Title: The H0 tension and sample variance

Speakers: Will Percival

Collection: Quantum Spacetime in the Cosmos: From Conception to Reality

Date: May 11, 2023 - 11:00 AM

URL: https://pirsa.org/23050128

Abstract: Local measurements of the expansion rate of the local universe differ from predictions of simple models fitted to large-scale cosmological measurements, at a statistically significant level. Sample variance (often called cosmic variance) is a key component of errors placed on measurements made from a small data set. For the Hubble constant, which parametrises the expansion rate, the size of the patch of the Universe covered by recent supernovae observations has a radius of 300Mpc. The smaller the patch, the larger the patch-to-patch fluctuations and the larger the error on the measured value of H0 from sample variance. Using the H0 measurement from supernovae as an example, I will consider a number of different ways to estimate sample variance using techniques developed for multiple uses, and show that they all approximately agree. The sample variance error on H0 measurements from the recent Pantheon supernovae sample is +/-1 kms^-1Mpc^-1, insufficient to explain the Hubble tension in a standard Lambda-CDM universe. This will demonstrate methods for comparing variations in expansion rate in the universe and what we mean by saying the universe is expanding (on average), or that galaxies move apart with particular velocities.

Zoom Link: https://pitp.zoom.us/j/99946149565?pwd=M2puMy9nSEtBZTg1MnRmSllHeUE0UT09

The H_0 tension and sample variance

Will Percival

Waterloo Centre for Astrophysics

University of Waterloo / Perimeter Institute

Sample variance discussion based on work with Zhongxu Zhai

arXiv:2207.02373

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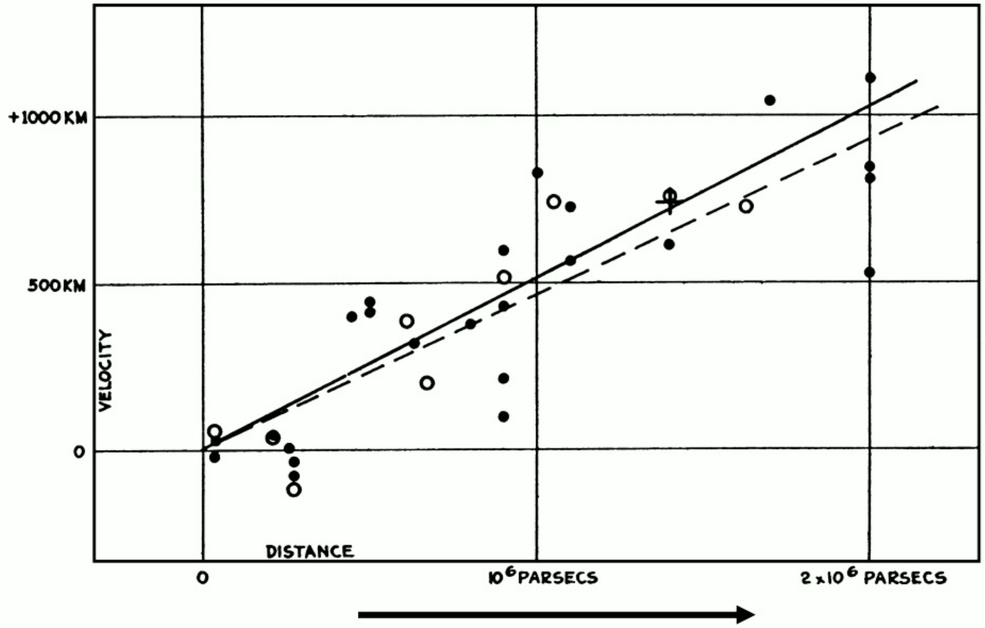
Long history of incorrect measurements!



$$H_0 = \frac{\text{velocity}}{\text{distance}}$$

Modern estimates move galaxy distances by a factor 7

Hubble 1929

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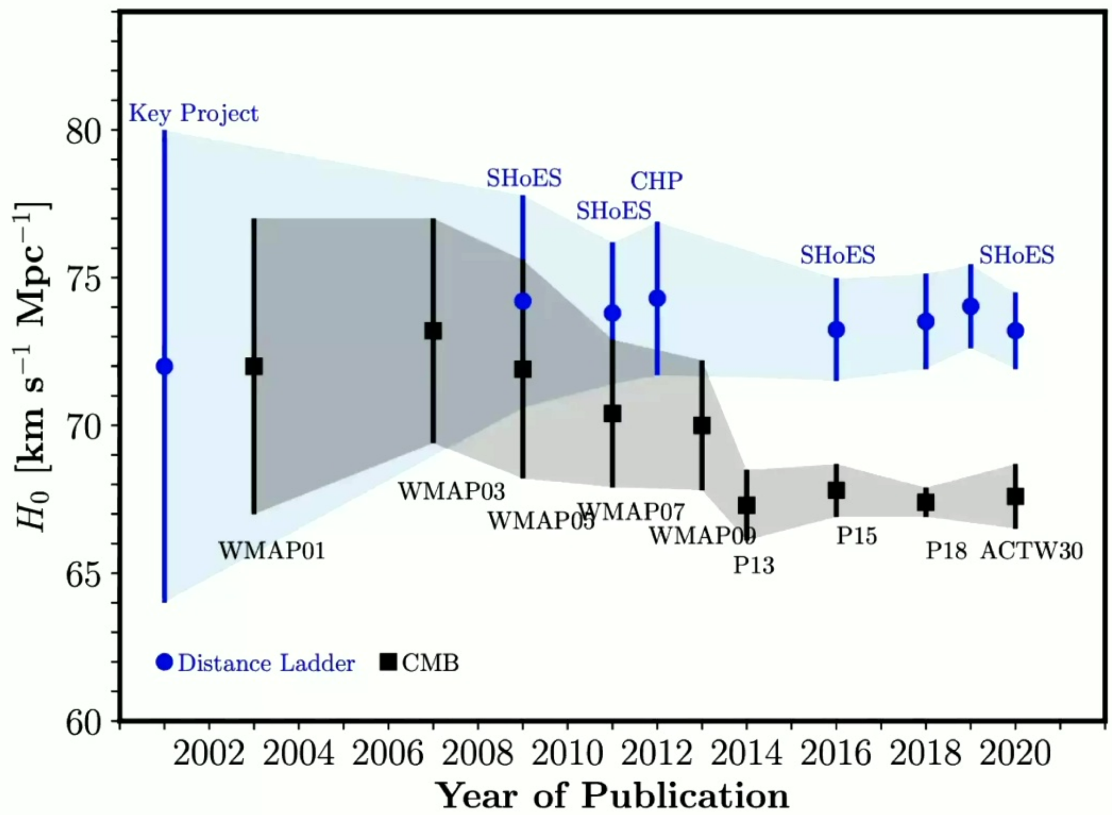
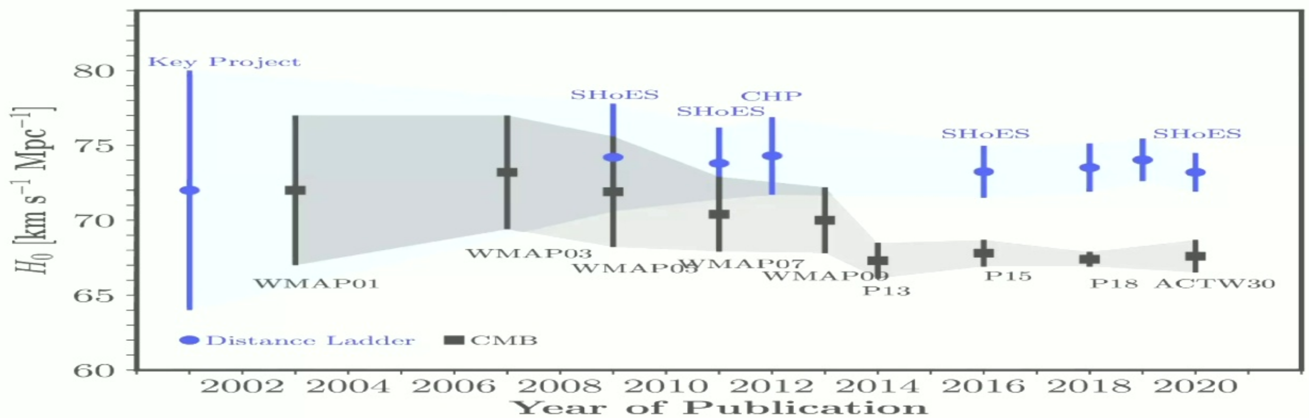
The emergence of the “current” Hubble tension



Freedman 2021

Other measurements



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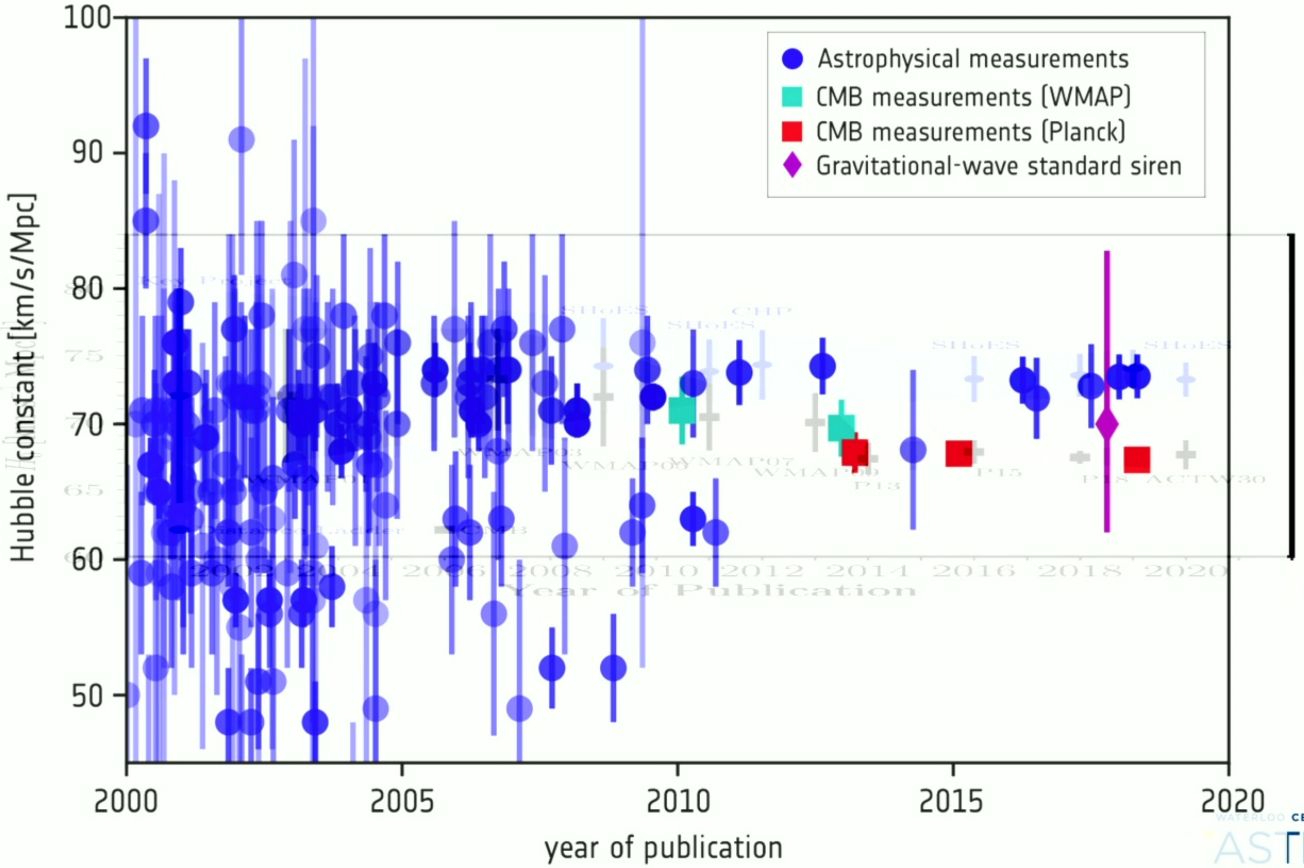

https://www.esa.int/ESA_Multimedia/Images/2018/07/Measurements_of_the_Hubble_constant

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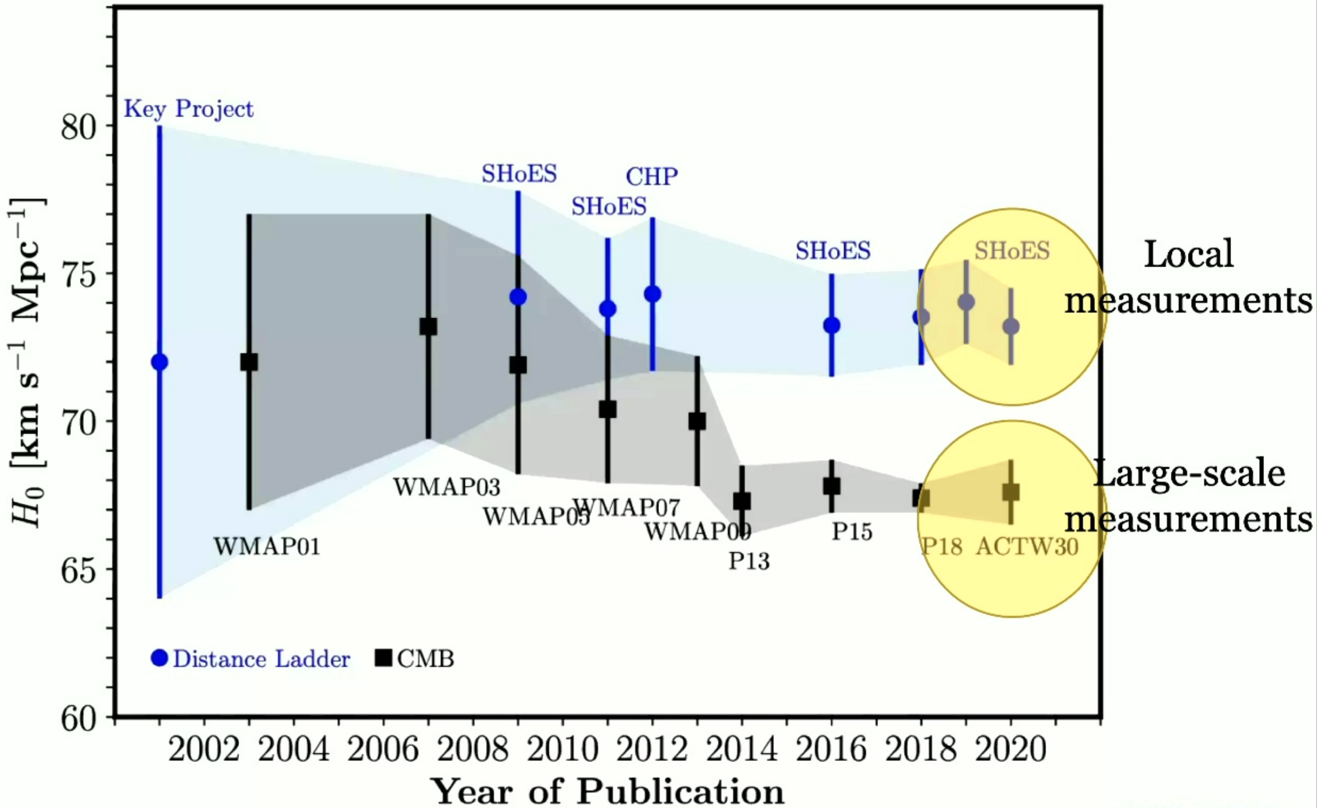

Freedman 2021

H_0 from local measurements

- Start with a local (absolute) calibrator to a galaxy
  - Parallax (sun-earth distance)
  - Detached eclipsing binaries (period)
  - Masers (acceleration)
- Use these to calibrate objects viewed further out
  - Cepheid variables (luminosity-period relation)
  - TRGB observations (universality of Helium flash)
- Use this to calibrate SN1a in cosmological volume (e.g. the Pantheon SN1a sample)
  - Measure H_o

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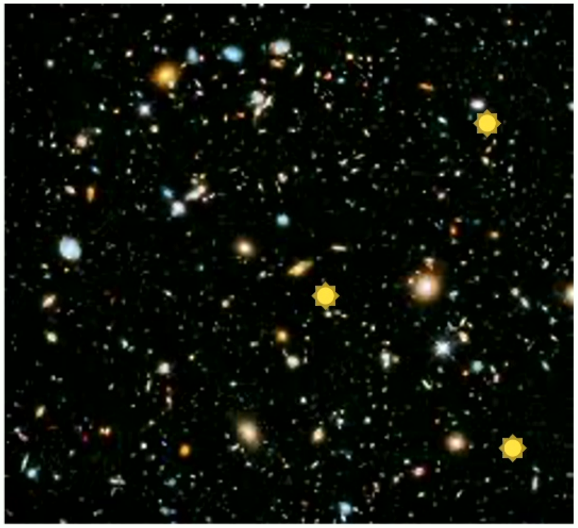
H_0 from local measurements

Example calibrator galaxy

Use calibration to determine M_{sn}
if SN1a goes off



Measure apparent brightness of distant SN
To estimate distances

$$\mu = m - M = 5\log(d_L/Mpc) + 25$$

$$d_L \simeq \frac{cz}{H_0} + O(z^2)$$

e.g. Riess et al. (20XX); Freedman et al. (20xx)

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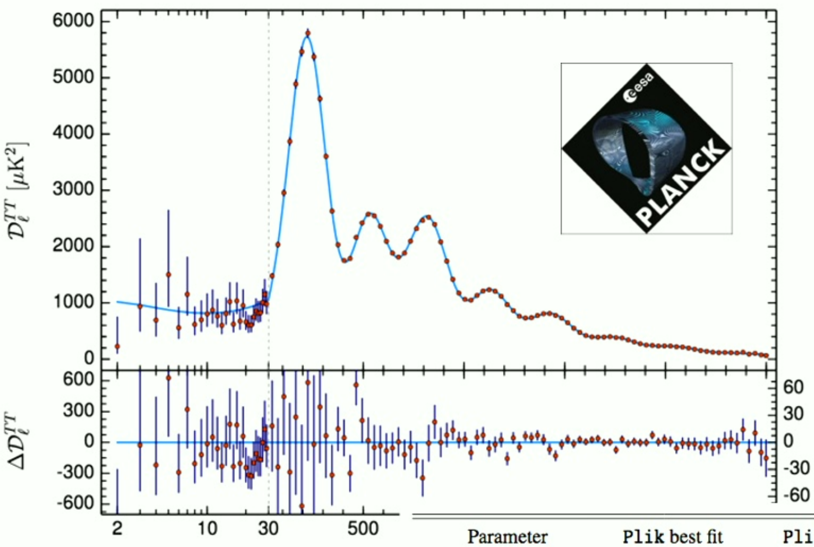
H_0 from the CMB



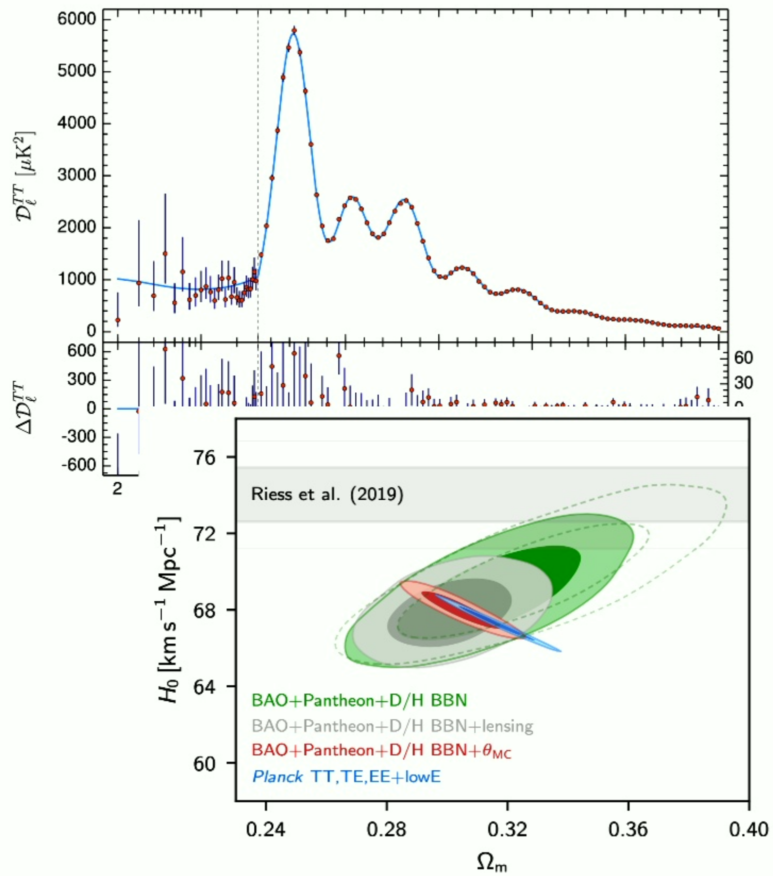
To measure H_0 we need an absolute calibration

For the CMB this is the temperature T=2.7255K

The projected peak positions, together with the theory for their intrinsic position gives H_0

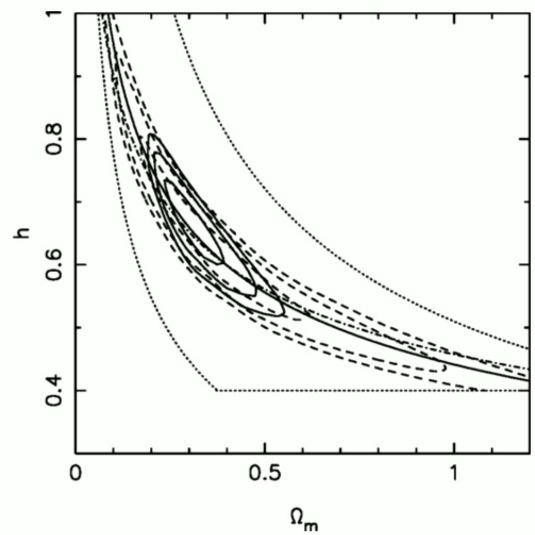
Parameter	Plik best fit	Plik [1]	CamSpec [2]	([2] − [1])/σ_1	Combined
$\Omega_b h^2$	0.022383	0.02237 ± 0.00015	0.02229 ± 0.00015	−0.5	0.02233 ± 0.00015
$\Omega_c h^2$	0.12011	0.1200 ± 0.0012	0.1197 ± 0.0012	−0.3	0.1198 ± 0.0012
$100\theta_{MC}$	1.040909	1.04092 ± 0.00031	1.04087 ± 0.00031	−0.2	1.04089 ± 0.00031
τ	0.0543	0.0544 ± 0.0073	$0.0536^{+0.0069}_{-0.0077}$	−0.1	0.0540 ± 0.0074
$\ln(10^{10}A_s)$	3.0448	3.044 ± 0.014	3.041 ± 0.015	−0.3	3.043 ± 0.014
n_s	0.96605	0.9649 ± 0.0042	0.9656 ± 0.0042	+0.2	0.9652 ± 0.0042
$\Omega_m h^2$	0.14314	0.1430 ± 0.0011	0.1426 ± 0.0011	−0.3	0.1428 ± 0.0011
H_0 [km s^{-1}Mpc^{-1}] . . .	67.32	67.36 ± 0.54	67.39 ± 0.54	+0.1	67.37 ± 0.54
Ω_m	0.3158	0.3153 ± 0.0073	0.3142 ± 0.0074	−0.2	0.3147 ± 0.0074
Age [Gyr]	13.7971	13.797 ± 0.023	13.805 ± 0.023	+0.4	13.801 ± 0.024
σ_8	0.8120	0.8111 ± 0.0060	0.8091 ± 0.0060	−0.3	0.8101 ± 0.0061
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$ . .	0.8331	0.832 ± 0.013	0.828 ± 0.013	−0.3	0.830 ± 0.013
z_{re}	7.68	7.67 ± 0.73	7.61 ± 0.75	−0.1	7.64 ± 0.74
$100\theta_*$	1.041085	1.04110 ± 0.00031	1.04106 ± 0.00031	−0.1	1.04108 ± 0.00031
r_{drag} [Mpc]	147.049	147.09 ± 0.26	147.26 ± 0.28	+0.6	147.18 ± 0.29

H_0 from the CMB



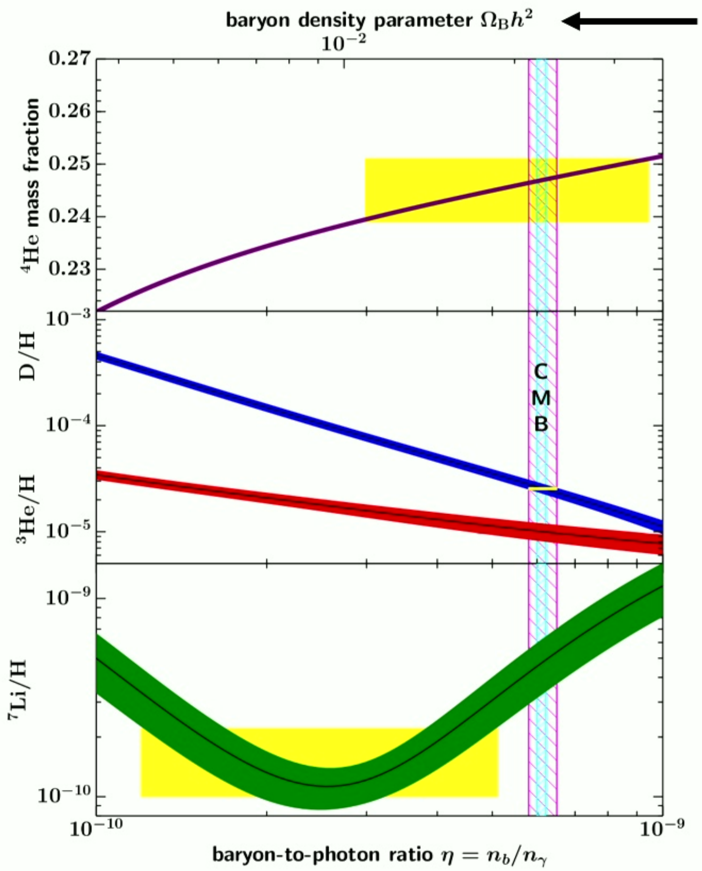
Planck 2018; arXiv:1807.06209

For flat ΛCDM models, there is a degeneracy between Ω_m and H_o



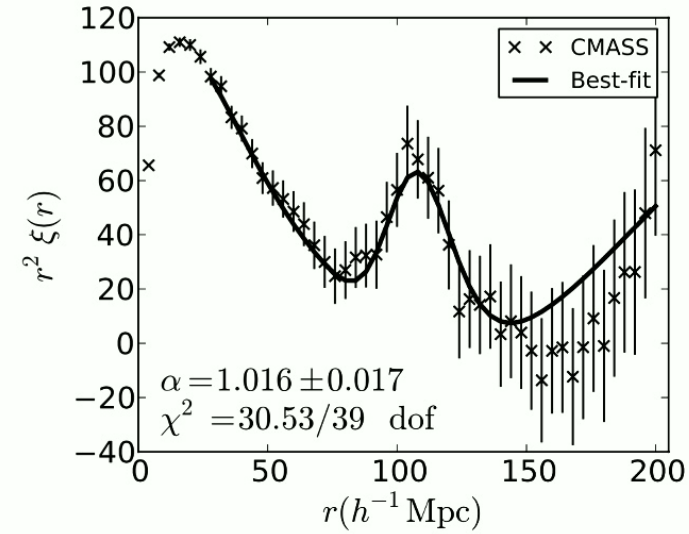
Percival et al 2002; arXiv:0206256

H_0 from BBN + BAO



← Uses CMB temperature

BAO peak position measured from galaxy surveys tells us the projected position of the sound horizon along and across line of sight and depends on Ω_b, Ω_c, h



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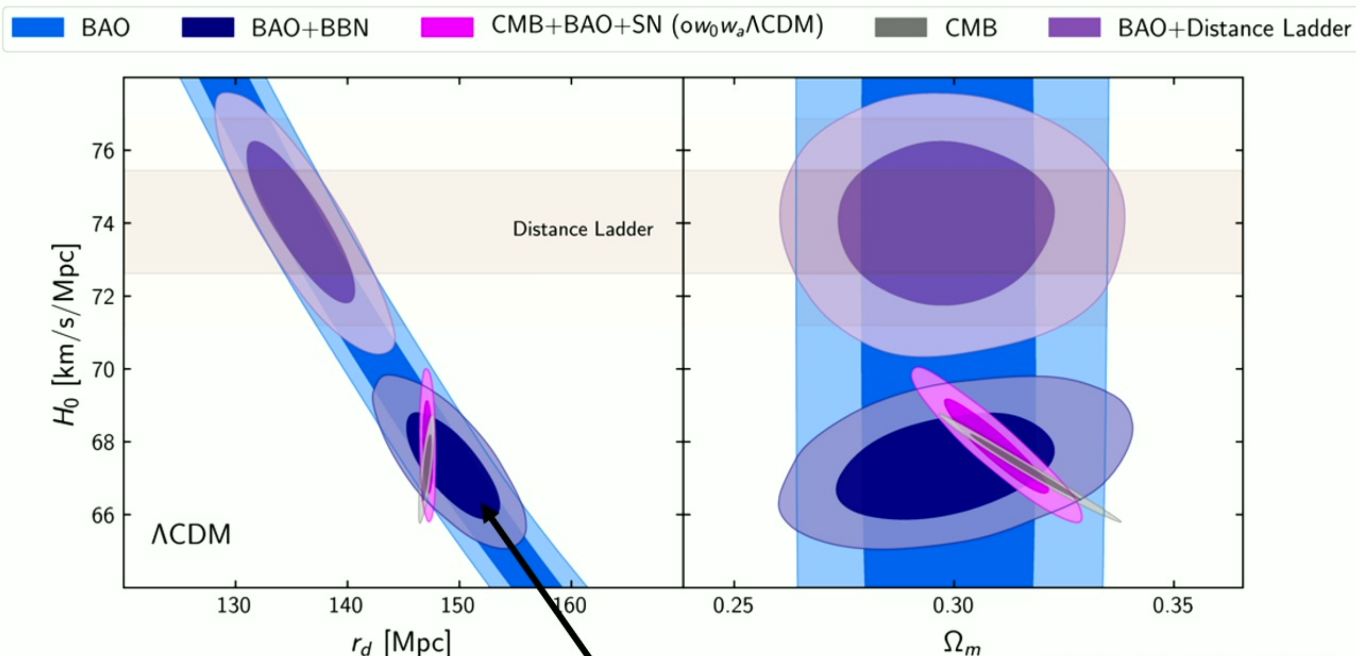
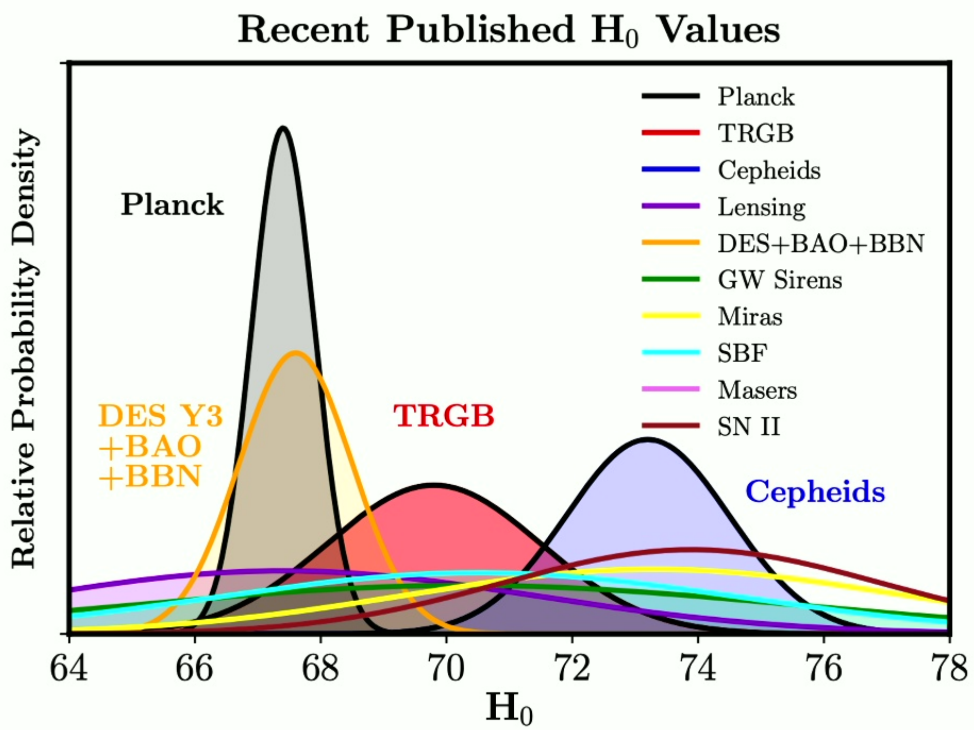


credit: Eva-Maria Mueller and SDSS

Measurement of H_0 independent of CMB

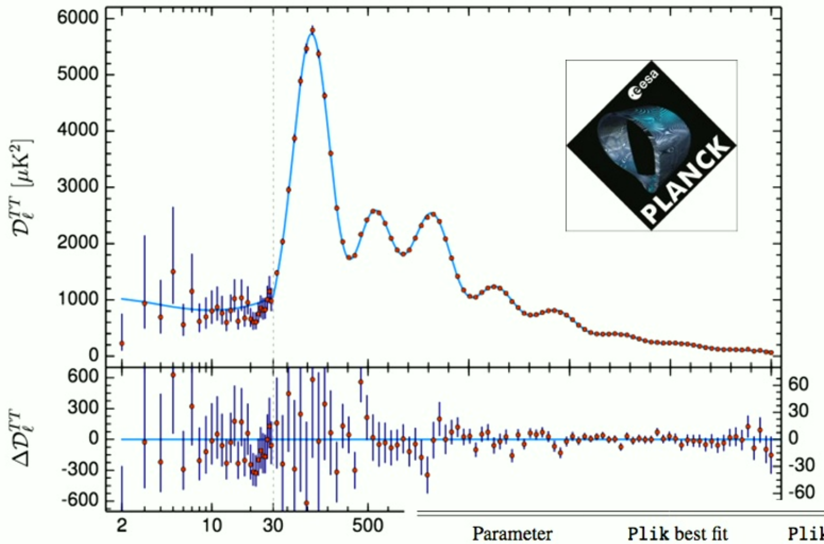
Alam et al. (2020), arXiv:2007.08991

Recent measurements



Freedman et al. (2021), arXiv:2106.15656

H_0 from the CMB



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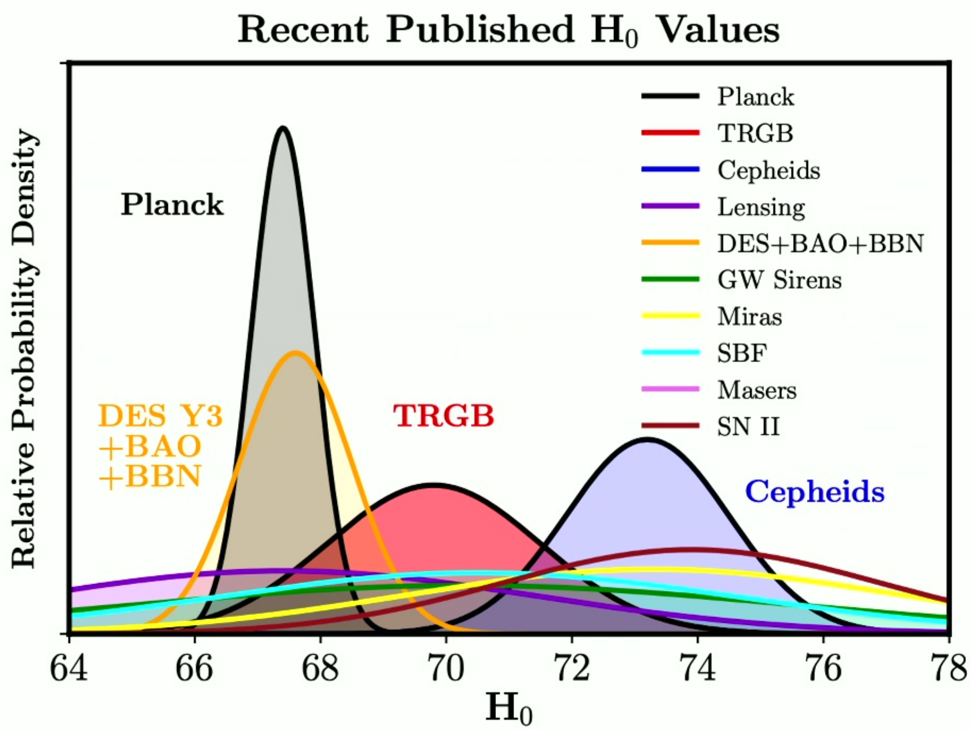

Freedman et al. (2021), arXiv:2106.15656

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All techniques calibrate distances

- Need an absolute measurement (H_0 is absolute)
  - CMB temperature
  - Earth-sun distance
- Theoretically link these to observed physical quantity
  - BBN, CMB physics, BAO position
  - Parallax, Cepheid period-luminosity relation, universality of SN1a
- Make projected distance observations (with errors)
  - CMB / BAO peak positions
  - Distance ladder up to SN1a brightness observations

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Each component could be wrong!

And most have been carefully examined without finding a solution

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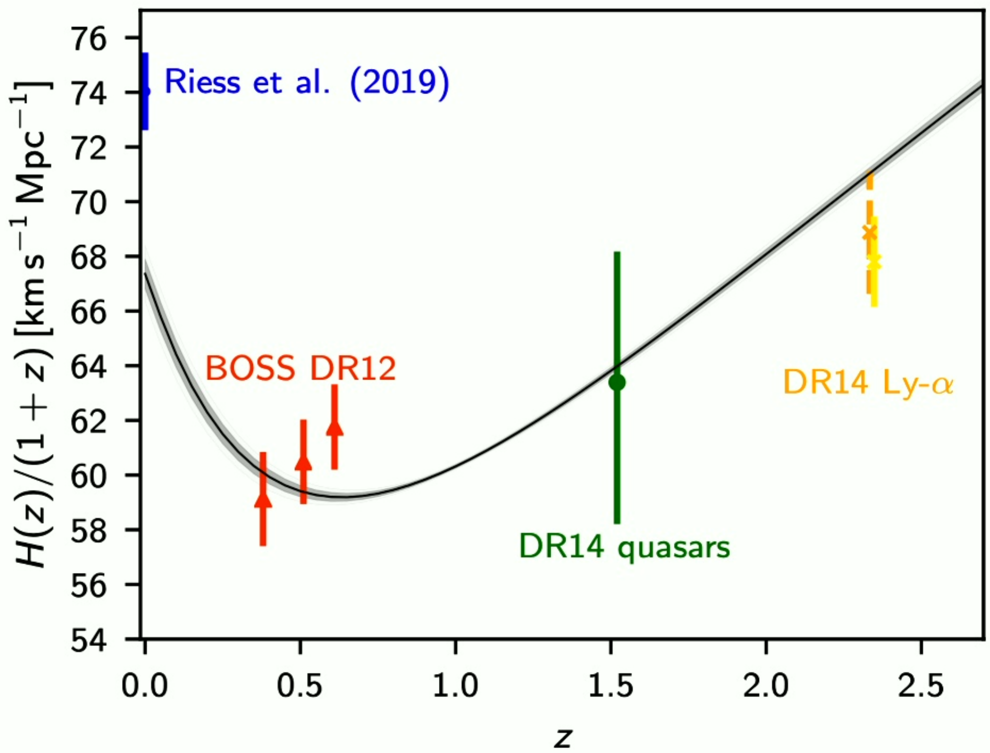
Difficult to change evolution at low redshifts

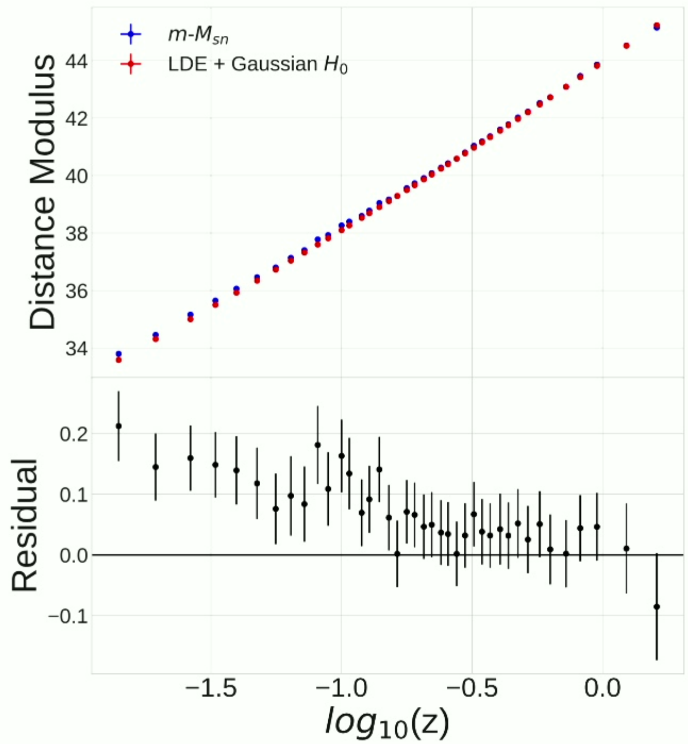


Planck 2018; arXiv:1807.06209

Difficult change evolution at very low redshift

Suppose you add in extra acceleration at z<0.1 to get a higher H_0

The distance ladder gets messed up – you're measuring distances from us



Greene & Cyr-Racine 2022; arXiv:2112.11567

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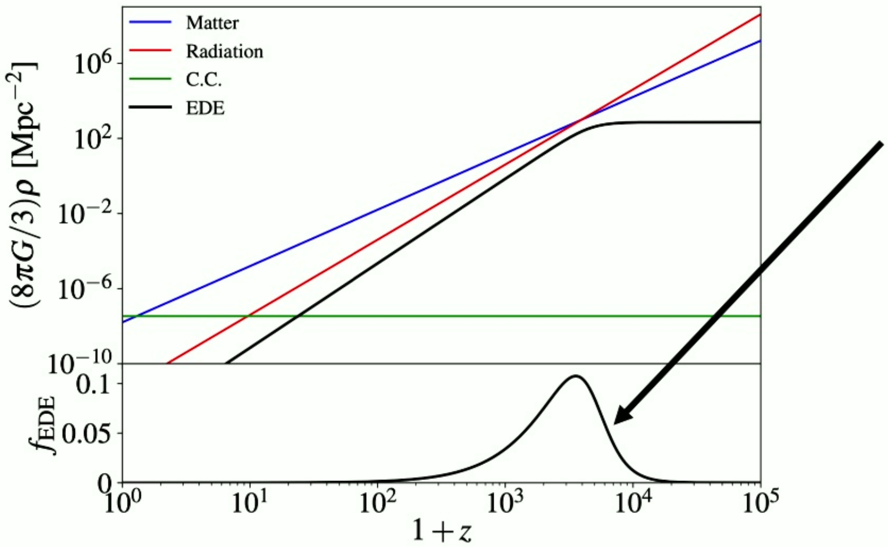
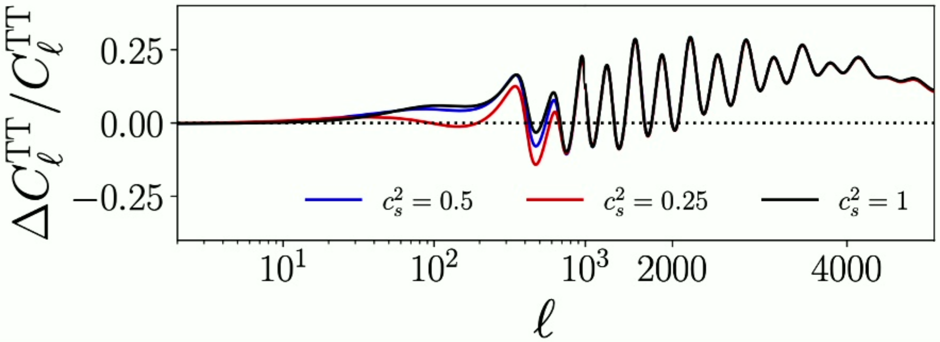
Early Dark Energy



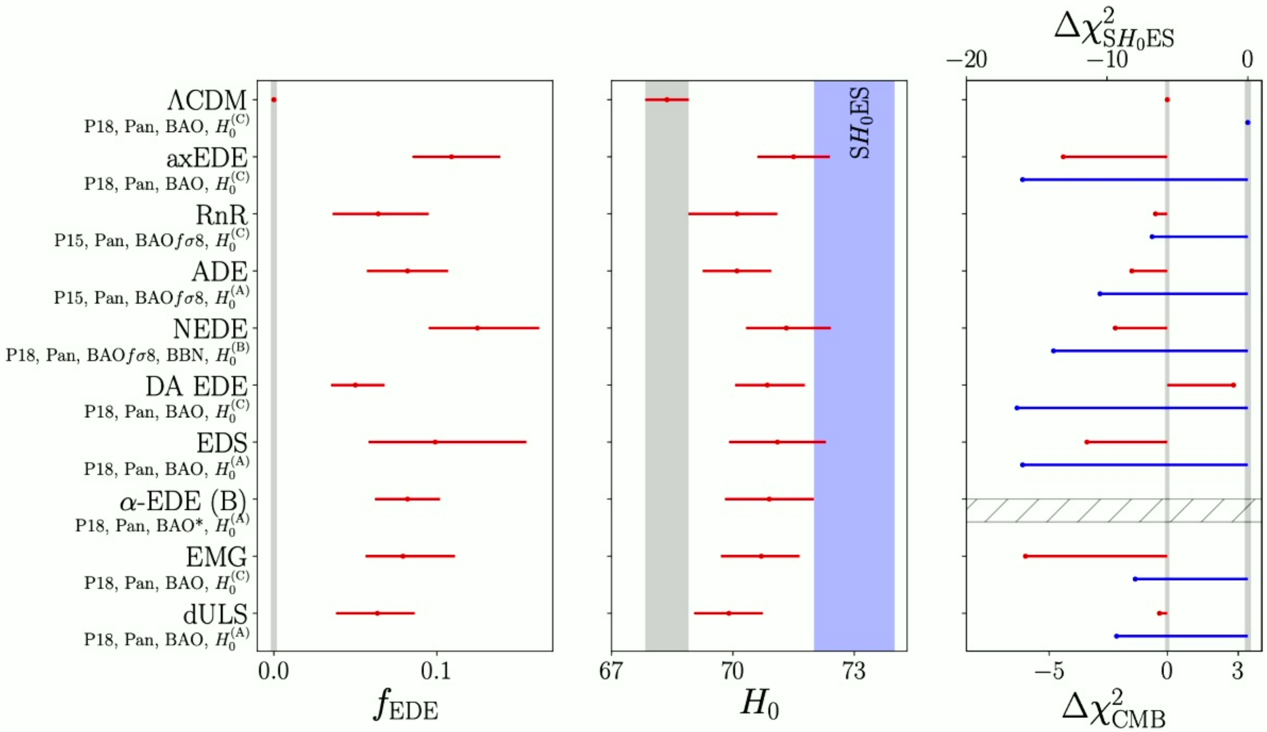
Introduce another period of acceleration after matter-radiation equality, before recombination. Component evolves to different w at later times, stopping acceleration

Extra expansion decreases r_s requiring a larger H_0 to fit the same peak positions



Poulin et al. 2023; arXiv:2302.09032

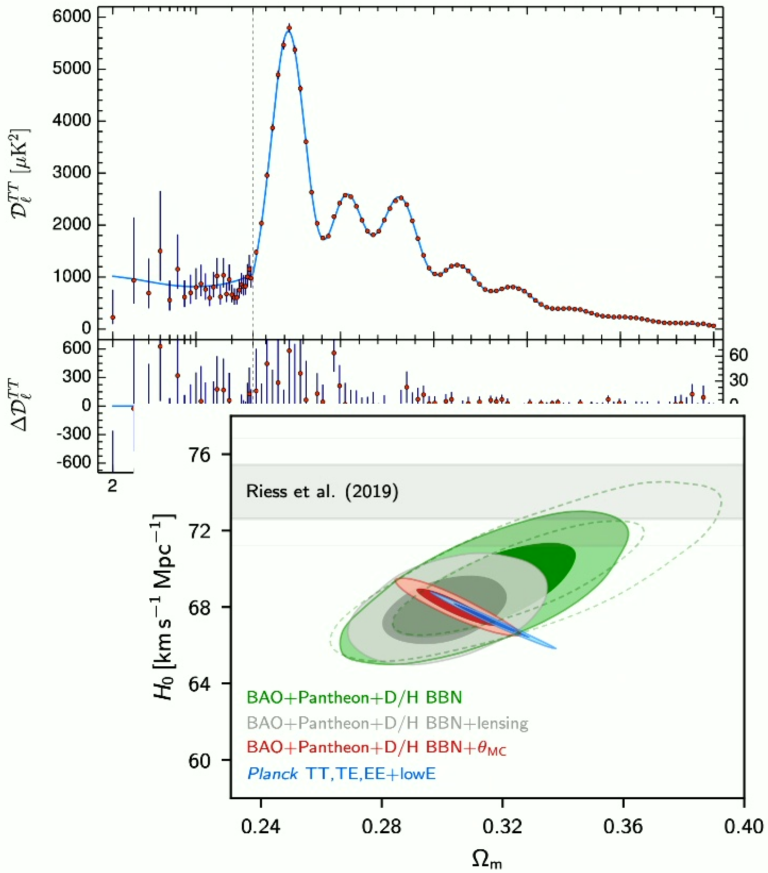
Early Dark Energy



Generic prediction of EDE model is to increase S_8 – see next talk

Poulin et al. 2023; arXiv:2302.09032

H_0 from the CMB



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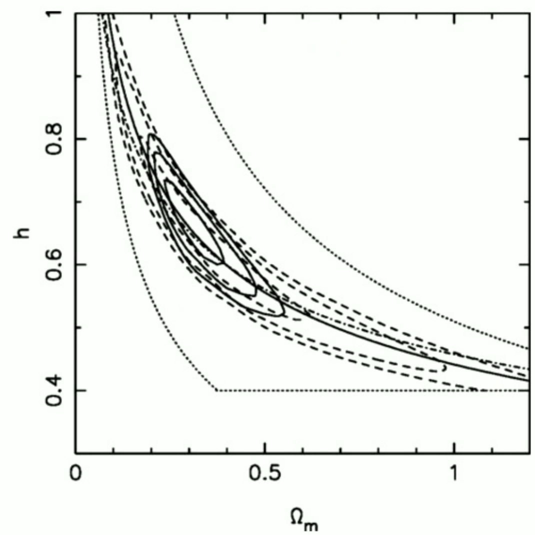

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