Gauged Quintessence

- dark energy with gauge symmetry

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Collaboration with

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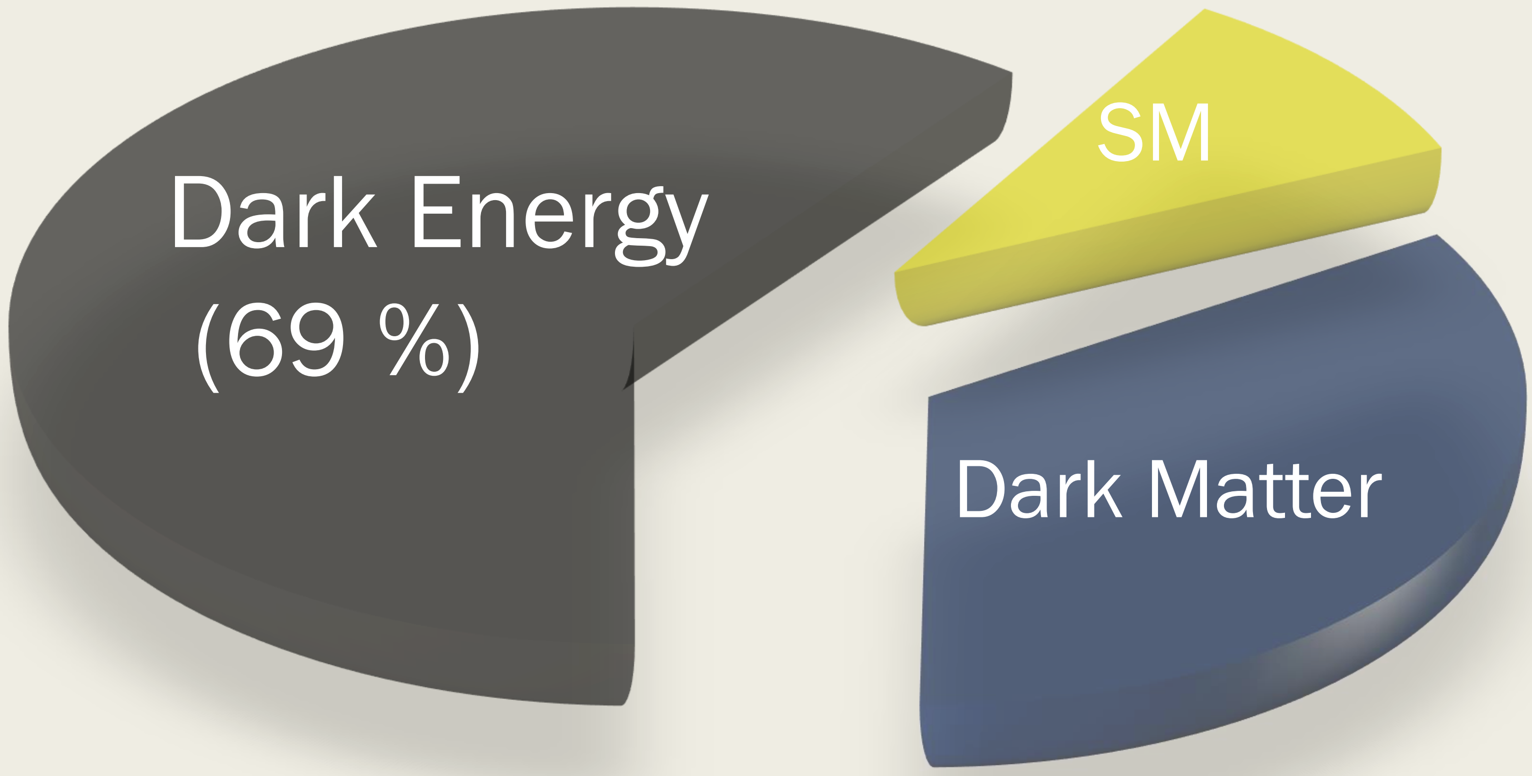
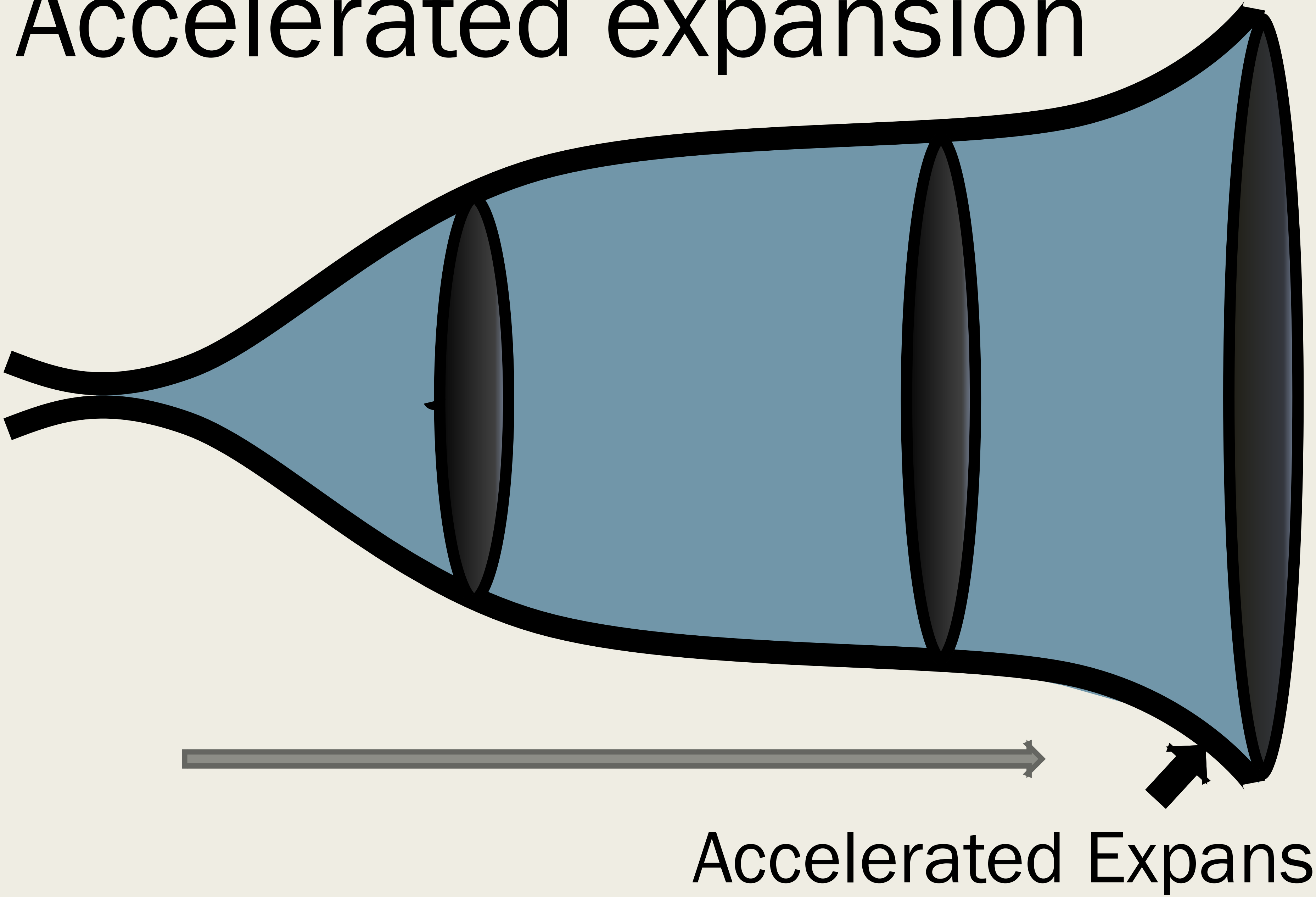
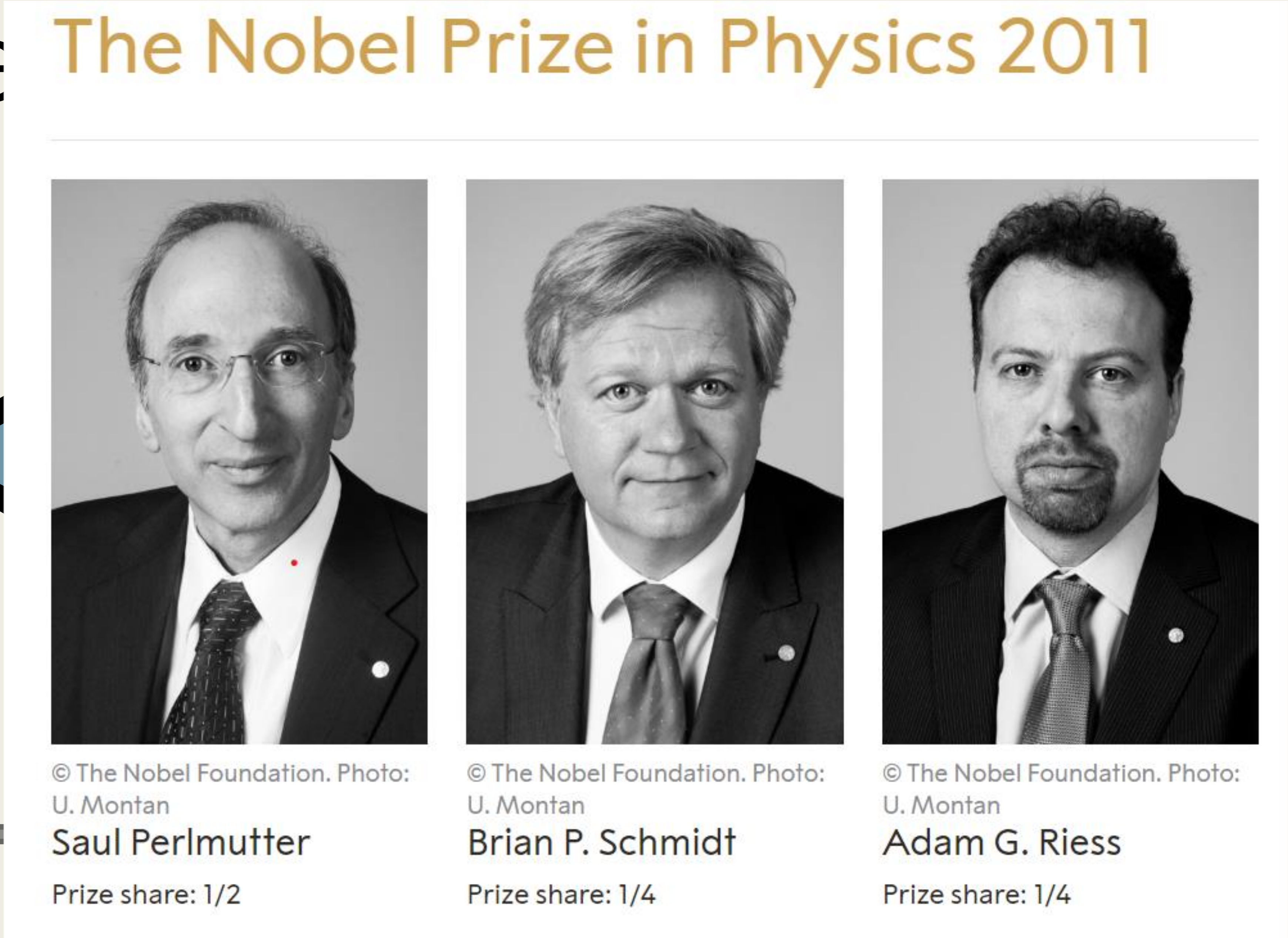
Dark energy



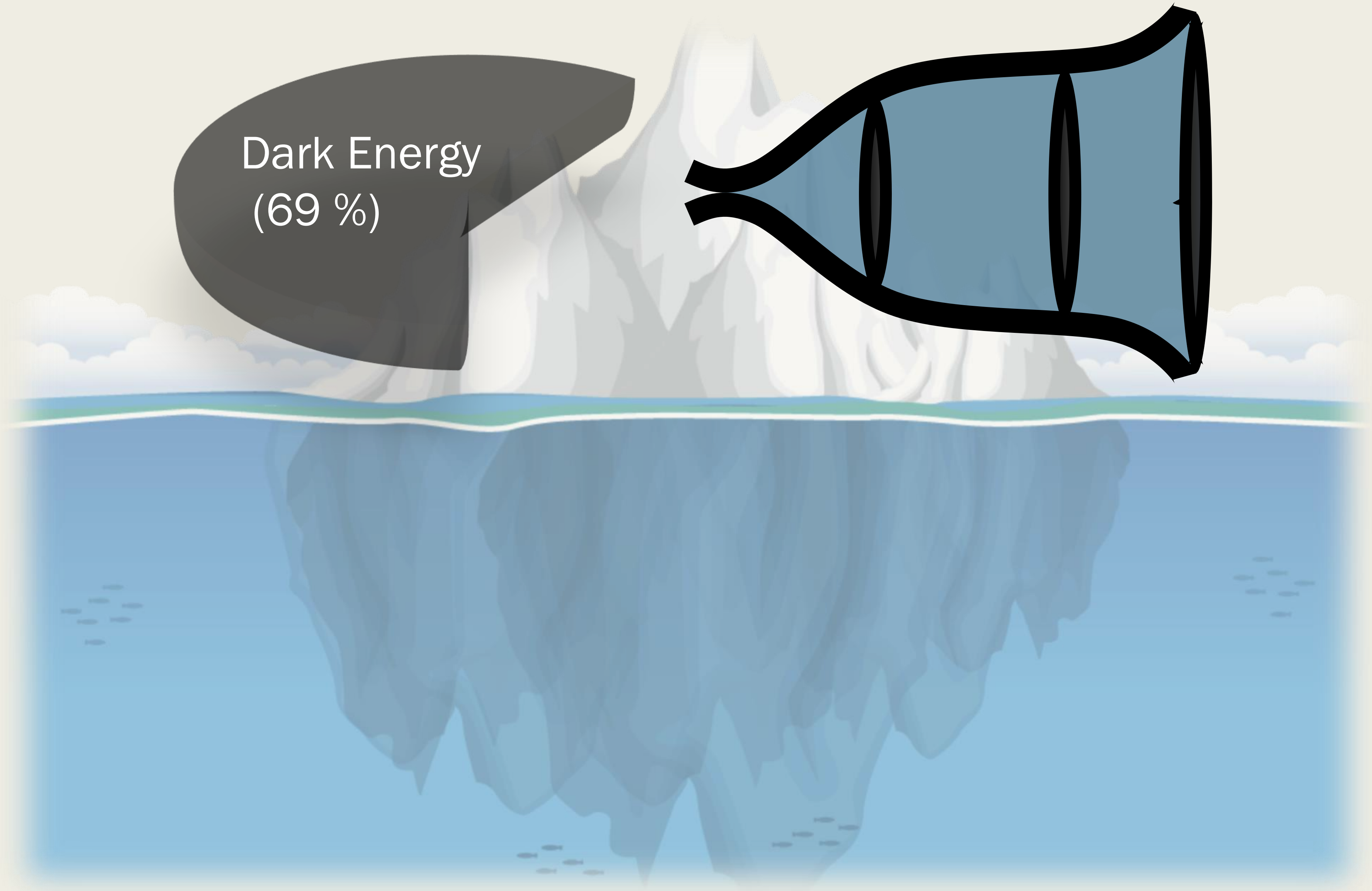
Accelerated expansion

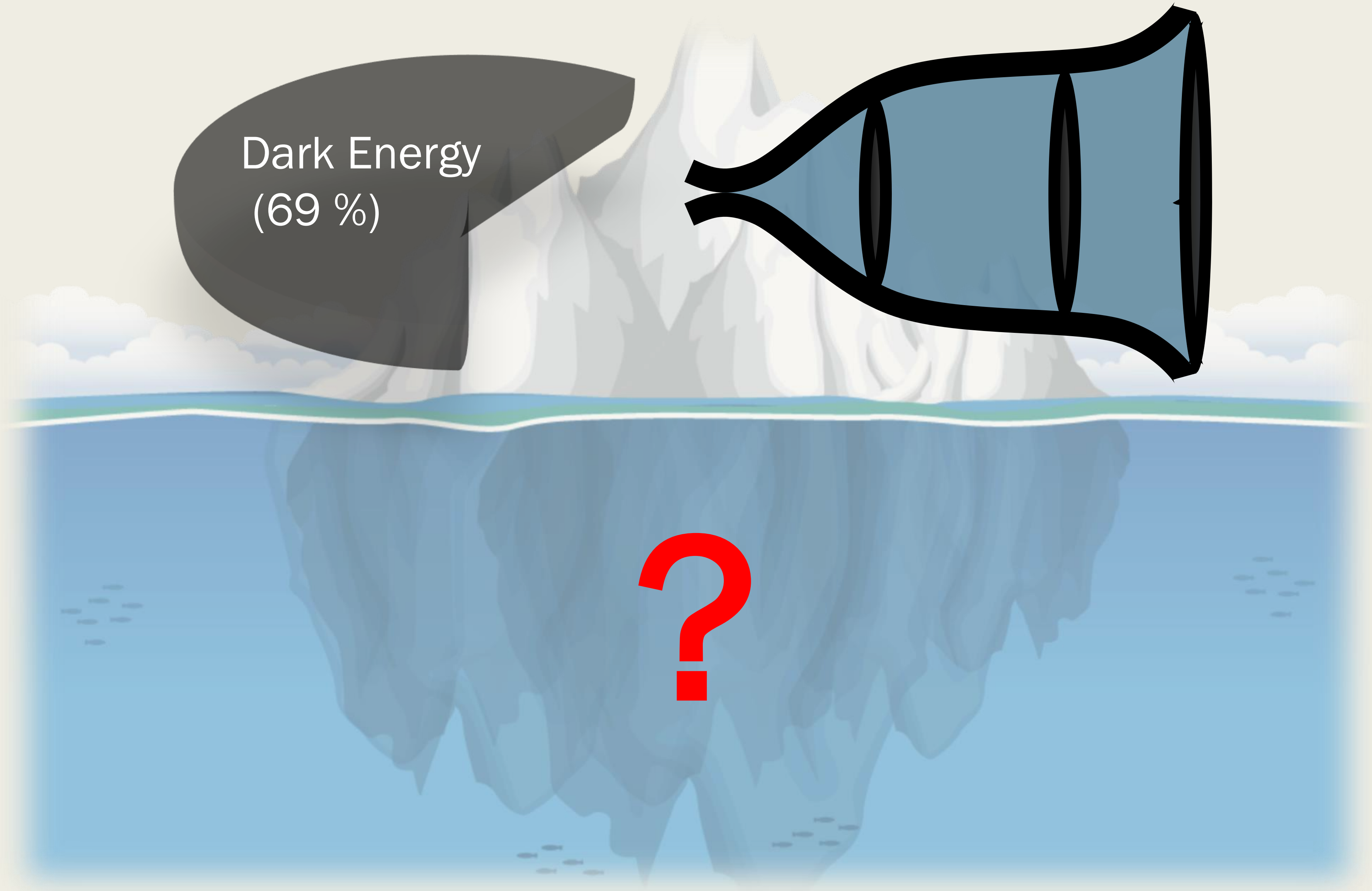


Acce

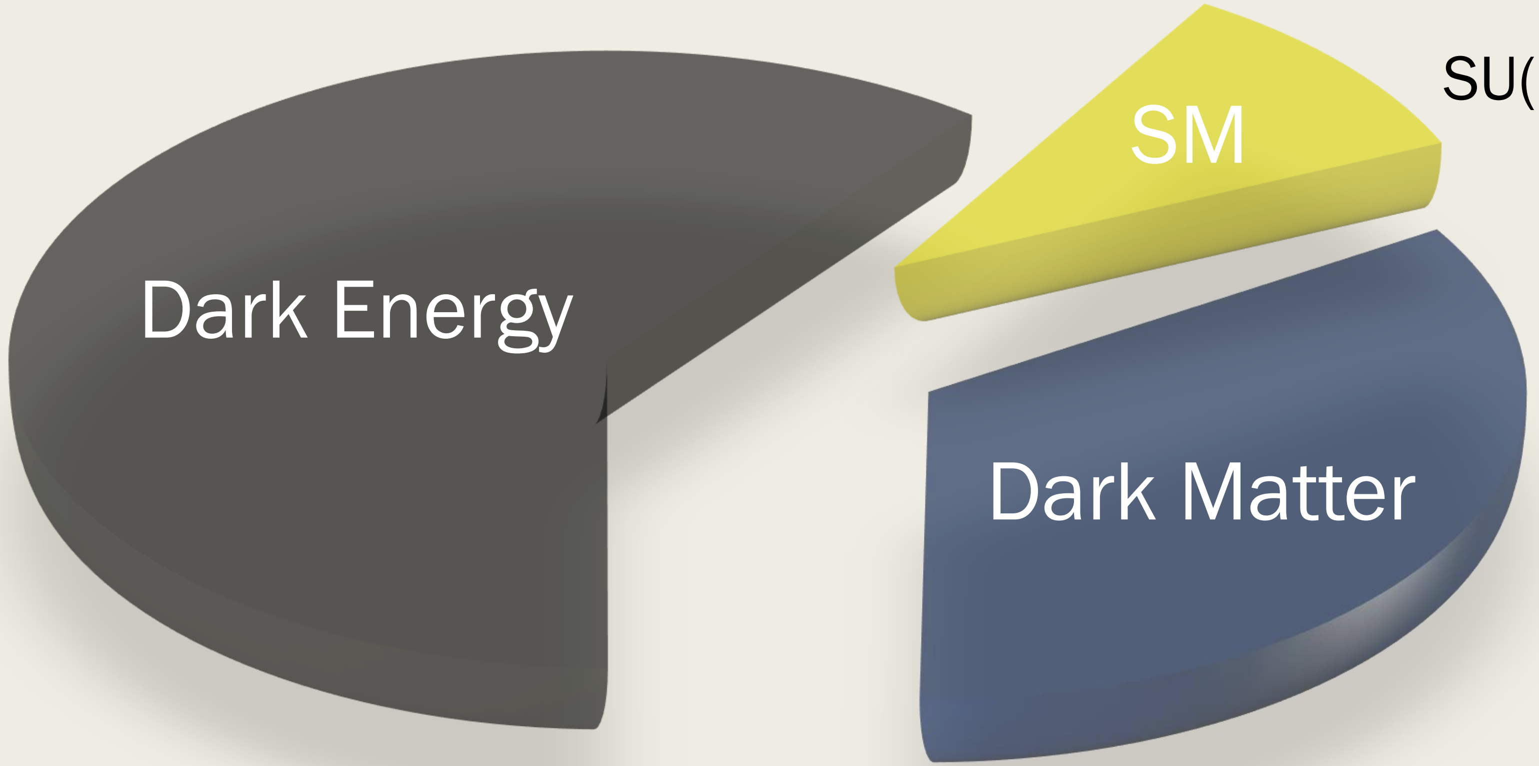


Accelerated Expansion


Dark Energy
(69 %)

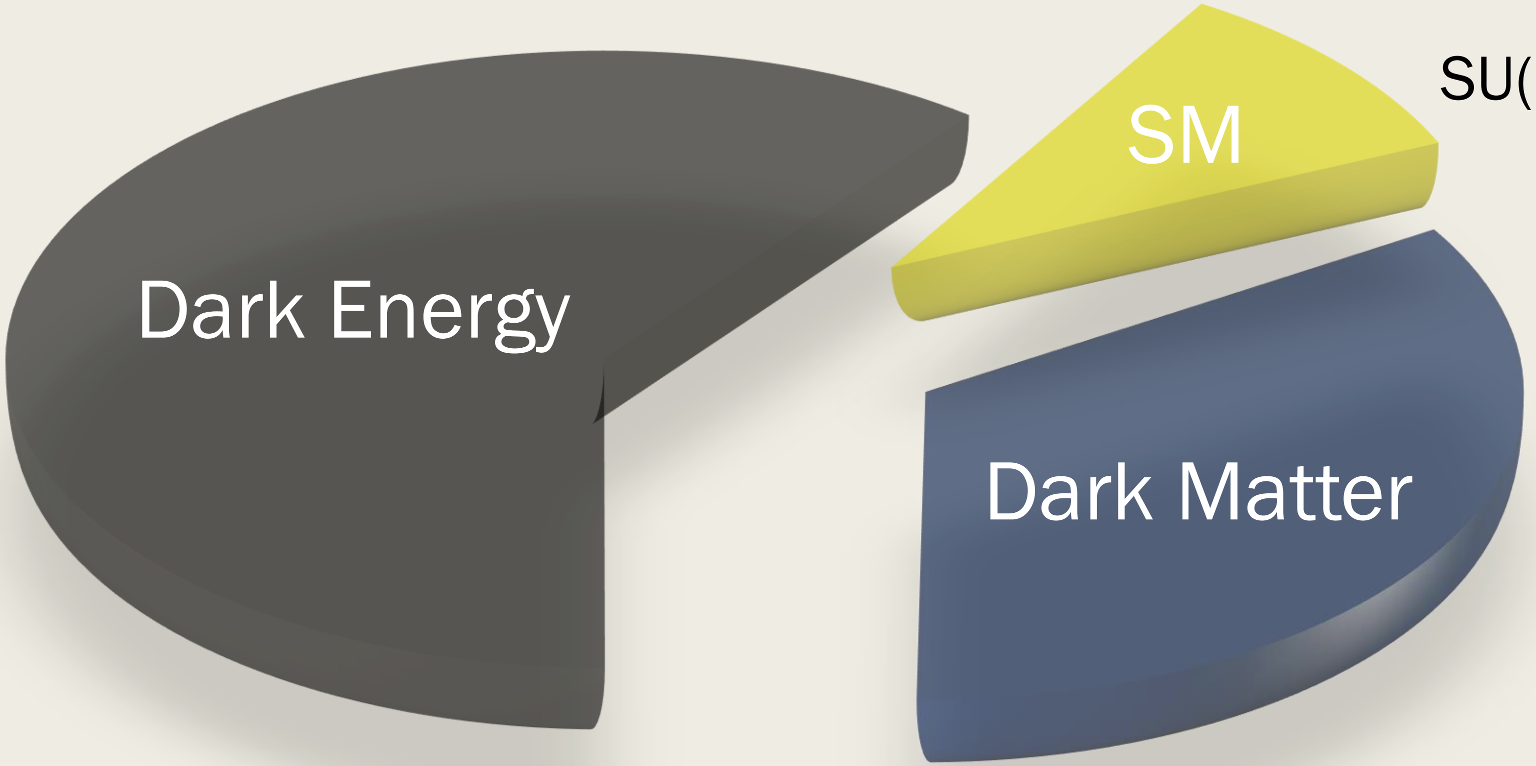

Dark Energy
(69 %)
?

SM gauge symmetry



SU(3) x SU(2) x U(1)

Dark energy with gauge symmetry



Dark energy under the gauge symmetry.
What would be interesting phenomenology?

Quintessence Dark energy

- A homogeneous scalar field

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

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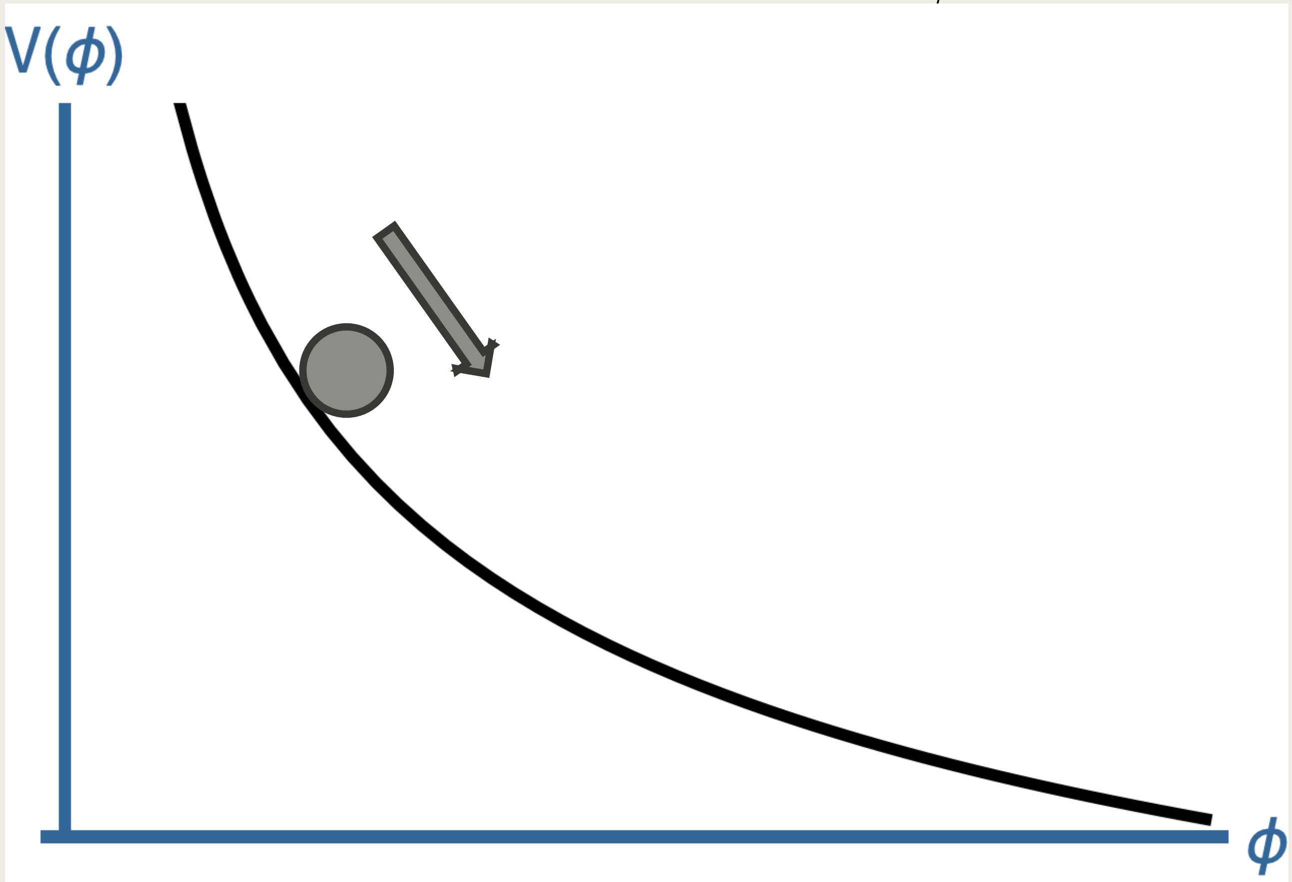


B Ratra and P J E Peebles (1988)

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

Quintessence Dark energy

- Energy density, Pressure, Equation of state

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

- Dark energy condition (accelerated expansion)

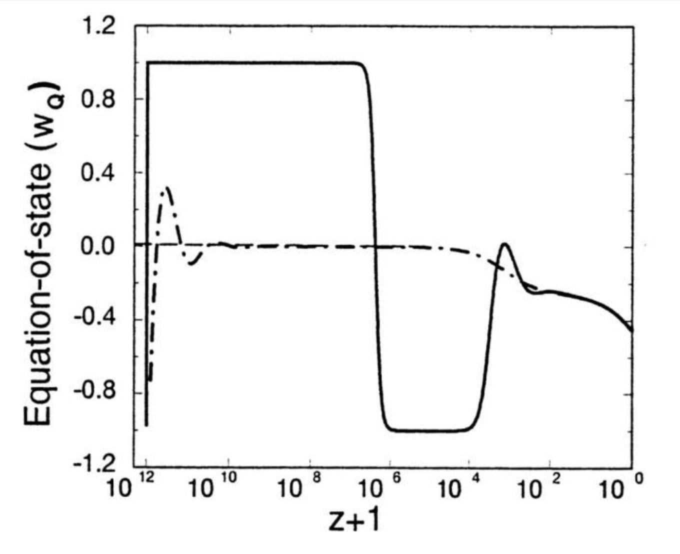
$$\frac{\dot{\phi}^2}{2} \ll V(\phi)$$

$$w < -1/3 \qquad \left(w \to \frac{-V(\phi)}{V(\phi)} = -1\right)$$

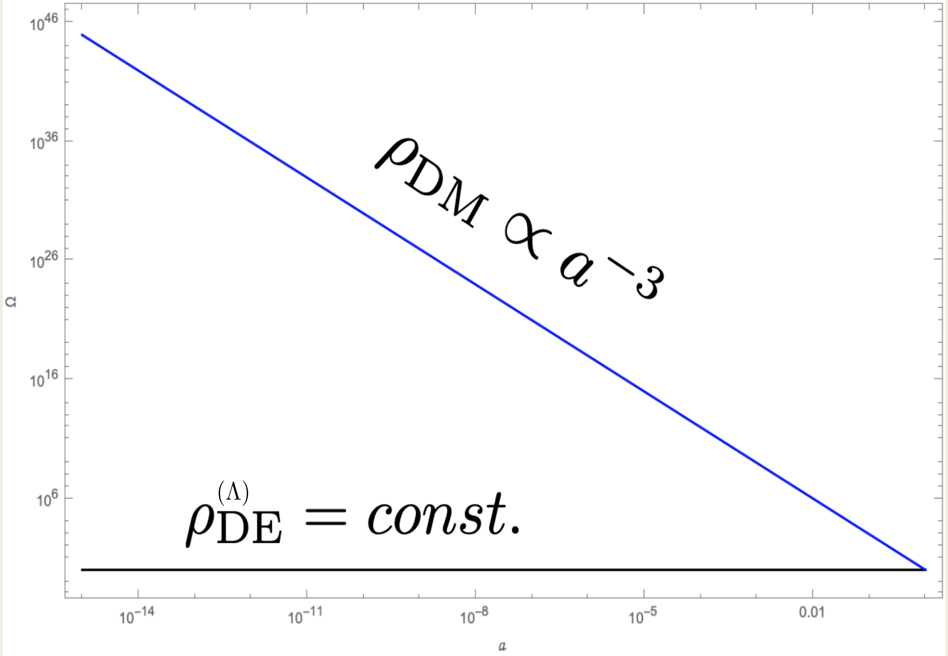
$$(\Lambda\mathrm{CDM} : w = -1)$$

Tracking solution

- Some of the potentials can give “Tracking solution” Steinhardt, Wang, Zlatev (1999)



< Late time solution converges



- Coincidence problem

  Fine tuning of the initial condition is not required.

Gauged Quintessence

- Complex scalar gauged under dark U(1) (quintessence + Dark gauge boson)

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

$$\Phi = \frac{1}{\sqrt{2}}\phi\, e^{i\eta}$$

$$\mathbb{X}_{\mu\nu} = \partial_\mu \mathbb{X}_\nu - \partial_\nu \mathbb{X}_\mu$$

$$D_\mu = \partial_\mu + i g_X \mathbb{X}_\mu$$

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

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

Quintessence (scalar)

Gauge boson

Quantum corrections

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

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

- Dark energy conditions

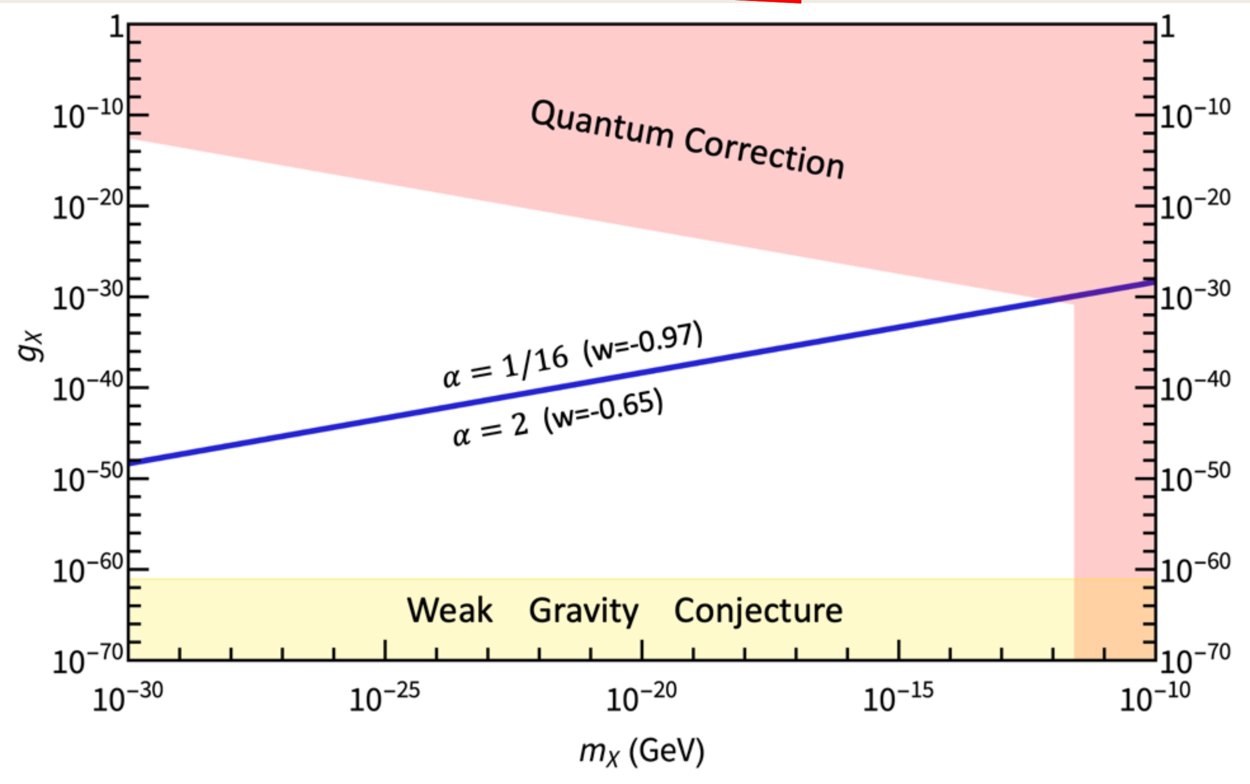
$$V_{\rm eff} \sim 10^{-123} M_{Pl}^4 \sim 3\times 10^{-47}\,{\rm GeV}^4$$

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

- Weak Gravity conjecture

Arkani-Hamed *et al.* (2007)

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



Gauge Potential & Gauge boson mass

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

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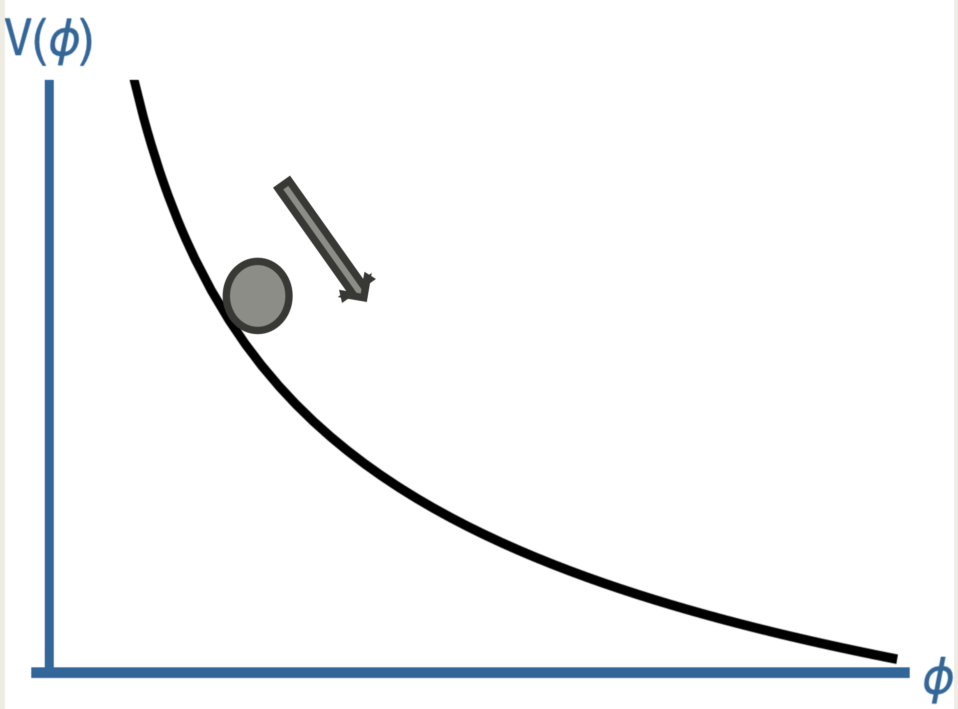

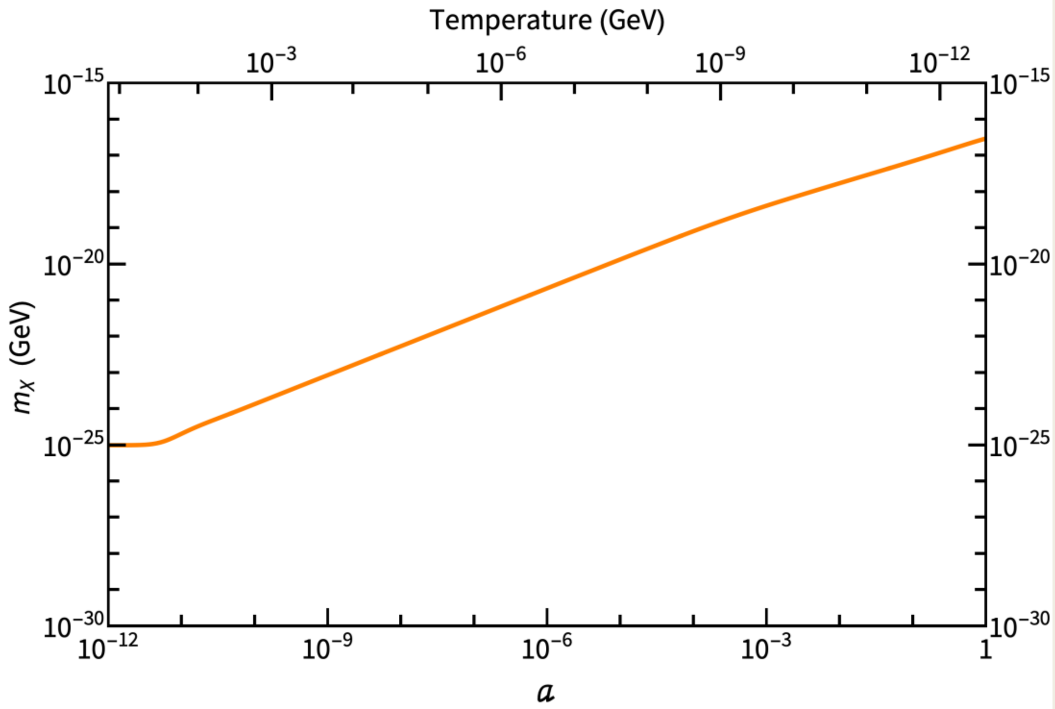

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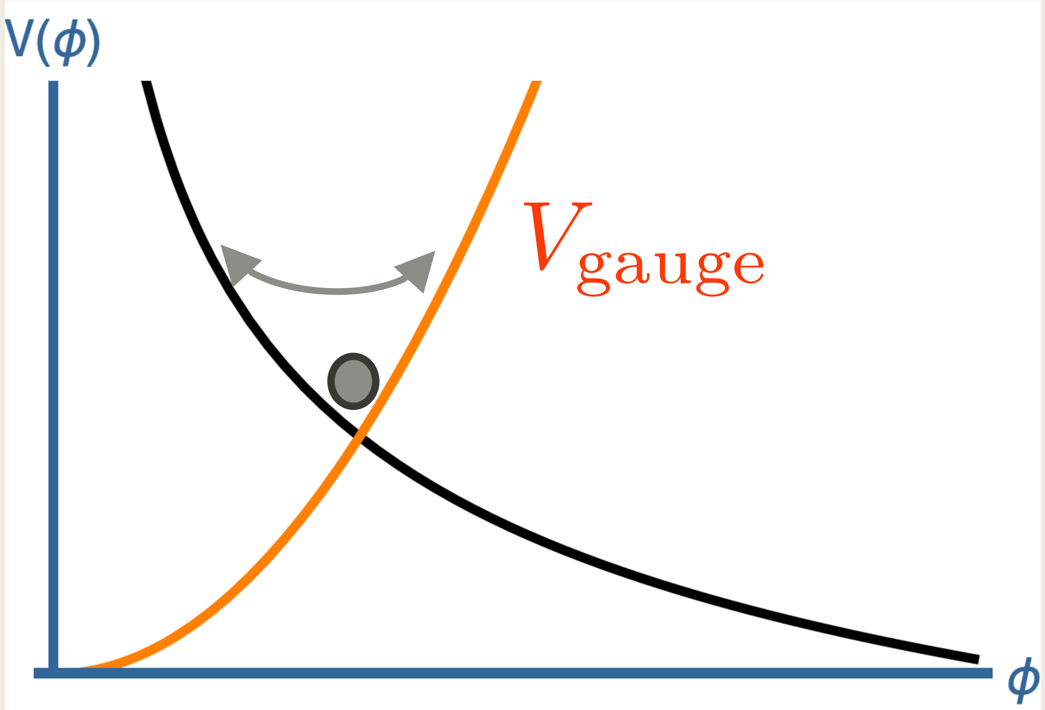
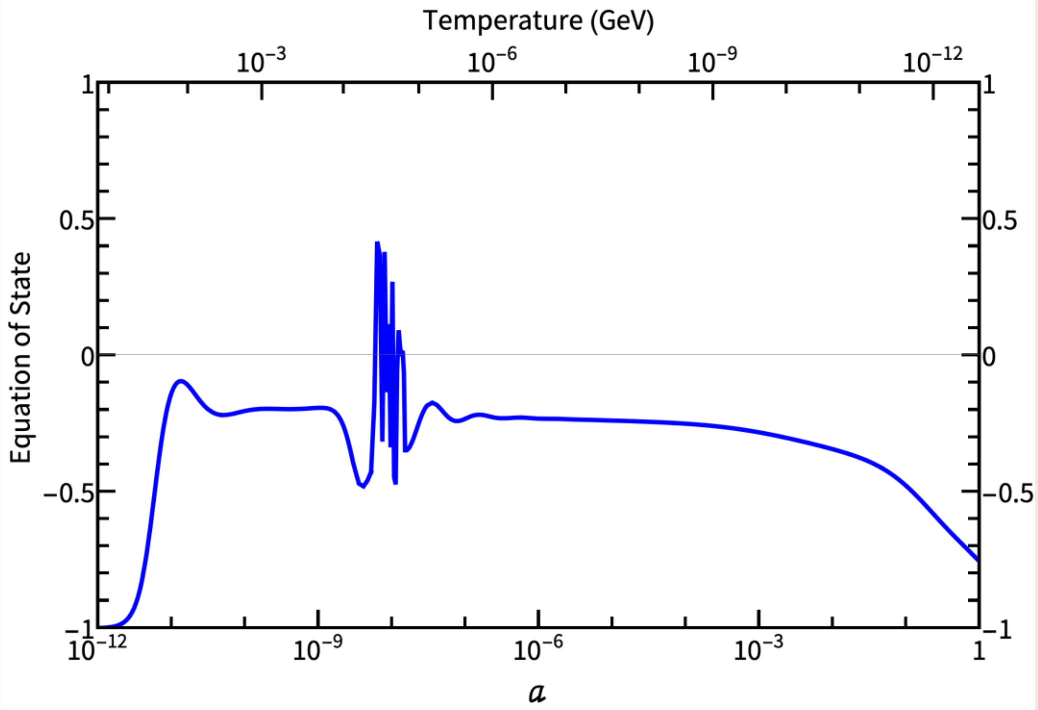




Coupled dynamics

- 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

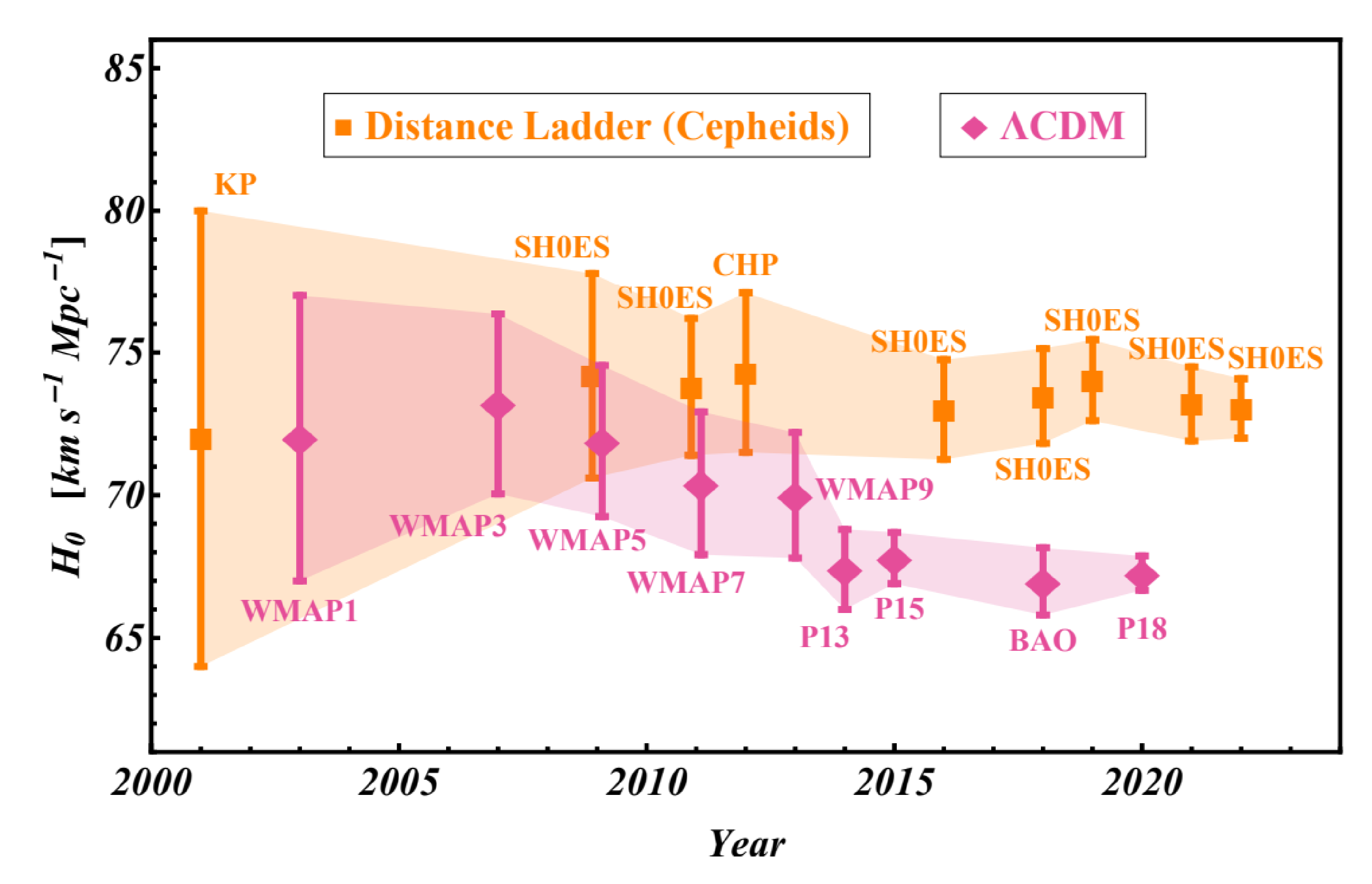
$$\dot{\rho}_\phi + 3H(\rho_\phi + p_\phi) = -2\frac{\dot{m}_X}{m_X} V_{\text{gauge}}$$

Flow of energy

$\dot{m}_X > 0 \quad : \quad \phi \to X$

$\dot{m}_X < 0 \quad : \quad X \to \phi$

Hubble tension



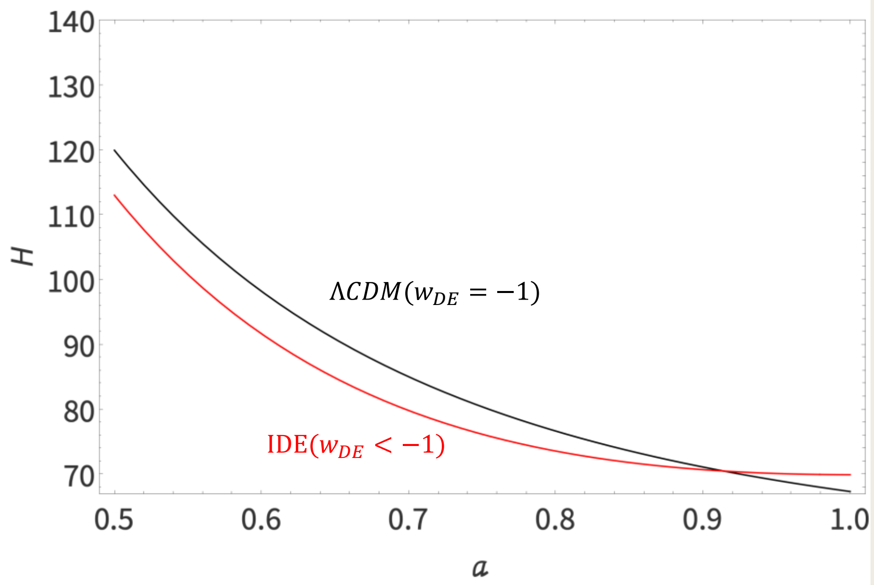
~ 5 σ

L Perivolaropoulos, F Skara (2021)

Interacting dark energy and Hubble tension

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

BH Lee *et al.* (2022)
E D Valentino, A Melchiorri, O Mena (2017)



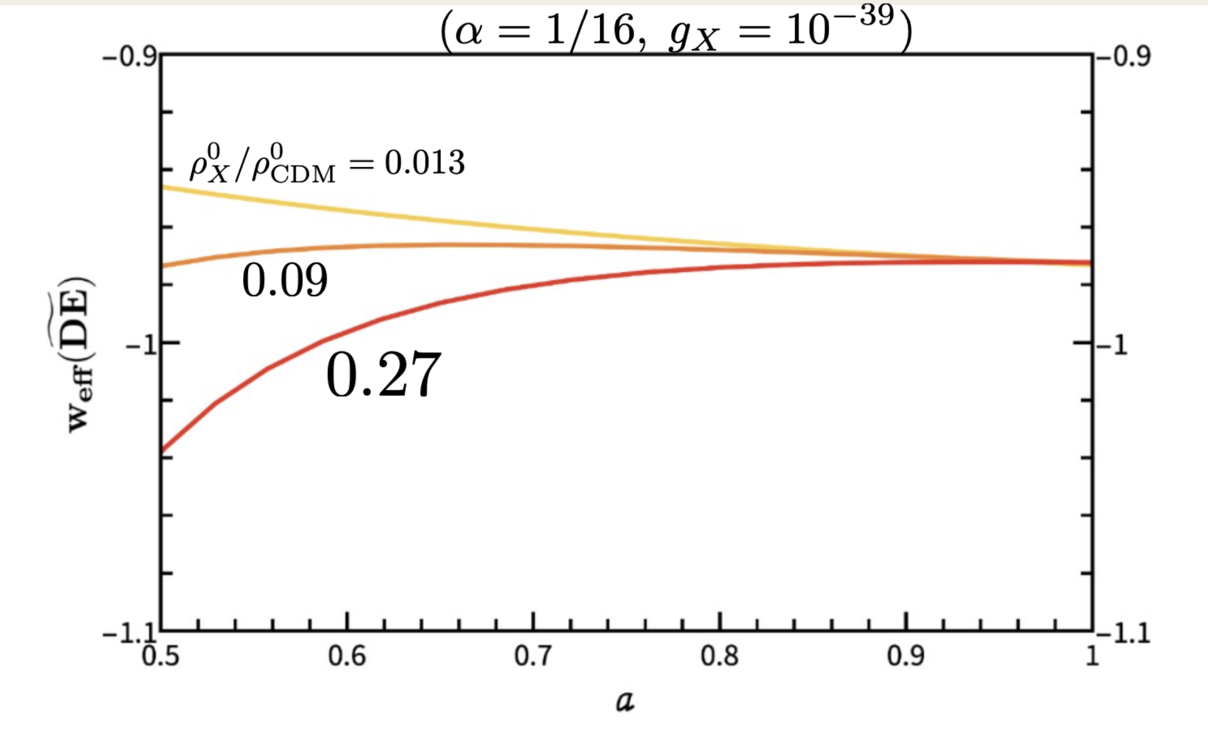
Gauged quintessence on H_0 tension

- Effective dark energy S Das, P S Corasaniti, J Khoury (2006)

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

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

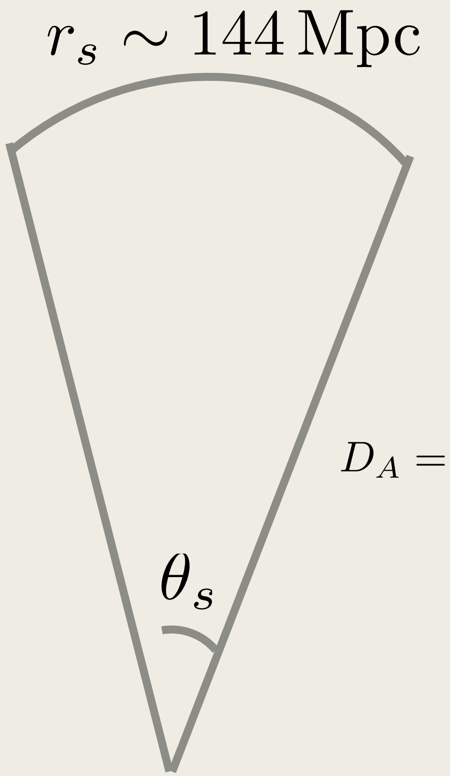
$$w_{\rm eff}(\widetilde{DE}) = -1 + \frac{1}{\rho_{\widetilde{DE}}}\left((1+w_0)\rho_\phi + \left(\frac{m_X}{m_X^0} - 1\right)\frac{\rho_X^0}{a^3}\right)$$



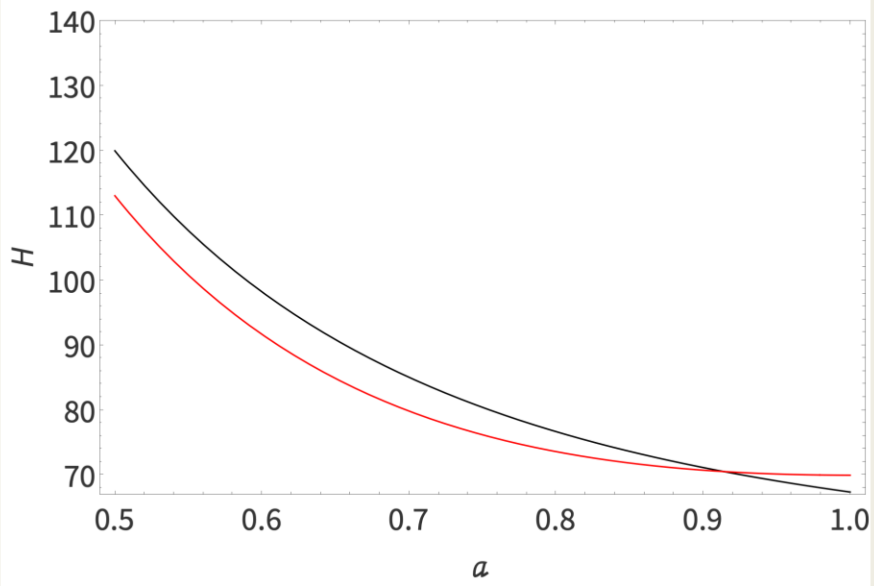
- If $\dot{m}_X > 0$, $w_{\rm eff}(\widetilde{DE})$ is lower than uncoupled quintessence
- ✓ Possibility of alleviating H0 tension

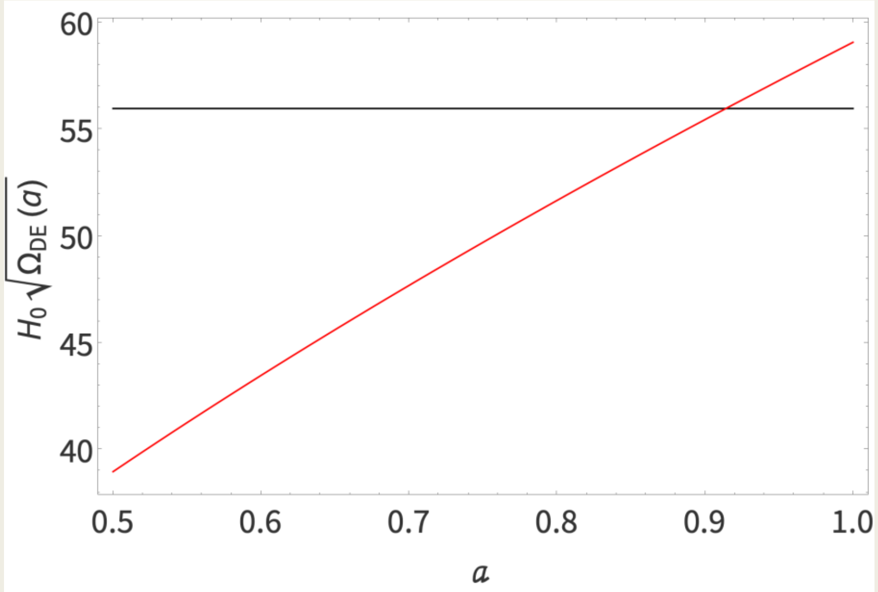
Summary

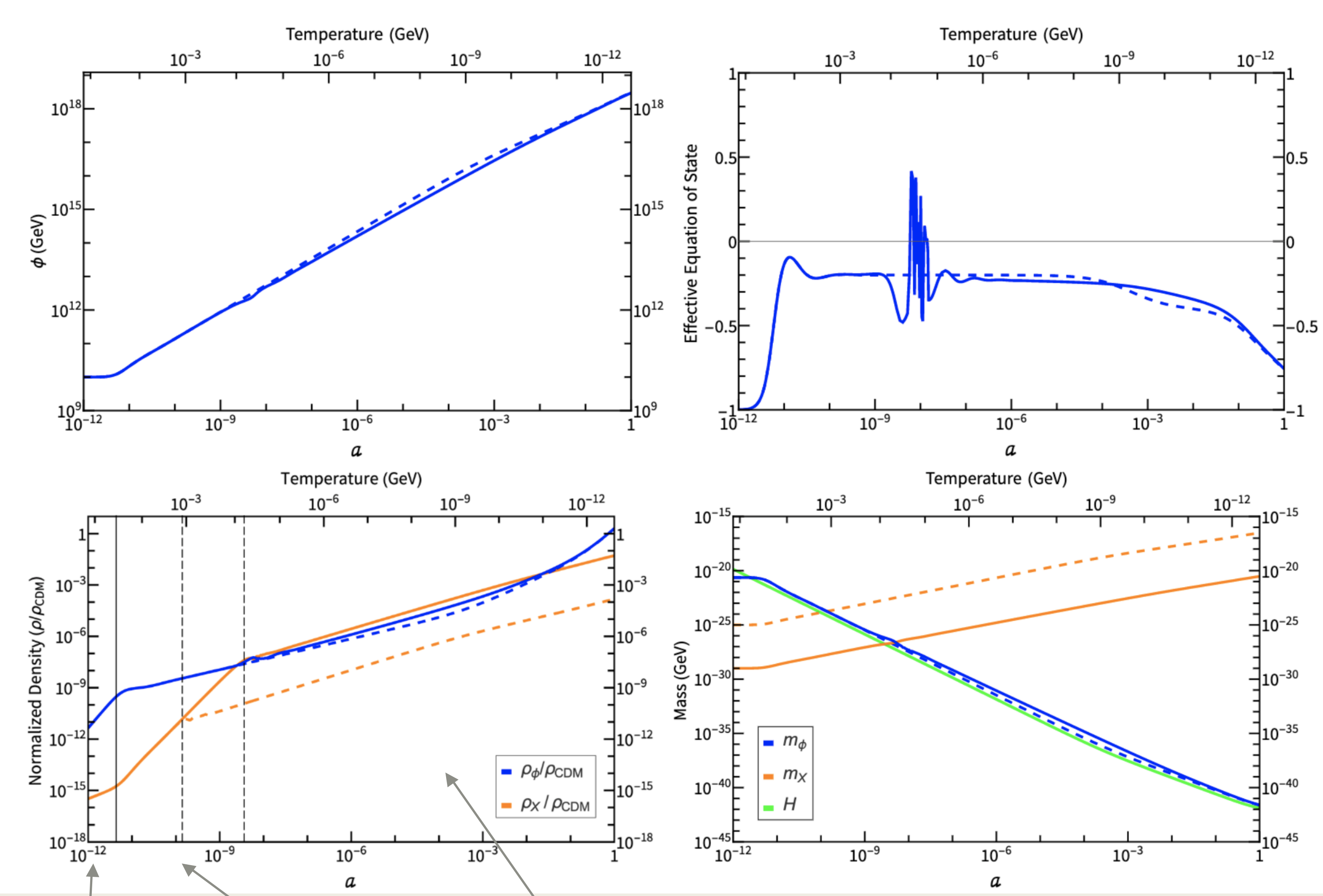
- Gauged quintessence: quintessence + U(1) gauge symmetry (dark gauge boson)
- Mass varying gauge boson, quintessence & dark gauge boson interaction
- Possibility of alleviating the Hubble tension (We need further investigation!)



$$D_A = \int \frac{da}{a^2 H(a)}$$







$H \gg m_\phi$
$H \gg m_X$

$H \lesssim m_\phi$
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