

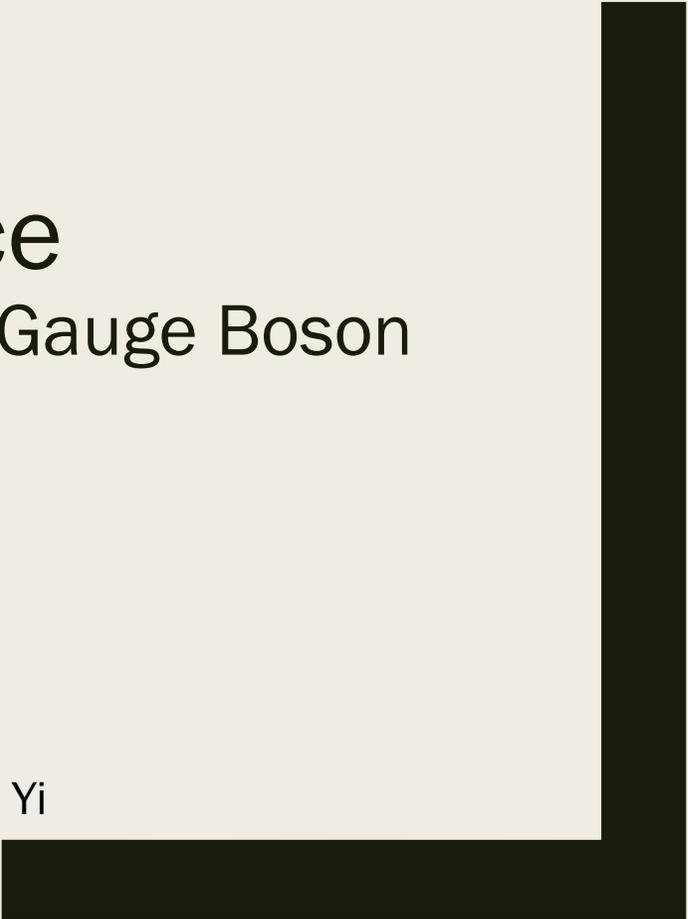


Gauged Quintessence

-The Interplay Between Dark Energy and Gauge Boson

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Gauged Quintessence [2208.09229]
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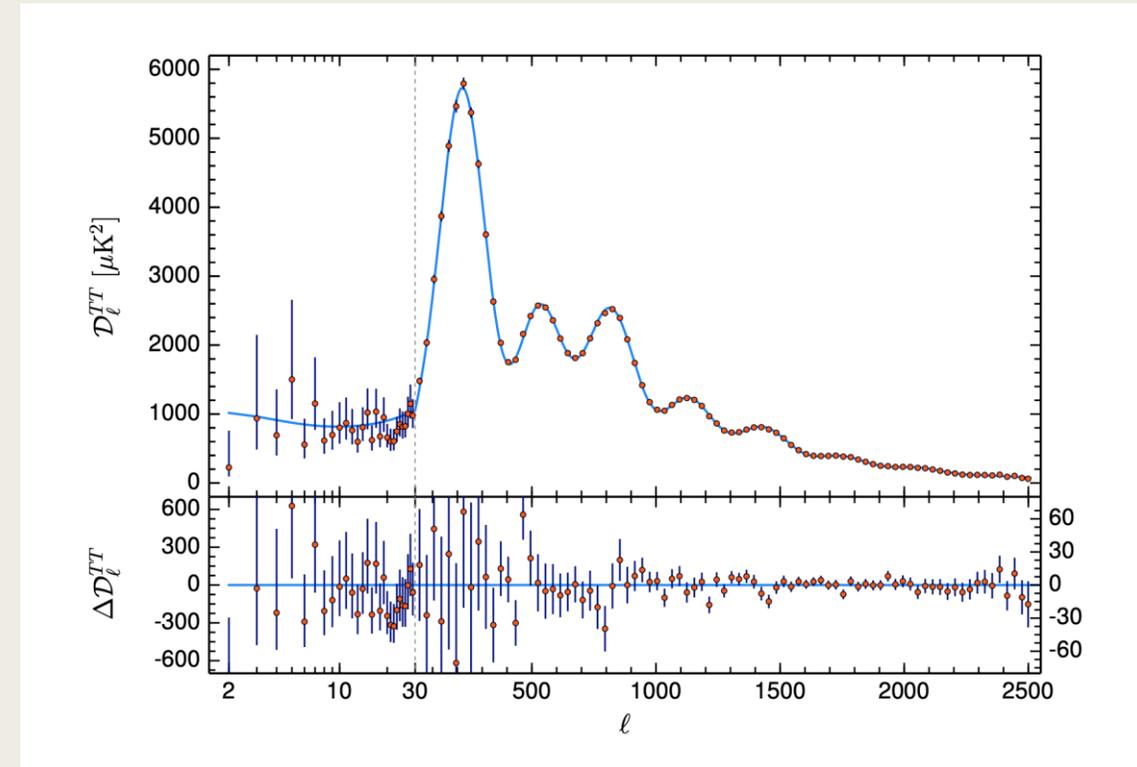
- Introduction
- Gauged quintessence model
- Remark on Hubble tension
- Summary

Invisible mysteries of the universe

Dark Energy
(69 %)

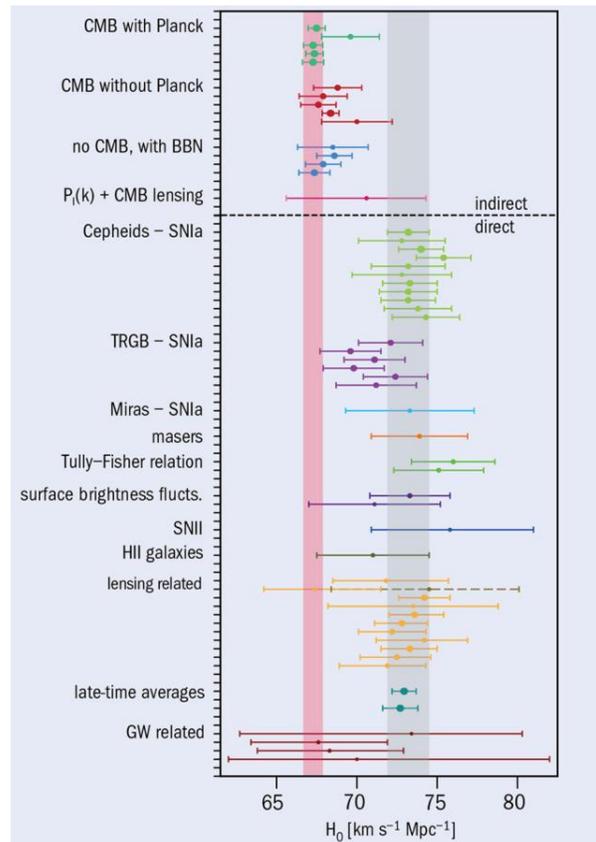
Dark Matter
(26 %)

Lambda-CDM Model



Λ CDM is not perfect

■ Hubble tension



Valentino et al CQG 38(2021)153001

■ Small scale problems

- Cusp/Core problem
- Missing satellite
- Too big to fail
- ... etc

Quintessence Dark energy

- The scalar field equation of motion

$$\mathcal{L} = -\frac{1}{2}\partial_\mu\phi\partial^\mu\phi - V(\phi) \quad \ddot{\phi} + 3H\dot{\phi} + \frac{\partial V}{\partial\phi} = 0$$

- Energy density, Pressure, Equation of state

$$\rho_\phi = \frac{\dot{\phi}^2}{2} + V(\phi) \quad p_\phi = \frac{\dot{\phi}^2}{2} - V(\phi) \quad w = \frac{p_\phi}{\rho_\phi} \quad \left(w \rightarrow \frac{-V(\phi)}{V(\phi)} = -1 \right)$$

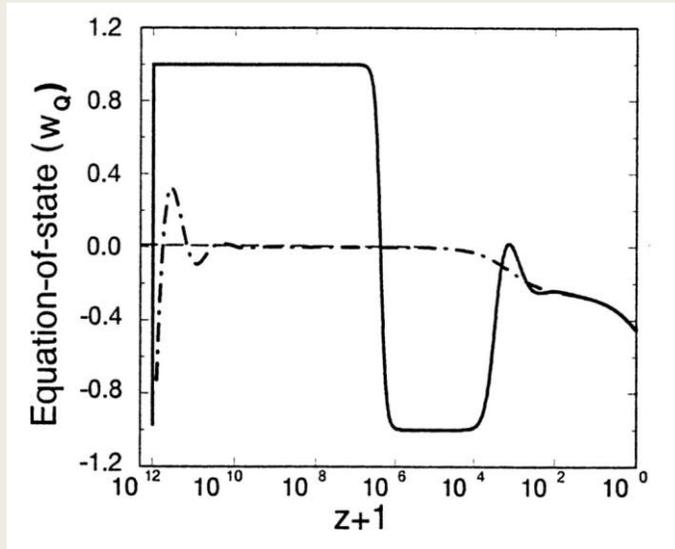
$\frac{\dot{\phi}^2}{2} \ll V(\phi)$

- Dark energy condition :

$$w < -1/3 \quad (\Lambda\text{CDM} : w = -1)$$

Tracking solution

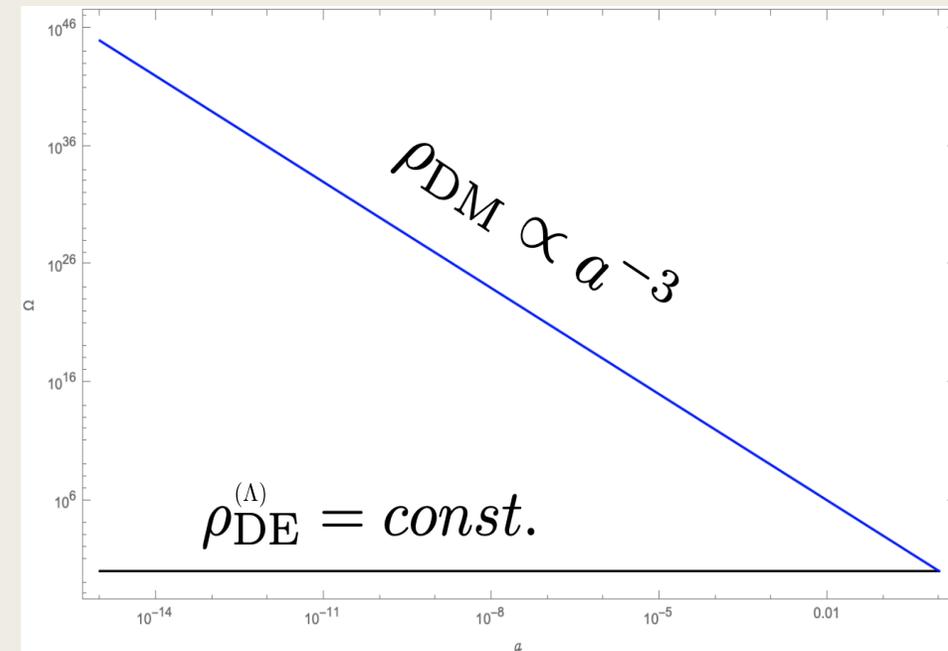
- Some of the potentials can give “Tracking solution” [Steinhardt, Wang, Zlatev Phys. Rev. D59\(1999\)123504](#)



< Late time solution converges

- Coincidence problem

Fine tuning of the initial condition is not required.



Gauged Quintessence

- Quintessence gauged under U(1) (quintessence + Dark gauge boson)

$$\mathcal{L} = -|D_\mu \Phi|^2 - V_0(\Phi) - \frac{1}{4} \mathbb{X}_{\mu\nu} \mathbb{X}^{\mu\nu}$$

$$\begin{aligned}\Phi &= \frac{1}{\sqrt{2}} \phi e^{i\eta} \\ \mathbb{X}_{\mu\nu} &= \partial_\mu \mathbb{X}_\nu - \partial_\nu \mathbb{X}_\mu \\ D_\mu &= \partial_\mu + ig_X \mathbb{X}_\mu\end{aligned}$$

- In Unitary gauge, ($\eta = 0$, $X_\mu = \mathbb{X}_\mu + \frac{1}{g_X} \partial_\mu \eta$)

$$\mathcal{L} = -\frac{1}{2} (\partial_\mu \phi)^2 - \frac{1}{4} X_{\mu\nu} X^{\mu\nu} - V_0(\phi) - \frac{1}{2} g_X^2 \phi^2 X_\mu X^\mu$$

- Ratra-Peebles potential [Ratra and Peebles Phys. Rev. D 37\(1988\)3406](#)

$$V_0(\phi) = \frac{M^{\alpha+4}}{\phi^\alpha}$$

Quantum corrections

$$V_{\text{eff}} = V_0 + \frac{1}{2}g_X^2 X_\mu X^\mu \phi^2 + \frac{\Lambda^2}{32\pi^2} V_0'' + \frac{(V_0'')^2}{64\pi^2} \left(\ln \frac{V_0''}{\Lambda^2} - \frac{3}{2} \right) + \frac{3(m_X^2|_0)^2}{64\pi^2} \left(\ln \frac{m_X^2|_0}{\Lambda^2} - \frac{5}{6} \right)$$

$$m_\phi^2 = V_0'' + g_X^2 X_\mu X^\mu + \frac{\Lambda^2}{32\pi^2} V_0'''' + \frac{V_0'' V_0''''}{32\pi^2} \left(\ln \frac{V_0''}{\Lambda^2} - 1 \right) + \frac{9g_X^2 m_X^2|_0}{16\pi^2} \left(\ln \frac{m_X^2|_0}{\Lambda^2} + \frac{1}{3} \right)$$

- Dark energy conditions

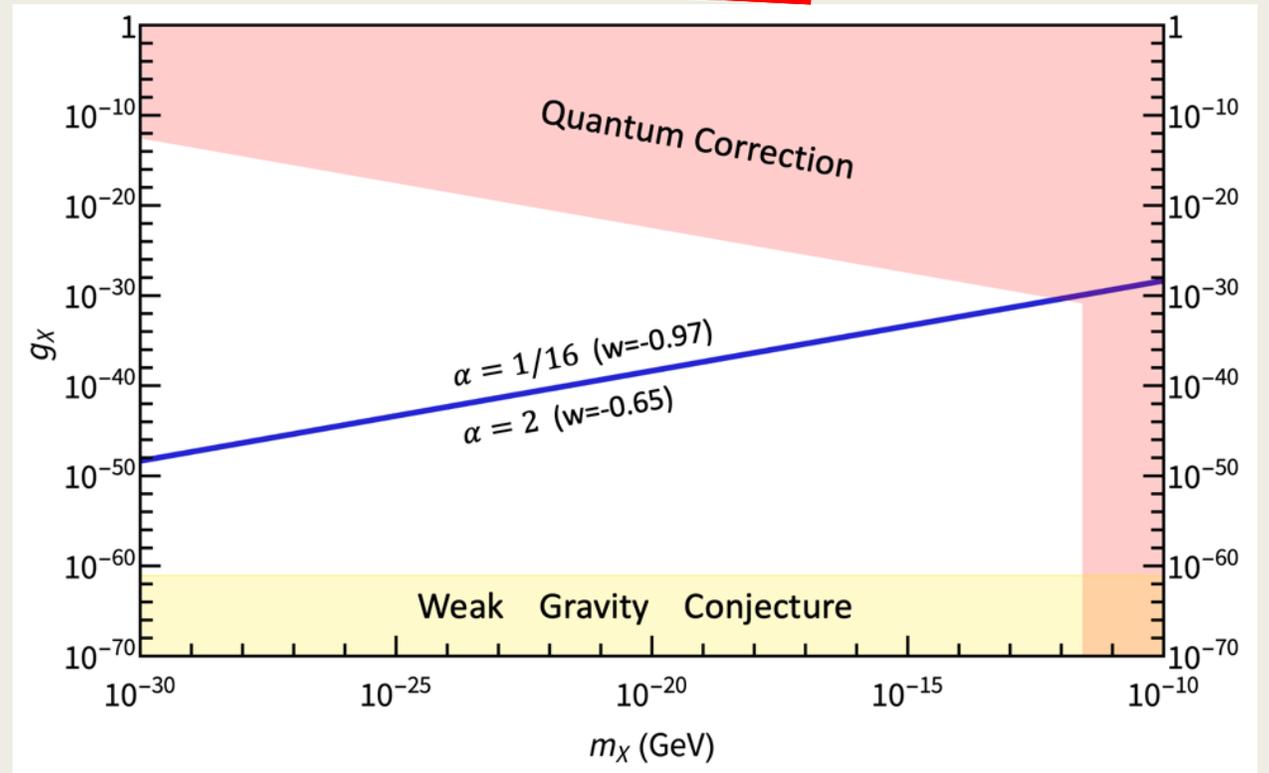
$$V_{\text{eff}} \sim 10^{-123} M_{Pl}^4 \sim 3 \times 10^{-47} \text{ GeV}^4$$

$$m_\phi \lesssim H_0 \sim 10^{-42} \text{ GeV}$$

- Weak Gravity conjecture

[Arkani-Hamed et al. JHEP06\(2007\)060](#)

$$\frac{m_\phi}{M_{pl}} \lesssim g_X$$



Gauge Potential

$$\mathcal{L} = -\frac{1}{2}(\partial_\mu\phi)^2 - \frac{1}{4}X_{\mu\nu}X^{\mu\nu} - V_0(\phi) - V_{1\text{-loop}}(\phi) - \frac{1}{2}g_X^2\phi^2 X_\mu X^\mu$$

- Additional potential of ϕ , and also, mass term of X

$$V_{\text{gauge}} = \frac{1}{2}g_X^2\phi^2 X_\mu X^\mu$$

- The tree level mass of ϕ , X

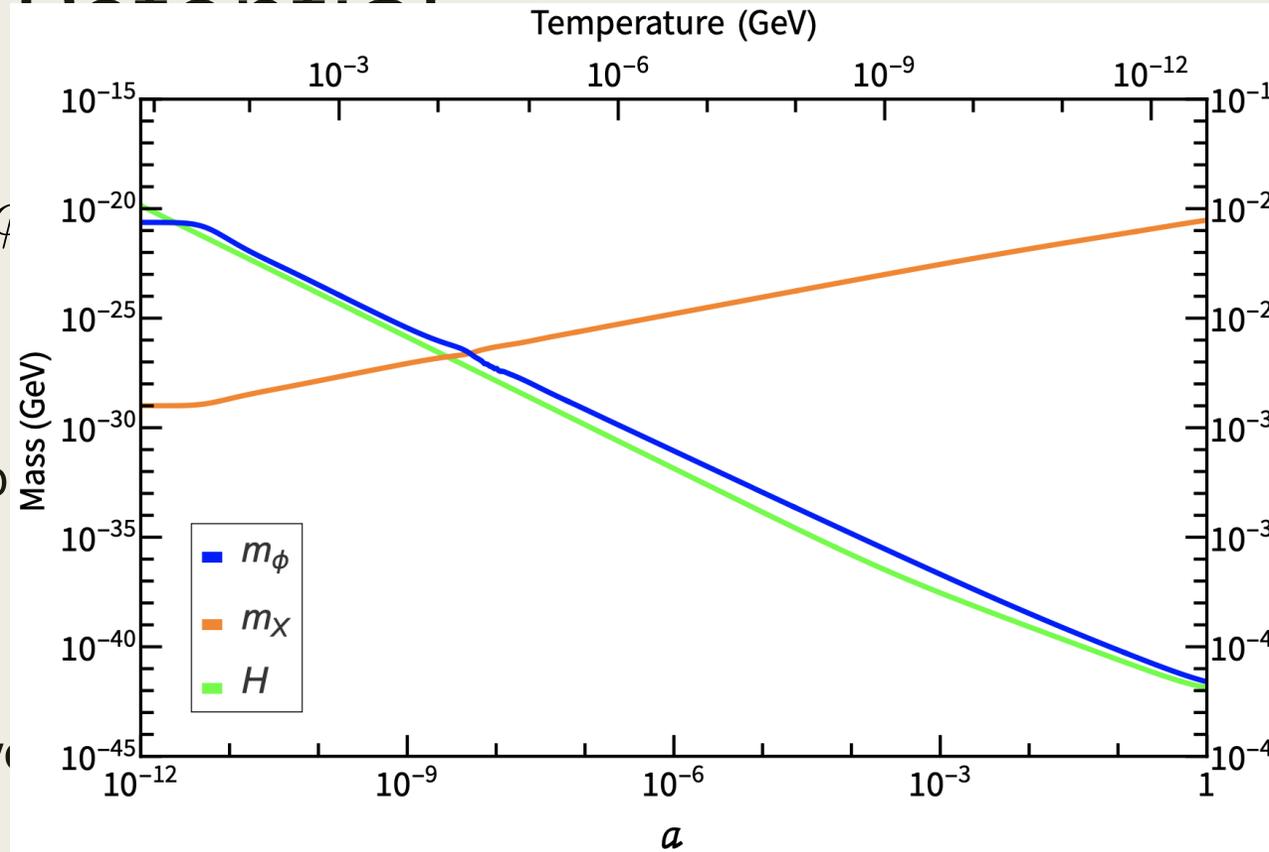
$$m_\phi^2|_0 = \frac{\partial^2 V_0}{\partial\phi^2} + \frac{\partial^2 V_{\text{gauge}}}{\partial\phi^2}, \quad m_X^2|_0 = g_X^2\phi^2$$

Gauge Potential

$$\mathcal{L} = -\frac{1}{2}(\partial_\mu \phi)^2$$

■ Additional p

■ The tree level



$$m_\phi^2|_0 = \frac{\partial^2 V_0}{\partial \phi^2} + \frac{\partial^2 V_{\text{gauge}}}{\partial \phi^2}, \quad m_X^2|_0 = g_X^2 \phi^2$$

Coupled dynamics

- The equations of motion

$$\ddot{\phi} + 3H\dot{\phi} + \frac{\partial V_0}{\partial \phi} + g_X^2 X_\mu X^\mu \phi = 0,$$

$$\partial_\mu X^{\mu\nu} + 3H X^{0\nu} - g_X^2 \phi^2 X^\nu = 0$$

Originated from V_{gauge}

- ❖ Gauge potential mediates energy flow between quintessence and dark gauge boson

$$\dot{\rho}_\phi + 3H(\rho_\phi + p_\phi) = -2 \frac{\dot{m}_X}{m_X} V_{\text{gauge}}$$

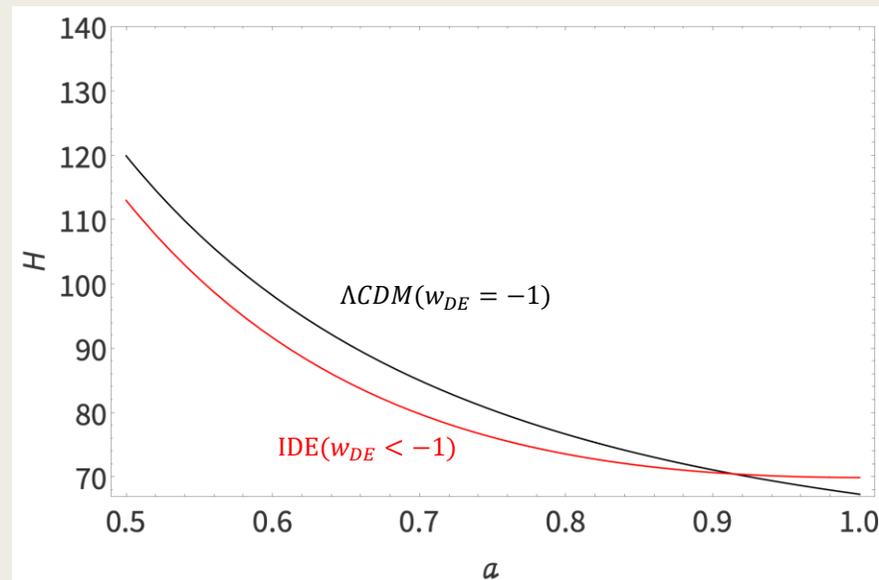
Flow of energy

$\dot{m}_X > 0$:	$\phi \rightarrow X$
$\dot{m}_X < 0$:	$X \rightarrow \phi$

Interacting dark energy and Hubble tension

- The energy can flow between dark energy (DE) \leftrightarrow dark matter (DM).
- The late-time expansion rate of the universe can be modified.
- H_0 increases, when Energy flows from DE \rightarrow DM ($w_{DE} < -1$).

[BH Lee et al. JCAP04\(2022\)004](#)
[E D Valentino, A Melchiorri, O Mena Phys. Rev. D 96\(2017\)043503](#)



Gauged quintessence on H_0 tension

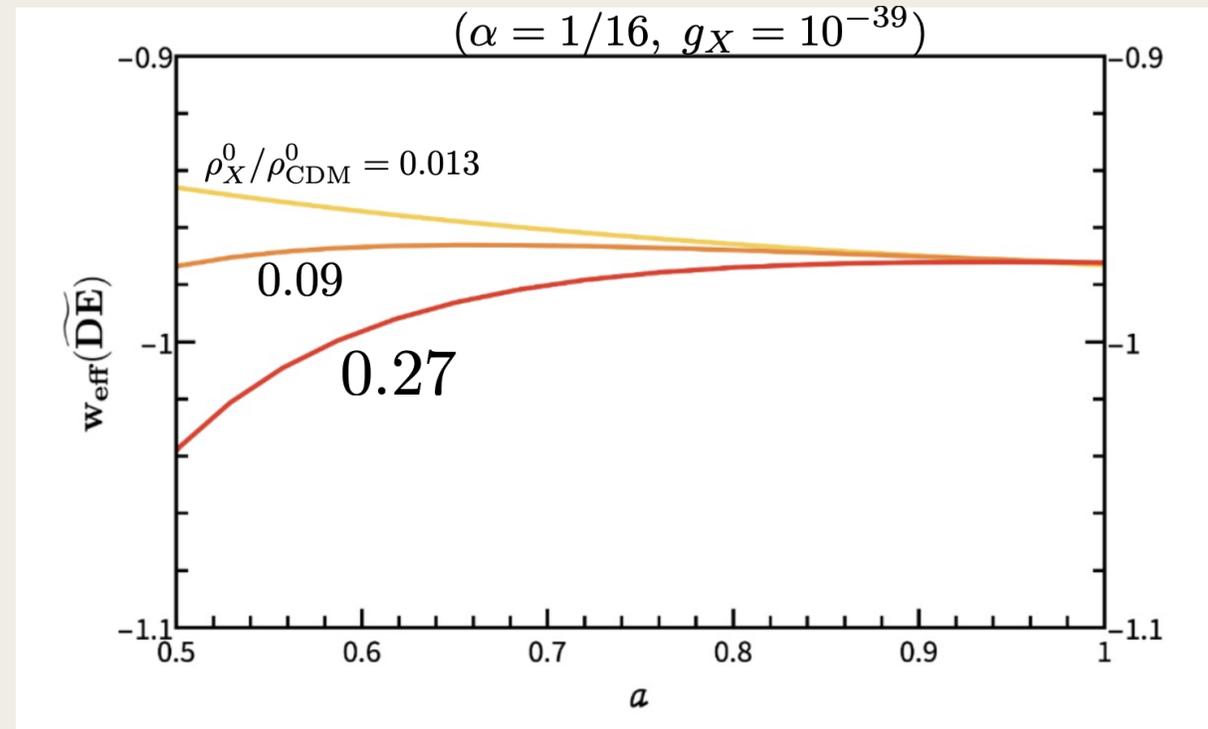
- Effective dark energy [S Das, P S Corasaniti, J Khoury Phys. Rev. D 73\(2006\)083509](#)

$$\rho_{\widetilde{CDM}} \equiv \frac{\rho_X^0 + \rho_{\text{CDM}}^0}{a^3}$$

$$\rho_{\widetilde{DE}} \equiv \rho_\phi + \left(\frac{m_X}{m_X^0} - 1 \right) \frac{\rho_X^0}{a^3}$$

$$w_{\text{eff}}(\widetilde{DE}) = -1 + \frac{1}{\rho_{\widetilde{DE}}} \left((1 + w_0)\rho_\phi + \left(\frac{m_X}{m_X^0} - 1 \right) \frac{\rho_X^0}{a^3} \right)$$

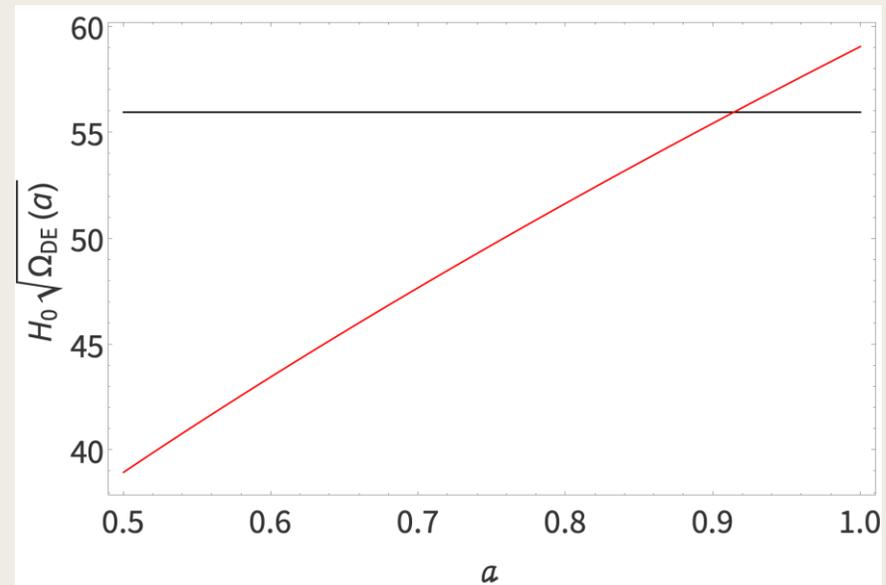
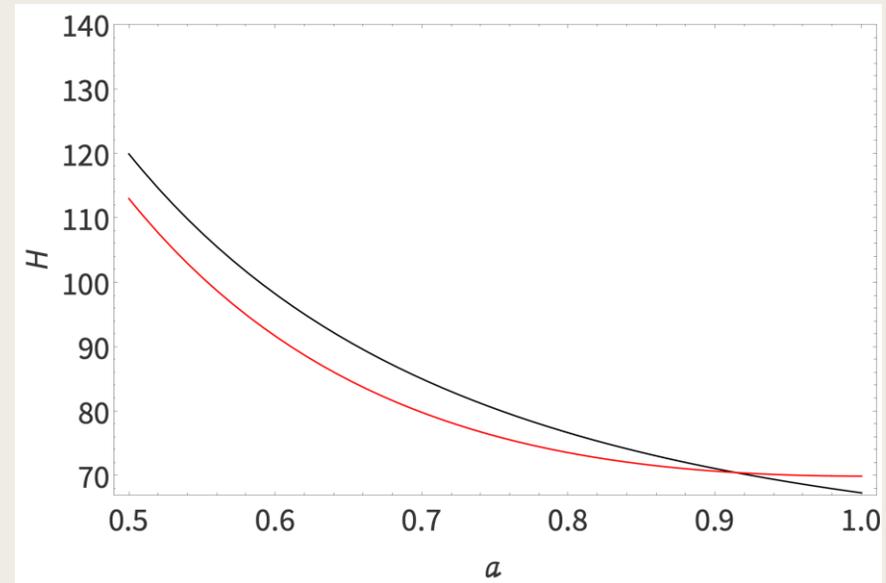
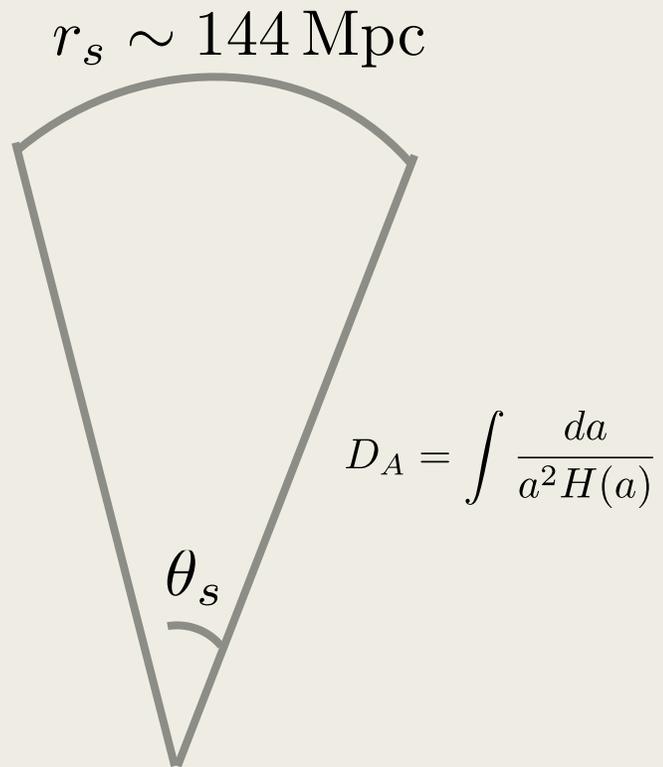
- If $\dot{m}_X > 0$, $w_{\text{eff}}(\widetilde{DE})$ is lower than uncoupled quintessence
- ✓ Possibility of alleviating H_0 tension

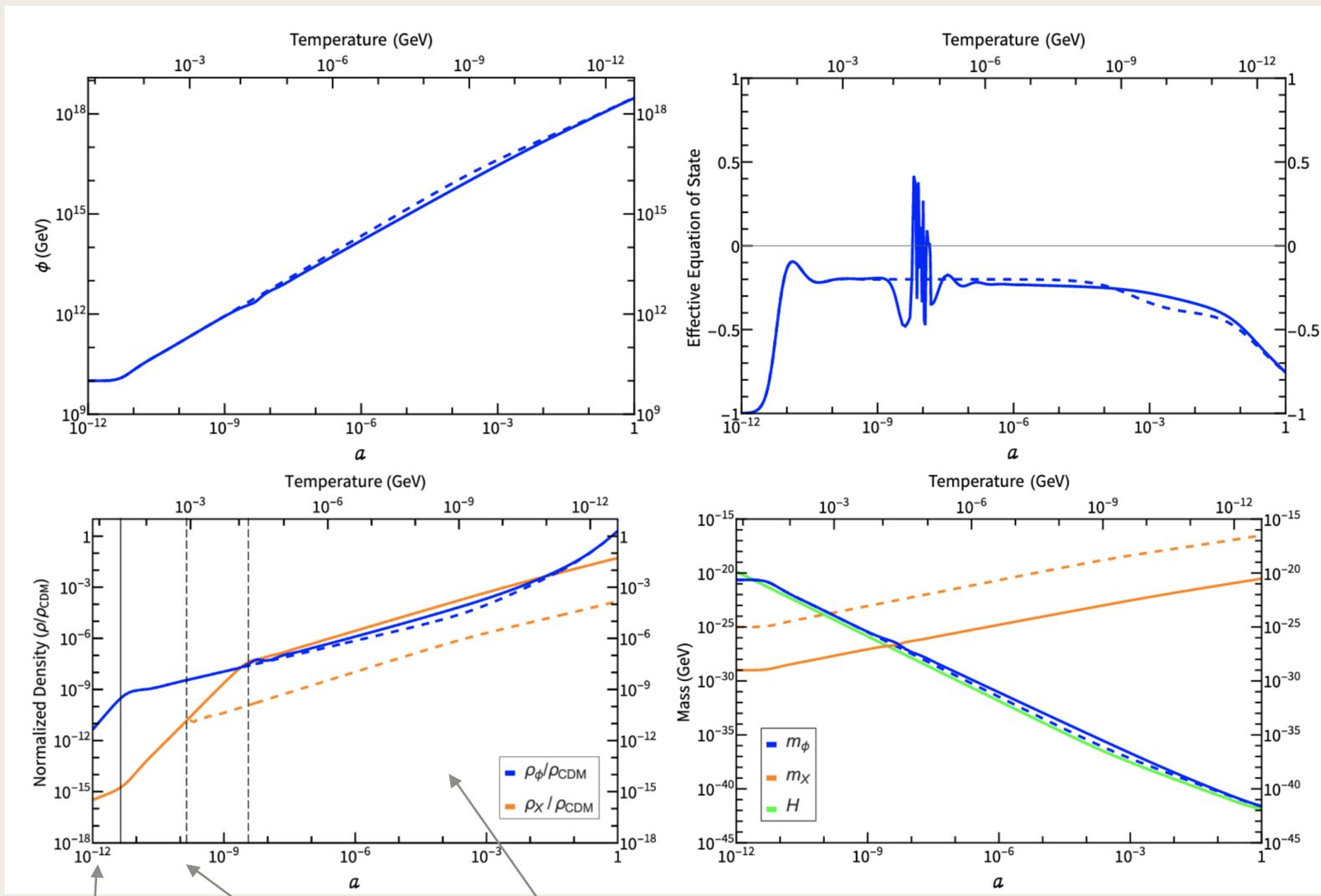


Summary

- Gauged quintessence: quintessence + $U(1)$ gauge symmetry (dark gauge boson)
- Tiny gauge coupling and dark gauge boson mass are required for the quintessence DE.
 - Due to the quantum correction
- Possibility of alleviating the Hubble tension (We need further investigation!)

Back up slides





$$\begin{aligned}
 H &\gg m_\phi \\
 H &\gg m_X
 \end{aligned}$$

$$\begin{aligned}
 H &\lesssim m_\phi \\
 H &\gg m_X
 \end{aligned}$$

$$\begin{aligned}
 H &\lesssim m_\phi \\
 H &\lesssim m_X
 \end{aligned}$$