Classical Cepheids as distance indicators and young population pulsating tracers

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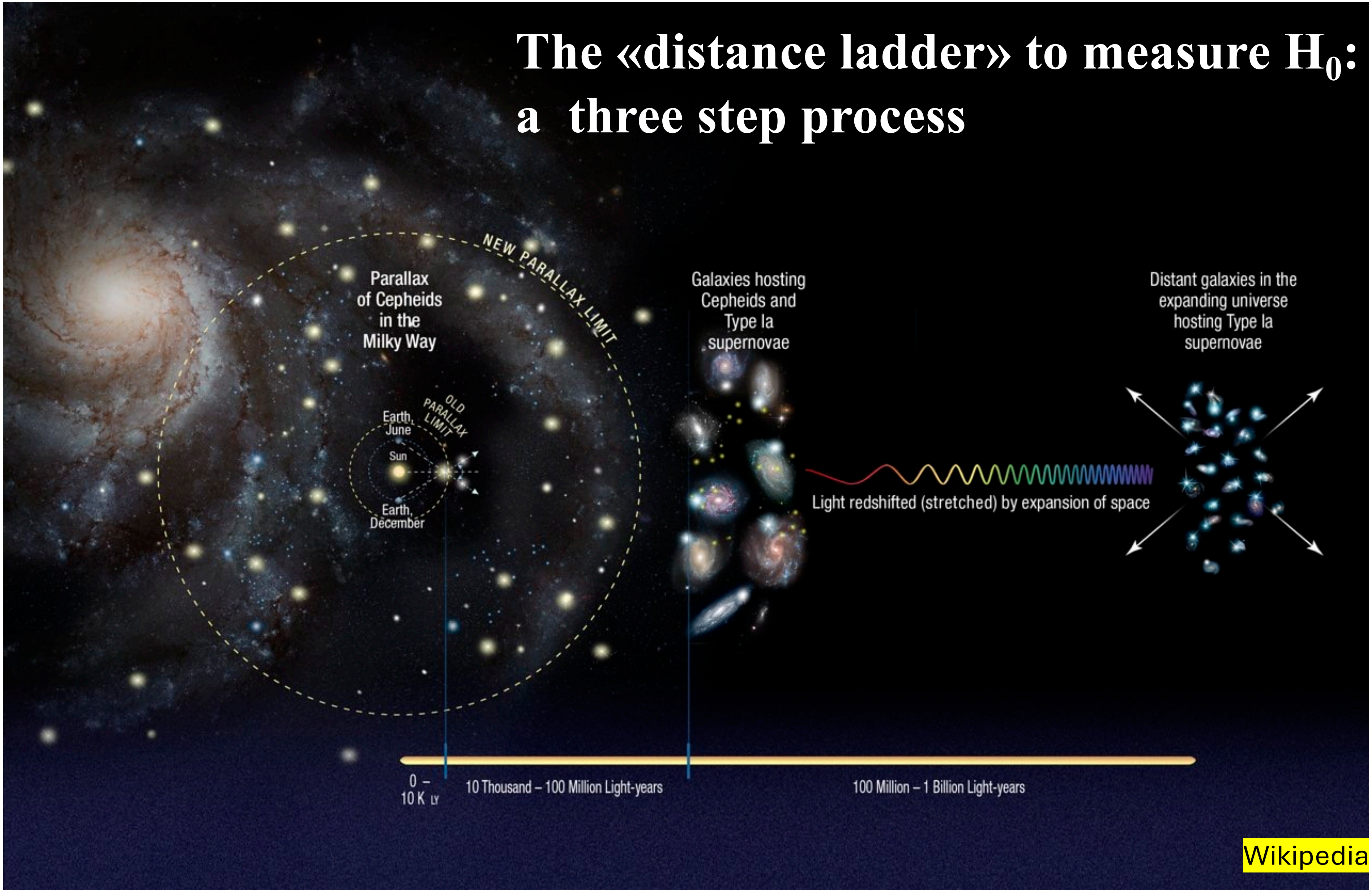
The «distance ladder» to measure H_0: a three step process

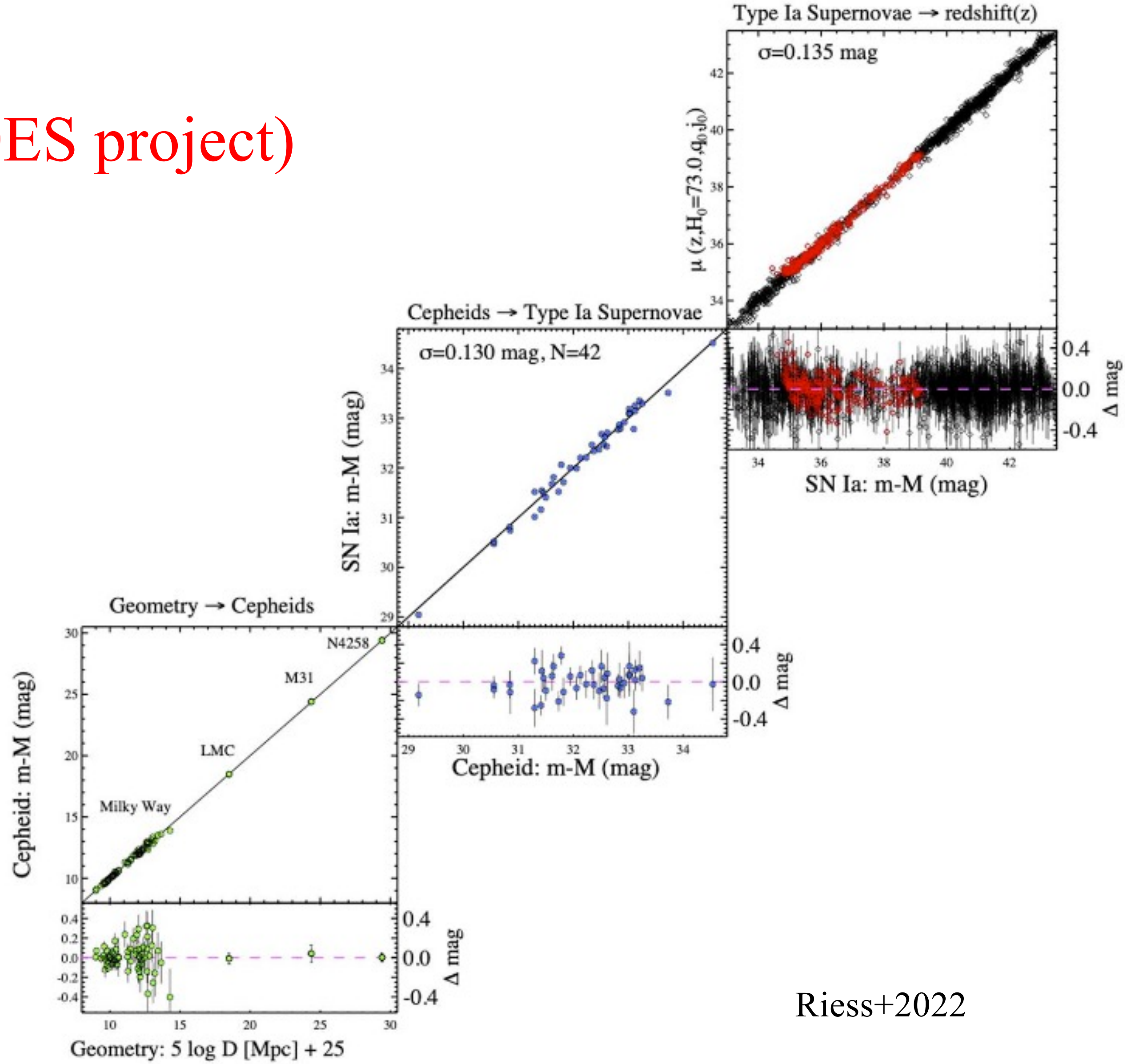


Cosmic distance ladder:
a three step process (SH0ES project)

STEP 1: Geometric distances to calibrate the PL (Wesenheit) relation of Cepheids in the HST bands (equivalent to H, V, I):

$$m_H^W = m_{F160W} - 0.386(m_{F555W} - m_{F814W}).$$

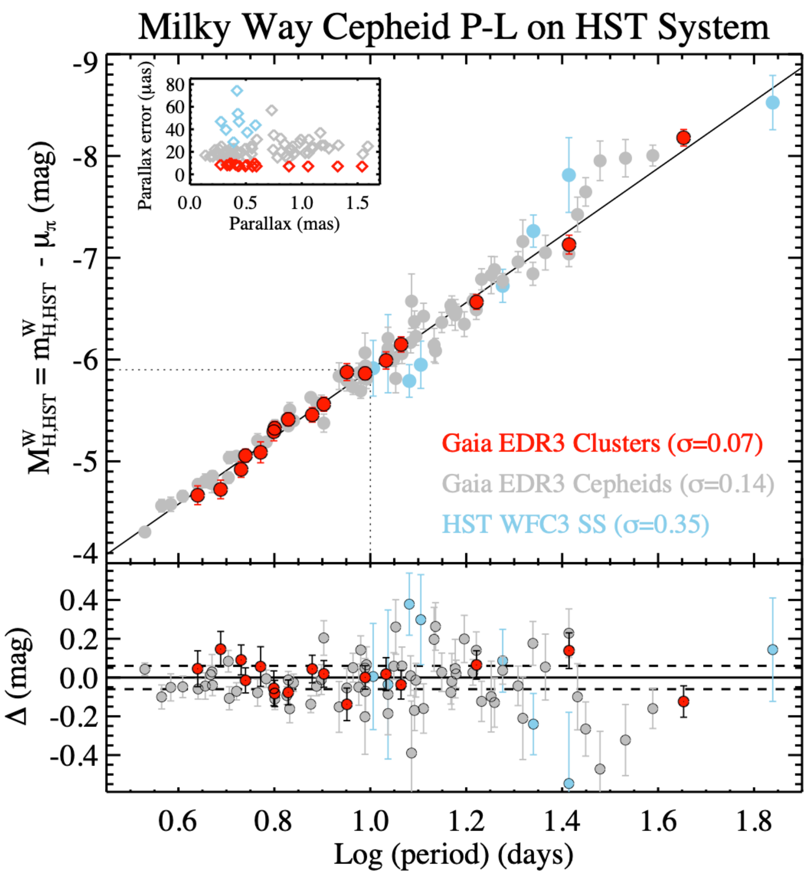
- Parallaxes in the MW (HST, Gaia)
- EB in the LMC
- Masers orbiting central supermassive black hole in NGC4258

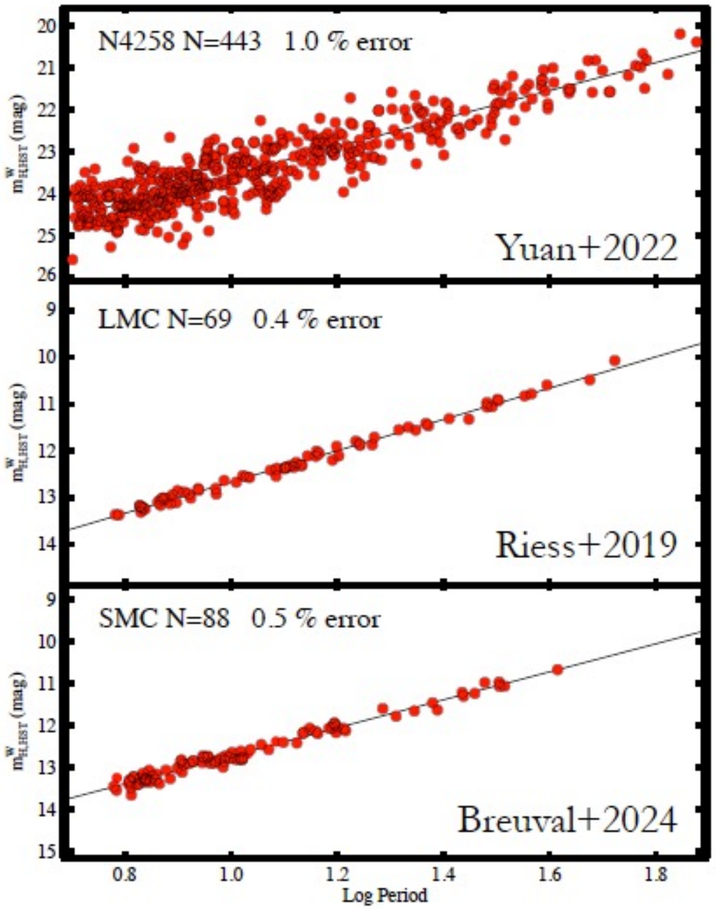


Riess+2022

Step 1: Geometry → Cepheids, 3 anchors

Gaia (and HST) Parallaxes to calibrate the PL of Cepheids in the MW (Riess+2022b)



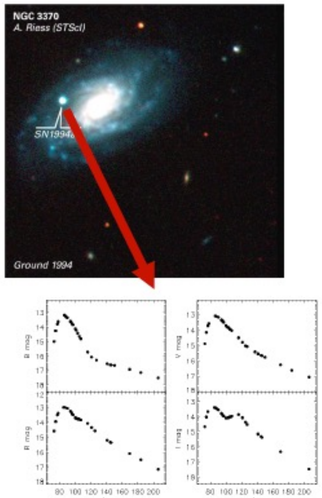


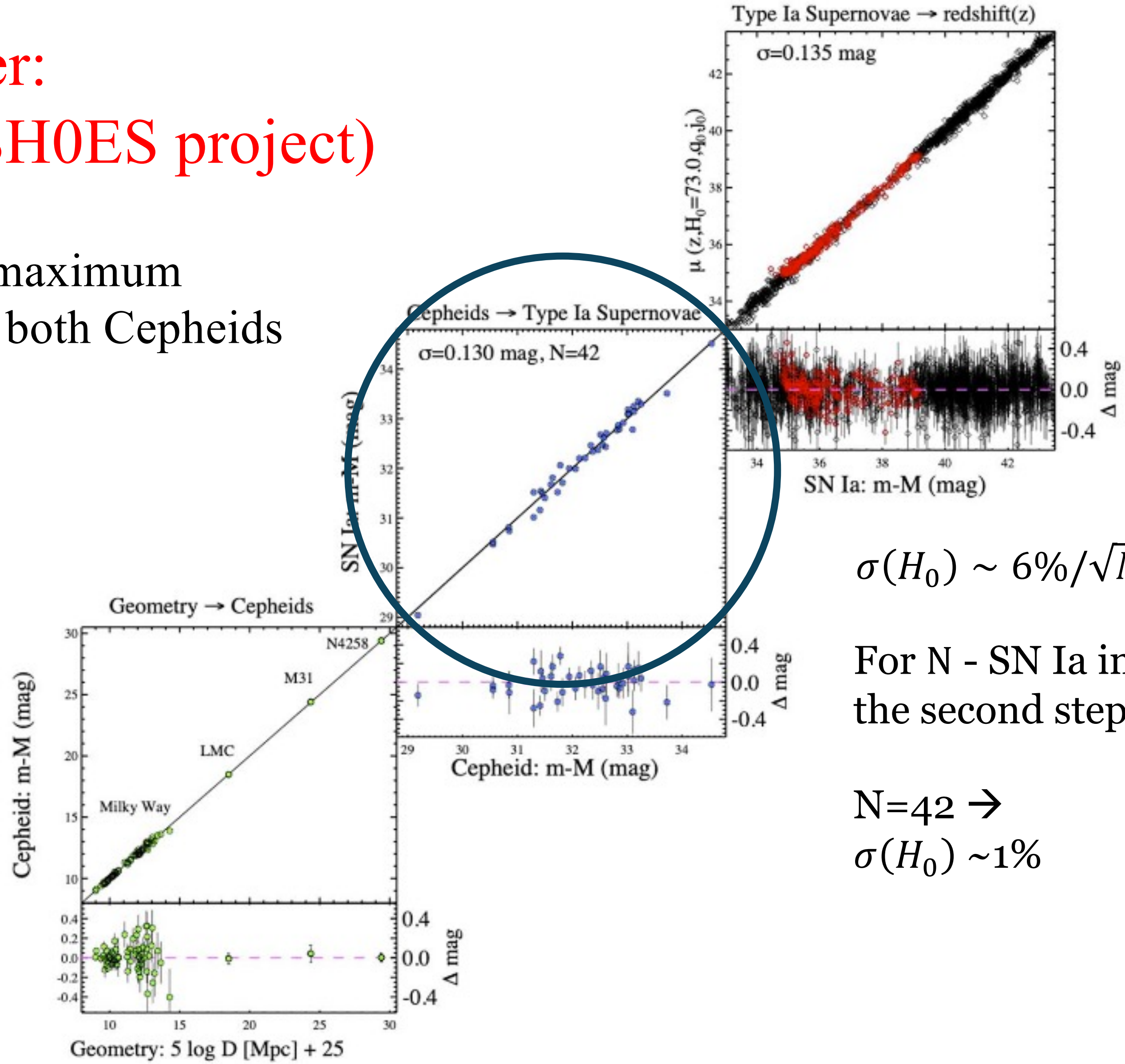
Water maser distances in NGC4258 (Reid+2019) to calibrate the PL in this galaxy.

Eclipsing binaries distances to LMC and SMC (Pietrzyński+2019; Graczyk+2020) to calibrate the Cepheid PL in these galaxy

Cosmic distance ladder:
a three step process (SH0ES project)

Step 2: Calibration of SNa Ia maximum luminosity in galaxies hosting both Cepheids and SNa Ia





$\sigma(H_0) \sim 6\%/\sqrt{N}$

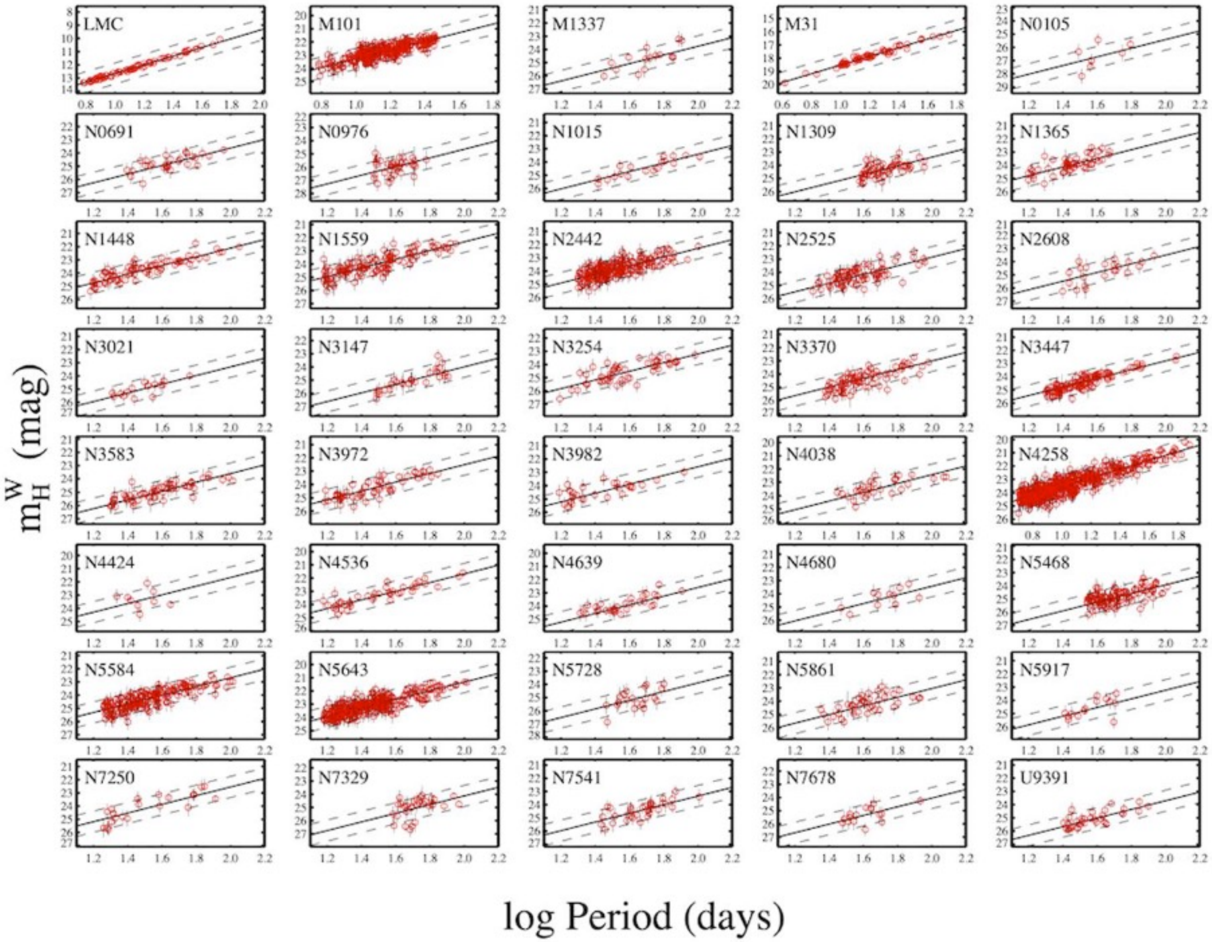
For N - SN Ia in the second step

N=42 →
$\sigma(H_0)$ ~1%

Riess+2022

Step 2: Cepheids → SNe Ia, 3 anchors

Measure PL zero points in distant galaxies hostig SNe Ia (assuming the same slope) – comparison with the zero point calibrated geometrically gives the distance of each SNe Ia host.



$$m_{B,i}^0 = \mu_{0,i} + M_B^0,$$

SNe Ia maximum-light apparent magnitude (corrected for variations around the fiducial color, luminosity, and any host dependence).

Distance modulum from Cepheids

SNe Ia Fiducial magnitude (what we want to calibrate)

Riess+2022

SNe Ia as Standard Candles

A good standard candle has the smallest possible range in luminosity

SNe Ia exhibit $\Delta M_B^{\text{peak}} \sim 1.5$ ($\times 4$ in L)

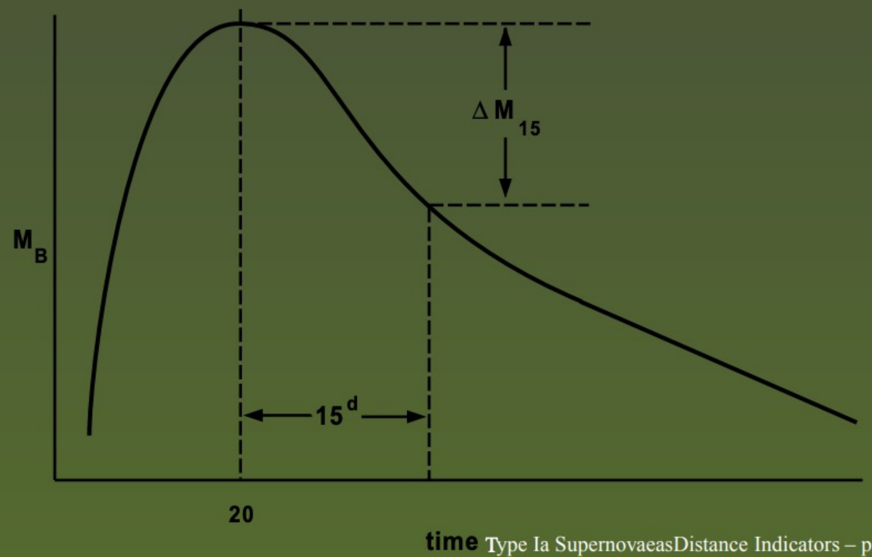
$\rightarrow$ too large for precision cosmology

Phillips ('93) discovered that the width of the lightcurve peak is correlated with the peak luminosity:

Brighter = Broader

Larger $M \leftrightarrow$ smaller Δm_{15}

Can use the $\Delta m_{15}/L$ relation to "standardize" the candle to $\sigma \sim 0.1$ mag



SNe Ia explode at approximately the same mass (Chandrasekar limit) → approximately the same luminosity

Maximum light $M_B \sim -19.3$ mag → visible well in the Hubble flow.

Credit:
P. Pinto

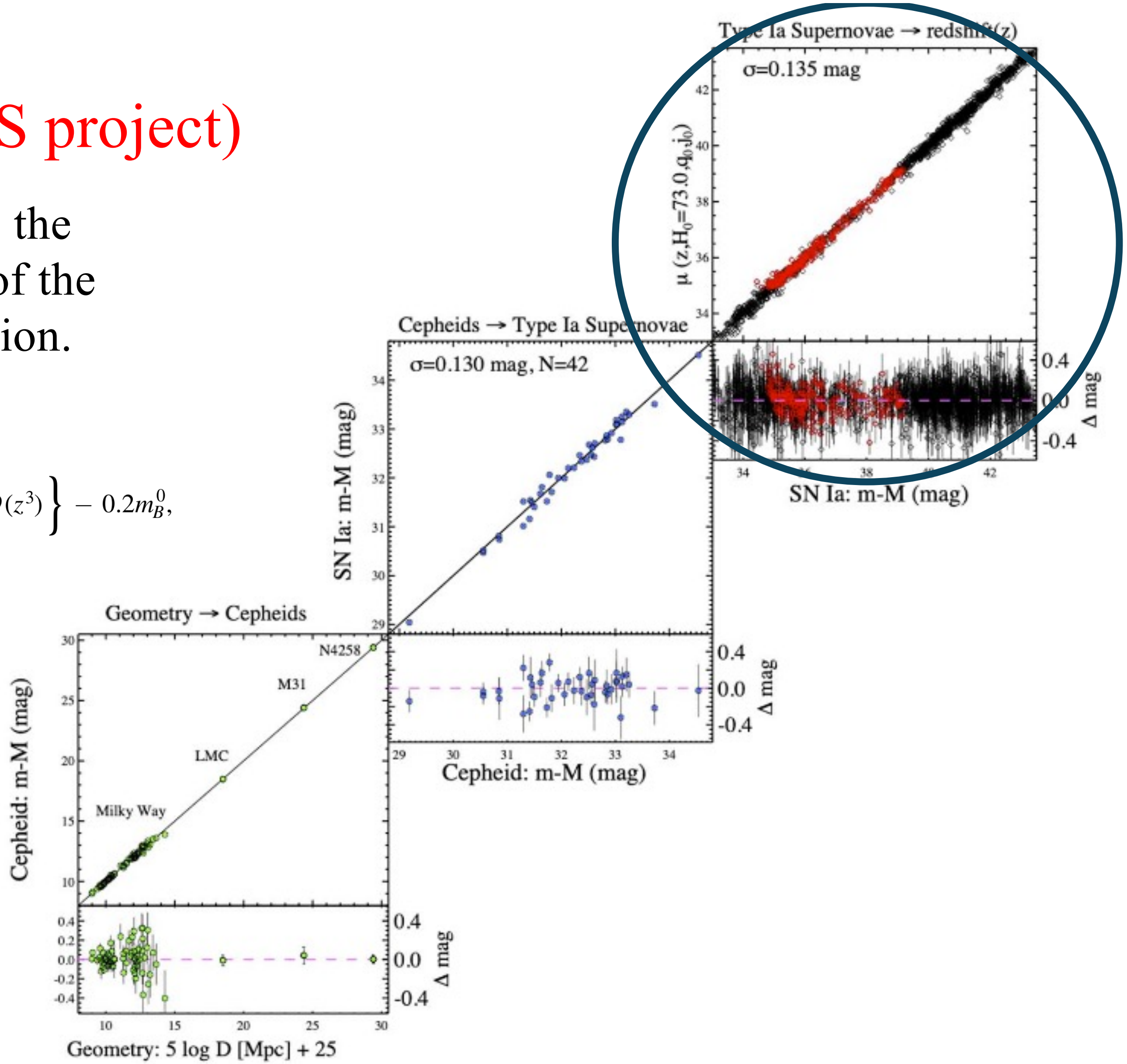
Cosmic distance ladder: a three step process (SH0ES project)

Step 3: A set of SNe Ia that measure the expansion rate, a_B i.e. the intercept of the distance or magnitude–redshift relation.

$$a_B = \log cz - 0.2m_B^0$$

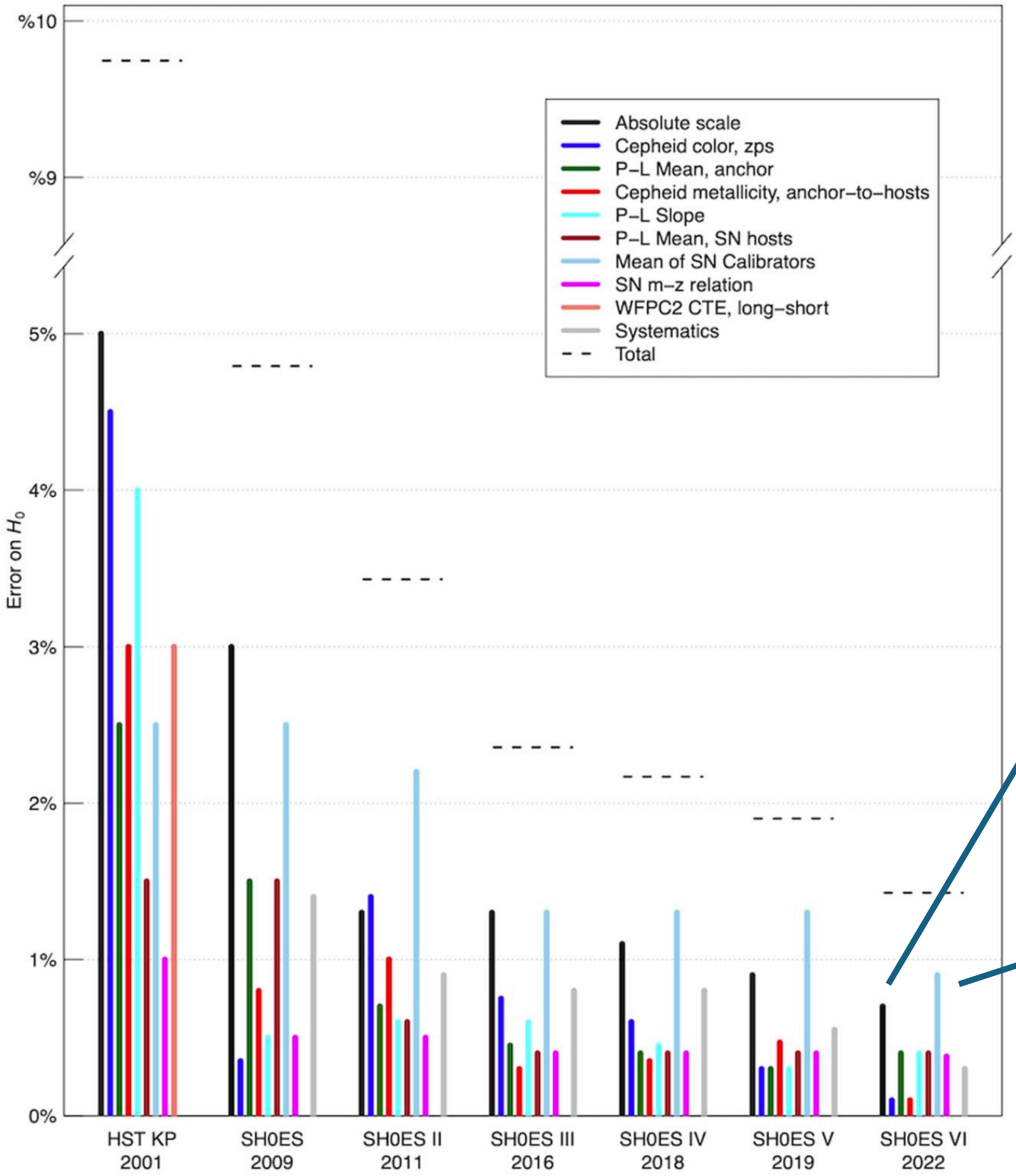
$$a_B = \log cz \left\{ 1 + \frac{1}{2}[1 - q_0]z - \frac{1}{6}[1 - q_0 - 3q_0^2 + j_0]z^2 + O(z^3) \right\} - 0.2m_B^0,$$

$$\log H_0 = 0.2M_B^0 + a_B + 5.$$



Riess+2022

Error budget

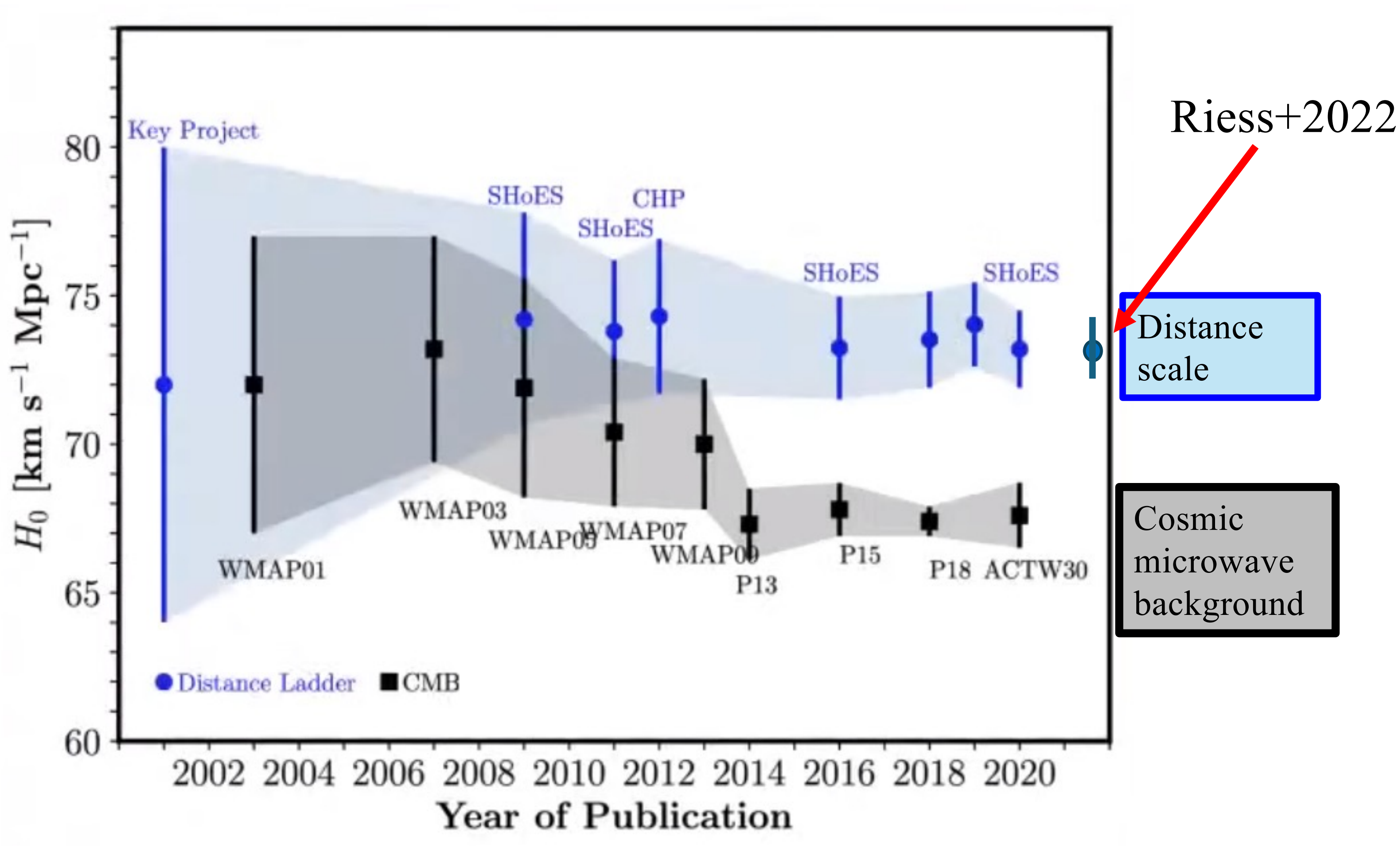


Step 1: Geometric calibration of the Cepheid PL

Step 2: Cepheid calibration of the SNe Ia peak luminosity

Riess+2022

Hubble tension

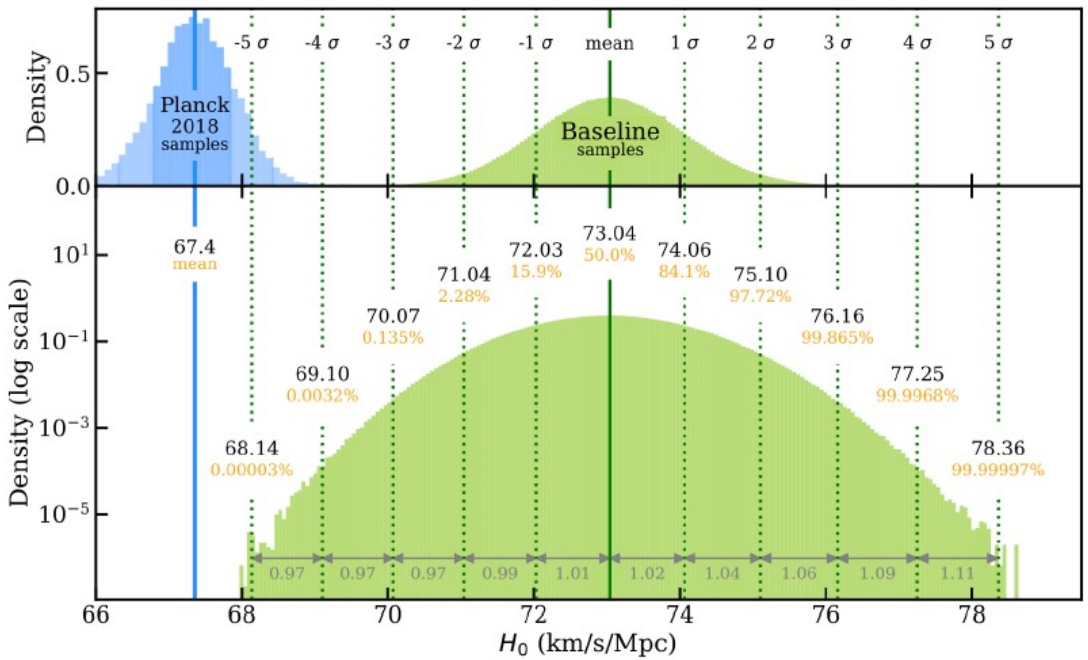


Credits: W. Freedman

Hubble tension

SH$_0$ES Baseline Fit: **H$_0$=73.04 +/- 1.04**, km s^{-1} Mpc^{-1}, w/ systematics

5.0σ from Planck + ΛCDM (5.3σ w/ Cluster Cepheids) X^2_{υ}=1.03, N=3500



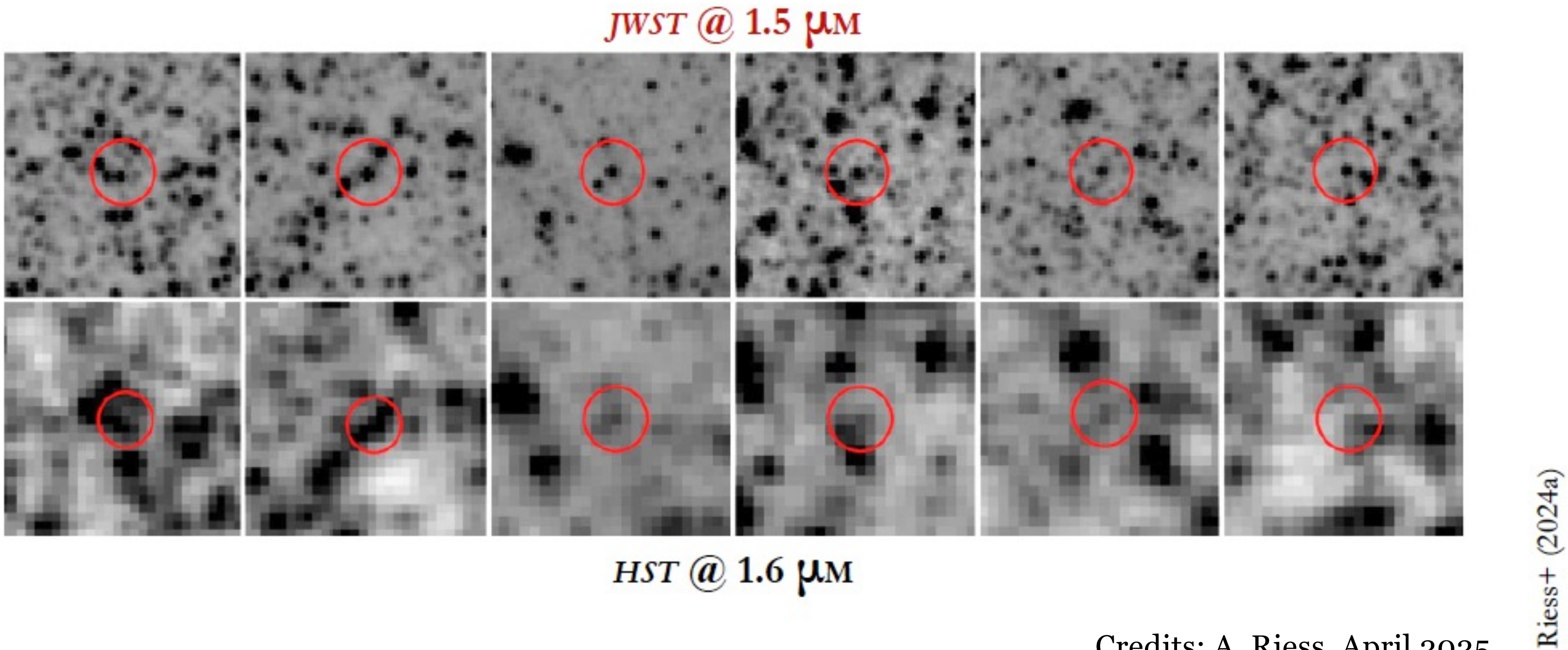
5.7σ from SN Ia Spectral Matching (Murakami et al. 2023, 73.2+/-0.9)

5.8σ 4th anchor SMC (Breuval et al. 2024, 73.17+/-0.86)

Credits: A. Riess, April 2025

H0 with JWST – game changer?

Crowding is less problematic with JWST

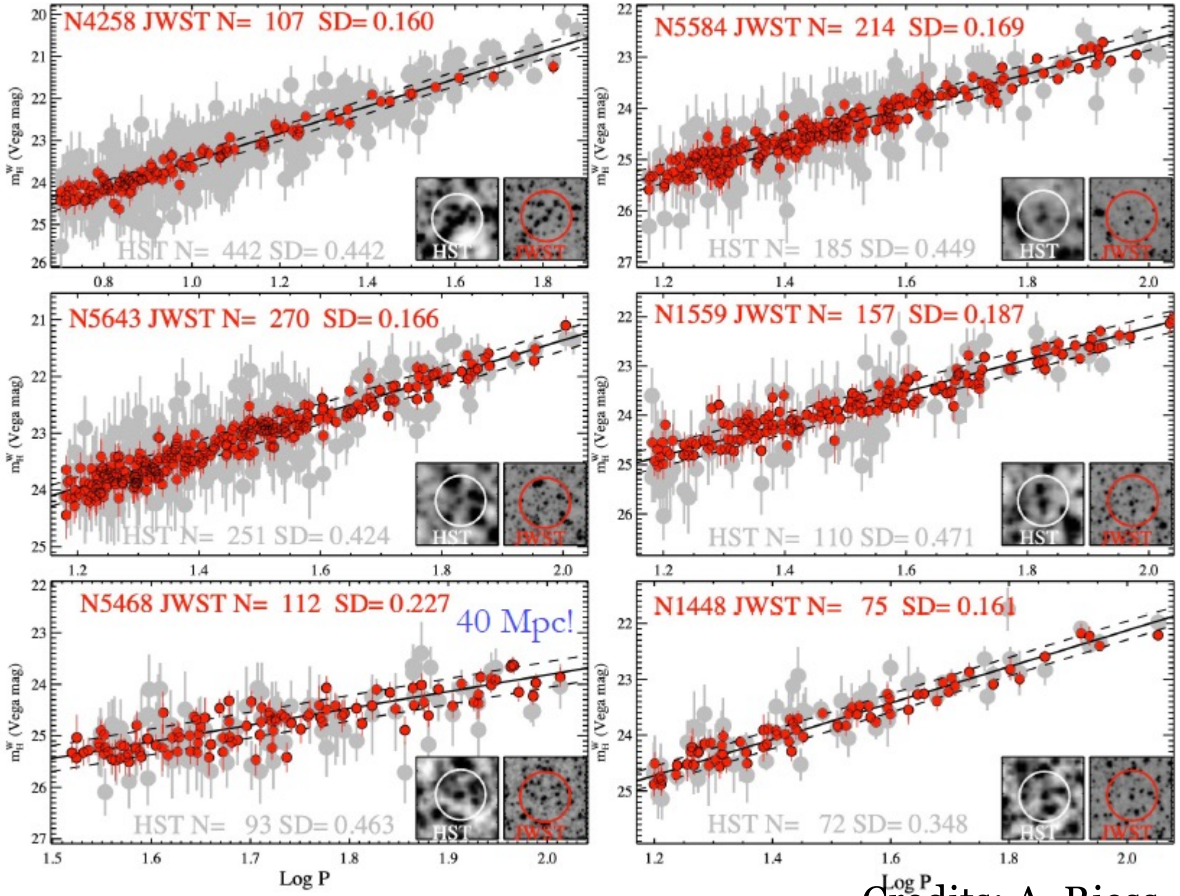


Credits: A. Riess, April 2025

H0 estimate with JWST

With 2 epochs and multi-color we can recover Cepheid phase, 2.5x less NIR scatter than HST!

Anchor galaxy (MASER)



Riess+ 23,24

Credits: A. Riess, April 2025

H_0 from JWST ? Too few SN Ia and anchors, not meaningful now

H_0 with JWST dominated by SN scatter (σ =5-6 km/s/Mpc per SN)

Error Source	HST Best	JWST Now
Geometric calibration	Gaia MW, LMC,SMC,N4258 0.4	NGC 4258 1.1
Mean of host distances	37 Hosts 0.3	10 Hosts (multi-method) 0.5
Mean of SN calibrators	42 SN Ia 0.8	10 SN Ia 2.0
SN Ia Hubble flow	300 SN Ia 0.5	300 SN Ia 0.5
Total Error in H0	1.0 km/s/Mpc	2.4 km/s/Mpc

- JWST confirms HST distance measures, no power for H_0 now
- ~5σ tension w/ HST→ ~ 2σ with JWST even if no change in distances, misleading to define tension w/ JWST

Credits: A. Riess, April 2025

Tip of the Red Giant Branch as standard candles

Classical Cepheids as standard candles have some drawbacks:

1) Young objects → observable only in late type galaxies

2) Typical disc objects:

    1) crowding effects can be severe a large distances;

    2) High reddening regions: the extinction law can be different from the Fitzpatrick 1999 adopted by the SH0ES group.

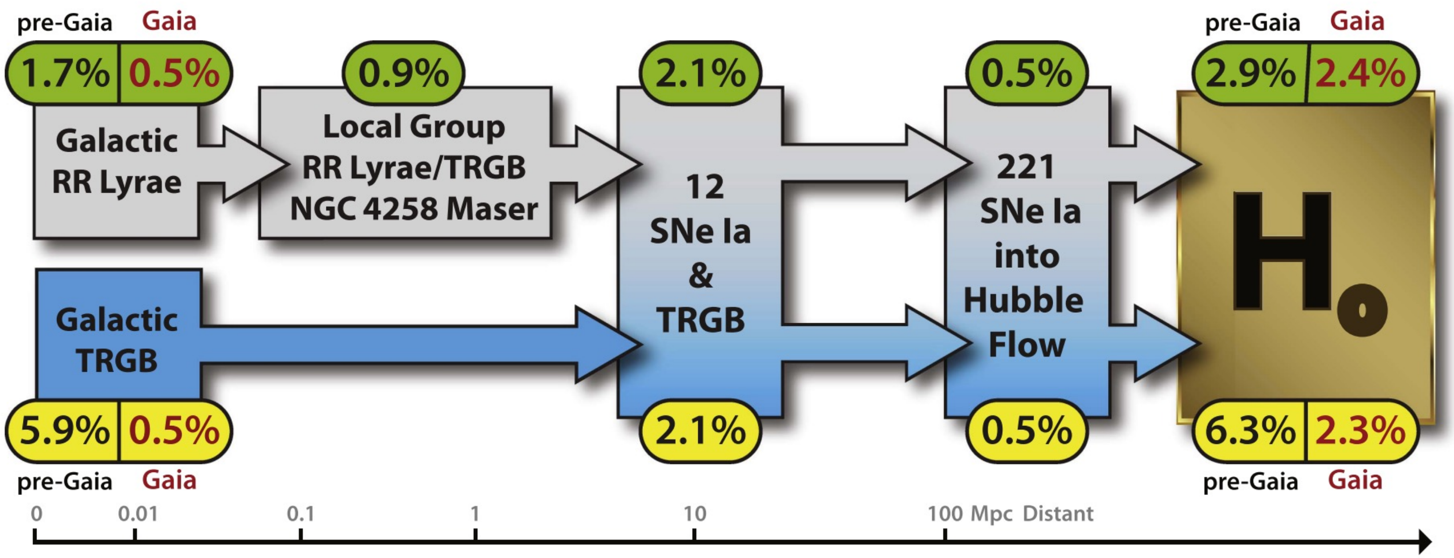
↓

Search for an alternative: Tip of the RGB
Carbon stars (JAGB)

Alternative routes to Ho

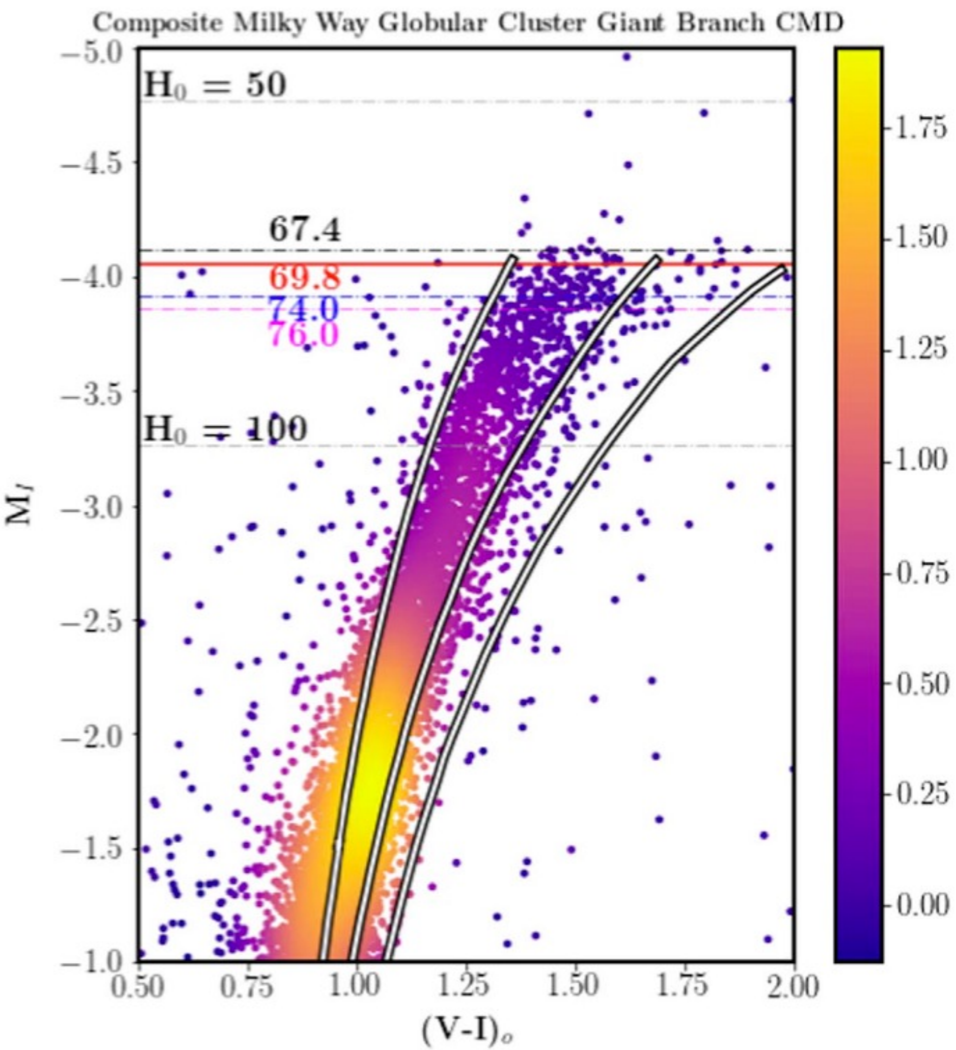
T2CEPs and RRLs in conjunction with the Tip of the Red Giant Branch (TRGB) are alternative distance indicators

Old stars (T>10 Gyrs) → Present also in late type galaxies where DCEPs are absent.



Beaton+2016

Tip of the Red Giant Branch as standard candles



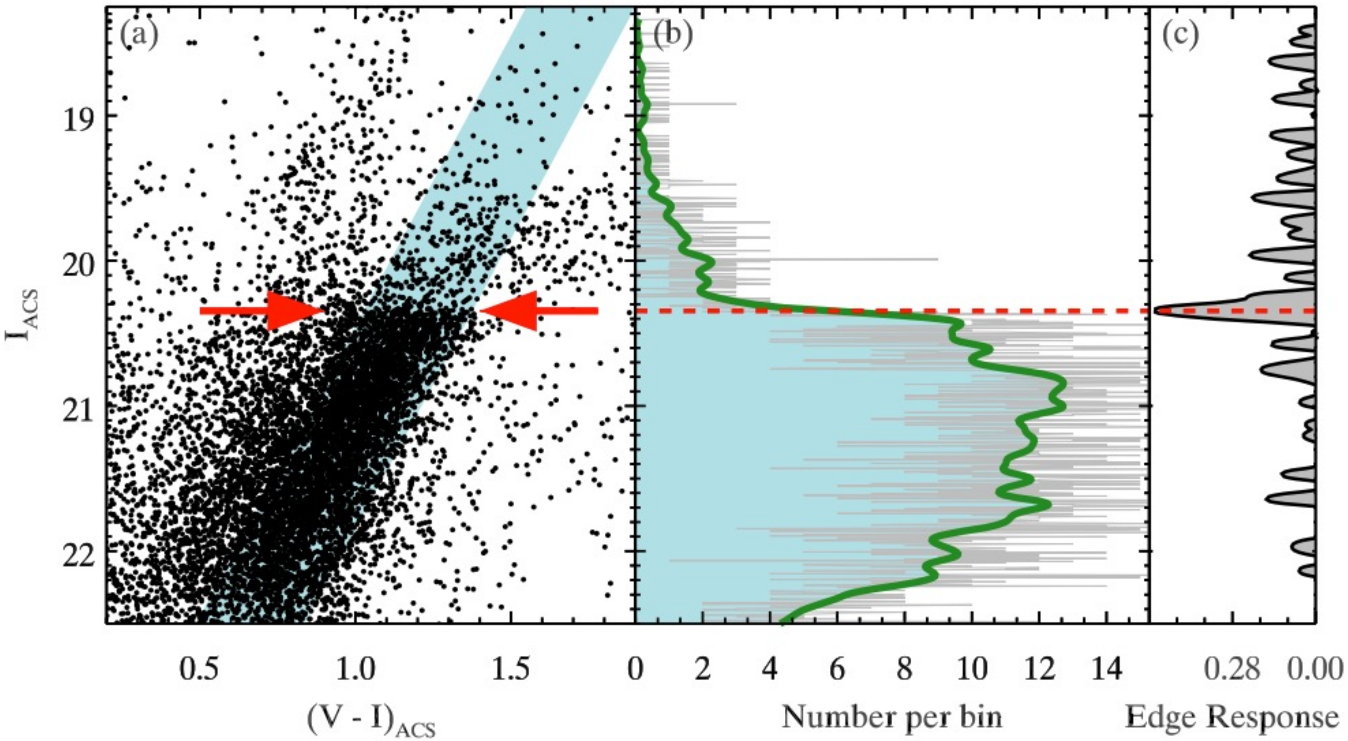
The TRGB is an excellent standard candle due to the unambiguous location of the core helium flash luminosity at the end phase of red giant branch (RGB) evolution for low-mass stars.

TRGB stars are present in all the galaxies and can be measured in their outskirts, thus mitigating the crowding and reddening effects.

In the I band the TRGB stars have stable absolute magnitude ~ -4 mag. Not depending on age, metallicity or colour.

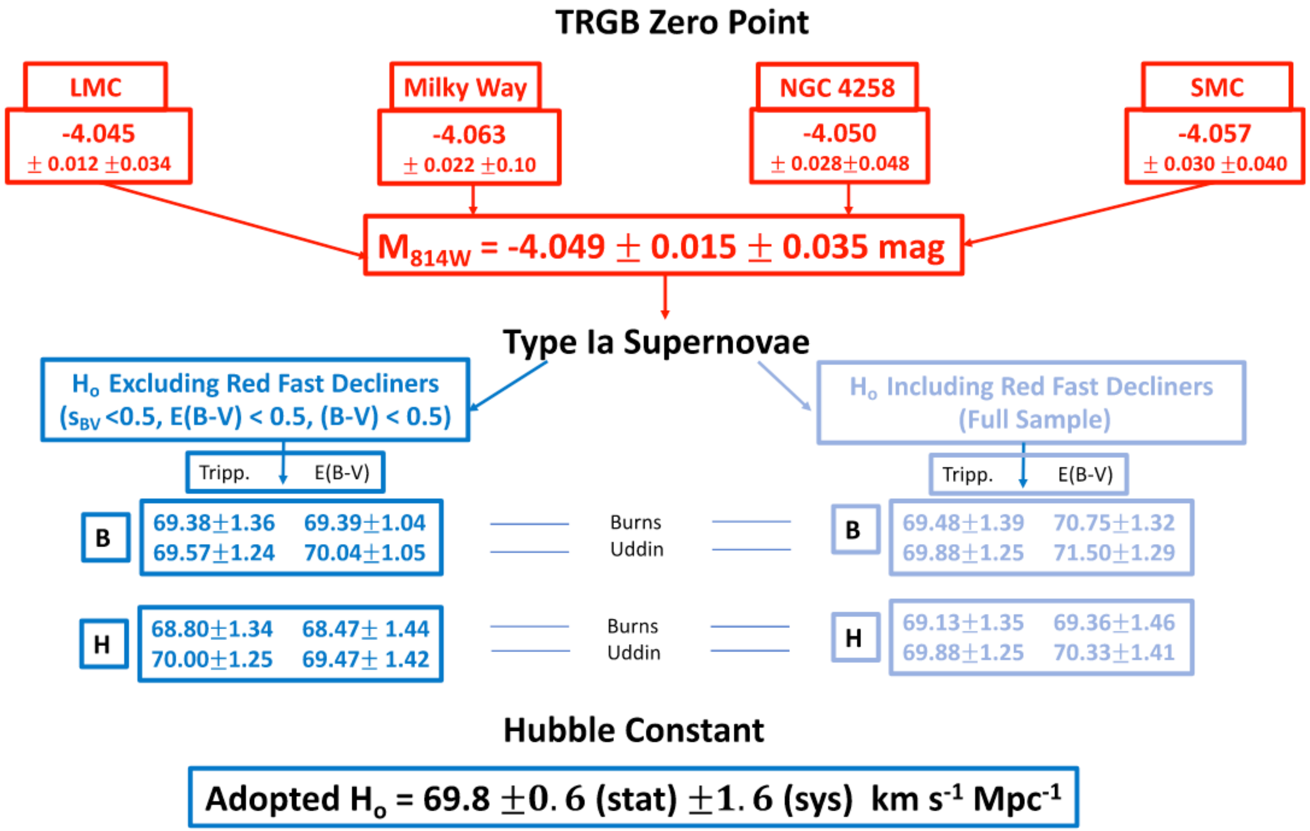
Fainter than Cepheids, improvements with future facilities (e.g. JWST, ELT)

Determination of TRGB peak



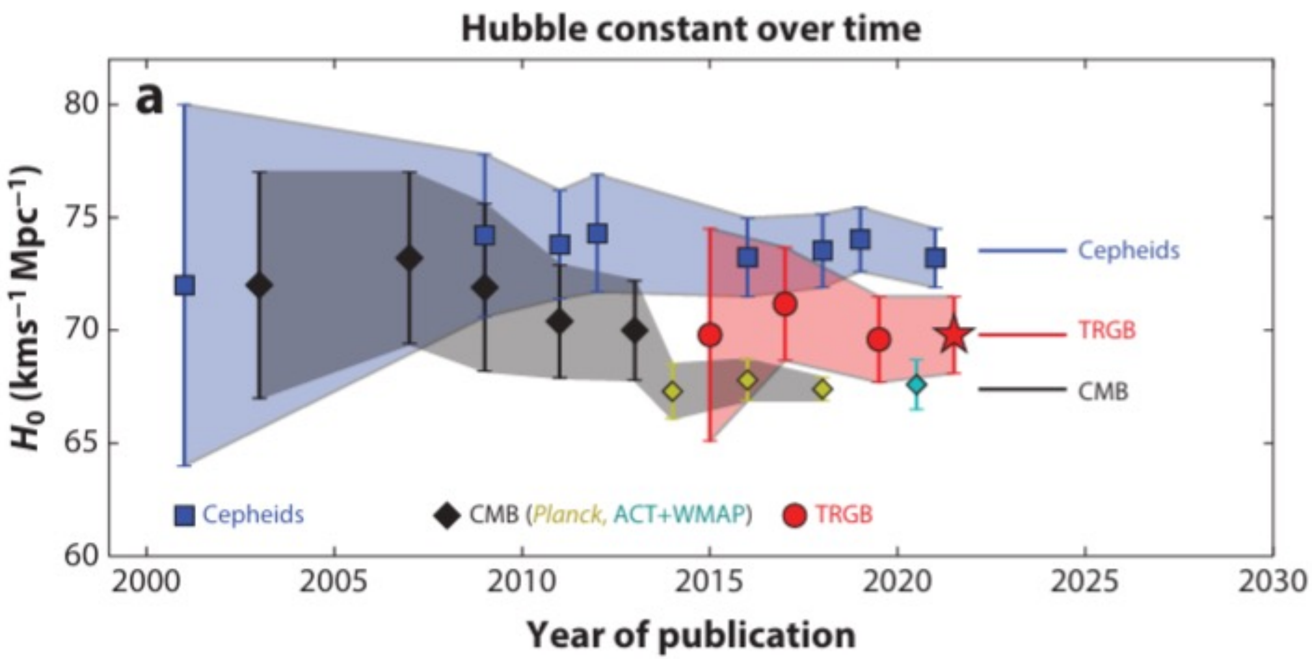
Hatt et al. 2017

Determination of H_0 with TRGB as primary distance indicators: Chicago Carnagie Hubble Program (Freedman, Madore)



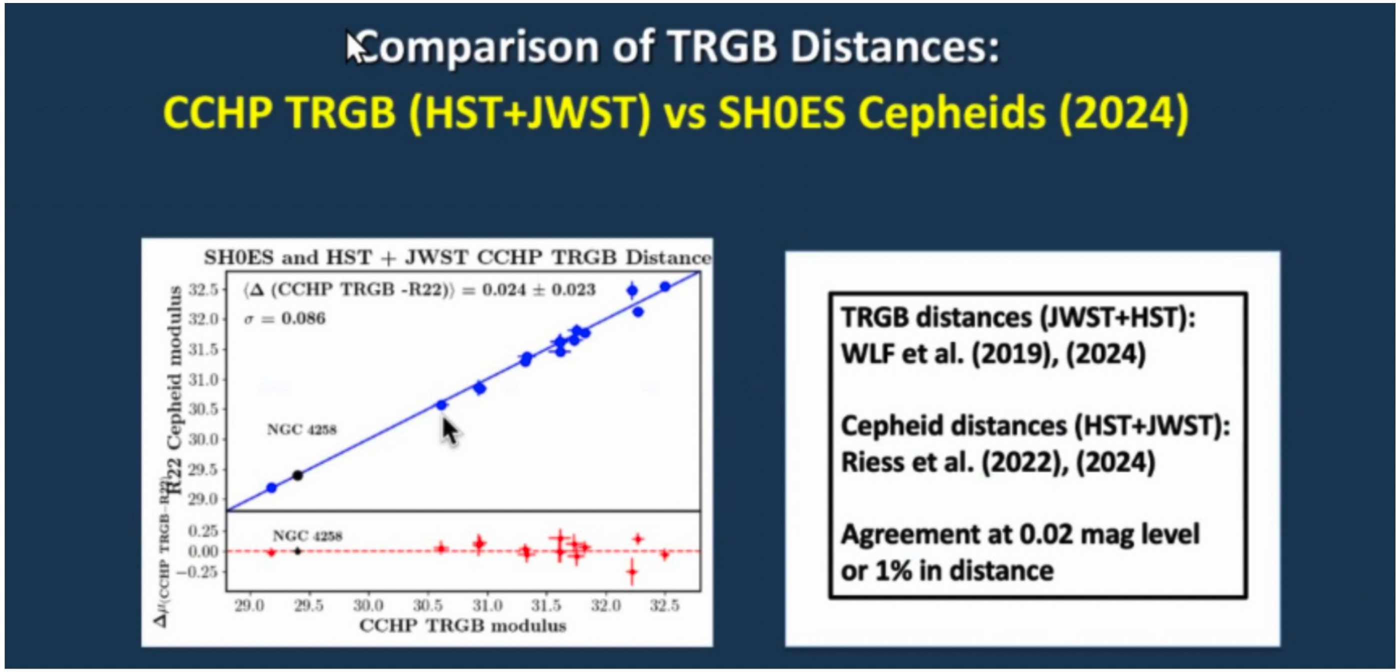
Freedman+2020

Hubble tension still holds using other standard candles



Are the Cepheids the problem?

Hubble tension still holds using other standard candles



No, TRGB and Cepheids gives the same distances for the Supernovae host galaxies.

The difference between SHOEs and CCHP groups resides in the choice of Supernovae samples in the third rung.

From W. Freedman talk

Metallicity dependence of the PL/PW relations in Cepheid variables.

Parametrization of the metallicity dependence of PLRs

The most general formulation uses four parameters, to take into account the possible metallicity effect on the slope of PLRs, which is predict by the models

$$M_\lambda = \alpha_\lambda + (\beta_\lambda + \delta_\lambda[Fe/H])\log P + \gamma_\lambda[Fe/H]$$

As this effect is mitigated at longer wavelength, usually δ_λ is ignored.

$$M_\lambda = \alpha_\lambda + \beta_\lambda \log P + \gamma_\lambda[Fe/H]$$

Intercept

Slope

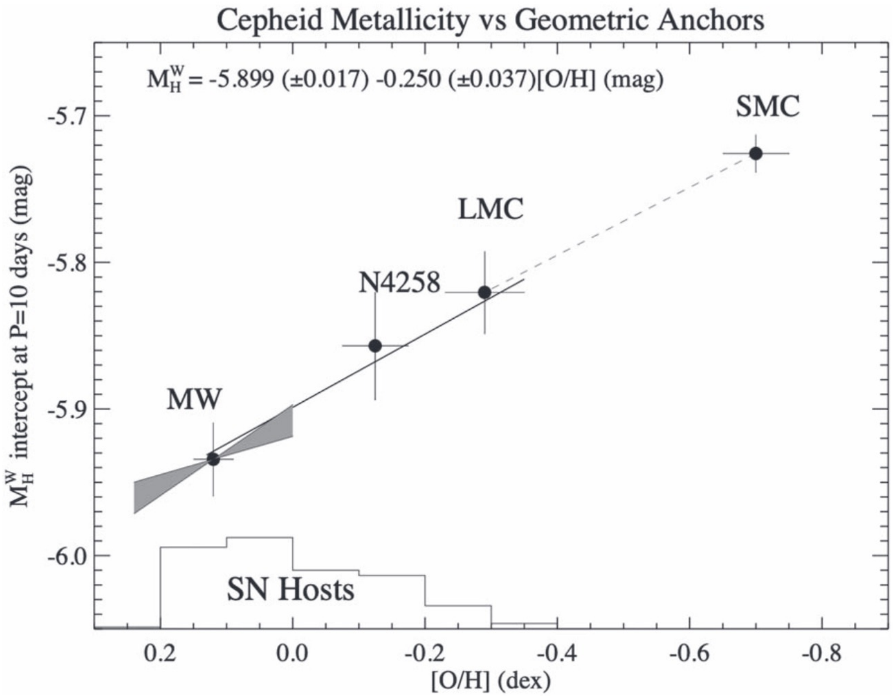
Metallicity term

Metallicity dependence in the SH0ES project

Does the SH0Es group take into account the metallicity dependence of the PW relation? Yes, it is an output of the H_0 calculation.

However, there is a strong assumption→ the slope of the PW is the same in all the systems, with no dependence on metallicity.

Metallicity dependence in the SH0ES project



According to the SH0ES group, the metallicity problem should be mitigated by the fact that SNIa host galaxies have metallicities similar to those of the anchors.
Same for the slope.

Yet, to reach the highest precision possible on H0, requires that we understand accurately the PLRs dependence on metallicity.

The metallicity won't solve the Hubble tension, but can contribute to assess the size of the tension (e.g. how many sigmas?).

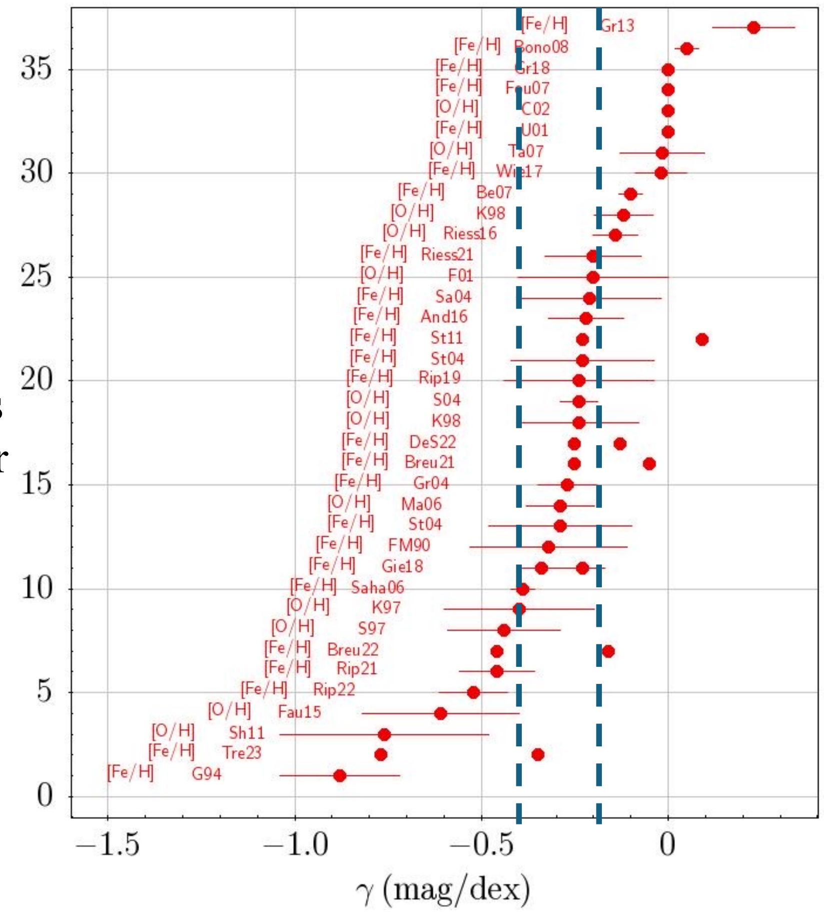
Riess+2022

Metallicity dependence of PL

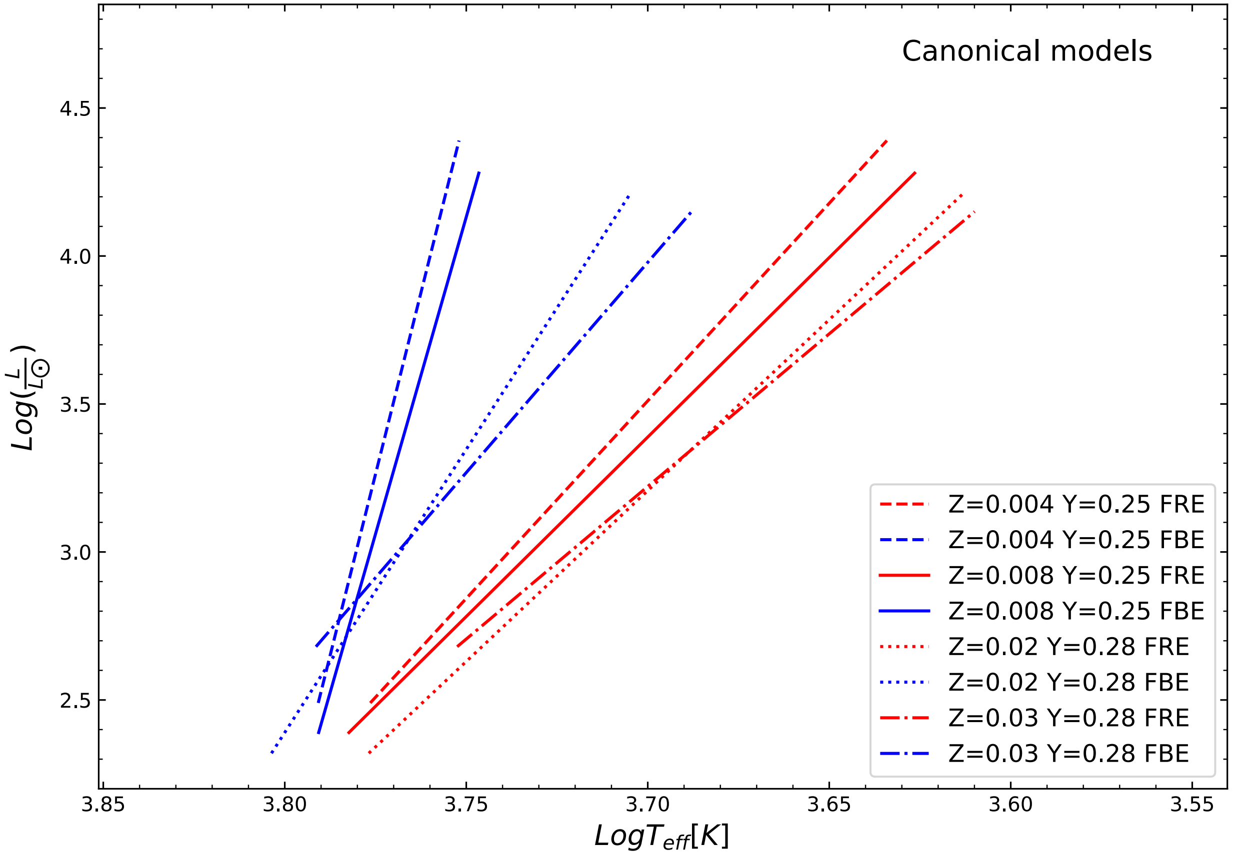
- Intercept of PL dependence on metallicity not well constrained empirically yet: most recent results:
  γ~-0.20: ~-0.40 mag/dex (e.g. Gieren+2018; Groenewegen+2018; Riess+2019,2021,2022; Ripepi+2019,2020,2021,2022; Breuval+2021,2022).

- The metallicity effect on both slope and zero point of the PLRs might not be critical for the estimate of H_0, but still relevant for measuring distances of individual galaxies:
  $\Delta\gamma \sim 0.2$ (mag/dex) if Δ[Fe/H] $\sim \pm 0.2$ dex →$\Delta\mu \pm 0.04$ mag → $\Delta D \pm 2\%$

- Important to better constraint Cepheids models



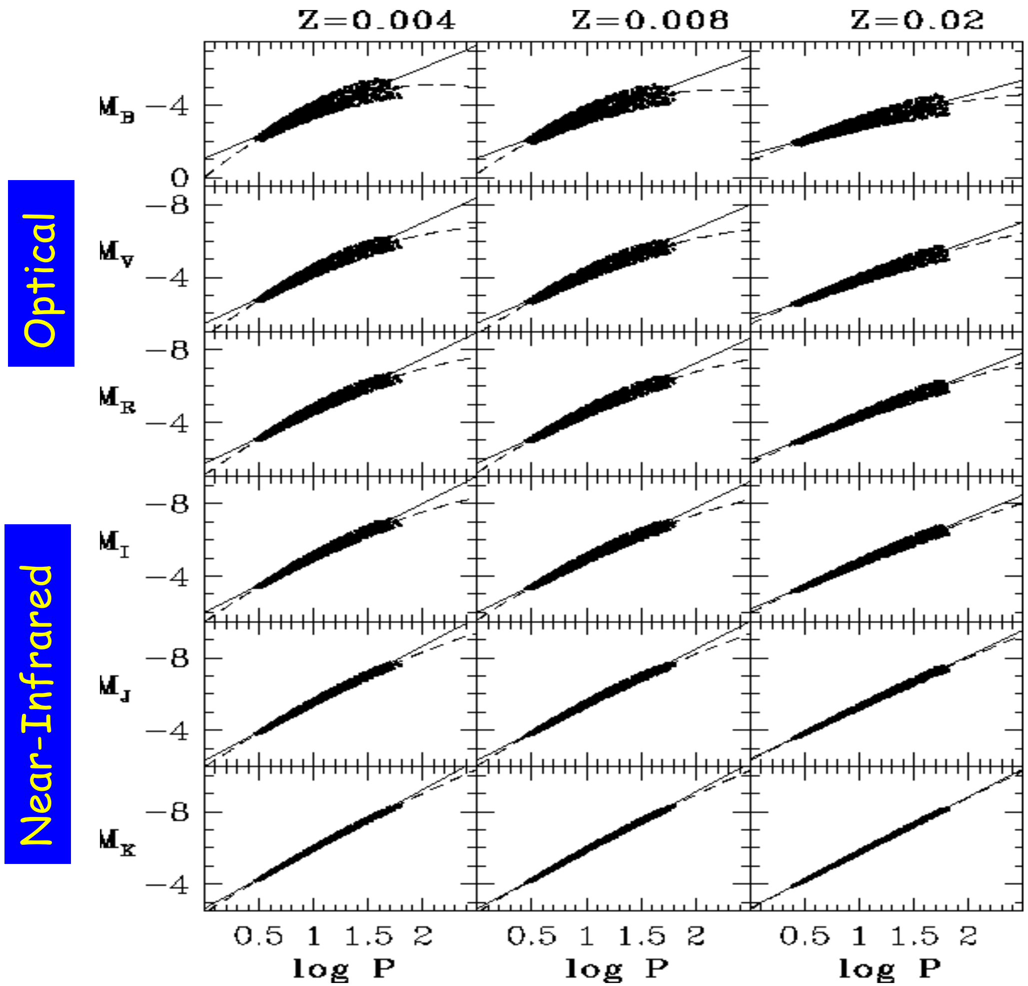
Period-Luminosity dependence on metallicity: Pulsation Theory



De Somma, Marconi et al. 2022 ApJS

The Cepheids instability strip shifts towards cooler temperatures as the metallicity increases → impact on the PLRs

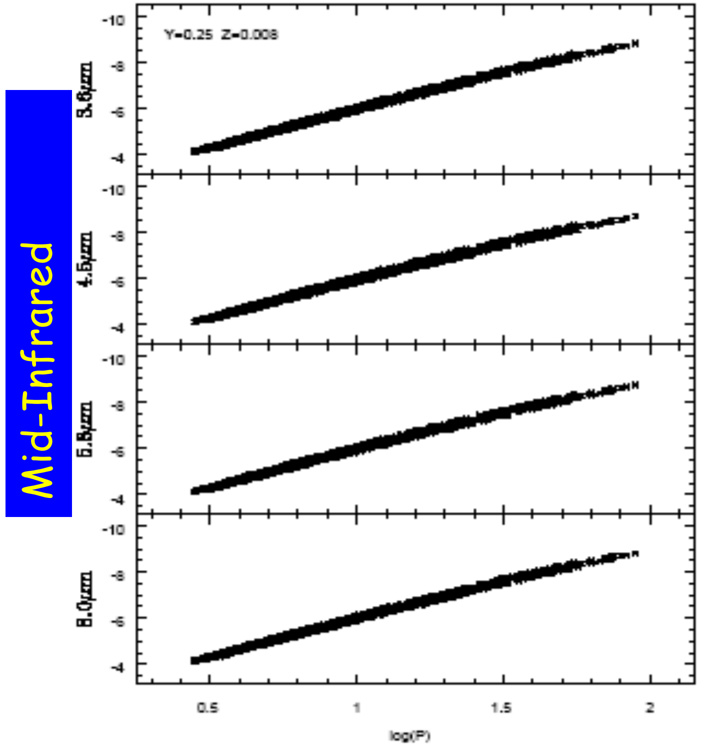
Synthetic multiband PL relations



Caputo et al. 2000 A&A

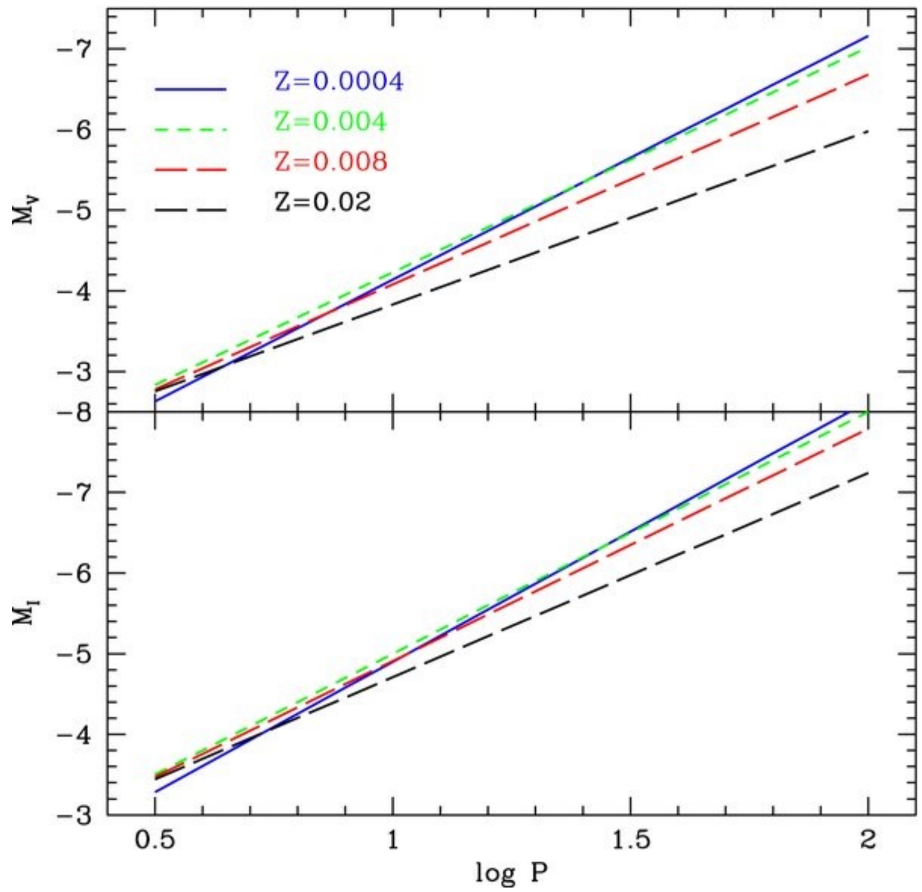
Synthetic multifilter PL relations

The effect reduces when moving towards longer wavelenghths



Universal slope?

- The Cepheids‘ PL relation is often considered “Universal“, for example the same slope is used for all the galaxies
- However, models predict different slopes at different metallicities.
- Smaller effect at low metallicities
- Smaller effect at longer wavelenghts

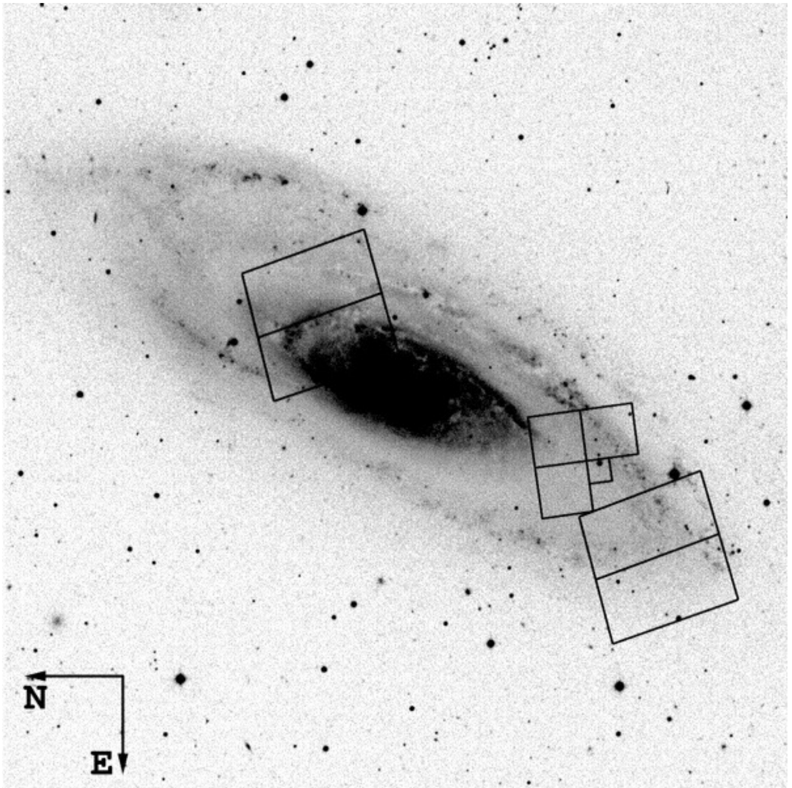


Marconi et al. 2010 ApJ (in agreement with results from the Araucaria project)

Metallicity dependence of the PL/PW relations in Cepheid variables: Methods

1. Measurement of PLR metallicity dependence: distant galaxies

NGC 4258 Distance ~7.6 Mpc



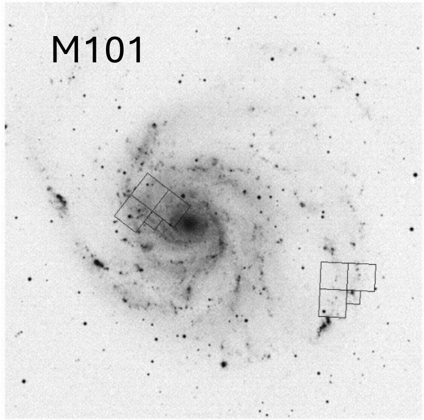
Macri et al. 2006

- Cepheids all at the same distance
- Observe Cepheids at different galactocentric radii
- Metallicity gradient of the disc → Cepheids in different fields have a range in metallicity
- Suppose that [O/H] scale as [Fe/H]
- Take a relation [O/H] vs galactocentric radii measured from HII regions with low resolution spectroscopy → estimate the [O/H] of Cepheids at different radii
- Look for trends in the residuals of the fitted PLRs vs [O/H]

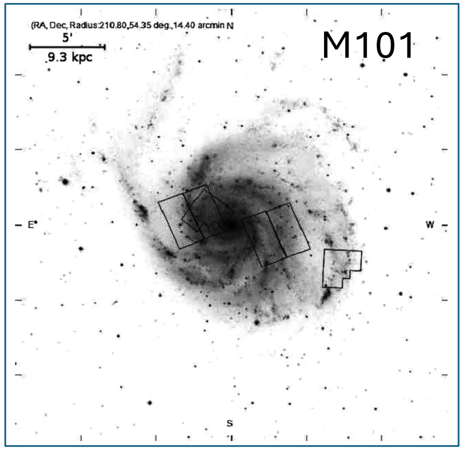
Empirical tests for metallicity effect

Several tests of the metallicity effect based on:

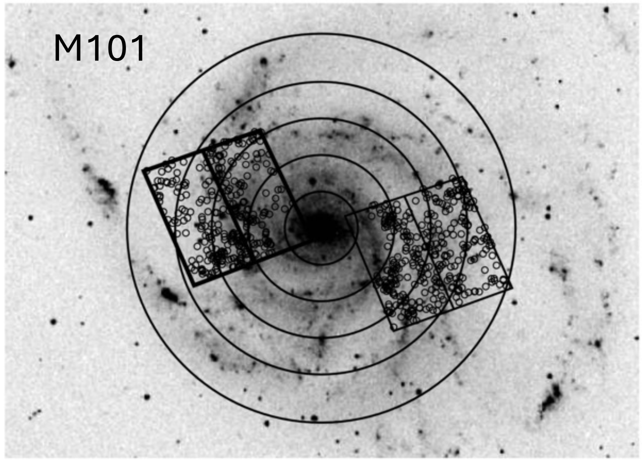
1) the comparison between Cepheids belonging to 2 fields of different metallicity (?) in the same galaxy



Kennicut et al. 1998
$\Delta\mu/\Delta[O/H] = -0.24 \pm 0.16$ mag dex^{-1}



Shappee & Stanek 2011:
$\Delta\mu/\Delta[O/H] = -0.76 \pm 0.3 \pm 0.2$ mag dex^{-1}



Mager et al. 2013:
$\Delta\mu/\Delta[O/H] = -0.33$ mag dex^{-1}

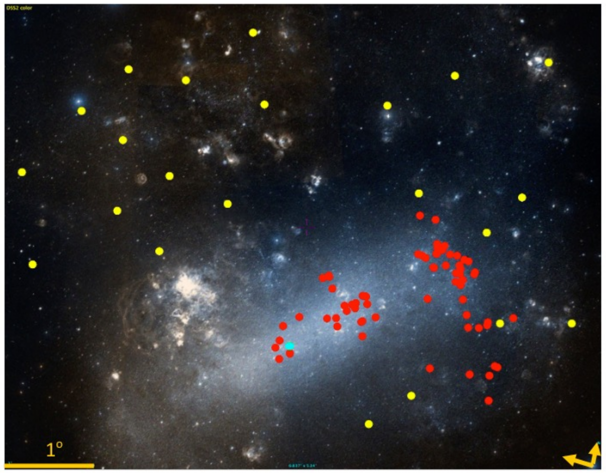
Caveats:

- Metallicity gradients in galaxies containing Cepheids are often poorly known.
- Blended Cepheids could be responsible for a large fraction of the difference in distance modulus between different fields (see M101 case, *Macri et al. 2006*).
- The period range covered by Galactic Cepheids does not coincide with the ones of the MCs.
- The metallicity gradient of galaxy's discs has a large dispersion at fixed galactocentric radii
- Reddening differences can simulate metallicity differences.

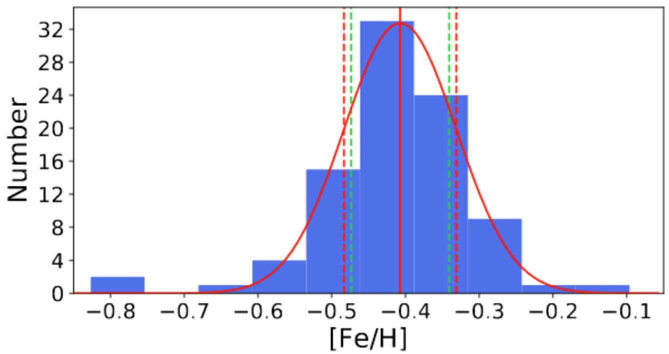
Measurement of PLR metallicity dependence: distant galaxies

Modern version applied to the LMC (Romaniello et al. 2022)

90 DCEPs observed with HiRes Spectroscopy (UVES@VLT) in the LMC

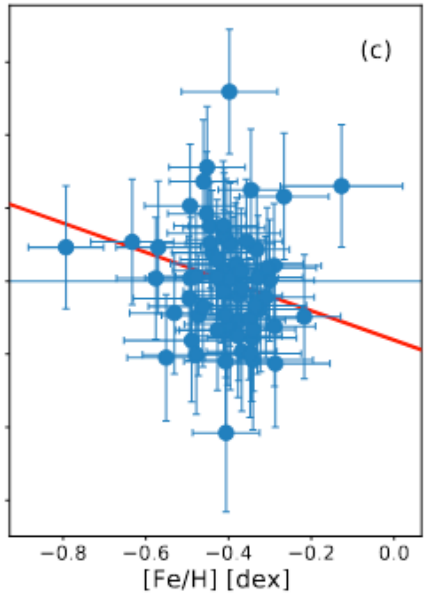


Too narrow range in [Fe/H]

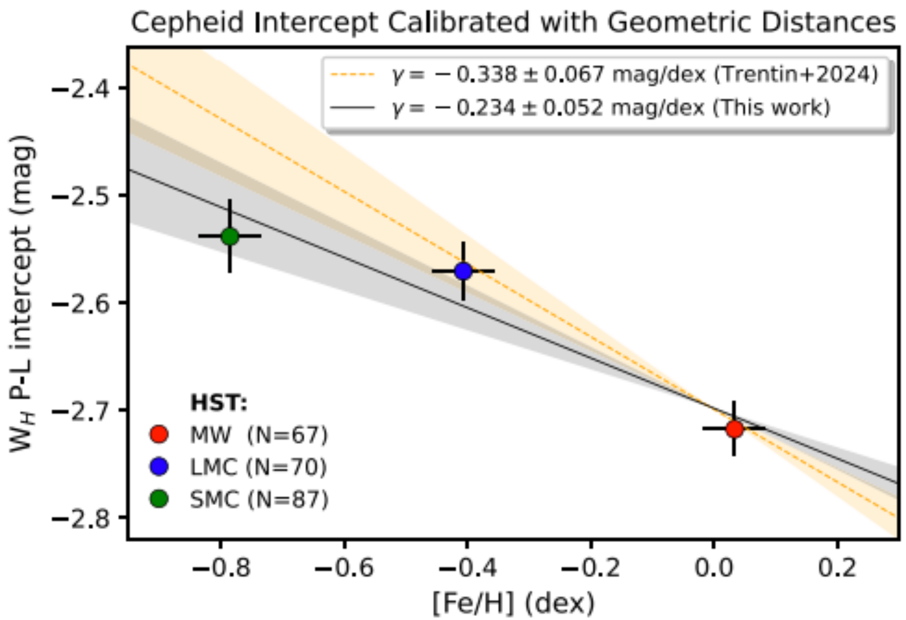


No measurable trend

ΔH



(Recent) Empirical Methods: 2
Metallicity dependence using, MW, LMC, SMC



Breuval+2024 SH0ES group

- Multiband PL relation with the **fixed slope** in the MW, LMC and SMC: $\alpha^* + \beta \times \log P$
- The value of "α^*" is fixed:
  - with the Gaia parallaxes in the MW for a sample of 67 DCEPs close to the Sun.
  - Geometric distances of LMC and SMC based on Detached Eclipsing Binaries (DEBs Pietrzyński+2019; Graczyk+2020)
- The MW is considered as "monometallic". LMC and SMC metallicities from High-Res spectroscopy.
- $\alpha^* = \alpha + \gamma\,[Fe/H]$

Gaia and the Direct method

4. The Direct method

- Large sample of Galactic DCEPs with [Fe/H] measured accurately from high-resolution spectroscopy (HiRes, resolution > 20,000) over a wide range of metallicities.

- Multiband photometry

- Distances from independent source (geometric)

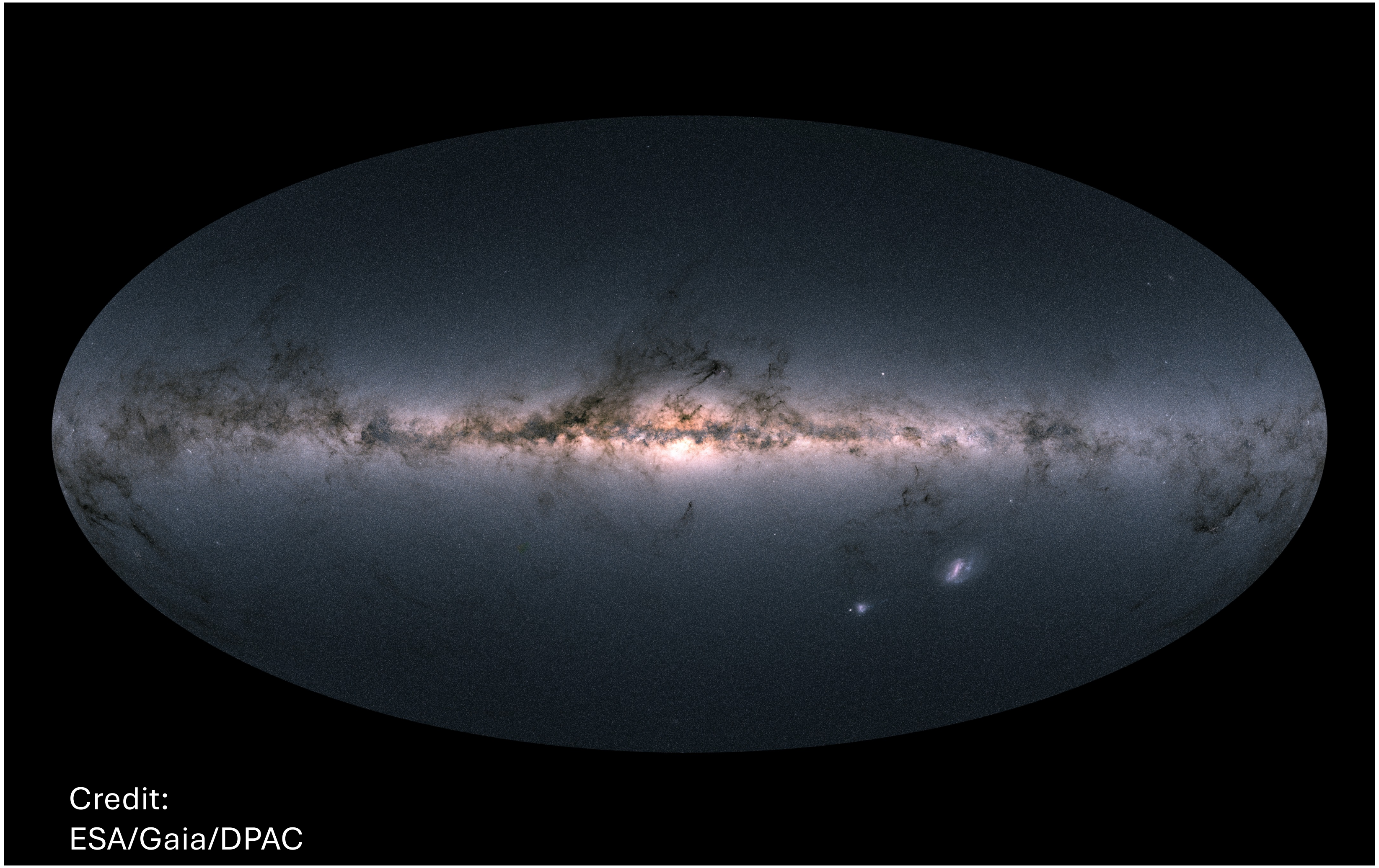
- Fit directly PLRs with the metallicity term to the data.

<u>NOT POSSIBLE UNTIL FEW YEARS AGO!</u>

1) Lack of accurate (geometric) distances

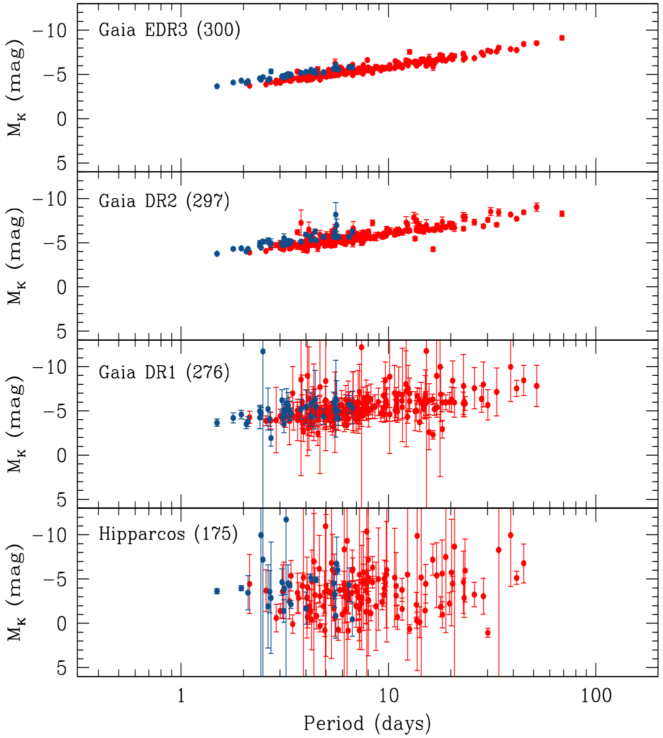
2) Lack of a large sample of MW Cepheids with homogeneous multi-band photometry and metallicities from high-resolution spectroscopy convering a large range of metallicities.

Distances: Gaia - the game changer



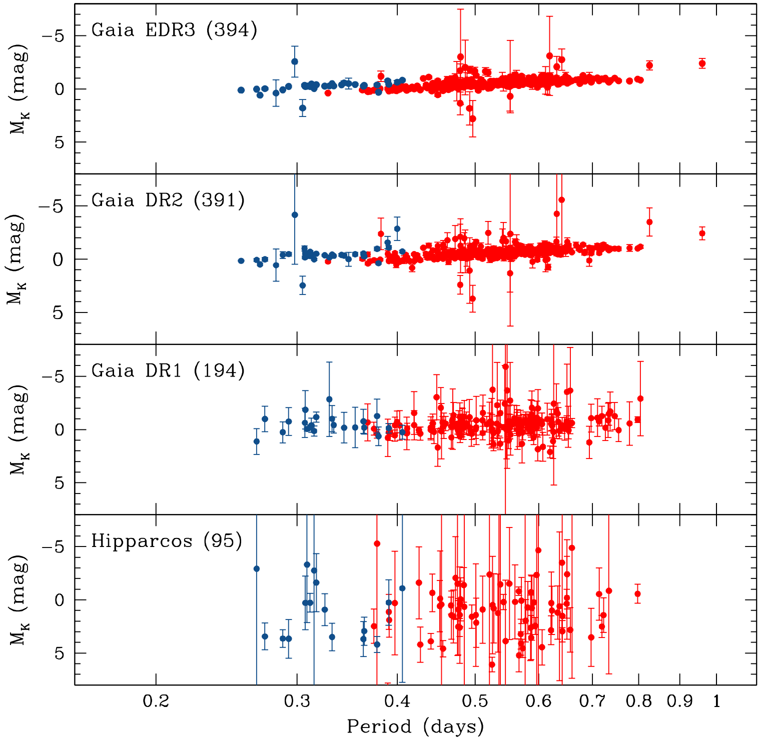
Distances: Gaia - the game changer

Cephheids



Credit: ESA/Gaia/DPAC, created by: V. Ripepi

RR Lyrae



Credit: ESA/Gaia/DPAC, created by: T. Muraveva & A. Garofalo

NIR PL relations of Cepheids and RR Lyrae before and after Gaia

C-MetaLL

Cepheids–Metallicity in the Leavitt Law

https://sites.google.com/inaf.it/c-metall/home

The C-MetaLL project

- Use Galactic Cepheids in conjunction with **Gaia parallaxes** to constrain the PLZ/PWZ relations but: i) **too narrow range in [Fe/H] in literature**; ii) **not enough stars with accurate NIR photometry, reddening estimates.**

1. Significantly enlarge (>~400 objects) the sample of Cepheids with metallicity measured from high-resolution spectroscopy *HARPS-N@TNG; GIANO-B@TNG; UVES@VLT; PEPSI@LBT; ESPADONS@CFHT (~400 stars observed already; 90% complete)*.

2. Enlarge the range of [Fe/H] adopted in the determination of the PLZ/PWZ relations up to values typical of the SMC or more metal poor.

3. Obtain multiband g,r,i,z,J,H,Ks photometry for a large sample of Cepheids to obtain precise average magnitudes and individual reddening measurements (*50% complete*).

MEASURE ACCURATE PLZ/PWZ RELATIONS BASED ON **HOMOGENEOUS** SPECTROSCOPY AND PHOTOMETRY

The Team

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I. Musella	**INAF-Capodimonte Observatory (Naples, IT)**	**Pulsational models**
M. Romaniello	**European Southern Observatory, Garching (DE)**	**Spectroscopy**
J. Storm	**Leibniz-Institute for Astrophysics Potsdam (DE)**	**Spectroscopy**
V. Testa	**INAF-Monte Porzio Observatory (Rome, IT)**	**Photometry**
E. Trentin	**Leibniz-Institute for Astrophysics Potsdam (DE)**	**Spectroscopy**
T. Sicignano	Scuola Sup. Meridionale (IT)	Photometry

G. Catanzaro & E. Trentin (PhD)

Abundance determination

A. Bhardwaj

Photometry

R. Molinaro

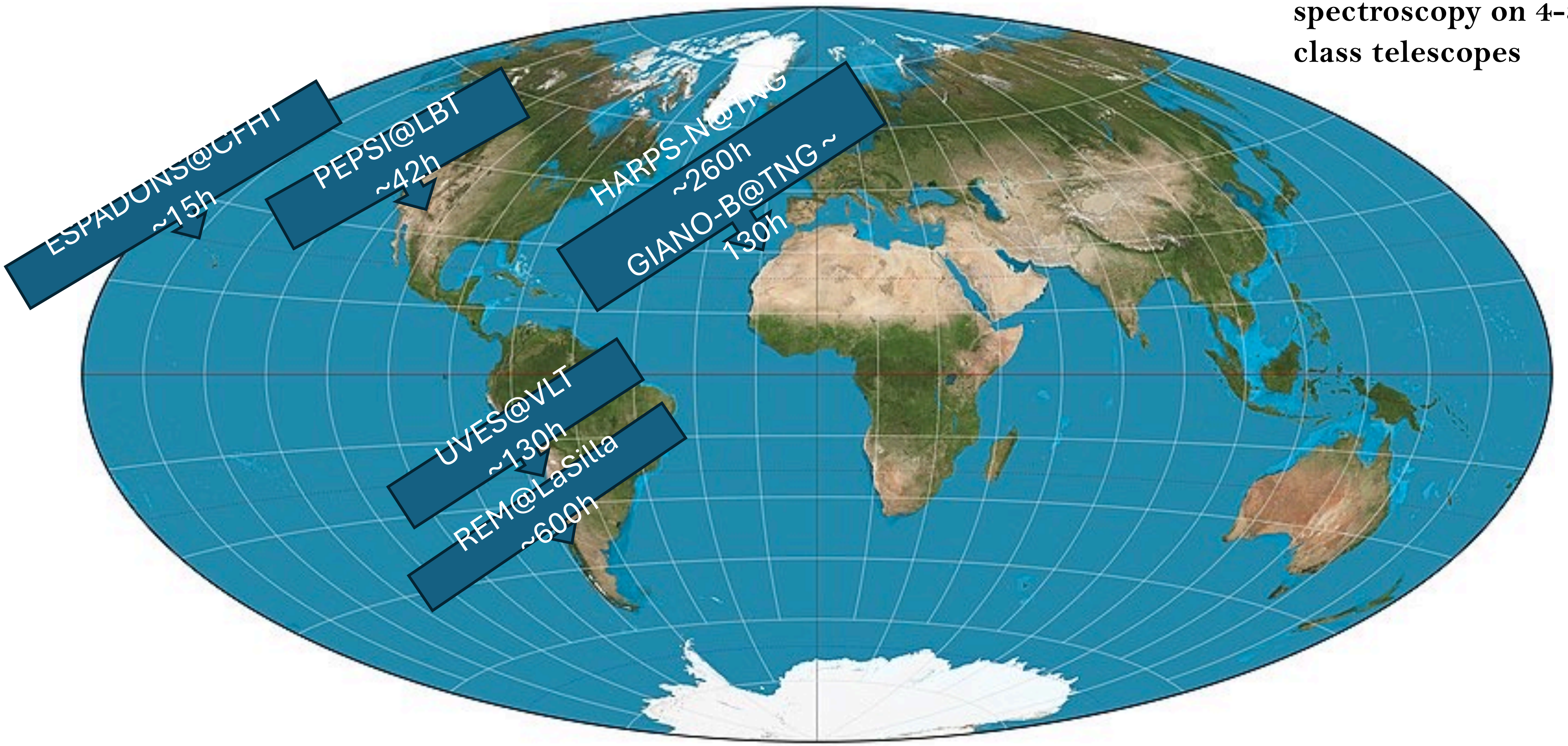
Data analysis

M. Marconi & G. De Somma

Pulsation theory

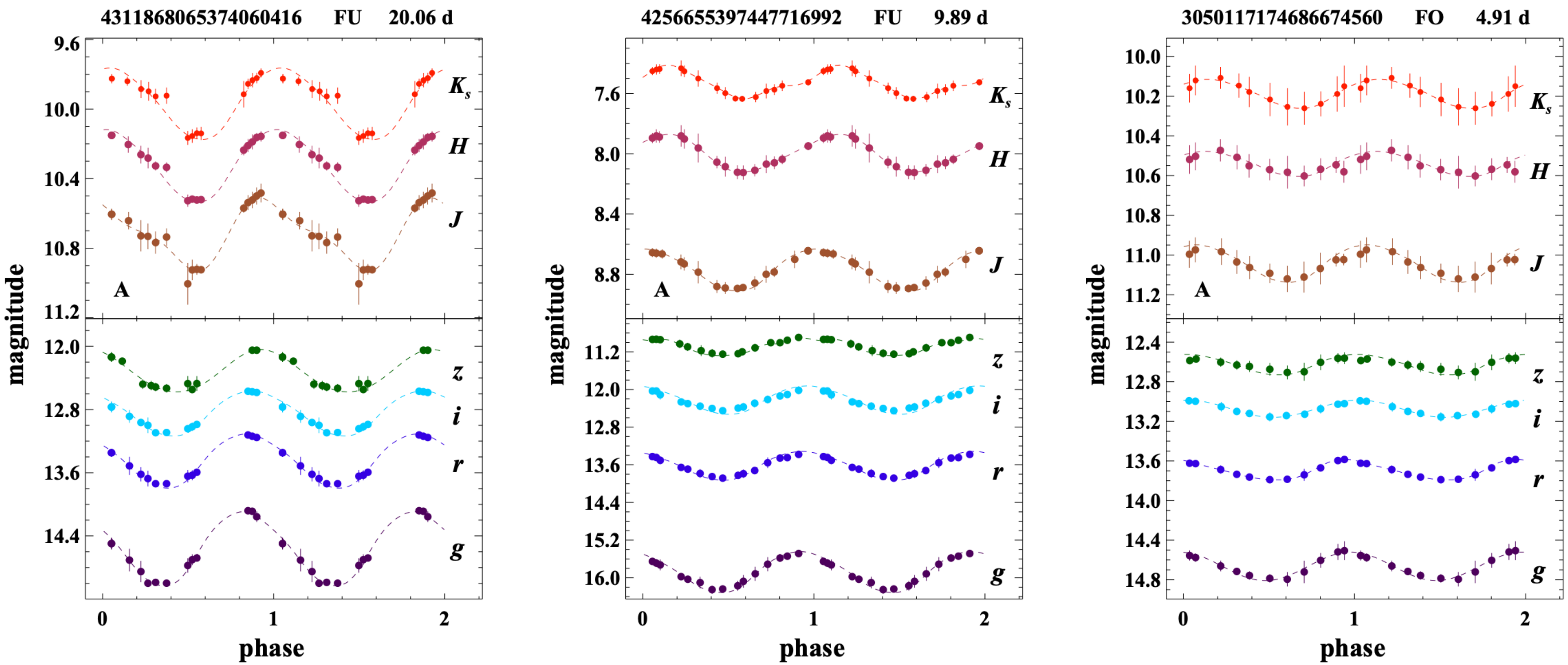
Observations

>500 h high-resolution spectroscopy on 4-8m class telescopes



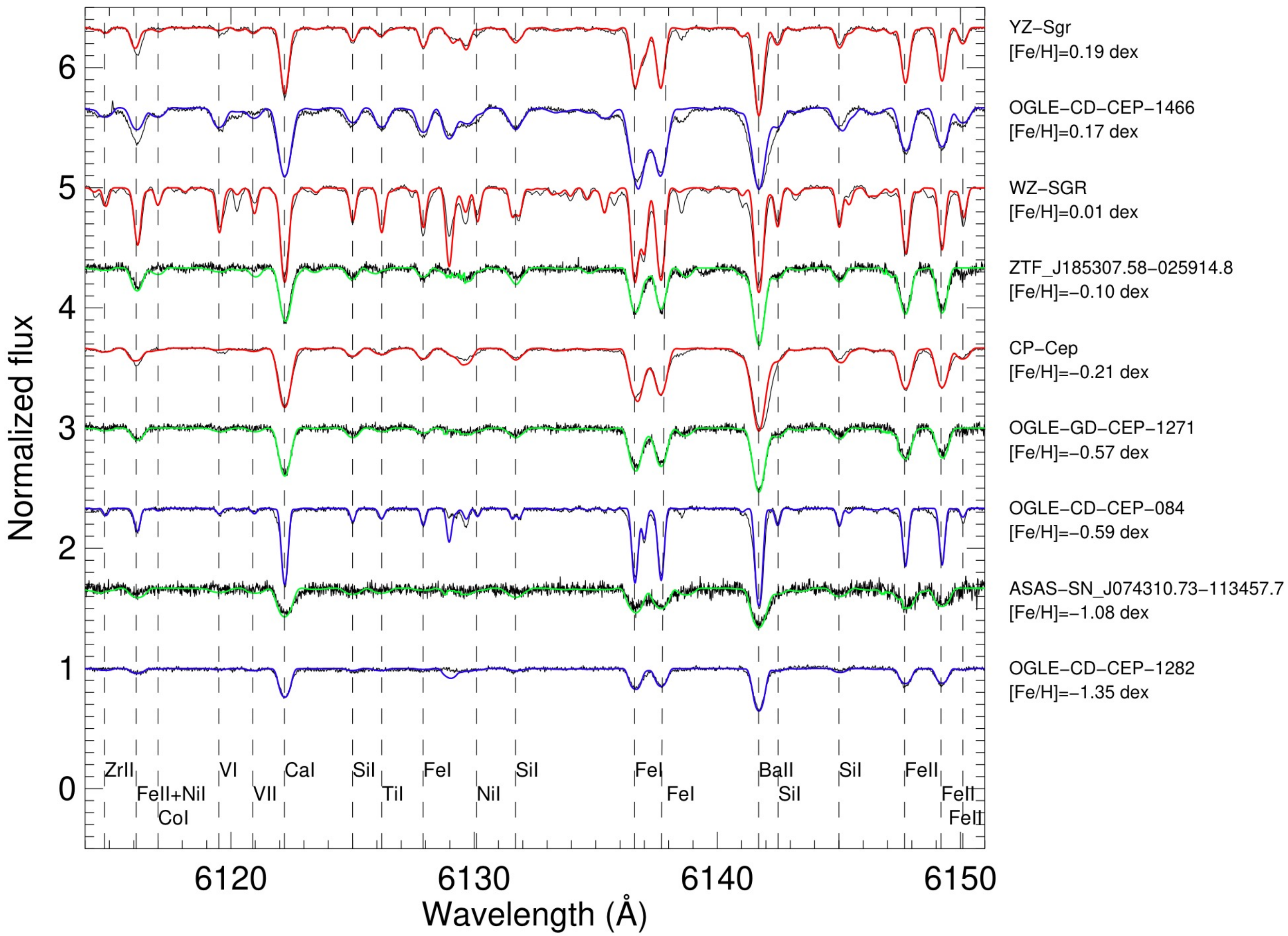
grizJHKs photometry (Bhardwaj et al. 2024, C-MetaLL-V)

Homogeneous optical (griz) and NIR (JHK) photometry of 78 Cepheids (49 F and 29 1O) REM telescope (La Silla, Chile)



Bhardwaj et al. 2024

Trentin et al. 2024b (C-MetaLL VI): Radial abundance gradients of 29 chemical species in the MW Disc



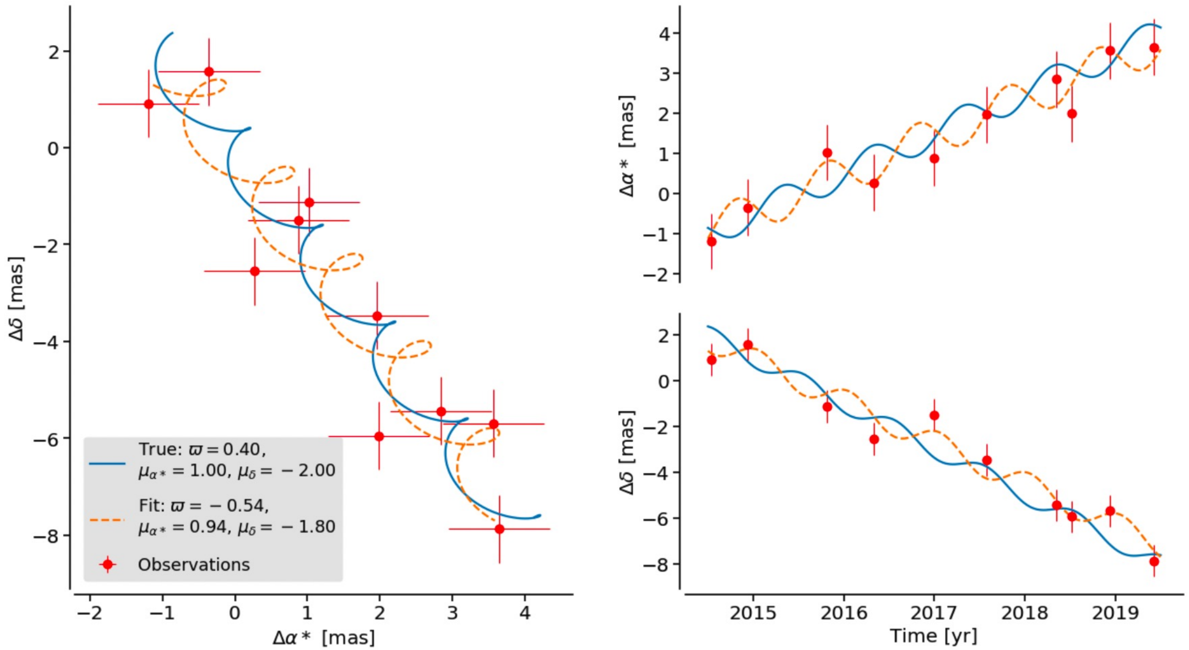
176 Classical Cepheids with abundances for 29 elements based on 331 HR spectra.

As metal-poor as the globular cluster M5 !!!

First a few words about Gaia parallaxes

Astrometric fit - the practice

- Precision of Gaia data largely depends on brightness (not distance!)
- Negative parallaxes are allowed, and for good reasons

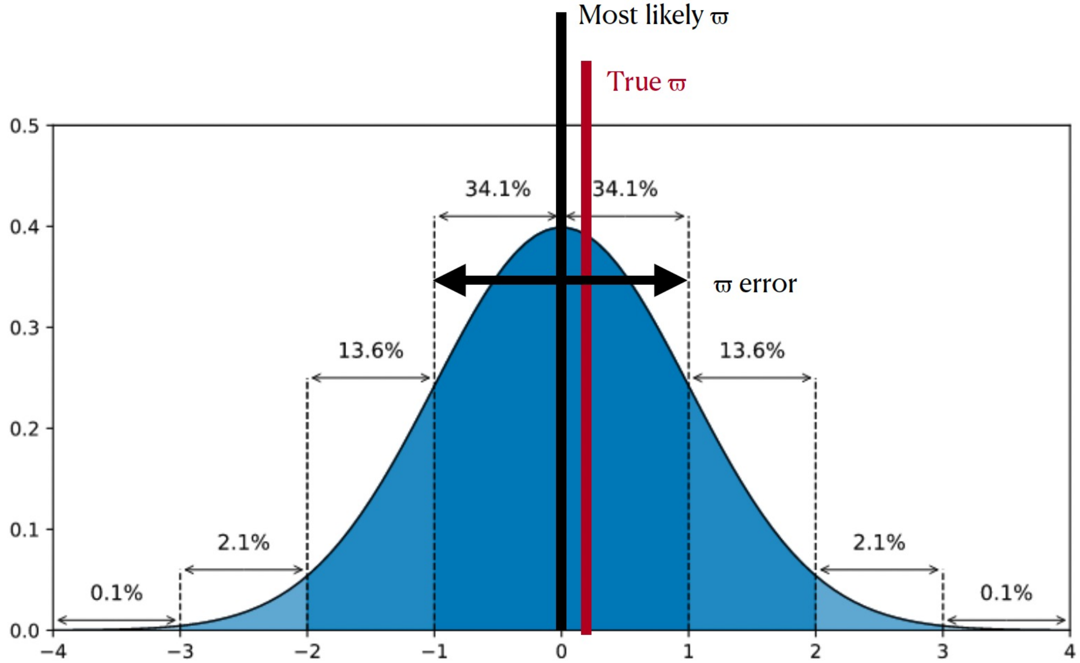


https://github.com/agabrown/astrometry-inference-tutorials/blob/master/luminosity-calibration/DemoNegativeParallax.ipynb

Credits: L. Molnar – Budapest school 2023

Astrometric fit - the practice

- Parallax is not a number but a probability distribution based on the aggregate of measurements



Credits: L. Molnar – Budapest school 2023

Conversion to distances

- Ideally, $\varpi = 1/d$
- Inversion of a probability distribution function is not straightforward
- Non-linear transformation: resulting distribution will NOT be Gaussian

- Main parameter: fractional uncertainty
- How tight the parallax function is (σ_ϖ/ϖ)

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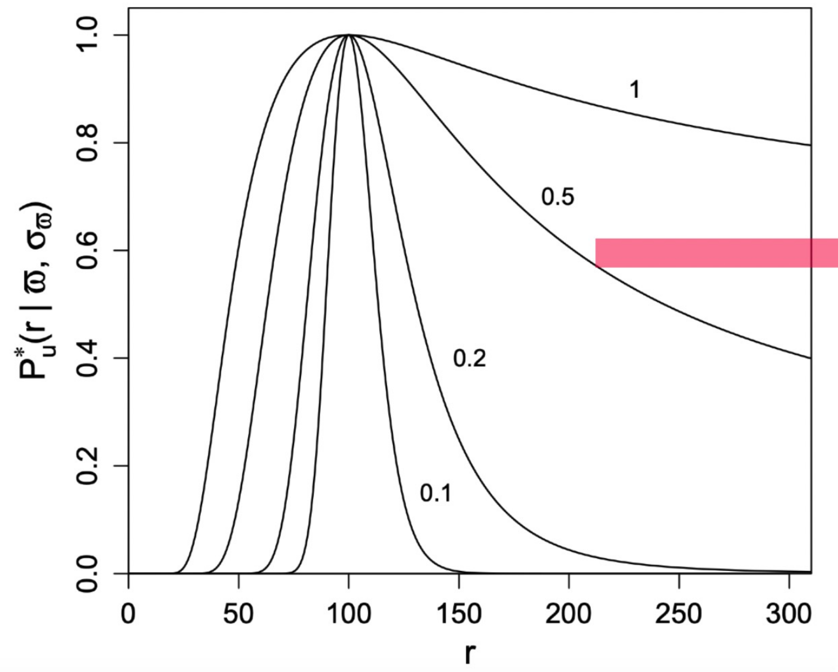
Conversion to distances

- If we invert this distribution naively (= with a uniform prior)



As fractional errors increase:

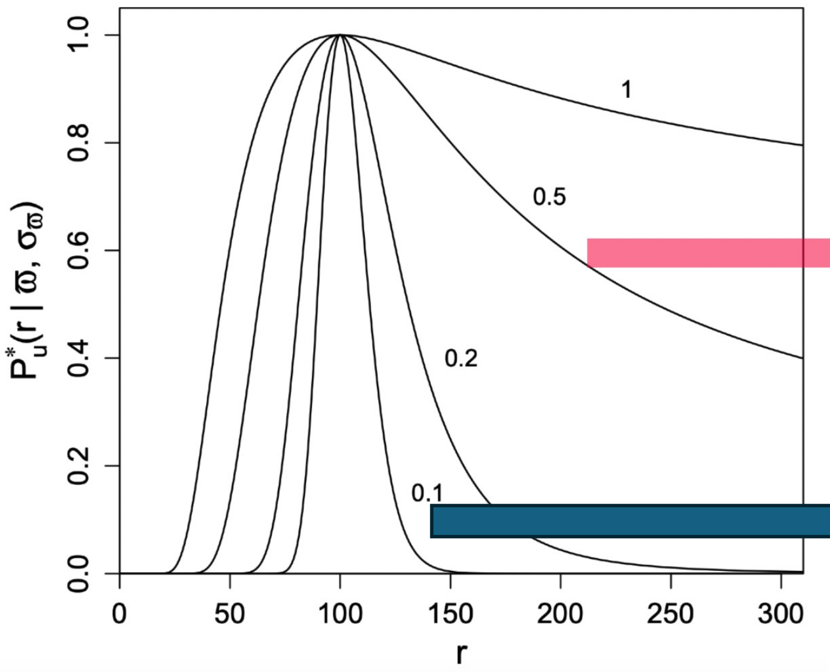
Distance distribution (or the posterior) and upper error range goes to infinity

Bailer-Jones (2015:) Estimating distances from parallax
https://ui.adsabs.harvard.edu/abs/2015PASP..127..994B/abstract

Credits: L. Molnar – Budapest school 2023

Conversion to distances

- If we invert this distribution naively (= with a uniform prior)



As fractional errors increase:

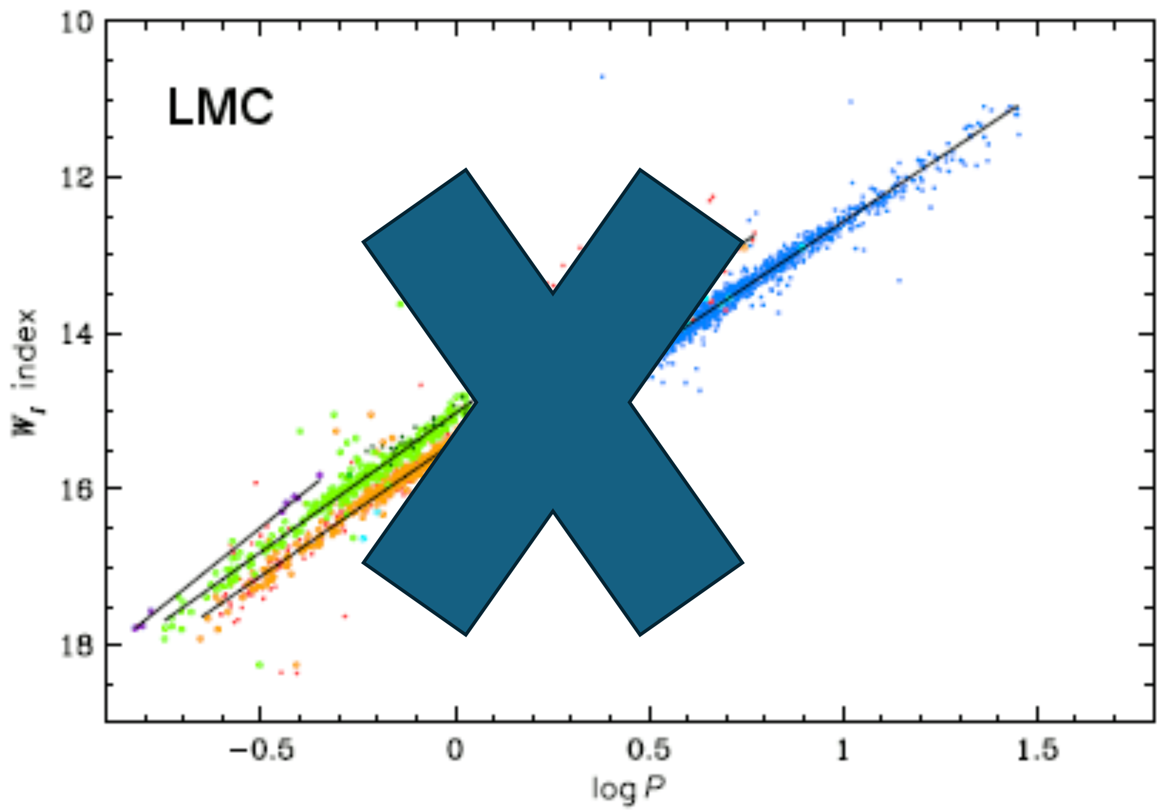
Distance distribution (or the posterior) and upper error range goes to infinity

You can safely invert the parallaxes only up to ~ σ_ϖ / ϖ <0.1

But if you do so you introduce bias (e.g. Lutz-Kelker bias!)

Bailer-Jones (2015:) Estimating distances from parallax
https://ui.adsabs.harvard.edu/abs/2015PASP..127..994B/abstract

Credits: L. Molnar – Budapest school 2023



Straight regression like in the LMC is impossible with MW Cepheids and Gaia parallaxes

Lutz–Kelker and Malmquist Bias in Parallax/magnitude -Selected Cepheid Samples

Lutz-Kelker bias:

- Statistical bias from selecting stars by fractional parallax error (e.g., $\sigma_{\varpi} \ / \ \varpi < 0.1$).
- Stars with underestimated parallaxes (appearing closer) are more likely included → Mean absolute magnitude biased – Cepheids appear brighter than they are.
- Stronger bias for larger parallax errors.

Malmquist bias:

- Selection bias in magnitude-limited samples – brighter stars are overrepresented.
- Intrinsically luminous Cepheids are visible at greater distances → Mean luminosity biased to higher brightness → distances underestimated.

Photometric parallax method

No assumption on the parallax (also negative parallaxes allowed) or on its fractional error.
This procedure allows us to estimate the Gaia parallaxes counter-offset directly from data (Riess+2021).

$$M_\lambda = \alpha_\lambda + (\beta_\lambda + \delta_\lambda[\mathrm{Fe/H}])\log P + \gamma_\lambda[\mathrm{Fe/H}]$$

$$\varpi_{\mathrm{Phot}} = 10^{-0.2(m_\lambda - M_\lambda - 10)} \ \text{(mas)}$$

$$\chi^2 = \sum \frac{(\varpi_{DR3} - \varpi_{Phot} + \epsilon)^2}{\sigma^2}$$

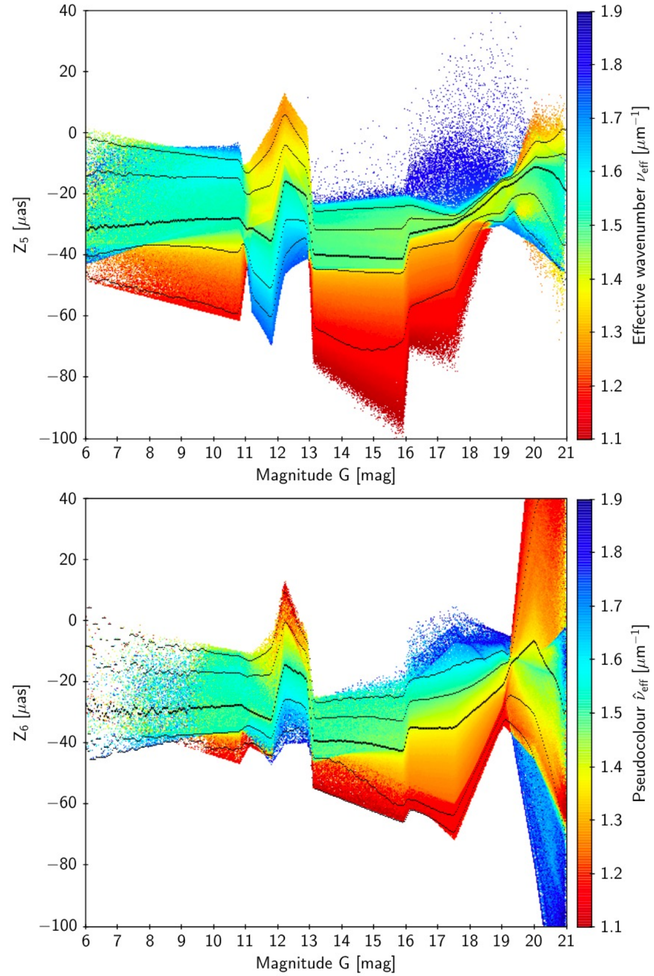
ϵ is the Gaia parallax **counter-correction**

Ripepi+, submitted A&A, arXiv:2508.17447

Gaia Parallax zero point offset (PZPO)

$\varpi_{\text{True}} = \varpi_{\text{Gaia}}$-PZPO

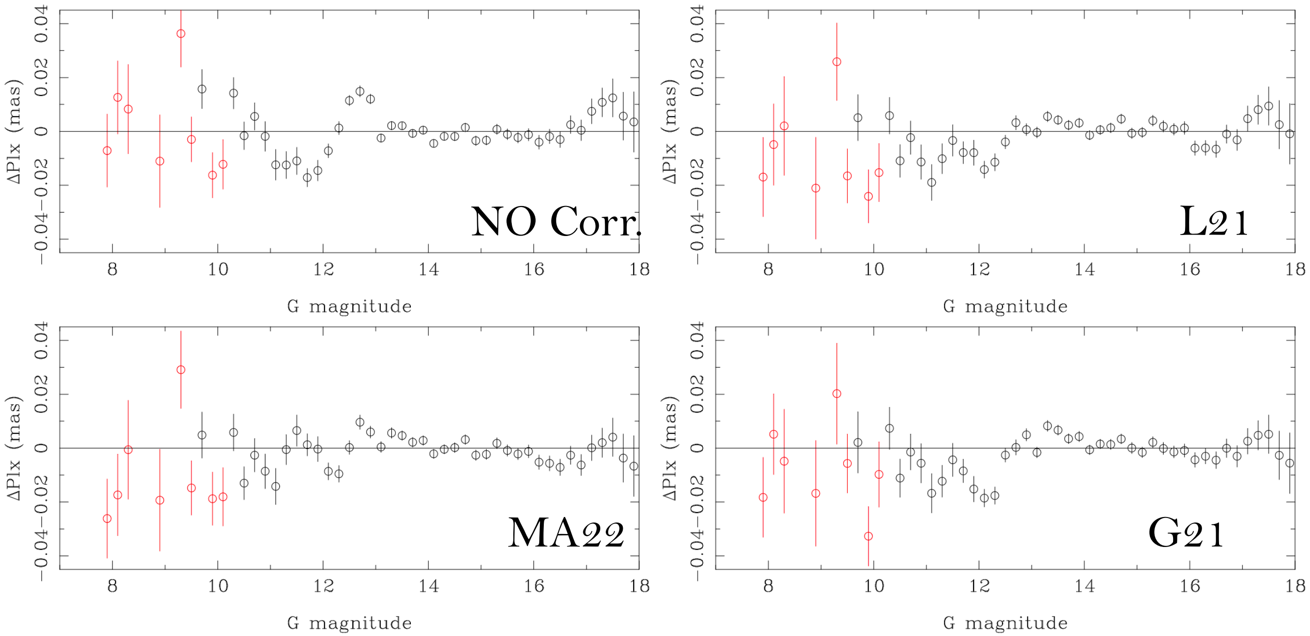
- The PZPO depends on Magnitude, colour, ecliptic latitude
- Lindegren+2021 (L21) provided individual offsets based on parallax comparison with QSO, Binaries and LMC
- Other corrections in the literature: Maíz Apellániz 2022 (MA22), Groenewegen 2021 (G21)



Lindegren+2021

Gaia Parallax zero point offset (PZPO)

$\varpi_{\mathrm{True}} = \varpi_{\mathrm{Gaia}}$-PZPO



Test of the correction using open clusters.
Residuals between individual and cluster parallaxes summed over all clusters and plotted against G magnitude. → no correction is perfect

G (mag)	no PZPO (μas)	L21 (μas)	MA22 (μas)	G21 (μas)
All	9.78	9.37	9.45	9.41
$G \leq 13$ mag	13.37	12.83	13.10	13.06
$13 < G < 17$ mag	2.35	3.48	3.60	3.39
$17 \leq G \leq 18$ mag	8.62	6.06	3.97	4.33

Reyes&Anderson2023, Groenewegen 2023

Groenewegen 2023

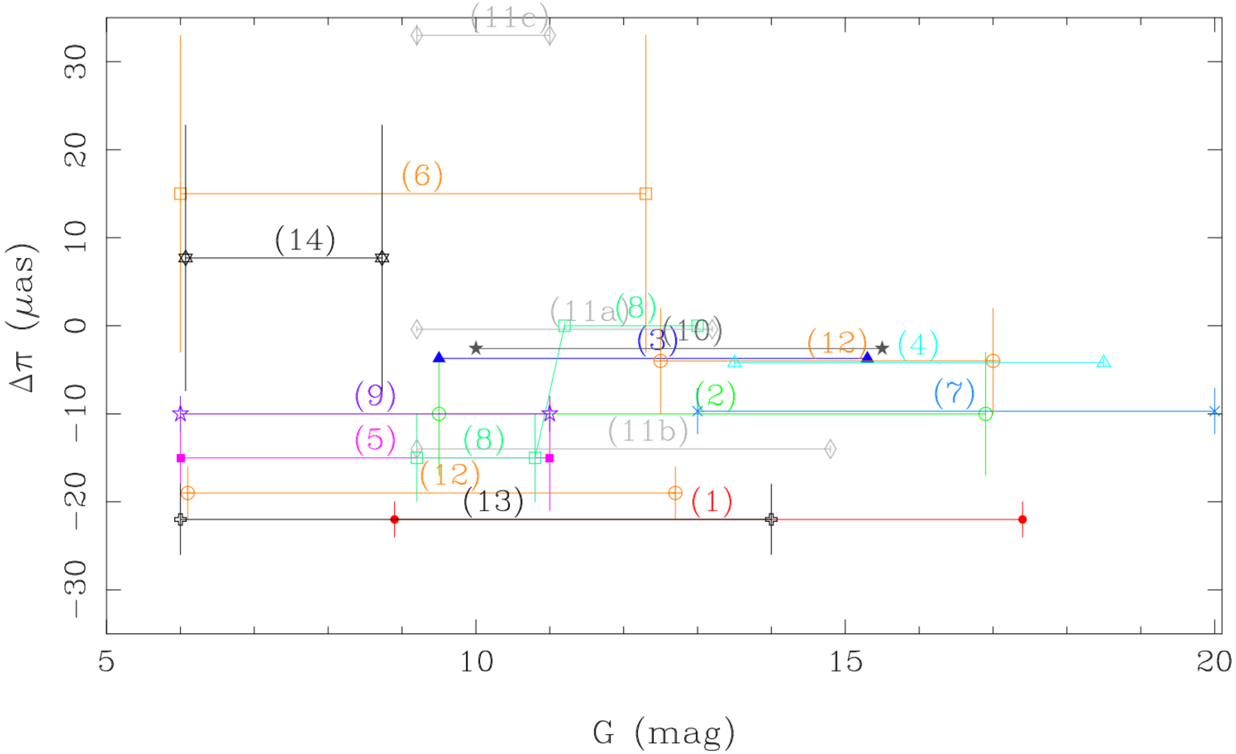


Figure 3. Countercorrection $\Delta\pi$ plotted against magnitude for (1) Bhardwaj et al. (2021), RRL; (2) Gilligan et al. (2021), RRL; (3) Huang et al. (2021b), red clump (5p solution); (4) Ren et al. (2021), WUMa EBs (5p solution); (5) Riess et al. (2021a), DCEP LMC; (6) Stassun and Torres (2021), EBs; (7) Vasiliev and Baumgardt (2021), globular clusters; (8) Zinn (2021), asteroseismology; (9) Flynn et al. (2022), open/globular clusters; $Bp - Rp > 1$ (10) Wang et al. (2022), giants; (11) Khan et al. (2023) red giants: asteroseismology, for the (a) *Kepler*, (b) *K2*, and (c) *TESS*-SCVZ fields ('E20', APOGEE DR17 values); (12) Cruz Reyes and Anderson (2023) Clusters ($G = 12.5 - 17$ mag, $0.8 < Bp - Rp < 2.75$ mag) and MW DCEPs; (13) Molinaro et al. (2023) MW DCEPS; (14) Groenewegen (2023) dynamical parallax of binary systems with spectroscopic and astrometric orbits.

PZPO counter-correction

$\varpi_{\text{True}} = \varpi_{\text{Gaia}}$-PZPO+$\Delta\varpi$

$\Delta\varpi$ is usually negative

No consensus on its value/error

The size of this counter-correction and the precision of its estimate may have a significant impact on the extra-galactic distance scale.

$\Delta\varpi = \pm 4$ μas → $\pm$ 0.02 mag at the distance of the LMC → 1% in distance → 1% on H0

Photometric parallax method

$$\chi^2 = \sum \frac{(\varpi_{DR3} - \varpi_{Phot} + \epsilon)^2}{\sigma^2}$$

Minimization of χ^2 using Cauchy-loss functions to minimize the impact of outliers. MCMC for robust parameter estimate (and errors).

$$\mathcal{L}_{\text{Cauchy}} = \frac{c^2}{2} \sum_i \log\left(1 + \left(\frac{r_i}{c}\right)^2\right),$$

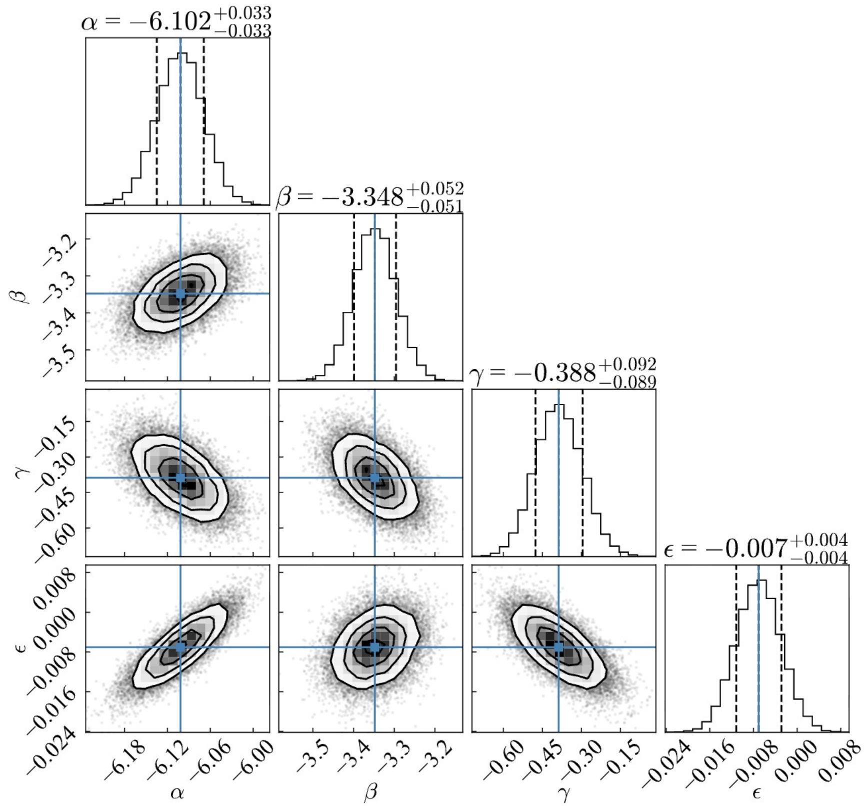
$$r_i = (\varpi_{DR3} - \varpi_{phot} + \epsilon)^2/\sigma^2$$

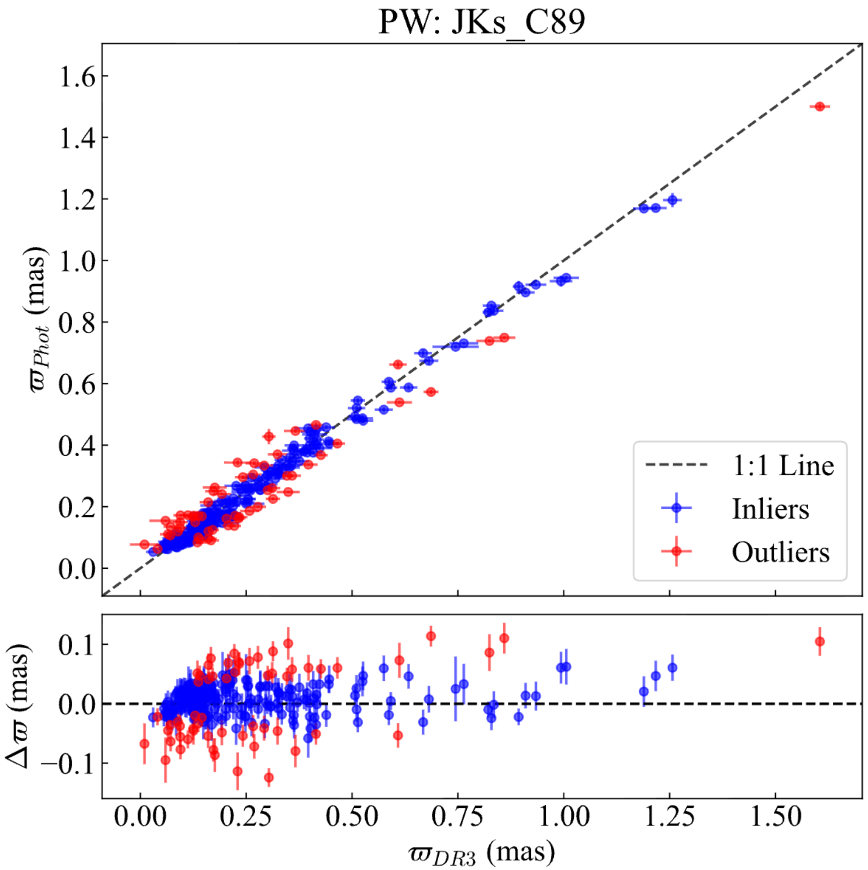
$$\log \mathcal{L}(\theta) = -\frac{1}{2}\mathcal{L}_{\text{Cauchy}}(\theta),$$

where $\theta = (\alpha, \beta, \gamma, \epsilon)$ is the vector of model parameters.

Ripepi+, submitted A&A, arXiv:2508.17447

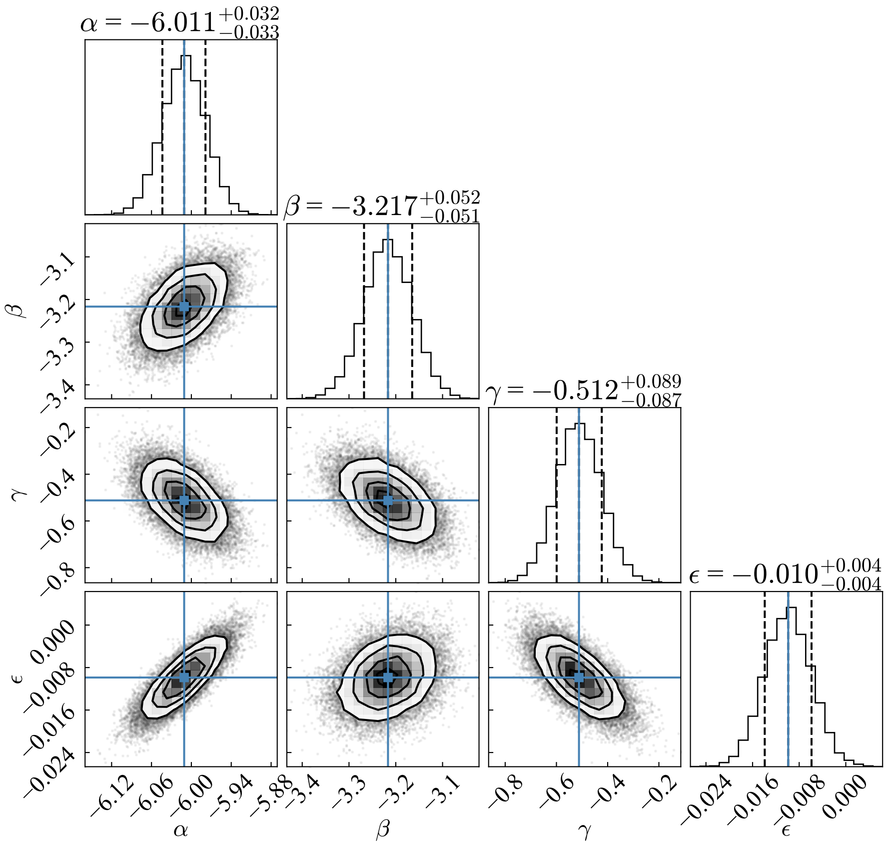
Results from the photometric parallax fit: JKs case

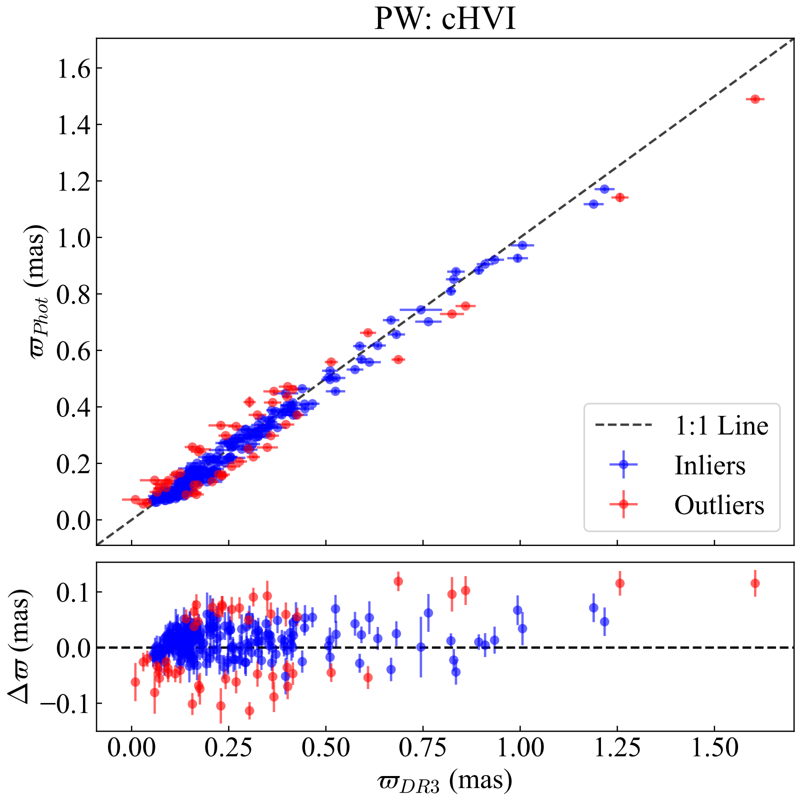




Ripepi+, submitted A&A, arXiv:2508.17447

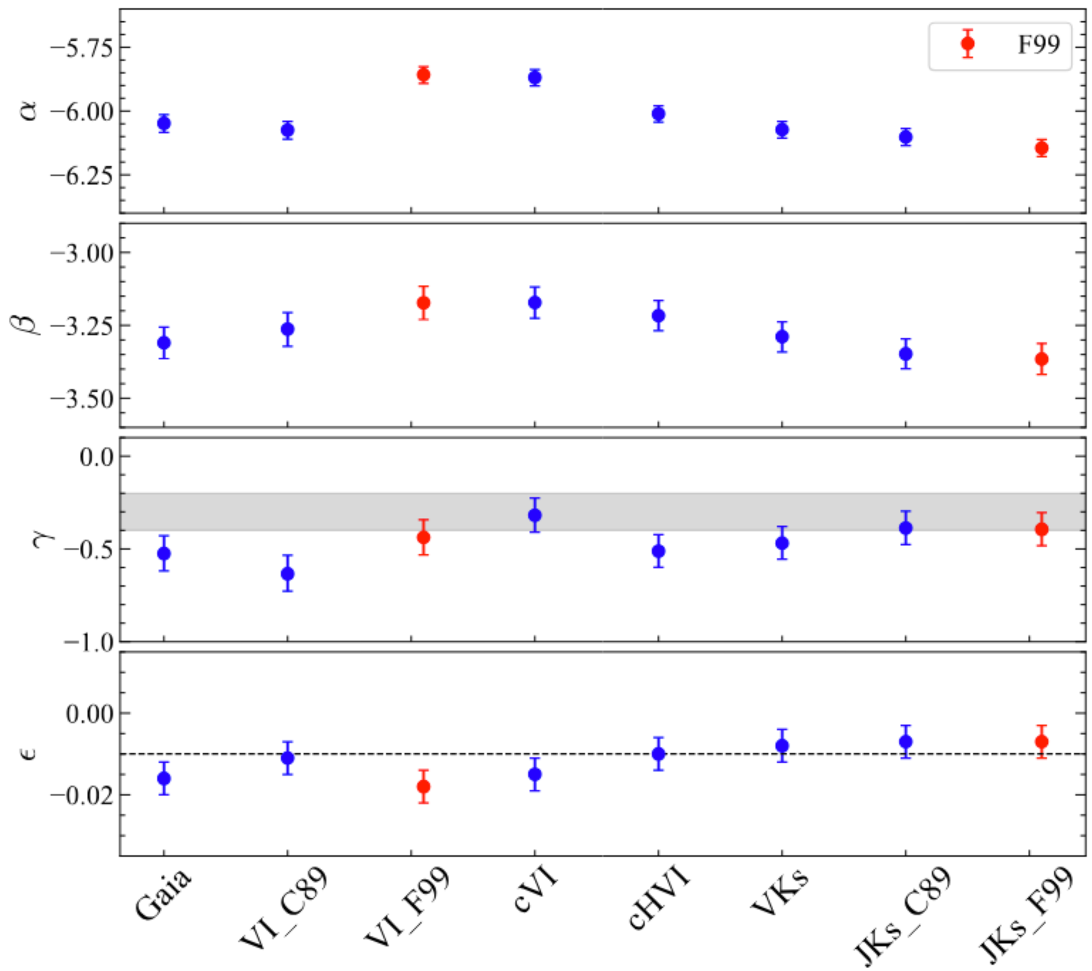
Results from the photometric parallax fit: HST HVI





Ripepi+, submitted A&A, arXiv:2508.17447

Results based on Phot. Parallax results



All four parameters calculated directly from data. No assumptions.

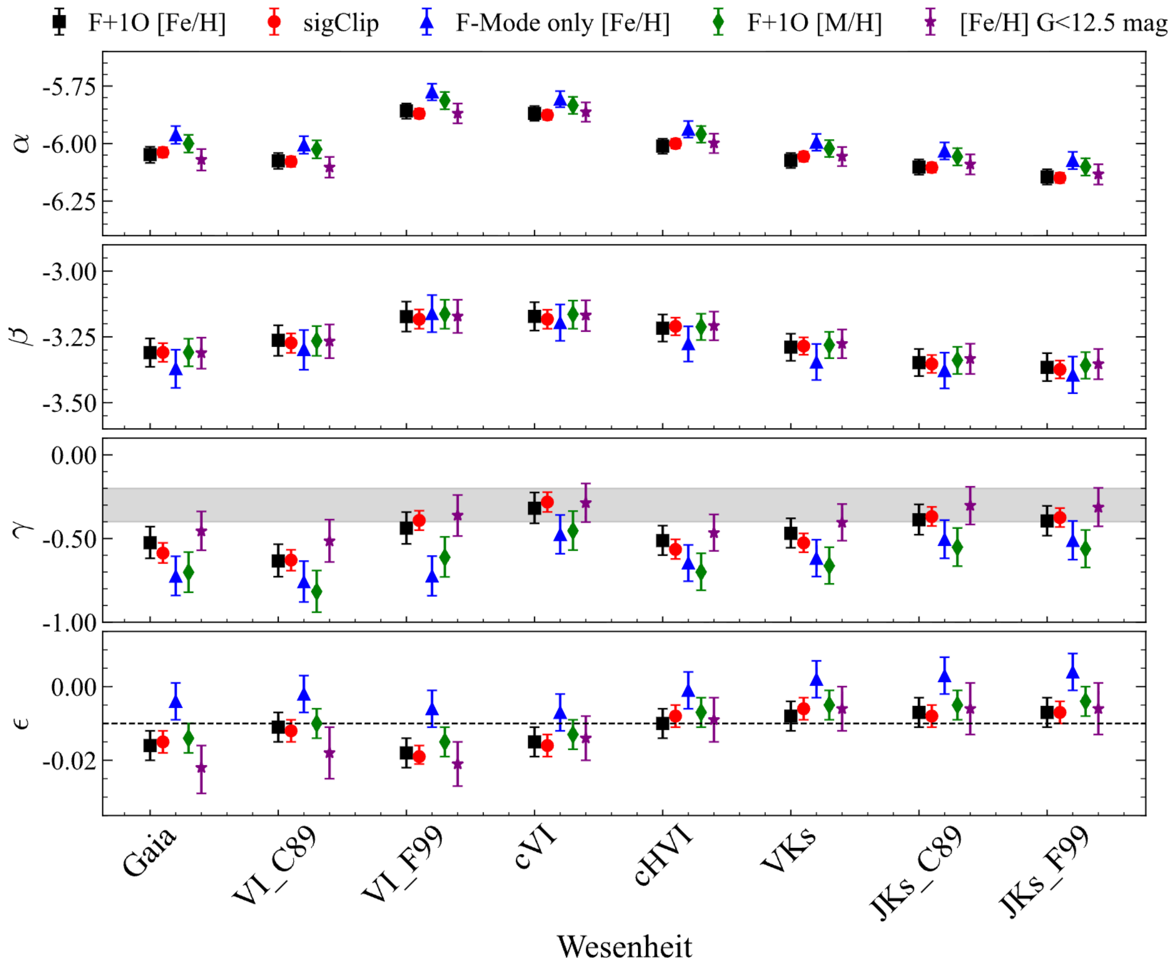
The γ term generally >= -0.4 mag/dex i.e. larger than other methods in literature, albeit still within 1 σ in many cases.

Mild impact of the Fitzpatrick1999 reddening law

Average counter-offset → 10 μas (range 7-18 μas, typical errors 4 μas)

Ripepi+, submitted A&A, arXiv:2508.17447

Variations



Several variations worsen the discrepancy with the literature

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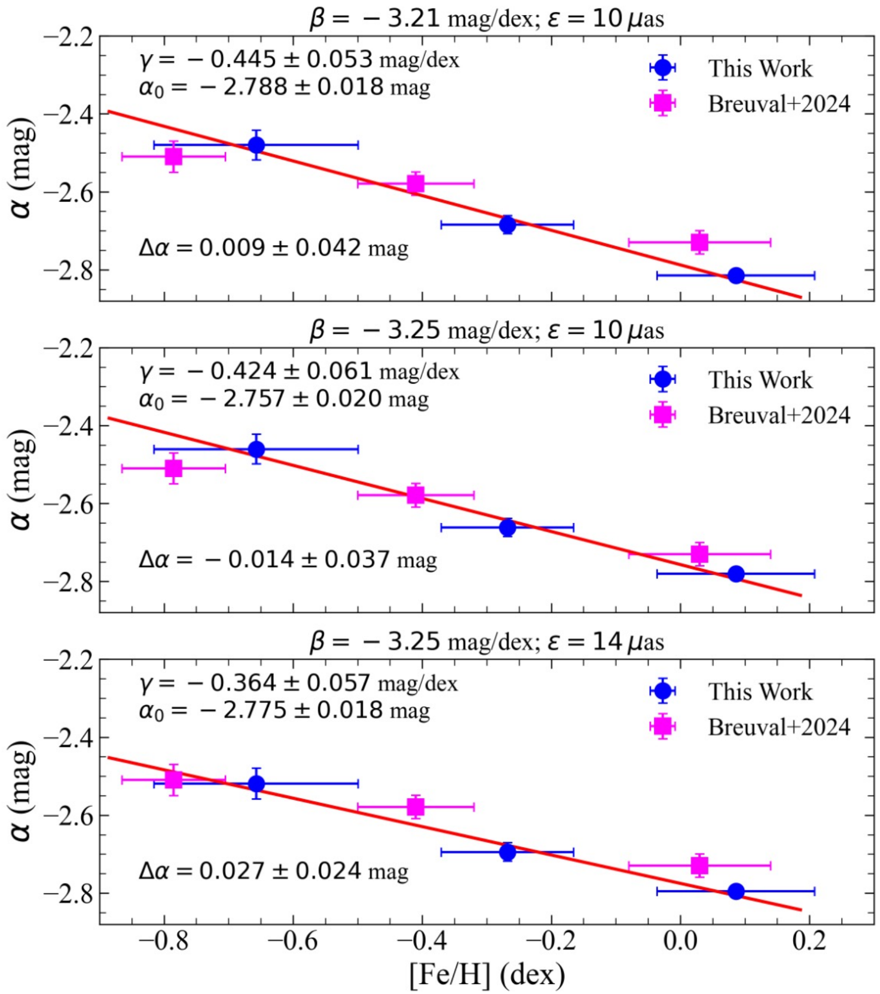
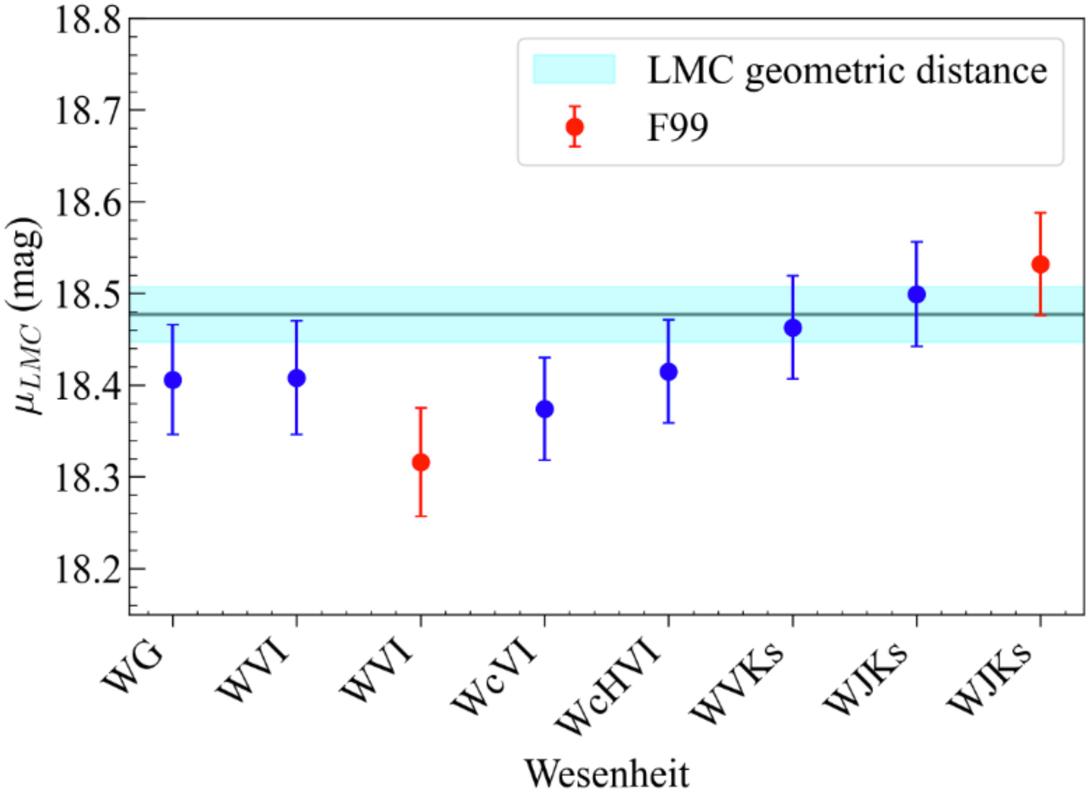
Variations



- Sample divided into three equally populated bins of [Fe/H] (to simulate Breuval+ technique)
- Slope and counter-offset imposed
- Photometric parallax with Cauchy-loss to determine α term for each bin
- Linear fit of resulting α term → γ term still larger than Breuval+2024

Ripepi+, submitted A&A, arXiv:2508.17447

Geometric LMC distance (Pietrzyński+2019) for validation



We can use the distance of the LMC to validate the results.

→ Apply the derived PWZ relations to multiband photometric data in the LMC, assuming the metallicity [Fe/H]=-0.41 dex (disp. 0.07 dex, Romaniello+2022).

→ HST data used for the HST cVI and cHVI Wesenheit relations

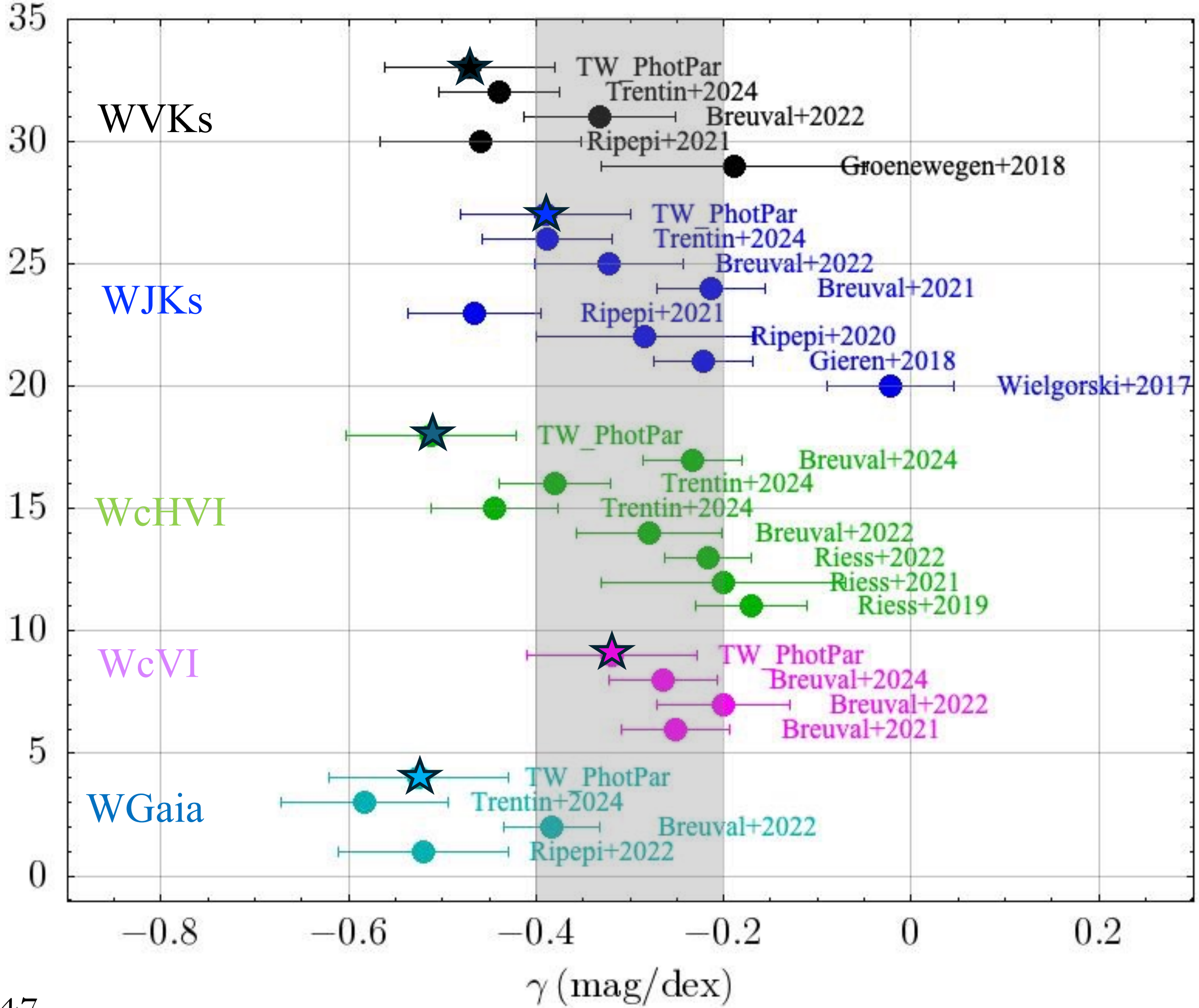
→ 1 σ agreement for the HST cVI,cHVI
$< 1\ \sigma$ agreement in the NIR

Ripepi+, submitted A&A, arXiv:2508.17447

Comparison with recent literature

- Significant discrepancy with recent literature (SH0ES group)
- If confirmed → H0 lower by 1-2% at maximim, not solving the H0 tension
- Nevertheless important to discover the origin of the discrepancy and the correct value of gamma.

→ Gaia DR4 is probably the key.



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