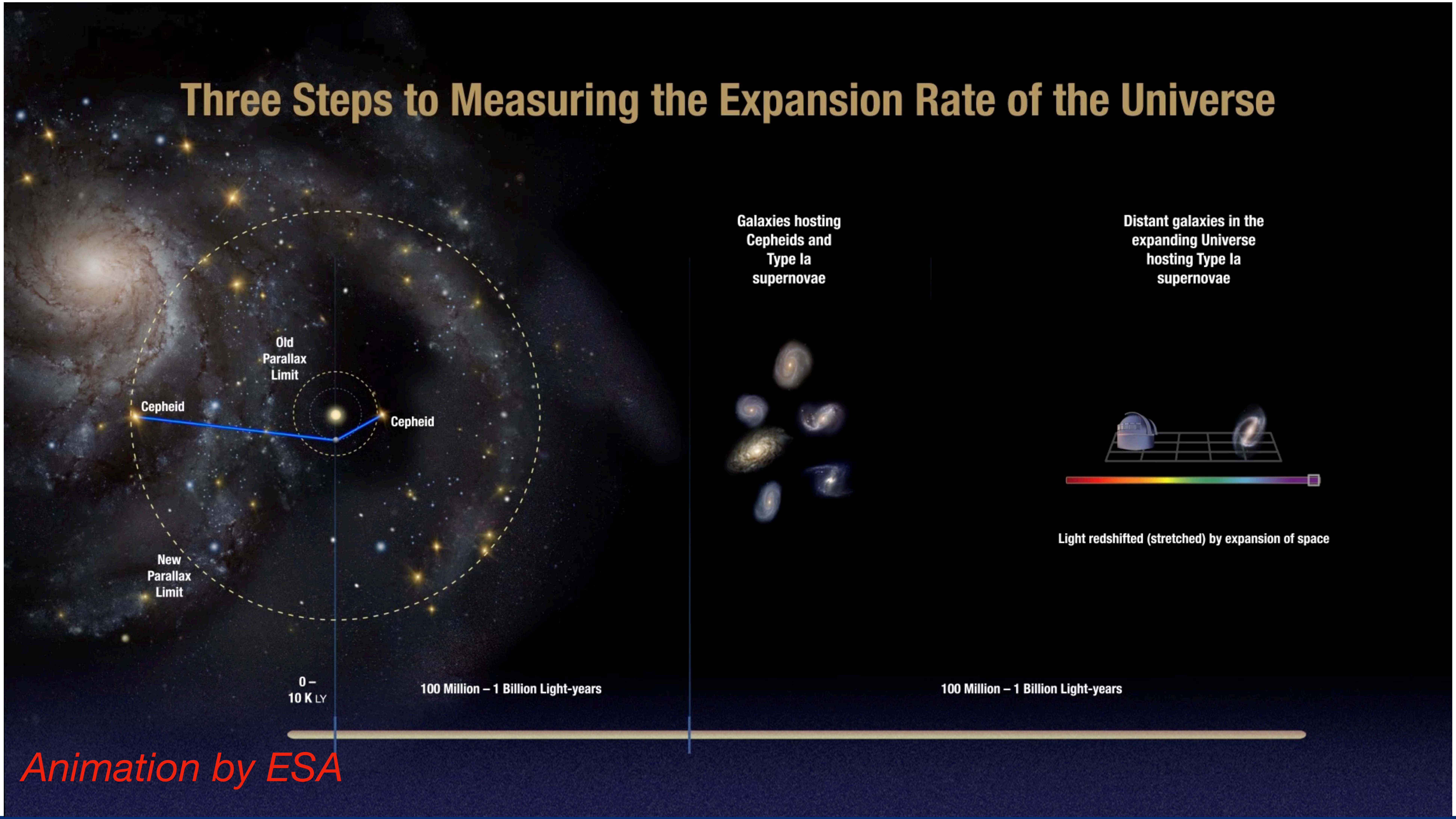
Two out of Three Ain’t Bad!

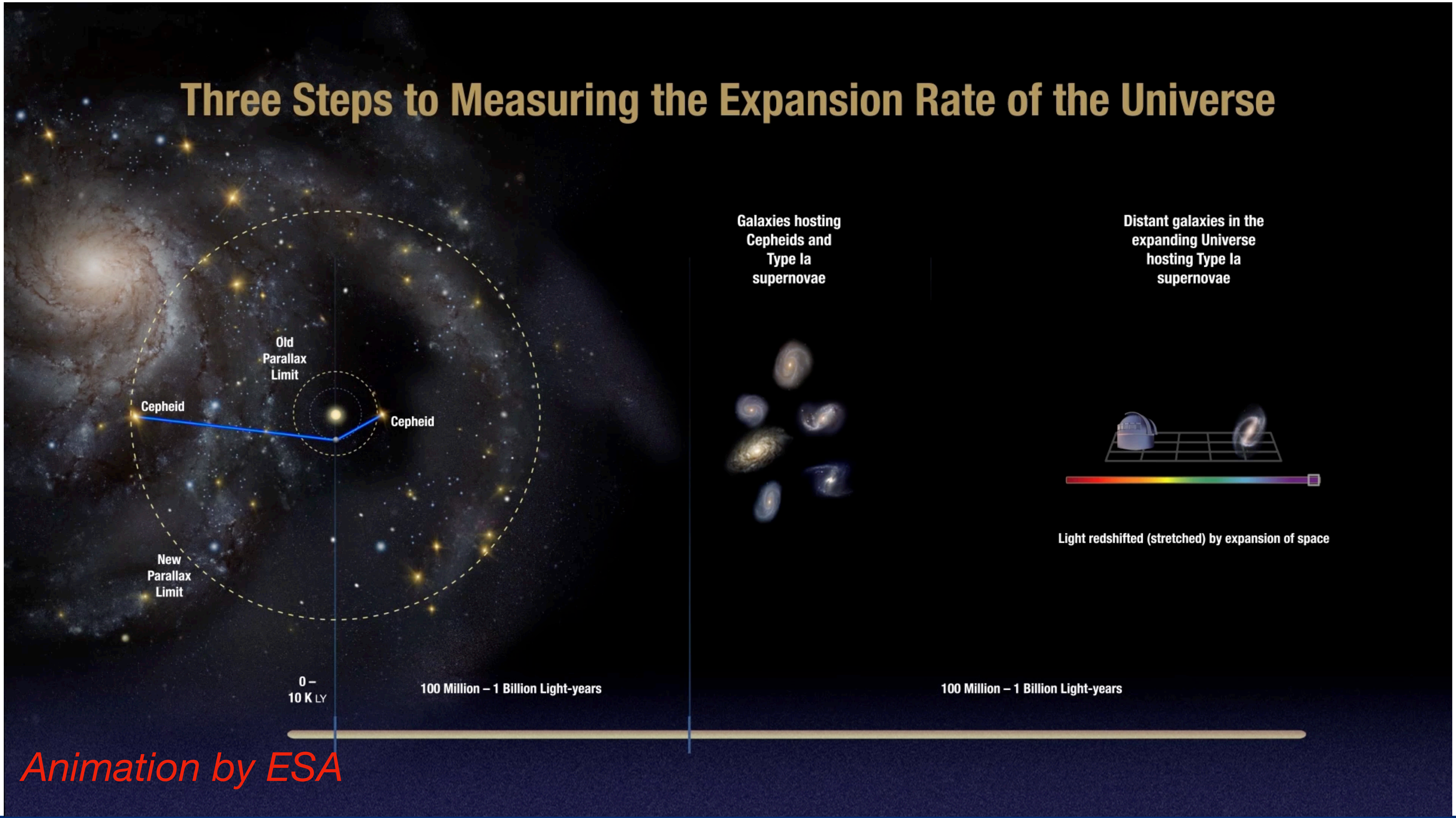
W. D’Arcy Kenworthy
with the SH0ES collaboration
DOI: 10.3847/1538-4357/ac80bd
arxiv: 2204.10886

Distance Ladder



Animation by ESA

Distance Ladder



Measurement of H_0

- Distance ladder measurement of H_0 in the local universe
- $H_0 = 73.2 \pm 1.0$ km/s/Mpc
- Murakami *et al.* 2022 (arXiv:2306.00070) improves this to $H_0 = 73.3 \pm .9$ km/s/Mpc

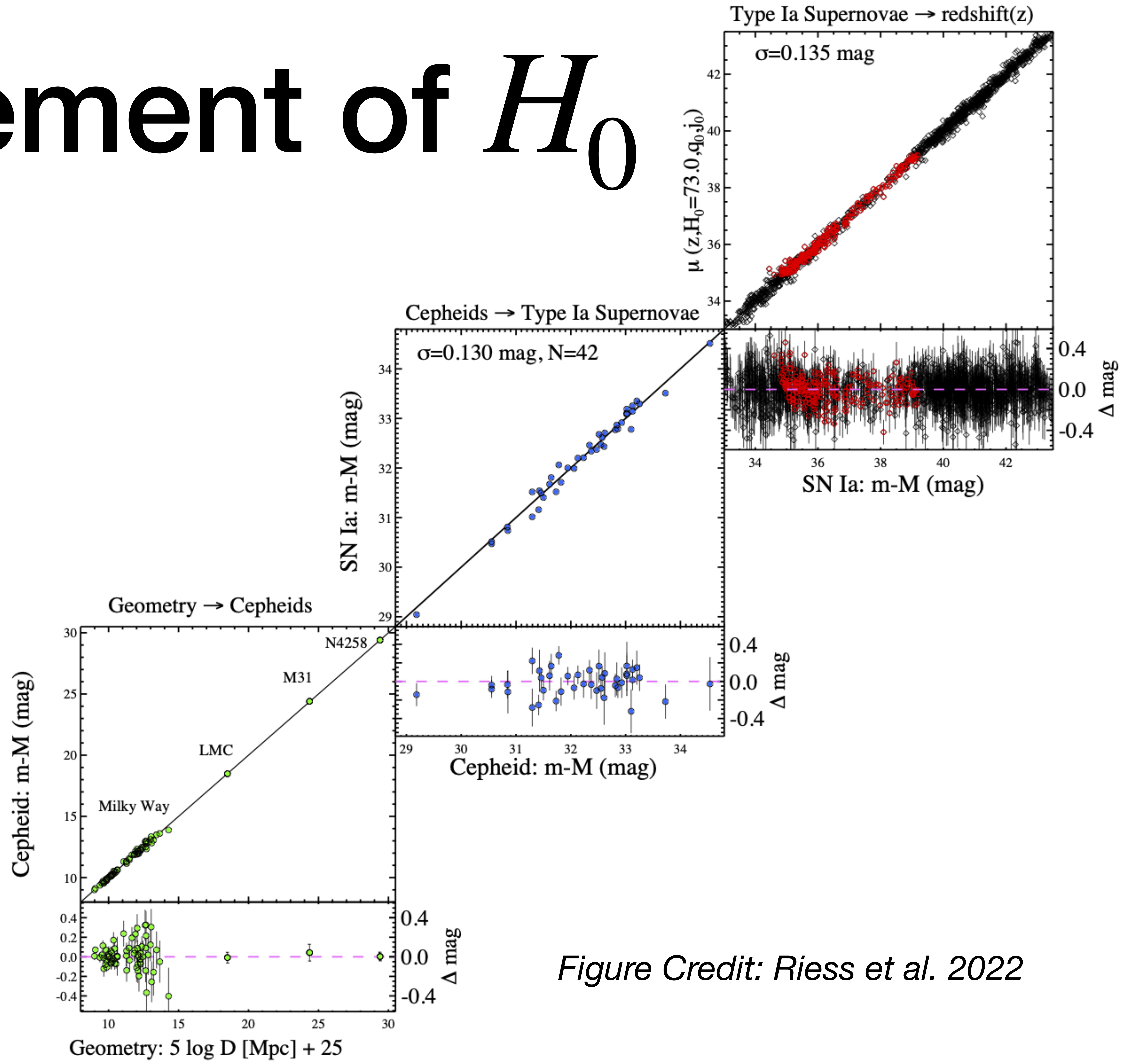


Figure Credit: Riess et al. 2022

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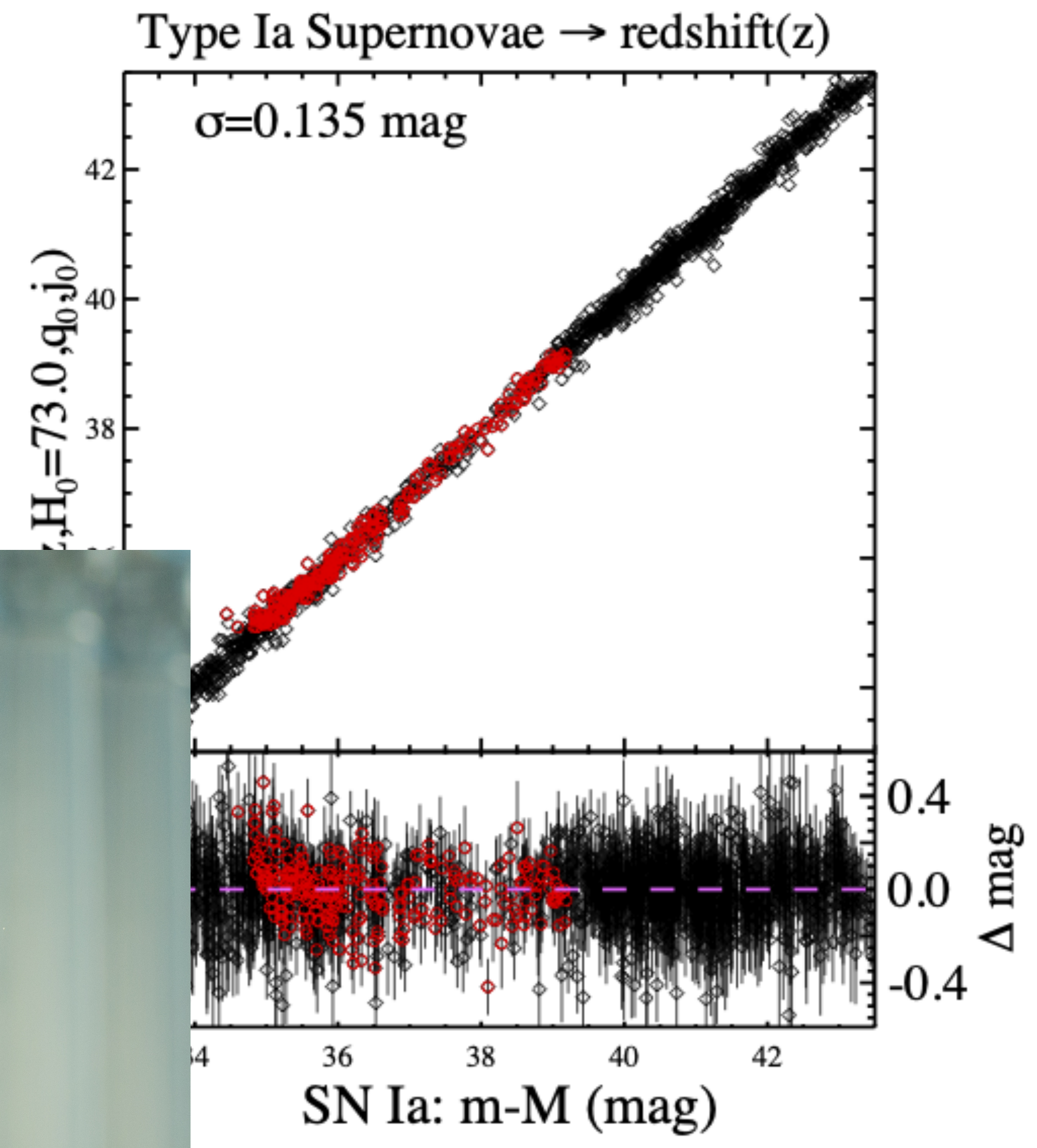

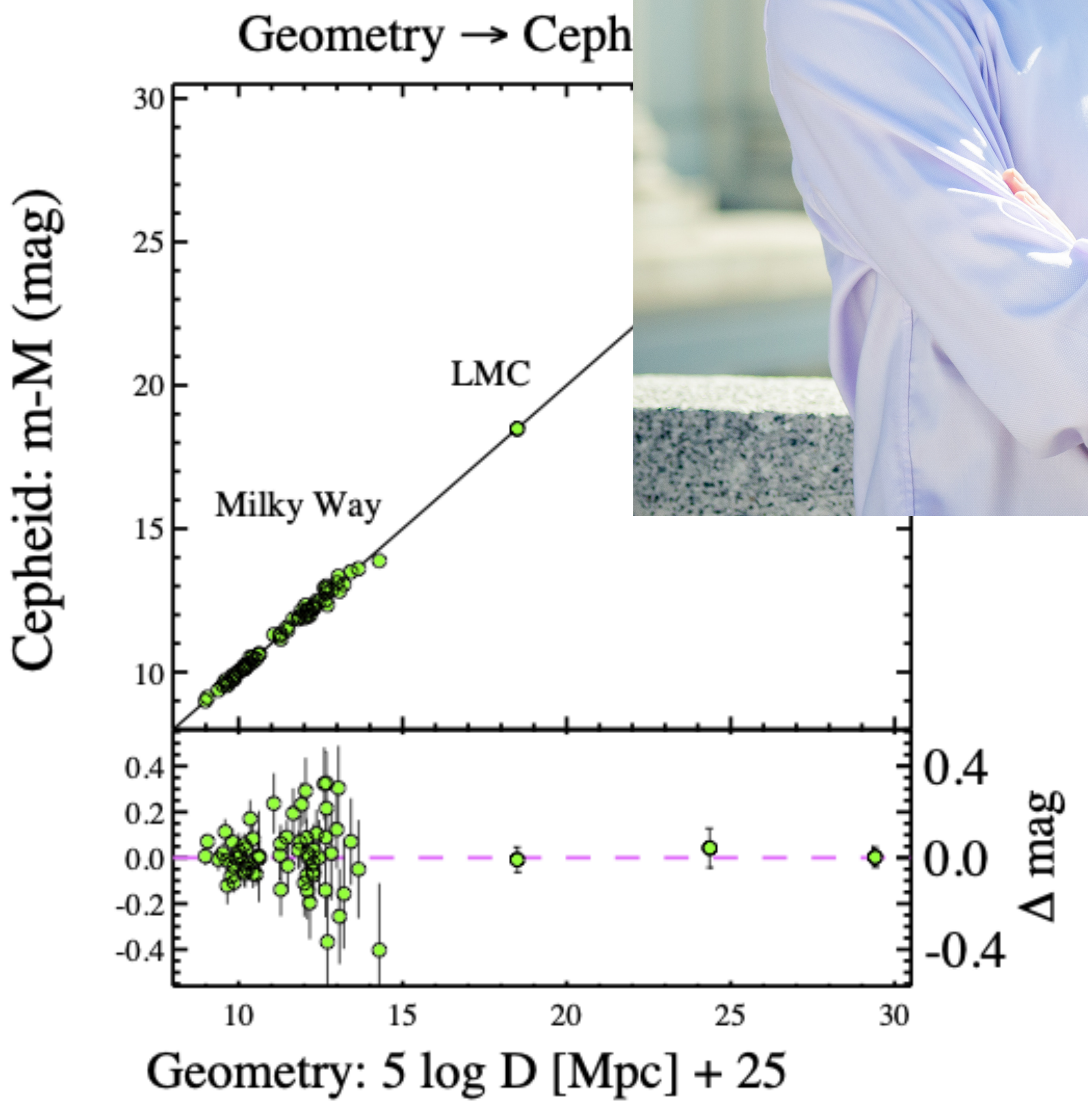

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Hubble Tension

- Distance ladder measurement of H_0 in the local universe
- $H_0 = 73.3 \pm .9$ km/s/Mpc
- Predictions from early universe measurements by Planck
- $H_0 = 67.4 \pm 0.5$ km/s/Mpc
- Disagreement at 5σ
- Many other measurements

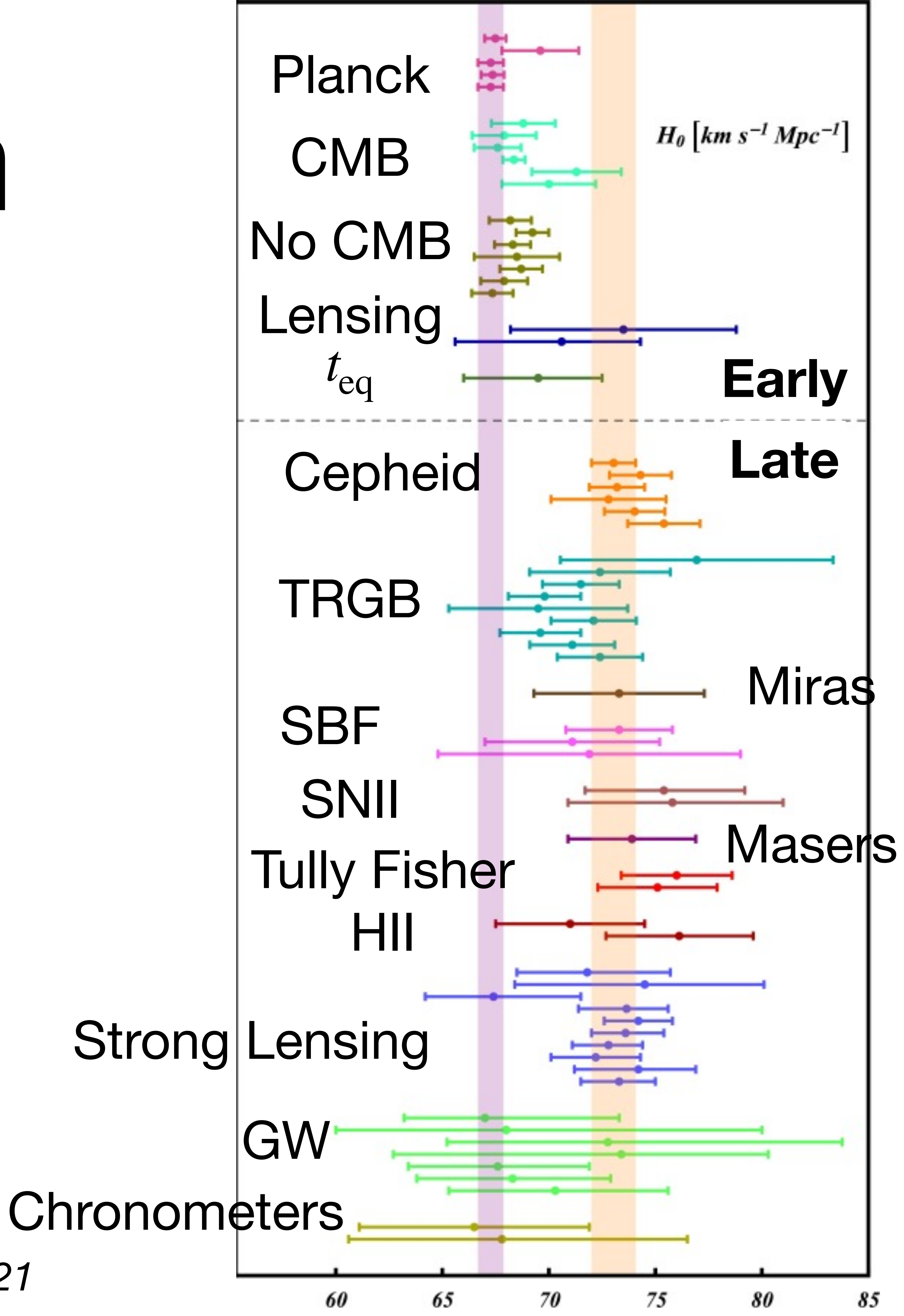


Figure Credit: di Valentino et al. 2021

Cepheid Variables

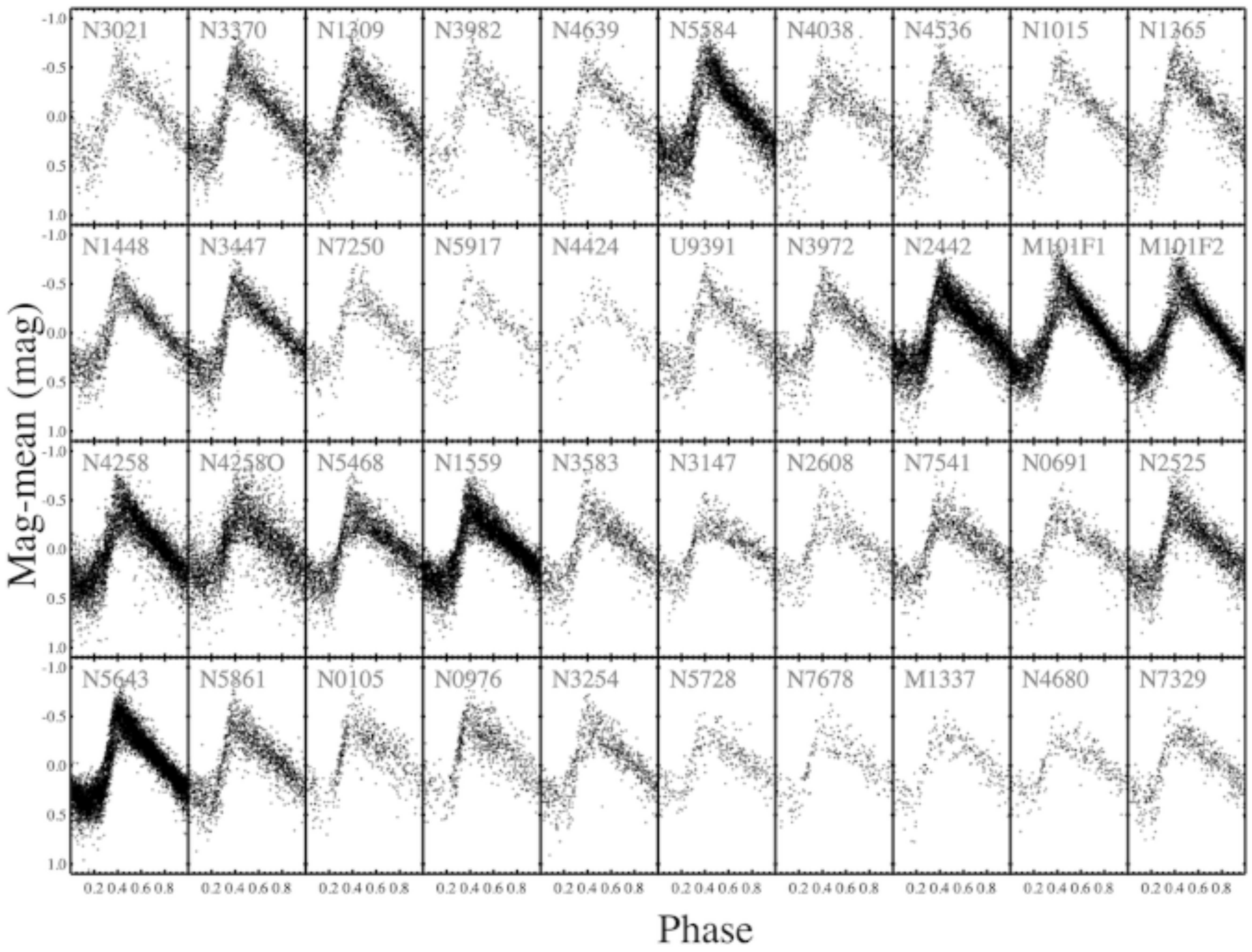
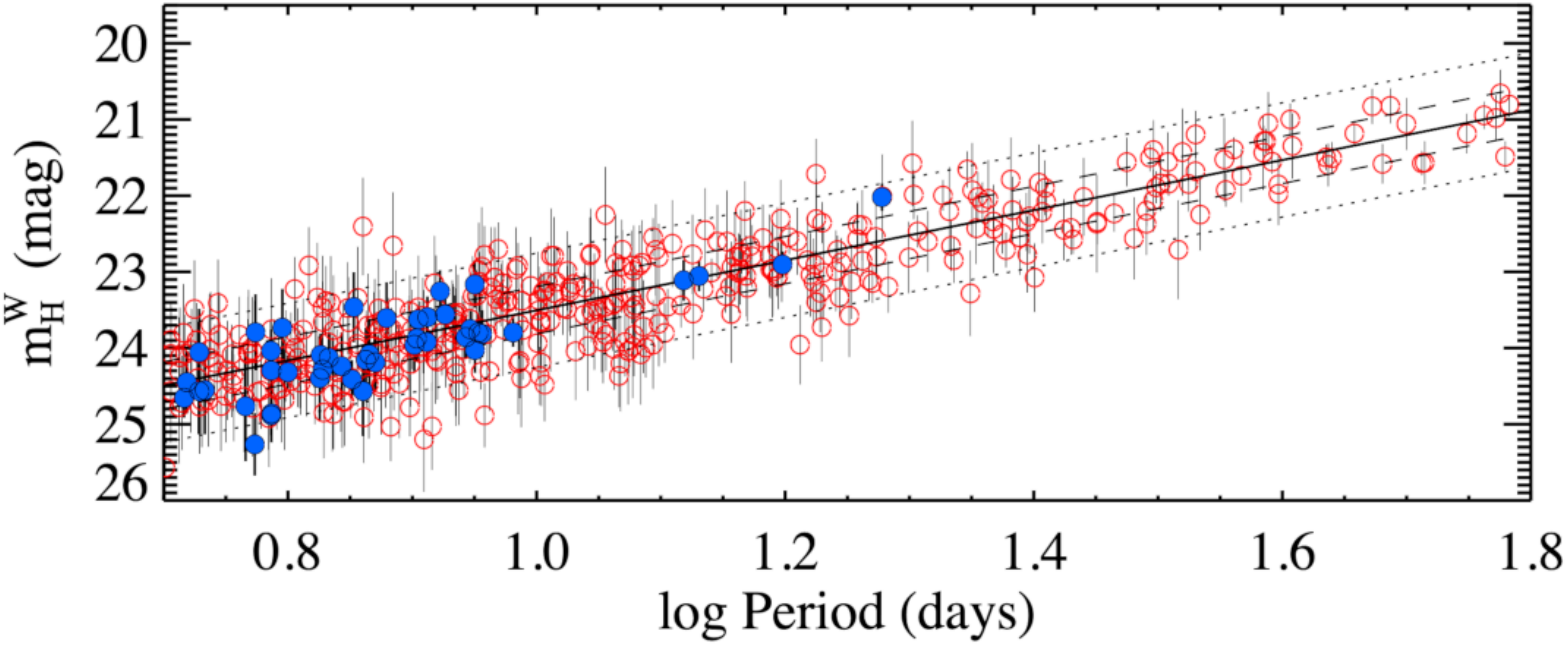


Figure Credit: Riess 2021

Cepheid PLR



Credit: Riess 2021

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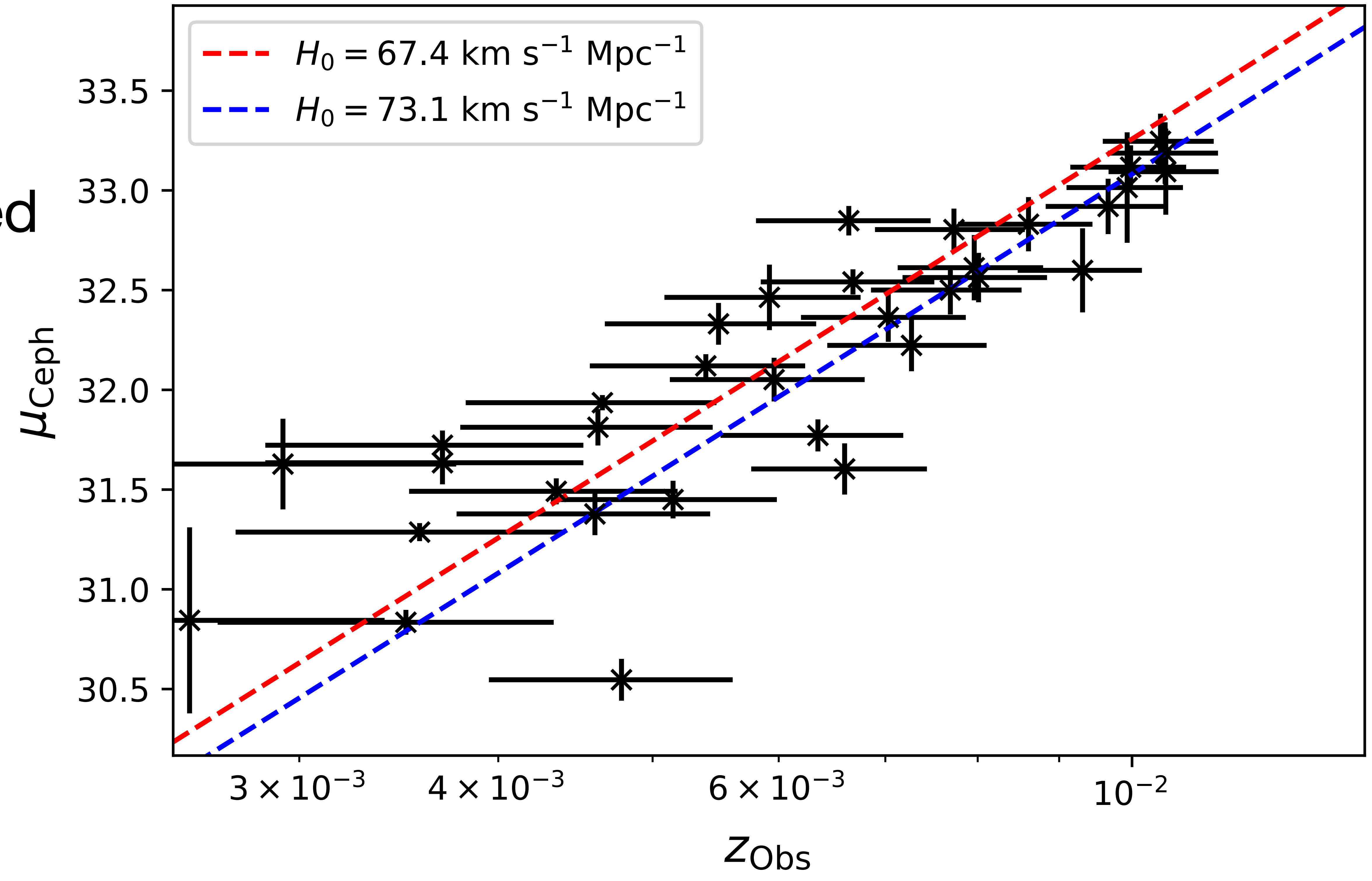
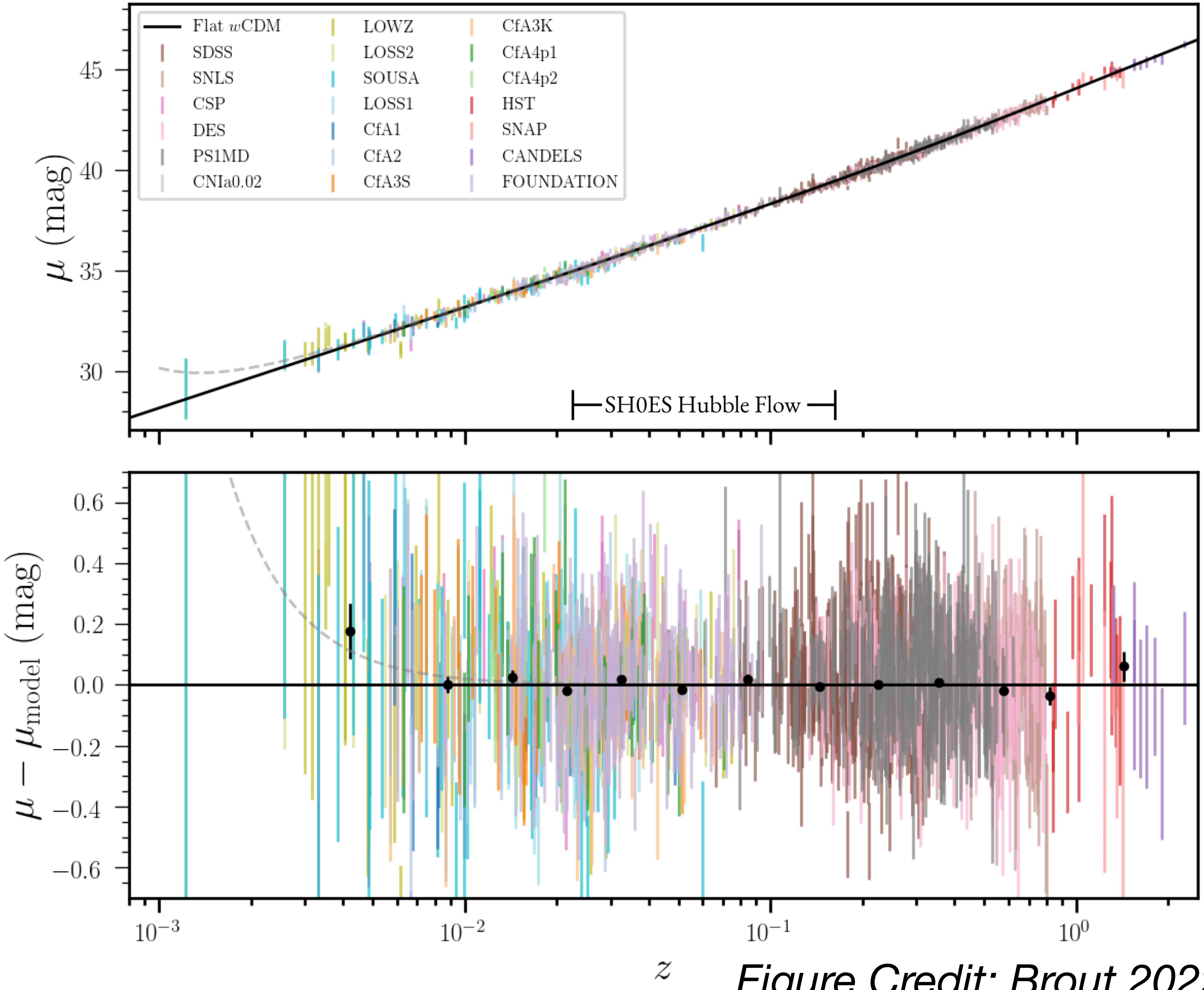
Two Rung Distance Ladder

- SN Ia are great, but each rung must be checked
- Goal: SNe Ia independent measurement of H0 from SH0ES Cepheid distances
- Obstacle: median redshift of sample is $z \sim 0.006$, peculiar velocities are ~20% of the signal, correlated across the sky



Tw... der



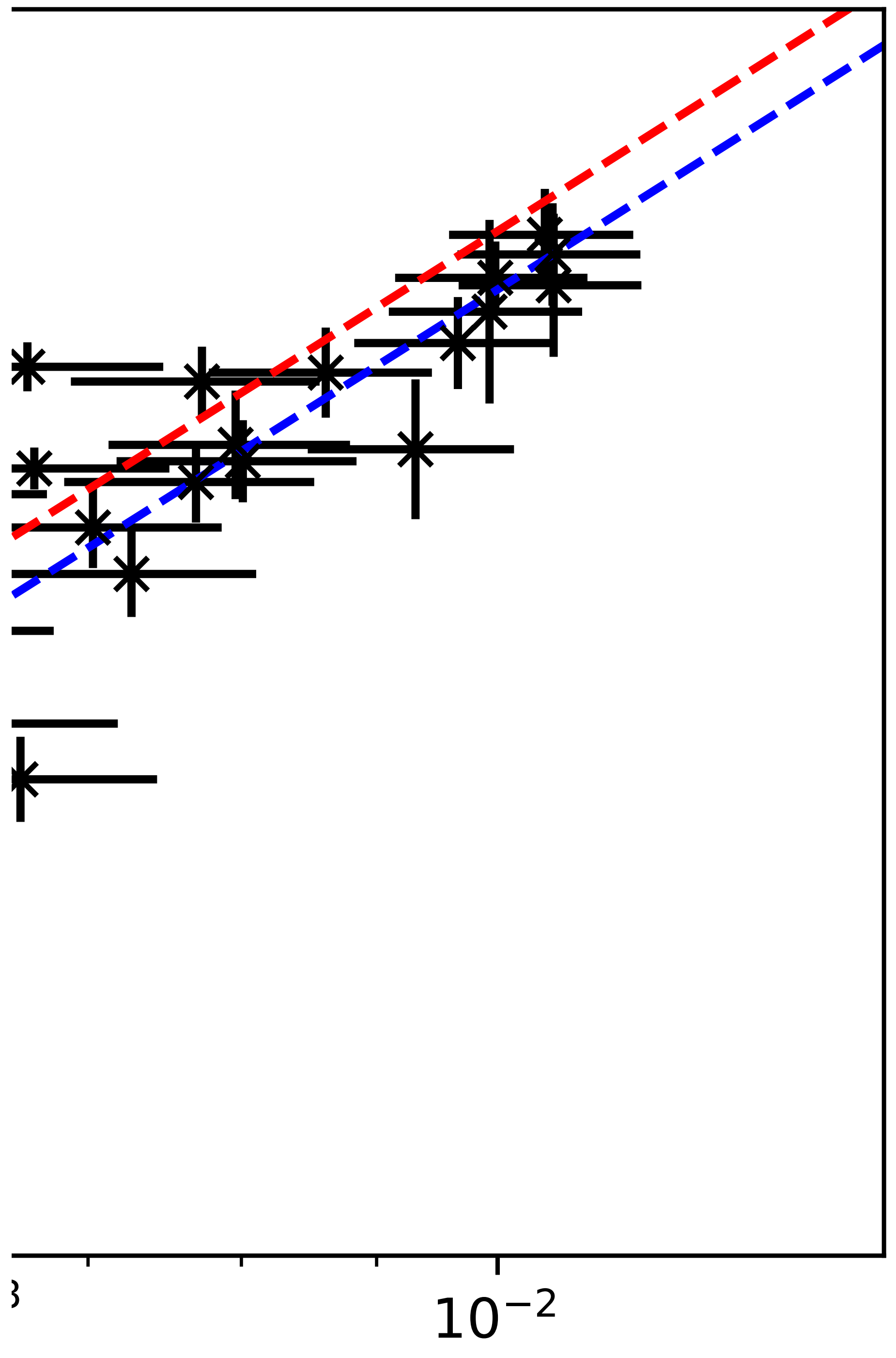


Figure Credit: Brout 2022

- SN Ia are g...
- Goal: SNe I... from SH0ES...
- Obstacle: n... $z \sim 0.006$, ... signal, corr...

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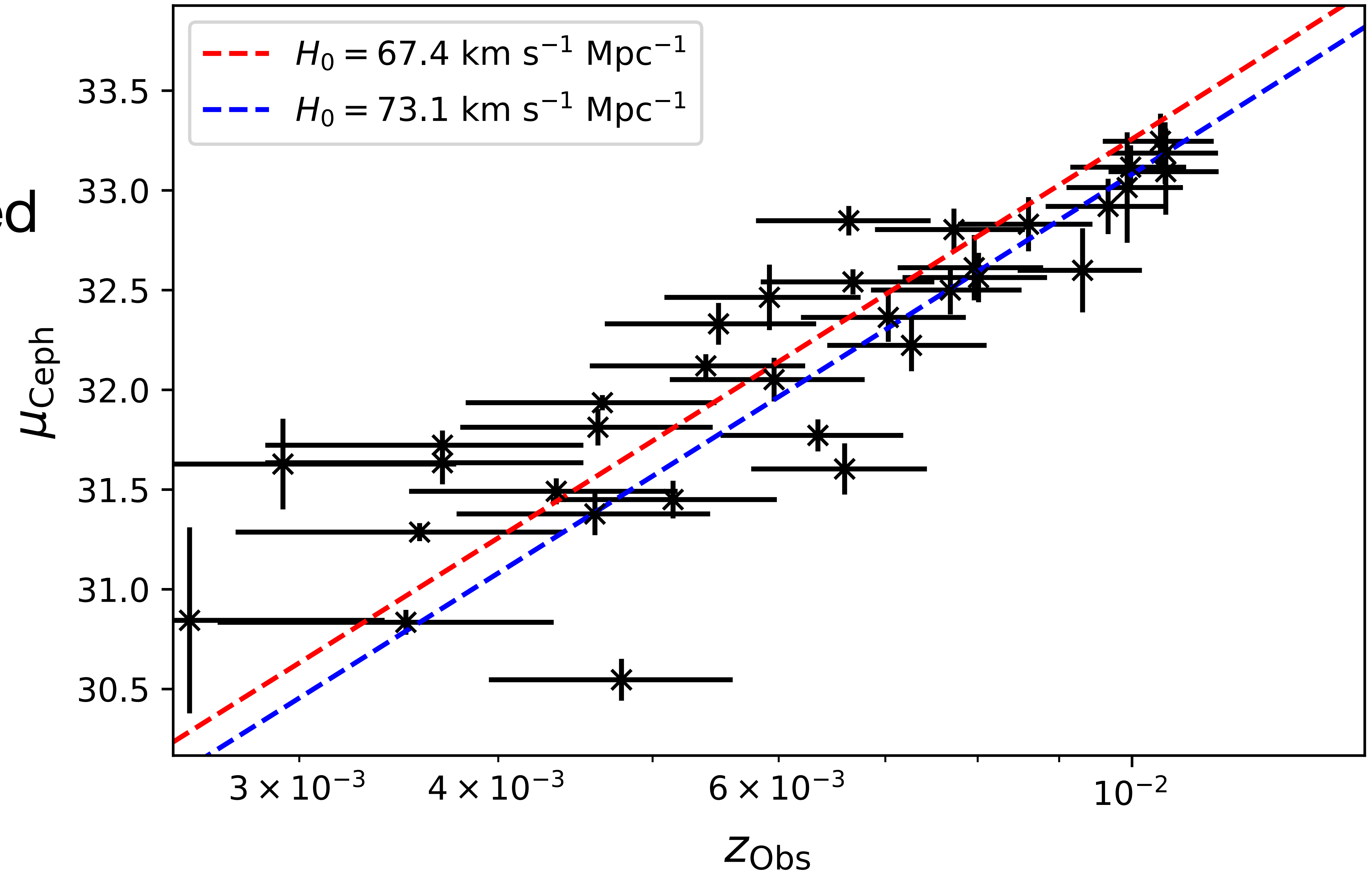

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Simulations were performed at the National Center for Supercomputer Applications
by Andrey Kravtsov (The University of Chicago) and Anatoly Klypin (New Mexico State University).
Visualizations by Andrey Kravtsov.

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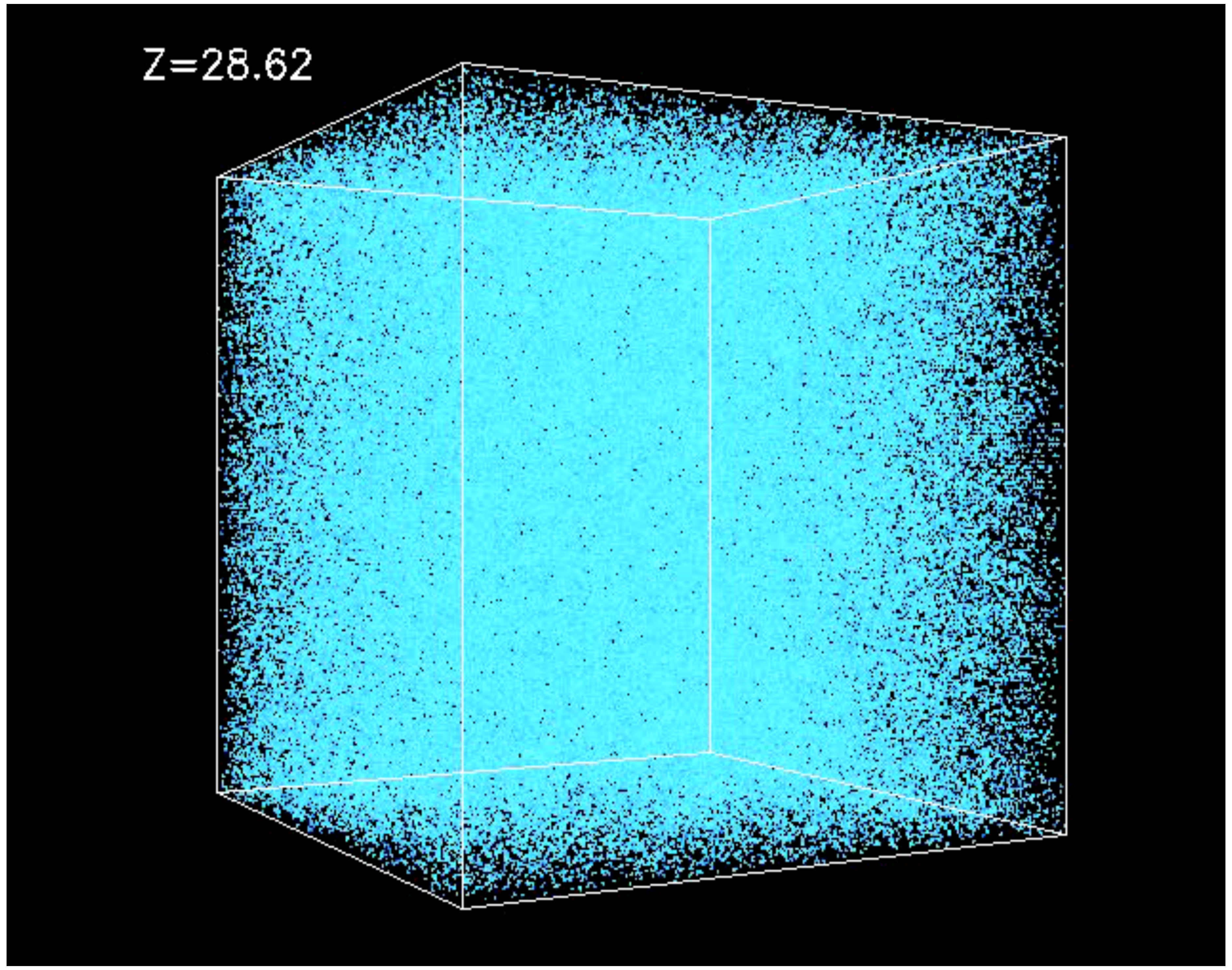

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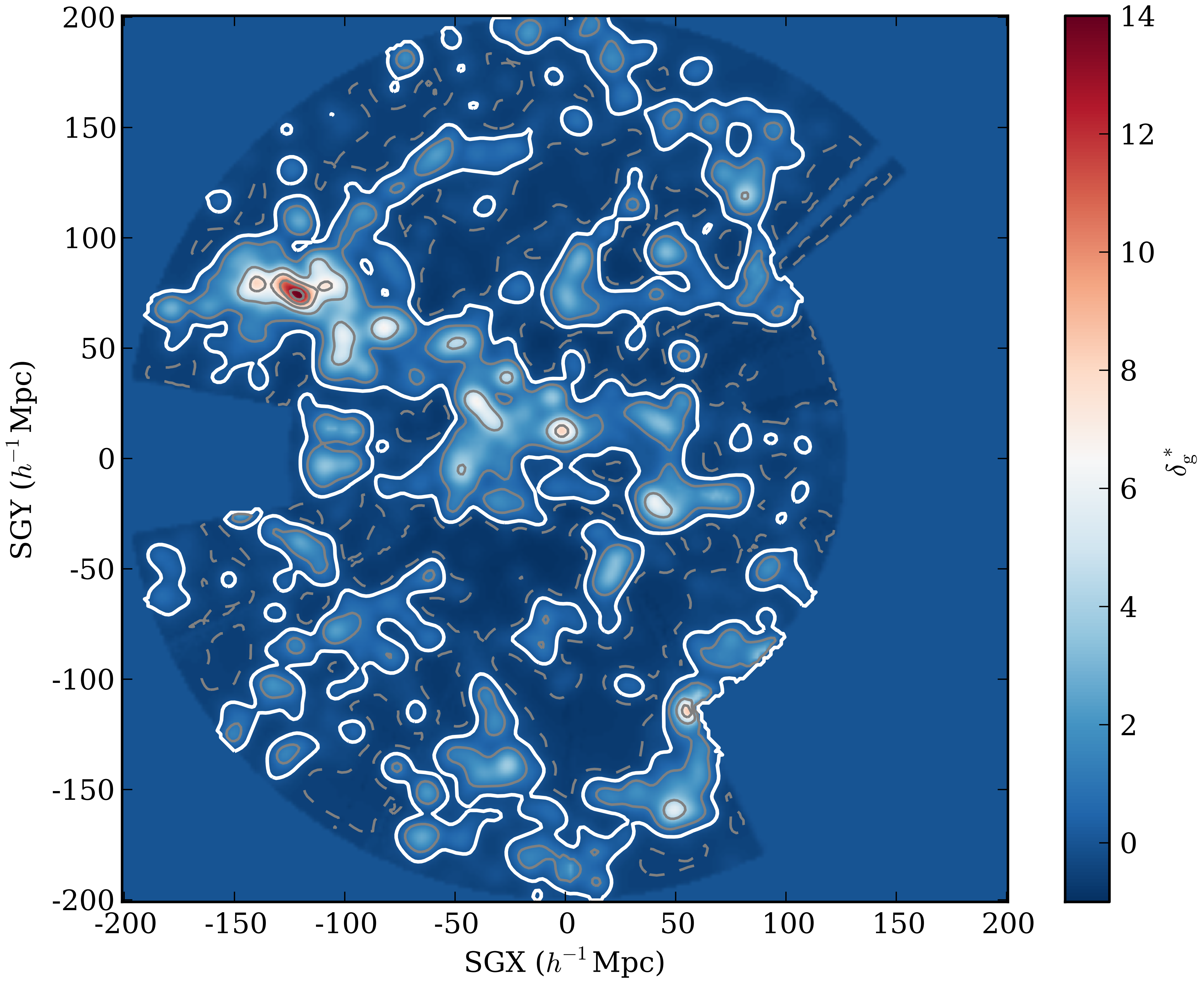
Peculiar Velocity Reconstructions

- Solution: Peculiar Velocity Reconstructions
- Galaxy redshift surveys
- Two of interest
  - Carrick *et al.* 2015
  - Lilow and Nusser 2021
- Uncertainties unclear
- Correlations remain



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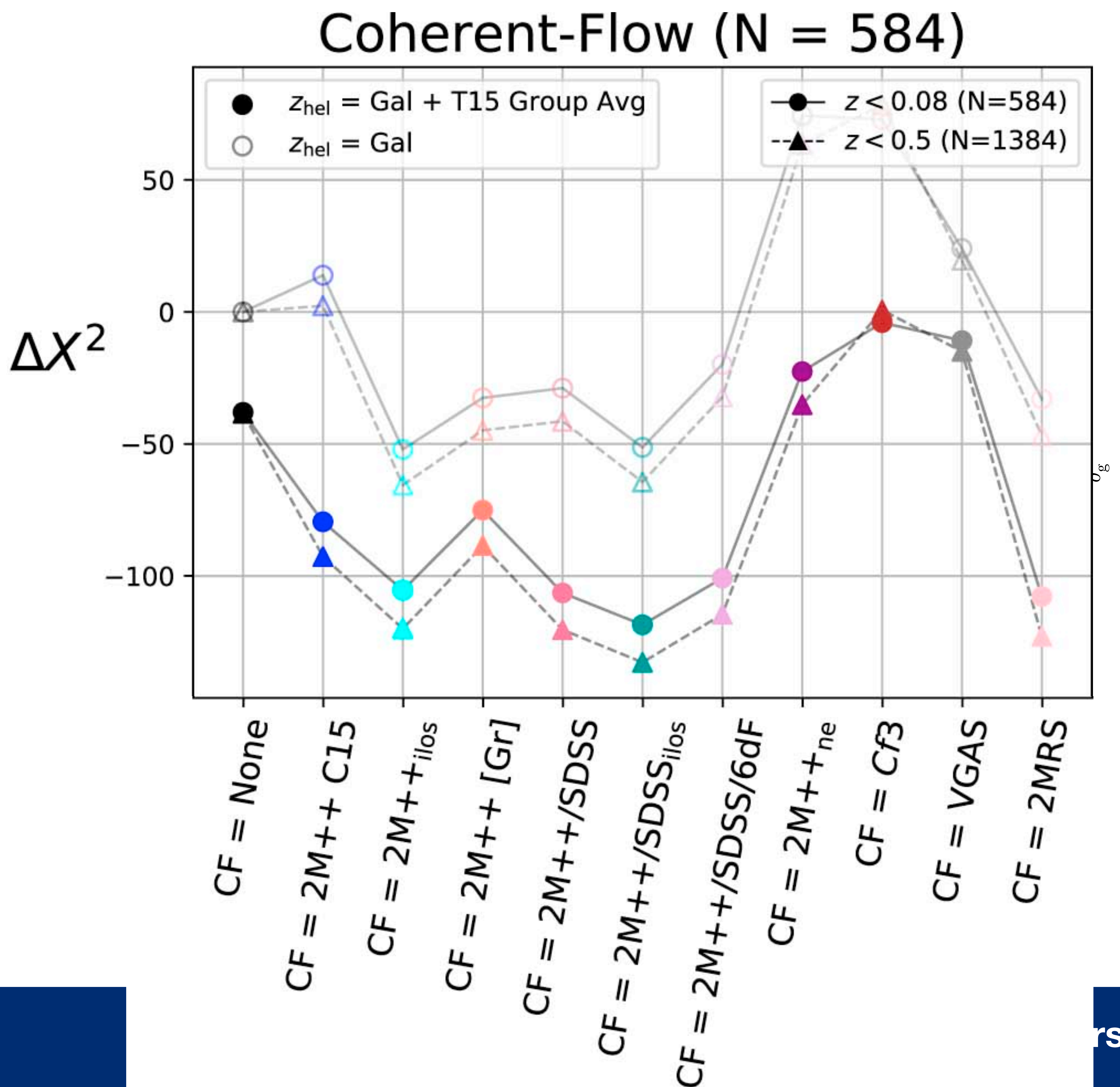

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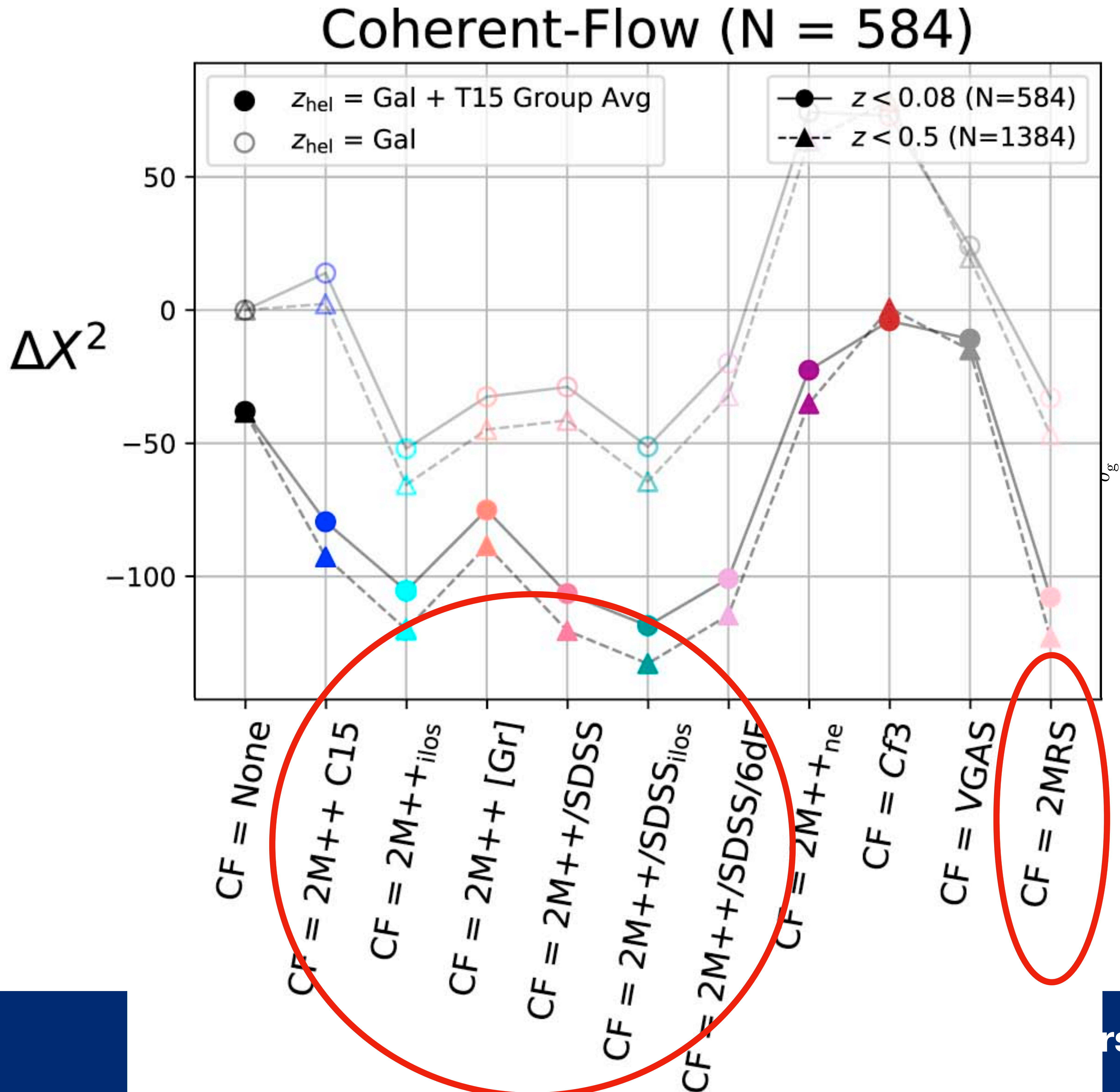

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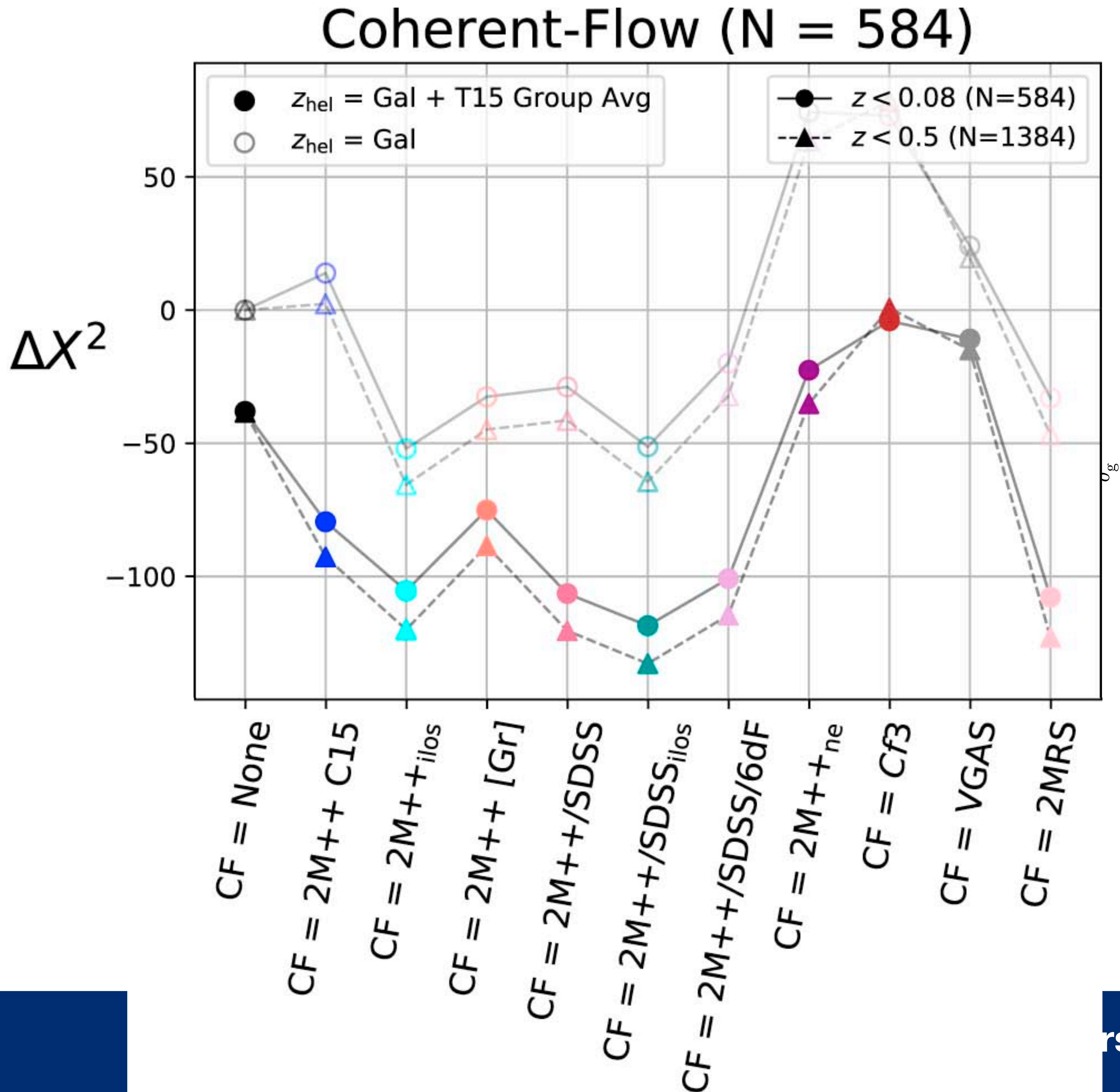

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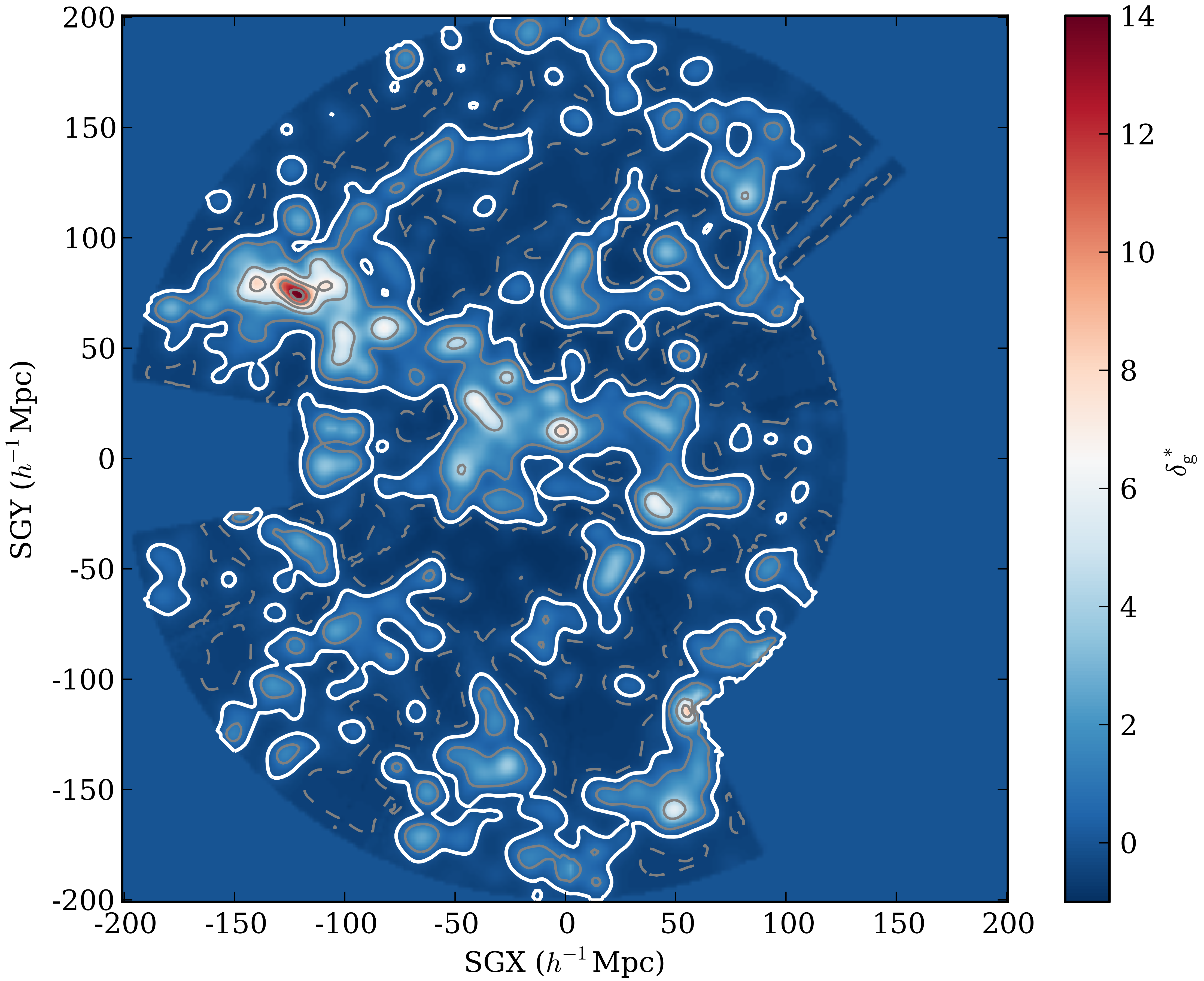

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Power Spectra

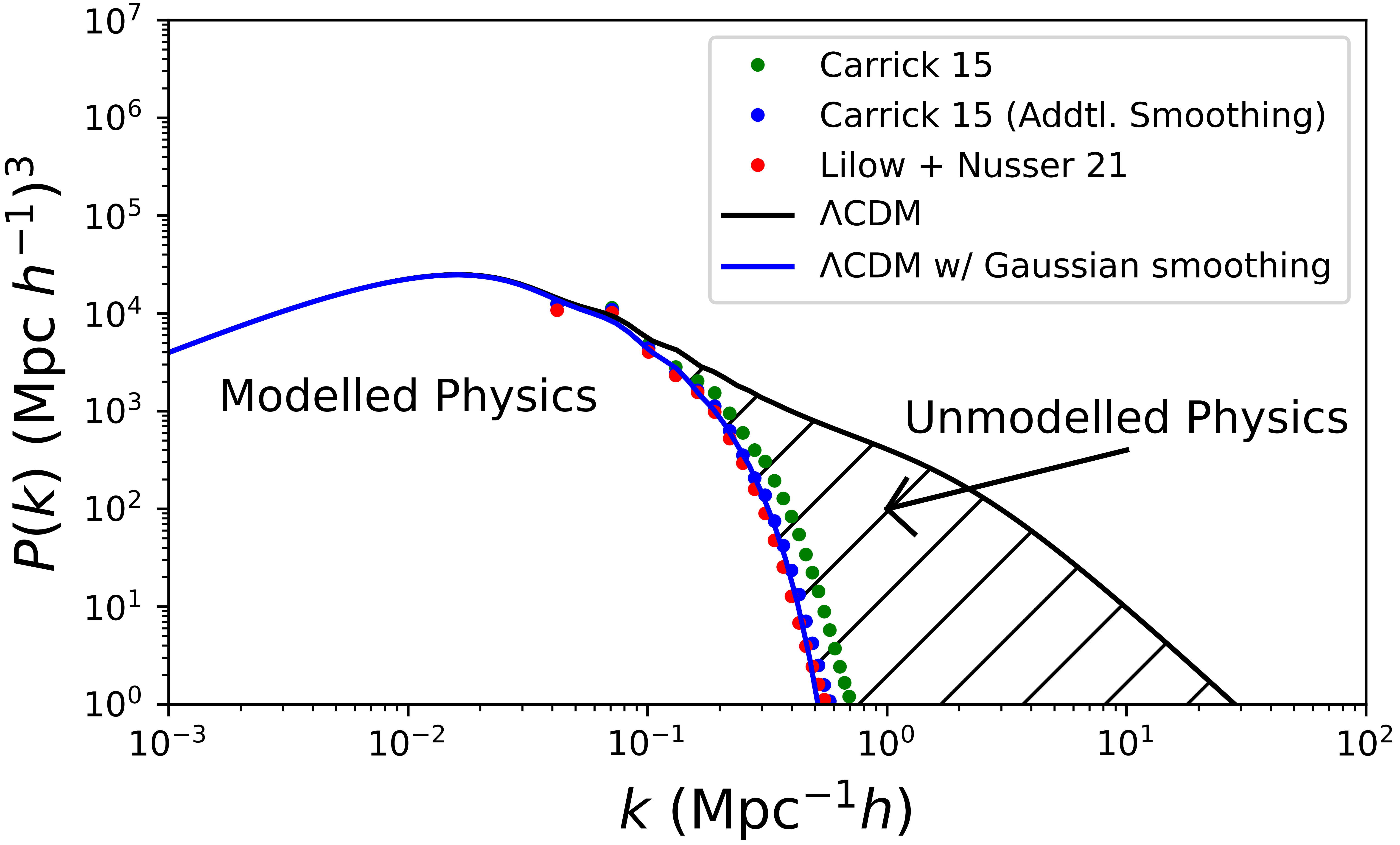
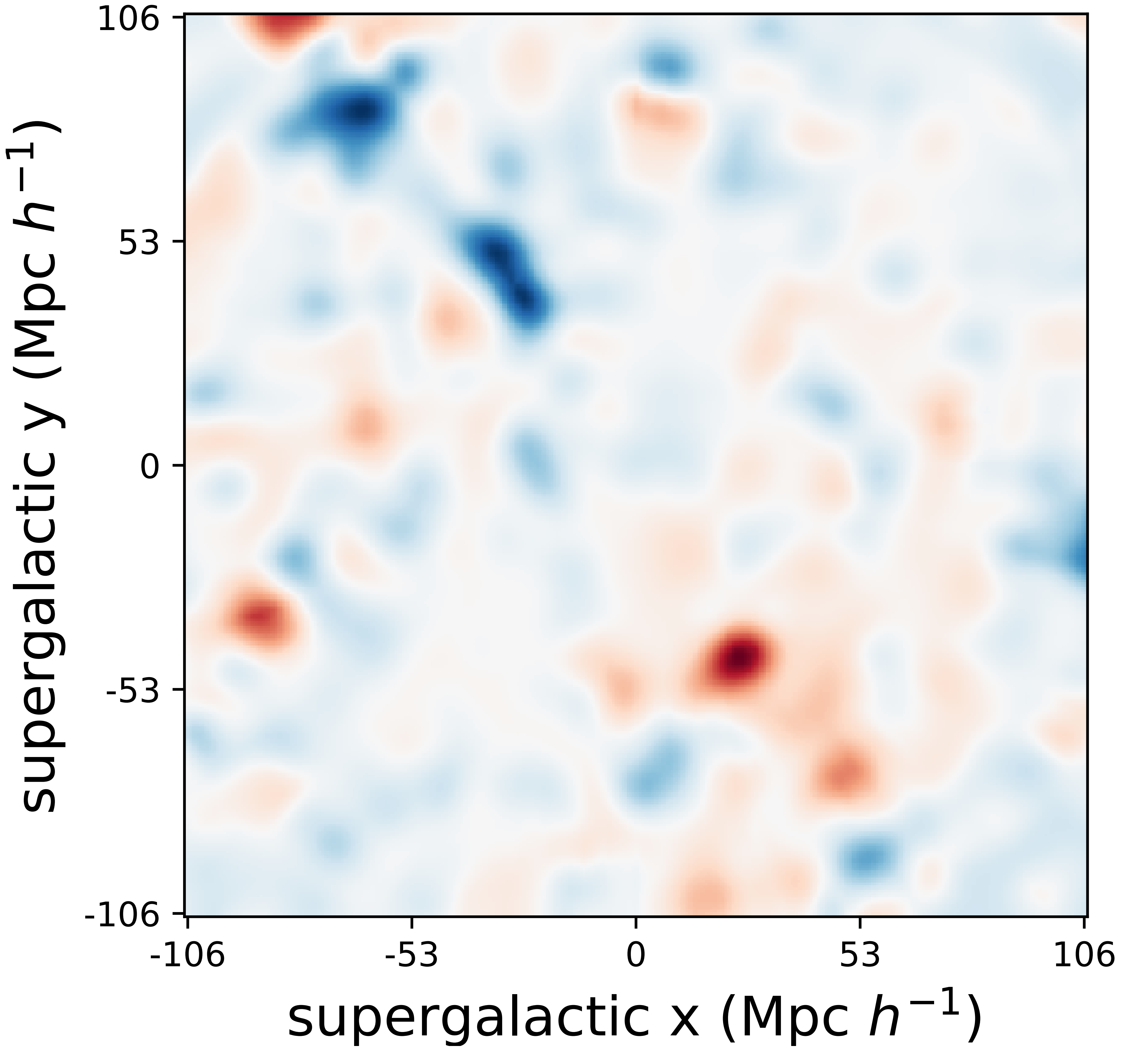


Figure Credit: Kenworthy et al. *2022*

Differences



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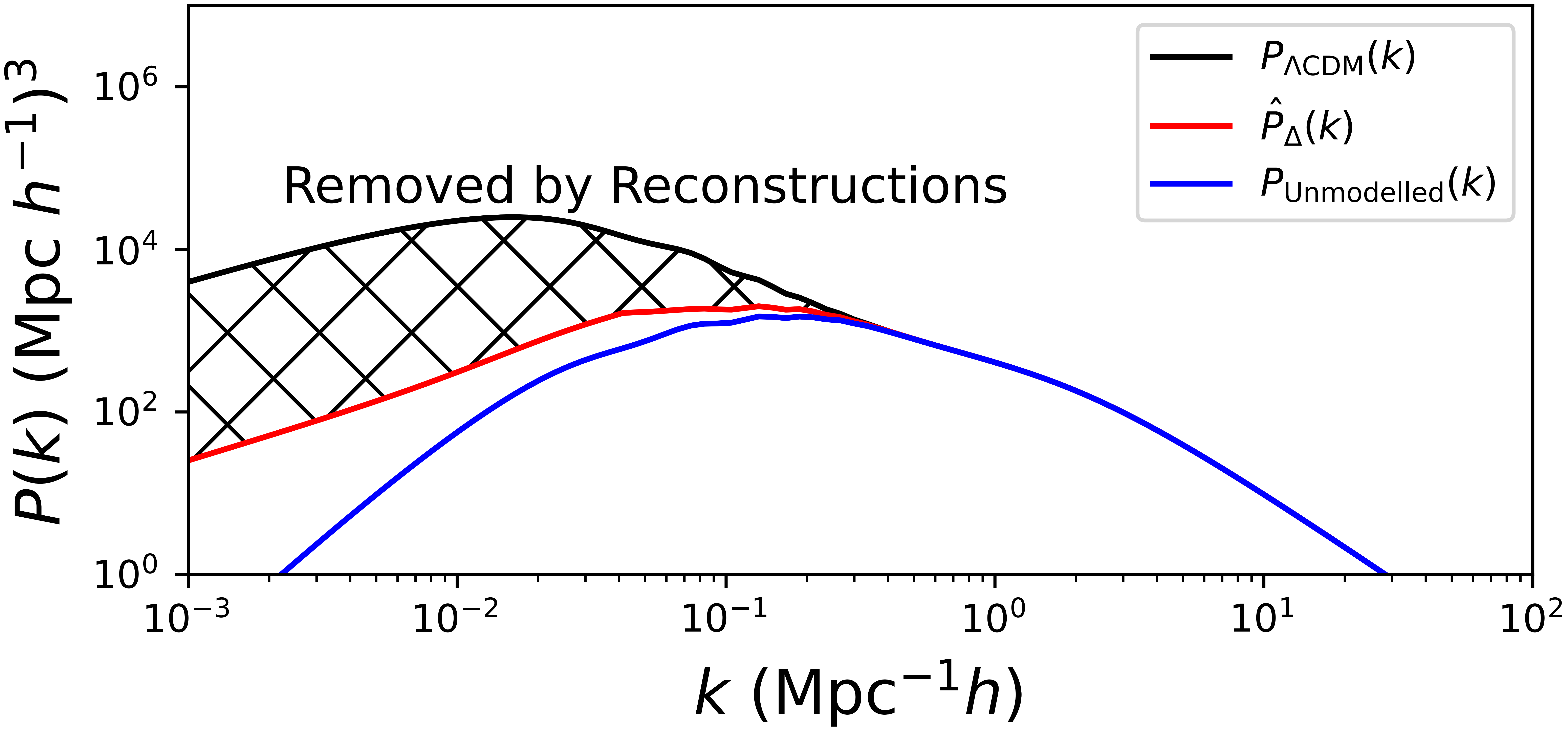
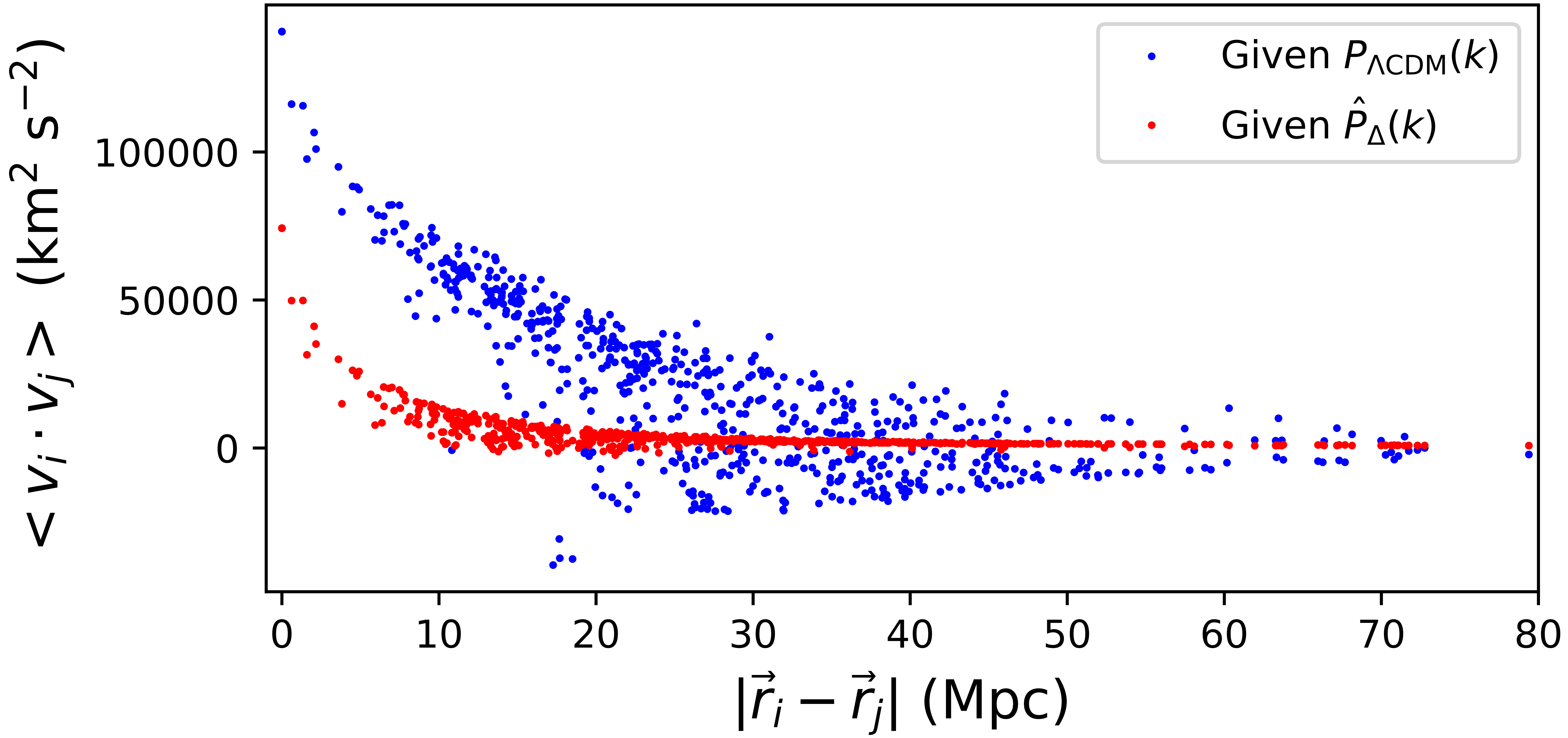


Figure Credit: Kenworthy et al. *2022*

Velocity Covariance

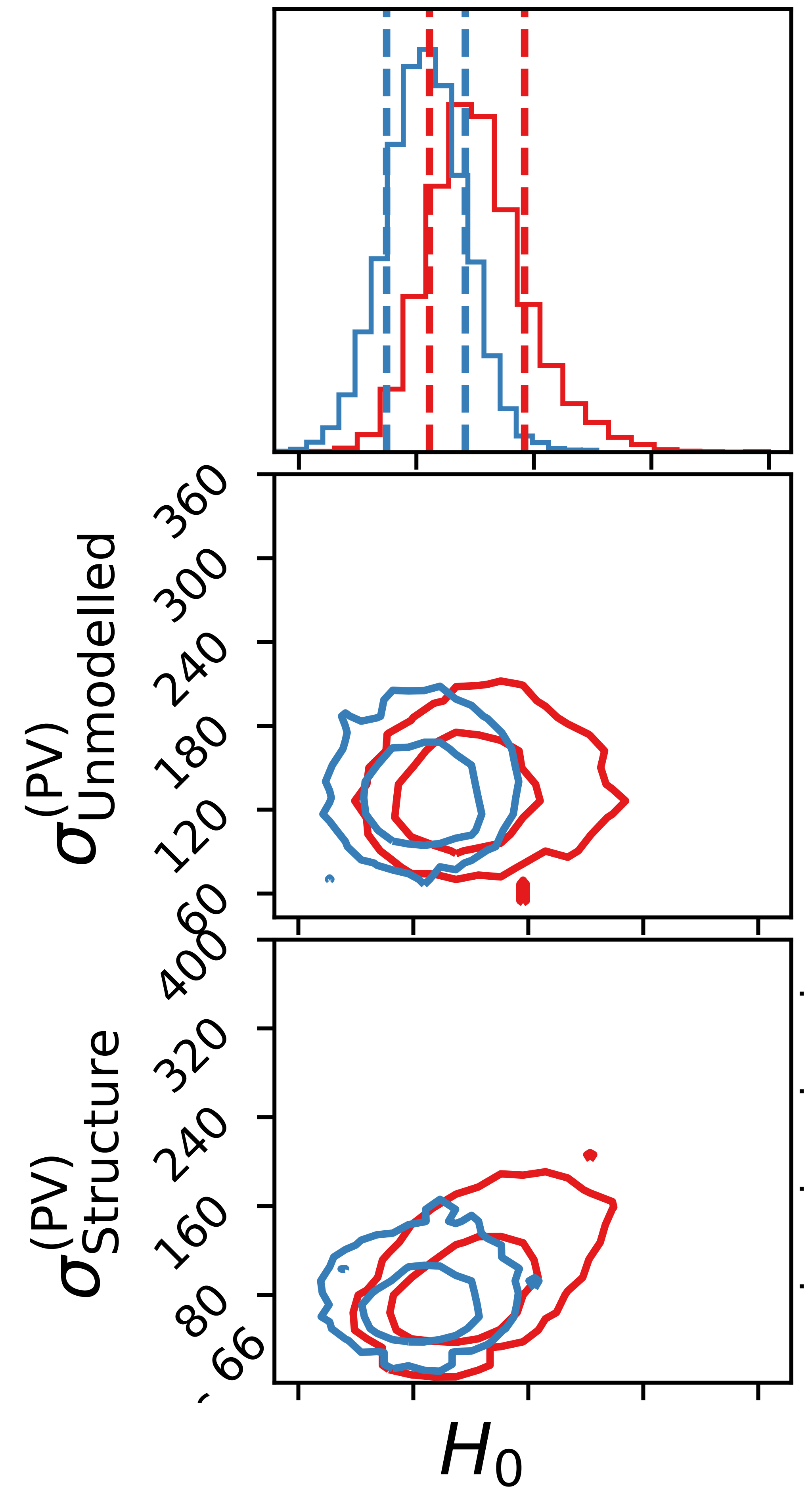


Velocity covariance between pairs of objects in our sample as a function of 3d separations. Red points show our error estimates

Figure Credit: Kenworthy et al. *2022*

Cosmology Dependence?

- Is our final measurement dependent on ΛCDM?
- Using theory *only* for the shape of the covariance, not the amplitude
- Effect is very small at second order (though depends on selection assumptions)
- Marginalized over cosmology parameters



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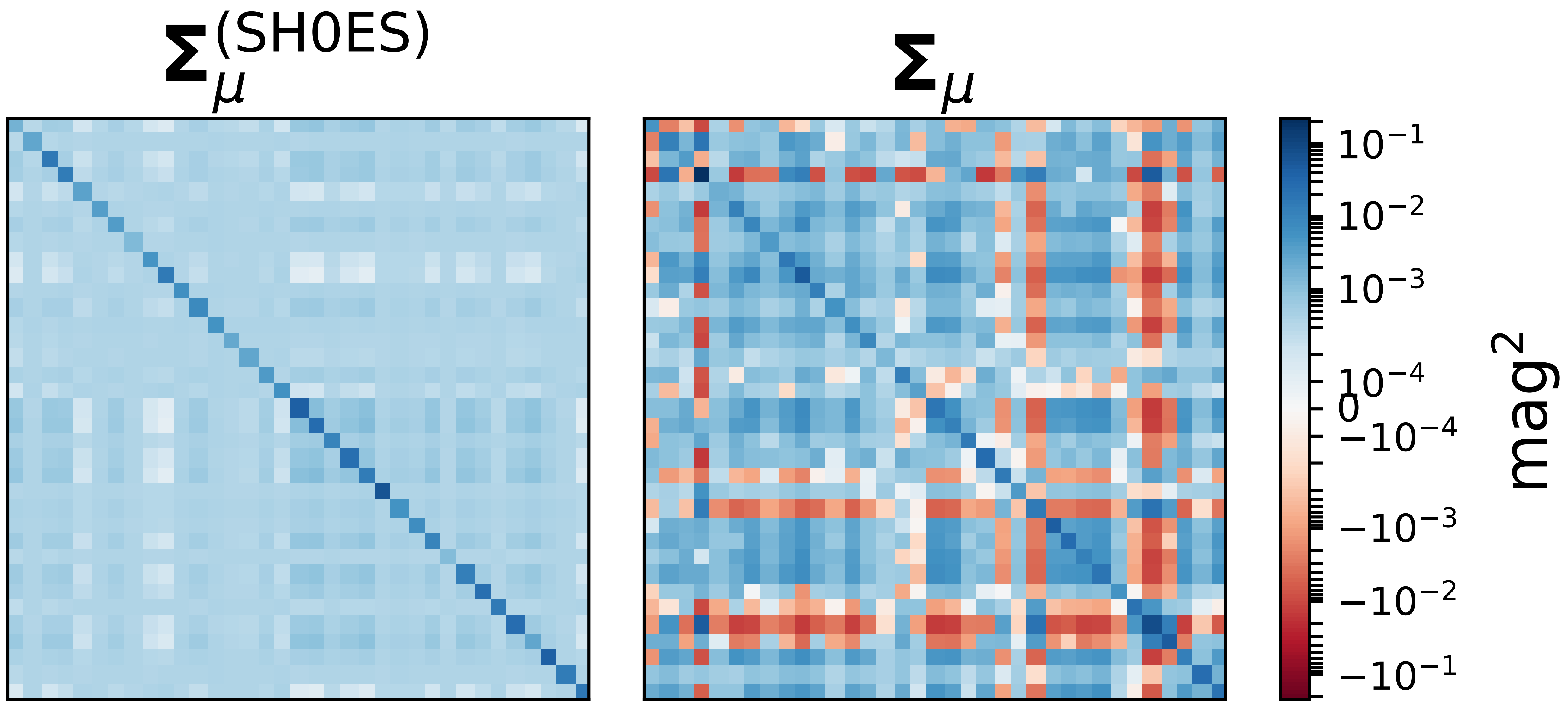
Cepheid Systematics

- Systematics included in covariance instead of analysis variants
- Accounted for:
  - Metallicity scale
  - Reddening/extinction
  - P-L law
  - outlier treatment



Covariance in Cepheid distance measurements

Figure Credit: Kenworthy et al. *2022*

Selection Effects

- Galaxies $\propto d^2$
- Implies a distance-dependent bias in redshifts
- Same effect seen in Pantheon+ analysis
- Two scenarios for SH0ES Cepheid samples:
  - Distance-limited: SH0ES used SN magnitudes to target nearby galaxies
  - Redshift-limited: SH0ES used redshifts to target nearby galaxies

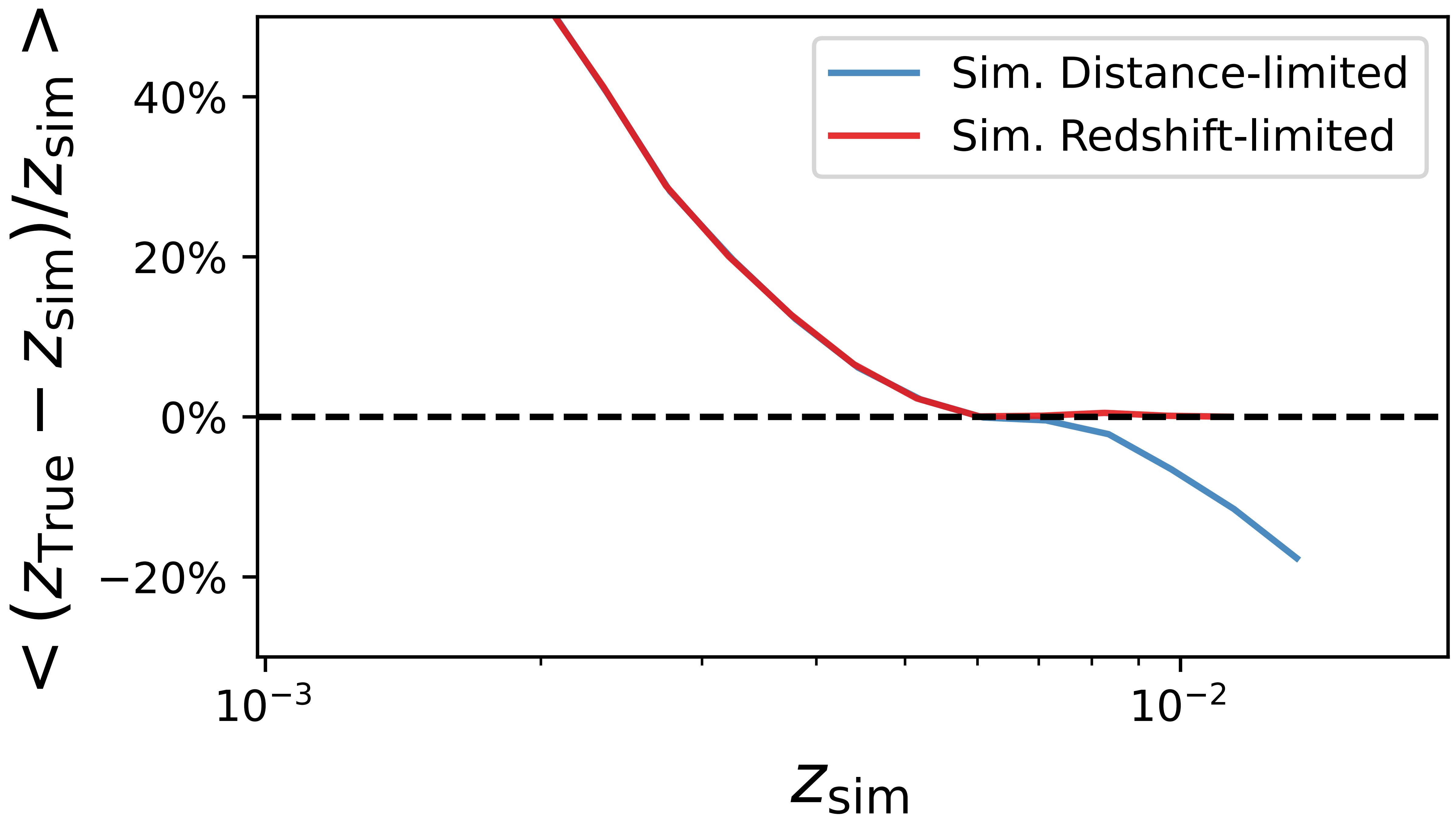


Figure Credit: Kenworthy et al. *2022, Brout* et al. *2022*

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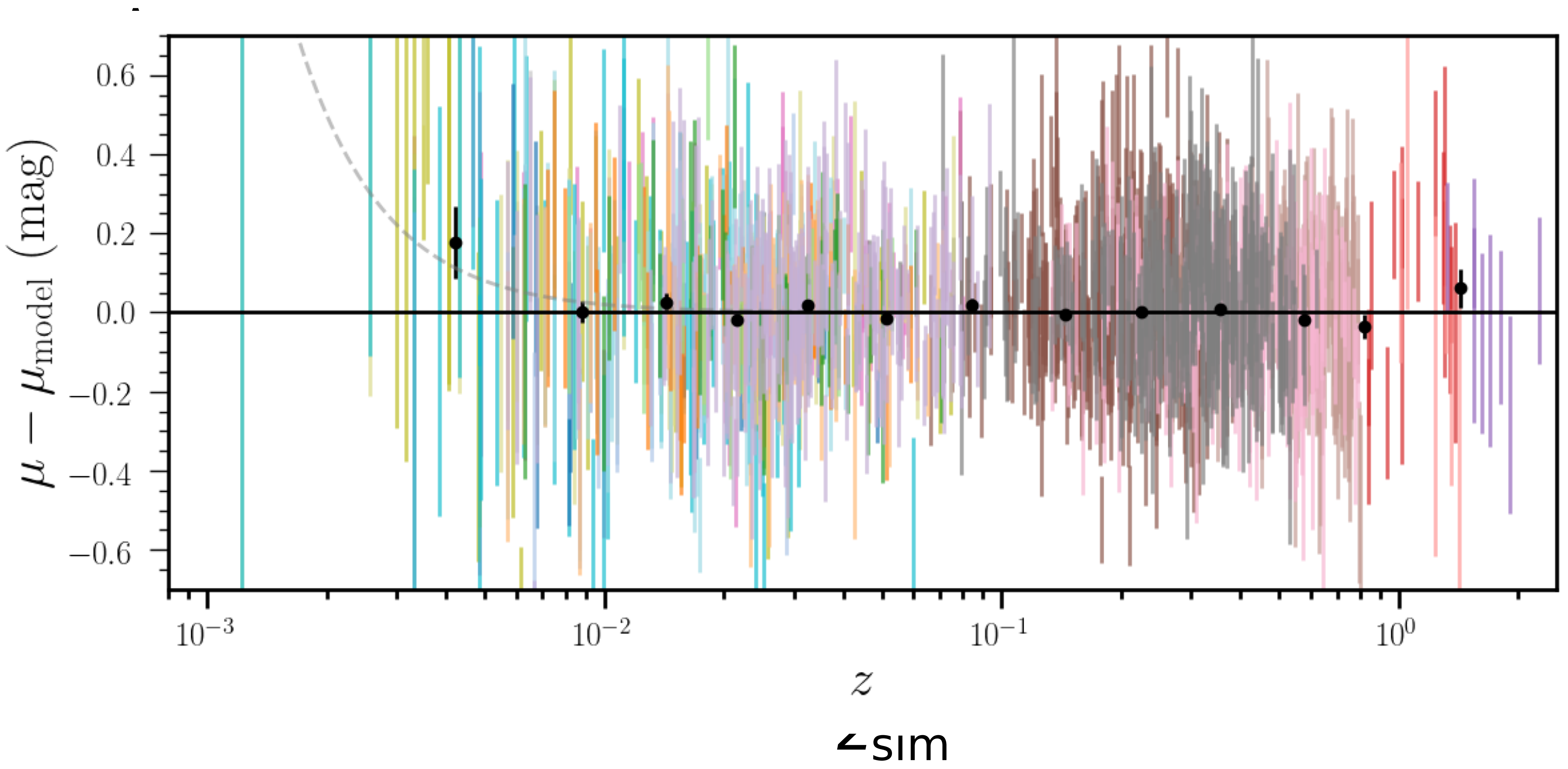

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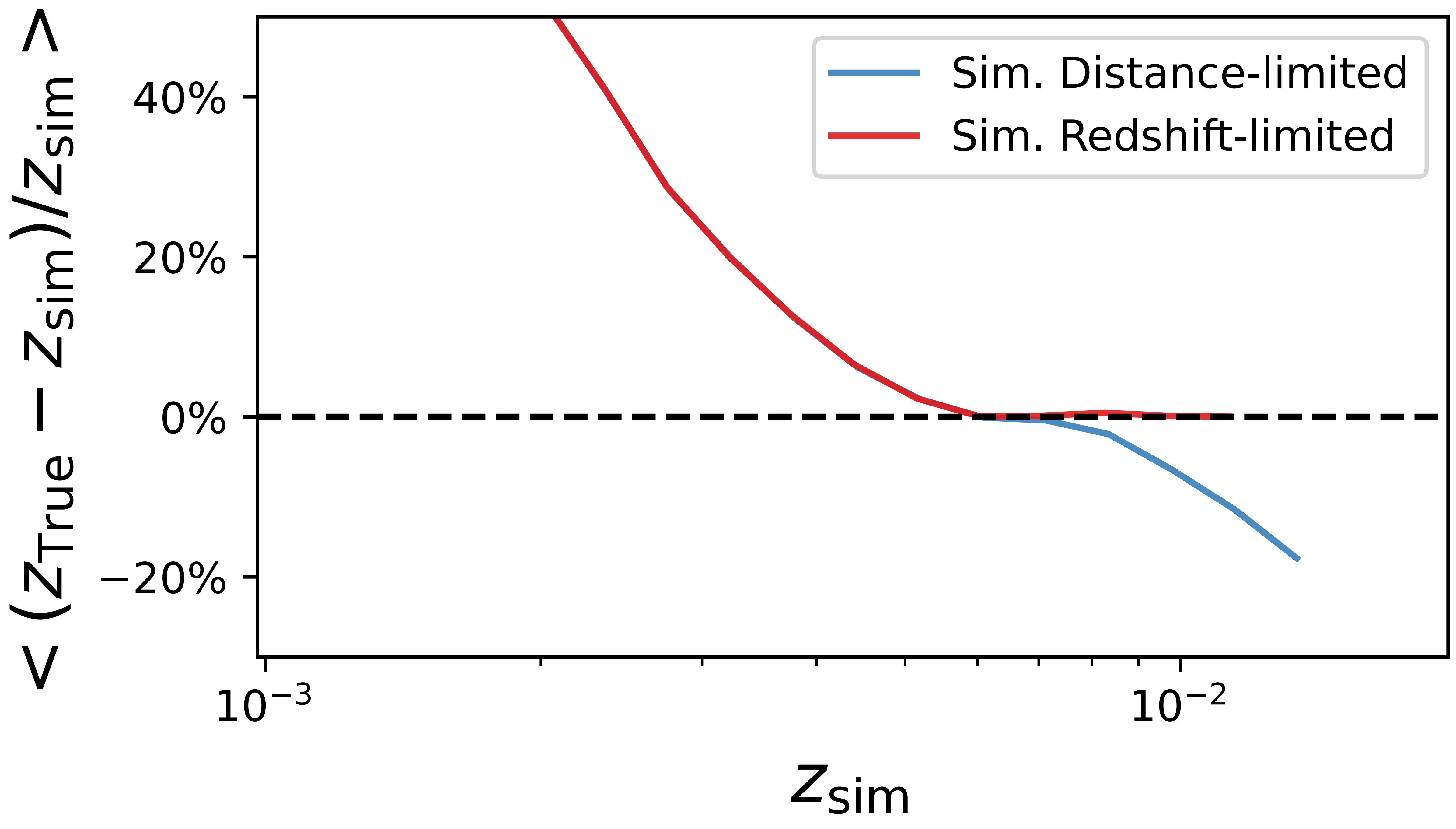

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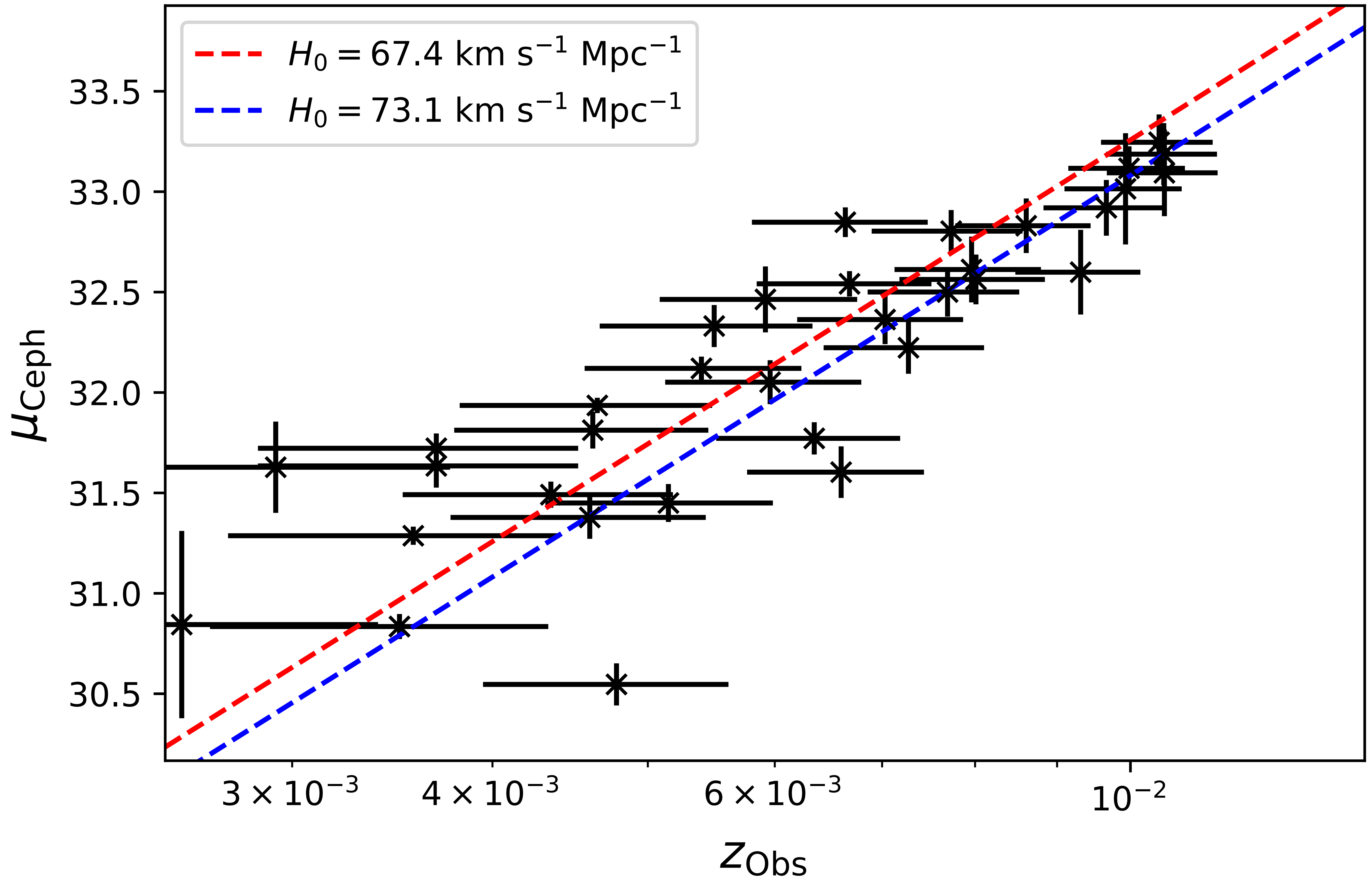
Modeling

- Hierarchical Bayesian model allows us to simultaneously model:
  - Parametrizations of reconstruction
  - Correlations of sample
  - Unique distance-redshift relations on each line of sight
  - Selection of SH0ES sample from Hubble flow
  - Cepheid systematics



Uncorrected Hubble Diagram

Modeling

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  - Selection of SH0ES sample from Hubble flow
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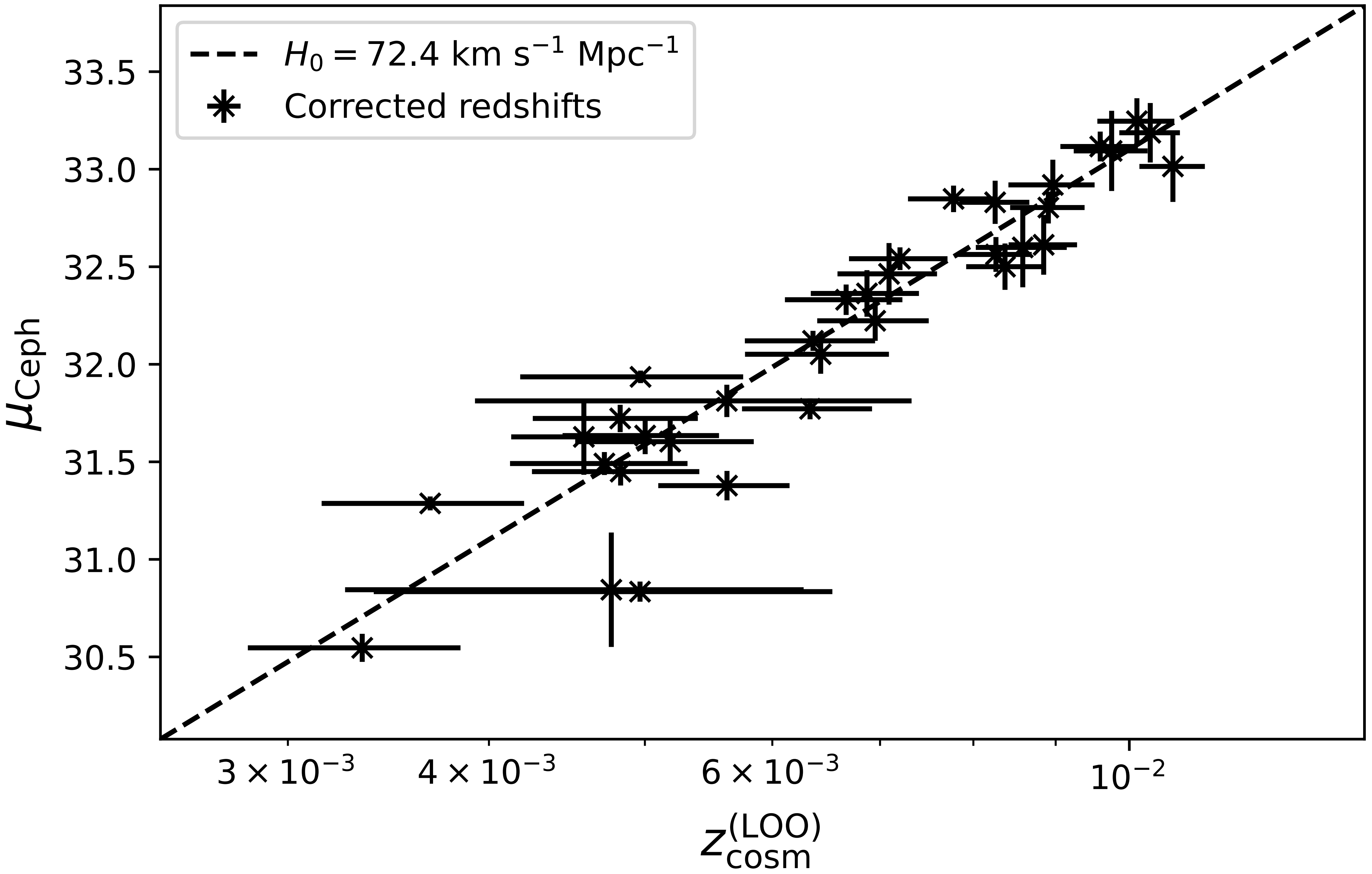
- Leave-one-out cross-validation



Assuming distance-limited selection, using Carrick 2015 reconstructions, and fitting PV amplitude

Residuals

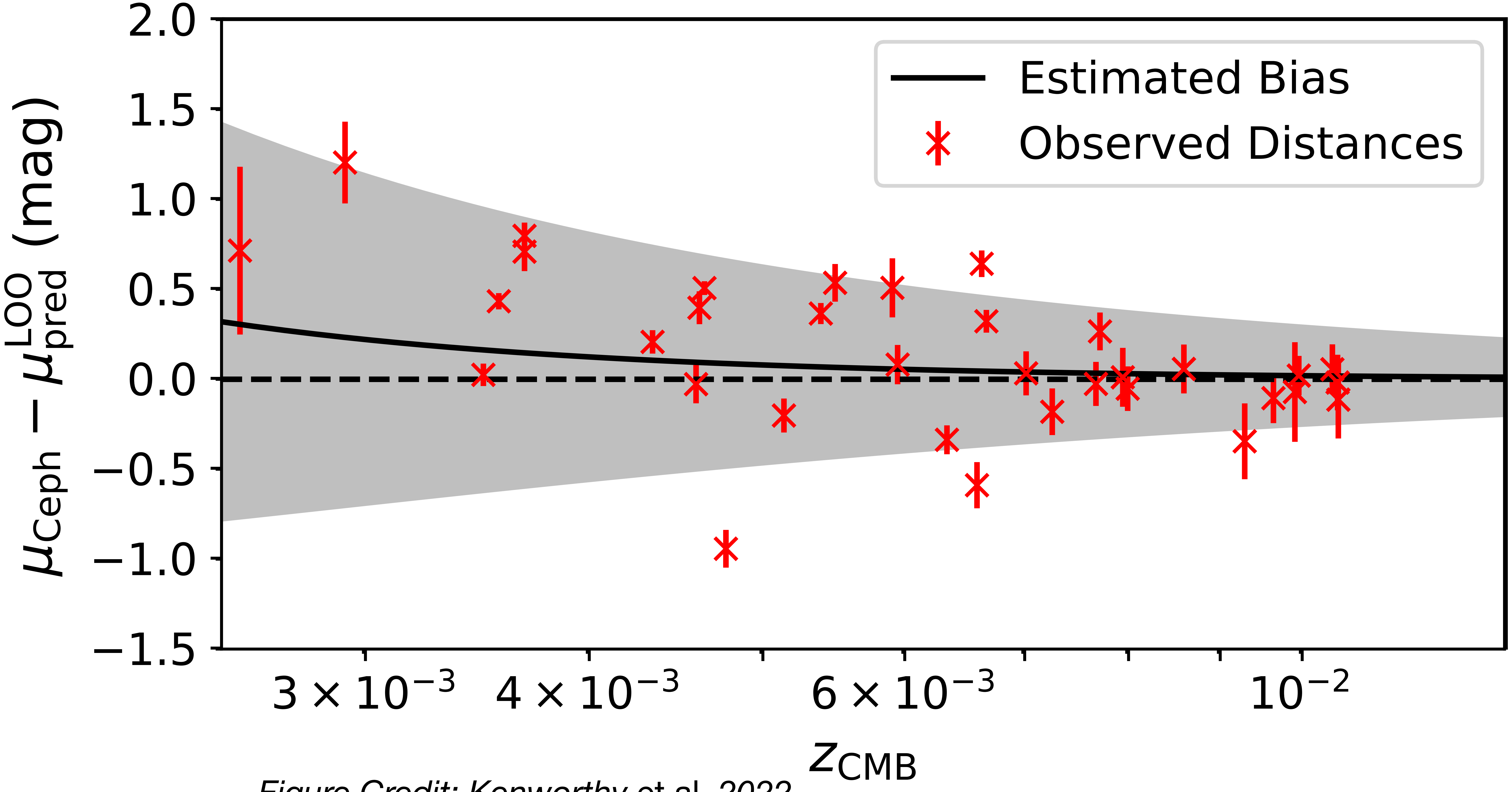


Figure Credit: Kenworthy et al. *2022*

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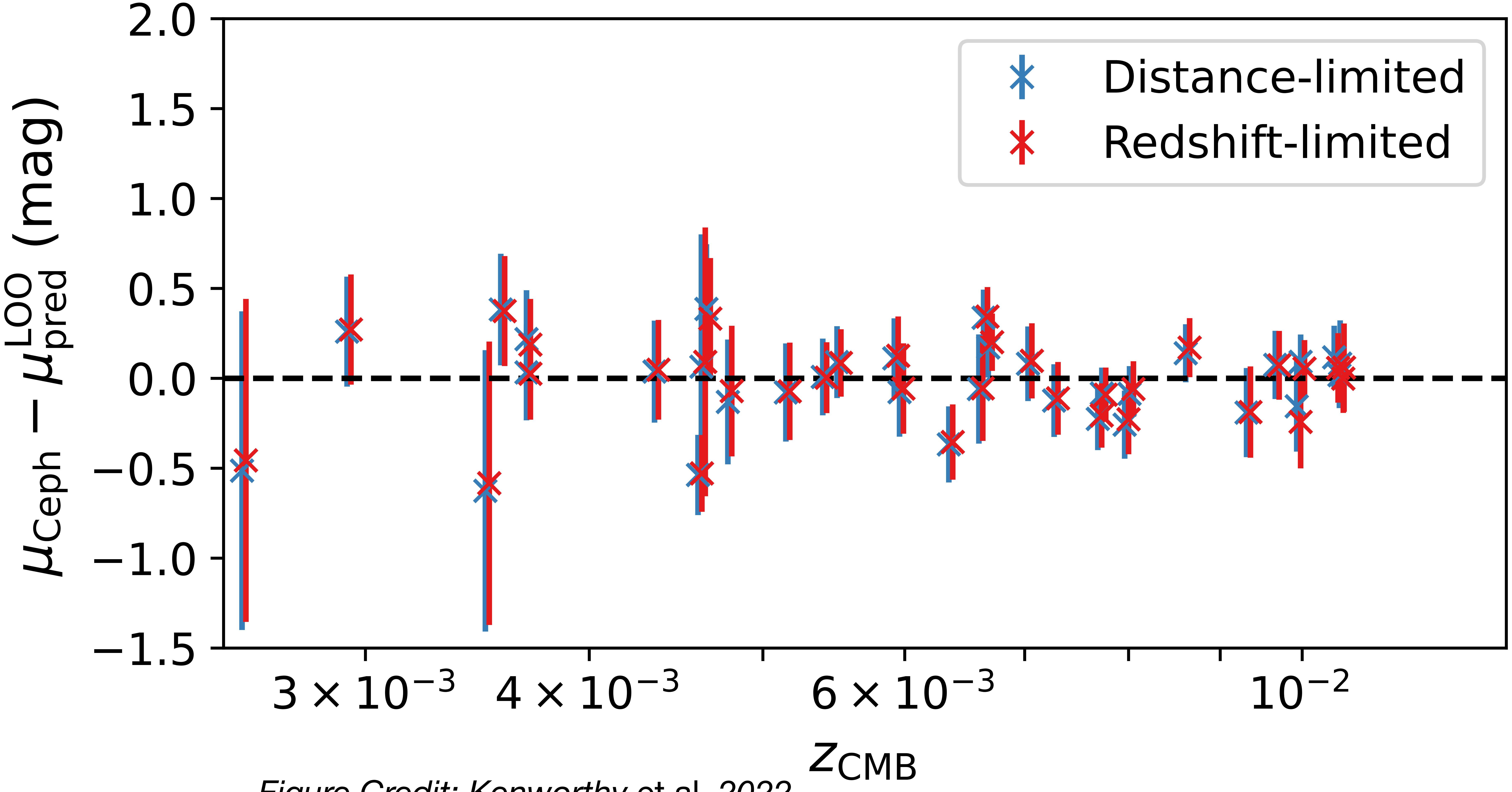

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Cepheid/SN comparison

- Check on agreement of the two
- $\chi^2 \approx 50$ with 72 DoF

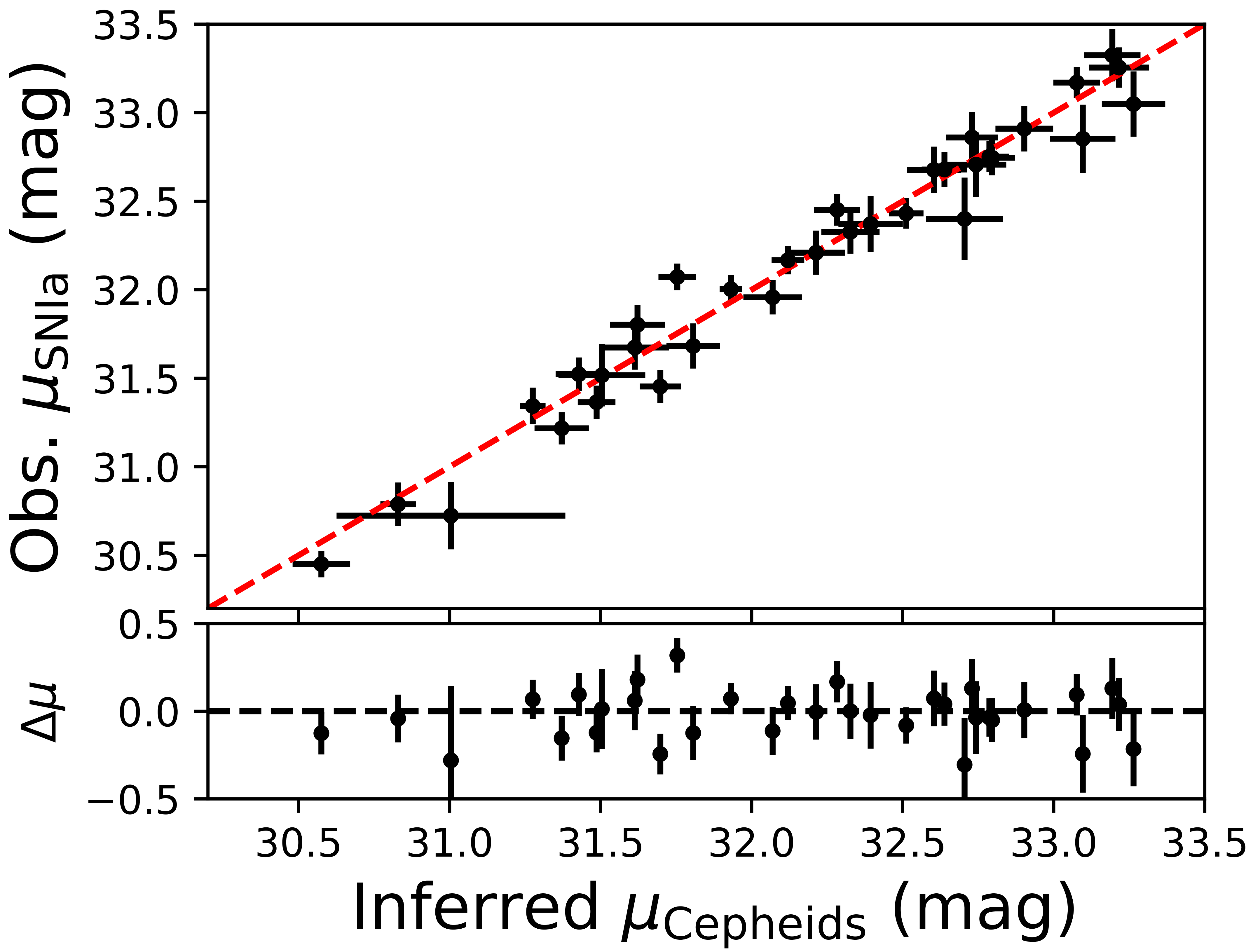


Figure Credit: Kenworthy et al. *2022*

Results

Evaluated 12 variant treatments of selection and modeling to evaluate associated systematics

Without galaxy reconstruction
$71.6^{+4.5}_{-4.6}$ km s^{-1} Mpc^{-1}

Fiducial Result: $72.8^{+2.4}_{-2.2}$ km s^{-1} Mpc^{-1}
2.4σ **discrepancy with Planck**

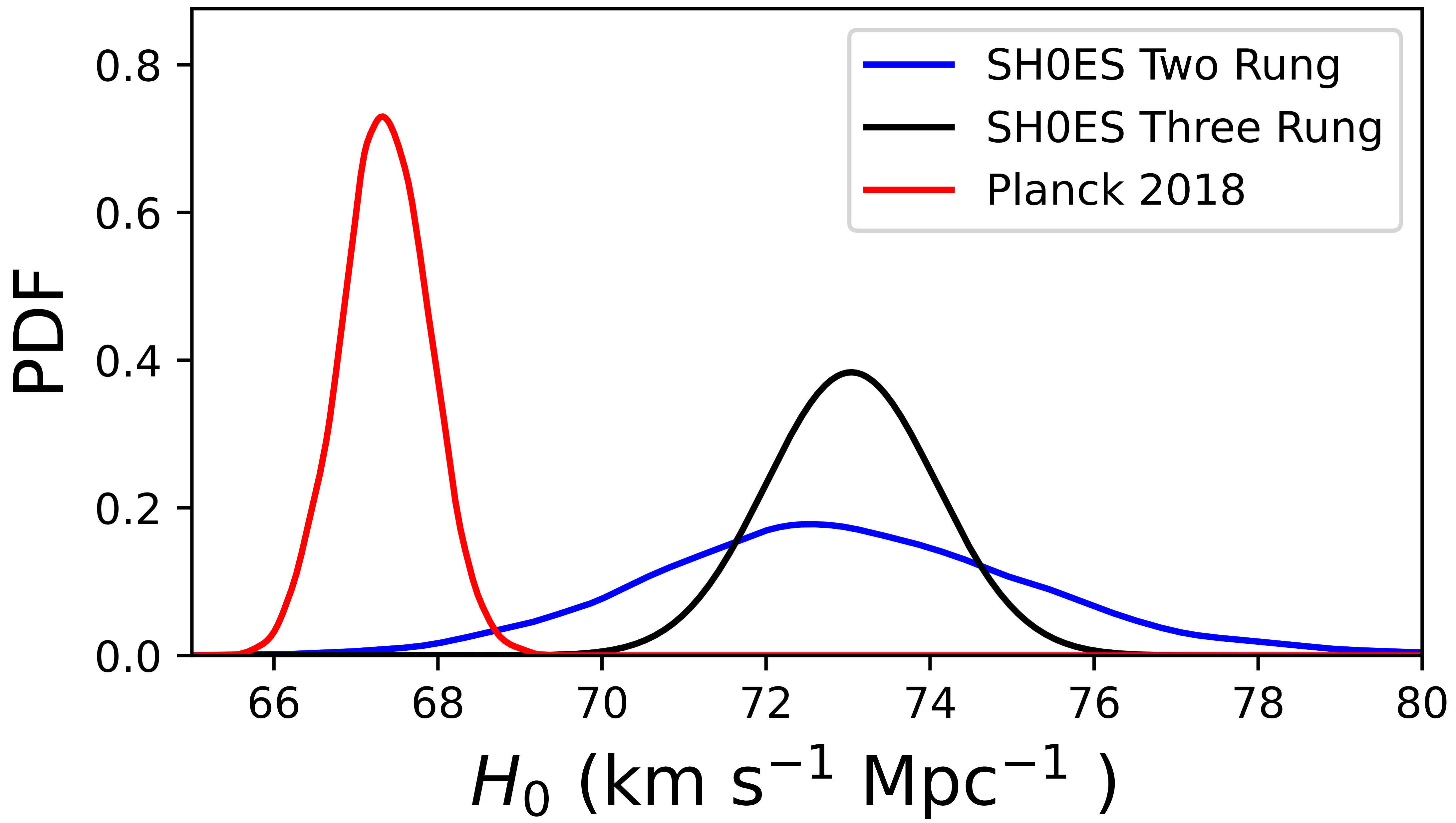


Figure Credit: Kenworthy et al. *2022*

Impact on Hubble Tension

- Messing with type Ia SNe alone **cannot** reduce tension below 2.4σ
- Peculiar velocity flow corrections are pretty good (3σ significance from Cepheids alone!)
- Extremely low redshift physics solutions also challenged (sample median at 20 Mpc!)

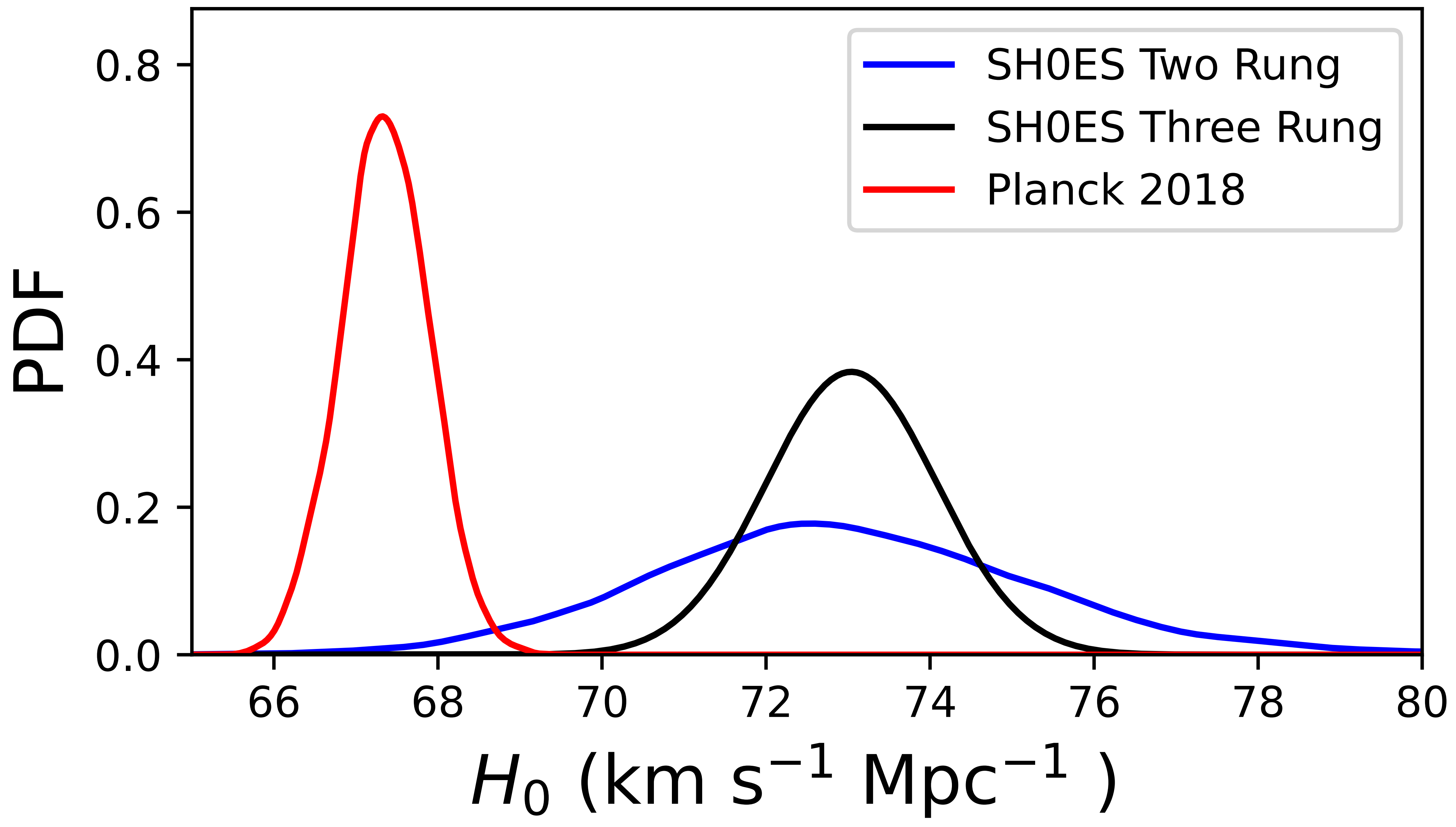
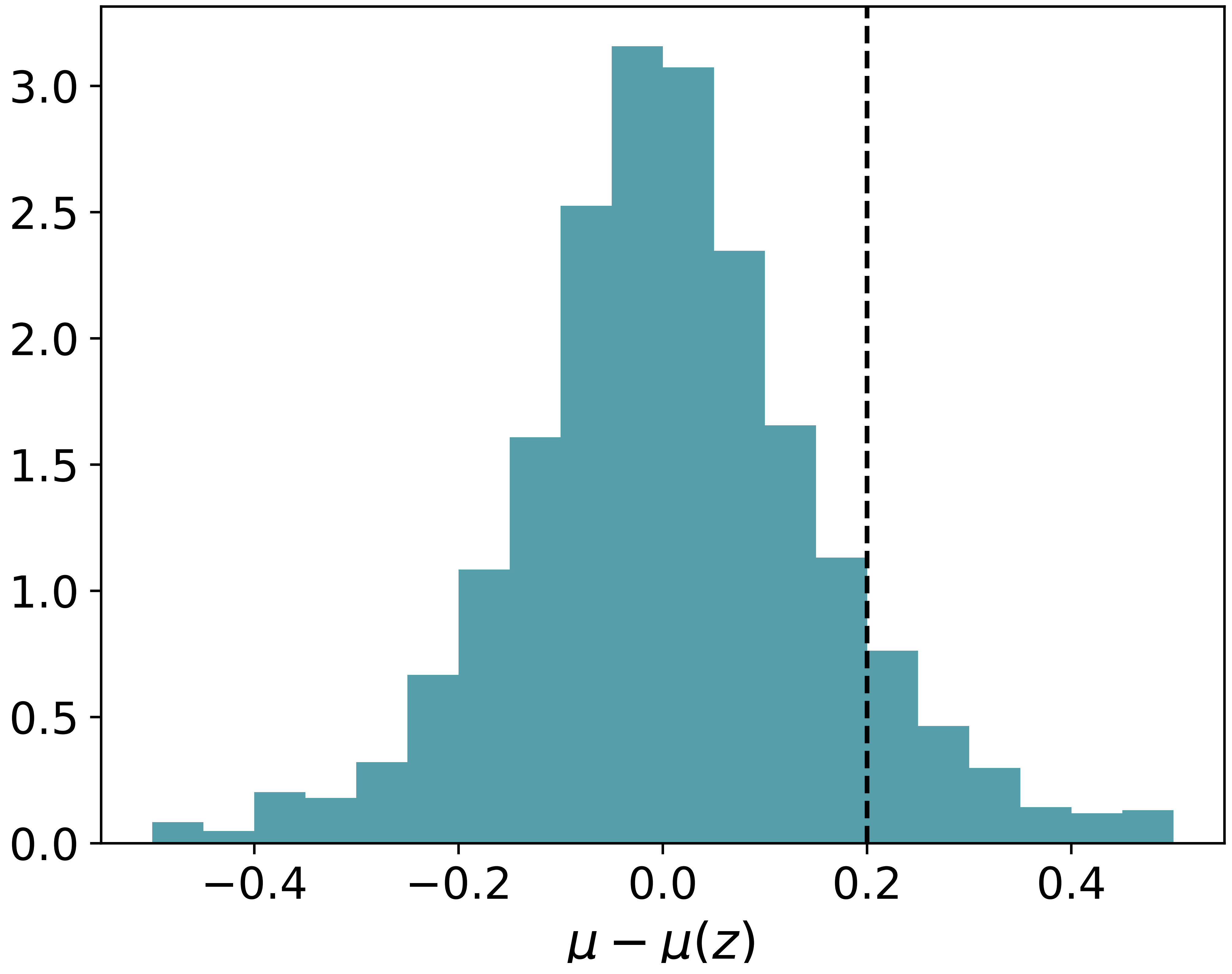


Figure Credit: Kenworthy et al. *2022*

SNe Ia

- SNe are necessary to measure the Hubble tension precisely
- Supernova Ia sample is extremely well constrained



Pantheon+ residuals

Voids at ~ Gpc scales?

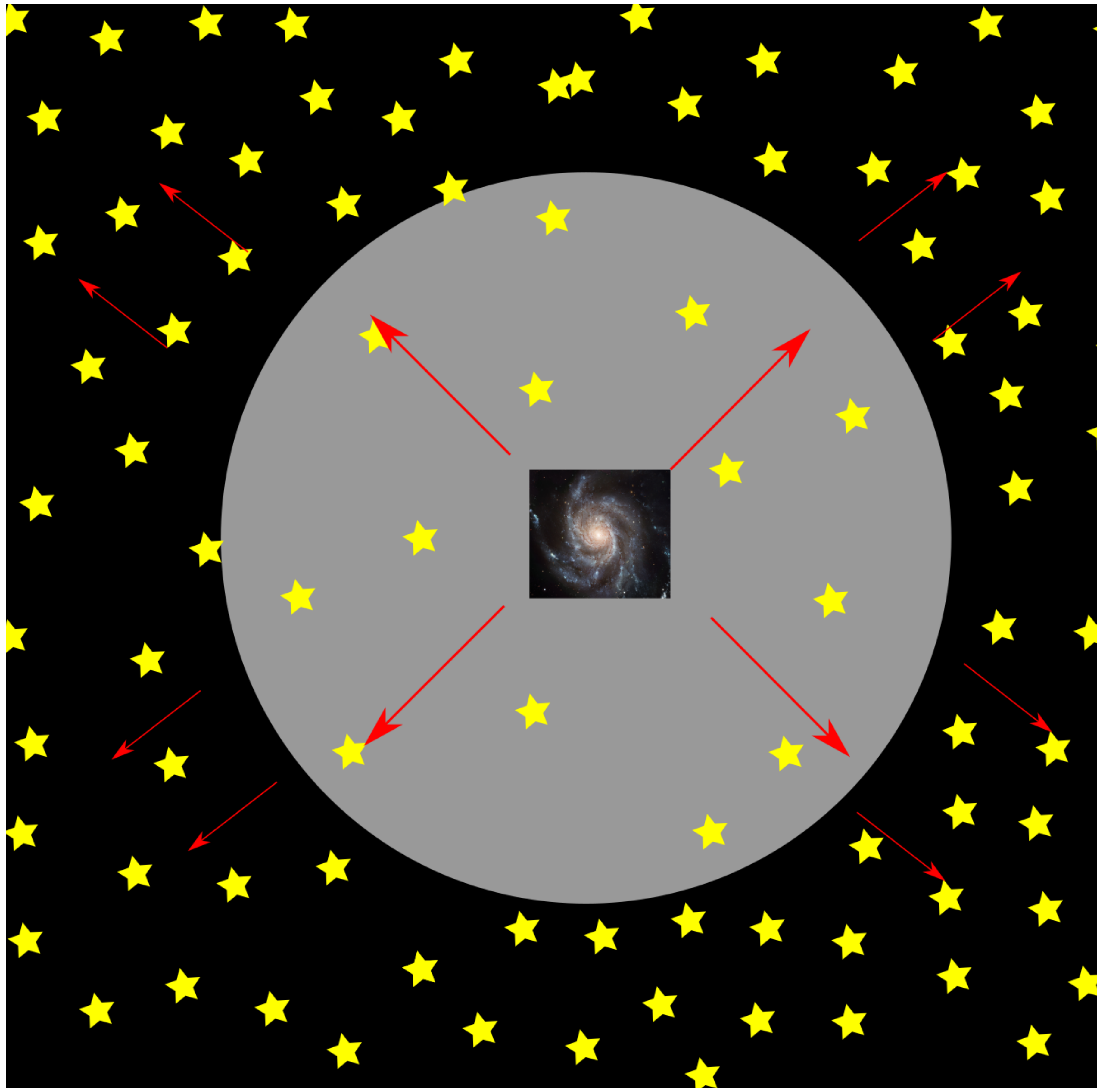
- Grey, underdense region will expand more quickly than black background

- Under-density increases local Hubble constant

$$\delta H_0 / H_0 = -f(\Omega_M)/3 \times \delta\rho/\rho$$

% change in $H_0 \approx -1/6 \times$ % change in density

- Theoretical effect on SH0ES is ~ 0.5-.7% (Wu and Huterer, 2017)



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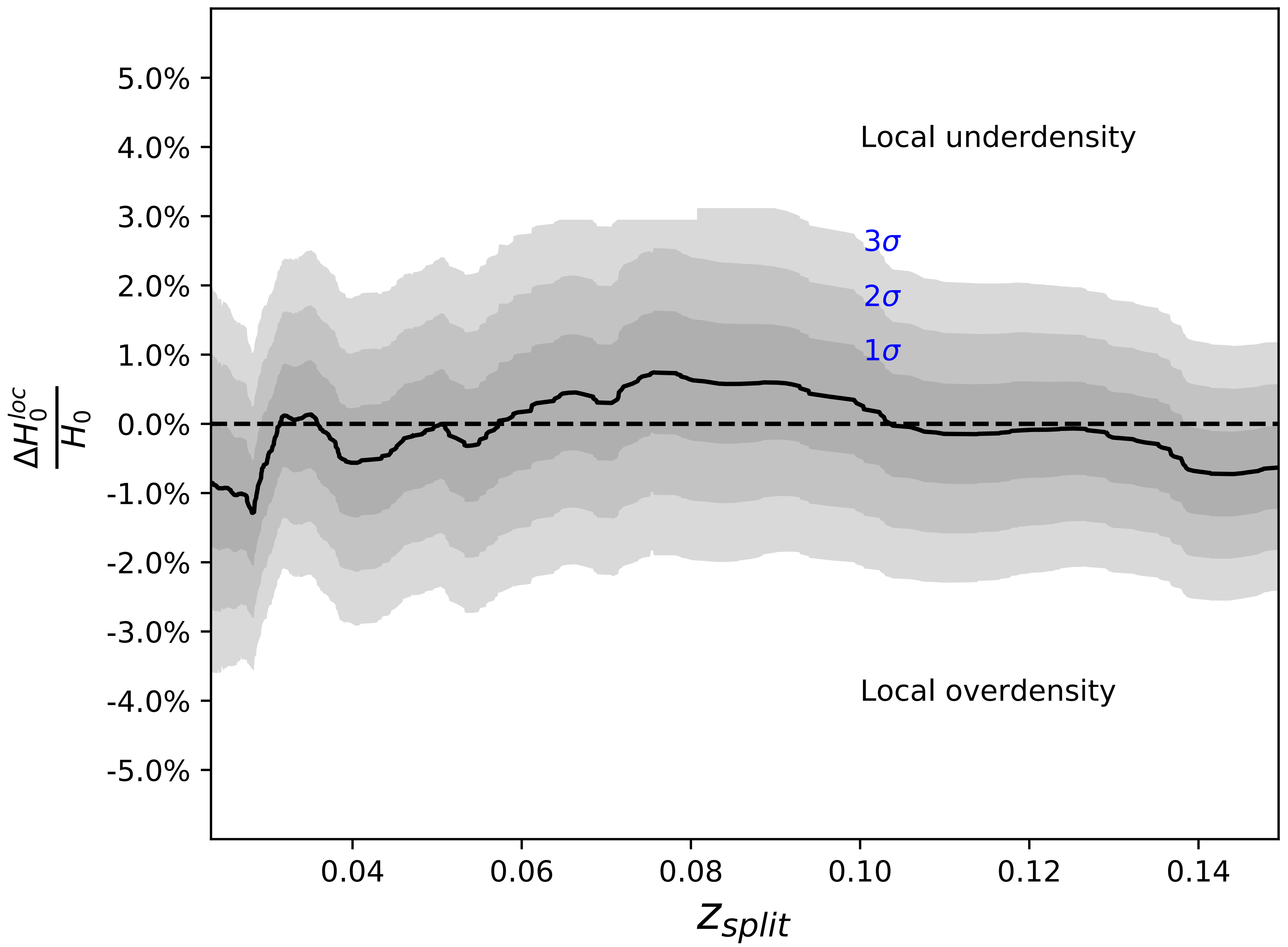
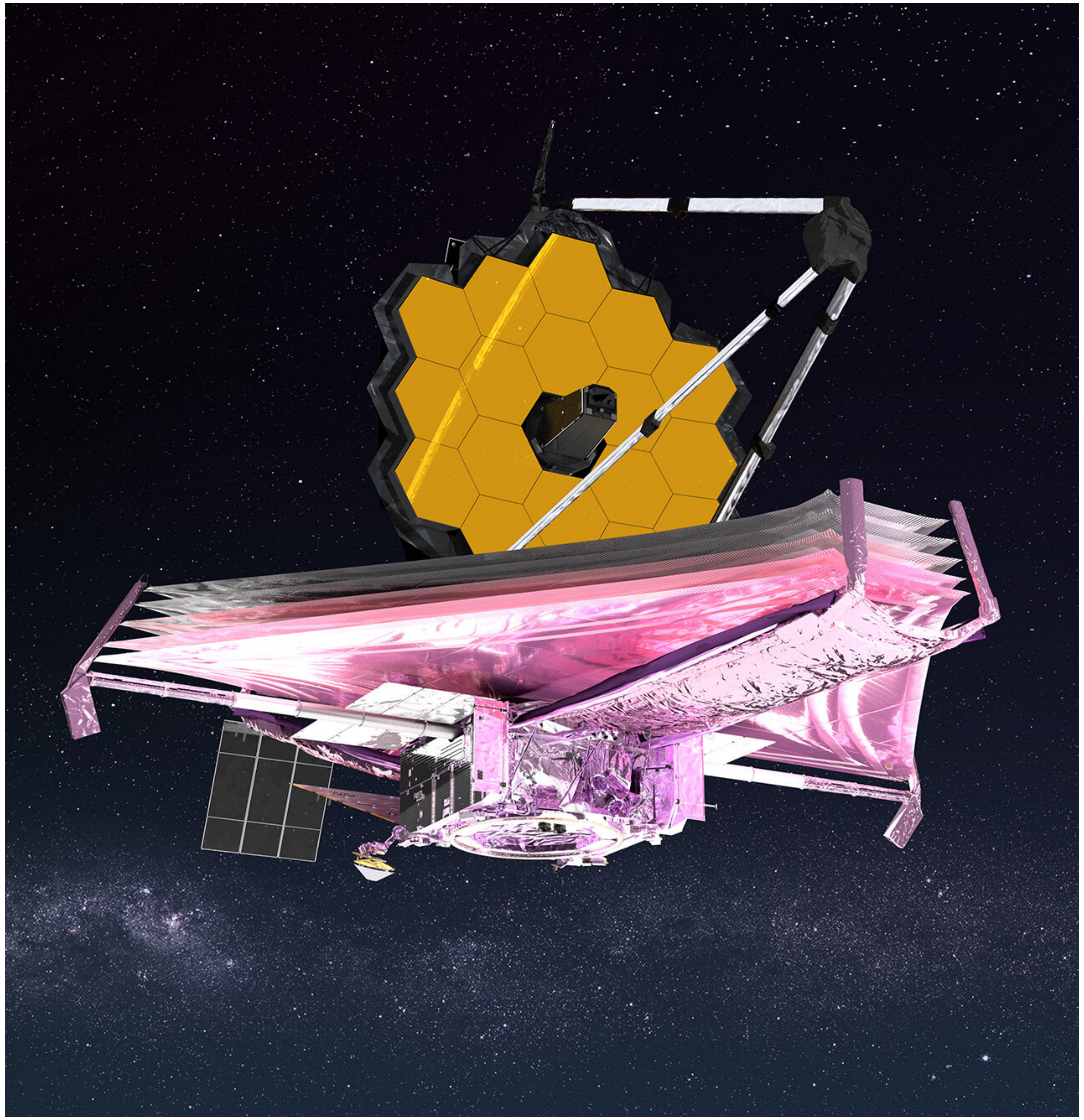


Difference in H_0 when measured above and below z_{split} There is no evidence for a void biasing the local measurement of the Hubble constant at any redshift. Smoothed for visualization

Figure Credit: Kenworthy et al. *2019*

JWST!



Crowded No More

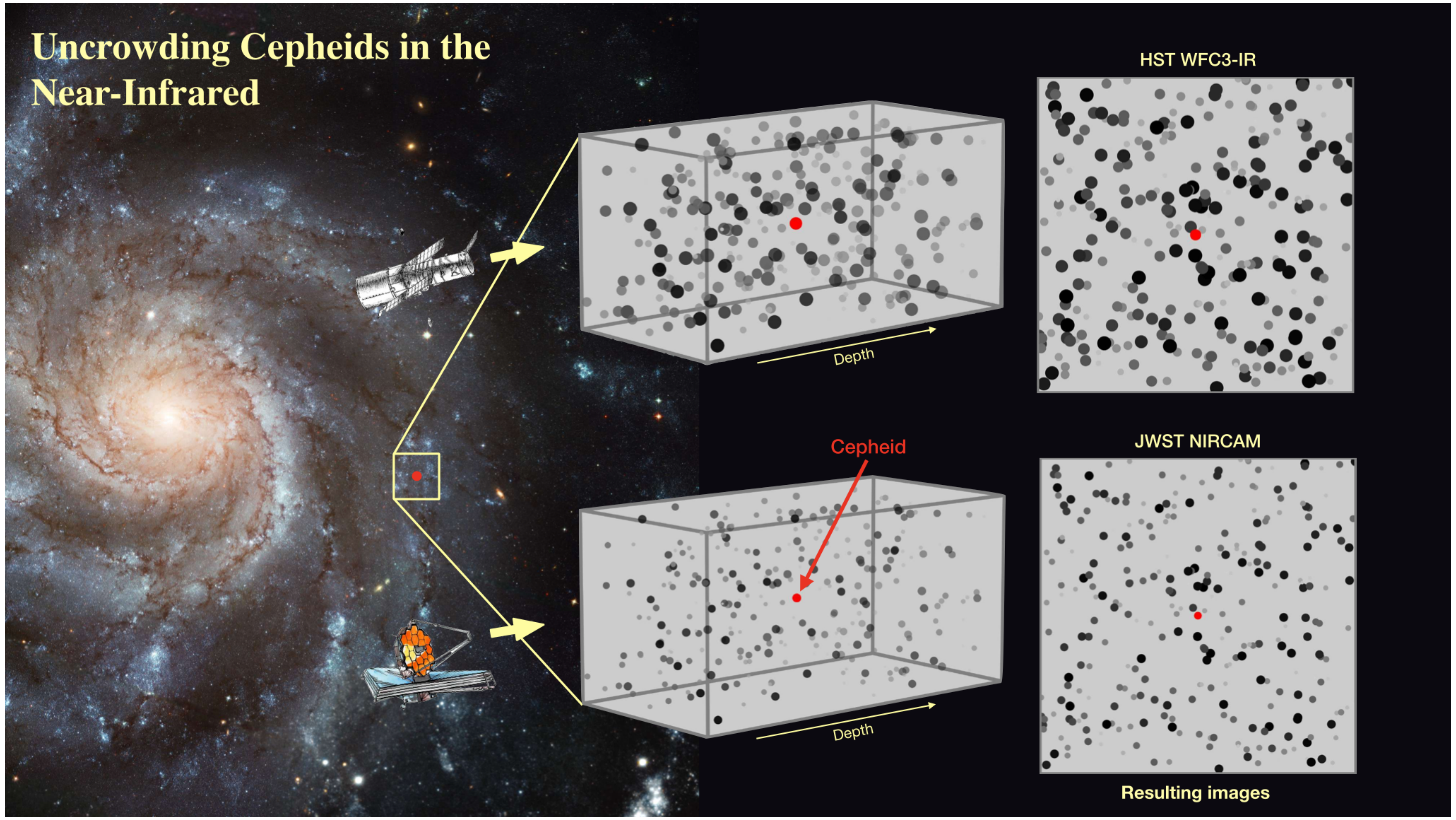
arXiv:2307.15806

Draft version August 2, 2023
Typeset using LaTeX default style in AASTeX631

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]

Cepheid Crowding



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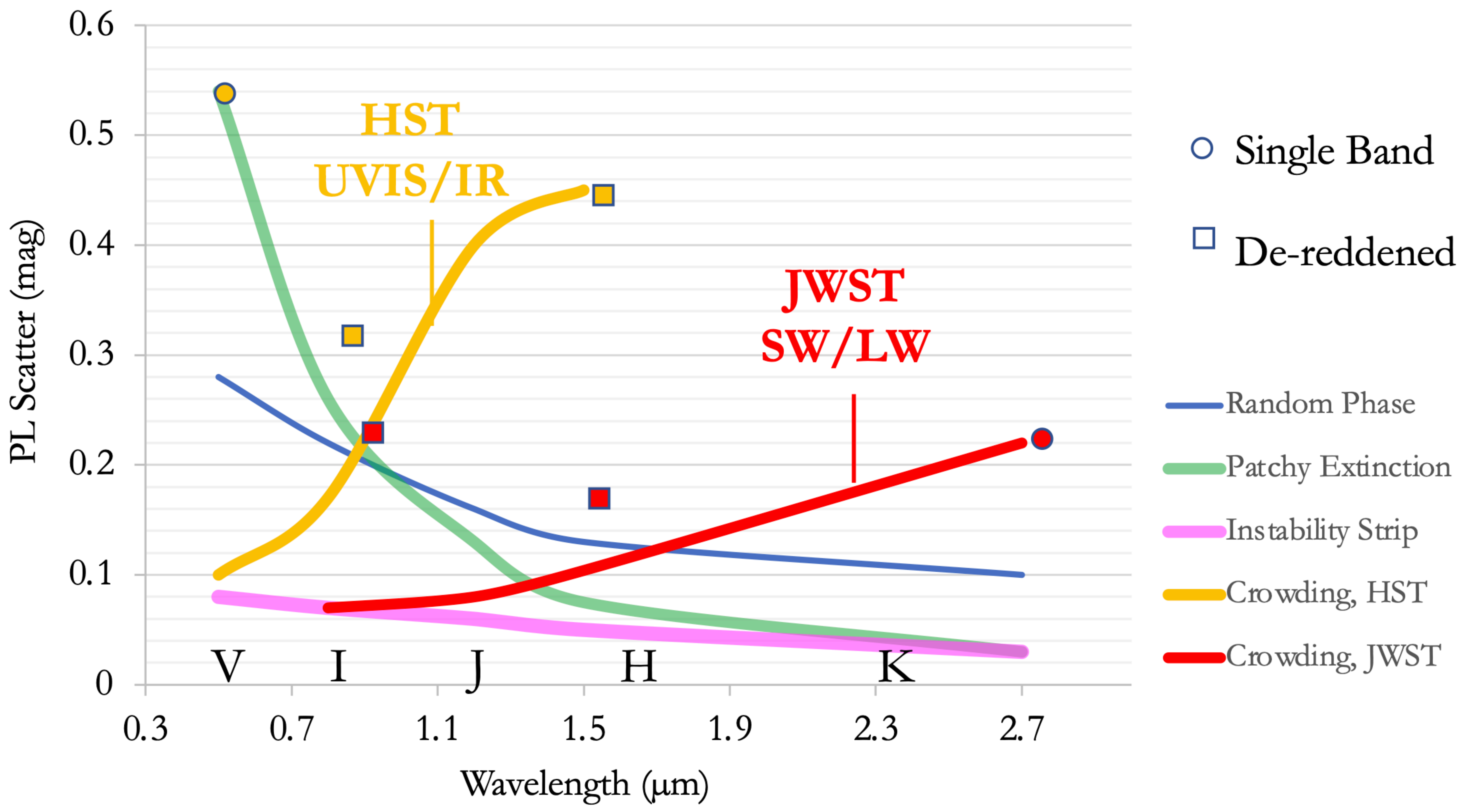
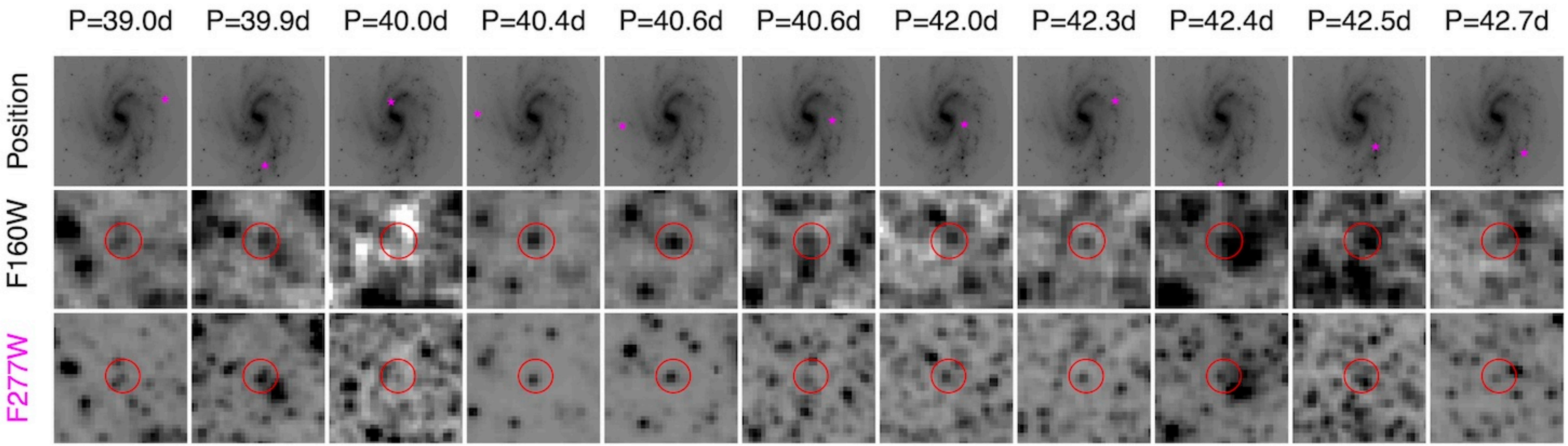
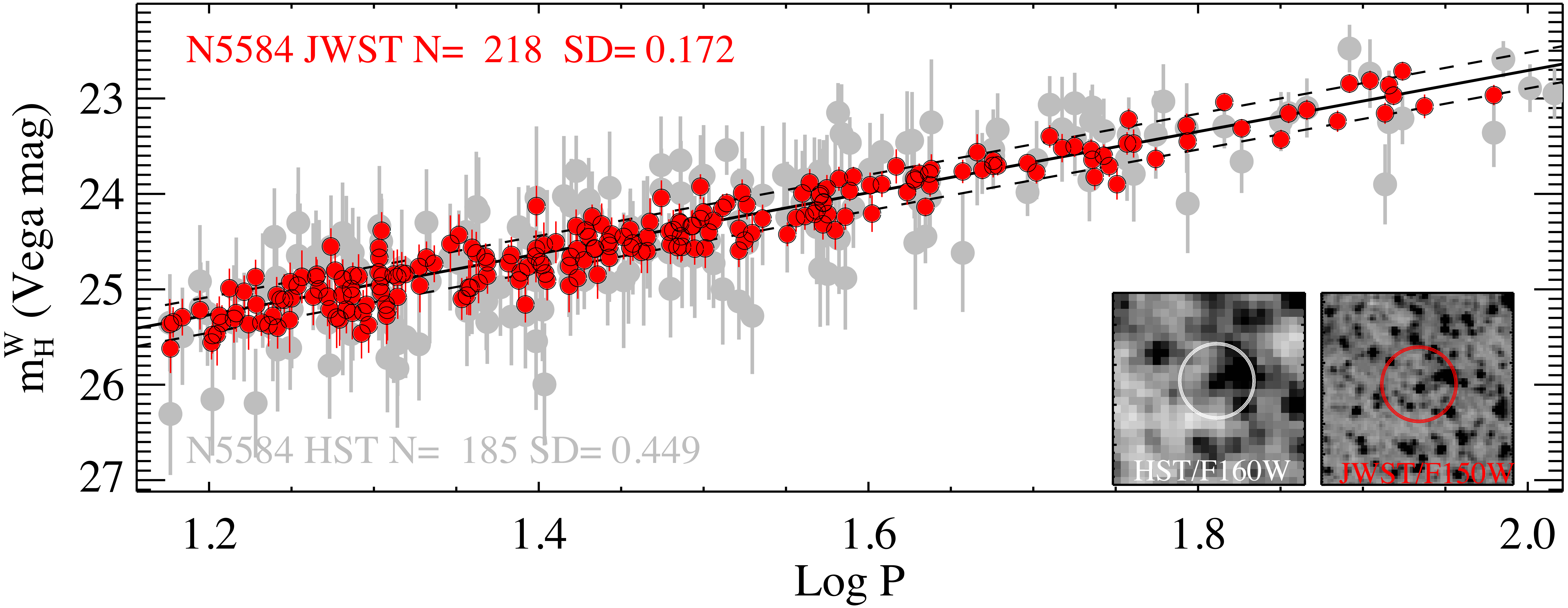


0.6
0.5
0.4
0.3
0.2
0.1
0
PL Scatter (mag)
HST
UVIS/IR
JWST
SW/LW
V
I
J
H
K
0.3
0.7
1.1
1.5
1.9
2.3
2.7
Wavelength (µm)
Single Band
De-reddened
Random Phase
Patchy Extinction
Instability Strip
Crowding, HST
Crowding, JWST

Postage Stamps



Cepheid PLR



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JWST Results

- NGC 4258, NGC 5584 presented here (more in progress)
- Scatter in PLR improved by factor of 2.5 with JWST
- Overall, JWST-HST offset is constrained to 0.02 ± 0.04 mag