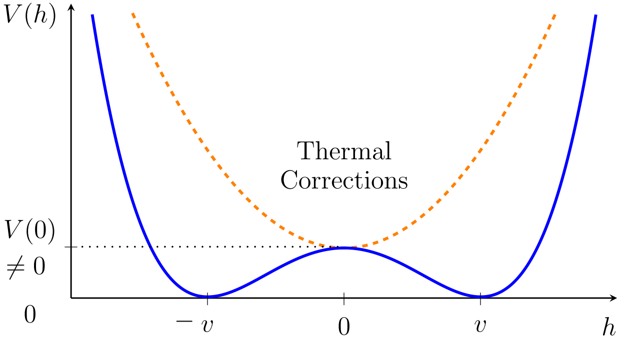
The quintessentially incorrect calculation!

The Higgs vacuum energy

The Higgs potential:

$$V(h) = \frac{\lambda}{4}\left(h^2 - v^2\right)^2$$



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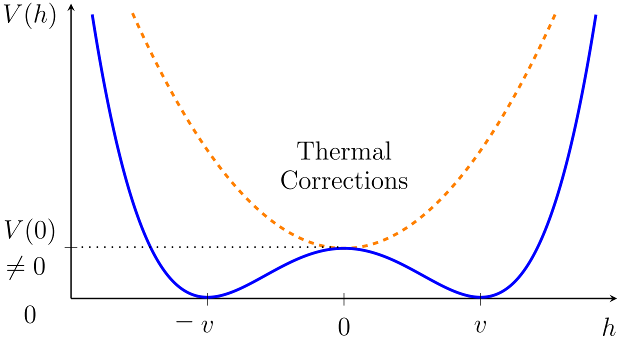

$$V(h_{\rm min}) = \begin{cases} V(0) = \frac{\lambda}{4} v^4\,, & T > T_{\rm EW} \\ V(v) = 0\,, & T < T_{\rm EW} \end{cases} \quad \Rightarrow \quad \Delta V = \frac{\lambda}{4} v^4 \sim 10^{55}\, \rho_\Lambda^{\rm obs}$$

Severe fine tuning! (but not of $\mathcal{O}(10^{120})$)

Dark energy sourced by fields

- Postulate a field with $V(\phi)$ and a cancellation:

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Quintessence: [Wetterich (87); Ratra (87); Peebles (87)]

Pros

- Avoids fine tuning of Λ_0

Cons

- $m_\phi \sim 10^{-33}$eV
- $\lambda_\phi \sim 0$ (no 5th forces)
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A very active field of research

The conspiracy of scales

The conspiracy of scales

- Starobinsky inflation and the Higgs

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- The *scalaron* ϕ couples to $V(h)$!

$$\sqrt{-g}\mathcal{L} = \frac{M_{\rm P}^2}{2}R - \frac{1}{2}(\partial_\mu\phi)^2 - \alpha^2 M_{\rm P}^4\left(1 - e^{-\sqrt{\frac{2}{3}}\phi/M_{\rm P}}\right)^2 - e^{-\sqrt{\frac{8}{3}}\phi/M_{\rm P}}V(h)$$

- **Minimum at $\phi \neq 0$ when $T > T_{\rm EW}$:**

$$e^{\sqrt{\frac{2}{3}}\phi_0/M_{\rm P}} = 1 + \frac{\lambda v^4}{4\alpha^2 M_{\rm P}^4}$$

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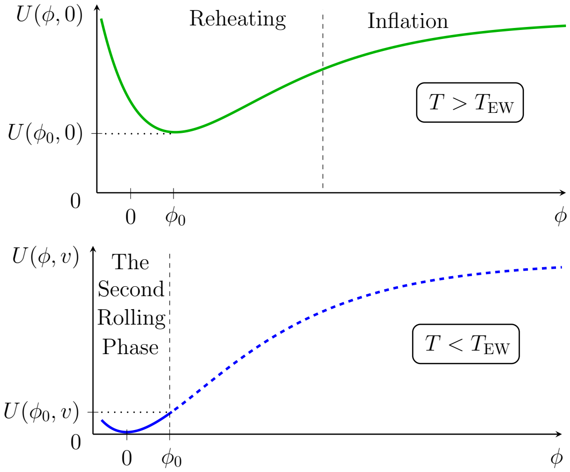

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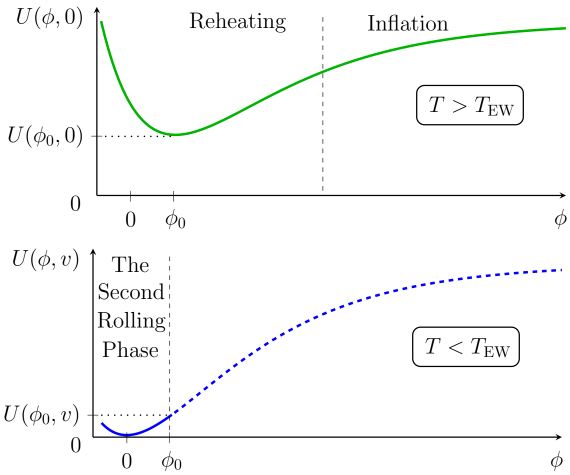

- Initial potential energy at $T = T_{\mathrm{EW}}$

$$U(\phi_0, v) \approx \frac{V^2(0)}{\alpha^2 M_P^4} = \frac{\lambda^2 v^8}{16\alpha^2 M_P^4} \approx 4.0 \cdot 10^{-48}\,\mathrm{GeV}^4$$

The conspiracy of scales

- A (very) surprising relation:

$$\rho_\Lambda \approx \frac{v^8}{\mathcal{P}_\zeta M_\mathrm{P}^4}$$

$(v \approx 246\text{GeV},\ \mathcal{P}_\zeta \approx 2.2 \cdot 10^{-9},\ M_\mathrm{P} \approx 2.44 \cdot 10^{18}\text{GeV})$

- Similar to

$$v \approx \sqrt{\rho_\Lambda^{1/4} M_\mathrm{P}}$$

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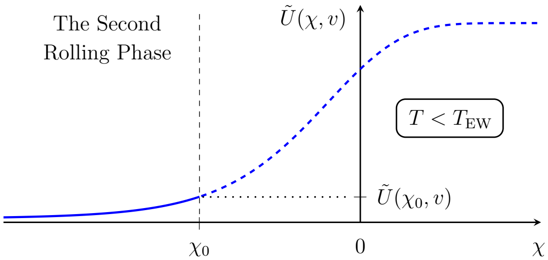
- Unfortunately, the scalaron is heavy

$$m_\phi \gg H$$

Need to prevent further rolling of ϕ!

The bait-and-switch

- Make kinetic term non-canonical



$$(\partial_\mu \phi)^2 \quad \longrightarrow \quad \left(b\frac{M_{\rm P}}{\phi}\right)^2 (\partial_\mu \phi)^2 \equiv (\partial_\mu \chi)^2$$

- Potential gets stretched

$$\tilde{U}(\chi_0, v) \sim \rho_\Lambda \,, \quad \tilde{U}''(\chi_0, v) \sim H^2$$

The bait-and-switch

- Minimum at $\chi_0 \sim 10^2 M_\mathrm{P}$

$\Rightarrow$ Potential cannot be stretched before the minimum is reached

Bait-and-switch mechanism: [arXiv:1807.04359]

Trigger stretching via the Higgs at $T = T_\mathrm{EW}$

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Pros

- New parameters $\mathcal{O}(1)$
- All couplings get suppressed (no 5th forces)
- No sensitivity to initial conditions

Cons

- No top-down motivation
- Higgs coupling sensitive to colliders bounds

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Let's try a multi-field model!

Assisted relaxation

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- A model with *two* fields, $\mathcal{L} = \mathcal{L}_\phi + \mathcal{L}_\sigma$;   [arXiv:1807.04359]
  - Inflaton, $V(\phi) = \frac{1}{2}m^2\phi^2$, and 'darkon' with:

$$-\sqrt{-g}\mathcal{L}_\sigma = b^2 \frac{1}{2} \frac{M_{\rm P}^2}{\phi^2 + \sigma^2} \partial_\mu \sigma \partial^\mu \sigma + \frac{1}{2} m^2 \sigma^2 + c \frac{\sigma}{M_{\rm P}} V(h)$$

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- After inflation $(\phi = 0)$ $\Rightarrow$ σ is light $\Rightarrow$ can source **DE**

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Same attractive features as previously, but avoids collider bounds

Benefits from multiple fields

- Many realizations when

$$\mathcal{L}_\phi = -G_{ab}(\phi)\partial_\mu\phi_a\partial^\mu\phi_b - V(\phi)$$

$\Rightarrow$ Rich model-building possibilities

- Talks: Achucarro, Sfakianakis, Turzynski, Welling
- Posters: Fumagalli, Christodoulis, Chiovoloni, Pinol, Ronayne, Wang

- Generalized Einstein theories

$$\mathcal{L}_{\rm GE} = \frac{M_{\rm P}^2}{2}R - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - e^{-2F(\phi)}\frac{1}{2}\partial_\mu\sigma\partial^\mu\sigma - U(\phi,\sigma)$$

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Thank You!