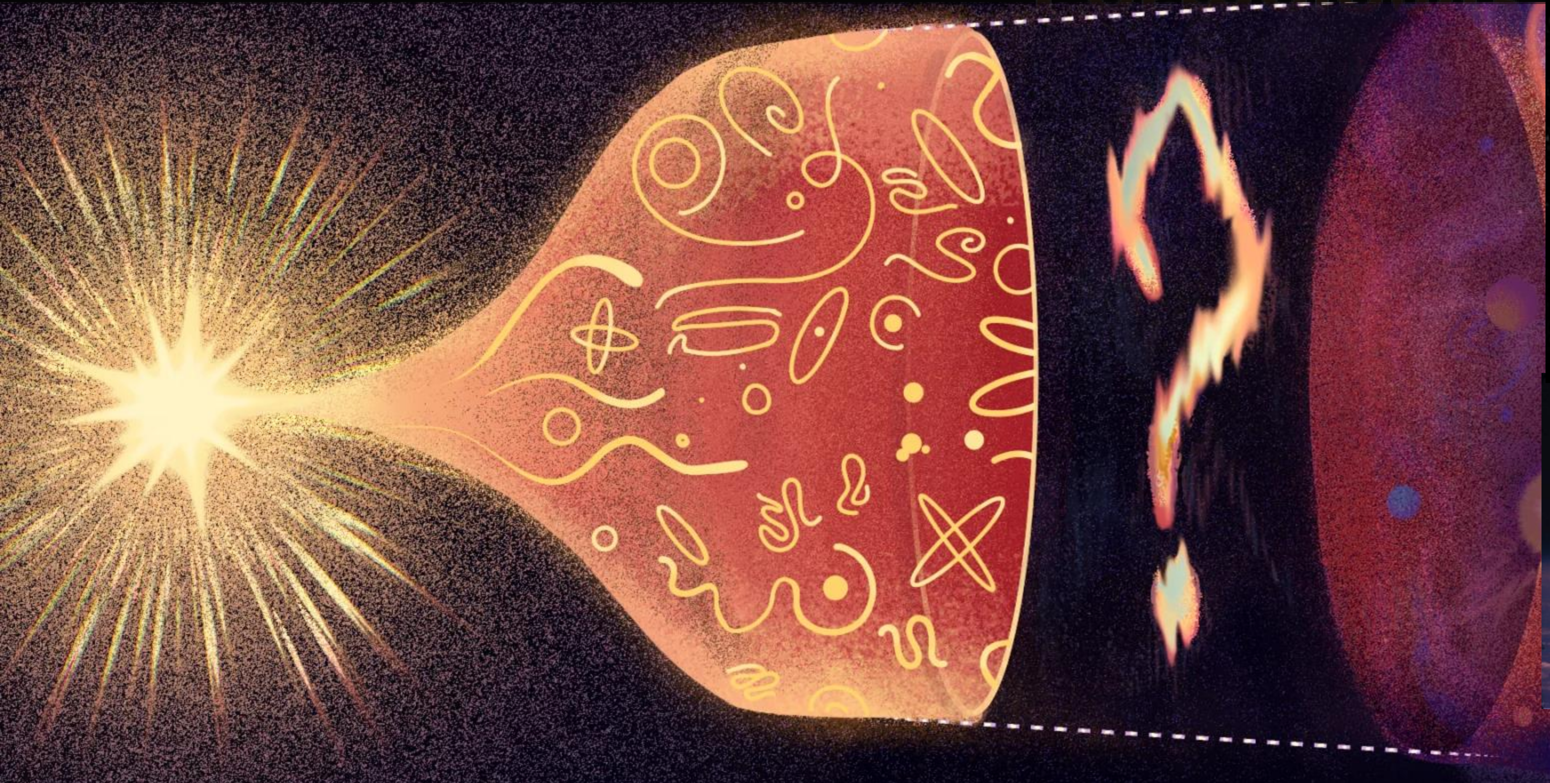
Status Report on the Chicago-Carnegie Hubble Program: Is There Missing Physics from the Standard Model of Cosmology?

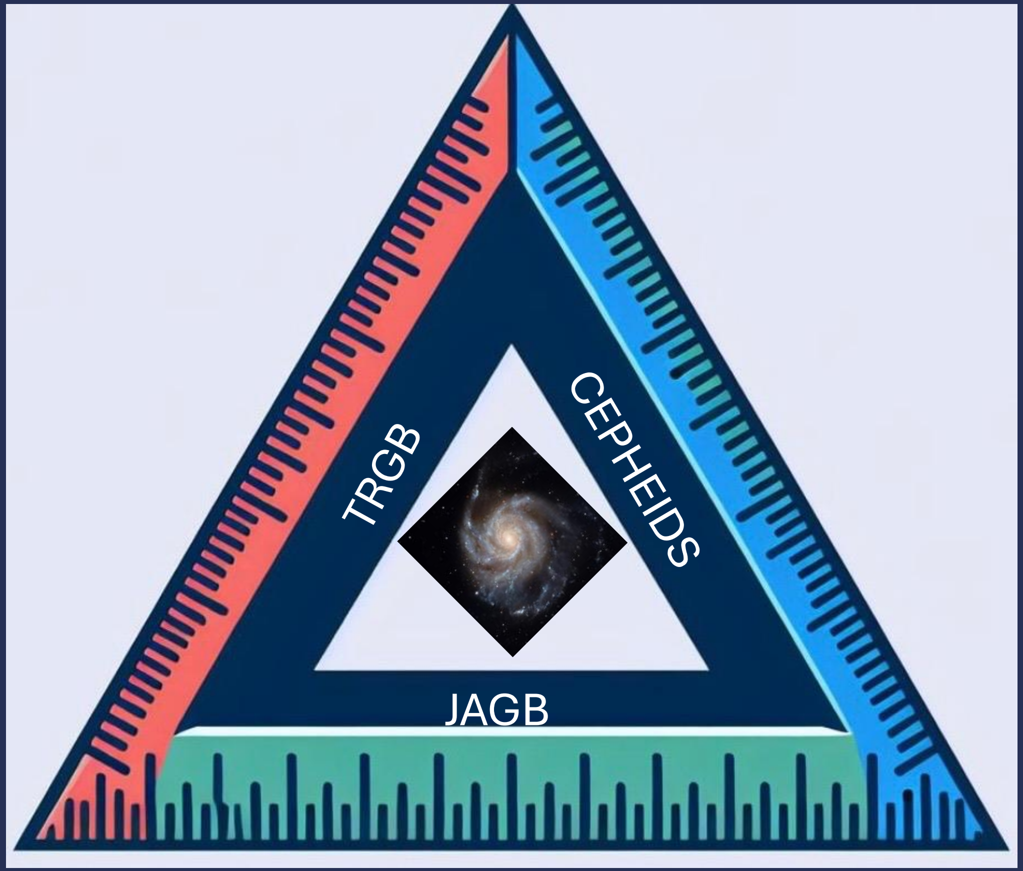


Wendy L. Freedman
University of Chicago

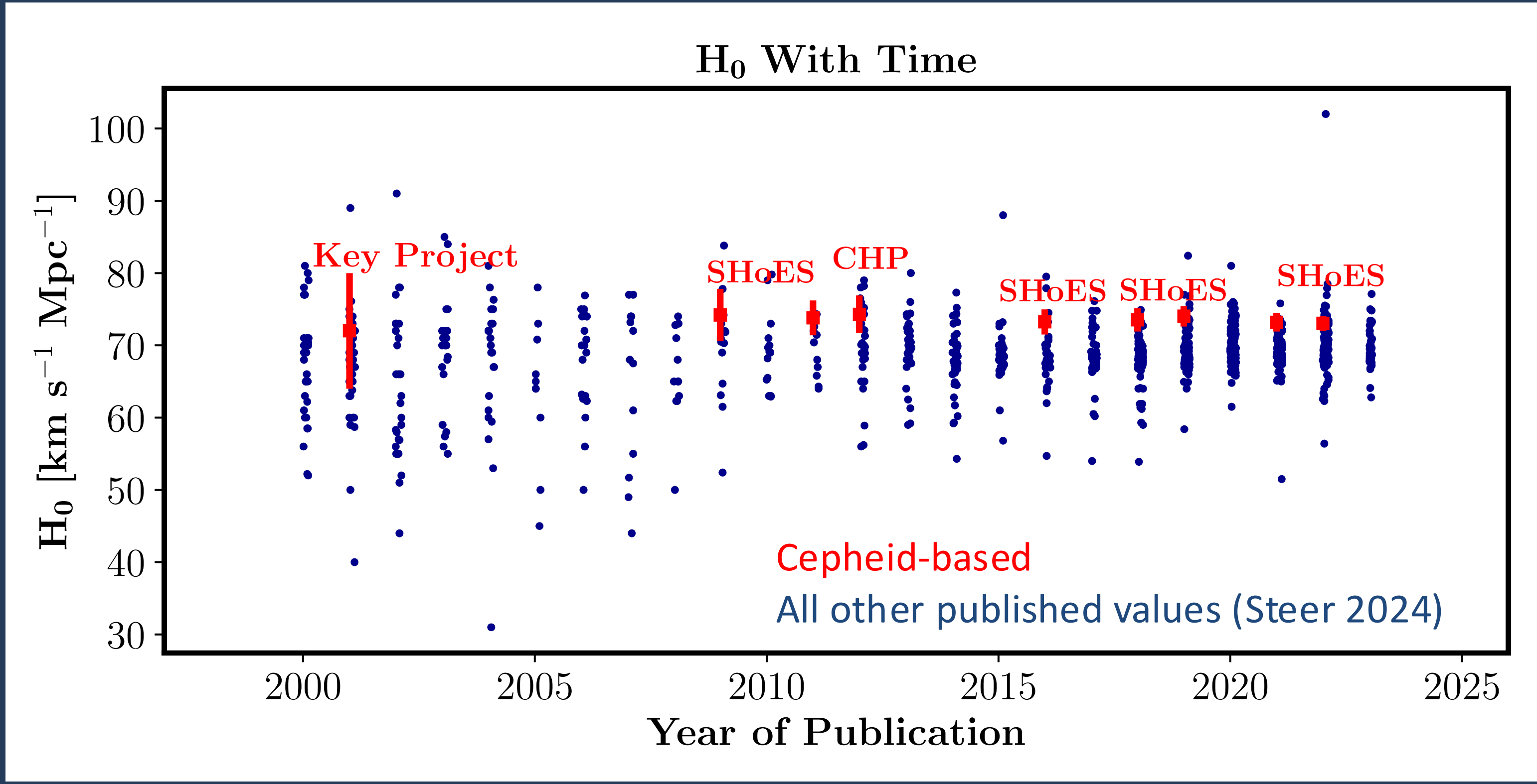
May 29, 2025
CMB@60
Accademia delle Scienze di Torino

Adapted from
Quanta magazine

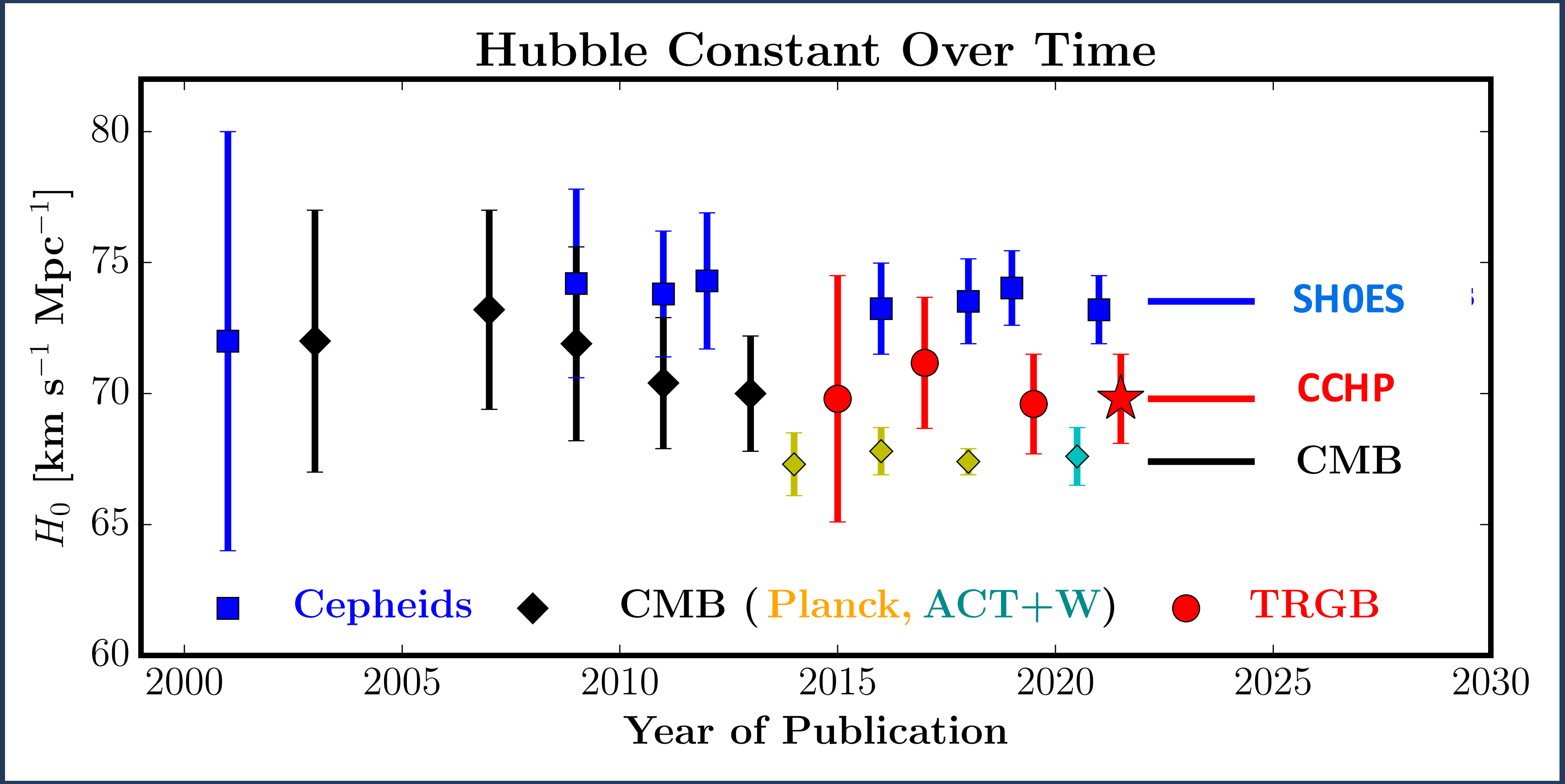
The Chicago Carnegie Hubble Program (CCHP)
Three Independent Astrophysical Distance Scales



Recent Measurements of the Hubble Constant



Recent Measurements of the Hubble Constant



Take Away Point:

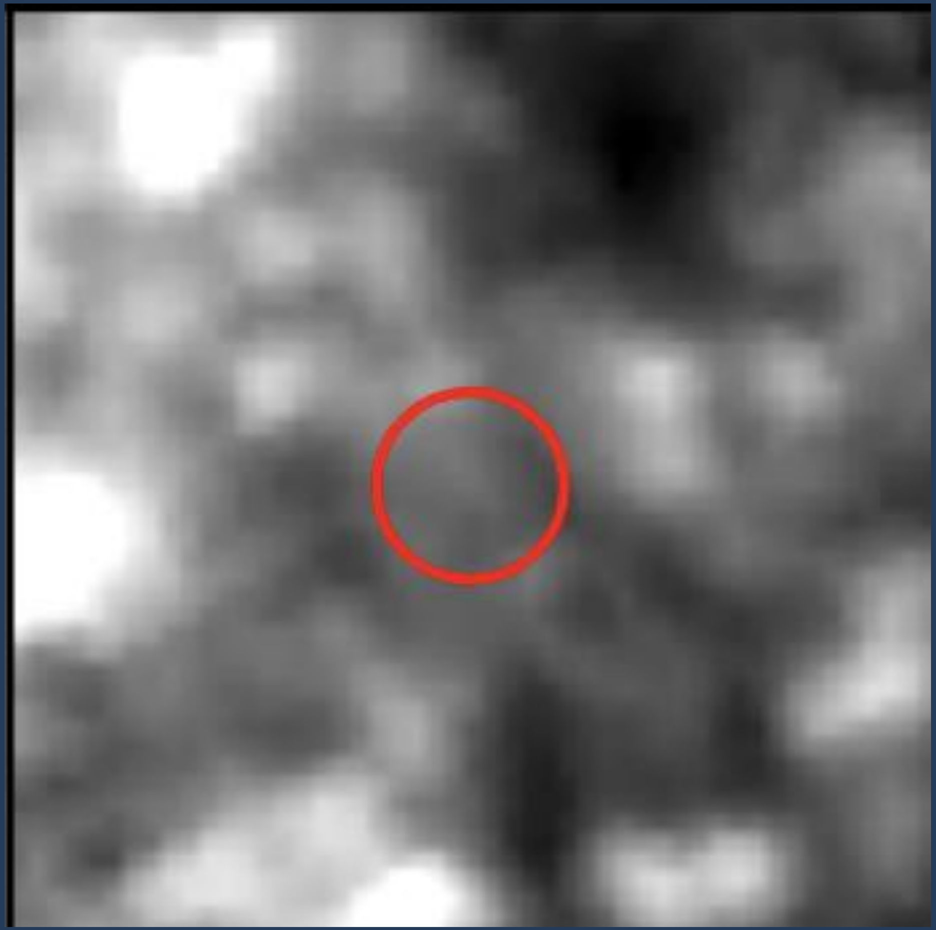
There are two ‘tensions’.

1. Between SH0ES and the CMB
   [physics beyond ΛCDM?]

2. Between SH0ES and the CCHP
   [astrophysics?]
   [calibration errors?]
   [crowding/blending]
   [issues with supernovae?]

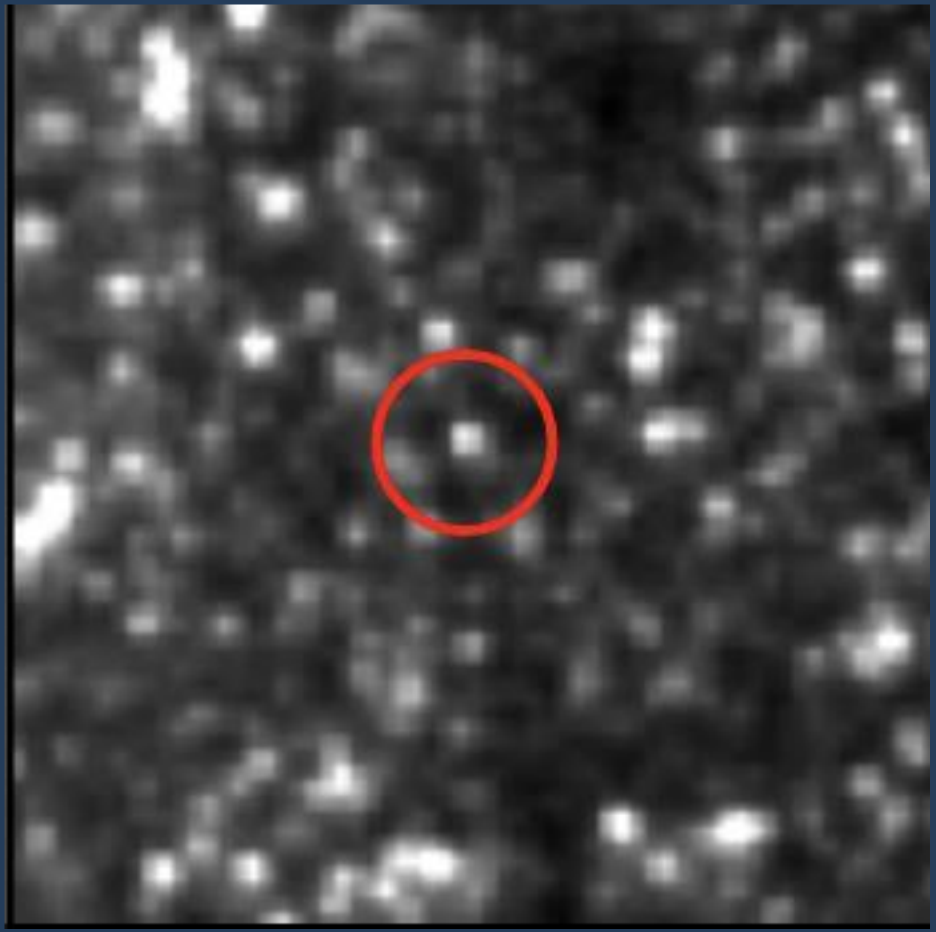
Freedman (2021) ApJ, 919, 16

HST Near-IR Data



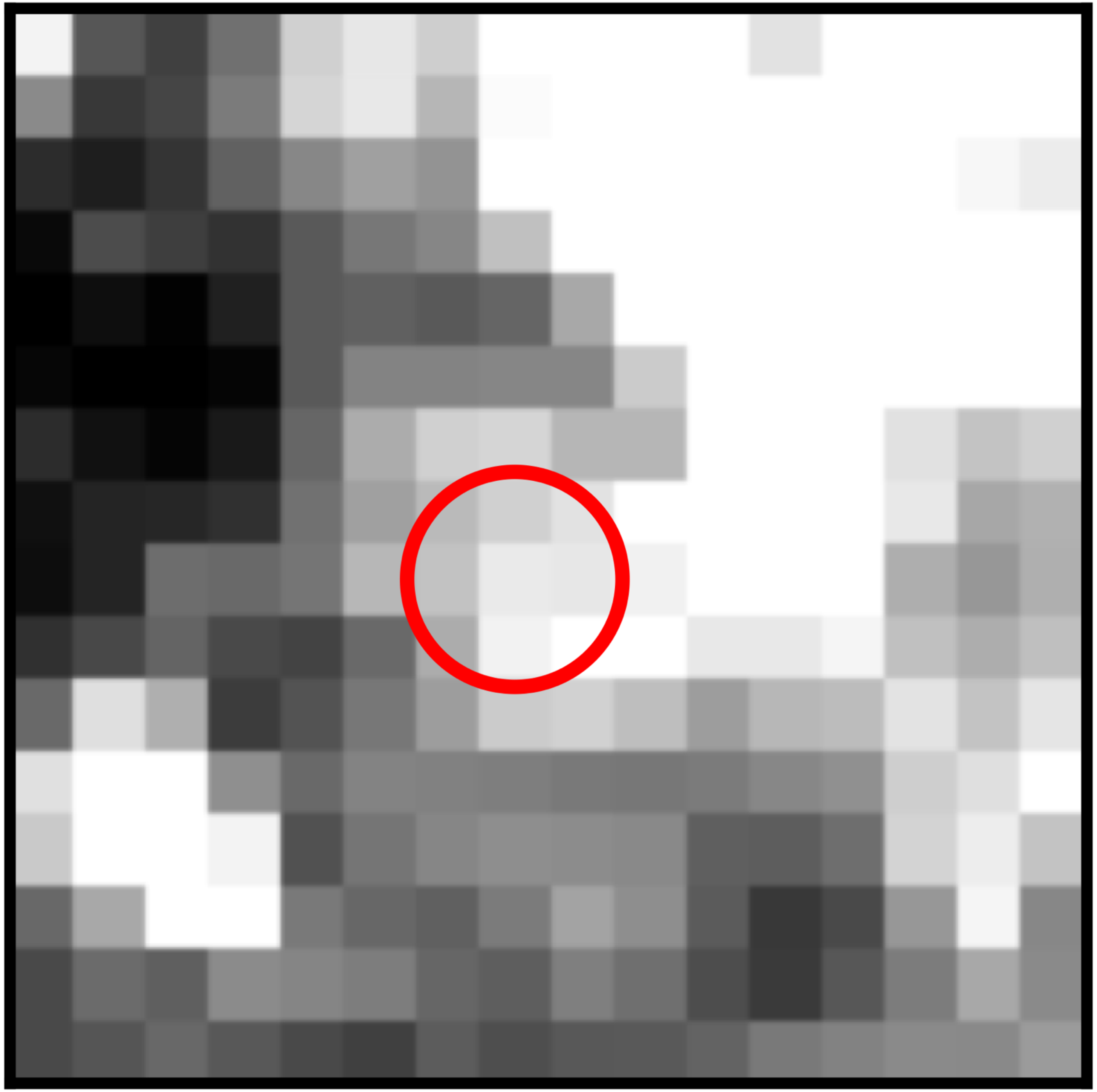
A Cepheid in NGC 7250 at a distance of 20 Mpc.

New JWST Near-IR Data



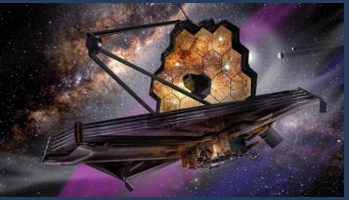
A Cepheid in NGC 7250 at a distance of 20 Mpc.

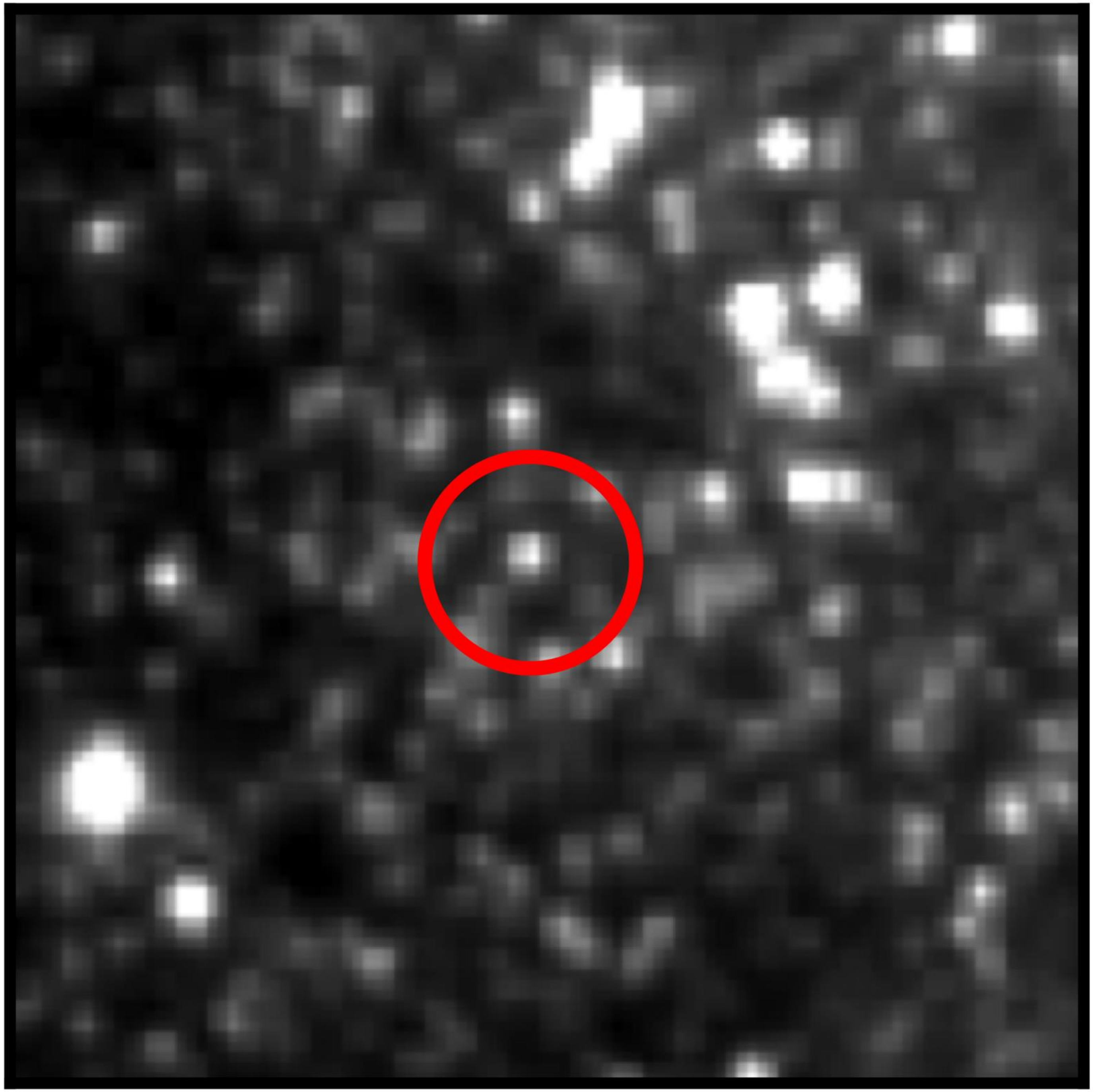
HST



HST: SNR 1-23
JWST : SNR 35-120

JWST





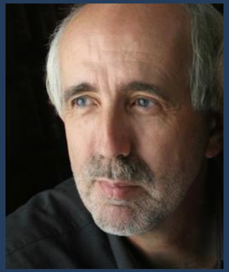
HST: SNR 1-23
JWST : SNR 35-120

Chicago-Carnegie Hubble Project (CCHP)

Taylor Hoyt

Kayla Owens

Abby Lee



Barry Madore

Wendy Freedman, PI

In Sung Jang

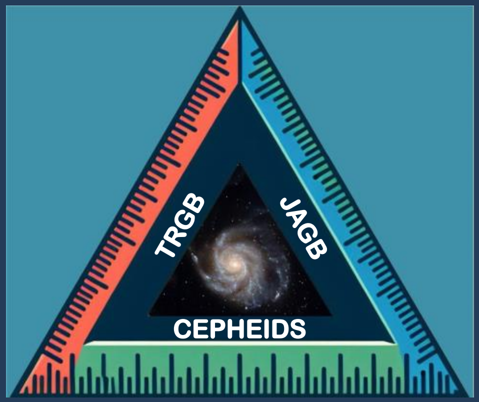
Our Initial Blinding Procedure

- Random numbers applied to each of our photometry catalogs

- All initial analysis carried out with arbitrary zero points and no knowledge of distances or H_0

(photometry quality cuts; PL relations for Cepheids; artificial star tests; Luminosity functions for TRGB and JAGB)

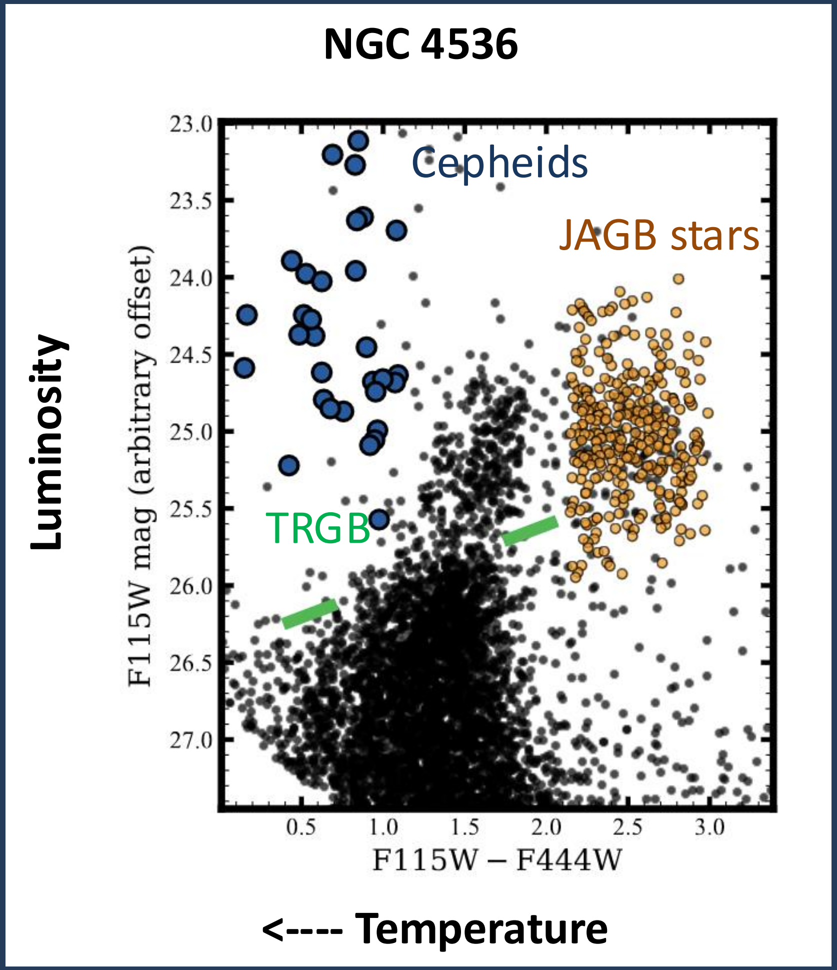
- JAGB analysis was carried out completely before unblinding



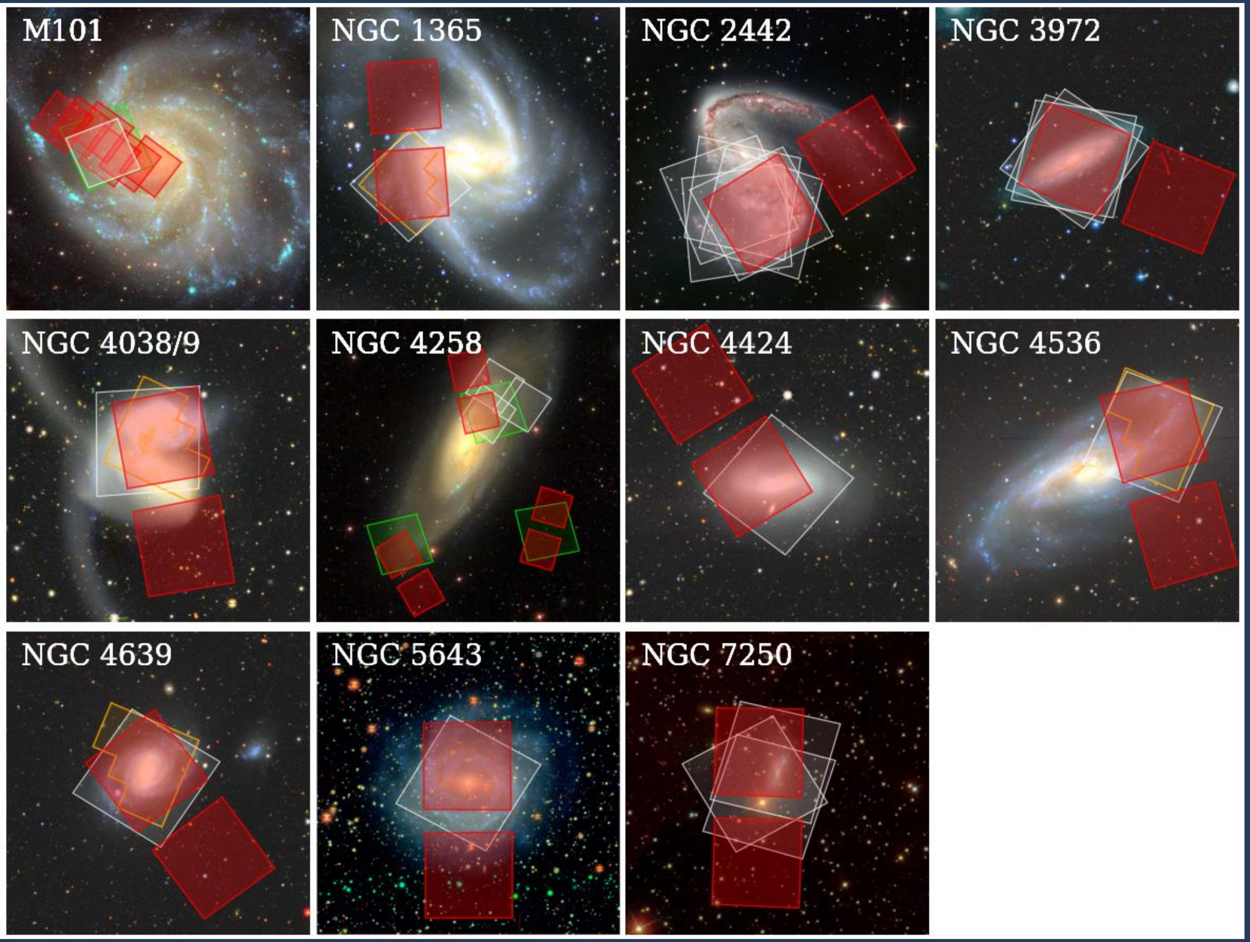
CCHP JWST Program

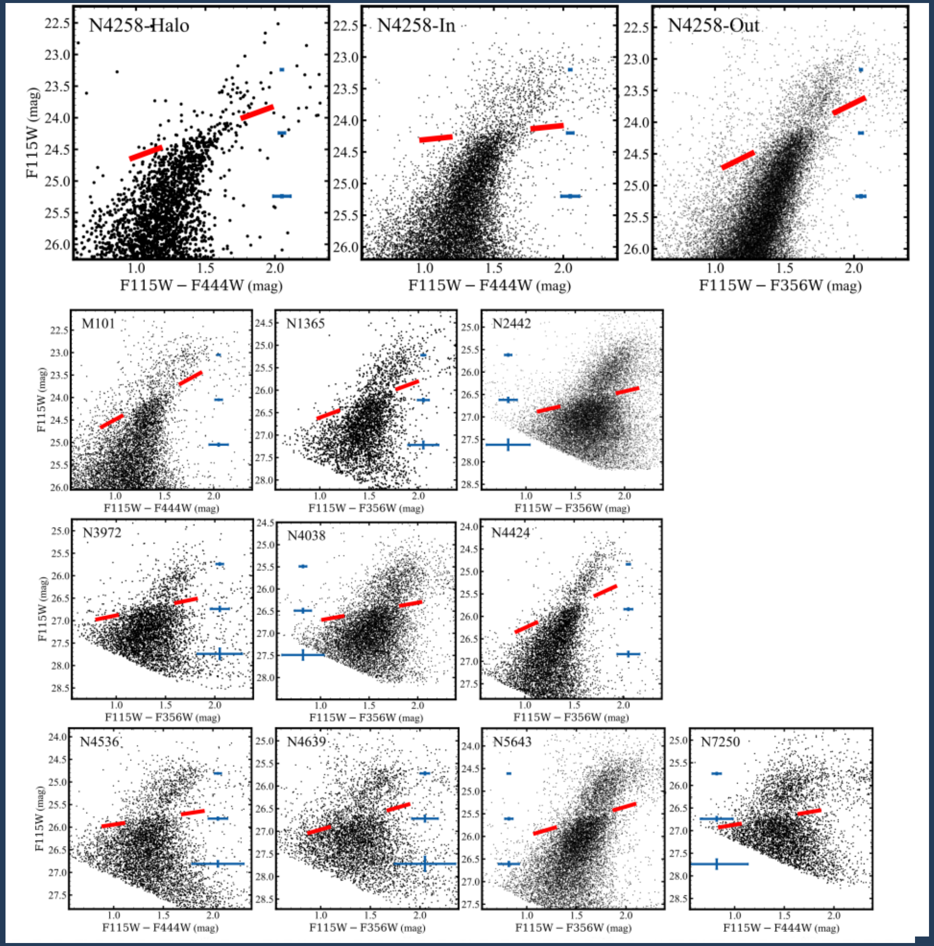
Three Independent Methods in the Same SN Ia Galaxies

1. Tip of the Red Giant Branch (TRGB)
2. JAGB/carbon stars
3. Cepheids



TRGB Results from JWST

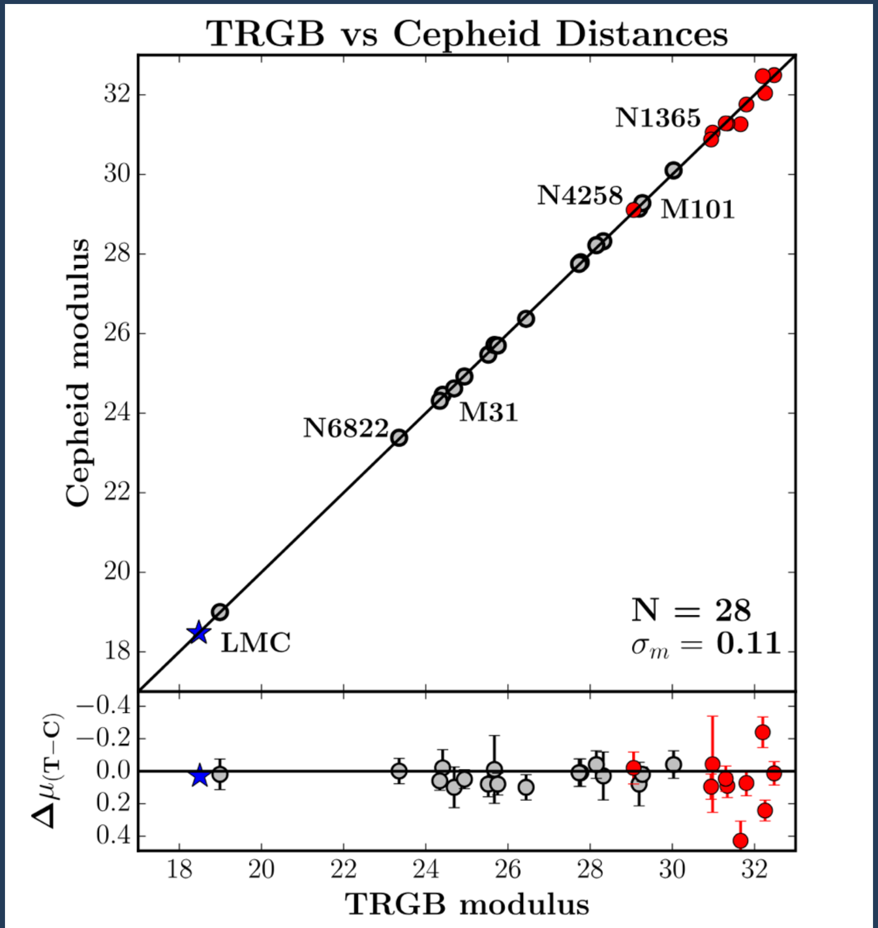




Hoyt et al., ApJ, submitted, arXiv: 2503.11769

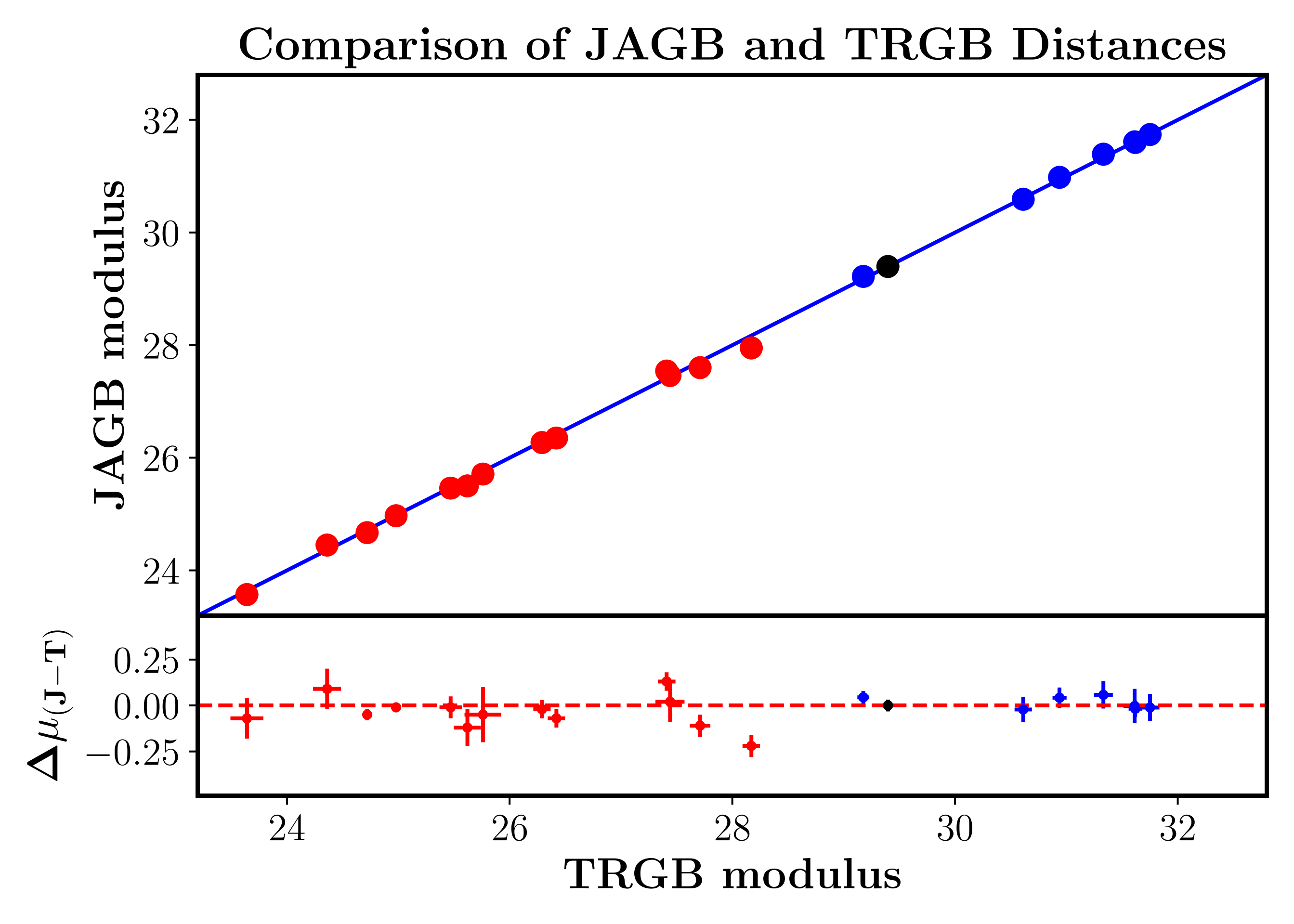
Progress in Measurement of Distances

WLF et al. (2019)



The weighted average difference in distance modulus (TRGB minus Cepheid) amounts to +0.059 mag.

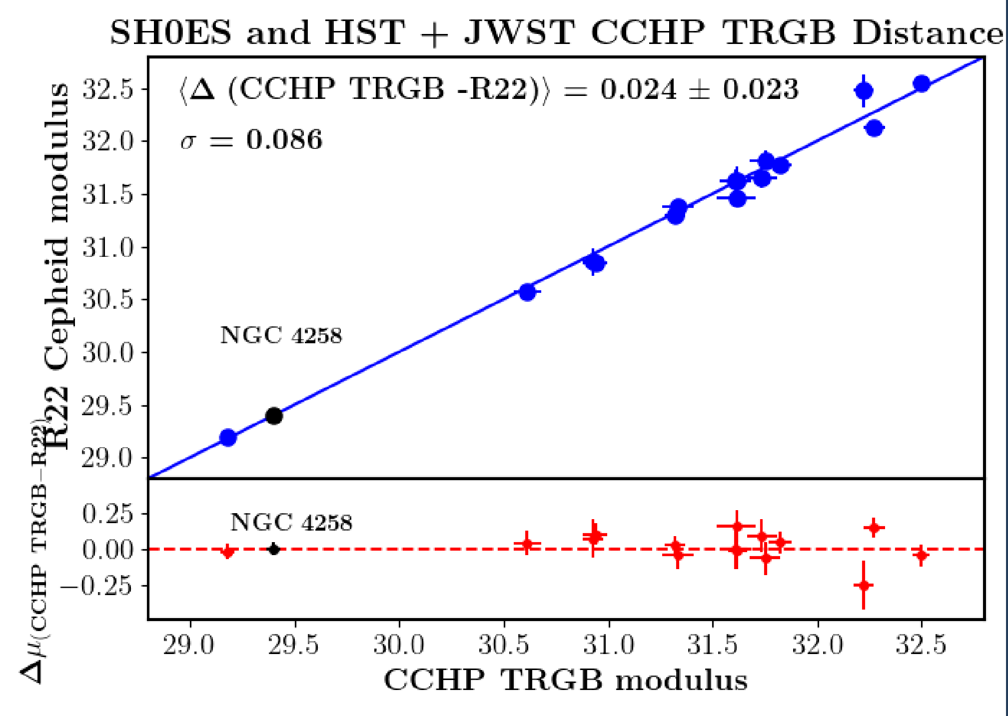
Comparison of Previously Published (Ground-Based + JWST) TRGB and JAGB Distances



WLF et al. (2025, ApJ, 985:203; arXiv 2408.06153)

Comparison of TRGB Distances:

CCHP TRGB (HST+JWST) vs SH$_0$ES Cepheids (2024)



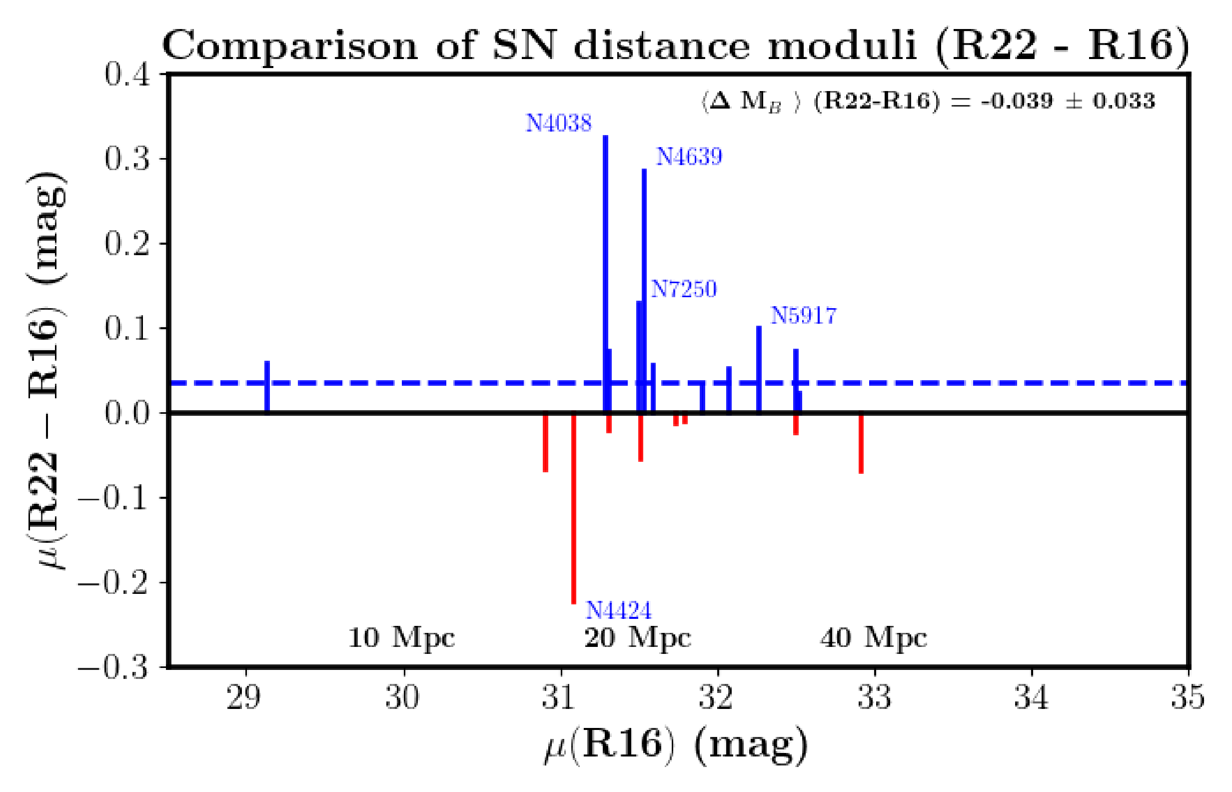
TRGB distances (JWST+HST):
WLF et al. (2019), (2024)

Cepheid distances (HST+JWST):
Riess et al. (2022), (2024)

Agreement at 0.02 mag level
or 1% in distance

NOTE: Distances have now converged to CCHP (2019) TRGB Distance Scale

Comparison of SH0ES 2016 vs 2022 Distances: Systematic Differences



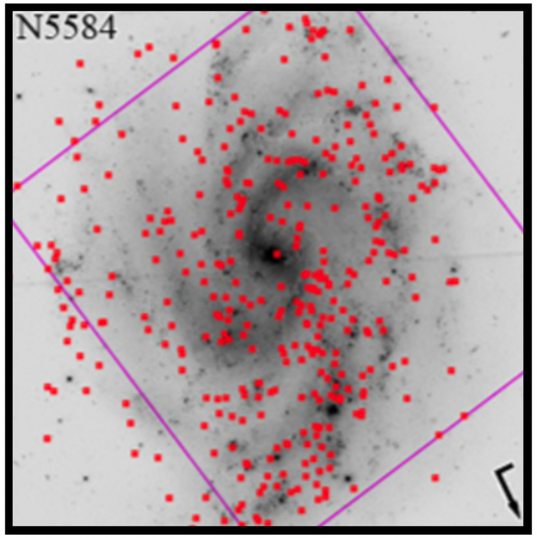
- Even for the nearest galaxies, updated distances (SH0ES 2016 compared to SH0ES 2022) resulted in a mean offset of 1.6%.
- Some differences were as large as 15% in distance.
- [For comparison, these amount to almost twice the size of the H_0 tension.]

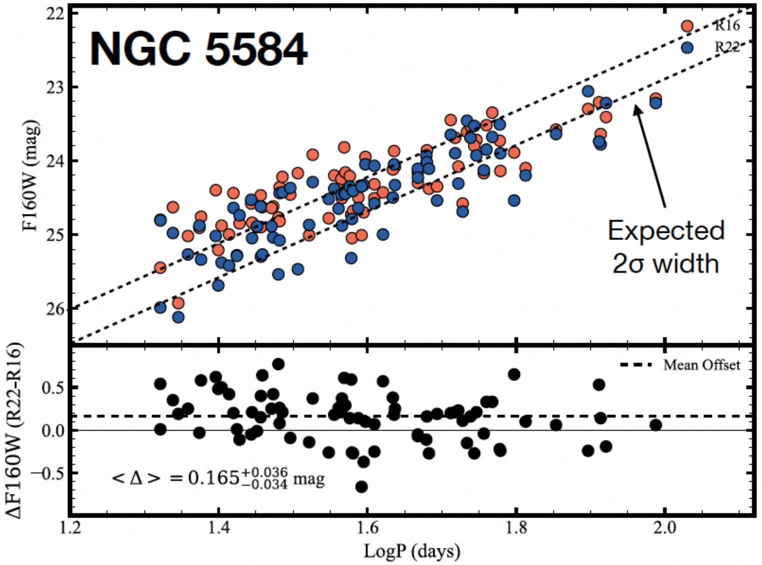
WLF et al. (2025, ApJ, in press; arXiv 2408.06153)

Comparison of SH0ES 2016 vs 2022 Distances: Systematic Differences

Several sigma shifts in SH0ES' Cepheid flux Measurements

Term	Description	Riess+ (2016)	Riess+ (2019)	This work
$\sigma_{PL}/\sqrt{n}$	Mean of P–L in SN Ia hosts	0.4	0.4	0.4





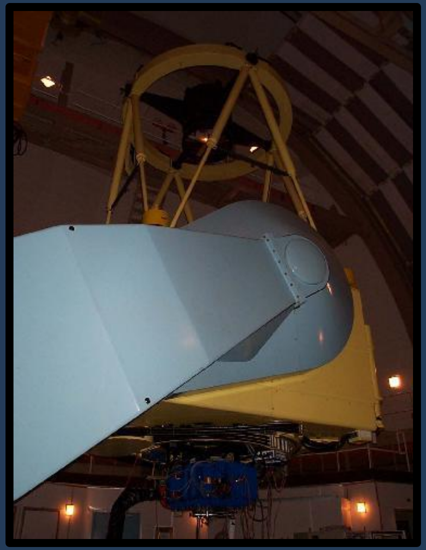
The average magnitude of a Cepheid in this galaxy shifted from R16 to R22 by -0.165 mag, equivalent to a ***<u>7.6% systematic shift equal to the entire size of the Hubble tension.</u>***

But their quoted distance stayed within 0.01 mag (0.2 sigma).

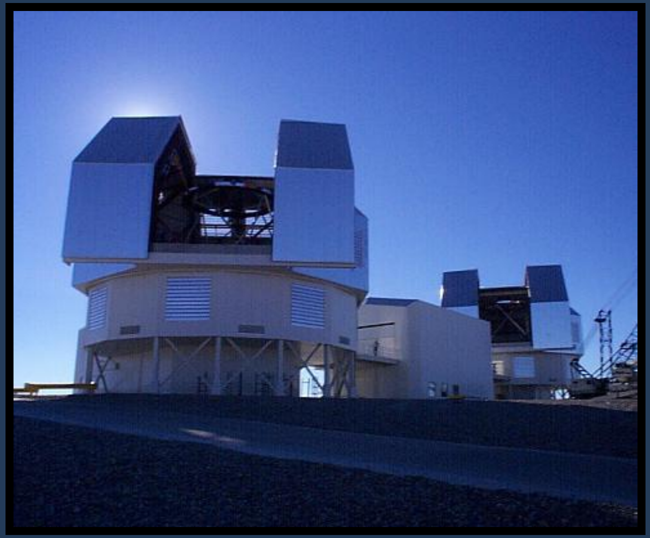
This Cepheid-SN host has the smallest quoted distance uncertainty (0.05 mag, or 2% in distance) of the SH0ES sample, i.e., it should be the *best* measured sample of Cepheids.

Carnegie Supernova Project-I (CSP)

Swope 1-meter



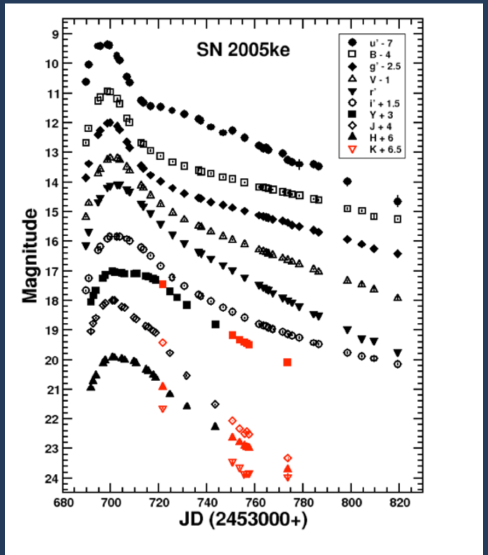
du Pont 2.5-meter

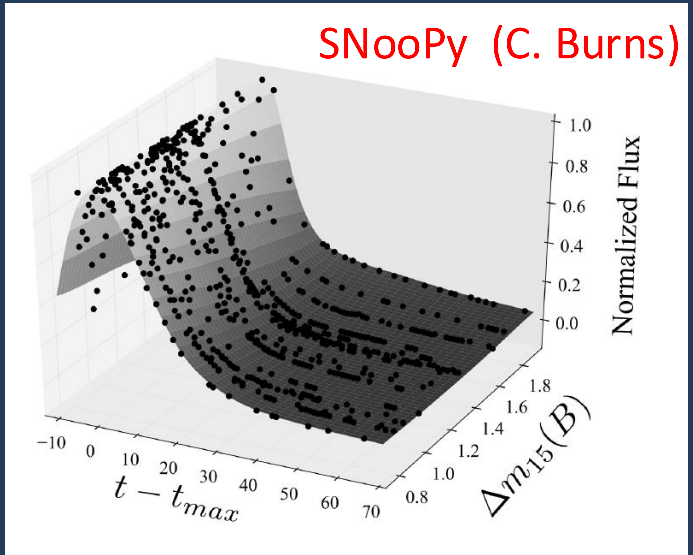


Magellan 6.5-meter

M. Phillips, W. Freedman co- PIs

Carnegie Supernova Project (CSP)
Dealing With Systematics



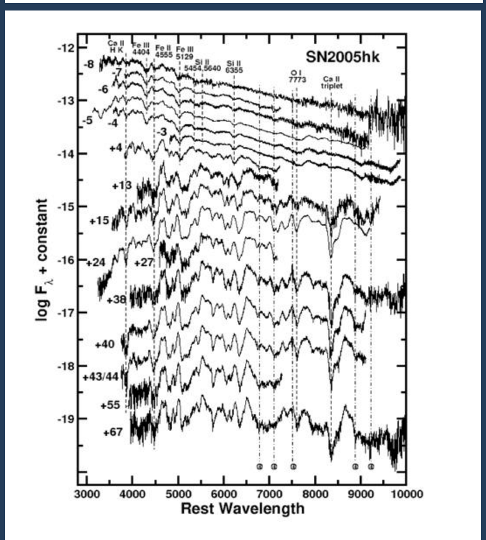


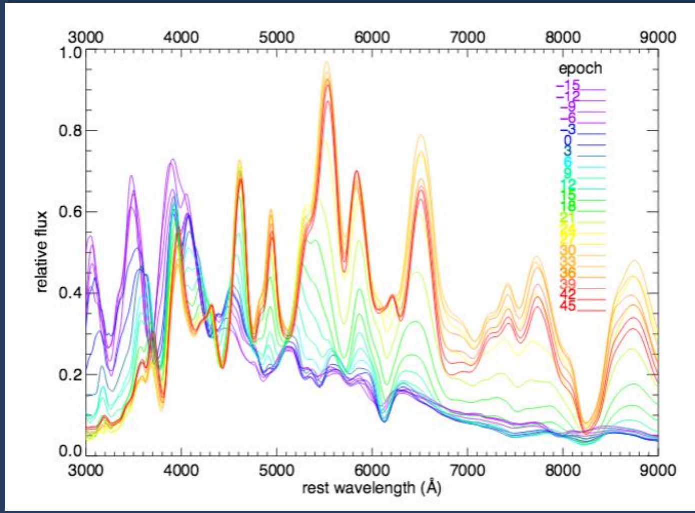
M. Phillips, W. Freedman, co-PIs

Well-sampled photometry and spectra

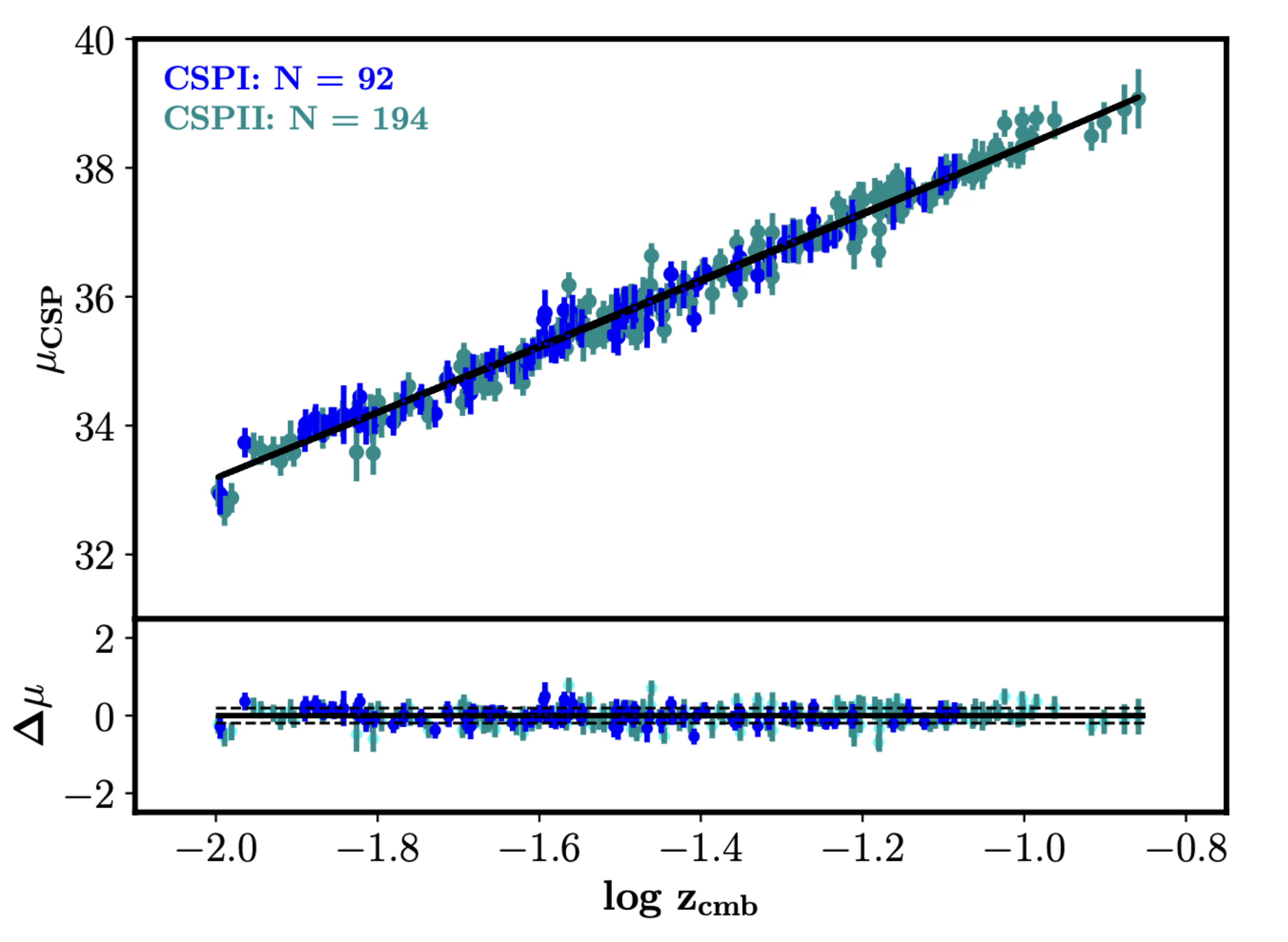
Most extensive, self-consistent data set for dealing with systematics

Input to MCMC analysis



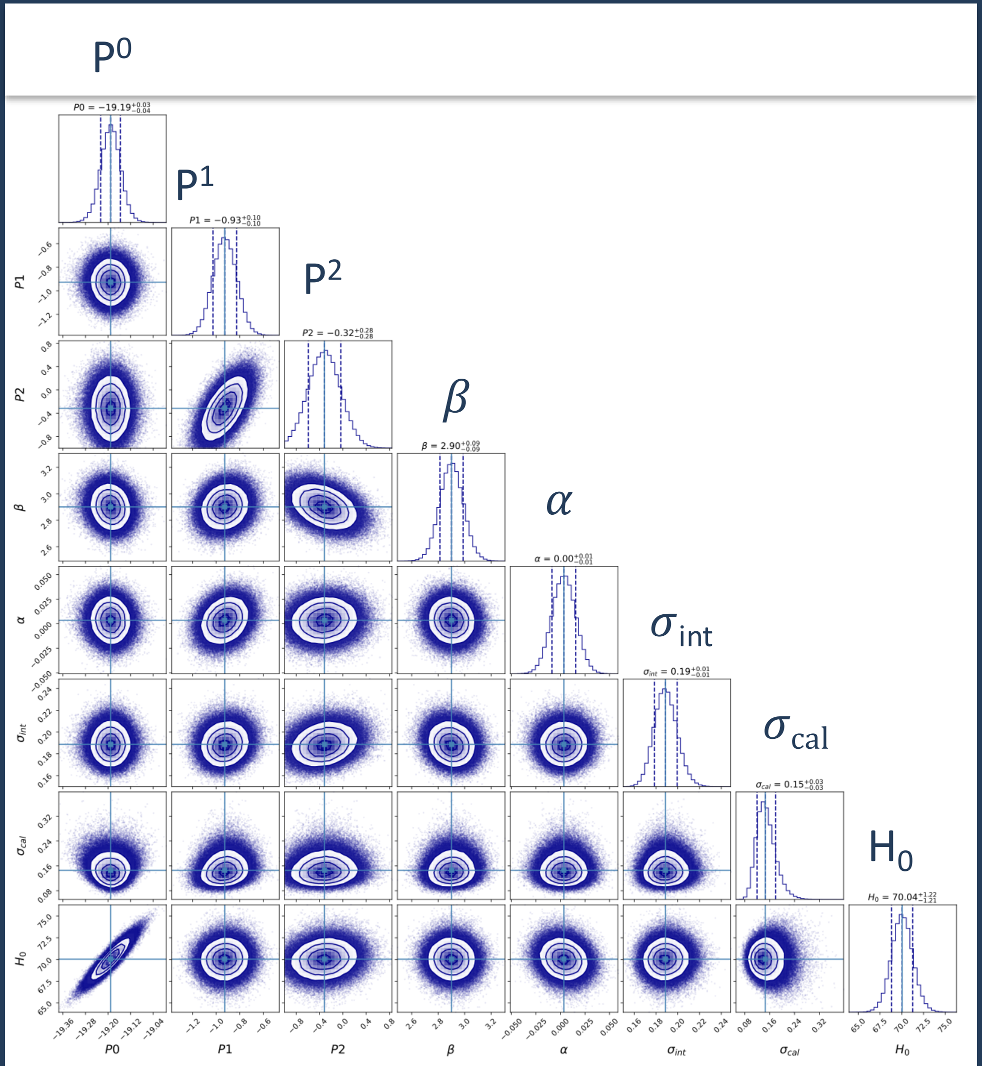


Carnegie Supernova Project (CSP)



WLF et al. (2025, ApJ, 985:203; arXiv 2408.06153)

H_0 Results : CSP + TRGB



EMCEE + pymc analyses

$$B_{corr} = P^0 - P^1(s_{BV}-1) - P^2(s_{BV}-1)^2 - \beta(B-V) - \alpha_M(\log_{10} M_*/M_\odot - M_0),$$

$$\mu(z, H_0, q_0) = 5\,\log_{10}\{\frac{(1+z_{hel})cz}{(1+z)H_0}(1+\frac{1-q_0}{2}z)\} + 25.$$

- **8 dimensions, 30,000 steps, 3000 step burn-in**
- **Assume v_{pec} = 240 km s^{-1} (Brout et al. 2022)**
- **H_0 = 70.4 $\pm$ 3% km s^{-1} Mpc^{-1}**

WLF et al. (2025, ApJ, 985:203; arXiv 2408.06153)

Now that the distances agree, where is the difference in H_0 between SH_0ES and CCHP coming from?

TAKEAWAY: **SH$_0$ES sample**

- The current supernova sample is small: 37 distances (42 supernovae), some of which have large uncertainties.

- **Half of the weight in the SH$_0$ES sample comes from just 12 supernovae** (29 % of the sample).

- The **effective size** of the R22 Cepheid sample is equivalent **to only 31 SNe Ia**, or 74% of the total sample.

- Thus an already small sample of 42 SNe Ia is not providing $1/\sqrt{N}$ statistical (increased sample size) gains.

$$N_{\text{eff}} = \frac{\left(\sum_{i=1}^{42} w_i\right)^2}{\sum_{i=1}^{42} w_i^2} = 31$$

TAKEAWAY: **CCHP sample**

- The CCHP (HST + JWST) supernova sample has 21 distances (24 supernovae)
- The TRGB sample has an advantage that the most distant galaxies (with the largest uncertainties and therefore lowest weights) are not in the sample.
- **Half of the weight in the CCHP sample comes from 9 supernovae** (38 % of the sample).
- The **effective size** of the CCHP TRGB sample is equivalent **to 21 SNe Ia**, or 88% of the total sample.

N_{eff}= 21

$\sqrt{31}$ / $\sqrt{21}$ = 1.2

i.e.,the SH_0ES and CCHP samples are statistically comparable.

Conclusion: the reason for the current difference between SH_0ES and CCHP is not the sample size. It is the change in the apparent magnitudes of SNe in the SH_0ES analysis.

Why Haven't the H_0 Values Converged?

For reference:

$< \Delta\mu > =$ 0.035 mag [1.6%] (Change in SH_0ES distance moduli between 2016 and 2022)

$< \Delta m_b >$ = 0.03** mag [1.4%] (Change in P+ apparent SN magnitudes between 2016 and 2022)

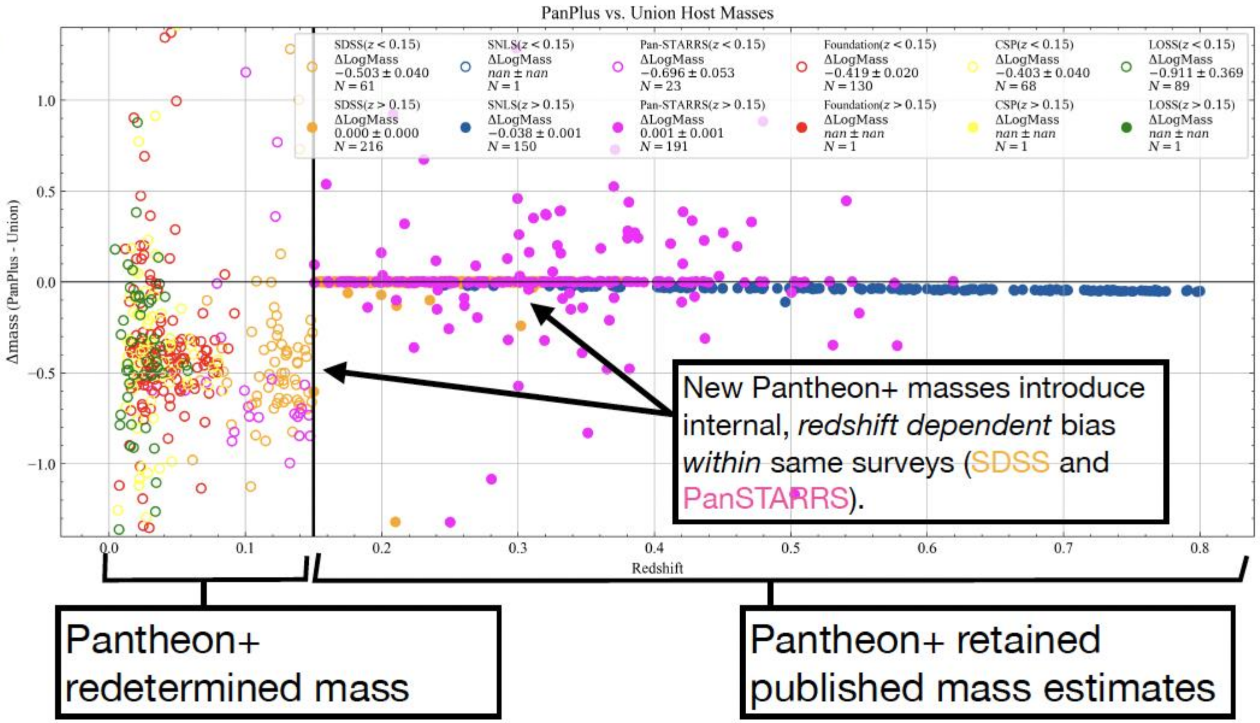
ΔH_0 (2022 – 2016) = 73.04 – 73.24 = -0.2 km s^{-1} Mpc^{-1} [0.3%] I.E., NO NET EFFECT ON SH_0ES H_0

** A difference of only 0.03 mag in the average magnitude of the local supernovae sample corresponds to a 1.4% difference in H_0, the entire quoted SH_0ES uncertainty.

A. Discrepancies and Inconsistencies in Pantheon+

Systematic, redshift dependent bias in host mass estimates

- 0.5 dex systematic bias in Pantheon+ masses estimated to z<0.15 SN host galaxies.
- Destroys internal self-consistency within and across SN surveys.
- This is the *exact same* discrepancy Efstathiou commented on between Pantheon+ and DES SNe. However, he claimed the DES SN distances were biased, but the reality is the *reverse*.
- That is, **<u>the new masses estimated by Pantheon+ to z<0.15 hosts have introduced an *artificial redshift evolution* that both suppresses the signal for evolving dark energy and biases their H0 to higher values.</u>**
- This mass bias results in a 0.02 mag bias in the low redshift SN bin, which accounts for half the suppression of evolving dark energy and is equal to 2/3 of the Pantheon+SH0ES *total* uncertainty on H0



How Robust is the 5 σ Tension in H_o ?

$$T = \frac{\Delta H}{\sqrt{\sigma_P^2 + \sigma_C^2}}$$

Correct Cepheid distances

Include SN uncertainty

$$H_0 = 71.2\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$$

$$\sigma_C = \sqrt{\sigma^2_{\mathrm{SH0ES}} + \sigma^2_{\mathrm{SN(sys)}}}$$

$H_{Planck} = 67.4$
$\sigma_{Planck} = 0.5$

$H_{Ceph} = 73.0$
$\sigma_{Ceph} = 1.0$

$H_{Planck} = 67.4$
$\sigma_{Planck} = 0.5$

$H_{Ceph} = 71.2$
$\sigma_{Ceph} = 1.4$

SH_0ES: Tension with Planck is 5 σ

Alternatively: Tension with Planck is 2.4 σ

Next Required Steps to Improve Accuracy

1) Increase the numbers of SN host galaxies with Cepheid, TRGB and JAGB distances measured with JWST.

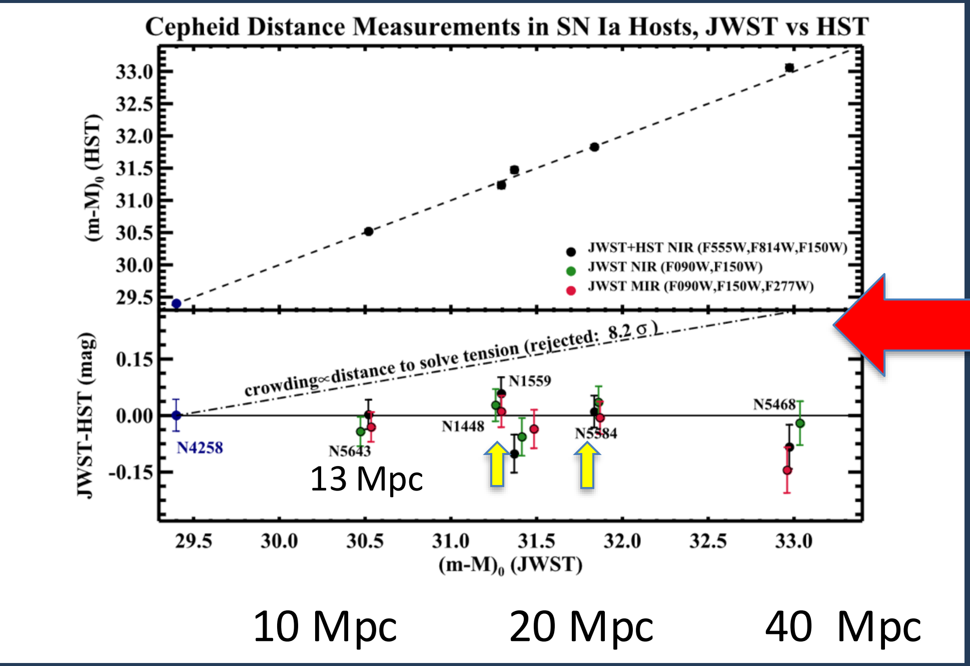
2) Strengthen Type Ia supernova absolute calibration (spectrophotometry).

3) Demonstrate that galaxies with distances > 30 Mpc have no systematic errors due to crowding.

Next Steps: Type Ia Supernova Hosts

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]



Riess et al. 2024

NOTE:

- No tests have been carried out > 40 Mpc
- There are no JWST data at these distances
- Tests to date have only been carried out on galaxies where there are no previous concerns about the photometry

- Riess+ 2024: rule out 0.3 mag at 40 Mpc (15% in distance)
- However, a 0.035 mag average shift (comparable to what has already been seen in the nearby sample) would result in a change to H_0 that exceeds the current total error bar.

Recent Results ACT DR6 arXiv:2503.14454

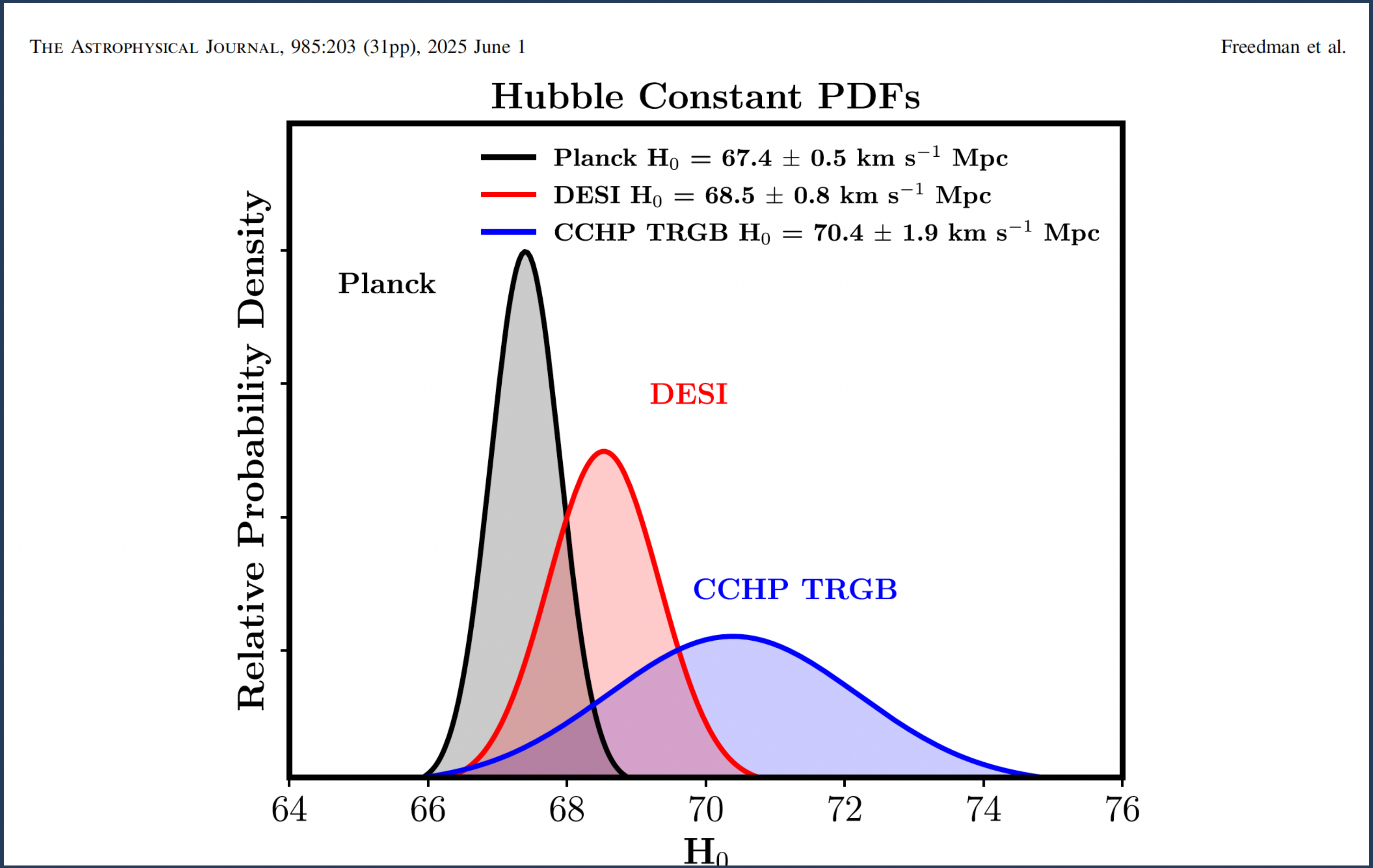
- No evidence for new light, relativistic species.

- No evidence for self-interacting dark radiation.

- $$H_0 = 69.9\ ^{+0.8}_{-1.5}\ \text{km/s/Mpc}.$$

- "The mild hint of EDE in the ACT DR4 analysis was largely driven by a fluctuation in the EE power spectrum at $\ell \sim 500$ and a broad trend in the joint ACT and Planck TE power spectrum (Hill et al. 2022). Our analysis of the new ACT DR6 spectra is a high-precision test as to whether these features were the first hints of a real signal, or simply a statistical fluctuation."

- "In general, models introduced to increase the Hubble constant or to decrease the amplitude of density fluctuations inferred from the primary CMB are not favored over ⊄CDM by our data."



WLF et al. (2025)

Concluding Remarks

- JWST has ushered in a new era of accuracy in our measurement of H_0, similar to what HST did three decades ago.

- Independent distances from the TRGB and JAGB/carbon stars agree at the percent level. All three distance measurements agree well at better than a few percent level.

- Differences in H_0 are now coming from the nearby supernovae sample, not the calibrating distances. **The nearby supernova sample needs to be augmented and improved if we are to reach 1% accuracy.**

  [Also issues with inconsistent low z vs high z bias corrections in Pantheon+
  The Hubble tension goes away when treat low and high z consistently – and resolve DES/P+ discrepancy.]

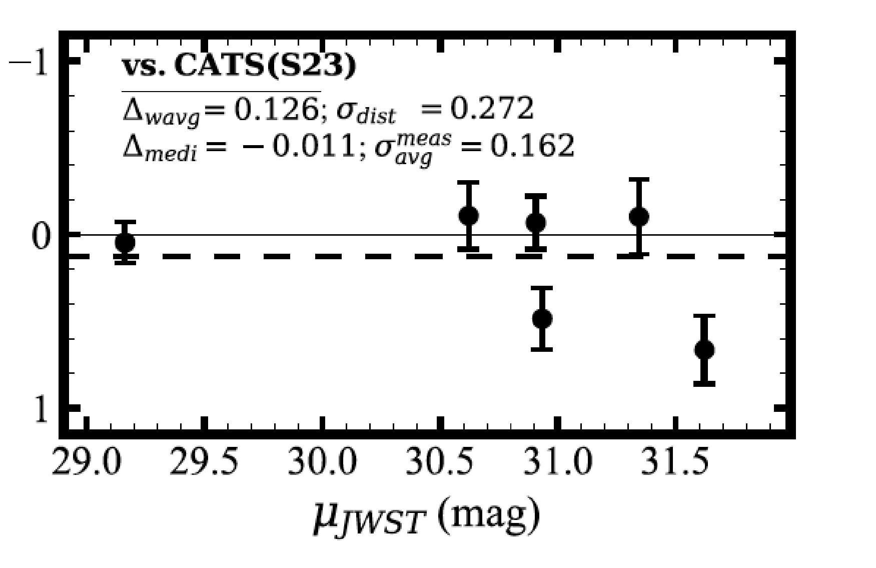
- In addition, more JWST data at higher resolution will be required to measure H_0 at a 1% level.

- Our CCHP TRGB (HST + JWST) sample is no longer subject to a small numbers bias and gives :

  Ho = 70.4 km s^{-1} Mpc^{-1} with a conservative uncertainty of < 3%

Comparison of TRGB Distances:

JWST vs CATS Distances

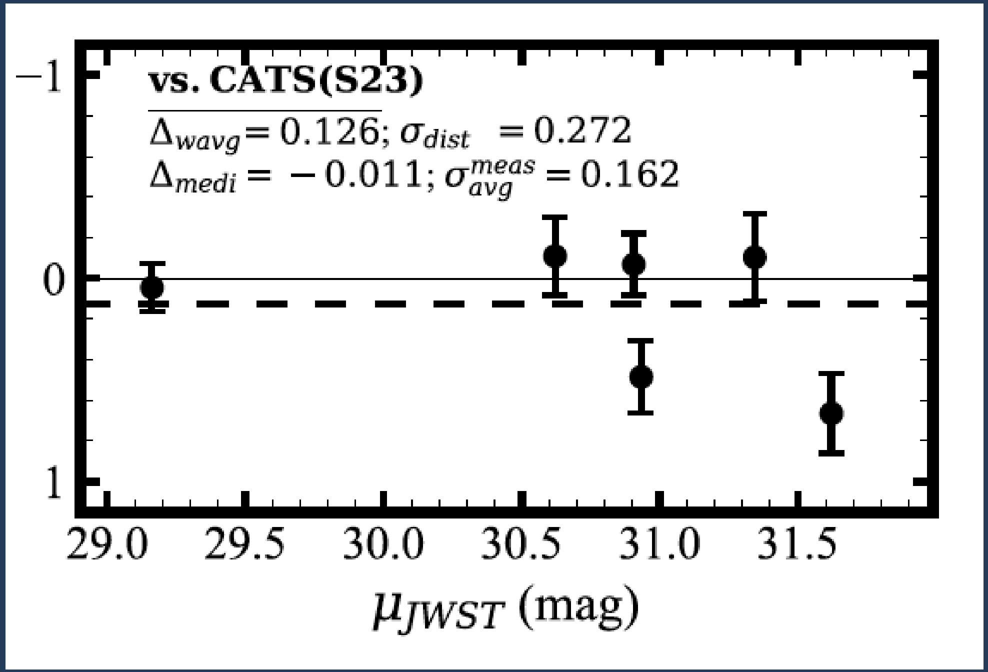


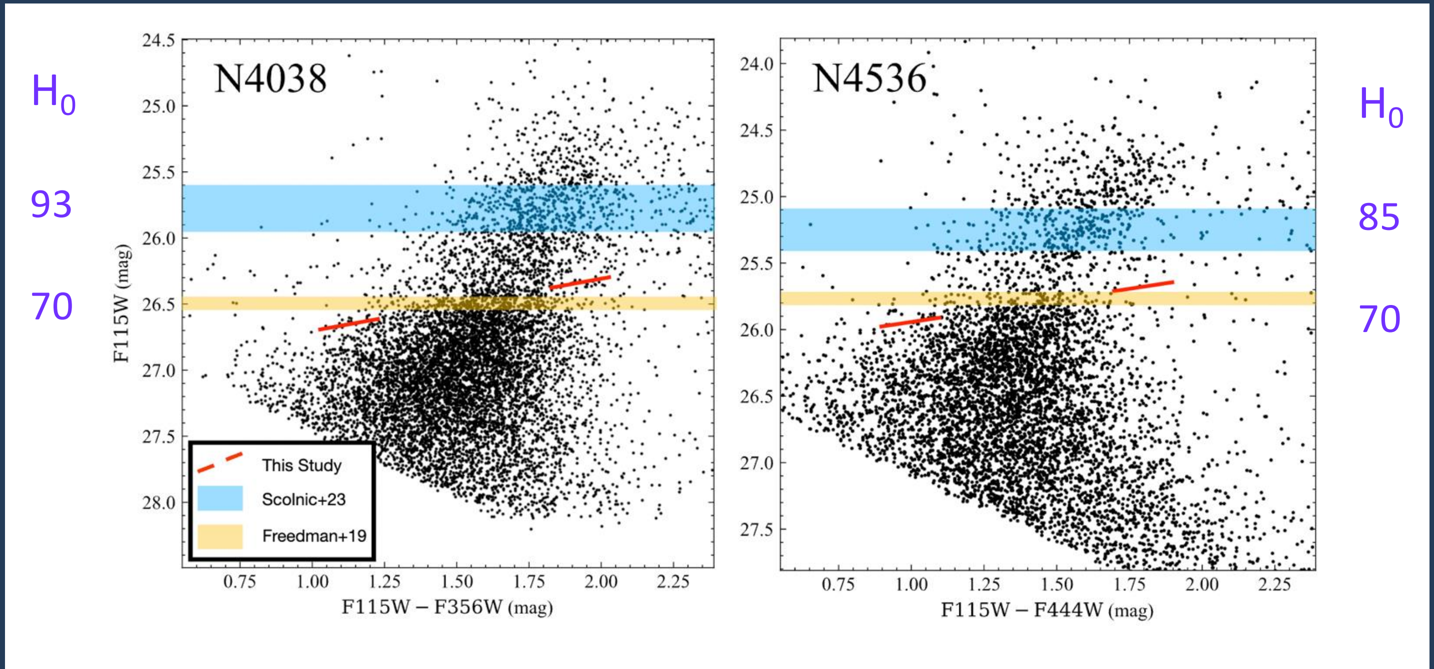
Disagreement <u>~ 6.5% level</u>
Scolnic et al. 2023

From Hoyt et al. 2024, in prep

Comparison of TRGB Distances:

JWST vs CATS Distances



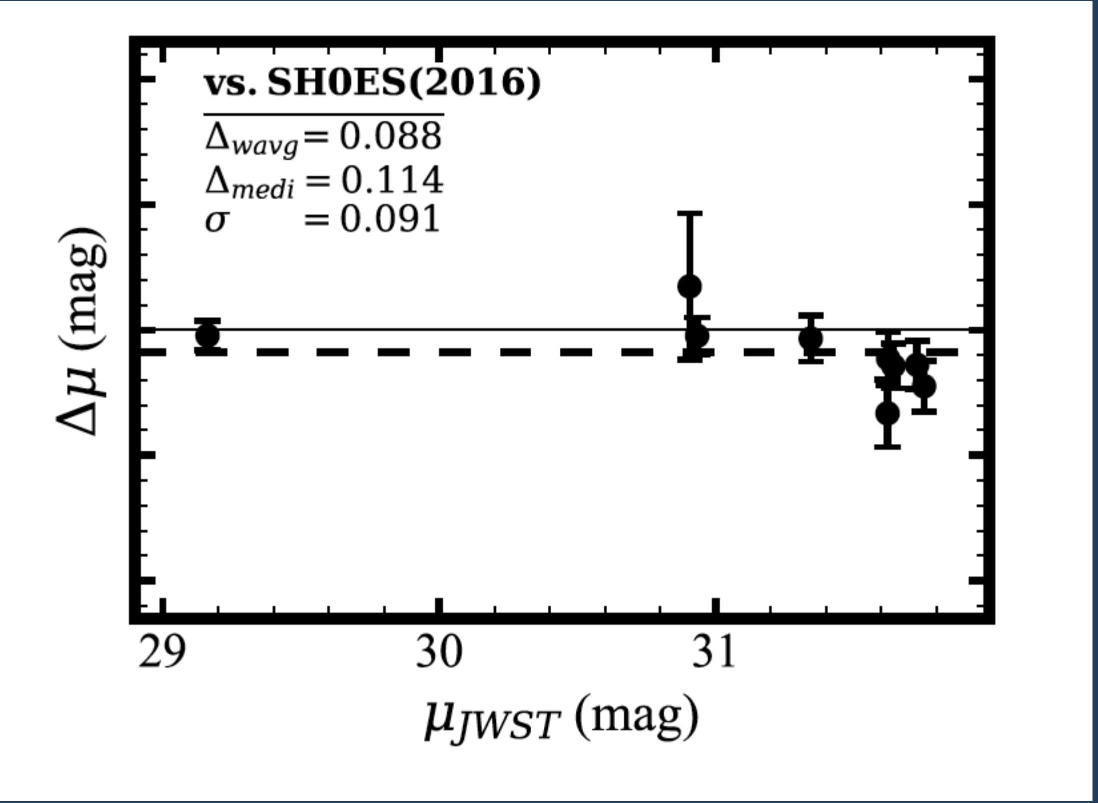


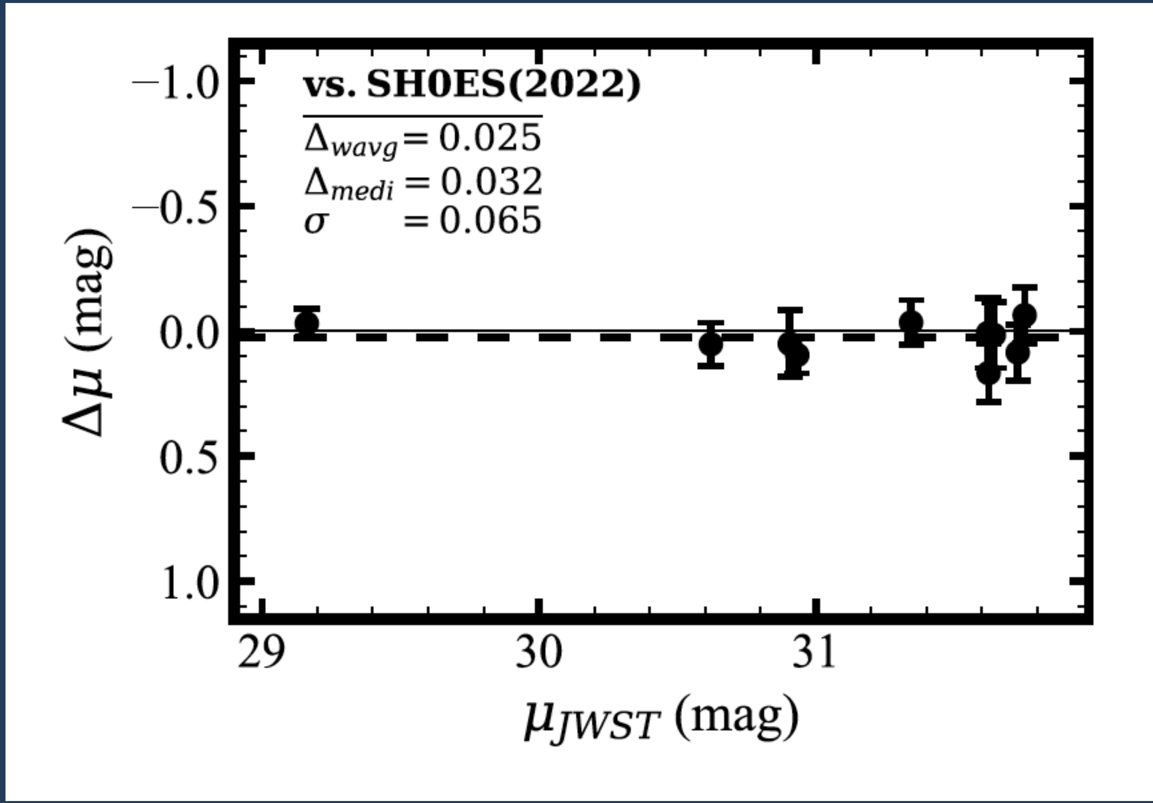
Disagreement ~ 6.5% level
Scolnic et al. 2023

From Hoyt et al. 2024, in prep

Comparison of TRGB Distances:

New JWST Measurements vs SH0ES 2016 and 2022 Cepheid Distances





Disagreement ~ 4% level
Riess et al. 2016

Agreement ~ 1% level
Riess et al. 2022

Metallicity coefficient γ (mag / dex)

Ripepi et al. 2021
Best estimates:
$-0.366 < \gamma < -0.465$

Gaia EDR3 measurements:
New spectroscopy

Breuval + Riess et al. 2021
$-0.048 < \gamma < -0.251$

Gaia EDR3 parallax measurements:
Effect in near-infrared as large as in optical, contrary to previous studies.

Udalski et al. 2001
$\gamma = 0$

The Optical Gravitational Lensing Experiment.
Cepheids in the Galaxy IC1613:
No Dependence of the Period–Luminosity Relation on Metallicity*

Ripepi et al. 2022
$-0.520 < \gamma < -0.725$

Gieren et al. 2021
$-0.221 < \gamma < -0.335$

Riess et al. 2016
$\gamma = -0.13 \pm 0.07$

Riess et al. 2021
$\gamma = -0.217 \pm 0.046$

$-0.5 < \gamma < 0$