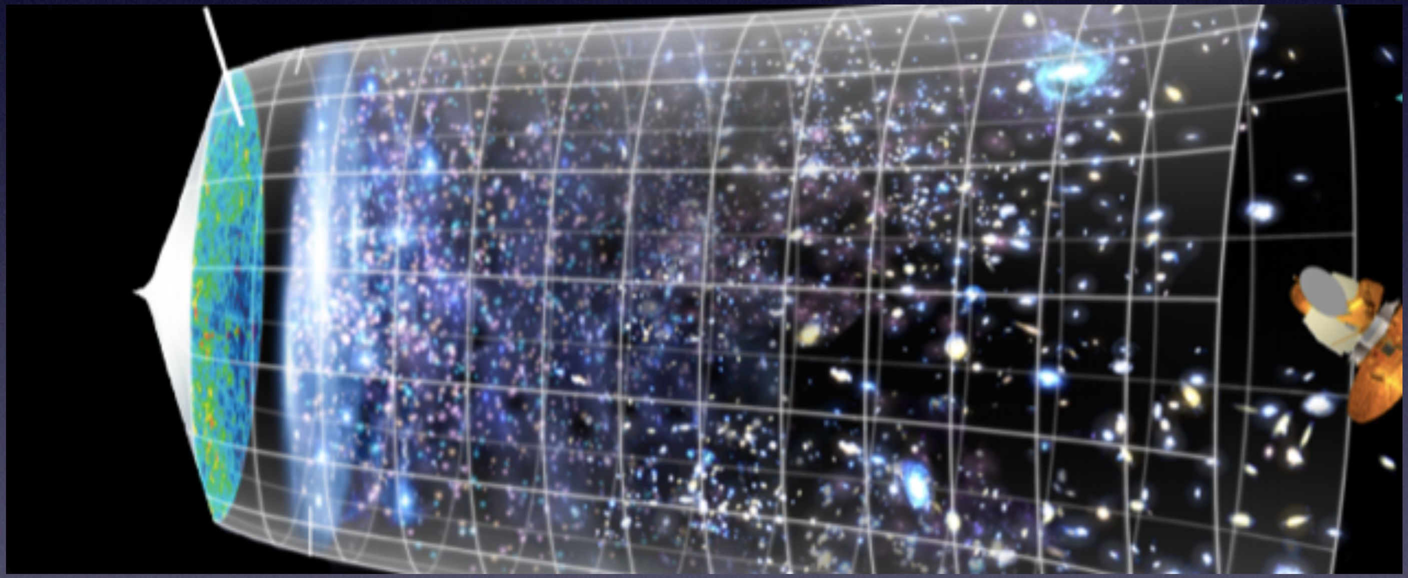
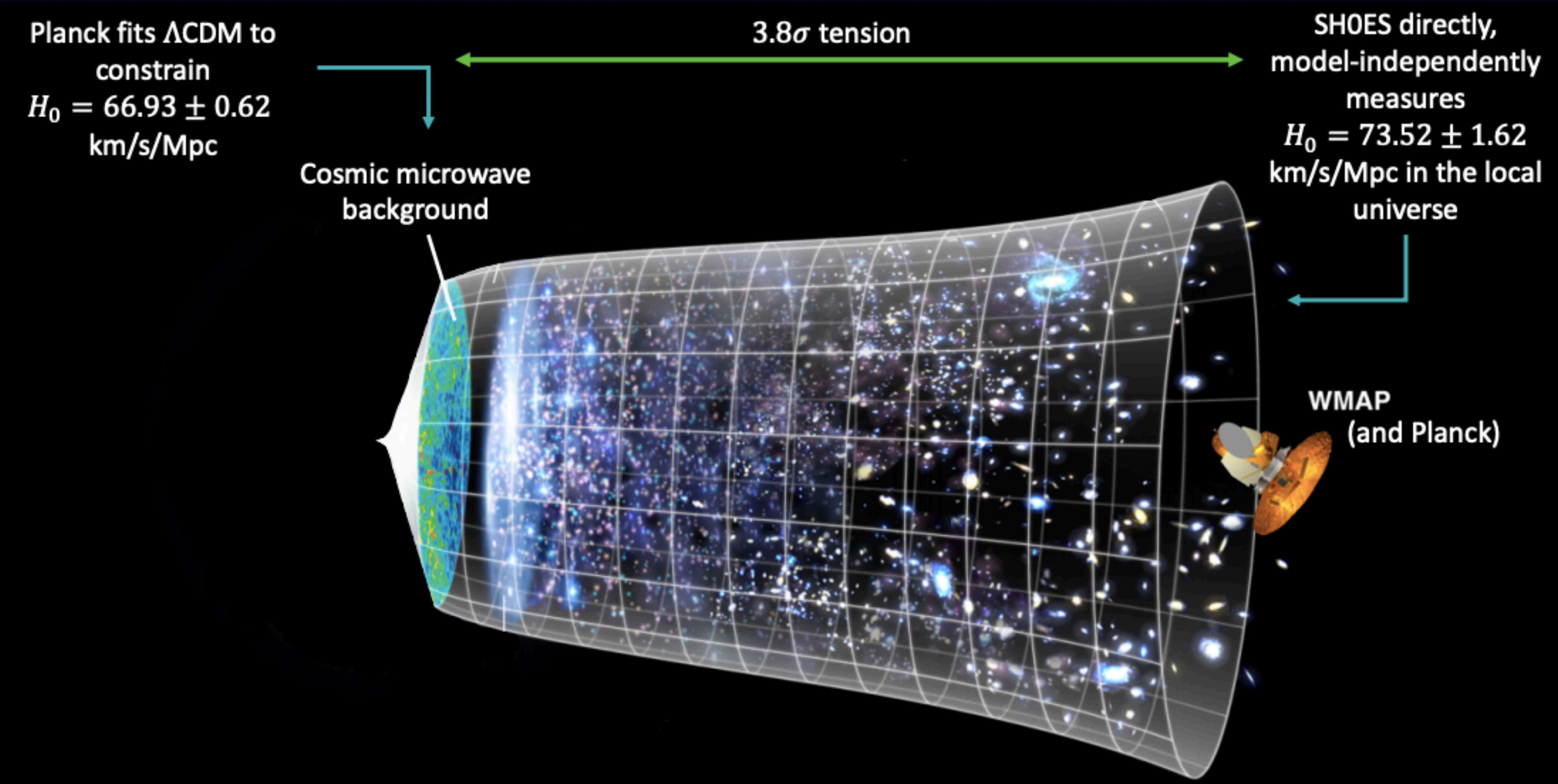
Mismatch between local and global H0:
A solution from dark matter decay



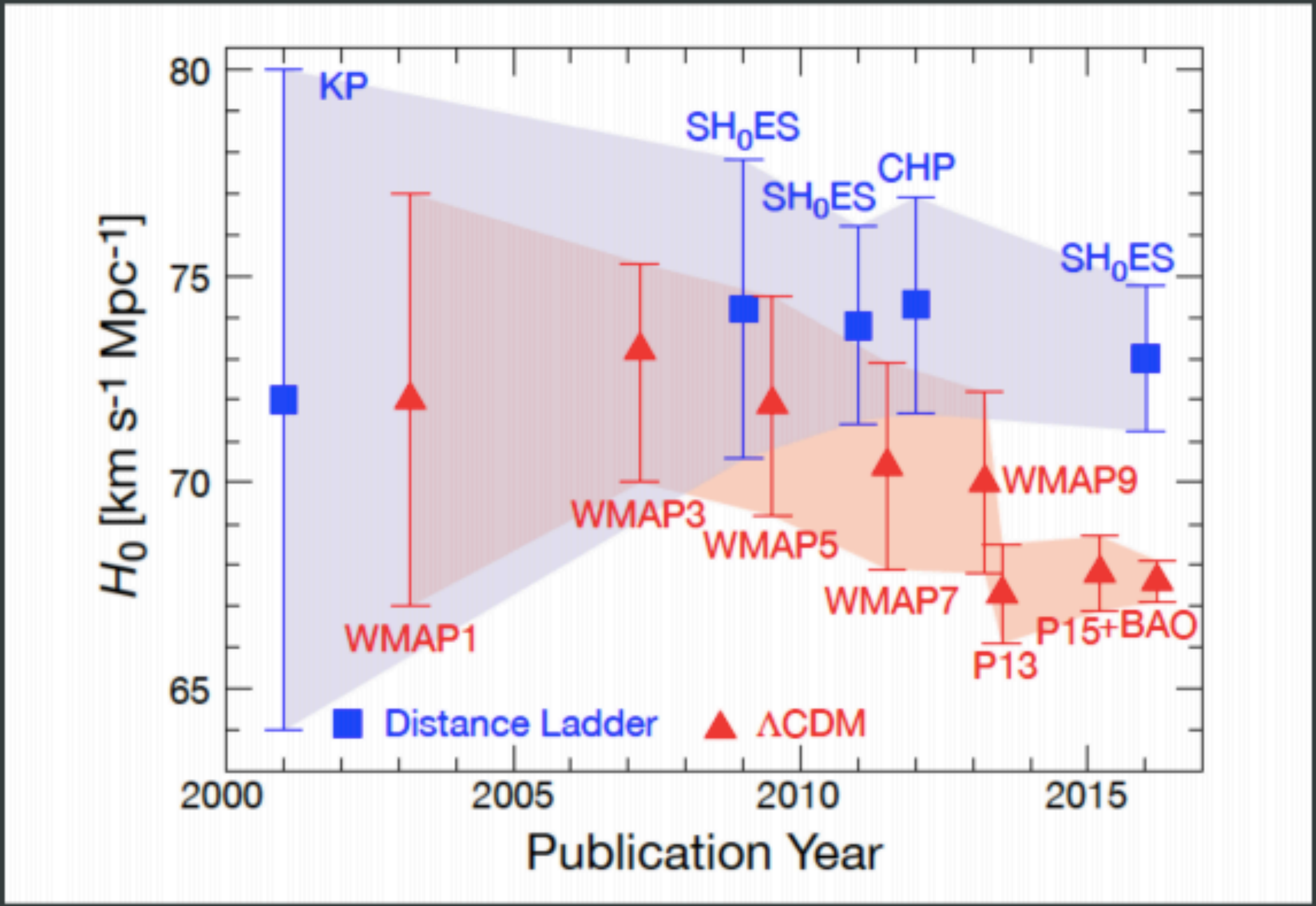
Subinoy Das, IIA Bangalore

IIT Bombay
14/8/2019

What is the mismatch?



Hubble tension

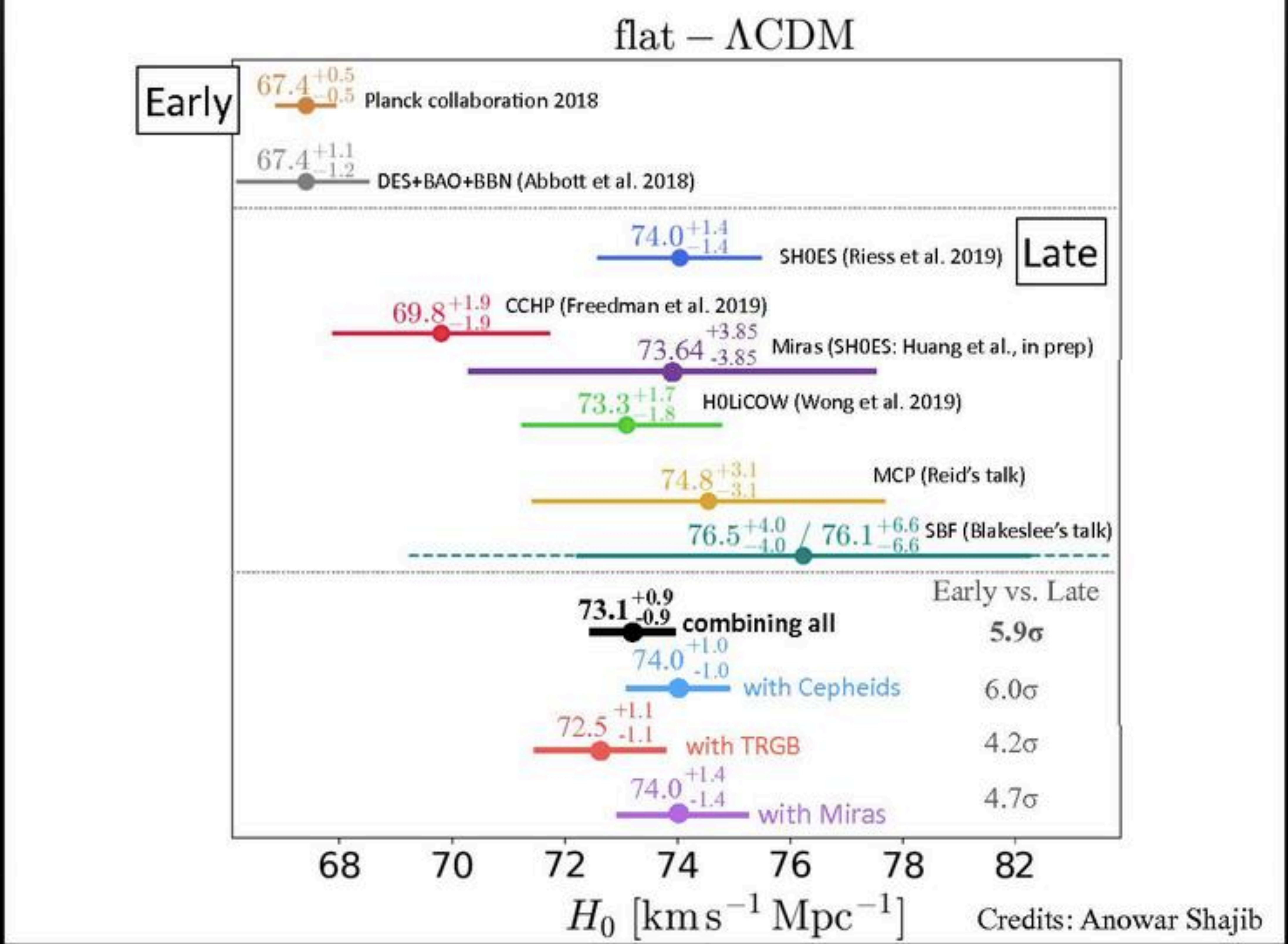


Freedman [1706.02739]

- Universe now appears to be expanding ~9% (+/- 2.4%) faster -than-expected based ΛCDM+Planck CMB This is *surprising*!

- If not an error, could be a vital *clue* pertaining to the 95% of the Universe (i.e., the dark sector) we don't understand.

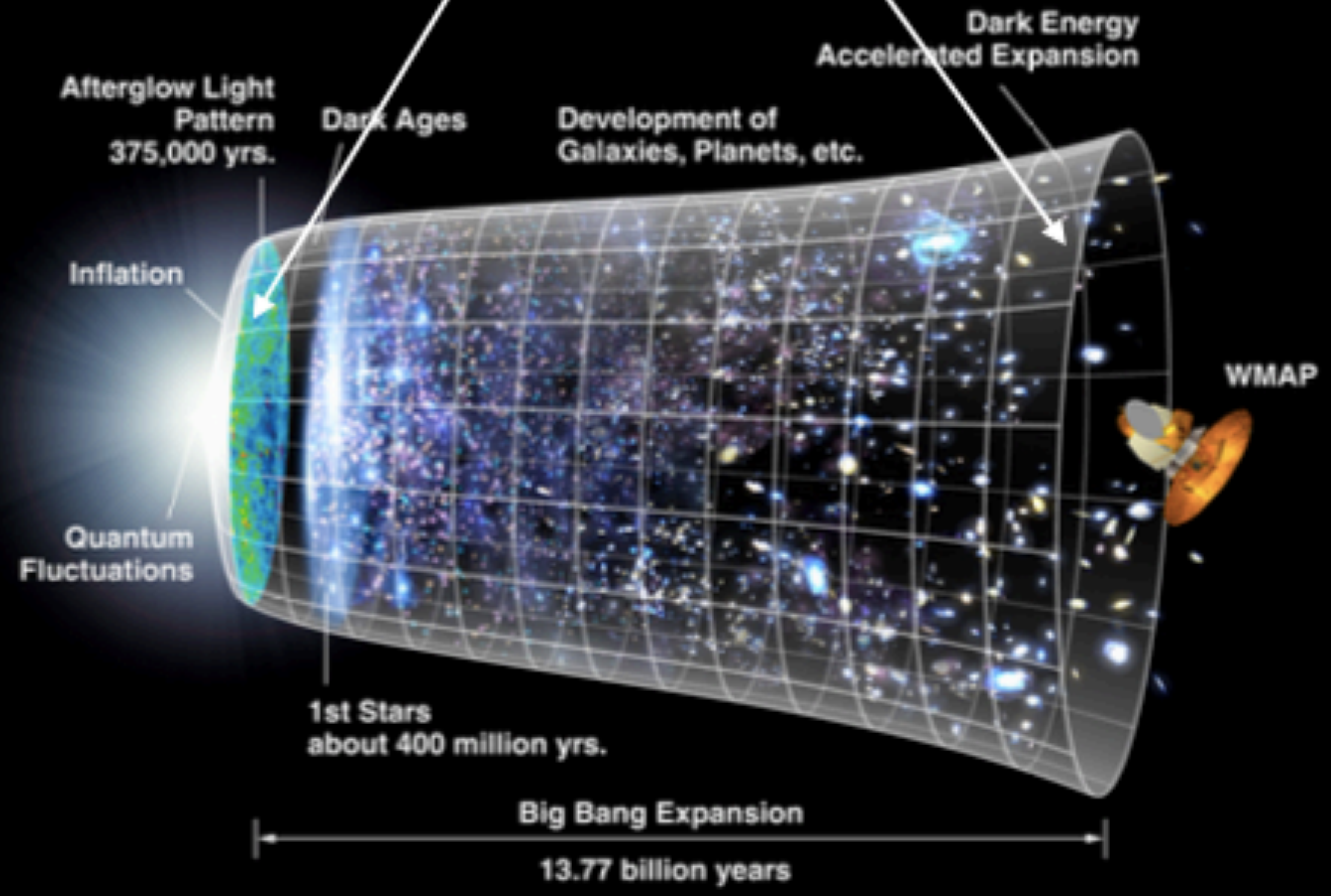
Let's summarize



We have two choices !

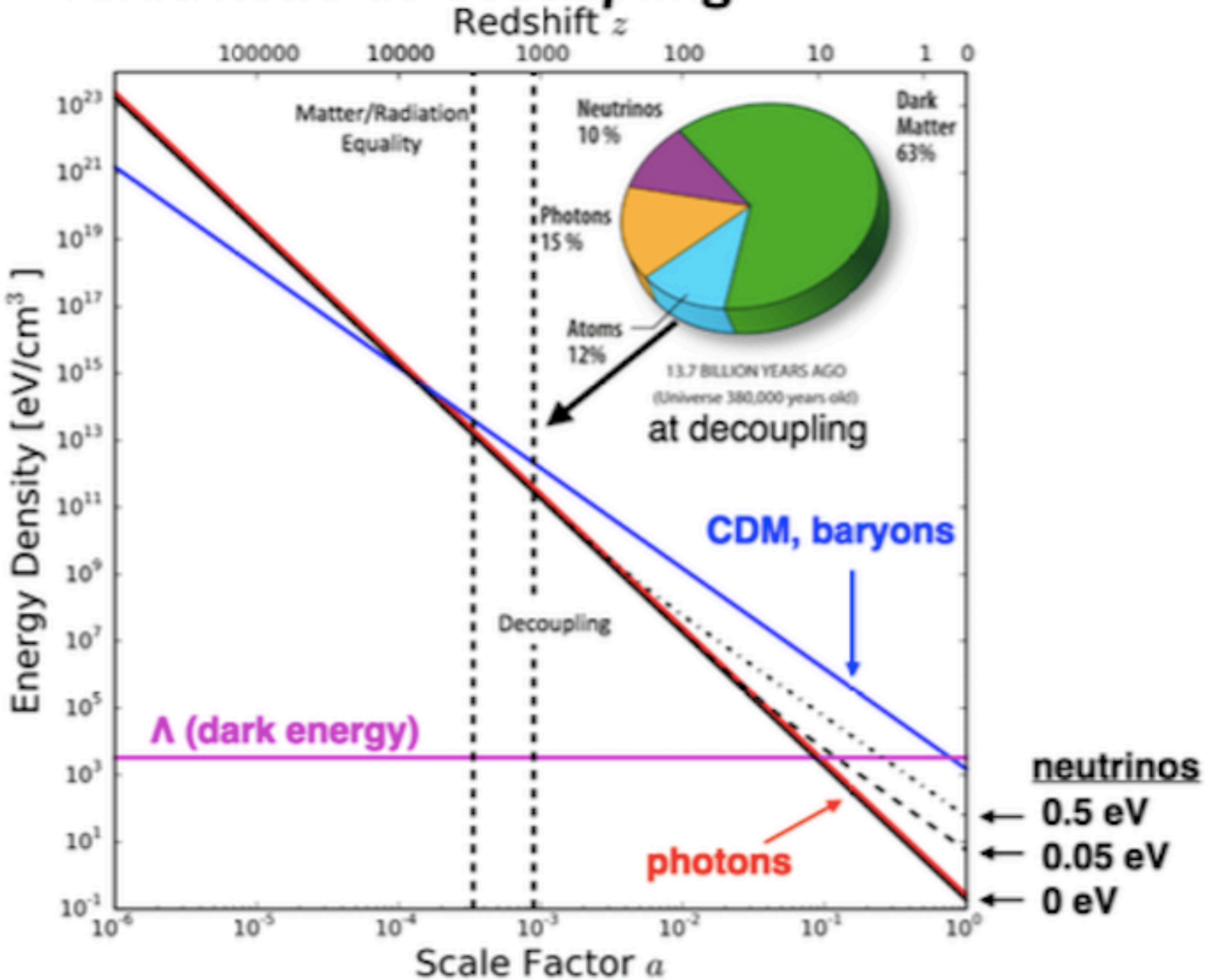
New physics
@CMB epoch

Different DE from w=-1



Neutrinos

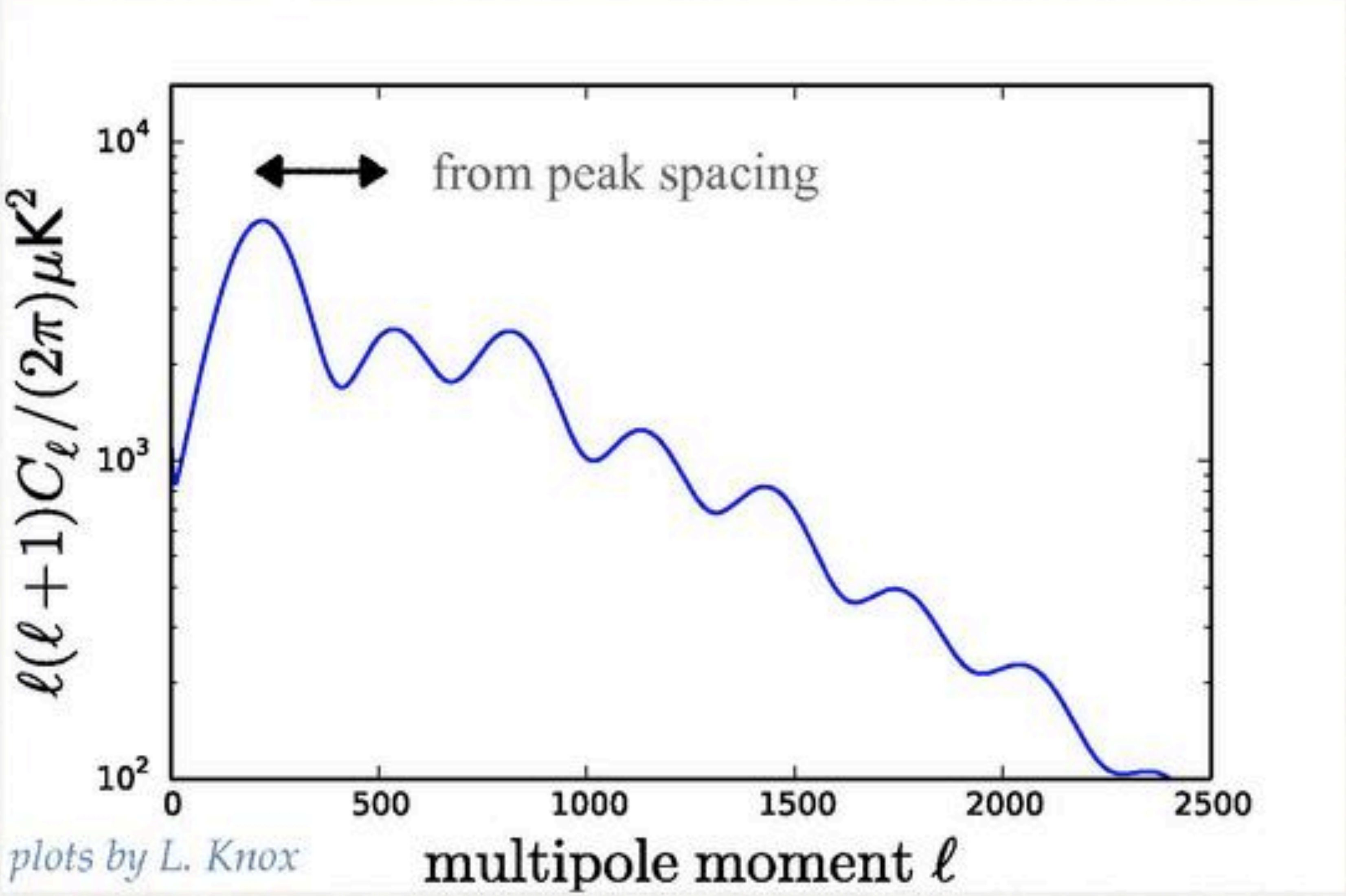
- relativistic at decoupling



How does CMB data measure H0?

- Inference of H_0 from the CMB is model dependent.
- It comes from the measurement of three angular scales $\theta_s, \theta_d, \theta_{eq}$.

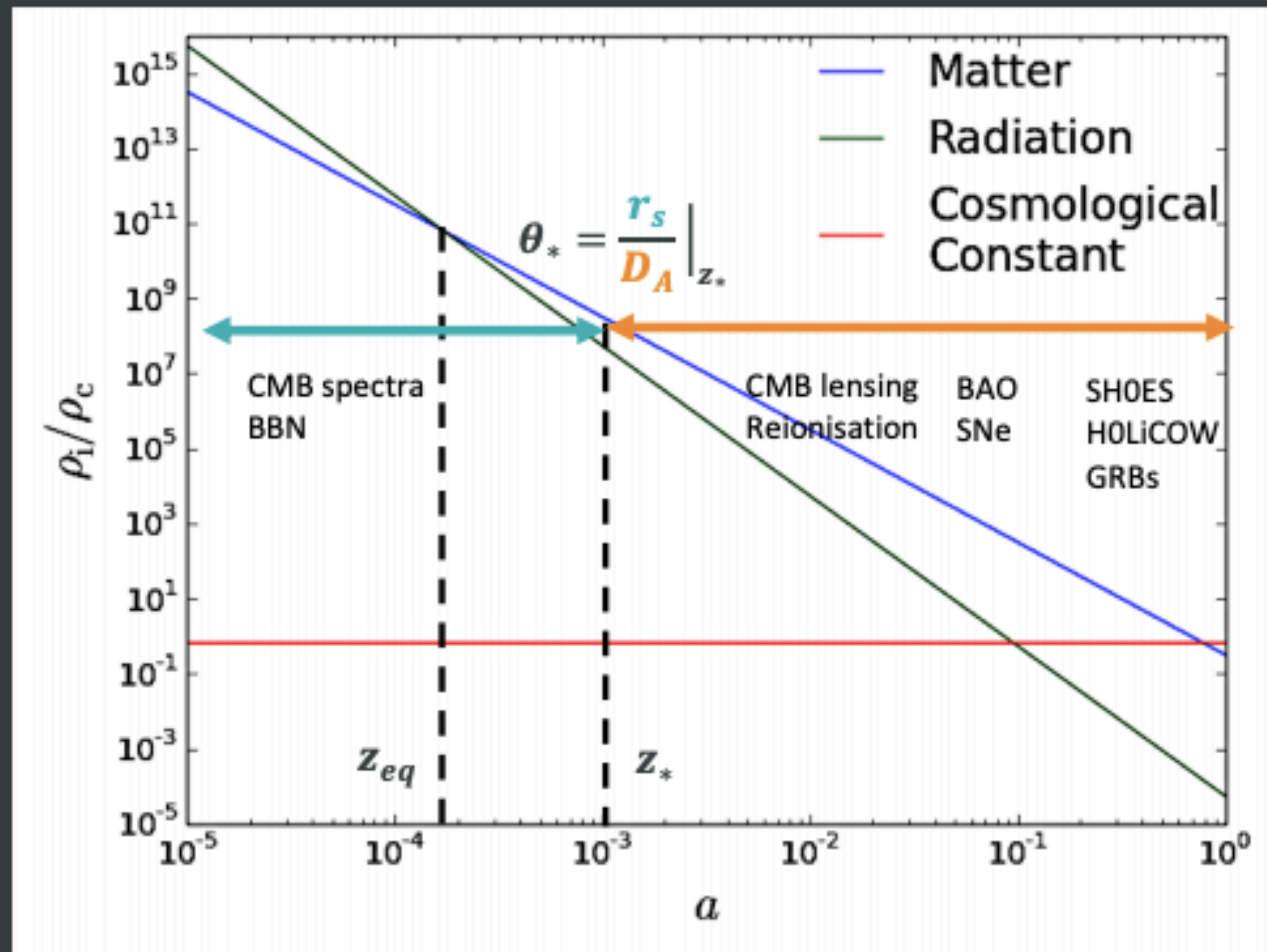
θ_s sound horizon at last scattering ~1.0404



Early Universe Modification

Precisely measured θ_* is an approximate proxy for CMB peak locations

$$H^2 \propto \rho_{tot}$$
$$r_S \propto 1/H_{pre}$$
$$D_A \propto 1/H_{post}$$
$$\theta_* \propto H_0$$



Effectively, keeping θ_* constant gives
$$r_S \propto 1/H_0$$

In support of an early universe modification:
Planck [1807.06209]
Bernal et al [1607.05617]
Evslin et al [1711.01051]
Aylor et al [1811.00537]

How to modify the Baryon-Photon Sound Horizon

- Can either change the sound speed, or the Hubble rate at early times.

$$c_s = \ldots + \frac{3\rho_b}{4\rho_\gamma})$$

$$r_s = \int_0^{a_d} da \frac{c_s(a)}{a^2 H(a)}$$

Can we change the Hubble rate before recombination without ruining everything else?

$$H^2(a) = \frac{8\pi G}{3} \sum_i \rho_i(a)$$

Solving H0: a "background-level" cookbook

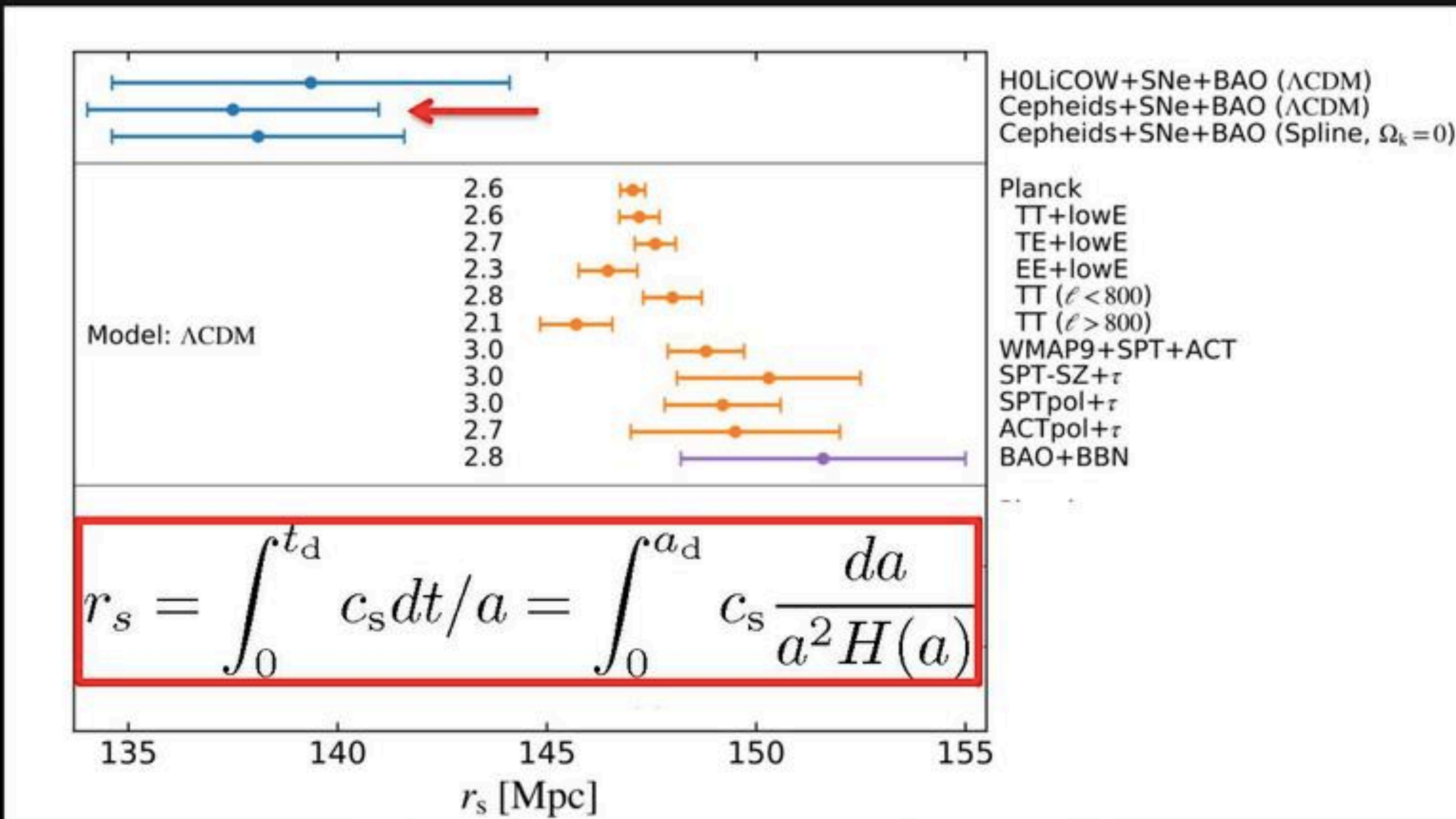
- physical scales: pre-recombination physics; DO NOT depend on H_0, but on physical densities $\omega_b, \omega_r, \omega_{cdm}, \omega_{nu}$ ...

$$\theta_X \equiv \frac{r_X(z_*)}{d_A(z_*)}$$

- angular diameter distance: post-recombination physics, contains information on H0

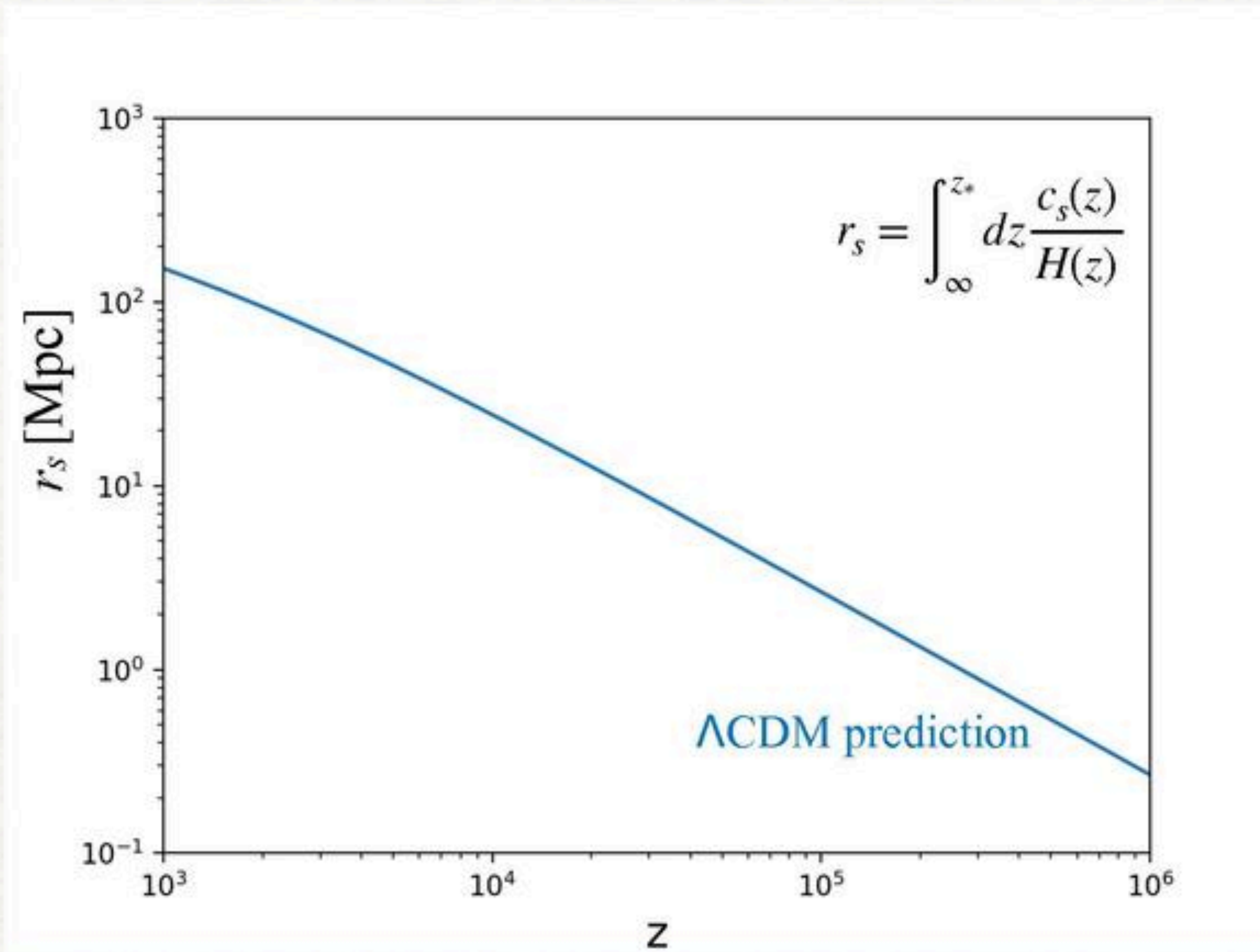
Any solution must keep these three scales fixed

Approach: Discrepancy in the baryon sound horizon



Early-Universe solution to H0

- r_s does not reach 10Mpc before ~ 25000 in ΛCDM



GOAL: decreasing r_s by 10Mpc while keeping r_s/r_d and r_s/r_{eq} fixed

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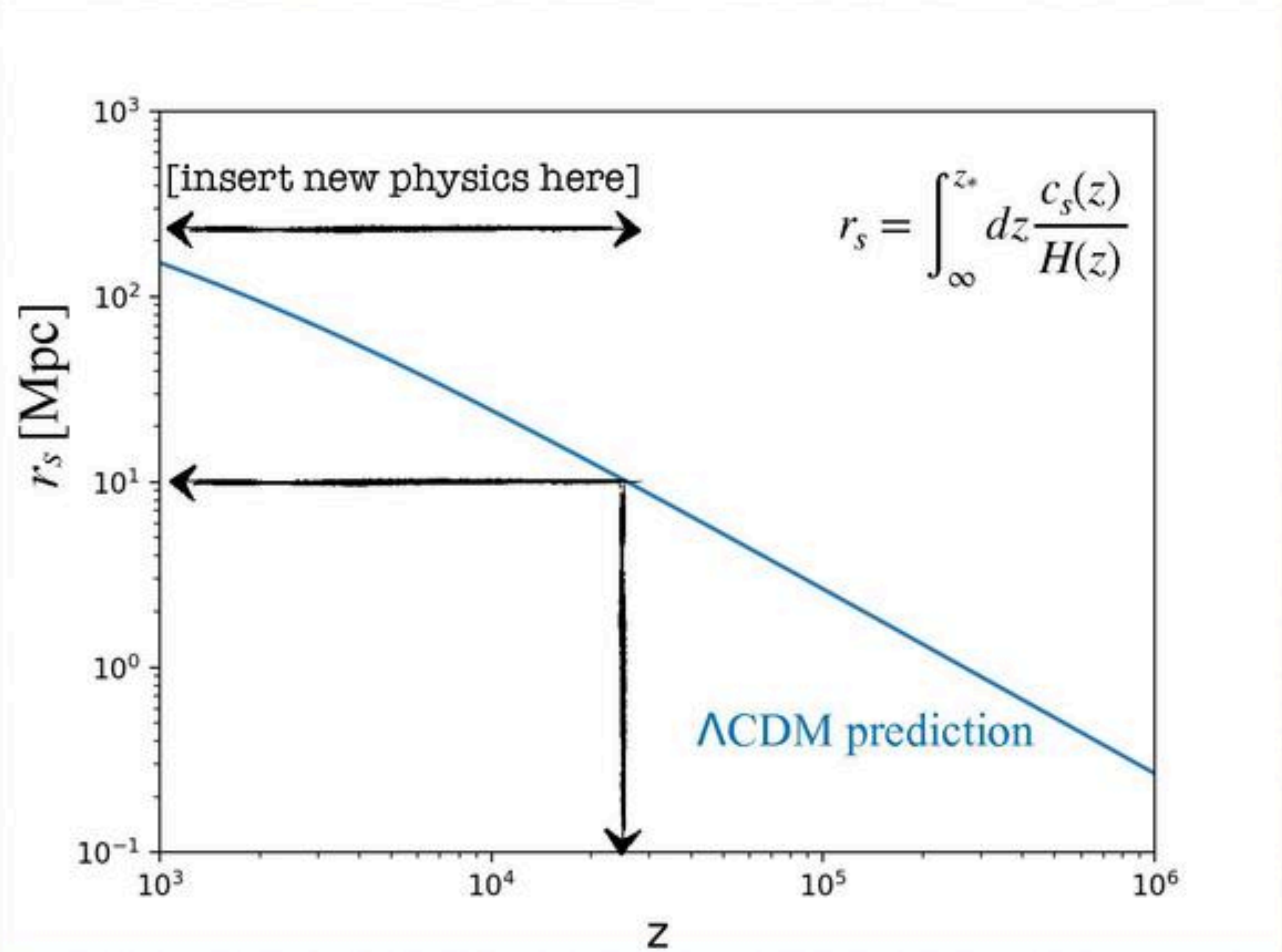


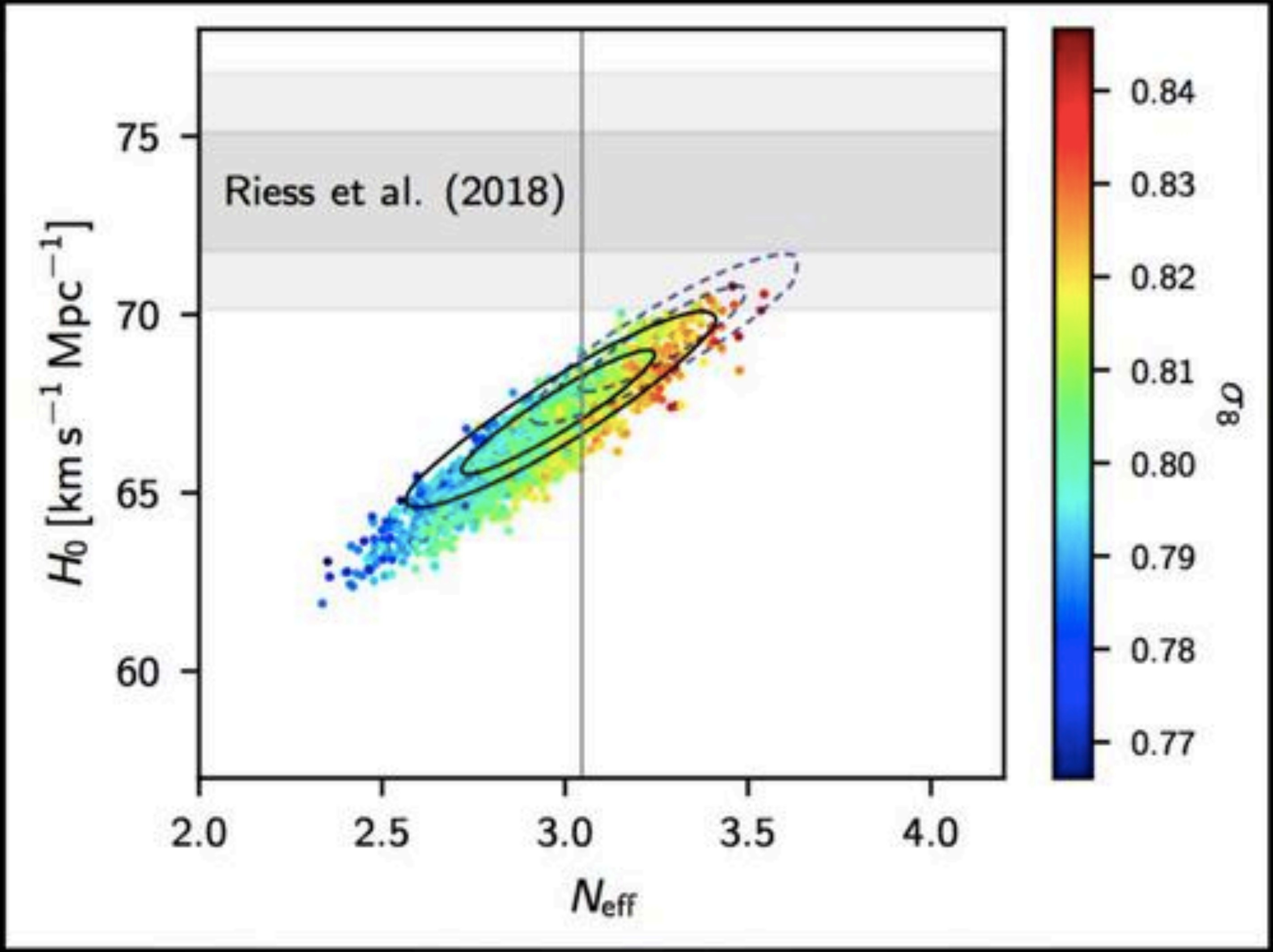
GOAL: decreasing r_s by 10Mpc while keeping r_s/r_d and r_s/r_{eq} fixed

Classical solution: N_{eff}

- The presence of extra relativistic species is a hallmark of many extensions of the Standard Model (*N*-Naturalness, Twin Higgs, etc.)

N_{eff} alone doesn't work…

- It can get you partially there, but at the price of degrading high-l CMB



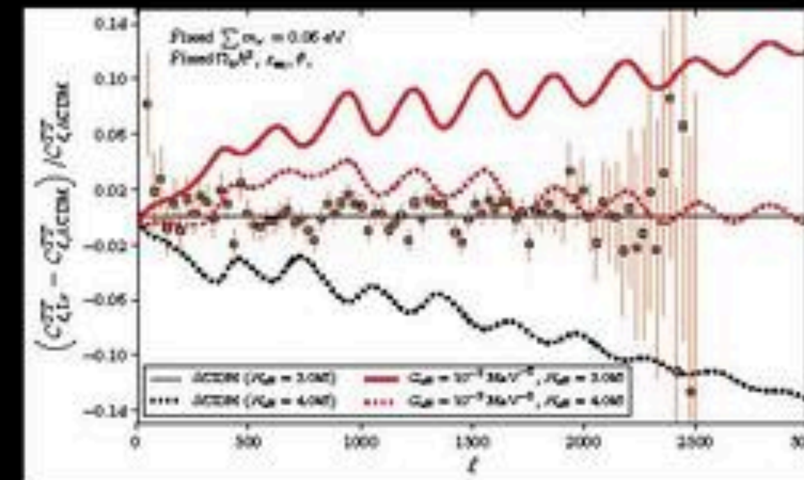
Planck Coll. (2018)

Why does the SIν work?

- N_{eff} increases Hubble at early times, hence reducing the sound horizon.

$$r_{\mathrm{s}} = \int_0^{a_{\mathrm{d}}} da \frac{c_{\mathrm{s}}(a)}{a^2 H(a)}$$

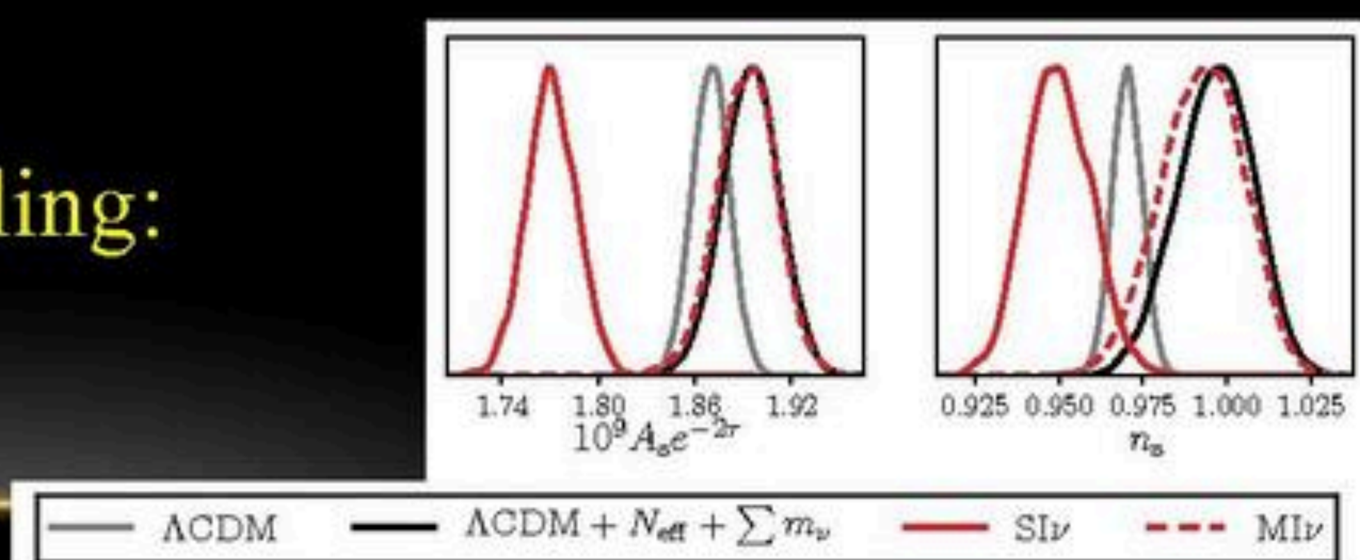
- The tightly-coupled neutrinos do not over damp or phase shift the photon-baryon fluctuations.



- Changes in the primordial spectrum of fluctuations (n_s, A_s) absorbs the remainder of the changes.

- Tooth fairy: need large coupling:

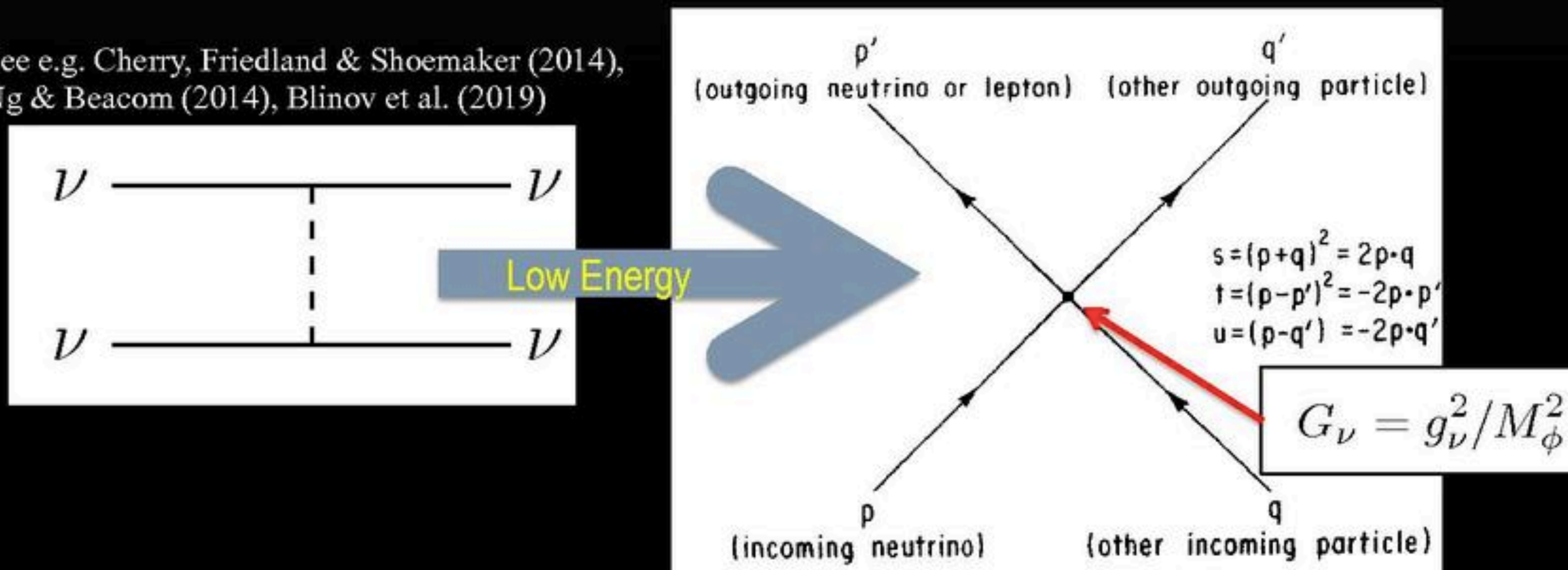
$$G_{\mathrm{eff}} \sim 10^{10} G_{\mathrm{F}}$$



Beyond Free-streaming Neutrinos

New Unknown Interaction: $\mathcal{L}_{\rm phen} \supset -\frac{1}{2}m_\phi^2\phi^2 + \frac{1}{2}(g_\phi^{\alpha\beta}\nu_\alpha\nu_\beta\phi + {\rm h.c.})$

See e.g. Cherry, Friedland & Shoemaker (2014), Ng & Beacom (2014), Blinov et al. (2019)



4-Fermion Interaction stronger than Fermi constant

$$G_\nu > G_{\rm F}$$

Reality check

Solutions	Solve H_0	S_8 tension	Tooth fairies	Model building
N_{eff}	No	Worse	None (?)	Easy
Localized energy injection	Yes	Worse	Coincidence Problem at eV scale, need complex potential	Hard
Interacting neutrinos	Yes (?)	Better	Need extremely strong interaction	Hard

Solution from Local energy injection at epoch of recombination:

Decaying dark matter.

K Pandey (IIA), T Karwal (JHU), SD 1902.10636

$$\dot{\rho}_{\rm dm} + 3H\rho_{\rm dm} = -Q$$
$$\dot{\rho}_{\rm dr} + 3H(1+w_{\rm dr})\rho_{\rm dr} = Q$$

$$Q = \Gamma\rho_{\rm dm},$$

$$3H^2M_{\rm Pl}^2 = \left[1 + \frac{7}{8}N_{\nu,\rm eff}\left(\frac{4}{11}\right)^{4/3}\right]\rho_\gamma + \frac{1}{1-\alpha_{\rm dr}}\rho_{\rm dm,0}a^{-(3+\alpha_{\rm dr})} + \rho_{\rm b,0}a^{-3}.$$

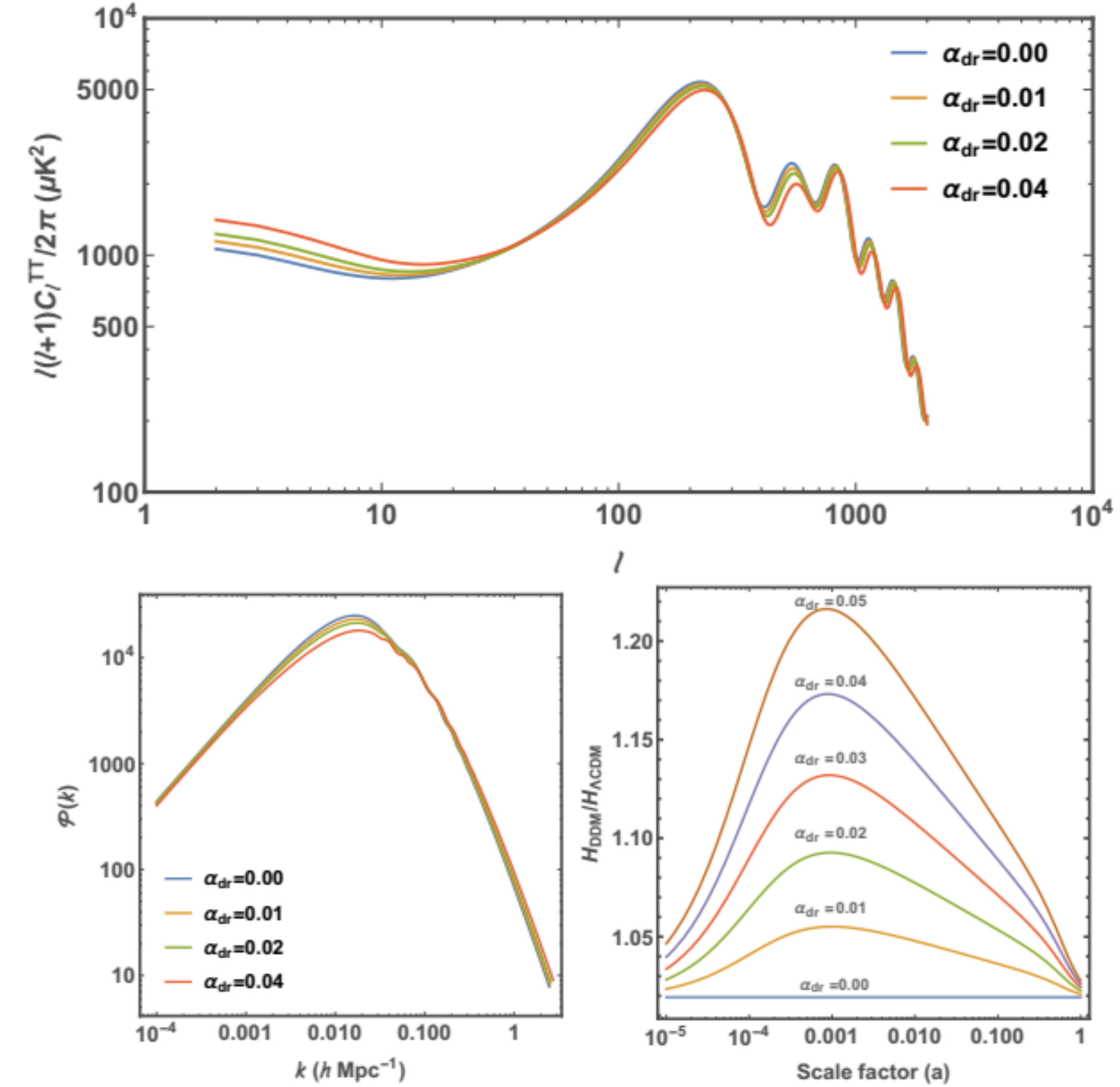


Figure 1. Shown here are the effects of DDM on various observables. These plots were produced using a modified version of CAMB, fixing all ΛCDM parameters, including $\Omega_{\mathrm{dm},0}$ and varying just α_{dr}. The blue line with $\alpha_{\mathrm{dr}} = 0$ represents a ΛCDM cosmology. *Top*: effect of non-zero α_{dr} on the CMB TT power spectrum; *left*: effect on the matter power spectrum; *right*: the DDM expansion rate relative to ΛCDM.

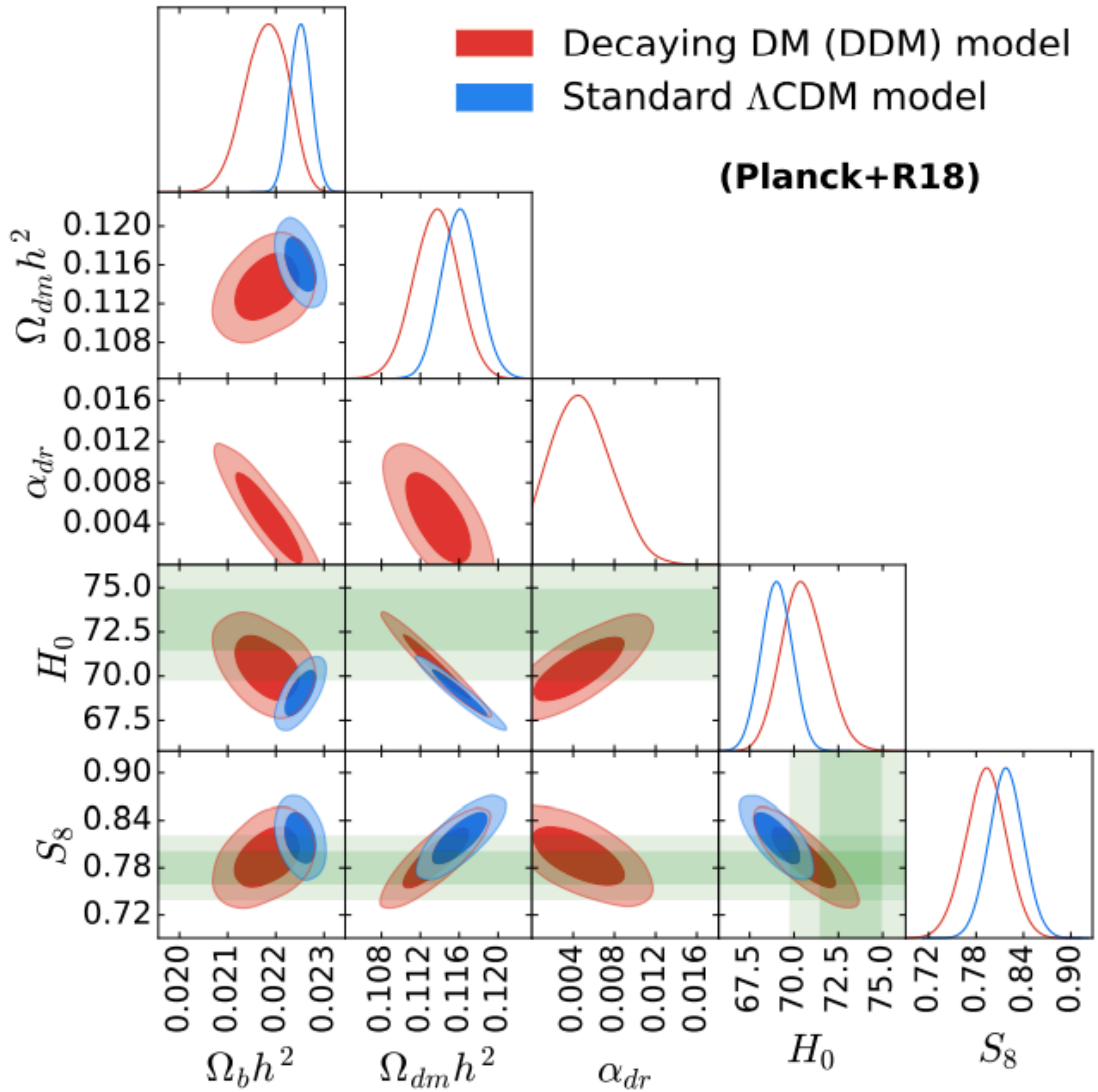
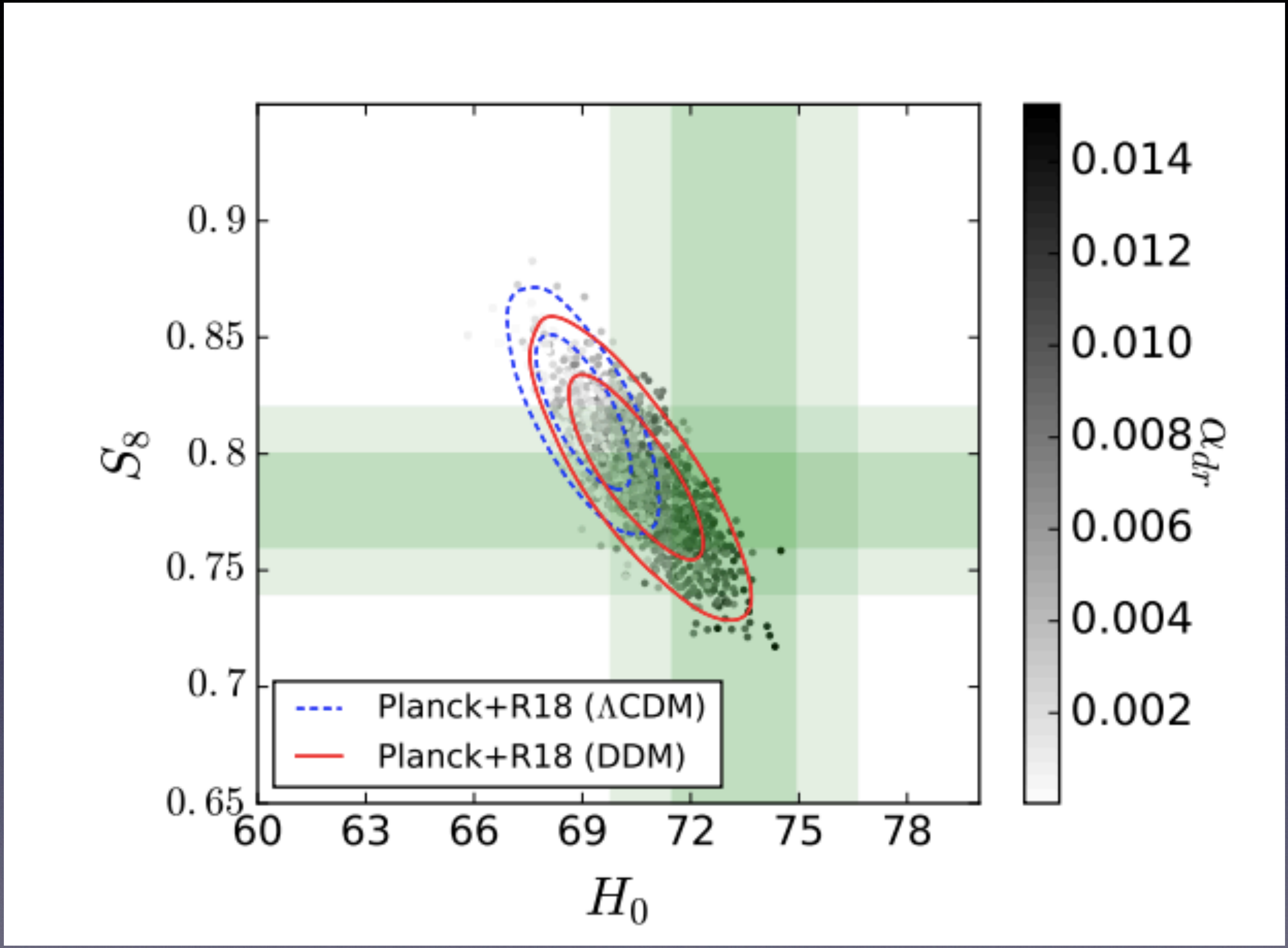


Figure 3. Comparison between the standard ΛCDM and the DDM models: Constraints on various cosmological parameters along with their covariances when tested against the Planck+R18. The green bands represent the constraints on H_0 and S_8 coming from [8, R18] and [12, DES-YI, 2017].


0.9
0.85
0.8
0.75
0.7
0.65
60
63
66
69
72
75
78
S_8
H_0
Planck+R18 (ΛCDM)
Planck+R18 (DDM)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
α_{dr}

Challenges with solving H_0 with DM decay

- Whole game of energy injection/ increasing H(z) is between $z=10^3$ to 10^4

- DM decay has to stop or ineffective after **t~ Myr** otherwise ruled out by late time observables

- DM decay rate ~ H(z) ~ T^2.
  But very hard to model from partiale physics

Important Take Home Messages

- As precision increases, cracks might be appearing in the standard cosmological model.
- We have yet to identify a complete solution that is palatable to both cosmologists and particle physicists.
- Main message: It is possible to find radically different cosmological model that nonetheless can provide excellent fit to the data.