Sample variance in the local measurements of H_0

Heidi Wu (Caltech→OSU)

with Dragan Huterer (U. Michigan)

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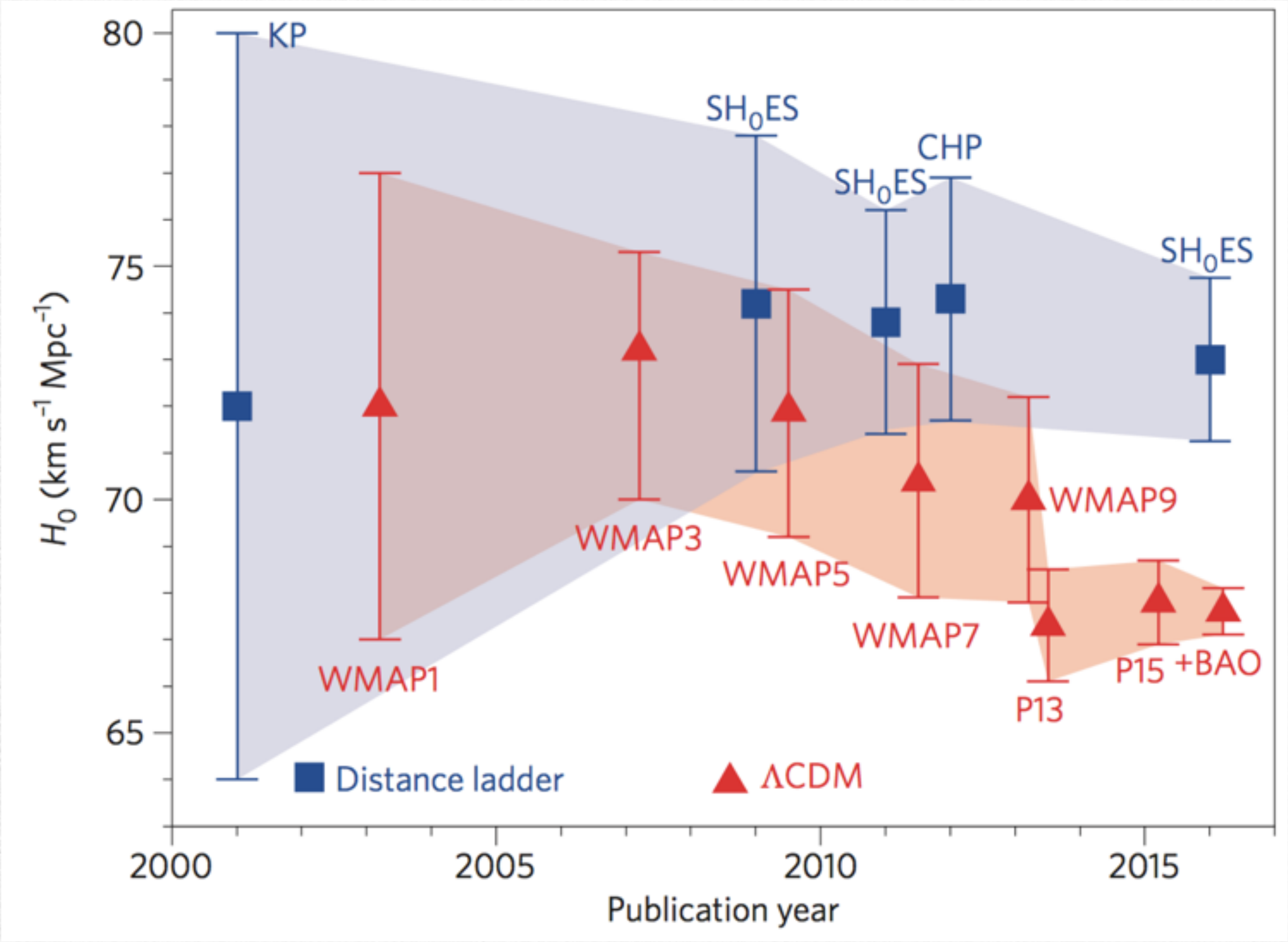
Tension in H_0 measurements



Beaton (2016); Freedman (2017)

$H_0^{local} = 73.24 \pm 1.74$ km s^{-1} Mpc^{-1}

(Riess et al. 2016)

$H_0^{CMB} = 66.93 \pm 0.62$ km s^{-1} Mpc^{-1}

(*Planck* int. XLVI 2016)

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Can we alleviate this tension by considering the **sample variance** of local measurements?

$H_0^{CMB} = 66.93 \pm 0.62$ km s^{-1} Mpc^{-1} (*Planck* int. XLVI. 2016)

- Measuring the sound horizon scale at recombination, which constrains $\Omega_c h^2$
- Re-analyses (*Planck* int. LI):
  - $\ell > 800$ pulls H_0 down
  - $\ell < 30$ pulls H_0 up

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- Beyond 6 parameters:
  - $\Delta N_{eff} = 0.39$ leads to 70.6 ± 1.0, but high σ_8 (*Planck* 15 XIII)
  - unchanged when including running, running of the running (Obied+17)

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- Distance ladder
  - 4 distance anchors (geometry + Cepheids)
  - 19 distance calibrators (Cepheids + SNe Ia)
  - 217 SNe Ia at $0.023 < z < 0.15$

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- Re-analyses
  - Cardona et al. (2017): 73.75 ± 2.11
  - Zhang et al. (2017): $72.5 \pm 3.1 \pm 0.77$ (blind)
  - Feeney et al. (2017): 72.72 ± 1.67
  - Follin & Knox (2017): 73.3 ± 1.7

Hubble Diagram (Hubble 1929)

$$v = H_0 \, d \quad (z << 1)$$

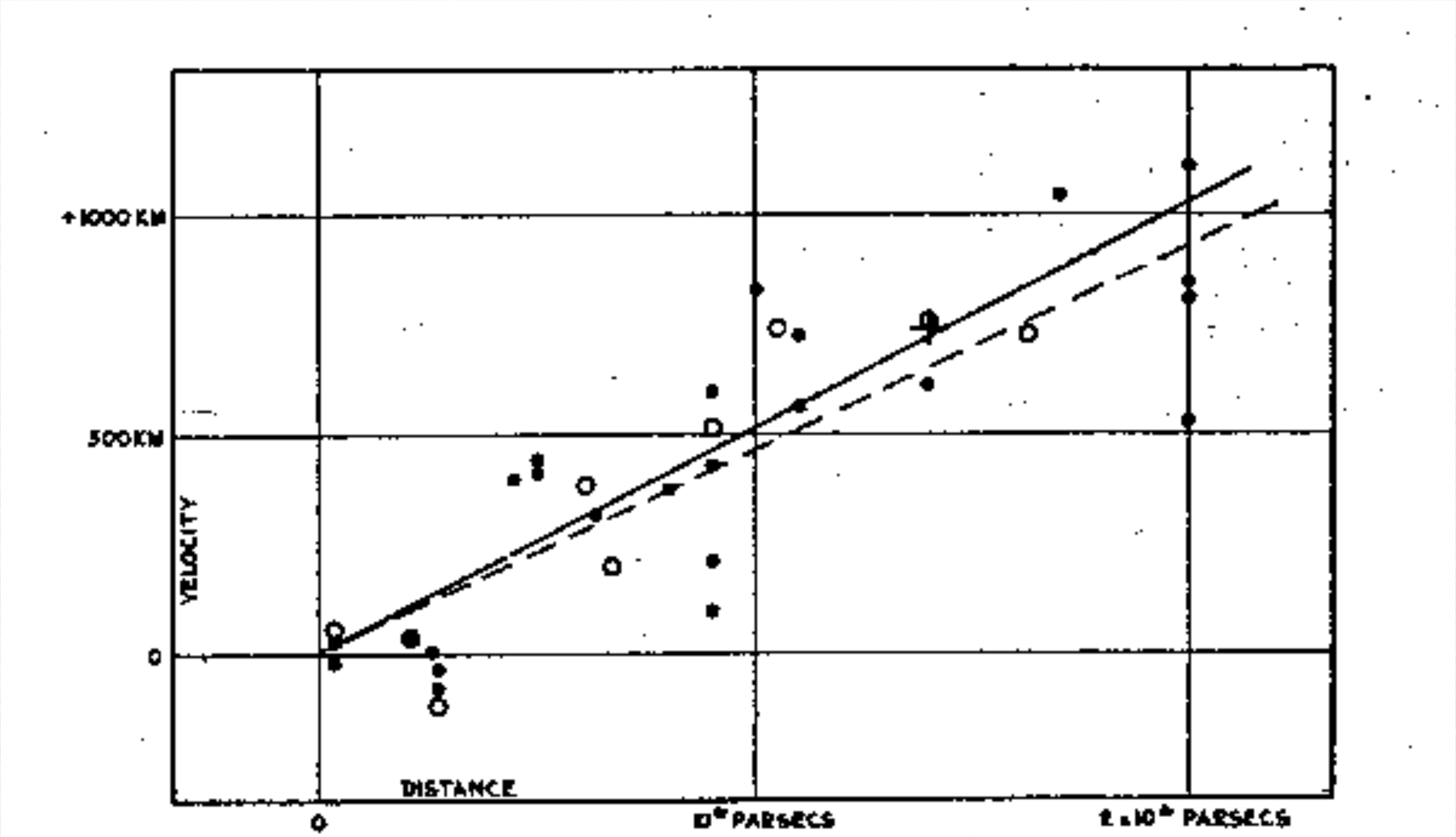

FIGURE 1

Hubble Diagram (Hubble 1929)

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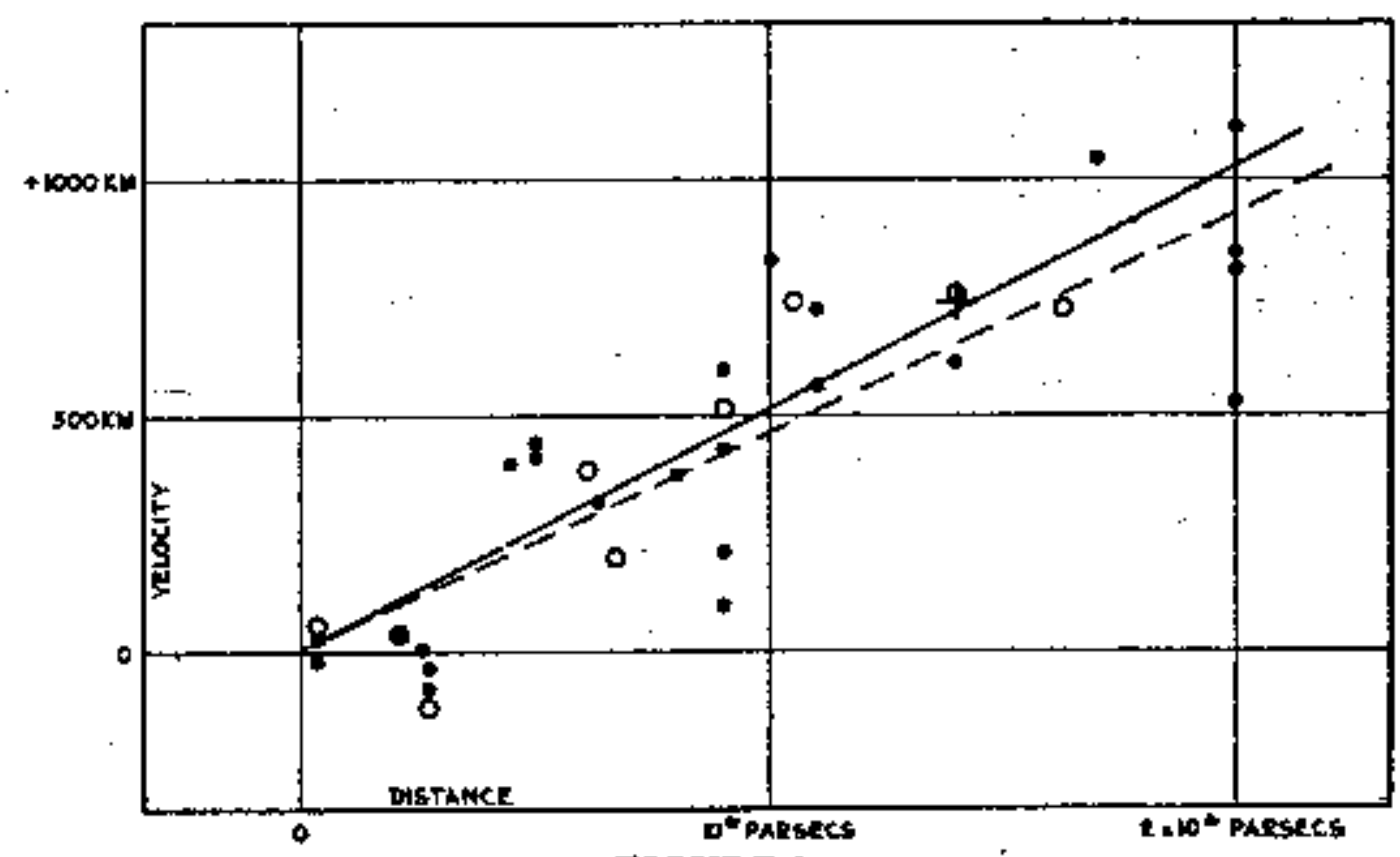
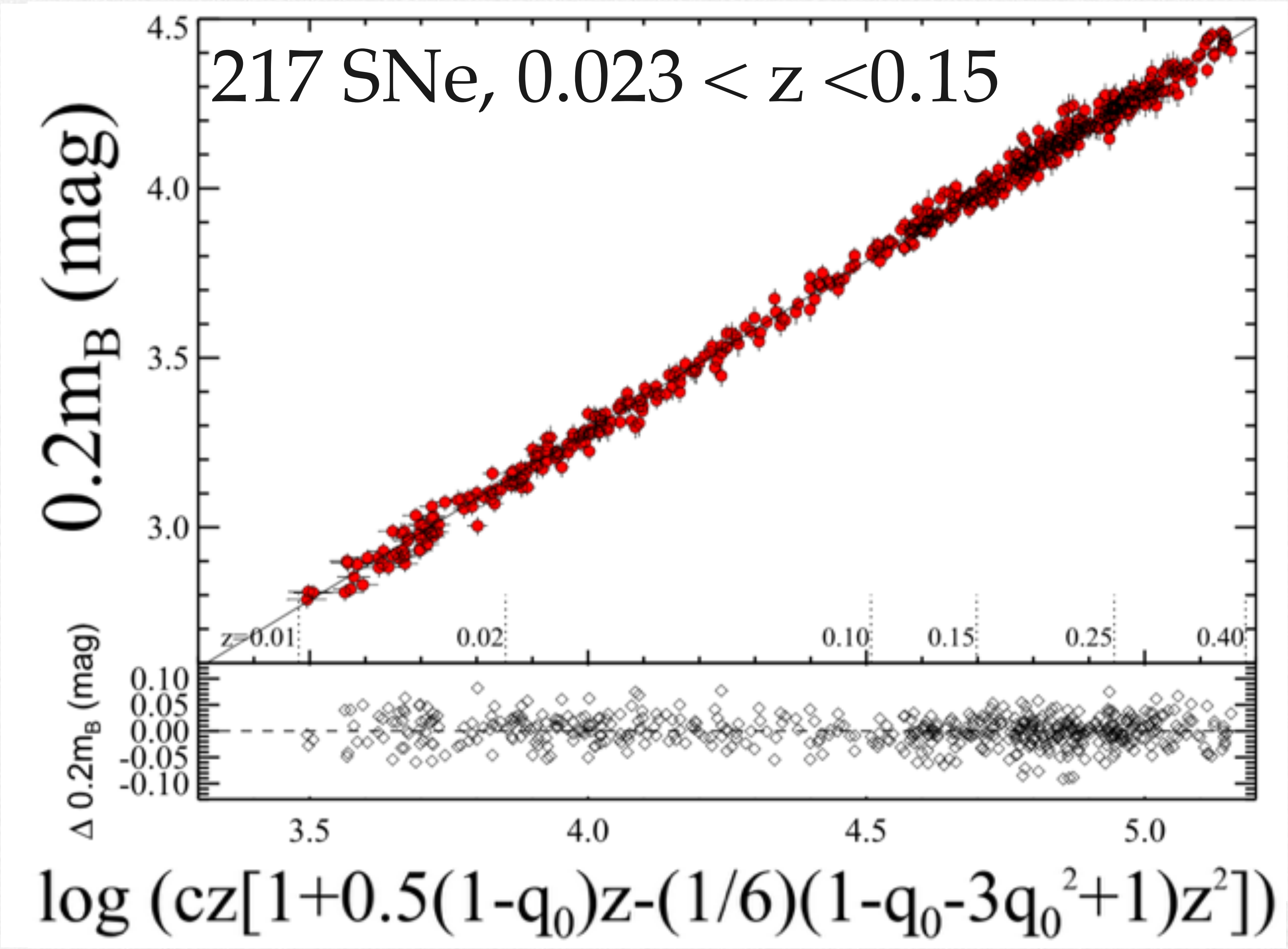


FIGURE 1

If v is biased high, H_0 will also be biased high.

Modern Hubble Diagram (Riess+2016)

m_B (apparent magnitude) vs. log(z)



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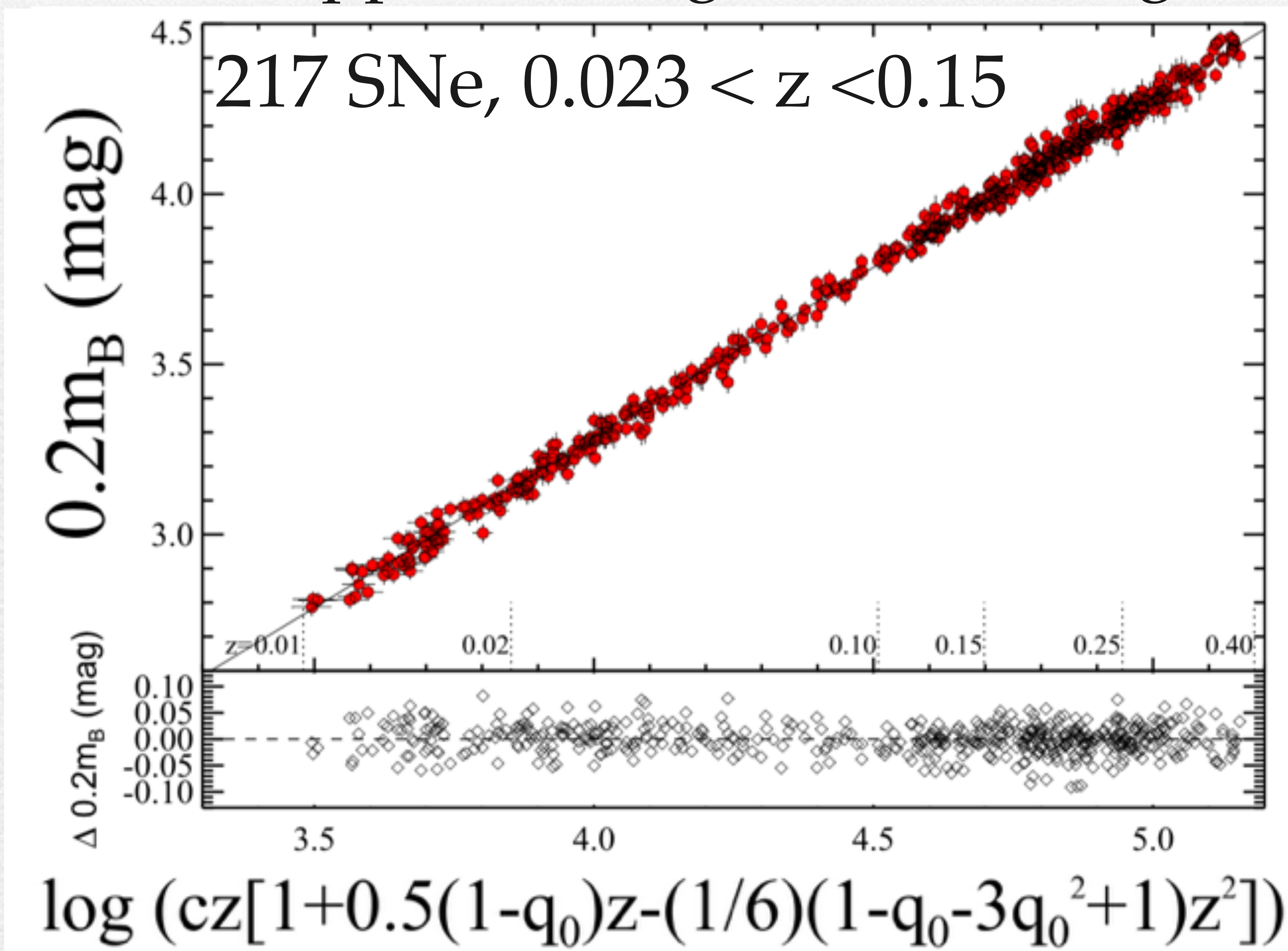

The **intercept** and the SN **absolute magnitude** determine H_0

For now let's assume that the *Planck* H_0 is the true global value.

How much ΔH_0^{loc} can come from **sample variance**?

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We use N-body simulations to characterize the variance of H_0^{loc} due to **SN sparseness** and **local density fluctuations**.

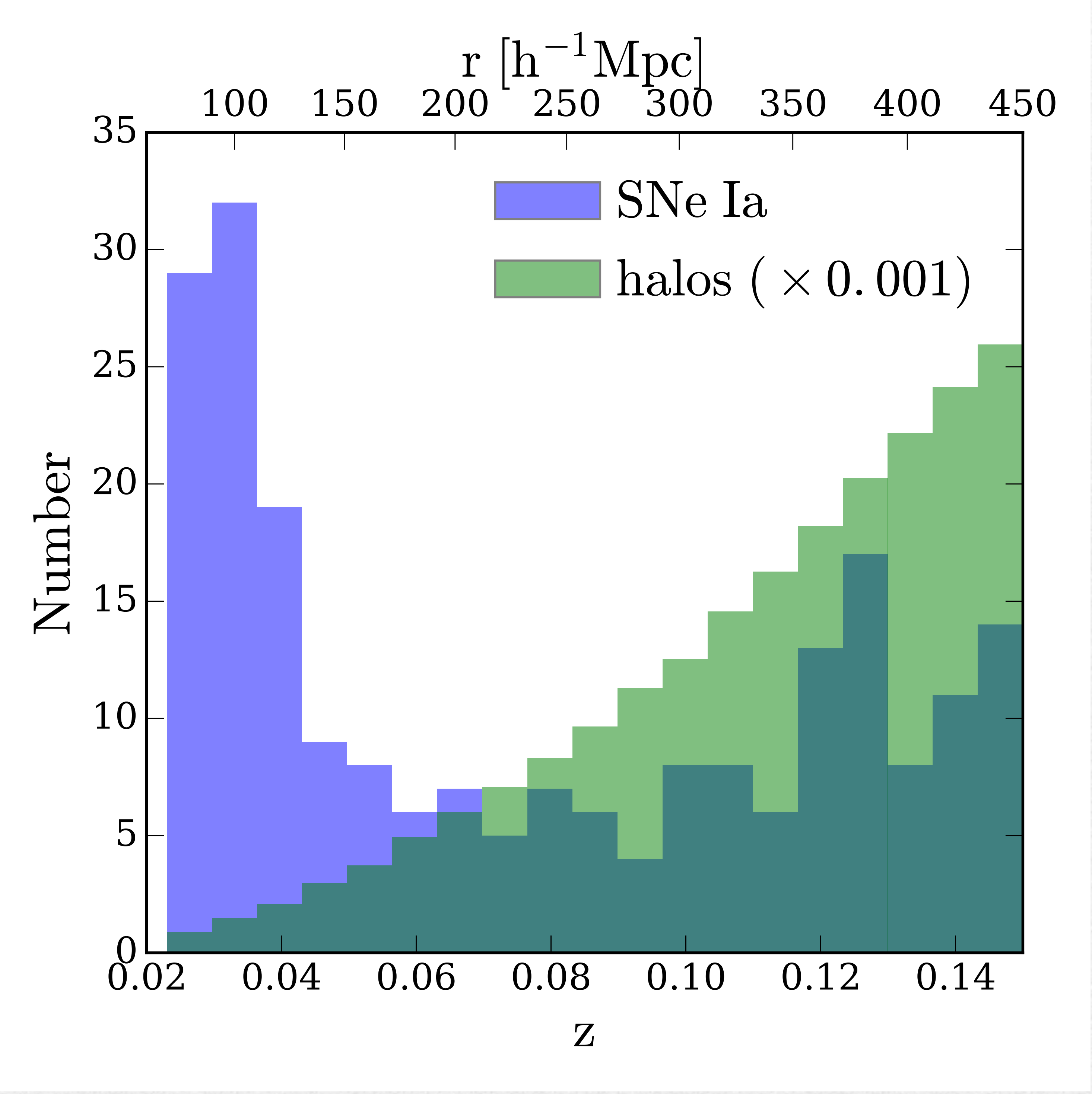
Dark Sky Simulations (Skillman et al. 2014)

- N-body simulations (2HOT)
- 8 h^{-1}Gpc, divided into 512 subvolumes of 1 h^{-1}Gpc
- resolving 2×10^{12} $M_{\odot}$ halos (about Milky Way mass)
- on-line database (yt + darksky.slac.stanford.edu)

SN sample used in Riess+16: "Supercal" (Scolnic et al. 2014, 2015)

- Uniform photometric calibration from Pan-STARRS1
- SALT2 light-curve model
- Correction of distance bias
- 217 Type Ia supernovae at $0.023 < z < 0.15$ (70 h^{-1}Mpc to 500 h^{-1}Mpc)

Redshift distribution 217 SNe Ia from Riess+16



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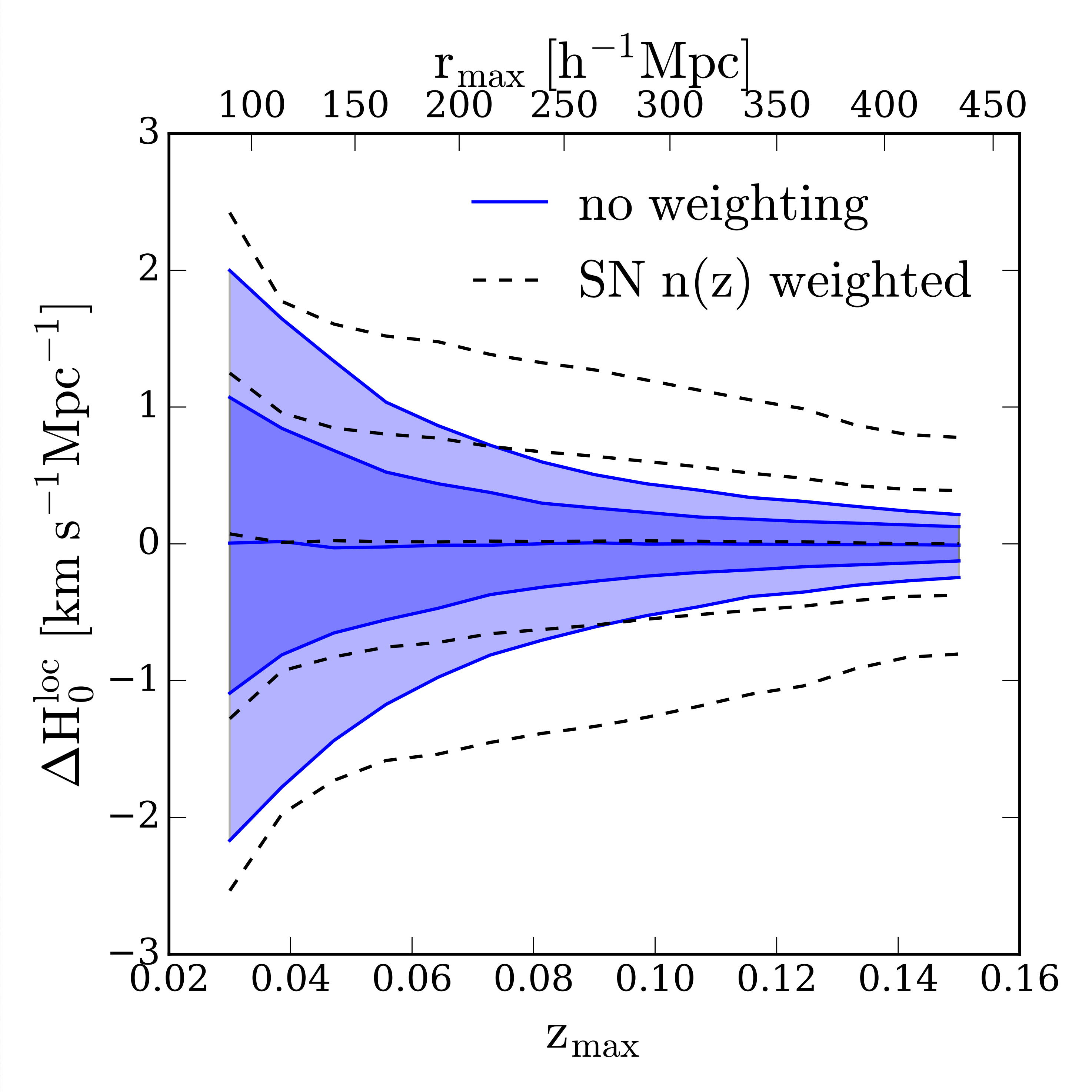
Skewed n(z) increases sample variance



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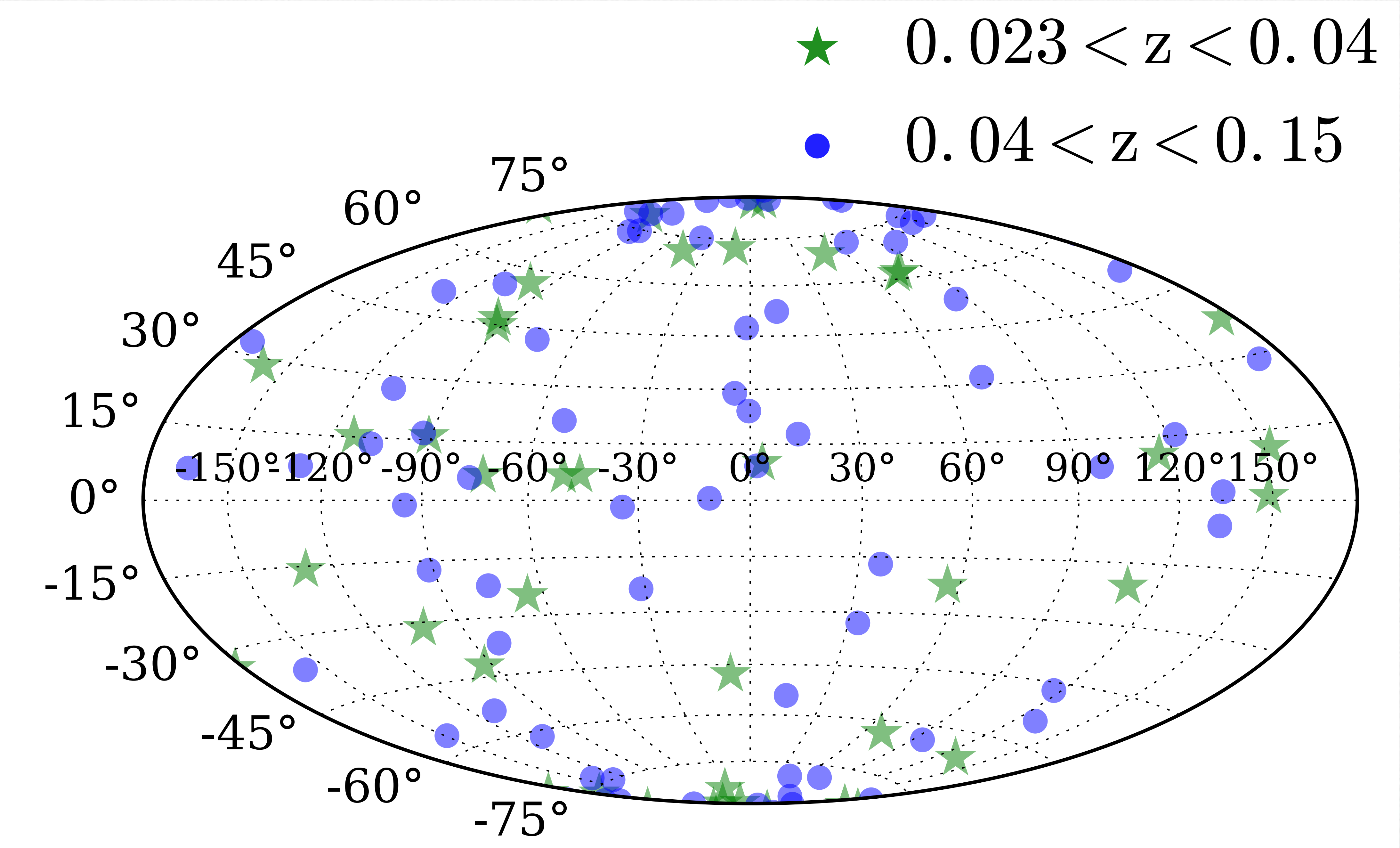
Angular distribution 217 SNe Ia from Riess+16



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Calculating H_0^{loc} sample variance from sims

Take a box, pick an observer

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Compare the 3d coordinates of observed SNe and halos

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Assign SNe to nearest halos

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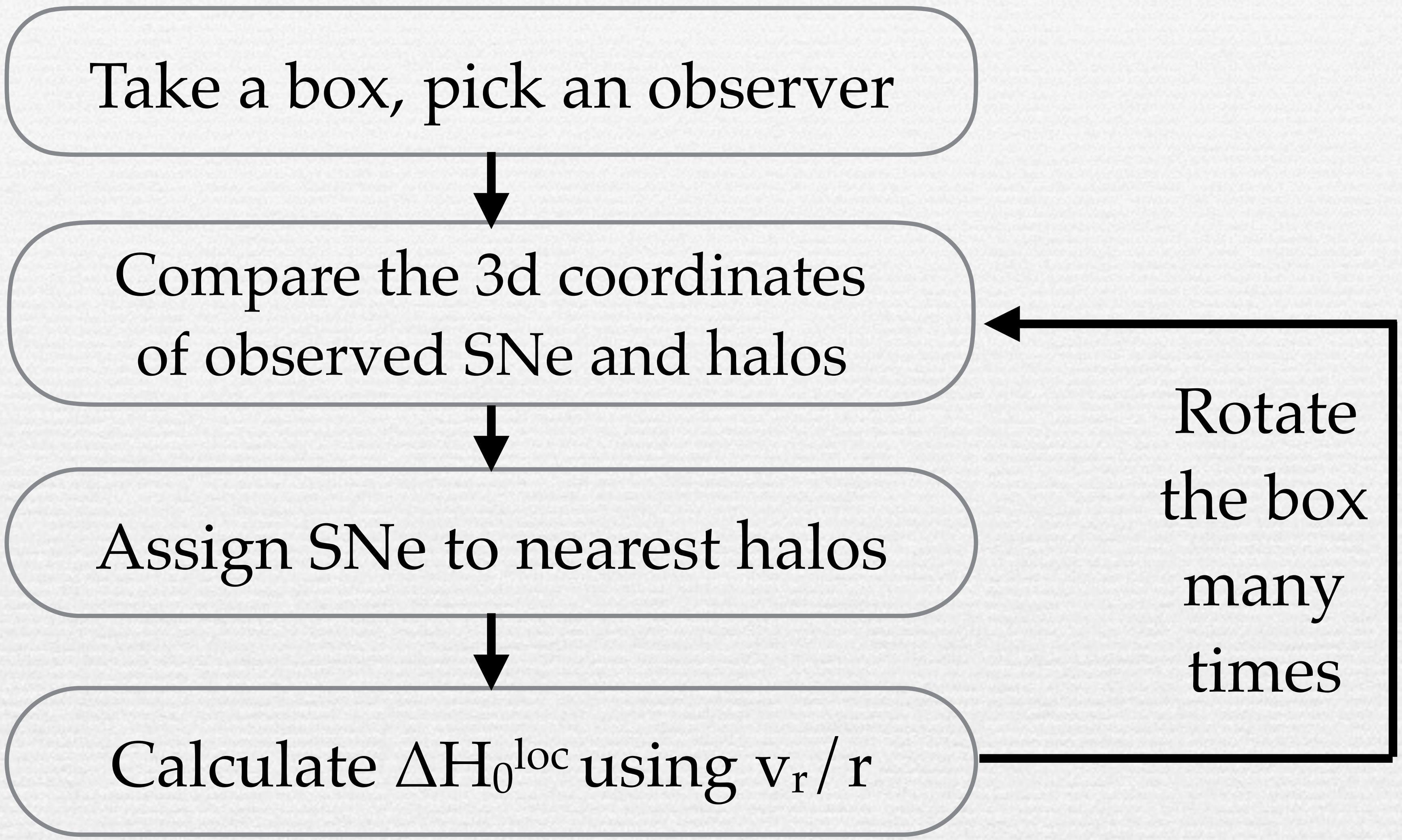
Calculate ΔH_0^{loc} using v_r/r

Calculating H_0^{loc} sample variance from sims



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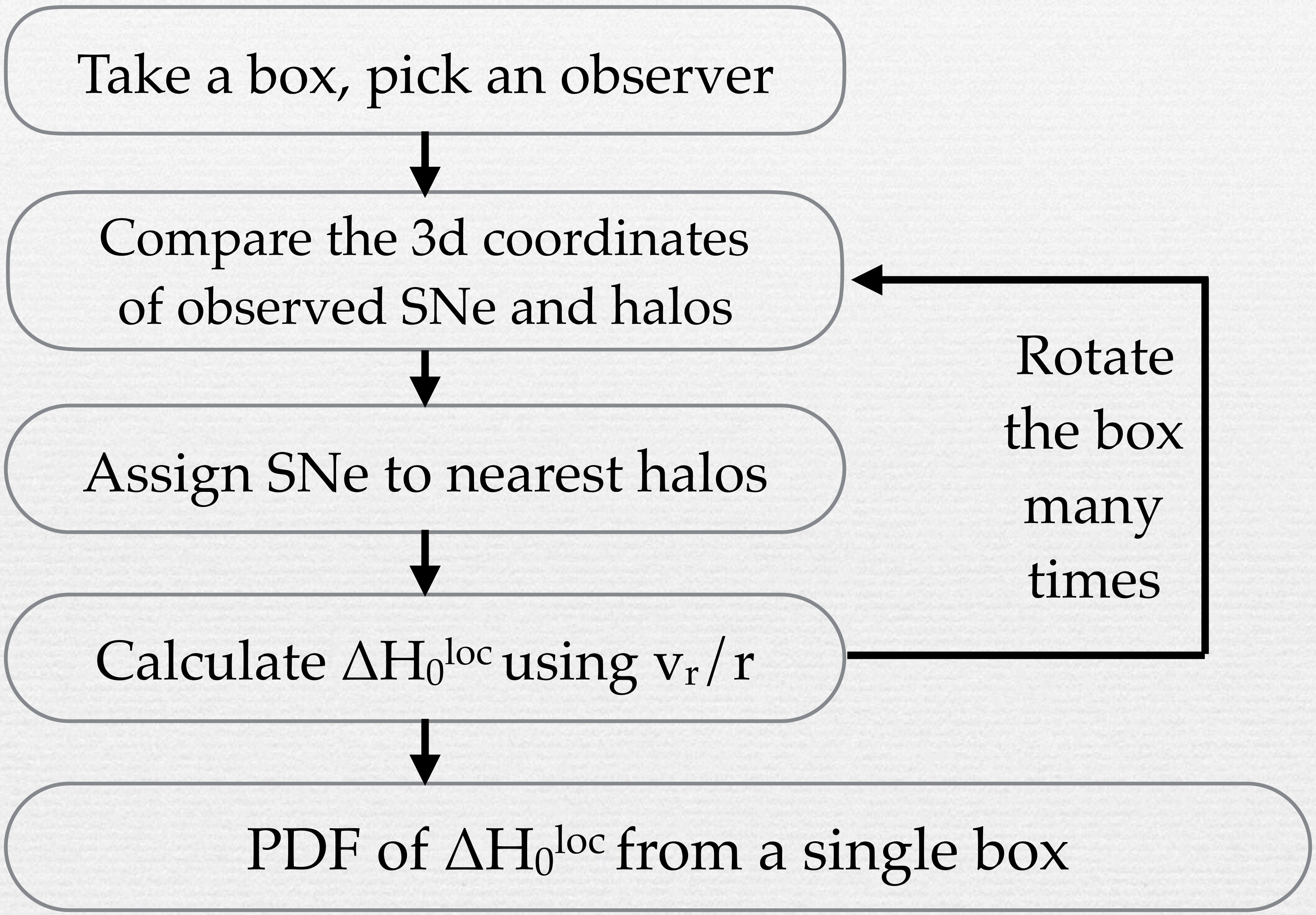

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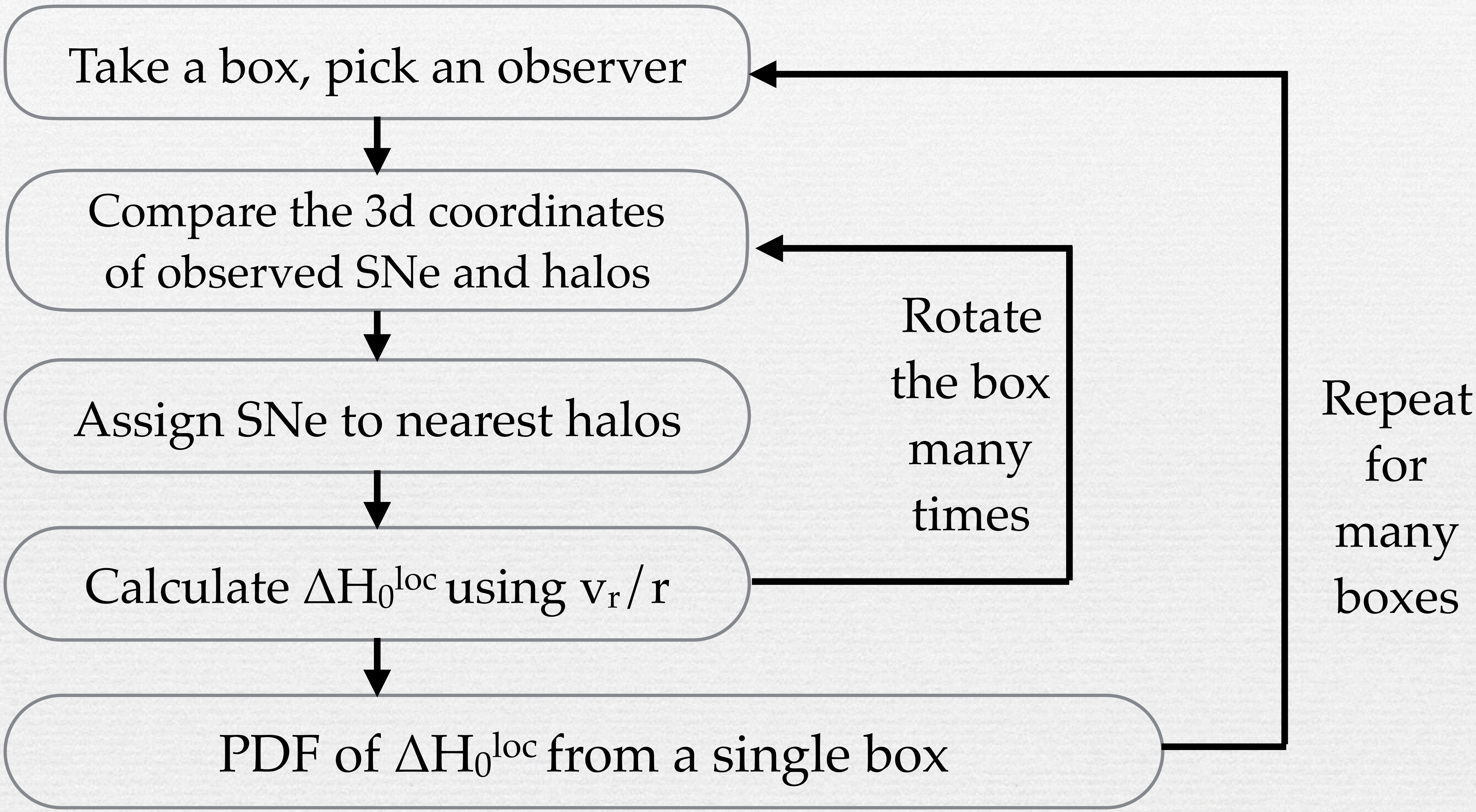

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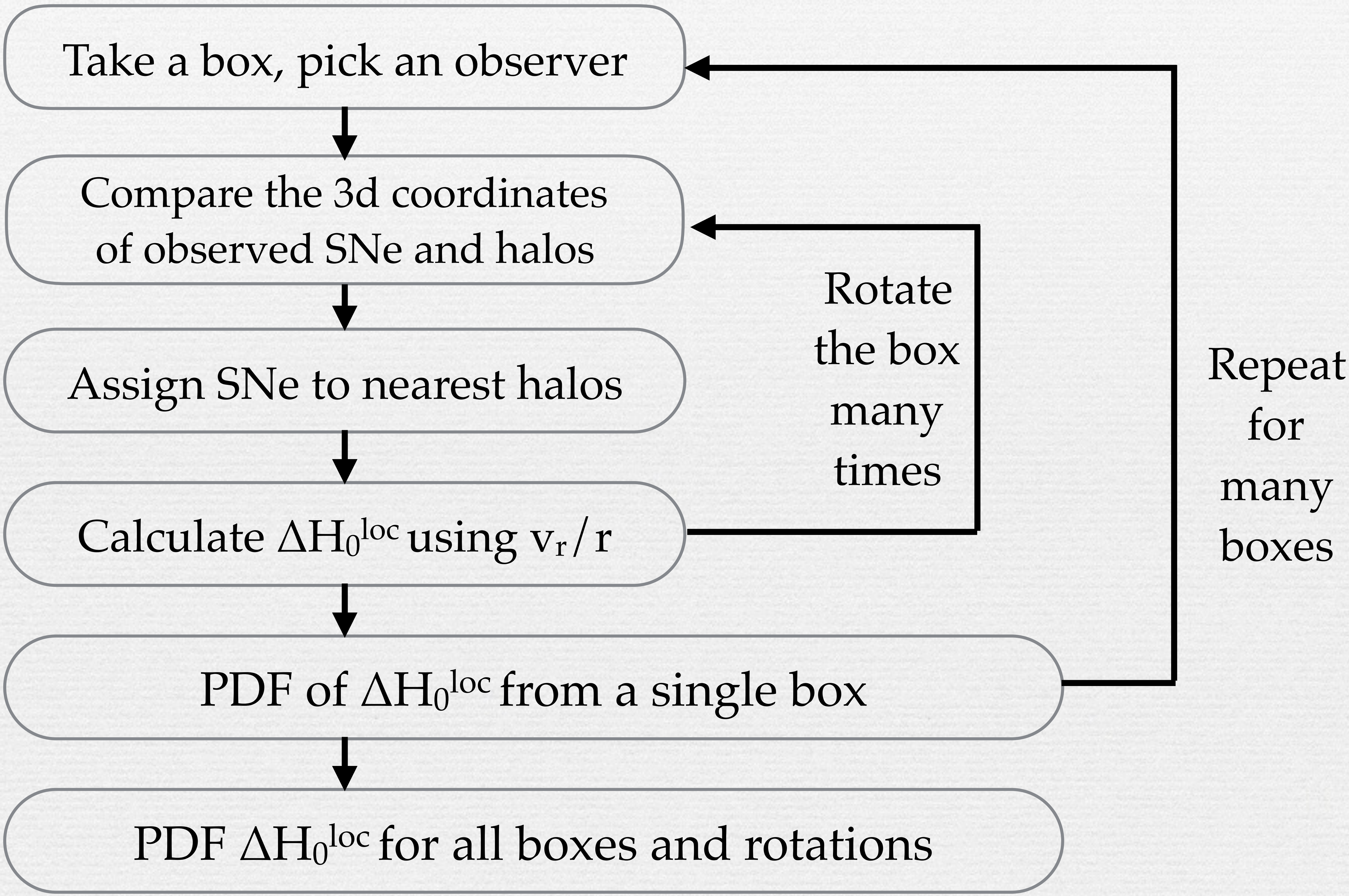
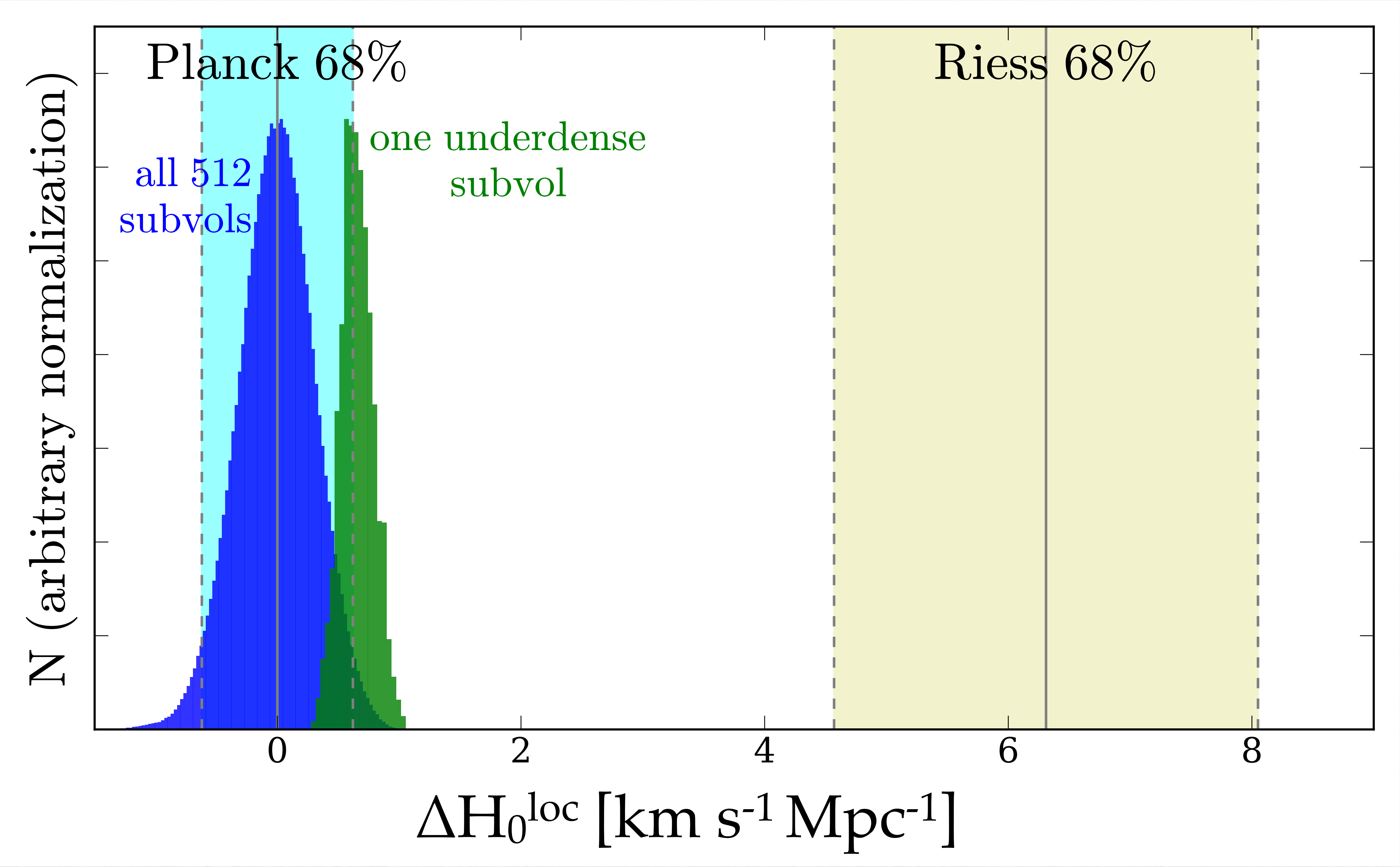


PDF of ΔH_0^{loc} from ~1.5 million realizations



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Sample variance of ΔH_0^{loc} under various assumptions

	all halos, no weighting	SN n(z) weighting	+3D distr. +rotations	$+(\Delta mag)^{-2}$ weighting
$\sigma\ (\Delta H_0^{loc})$ [km s^{-1} Mpc^{-1}]	0.12	0.38	0.42	**0.31**

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Bias in H_0^{loc} vs. density contrast

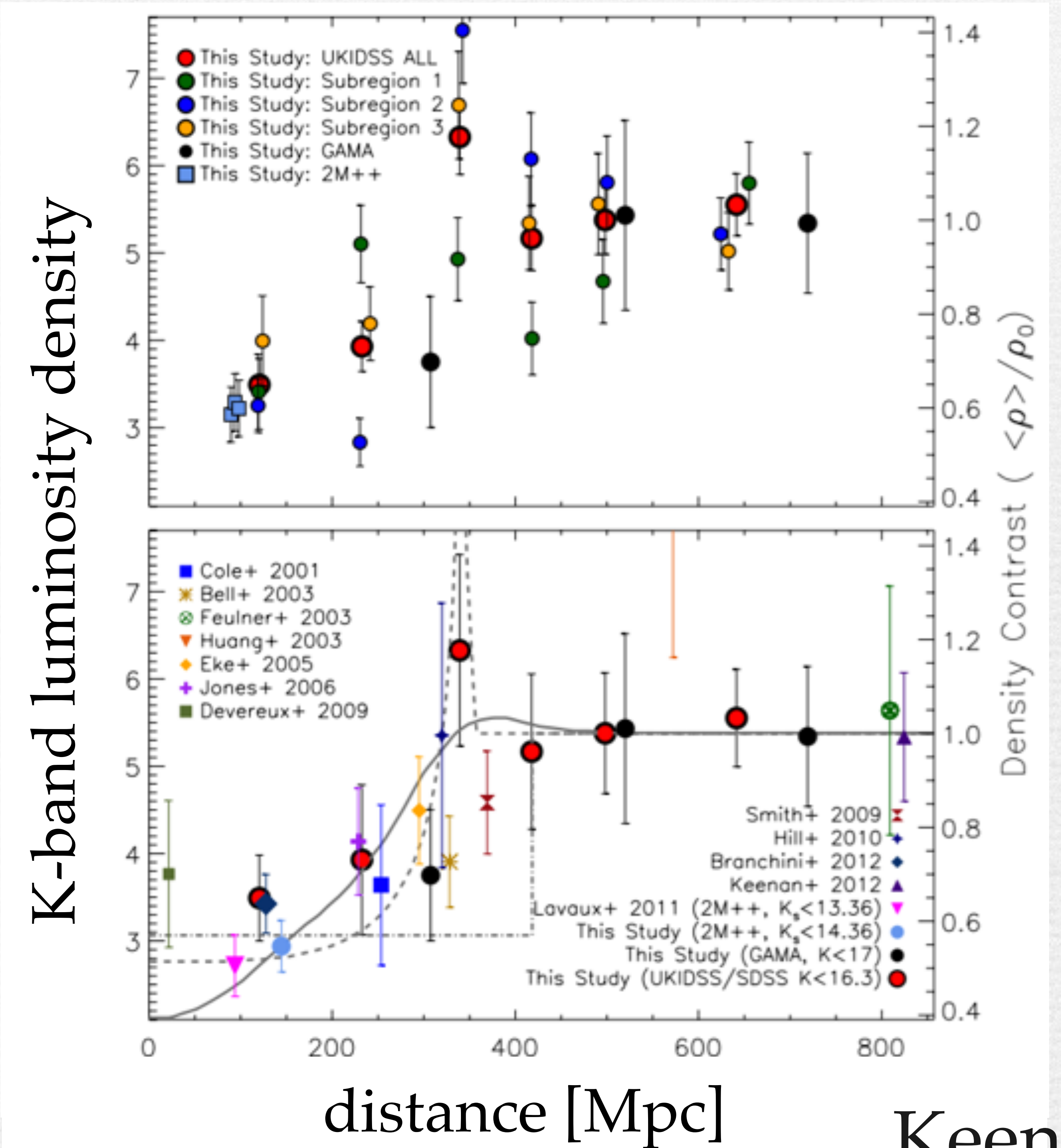
From linear theory:

$$\frac{\Delta H}{H} = -\frac{1}{3}\delta f(\Omega_M)$$

$$f(\Omega_M, z) \approx \left(\Omega_M(z)\right)^{\gamma} \approx 0.5$$

Observations of δ are highly uncertain

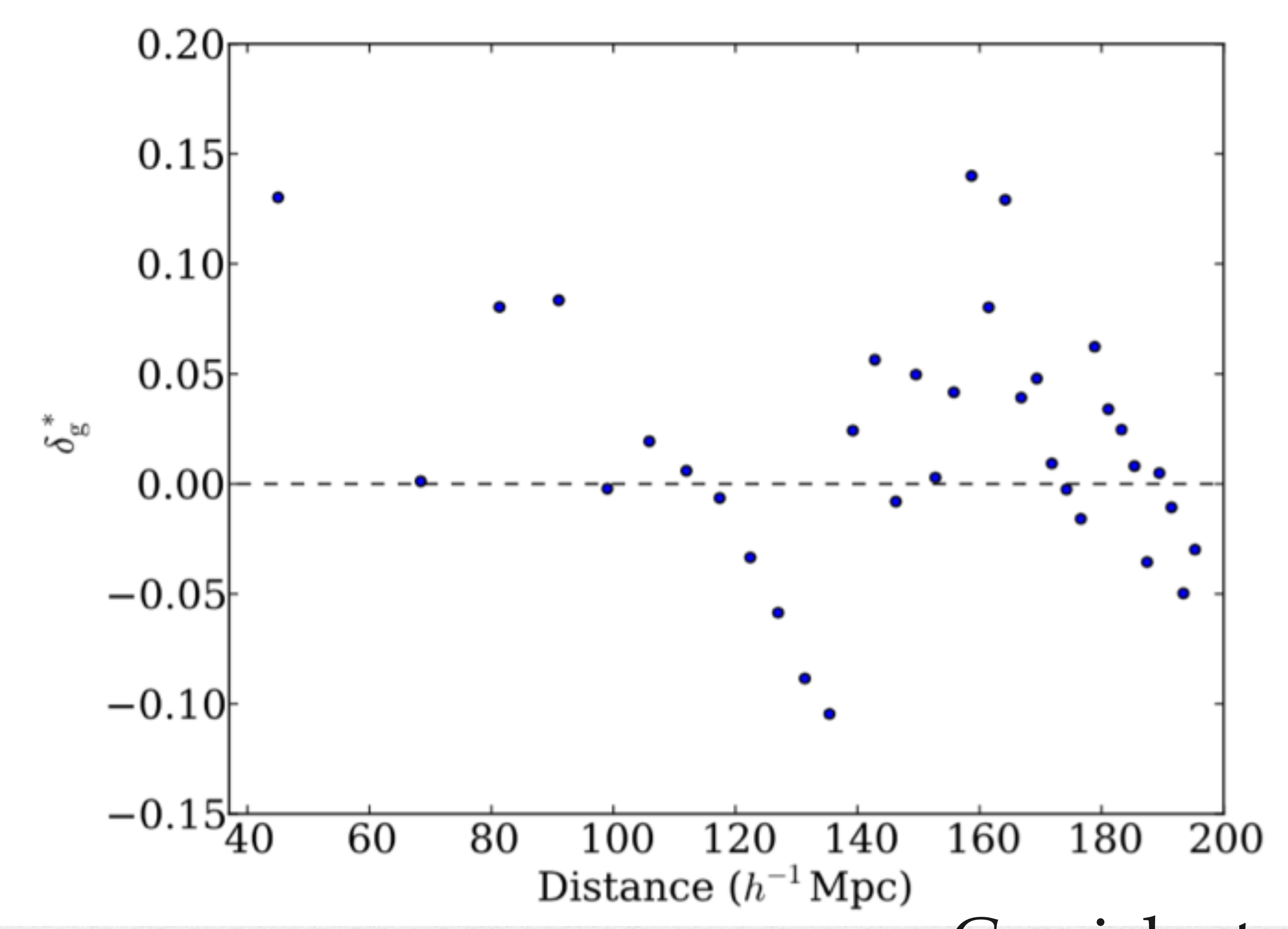
Evidence of a local under-density?



Keenan et al. (2013)

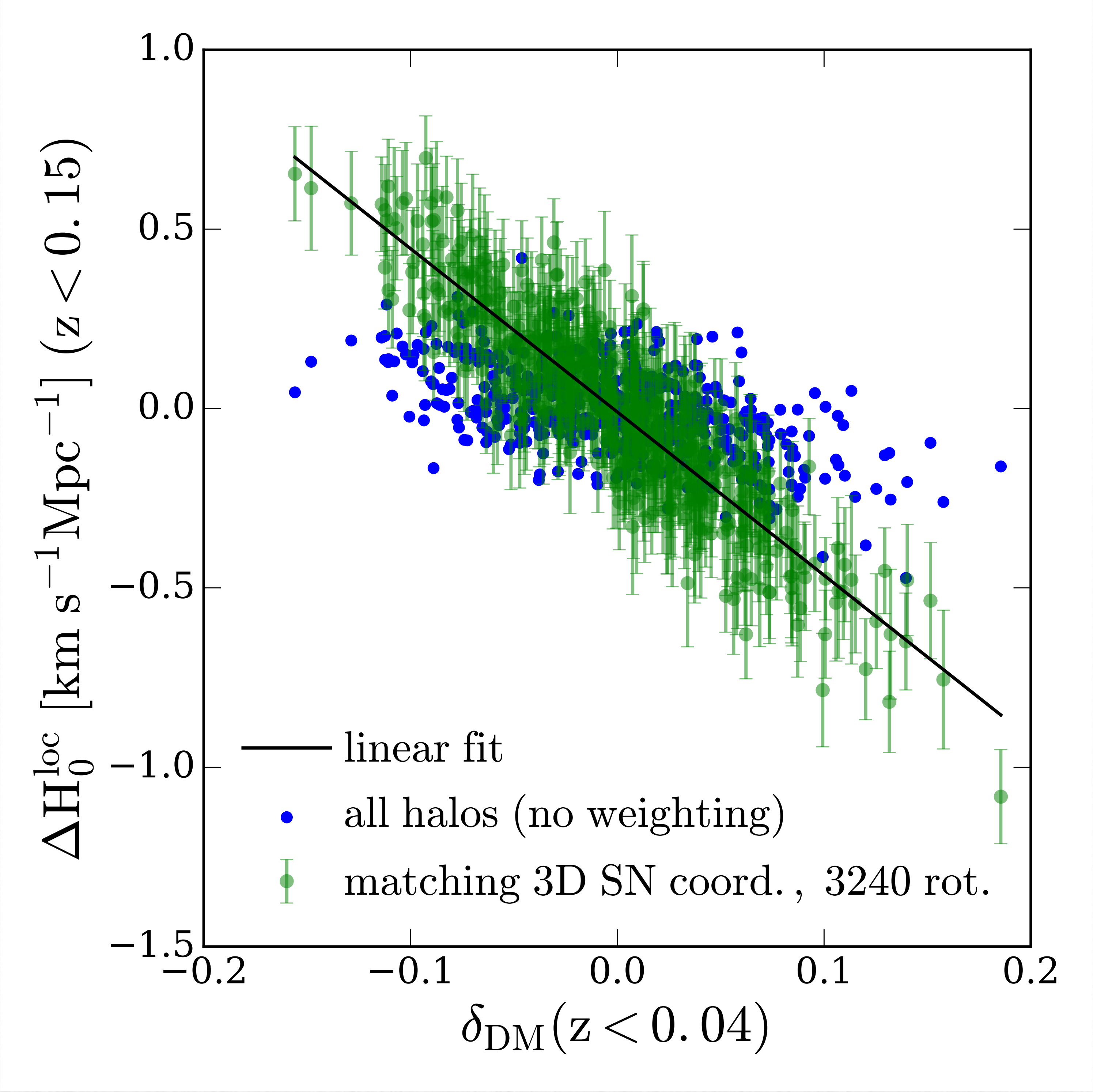
Evidence of a local under-density?

galaxy luminosity density from 2M++



Carrick et al. (2015)

$\Delta H_0^{loc} \propto$ density contrast



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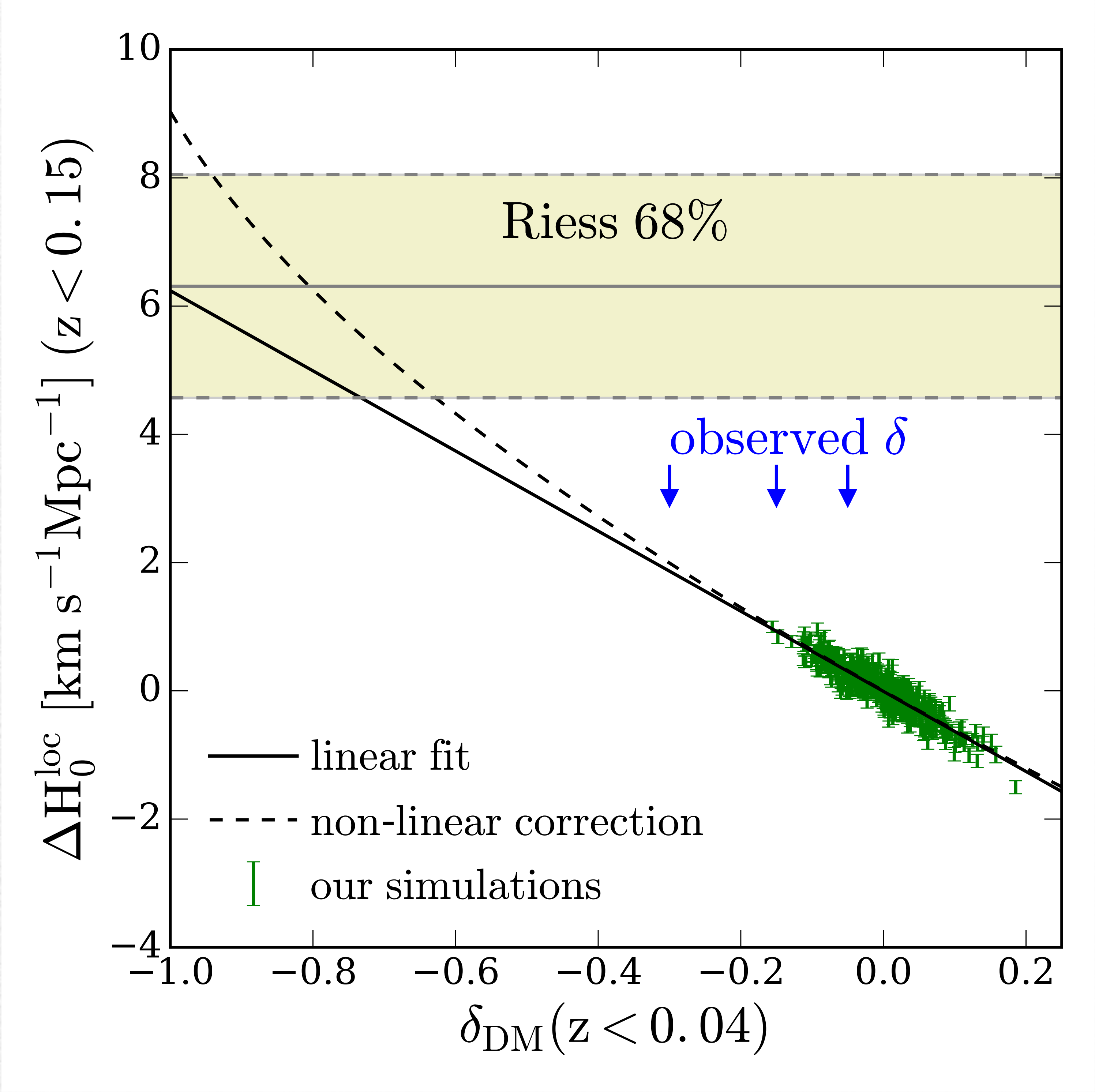
Comparison with observations



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Other distance calibrations for SNe:

- Tully-Fisher relation: e.g. Sorce+12 (75.2 ± 3.0)
- Tip of the red giant branch (TRGB): e.g. Tammann+13 (63.7 ± 2.3)

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Other independent probes for H_0:

- Time delay of gravitational lensing: e.g. Suyu+13, Bonvin+17 ($71.9^{+2.4}_{-3.0}$)
- Baryon acoustic oscillations: e.g. Aubourg+15 (67.3 ±1.1), Addison+17
- Gravitational wave from binary neutron stars

Summary

- Sample variance in H_0^{loc} is ~ 0.3 km s^{-1} Mpc^{-1}, which is too small to alleviate the tension between local (~73) and CMB (~67) measurements.
- This tension would require a 80% underdensity to alleviate, which is highly unlikely in a ΛCDM universe.

Summary

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We're still not sure if there is a Hubble bubble.
Even if there is, it cannot resolve the tension.