Axion-like potential in late-universe models

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DESI

$$\omega_{eff} = \omega_0 + \omega_a(1 - a)$$

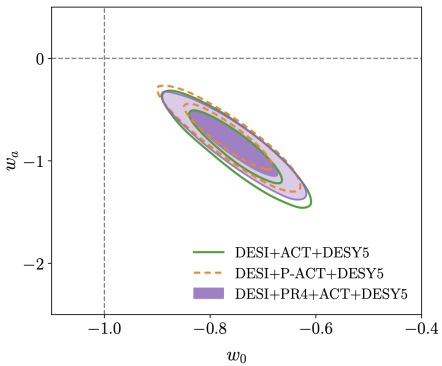


Figure: w0 and wa constraints from [Garcia-Quintero et al., 2025]

The model [Khoury et al., 2025]

$$\mathcal{L} = -\frac{1}{2}(\partial\phi)^2 + \mathrm{i}\bar{\psi}D\psi - V(\phi) - m_\psi(\phi)\bar{\psi}\psi\,, \tag{1}$$

$$m_\psi(\phi) \equiv m_0 A(\phi)\,. \tag{2}$$

The scalar field potential is

$$V(\phi) = \Lambda^4\left[1 + v - \sqrt{1 - \xi\sin^2\left(\frac{\phi}{2f}\right)}\right], \tag{3}$$

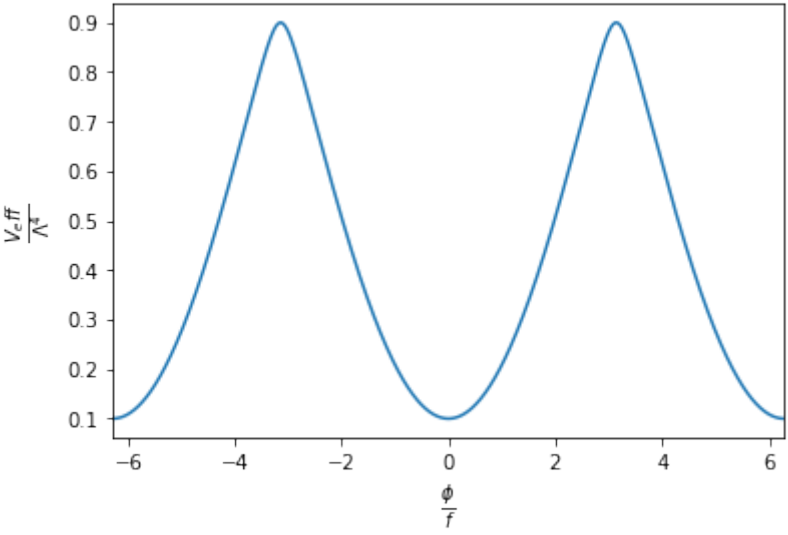
$$A(\phi) = 1 + 2\frac{\sigma_{\mathrm{N}}}{m_0}\sqrt{1 - \xi\sin^2\left(\frac{\phi}{2f}\right)}\,. \tag{4}$$

$$\xi = \frac{4m_{\mathrm{u}}m_{\mathrm{d}}}{(m_{\mathrm{u}} + m_{\mathrm{d}})^2}\,. \tag{5}$$

The scale is given in terms of the pion mass m and decay constant f, and set to the DE (meV) scale:

$$\Lambda^4 = m_\pi^2 f_\pi^2 meV^4 \tag{6}$$

Effective potential of the model



EOM

$$\phi'' + 2aH\phi' = -a^2 \left(\frac{\mathrm{d}V}{\mathrm{d}\phi} + \frac{\mathrm{d}\ln A(\phi)}{\mathrm{d}\phi} \rho_{\mathrm{DM}}(\phi) \right) , \tag{7}$$

Due to DM's coupling to ϕ, the DM density conservation equation is modified to

$$\rho'_{\mathrm{DM}} + 3aH\rho_{\mathrm{DM}} = \phi' \frac{\mathrm{d}\ln A(\phi)}{\mathrm{d}\phi} \rho_{\mathrm{DM}} \, . \tag{8}$$

The Friedmann equation is

$$3H^2 M_{\mathrm{Pl}}^2 = \rho_{\mathrm{DM}}(\phi) + \rho_\phi + \rho_{\mathrm{B}} + \rho_{\mathrm{rad}} \, , \tag{9}$$

EOS

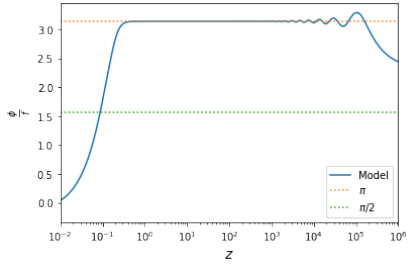
The corresponding effective DE equation of state is

$$w_{\rm eff} = \frac{w_\phi}{1 + \left[\frac{A(\phi)}{A(\phi_0)} - 1\right] \frac{\rho^0_{\rm DM}}{a^3 \rho_\phi}} \ , \tag{10}$$

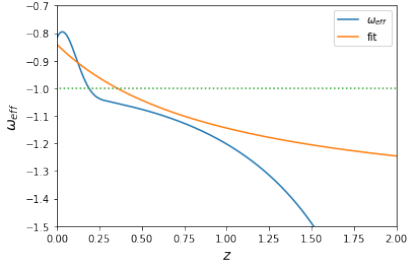
where $w_\phi = \frac{\phi'^2 - 2a^2 V(\phi)}{\phi'^2 + 2a^2 V(\phi)}$ is the standard scalar equation of state parameter.
The DESI results suggest that $w_{\rm eff} < -1$ in the past, but grew to a value $w_{\rm eff} > -1$ at present. This can be achieved with (10) provided that

$$\frac{A(\phi)}{A(\phi_0)} < 1 \tag{11}$$

at early times. This corresponds physically to a DM mass that increases with time.



Evolution of ϕ



DE EOS evolution

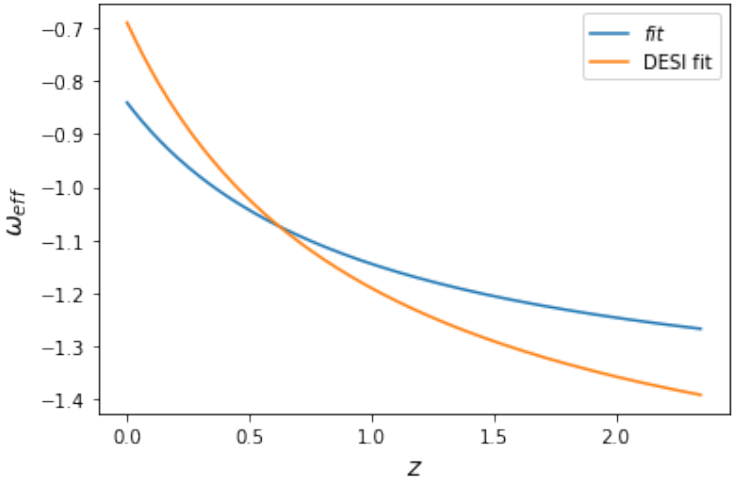


Figure: Comparison of fits

$$v = 4.0, \xi = 0.99, f = 0.03, \frac{\sigma_n}{m_0} = 0.035, \phi = 2.3$$

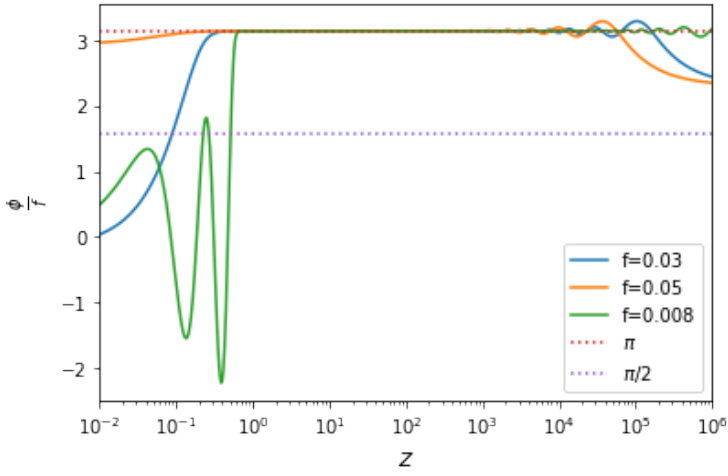


Figure: ϕ evolution for different f

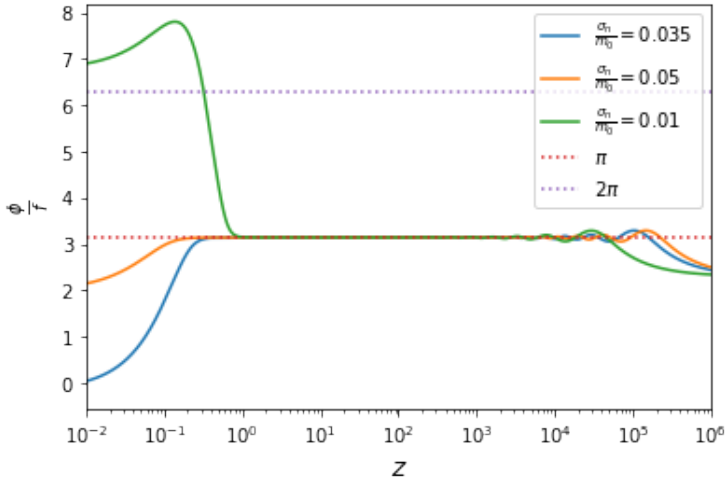


Figure: ϕ evolution for different $\frac{\sigma_n}{m_0}$

$$v = 0.8, \xi = 0.99, f = 0.08, \frac{\sigma_n}{m_0} = 0.035, \phi = 2.3$$

References

Garcia-Quintero, C. et al. (2025).
Cosmological implications of DESI DR2 BAO measurements in light of the latest ACT DR6 CMB data.
Phys. Rev. D, 112(8):083529.

Khoury, J., Lin, M.-X., and Trodden, M. (2025).
Apparent $w < -1$ and a Lower S_8 from Dark Axion and Dark Baryons Interactions.