The Price of Shifting the Hubble Constant

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Reference: Phys. Rev. D 97,103511(2018)
Jarah Evslin, Anjan A Sen, Ruchika
Institute for Fundamental Physics of the Universe
Trieste, Italy

Outline of the Talk

- Hubble Expansion of Universe and what it is governed by?
- How it is measured?
- How it differs, when measured by low red-shift and high red-shift observations?
- Is something wrong with the systematics OR some interesting physics is waiting to be known?
- Possible solutions
- Conclusion

Basic Cosmology ◇

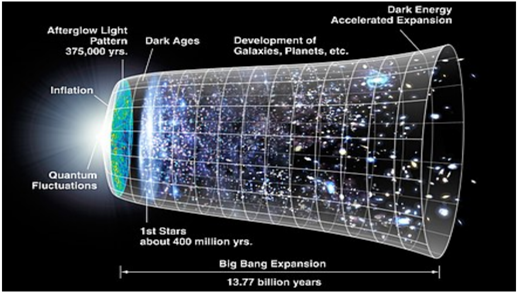
Einstein Equation

$$G^{\mu}_{\nu} = 8\pi G T^{\mu}_{\nu}$$

Geometry $\Rightarrow$ Energy Density

$\Downarrow$ $\Downarrow$

FLRW Universe   Total Energy Content



Basic Cosmology ◇

So, the Hubble Parameter equation

$$H^2 = \frac{8\pi G\rho}{3} - \frac{k}{a^2}$$

where H = $\frac{\dot{a}}{a}$

where a(t) = scale factor

Or simply,

$$\left[\frac{\dot{a}}{a}\right]^2 \propto \rho_{total}$$

Basic Cosmology ◇

So, the Hubble Parameter equation

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where H $= \frac{\dot{a}}{a}$

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Or simply,

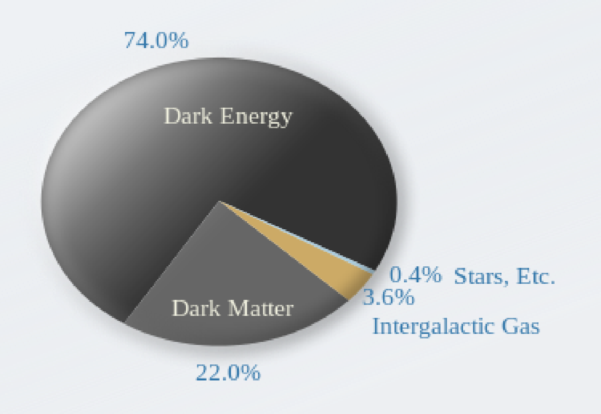
$$\left[\frac{\dot{a}}{a}\right]^2 \propto \rho_{total}$$

So, Now the question is:

What does this ρ_{total} comprise of?

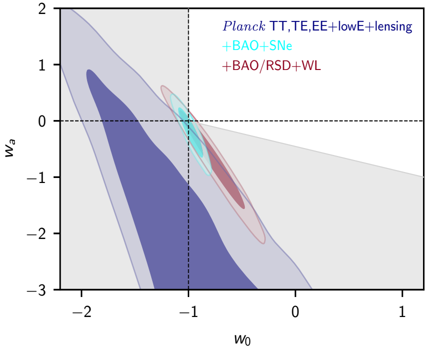
Or, What does this expansion govered by?

Present(z=0) ◇


74.0%
Dark Energy
0.4% Stars, Etc.
3.6%
Intergalactic Gas
Dark Matter
22.0%

Cosmology after Planck-2018 ◇

Concordance ΛCDM model (P.Ade et al. A& A 2018):
$H_0 = 67.37 \pm 0.54 Km/sec/Mpc$



P.Ade et al. A&A, 2018

CPL Parameterisation: $w = w_0 + w_a(1 - a)$

Tensions in H_0 ◇

◇ Planck-2018 measurement : $H_0 = 67.37 \pm 0.54$ Km/s/M pc (Aghanim et al. 2018)

Tension with Plank H_0 Measurements

◇ Recent measurement using local measurements by HST (R18):

$H_0 = 73.48 \pm 1.66$ Km/s/M pc (Riess et al. 2018)

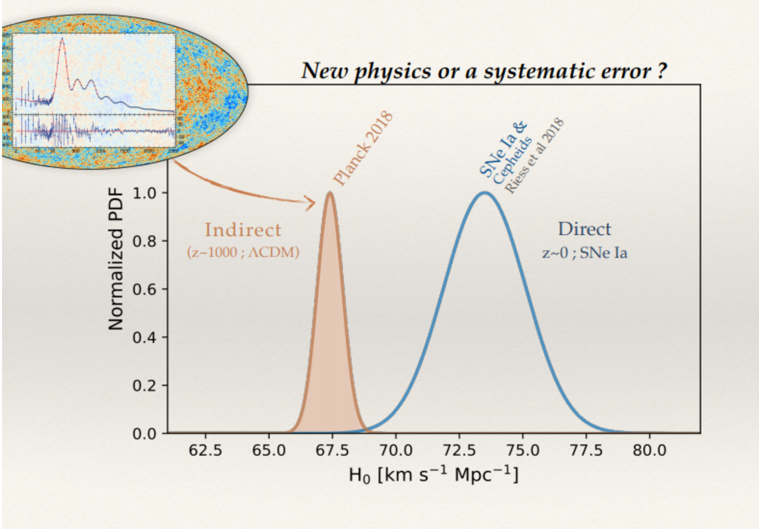
(3.7 σ higher than the Planck-2018)

◇ R18 measurement is also consistent with independent measurement by H0liCOW using Time-Delay Strong Lensing Probe:

$H_0 = 71.9^{+2.4}_{-3.0}$ Km/s/M pc (Bonvin et al. 2017)

(1.84 σ higher than the Planck-2018)

Tensions with ΛCDM ◇



Mickael Rigault| TevPA 2018 | Berlin

Let's Discuss

Possibility of New Physics!

Here we ask ourselves these questions. ◇

- Is H_0 tension correlated to any other Cosmological Parameter?
  → Answer is: Yes, Since BAO measures the combination of $r_d H_0$.

- Can we break this degenracy of $r_d H_0$ and how?
  → Answer is: Yes, If we can measure H_0 independently, then one can estimate r_d.

Data Used ◇

- ⋆ BAO measurements from 6dF, SDSS-DR7(MGS) and eBOSS.
- ⋆ BAO measurements from BOSS DR12 and Lyman-alpha forest sample.
- ⋆ Time-delay distance measurement through Strong Lensing by H0LiCow.
- ⋆ Angular Diameter Distance measurements by Megamaser Cosmology Project for galaxies UGC3789, NGC6264 and NGC5765b.
- ⋆ Distance ladder measurement of $H_0 = 73.24 \pm 1.24$ Km/s/M pc by Riess et al. (2016)

Results ◇

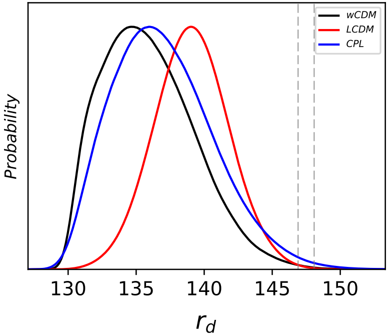
Maximum Likelihood values and 1D marginalised 68% confidence intervals of parameters for respective models.

Taking value of $H_0 = 73.24 \pm 1.24$ Km/s/M pc.

	$\Omega_m 0$	r_d	w_0	w_a
ΛCDM	0.295 ± 0.019	139.2 ± 3.2	N/A	N/A
wCDM	0.277 ± 0.027	135.3 ± 3.8	-0.76 ± 0.14	N/A
CPL	0.241 ± 0.084	136.4 ± 3.9	-0.77 ± 0.17	0.44 ± 0.53

Also, $H_0 = 136.41 \pm 3.82$ confirmed model independently by Salvatore et al.(2018).

Results ◇



$r_d = 147.26 \pm 0.29 Mpc$ (Planck)

- ΛCDM: 2.52 σ away from Planck
- wCDM : 3.14 σ away from Planck
- CPL : 2.79 σ away from Planck

So, our results are quite model independent.

So, The Price of shift in Hubble constant is the shift in r_d.

Results ◇

	Planck		Local Measurements
H_0	$67.37 \pm 0.54 Km/sec/Mpc$	$\Rightarrow$	73.24 ± 1.24 Km/s/M pc.

Results ◇

	Planck		Local Measurements
H_0	$67.37 \pm 0.54 Km/sec/Mpc$	$\Rightarrow$	73.24 ± 1.24 Km/s/M pc.
r_d	$147.26 \pm 0.29 Mpc$	$\Leftarrow$	$139.2 \pm 3.2 Mpc$

Interpretation ◇

r_d is the Sound Horizon at drag epoch

$$r_d = \int_0^{t(zd)} c_s(1+z)dt$$

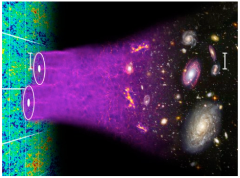
where $c_s = \frac{1}{\sqrt{3(1+R)}}$

and $R = 3\frac{\rho_b}{\rho_r}$

Physics: sound waves in early Universe propagate until radiation and matter decouple.

Lower r_d as compared to Planck suggets:

◇ changing z_d
◇ modifying the speed of sound
◇ changing the age of universe at drag epoch
◇ changing primodial fluctuations



Credit: Blake & Moorfield

Checking Consistency with CMB ⋄

- ⋄ Is the reduction in r_d consistent with CMB constraints?
- ⋄ CMB best constrains the angular size of the acoustic scale θ.
- ⋄ Ignoring the small difference between drag epoch and recombination epoch $\theta = r_d/D_A(z)$.

$$\text{Higher } H_0 \Rightarrow \text{Lower } r_d (\text{BAO constraints } r_d H_0\ )$$
$$\Rightarrow \text{Lower } D_A (D_A \propto 1/H_0)$$
$$\Rightarrow \theta \text{ Intact}$$

- ⋄ This is fortunate, since any shift in acoustic scale, will shift all the peaks.

Conclusion ⋄

- ⋄ Along with Hubble Tension, there is a similar tension involving sound horizon at drag epoch from low-redshift and Planck measurements.
- ⋄ It does not depend on dark energy behaviour.
- ⋄ One Solution: One needs to modify the early Universe cosmology.

THANK YOU!