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# The new measurement of the Hubble Constant from the SH0ES and Pantheon+ teams

📰 Riess, A. et al., 2022, ArXiv: 2112.04510

Collaborators: Adam Riess, Wenlong Yuan, Lucas Macri, Dan Scolnic, Dillon Brout, Stefano Casertano, David Jones, Yukei Murakami, Gagandeep Anand, Thomas Brink, Alexei Filippenko, Samantha Hoffmann, Saurabh Jha, D'Arcy Kenworthy, John Mackenty, Benjamin Stahl, Weikang Zheng

*Rencontres de Blois, 23-28 May 2022, France*

- End-to-end test of the standard model

- Planck Collaboration 2020:

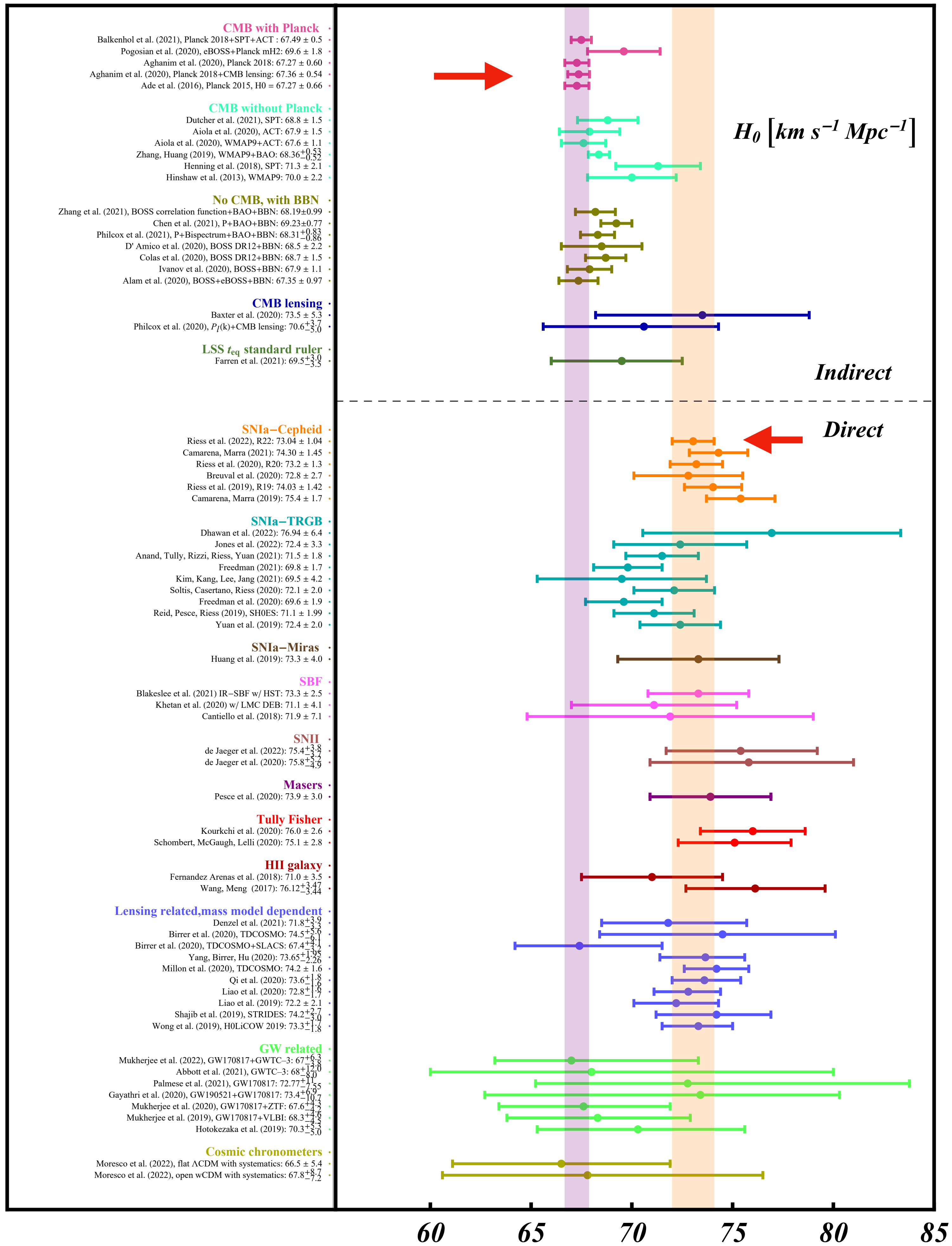
  **$H_0$ = 67.4 ± 0.5 km/s/Mpc**

- Riess et al. 2022:

  **$H_0$ = 73.04 ± 1.04 km/s/Mpc**

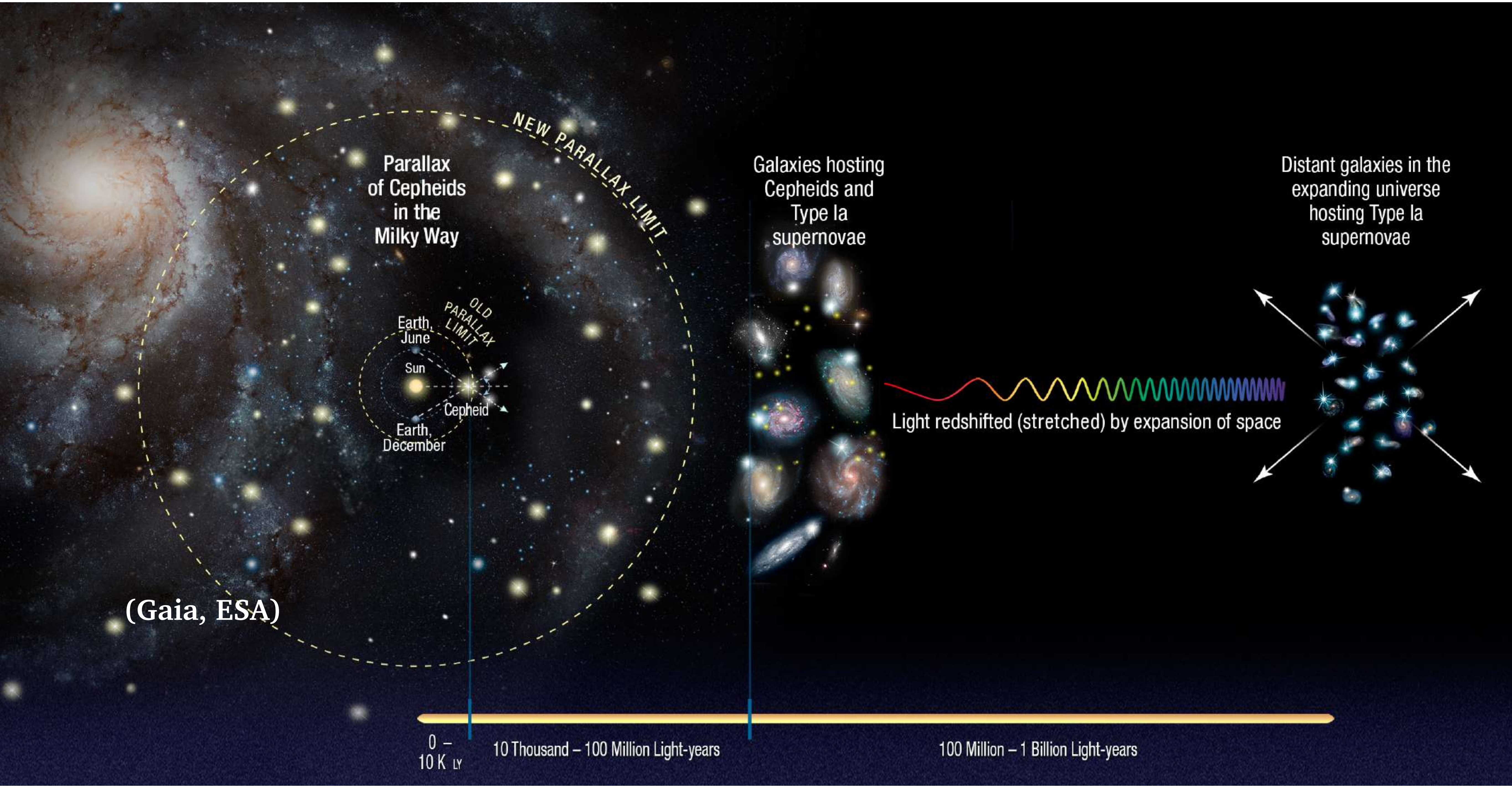
5$\sigma$ tension ➞ new physics beyond ΛCDM ?

(see talk by V. Poulin on Friday)



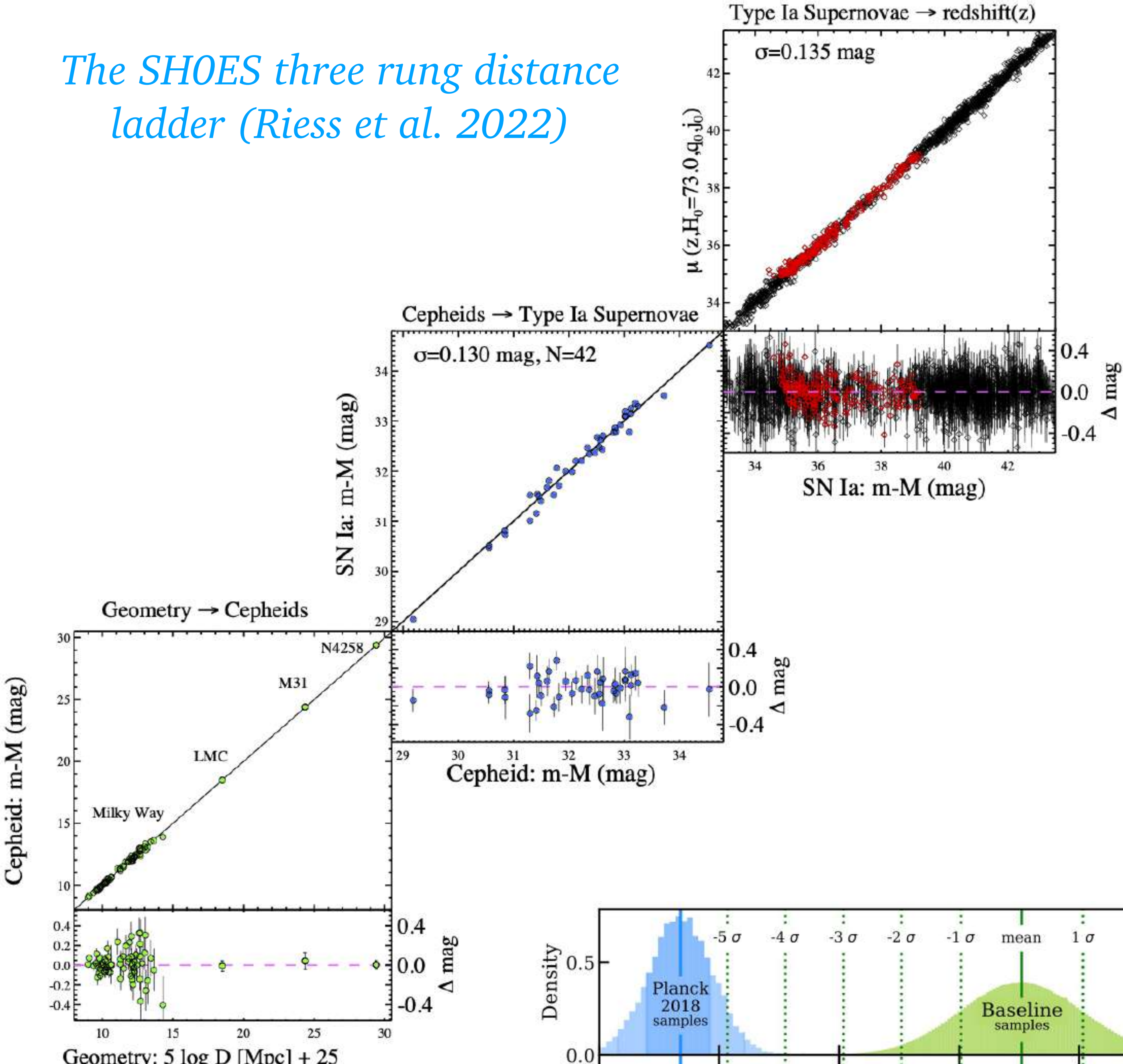
**1st rung** **2nd rung** **3rd rung**

3 "anchors":
Milky Way + LMC + NGC 4258




*The SH0ES three rung distance ladder (A. Feild and A. Riess, STScI/JHU)*

*The SH0ES three rung distance ladder (Riess et al. 2022)*

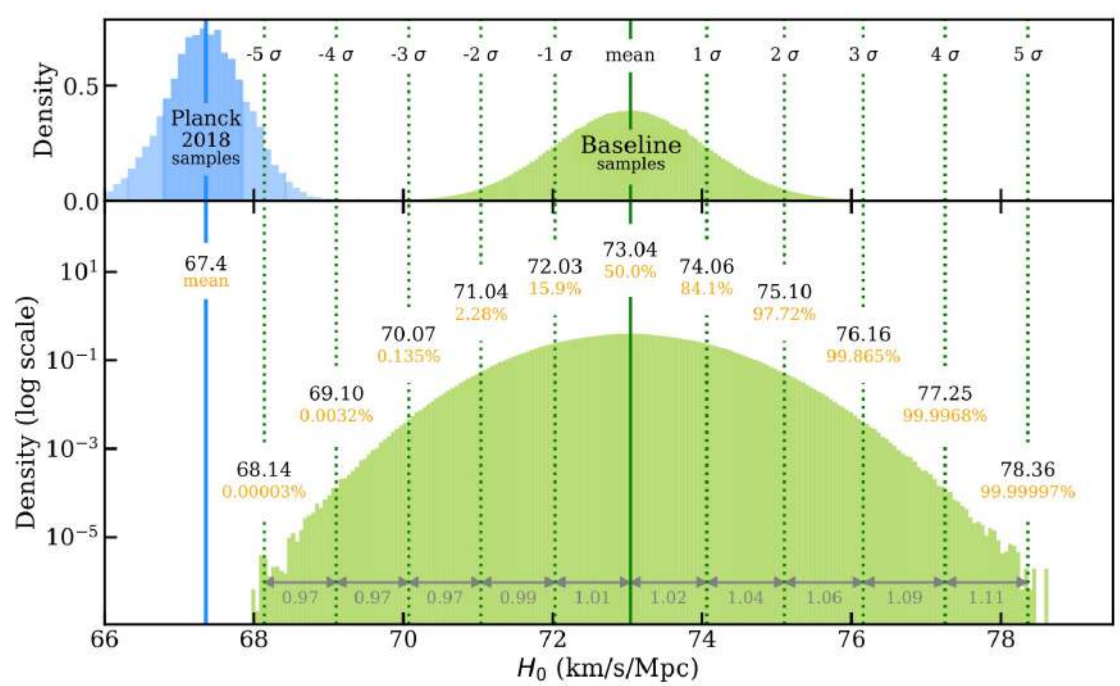


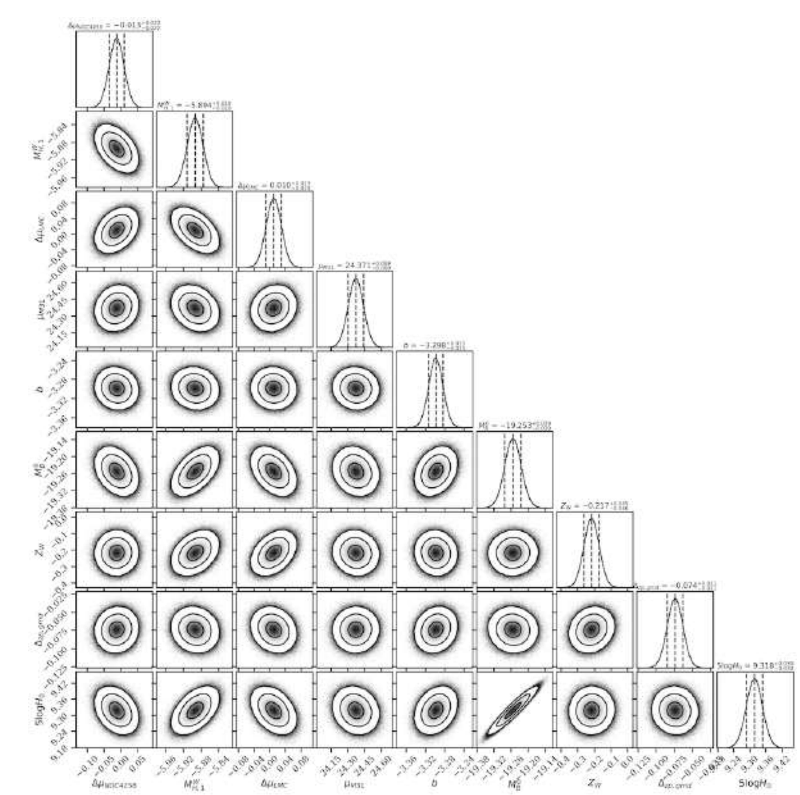

→ simultaneous fit of the 3 rungs, including covariance to better estimate errors and interdependence between parameters

→ 5 free parameters (Cepheids and SNIa luminosities, PL slope, $\gamma$ term, and 5 log $H_0$)

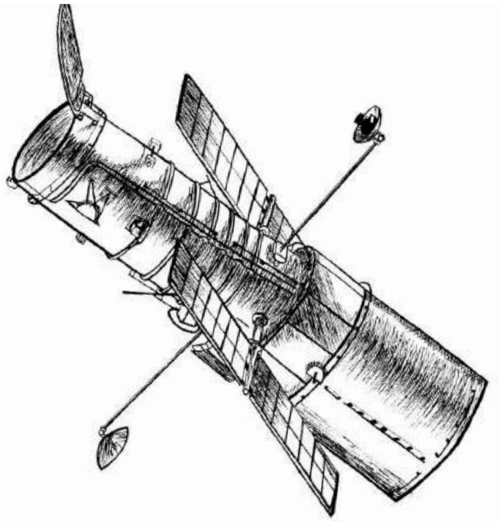
→ 100 million MCMC

**$H_0$ = 73.04 ± 1.04 km/s/Mpc**



## Main results



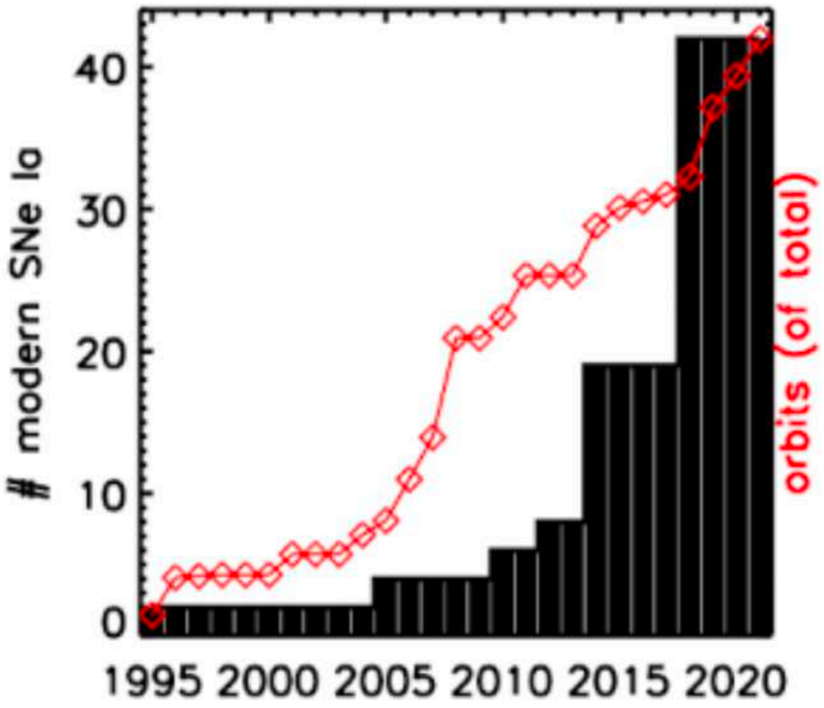
→ reducing systematic errors:
  - NIR to avoid the effect of dust
  - 3 filters and 1 single instrument on HST (combined -> independent of dust)
  - consistent measurements between the 3 rungs
    (Pantheon+: Scolnic et al. 2022, Brout et al. 2022)

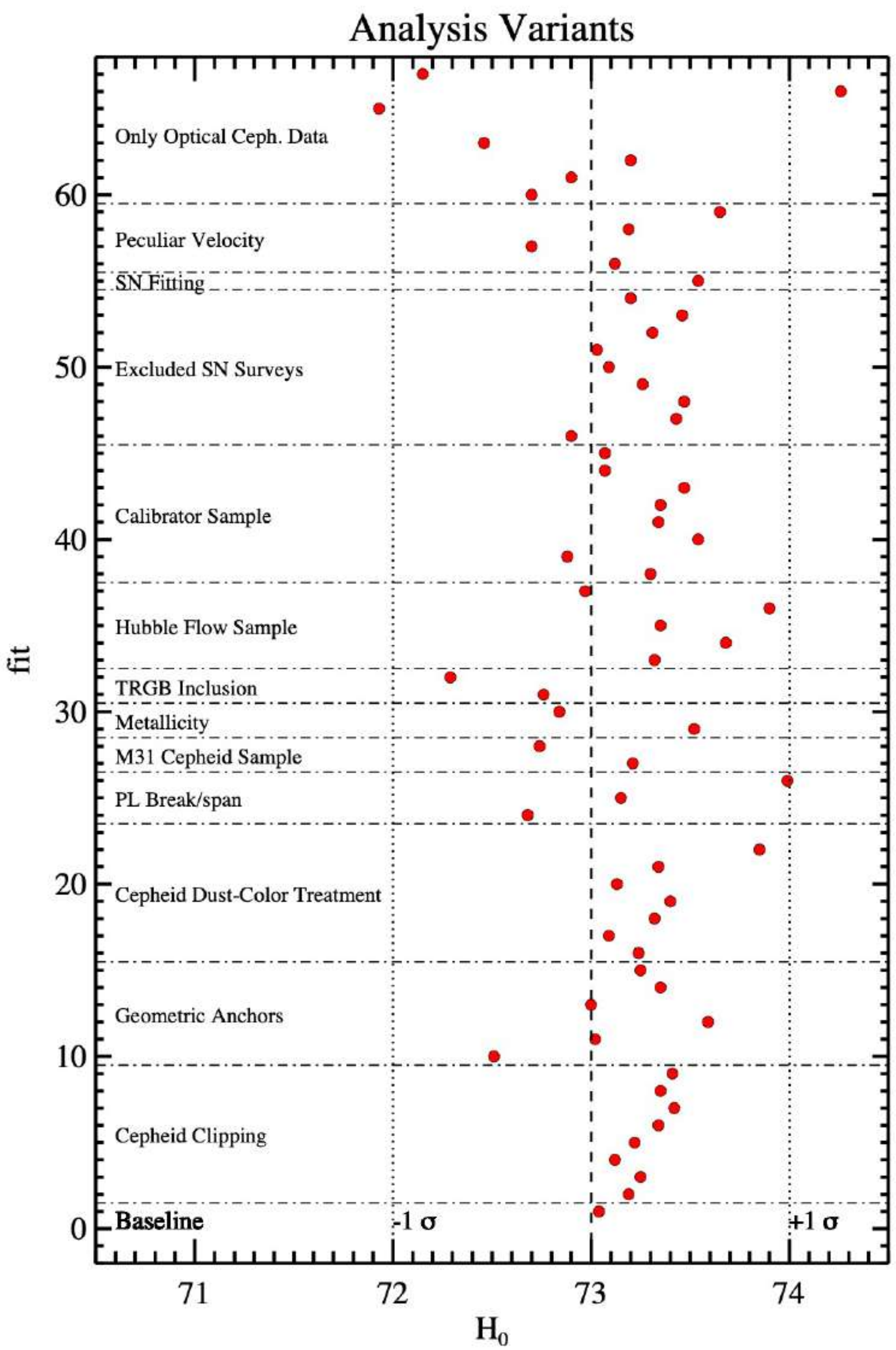
→ get realistic errors by including statistical uncertainties and systematics in a covariance matrix

→ 42 supernovae in calibrator galaxies (only 19 in 2016)

→ 18 HST proposals and 1000 orbits of HST

→ other improvements:
  - triple the number of Cepheids in the NGC 4258 host galaxy,
  - data reprocessed with STScI calibration tools,
  - 67 variants of the analysis:
    - removing anchors
    - changing reddening law
    - cut in Cepheid periods
    - change/ignore metallicity dependence



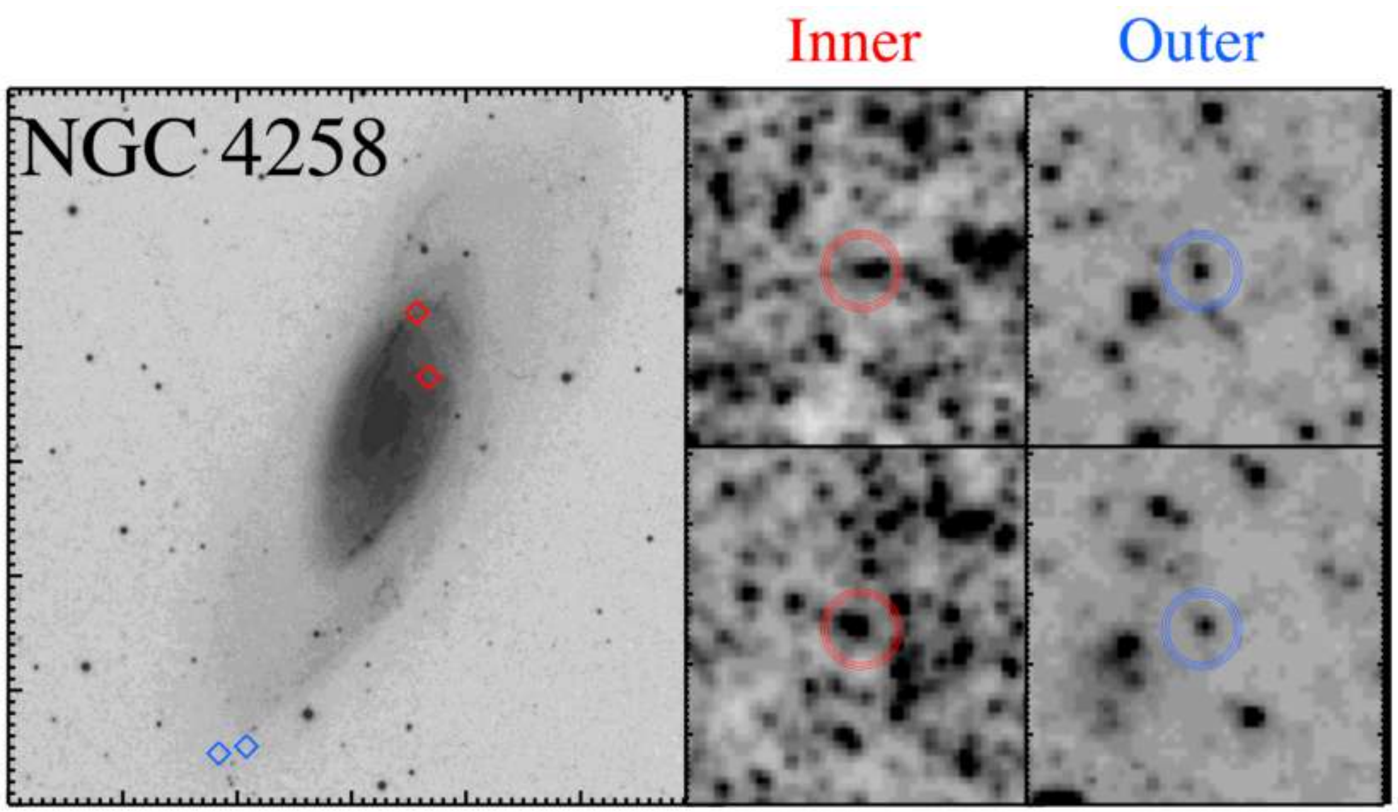



- Optical Cepheid data only (72.7)
- Different pec. vel map or none (73.1,72.7)
- SN scatter ind. wave+mass step (73.5)
- No pre-2000 SNe (73.2)
- closest half hosts (73.1)
- most crowded half (73.4)
- least crowded half (73.3)
- Skip "local hole" z>0.06 (73.4)
- All host types (73.3)
- include TRGB (consistent) jointly (72.5)
- No metallicity term (73.5)
- Break in PL at P=10 days (72.7)
- No dust correction (74.8)
- Individual host dust law (73.9)
- Free param dust law (73.3)
- Low $R_V$=2.5 dust law (73.2)
- Two of three anchors (73.0,73.4,73.2)
- No outlier rejection (73.4)

→ We propagate the scatter of these variants as an additional systematic

→ no indication of any measurement inconsistency or any source of systematics that could solve the tension

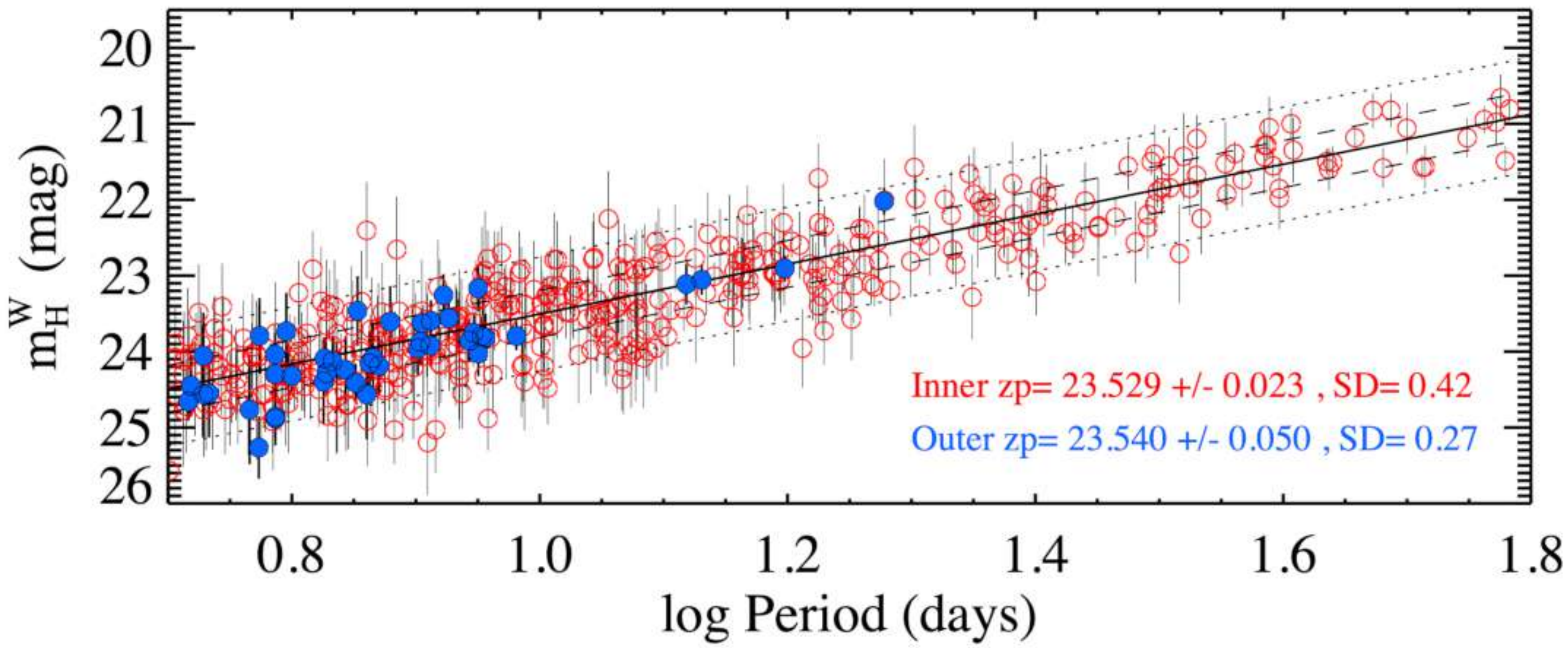
**Does the crowded and dense backgrounds compromise the accuracy on $H_0$ ?**




→ Add artificial stars of known brightness in the vicinity of Cepheids and we re-measure their contribution

→ +4 other tests of crowding

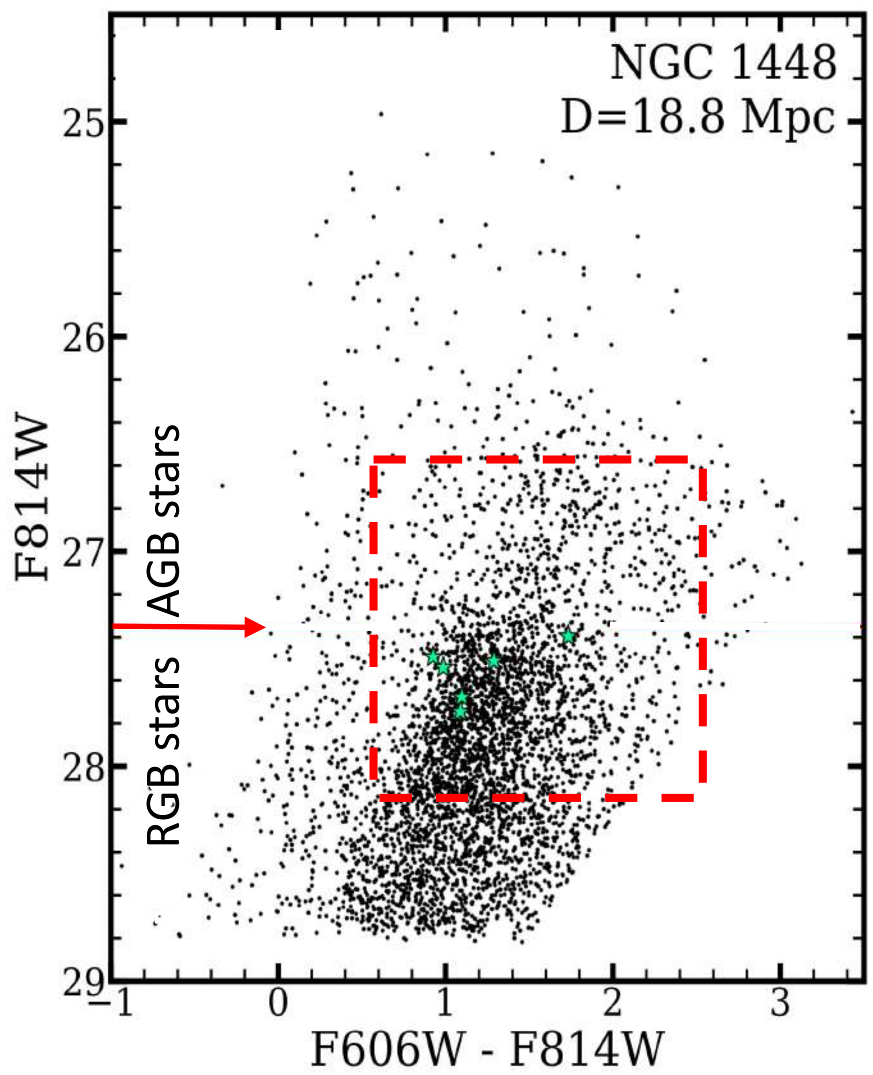
→ More noise in crowded regions (red) but the mean agrees very well.

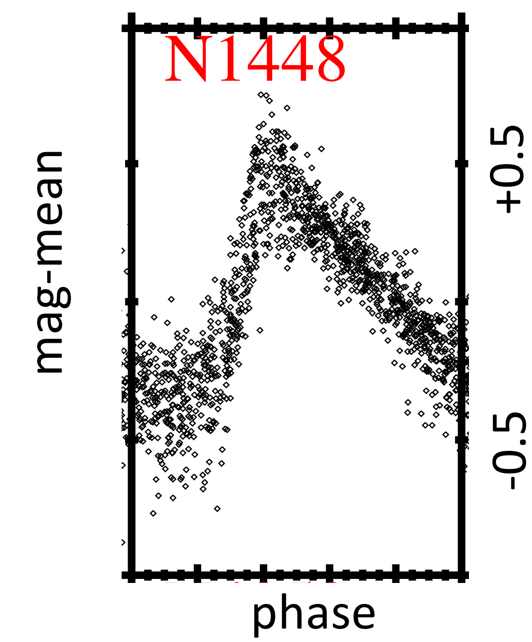


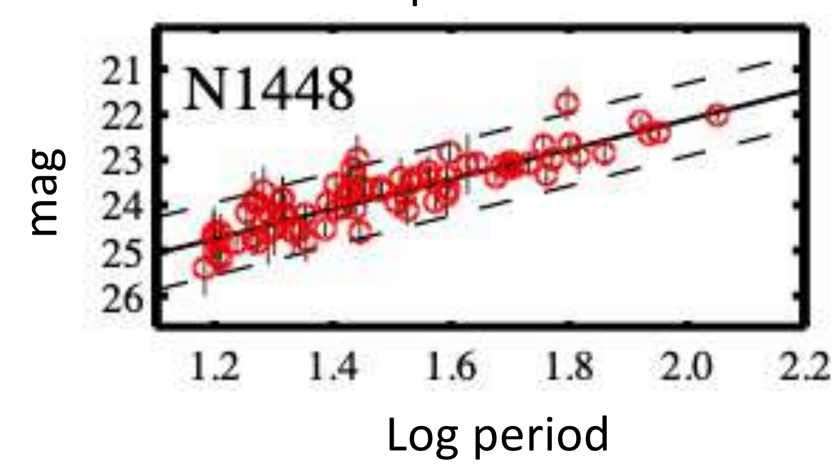
# Are TRGB and Cepheid distances consistent ?

➞ **TRGB**: measure precisely the brightness of the discontinuity/break in the color-mag diagram

➞ **Cepheids**: find light curves, periods, measure Period-Luminosity relation



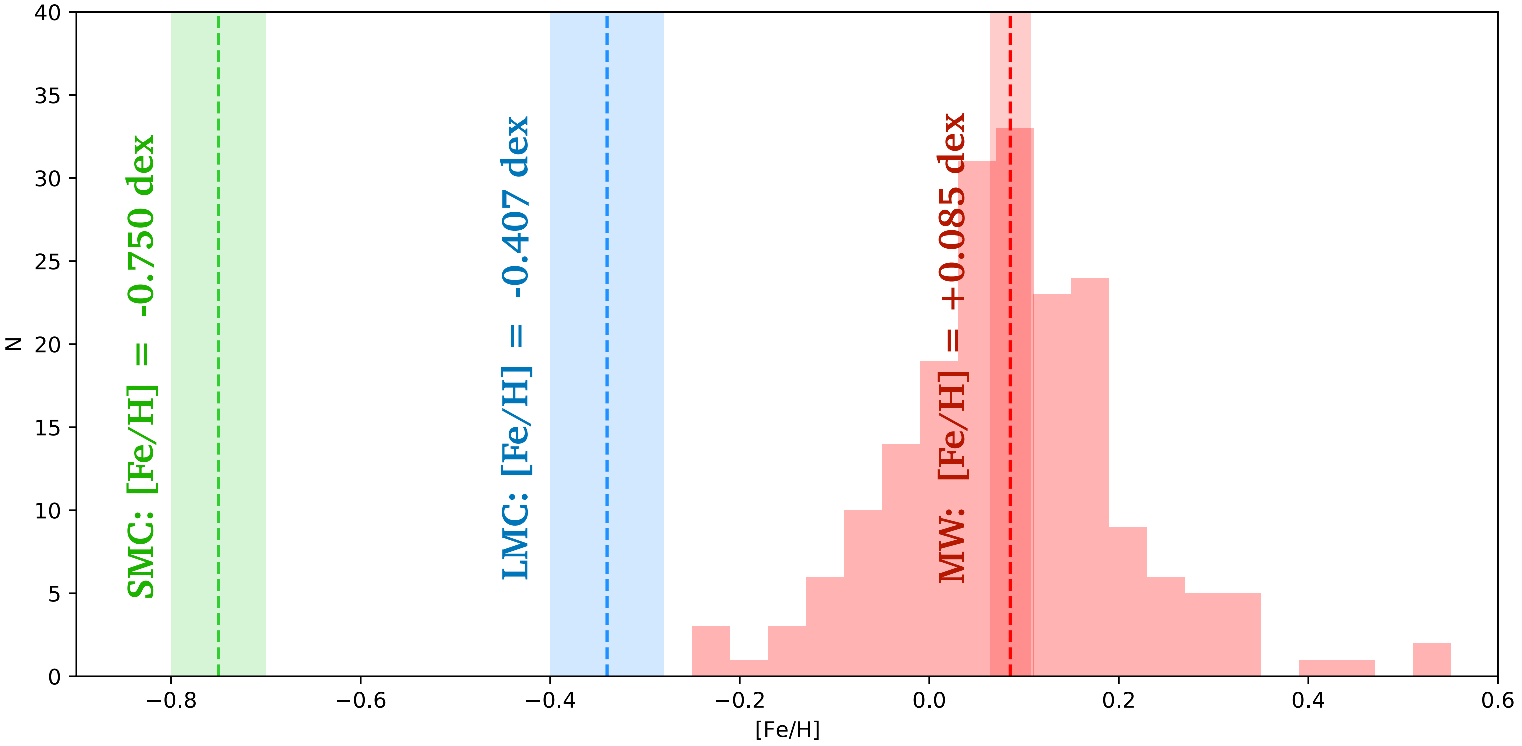



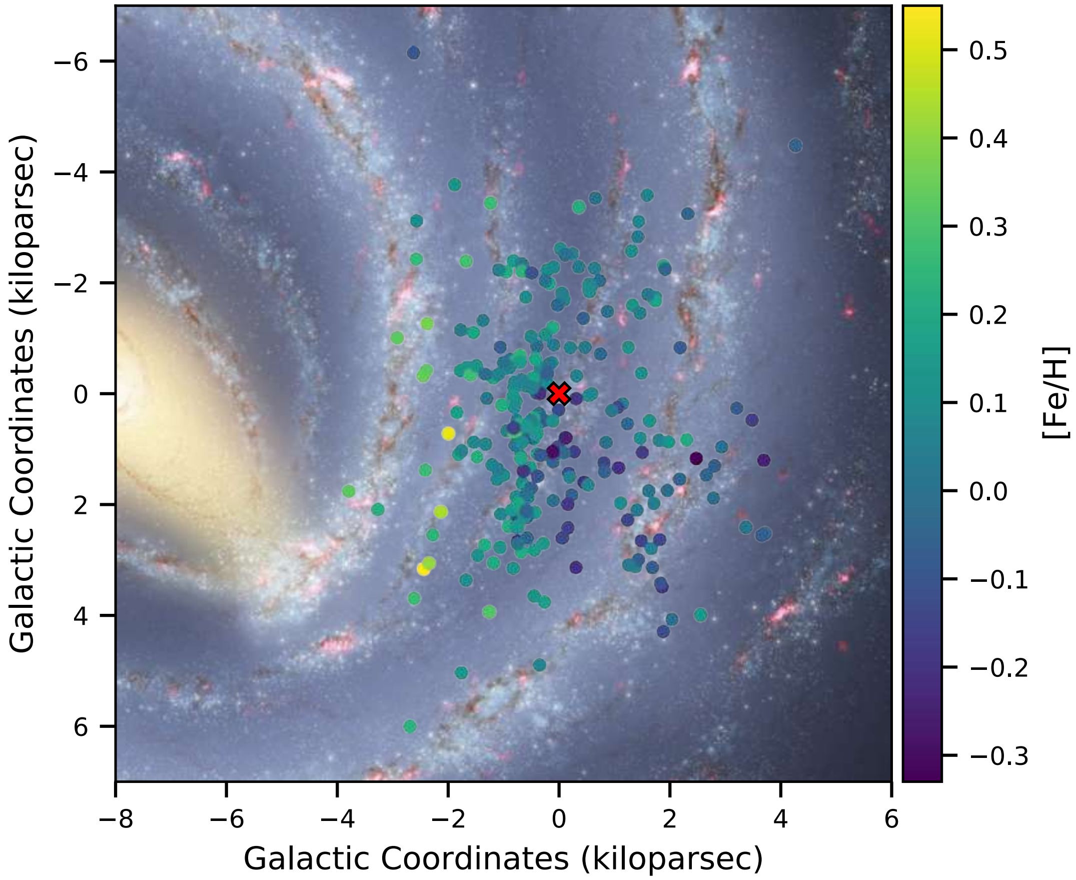

➞ 8 galaxies for which we have both TRGB and Cepheid distances

➞ Included simultaneously: $H_0 = 72.5 \pm 1$ km/s/Mpc

## How to account for metallicity differences for Cepheids ?




*Metallicity range covered by Milky Way and Magellanic Cloud Cepheids (Breuval 2021)*




### Method:

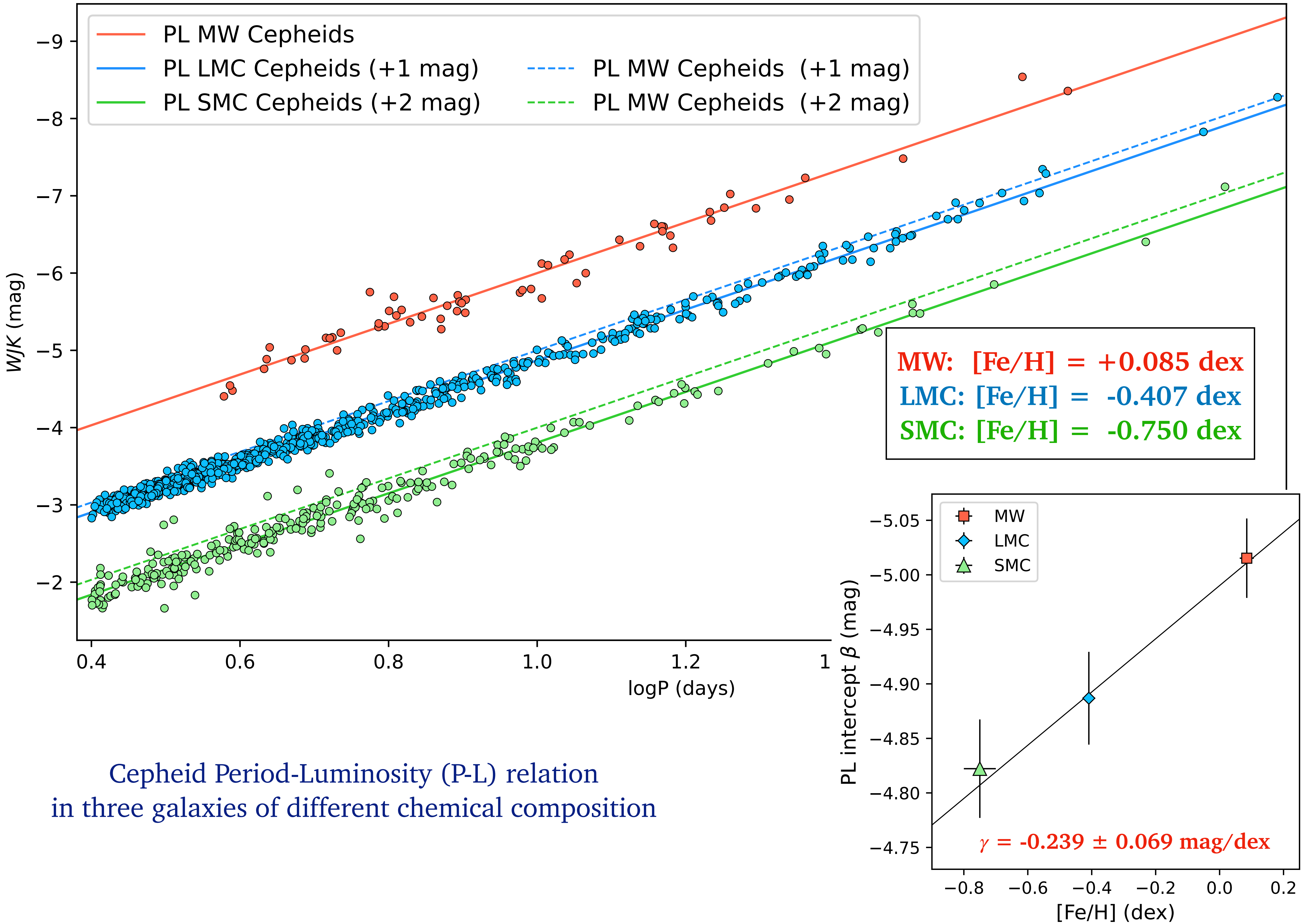
- → Host-to-host direct comparison
- → Large metallicity coverage ($\sim$ 1 dex)
- → Consistent data sets (distances, photometry, extinction...)

$$\mathbf{M = a\ logP + b + \gamma\ [Fe/H]}$$

### Distances:

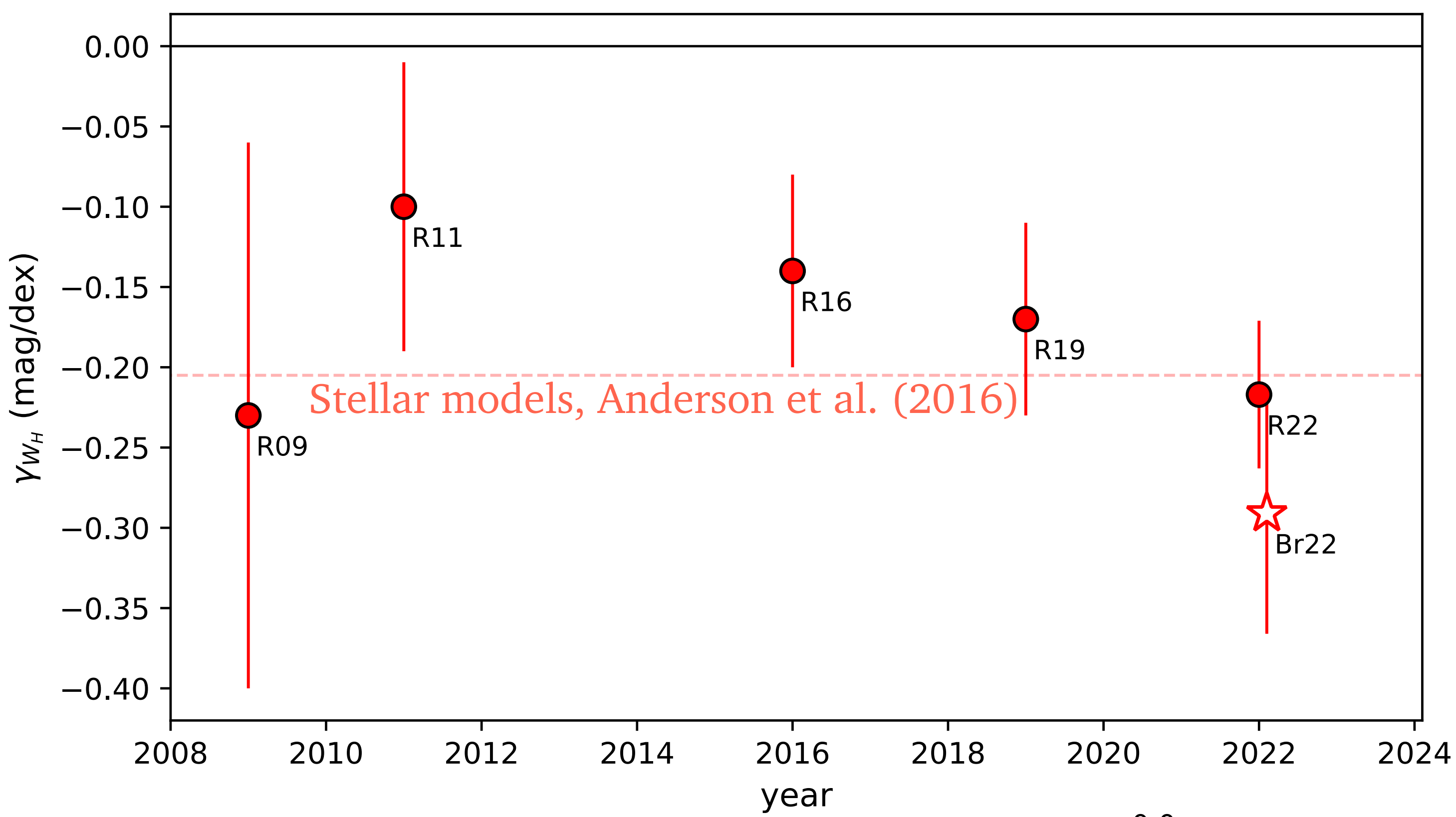
- → Gaia EDR3 in Milky Way
- → Eclipsing binaries in Magellanic Clouds

## How to account for metallicity differences for Cepheids ?




Cepheid Period-Luminosity (P-L) relation
in three galaxies of different chemical composition

# How to account for metallicity differences for Cepheids ?

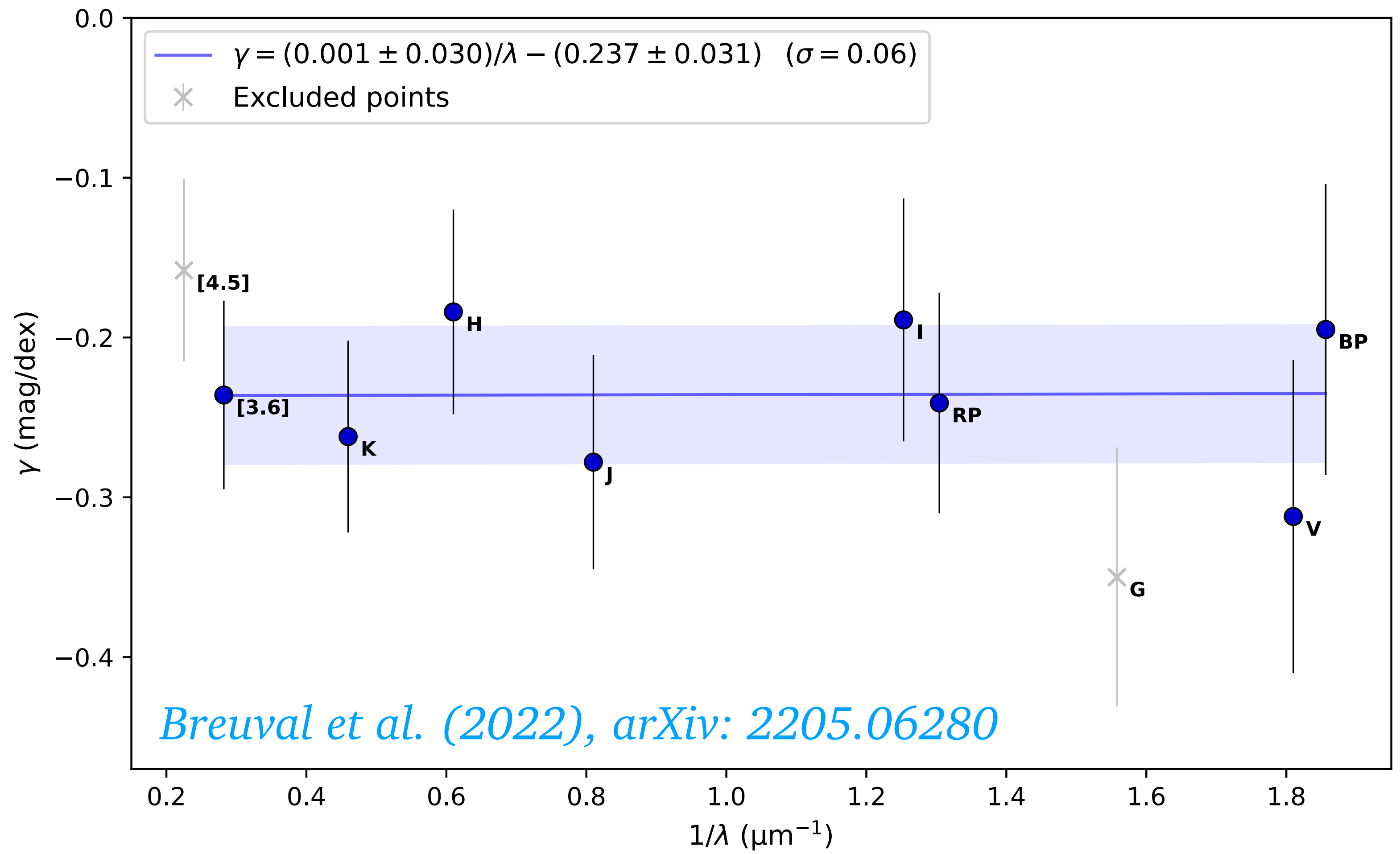



→ good agreement with SH0ES results and with stellar models

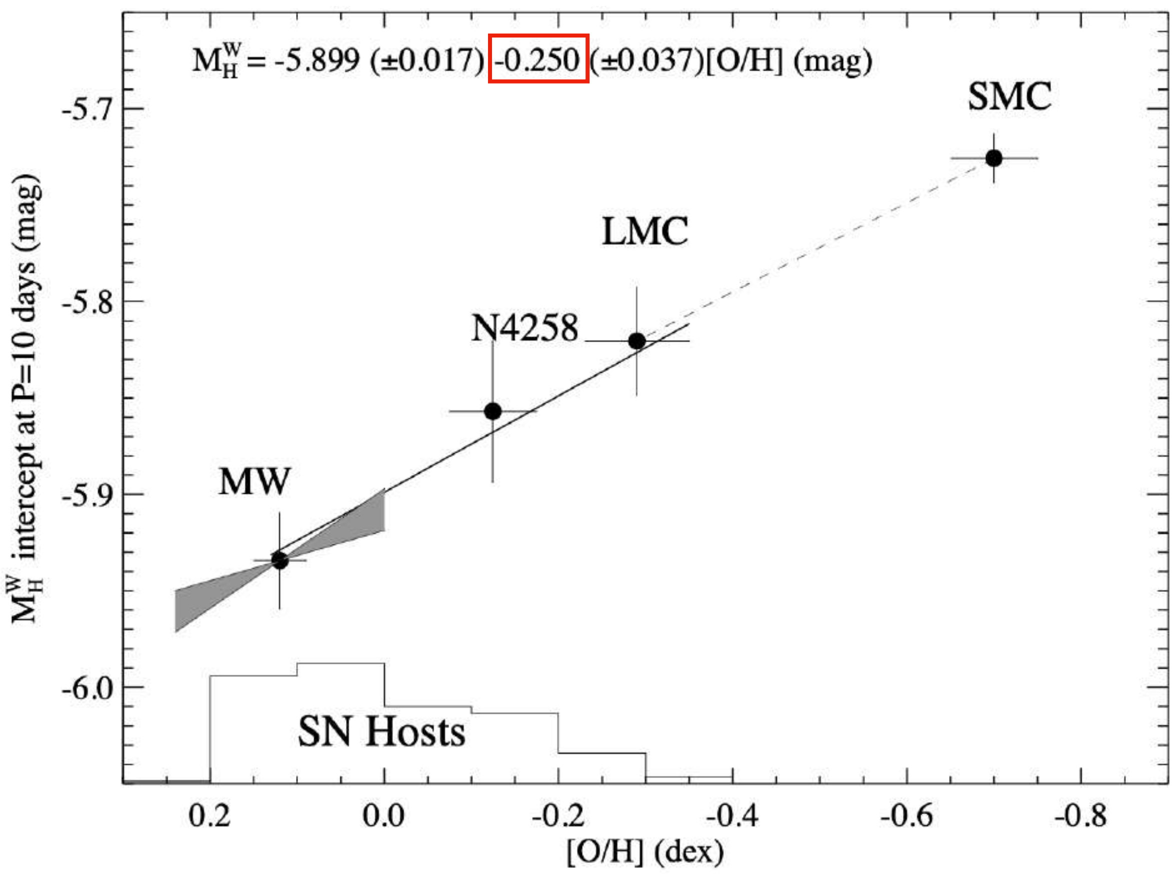
→ Metal-rich Cepheids are brighter that metal-poor ones

→ 10 filters (*Gaia*, *Spitzer*, ground NIR and optical) + 5 reddening-free Wesenheit magnitudes

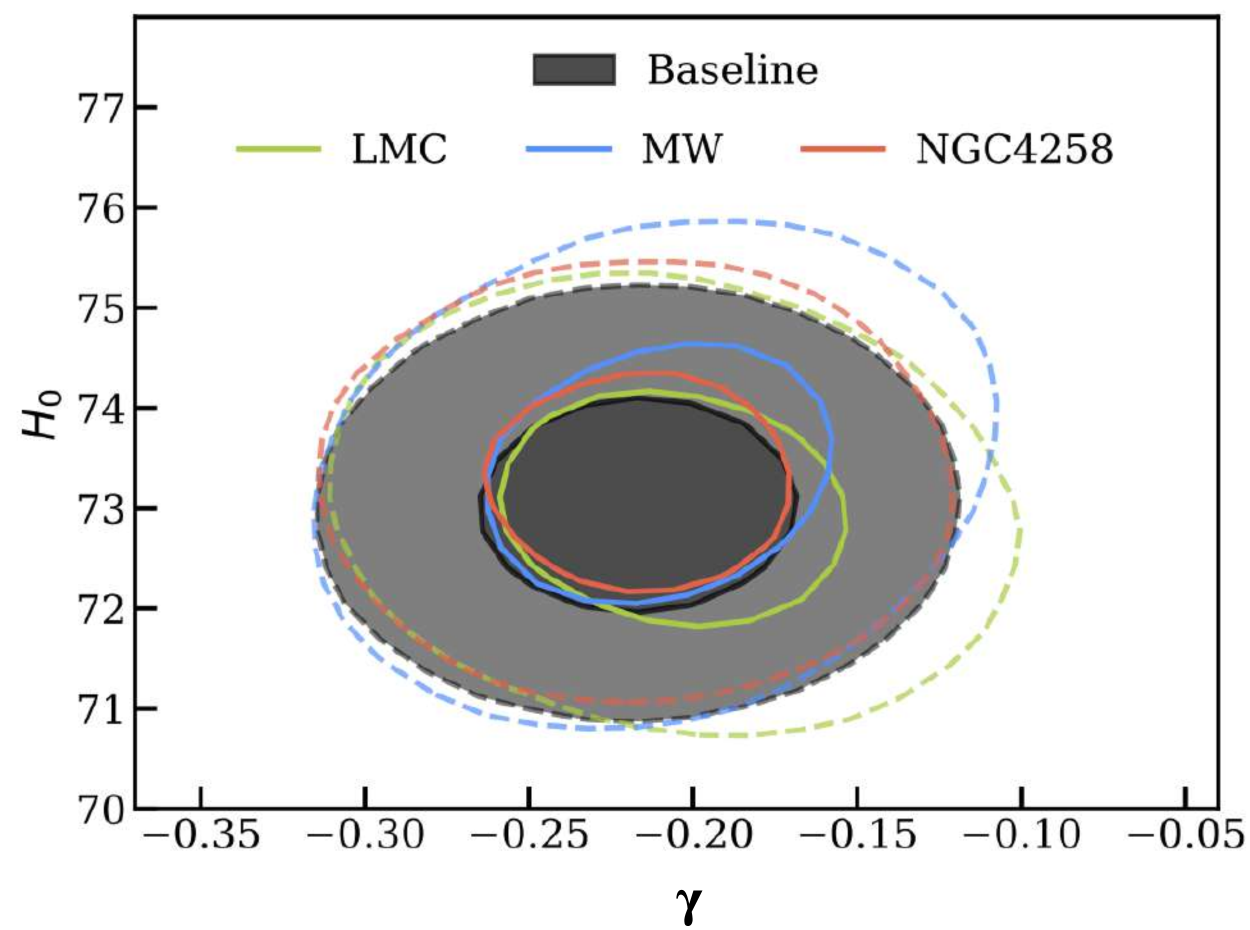
→ No wavelength dependence



## How to account for metallicity differences for Cepheids ?




→ Overall same metallicity between anchors and Cepheids in host galaxies



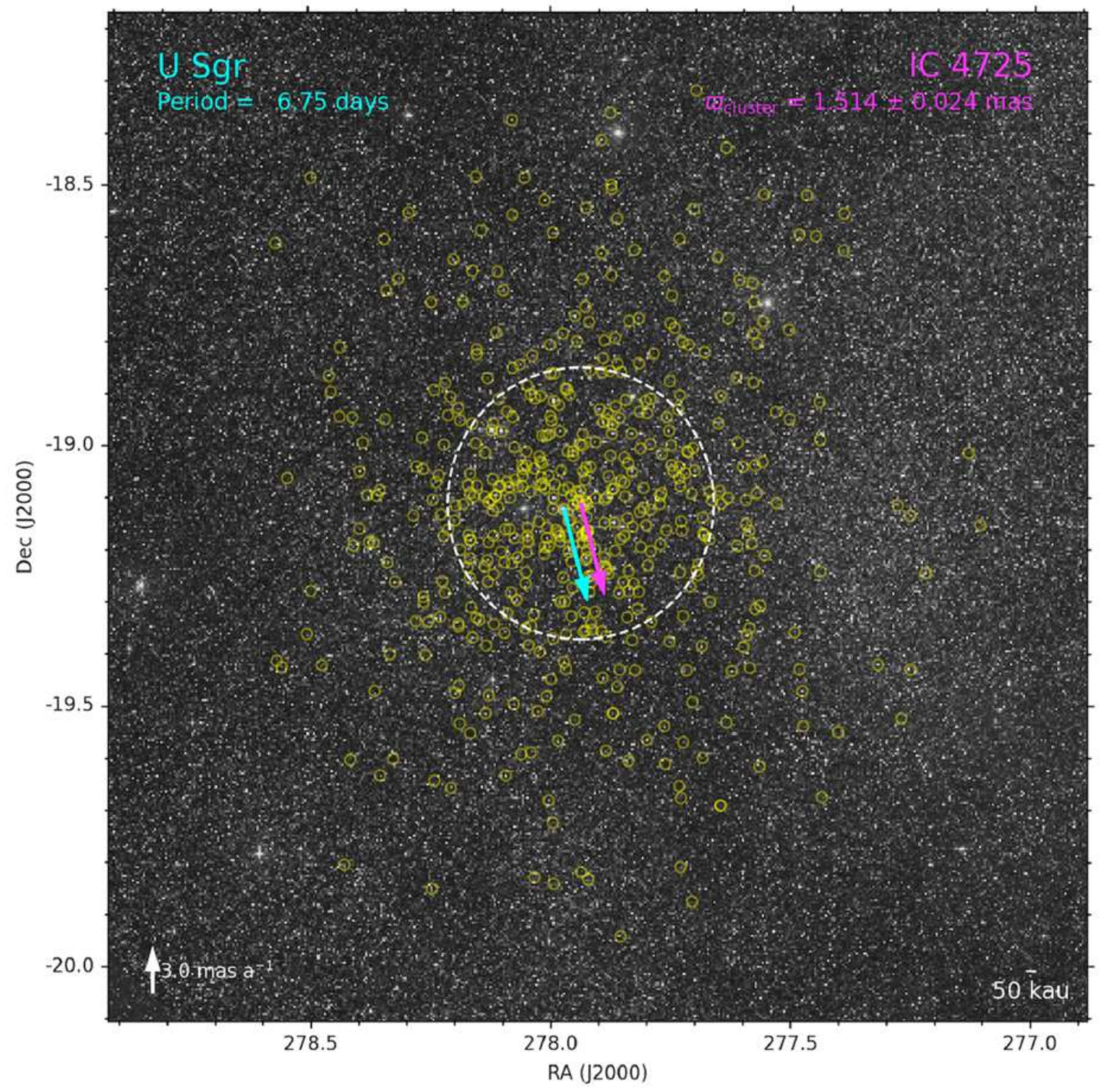

→ No correlation between H0 and the metallicity term

→ Need to account for this term to make anchors consistent (we fit simultaneously anchors that have a different metallicity)

# Perspectives

→ JWST (24h in cycle 1), Gaia DR4 (more precise parallaxes), LIGO (standard sirens)...

→ Cepheids in clusters:



## Conclusion

→ Main result: baseline fit **$H_0$ = 73.04 ± 1.04 km/s/Mpc** including systematics

→ Consistent and improved Cepheid calibration with HST, total of 42 SNIa, consistent with TRGB

→ 67 variants of the analysis: no indication of any excess noise or systematics to solve the tension

→ Three anchors (MW, LMC, NGC 4258) consistent with each other, which results from the correction of the metallicity effect

→ Standardized brightness of SNIa, consistent Cepheid measurements across the distance ladder

→ Very consistent measurements thanks to a single photometric system with HST

→ The source of the Hubble tension remains unknown

Thank you!


Riess, A. et al., 2022, ArXiv: 2112.04510

Breuval, L. et al., 2022, ArXiv: 2205.06280



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