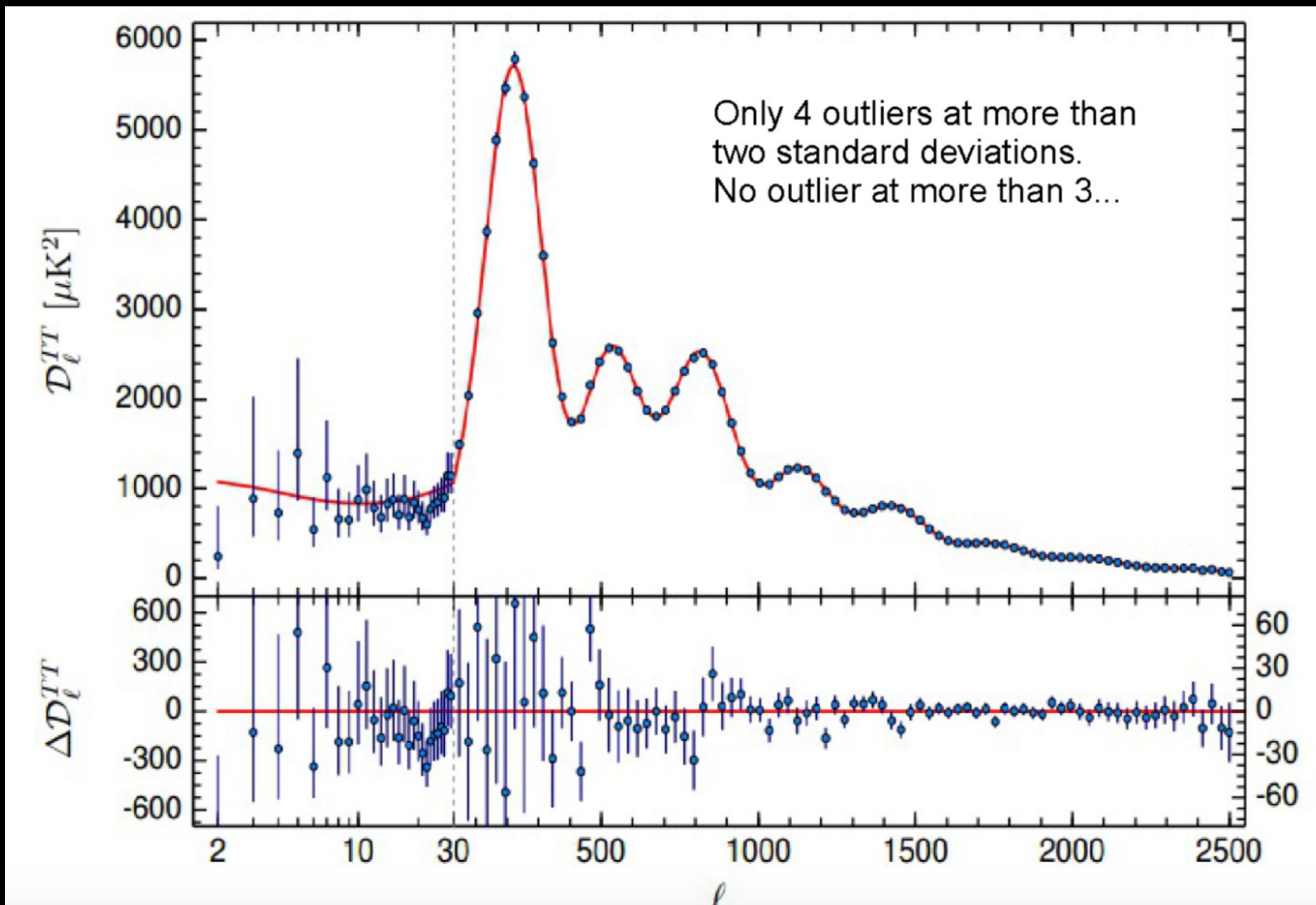
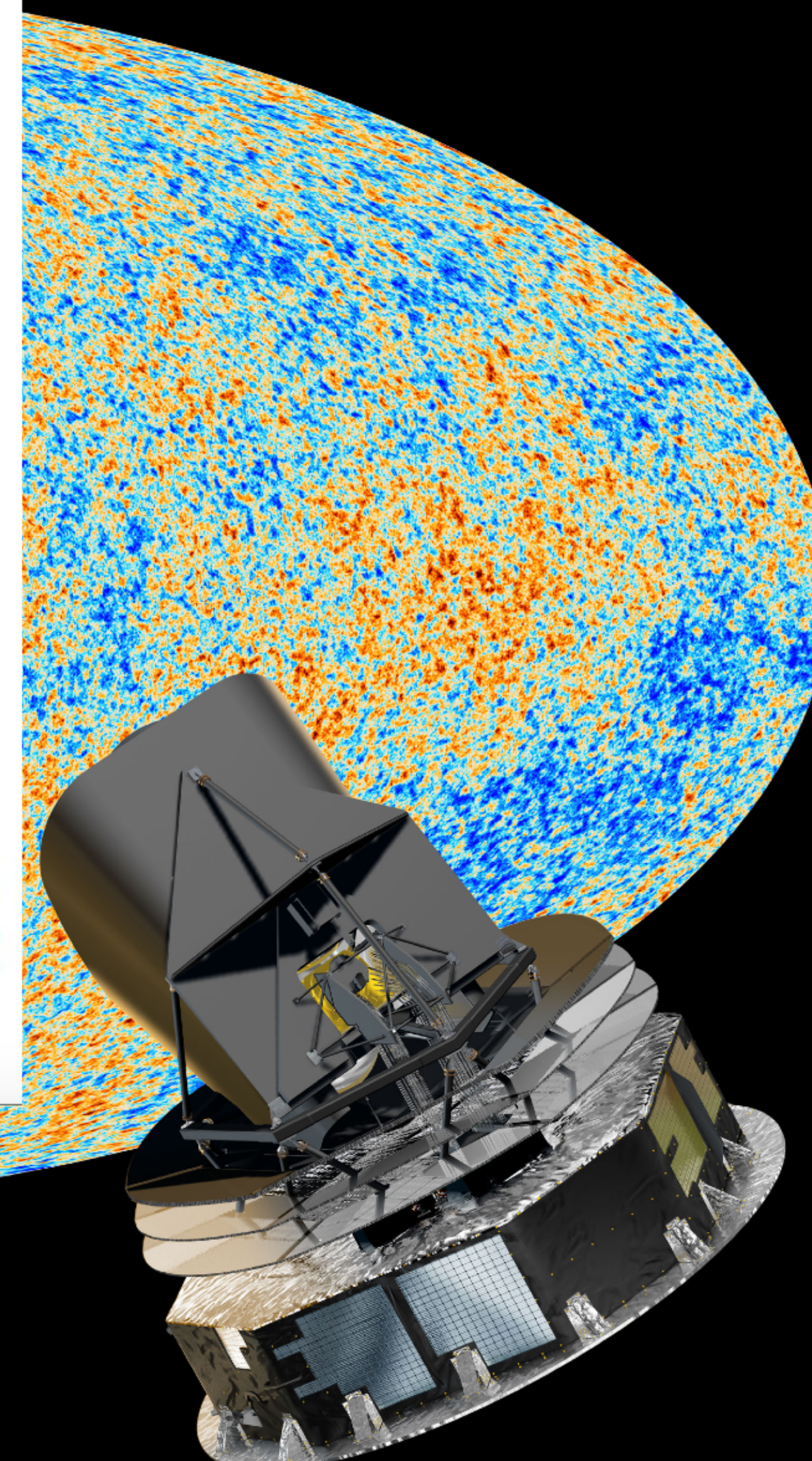
THE H0 PUZZLE

GRAVITY, STRINGS AND SUPERSYMMETRY BREAKING
03—05 APR 2025
PISA,SNS PALAZZO DELLA CAROVANA

ALESSANDRO MELCHIORRI
UNIVERSITY OF ROME “SAPIENZA”

A PERFECT (LCDM) UNIVERSE ?





The recent CMB measurements made by the Planck satellite are in perfect agreement with the expectations of the LCDM model.

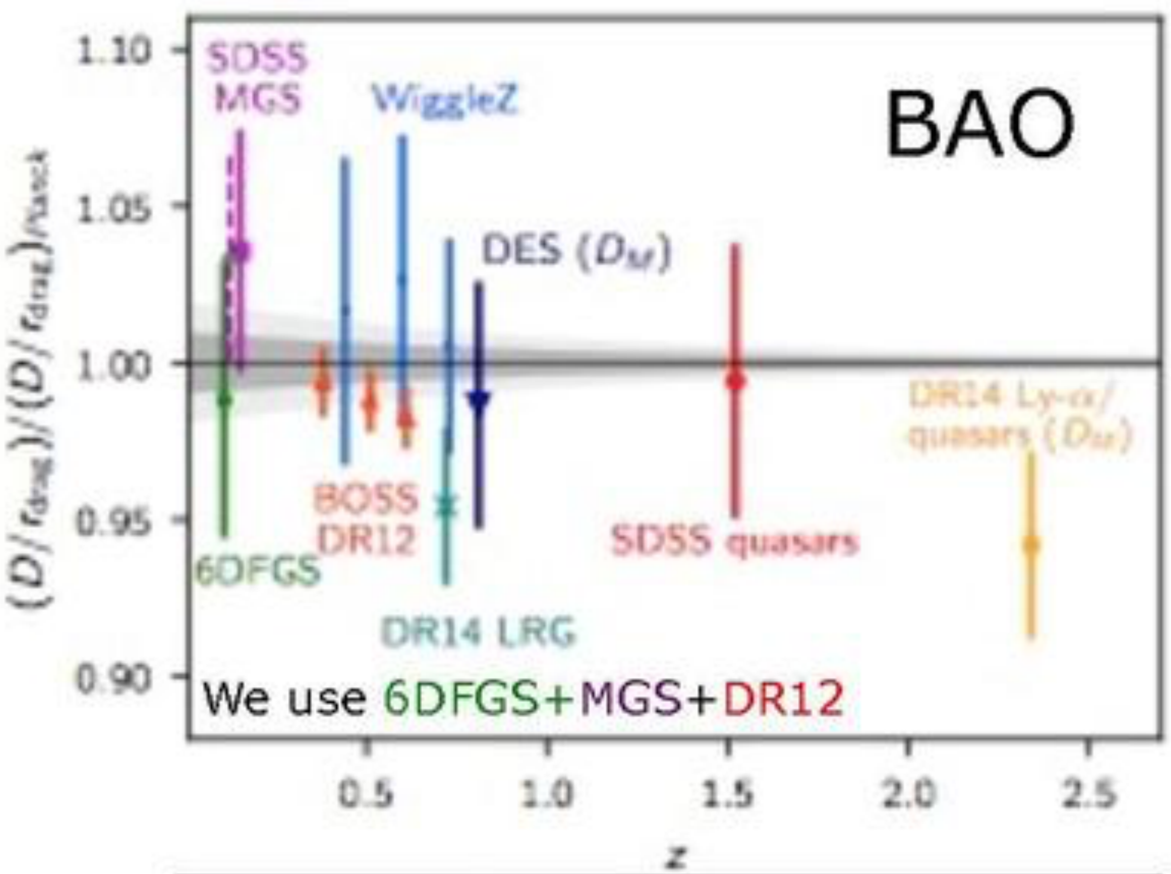
Planck collaboration, arXiv:1502.01589

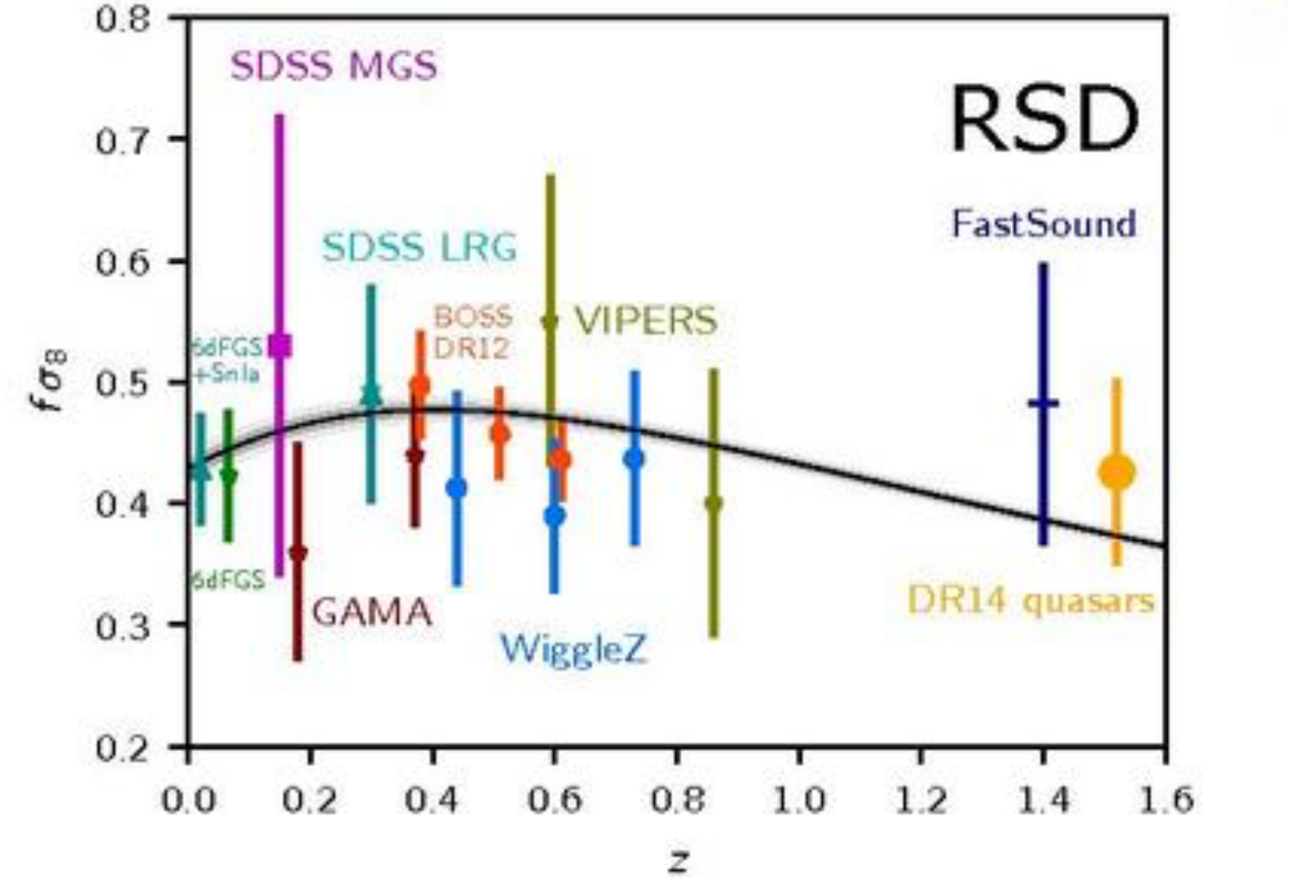
Cosmological Parameters from Planck 2018

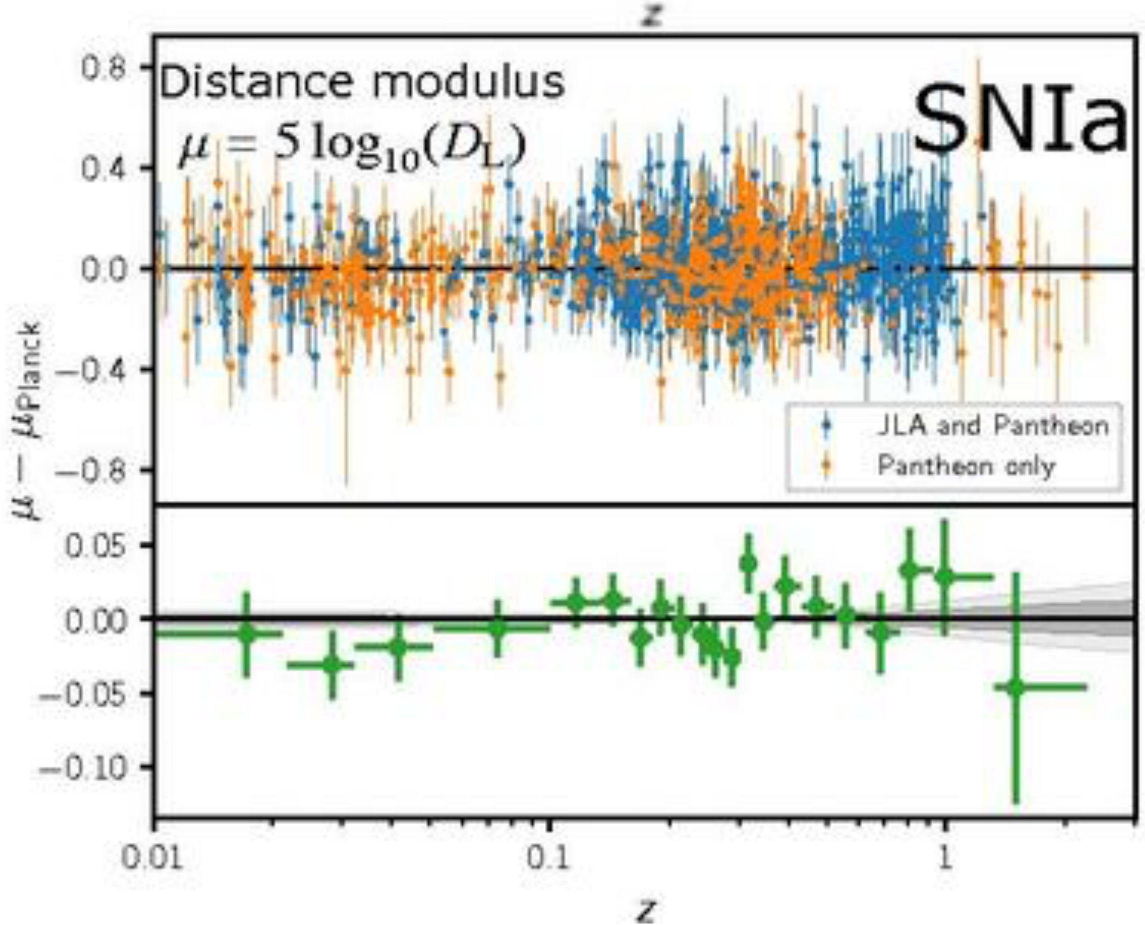
Parameter	Plik best fit	Plik [1]	CamSpec [2]	$([2]-[1])/\sigma_1$	Combined
$\Omega_b h^2$	0.022383	0.02237 ± 0.00015	0.02229 ± 0.00015	-0.5	0.02233 ± 0.00015
$\Omega_c h^2$	0.12011	0.1200 ± 0.0012	0.1197 ± 0.0012	-0.3	0.1198 ± 0.0012
$100\theta_{MC}$	1.040909	1.04092 ± 0.00031	1.04087 ± 0.00031	-0.2	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

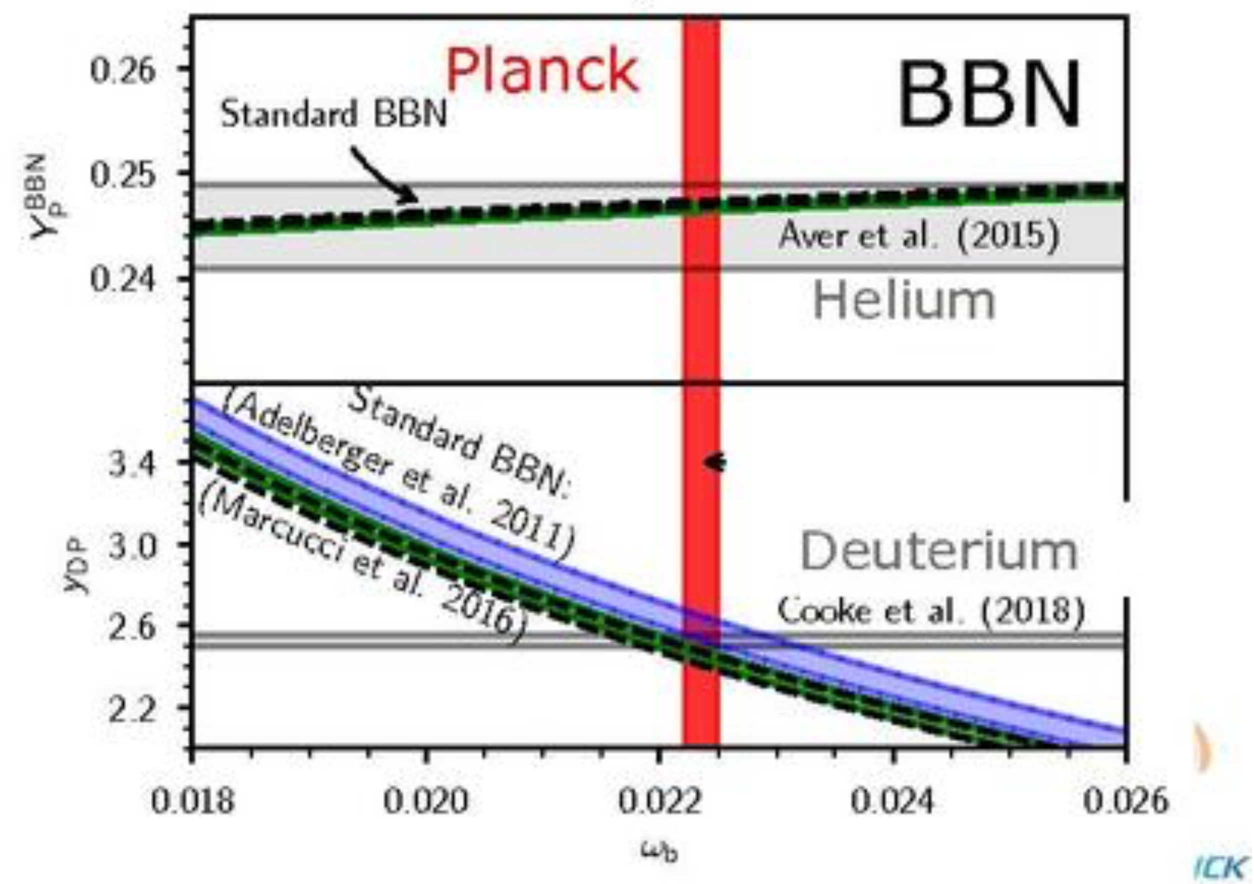
The 6 parameters of the LCDM model are measured with incredible precision. From these parameters we can also derive precise constraints on more parameters (like the age of the universe) that are not directly measured by the CMB.

Good consistency with BAO, RSD, SnIa, BBN









Planck 2018 results. VI. Cosmological parameters

• The 6-parameter base-ΛCDM model provides a good fit to the *Planck* TT, TE, and EE power spectra and to the *Planck* CMB lensing measurements, either individually or in combination with each other.

The clustering of galaxies in the completed SDSS-III Baryon Oscillation Spectroscopic Survey: cosmological analysis of the DR12 galaxy sample

4) Combining with the Planck 2015 power spectrum likelihood, we find no preference for a model that includes additional parameters beyond the vanilla spatially flat ΛCDM model. This remains true when combined with JLA SNe data.

Dark Energy Survey Year 1 Results: Cosmological Constraints from Cosmic Shear

$w = -0.82^{+0.26}_{-0.48}$. We find no evidence preferring the addition of $w \neq -1$ using cosmic shear alone, and no constraint beyond our prior on the neutrino mass density.

Our constraints from cosmic shear lie between the previous cosmic shear results from KiDS-450 and CMB data from Planck. Though we find results that are consistent with previous cosmic shear constraints in $S_8 - \Omega_m$, preferring a slightly lower value of S_8 than Planck, we nevertheless see no evidence for disagreement of our weak lensing data with data from the CMB. Significantly tighter cosmological constraints

Measuring Dark Energy Properties with Photometrically Classified Pan-STARRS Supernovae. II. Cosmological Parameters

After including CMB data, we find that PS1 SN data are fully consistent with a flat ΛCDM cosmology, with w =-0.986±0.058. Combining SNe with CMB and BAO constraints gives w = -0.984±0.048 and adding H_0 constraints yields w = -1.040±0.046. If we allow w to be parameterized by a constant component (w_0) and a component that evolves with redshift (w_a), we find no evidence for a z-dependent value of w. Our constraints differ from

Improved cosmological constraints from a joint analysis of the SDSS-II and SNLS supernova samples

Combining our sample with the *Planck* CMB measurement, we find no evidence for dynamical dark energy. Assuming a flat universe, we measure a constant dark-energy equation of state parameter of $w = -1.018 \pm 0.057$, where both statistical and systematic uncertainties are included. In all the cases we considered, our results are compatible with the cosmological constant hypothesis.

No evidence for extensions to the standard cosmological model

The main aim of this paper is to compute Bayesian Evidence values for the many models and datasets produced in the primary *Planck* analysis, where we find that the 6-parameter flat ΛCDM model is preferred, with no evidence in favour of extensions. As is usual with Evidence

CONSEQUENCES I: WE CAN TEST FUNDAMENTAL PHYSICS WITH COSMOLOGY.

arXiv.org > astro-ph > arXiv:1911.09073

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Astrophysics > Cosmology and Nongalactic Astrophysics

Hints, neutrino bounds and WDM constraints from SDSS DR14 Lyman-α and Planck full-survey data

Nathalie Palanque-Delabrouille, Christophe Yèche, Nils Schöneberg, Julien Lesgourgues, Michael Walther, Solène Chabanier, Eric Armengaud

(Submitted on 20 Nov 2019 (v1), last revised 21 Nov 2019 (this version, v2))

The Ly-α forest 1D flux power spectrum is a powerful probe of several cosmological parameters. Assuming a ΛCDM cosmology including massive neutrinos, we find that the latest SDSS DR14 BOSS and eBOSS Ly-α forest data is in very good agreement with current weak lensing constraints on (Ω_m, σ_8) and has the same small level of tension with Planck. We did not identify a systematic effect in the data analysis that could explain this small tension, but we show that it can be reduced in extended cosmological models where the spectral index is not the same on the very different times and scales probed by CMB and Ly-α data. A particular case is that of a ΛCDM model including a running of the spectral index on top of massive neutrinos. With combined Ly-α and Planck data, we find a slight (3σ) preference for negative running, $\alpha_s = -0.010 \pm 0.004$ (68% CL). Neutrino mass bounds are found to be robust against different assumptions. In the ΛCDM model with running, we find $\sum m_\nu < 0.11$ eV at the 95% confidence level for combined Ly-α and Planck (temperature and polarisation) data, or $\sum m_\nu < 0.09$ eV when adding CMB lensing and BAO data. We further provide strong and nearly model-independent bounds on the mass of thermal warm dark matter: $m_X > 10$ keV (95% CL) from Ly-α data alone.

CONSEQUENCES I: WE CAN TEST FUNDAMENTAL PHYSICS WITH COSMOLOGY.

arXiv.org > astro-ph > arXiv:2002.04035

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Astrophysics > Cosmology and Nongalactic Astrophysics

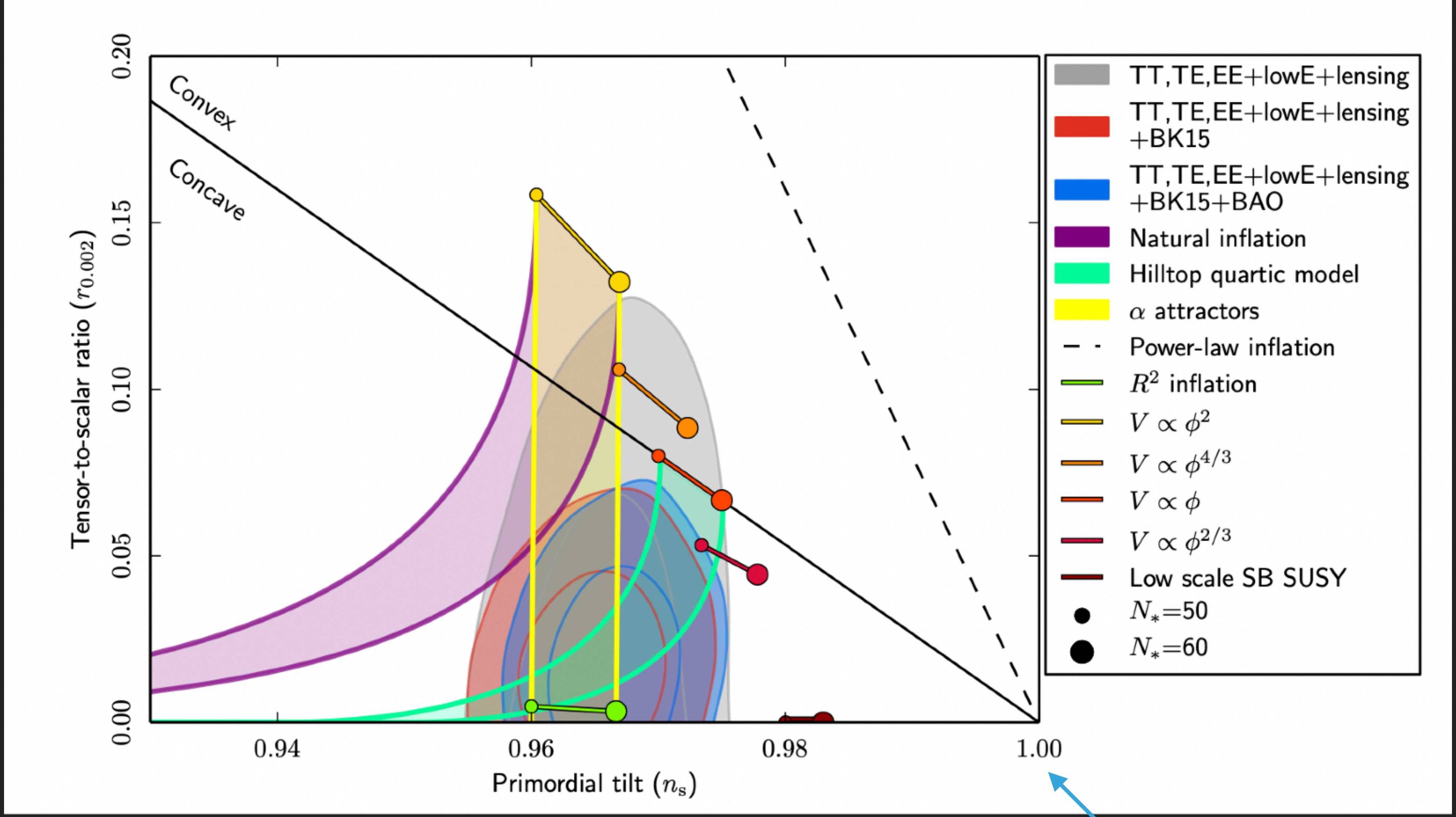
Combining Full-Shape and BAO Analyses of Galaxy Power Spectra: A 1.6% CMB-independent constraint on H0

Oliver H.E. Philcox, Mikhail M. Ivanov, Marko Simonović, Matias Zaldarriaga

(Submitted on 10 Feb 2020)

We present cosmological constraints from a joint analysis of the pre- and post-reconstruction galaxy power spectrum multipoles from the final data release of the Baryon Oscillation Spectroscopic Survey (BOSS). Geometric constraints are obtained from the positions of BAO peaks in reconstructed spectra, which are analyzed in combination with the unreconstructed spectra in a full-shape (FS) likelihood using a joint covariance matrix, giving stronger parameter constraints than BAO-only or FS-only analyses. We introduce a new method for obtaining constraints from reconstructed spectra based on a correlated theoretical error, which is shown to be simple, robust, and applicable to any flavor of density-field reconstruction. Assuming ΛCDM with massive neutrinos, we analyze clustering data from two redshift bins $z_{\rm eff} = 0.38, 0.61$ and obtain 1.6% constraints on the Hubble constant H_0, using only a single prior on the current baryon density ω_b from Big Bang Nucleosynthesis and no knowledge of the power spectrum slope n_s. This gives $H_0 = 68.6 \pm 1.1\,\mathrm{km\,s^{-1}Mpc^{-1}}$, with the inclusion of BAO data sharpening the measurement by 40%, representing one of the strongest current constraints on H_0 independent of cosmic microwave background data. Restricting to the best-fit slope n_s from Planck (but without additional priors on the spectral shape), we obtain a 1% H_0 measurement of $67.8 \pm 0.7\,\mathrm{km\,s^{-1}Mpc^{-1}}$. Finally, we find strong constraints on the cosmological parameters from a joint analysis of the FS, BAO, and Planck data. This sets new bounds on the sum of neutrino masses $\sum m_\nu < 0.14\,\mathrm{eV}$ (at 95% confidence) and the effective number of relativistic degrees of freedom $N_{\rm eff} = 2.90^{+0.15}_{-0.16}$, though contours are not appreciably narrowed by the inclusion of BAO data.

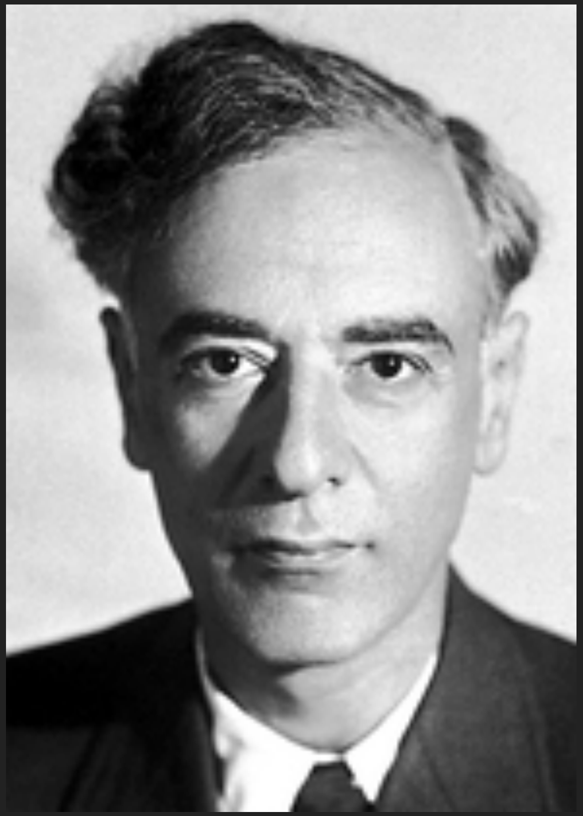
CONSEQUENCES I: WE CAN TEST FUNDAMENTAL PHYSICS WITH COSMOLOGY.



Harrison Zeldovich spectrum is highly excluded. Major evidence for inflation.

CONSEQUENCES II: WE (COSMOLOGISTS) MAY START IN LOOKING FOR ANOTHER JOB ...

BUT IT IS TRUE ?



“Cosmologists are often in error but seldom in doubt.”
Lev Landau

THE CURRENT COSMOLOGICAL SCENARIO IS BASED ON "UNKNOWN" PHYSICS

Dark Matter: needed to form structure.

Inflation: needed for primordial homogeneity

Dark Energy: needed for explaining the current state of accelerated expansion.


Cosmology
@2023
Dark Matter
Inflation
Dark Energy

THE CURRENT "STANDARD" COSMOLOGICAL MODEL IS ALSO BASED ON SEVERAL (QUESTIONABLE) ASSUMPTIONS !

WE SHOULD LOOK FOR ANOMALIES NOT BECAUSE THEY COULD PROVIDE INDICATION FOR "NEW PHYSICS" BUT BECAUSE THEY CAN SHED LIGHT ON WHAT ACTUALLY ARE DARK ENERGY, DARK MATTER AND INFLATION !

LCDM IS NOT THE COSMOLOGICAL EQUIVALENT OF THE STANDARD MODEL OF PARTICLES PHYSICS (WHERE ALL PARTICLES , CROSS SECTION, ETC HAVE BEEN MEASURED IN LABORATORY) !

DO WE HAVE ANOMALIES ?

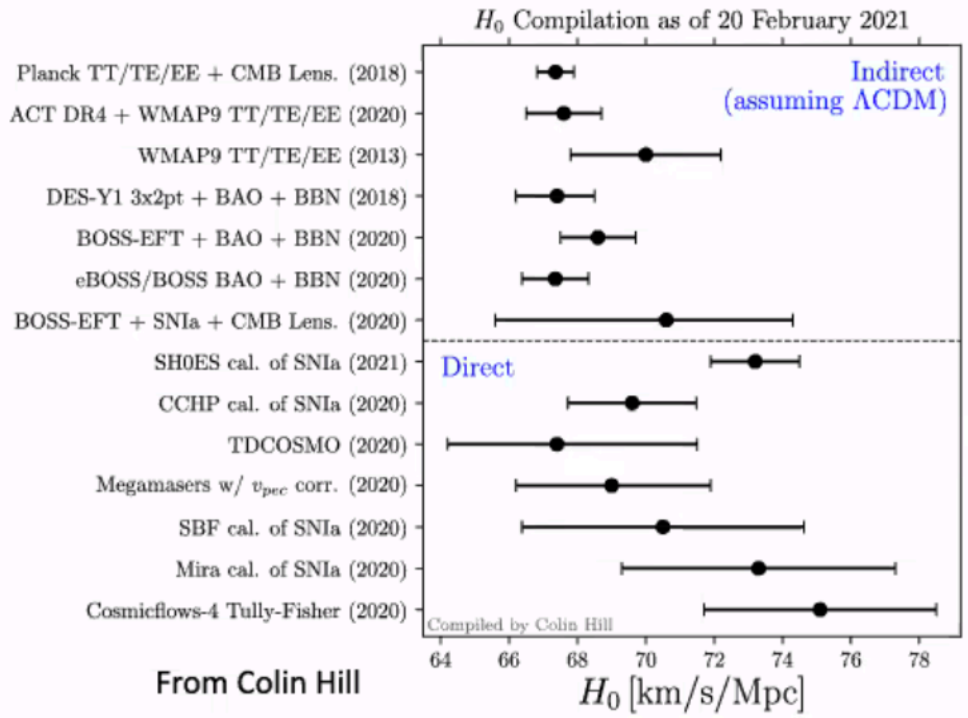
CAVEAT: This opinion is NOT shared by other cosmologists !

Some thoughts and opinions - Jo Dunkley, Grand Panel

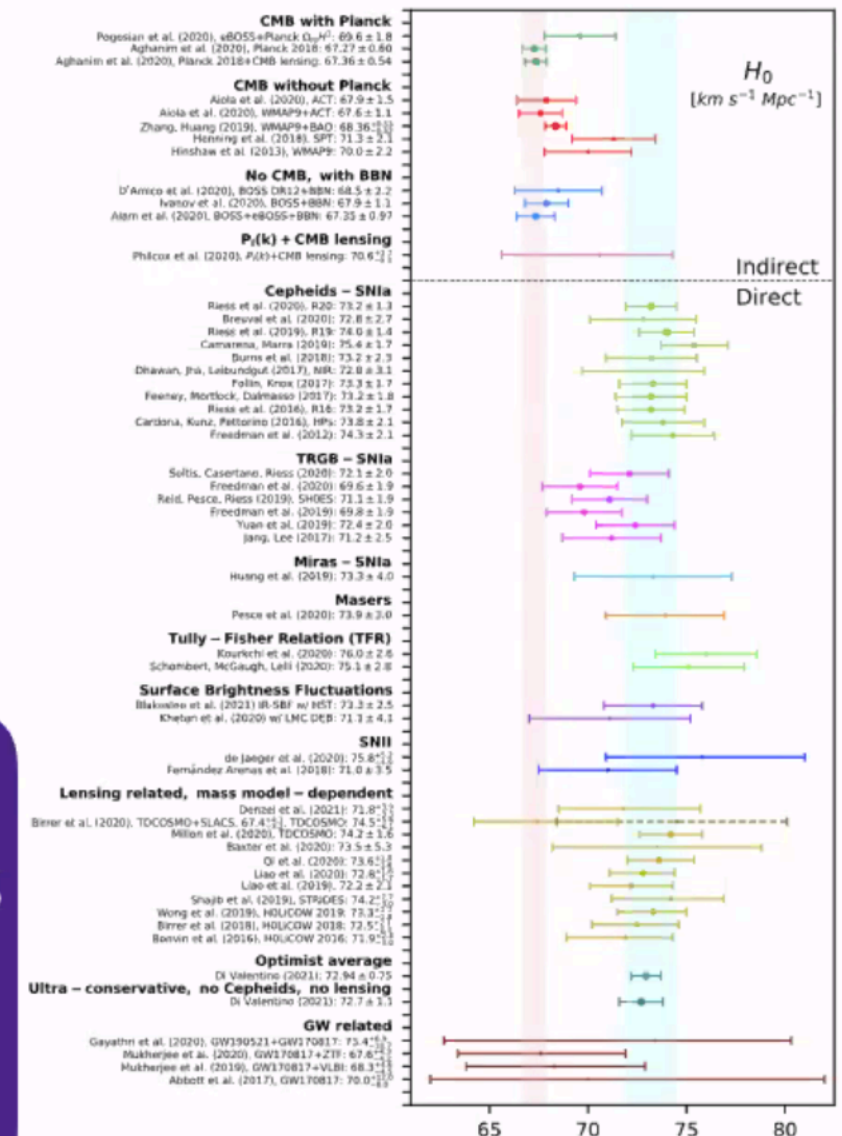
We as a community don't agree on the existence/severity of the tension

To take *really* seriously the need to abandon LCDM I would be compelled by a 5 sigma disagreement with CMB/LSS by **two different** local measurements

There are 'always' uncharacterized systematic errors - e.g. Planck estimate additional 0.5sigma



From Colin Hill



From Eleonora Di Valentino

What do I want to see next?

- Equal prior given to the SH0ES/TRGB results
- To make progress on non-LCDM, accessible CLASS/CAMB codes with modified theories, so the suite of alternatives can be easily tested with new CMB/LSS data.
- More CMB/LSS data to test the non-LCDM models
- More direct data to test the value of H0 (including GWs)

UROS SELJAK'S CONCLUDING REMARKS AT RECENT COSMOLOGY IN MIRAMARE 2023 CONFERENCE

Summary

- Lambda CDM is the current standard model of our universe and currently explains all the data
- Recent analyses do not support claims of tensions in the data (e.g. Hubble and amplitude tensions)
- Next generation surveys are coming online soon (DESI, Euclid, Rubin, SO etc.)
- Next generation analyses are being developed and in some cases will be equivalent to an order of magnitude increase in data volume

HUBBLE LAW

$$v = H_0 \times d$$

Where:

- v = velocity at which the galaxy is receding (in km/s)
- d = distance to the galaxy (in megaparsecs, Mpc)
- H_0 = **Hubble constant**, the proportionality constant (in km/s/Mpc)

Just a reminder:
– It's not a law in the strict sense.
– It's valid only at low redshifts (z < 1).
– It wasn't first discovered by Hubble.

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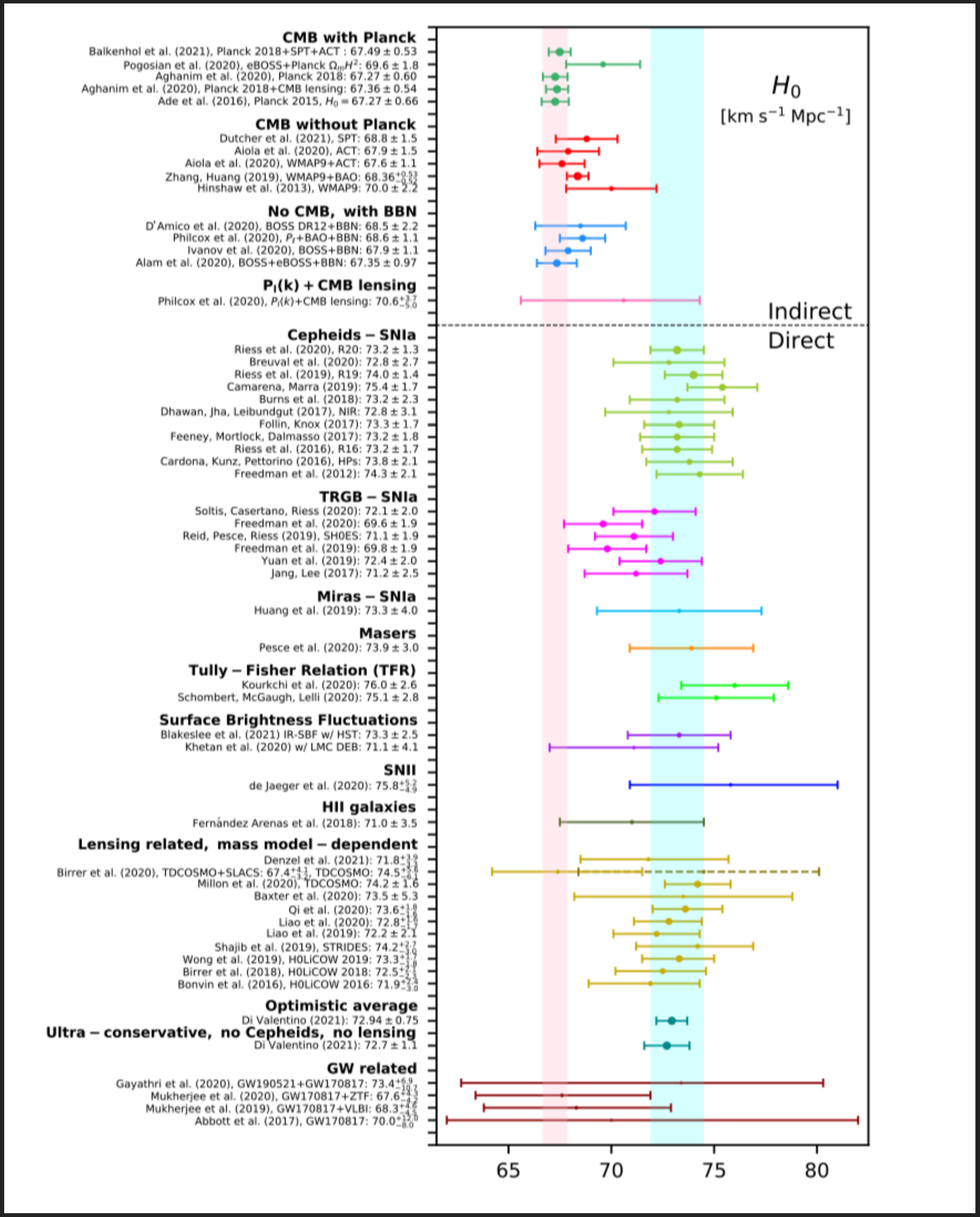
FRIEDMANN

$$\left(\frac{H(z)}{H_0}\right)^2 = \Omega_m(1+z)^3 + \Omega_r(1+z)^4 + \Omega_k(1+z)^2 + \Omega_\Lambda$$

- $H(z)$: Hubble parameter at redshift z
- H_0: Hubble constant today (i.e., $H(z=0)$)
- Ω_m: Matter density parameter (dark matter + baryonic matter)
- Ω_r: Radiation density parameter (photons + neutrinos)
- Ω_k: Curvature density parameter
- Ω_Λ: Dark energy (cosmological constant) density parameter
- $(1+z)$: Redshift factor, relates scale factor a by $a = \frac{1}{1+z}$

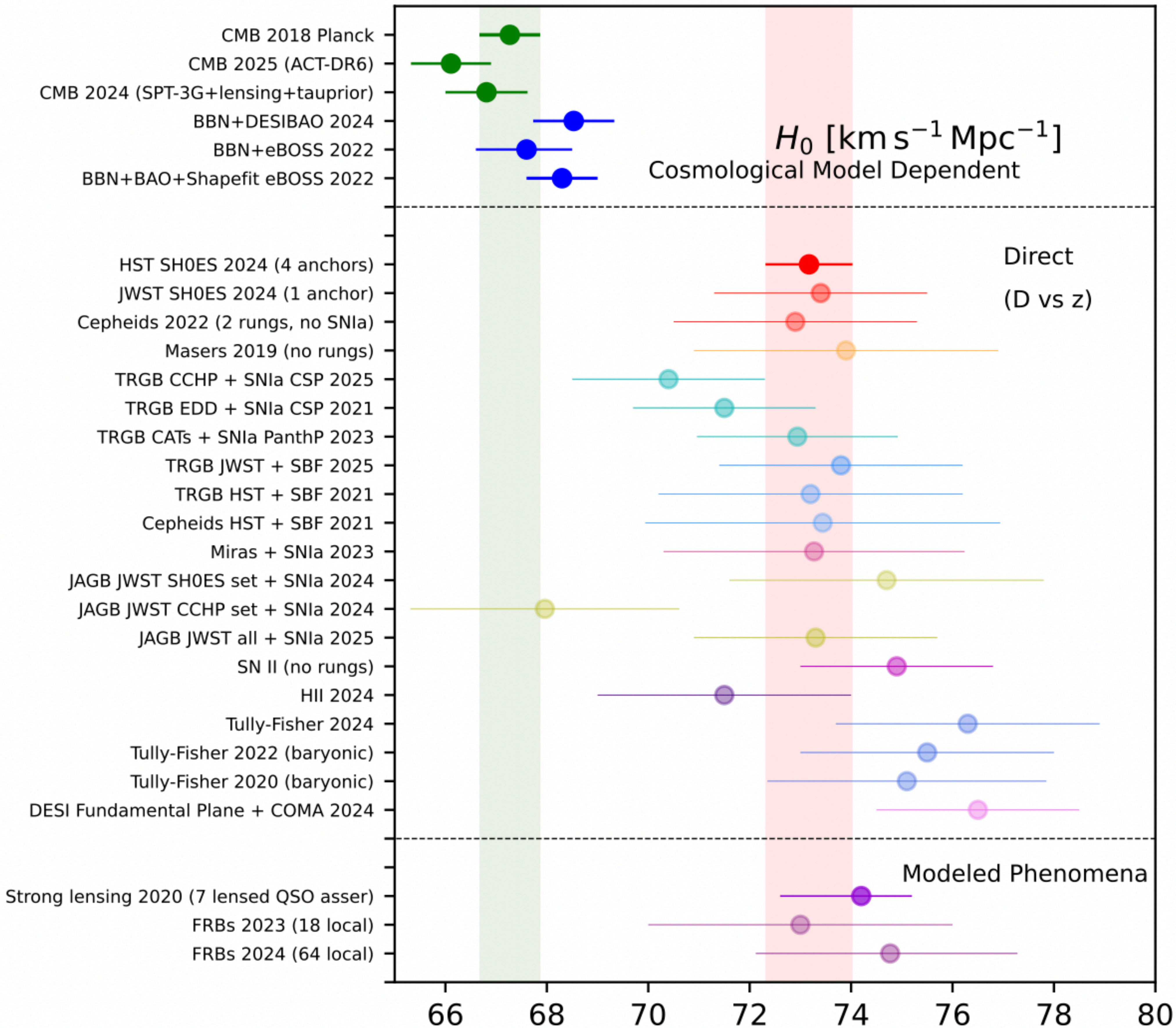
The Hubble constant enters in the Friedmann equation(s). It may be constrained also with high redshift observations.

HUBBLE TENSION



The value of the Hubble constant derived by Planck assuming LCDM (high redshift!) is (at least) 5 sigmas away from the SHOES result (low redshift).

A recent review on the subject: Di Valentino, Mena, Pan, Visinelli et al, arXiv:2103.01183



Most recent review: Di Valentino et al, https://arxiv.org/pdf/2504.01669

[Submitted on 2 Apr 2025]

The CosmoVerse White Paper: Addressing observational tensions in cosmology with systematics and fundamental physics

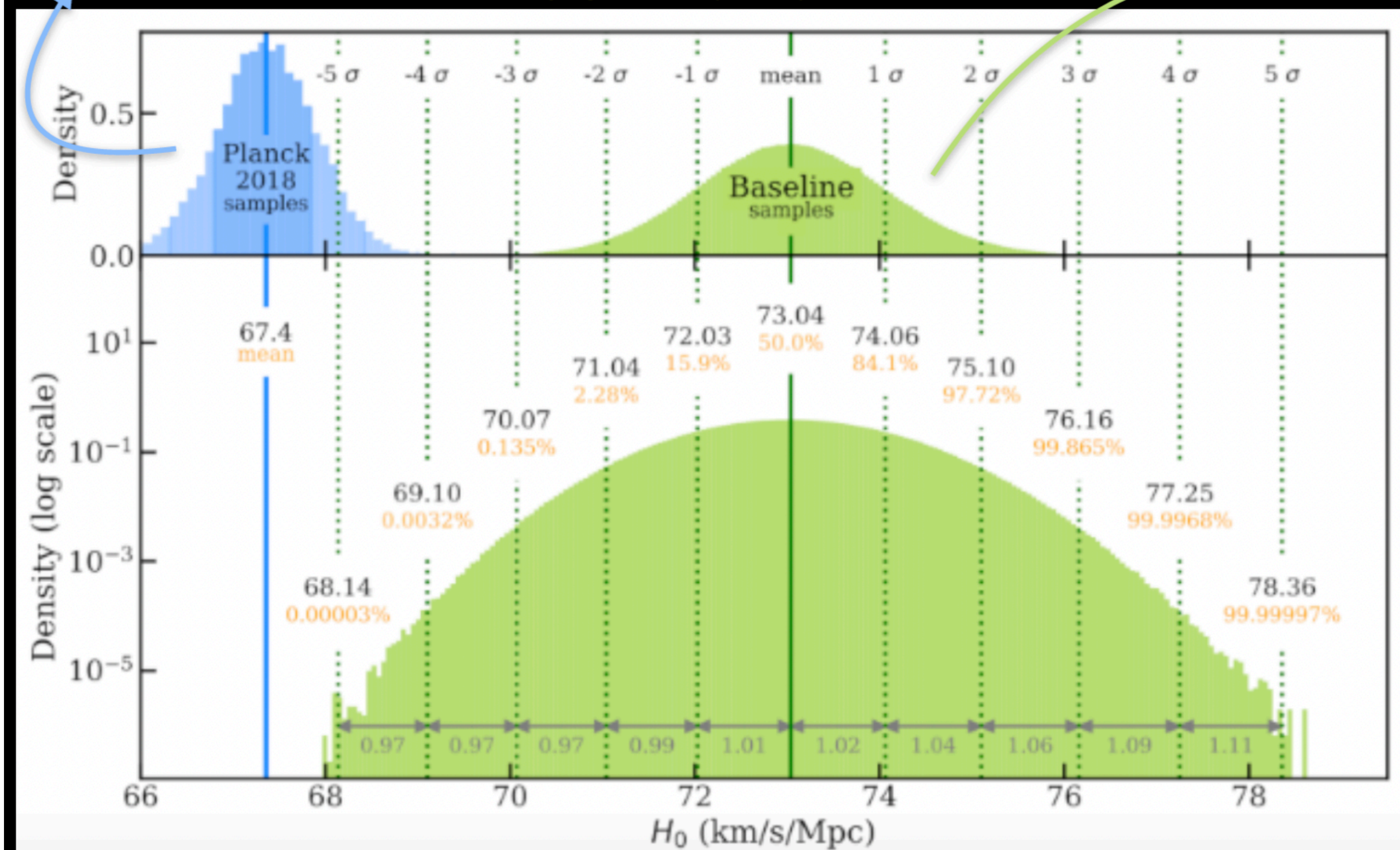
Eleonora Di Valentino, Jackson Levi Said, Adam Riess, Agnieszka Pollo, Vivian Poulin, Adrià Gómez-Valent, Amanda Weltman, Antonella Palmese, Caroline D. Huang, Carsten van de Bruck, Chandra Shekhar Saraf, Cheng-Yu Kuo, Cora Uhlemann, Daniela Grandón, Dante Paz, Dominique Eckert, Elsa M. Teixeira, Emmanuel N. Saridakis, Eoin Ó Colgáin, Florian Beutler, Florian Niedermann, Francesco Bajardi, Gabriela Barenboim, Giulia Gubitosi, Ilaria Musella, Indranil Banik, Istvan Szapudi, Jack Singal, Jaume Haro Cases, Jens Chluba, Jesús Torrado, Jurgen Mifsud, Karsten Jedamzik, Khaled Said, Konstantinos Dialektopoulos, Laura Herold, Leandros Perivolaropoulos, Lei Zu, Lluís Galbany, Louise Breuval, Luca Visinelli, Luis A. Escamilla, Luis A. Anchordoqui, M.M. Sheikh-Jabbari, Margherita Lembo, Maria Giovanna Dainotti, Maria Vincenzi, Marika Asgari, Martina Gerbino, Matteo Forconi, Michele Cantiello, Michele Moresco, Micol Benetti, Nils Schöneberg, Özgür Akarsu, Rafael C. Nunes, Reginald Christian Bernardo, Ricardo Chávez, Richard I. Anderson, Richard Watkins, Salvatore Capozziello, Siyang Li, Sunny Vagnozzi, Supriya Pan, Tommaso Treu, Vid Irsic, Will Handley, William Giarè, Yukei Murakami, Adèle Poudou, Alan Heavens, Alan Kogut, Alba Domi, Aleksander Łukasz Lenart, Alessandro Melchiorri, Alessandro Vadalà, Alexandra Amon, Alexander Bonilla, Alexander Reeves, Alexander Zhuk, Alfio Bonanno, Ali Övgün, Alice Pisani, Alireza Talebian, Amare Abebe, Amin Aboubrahim, Ana Luisa González Morán, András Kovács, Andreas Papatriantafyllou, Andrew R. Liddle, Andronikos Paliathanasis, Andrzej Borowiec, Anil Kumar Yadav, Anita Yadav, Anjan Ananda Sen, Anjitha John William Mini Latha, Anne Christine Davis, Anowar J. Shajib, Anthony Walters, Anto Idicherian Lonappan et al. (438 additional authors not shown)

H0 tension

If we compare the H0 estimates using these 2 methods they disagree.

The Planck estimate assuming a "vanilla" ΛCDM cosmological model:
H0 = 67.36 ± 0.54 km/s/Mpc

Planck 2018, Astron.Astrophys. 641 (2020) A6



The latest local measurements obtained by the SH0ES collaboration

H0=73.17 +/- 0.86 km/s/Mpc

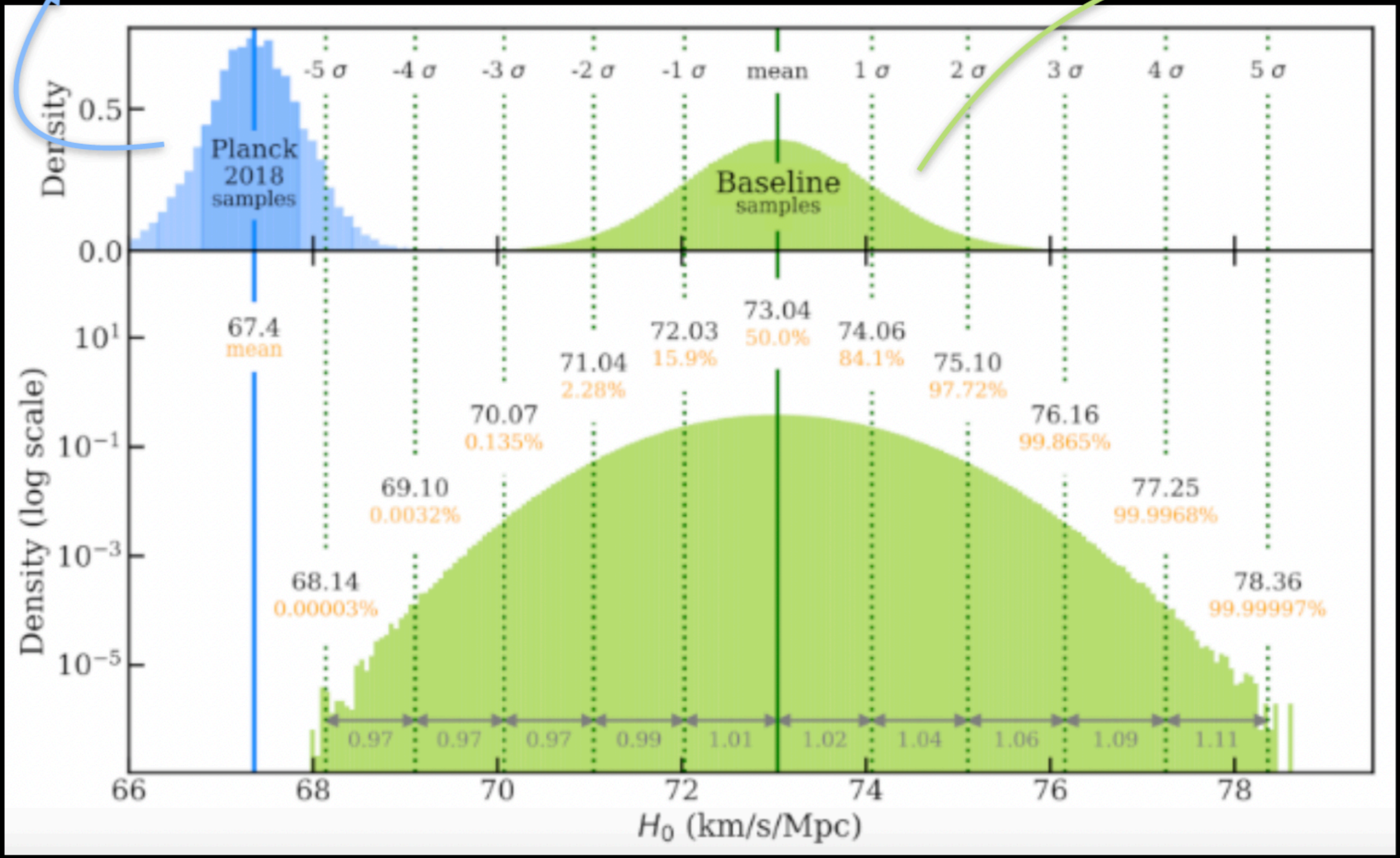
Breuval et al, 2024

5σ = one in 3.5 million implausible to reconcile the two by chance

The Planck estimate assuming a “vanilla"
ΛCDM cosmological model:
H0 = 67.36 ± 0.54 km/s/Mpc

Planck 2018, Astron.Astrophys. 641 (2020) A6

Distance Ladder



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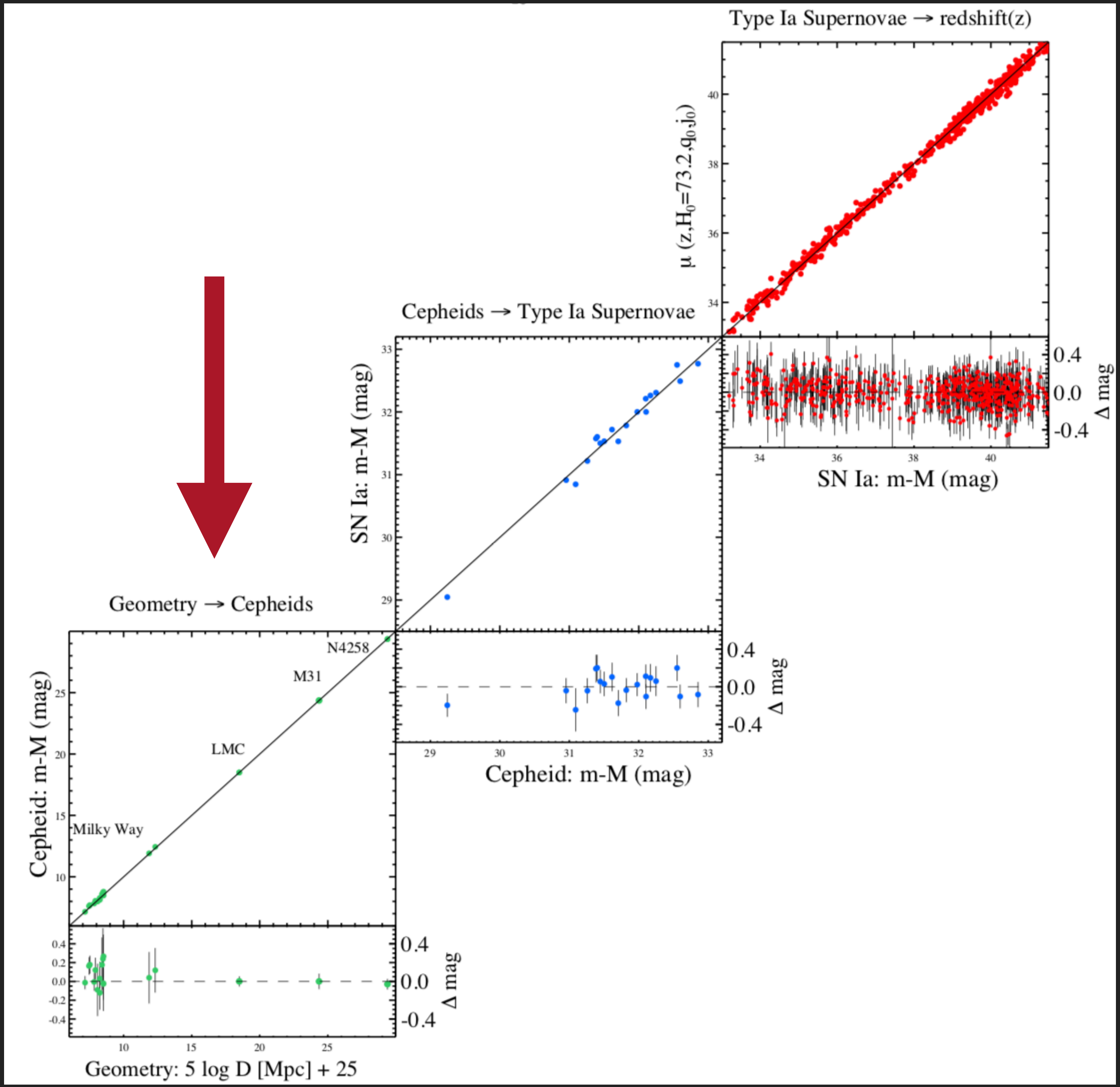
Breuval et al, 2024

HUBBLE TENSION

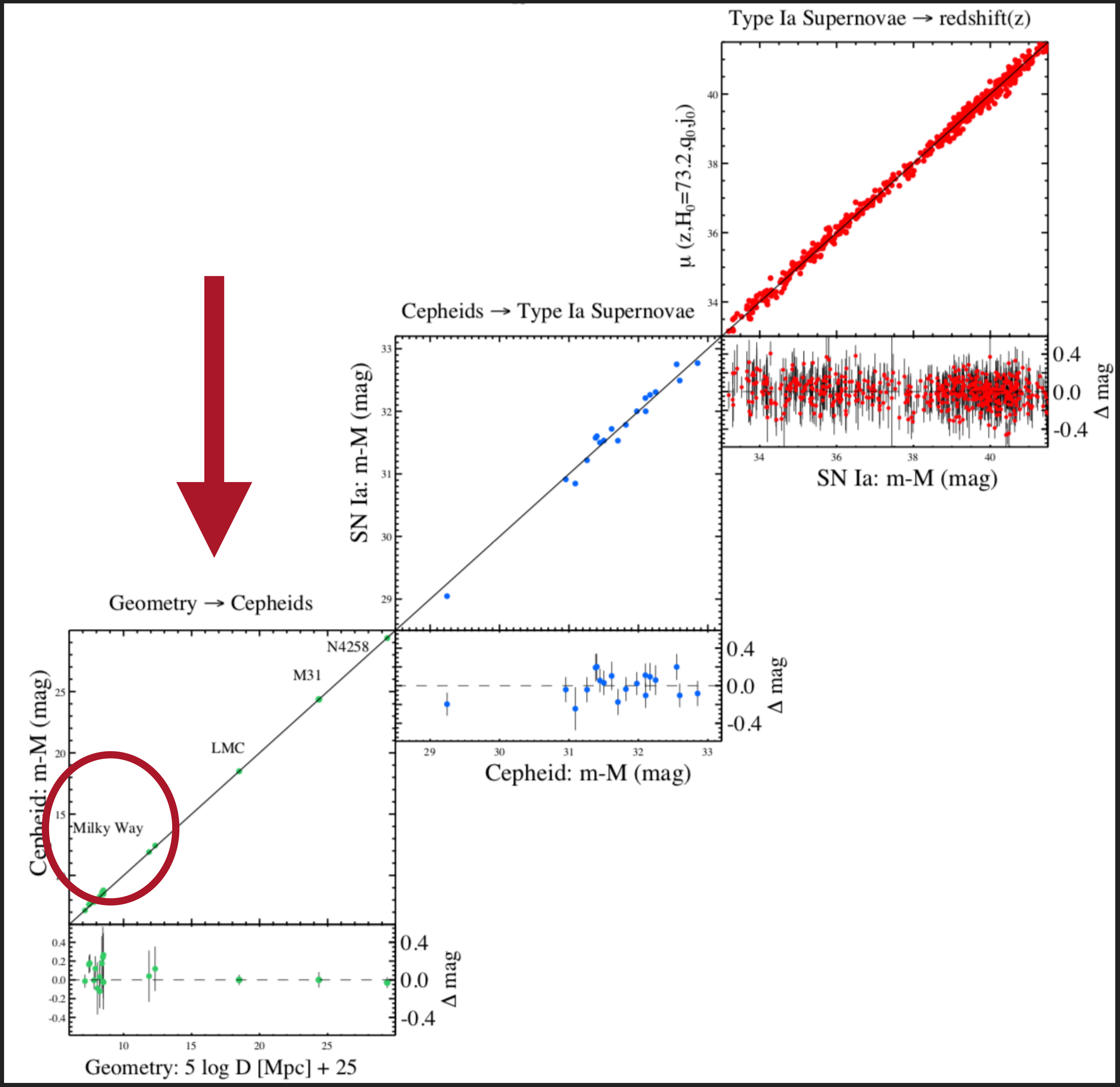
In the measurement of the **Hubble constant (H_0)** using **Cepheid variable stars**, it's crucial to **calibrate** their intrinsic brightness accurately. This calibration relies on using **"anchor" galaxies or systems** where the distance is already well known by **independent geometric methods**.



HUBBLE TENSION

1. **Milky Way (MW) Cepheids – Parallax Measurements**

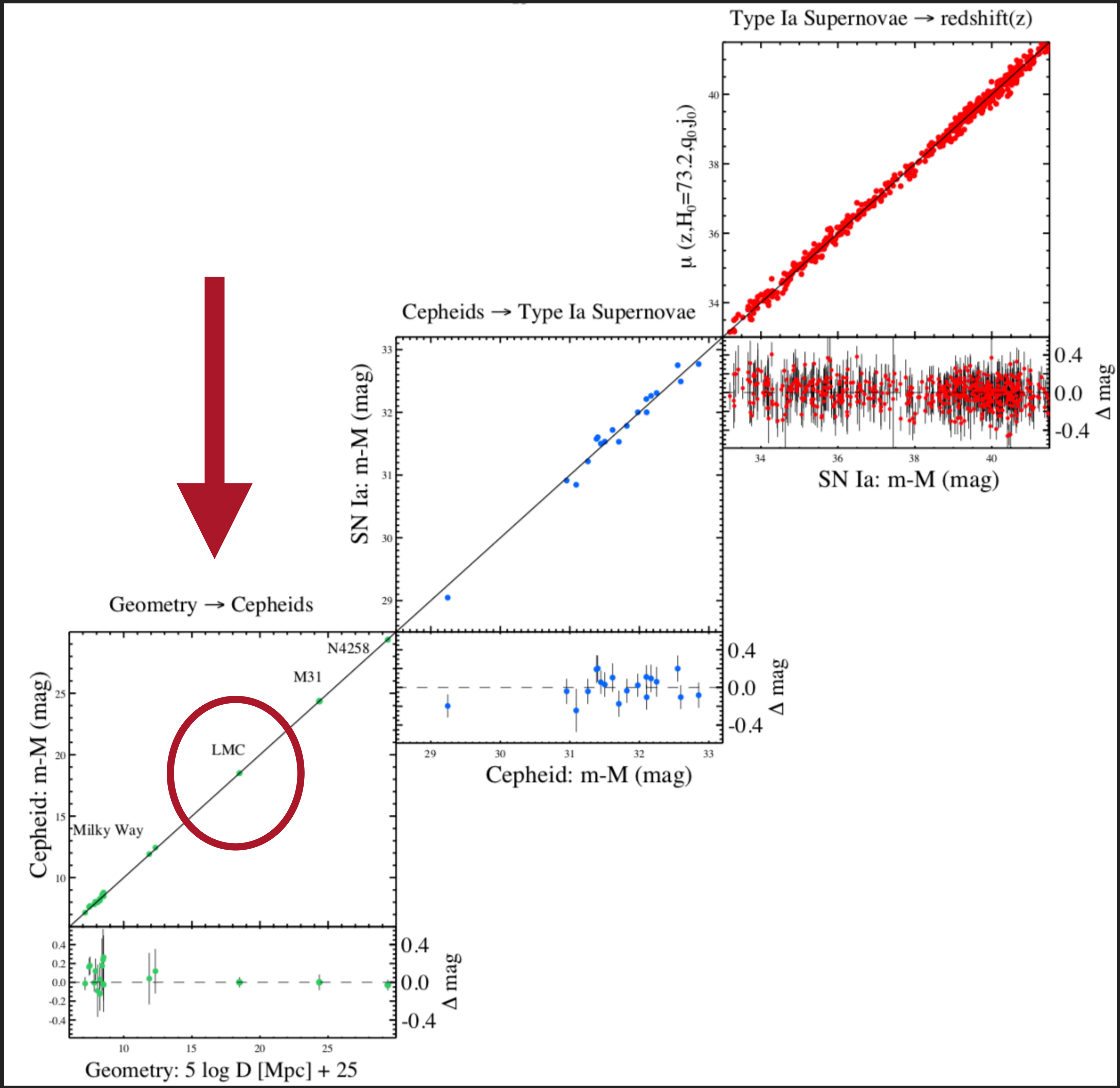
- **Method:** Geometric parallax using Hubble Space Telescope (HST) and now **Gaia**.
- **Why important:** These are **individual Cepheids** in our own galaxy with **direct distance measurements**.
- **Uncertainty:** Improving rapidly with Gaia DR3+.



HUBBLE TENSION

2. Large Magellanic Cloud (LMC) – Detached Eclipsing Binaries

- **Method:** Distance to LMC determined from **detached eclipsing binary systems (DEBs)**.
- **Why important:** Provides an independent and very precise measurement to a **galaxy rich in Cepheids**.
- **Uncertainty:** ~1.2% (extremely precise for extragalactic standards).



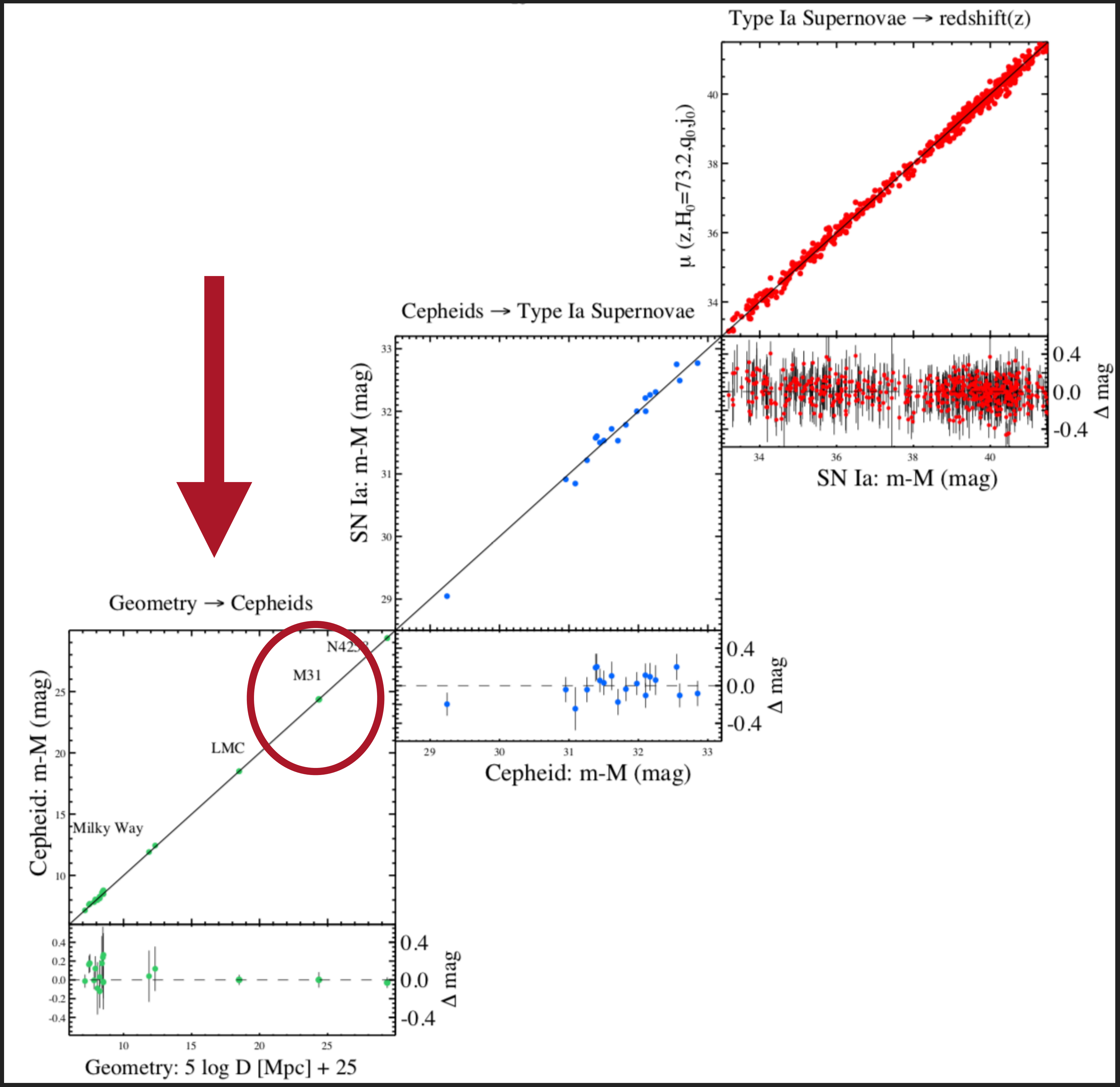
HUBBLE TENSION

3. M31 (Andromeda)

– Detached Eclipsing Binaries

- **Tip of the Red Giant Branch.**
- **The Tip of the Red Giant Branch (TRGB) is the point where low-mass stars reach their brightest moment before igniting helium in their cores. It appears as a sharp cutoff in brightness in a galaxy's color-magnitude diagram.**

- The TRGB has a **nearly constant absolute magnitude** (especially in the I-band).
- It serves as a **standard candle** to measure accurate distances to galaxies, especially those without Cepheids.
- It is especially reliable in **old stellar populations** and **low-metallicity environments**.



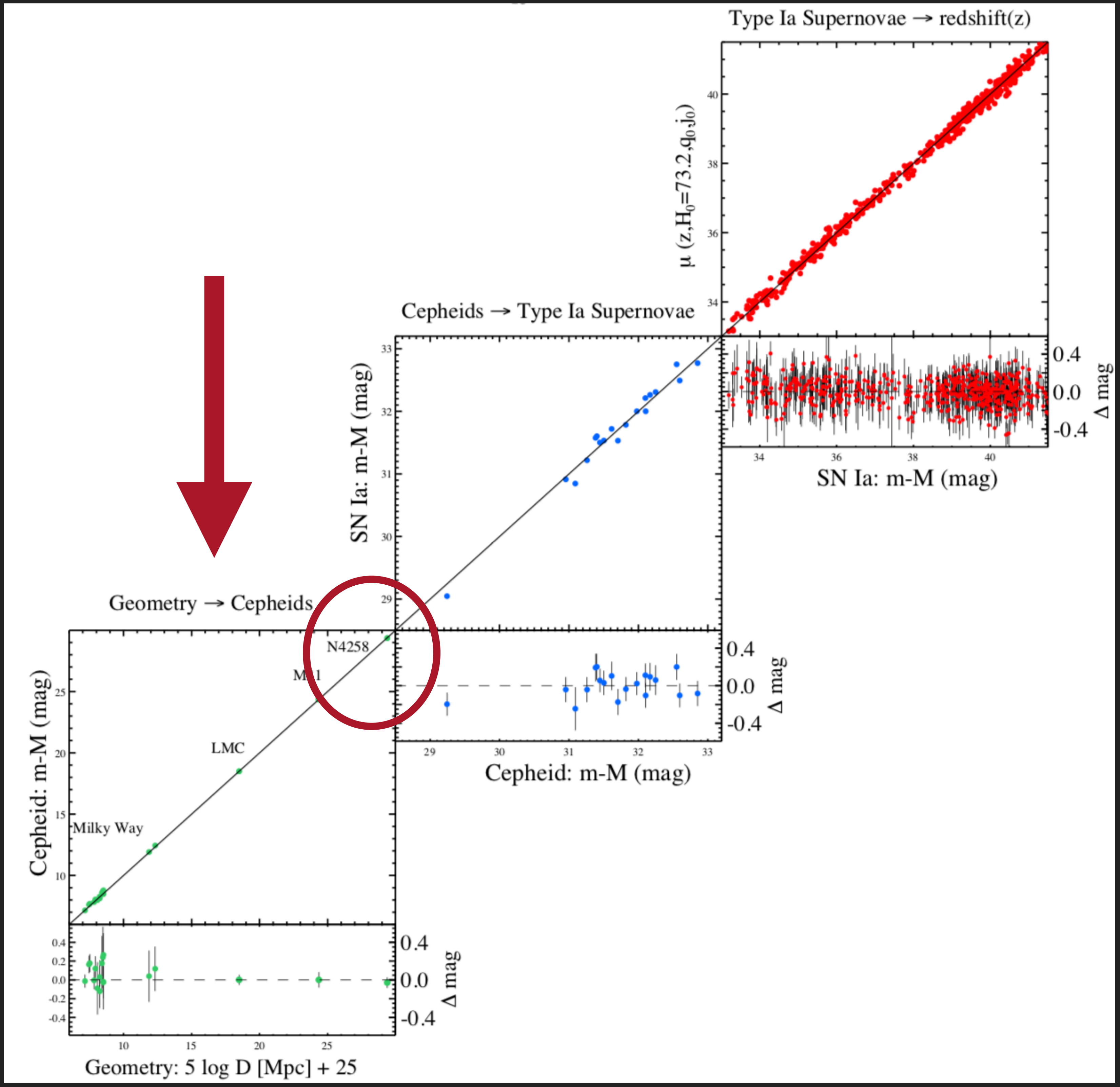
HUBBLE TENSION

3. NGC 4258 – Megamaser Galaxy

- **Method:** Very Long Baseline Interferometry (VLBI) observations of **water masers** orbiting the central black hole.
- **You measure velocity of the masers (from redshift/blueshift and angular size of the disk)**

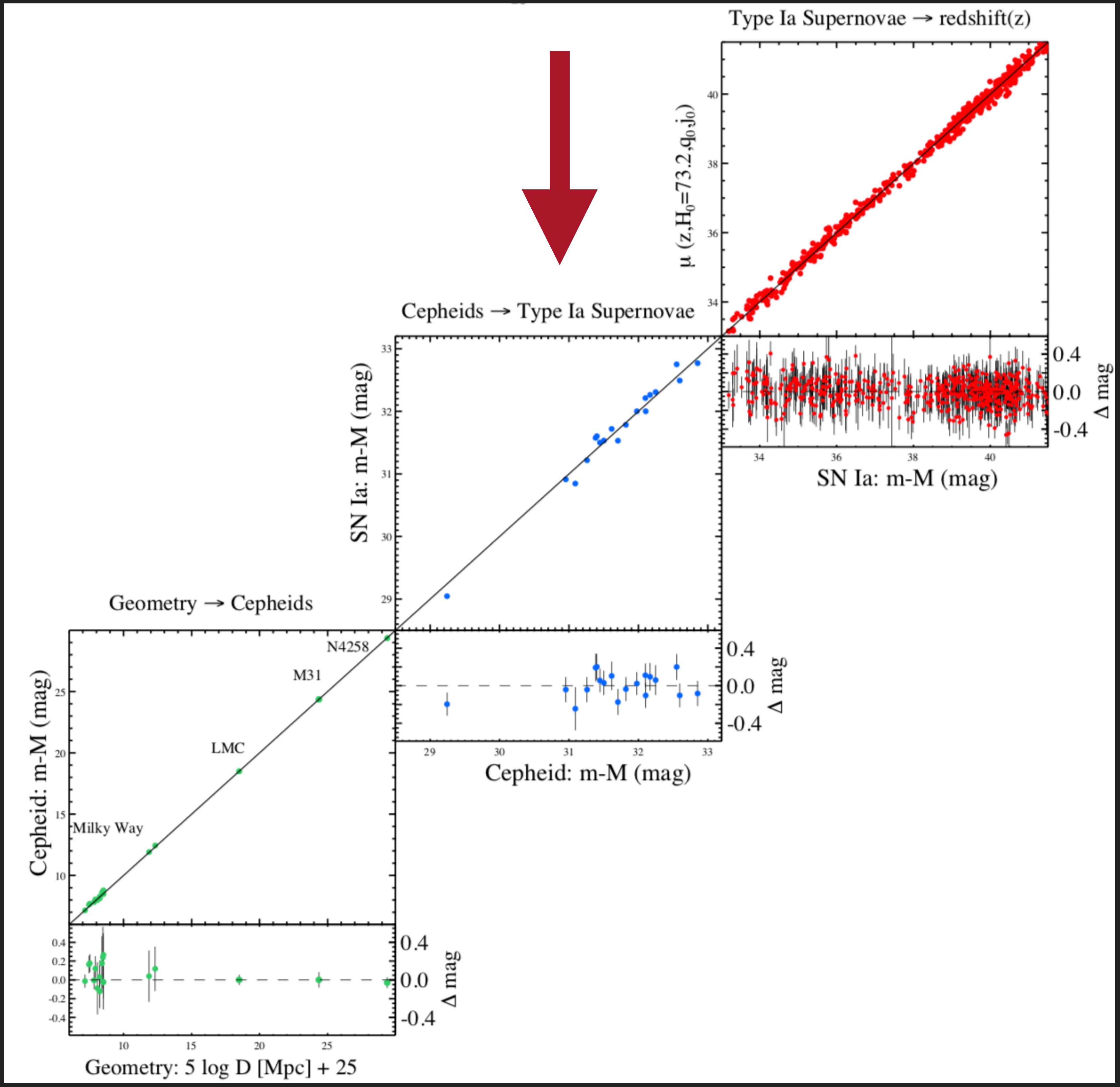
$$v = \sqrt{\frac{GM}{r}} \quad \text{and} \quad \theta = \frac{r}{D}$$

- **Uncertainty:** ~3% in distance, highly reliable and independent of stellar models.

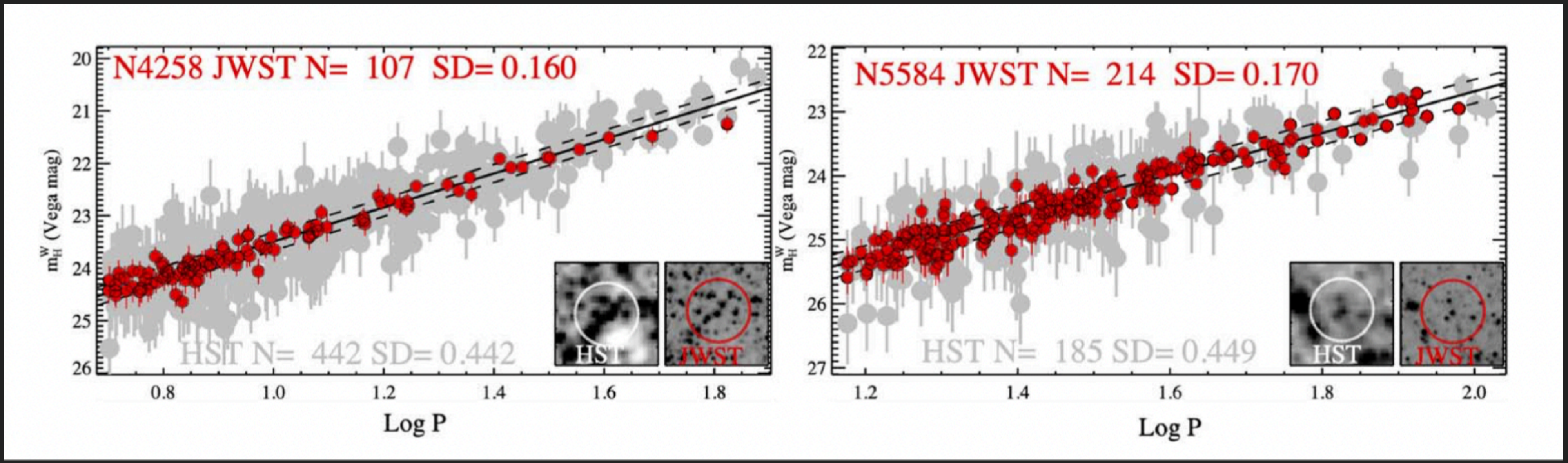


HUBBLE TENSION

Step 2: You use Cepheids to calibrate SN-Ia



CROWDING AND JWST



Crowding happens when **multiple stars appear very close together on the sky**, especially in the **dense regions of distant galaxies**.

In this case:

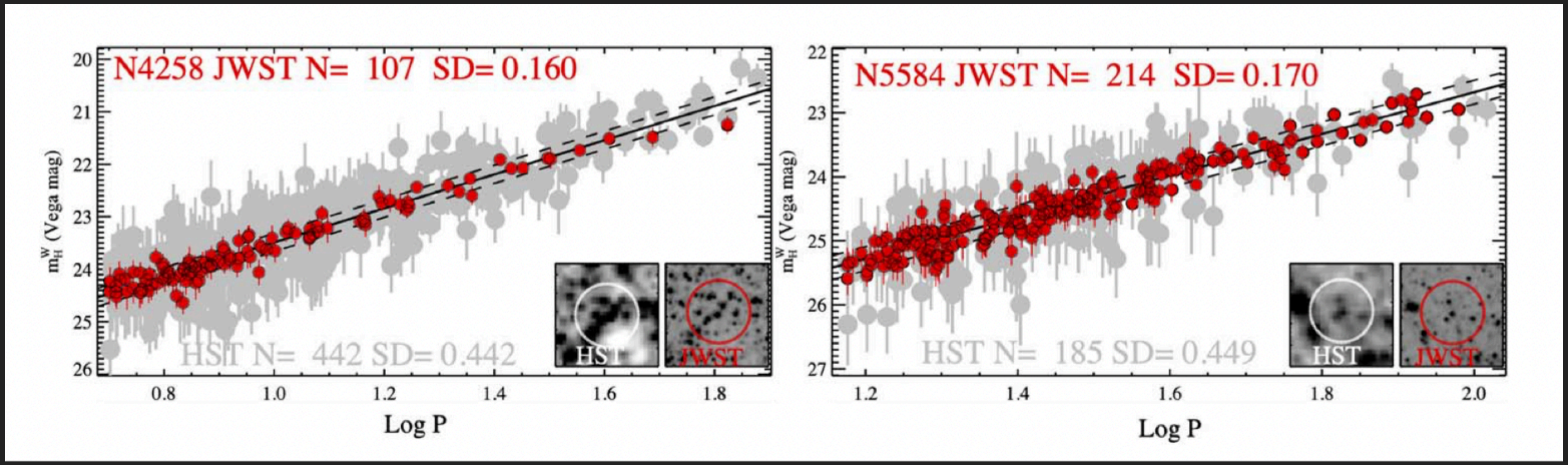
- The telescope can't resolve them as separate stars
- The light from **neighboring stars blends** with the Cepheid
- This makes the **Cepheid appear brighter** than it really is

If a Cepheid looks **too bright**, you:

- **Underestimate the distance** to the galaxy
- **Overestimate the Hubble constant (H_0)** when building the distance ladder

This is a **systematic error** that affects the reliability of cosmological measurements using Cepheids.

CROWDING AND JWST



JWST (James Webb Space Telescope) dramatically improves this situation:

1. Higher spatial resolution

- JWST has **~2× better angular resolution** than Hubble in the near-infrared (especially with NIRCam)
- This means it can **separate individual stars** in crowded fields that were previously blended

2. Better photometric precision

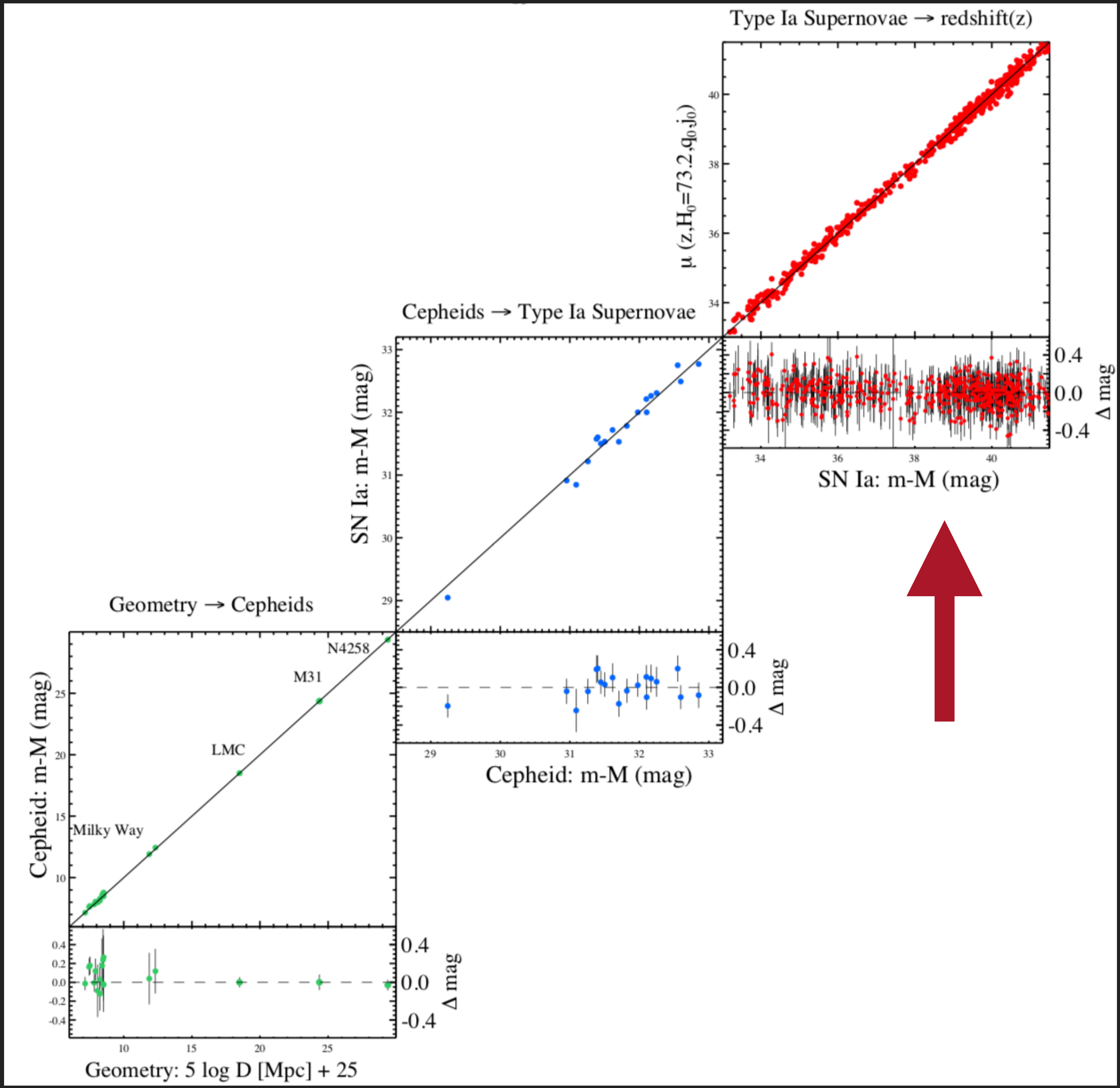
- More accurate **brightness measurements** of Cepheids
- Less contamination from background stars → more reliable light curves

3. Longer wavelengths (IR)

- Infrared observations are **less affected by dust**, and also:
- **Reduce the effect of crowding**, because the surrounding population is dimmer in the IR.

HUBBLE TENSION

Step 3: You use SN-Ia to measure Hubble law and determine H0



arXiv > astro-ph > arXiv:2404.08038

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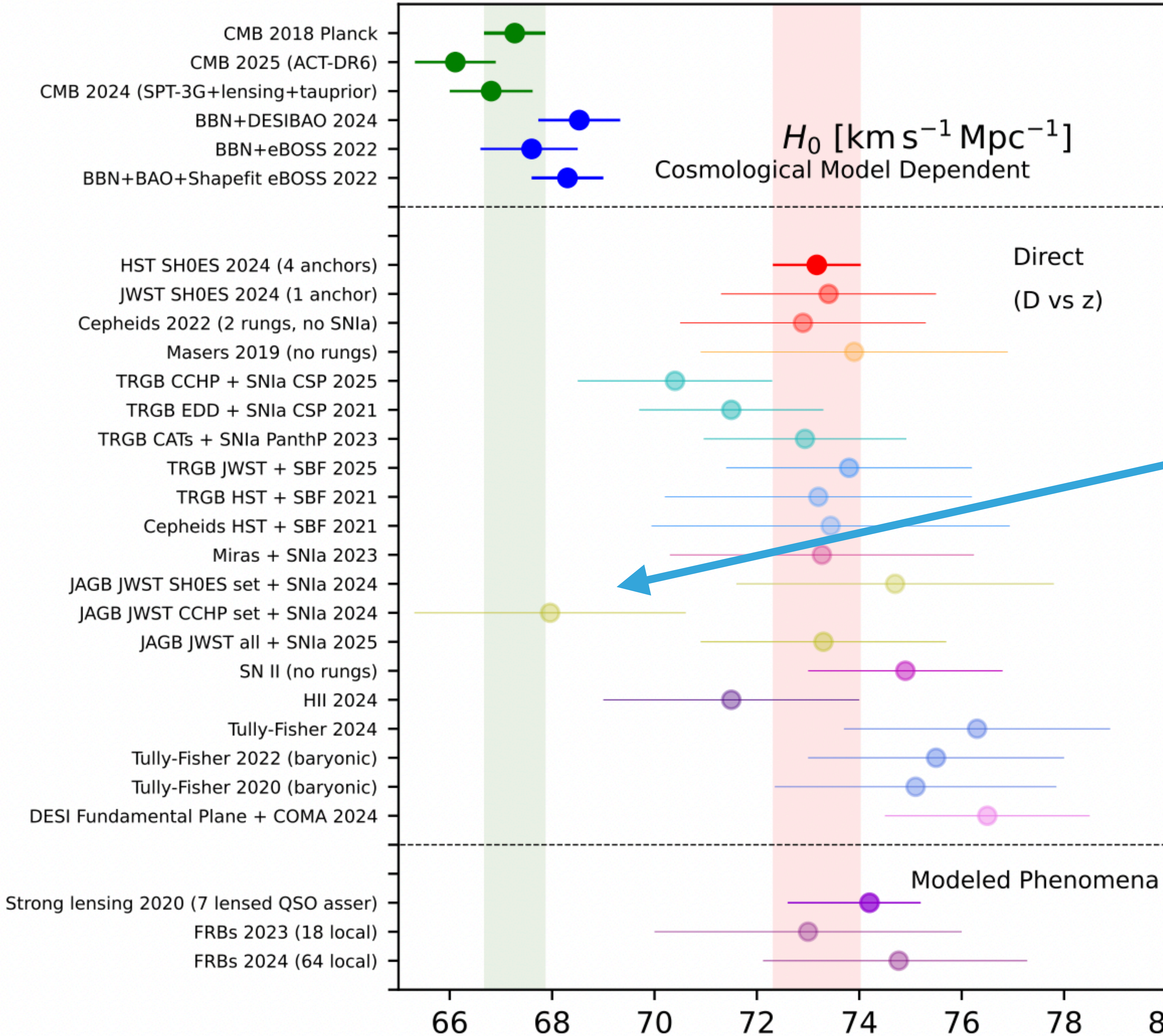
[Submitted on 11 Apr 2024]

Small Magellanic Cloud Cepheids Observed with the Hubble Space Telescope Provide a New Anchor for the SH0ES Distance Ladder

Louise Breuval, Adam G. Riess, Stefano Casertano, Wenlong Yuan, Lucas M. Macri, Martino Romaniello, Yukei S. Murakami, Daniel Scolnic, Gagandeep S. Anand, Igor Soszyński

We present photometric measurements of 88 Cepheid variables in the core of the Small Magellanic Cloud (SMC), the first sample obtained with the Hubble Space Telescope (HST) and Wide Field Camera 3, in the same homogeneous photometric system as past measurements of all Cepheids on the SH0ES distance ladder. We limit the sample to the inner core and model the geometry to reduce errors in prior studies due to the non-trivial depth of this Cloud. Without crowding present in ground-based studies, we obtain an unprecedentedly low dispersion of 0.102 mag for a Period-Luminosity relation in the SMC, approaching the width of the Cepheid instability strip. The new geometric distance to 15 late-type detached eclipsing binaries in the SMC offers a rare opportunity to improve the foundation of the distance ladder, increasing the number of calibrating galaxies from three to four. With the SMC as the only anchor, we find $H_0 = 74.1 \pm 2.1$ km s^{-1} Mpc^{-1}. Combining these four geometric distances with our HST photometry of SMC Cepheids, we obtain $H_0 = 73.17 \pm 0.86$ km s^{-1} Mpc^{-1}. By including the SMC in the distance ladder, we also double the range where the metallicity ([Fe/H]) dependence of the Cepheid Period-Luminosity relation can be calibrated, and we find $\gamma = -0.22 \pm 0.05$ mag dex^{-1}. Our local measurement of H_0 based on Cepheids and Type Ia supernovae shows a 5.8σ tension with the value inferred from the CMB assuming a ΛCDM cosmology, reinforcing the possibility of physics beyond ΛCDM.



Several other methods

agree with HST shoes.

But this recent one

seems to disagree.

What's that?

Most recent review: Di Valentino et al, https://arxiv.org/pdf/2504.01669

J-band Asymptotic Giant Branch (JAGB)

Using **J-band Asymptotic Giant Branch (JAGB)** stars to determine the **Hubble constant (H_0)** is a **new and promising method** for building the **cosmic distance ladder**, independently of Cepheids or TRGB.

Here's how it works:

- The **brightest AGB stars** (JAGB) in the **J-band (~1.2 μm)** have a **nearly constant absolute magnitude** (like standard candles)
- These stars appear in **old stellar populations** (e.g., halos of galaxies, elliptical galaxies)
- Their brightness cutoff can be measured in **color–magnitude diagrams (CMDs)**
- Less affected by dust than optical methods

In practice, the **absolute magnitude** of the JAGB tip in the J-band is approximately:

M_[JAGB] ≈−6.2±0.1

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[Submitted on 9 Jan 2024 (v1), last revised 29 Feb 2024 (this version, v2)]

Reconnaissance with JWST of the J-region Asymptotic Giant Branch in Distance Ladder Galaxies: From Irregular Luminosity Functions to Approximation of the Hubble Constant

Siyang Li, Adam G. Riess, Stefano Casertano, Gagandeep S. Anand, Daniel M. Scolnic, Wenlong Yuan, Louise Breuval, Caroline D. Huang

We study stars in the J-regions of the asymptotic giant branch (JAGB) of near-infrared color magnitude diagrams in the maser host NGC 4258 and 4 hosts of 6 Type Ia supernovae (SN Ia): NGC 1448, NGC 1559, NGC 5584, and NGC 5643. These clumps of stars are readily apparent near $1.0 < F150W - F277W < 1.5$ and m_{F150W} =22-25 mag with James Webb Space Telescope NIRCam photometry. Various methods have been proposed to assign an apparent reference magnitude for this recently proposed standard candle, including the mode, median, sigma-clipped mean or a modeled luminosity function parameter. We test the consistency of these by measuring intra-host variations, finding differences of up to ~0.2 mag that significantly exceed statistical uncertainties. Brightness differences appear intrinsic, and are further amplified by the non-uniform shape of the JAGB luminosity function, also apparent in the LMC and SMC. We follow a 'many methods' approach to consistently measure JAGB magnitudes and distances to the SN Ia host sample calibrated by NGC 4258. We find broad agreement with distances measured from Cepheids, tip of the red giant branch (TRGB), and Miras. However, the SN host mean distance estimated via the JAGB method necessary to estimate H_0 differs by ~0.19 mag amongst the above definitions, a result of different levels of luminosity function asymmetry. The methods yield a full range of $71 - 78$ km s^{-1} Mpc^{-1}, i.e., a fiducial result of $H_0 = 74.7 \pm 2.1$ (stat) ±2.3 (sys) (±3.1 if combined in quadrature) km s^{-1} Mpc^{-1}, with systematic errors limited by the differences in methods. Future work may seek to further standardize and refine this promising tool, making it more competitive with established distance indicators.

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[Submitted on 12 Aug 2024 (v1), last revised 17 Mar 2025 (this version, v3)]

Status Report on the Chicago-Carnegie Hubble Program (CCHP): Measurement of the Hubble Constant Using the Hubble and James Webb Space Telescopes

Wendy L. Freedman, Barry F. Madore, In Sung Jang, Taylor J. Hoyt, Abigail J. Lee, Kayla A. Owens

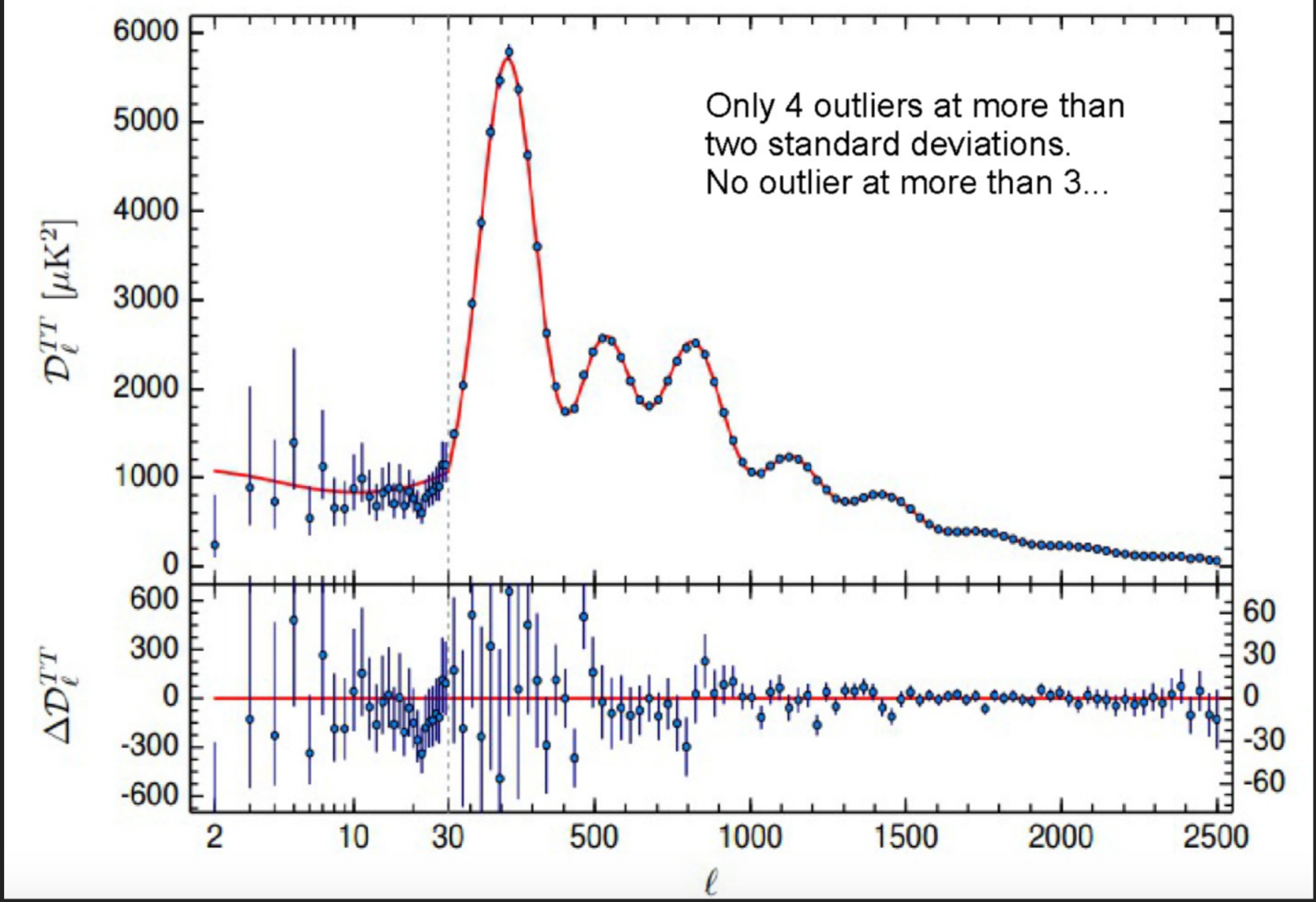
We present the latest results from the Chicago-Carnegie Hubble Program (\cchp) to measure the Hubble constant, using data from the James Webb Space Telescope (JWST). The overall program aims to calibrate three independent methods: (1) Tip of the Red Giant Branch (TRGB) stars, (2) JAGB (J-Region Asymptotic Giant Branch) stars, and (3) Cepheids. To date, our program includes 10 nearby galaxies, hosting 11 Type Ia supernovae (SNe Ia) suitable for measuring the Hubble constant (H_0). It also includes the galaxy NGC 4258, whose geometric distance provides the zero-point calibration. In this paper we discuss our results from the TRGB and JAGB methods. Our current best (highest precision) estimate is H_0 = 70.39 ± 1.22 (stat) ± 1.33 (sys) ± 0.70 (σ_{SN}), based on the TRGB method alone, with a total of 24 SN Ia calibrators from both HST and JWST data. Based on our new JWST data only, and tying into SNe Ia, we find values of H_0 = 68.81 ± 1.79 (stat) ± 1.32 (sys) for the TRGB, and H_0 = 67.80 ± 2.17 (stat) ± 1.64 (sys) km/s/Mpc for the JAGB method. The distances measured using the TRGB and the JAGB method agree, on average, at a level better than 1%, and with the SH0ES Cepheid distances at just over the 1% level. Our results are consistent with the current standard LambdaCDM model, without the need for the inclusion of additional new physics. Future JWST data will be required to increase the precision and accuracy of the local distance scale.

[Submitted on 7 Feb 2025 (v1), last revised 12 Feb 2025 (this version, v2)]

JAGB 2.0: Improved Constraints on the J-region Asymptotic Giant Branch-based Hubble Constant from an Expanded Sample of JWST Observations

Siyang Li, Adam G. Riess, Daniel Scolnic, Stefano Casertano, Gagandeep S. Anand

The J-region Asymptotic Giant Branch (JAGB) is an overdensity of stars in the near-infrared, attributed to carbon-rich asymptotic giant branch stars, and recently used as a standard candle for measuring extragalactic distances and the Hubble constant. Using JWST in Cycle 2, we extend JAGB measurements to 6 hosts of 9 Type Ia supernovae (SNe Ia) (NGC 2525, NGC 3147, NGC 3370, NGC 3447, NGC 5468, and NGC 5861), with two at $D \sim 40$ Mpc, all calibrated by the maser host NGC 4258. We investigate the effects of incompleteness and find that we are unable to recover a robust JAGB measurement in one of the two most distant hosts at $R \sim 40$ Mpc, NGC 3147. We compile all JWST JAGB observations in SNe Ia hosts, 15 galaxies hosting 18 SNe Ia, from the SH0ES and CCHP programs and employ all literature measures (mode, mean, median, model). We find no significant mean difference between these distances and those from HST Cepheids, -0.03 ± 0.02 (stat) $\pm$ 0.05 (sys) mag. We find a difference of 0.11 $\pm$ 0.02 mag between JAGB mode measurements in the CCHP analyses of two fields in NGC 4258, a feature also seen in two SH0ES fields (see field-to-field variations in Li et al. 2024a), indicating significant field-to-field variation of JAGB measurements in NGC 4258 which produce a large absolute calibration uncertainty. Variations are also seen in the shape of the JAGB LF across galaxies so that different measures produce different values of the Hubble constant. We look for but do not (yet) find a standardizing relation between JAGB LF skew or color dependence and the apparent variation. Using the middle result of all JAGB measures to calibrate SNe Ia yields a Hubble constant of H_0 = 73.3 $\pm$ 1.4 (stat) $\pm$ 2.0 (sys) km/s/Mpc with the systematic dominated by apparent differences across NGC 4258 calibrating fields or their measures.

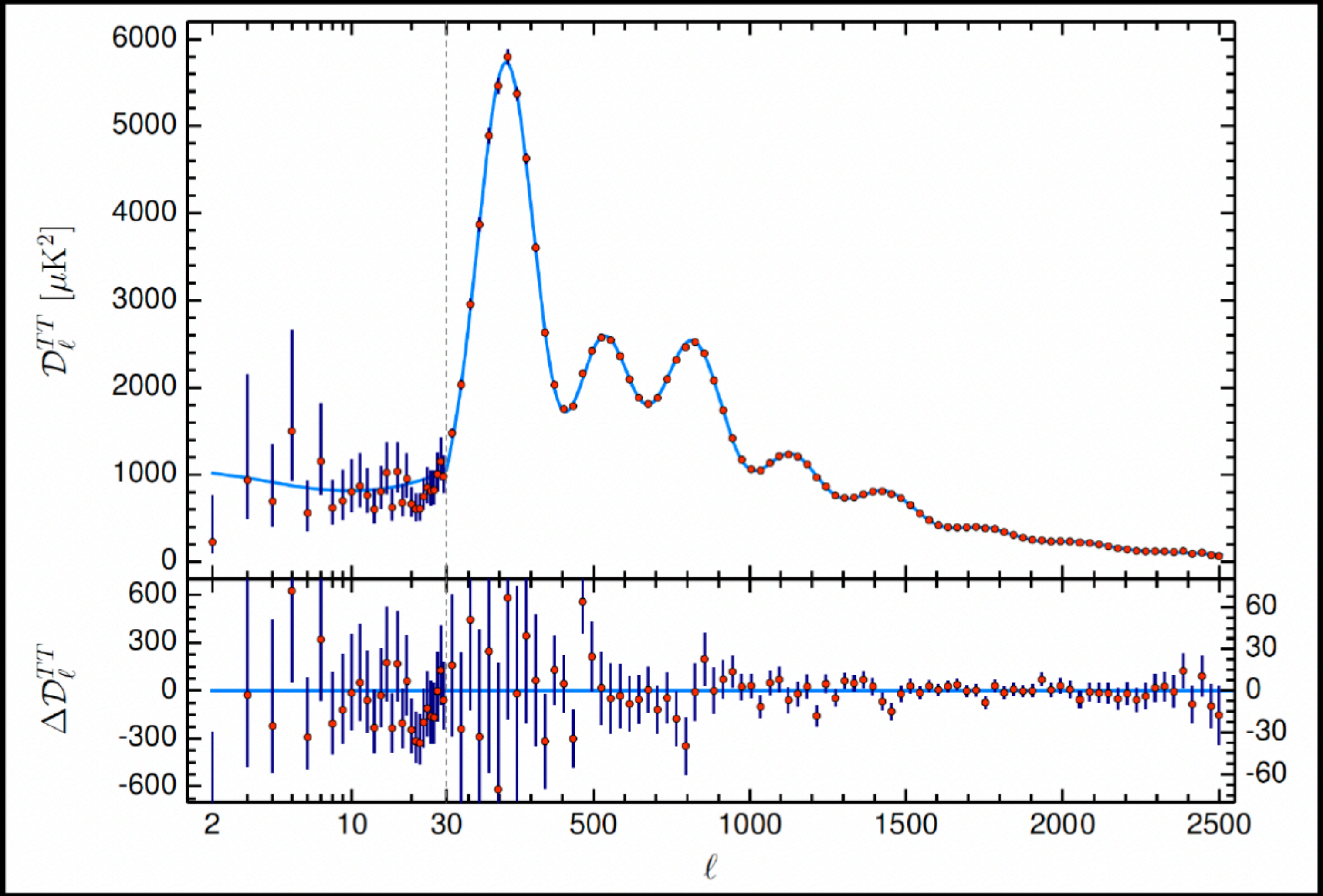


Only 4 outliers at more than two standard deviations.
No outlier at more than 3...
6000
5000
4000
3000
2000
1000
0
$\mathcal{D}_\ell^{TT}$ [μK^2]
600
300
0
-300
-600
$\Delta\mathcal{D}_\ell^{TT}$
60
30
0
-30
-60
2
10
30
500
1000
1500
2000
2500
ℓ

Cosmological parameters:
($\Omega_b h^2$, $\Omega_m h^2$, H0 , n_s , τ, As)

Theoretical model

We compare the angular power spectra we computed with the data and, using a bayesian analysis, we get a combination of cosmological parameter values in agreement with these.



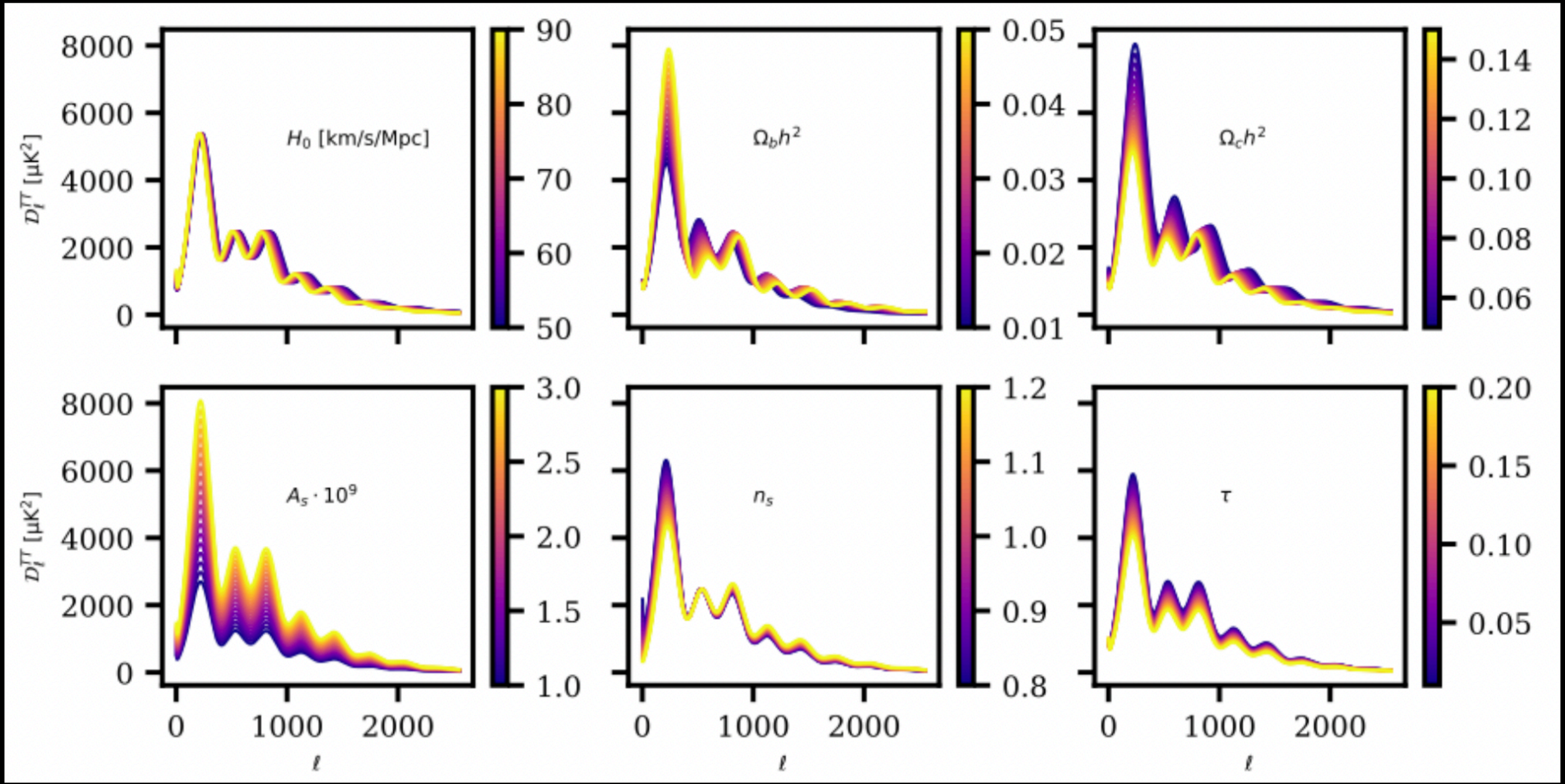
Planck 2018, Astron.Astrophys. 641 (2020) A6

Parameter constraints

Cosmological parameters: ($\Omega_b h^2$, $\Omega_m h^2$, H0 , n_s , τ, As)

Theoretical model

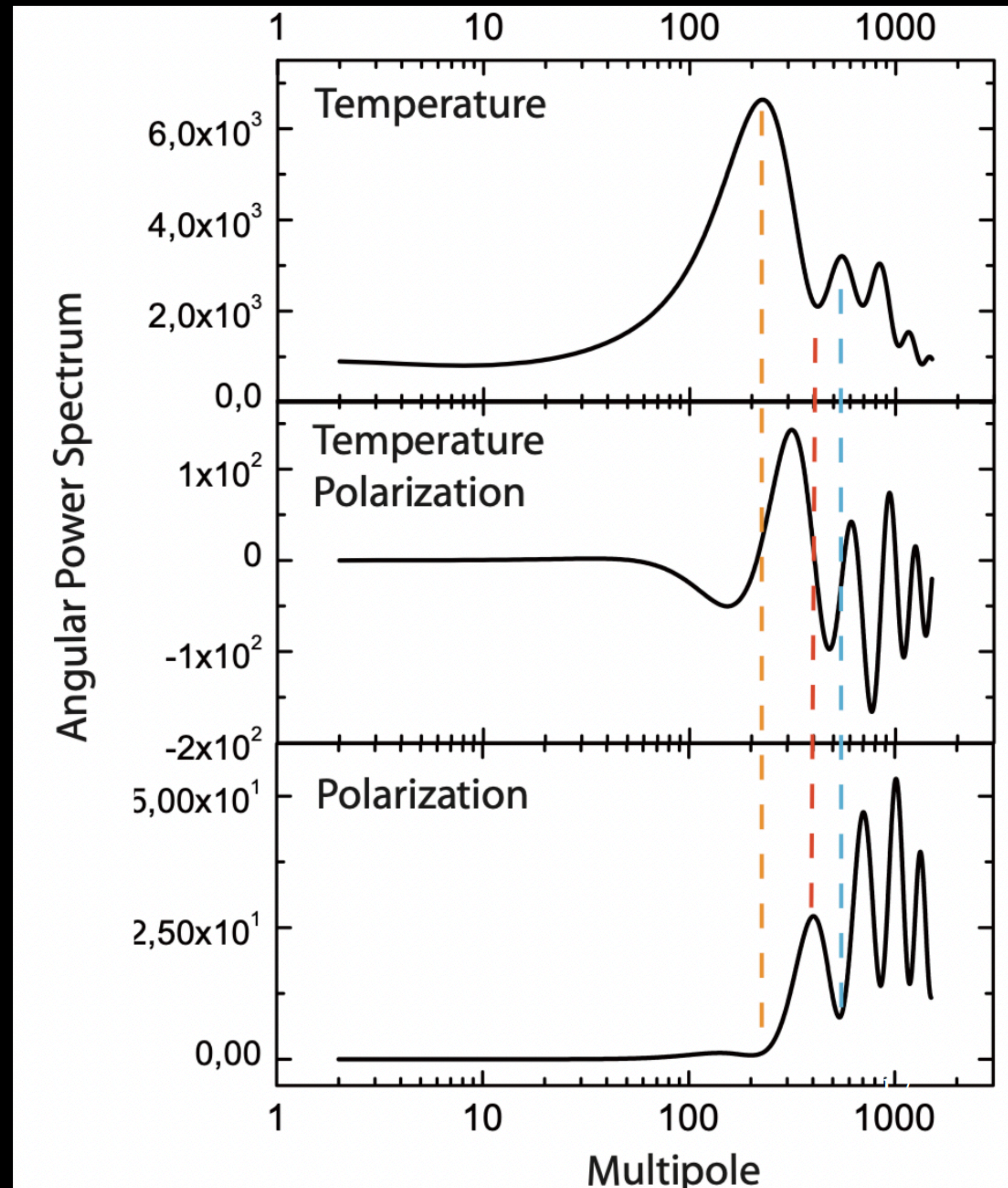
We choose a set of cosmological parameters that describes our theoretical model and compute the angular power spectra. Because of the correlations present between the parameters, variation of different quantities can produce similar effects on the CMB.



Lemos & Shah, arXiv:2307.13083

We can extract 4 independent angular spectra from the CMB:

- Temperature
- Cross Temperature Polarization E
- Polarization type E (density fluctuations)
- Polarization type B (gravitational waves)



Borstnik et al., hep-ph/0401043

CMB constraints

Parameter	TT+lowE 68% limits	TE+lowE 68% limits	EE+lowE 68% limits	TT,TE,EE+lowE 68% limits	TT,TE,EE+lowE+lensing 68% limits	TT,TE,EE+lowE+lensing+BAO 68% limits
$\Omega_b h^2$	0.02212 ± 0.00022	0.02249 ± 0.00025	0.0240 ± 0.0012	0.02236 ± 0.00015	0.02237 ± 0.00015	0.02242 ± 0.00014
$\Omega_c h^2$	0.1206 ± 0.0021	0.1177 ± 0.0020	0.1158 ± 0.0046	0.1202 ± 0.0014	0.1200 ± 0.0012	0.11933 ± 0.00091
$100\theta_{MC}$	1.04077 ± 0.00047	1.04139 ± 0.00049	1.03999 ± 0.00089	1.04090 ± 0.00031	1.04092 ± 0.00031	1.04101 ± 0.00029
τ	0.0522 ± 0.0080	0.0496 ± 0.0085	0.0527 ± 0.0090	$0.0544^{+0.0070}_{-0.0081}$	0.0544 ± 0.0073	0.0561 ± 0.0071
$\ln(10^{10} A_s)$	3.040 ± 0.016	$3.018^{+0.020}_{-0.018}$	3.052 ± 0.022	3.045 ± 0.016	3.044 ± 0.014	3.047 ± 0.014
n_s	0.9626 ± 0.0057	0.967 ± 0.011	0.980 ± 0.015	0.9649 ± 0.0044	0.9649 ± 0.0042	0.9665 ± 0.0038
H_0 [km s^{-1} Mpc^{-1}] . .	66.88 ± 0.92	68.44 ± 0.91	69.9 ± 2.7	67.27 ± 0.60	67.36 ± 0.54	67.66 ± 0.42
Ω_Λ	0.679 ± 0.013	0.699 ± 0.012	$0.711^{+0.033}_{-0.026}$	0.6834 ± 0.0084	0.6847 ± 0.0073	0.6889 ± 0.0056
Ω_m	0.321 ± 0.013	0.301 ± 0.012	$0.289^{+0.026}_{-0.033}$	0.3166 ± 0.0084	0.3153 ± 0.0073	0.3111 ± 0.0056
$\Omega_m h^2$	0.1434 ± 0.0020	0.1408 ± 0.0019	$0.1404^{+0.0034}_{-0.0039}$	0.1432 ± 0.0013	0.1430 ± 0.0011	0.14240 ± 0.00087
$\Omega_m h^3$	0.09589 ± 0.00046	0.09635 ± 0.00051	$0.0981^{+0.0016}_{-0.0018}$	0.09633 ± 0.00029	0.09633 ± 0.00030	0.09635 ± 0.00030
σ_8	0.8118 ± 0.0089	0.793 ± 0.011	0.796 ± 0.018	0.8120 ± 0.0073	0.8111 ± 0.0060	0.8102 ± 0.0060
$S_8 \equiv \sigma_8(\Omega_m/0.3)^{0.5}$.	0.840 ± 0.024	0.794 ± 0.024	$0.781^{+0.052}_{-0.060}$	0.834 ± 0.016	0.832 ± 0.013	0.825 ± 0.011

Planck 2018, Astron.Astrophys. 641 (2020) A6

2018 Planck results are a wonderful confirmation of the flat standard ΛCDM cosmological model, but are model dependent!

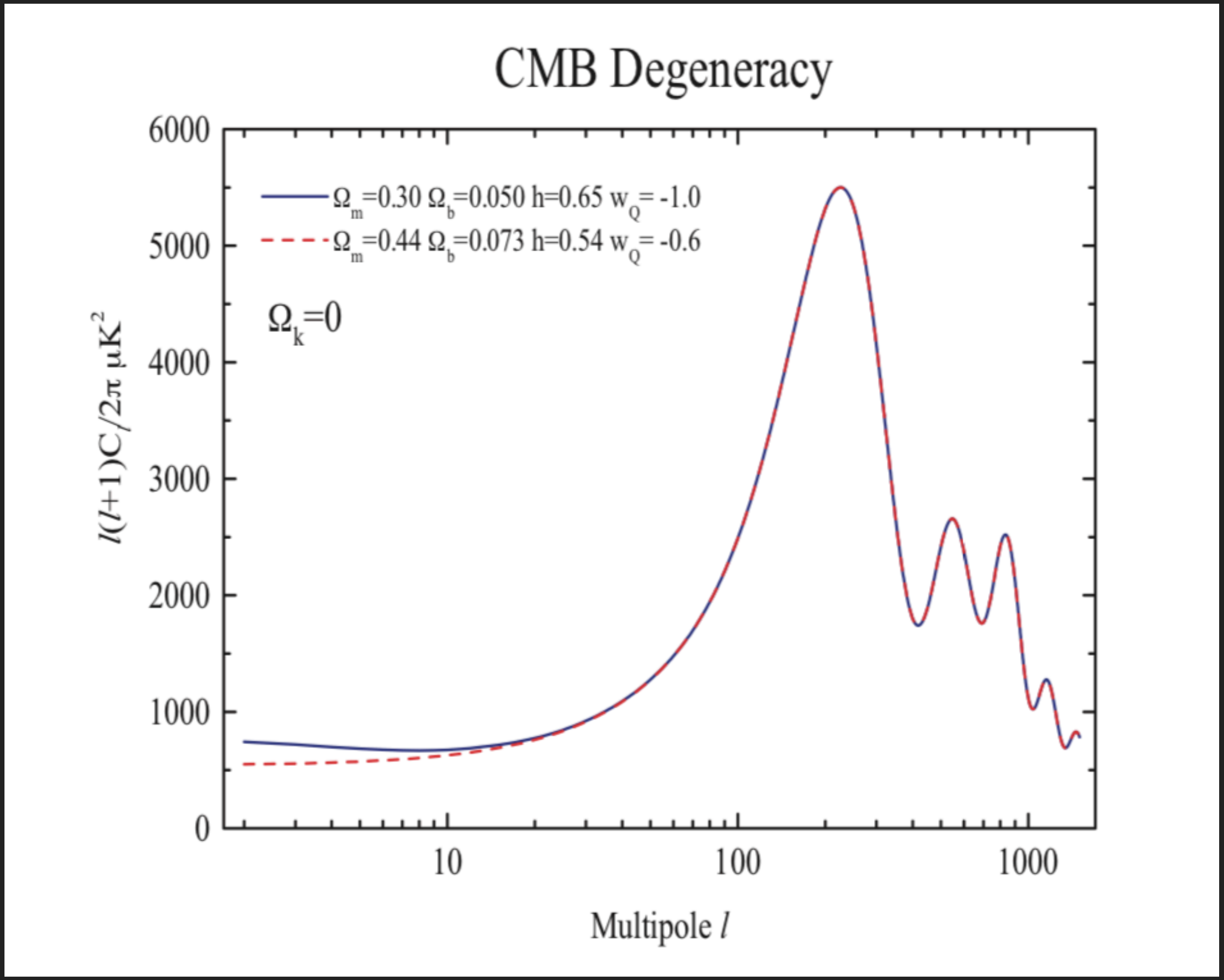
- The cosmological constraints are obtained assuming a cosmological model.
- The results are affected by the degeneracy between the parameters that induce similar effects on the observables.

HUBBLE TENSION

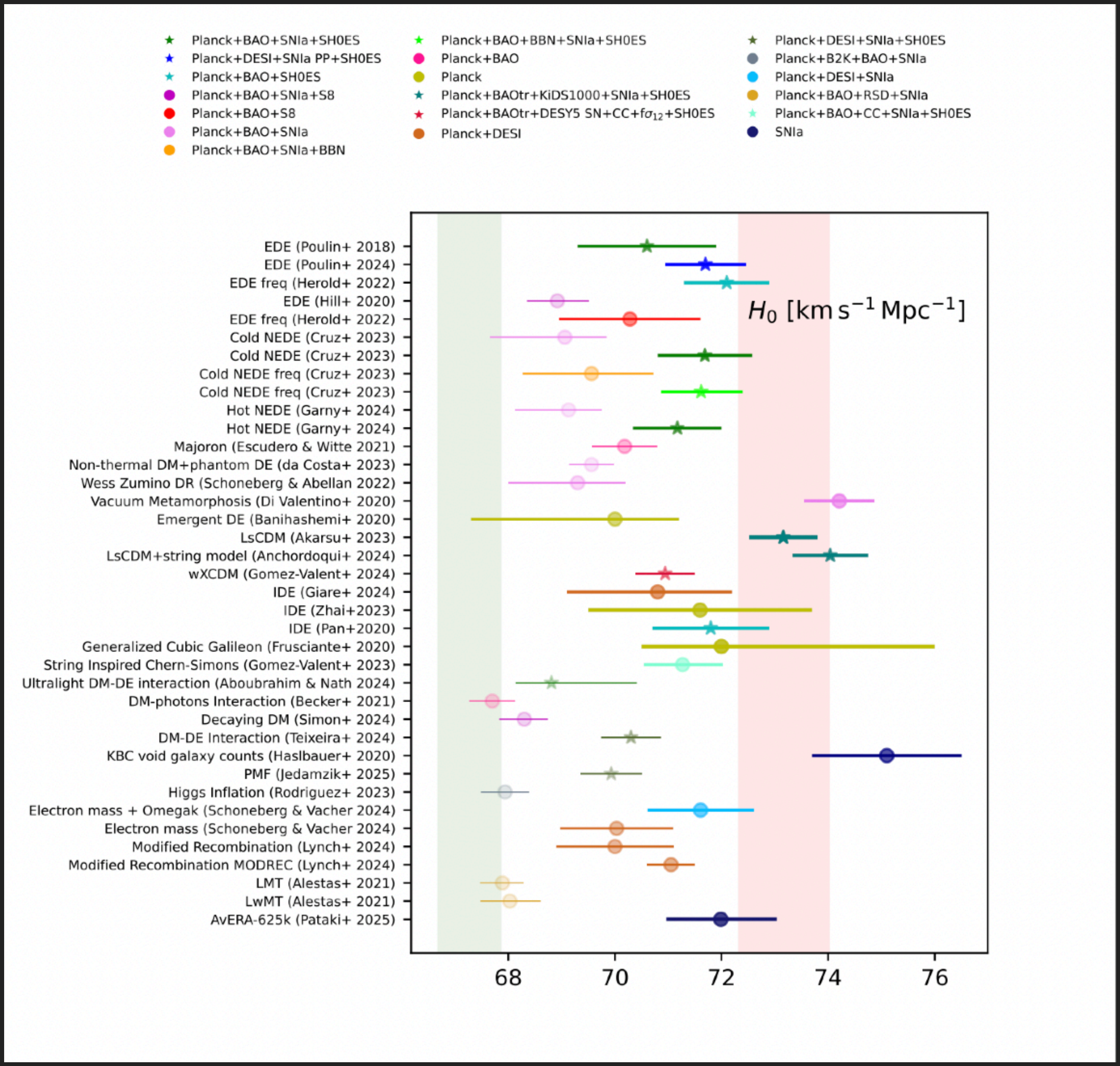
Primary CMB anisotropies DO NOT measure the Hubble constant !

Geometrical degeneracy with Dark Energy and Curvature.

Current CMB H0 constraints come from the assumption of LCDM

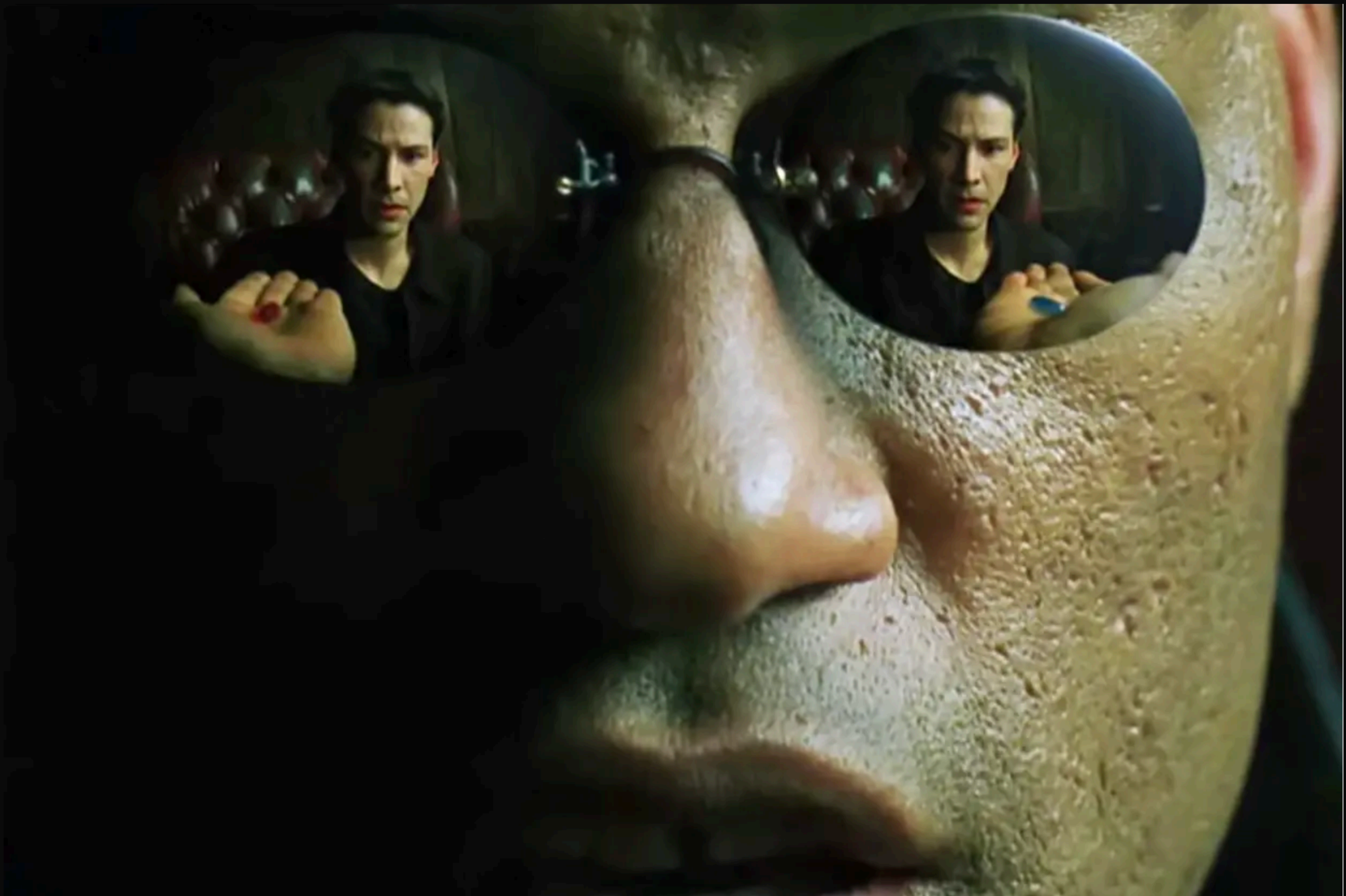


SOLVING HUBBLE TENSION MODIFYING LCDM



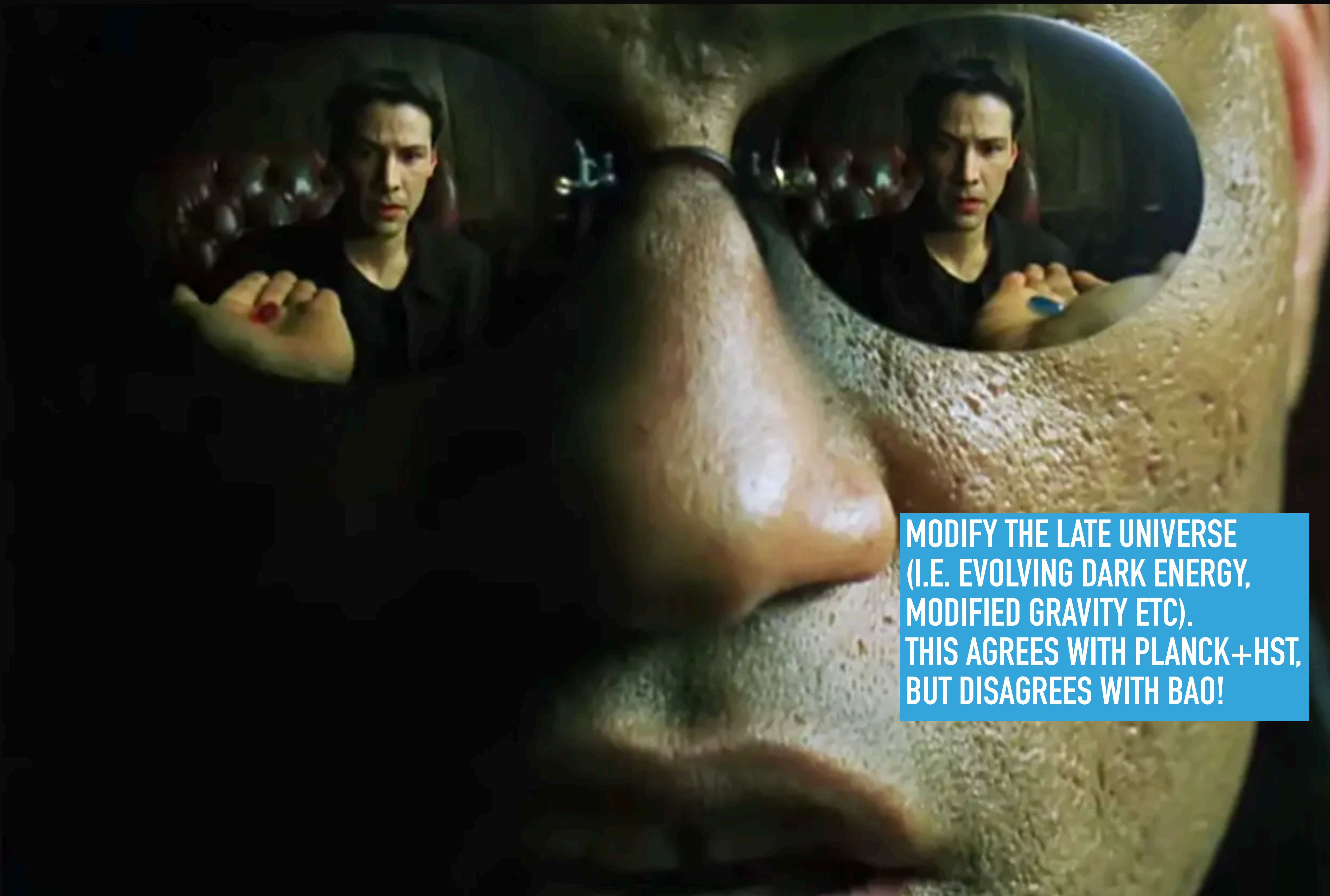
Most recent review: Di Valentino et al, https://arxiv.org/pdf/2504.01669

Theoretical solutions (in pills)



Theoretical solutions (in pills)

Theoretical solutions (in pills)



MODIFY THE LATE UNIVERSE
(I.E. EVOLVING DARK ENERGY,
MODIFIED GRAVITY ETC).
THIS AGREES WITH PLANCK+HST,
BUT DISAGREES WITH BAO!

If you want to have Planck in agreement with HST you need $w<-1$.

But this disagrees with Planck+BAO

Then you may think of an EDE component that changes the acoustic horizon at CMB.

This may help a bit but there is no sign of it in CMB data (just disappeared also from recent ACT).

No way to combine all three!

One of them has to go…

This is the solution favored by the majority of cosmologists specializing in the CMB (and Inflation).

But even BAO are starting to fall out of favor…