Two out of Three Ain't Bad!

By D'Arcy Kenworthy
with the SH0ES collaboration
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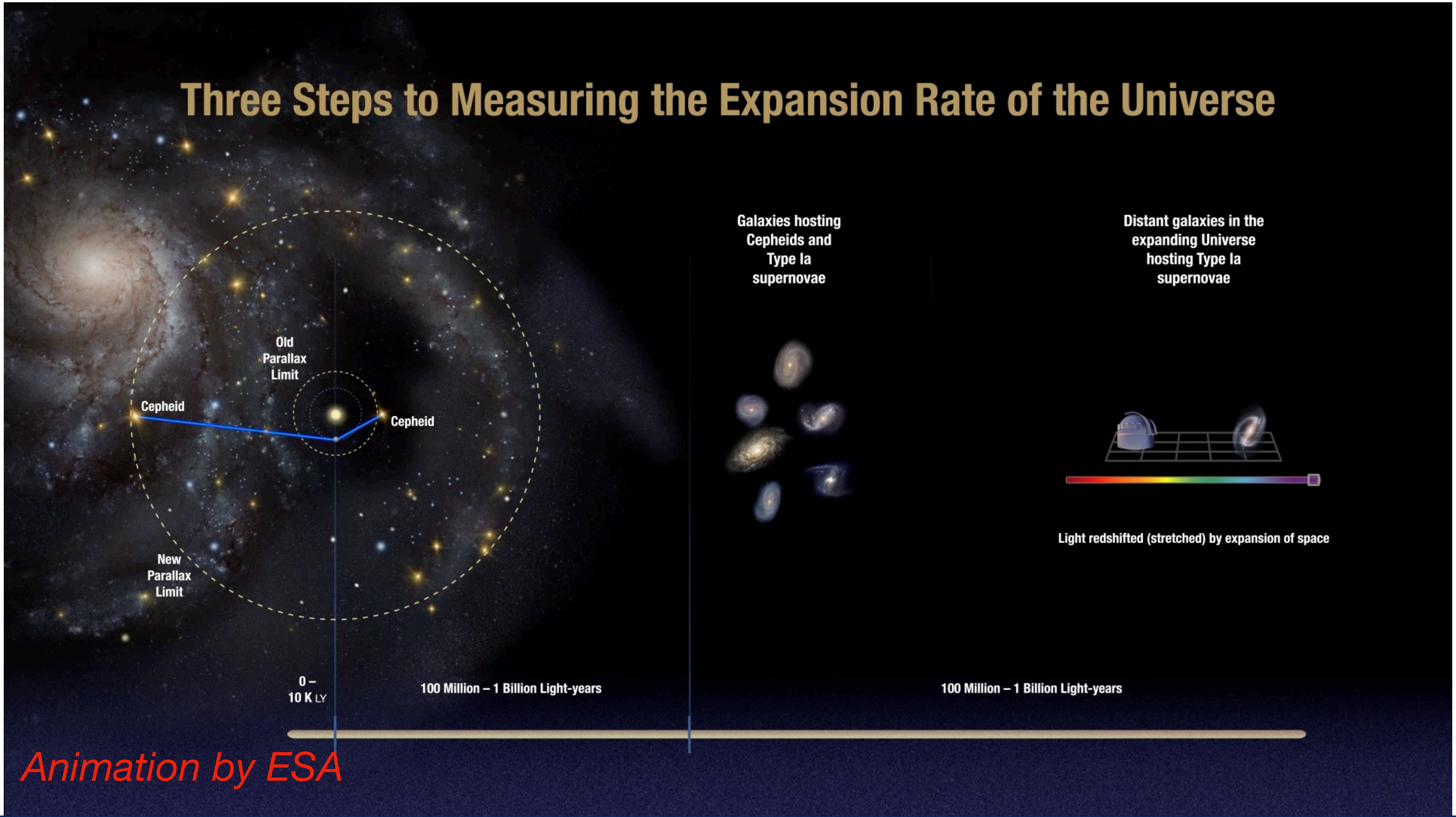
Distance Ladder



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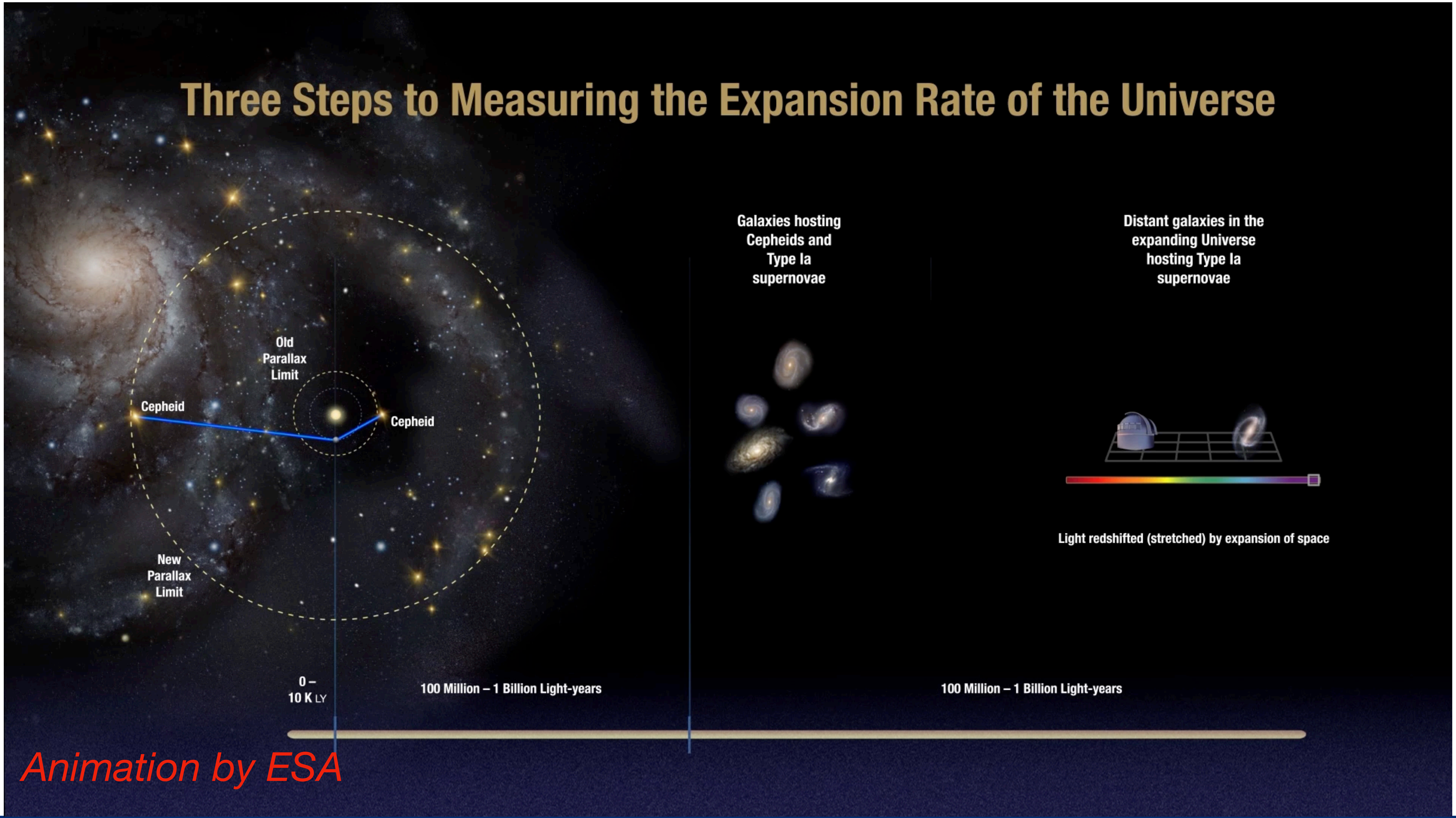


Measurement of H_0

- 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

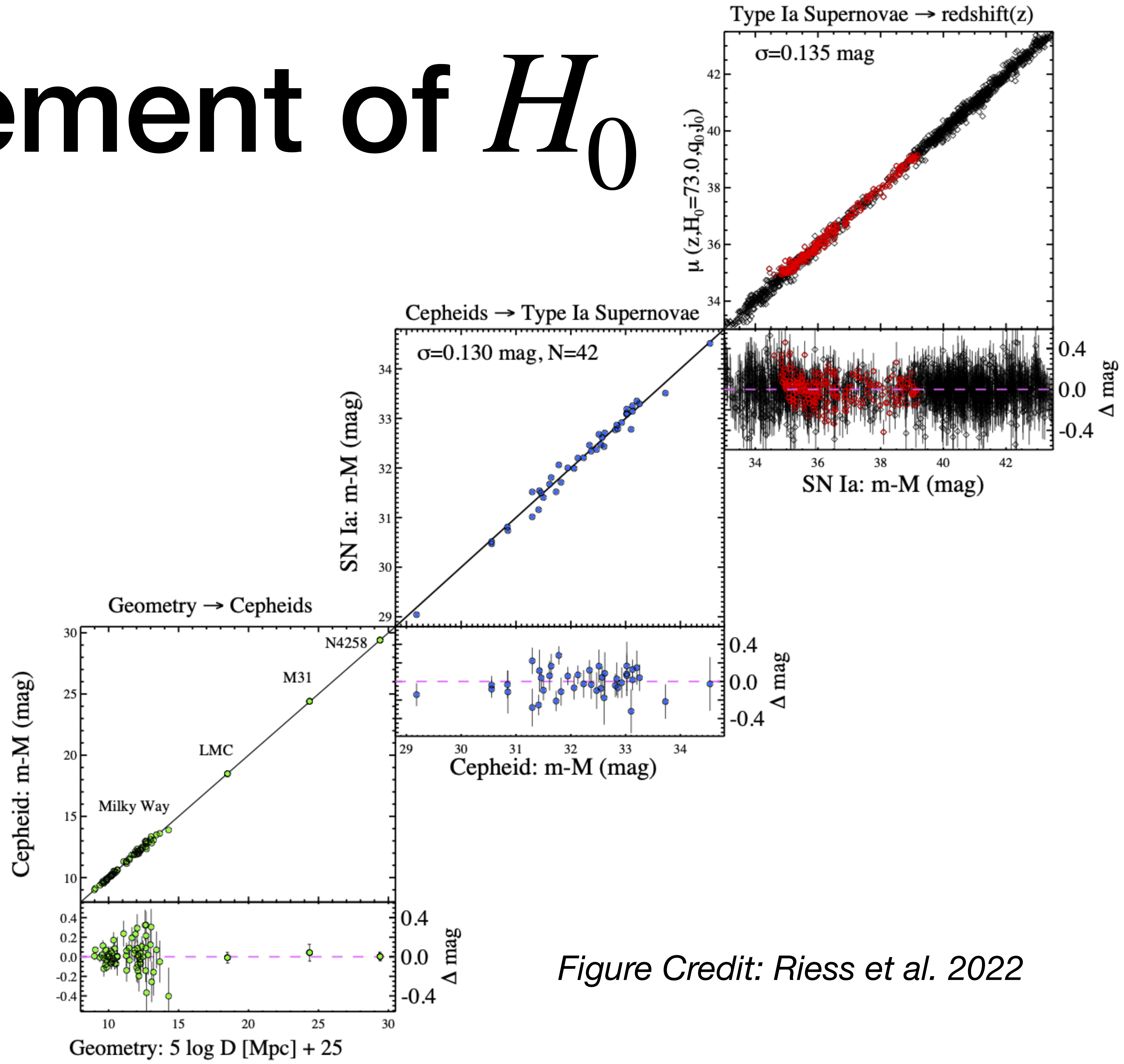


Figure Credit: Riess et al. 2022

Hubble Tension

- Distance ladder measurement of H_0 in the local universe
- $H_0 = 73.2 \pm 1.04$ 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

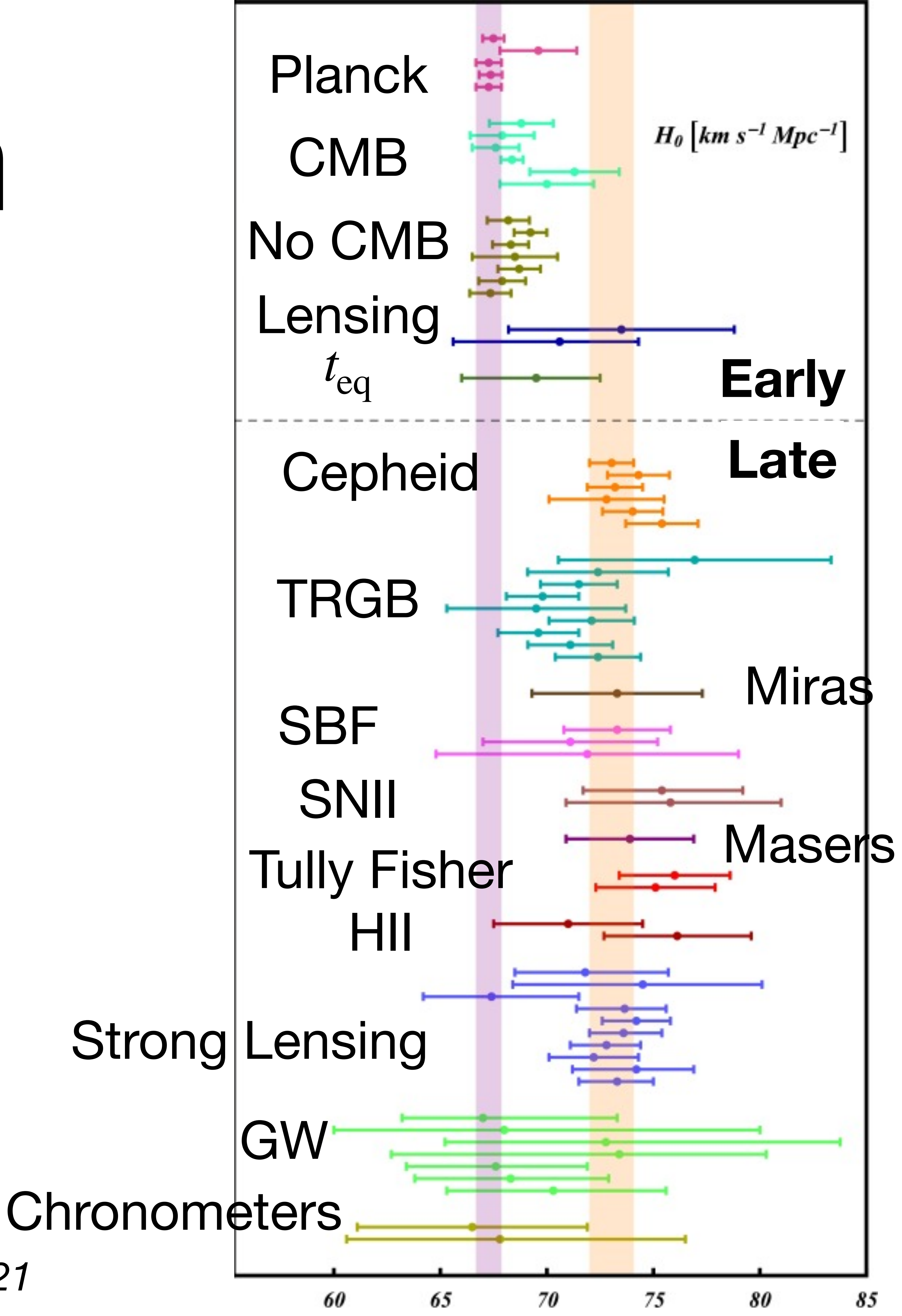
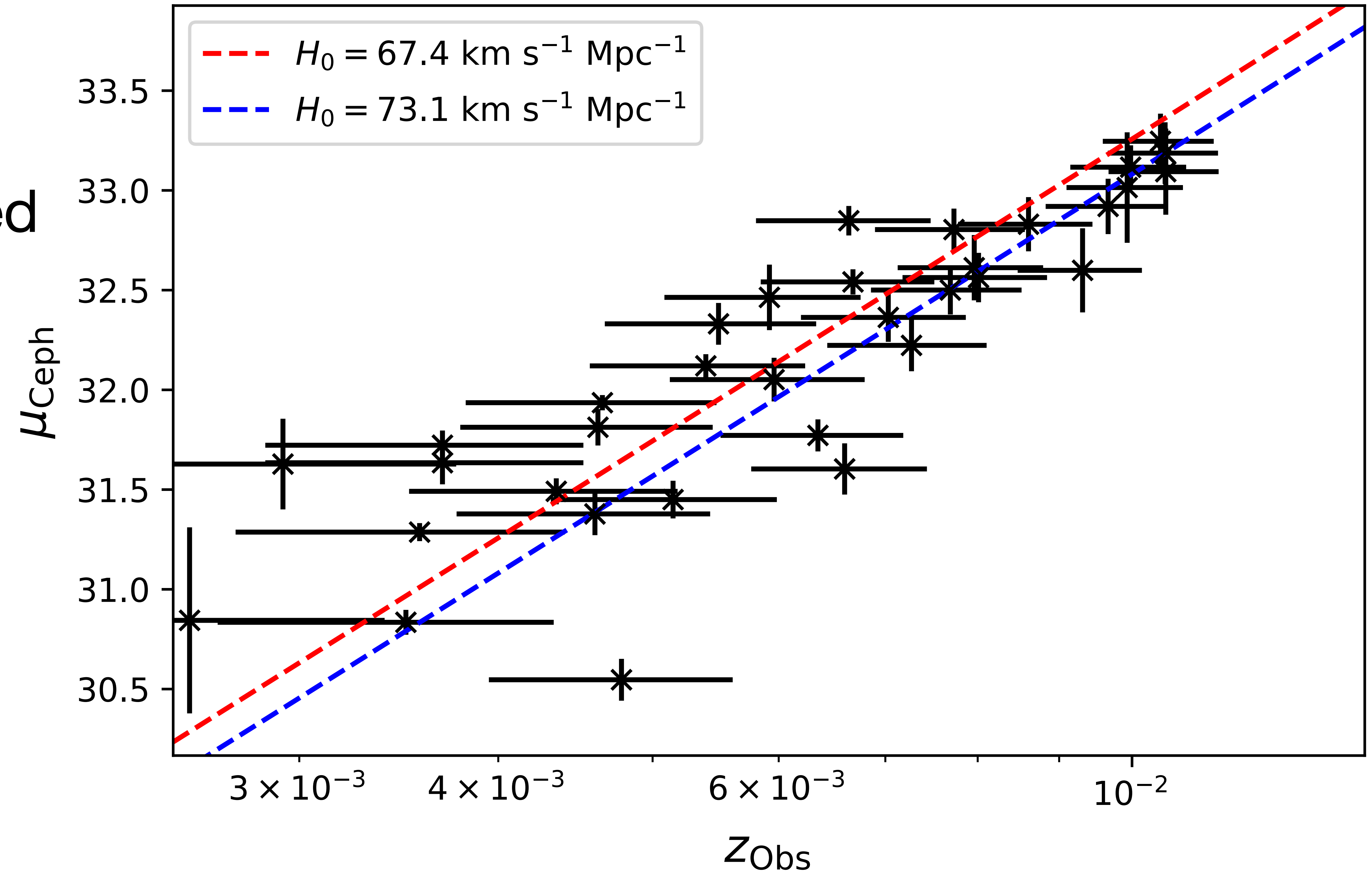


Figure Credit: di Valentino et al. 2021

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



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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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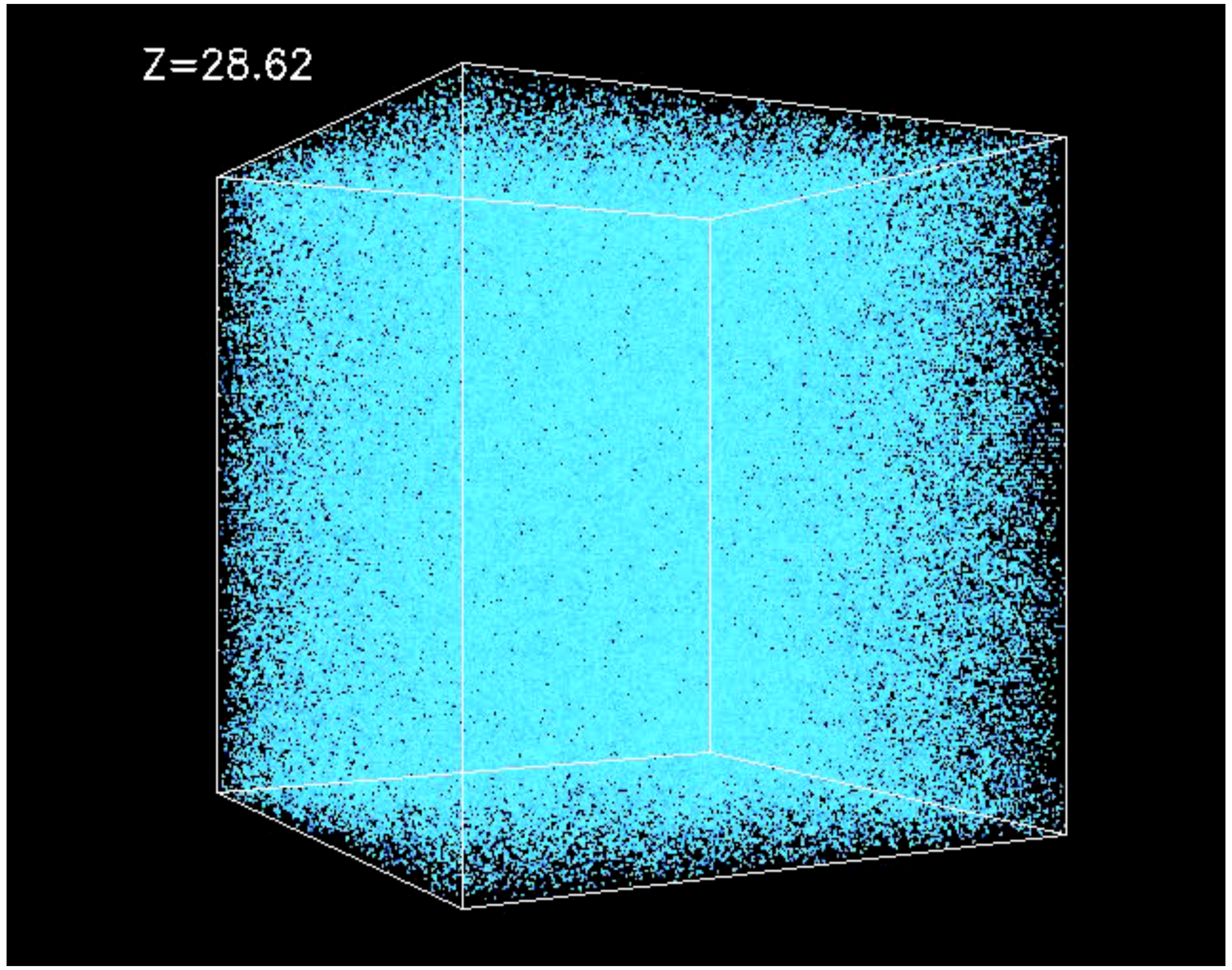

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Voids at ~ Gpc scales?

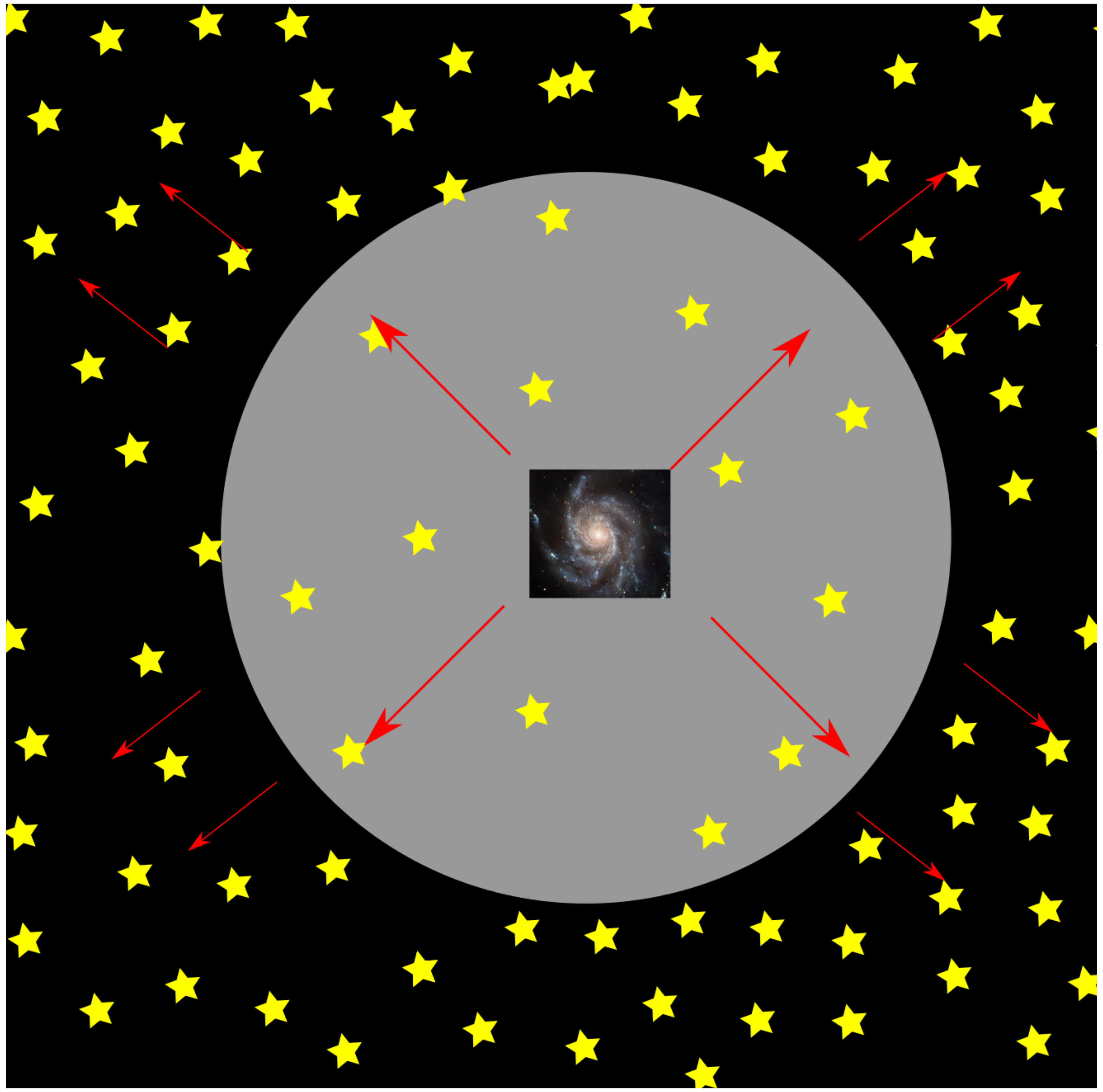
- Grey, underdense region will expand more quickly than black background

- 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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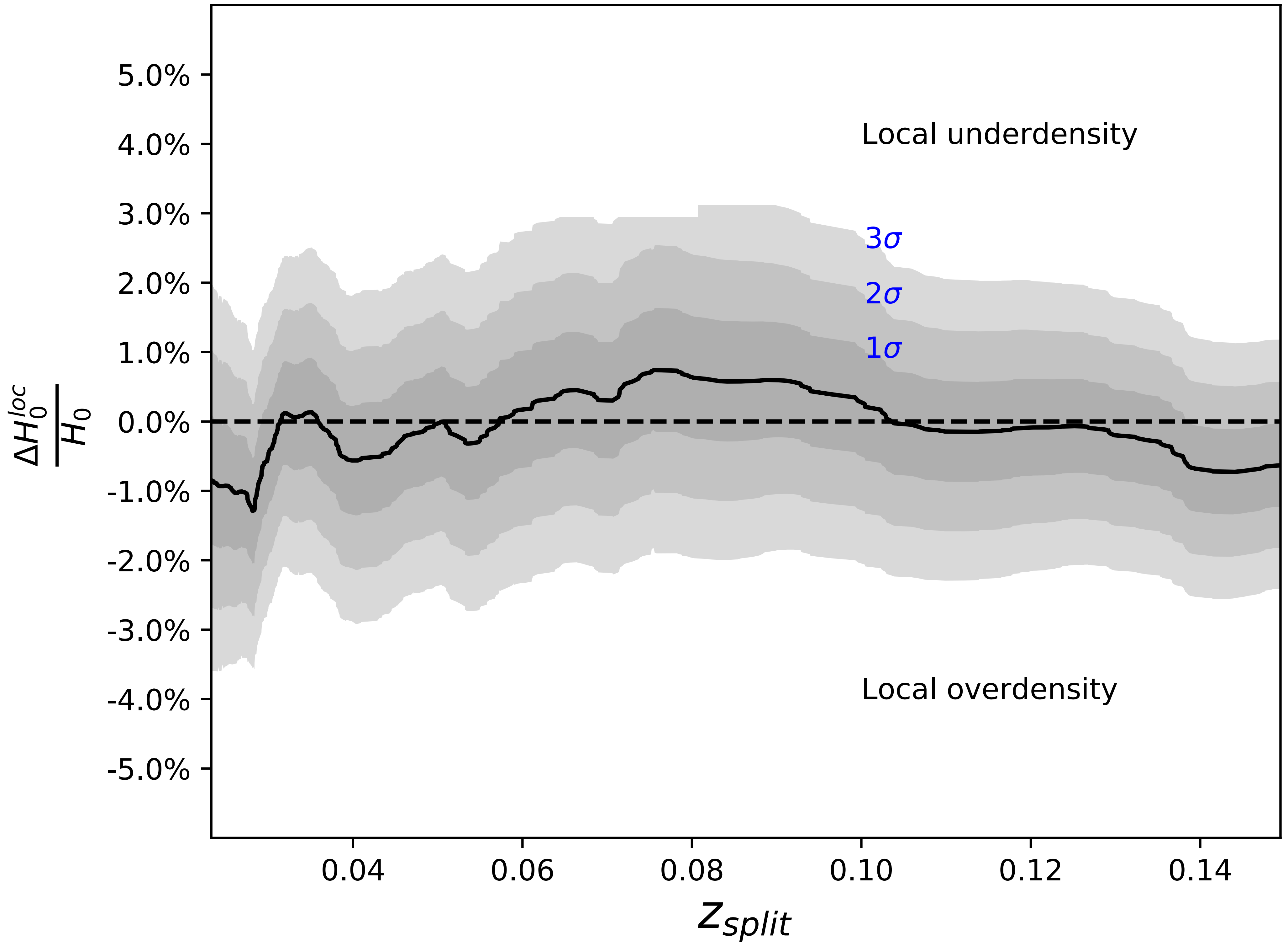

Difference in H_0 when measured above and below z_{split} There is no evidence for a void biasing the local measurement of the Hubble constant at any redshift. Smoothed for visualization

Figure Credit: Kenworthy et al. *2019*

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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

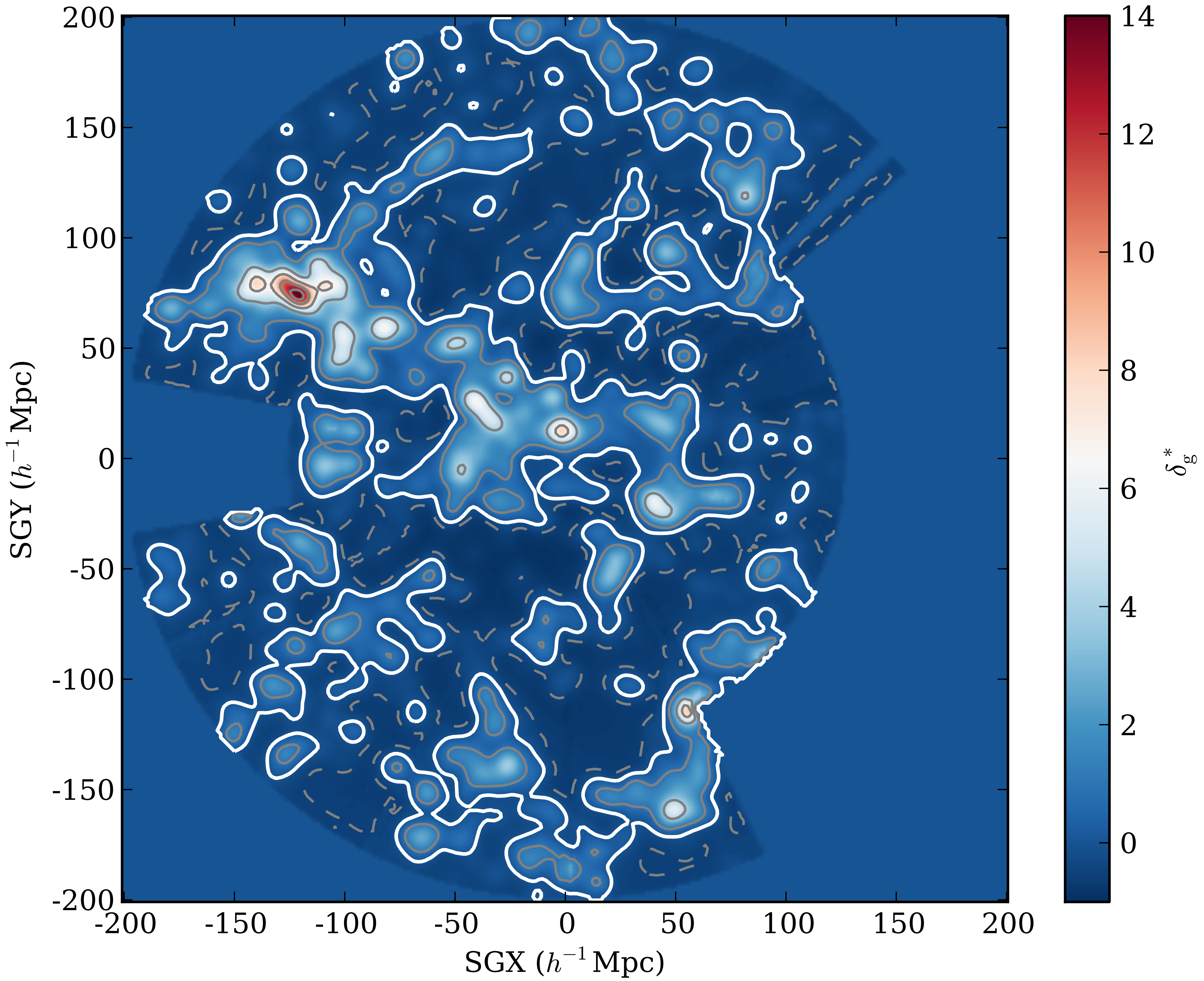
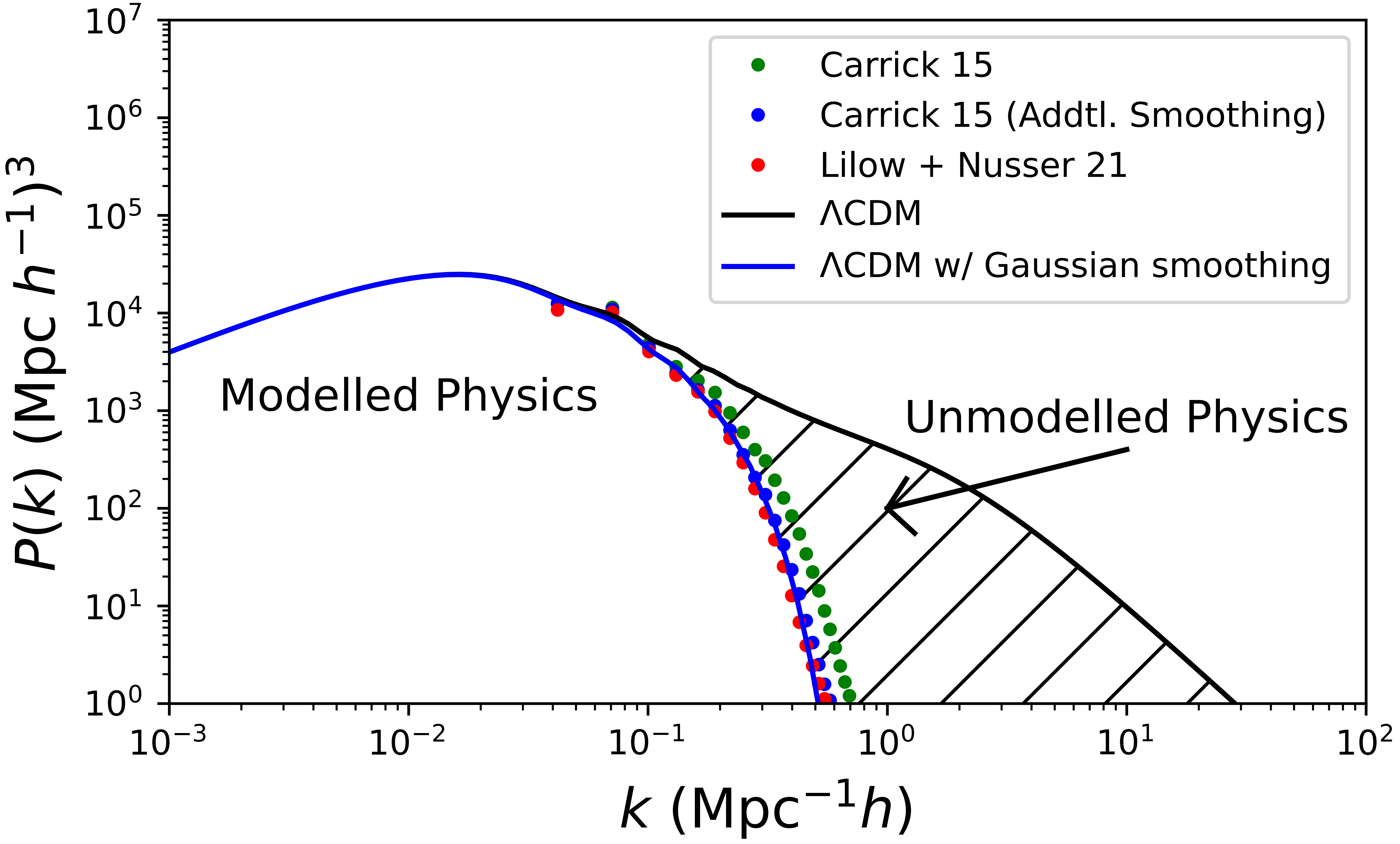


Figure Credit: Carrick et al. 2015

Power Spectra



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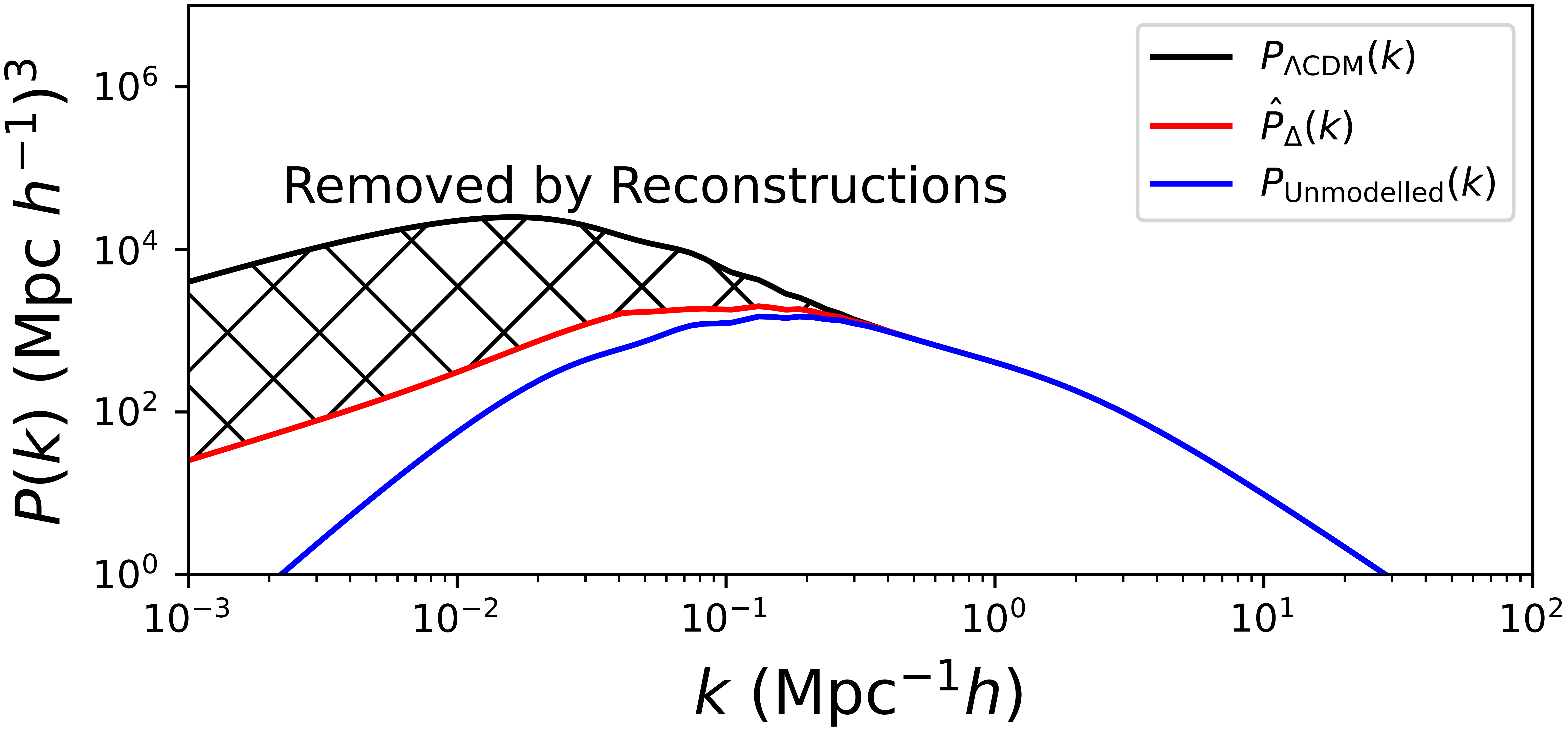

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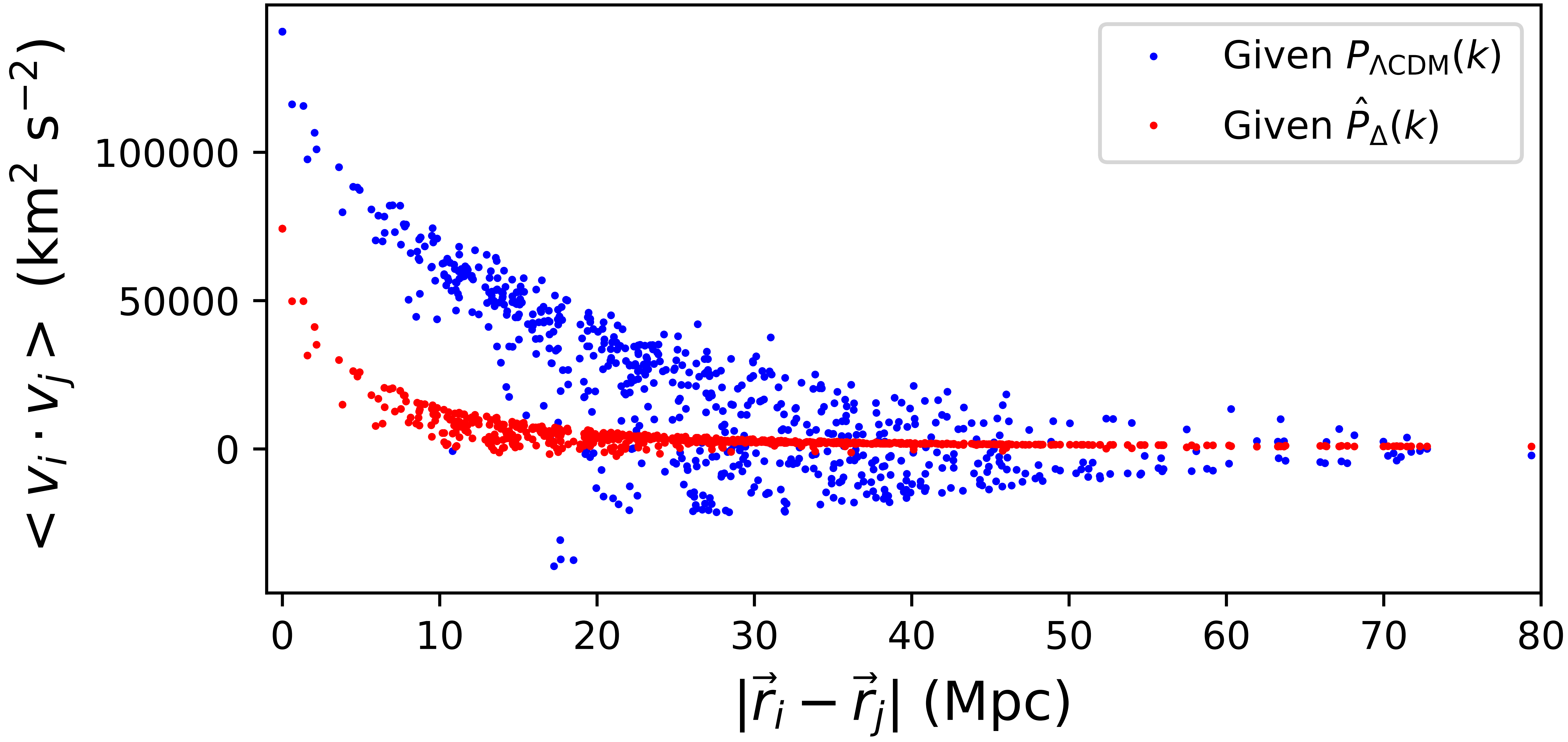
Velocity Covariance



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*

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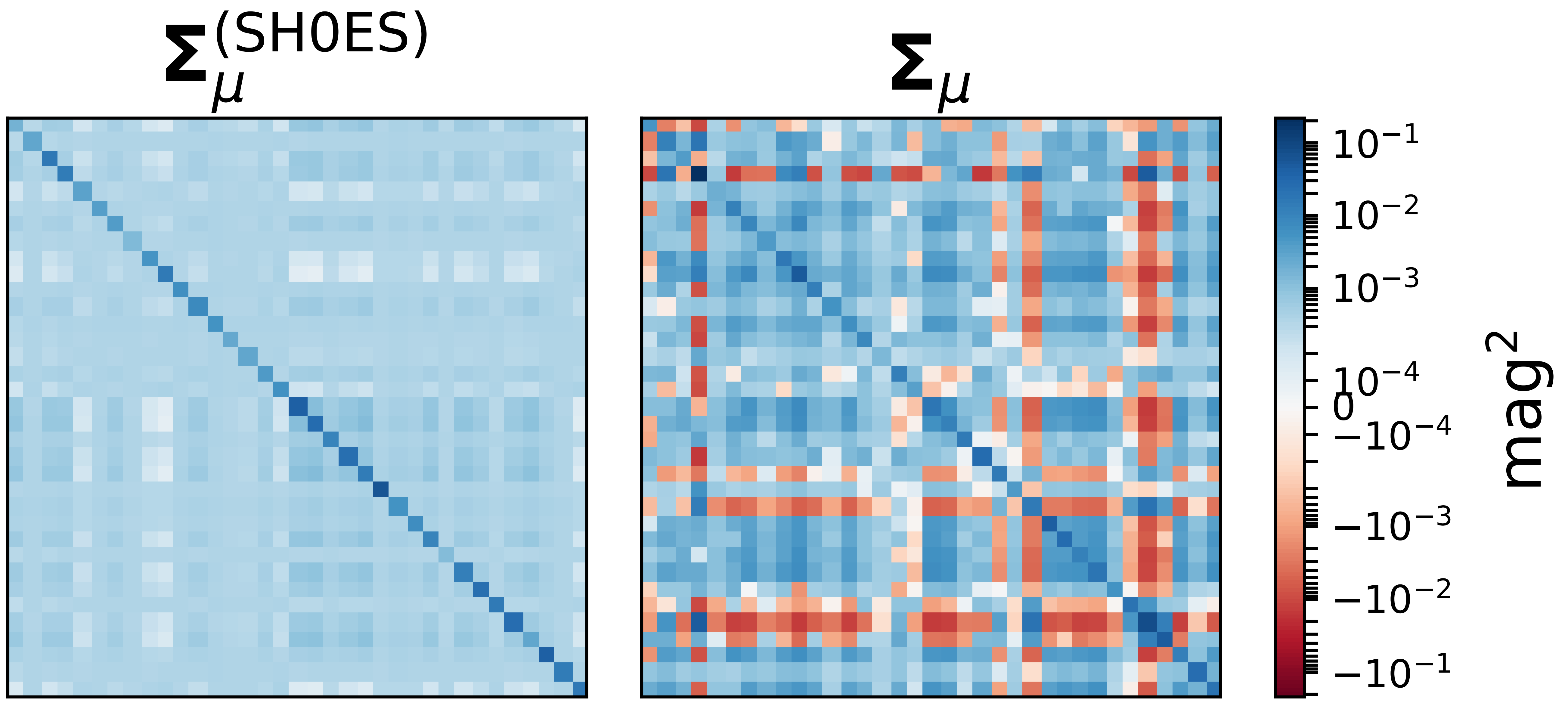
Cepheid Systematics

- More sensitive to Cepheid distance systematics
- 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

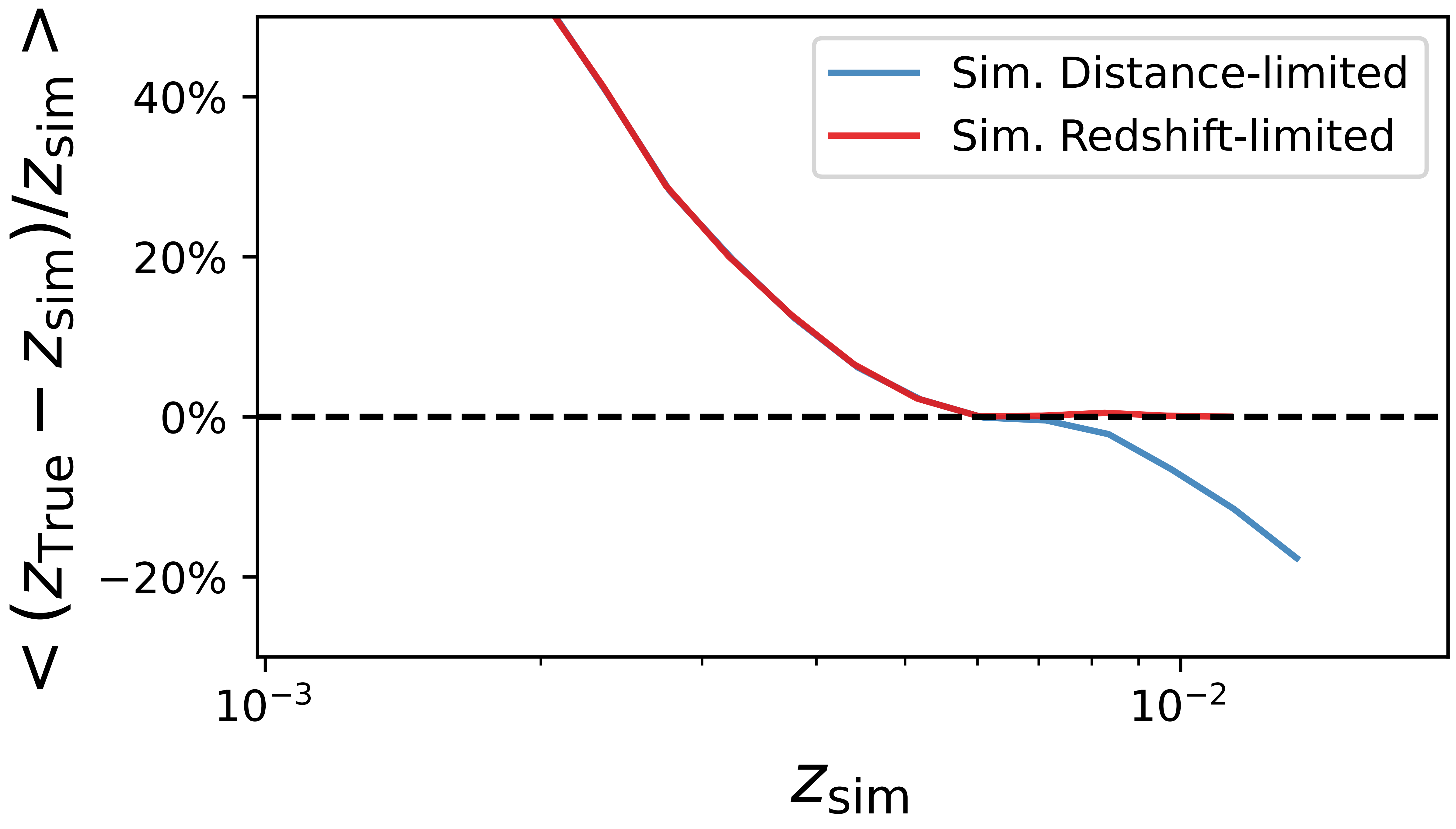


Figure Credit: Kenworthy et al. *2022, Brout* et al. *2022*

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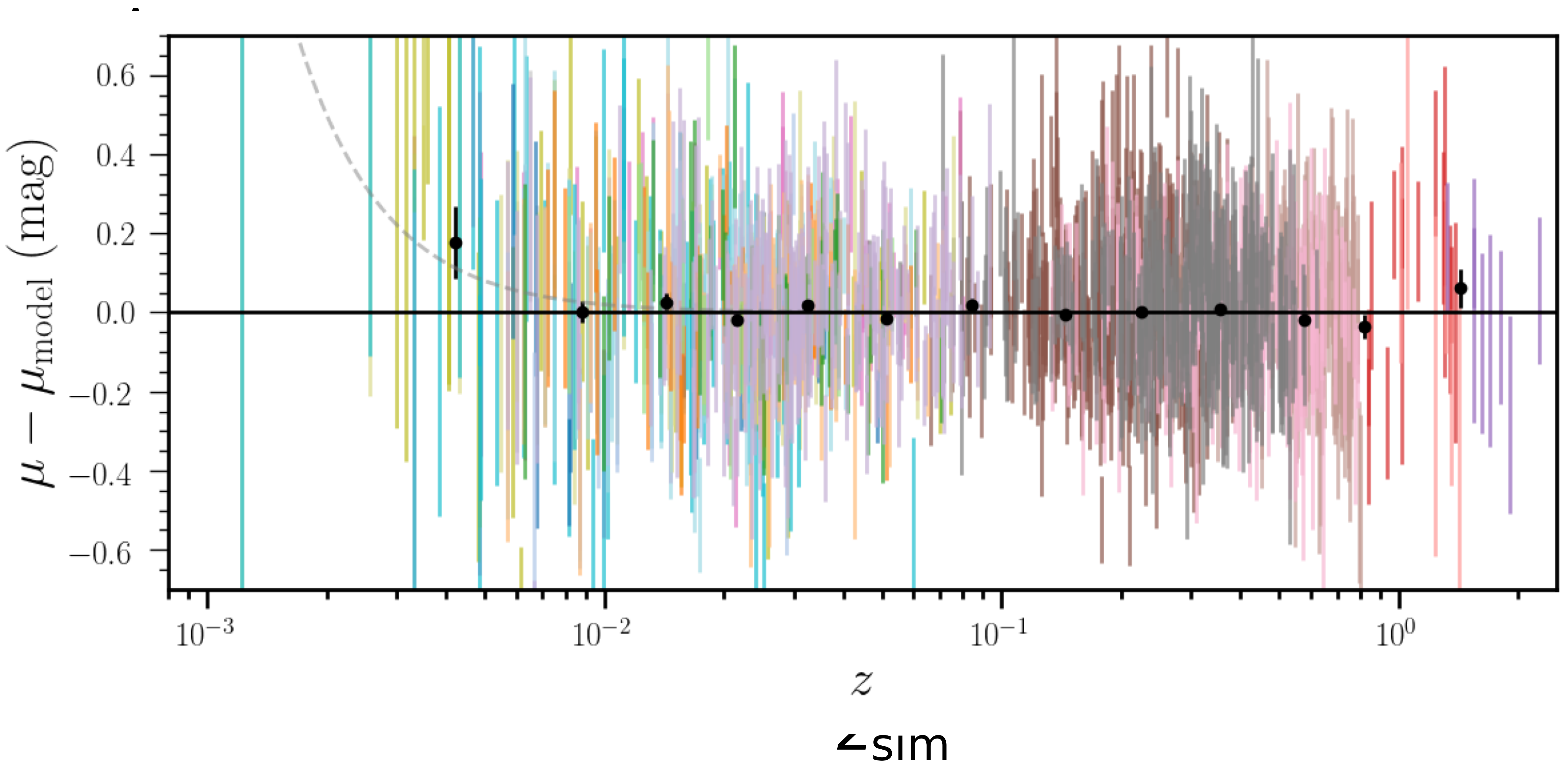

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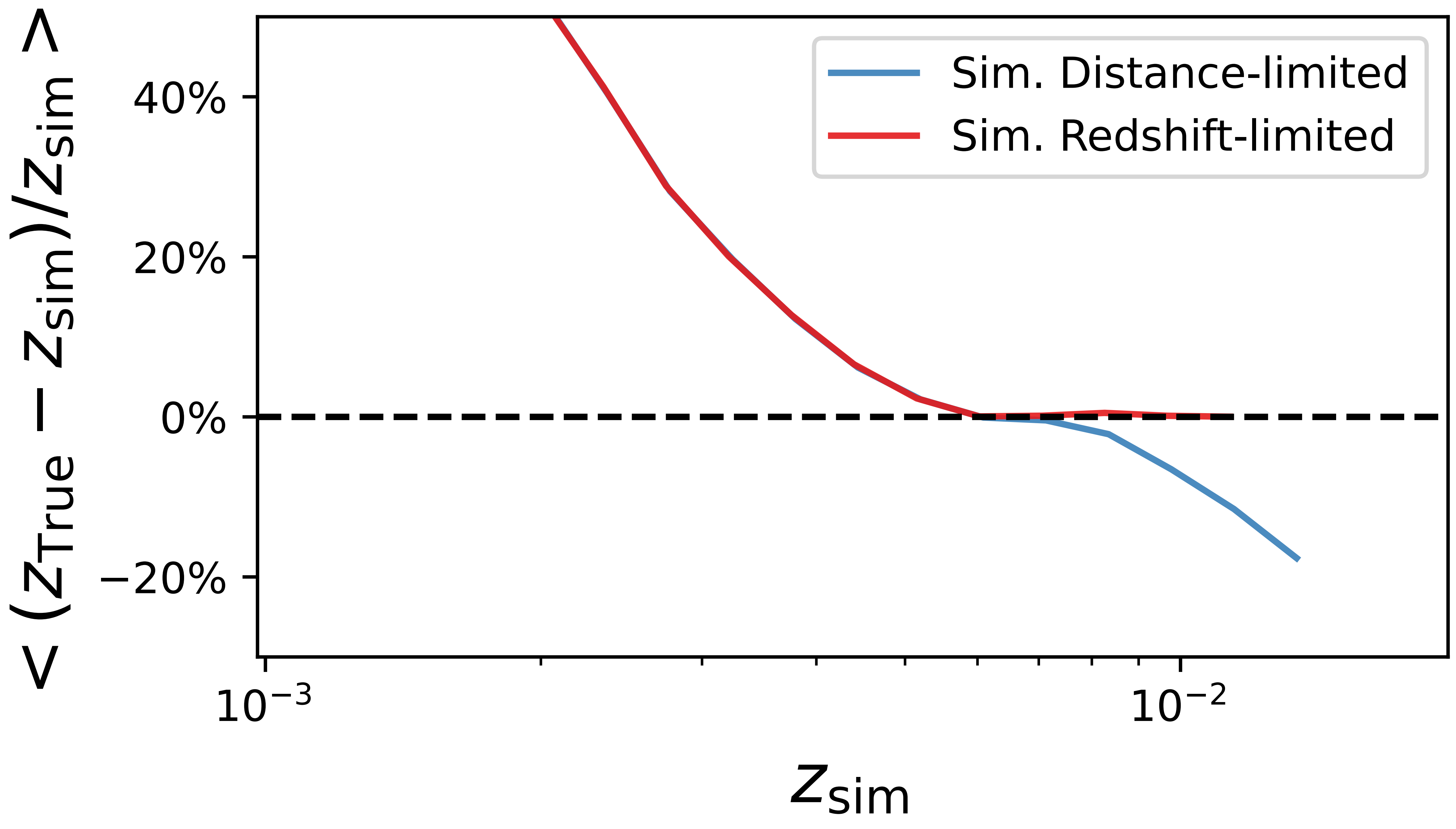

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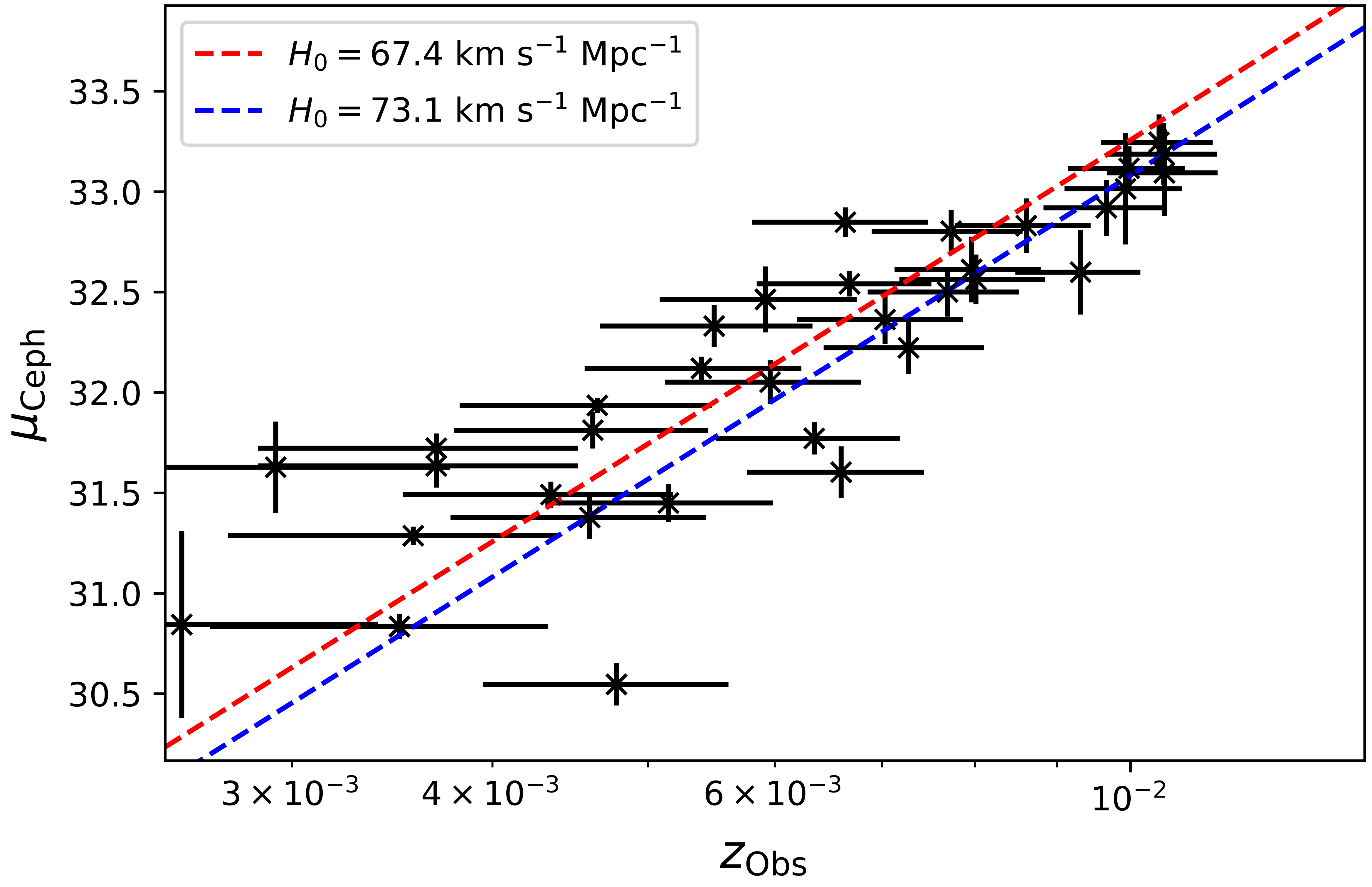
Modeling

- 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

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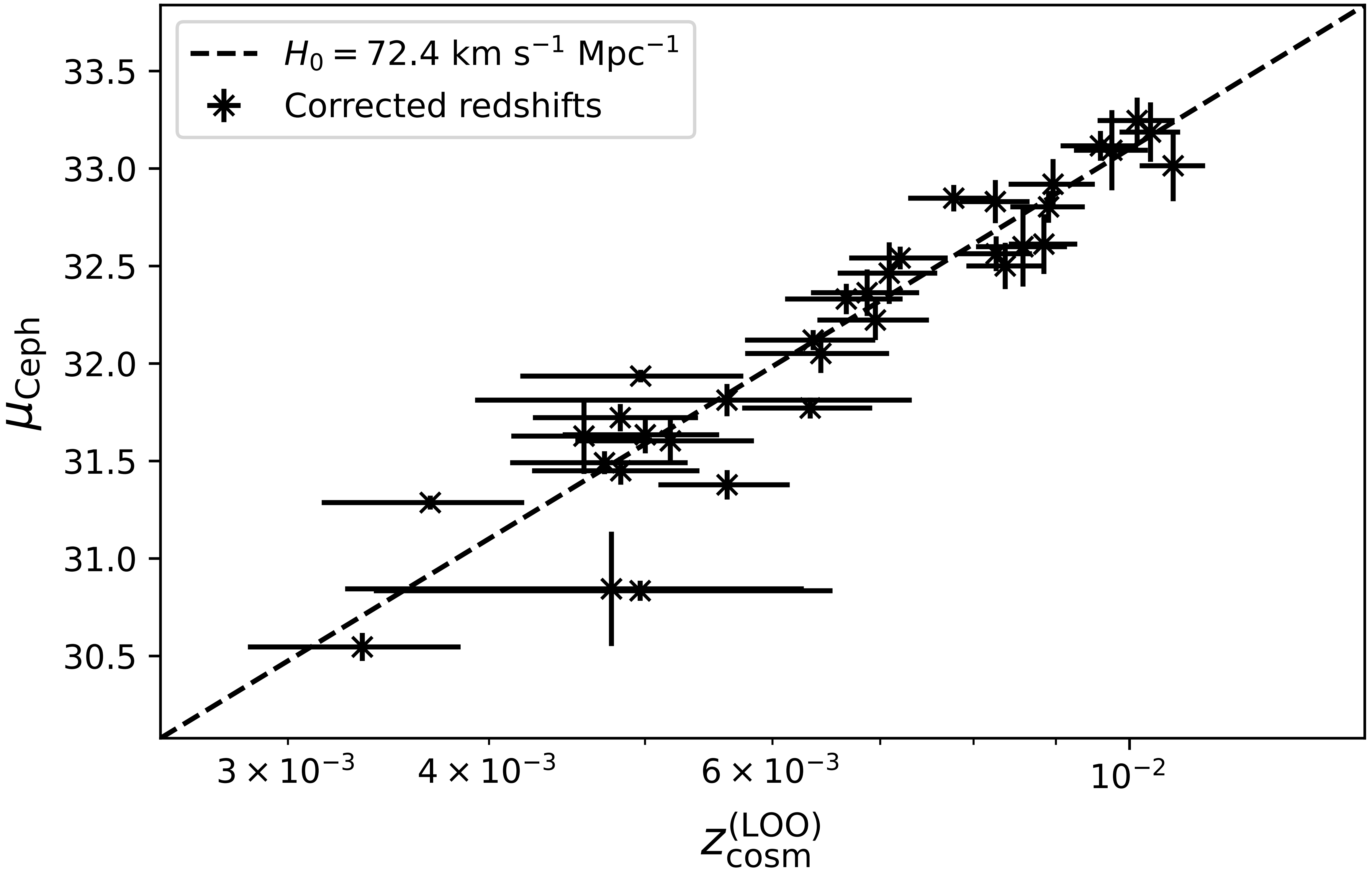

Assuming distance-limited selection, using Carrick 2015 reconstructions, and fitting PV amplitude

Residuals

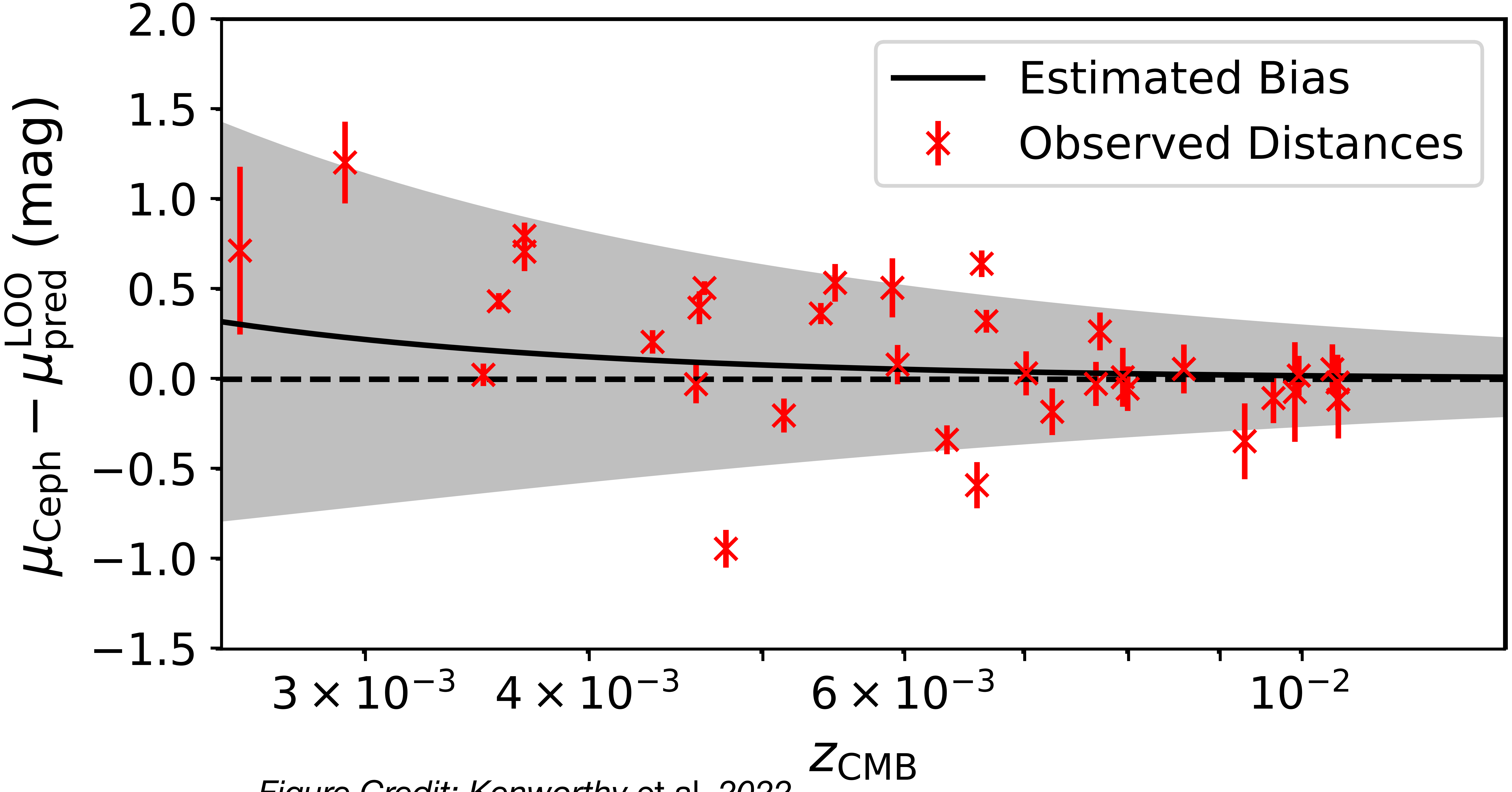

Figure Credit: Kenworthy et al. *2022*

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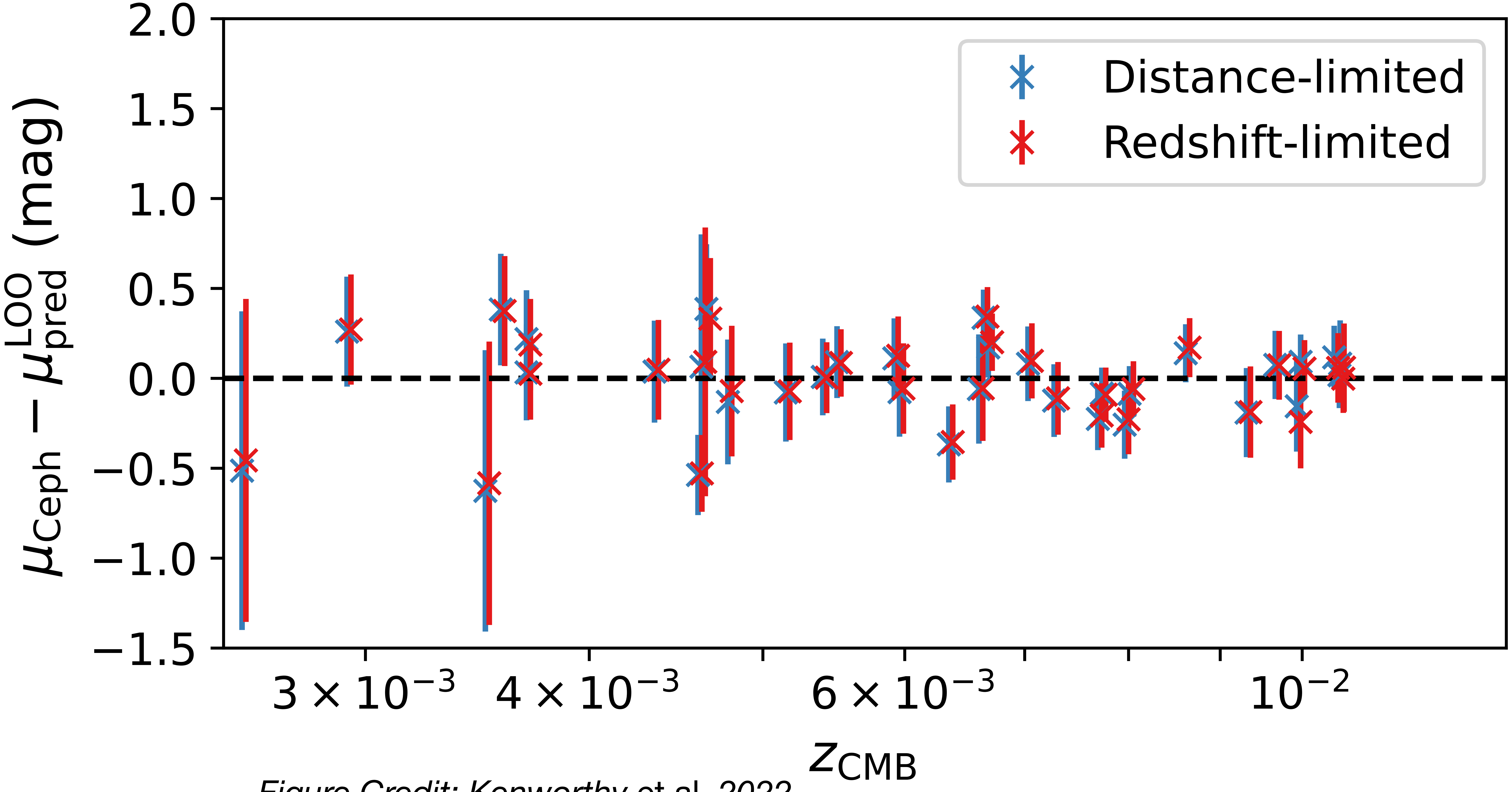

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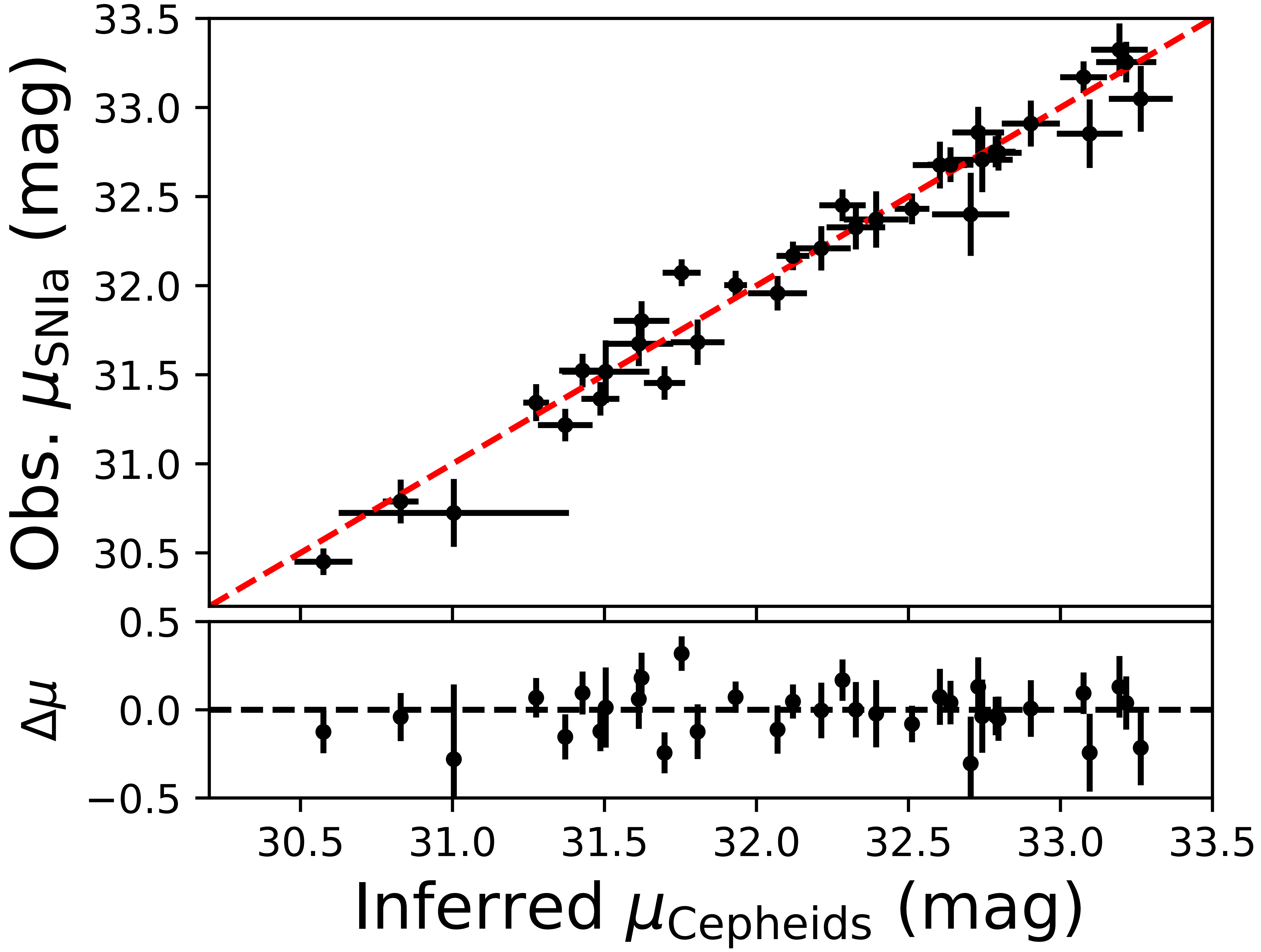
Cepheid/SN comparison

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



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Results

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

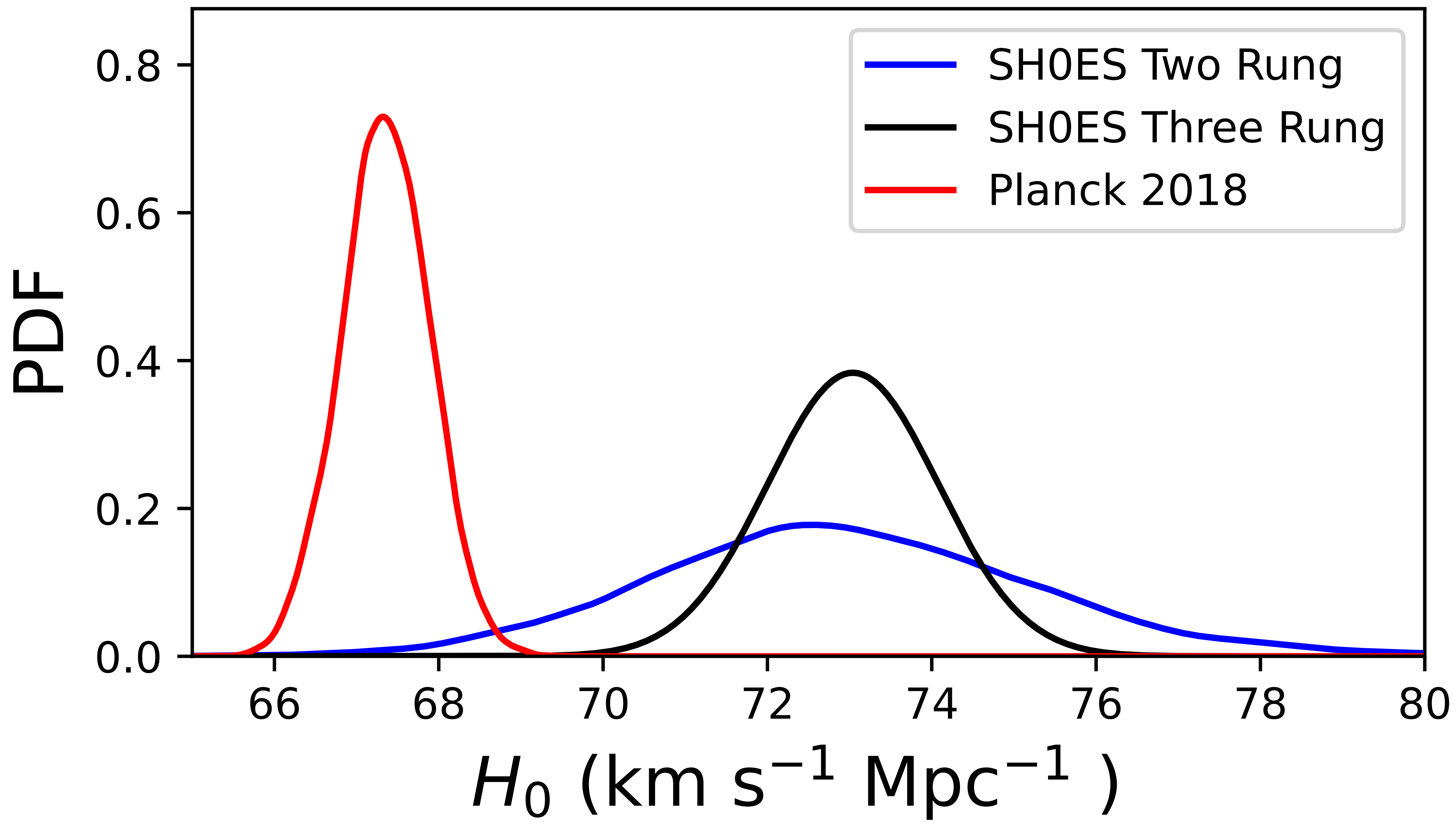
Without galaxy reconstruction

$71.6^{+4.5}_{-4.6}$ km s^{-1} Mpc^{-1}

Fiducial Result: $72.8^{+2.4}_{-2.2}$ km s^{-1} Mpc^{-1}

2.4σ **discrepancy with Planck**

Conclusion: SNe Ia systematics are unlikely to be the source of the Hubble tension



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