The Role of Supernova Host Galaxies in Understanding the Hubble Tension

David Jones
Moore Fellow, UC Santa Cruz
and the SH0ES team

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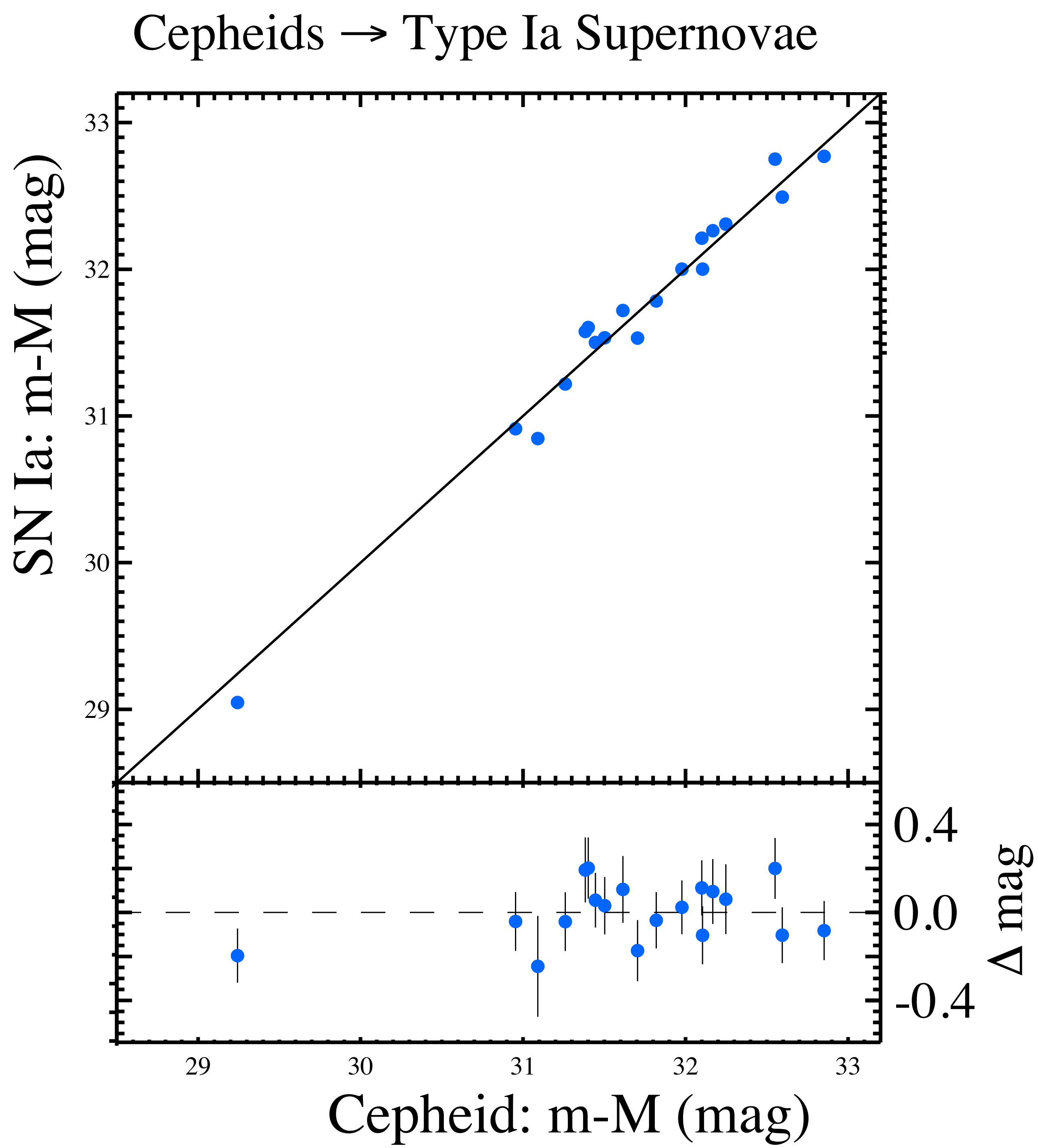
Measuring H_0 from the Distance Ladder
Step 2: Cepheids in galaxies with SNe Ia

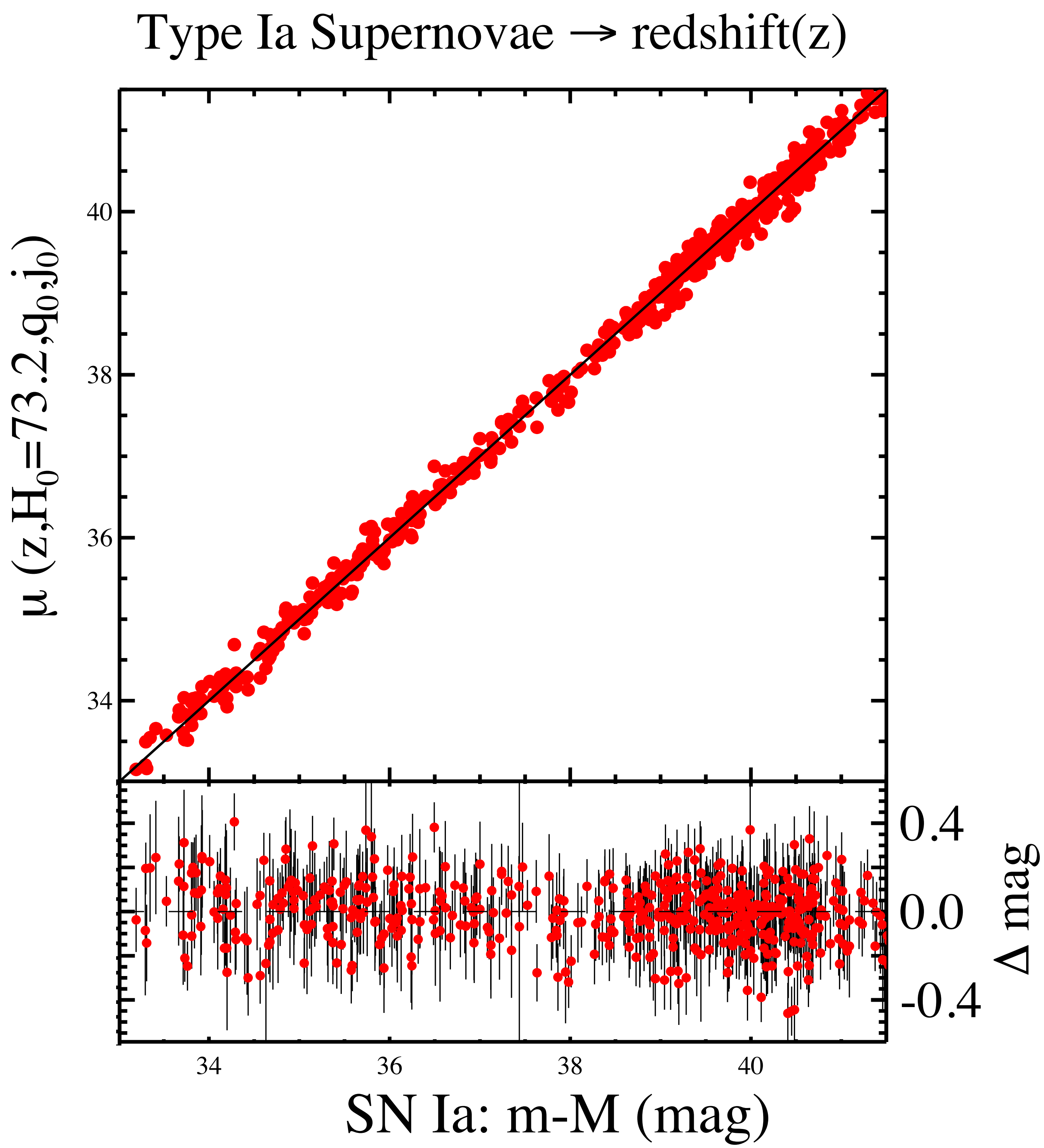
19 galaxies, and the next SH0ES analysis will have 38
HST Prop 15145,15640 (PI: Riess)



Riess+16

Measuring H_0 from the Distance Ladder
Step 3: SNe Ia in the Hubble Flow

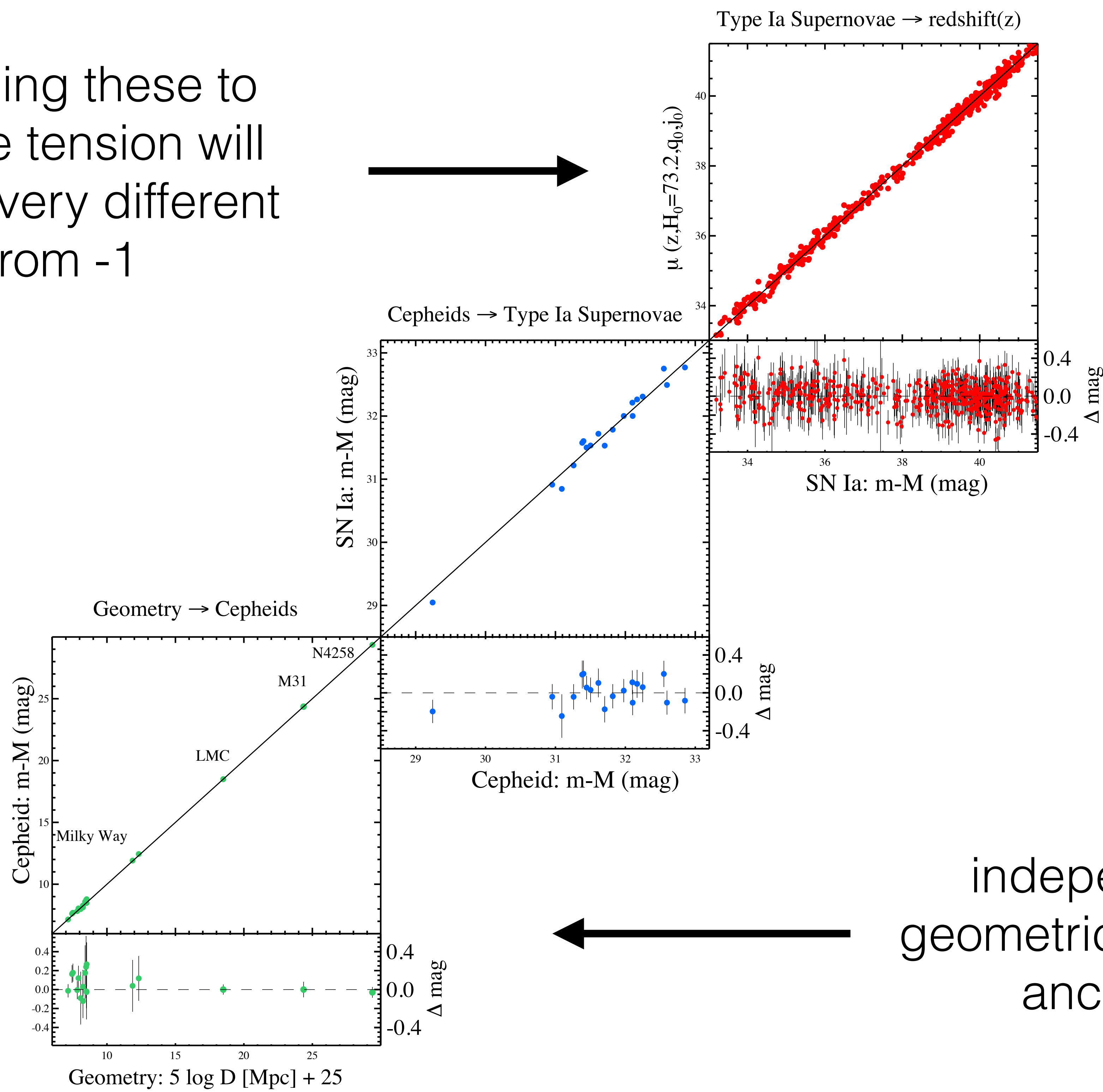
~200 SNe, and we're working on getting that number to 800 (Foundation; Foley+18)



Everything together

This measurement would have to be off by **~0.18 mag** to account for the H_0 tension!

changing these to resolve tension will give *w* very different from -1

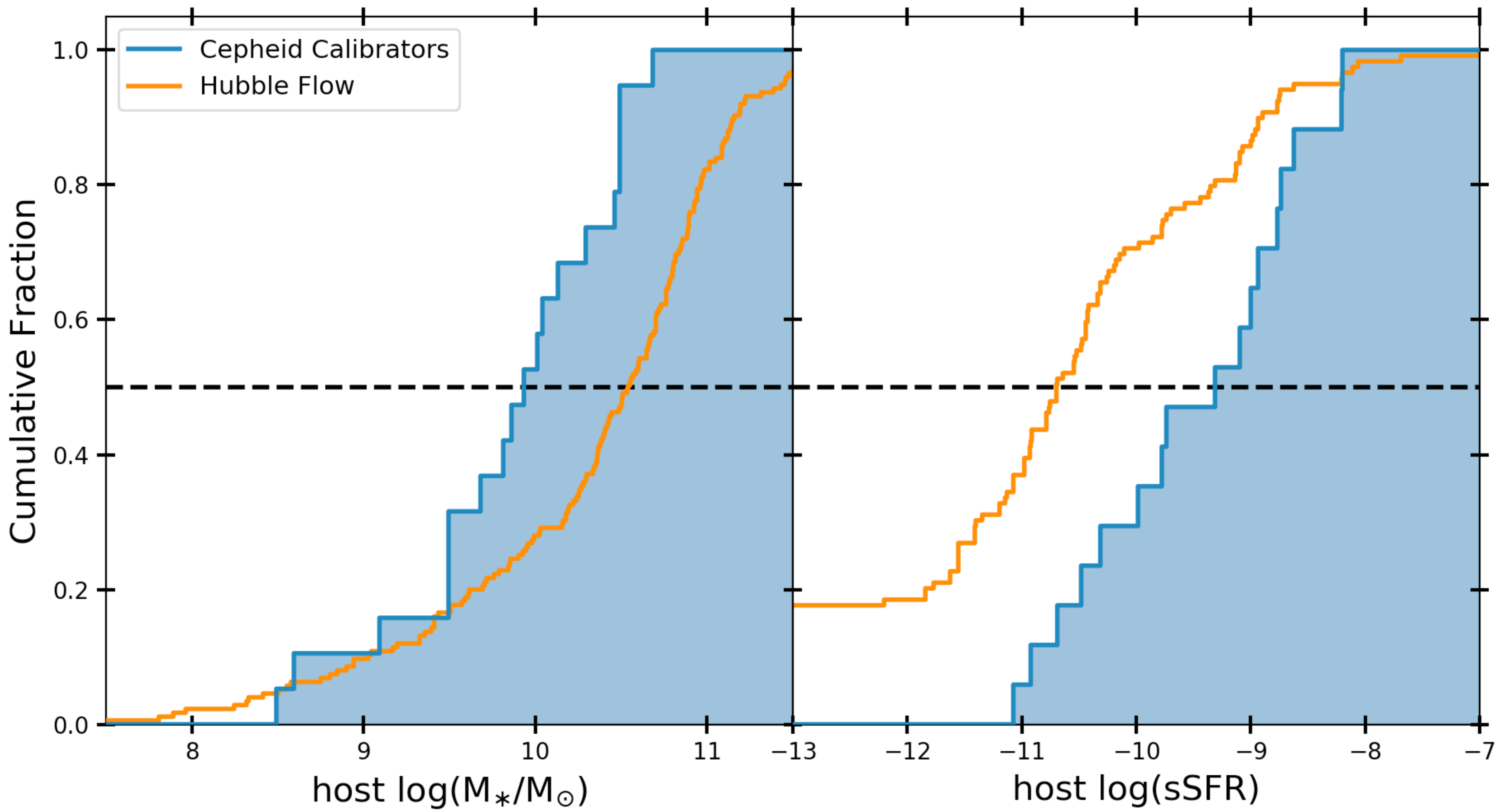


independent geometric distance anchors

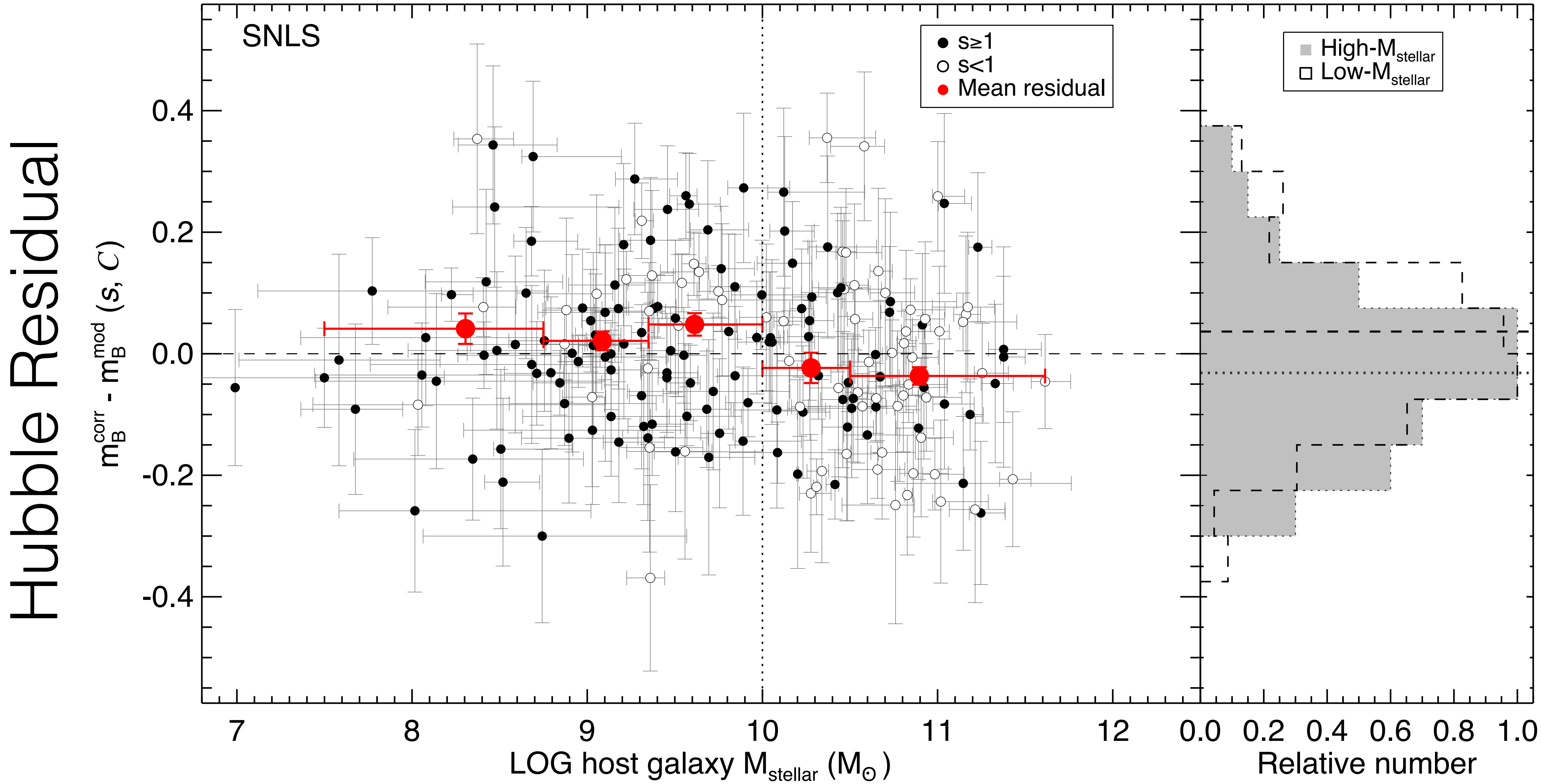
Riess+16

The Role of Supernova Host Galaxies

- Two steps on the ladder depend on SN Ia distances, and observational biases are in play
  - SN Ia must be in star-forming galaxies to be calibrated by Cepheids



The Role of Supernova Host Galaxies

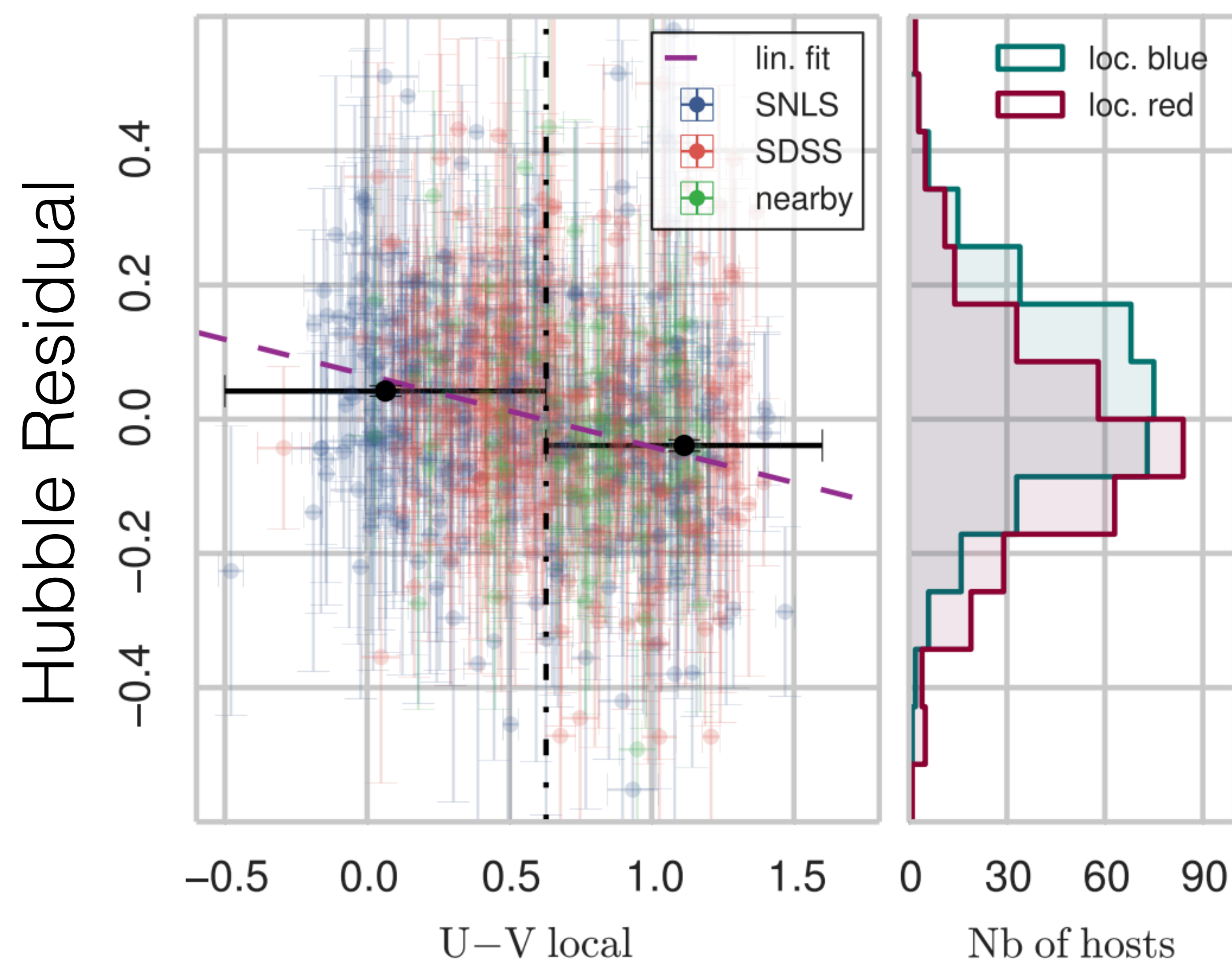


Distances inferred from SN Ia appear to depend on their host galaxy mass (+/- 0.03 mag) and we don't know why

Kelly+10, Lampeitl+10, figure from Sullivan+10

The Relationship Between SN Ia and their Host Galaxies

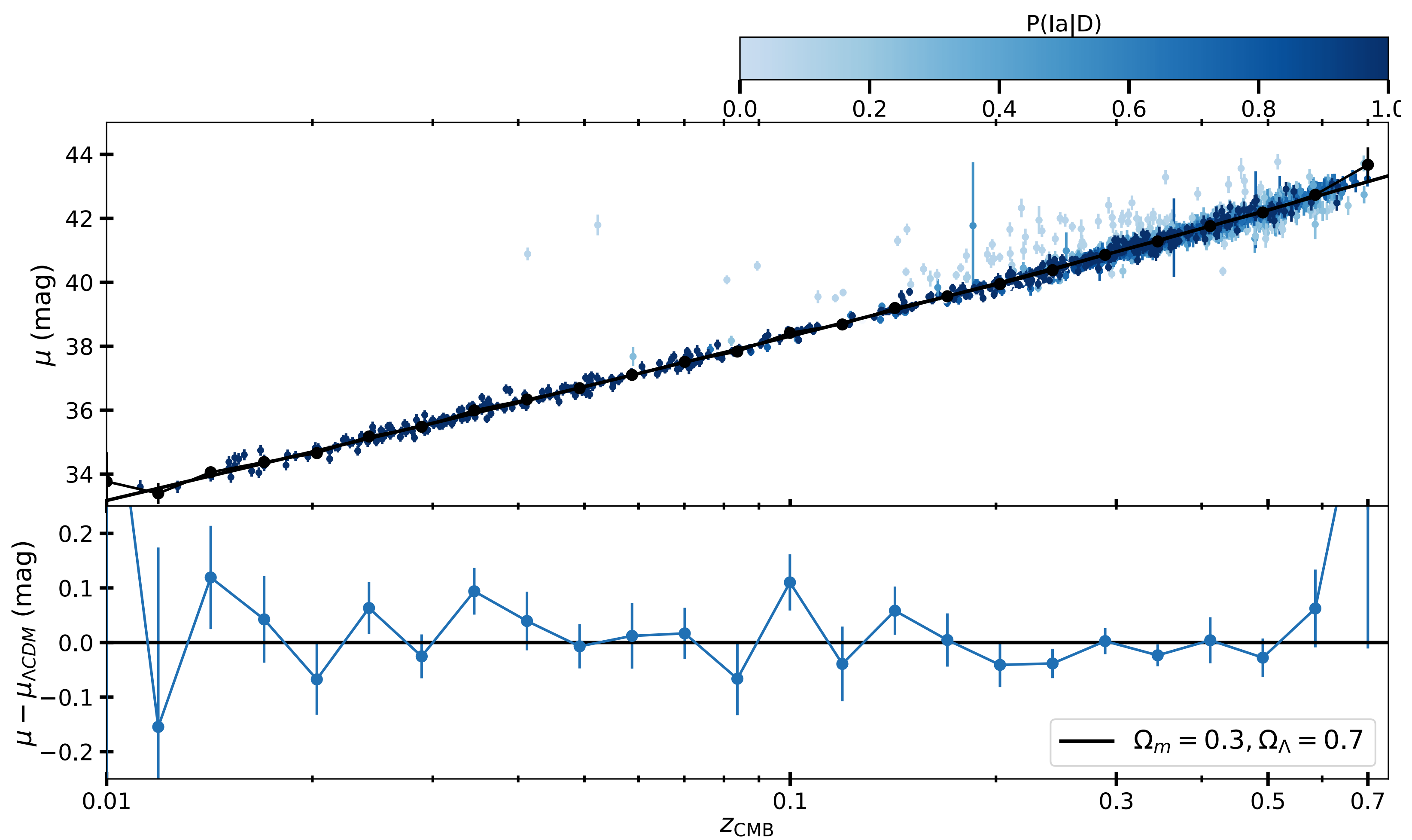
- We correct for host mass step, but what if the host mass dependence is tracing:
  - Metallicity: Hayden+13
  - Star formation rate: Rigault+13, Rigault+15, Jones+15
  - Specific star formation rate: Rigault+18
  - *U* - *V* color: Roman+18
  - Stellar ages: Rose+19
  - Host galaxy dust: Scolnic+14
- What if the global host galaxy properties aren't precise enough?
- We need to learn:
  - If we use the wrong "step", how much is H_0 biased?



Measuring Host Galaxy Systematics by Building a Better Census of Nearby SN Ia Hosts

- The Foundation Supernova Survey will observe up to 800 $z < 0.1$ SN Ia on the Pan-STARRS telescope (PIs: Scolnic, Foley, Rest)
  - mmag-level photometric calibration
  - well-tested reduction and analysis pipeline
  - 5 Cepheid calibrators and counting
  - untargeted survey, understand selection effects better
- First data release: Foley+18
- Host Galaxies: Jones+18
- Dark energy: Jones+19
- H_0: Scolnic+in prep

Combined Hubble diagram from the PS1 telescope: ~1,400 SNe to date (including some CC SN contaminants in the high-z sample)



Jones+19, arXiv: 1811.09286

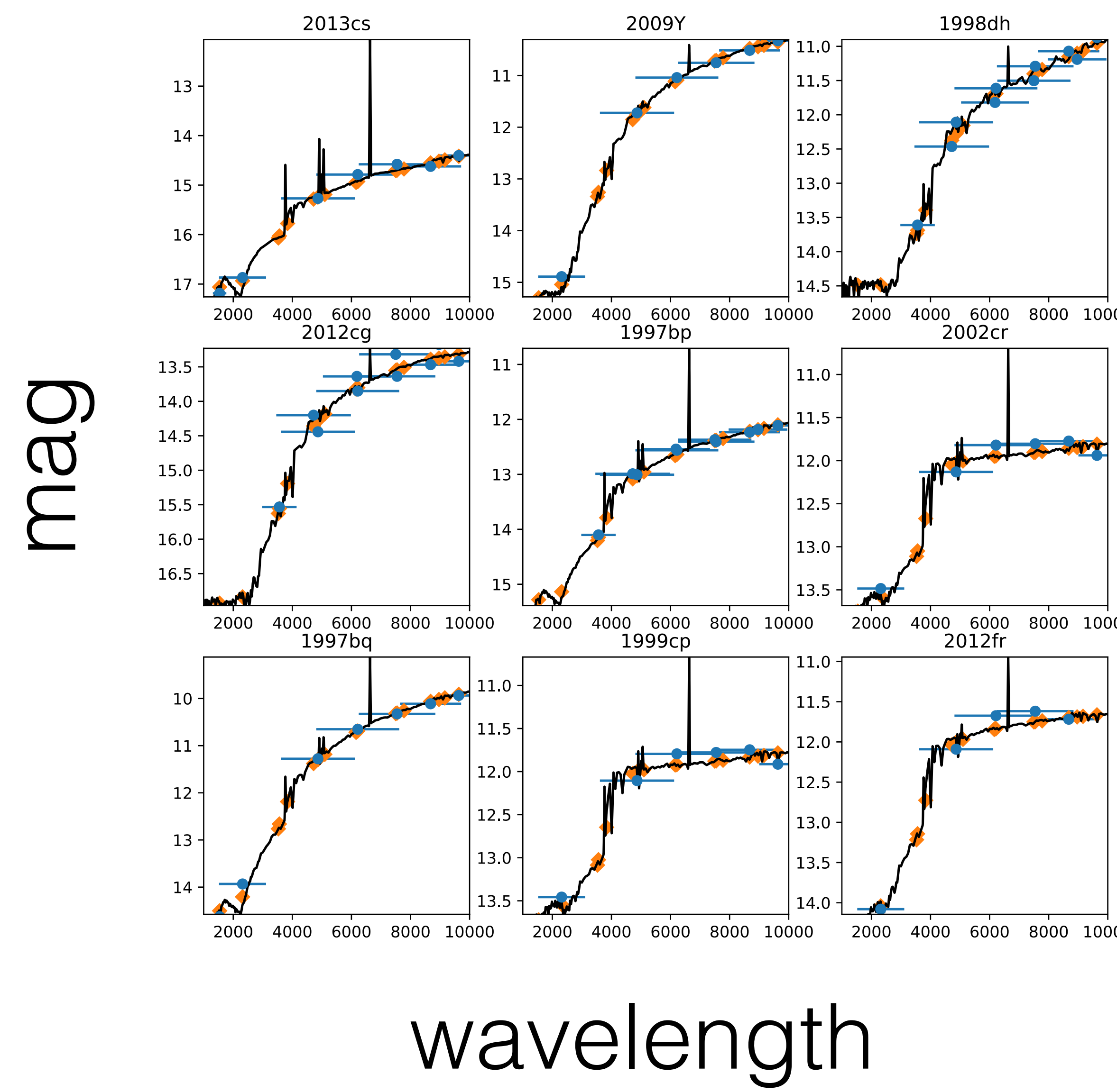
Exploring Local and Global Host Galaxy Biases

Should Type Ia Supernova Distances Be Corrected for Their Local Environments?

D. O. Jones[1], A. G. Riess[2,3], D. M. Scolnic[4,11], Y.-C. Pan[5,6,12], E. Johnson[2], D. A. Coulter[1], K. G. Dettman[7], M. M. Foley[8], R. J. Foley[1], M. E. Huber[9], S. W. Jha[7], C. D. Kilpatrick[1], R. P. Kirshner[8,10], A. Rest[2,3], A. S. B. Schultz[9], and M. R. Siebert[1]

- Already with Foundation DR1 and previous low-*z* data, we can **double** the low-*z* sample size when looking for local and global effects
- We looked at global/local host mass, host *u*-*g* color, and sSFR

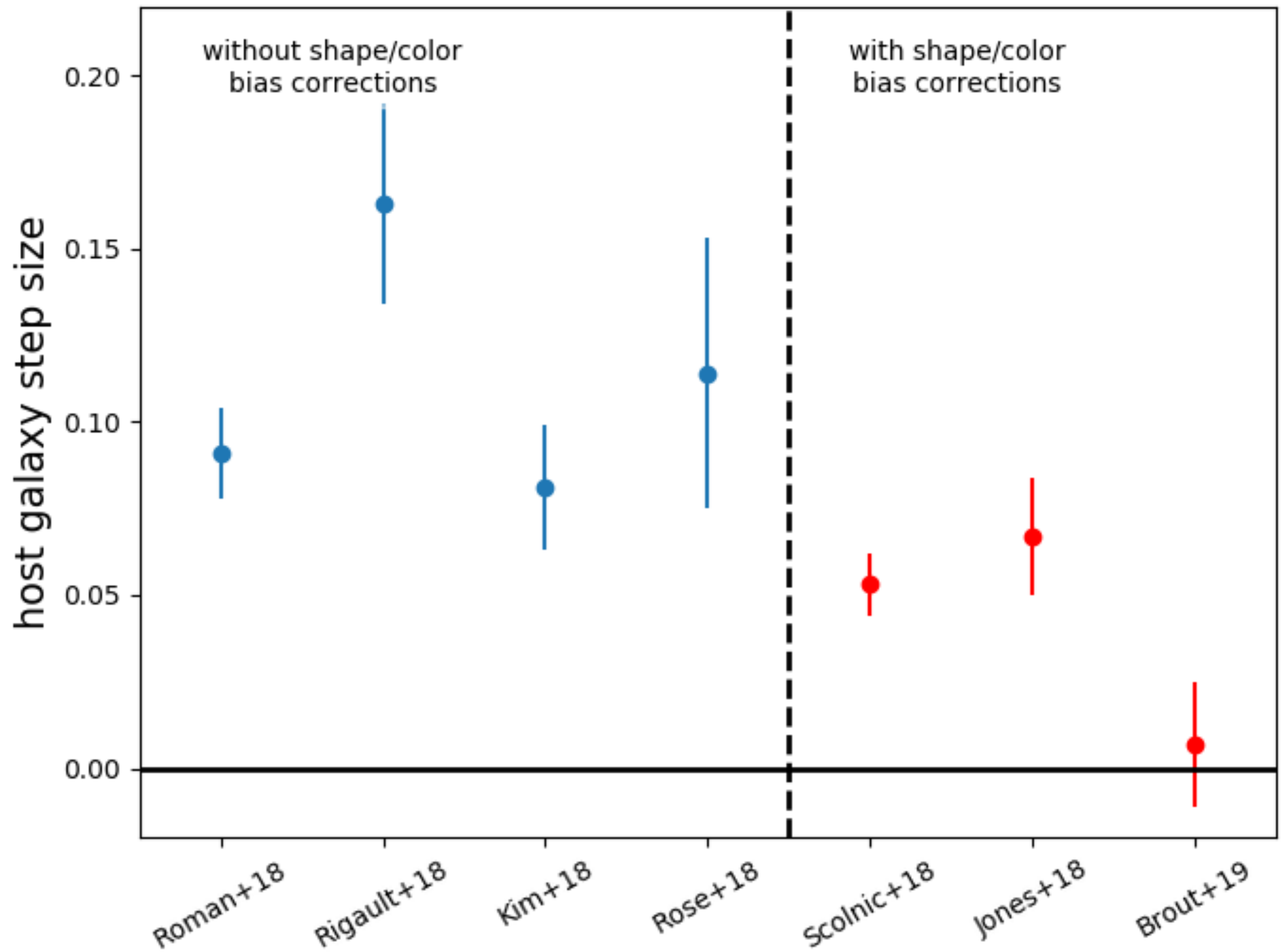
sample SED fits from the Cepheid calibrator set



Importance of Bias Corrections

- Because SN shape and color correlate with host galaxy properties, bias corrections on SN shape and color parameters are important! (Kessler+17).
  - In Foundation we measured a host mass step **twice as large** when neglecting bias corrections
  - DES+18 measured host mass step = 0 after bias corrections

without bias corrections with bias corrections



disclaimer: different host quantities measured here

Importance of Bias Corrections

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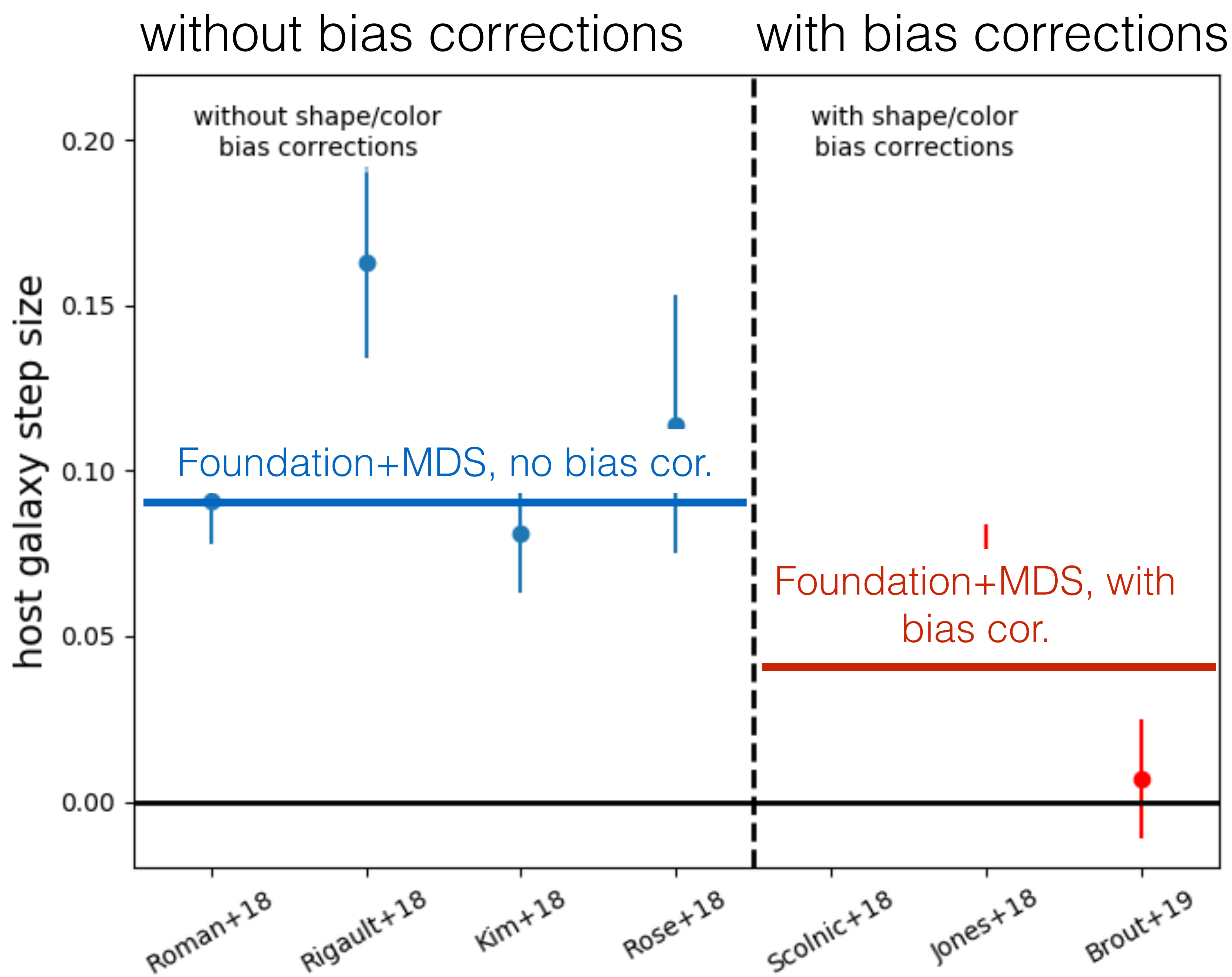
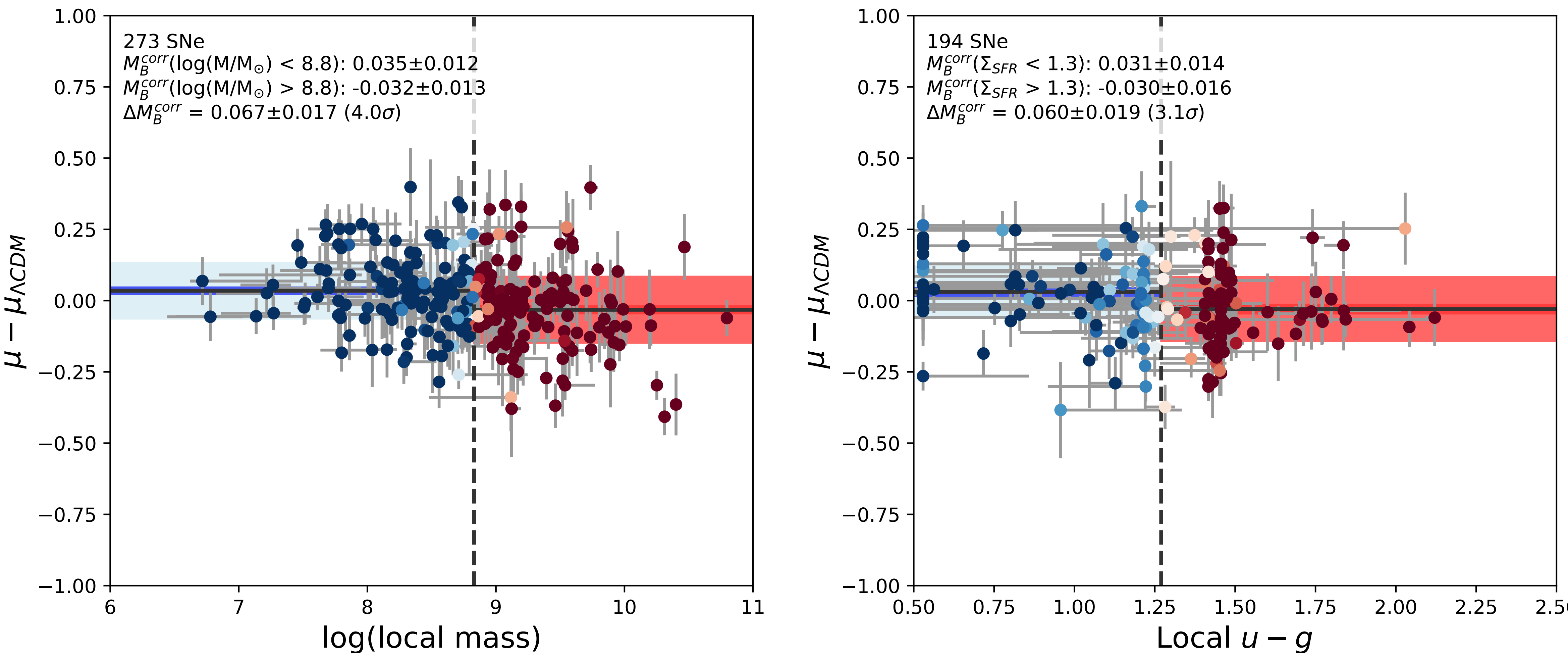


Exploring Local and Global Host Galaxy Biases

- We examined variables of mass, *u* - *g* color, and sSFR
- Local steps were significant, and so were the corresponding global steps



Jones+18; arXiv: 1805.05911

Exploring Local and Global Host Galaxy Biases

- We examined variables of mass, *u* - *g* color, and sSFR
- Local steps were significant, and so were the corresponding global steps
- We found that a global step is usually similar or ~a couple hundredths of mag less than a local step (confirmed by Kim+18, Roman+18, Rose+19)

host mass step	
local step	0.067 ± 0.017 mag
global step	0.058 ± 0.018 mag
host color step	
local step	0.060 ± 0.019 mag
global step	0.061 ± 0.020 mag

- But, a couple weird artifacts:
  - we found 3-sigma local mass step after global correction
  - we found targeted (calibrator sample/previous low-z sample) had smaller step than Foundation

What Effect Could Host Galaxy Biases Have on H_0?

- Predicted percent bias is proportional to size of step * (fraction of red/high-mass SNe in hubble flow - fraction of red/high-mass SNe in Cepheid galaxies)
- Before applying a new step, existing 0.7% correction for host mass step must be removed

$$\log(H_0^{\mathrm{corr}}) = \log(H_0) - \underbrace{\frac{1}{5}(\psi^{\mathrm{HF}} - \psi^{C}) \times \delta\langle M_B^{\mathrm{corr}}\rangle_{\mathrm{SF}}}_{\text{LSF bias correction}}.$$

fraction in Hubble Flow

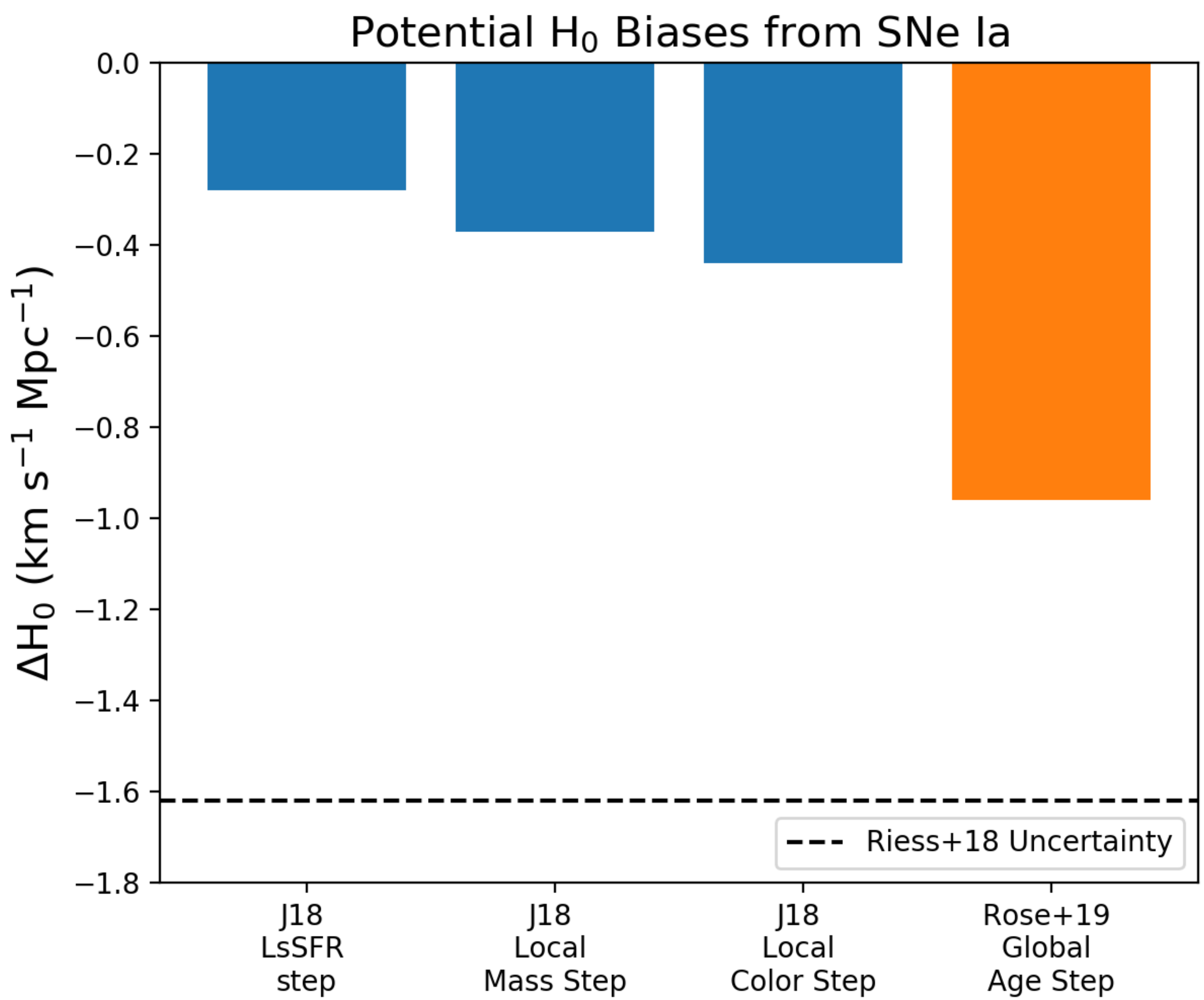
fraction in calibrators

step size

Rigault+15

What Effect Could Host Galaxy Biases Have on H_0?

local mass step is the only step detected at > 2 sigma significance after global correction, but only shifts H_0 by -0.28 km s^{-1} Mpc^{-1}

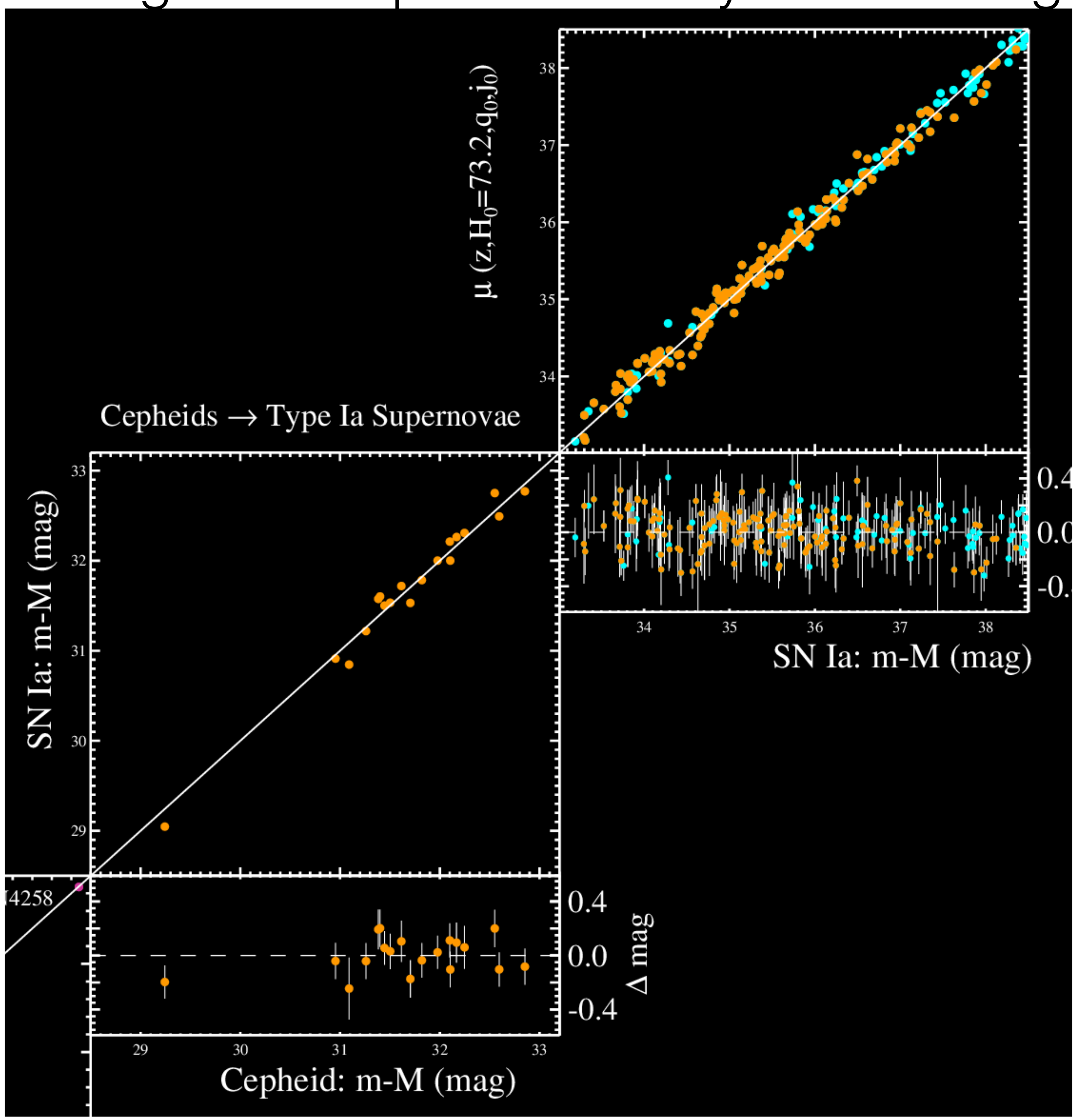


Rose+19, but didn't take into account SH0ES mass correction

for another view, see Rigault+18

What Effect Could Host Galaxy Biases Have on H_0?

Orange dots: spiral or locally star-forming

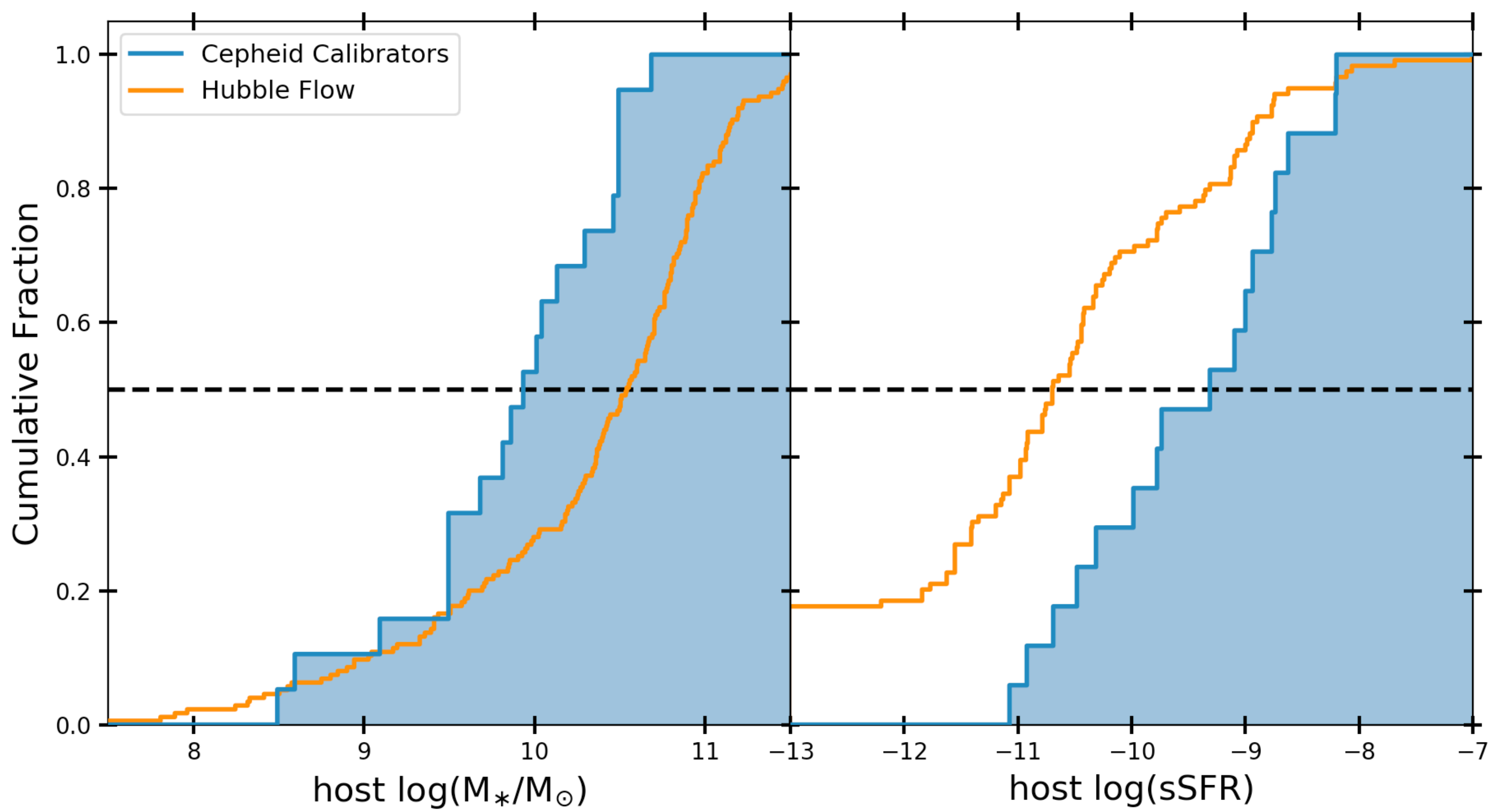


Analysis Variants	H_0
Best Fit (R16, w/ HST,Gaia , R18=73.53)	73.24
Reddening Law: LMC-like (R_V=2.5, not 3.3)	73.15
Reddening Law: Bulge-like (N15)	73.39
No Cepheid Outlier Rejection (normally 2%)	73.49
No Correction for Cepheid Extinction	74.79
No Truncation for Incomplete Period Range	74.39
Metallicity Gradient: None (normally fit)	73.30
Period-Luminosity: Single Slope	73.26
Period-Luminosity: Restrict to P>10 days	71.64
Period-Luminosity: Restrict to P<60 days	73.06
Supernovae z>0.01 (normally z>0.023)	73.38
Supernova Fitter: MLCS (normally SALT)	74.39
Supernova Hosts: Spiral (usually all types)	73.37
Supernova Hosts: Locally Star Forming	73.54
Cepheid Measurements: Optical Only	71.74

Riess+16

Host Galaxies in the Next SH0ES Analysis

- 38 Cepheid calibrators, instead of 19
- At $z > 0.01$, only SNe in galaxies that likely contain Cepheids will be used

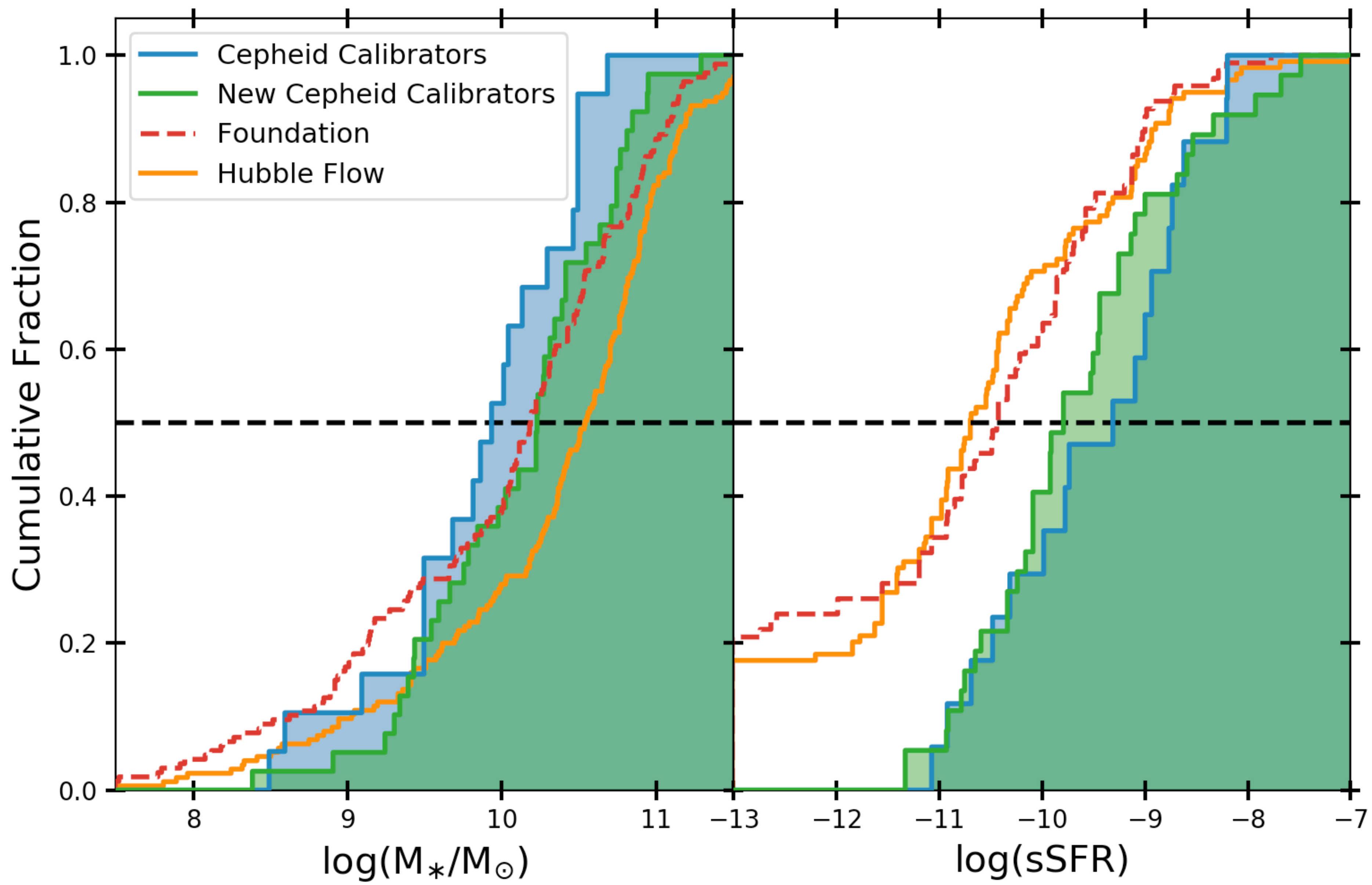


Riess+16 calibrators

Host Galaxies in the Next SH0ES Analysis

- 38 Cepheid calibrators, instead of 19
- At $z > 0.01$, only SNe in galaxies that likely contain Cepheids will be used
- Foundation will get spectra of every host galaxy at the SN location

calibrators for next SH0ES analysis



Conclusions

- No known relationship between SNe Ia and their host galaxies can convincingly explain the Hubble tension - our team can't find a way to get a bias larger than -0.5 km s^{-1} Mpc^{-1}
- The Foundation Supernova Survey will stress-test measurements of host galaxy biases and reduce the SN Ia systematics on H_0
- The next H_0 analysis will double the number of SNe Ia in Cepheid calibrator galaxies and will **only** use Hubble flow galaxies that are likely to have Cepheids