Low-redshift estimates of the absolute scale of baryon acoustic oscillations

Ruchika

INFN, Roma

April 25, 2023

Reference: arxiv 2303.15066

Thais Lemos, Ruchika, Joel C. Carvalho, Jailson Alcaniz

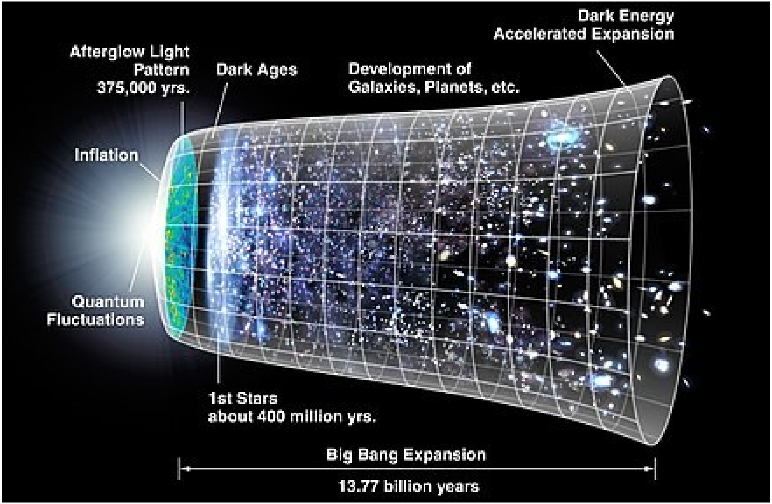
Future Cosmology School

Cargese, France

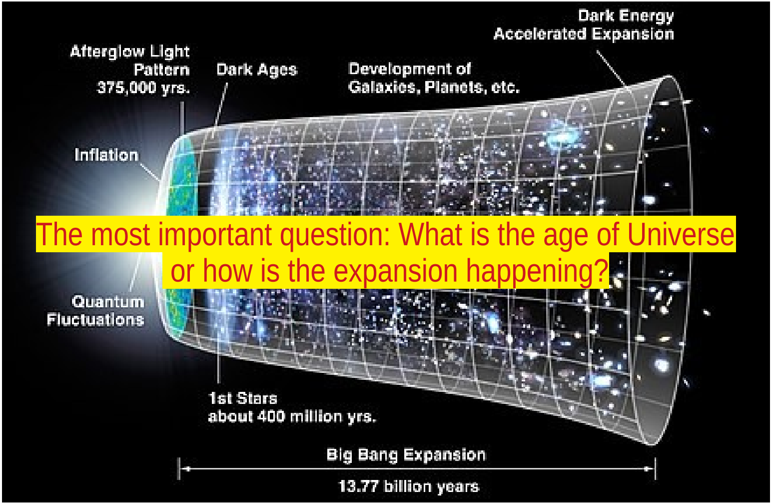
Outline of the Talk

- Present state of Universe
- Ongoing tensions in recent cosmology
- Is rd tension related to Hubble tension?
- At present, r_d estimation is biased by the model and high redshift CMB data.
- How we measure r_s from low-redshift measurements in a completely model independent way?
- Does low-redshift estimation of r_s consistent with the one derived from high-redshift CMB observations?
- Conclusion

A growing Universe ◇



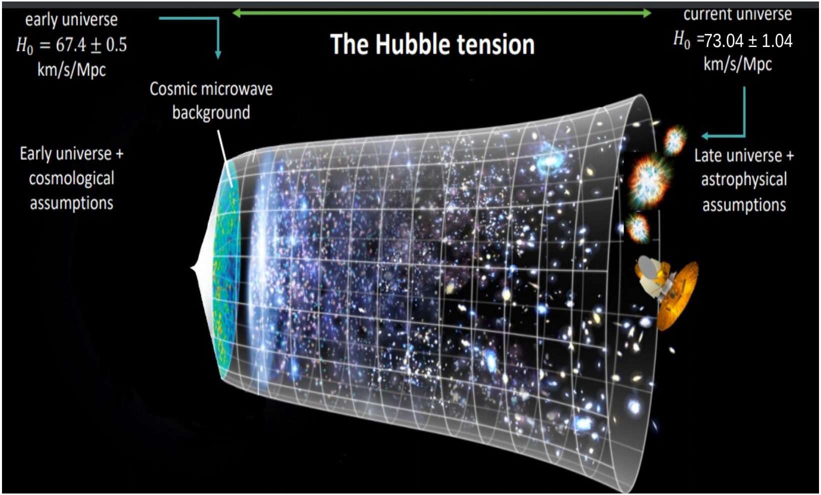
A growing Universe ◇



The most important question: What is the age of Universe or how is the expansion happening?

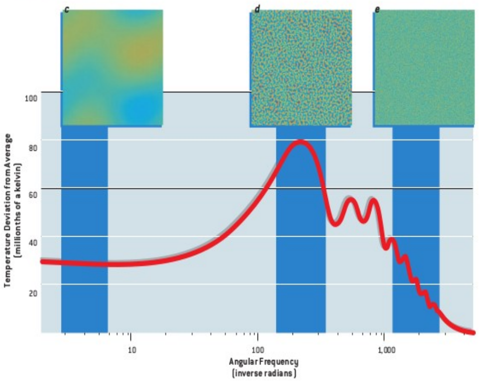
A growing universe ... and tension ◇

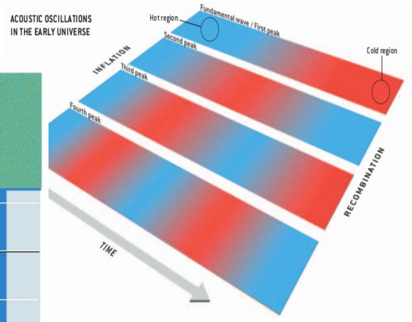
> 5 sigma



Another important derived parameter: r_d

Another standard object like SNI-a ◇





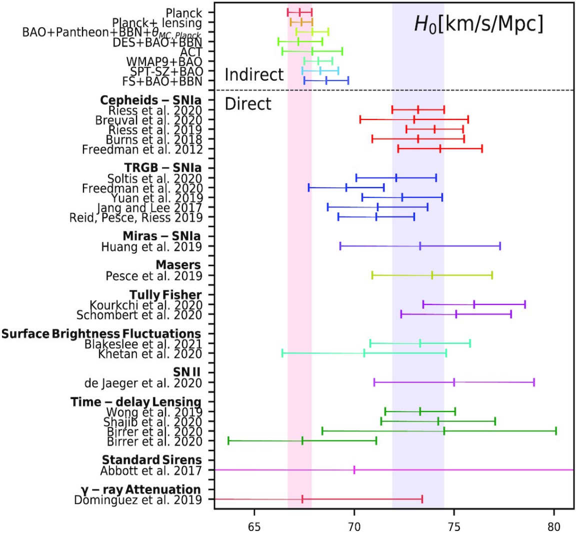
$$r_s^\star = \int_0^{t_\star} \frac{dt}{a(t)}\, c_s(t) = \int_{z_\star}^{\infty} \frac{dz}{H(z)}\, c_s(t),$$

By Wayne Hu and Martin White

Current state - Tensions (Hubble Tension) ◇

Current state : > 5 sigma tension between Planck and SH0ES 2022

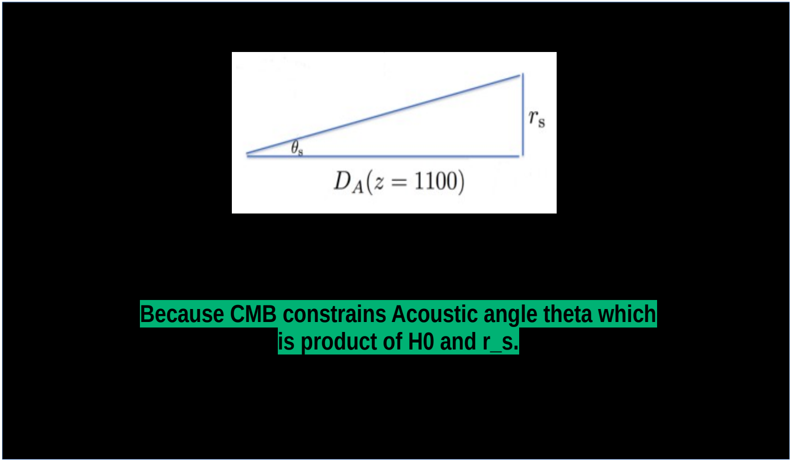
Questions that follow: Is ΛCDM the right theoretical model?



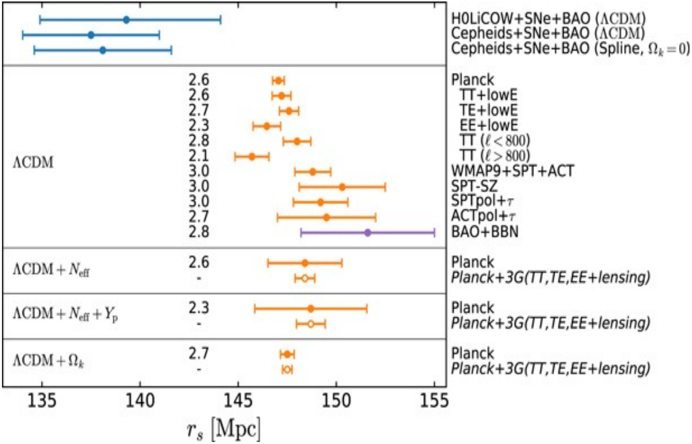
Di Valentino : Mon.Not.Roy.Astron.Soc. 502 (2021)

Current state - "Crisis" in Cosmology ⋄

Price of shift in Hubble Constant is the shift in r_d ◇

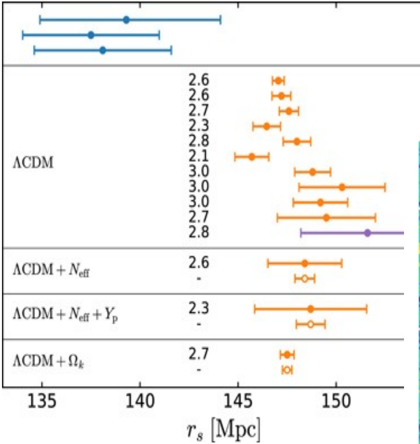


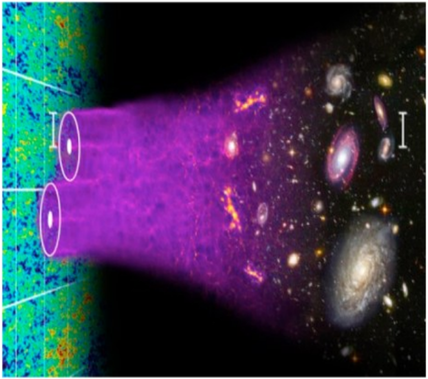
Price of shift in Hubble Constant is the shift in r_d ◇



Aylor et al. [Astrophys.J. 874 (2019)]

Current state - Tensions (r_d Tension) $\diamond$



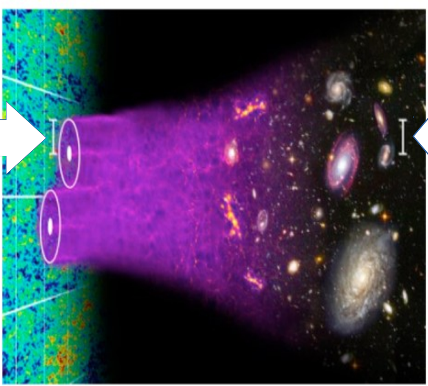


Aylor et al. [Astrophys.J. 874 (2019)]

Credit: Blake & Moorfield

Our Work ◇

Assumed ΛCDM Cosmology
(z=1100)
CMB



Credit: Blake & Moorfield

Our Work :
Model Independent Way
(at low redshifts)

Our Work ◇

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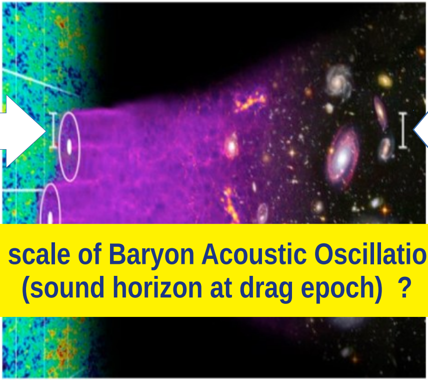

Our Work :
Model Independent Way
(at low redshifts)

Is r_s (absolute scale of Baryon Acoustic Oscillations) same as r_d (sound horizon at drag epoch) ?

Credit: Blake & Moorfield

Notation : r_d

Notation : r_s

Our Work ◇

Assumed ΛCDM Cosmology
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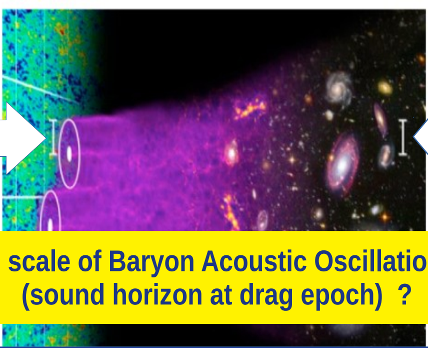

Our Work :
Model Independent Way
(at low redshifts)

Is r_s (absolute scale of Baryon Acoustic Oscillations) same as r_d (sound horizon at drag epoch) ?

Notation : r_d

Probe of standard assumptions of early universe cosmology

Notation : r_s

Our Work ◇

Observables Used

- Luminosity Distance measured

$$M = m - 5\log_{10}\frac{D_L}{10\,\mathrm{pc}}$$

- Angular Diameter Distance inferred

$$D_L = (1+z)^2 D_A$$ (Assuming CDDR is valid)

- 2D BAO measurements from angular separation of pairs of galaxies measured

$$\theta_{BAO}(z)[^\circ]$$

Data Used

- Supernoave Type-Ia

  Pantheon Sample which comprises 1048 SNe data points ranging in the redshift interval $0.01 \leq z \leq 2.3$

- Transversal BAO data

  11 θ _BAO (z) measurements obtained from public data of the Sloan Digital Sky Survey (SDSS), namely DR10, DR11, and DR12

Our Work ◇

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$$\theta_{\mathrm{BAO}}(z) = \frac{r_s}{(1+z)d_A(z)}$$

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Observables Used

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Calculates absolute scale for BAO in model independent way

$$\theta_{\mathrm{BAO}}(z) = \frac{r_s}{(1+z)d_A(z)}$$

Methodology ◇

Methodology

redshift interval
$0.44 \leq z \leq 0.66$

	Snel-a Data	BAO Data
Binning	Binned data into 11 bins	Have 11 data points
Gaussian Processes	Constructed a Gaussian Function	Have 11 data points

Methodology ◇

Methodology

redshift interval
$0.44 \leq z \leq 0.66$

Snel-a Data | BAO Data

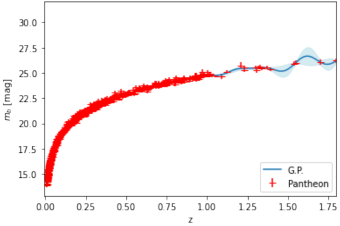
- Binning | Binned data into 11 bins | Have 11 data points

Example:

2D BAO			Type Ia SNe	Binning	
n-th bin	$z_{\rm bao}$	$\theta_{\rm BAO}$	$[z_l^{\rm a}, z_r^{\rm a}]$	$z_{\rm SN}$	n_a
1	0.45	4.77 ± 0.17	[0.44007, 0.45173]	0.44730	10
2	0.47	5.02 ± 0.25	[0.4664, 0.47175]	0.46925	7

- Gaussian Processes | Constructed a Gaussian Function | Have 11 data points

Example:



Results ◇

Table 2 Estimates of the absolute BAO scale from 2D BAO and SNe data for binning and GP methods. In this analysis, we assume the value of absolute magnitude as M_B=-19.214 ± 0.037 (SH0ES 2021$_a$) [42].

2D BAO			Type Ia SNe	Binning					GP			
n-th bin	$z_{\rm bao}$	$\theta_{\rm BAO}$	$[z_l^a, z_r^a]$	$z_{\rm SN}$	n_a	d_L (Mpc)	d_A (Mpc)	r_s(Mpc)	$z_{\rm GP} = z_{\rm bao}$	d_L (Mpc)	d_A (Mpc)	r_s(Mpc)
1	0.45	4.77 ± 0.17	[0.44007, 0.45173]	0.44730	10	2304.34 ± 226.62	1096.00 ± 107.79	132.39 ± 13.85	0.45	2361.35 ± 45.00	1123.06 ± 21.40	135.57 ± 5.48
2	0.47	5.02 ± 0.25	[0.4664,0.47175]	0.46925	7	2606.23 ± 300.43	1206.08 ± 139.03	155.20 ± 19.49	0.47	2486.40 ± 47.71	1150.42 ± 22.07	148.18 ± 7.91
3	0.49	4.99 ± 0.21	[0.4804, 0.49737]	0.48635	7	2581.83 ± 206.25	1162.93 ± 92.90	150.69 ± 13.61	0.49	2609.44 ± 50.48	1175.31 ± 22.74	152.52 ± 7.06
4	0.51	4.81 ± 0.17	[0.50718, 0.51476]	0.51092	9	2753.04 ± 246.42	1207.42 ± 108.07	153.13 ± 14.74	0.51	2734.46 ± 53.36	1199.05 ± 23.40	152.01 ± 6.14
5	0.53	4.29 ± 0.30	[0.52851, 0.53433]	0.53235	4	2697.60 ± 203.15	1152.38 ± 86.78	132.04 ± 13.57	0.53	2861.86 ± 56.19	1222.48 ± 24.00	140.05 ± 10.17
6	0.55	4.25 ± 0.25	[0.54539, 0.55381]	0.55009	6	2958.21± 286.74	1231.30 ± 119.35	141.56 ± 16.05	0.55	2996.40 ± 58.93	1246.98 ± 24.52	143.38 ± 8.89
7	0.57	4.59 ± 0.36	[0.565, 0.575]	-	0	-	-	-	0.57	3134.79 ± 61.61	1271.70 ± 24.99	159.95 ± 12.93
8	0.59	4.39 ± 0.33	[0.58575, 0.59185]	0.58878	5	3304.57 ± 286.21	1307.13 ± 113.21	159.31 ± 18.27	0.59	3275.58 ± 64.78	1295.44 ± 25.62	157.83 ± 12.27
9	0.61	3.85 ± 0.31	[0.60825, 0.61124]	0.61	4	3551.85 ± 328.27	1370.26 ± 126.64	148.43 ± 18.05	0.61	3409.94 ± 68.98	1315.44 ± 26.61	142.31 ± 11.81
10	0.63	3.90 ± 0.43	[0.62522, 0.63222]	0.62964	6	3346.38 ± 340.44	1259.50 ± 128.13	140.10 ± 20.99	0.63	3536.01 ± 74.38	1330.64 ± 27.99	147.65 ± 16.57
11	0.65	3.55 ± 0.16	[0.64191, 0.64864]	0.64509	5	3654.40 ± 307.19	1342.29 ± 112.83	137.20 ± 13.09	0.65	3651.93 ± 79.92	1341.31 ± 29.35	137.13 ± 6.87

Results ◇

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n-th bin	z_{bao}	θ_{BAO}	$[z_l^a, z_r^a]$	z_{SN}	n_a	d_L (Mpc)	d_A (Mpc)	r_s(Mpc)	$z_{GP} = z_{bao}$	d_L (Mpc)	d_A (Mpc)	r_s(Mpc)
1	0.45	4.77 ± 0.17	[0.44007, 0.45173]	0.44730	10	2304.34 ± 226.62	1096.00 ± 107.79	132.39 ± 13.85	0.45	2361.35 ± 45.00	1123.06 ± 21.40	135.57 ± 5.48
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3	0.49	4.99 ± 0.21	[0.4804, [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ± 50.48	1175.31 ± 22.74	152.52 ± 7.06
4	0.51	4.81 ± 0.17	[0.5071							± 53.36	1199.05 ± 23.40	152.01 ± 6.14
5	0.53	4.29 ± 0.30	[0.5285							± 56.19	1222.48 ± 24.00	140.05 ± 10.17
6	0.55	4.25 ± 0.25	[0.5453							± 58.93	1246.98 ± 24.52	143.38 ± 8.89
7	0.57	4.59 ± 0.36	[0.56							± 61.61	1271.70 ± 24.99	159.95 ± 12.93
8	0.59	4.39 ± 0.33	[0.5857							± 64.78	1295.44 ± 25.62	157.83 ± 12.27
9	0.61	3.85 ± 0.31	[0.6082							± 68.98	1315.44 ± 26.61	142.31 ± 11.81
10	0.63	3.90 ± 0.43	[0.6252							± 74.38	1330.64 ± 27.99	147.65 ± 16.57
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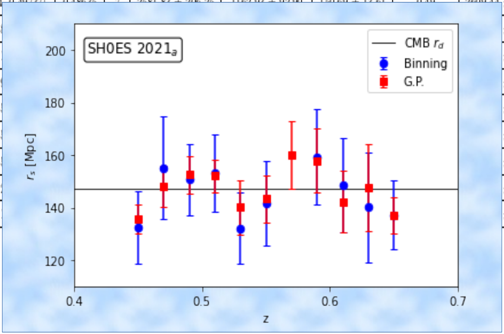

Results ◇

		Binning			G.P.		
Measurement	H_0(Km/s/Mpc)	r_s(Mpc)	$\eta = \frac{r_s}{r_d}$	σ	r_s(Mpc)	η	σ
Planck CMB + Lensing	67.36 ± 0.54	159.44 ± 17.88	1.08	0.7	161.59 ± 10.96	1.1	1.32
ACT + WMAP CMB	67.6 ± 1.1	158.70 ± 17.93	1.08	0.65	160.84 ± 11.13	1.09	1.23
BOSS DR12 + BBN	68.5 ± 2.2	156.53 ± 18.21	1.06	0.52	158.64 ± 11.83	1.08	0.98
SH0ES 2021	73.2 ± 1.3	146.82 ± 16.76	0.99	0.02	148.80 ± 10.35	1.01	0.16
Masers	73.9 ± 3.0	145.41 ± 17.29	0.99	0.10	147.37 ± 11.57	1.00	0.02
SH0ES 2019	74.0 ± 1.4	145.14 ± 16.44	0.99	0.12	147.10 ± 10.25	1.00	0.00
SH0ES 2021_a	74.1 ± 1.3	145.01 ± 16.39	0.98	0.13	146.96 ± 10.19	0.99	0.013
Tully Fisher	76.0 ± 2.6	141.45 ± 16.45	0.96	0.34	143.35 ± 10.80	0.97	0.35

Results ◇

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Measurement	H_0(Km/s/Mpc)	r_s(Mpc)	$\eta = \frac{r_s}{r_d}$	σ	r_s(Mpc)	η	σ
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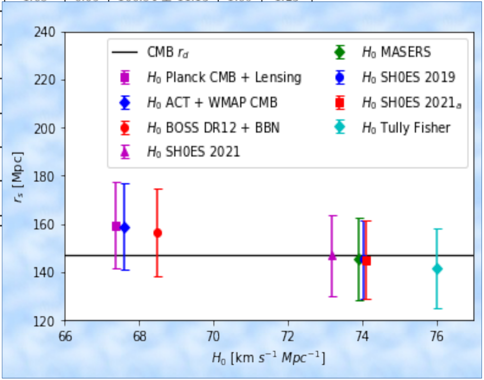
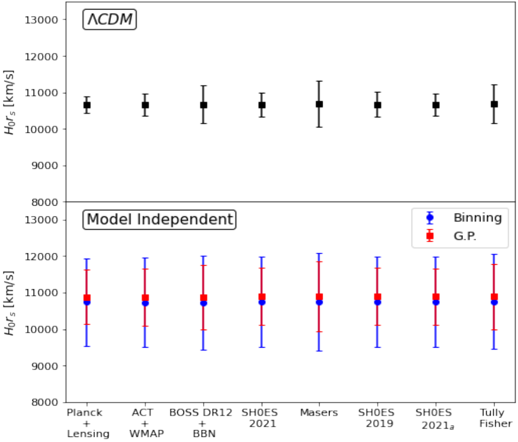
Tully Fisher	76.0 ± 2.6	141.45 ± 16.45					



Results : Consistency with ΛCDM ◇



Conclusion ◇

- **Results from both the methods agree with each other and with the CMB estimate within 1σ.**
- **To note :** Compatible because of high error estimates on r_s.
- **Motivation:** Can test the robustness of the ΛCDM model and standard assumptions taken at high-redshift universe in future.

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- **To note :** Compatible because of high error estimates on r_s.
- **Motivation:** Can test the robustness of the ΛCDM model and standard assumptions taken at high-redshift universe in future.

And, the Future is DESI, Euclid, J-PAS...

Grazie Mille!

Theoretical Model explaining CMB Observations ◇

Concordance ΛCDM model (P.Ade et al. A& A 2018):

- Mainly 6 parameters
- $\Omega_b h^2$- fractional density of baryons
- $\Omega_c h^2$- fractional density of CDM
- H_0-Hubble Parameter
- n_s-scalar spectrum power law index
- τ- the optical depth due to reionisation
- $\ln(10^{10} A_s)$-amplitude of primodial power spectra