A Symmetry of Cosmological Observables, and a High Hubble Constant as an Indicator of a Mirror World Dark Sector

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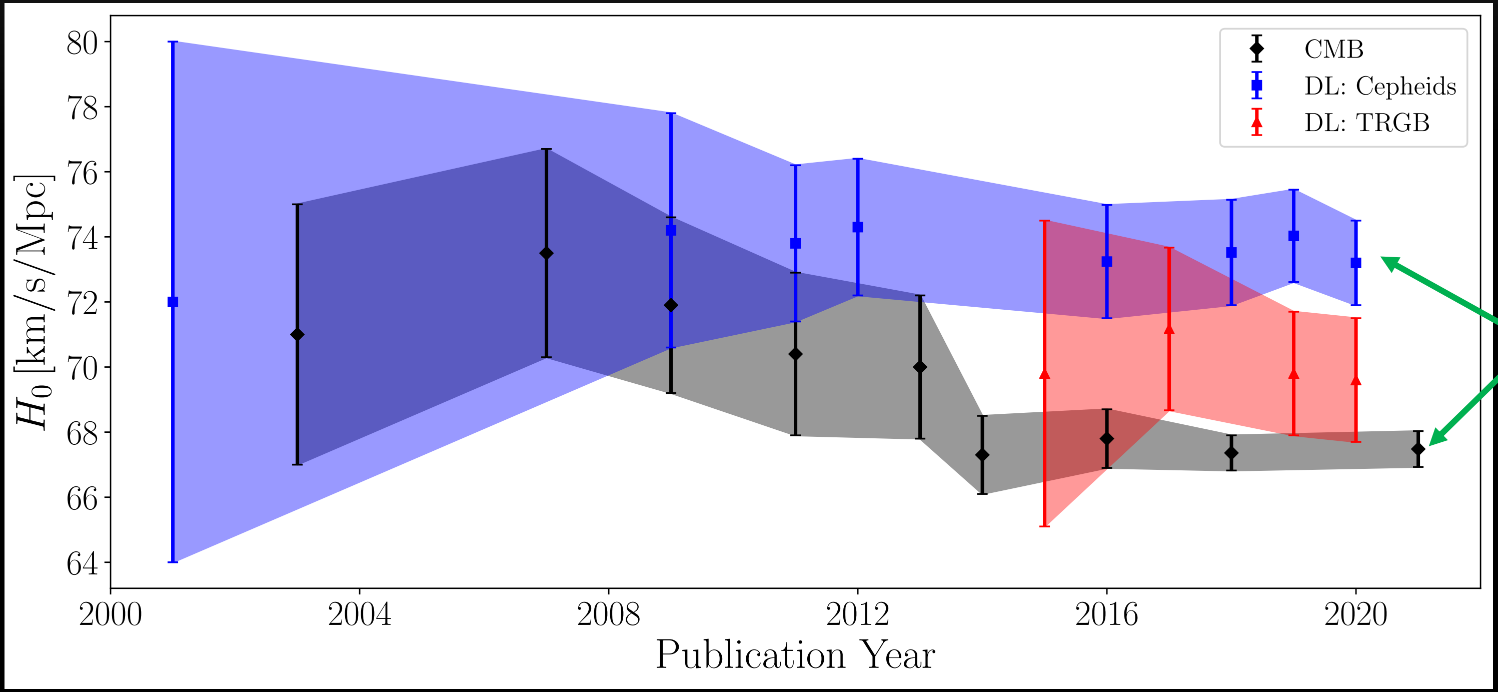
With Fei Ge and Lloyd Knox, arXiv: 2107:13000, submitted

What is the current expansion rate of our Universe?

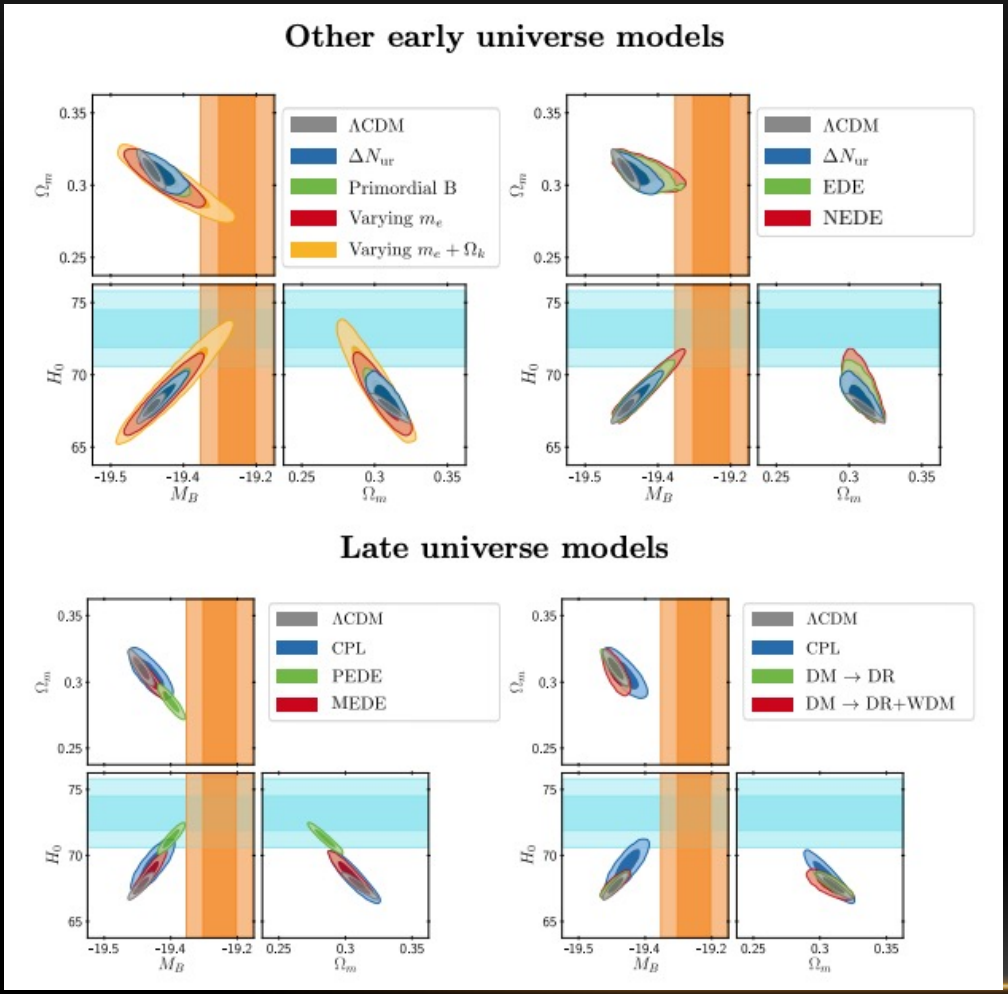


Cyr-Racine (2021), adapted from Freedman et al. (2019)

CMB and the cepheid-calibrated distance ladder disagree

CMB: Cosmic Microwave background
DL: Distance ladder
TRGB: Tip of the red giant branch

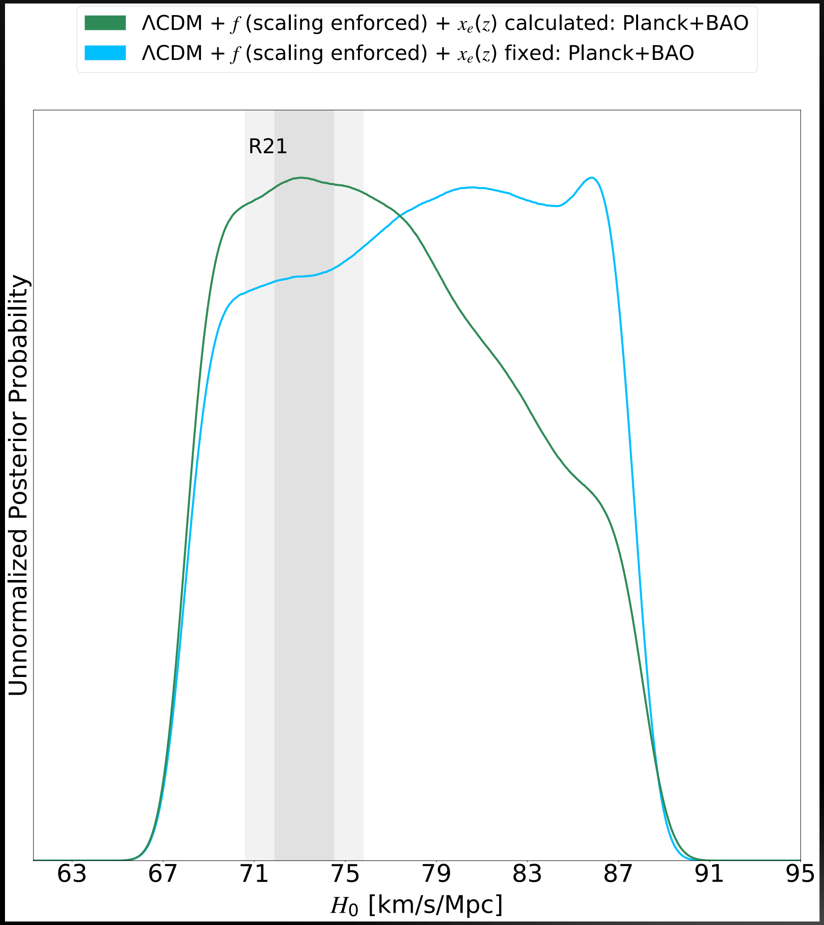
Why is it so hard to get a large Hubble constant from the CMB + BAO?



Schöneberg et al., arXi:2107.10291

- Lots of ideas out here! Why are they all struggling to get a large value of the Hubble rate?

Main Message: CMB + BAO can be made compatible with a **very** large value of H_0

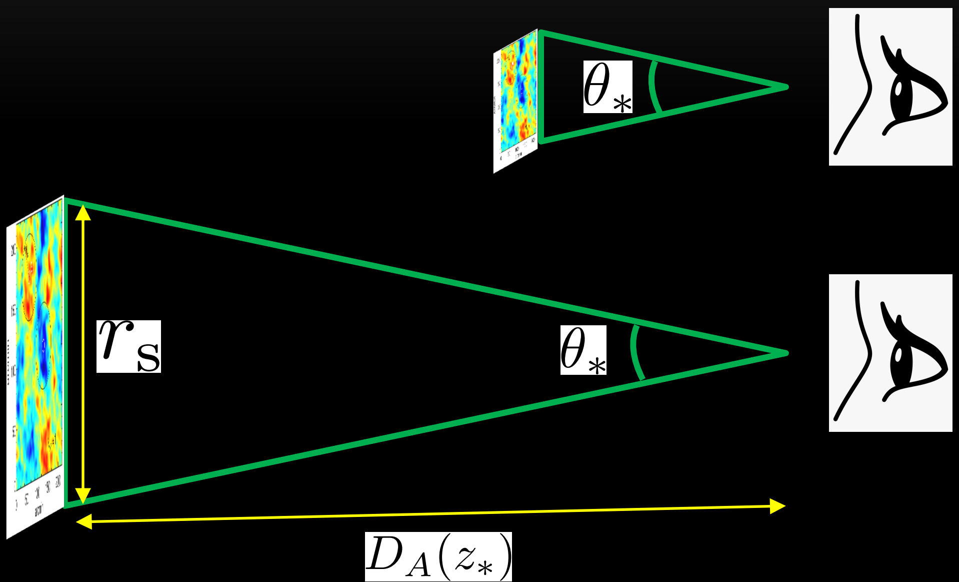


- CMB, BAO, and other cosmological observables have a fundamental symmetry that allows them to be compatible with a broad range of H_0 values.
- But there is a price to pay…

Cyr-Racine , Ge & Knox, arXi:2107.13000

Symmetry: Basic geometry and the dimensional analysis

- Dimensionless observables seen in projection on the sky have an intrinsic scale invariance.
- By dimensional analysis, ODEs for the evolution of dimensionless quantities can only depend on dimensionless ratios.

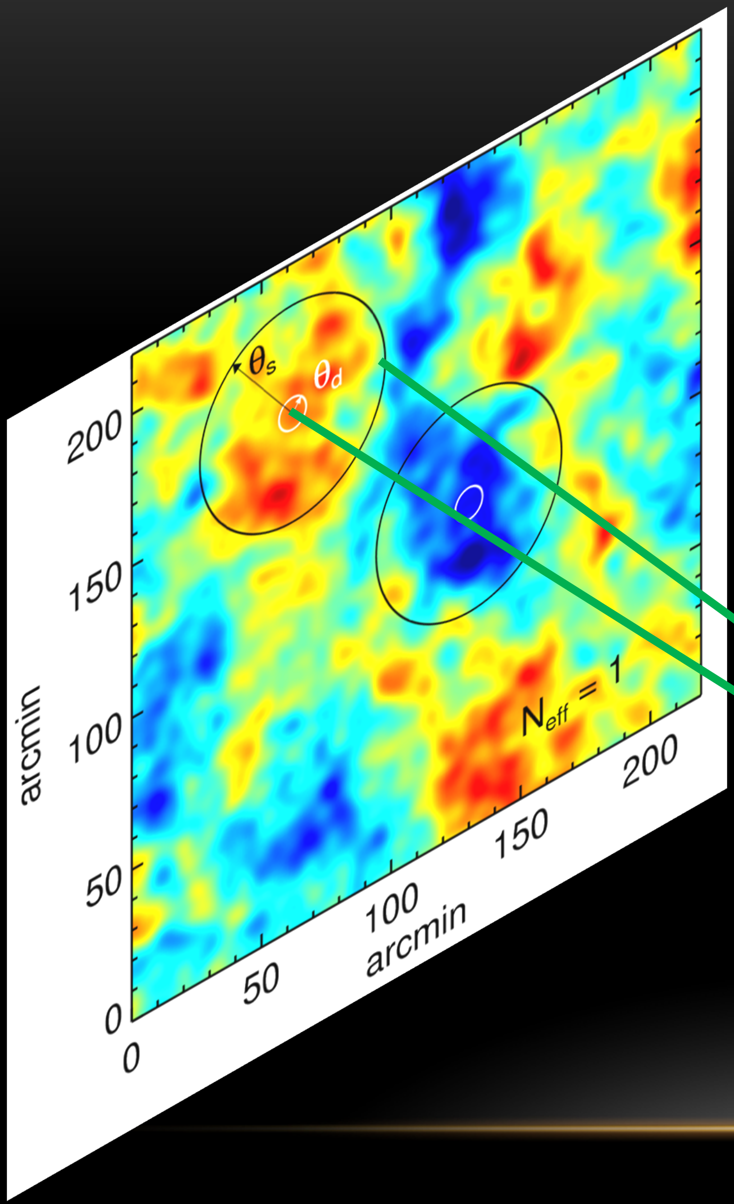


Photon-baryon scattering rate

$$k/H,\ \dot{\kappa}/H$$

Nothing special about cosmology here!

Invariance of angles under uniform rescaling of the Hubble rate

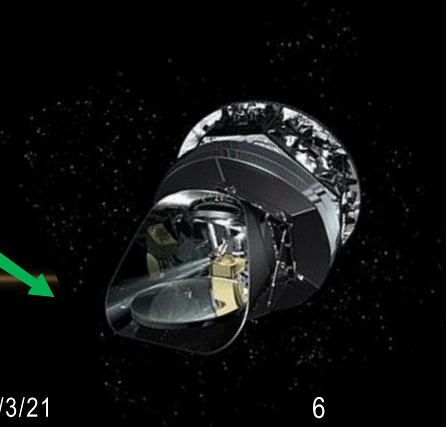


- All angles on the CMB sky are invariant under this scaling (for constant f):

$$\boxed{H \to fH}$$

$$\theta_* = \frac{r_s}{D_A(z_*)}$$ where

$$r_s = \int_{z_*}^{\infty} dz \frac{c_s(z)}{H(z)} \qquad D_A(z_*) = \int_0^{z_*} dz \frac{1}{H(z)}$$



But what if **all** length scales are uniformly rescaled?

- Instead of just rescaling H, do the transformation:

$$H \to fH,\ k \to fk,\ \dot{\kappa} \to f\dot{\kappa}.$$

- By dimensional analysis, all factors of f cancel out in the equations of motion (EOM).

This leaves the photon-baryon (and dark matter and massless neutrinos) EOM invariant.

Special feature of our Universe: Initial conditions

- We happen to live in a Universe in which the initial scalar fluctuations have no intrinsic scale.

$$P(k) = A_{\rm s}(k/k_{\rm p})^{n_{\rm s}-1}$$

- Since $n_s < 1$, the different Fourier modes have slightly different primordial amplitudes.
- Thus, the transformation $k \to fk$ will modify the amplitude of fluctuations (CMB, P_m(k), etc.)
- However, since power laws have no scale, this can be corrected with a trivial rescaling:

$$A_{\rm s} \to A_{\rm s}/f^{n_{\rm s}-1}$$

Zahn and Zaldarriaga (2003)

The scaling "recipe"

1. Increase Hubble rate at all times by scaling up every energy density:

$$G\rho_i \to f^2 G\rho_i \quad \Rightarrow \quad H \to fH$$

2. Scale up the photon scattering rate $\dot{\kappa} = a n_e \sigma_{\mathrm{T}}$ according to:

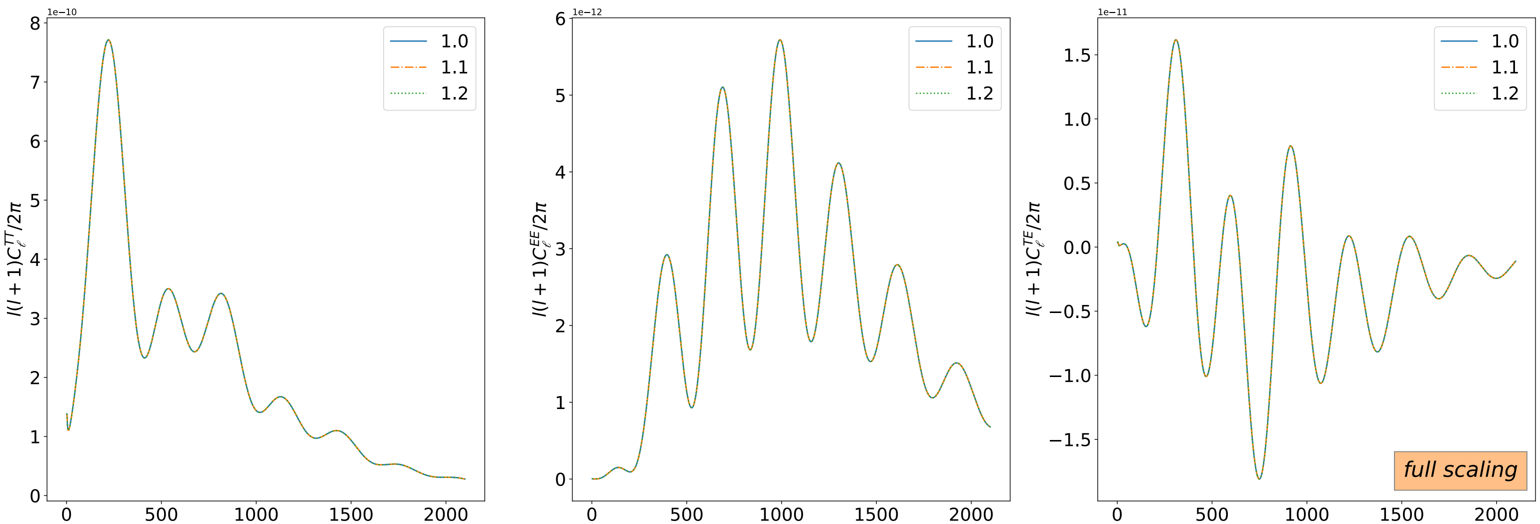
$$\sigma_{\mathrm{T}} n_e(a) \to f \sigma_{\mathrm{T}} n_e(a)$$

3. Adjust the initial amplitude of scalar fluctuations according to

$$A_{\mathrm{s}} \to A_{\mathrm{s}} / f^{n_{\mathrm{s}}-1}$$

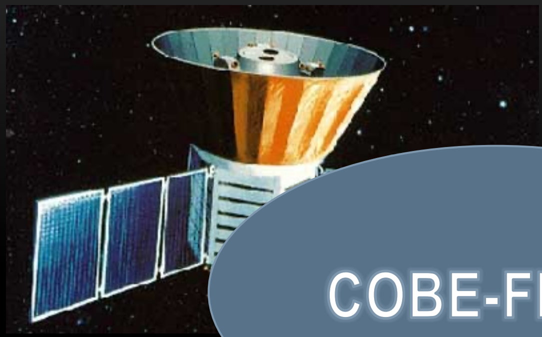
This works

- This really leaves the CMB temp/pol invariant (fixing recombination history here)



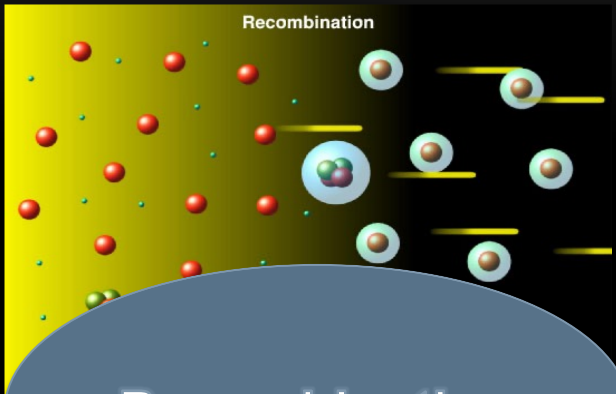
$$H_0 = 67.5, 74.3, 81 \mathrm{km/s/Mpc}$$

Reality check: 3 main symmetry breaking effects

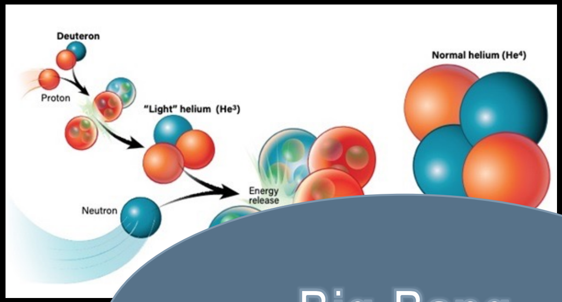


COBE-FIRAS

Symmetry Breaking



Recombination



Big-Bang Nucleosynthesis

Getting around COBE: Mirror World

- We can't easily increase the densities of photons/baryons
- So instead add mirror "dark" particles!

Stranger Things

Chacko et al. (2005, a,b,c), Craig & Howe (2014), Craig et al. (2015), Farina (2015), Barbieri et al. (2016), Chacko et al. (2017), Csaki et al. (2017), Hochberg et al. (2017), Harigaya et al. (2017), Ibe et al. (2019), Terning et al. (2019), Curtin & Gryba (2021), Blinov et al. (2021) and many more

Adjusting the photon scattering rate

- The mirror world ingredients ensure that we "effectively" implement the rescaling

$$\sqrt{G\rho_i(a)} \to f\sqrt{G\rho_i(a)}, \quad \Rightarrow \quad H \to fH$$

while leaving the perturbation evolution invariant.

- It does not however implement the necessary scaling

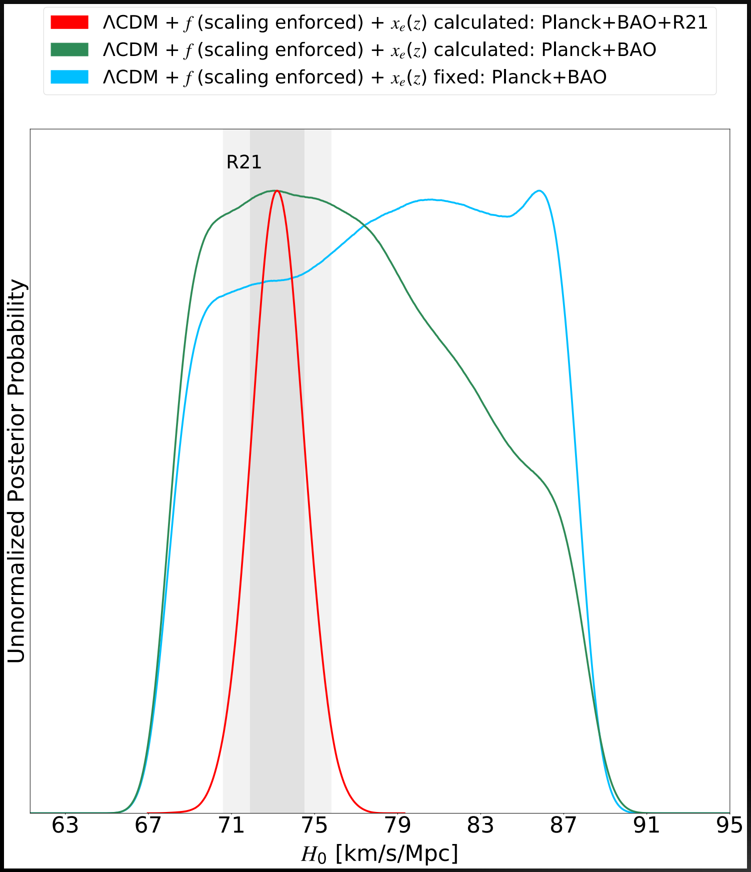
$$\sigma_{\rm T} n_e(a) \to f\sigma_{\rm T} n_e(a)$$

- Since $n_e \propto (1 - Y_{\rm P})$, one can implement this scaling by adjusting the helium fraction according to

$$(1 - Y_{\rm P}) \to f(1 - Y_{\rm P})$$

Not unique! There are other ways to implement this scaling.

Second Test: Compatibility with the cepheid-calibrated distance ladder

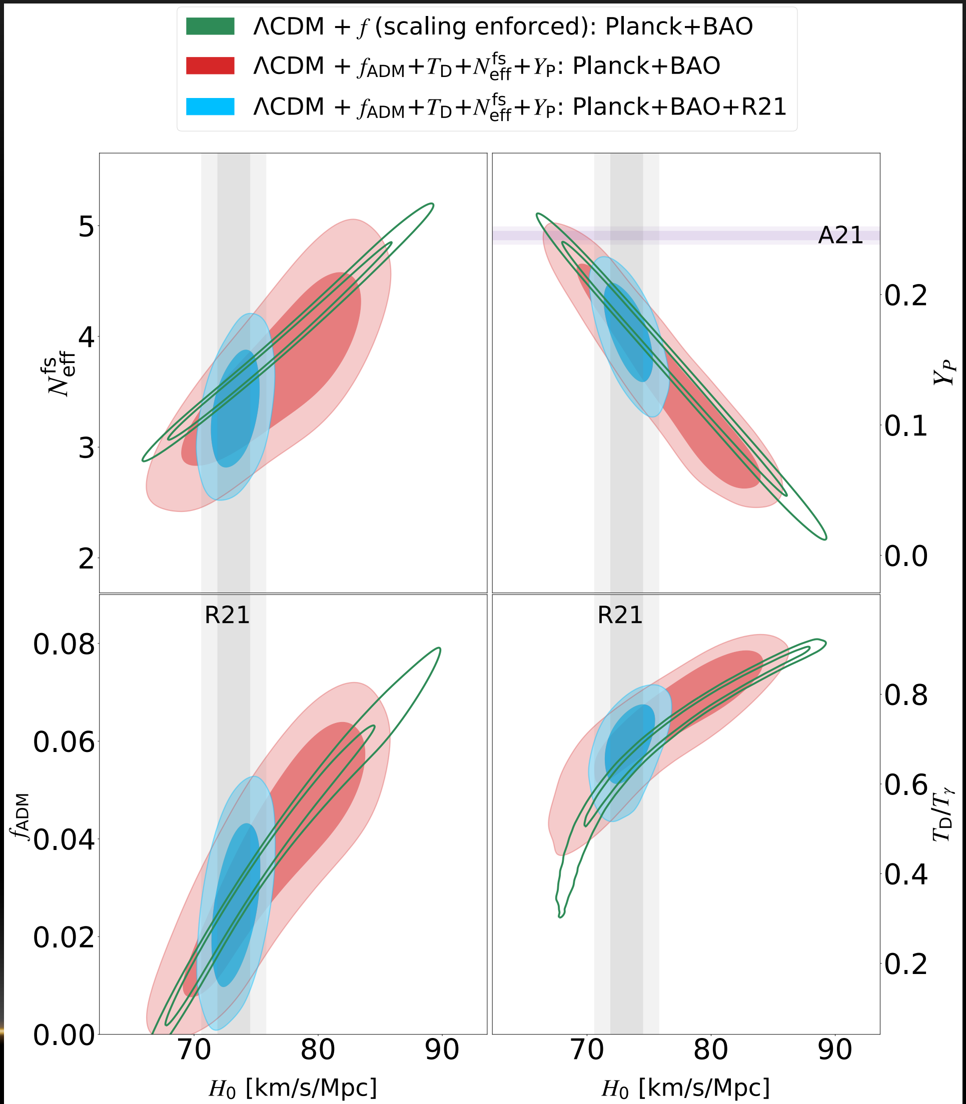


- The symmetry allows us to completely eliminate the Hubble tension between CMB + BAO and the local distance ladder (R21 here).

Mirror Sector Freedom

At face value, the direct Hubble measurements predict ~3% in atomic dark matter, and a dark photon bath with a neutrino-like temperature.

However, Y_P is low!



Open Questions

- Can we achieve a higher photon scattering rate and have consistency with BBN and Y_P ?
- Can we detect the 3% of atomic DM?
- Can a consistent mirror sector be built?
- Impact of nonlinear evolution?