The Hubble tension:
where we are;
where we are going.

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POTOR 10, 16-20 Września 2024r.

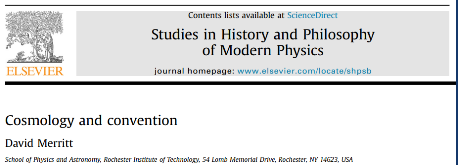
What to say about the Hubble tension?

Everything has been told, and is told everyday. Some reviews:

- Di Valentino et al., 2203.06142 (163 pages)
- Kamionkowski & Riess, 2211.04492
- Verde et al., 2311.13305 (*"A tale of many H_0"*)

Polarization of community in 2(+1) groups:

- Theoreticians: *"We are on the verge of a paradigm shift in cosmology"*
  - "We have a lot of models, but no new theory" (cit. Sakellariadou M.)
- Astronomers: *"There is hidden systematics in data"*
  - "Who among us is wrong?"
- "Conventionalist bias"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Cosmology and convention

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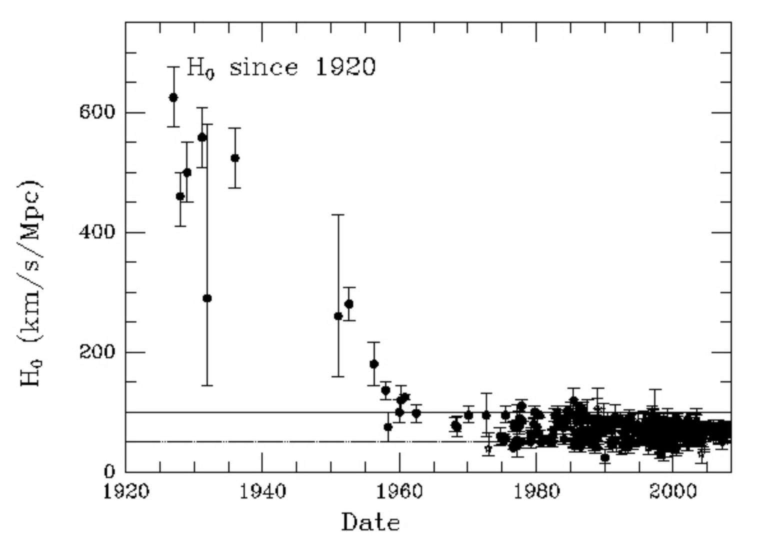
Lessons from the past: Hubble's constant "prehistory"



https://lweb.cfa.harvard.edu/~dfabricant/huchra/hubble/

Lessons from the past: Hubble's constant "prehistory"

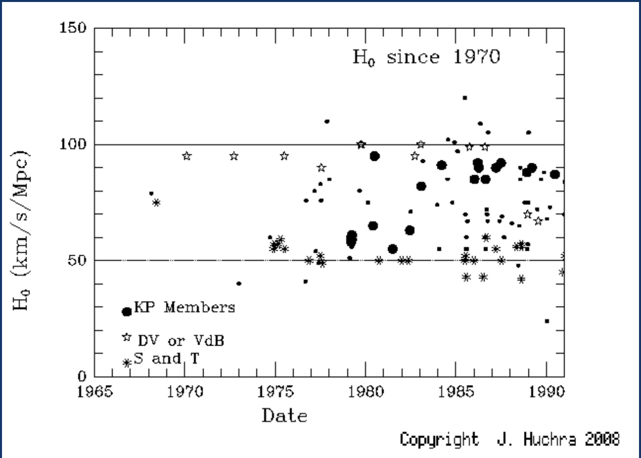
Why H_0 was such an "incredible shrinking constant"? (Trimble V., 1996, PASP 108, 1073)

Wrong calibration of the Cepheid P-L relation (30 years to solve)

- small-number statistics
- neglect contribution of peculiar motion
- poor data:
  - some Hubble bright stars where not star, but stars+gas
- missing interstellar absorption:
  - Cepheids zero point should be brighter - lower H0 ($\downarrow M_B \equiv \downarrow H_0$)
- Malmquist bias: magnitude-limited samples
  - more distant objects look closer because brighter ones are selected
  - distance to $M31$ from Hubble, 275 kpc vs real distance to $M31$, 765 kpc
  - bias in the Cepheid relation to brigthter zero point
- N.B. age problem: Hubble value implied an age of $\sim 2 \cdot 10^9$ yrs.

Lessons from the past: Hubble's constant "middle ages"

Approaching the (second) *Great Debate* (1996)



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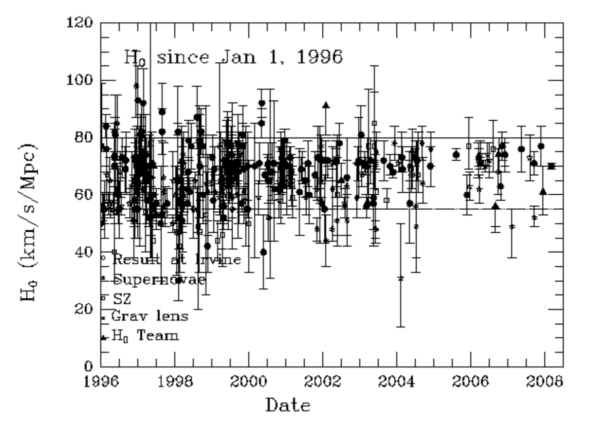
Lessons from the past: Hubble's constant "modern era"

After the 1996 debate: ladder measurements of H_0 were at odds with the favored cosmological model of the time, CDM with $\Lambda = 0$



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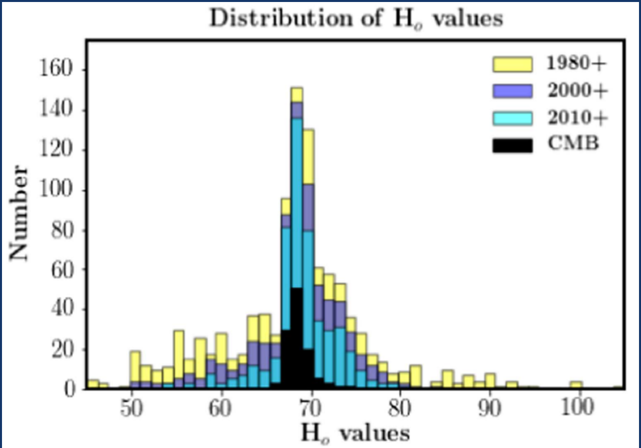
Lessons from the past: Hubble's constant "modern era"

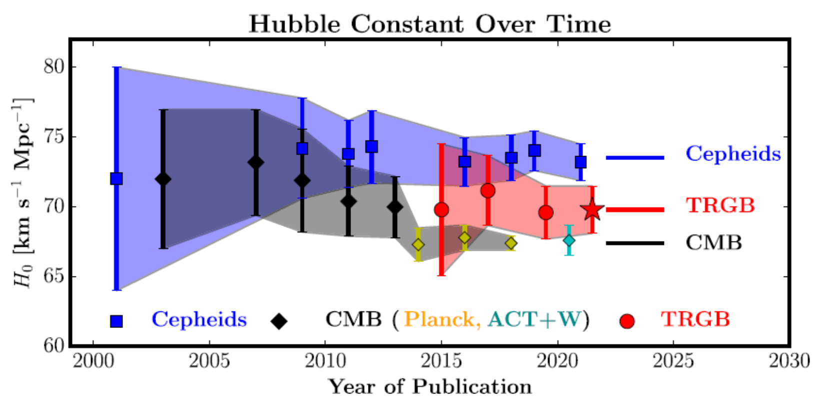
The intruder: the Cosmic Microwave Background radiation (CMB).



Freedman W. L., arXiv:2106.15656

The Hubble's constant "contemporary era"

Now: ladder measurements of H_0 are at odds with the favored cosmological model of the time, CDM with $\Lambda \neq 0$



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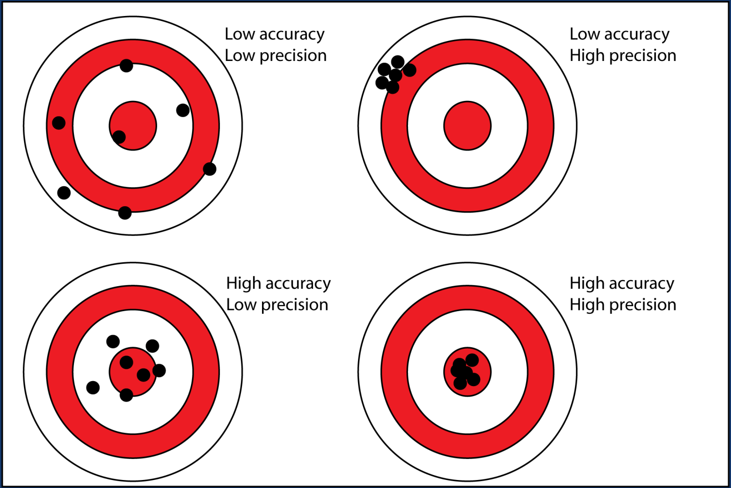
The Hubble's constant "contemporary era"

H_0 between precision and accuracy: where we are now?



Approaching the third Great Debate?

The start: the *SH0ES* Team.

A Comprehensive Measurement of the Local Value of the Hubble Constant with 1 km s^{-1} Mpc^{-1} Uncertainty from the *Hubble Space Telescope* and the SH0ES Team

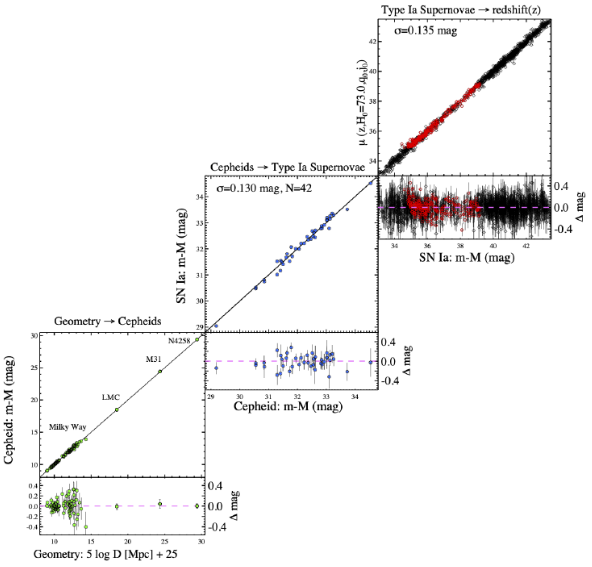
Adam G. Riess,[1,2] Wenlong Yuan,[2] Lucas M. Macri,[3] Dan Scolnic,[4] Dillon Brout,[5] Stefano Casertano,[1] David O. Jones,[6] Yukei Murakami,[2] Gagandeep S. Anand,[1] Louise Breuval,[2,7] Thomas G. Brink,[8] Alexei V. Filippenko,[8,9] Samantha Hoffmann,[1] Saurabh W. Jha,[10] W. D'arcy Kenworthy,[2] John Mackenty,[1] Benjamin E. Stahl,[8] and WeiKang Zheng[8]

JWST Observations Reject Unrecognized Crowding of Cepheid Photometry as an Explanation for the Hubble Tension at 8σ Confidence

Adam G. Riess,[1,2] Gagandeep S. Anand,[1] Wenlong Yuan,[2] Stefano Casertano,[1] Andrew Dolphin,[3] Lucas M. Macri,[4] Louise Breuval,[2] Dan Scolnic,[5] Marshall Perrin,[1] and Richard I. Anderson[6]

arXiv:2112.04510, arXiv:2401.04773

The Cosmic Distance Ladder



The Cosmic Distance Ladder: the first rung

Cepheids calibrated with anchors (non SNeIa hosts)

$$m^W_{H,i,j} = \mu_{0,i} + M^W_H + b_W\left(\log P_{i,j} - 1\right) + Z_W[O/H]_{i,j}$$

- 980 Cepheids in 4 anchors (LMC, SMC, NGC4258, M31) + MW

$$m^W_{H,LMC,j} = \mu_{0,LMC} + M^W_H + b_W\left(\log P_{LMC,j} - 1\right) + Z_W[O/H]_{LMC,j}$$

- MW: parallaxes; NGC4258: maser; LMC/SMC: eclipsing binaries;
- NGC4258: $\Delta\mu_{NGC4258}$; LMC/SMC: $\Delta\mu_{LMC}$; M31: $\mu_{0,M31}$;
- LMC data both from ground telescopes and Gaia: zp;

The Cosmic Distance Ladder: the second rung

SNeIa calibrated with Cepheids

- 37 Cepheid+SNeIa hosts: 2150 Cepheids, 42 SNeIa (77 data points)

$$m^0_{B,i,j} = \mu_{0,i} + M_B$$

$$m^0_{B,i,j} = m_{B,i,j} - \alpha\, x_{1,i,j} - \beta\, \mathcal{C}_{\rangle,|}$$

- α and β fitted a priori independently from *Pantheon+* sample
- 37 $\mu_{0,i}$;

Hubble flow SNeIa from *Pantheon+*

- 238 Hubble flow SNeIa (277 data points), $0.023 \leq z \leq 0.15$

$$\mu_{0,HF} = m^0_{B,HF} - M_B = 5\log\left(d_L/Mpc\right) + 25$$

$$d_L(z_{HF}) = (1 + z_{HF})\frac{c}{H_0}\int_0^{z_{HF}} \frac{dz'}{H(z')/H_0} = \frac{D_L(z_{HF})}{H_0}$$

- cosmography: "cosmological model independent" approach

$$\log D_L(z_{HF}) \approx \log\left[c z_{HF}\left(1 + \frac{1-q_0}{2}z_{HF} - \frac{1 - q_0 - 3q_0^2 + j_0}{6}z_{HF}^2 + \ldots\right)\right]$$

$$m^0_{B,HF} - \log D_L(z_{HF}) - 25 = M_B - 5\log\ H_0$$

- $q_0 = -0.55$ and $j_0 = 1$ values have minimal impact

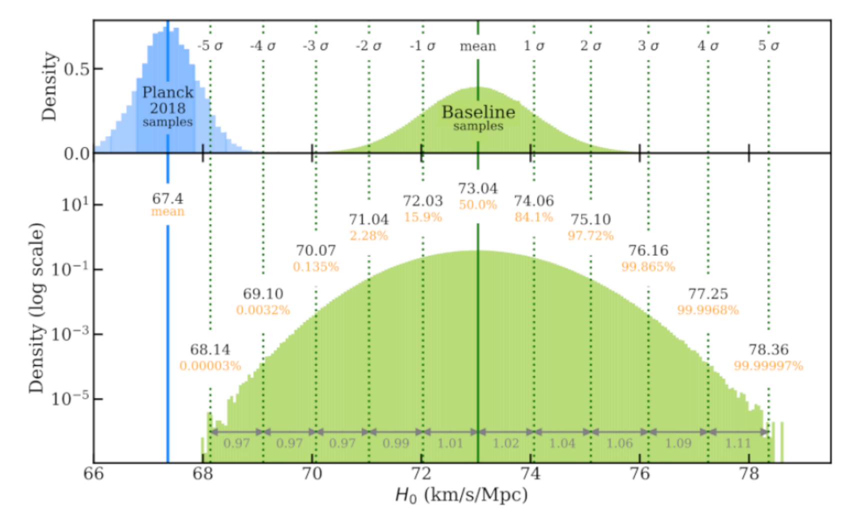
The Cosmic Distance Ladder: summary

We get H_0 from a simultaneous fit:

$$\text{Geometric Distances} + \text{Cepheids data from anchors}$$
$$\Downarrow$$
$$\text{Cepheids calibration } M_H^W \text{ and slopes } b_W, Z_W \text{ in anchors}$$
$$\Downarrow$$
$$\text{Distances } \mu_{0,i} \text{ of Cepheids+SNeIa hosts}$$
$$\Downarrow$$
$$\text{SNeIa calibration } M_B$$
$$\Downarrow$$
$$H_0 \text{ from Hubble flow SNeIa}$$

- 46 free parameters: only 1 is cosmological
- 3492×3492 covariance matrix
- $H_0 = 73.04 \pm 1.04 \; km\,s^{-1}\,Mpc^{-1}$ (1.4% error)

The Cosmic Distance Ladder: summary



SH0ES error budget

Multiple variants analysis (67): H_0 from 71.93 to 74.78;

Table 7. H_0 Error Budgets (%), terms approximated from global fit

Term	Description	Riess+ (2016)			Riess+ (2019)			This work		
		LMC	MW	4258	LMC	MW	4258	LMC	MW	4258
$\sigma_{\mu,\mathrm{anchor}}$	Anchor distance	2.1	2.1	2.6	1.2	1.5	2.6	1.2	1.0^a	1.5^b
$\sigma_{\mathrm{PL,anchor}}$	Mean of P–L in anchor	0.1	...	1.5	0.4	...	1.5	0.4	...	1.0
$R\sigma_{\lambda,1,2}$	zeropoints, anchor-to-hosts	1.4	1.4	0.0	0.1	0.7	0.0	0.1	0.1^a	0.0
σ_Z	Cepheid metallicity, anchor-hosts	0.8	0.2	0.2	0.9	0.2	0.2	0.5	0.15	0.15
	subtotal per anchor	2.6	2.5	3.0	1.5	1.7	3.0	1.4	1.0	1.8
All Anchor subtotal			1.6			1.0			0.7	
$\sigma_{\mathrm{PL}}/\sqrt{n}$	Mean of P–L in SN Ia hosts		0.4			0.4			0.4	
$\sigma_{\mathrm{SN}}/\sqrt{n}$	Mean of SN Ia calibrators (# SN)		1.3 (19)			1.3 (19)			0.9 (42-46)	
σ_{m-z}	SN Ia m–z relation		0.4			0.4			0.4	
σ_{PL}	P–L slope, $\Delta \log P$, anchor-hosts		0.6			0.3			0.3	
statistical error, $\sigma_{\mathrm{H_0}}$			2.2			1.8			1.3	
Analysis systematics[c]			0.8			0.6			0.3	
Total uncertainty on $\sigma_{\mathrm{H_0}}$ [%]			2.4			1.9			1.35	

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SH0ES error budget. Any room for improvement?

Breuval et al. 2024 (2404.08038): 88 new Cepheids + 15 DEB in SMC,

$H_0 = 73.17 \pm 0.86\ km\,s^{-1}\ Mpc^{-1}$ (1.2% error)

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SH0ES error budget. Any room for improvement?

SH0ES uses $\log(D_L$-series) !!! Proper use: μ-series; $\mu < \log D_L \Rightarrow \downarrow H_0$
Effect $\lesssim 0.01\%$, no change in H_0

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"Old" Cepheids problems: metallicity?

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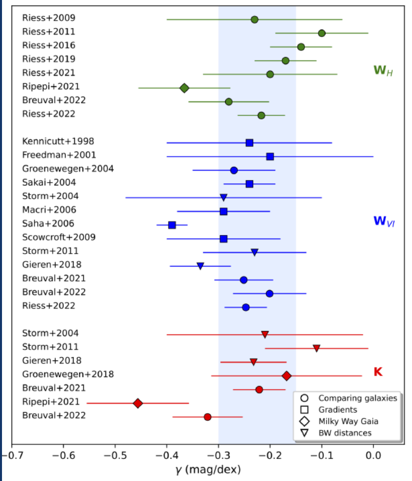
"Old" Cepheids problems: metallicity? NO: $\sim 0.5\, km\, s^{-1}\, Mpc^{-1}$ ($\uparrow$)



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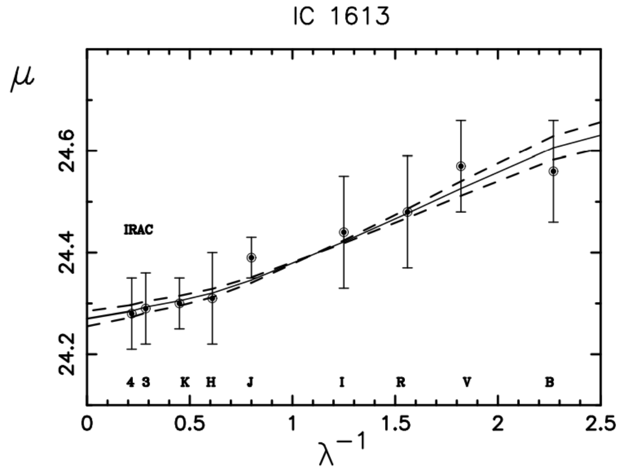
SH0ES error budget. Any room for improvement?

"Old" Cepheids problems: Dust? NO: well constrained from multi-bands



SH0ES error budget. Any room for improvement?

- One instrument for all Cepheids, HST. Good:
  - Multiple photometric systems/instruments for Cepheids, $1.4 - 1.8\%$ systematic error in distance measurements

  $\rightarrow$ SNeIa from *Pantheon+*, an homogenized sample from 18 surveys

- One instrument for all Cepheids, HST. Good?

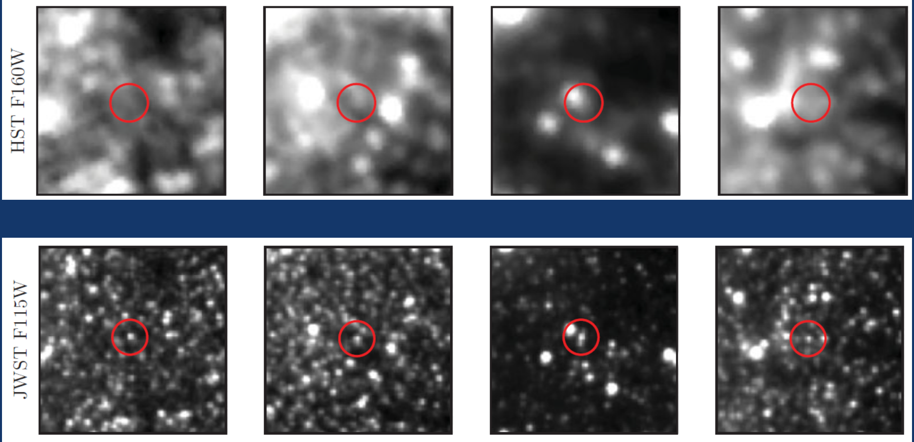
  $\rightarrow$ But what if hidden systematics?

  $\rightarrow$ Cross-check from JWST

  $\rightarrow$ Useful to solve "crowding"

SH0ES error budget. Any room for improvement?

Crowding



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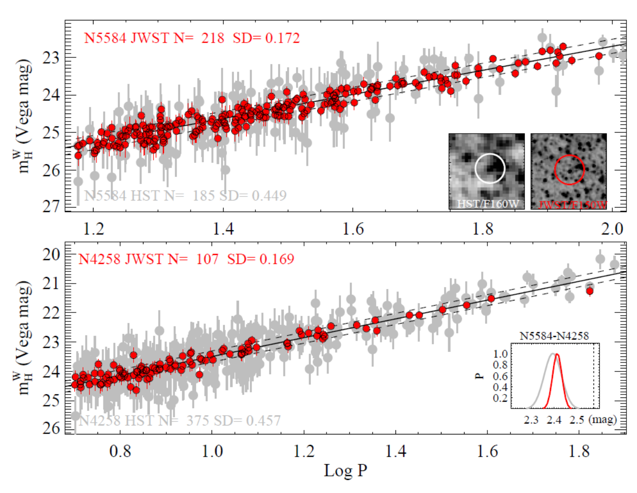

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  - ✓ Cross-check from JWST
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  - ✓ JWST = 2.5 times reduction in the dispersion of the Cepheid P–L relations;
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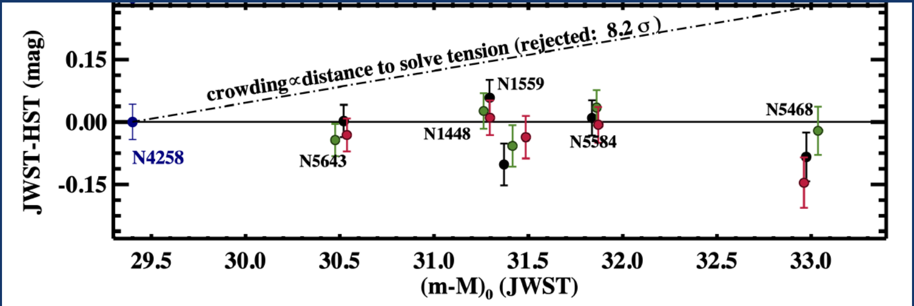
  - ✓ no significant difference in the mean distance measurements from HST and JWST
  - $\rightarrow$ NGC7250 at $20\,Mpc$, area 8 times larger than NGC4258 at $7\,Mpc$; at $40\,Mpc$, area 33 times larger. Any distance effects?

SH0ES error budget. Any room for improvement?

Model: crowding linear with distance to solve Hubble tension, i.e. on average $5\log(73/67.5) = 0.17\,mag$ or $\sim 0.07\,mag$ bias per mag of distance



SH0ES error budget. Any room for improvement?

- One instrument for all Cepheids, HST. Good:
  - Multiple photometric systems/instruments for Cepheids, $1.4 - 1.8\%$ systematic error in distance measurements
  - → SNeIa from *Pantheon+*, an homogenized sample from 18 surveys

- One instrument for all Cepheids, HST. Good?
  - → But what if hidden systematics?
  - ✓ Cross-check from JWST
  - ✓ Useful to solve "crowding"
  - ✓ JWST = 2.5 times reduction in the dispersion of the Cepheid P–L relations
  - ✓ no significant difference in the mean distance measurements from HST and JWST
  - ✓ NGC7250 at 20 Mpc, area 8 times larger than NGC4258 at 7 Mpc; at 40 Mpc, area 33 times larger. Any distance effect?
  - ✓ No, rejected at 8.2σ, more than Hubble tension itself

Approaching the third Great Debate?

The contestant: the Chicago-Carnegie Hubble Program (*CCHP*).

Status Report on the Chicago-Carnegie Hubble Program (CCHP): Three Independent Astrophysical Determinations of the Hubble Constant Using the James Webb Space Telescope

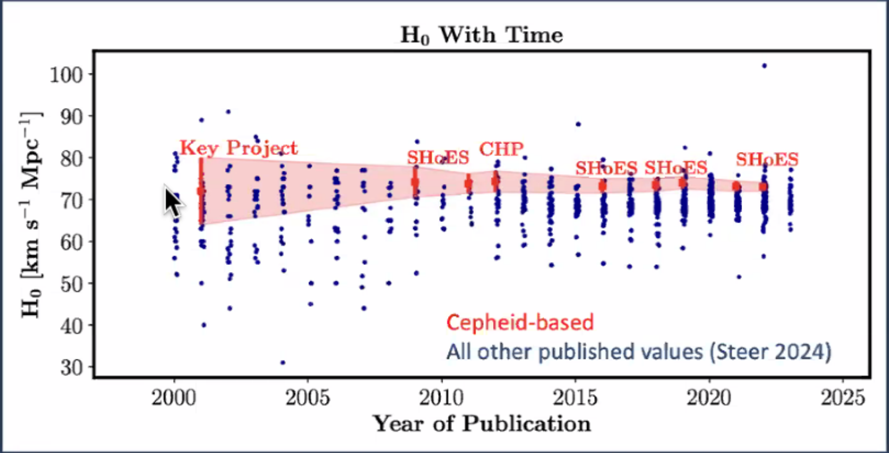
*

Wendy L. Freedman,[1] Barry F. Madore,[2] In Sung Jang,[3,4] Taylor J. Hoyt,[5] Abigail J. Lee,[3,4,†] and Kayla A. Owens[3,4]

arXiv:2408.06153

A different strategy: hosts with multiple independent calibrators

What if there is a Cepheid-bias?

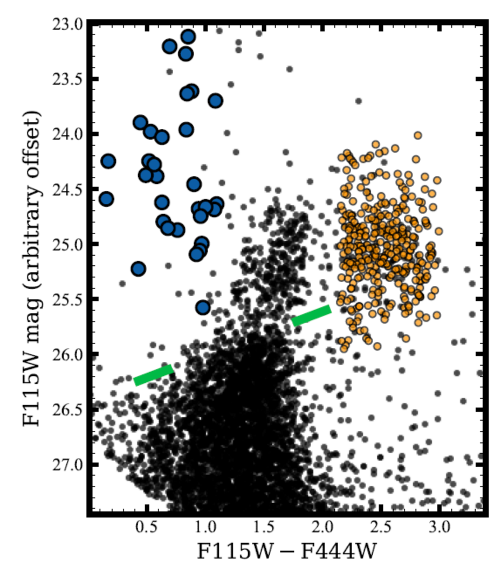


A different strategy: hosts with multiple independent calibrators

CCHP:

- 10 galaxies + $NGC4258$ (anchor), $D \lesssim 23\,Mpc$
- 3 independent methods
  - Cepheids
  - Tip of the Red Giant Branch (TRGB)
  - Carbon-rich Asymptotic Giant Branch stars in the J band (JAGB)
- same 2 instruments for everything (new *JWST* + archival *HST*)
- comparing with *SH0ES* data
- blinding procedure: *"during the entire year and a half of the photometric analysis, no one in the group had any knowledge of what the true distances or the value of H_0 might be."* (cit.)

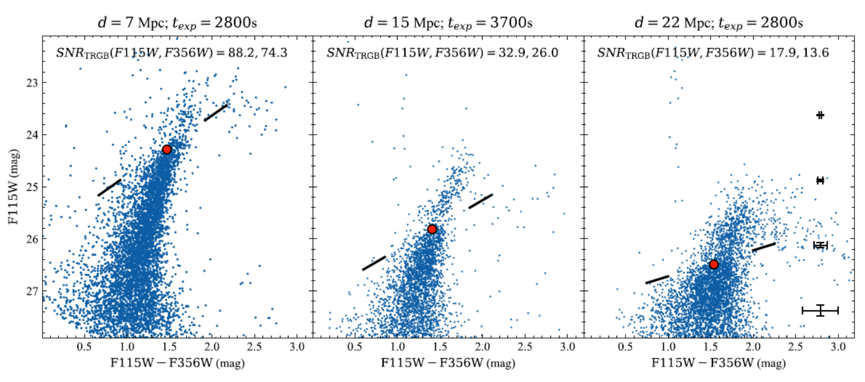
A different strategy: hosts with multiple independent calibrators



A different strategy: hosts with multiple independent calibrators

TRGB:

- Well-based physics: luminosity of $M_{core}^{He} \sim 0.47\, M_{\odot}$ with $T \approx 10^8\, K$



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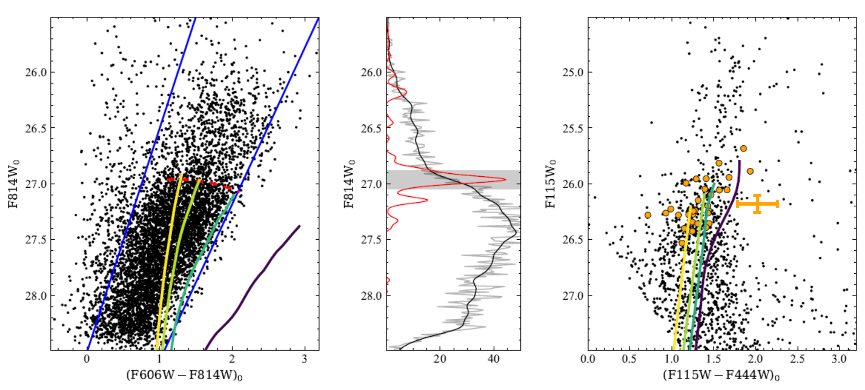

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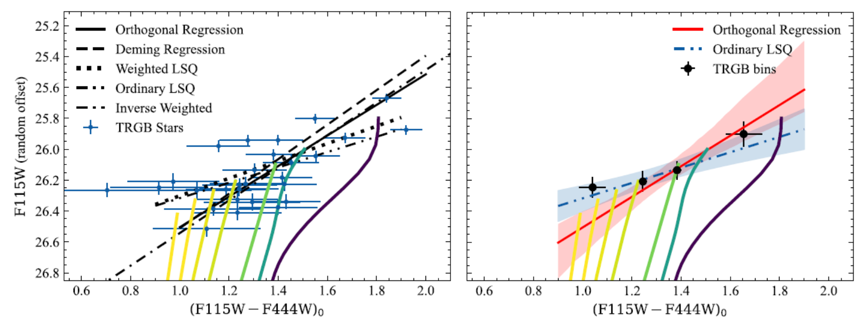

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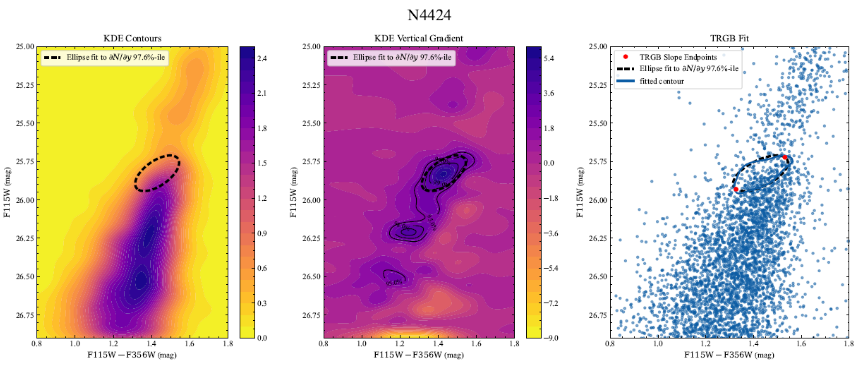

A different strategy: hosts with multiple independent calibrators

TRGB:

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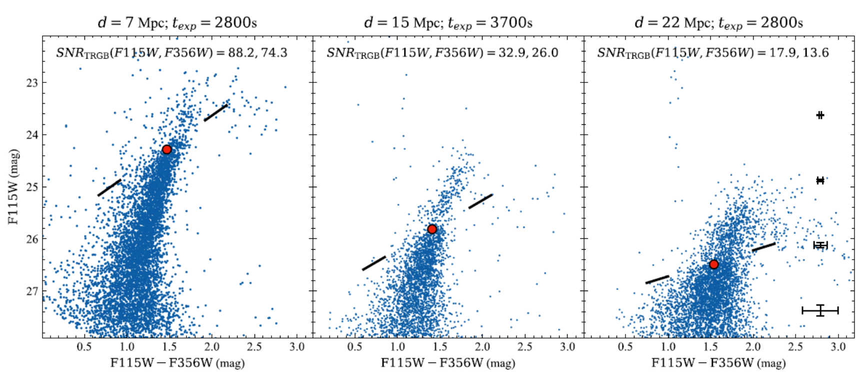
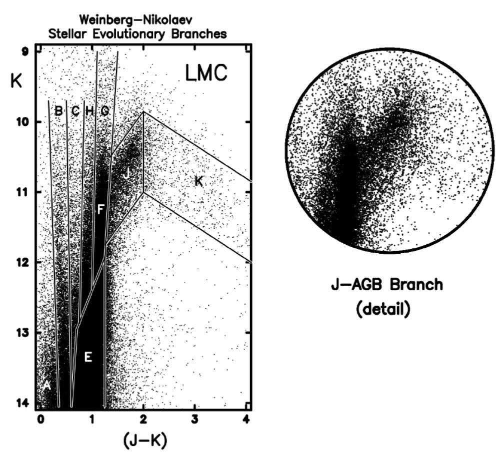


A different strategy: hosts with multiple independent calibrators

JAGB $\equiv$ constant luminosities:

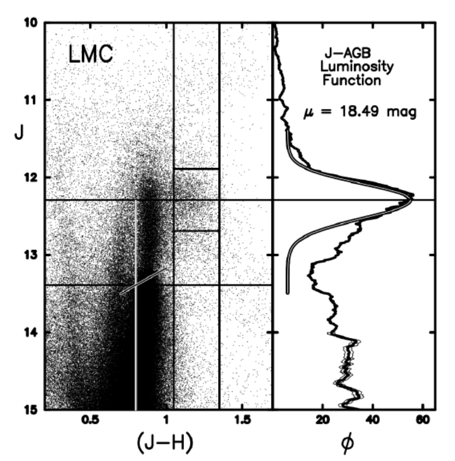
- LMC: JAGB+DEB



A different strategy: hosts with multiple independent calibrators

JAGB $\equiv$ constant luminosities:

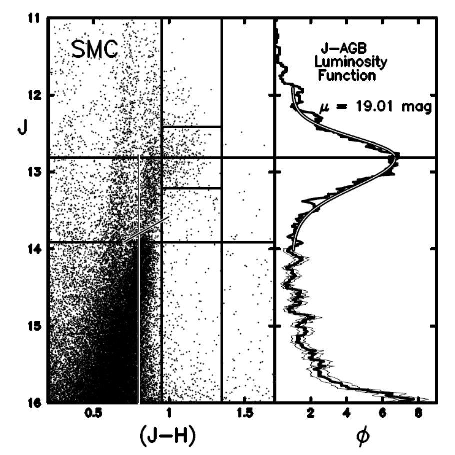
- LMC: JAGB+DEB



A different strategy: hosts with multiple independent calibrators

JAGB $\equiv$ constant luminosities:

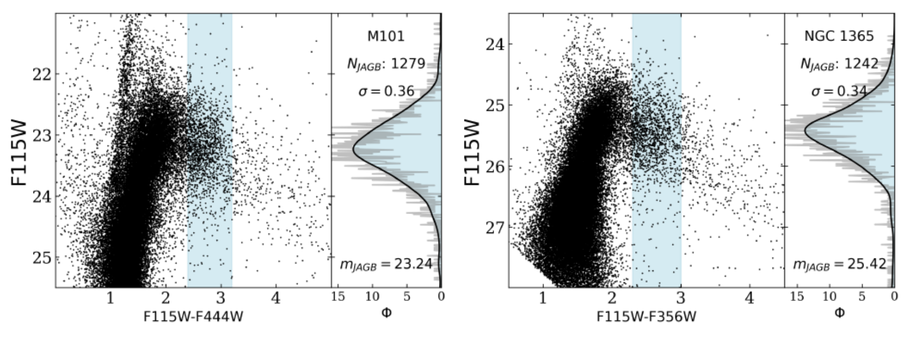
- LMC: JAGB+DEB; SMC: JAGB+DEB



A different strategy: hosts with multiple independent calibrators

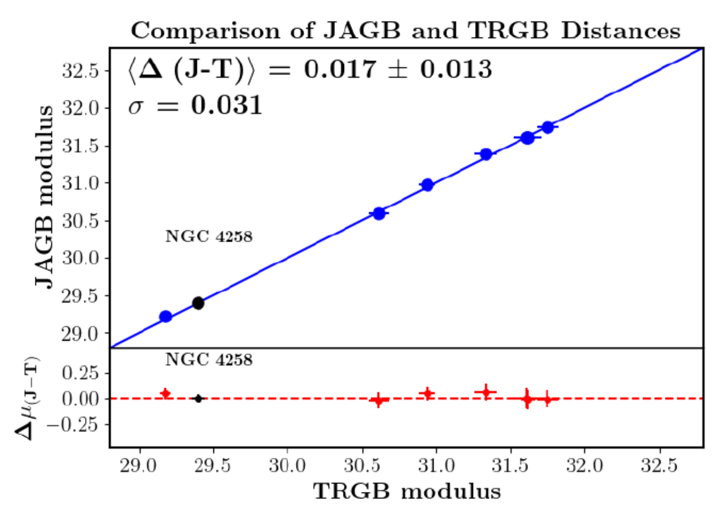
JAGB $\equiv$ constant luminosities:

- LMC: JAGB+DEB; SMC: JAGB+DEB; and more...



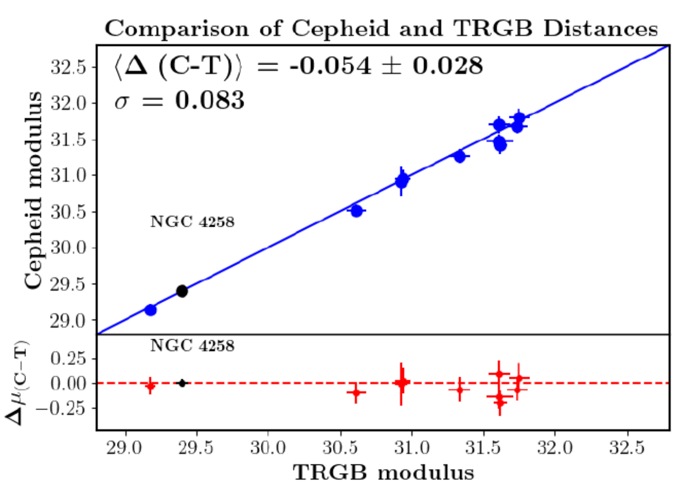
A different strategy: hosts with multiple independent calibrators

Results of CCHP project: comparing distances



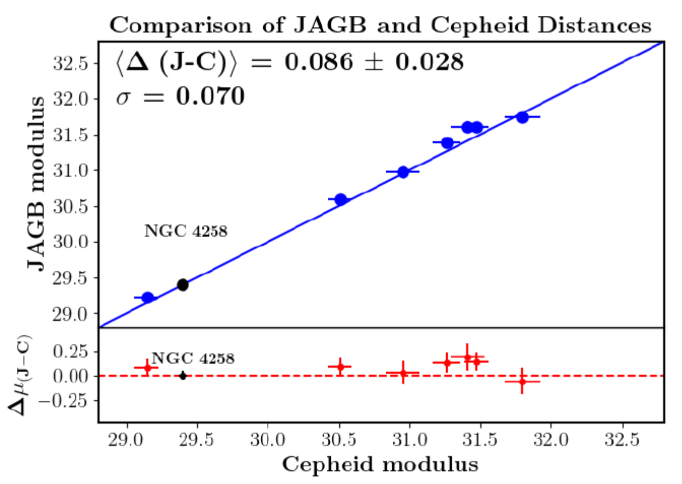
A different strategy: hosts with multiple independent calibrators

Results of CCHP project: comparing distances



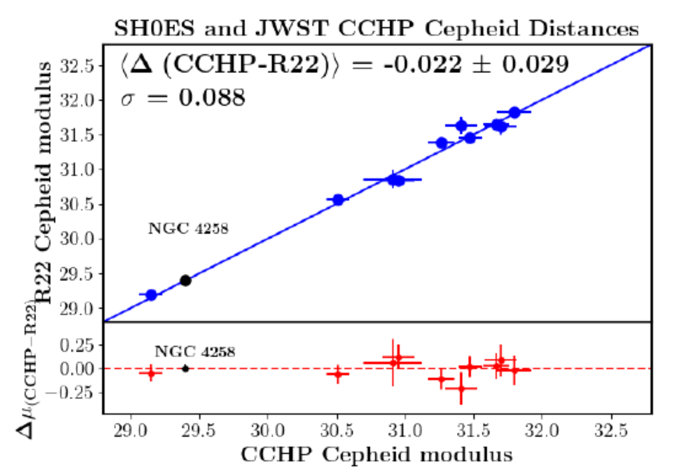
A different strategy: hosts with multiple independent calibrators

Results of CCHP project: comparing distances



A different strategy: hosts with multiple independent calibrators

Results of CCHP project: comparing distances



A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*:

- 3 independent distances, 10 hosts vs. 1 distance, 37 hosts
  - not free parameters vs. free parameters (?)
- 11 calibrating SNeIa (JWST) vs. 42 (HST)
- 287 SNeIa at $z > 0.01$ vs. 277 SNeIa at $z > 0.023$
- CSP homogenized in the run vs. *Pantheon+* a posteriori
- 9 parameters (1 cosmological) vs. 46 (1 cosmological)

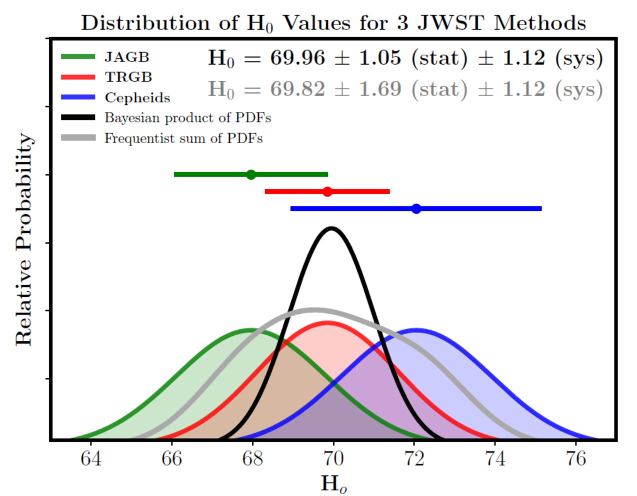
Table 3. pymc MCMC Parameter Output

Parameter	TRGB	JAGB	Cepheids
P^0 (mag)	-19.20 ± 0.05	-19.26 ± 0.05	-19.13 ± 0.05
P^1 (mag)	-0.90 ± 0.10	-0.90 ± 0.10	-0.90 ± 0.10
P^2 (mag)	-0.28 ± 0.29	-0.29 ± 0.29	-0.29 ± 0.28
β	2.91 ± 0.09	2.92 ± 0.09	2.92 ± 0.09
α (mag/dex)	0.00 ± 0.01	0.00 ± 0.01	0.00 ± 0.01
$\sigma_{\rm cal}$ (mag)	0.14 ± 0.05	0.11 ± 0.05	0.12 ± 0.06
$\sigma_{\rm int}$ (mag)	0.19 ± 0.01	0.19 ± 0.01	0.19 ± 0.01
$V_{\rm pec}$ (km s^{-1})	174 ± 99	175 ± 99	175 ± 99
H_0	69.85 ± 1.75	67.96 ± 1.57^a	72.05 ± 1.86

A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*:

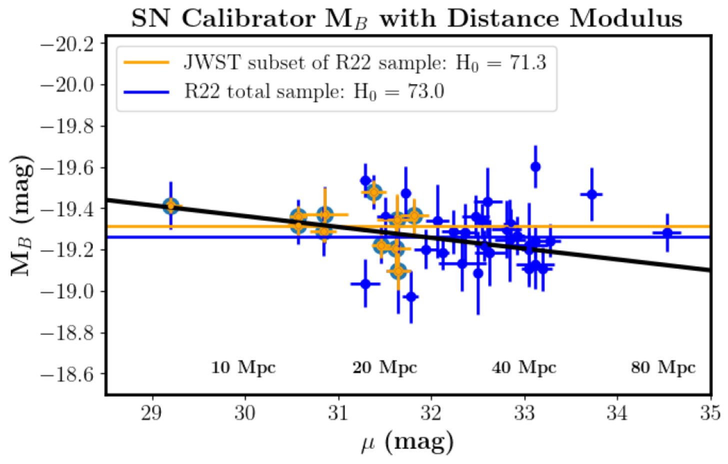
- JAGB: 67.96 ± 1.57, TRGB: 69.85 ± 1.75, Cepheids: 72.05 ± 1.86



A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*: does *SH0ES* have problems?

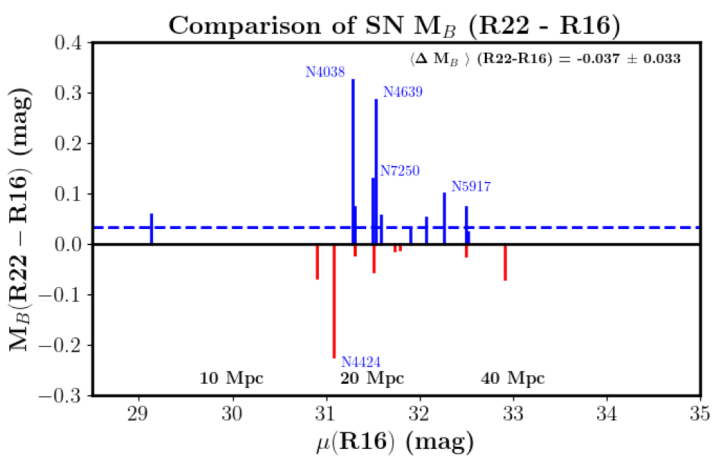
- SNeIa calibration M_B. Small sample? Poorer resolution?



A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*: does *SH0ES* have problems?

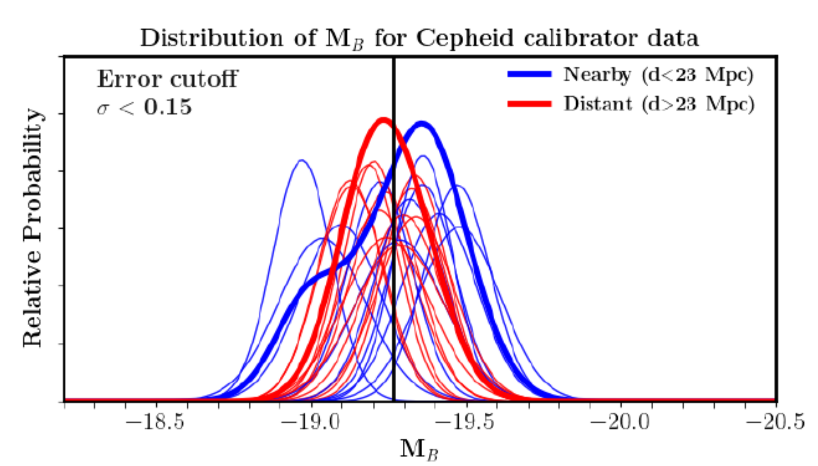
- Variations in M_B due to reanalysis: $M_B \downarrow -0.037 \Rightarrow H_0 \downarrow 1.7\%$



A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*: does *SH0ES* have problems?

- SNeIa calibration M_B: bimodality, nearby vs. distant?



A different strategy: hosts with multiple independent calibrators

Results of CCHP project + CSP vs. *SH0ES*: does *SH0ES* have problems?

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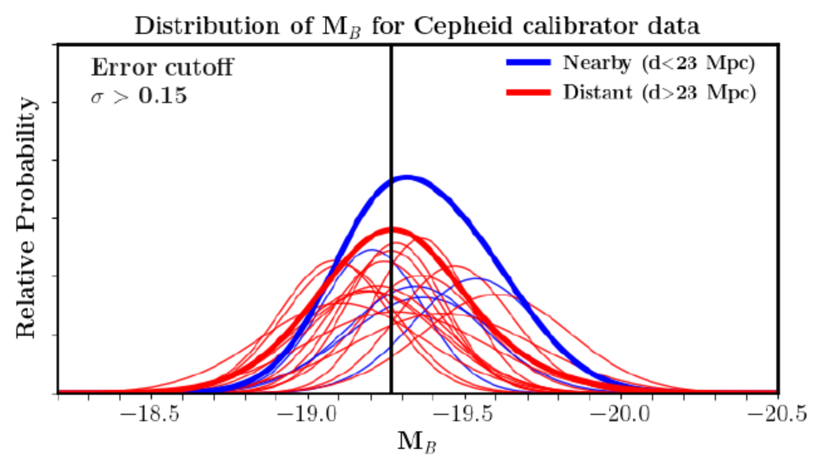


Approaching the third Great Debate?

The counterattack from *SH0ES*.

***JWST* Validates *HST* Distance Measurements:**
Selection of Supernova Subsample Explains Differences in *JWST* Estimates of Local H_0

Adam G. Riess,[1,2] Dan Scolnic,[3] Gagandeep S. Anand,[1] Louise Breuval,[2] Stefano Casertano,[1] Lucas M. Macri,[4] Siyang Li,[2] Wenlong Yuan,[2] Caroline D. Huang,[5] Saurabh Jha,[6] Yukei S. Murakami,[2] Rachael Beaton,[1] Dillon Brout,[7] Tianrui Wu,[3] Graeme E. Addison,[2] Charles Bennett,[2] Richard I. Anderson,[8] Alexei V. Filippenko,[9] and Anthony Carr[10,11]

arXiv:2408.11770

Have we really found the possible culprit(s)?

Reply of *SH0ES*:

- full HST Cepheid *SH0ES* sample, 42 SNe Ia in 37 hosts, 4 different anchors $\equiv$ ideal reference for all other samples
- *SH0ES*:
  1. JWST more precise but fewer statistics than HST
  2. JWST: hosts (5) by numbers of Cepheids and SNeIa (8) per host
  3. +HST: $D \leq 80\ Mpc$
  4. 1 anchor, NGC4258 (re-analysis)
- CCHP:
  1. just a sub-sample of HST *SH0ES*
  2. JWST: hosts (10) with SNeIa (11) to measure Cepheids, TRGB and JAGB
  3. $D \leq 25\ Mpc$
  4. 1 anchor, NGC4258

Have we really found the possible culprit(s)?

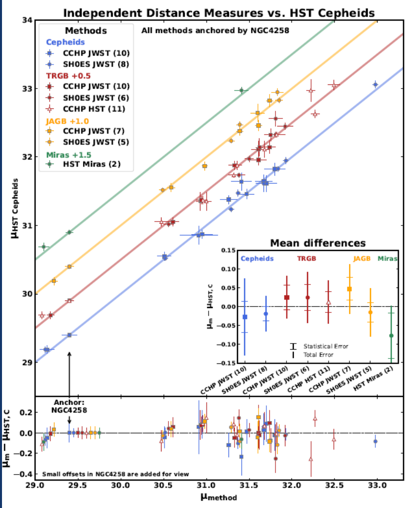
Perfect agreement (in the distances)

	HST Cepheids		JWST Cepheids				JWST TRGB				HST TRGB		JWST JAGB				Miras	
Host	R22	err	CCHP	err	SH0ES	err	CCHP	err	SH0ES	err	F21	err	CCHP	err	SH0ES	err	H24	err
N4258	29.4	0.025	29.4	0.087	29.4	0.03	29.4	0.035	29.4	0.05	29.4	0.04	29.4	0.05	29.4	0.05	29.4	0.04
M101	29.188	0.055	29.14	0.08	29.12	0.03	29.18	0.04	-	-	29.08	0.04	29.22	0.04	-	-	29.1	0.06
N1309	32.552	0.069	-	-	-	-	-	-	-	-	32.49	0.07[b]	-	-	-	-	-	-
N1365	31.378	0.061	31.26	0.1	-	-	31.33	0.07	-	-	31.36	0.05	31.39	0.04	-	-	-	-
N1448	31.298*	0.051	-	-	31.289	0.03	-	-	31.38	0.07	31.32	0.06	-	-	31.29	0.04	-	-
N1559	31.500*	0.071	-	-	31.371	0.03	-	-	31.5	0.05	-	-	-	-	31.39	0.04	31.41	0.08
N2442	31.459	0.073	31.47	0.09	-	-	31.61	0.09	-	-	-	-	31.61	0.04	-	-	-	-
N2525	32.059	0.11	-	-	-	-	-	-	31.81	0.08	-	-	-	-	-	-	-	-
N3021	32.473	0.162	-	-	-	-	-	-	-	-	32.22[b]	0.05	-	-	-	-	-	-
N3370	32.130	0.06	-	-	-	-	-	-	-	-	32.27[b]	0.05	-	-	-	-	-	-
N3447	31.947	0.05	-	-	31.95	0.03	-	-	31.92	0.09	-	-	-	-	31.85	0.07	-	-
N3972	31.644	0.096	31.67	0.1	-	-	31.74	0.07	-	-	-	-	-	-	-	-	-	-
N4038	31.612	0.121	31.7	0.12	31.67	0.035	31.61	0.08	-	-	31.68	0.05	-	-	-	-	-	-
N4424	30.854	0.133	30.91	0.22	-	-	30.93	0.05	-	-	31.0	0.06	-	-	-	-	-	-
N4536	30.870	0.061	30.95	0.12	-	-	30.94	0.06	-	-	30.96	0.05	30.98	0.03	-	-	-	-
N4639	31.823	0.091	31.8	0.12	-	-	31.75	0.07	-	-	-	-	31.74	0.04	-	-	-	-
N5468	33.127*	0.082	-	-	32.975	0.03	-	-	-	-	-	-	-	-	-	-	-	-
N5584	31.766*	0.062	-	-	31.838	0.03	-	-	31.81[b]	0.09	31.82	0.1	-	-	31.85	0.04	-	-
N5643	30.553*	0.063	30.51	0.08	30.52	0.03	30.61	0.07	30.56	0.06	30.475	0.08	30.59	0.04	30.49	0.04	-	-
N7250	31.642	0.13	31.41	0.12	-	-	31.62	0.04	-	-	-	-	31.6	0.08	-	-	-	-

*R24 Table 3 refit R22 *HST* Cepheids to a common P–L slope with *JWST* at the same wavelength to negate common error. These *HST* distance-modulus values (mag) improve the Cepheid comparison with *JWST* and are N5643, 30.518 ± 0.033; N5584, 31.828 ± 0.037; N1559, 31.473 ± 0.045; N1448, 31.236 ± 0.034; N5468, 33.058 ± 0.052. [a]N2525 qualifies for the $D < 25$ Mpc TRGB sample based on its distance. The uncertainties for the CCHP JWST measures in NGC 4258 were derived from table 5 in F24 after removing the 1.5% geometric distance uncertainty. [b] The HST TRGB distances given in F21 for NGC 1309, 3021, 3370, and 5584, all at the far end of the measurable range, are contentious as Anand et al. (2022) have reanalyzed them and could not detect the TRGB. We include them here to keep the F21 sample complete.

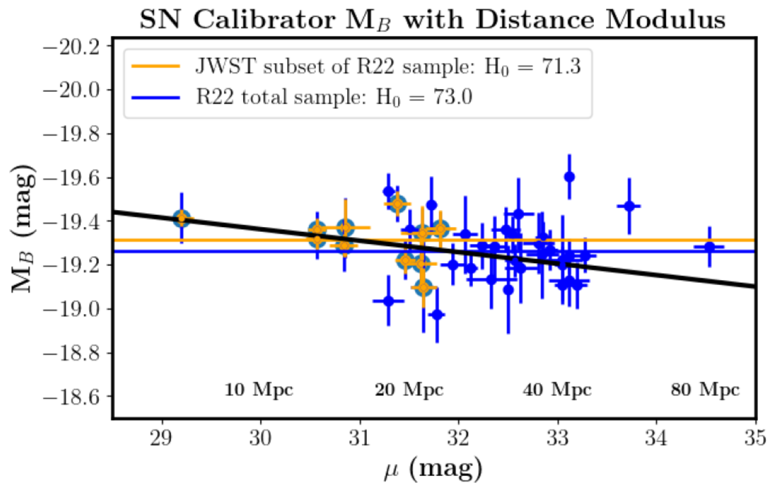
Have we really found the possible culprit(s)?

No systematic difference (in the distances)



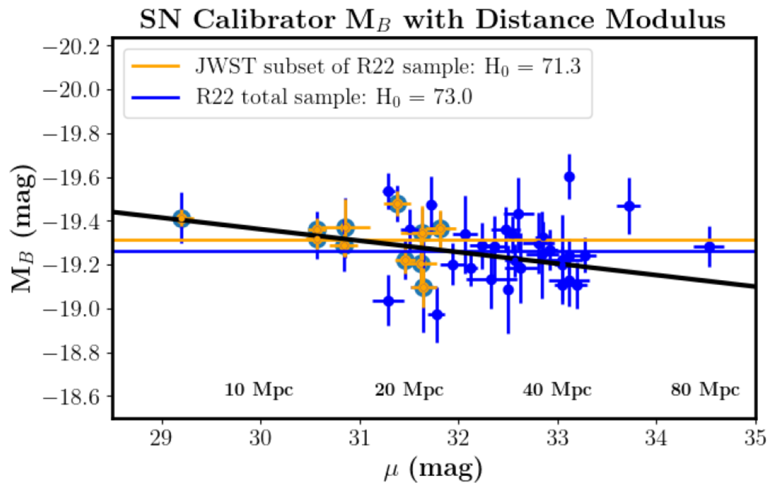
Have we really found the possible culprit(s)?

Non linearity (of Cepheid distances found from CCHP)?



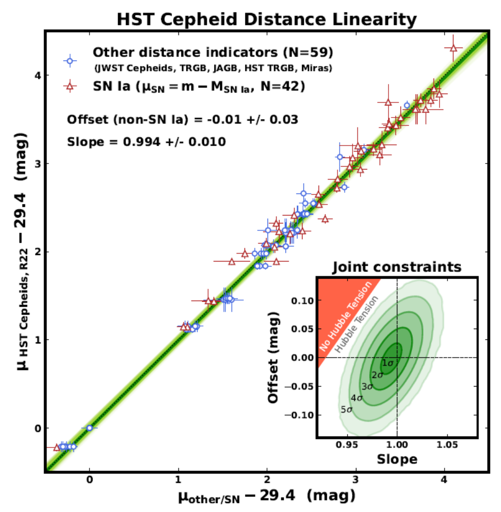
Have we really found the possible culprit(s)?

Non linearity? Nope?! Because $M_B = m_B - \mu$ (??)



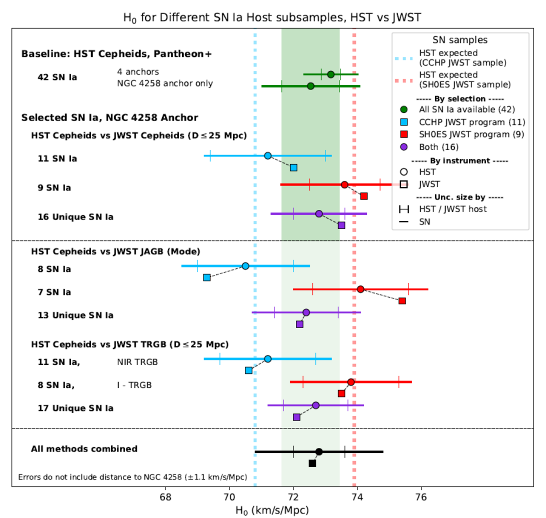
Have we really found the possible culprit(s)?

Non linearity? Independent axis: linearity $\neq$ Hubble tension at 7σ



Have we really found the possible culprit(s)?

Subsample bias (*SH0ES* still using *Pantheon+* SNeIa)



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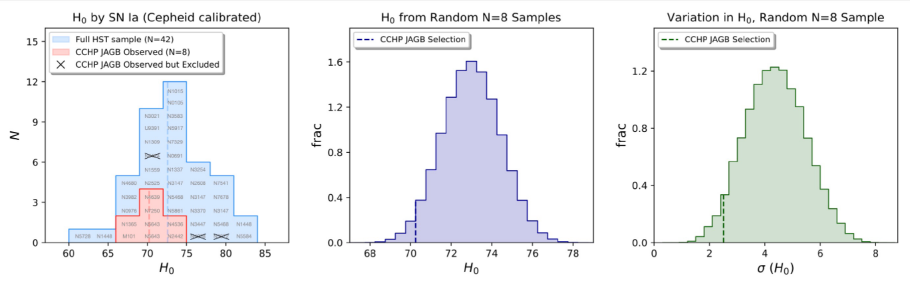

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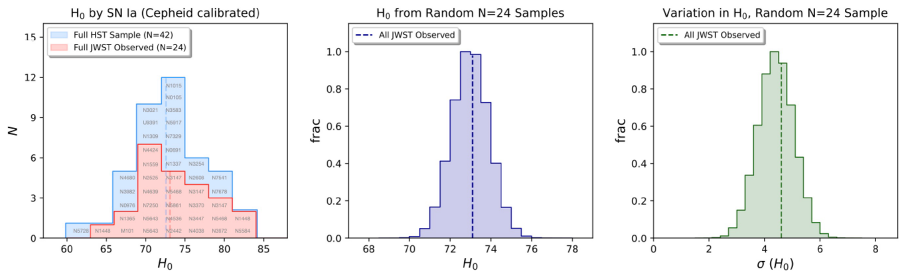
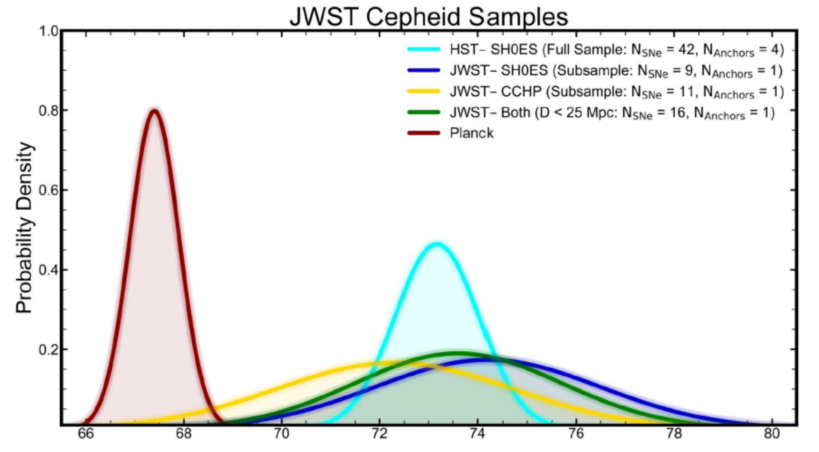
Subsample bias (*SH0ES* still using *Pantheon+* SNeIa)



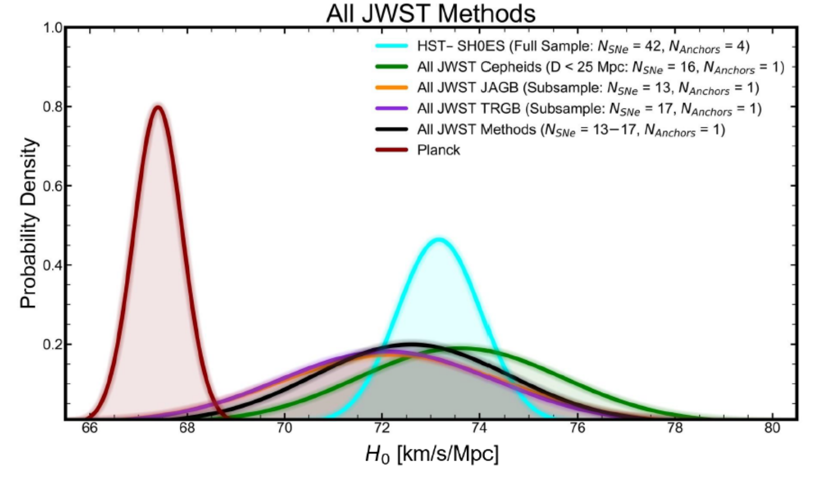
Have we really found the possible culprit(s)?

End? (for now)



Have we really found the possible culprit(s)?

End? For now: $H_0 = 72.6 \pm 2.0\, km\, s^{-1}\, Mpc^{-1}$



Where we are? Where are we going?

arXiv:2407.18292, arXiv:2408.04530, arXiv:2408.11031

Are we shifting from current "convention"...

... moving beyond early vs. late times H_0?...

- Distance Ladder-based sample: $H_0 = 72.8 \pm 0.5\, km\, s^{-1}\, Mpc^{-1}$
- Independent (NO CMB) sample: $H_0 = 69.0 \pm 0.5\, km\, s^{-1}\, Mpc^{-1}$

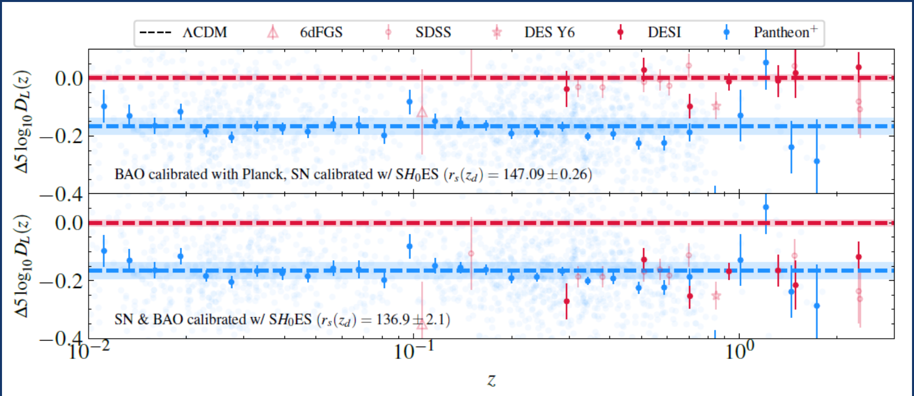
> suggesting that the two samples are fundamentally distinct, with a probability of less than 0.01% that they are drawn from the same underlying distribution. These findings suggest that the core of the Hubble tension lies not between early and late-time measurements, but between distance ladder measurements and all other H_0 determinations. This discrepancy points to either a systematic effect influencing all distance ladder measurements or a fundamental physics anomaly affecting at least one rung of the distance ladder.

But introducing:

- unknown unknowns
- new physics of calibrators (mostly astrophysics?)
- subtly but deeply questioning *SH0ES*?!

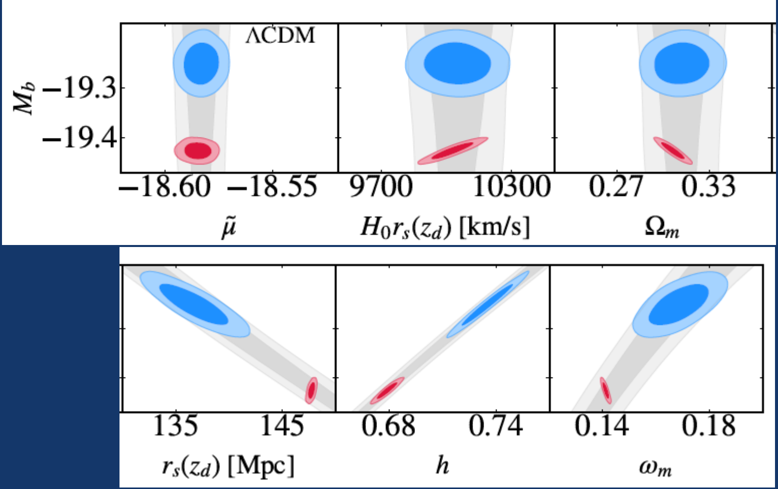
Are we shifting far from current "convention"...

... or just rebranding the problem as a "Cosmic calibration tension"...



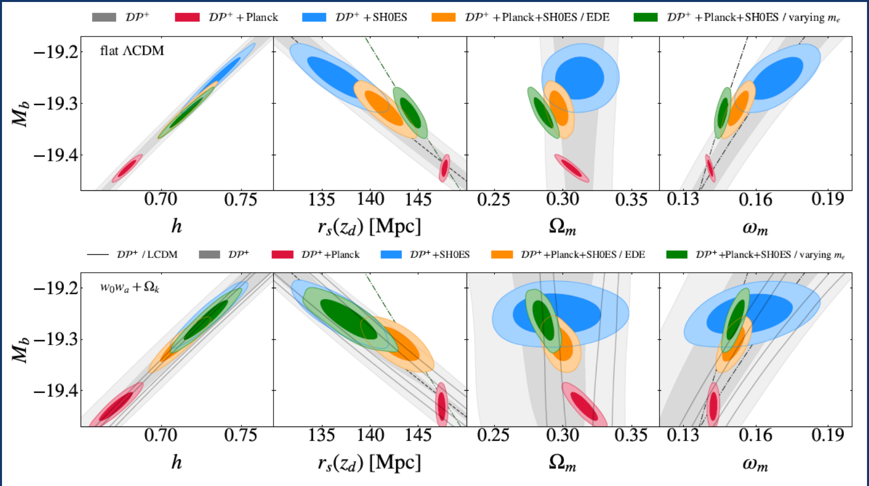
Are we shifting far from current "convention"?

. . . because of multi-dimensional cosmological degeneracies. . .



Are we shifting far from current "convention"?

... which neither only-late nor only-early times models can accommodate?



Are we shifting far from current "convention"?

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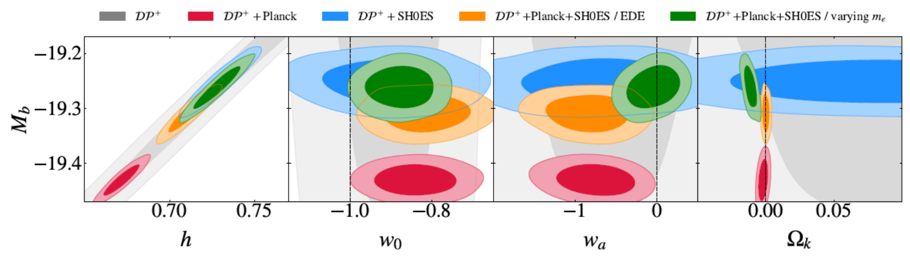
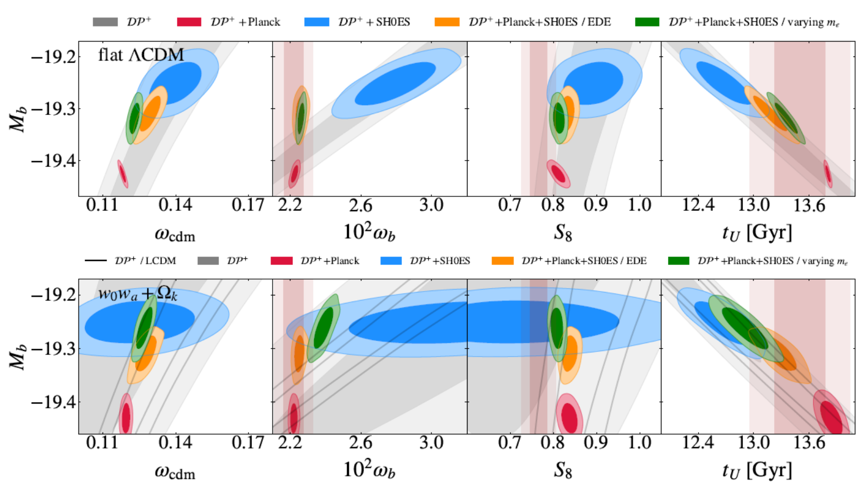


Are we shifting far from current “convention”?

... which neither only-late nor only-early times models can accommodate?



Final remarks

Bahcall J. N., 1996, PASP 108, 1097

The biggest surprise for me in listening to the debate was to learn about the great amount of precision data regarding ordinary stars, supernovae, galaxies, and galaxy clusters that is being obtained in order to determine H_0. These data are providing new discoveries and deep insights into many astrophysical problems. It is almost worth having a big controversy just to stimulate the enormous research activity that is motivated by a desire to measure the Hubble constant. On the long term, it could turn out that the incidental results obtained from the Hubble-constant controversy are even more important than the precise value of H_0.

Final remarks

Bahcall J. N., 1996, PASP 108, 1097

There was, in the actual discussion, much less disagreement than I had anticipated. The two preferred values for H_0 almost overlap when systematic uncertainties are added to the statistical uncertainties. After much careful work and critical evaluation, we no longer have a disagreement by a factor of two. This is great progress!

Final remarks

Bahcall J. N., 1996, PASP 108, 1097

I was, however, struck by the lack of a clear path to a final consensus. I had hoped that the participants in the debate would agree on some measurement, or set of measurements, the results of which would be decisive. Instead, there were, as is perhaps appropriate for a debate, a number of arguments given to show that the evidence presented by the other side was biased or not sufficient for the conclusions being

Final remarks

Bahcall J. N., 1996, PASP 108, 1097

I did not succeed in getting agreement about what needs to be done to determine, with widespread consensus, a more accurate value of H_0. In my eyes, I therefore failed in my primary goal as a moderator. Moreover, I did not hear discussed a particular measurement, or set of measurements, the results of which would be so persuasive that everyone would say: "That is so simple and clear, it must give the correct value of H_0." I therefore had to struggle to prevent myself from asking what I am sure everyone present would have regarded as a silly question, namely: Is the value of H_0 that is being debated operationally well defined?

Personal announcement

2 Postdoctoral positions in Cosmology and Computational Science

Szczecin U., Warsaw, Inst. Fund. Tech. Res. • Europe

astro-ph nlin physics cs PostDoc

Deadline on Oct 31, 2024

Job description:
The Szczecin Cosmology Group at the Institute of Physics of the University of Szczecin (http://cosmo.usz.edu.pl) and the Division of Intelligent Systems at the Department of Intelligent Technologies (https://www.ippt.pan.pl/en/research-units/zti#division-of-intelligent-systems) of the Institute of Fundamental Technological Research of the Polish Academy of Sciences (IPPT-PAN) in Warsaw, invite applications for 2 Postdoctoral positions.

The positions are available through the OPUS 26 grant of the Polish National Science Center (NCN) led by prof. Vincenzo Salzano, at the University of Szczecin, as P.I., and entitled *"Can a slime mold help us alleviate cosmological tensions?"*. Co-P.I. will be prof. Tomasz Denkiewicz, at the University of Szcecin, and dr. Jacek Szklarski at IPPT-PAN.

https://inspirehep.net/jobs/2804674

DZIĘKUJĘ BARDZO!


I STICK TO
MY OPINION
PLEASE DO NOT
CONFUSE ME WITH
FACTS