Cepheids, Distances, H_0

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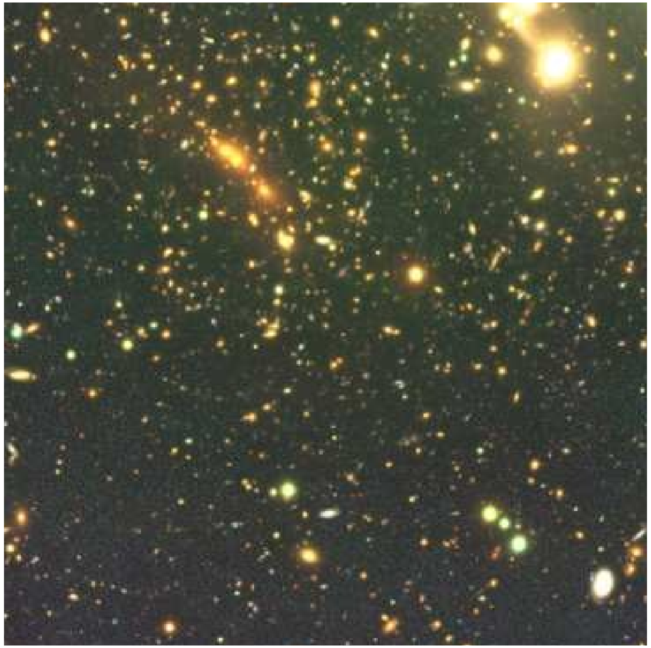

Anomalies ?
Really ?

Annecy, November 2023

 (2101.05463)

Disclaimer

- I was volunteered to report on Cepheids in the context on H_0
- I interpret it as studying SH0ES (and what other people write about these analyses)
- I never published on these subjects, neither comments nor results
- I have been working on related subjects: photometry of variable point sources.

Papers (1)

- Sociology:
  - The measurement was carried out by Wendy Freedman et al in the (late) 1990s : 70 +/-3(stat) +/-7 (sys) : HST key program
  - A. Riess started in ~2005 to improve on this, the SH0ES project was awarded about 1000 HST orbits since then.
  - In ~ 2015 (?) Wendy came back to the subject
  - I was told Adam and Wendy are not in the best terms.
- The latest (invited) review I could find is : 2309.05618, by W. Freedman and B. Madore (They are continuing collaborators) “F23”
- The latest SH0ES paper I read is 2112.04510, often called “R22”
- Previous papers: R11, R16, ….

The local H0 measurement(s), as of today

- Requires (absolute) distances and redshifts.
- In the Hubble flow, z>~0.02 or ~80 Mpc
- Distances are obtained via a 3 rung ladder:
  - Supernovae (Ia) in the Hubble flow
  - Local supernovae in galaxies with observable Cepheids (<80 Mpc)
  - Cepheids at known distances (Milky Way, LMC)
- "Local" calibrators :
  - LMC: (detached) eclipsing binaries (DEBs)
  - Milky Way : parallaxes
  - NGC4258 : Hydrogen Maser

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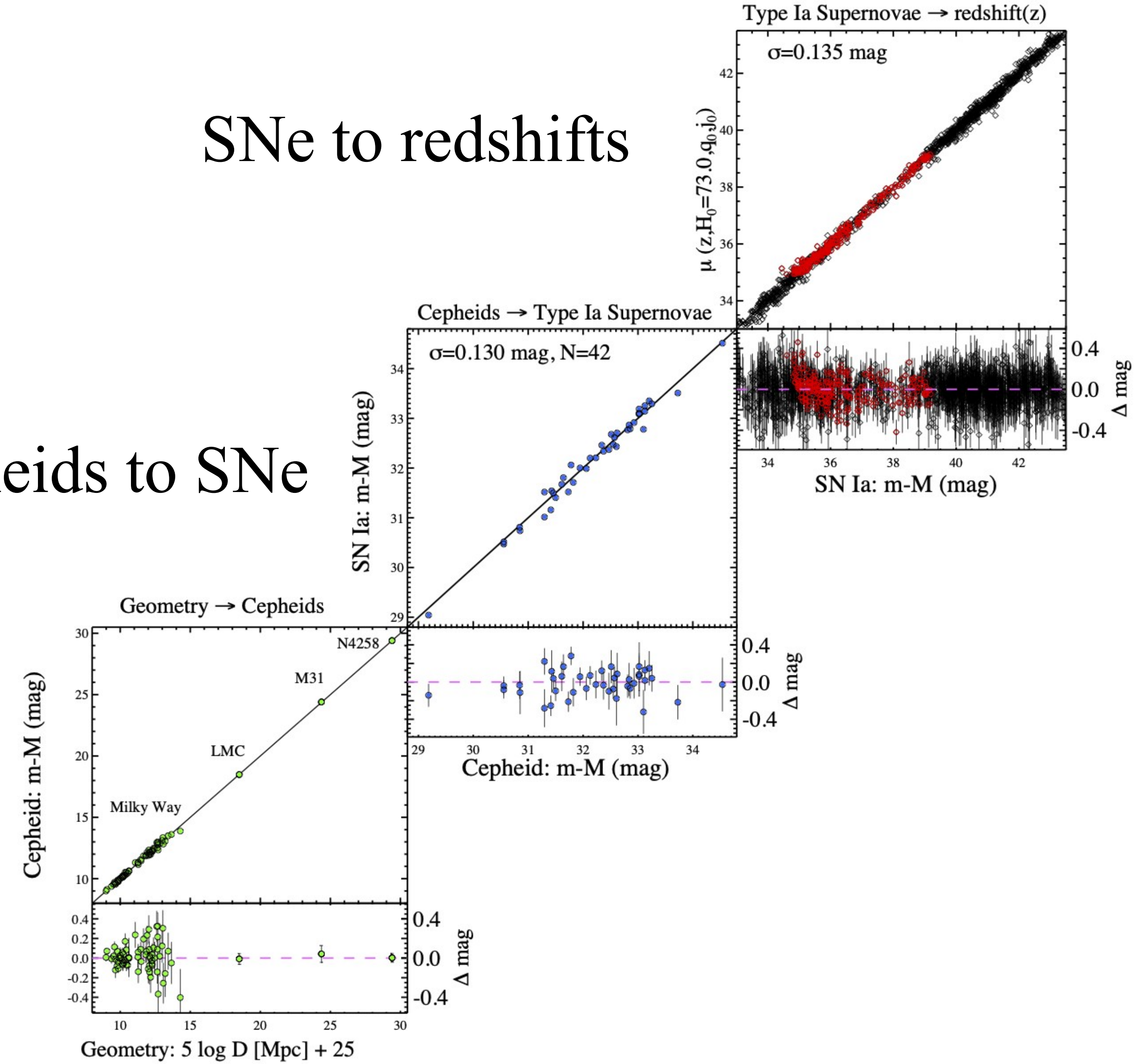
You can replace “cepheid” by any other (bright) distance indicator (e.g. TRGB)

SNe to redshifts

R22, fig12.

Cepheids to SNe

Actual distances to Cepheids



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Supernovae statistics (1)

- The scatter of SNe is typically 0.14 mag (i.e. ~7% in distance)
- In order to get 1% precision, one needs ~50 events (2^{nd} rung)
  - Current statistics is 42.
- Usable SN events (nearby galaxy with observable cepheids, moderate extinction) occur at ~$1y^{-1}$ rate.
- This is the core limitation for H_0 statistical precision.
- We already have more SNe in the Hubble flow than we need.
- Selecting SNe in galaxies with cepheids actually selects late type SN hosts : galaxies still forming stars.

Supernovae statistics (2)

- With JWST, it is likely that the SN distance limit increases, because of improved sensitivity and improved image quality as compared to HST.
- Things may speed up….
- … if significant chunks of time are allocated.
- There are competing teams, rather than big consortia. Stay tuned.
- Nevertheless, I don't think that increasing the (calibrator) SN statistics is the most pressing issue in this matter.

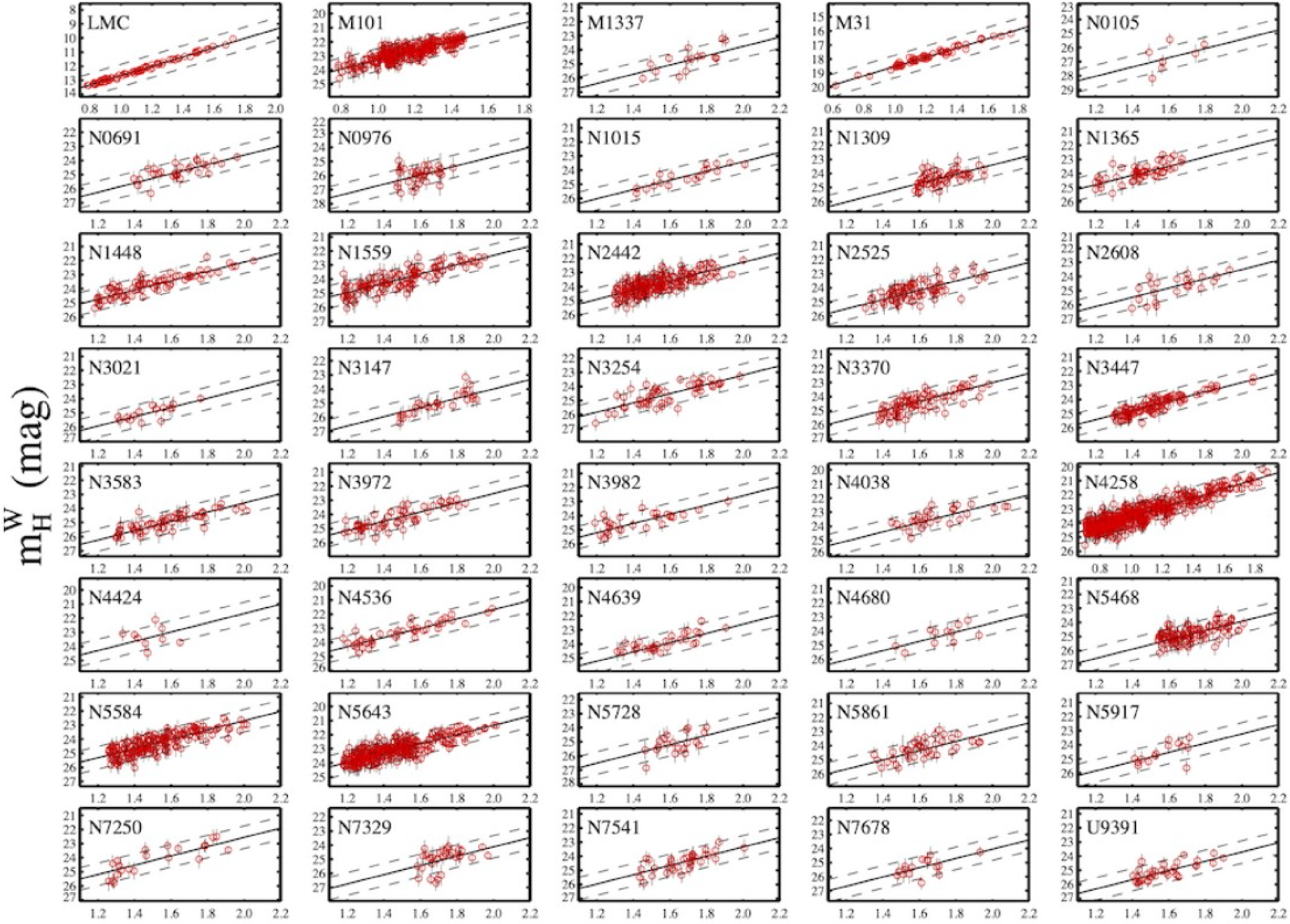
Cepheids (in a single slide !)

- These are bright (super) giants variables. Luminosity : $10^{3\text{-}4}$ Sun
- Variability: from a few tenths to ~1 mag.
- Henrietta Leavitt + (1908) : the period-luminosity relation discovered in the LMC
- Since then, many refinements: two populations, extinction, metallicity corrections, color terms, precise photometry, etc...
- Are we at the end of refinements ?
- However, further refinements are confined within the empirical dispersion around the PL relation, ~0.08 mag rms in the NIR

Cepheids from R22

NIR Extinction-corrected magnitudes vs log(Period)

In distant hosts m~25 for P~10 d.



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The use of cepheids

- They are used to bridge the local distance calibrations with the nearby SN host galaxies.
  - The farthest SN/cepheids galaxies are at the limit of HST capabilities
- So there are basically two kinds of potential problems:
  - The quality of calibrators
  - The photometry of cepheids in SN host galaxies
- Then, there could be problems in the comparison
  - Different populations
  - systematics which do not cancel out (metallicity !)
  - ….

Cepheid calibrators in R22

- Milky Way: (mostly) Gaia early DR3 (EDR3) :
  - 0.9% systematics (in distance) related to parallax offset, 1% with statistics.
- LMC : detached eclipsing binaries:
  - 0.0263 mag or 1.2%   (49.5 kpc)
- NGC4258: Water maser:
  - 1.5% in distance (7.6 Mpc)
- Added complexity: M31 is used (without a geometrical anchor) to constrain the P-L slope of cepheids.

Parallaxes of Cepheids in the Milky Way

- R22 mostly uses Gaia Early Data Release 3
- In Gaia EDR3 parallaxes have issues (5.2 of F23):
  - Underestimated uncertainties
  - Global offset (discussed by the Gaia team)
  - Color and magnitude dependent corrections (idem)
  - Leads to about 4% distance uncertainties for Cepheids rather than 1% as assumed in R22
  - Requires a new assessment with DR3 (out since June 22)
- For both Cepheids and TRGB, Gaia is anyway expected to provide the ultimate calibration.

Detached Eclipsing Binaries

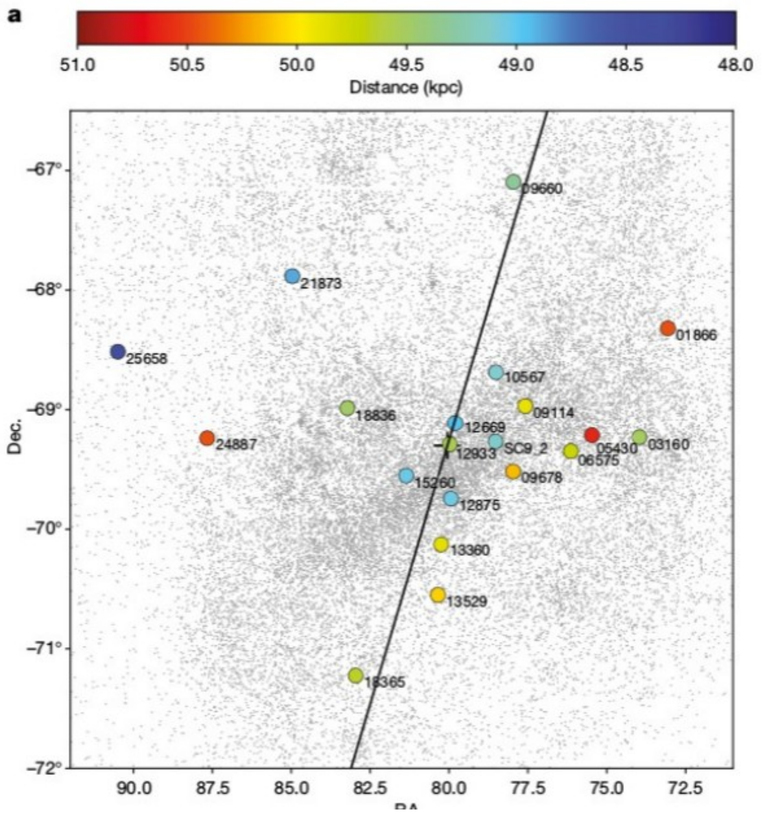
- Eclipsing binaries: orbiting stars which eclipse each other: the rotation plane contains the observer. “Detached” means not distorted by gravitational attraction
- Rotation velocity obtained from period and doppler shifts
- Occultations provide physical diameters
- The intrinsic surface brightness can be calibrated for certain types of stars (typically as a function of color): red clump giant
  - Proxy for star temperature : V-K
- Such stars exist locally and their angular diameters can be measured by Pioneer on VLTI (!). This is a major change since the HST key program.

Distance to the LMC : 1903.08096

- 41 Milky Way (local) red clump stars:
  - With “physical” radii (VLTI) : accuracy 2.7%   (A&A 616 A68, 2018)
  - With V (Gen. Cat. of Photometric Data) and K magnitudes → brightness and color
  - The paper more or less shows that reddening is negligible (<d><~40 pc)
- 20 DEBs in the LMC:
  - V photometry source ? (I guess it is OGLE) Extinction ? K band photometry ?
  - Linearity of photometry w.r.t MW ?
  - Quality of radii: cross check with a single DEB in the MW which has a GAIA parallax.

Distance to the LMC : 1903.08096 (2)

- The reported distance uncertainty is 1.1%
- My sense is that the accuracy of geometric star radii (from occultation in lighcurves) deserves a more detailed discussion
- I don’t understand what secures the linearity of V mag measurements between V~5 (MW) and V~21 (LMC)
- I don’t understand why the interferometric radius scale uncertainty (2.7%) is not propagated into the final error budget.



Geometrical priors

- LMC : $\mu_{lmc} = 18.477 \pm 0.0263$ mag
- SMC : $\Delta\mu_{lmc\text{-}smc} = 0.500 \pm 0.017$ (used to fit the metallicity term)
- NGC4258 : $\mu_{n4258} = 29.398 \pm 0.032$ mag
- Milky way: 2 sources : zero point of Gaia parallaxes (1% or 0.02) and average of 66 Gaia Cepheids : 0.024
- MW+N4258+LMC : formal distance scale uncertainty = 0.015 mag.

Measuring Cepheids

- One has to observe from space in order to resolve stars in distant galaxies (HST scientific rationale).
- In order to reduce systematics, all cepheids involved in H_0 measurements should be observed with the same instrument and bands, i.e. the HST (or JWST).
- NIR observations are obviously favored in order to reduce extinction corrections, significant in late type galaxies. However, angular resolution is degraded as compared to visible.
- One needs to measure apparent brightnesses, which is difficult in crowded stellar fields.

WFC3 on HST

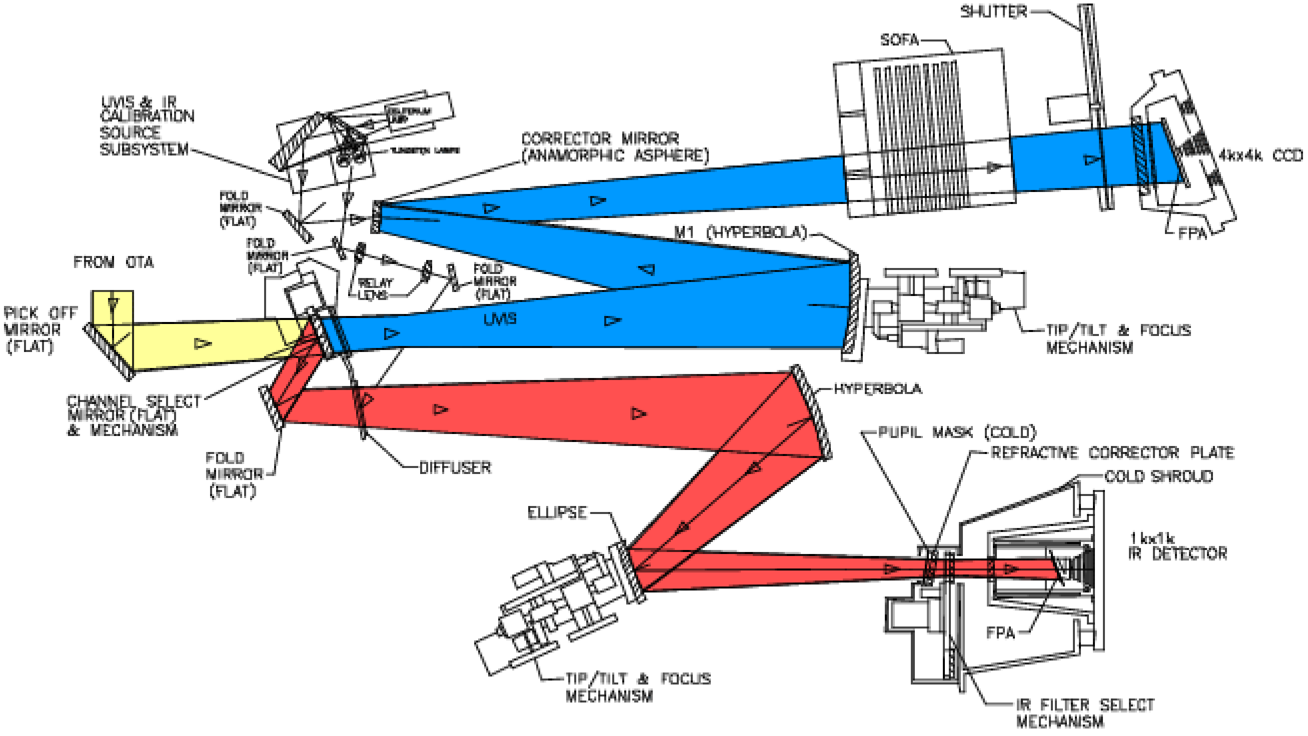
Installed in 2009.

Dual instrument:
UV/visible and NIR

Plate scales:
0.04 and 0.13”/pix

FOV : ~ 2.5’ and 2’

10 hours, S/N~10
at m~29 and m~28



SH0ES HST observations

- 3 bands in the visible : F350LP (open beam), F555X(V), F814W(I)
  - Used to find Cepheids, measure their periods, positions, V and I.
- 1 NIR band : F160W (H)
- On HST/WFC3, the pixel size is 0.04” in the visible and 0.13” in the NIR

  → In R22 (and before), positions are measured in the visible and enforced for NIR photometry, using some mappings of the distortions.

Cepheids "standardization"

$$m_H^W = m_H - R\,(m_V - m_I),$$

R is modest, ~0.4
because it refers to H band

$$m_{H,i,j}^W = \mu_{0,i} + M_{H,1}^W + b_W\,(\log\,P_{i,j} - 1) + Z_W\,[\mathrm{O/H}]_{i,j},$$

Expected mag.

Abs. Mag.
of a P=10d
Cepheid

PL slope

Metallicity correction

Metallicities

- The dependence of Cepheids P-L (or P-L-C) relation with metallicity was uncovered in the 50's (?) and led to a revision of the distance to the LMC (because MW and LMC have a different average metallicity).
- In R22, the metallicity is assessed by spectroscopy and some spatial gradient across galaxies is fitted.
- For SN host galaxies (2nd rung), I do not imagine a mechanism that biases distances.
- For the first rung, uncertainties in metallicities translate to potential shifts of the other parameters of the P-L-C relation

First rung: origin of data

R22

Table 4. Ancillary Cepheid Data

Sample	Reference	N	$\langle P \rangle$ [d]	$\langle$[O/H]$\rangle$ [dex]	Photometry	Selection	Notes
MW *Gaia* EDR3 +*HST*	Riess et al. (2021)	66	12.5	0.13	*HST* m_H, m_V, m_I	see ref.	$M^W_{H,1,Gaia} = -5.903$, $\sigma_{Gaia} = 0.024^a$, $Z_W = -0.20 \pm 0.12$
MW WFC3 SS	Riess et al. (2018a)	8	22.6	0.05	*HST* m_H, m_V, m_I	see ref.	$M^W_{H,1,HST} = -5.810$, $\sigma_{HST} = 0.054^a$
LMC *HST*	Riess et al. (2019b)	70	16.0	-0.29^b	*HST* m_H, m_V, m_I	see ref.	
LMC ground	Macri et al. (2015)	272	12.6	-0.29^b	ground m_H, m_V, m_I	$P > 5$ d	m_H transformed to 2MASS[5]
SMC ground	Kato et al. (2007)	145	9.9	-0.72^b	ground m_H, m_V, m_I	$P > 5$ d, $r < 0.6°$	m_H transformed to 2MASS[5]
M31 SH0ES	Li et al. (2021)	55	19.1	-0.11	*HST* m_H, m_V, m_I	$P > 4$ d	
M31 PHAT	Kodric et al. (2018)	463	10.5	0.12	*HST* m_H, m_J	$P > 4$ d	m_H, m_J transformed to m_H, m_V, m_I

NOTE—(a) measured following Riess et al. (2021) with global fit P–Lparameters (b) From Romaniello et al. (2021) and Romaniello et al. (2008).

Very strange

How do you cook up 3 magnitudes out of 2?

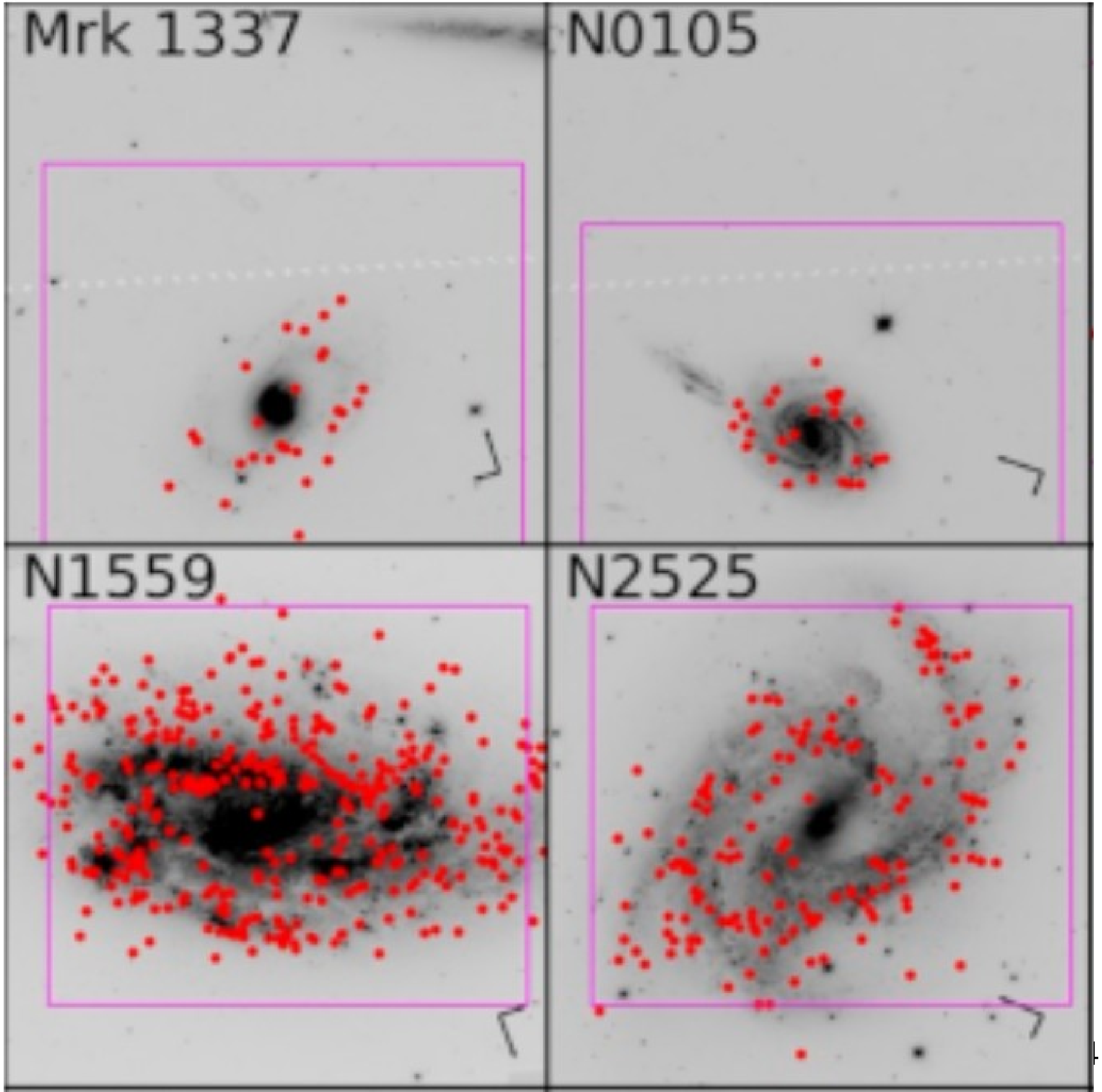
Adding many LMC cepheids into the "training" sample allows R22 to "saturate" the uncertainty on distance to the LMC (using DEBs).

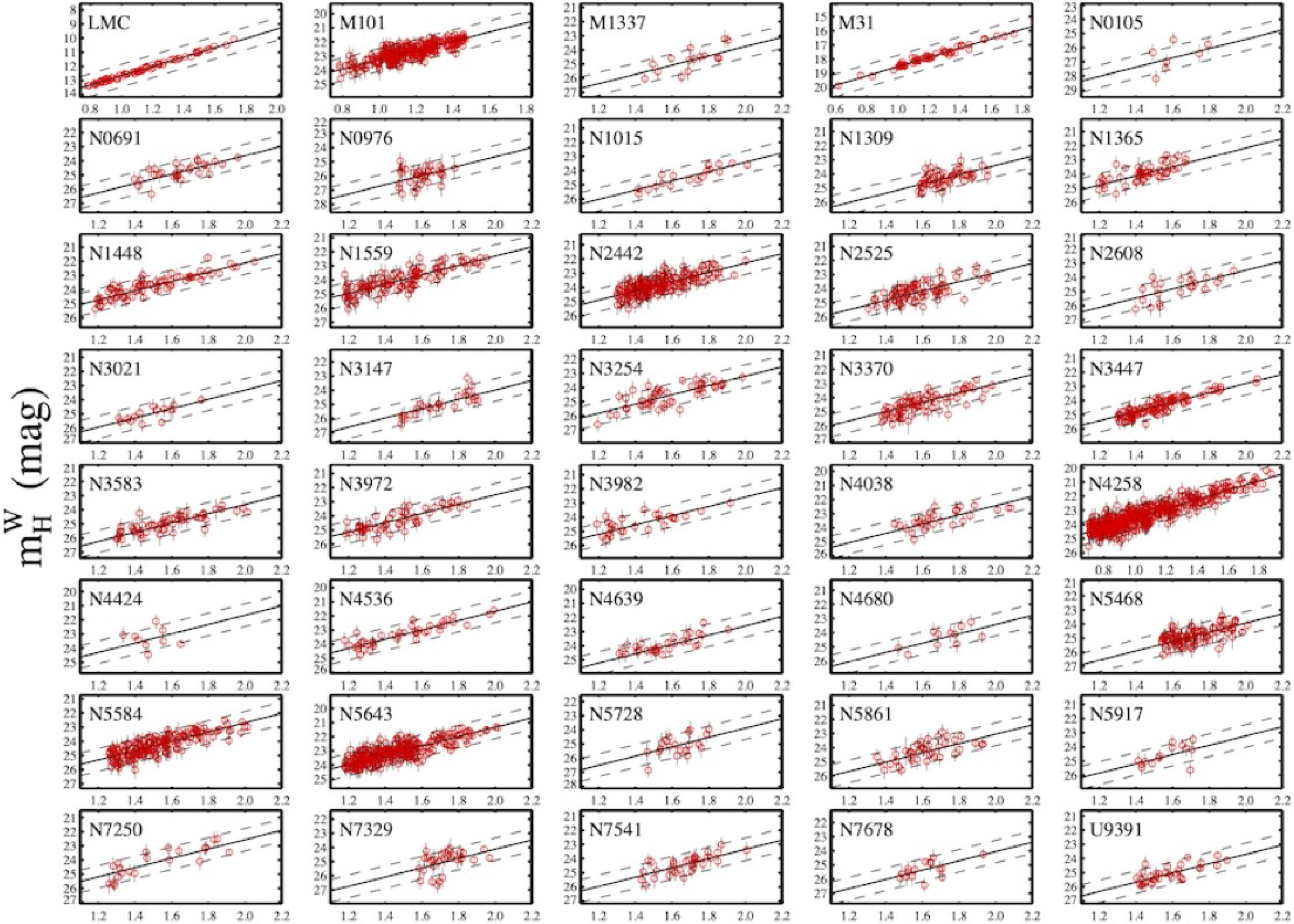
A few SN host galaxies with the location of selected cepheids.

For each host, a period cut is defined in order to avoid a magnitude bias due to missing detections.

Distant galaxies deliver a small number of eligible cepheids

The distribution of periods varies with distance




m_H^W (mag)
LMC
M101
M1337
M31
N0105
N0691
N0976
N1015
N1309
N1365
N1448
N1559
N2442
N2525
N2608
N3021
N3147
N3254
N3370
N3447
N3583
N3972
N3982
N4038
N4258
N4424
N4536
N4639
N4680
N5468
N5584
N5643
N5728
N5861
N5917
N7250
N7329
N7541
N7678
U9391

R22

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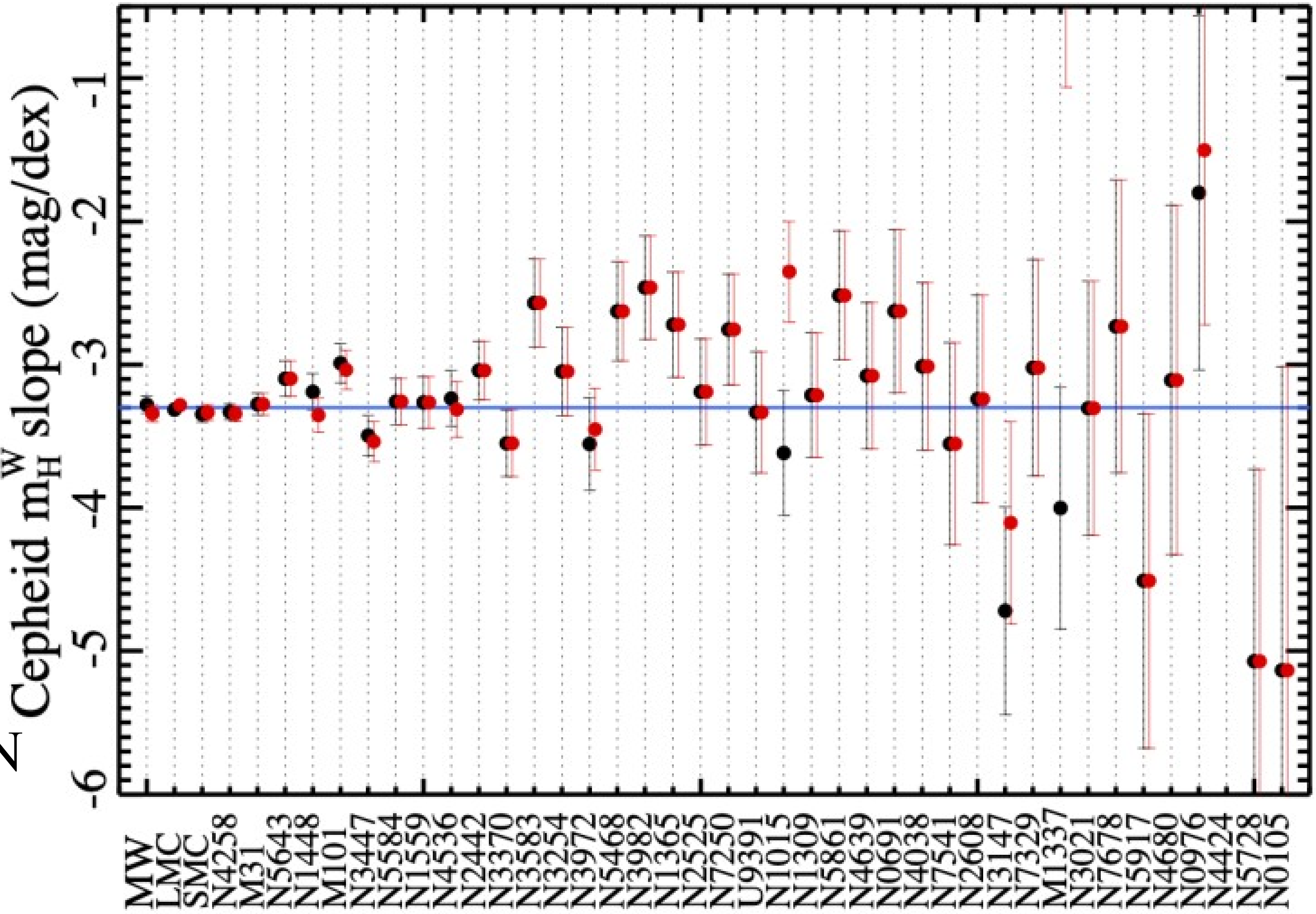
R22 PL slopes

This is a test.
In the end,
a single slope
is fitted across
all cepheids.

The range of S/N
is huge.



The photometry of cepheids

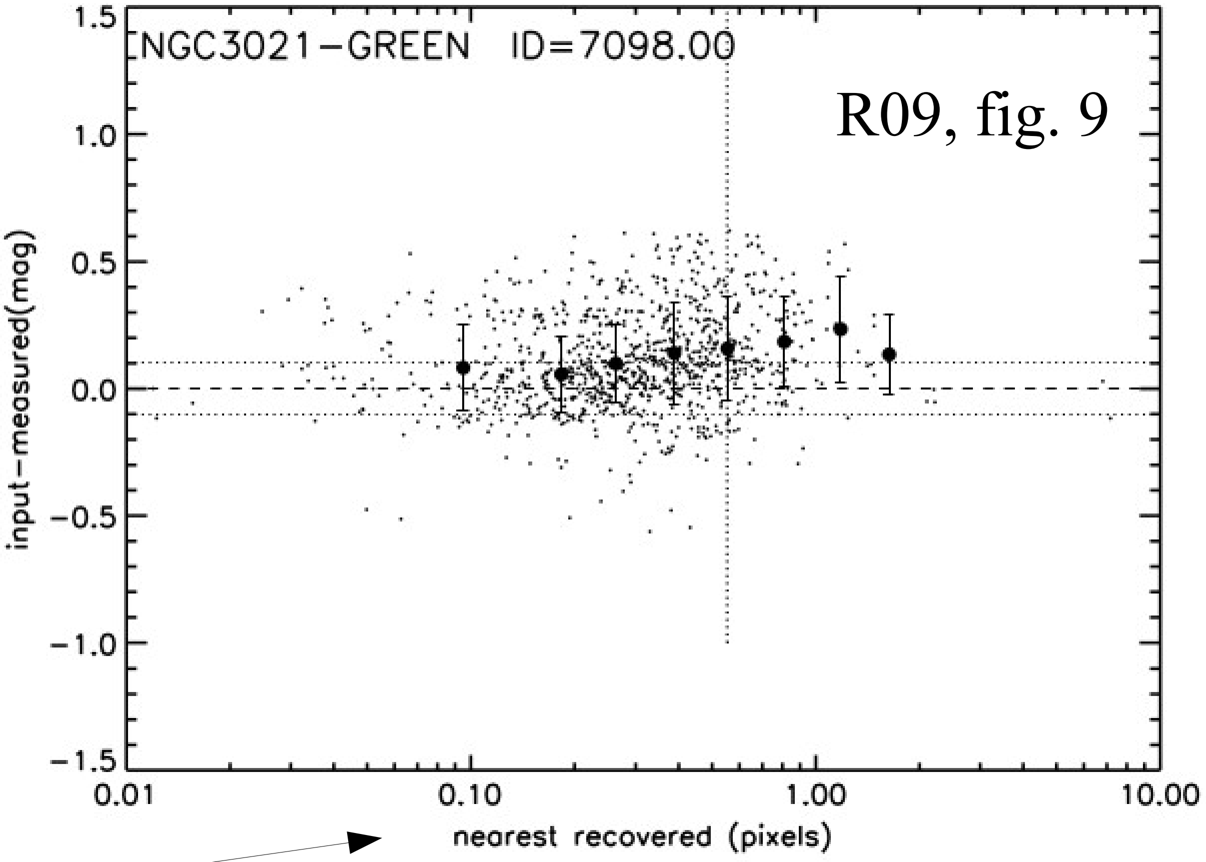
- Because most are faint, PSF photometry is the right choice.
- Fields are crowded, and estimating the background is difficult
- Local averages and variance are evaluated by adding 100 (1000?) artificial stars in the images (of the same flux as a given cepheid in a given image) and measuring the average and variance of these mock fluxes
- The flux noise is the result of 3 components:
  - the sky and the shot noise from the object itself: Poisson/Gauss
  - The background stars: R22 argue that this is log-normal

The photometry is polluted by underlying objects

This affects both the flux value and its uncertainty

This is measured by inserting 1000 artificial stars in the images around each cepheid

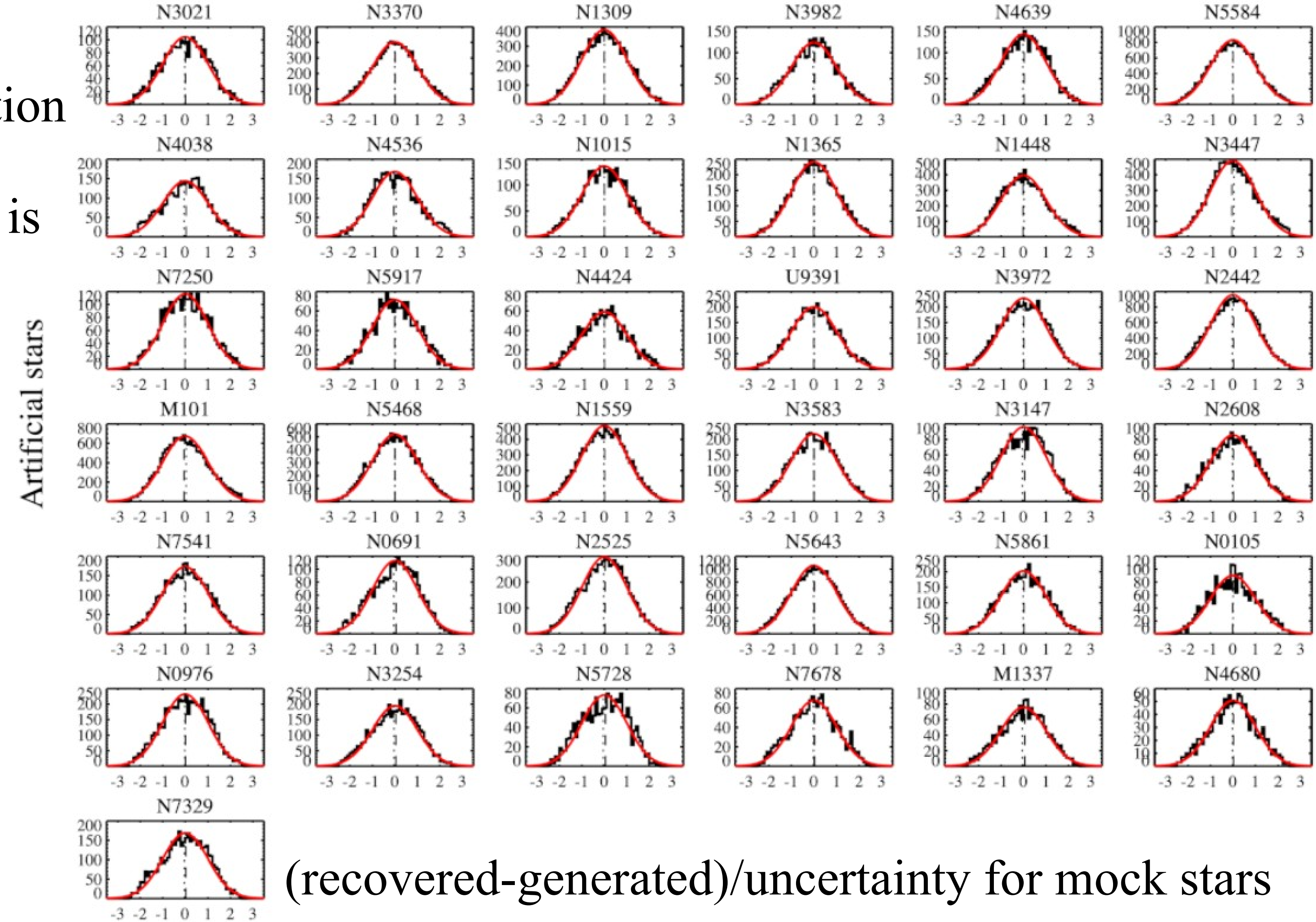
The flux/mag bias depends on the distance of the star to the nearest detected object (I think...)



The reported uncertainty reflects the formal uncertainty of PSF photometry and the scatter of the above graph.

σ=1 by definition

The skewness is small: Median-mean ~ 0.03



(recovered-generated)/uncertainty for mock stars

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Sample of cepheid photometry outcome (R11)

Table 2
WFC3–IR Cepheids

Field	α (J2000)	δ (J2000)	ID	P (days)	$V-I$ (mag)	$F160W$ (mag)	σ (mag)	Offset (pixel)	Bias (mag)	IM_{rms}	[O/H]	Flag
n4536	188.590	2.16830	27185	13.00	0.97	24.91	0.31	1.64	0.13	2.16	8.54	
n4536	188.604	2.18312	42353	13.07	0.73	26.29	0.74	3.32	0.37	4.30	8.97	Rej
n4536	188.584	2.18070	50718	13.73	0.88	24.51	0.42	0.88	0.28	11.4	8.64	
n4536	188.583	2.19700	72331	13.91	0.89	24.84	0.44	0.07	0.22	1.40	8.81	
n4536	188.590	2.19545	65694	14.38	0.98	25.26	0.38	2.91	0.39	30.8	8.90	
n4536	188.587	2.18864	58805	14.44	1.13	23.41	0.35	3.94	0.26	47.9	8.78	Rej
n4536	188.586	2.18406	53703	14.53	0.72	25.38	0.47	0.63	0.27	14.9	8.72	
n4536	188.592	2.20025	70938	14.62	0.64	25.81	0.58	2.39	0.30	17.4	8.94	Rej
n4536	188.594	2.17693	40098	14.64	0.95	25.12	0.52	4.40	0.63	12.9	8.72	
n4536	188.597	2.18489	48539	15.03	0.90	23.53	0.31	0.46	0.29	7.28	8.89	Rej

Bias (corrections) are large and scattered
Uncertainties are large (~0.35) while N4536 is the ~10th SN host distance-wise in R22.

Log-normal photometry error distributions

- Definition : X is log-normal if Y=log(X) is normal
- There are then 2 parameters, E[Y] and Var[Y]
- R22 (and before) argue that measured *magnitudes* have Gaussian errors, because the background (undetected stars) is log-normal.
- I don’t understand how that can be valid at all distances, because the relative contributions of background stars (deemed log-normal) and sky (Gaussian) vary a lot with distance.
- Gaussian distributions in magnitudes seem to describe the observed distributions, but I could not find a detailed test of sensitivity of the distance to the assumed error distribution.

A small difference between median and mean?

- For a perfect log-normal flux distributions, magnitudes are Gaussian (by definition)
- Is med-mean=0.03 small ?
- If measured fluxes are Gaussian then M=log(F) :
  - Median(M) = log(median(F))) = log(E[F])
- E[M] = log(E[F]) -1/2 Var[F]/E[F]^2+ ….
- So that, for the log of a Gaussian, the difference between median and mean is a proxy for S/N

$$\frac{\sigma_X^2}{\mu_X^2} = 2(med[Y] - E[Y])$$

For a difference of 0.03, $\mu \sim 4\,\sigma$

The Astrophysical Journal Letters, 956:L18 (22pp), 2023 October 10 https://doi.org/10.3847/2041-8213/acf769

Crowded No More: The Accuracy of the Hubble Constant Tested with High-resolution Observations of Cepheids by JWST

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]

- Bottom line: remeasuring ~300 Cepheids in 2 galaxies reduces the scatter (by about a factor of 2) but does not change the average (distance)
- The quality of the test (1 σ) is 0.03 which is marginal, especially because the chosen Cepheid galaxies are one calibrator and one “average”, while the largest bias is expected at the largest distances.
- Reminder: TRGB is essentially immune to confusion (and much less to extinction)

Linearity of measured fluxes

- Between Galactic cepheids and the most distant ones measured by WFC3 (NIR) , there are flux ratios well above 10^6
- Part of the gap is bridged by changing exposure times, but measured signal levels are anyway **very** different.
- On top of "classical" amplifier (or video chain) non-linearity, NIR sensors exhibit "count-rate" non-linearity which were large for NICMOS.
- What are they for the HgCdTe sensors of WFC3 (NIR) ?

Counting Rate Non Linearity of WFC3/NIR

- Various sources of constraints:
  - Measurements of same stars in using visible and IR detectors in similar (~z) bands
  - Extrapolating pure hydrogen WD models (over a large range in magnitude) to NIR and comparing to data
- They assume than CRNL is constant as a function of flux and expressed in mag/dex.
- The final figure is ~0.0075 mag/dex with a 10% uncertainty, that is 0.045 for 10^6 in flux.
- It seems to be applied to measured magnitudes rather than pixels (?!)

Internal report : https://ui.adsabs.harvard.edu/abs/2019wfc..rept....1R/

Other source of non-linearity: the brighter-fatter effect

- The brighter-fatter effect affects CCD images: bright stars appear bigger than faint stars, by a few % depending on sensors.
- It is due to stored charges distorting the electric field in the sensor and displacing pixel boundaries.
- The effect also affects NIR detectors (e.g. 2310.01920).
- In the analyses presented in R22, it may affect ratios of fluxes of bright Cepheids (MW) and distant ones, at the few % level.
- I have not seen it mentioned.

PSF photometry

$$\chi^2 = \sum_{\text{pixels}} (f \times \psi(x_p - x_0, y_p - y_0) - I_p - s)^2 \, w_p$$

flux

coordinates

Image value

sky

pixel weight

$$\hat{f} = \frac{\sum_{\text{pixels}} \psi_p (I_p - s) w_p}{\sum_{\text{pixels}} \psi_p^2 w_p}$$

If the weights w_p are the inverse of the variance of I_p, then the least-squares flux estimator has the smallest possible variance (Cramer-Rao inequality)

$$\hat{f} = \frac{\sum_{\text{pixels}} \psi_p (I_p - s) w_p}{\sum_{\text{pixels}} \psi_p^2 w_p}$$

$w_p \to s^{-1} \equiv w$ **low** **high** $w_p \to (f\psi_p)^{-1}$

$$\hat{f} = \frac{\sum_{\text{pixels}} \psi_p (I_p - s)}{\sum_{\text{pixels}} \psi_p^2}$$

$$\hat{f} = \sum_{\text{pixels}} (I_p - s)$$

For this science (and many others) we are interested in accurate flux ratios
The simplest way for that is to impose the low-flux weighting scheme at all fluxes: then even an approximate PSF delivers correct flux ratios.
R22 relies on DAOphot which does **not** use this weighting scheme (at least by default).

PSF photometry: the position problem (1)

All (recent) SH0ES analyses rely on NIR "forced photometry", i.e. PSF photometry at the cepheid position measured in visible bands.

The flux is underestimated :
(this is for a Gaussian PSF, it is usually Somehow larger than that for actual PSFs)

$$\frac{\delta f}{f} = -\left[\frac{\delta_x}{\sigma_{PSF}}\right]^2$$

In H band $\sigma_{PSF} \sim 65$ mas , ~32 mas in I band.

The position is measure in V and I band and transferred to H band (the transfer has an accuracy of ~ 2 mas → no serious effect)

PSF photometry: the position problem (2)

- For cepheids in crowded environments, the position is shifted by the unresolved stars (in the V and I images), beyond the position uncertainty expected from shot noise.
- The fake star injection algorithm does not seem to go through a position measurement step, in order to account for shifted positions.
- I have not seen cepheid positions addressed in the papers.

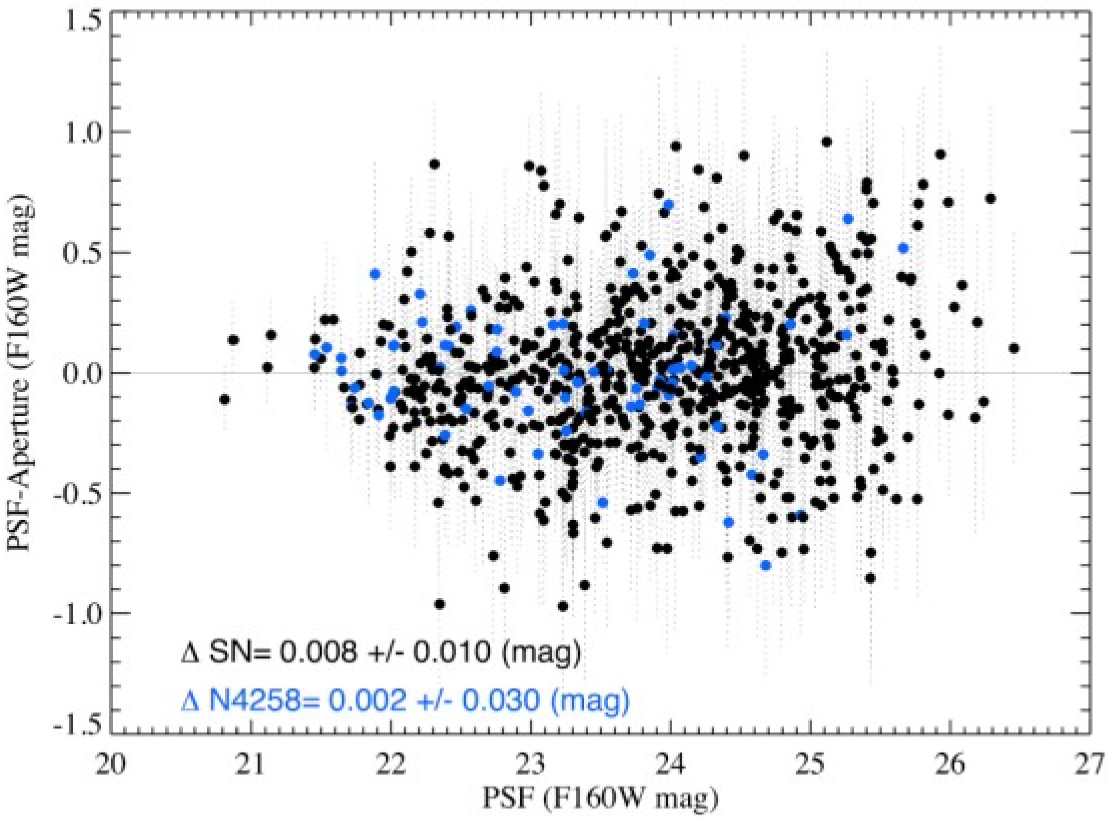
Practical test of R22 PSF photometry

Aperture flux is determined in a very small aperture r = 0.11” ~ 1.5 FWHM
Background is the local mean In an annulus.

Aperture correction is computed from the PSF model.

Comments:

- Given the small aperture, not sure it is sensitive to position error (due to crowding)
- The scatter is huge, for estimates from the same pixels.



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Photometry of Cepheids : outlier rejection

From 2007.10716, discussing R16

Residuals of the PL fit of Cepheids from R11. Blue points are rejected outliers.

There are a lot of poor measurements whose average is should be accurate to ~0.04

G . Efstathiou (2007.10716) questions if the outlier rejection allows the required accuracy.

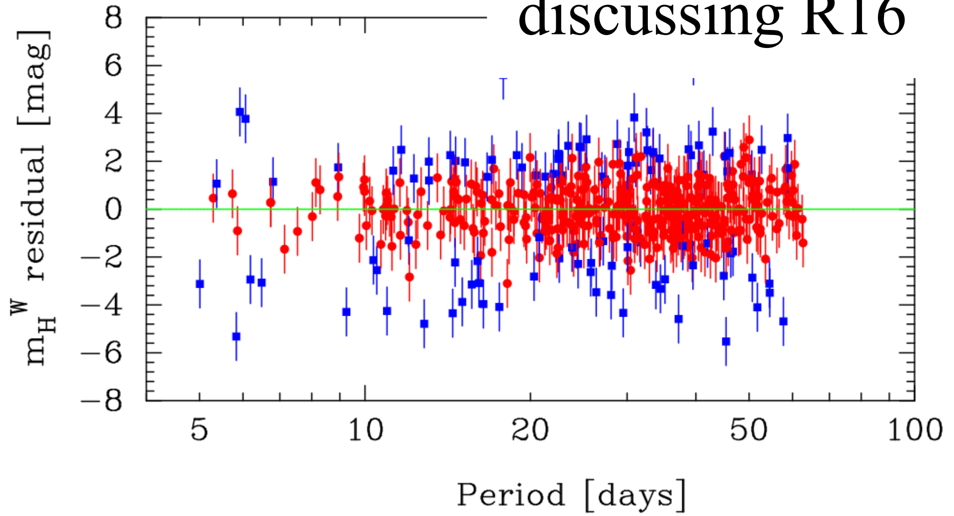


Figure 2.1: R11 PL magnitude residuals relative to the global fit 5 of Table 2 in E14. Red points show residuals for Cepheids that are accepted by R11 while blue points are rejected by R11.

Since then, a color cut has been applied to reject interlopers, but there are still many bad measurements, rejected on such plots

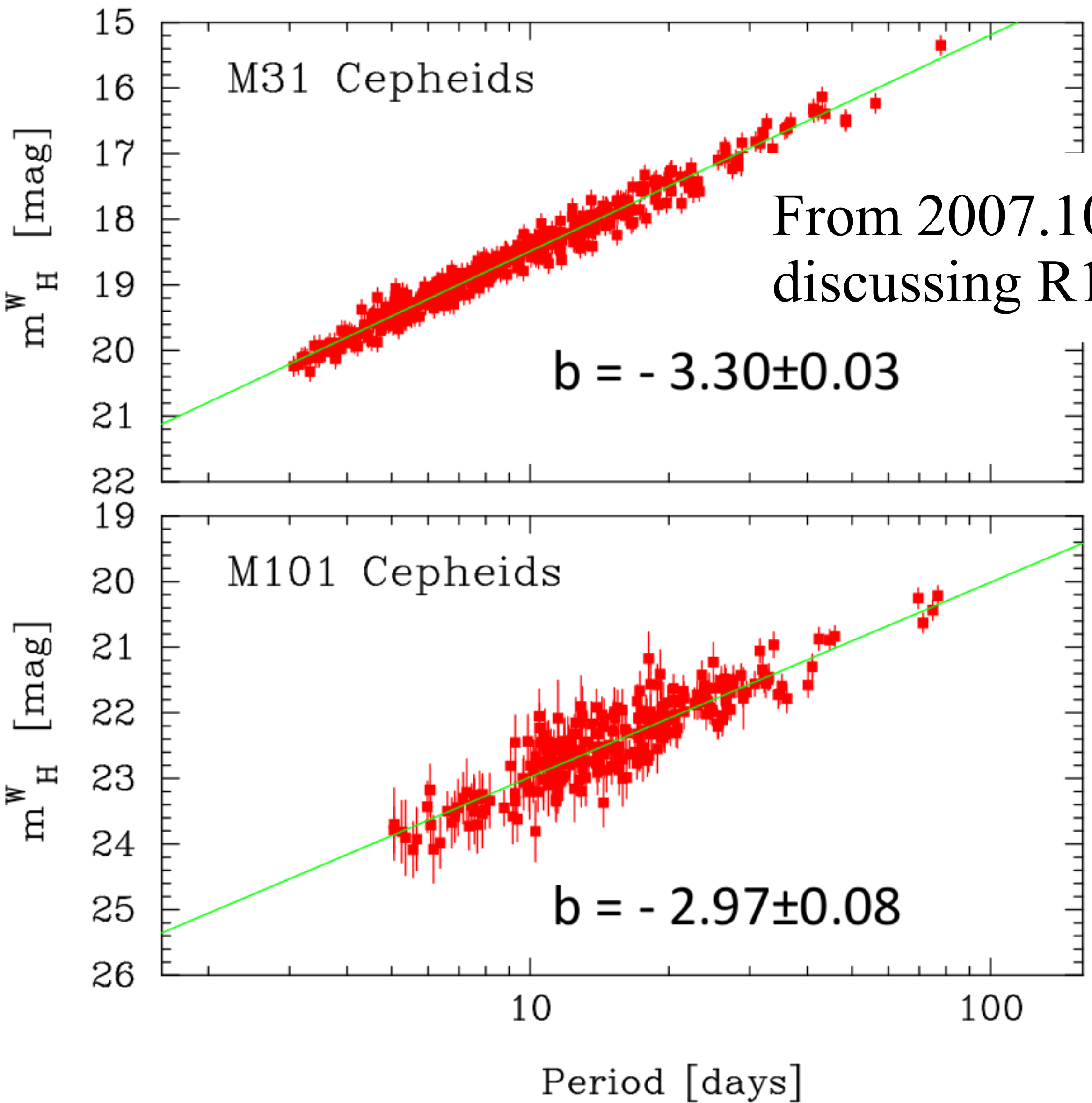
Is the PL slope universal?

The slopes are not compatible (>3σ)

Imposing b=-3.3 lowers H_0 by 1.7

It is unlikely that this reflects that the slope depends on metallicity

Non-linearity of photometry ?



From 2007.10716, discussing R16

Summary: photometry of cepheids, potential issues

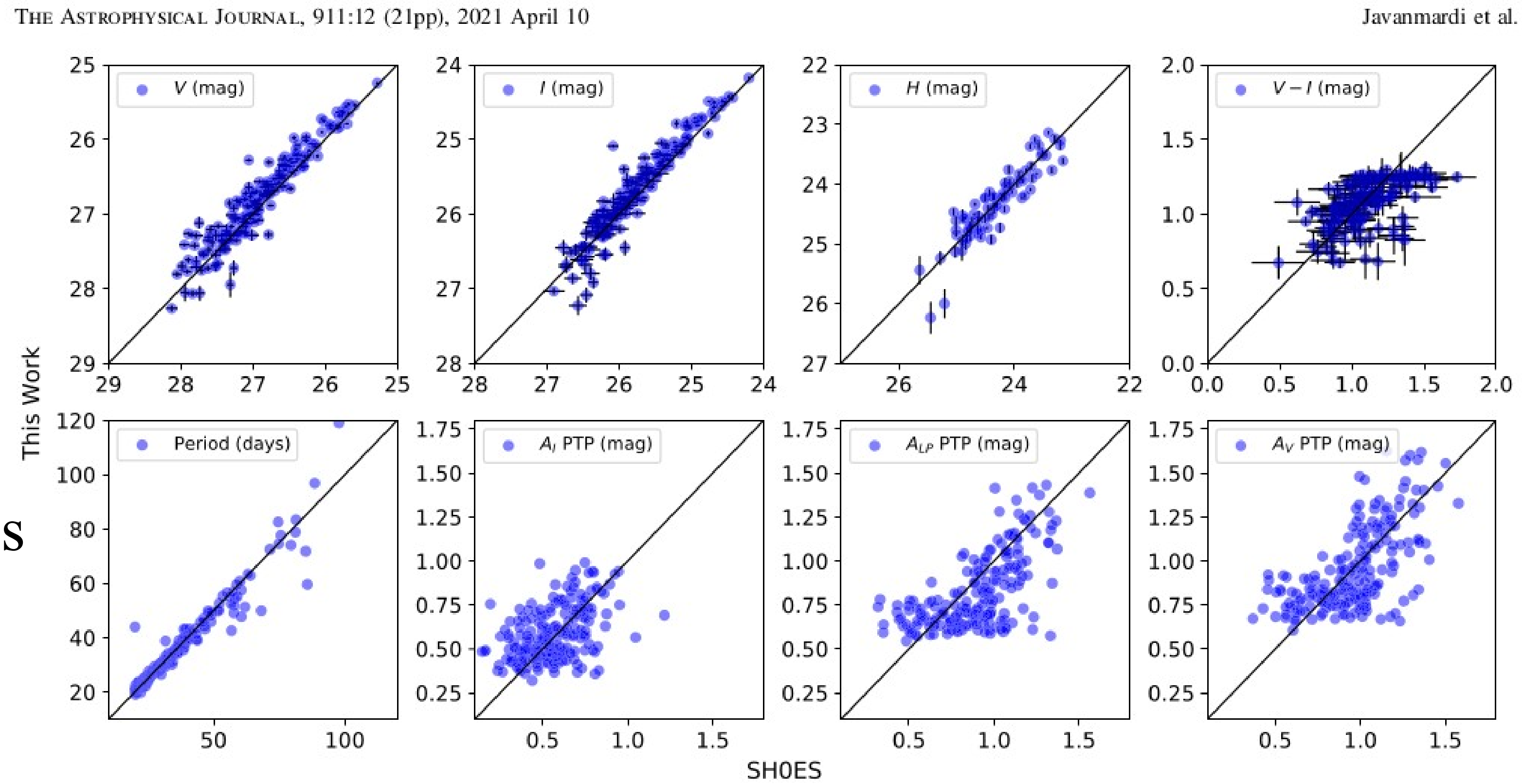
- Average of numerous poor measurements:
  - Average of fluxes or distance moduli
  - Accuracy of background subtraction might depend on flux
  - Outlier rejection
  - Position variance (and associated flux bias) certainly depends on flux.
- PSF photometry of bright vs faint objects: brighter-fatter and accuracy of the PSF model.
- Linearity of the device.

There are indeed brave people that redid the photometry for N5584

Javanmardi+ 2021

The scatter seems large given that it is the same data

Uncertainty on distance moduli is 0.045 and agrees with SH0ES



P. Astier

Supernovae Ia (1)

- The 42 “calibrators” happen in galaxies hosting Cepheids, which eliminates SNe Ia in late type hosts.
- We know that the intrinsic brightness of SNe Ia depends on the host galaxy type, presumably of the stellar age or the star formation rate.
- In cosmological analyses, this is handled through the “mass step”, an offset applied to all supernovae of a given host type (indexed originally by host stellar mass (e.g. Sullivan+ 2010))
- Rather than correcting distances of Hubble diagram events, R22 selects those in galaxies that may host Cepheids.

Supernovae Ia (2)

- Selecting the same SN demography seems totally reasonable.
- There were tensed exchanges on this subject because initially, the SH0ES team argued that they did not see any effect related to SFR, at variance with all other actors in the field.
- Assuming (very unlikely) that R22 misses the whole “mass step effect”, the average brightness correction is at most 0.05 mag
- Regarding more general SN selection, the used cuts are at about 2 sigma in the standard variables x1 and c:
  - $|x1|<2$, $|c|<0.2$
- Replicating the analysis with NIR SN data (less events…) gives the same results 72.3 +/- 2 (Galbany+ 23, 2308.01875)

Supernovae Ia (3)

- I my opinion, there is no significant gain to expect at collecting new SN samples for improving SH0ES.
- It would be better to collect all events (calibrators and HD) with the same instrument, but it is very unlikely that some part of the current data is grossly wrong.
- Switching from Cepheids/HST to TRGB/JWST, the rate of SN calibrators increases from ~1/y to more than 5. This is the only practical way to replace/enlarge the calibrator sample rapidly, if there is a good reason to do that.
- ZTF can do (and has partially done) the SN part, but the JWST proposals did not fare well (?!).

The result (R22)

$$H_0 = 73.04 \pm 1.01 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

The difference with 67 km s^{-1} Mpc^{-1} is 0.185 mag.

The uncertainty from the fit, accounts for: uncertainty of the anchors
shot noise, dispersion of Cepheids and SNe, uncertainties on standardizations,
There is not much room for improvement with 42 calibrator SNe

Is there any point at reducing this formal uncertainty ?
Introducing more redundancy is the way to go.

R22: systematics/ variants

- Systematics are evaluated by studying "variants", which consist in changing some point of the analysis (but one at a time):
  - Cepheid clipping, selecting anchors, color correction, PL relation M31 handling, Metallicity handling, SNe handling,…
- The rms of H_0 over variants is 0.3
- R22 add 0.3 to 1.01 (in quadrature) and find 1.04. I find 1.05.
- I don't understand why the **rms** over variants is a measure of systematic uncertainty: the potential sources seem to add up, because all are potentially active.
- If adding up the changes measured on variants, the uncertainty becomes ~1.4 .

Internal consistency: are anchors compatible ? (1)

- As shown before, M31, introduced to nail the cepheid PL slope has a different slope than the other hosts.
- One key aspect to reduce uncertainty is to average three anchors, but the average only makes sense if they are compatible
- G. Efstathiou claims that it is not the case: LMC and N4258 both host cepheids and both have geometrical distances. This allows a null test, failed at >3σ :

$$\Delta\mu_{\rm N4258} = (\mu_{\rm N4258} - \mu^{P}_{\rm N4258}) = 0.177 \pm 0.051,$$

2007.10716

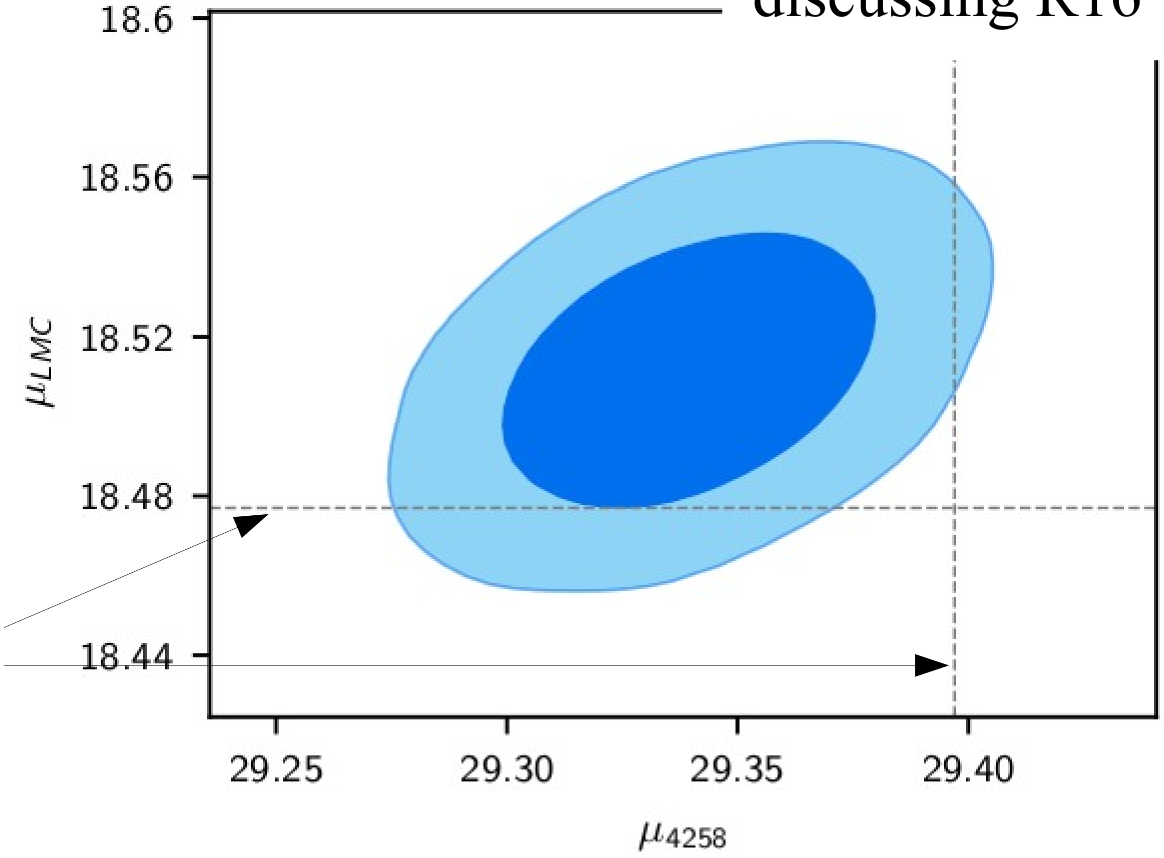
- In 2007.10716, SH0ES replies that the residual is closer to 2 σ (0.1 mag), but they seemingly had not carried out the test.

LMC and NGC4258

From 2007.10716, discussing R16

The outcome of the full fit, regarding a posteriori distance moduli to the LMC and N4258

A priori constraints



Internal consistency: are anchors compatible ? (2)

- So, two geometrical anchors are questionable
- The third one, the Milky Way is also questionable (2309.05618, 5.2)
  - Quality of "zero point" of Gaia parallaxes (which dominate the sample)
  - Position-dependent offsets, "color terms"
  - Linearity of cepheid photometry
- It is clear that more anchors would be welcome.
- It is not clear if Gaia can deliver a (statistical) parallax of the LMC, because of "zero point" parallax uncertainty.

Gravitational waves ?

- There is a single event which has both a "gravitational brightness" and a redshift: a binary neutron star event : GW170817
- The redshift was obtained from a spectrum of the electromagnetic counterpart.
- This delivers H_0 because the "intrinsic luminosity" can be derived from the waveform (these are calibratable candles), using GR
- H0 = 70 +12 – 8 km/s/Mpc
- There is just no ladder at all in this approach: great!
- Why do we still bother with cepheids ? These events are very scarce (typically 1/y nowadays) and no other optical counterpart has been detected since, among ~ 100 coalescence events.

Comments/conclusions (1)

- There have been other analyses of the SH0ES data, that usually find the same result (see references in R22).
- Reproducing the photometry of cepheids is difficult and tedious. I am not sure it is useless, given the scatter in the Javanmardi+ (2021) comparison. Instrumental aspects may deserve a critical look. Brighter-fatter was not corrected, non-linearity may be trickier than a power law.
- There are potentially serious issues when comparing (very) bright and (very) faint cepheids.
- The quality of anchors is arguable: they could be more consistent and the published uncertainties are propagated as such, while they are likely optimistic: uncertainties are uncertain.

Summary/conclusions(2)

- The handling of systematics in R22 (and before) is arguable, and mostly does not address many photometry potential issues. The analysis relies on averaging (how?) a lot of (very) poor measurements, a bad situation in general.
- I think we need more redundancy, as opposed to more cepheids or new SNe in the second rung.
- TRGB (in the SN hosts that already have cepheid data) is probably the natural next step, underway in fact.
- HST/JWST is the bottleneck for this science. The standard time allocation scheme is probably not the best way to cook up an observing program.

If I had to bet (I wish I didn't)

- I cannot imagine how the SN part of the analysis could be wrong. I don't know about CSP from Freedman et al.
- I have suspicions about the photometry of cepheids, but I doubt that it could reconcile with Planck. But it is worth investigating, even if crowding seems settled.
- If I had to bet, I would first question the anchors.

END

PSF photometry: the position problem (2)

How large is the variance of the position:

$$\frac{\delta f}{f} = -\left[\frac{\delta x}{\sigma_{PSF}}\right]^2$$

Shot noise: $\sim\sigma_{PSF,I}/(S/N)_I$

$\rightarrow$ negligible if $(S/N)_I>6$

$$\frac{\delta f_H}{f_H} = -\left[\frac{\delta_{x,I}}{\sigma_{PSF,H}}\right]^2 \simeq 0.25(S/N)_I^{-2}$$

Confusion/structured background : some (flux-dependent) fraction of $\sigma_{PSF,I}$, but ½ is easily conceivable since background corrections are commonly 0.4 mag

This would give a bias > 0.1 mag.

I don't think that measuring fake stars addresses this potential issue.