THE HUBBLE CONSTANT IN THE AXI-HIGGS UNIVERSE

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in collaboration with

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(**arXiv:2102.11257** and **arXiv:2105.01631**)

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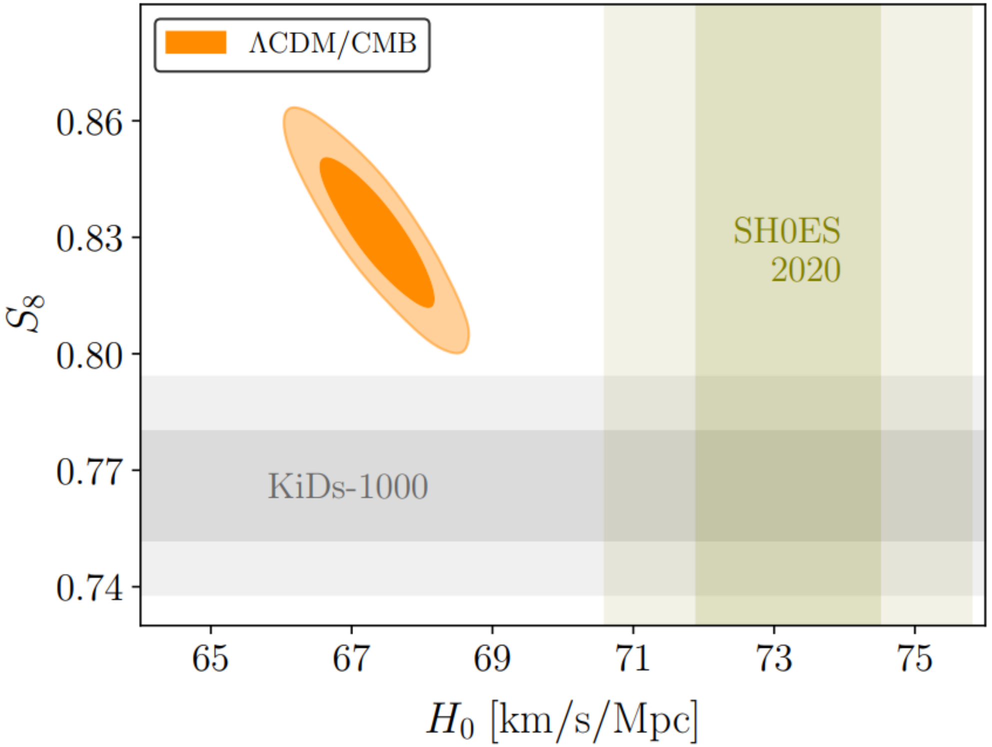
H_0 and S_8 tensions

$$H_{0,\Lambda\mathrm{CDM}} = 67.36 \pm 0.54, \qquad H_{0,\mathrm{SH0ES2020}} = 73.2 \pm 1.3$$
$$S_{8,\Lambda\mathrm{CDM}} = 0.832 \pm 0.013, \qquad S_{8,\mathrm{KiDs-1000}} = 0.766 \pm 0.014$$



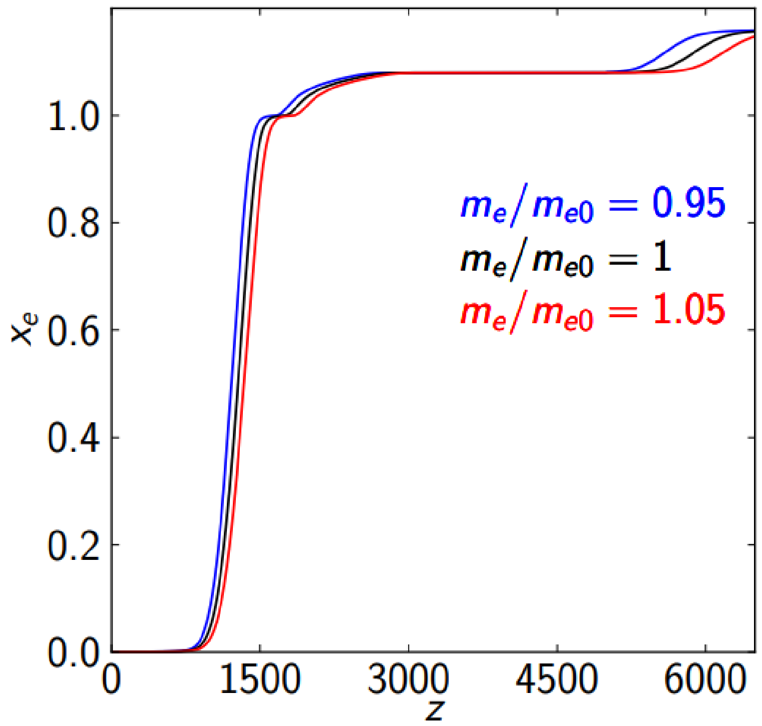
General strategy:

- Increase H_0 by reducing r_* (or r_d)
- Decrease S_8 by suppressing structure formation

see **arXiv:1807.06209**

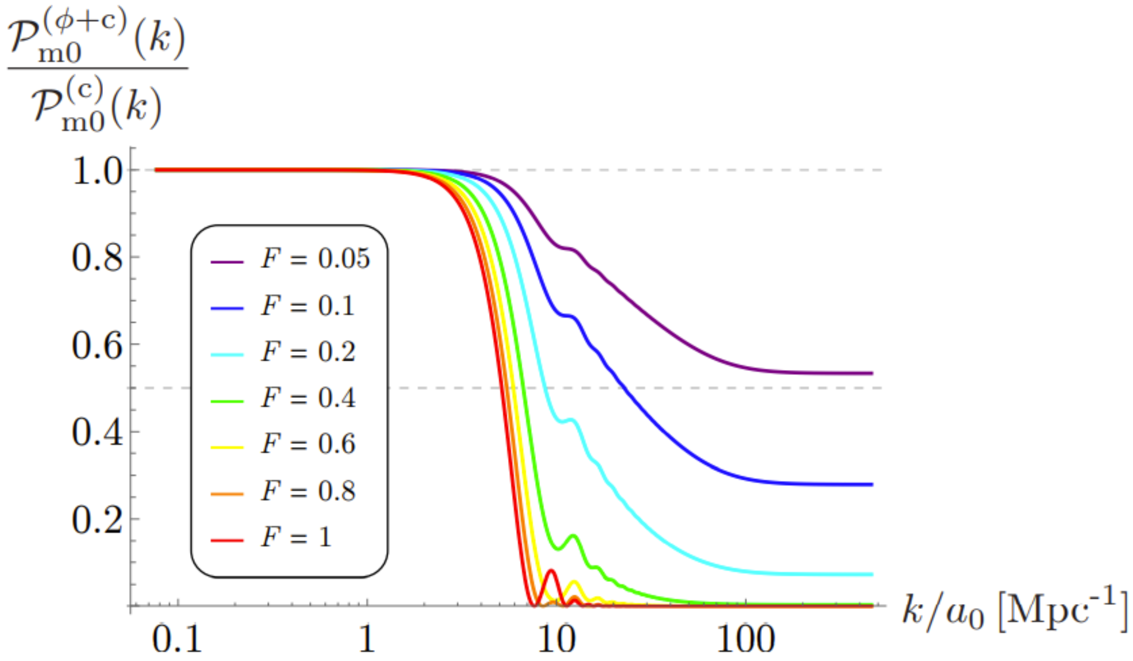
Some existing frameworks

ΛCDM + m_e: An increase of m_e
→ electrons recombine faster
→ reduce sound horizon r_* (or r_d)



see **arXiv:1406.7482**, **1912.03986**

Axion cosmology: Axion is part of DM
→ Axion has finite Jeans scale
→ Small-scale structure is suppressed



see **arXiv:1410.2896**, **1708.00015**

Axi-Higgs model

- The Higgs VEV is driven by the axion

$$v = v_0(1 + \delta v) = 246\ \mathrm{GeV}\left(1 + \frac{Ca^2}{2M_{Pl}^2}\right)$$

- Axion field evolves following misalignment mechanism:

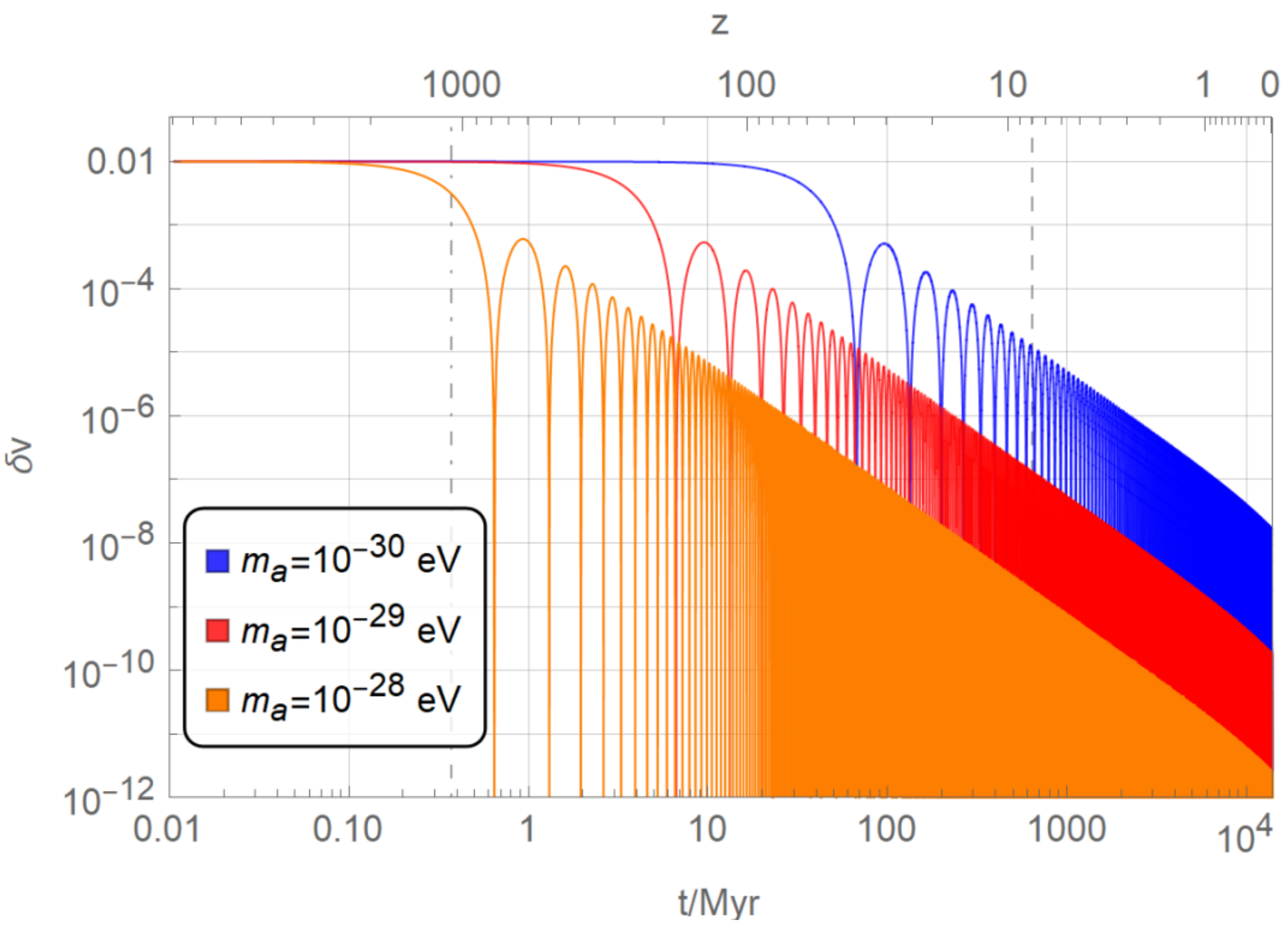
$$\ddot{a} + 3H\dot{a} + m_a^2 a = 0$$

with axion abundance given by

$$\rho_a \propto a_{\mathrm{ini}}^2 \text{ at early times}$$

$$\rho_a \propto \omega_a(1 + z)^3 \text{ at late times}$$

Higgs-VEV evolution



Axi-Higgs with $m_a \simeq 10^{-30} - 10^{-29}$ eV

- similar to $\Lambda\mathrm{CDM} + m_e$ before recombination
- similar to axion cosmology after recombination

Axi-Higgs introduces two additional parameters: δv_{ini} and ω_a

Axi-Higgs modifies ΛCDM

Recombination redshift:

$$\delta v_{\rm ini} = \delta m_e \simeq \delta z_*$$

Recombination sound horizon:

$$r_* = \int_{z_*(1+\delta z_*)}^{\infty} \frac{c_s(z)}{H(z)} dz,$$

Hubble function:

$$H^2(z) \propto \omega_r(1+z)^4 + (\omega_b + \omega_c)(1+z^3) + \omega_\Lambda + \rho_a(z)$$

Axion perturbations:

$$\ddot{\delta}_a + 2H\dot{\delta}_a + \left(k^2 c_{s,\rm eff}^2/a^2 - 4\pi G\rho_a\right)\delta_a = 0$$

Matter clustering:

$$\sigma_8 \propto \int (\delta_{\rm c} + \delta_a)$$

How can we estimate these changes quantitatively?

Leading-order perturbative approach

Expanding cosmological observables: $\delta Y = \sum \frac{\partial \ln Y}{\partial \ln X} \delta X$

We are interested in: $\theta_* = r_*/D_*$ and $S_8 = \sigma_8 (\Omega_m/0.3)^{0.5}$

$$\delta\theta_* = -0.06\delta\omega_b + 0.12\delta\omega_c + 0.19\delta H_0 - 0.68\delta v_{\rm ini} + 2.7\omega_a$$

CMB data requires θ_* *fixed* $\rightarrow \delta\theta_* = 0$
$\rightarrow \delta v > 0$ *implies* $\delta H_0 > 0 \rightarrow$ *Hubble tension alleviated!*

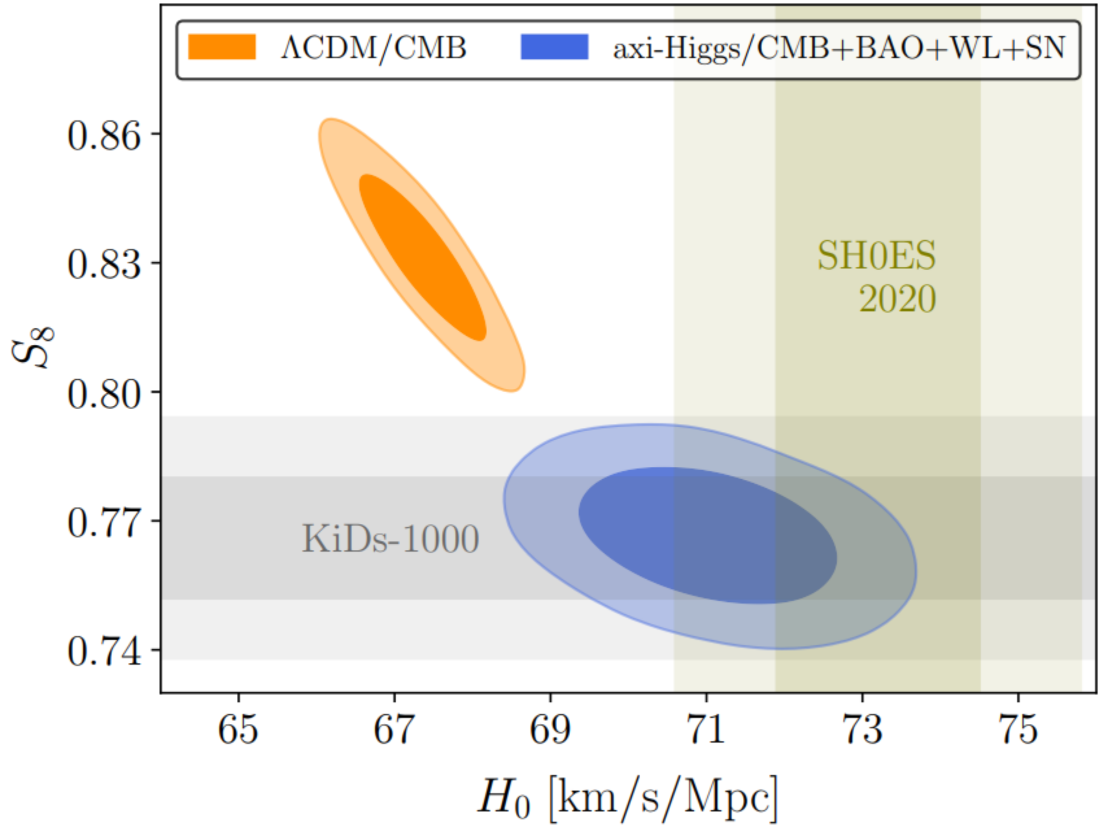
$$\delta S_8 = -0.10\delta\omega_b + 1.05\delta\omega_c - 0.77\delta H_0 + 0.05\delta v_{\rm ini} - 15.3\omega_a$$

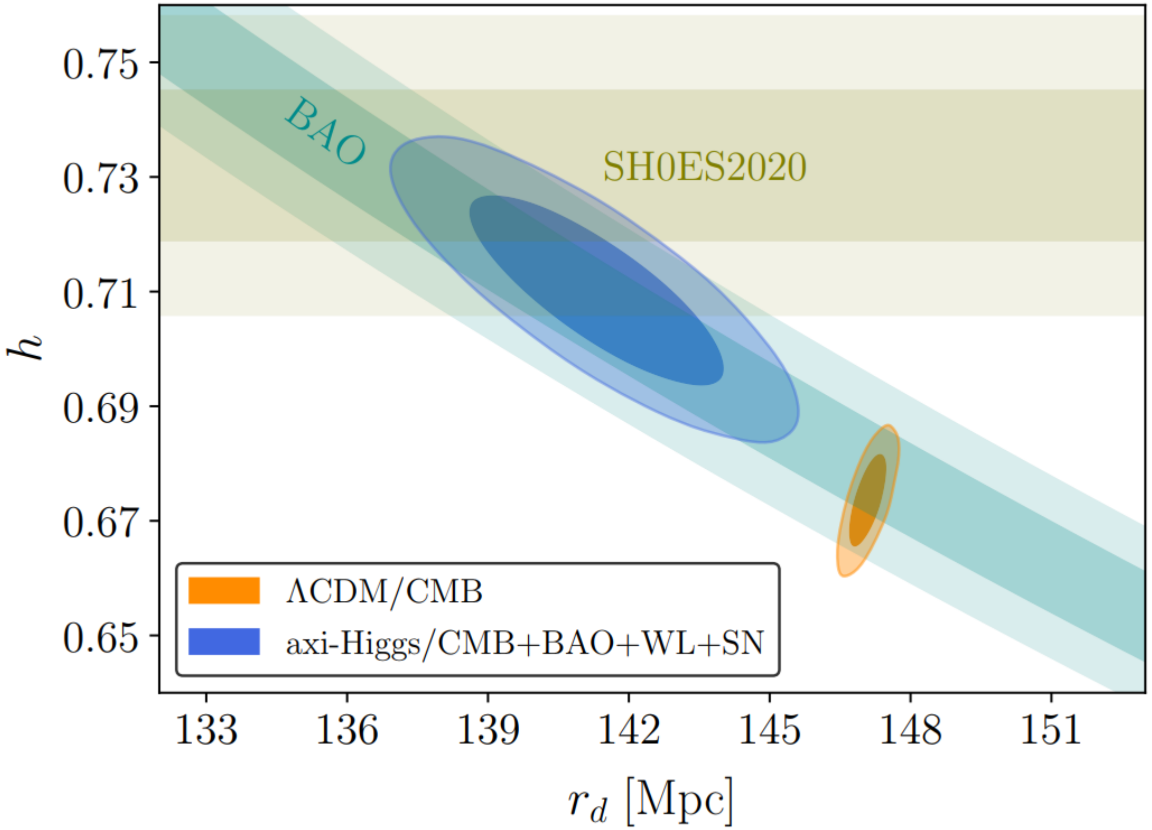
Axion has finite relic abundance $\rightarrow \omega_a > 0$
$\rightarrow \delta S_8 < 0 \rightarrow$ S_8 *tension alleviated!*

Axi-Higgs constraints

$\omega_b = 0.02329 \pm 0.00022$ $\omega_c = 0.1247 \pm 0.0024$ $H_0 = 71.1 \pm 1.1$

$v/v_0 = 1.039 \pm 0.011$ $\omega_a = 0.0050 \pm 0.0013$ $S_8 = 0.766 \pm 0.011$





Discussion

- The shifting of the Higgs VEV has significant impact on BBN, helps alleviate the well-known $\mathrm{Lithium}$ puzzle.
- Axi-Higgs could be tested by quasar spectral lines or atomic-clock precision measurements.

THANK YOU FOR LISTENING!

Backup

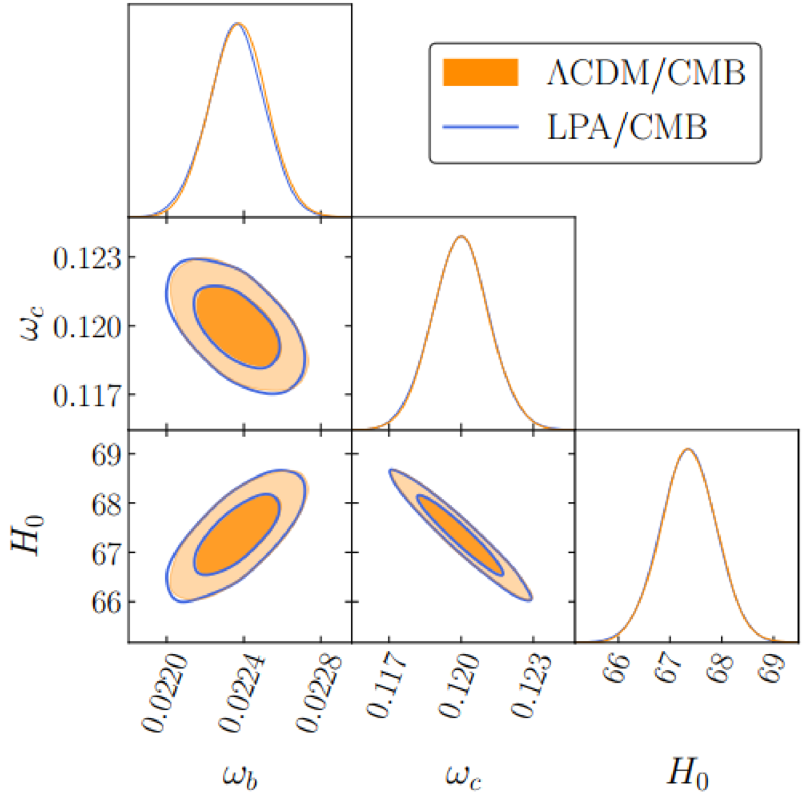
LPA equations for CMB observables:

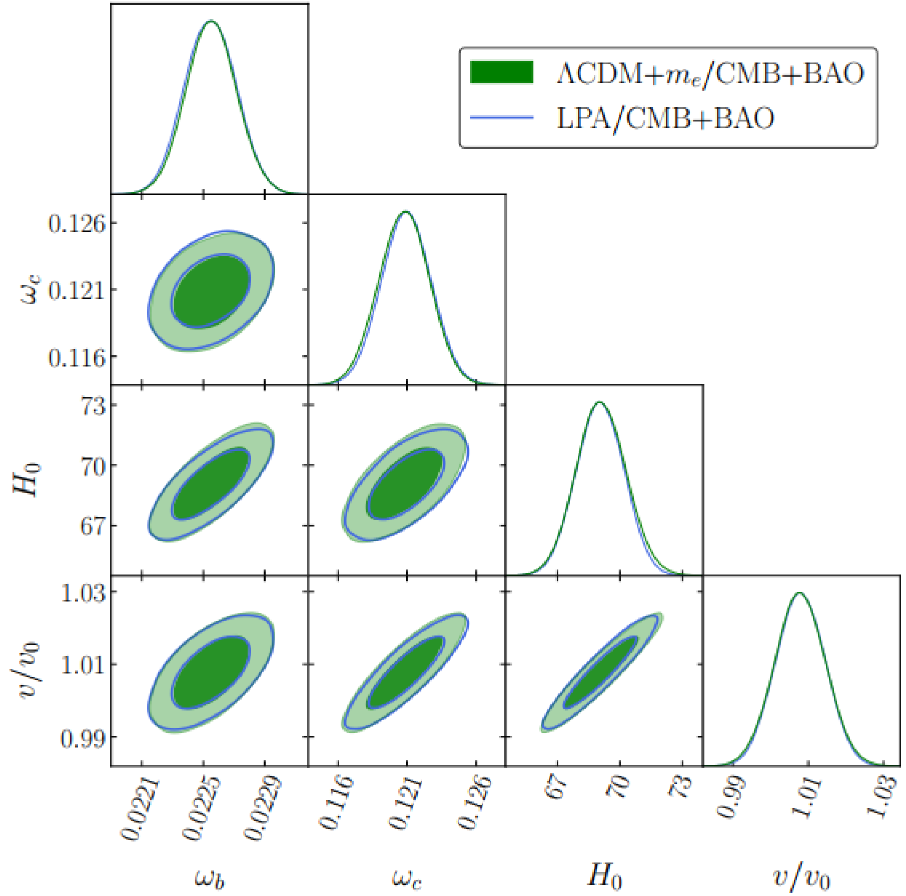
$$\delta\theta_* = -0.06\delta\omega_b + 0.12\delta\omega_c + 0.19\delta H_0 - 0.68\delta v + 2.7\omega_a$$

$$\delta l_{\mathrm{eq}} = 0.09\delta\omega_b + 0.51\delta\omega_c - 0.19\delta H_0 + 0.02\delta v - 2.7\omega_a$$

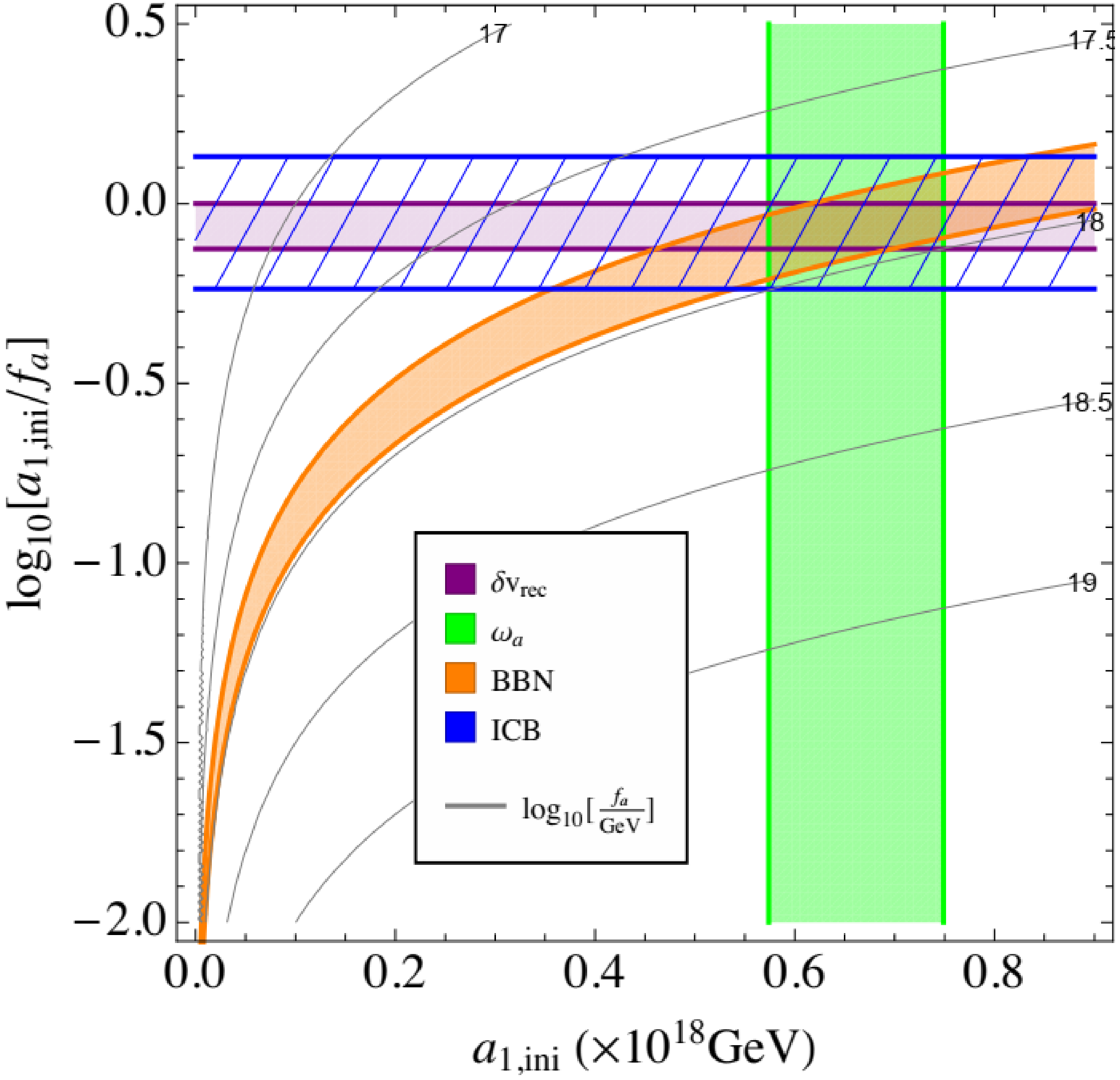
$$\delta l_D = 0.25\delta\omega_b - 0.10\delta\omega_c - 0.19\delta H_0 + 0.45\delta v - 2.7\omega_a$$

LPA tests with ΛCDM and $\Lambda\text{CDM} + m_e$:

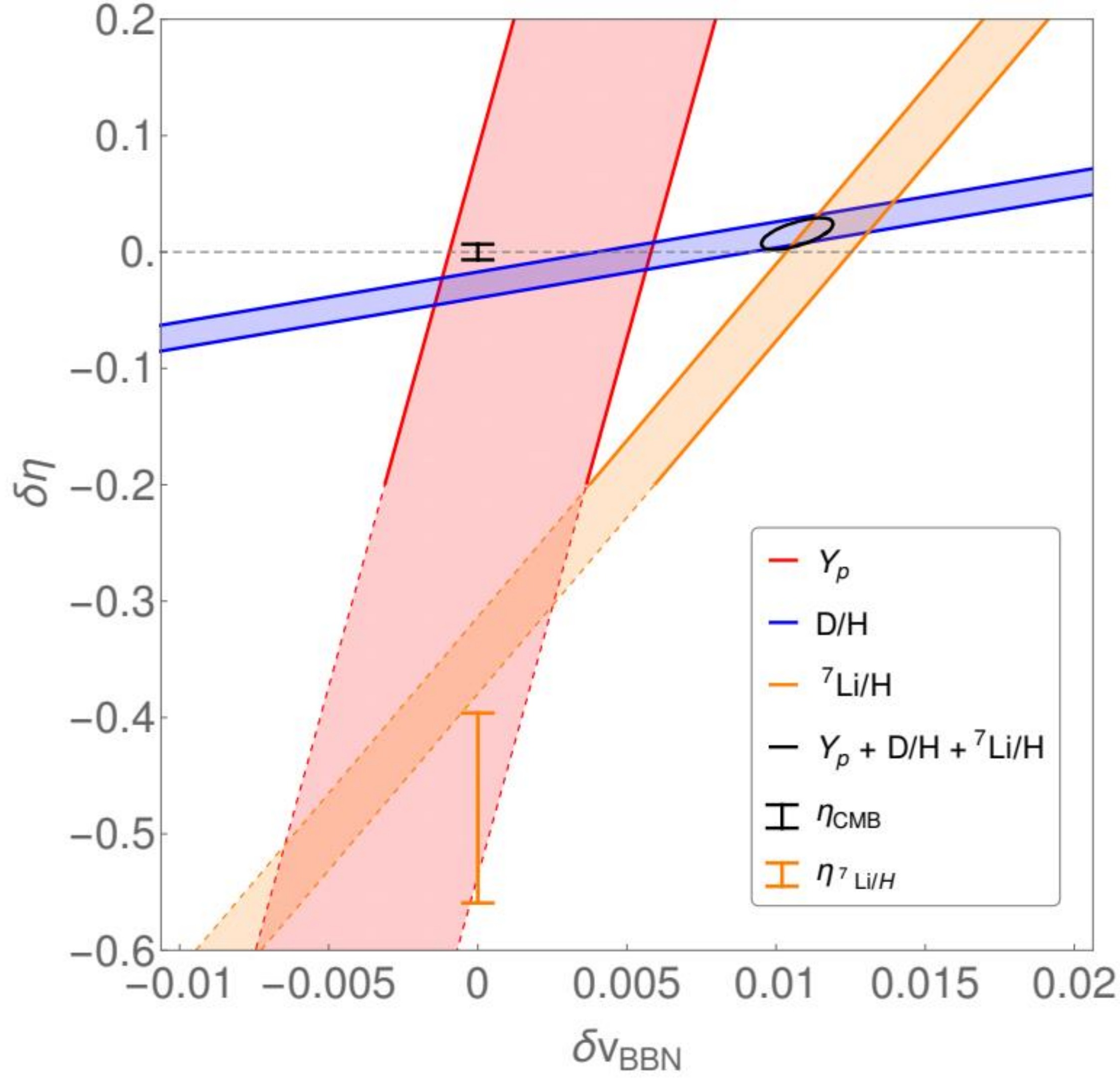


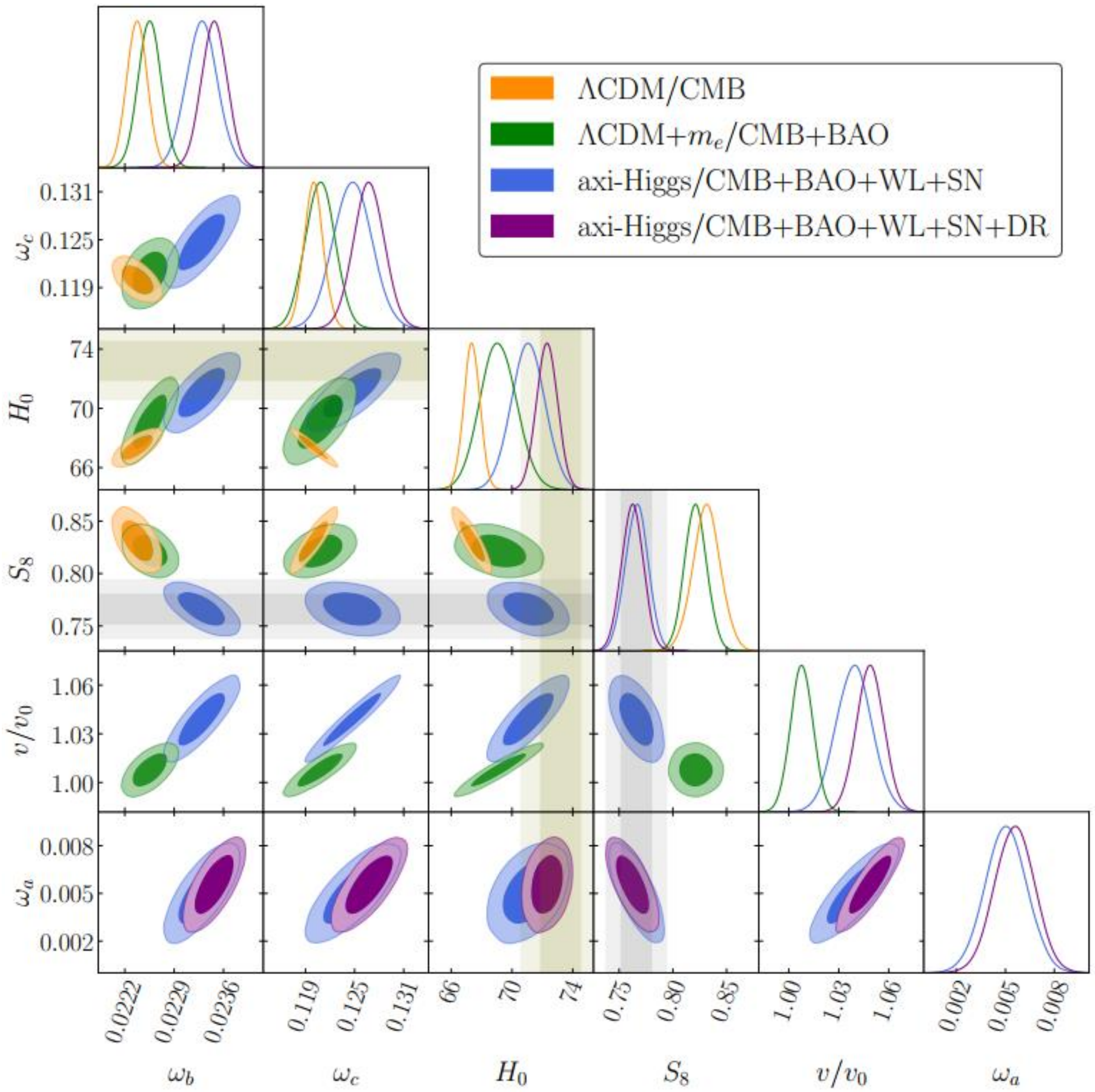


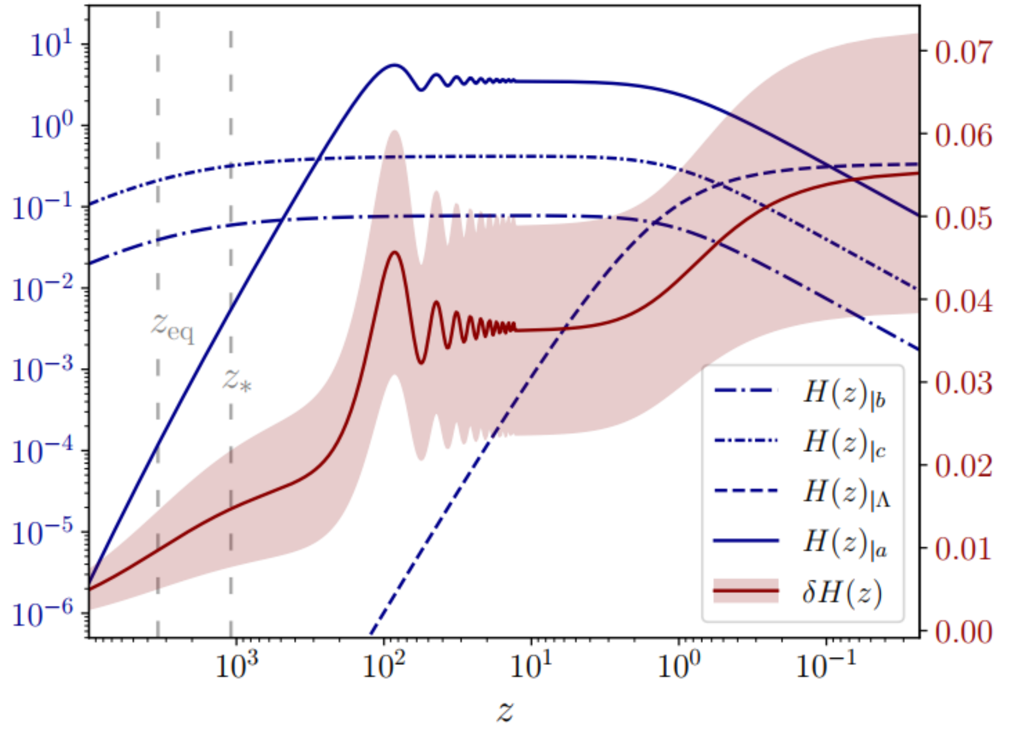
Axi-Higgs overall:

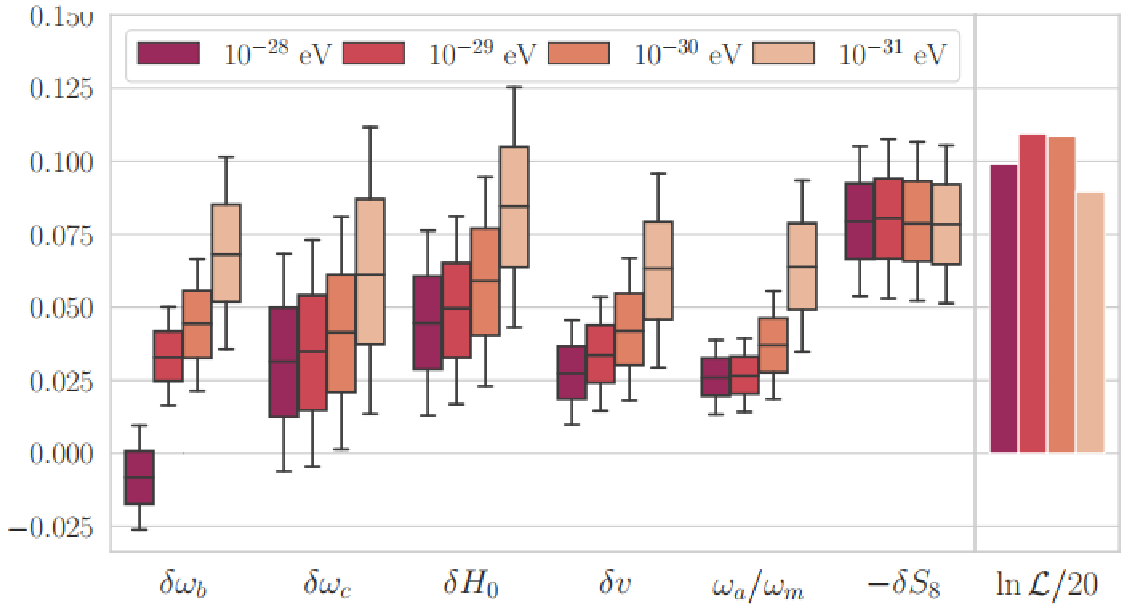


BBN constraint:




ΛCDM/CMB
ΛCDM+m_e/CMB+BAO
axi-Higgs/CMB+BAO+WL+SN
axi-Higgs/CMB+BAO+WL+SN+DR
ω_c
H_0
S_8
v/v_0
ω_a
ω_b


$z_{\rm eq}$
z_*
$H(z)_{|b}$
$H(z)_{|c}$
$H(z)_{|\Lambda}$
$H(z)_{|a}$
$\delta H(z)$
z


10^{-28} eV
10^{-29} eV
10^{-30} eV
10^{-31} eV
$\delta\omega_b$
$\delta\omega_c$
δH_0
δv
ω_a/ω_m
$-\delta S_8$
$\ln \mathcal{L}/20$