New physics at low redshift cannot be the sole explanation for the H0 tension

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Cosmology From Home

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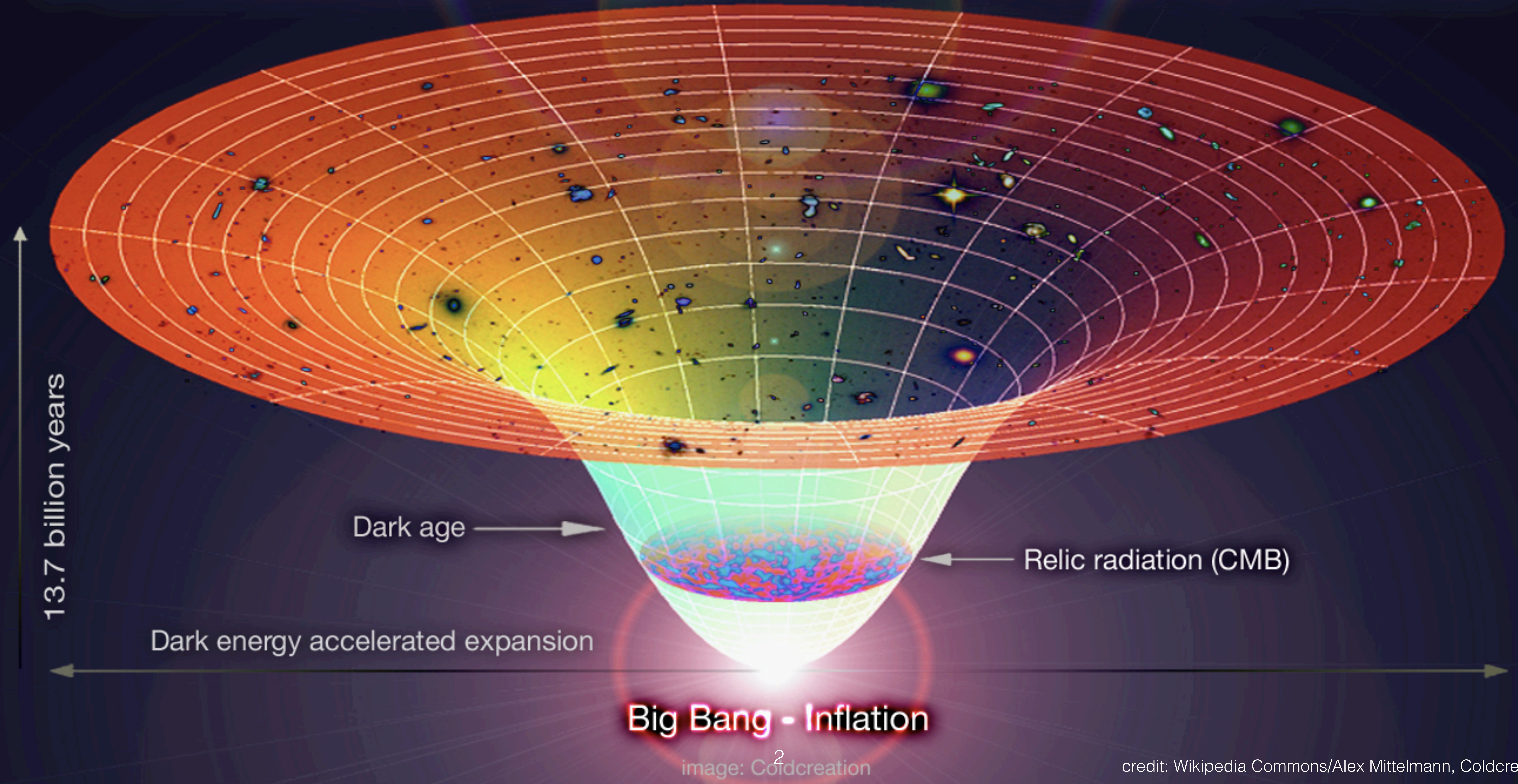
Accelerated Expansion of the Universe

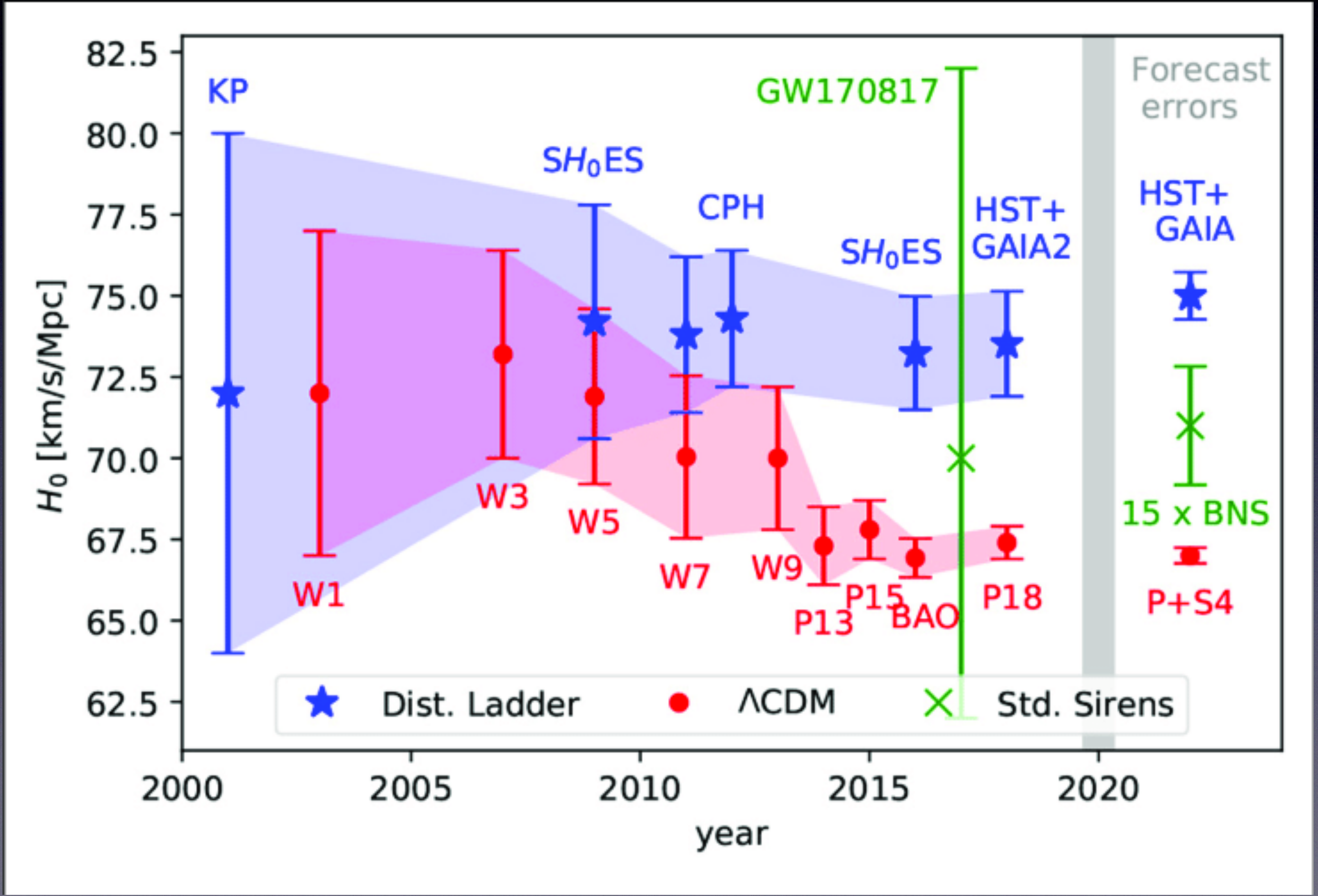


credit: Wikipedia Commons/Alex Mittelmann, Coldcreations

Testing the Concordance Model

- ΛCDM + GR
- Λ - test via low-redshift distances *
- CDM - test via small scale structure
- GR - test via growth rate measurements
- Inflation - CMB, LSS
- Testing FLRW (homogeneity + isotropy)

H0 Tension

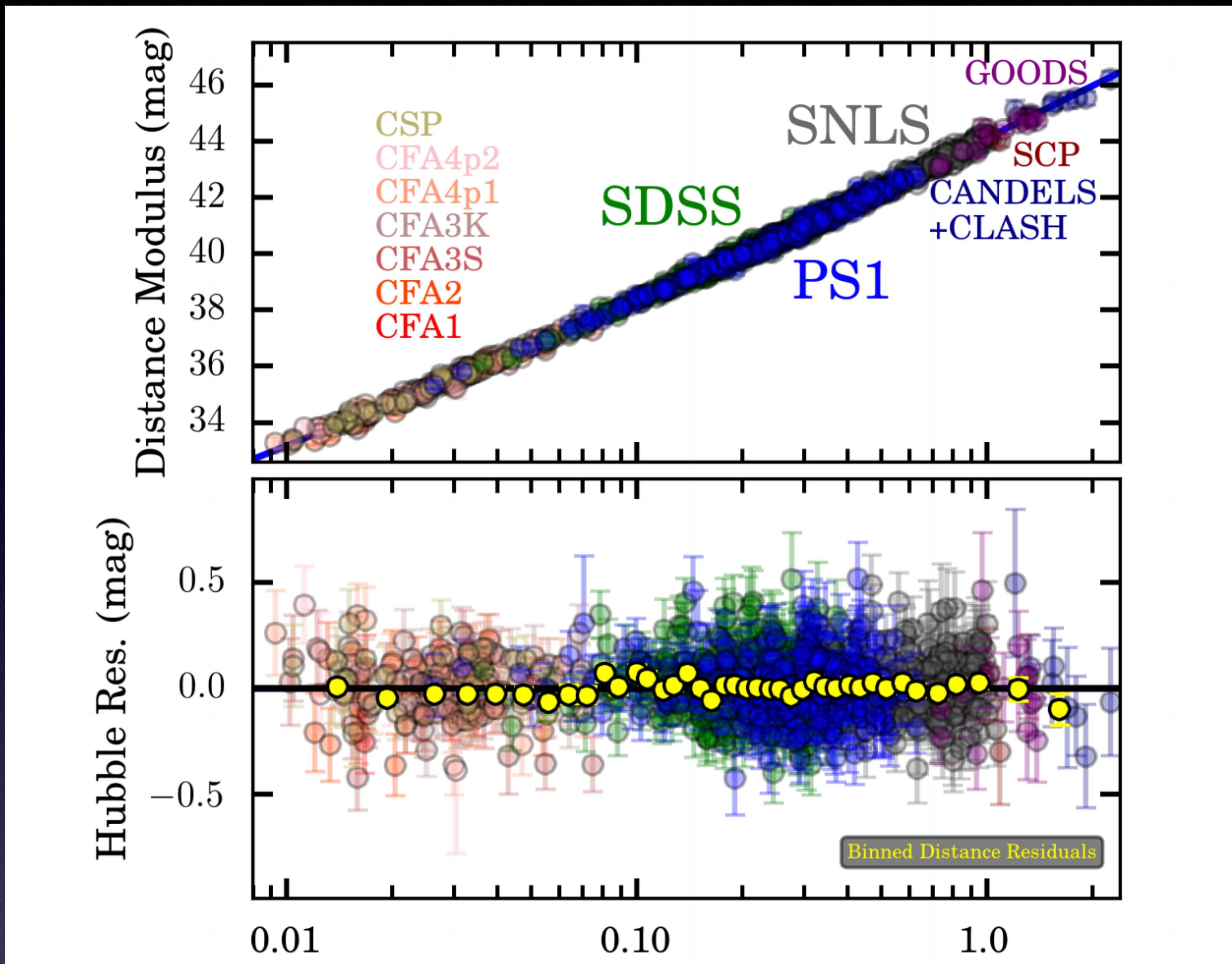


Ezquiaga et al. (2018) Arxiv:1807.09241

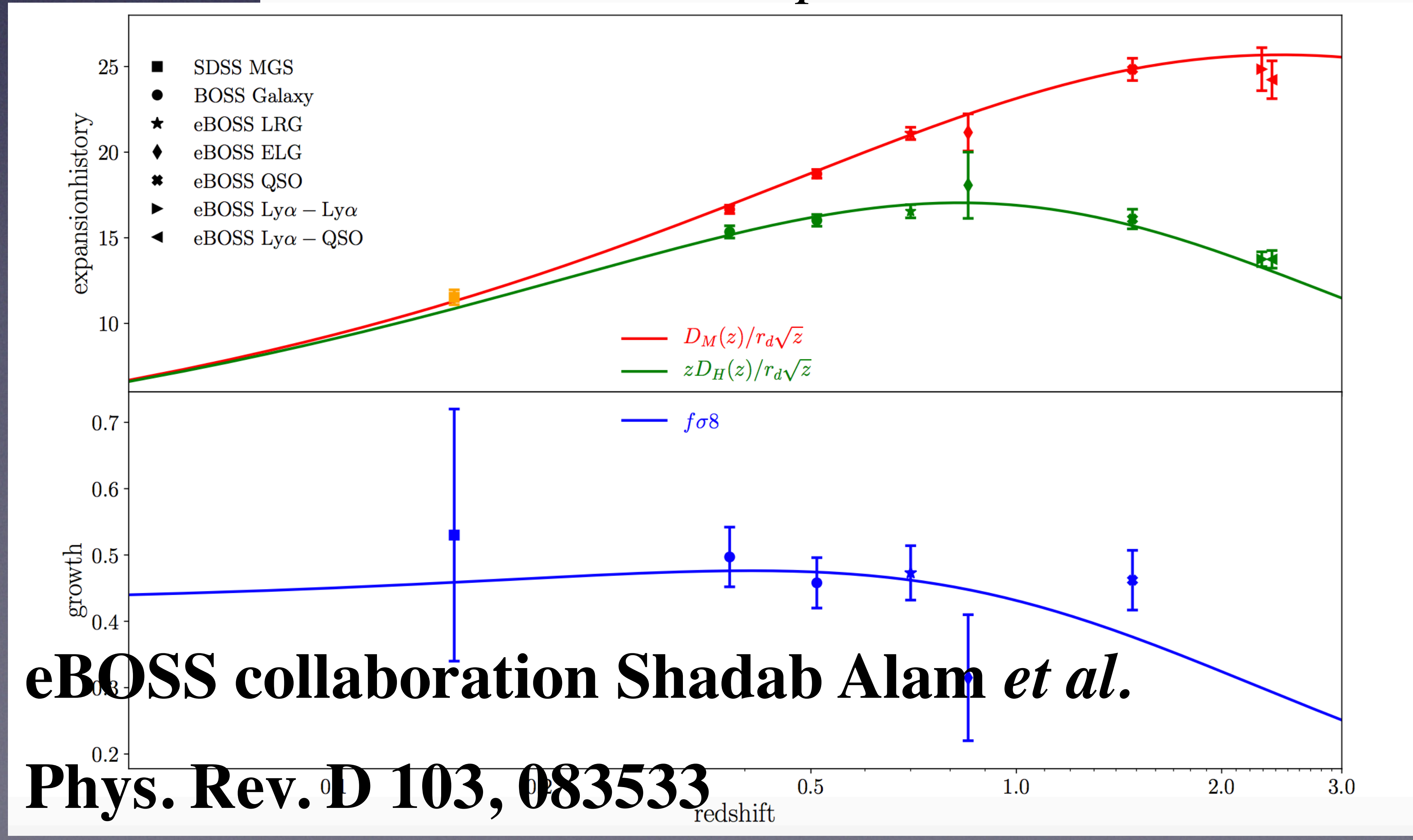
- Inferences from the CMB predict H(z=0) = 67.36 +/- 0.54 km/s/Mpc
- Measuring H0 directly gives 73.04 +/- 1.04 km/s/Mpc
- Difference is now at >5-σ.
- No obvious systematics
- Potentially a challenge for LCDM

Guardrails

- BAO measure both DA(z) and H(z)
- 5 tracers in 7 redshift bins z~0.1 to 2.3
- The curves are predictions from just the Planck data (not fits to the eBOSS data)
- SN measure luminosity distances DL(z)
- 1048 SN from z~0.01 to 2.3
- Both datasets are unanchored and thus cannot tell which value of H0 is correct
- Can only constrain a mutual scale H0rd
- They can constrain the possible expansion histories that map between z=0 and z=z*



Scolnic *et al* 2018 *ApJ* **859** 101



eBOSS collaboration Shadab Alam *et al.*

Phys. Rev. D 103, 083533

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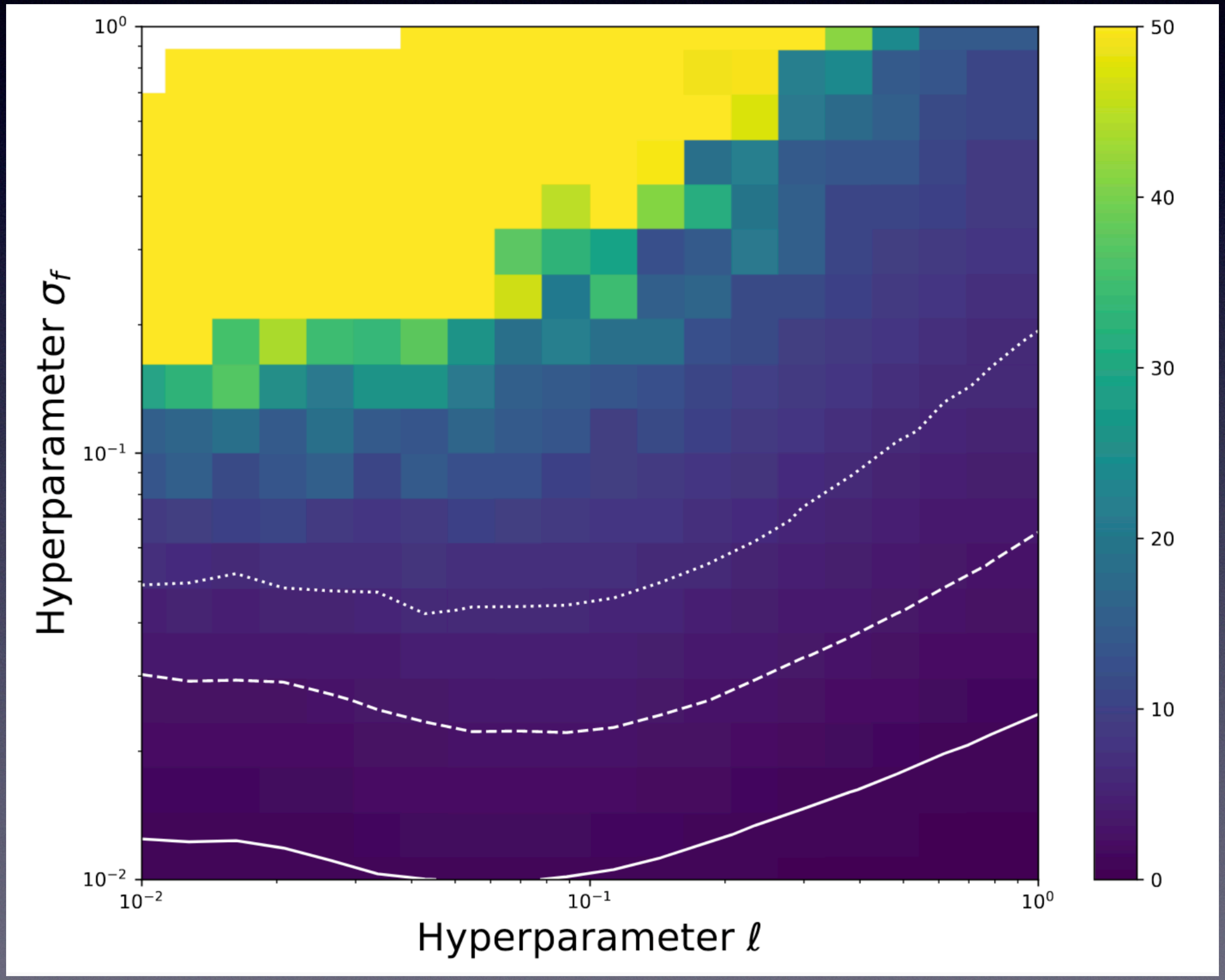
Guardrails: important datasets to understand potential solutions

- Joint BAO+SN datasets are consistent with LCDM
- Posterior of hyperparameters of GP regression
- σ_f controls how different GP reconstruction is from LCDM
- If σ_f is consistent with 0 -> LCDM is correct



Keeley *et al* 2021 *AJ* **161** 151

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Case for low-z solutions

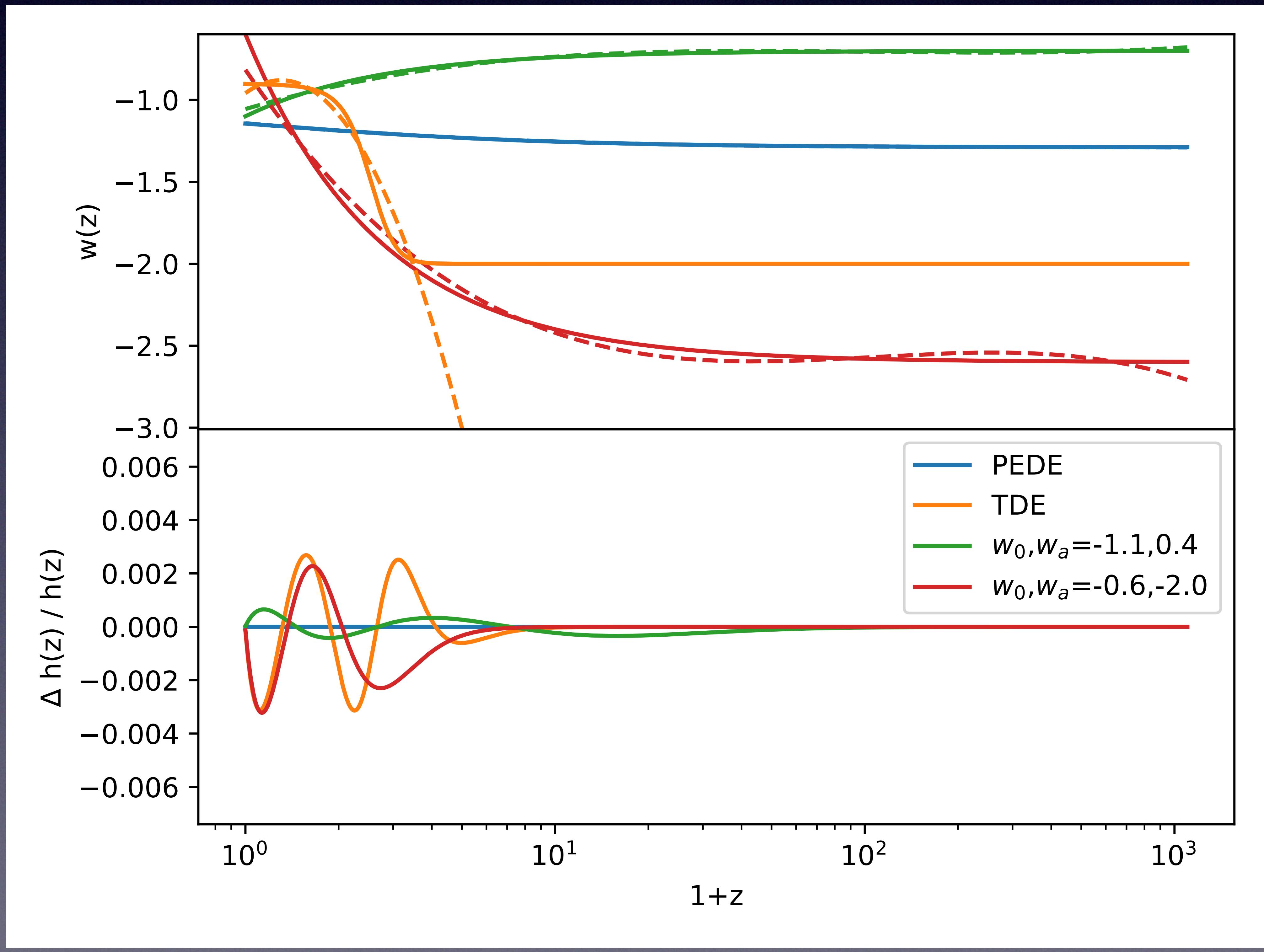
- CMB -> Cepheids projection over 3 orders of magnitude in scale factor
- Natural to expect adding new physics between the CMB and today would solve the H0 tension
- The physics at the CMB is non-trivial
- Such solutions inherit the high-redshift successes of LCDM
- CMB does not measure H0 only predicts it
- The CMB constrains H0 via the constraint on $\theta_s = r_s(z_*)/D_A(z_*)$
- Geometric degeneracy -> there exists w(z) such that the CMB is well fit and predicts any* value of H0

Throwing everything at the wall

- The strategy is to throw whatever extensions to LCDM we can think of at the datasets and see if anything sticks
- Curved CPL - $w(z) = w_0 + w_a \frac{z}{1+z}$
- Chebyshev polynomials - $w(z) = -\sum_{1}^{4} c_i T_i(x),\ x = \log(1+z)/\log(1+z_*)$
- GP regression
- If these very broad cases cannot resolve the H0 tension, then we must conclude low-z physics as a whole cannot solve the H0 tension

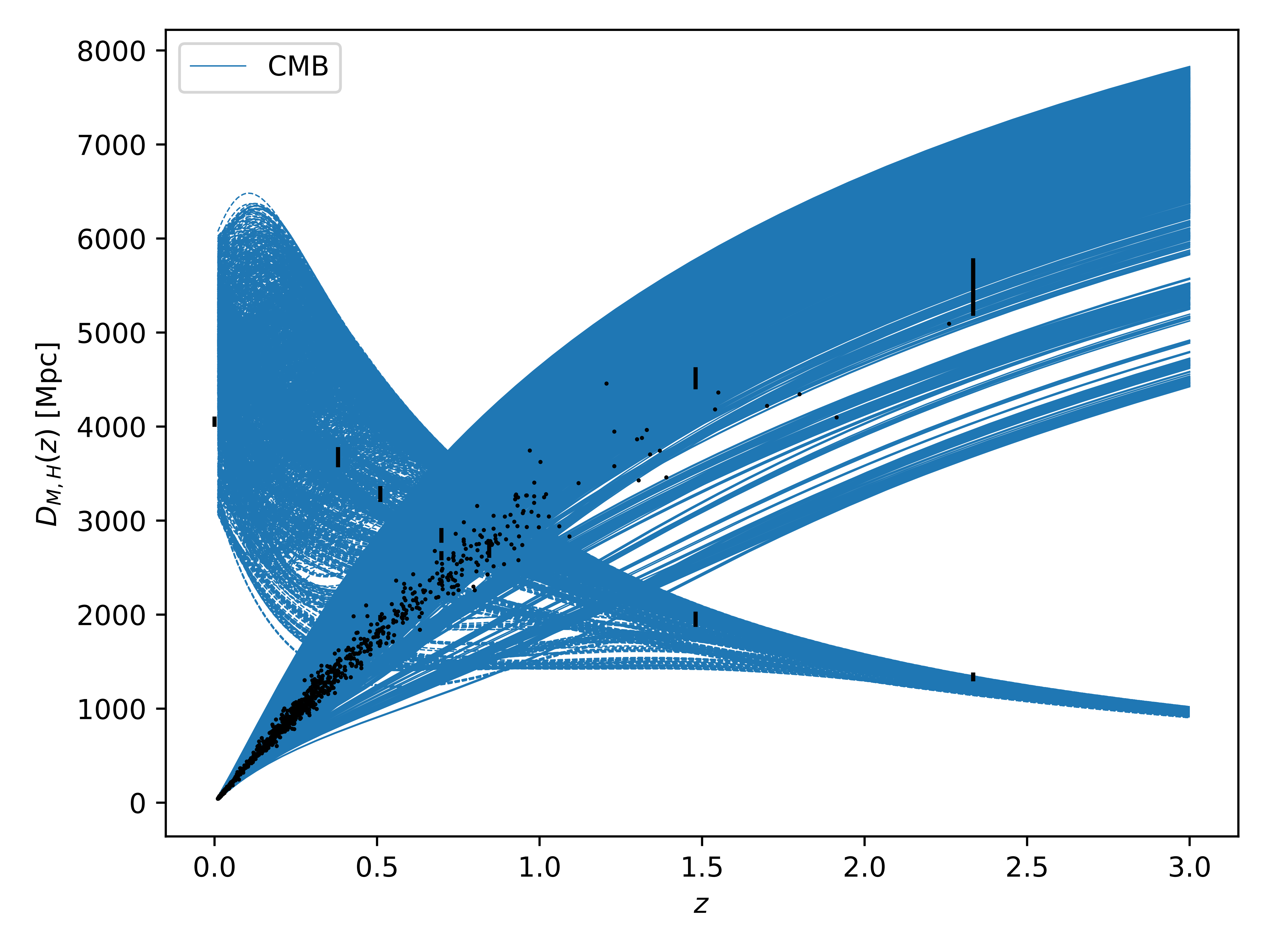
Matches Example Models

- Chebyshev parametrization is flexible enough to approximate a variety of evolving dark energy models.
- Two such models TDE model and the PEDE model
- PEDE: slowly varying, purely phantom (w<-1)
- TDE: quickly evolving, transitions between phantom and quintessent (w>-1)
- PEDE model equation of state can be matched exactly
- TDE equation of state is a less exact match. However, the corresponding H(z) and DM(z) values are all within <0.5%



More Flexible than Data

- Test whether Chebyeshev parametrization can bracket the data.
- Whatever cosmological functions (H(z), DM(z)) still allowed by data find a sufficiently close match somewhere in the Chebyeshev parametrization.
- Calculate posterior predictive distribution of DH(z) and DM(z) from CMB data.
- Distribution spans the data -> model flexible enough to contain a low-redshift solution to the H0 tension should one exist.



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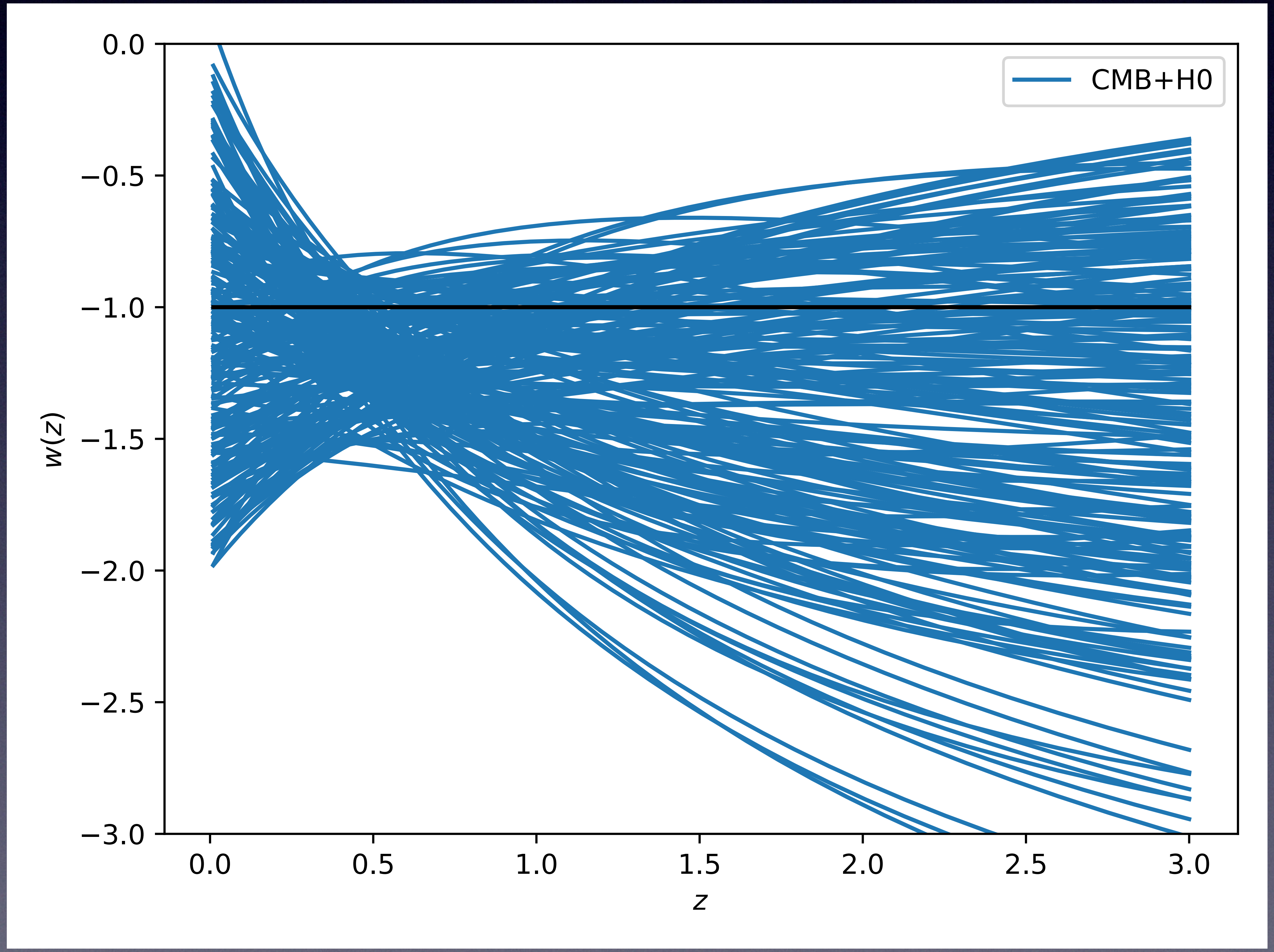
ArXiv:2206.08440

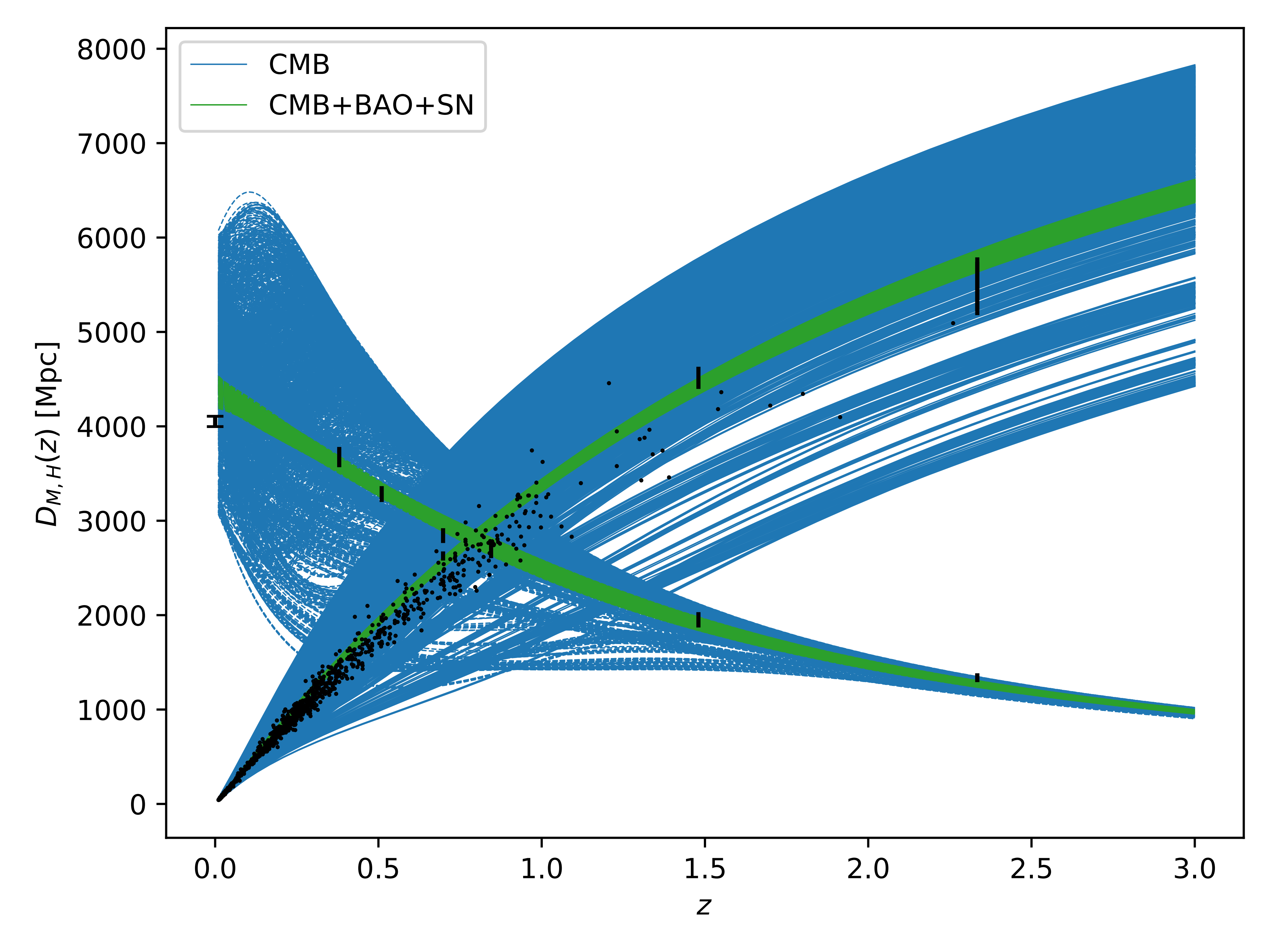
Example w(z) that match CMB+H0

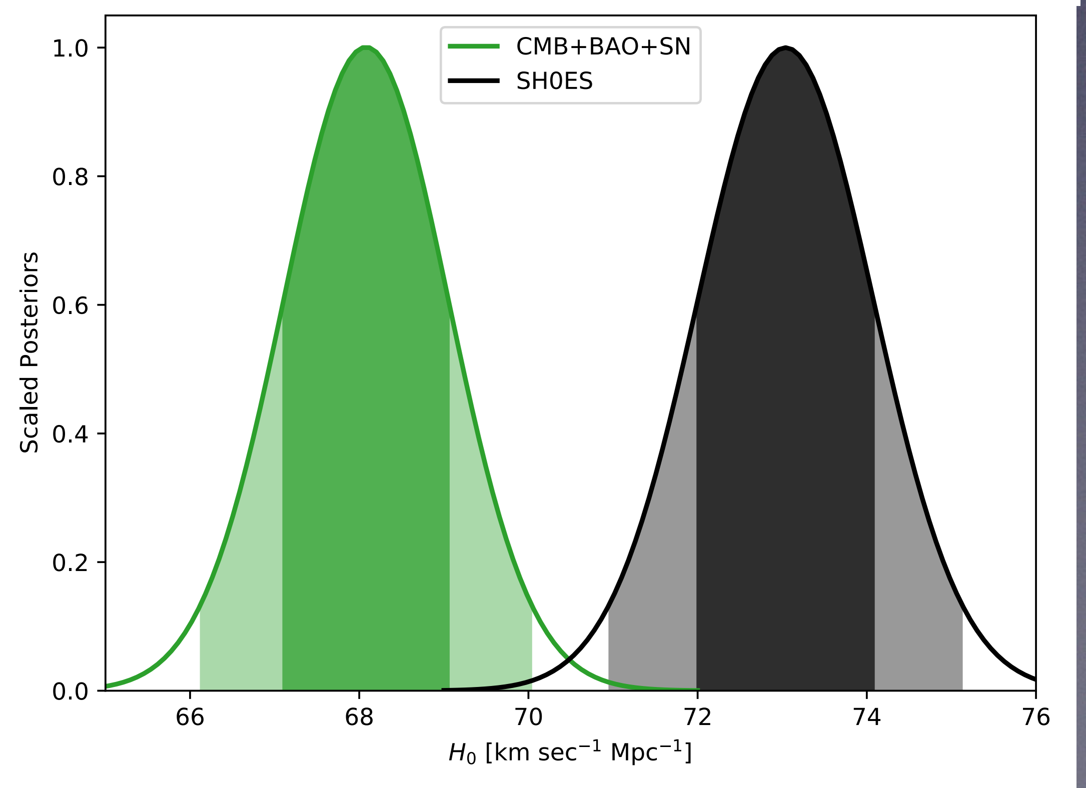
- PPD of w(z) from CMB+H0 dataset
- Variety of w(z) functions that can achieve a H0 value consistent with the SH0ES constraint
- Most examples have a phantom crossing



CMB+SN+H0 constraints

- Test whether solution actually exists.
- Constrain using CMB+BAO+SN datasets
- SH0ES constraint lies outside the PPD
- Find that H0 = 68.08 +/- 0.97 km/sec/Mpc
- Relaxes tension but does not offer a satisfying solution
- Chebyeshev parametrization does not solve the H0 tension -> no instance of new physics that only plays a role at low redshift would solve the H0 tension





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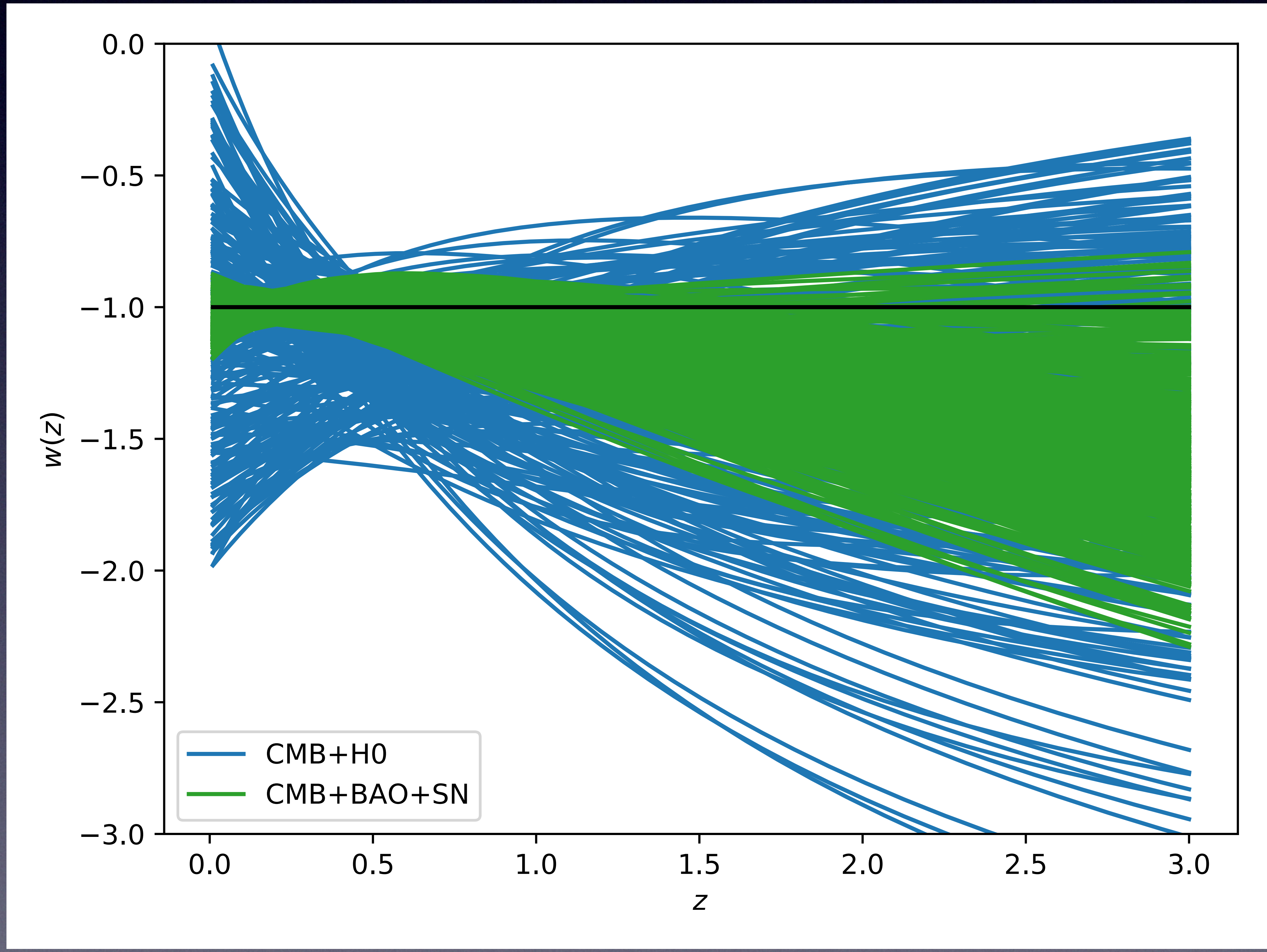
CMB+SN+H0 in terms of w(z)

- PPD for w(z) using CMB+BAO+SN
- Curves converge around w(z)=-1
- CMB+BAO+SN dataset shows no preference for any deviation fro ΛCDM.
- A lot of flexibility still allowed in the phantom regime especially above z>1
- Data become less constraining above z>1
- Dark energy is less dominant above z>1, and so w(z) is less relevant for the fit
- For same w(z=0), w(z=2) can vary from -1 to -2 with only small change in fit



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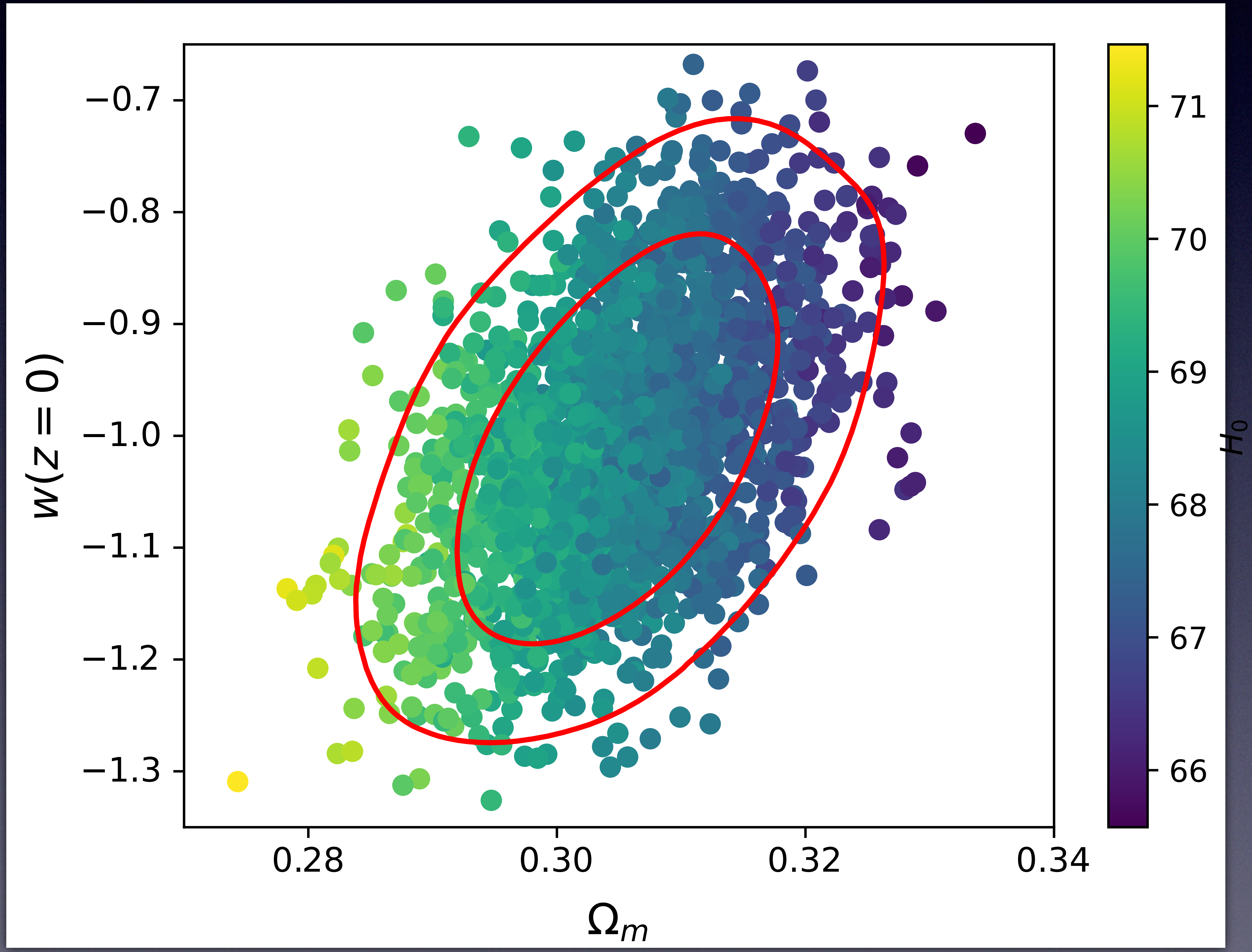
Correlations

- The extended parameters of the Chebyeshev model are correlated with the standard LCDM model
- posterior for the Chebyeshev model using the joint CMB+BAO+SN dataset.
- w(z=0) is most stringently constrained
- High H0 value requires a low Ω_m value to satisfy the constraint on $\Omega_m h^2$ from the CMB
- Low w(z=0) value and a low Ω_m value make a poor fit to the SN data which want w(z=0)=-1 and $\Omega_m \sim 0.3$



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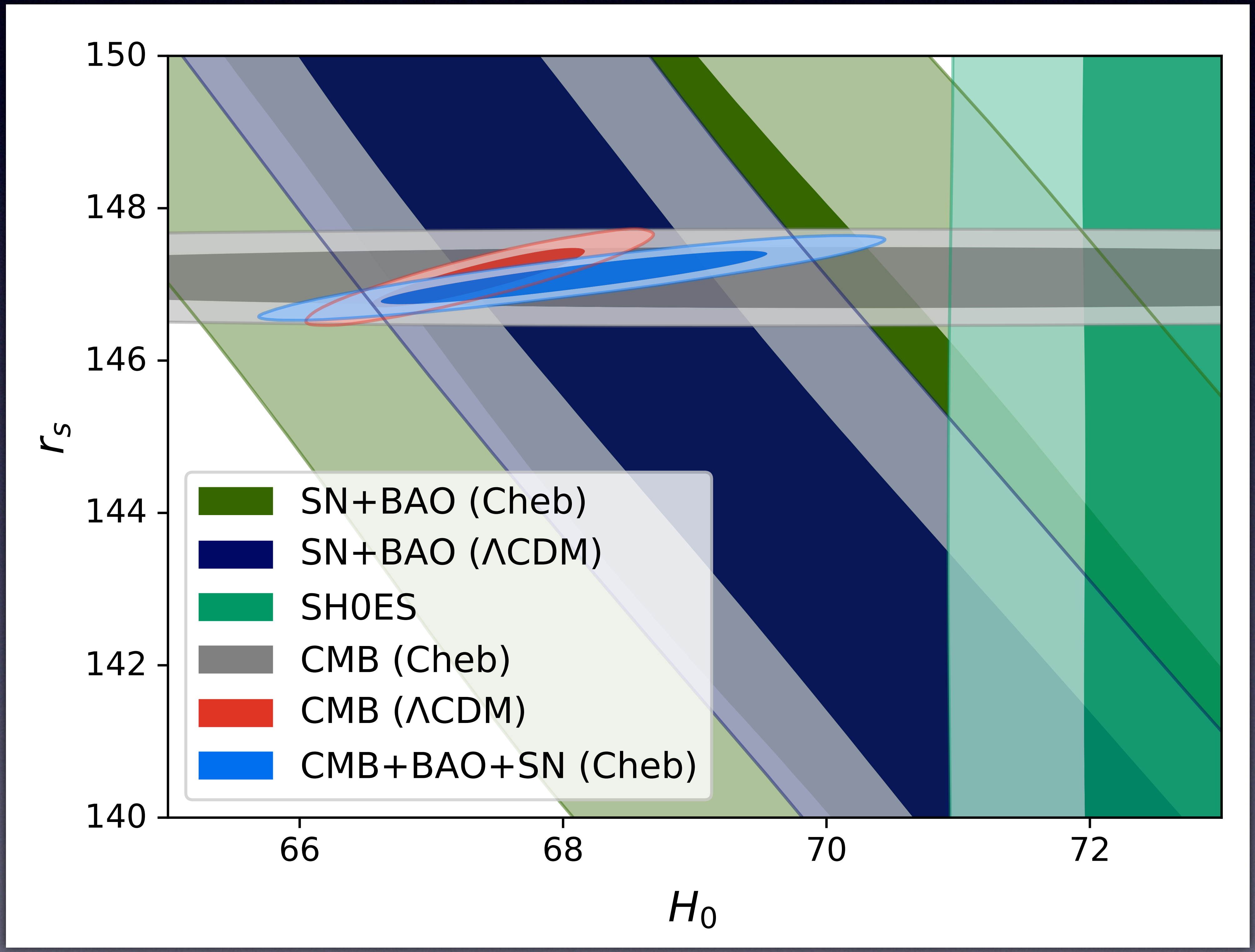
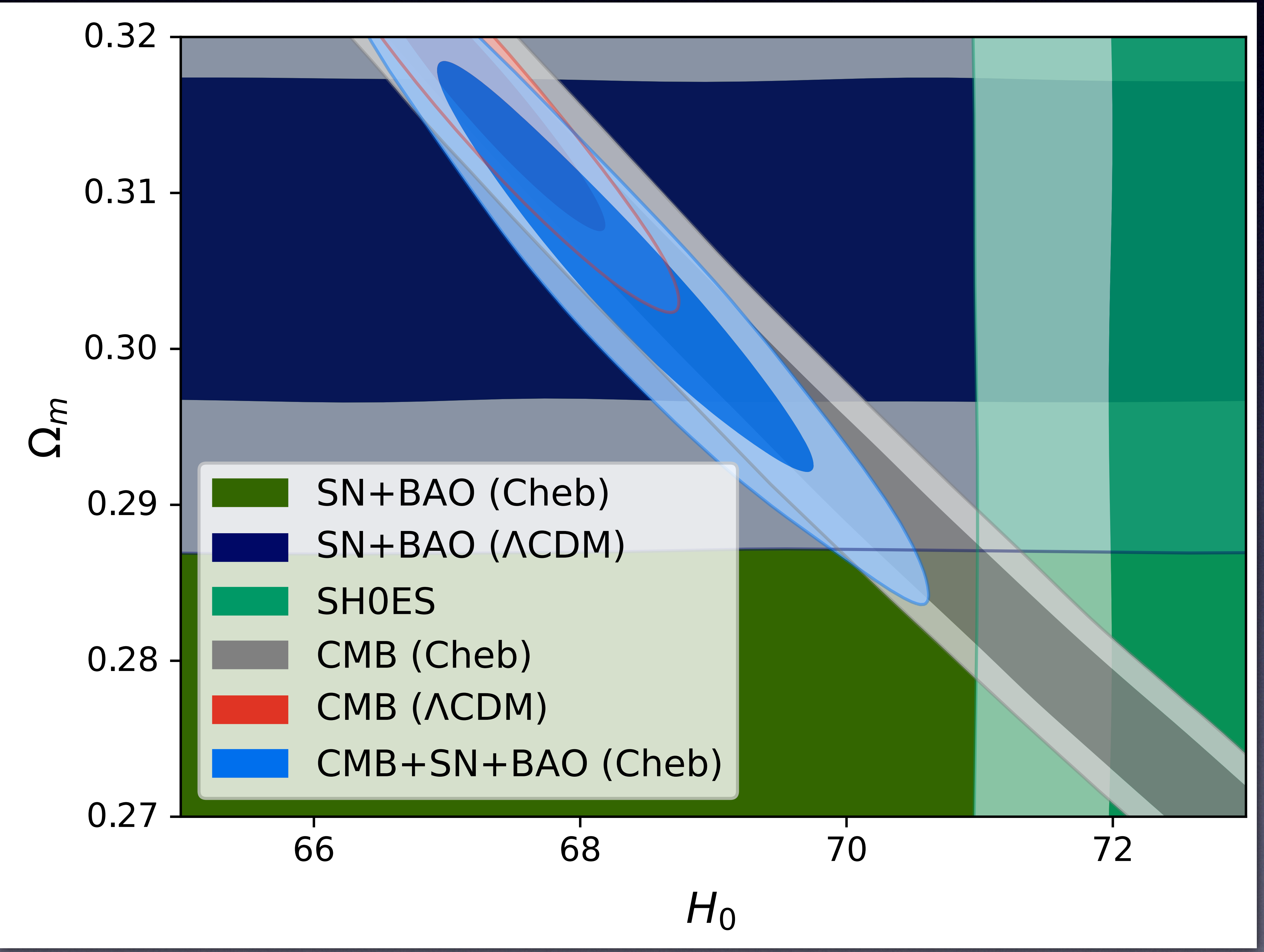
Tension Triangles: H0-rs

- Constraints for the Chebyeshev model using the CMB (grey), the BAO+SN (olive), and CMB+BAO+SN (blue) and for the LCDM model using the CMB (red) and BAO+SN (navy).
- The beyond-LCDM parameters that expand the Planck posterior towards SH0ES constraint are different from the ones that expand the BAO+SN posterior.
- ``tension triangle'' - constraints never overlapping at any one point
- Need to modify rs as part of solving the H0 tension



Tension Triangles: H0-Ω_m

- Tension triangle also in the parameters H0 and Ω_m.
- Teason why simply modifying rs cannot fully reslove the H0 tension
- $\Omega_m h^2$ measured by CMB independently of low-redshift physics.
- Why Chebyeshev constraint from the CMB lies along the line of $\Omega_m h^2 \sim 0.14$
- Chebyeshev parametrization breaks degeneracy between $\Omega_m h^2$and H0 in LCDM



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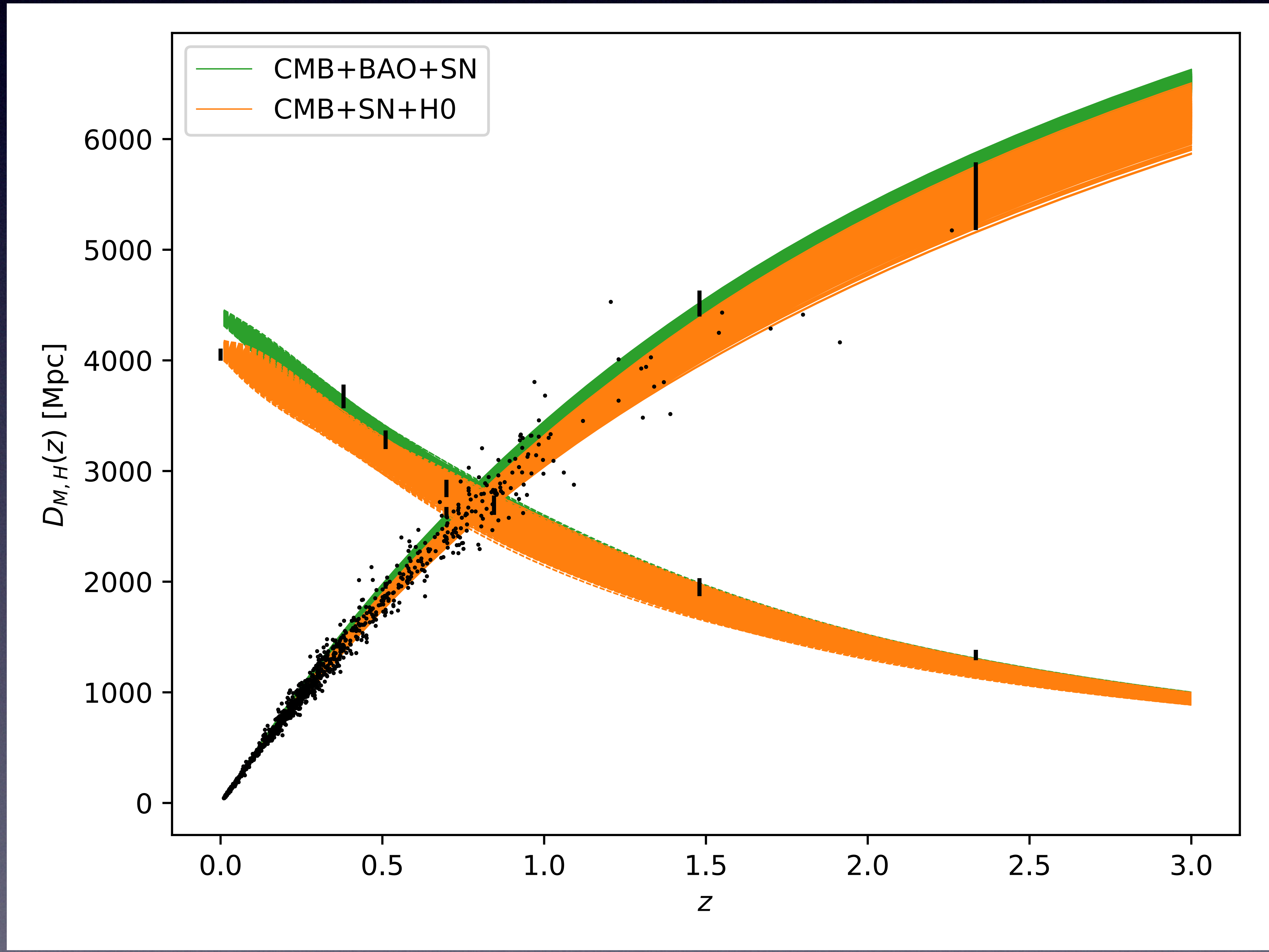
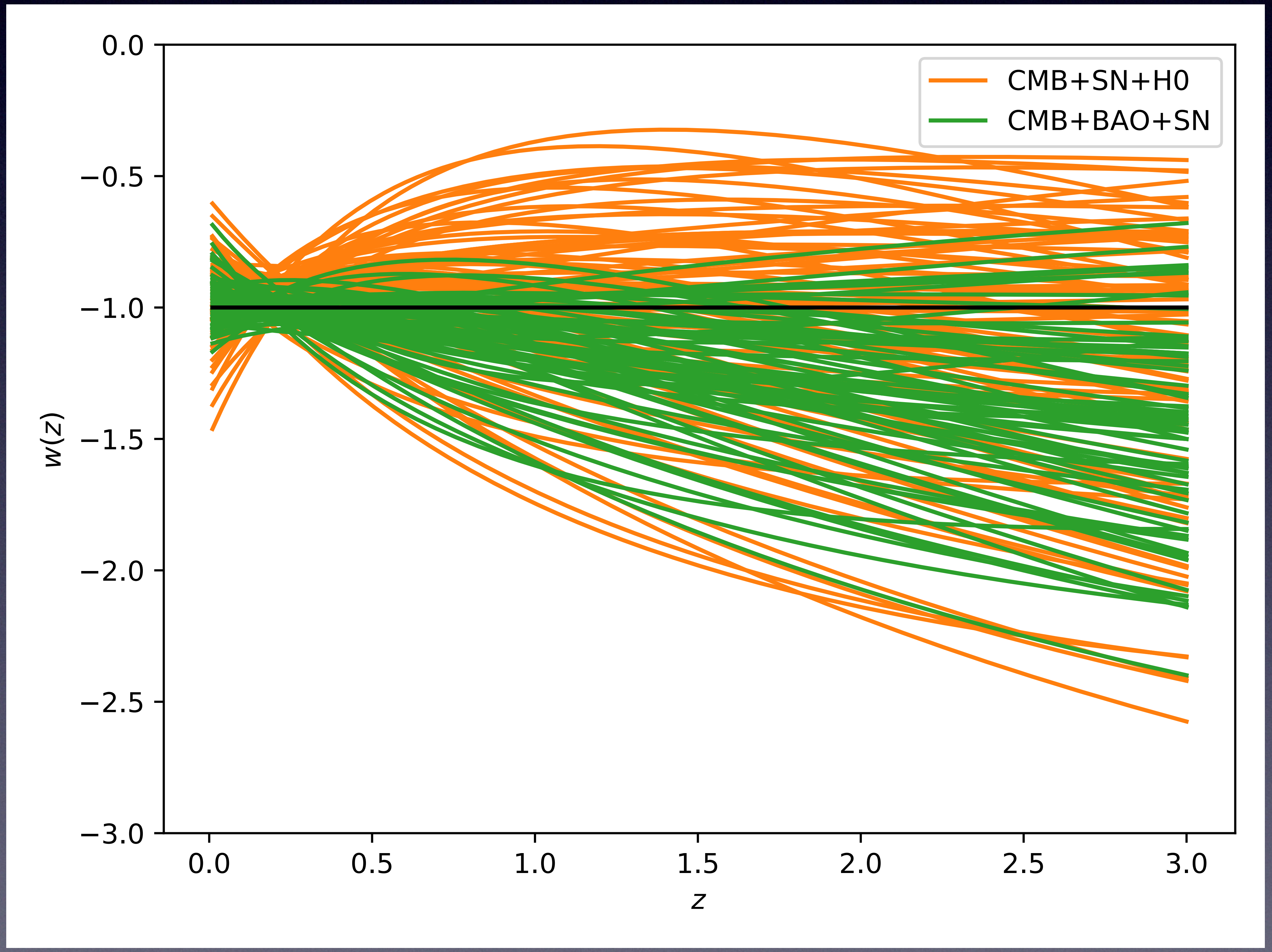
Results w/o BAO

- W/o BAO, the Chebyeshev parametrization has no problem fitting the H0 constraint



Results w/o BAO

- W/o BAO constraint, preferred w(z) all have some sort of evolution
- They all have some sort of phantom crossing
- Highlights the BAO rule out low-z solution



Conclusions

- Even though it is very flexible, the Chebyeshev parameterization, cannot adequately explains the H0 tension
- Thus, there is no satisfactory low-redshift solution to the H0 tension
- The BAO constraint is the last nail in the coffin for this class of models
- The community should look for high-redshift modifications to LCDM