The Hubble constant in the axi-Higgs universe

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$H_0$ and $S_8$ tensions in $\Lambda$CDM

$H_0 = 67.36 \pm 0.54 \ (\Lambda$CDM$)$

$H_0 = 73.2 \pm 1.3 \ ($SH0ES$)$

→ $4.1\sigma$ discrepancy

$S_8 = 0.832 \pm 0.013 \ (\Lambda$CDM$)$

$S_8 = 0.766^{+0.020}_{-0.014} \ ($KiDs-1000$)$

→ $2.8\sigma$ discrepancy

Planck 2018 (1807.06209)
When $m_e$ increases
→ electrons recombine faster
→ earlier recombination
→ reduced sound horizon

$$r_S(z_*) = \int_{z_*}^{\infty} \frac{c_s(z)}{H(z)}$$

→ increasing $H_0$
$H_0$ and $S_8$ in $\Lambda$CDM + $m_e$

$H_0 = 69.1 \pm 1.2$ ($\Lambda$CDM + $m_e$)

$H_0 = 73.2 \pm 1.3$ (SH0ES)

$\rightarrow 2.2\sigma$ discrepancy

$S_8 = 0.821 \pm 0.010$ ($\Lambda$CDM + $m_e$)

$S_8 = 0.766_{-0.014}^{+0.020}$ (KiDs-1000)

$\rightarrow 2.5\sigma$ discrepancy

Hart & Chluba (1912.03986)
Axi-Higgs theoretical model

- The Higgs field coupled to an ultralight axion

\[ V = m_a^2 f_a^2 \left(1 - \cos \frac{\phi}{f_a}\right) + |K(\phi)(m_s^2 F(\phi) - \kappa h^+ h)|^2 \]

- The axion evolves following misalignment mechanism:

\[ \ddot{\phi} + 3H \dot{\phi} + m_a^2 \phi = 0 \]
Axi-Higgs effective model

• The Higgs VEV is driven by the axion

\[ v = v_0(1 + \delta v) = 246 \text{ GeV} \left(1 + \frac{C \phi^2}{2M_{Pl}^2}\right) \]

• Axion density is given by

\[ \delta v \propto \rho_a \sim \text{const at early times } z \gg z_a \]

\[ \delta v \propto \rho_a \propto (1 + z)^3 \text{ at late times } z \ll z_a \]

with \( z_a \) depending on \( m_a \)
Axi-Higgs is approximately equivalent to $\Lambda$CDM $+ m_e + \omega_\alpha$

- similar to $\Lambda$CDM $+ m_e$ before recombination
- similar to axion cosmology after recombination
Axion perturbative cosmology

Axion has finite Jeans scale

→ Suppress small-scale structures

→ Reduce $\sigma_8$ by definition

$$\sigma_8^2 = \int_0^\infty P(k) W^2(kR_8) dk$$

→ Reduce $S_8$ as a consequence

$$S_8 = \sigma_8 (\Omega_m/0.3)^{0.5}$$
$H_0$ and $S_8$ in axi-Higgs

$H_0 = 69.9 \pm 1.8$ (axi-Higgs)

$H_0 = 73.2 \pm 1.3$ (SH0ES)

$\rightarrow 1.5\sigma$ discrepancy

$S_8 = 0.8031 \pm 0.0098$ (axi-Higgs)

$S_8 = 0.766^{+0.020}_{-0.014}$ (KiDs-1000)

$\rightarrow 1.7\sigma$ discrepancy
Summary and Discussion

• Axi-Higgs can alleviate $H_0$ and $S_8$ tensions simultaneously

• Axi-Higgs also alleviates the well-known Lithium puzzle in BBN

• Axi-Higgs could be tested by quasar absorption lines