

Hubble Tension: Recent Results and Perspectives

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Edwin Hubble and the Expansion of the Universe (1929)



In 1929 Hubble measured the red shift (or, redshift) of nearby galaxies and found that they nearly all move away from us

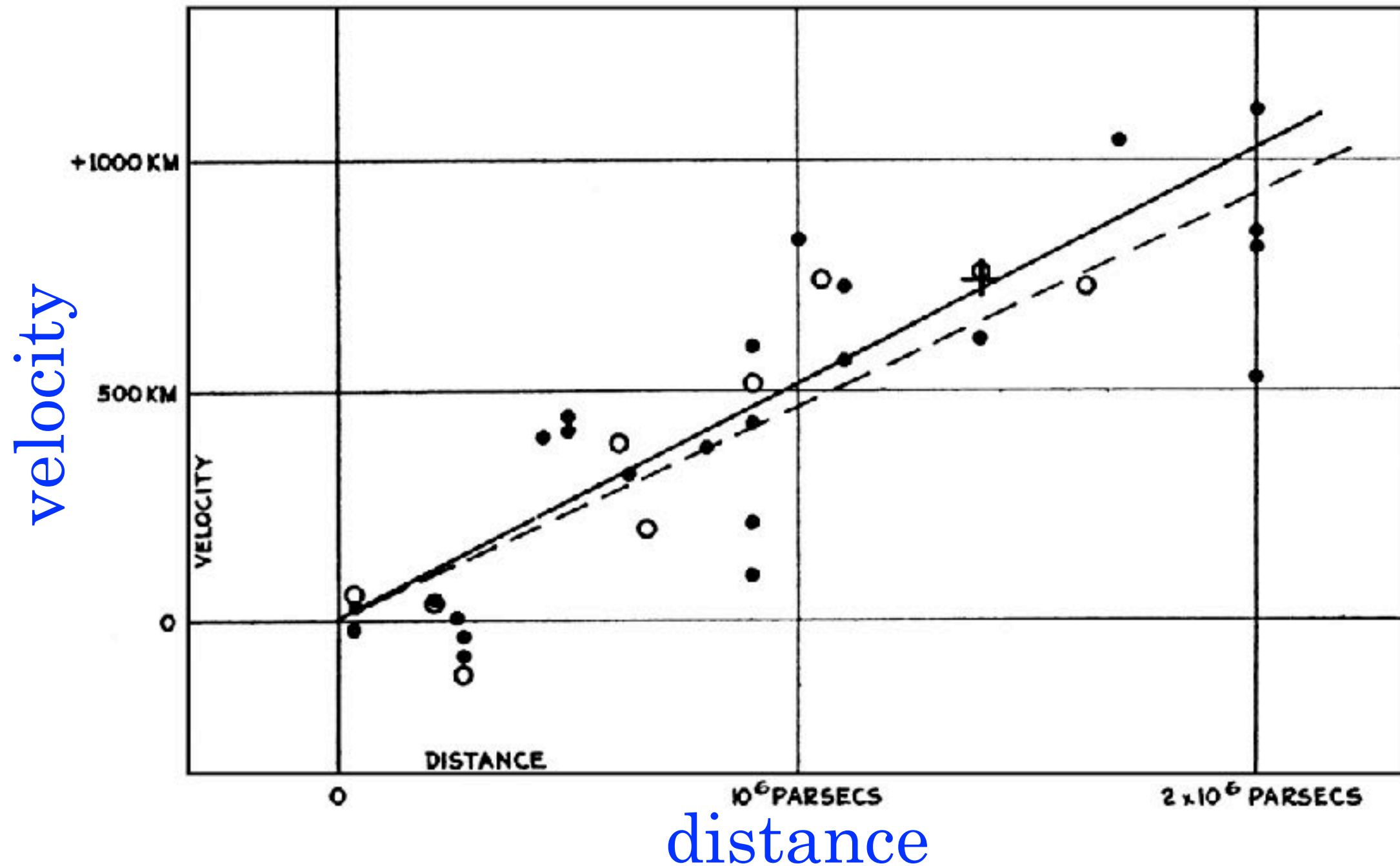
⇒

The Universe is Expanding!

100 inch Hooker telescope
(Mt Wilson, CA)



The original Hubble diagram

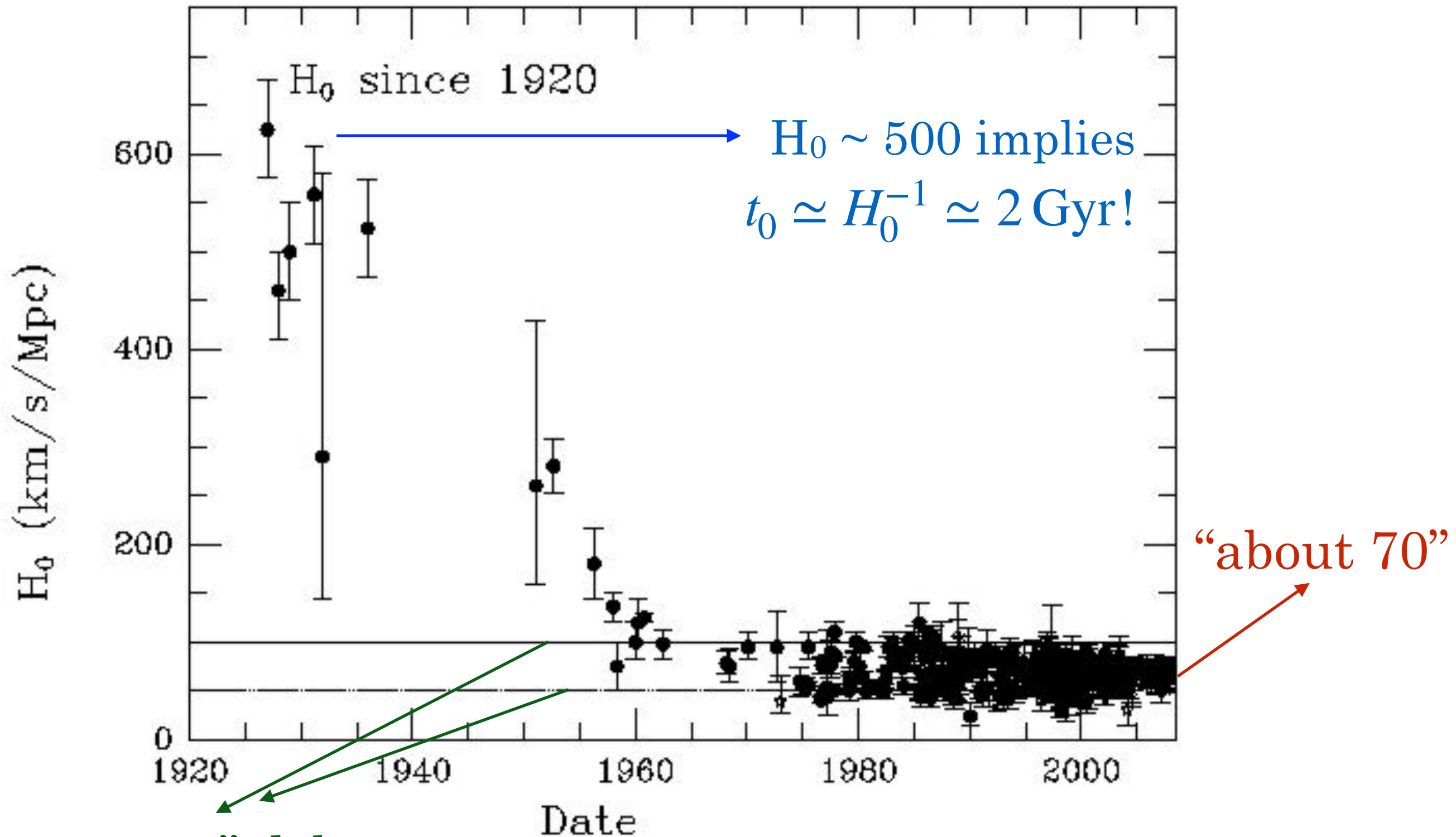


Slope of this relation (velocity vs. distance) is called the Hubble constant H_0 .

Modern value:

$$H_0 \approx 70 \text{ km/sec/megaparsec} \quad (\text{will return to } H_0 \text{ value!})$$

Brief history of H_0 measurements

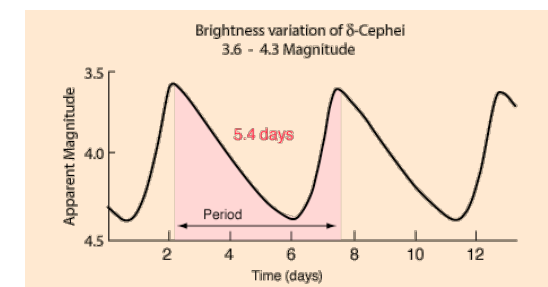


Since
~2015

Hubble tension!

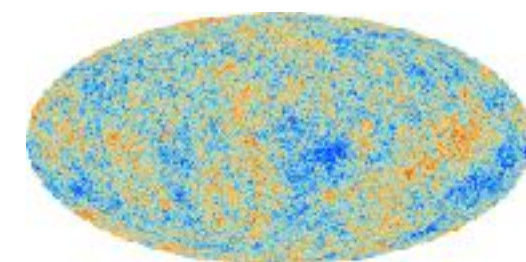
Type Ia supernovae + Cepheid distances give

$$H_0 = 73.04 \pm 1.04 \text{ (km/s/Mpc)}$$



Cosmic Microwave Anisotropies give

$$H_0 = 67.36 \pm 0.54 \text{ (km/s/Mpc)}$$

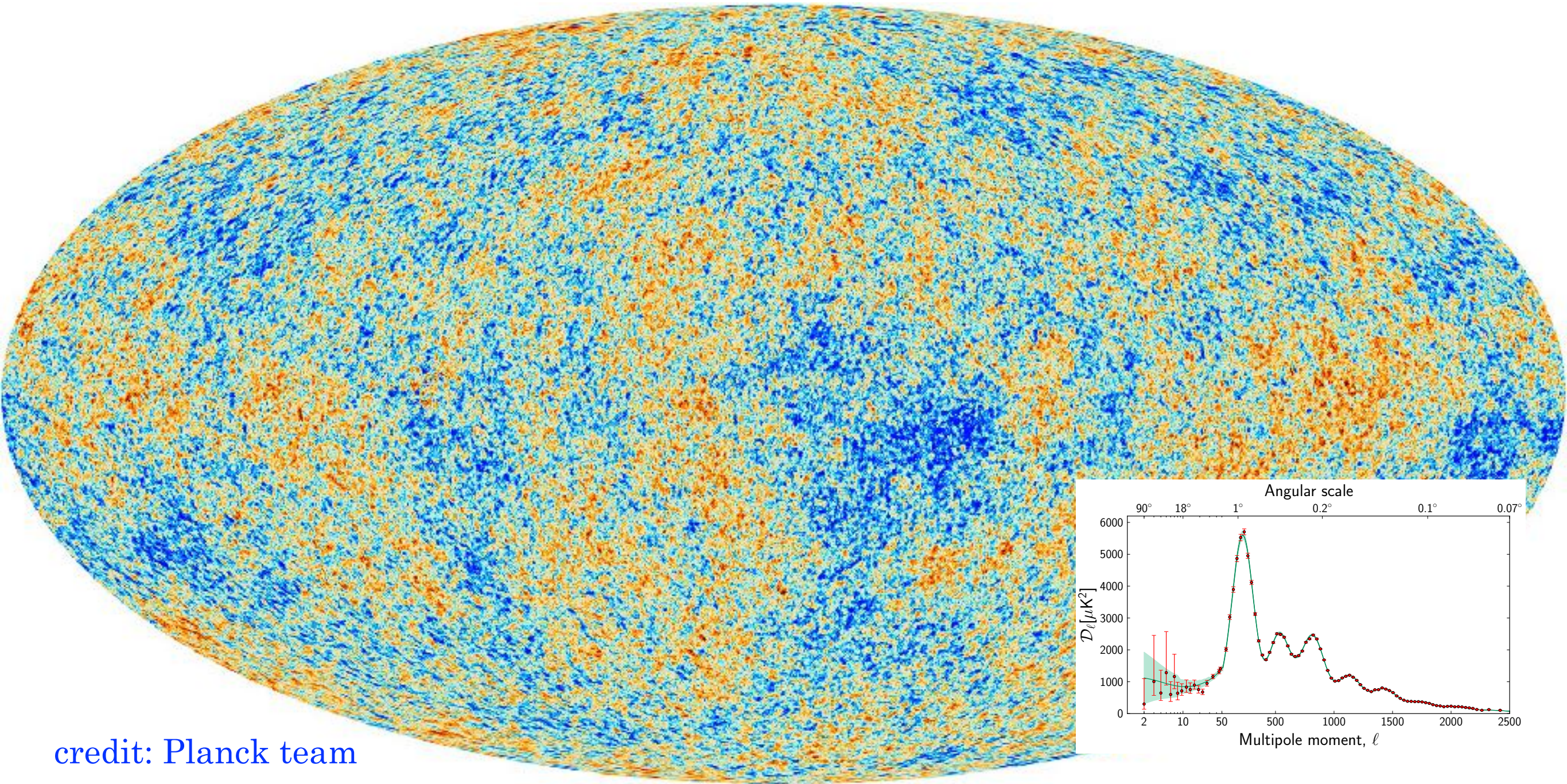


These two measurements are

⇒ **discrepant at around 7 sigma confidence**

(numbers above are 5-sigma apart, later I will show 7-sigma result)

Cosmic Microwave Background (CMB) Anisotropies



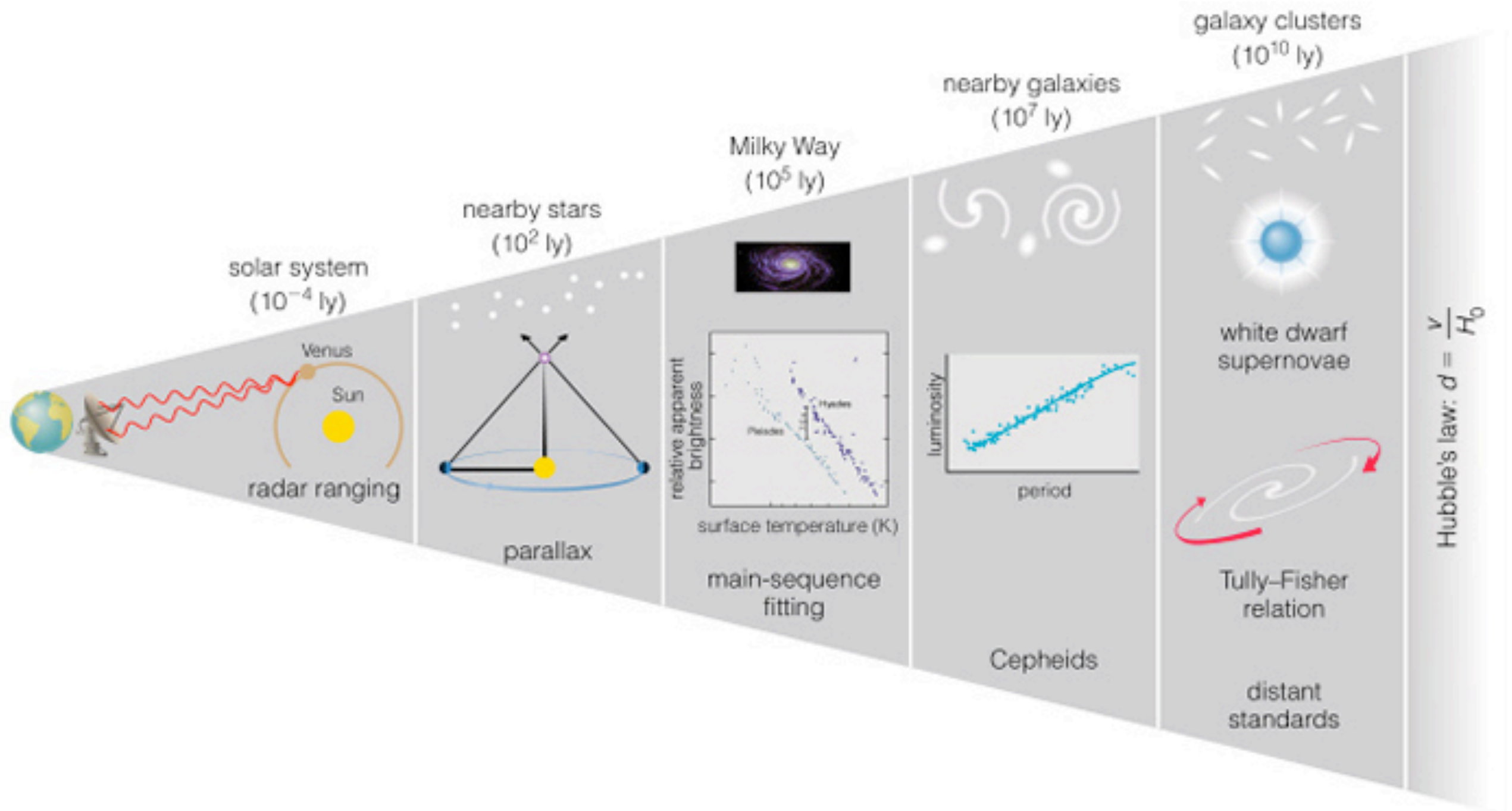
credit: Planck team

$$H_0 = (67.36 \pm 0.54) \text{ km/s/Mpc} \quad [\text{flat } \Lambda\text{CDM}]$$

$$H_0 = (63.6 \pm 2.2) \text{ km/s/Mpc} \quad [\text{curved } \Lambda\text{CDM}]$$

Planck Collaboration XVIII (2018)

Distance ladder (“local”) measurement of distance, and thus H_0

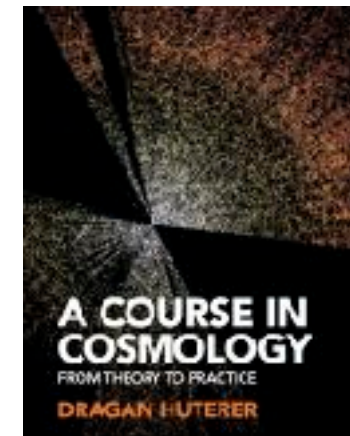


Distance ladder basics

(with no magnitudes!)

Luminosity distance:

$$d_L(z) = \frac{c(1+z)}{H_0} \int \frac{dz}{E(z, \Omega_m, \Omega_{DE}, \dots)} \xrightarrow{z \ll 1} \frac{cz}{H_0} + O(z^2)$$



Type Ia supernova (SNIa) are standard candles

so L is constant in $f = \frac{L}{4\pi d_L^2}$

so you only measure relative distances, Cd_L ($C = \text{const}$)

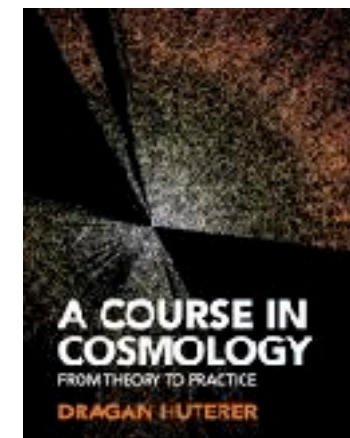
so SNIa cosmology only uses the shape of the $d_L(z)$ curve
(and wins 2011 Nobel Prize for discovery of $\Omega_{DE} > 0$)

But what if we want to measure H_0 ?

This won't work since measurements of Cd_L can never get you H_0

Distance ladder basics

(with no magnitudes!)



What if we want to measure H_0 ?

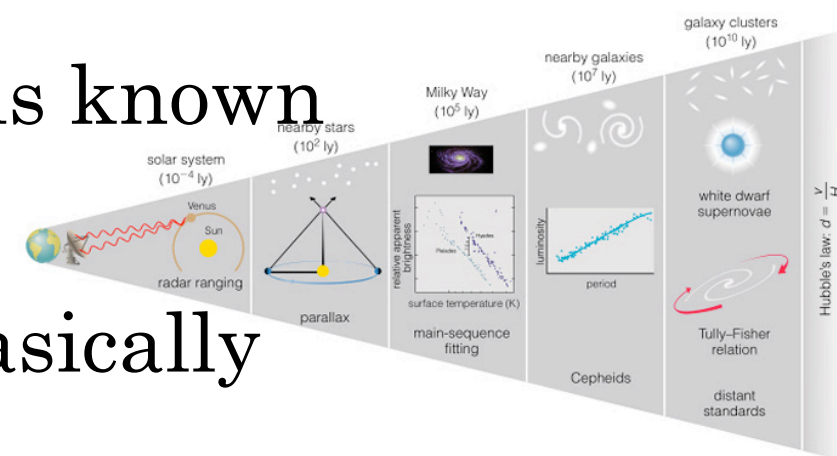
$$d_L(z) = \frac{c(1+z)}{H_0} \int \frac{dz}{E(z, \Omega_m, \Omega_{DE}, \dots)} \xrightarrow{z \ll 1} \frac{cz}{H_0} + O(z^2)$$

We have to *anchor* the distances

$\Rightarrow$ find some objects whose absolute distance is known

(so, solve for C in Cd_L)

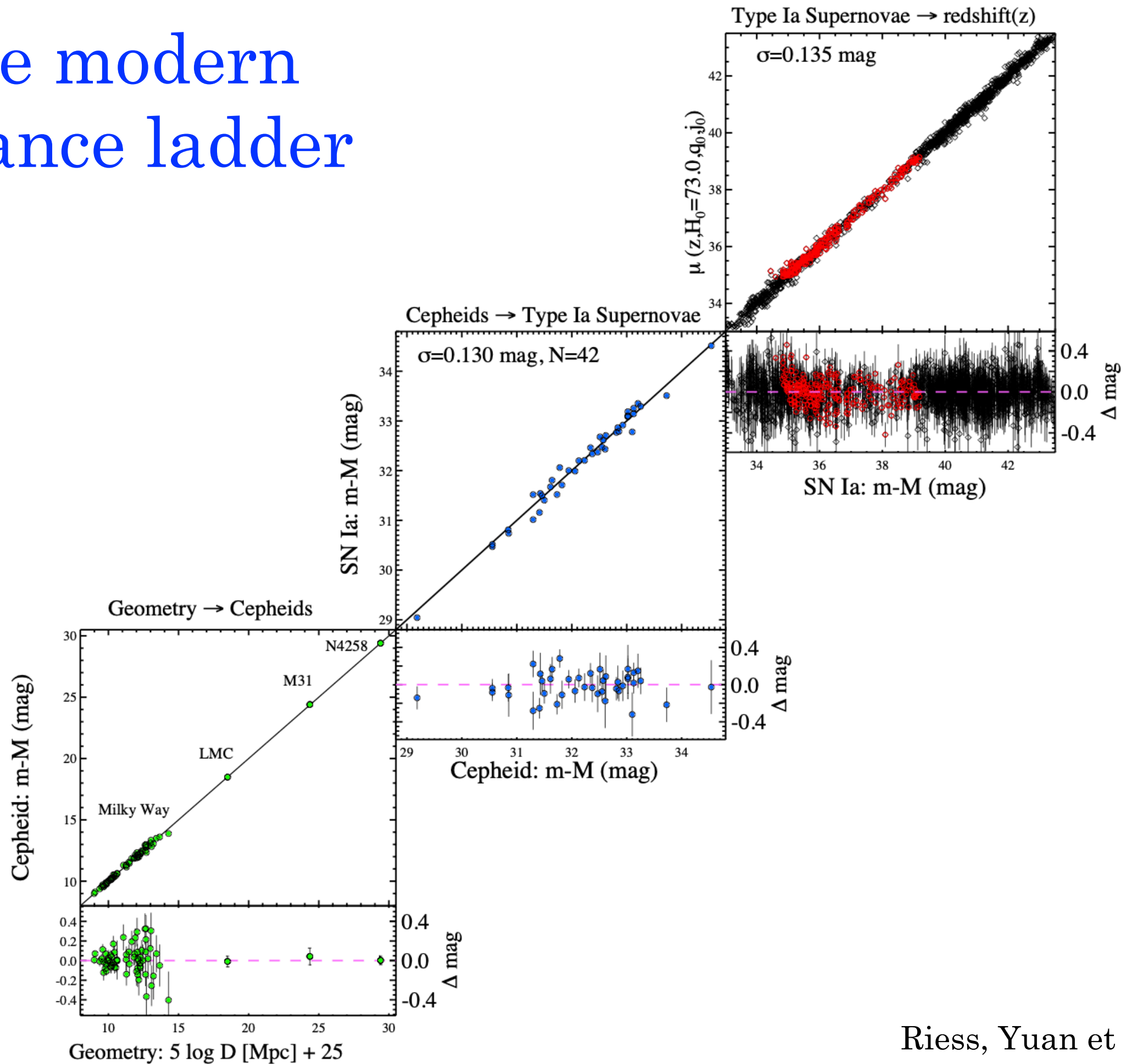
$\Rightarrow$ Cepheids, etc - the whole distance ladder basically



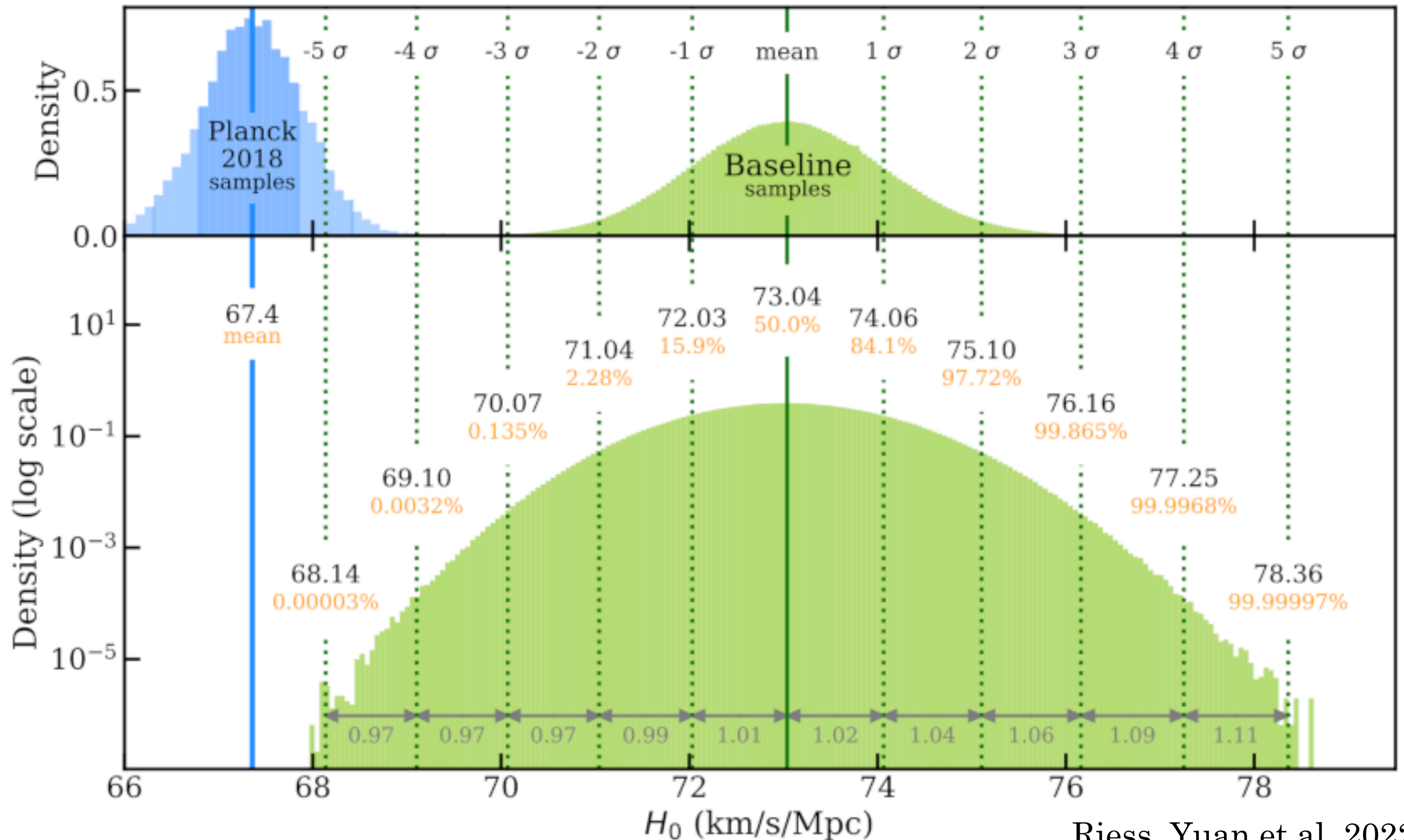
But *also* need SNIa in order to explore the beyond-very-local universe (to “reach the Hubble flow”, and decrease sample variance)

This is the principle behind local (distance-ladder) measurements of H_0

The modern distance ladder

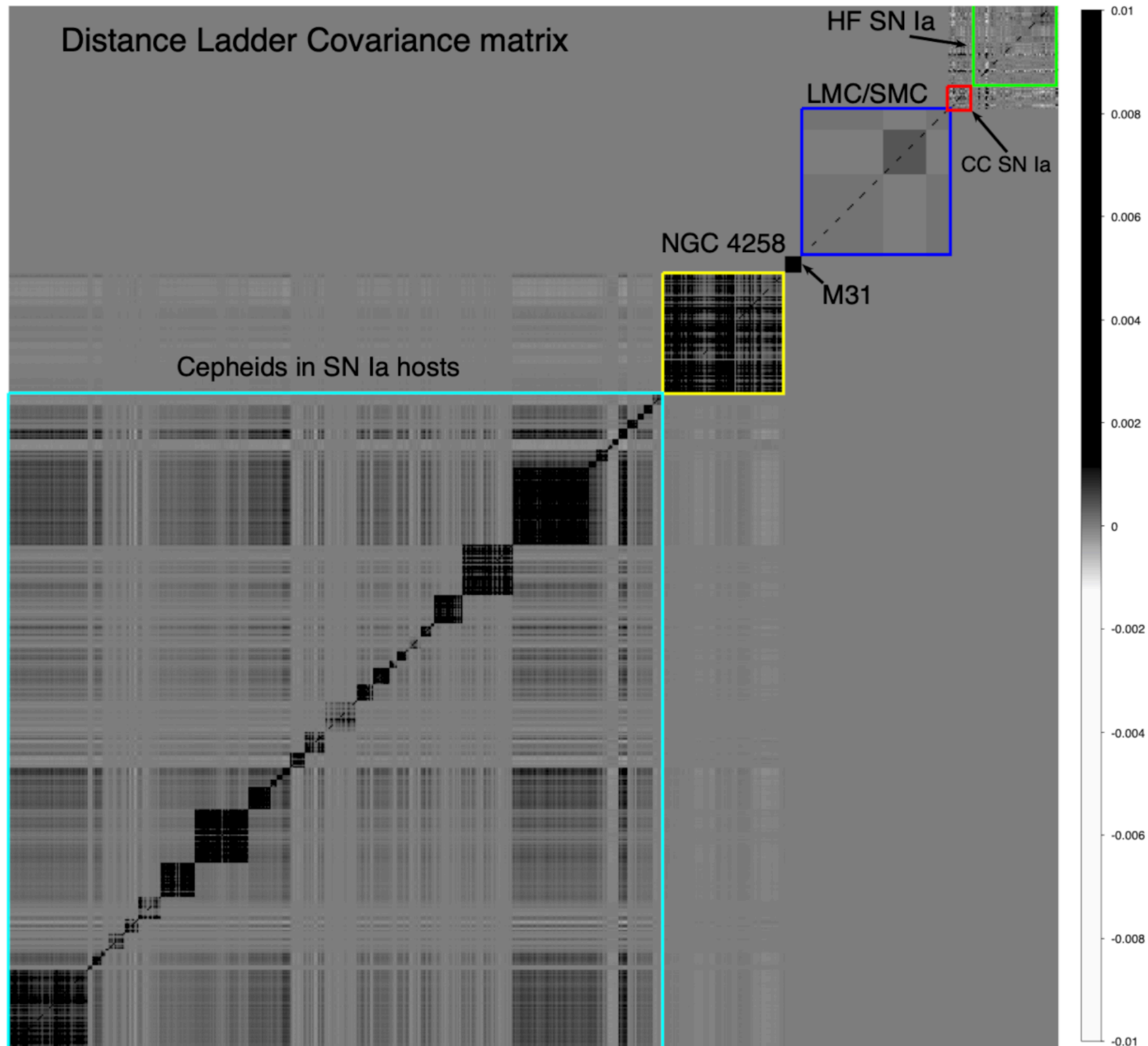


Discrepancy between Planck and distance ladder H_0 is 5.0 sigma (99.99997%)

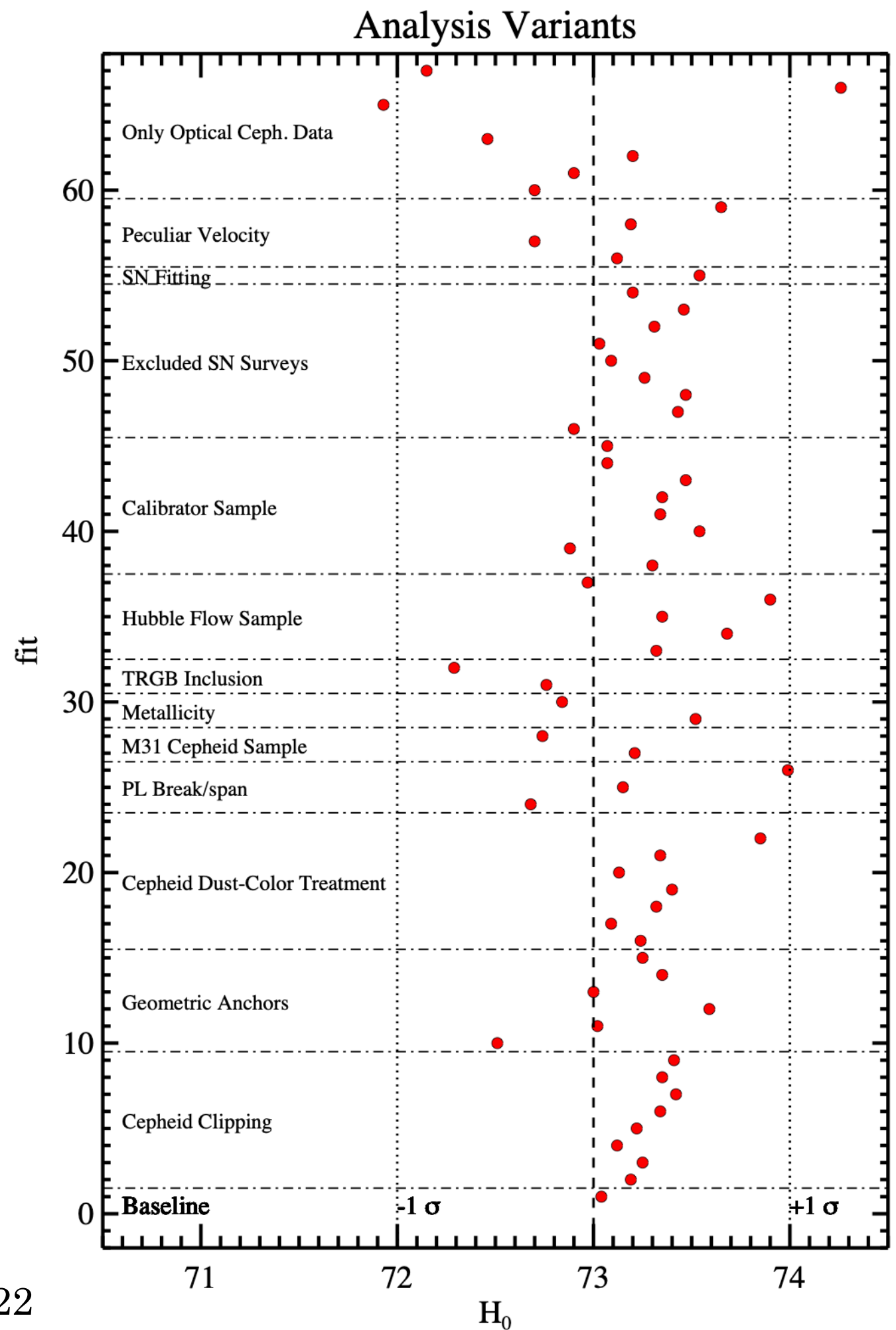


Distance ladder:

Full covariance between the measurements



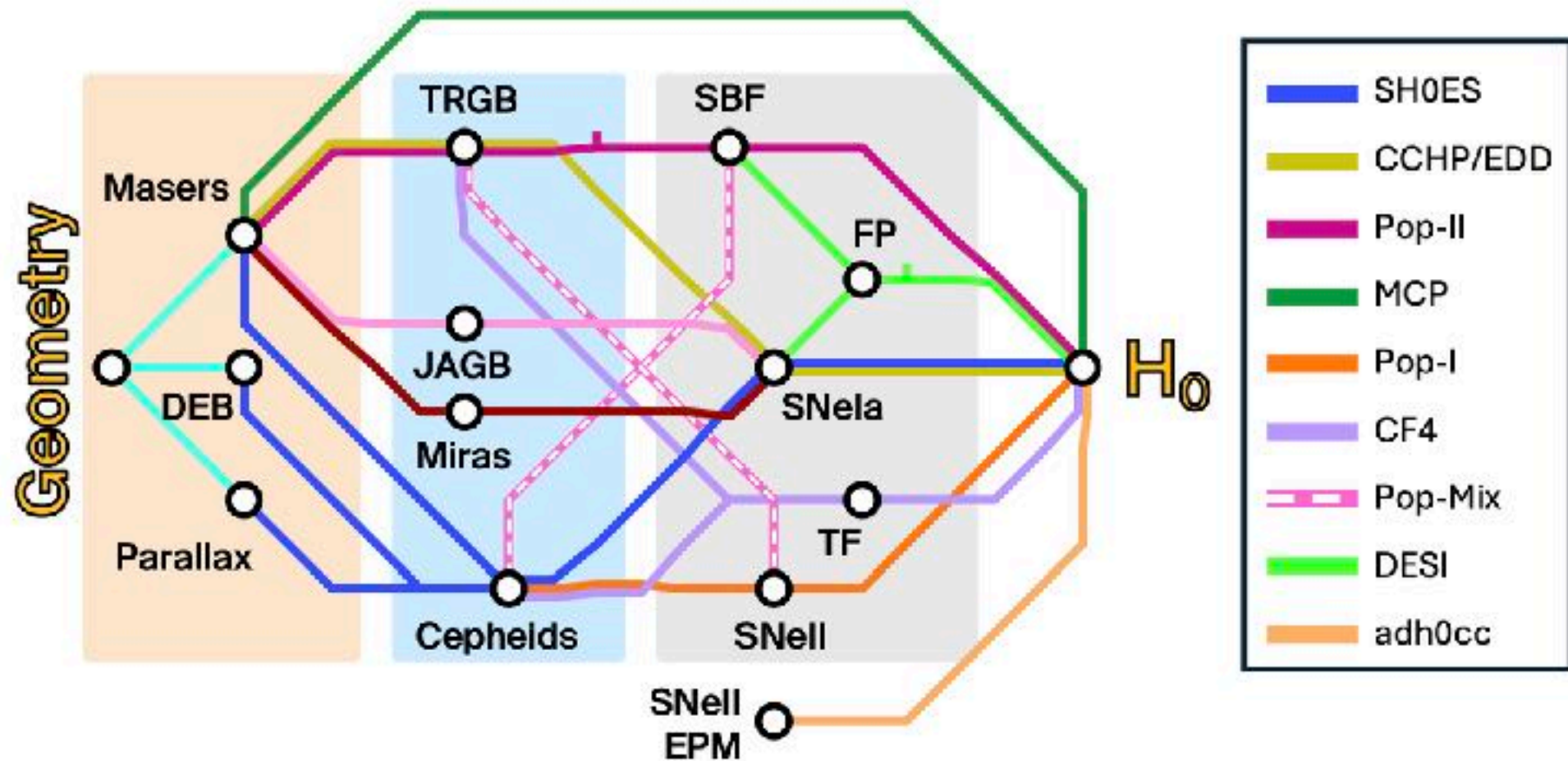
Distance ladder: Robustness to variations in the analysis



Local Distance Network

Casertano et al (2026)

The Local Distance Network to H_0



$$H_0 = 73.50 \pm 0.81 \text{ (km/s/Mpc)}$$

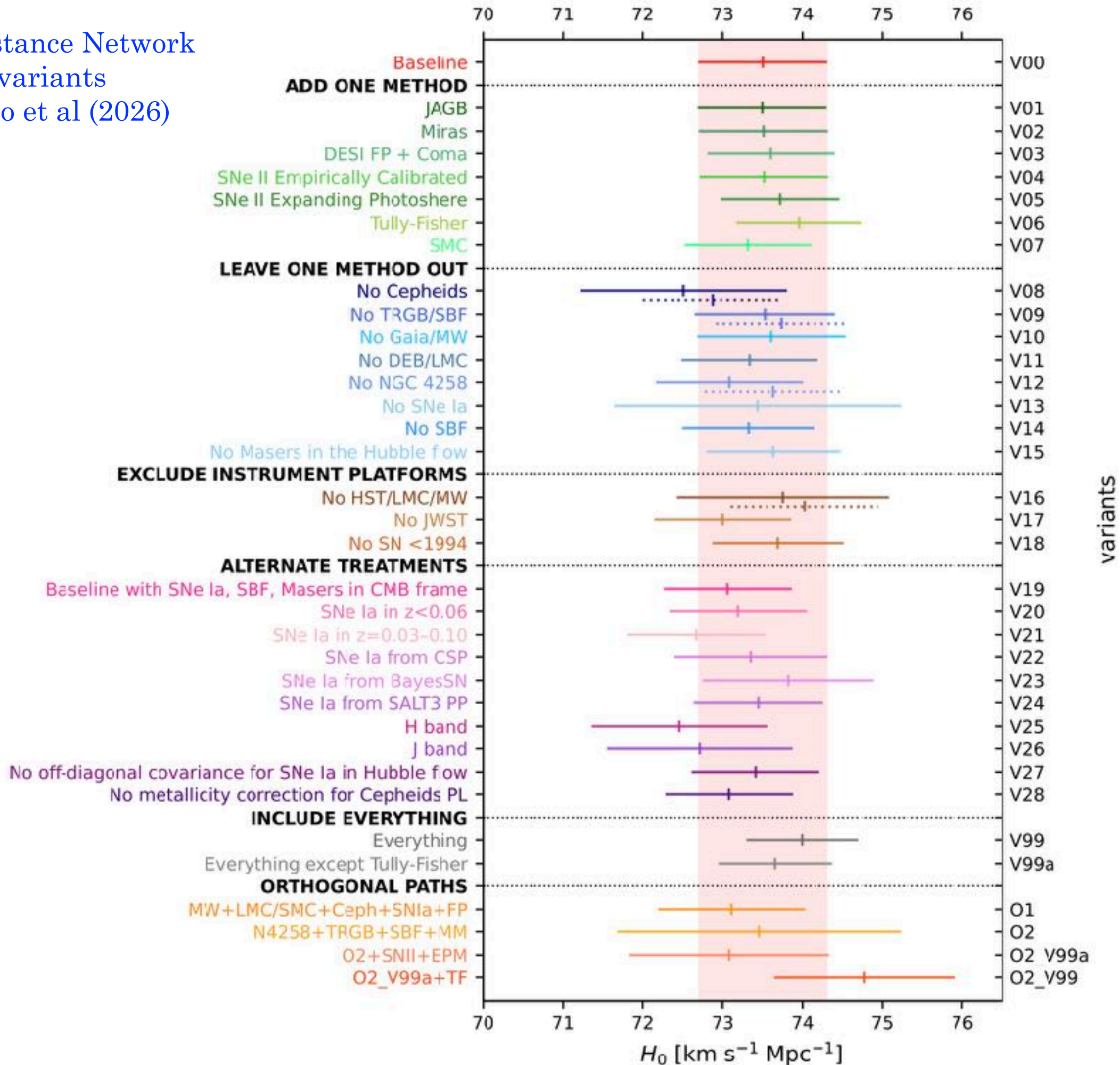
versus

CMB (Planck + SPT + ACT)

$$H_0 = 67.24 \pm 0.35 \text{ (km/s/Mpc)}$$

$\Rightarrow$ **7 sigma discrepancy**

Local Distance Network
analysis variants
Casertano et al (2026)



Theoretical explanations for the Hubble tension:

1. “**Early-universe**” explanations: modify physics before recombination ($z > 1000$, or $t < 300,000$ yrs after the Big Bang)

Typically, *early* dark energy is introduced to change the sound horizon

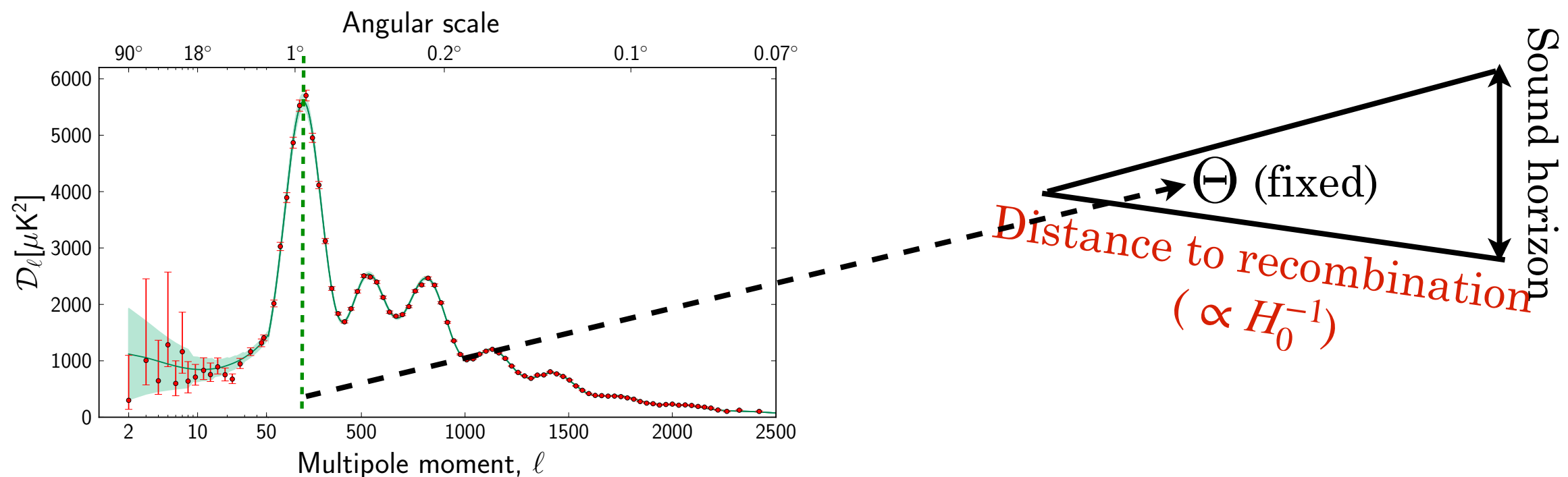
2. “**Late-universe**” explanations: modify physics at late times ($z \sim 1$, or $t \sim 5$ Gyr after the Big Bang)

Typically, temporal evolution of *late-time* dark energy is modified

“Early universe” theory explanations:

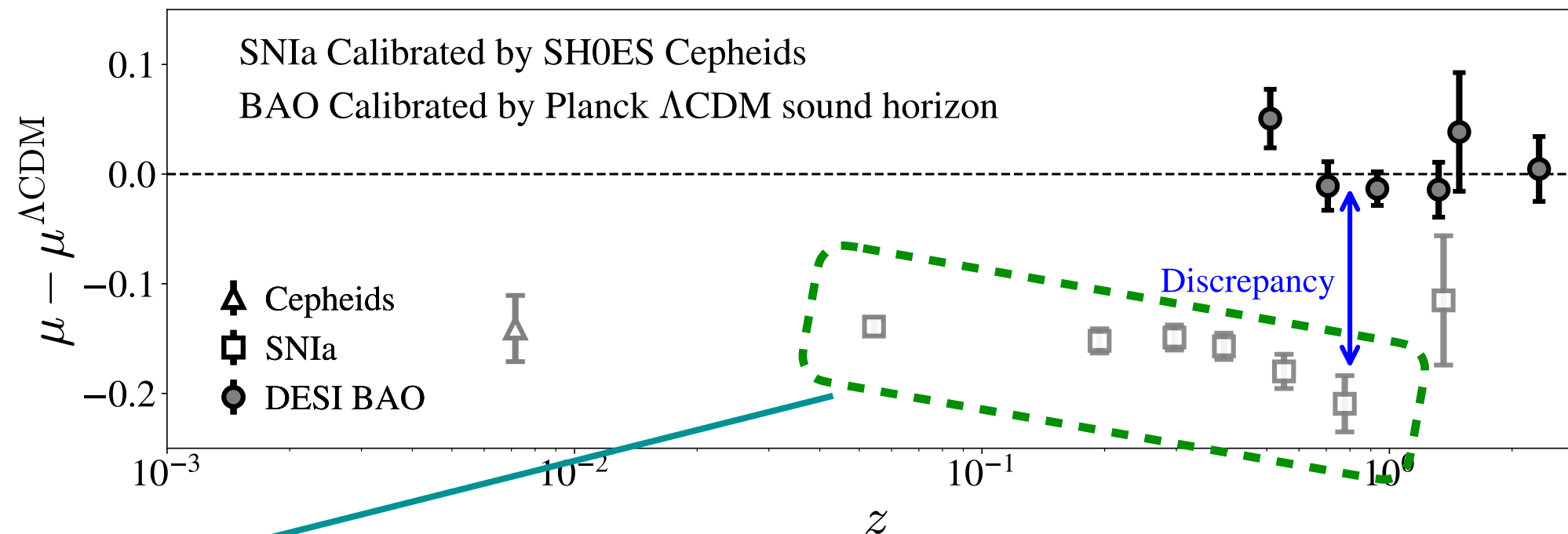
They can work, but they are fine-tuned

- Accept the local (distance-ladder) measurement of ~ 73 km/s/Mpc as true, global value
- Change theory so that the **value from CMB increases from ~ 67 to ~ 73**
- Because angle to sound horizon θ is so well measured, and **distance to recombination decreases with increasing H_0** , introduce new physics that **decreases the sound horizon**



“Late universe” theory explanations

They just don't work!



- SNIa data can move up and down by a constant, but tension always persists
- Discontinuity (so, tension) either between SNIa and Cepheids, or else between SNIa and BAO
- A successful solution would have to make absolute magnitude (luminosity) of SNIa time-dependent (*extremely* contrived; we show a “physical” example)



Bansal & Huterer, arXiv:2602.06293

See also Efstathiou (2025), Poulin et al (2025), Dainotti et al (2021)...

Theory explanations summary

There are hundreds of other proposed models, but most of them “unnatural” and fine-tuned.

Most of them struggle to lift the global H_0 from 67 to 73
(despite being tuned)

In particular, majority of proposed solutions introduce new parameters, but are either

*** **unnatural**, or else

*** **do not substantially improve the fit to the data**

No compelling theory explanation yet.

Is it just the sample variance?!

- There are literally hundreds of models out there
- However, there is only **ONE** simple model.

Sample/cosmic variance! Is it possible that:

⇒ Global H_0 is ~ 67 , but H_0 in our local volume is ~ 73
(equivalent to: “we live in a void”)

However that model is completely ruled out.

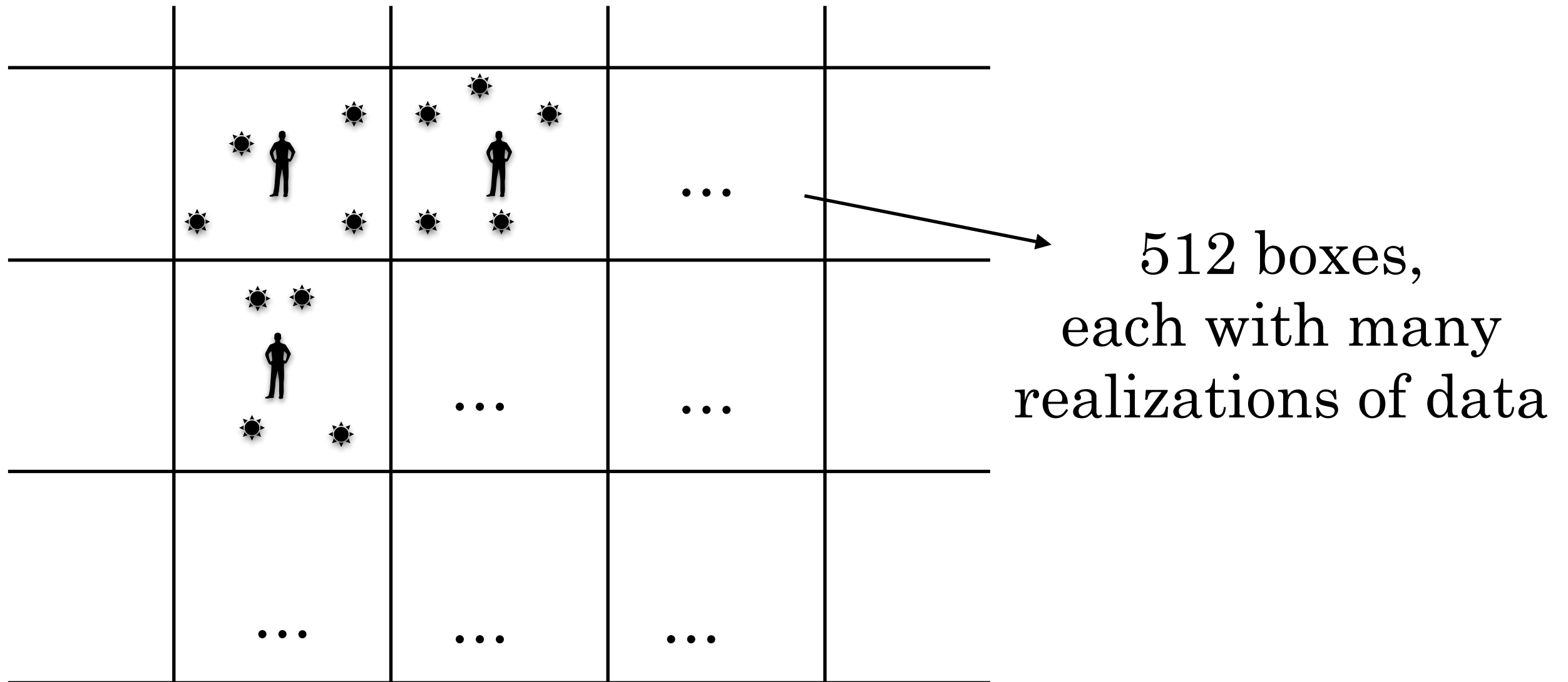
Wu & Huterer (2017), Kenworthy, Scolnic & Riess (2019)

essentially because local measurements map out a pretty
big local volume (so cosmic variance is small)

$$\sigma^{\text{CV}}(H_0) \simeq 0.3 \text{ km/s/Mpc} \simeq \frac{1}{20} (H_0^{\text{SHOES}} - H_0^{\text{CMB}})$$

as explained on next slide...

In [Wu & Huterer \(2017\)](#), we determined the **sample variance** of H_0 from the distance-ladder measurement both precisely and robustly by repeating the analysis about **3 million times** on numerical (*Nbody*) *Λ*CDM simulations



$$\sigma^{\text{CV}}(H_0) \simeq 0.3 \text{ km/s/Mpc}$$

20 times too small to explain the Hub tension

Ongoing or upcoming “ H_0 experiments”:

- **CMB surveys:**

- ▶ Simons Observatory (ground)
- ▶ LiteBird (space)

- **Galaxy surveys from the ground**

- ▶ Vera Rubin Telescope (LSST)
- ▶ Dark Energy Spectroscopic Instrument (DESI)

- **Galaxy surveys from space:**

- ▶ Euclid
- ▶ Nancy Grace Roman Space Telescope (just launched!)
- ▶ James Webb Space Telescope (JWST; for distance ladder)

Summary

- There is a statistically very significant (~ 7 -sigma) discrepancy between the Hubble constant measured by the CMB (~ 67 km/s/Mpc) and local, distance-ladder measurements (~ 73)
- Both measurements appear very reliable and have been tested against known systematics (though the CMB is certainly the more mature of the two)
- Theory explanations lag far behind. The “most reasonable” model, that of sample variance, is ruled out
- Hubble tension may be an indicator of new physics in the dark sectors (or... a large and unexpected systematic)