New Measurements of H0 and w from Type Ia Supernovae

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Pont 2017

The National Science Foundation

The University of Chicago

The Kavli Foundation

Just as a reminder, this is where we are at in terms of understanding the universe.

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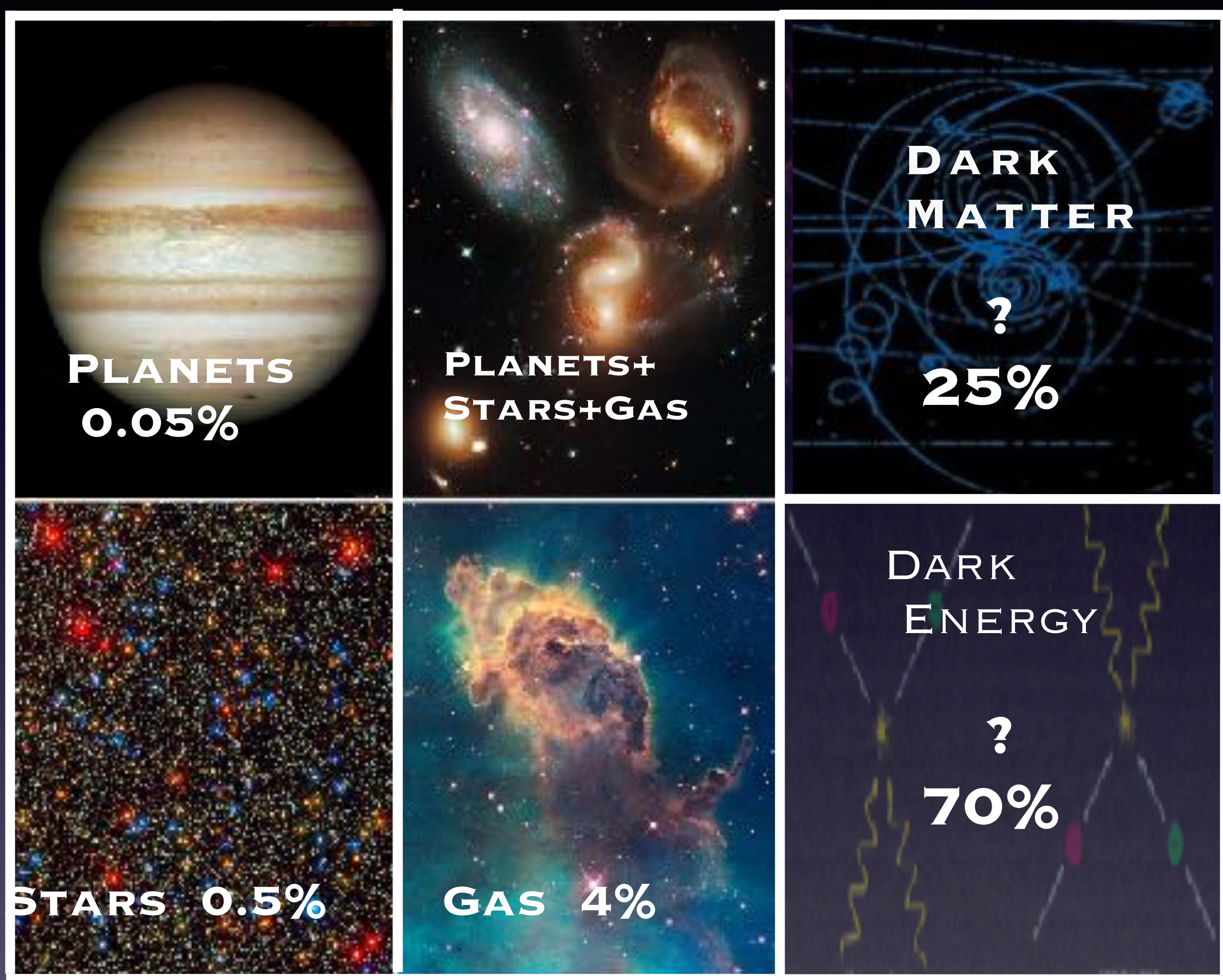
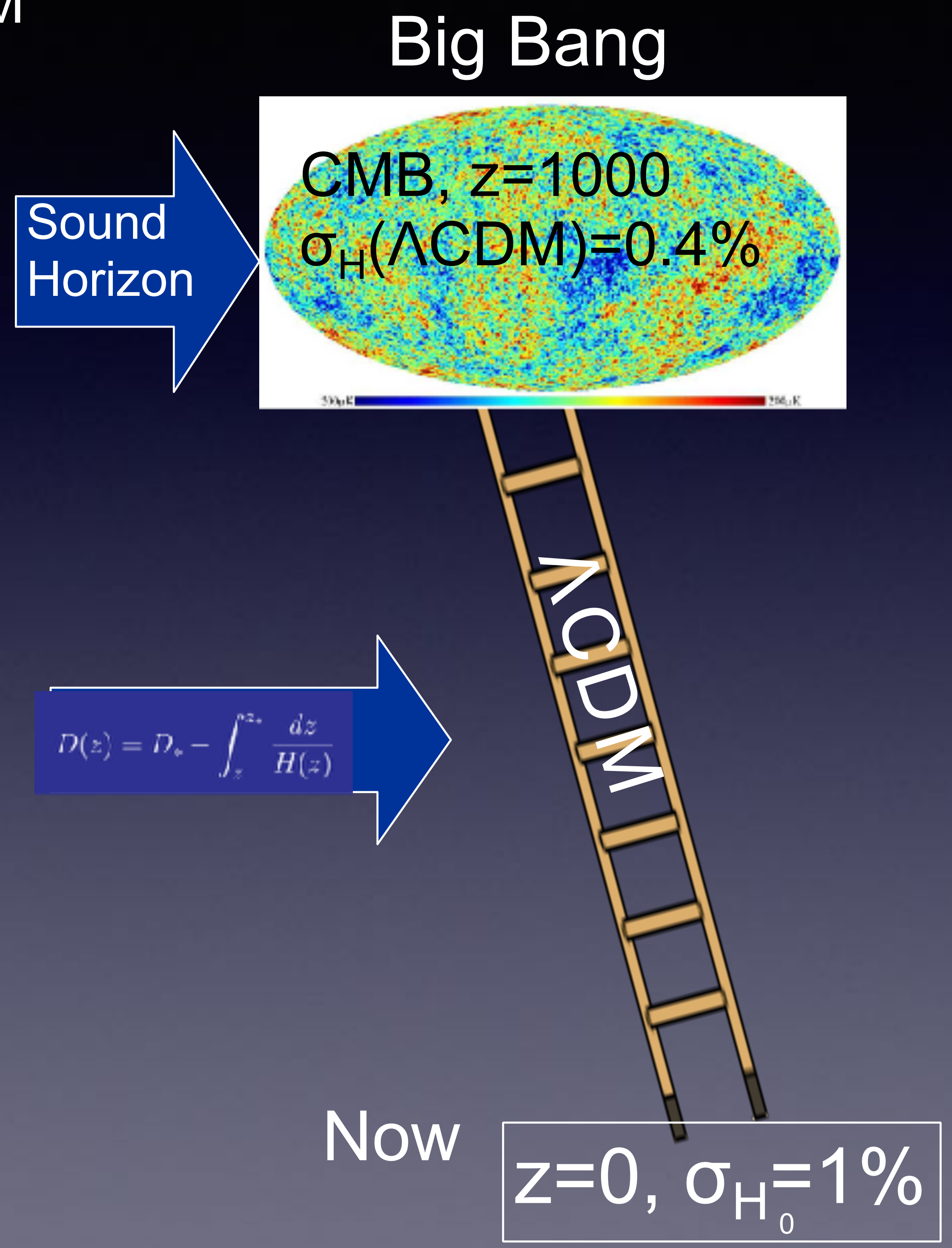
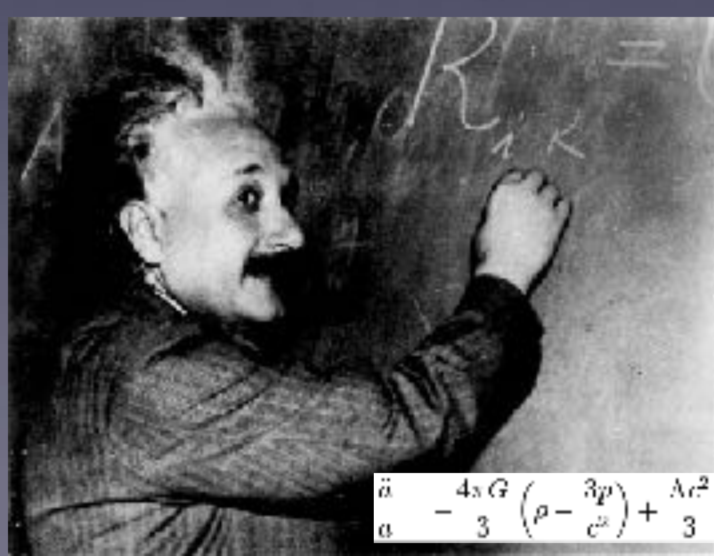
Ultimate "End-to-end" test for ΛCDM: Predict and Measure H_0

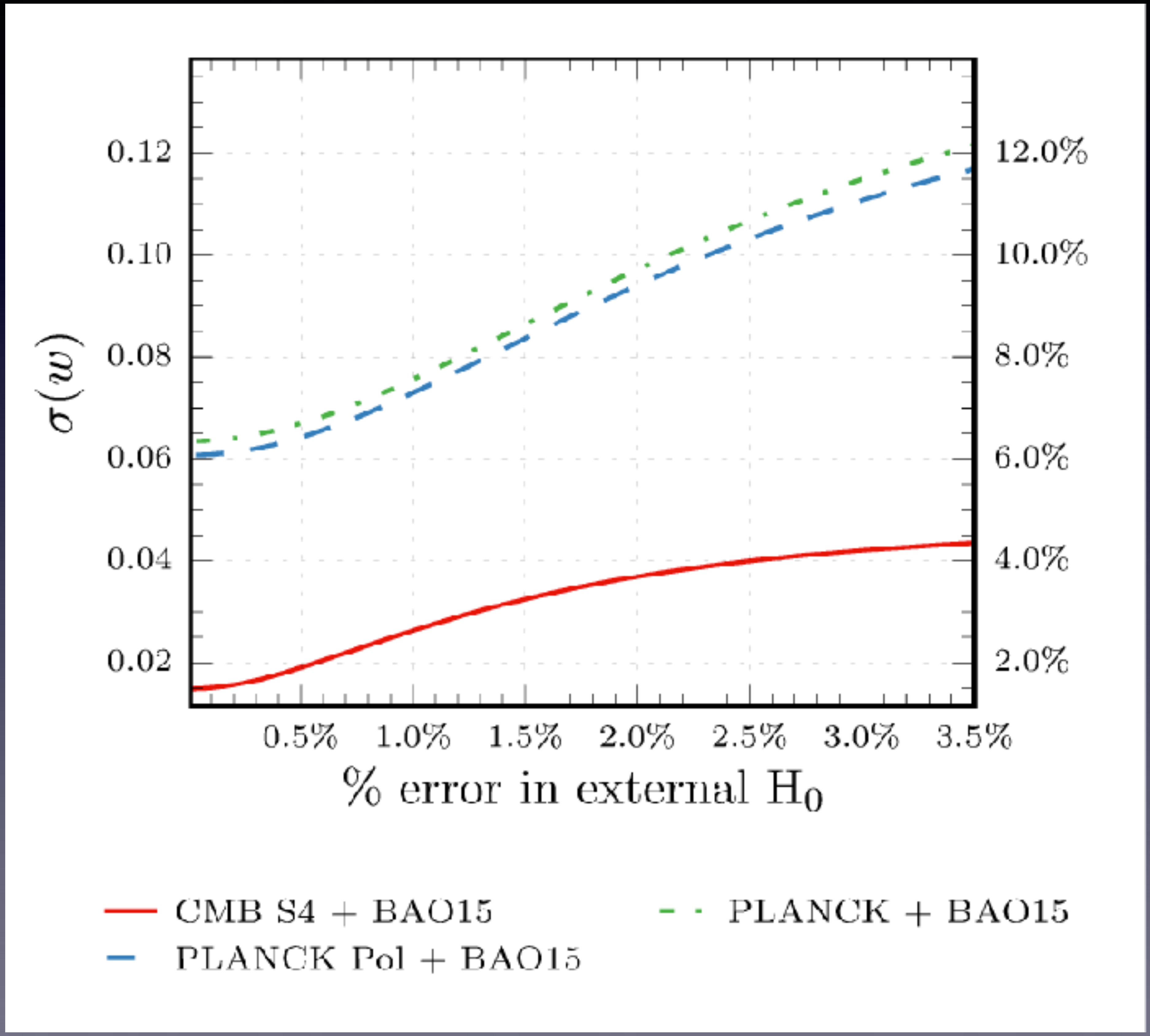
The Standard Model of Cosmology, ΛCDM



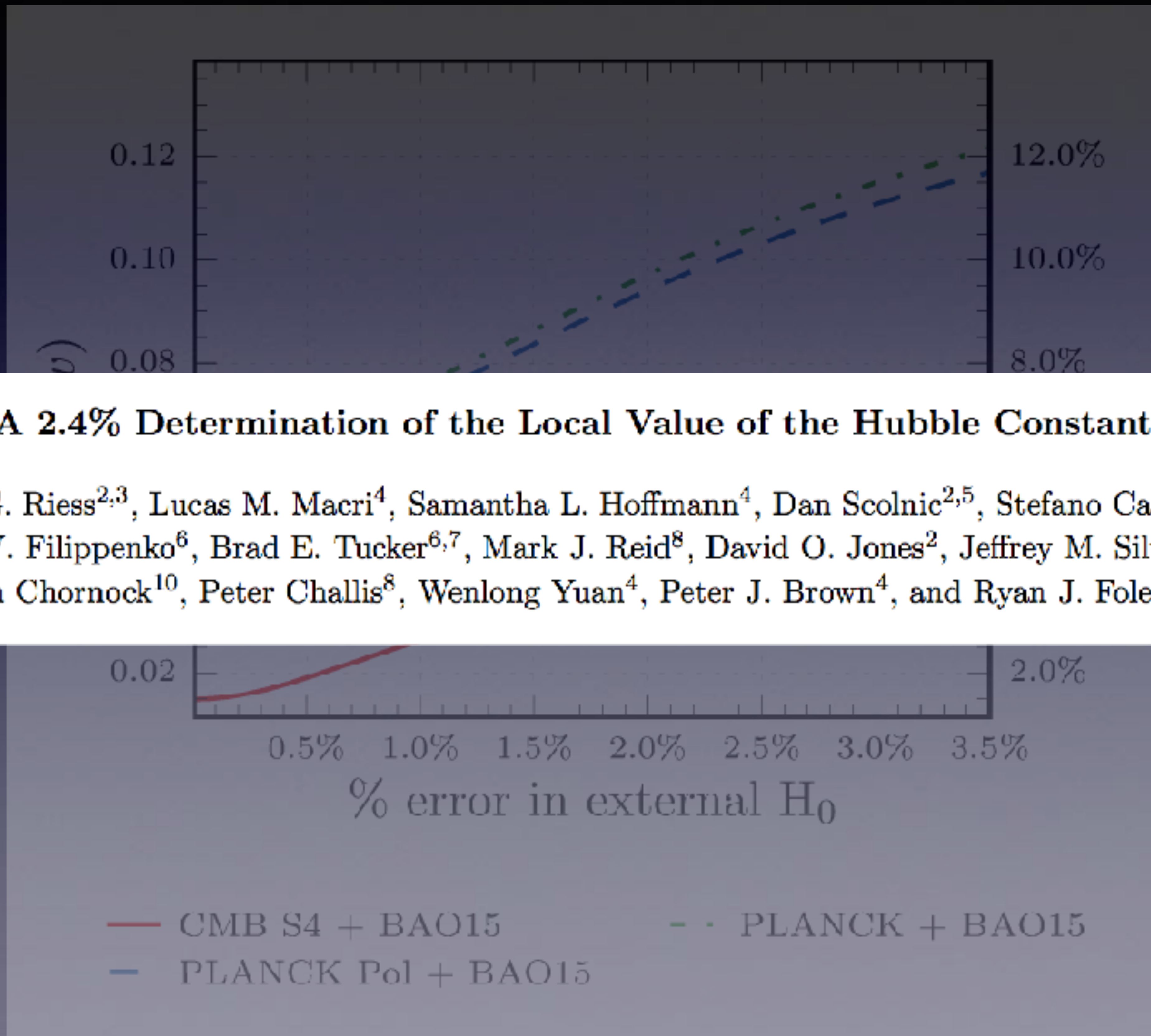




Put another way, combining local and CMB-inferred values of H0 constrains dark energy (w)

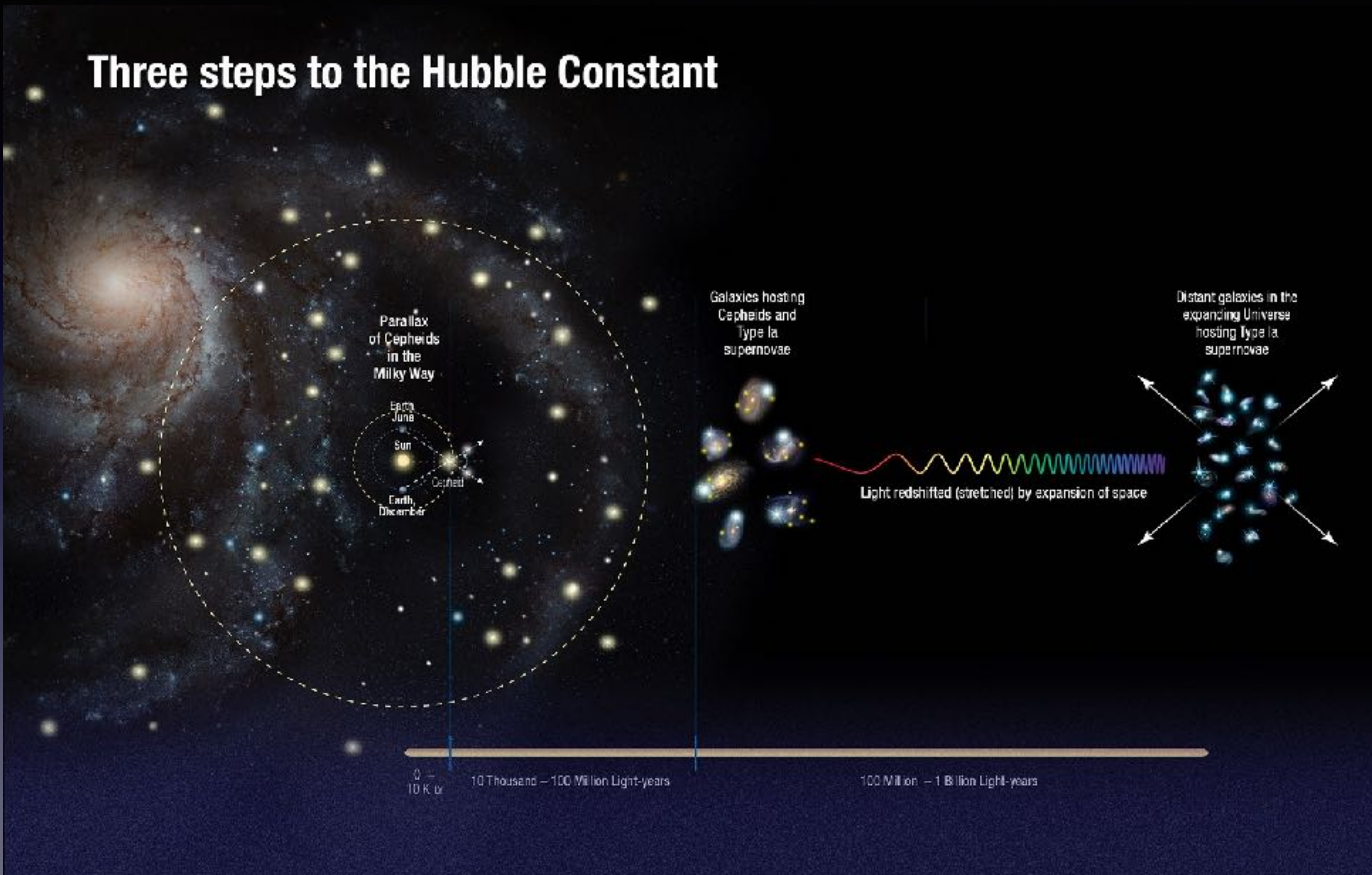


Based on Manzotti, Dodelson, Park 2016

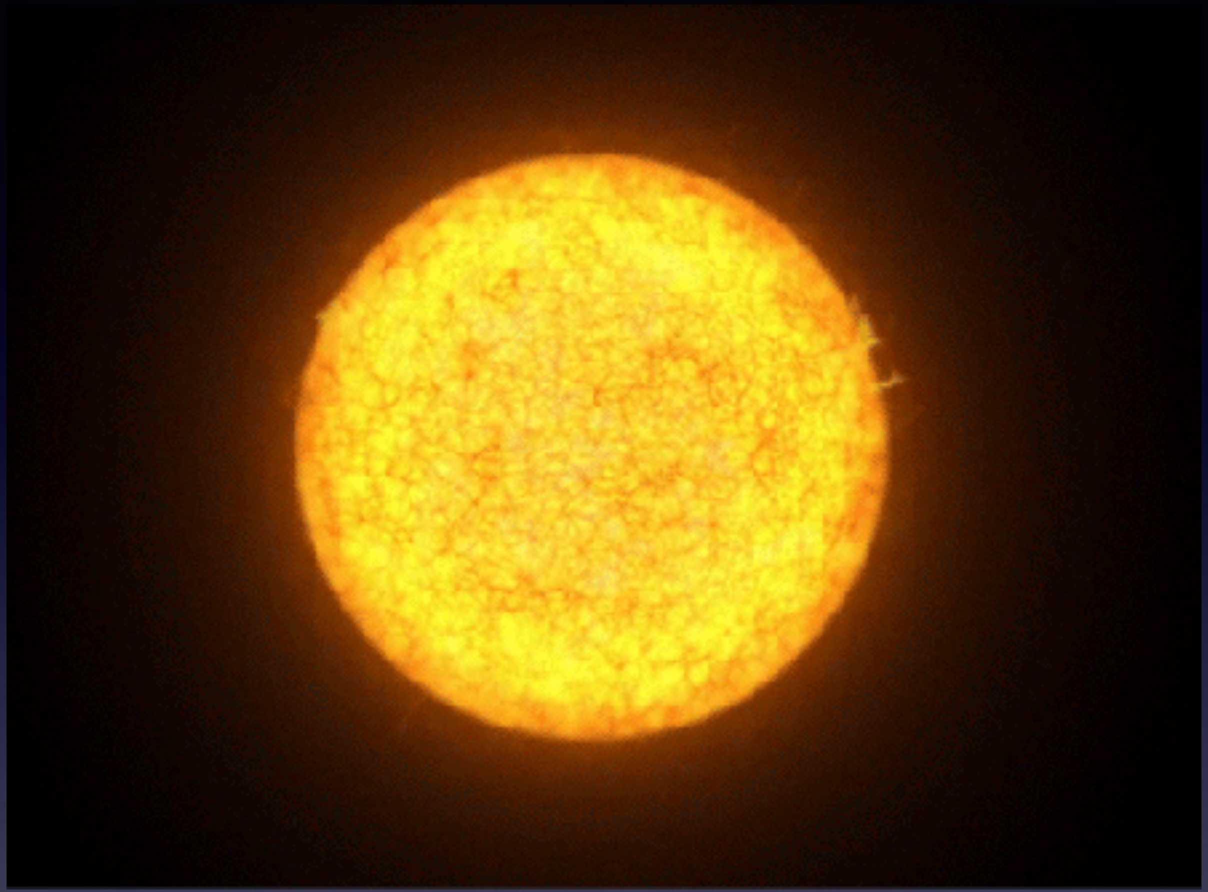


A 2.4% Determination of the Local Value of the Hubble Constant[1]

Adam G. Riess[2,3], Lucas M. Macri[4], Samantha L. Hoffmann[4], Dan Scolnic[2,5], Stefano Casertano[3], Alexei V. Filippenko[6], Brad E. Tucker[6,7], Mark J. Reid[8], David O. Jones[2], Jeffrey M. Silverman[9], Ryan Chornock[10], Peter Challis[8], Wenlong Yuan[4], Peter J. Brown[4], and Ryan J. Foley[11,12]


Three steps to the Hubble Constant
Parallax of Cepheids in the Milky Way
Earth, June
Sun
Cepheid
Earth, December
Galaxies hosting Cepheids and Type Ia supernovae
Distant galaxies in the expanding Universe hosting Type Ia supernovae
Light redshifted (stretched) by expansion of space
0 – 10 K ly
10 Thousand – 100 Million Light-years
100 Million – 1 Billion Light-years

Standard Candles: Cepheids



-Pulsates radially, varying in both diameter and temperature and brightness changes with a well-defined stable period and amplitude.

-Direct relationship between luminosity and pulsation period

-Many cepheids per galaxy

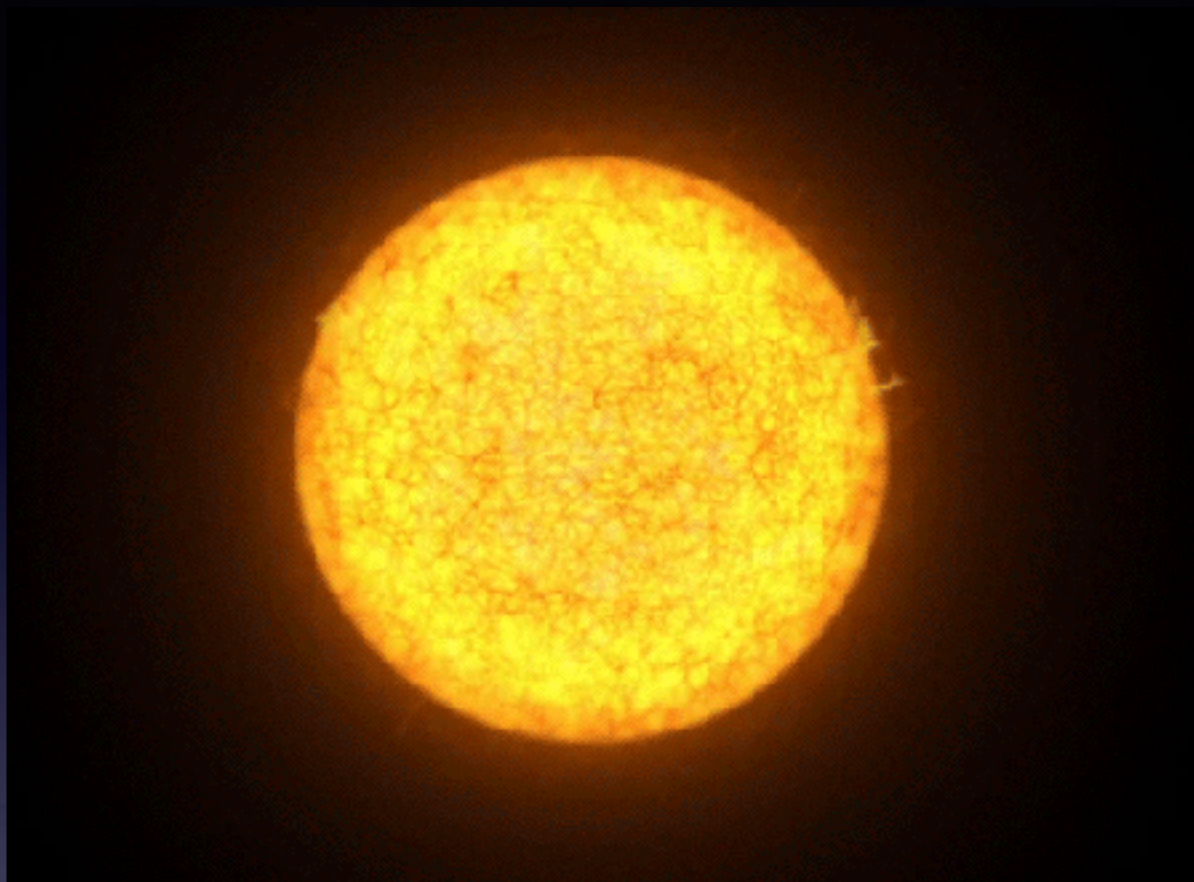
Standard Candles: Supernovae

-Carbon-Oxygen white dwarf accretes matter from companion, reaches near Chandrasekhar limit, explodes.

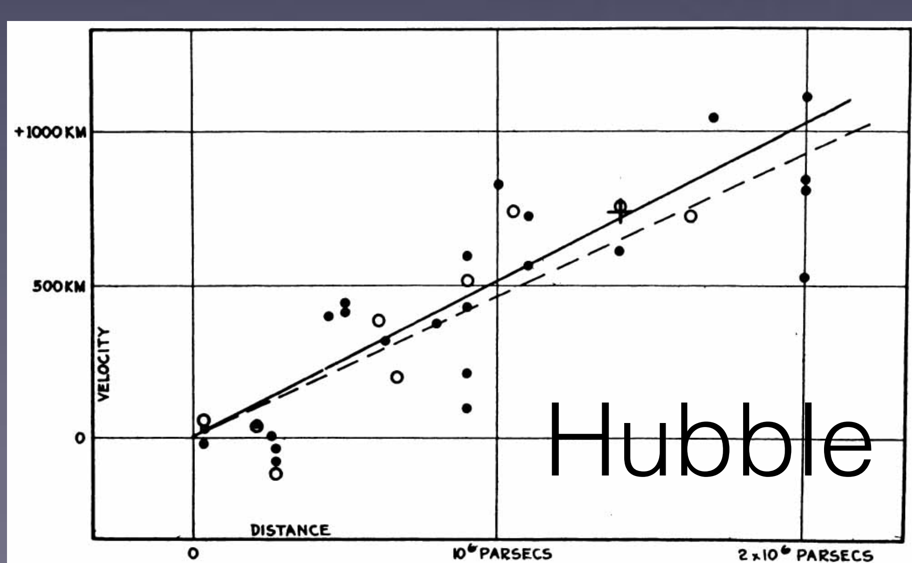
-Magnitude of explosion similar, differences can be traced to observables of explosion

-1 SN per galaxy per century

Standard Candles: Cepheids



Led to discovery of expanding universe



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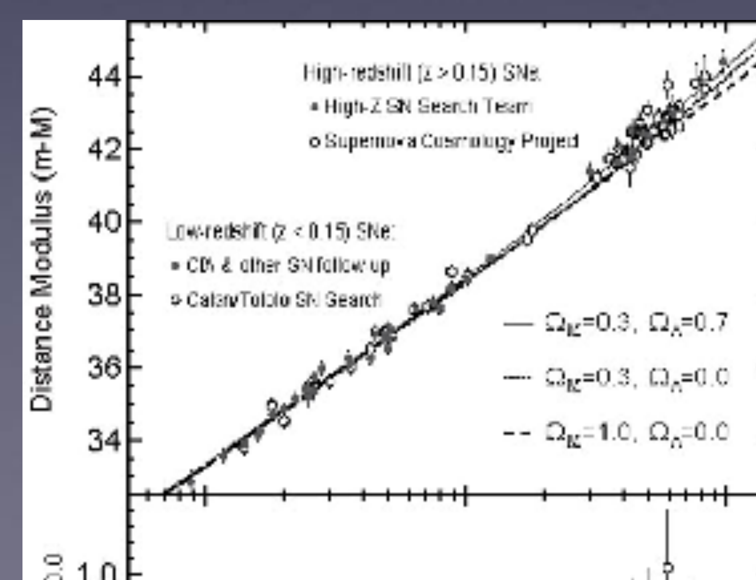
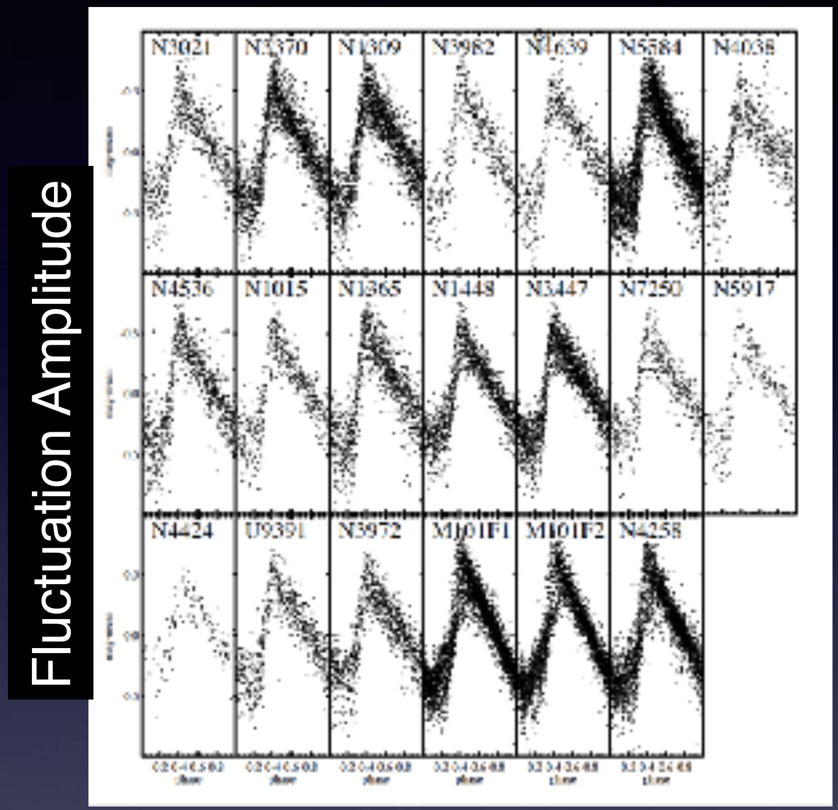
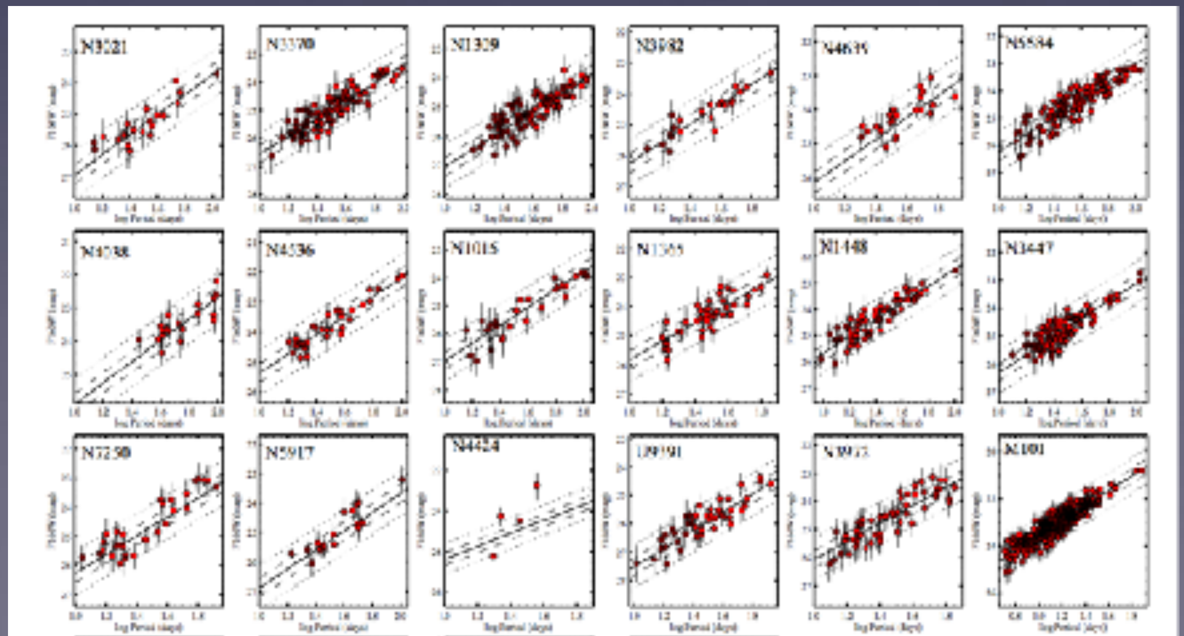


Distances from Cepheids

1. For each cepheid, measure period and mean luminosity



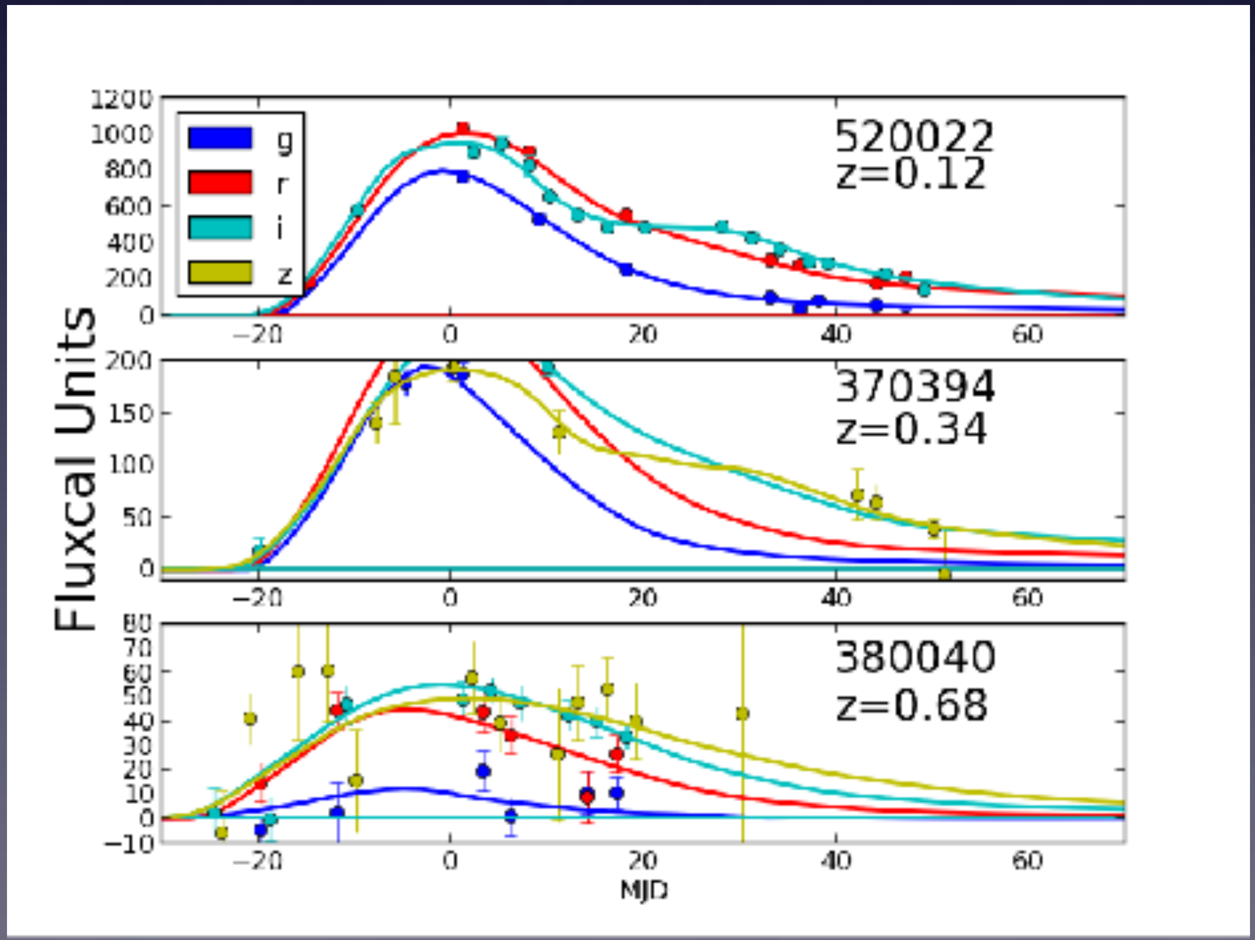
2. For each galaxy, measure PL relation to get distance.

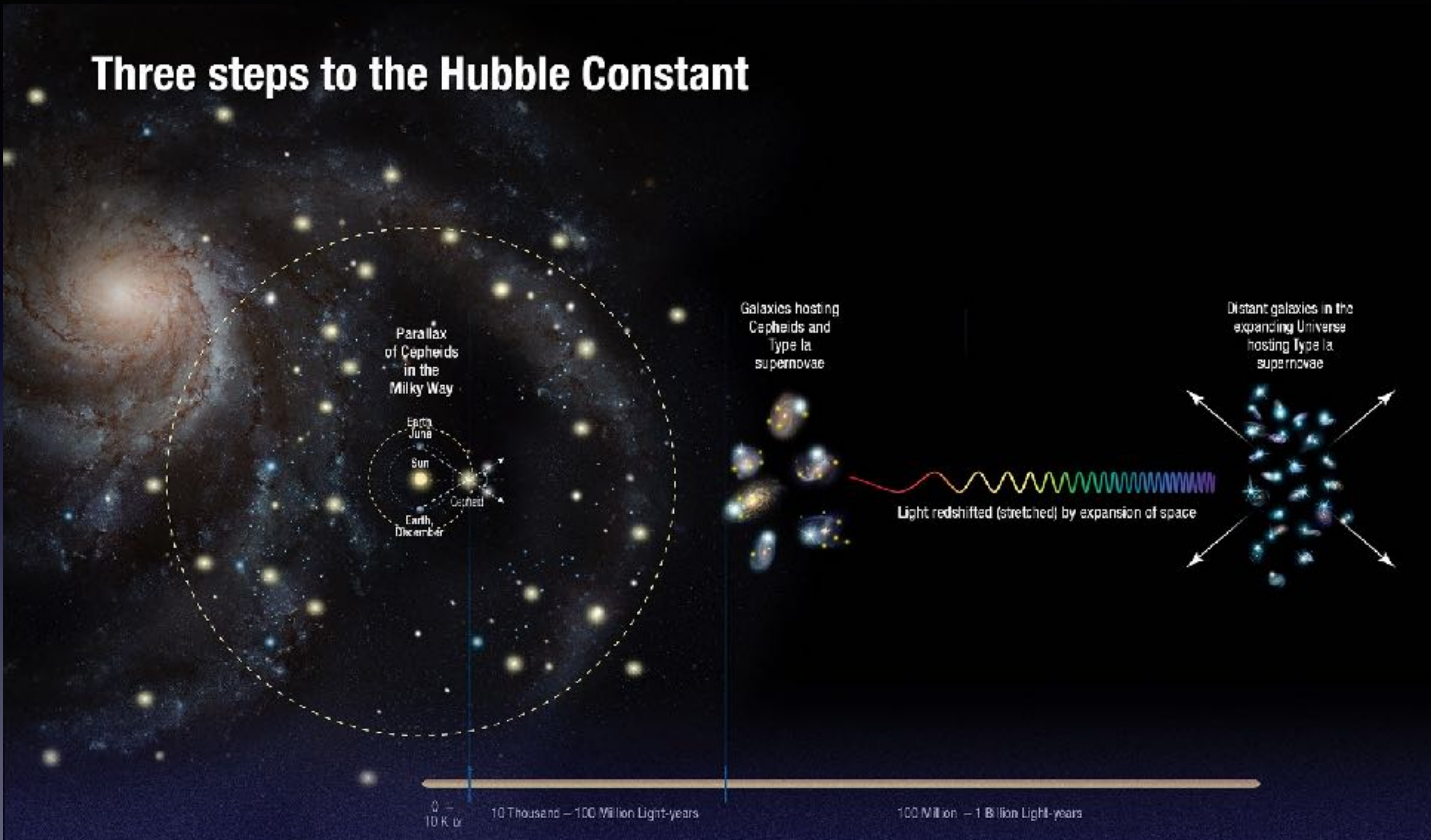


Distances from SNe

1. For each SN, we measure a width, color and amplitude to standardize the SNe

2. Since, intrinsic luminosity is known (to 10%) – and apparent luminosity can be measured, the ratio of the two can provide the luminosity-distance (d_L) of the supernova





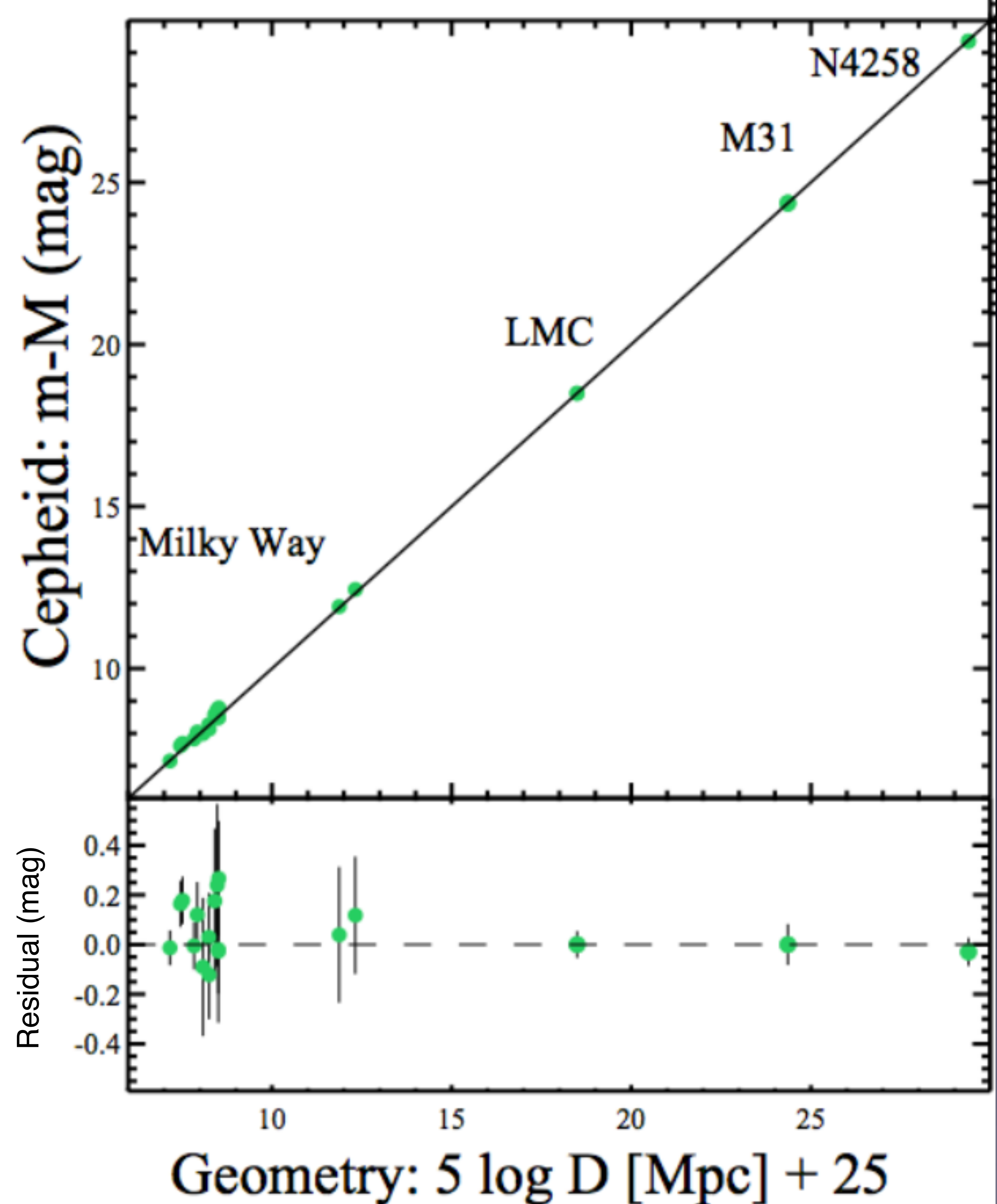
Combines cepheids and supernovae analysis

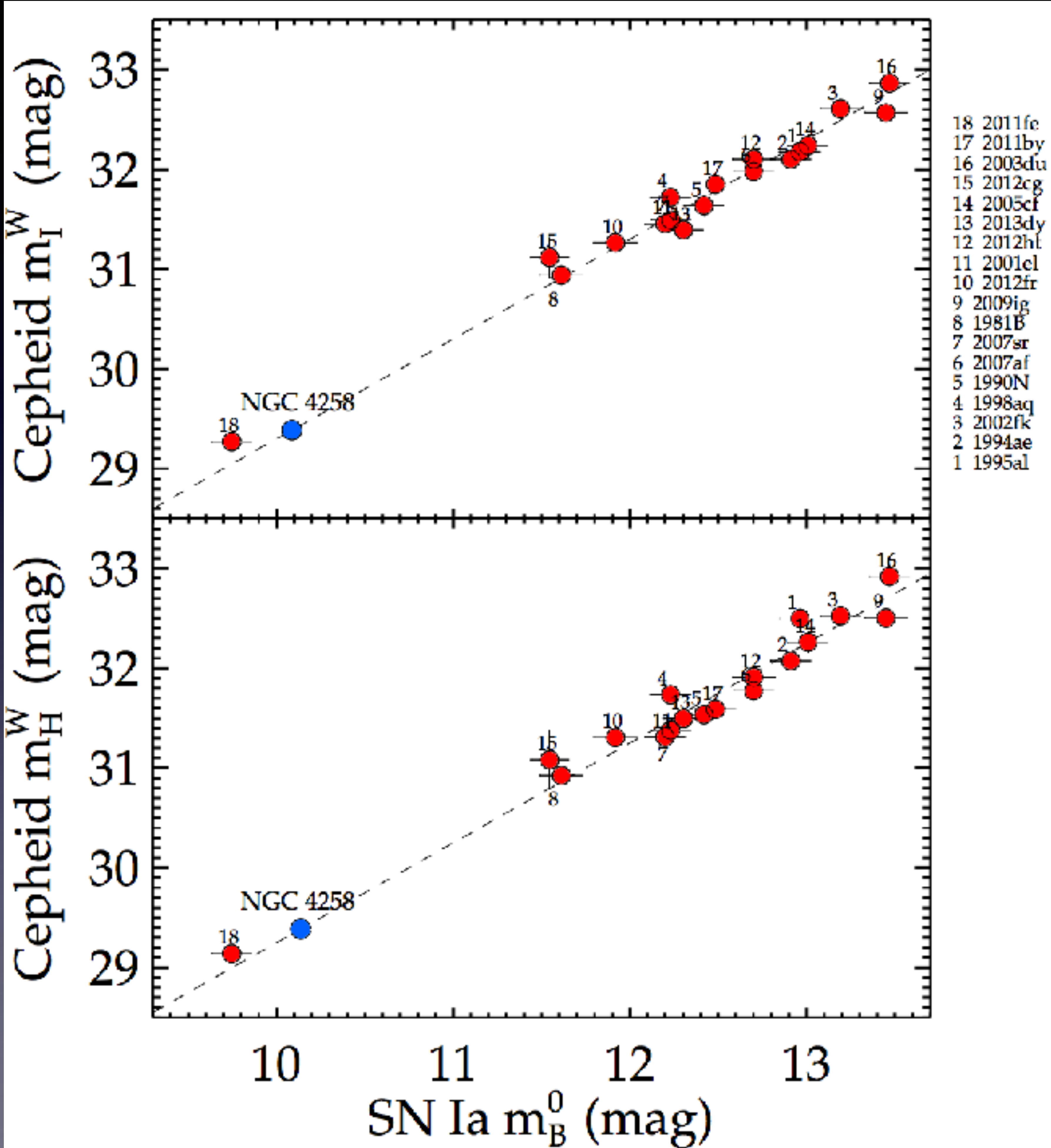
There are 4 different anchors that span 23 mags with <2% error!

MW - direct measurements of parallax from cepheids

NGC 4258 - Keplerian motion from masers - (small clouds of gas in star-forming regions that strongly amplify radio waves)

LMC/M31 - Detached Eclipsing Binaries



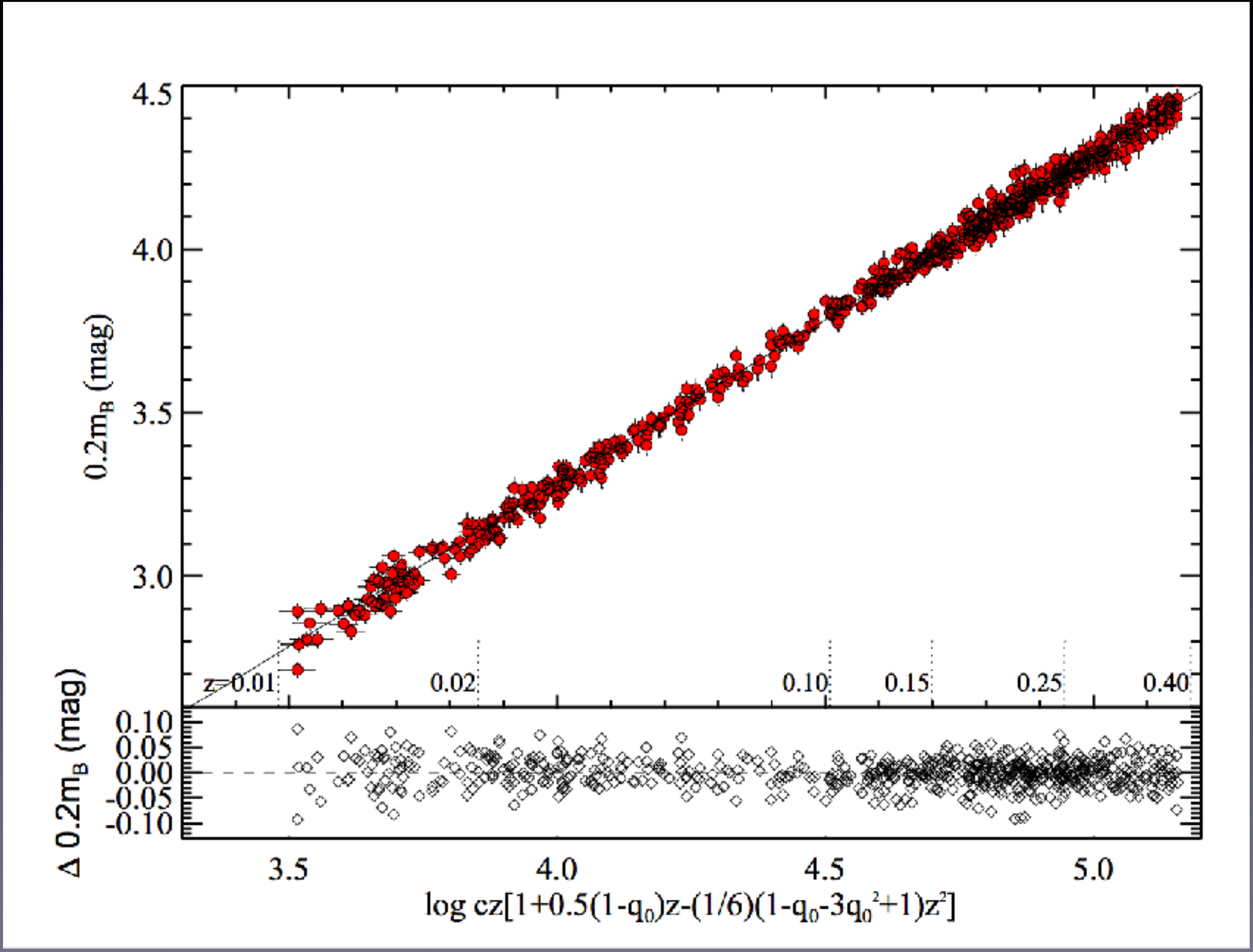


Observations of cepheids in optical and IR.

IR: small sensitivity to reddening and metallicity

Most scatter from SNe, not cepheids

For last step, we have ~300 low-z SNe so intercept is well constructed



To improve systematic uncertainty, the key is to improve calibration between surveys

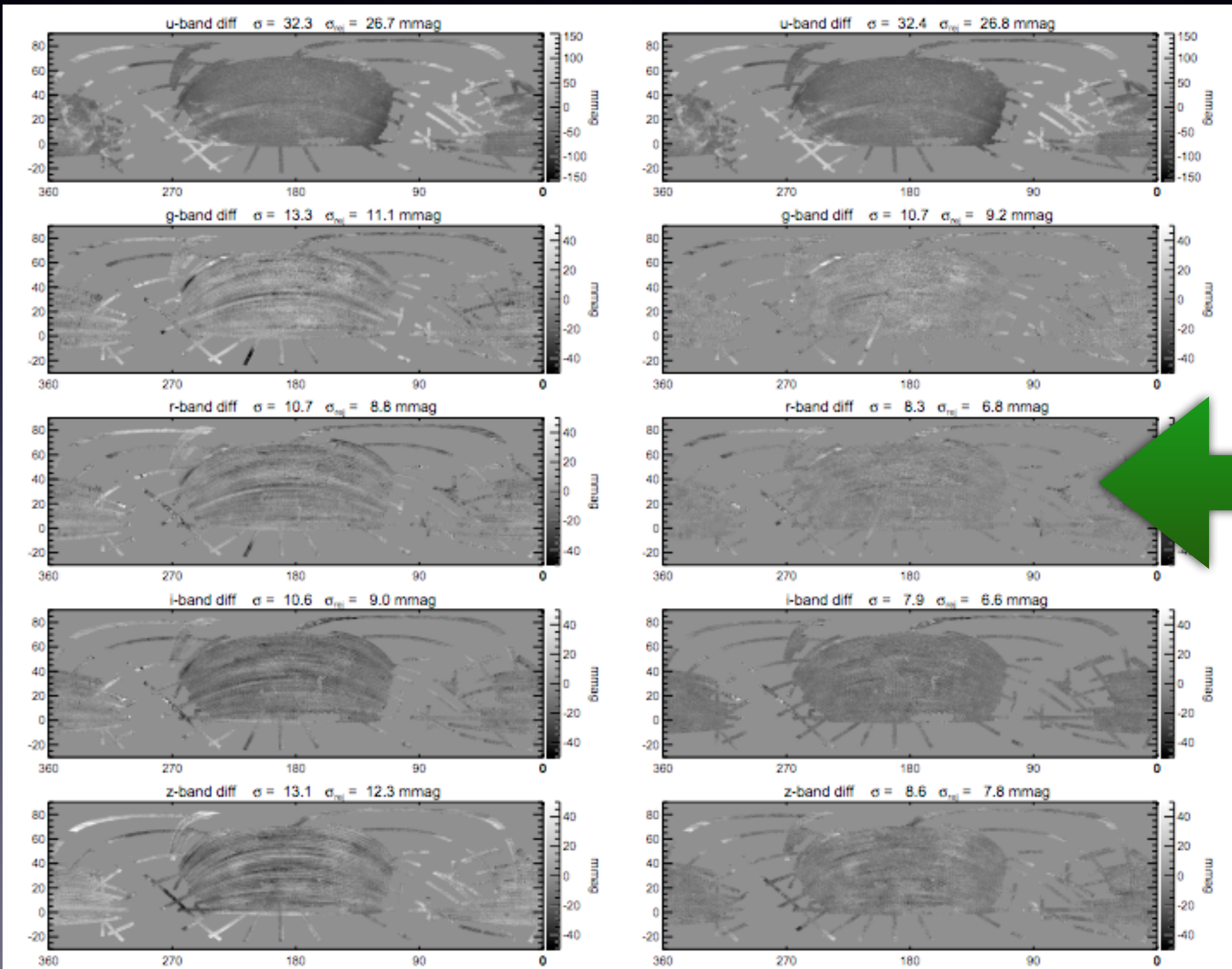


FIG. 1.— The mean difference (PS1 minus SDSS) in 15 arcminute

FIG. 2.— Same as Fig. 1, but after recalibration. The cali-

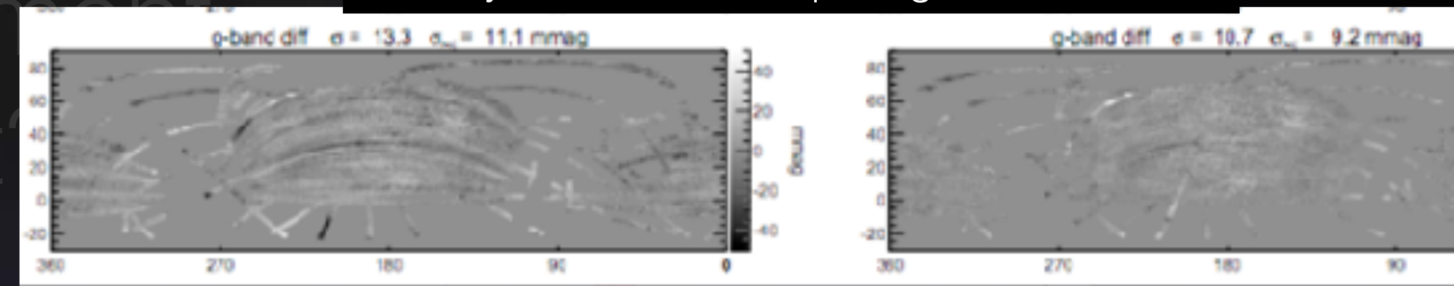
Schlafly, Finkbeiner et al. did PS1 Ubercal, relative calibration across sky <5mmag, <3 mmag for MD fields

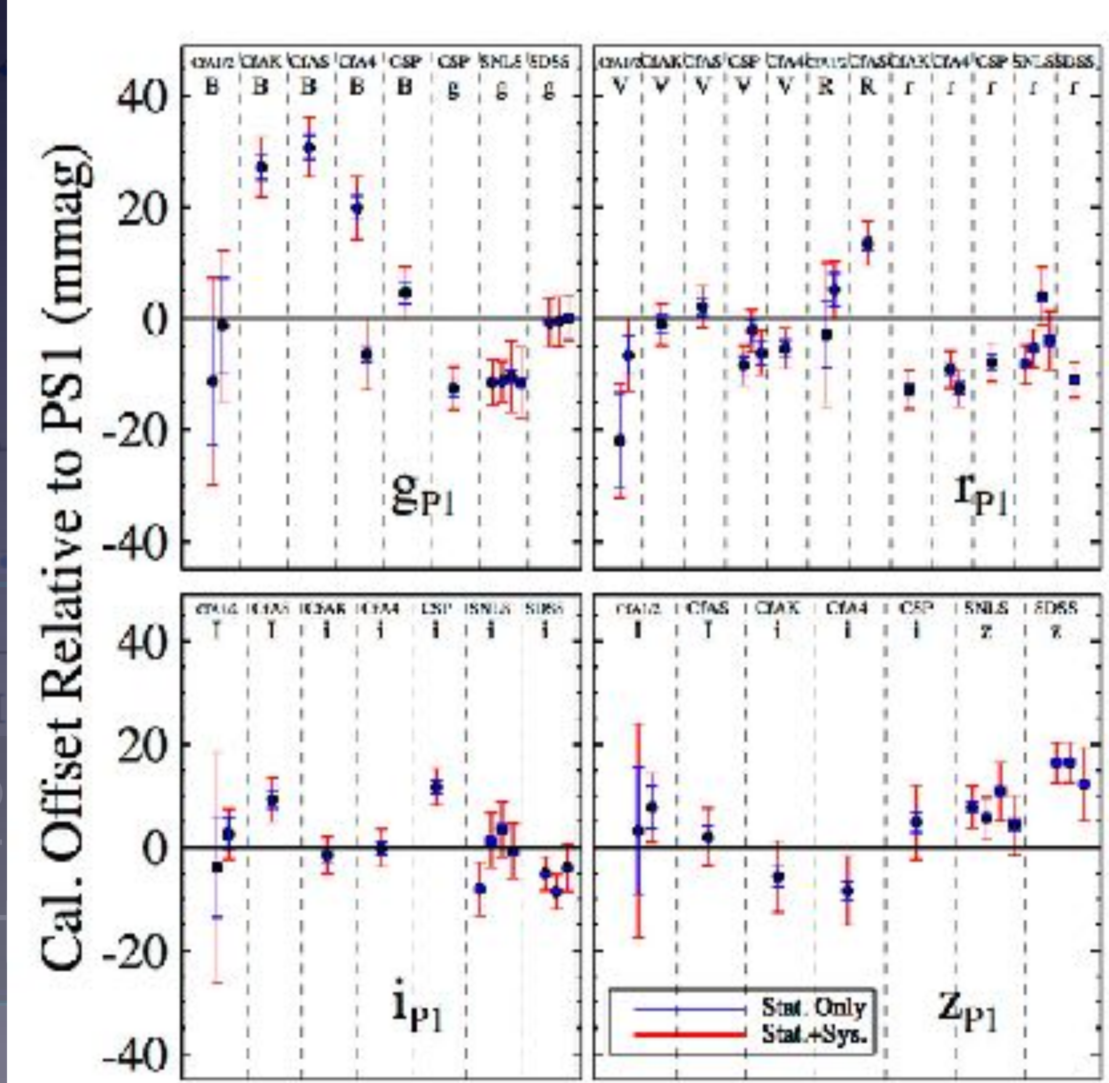
Compared PS1 to SDSS, found SDSS issues

Scolnic et al. 2015 cross-calibrates all supernova samples!

For Hubble flow:
0.4%
Uncertainty
already small due to high statistics and able to take advantage of PS1’s Ubercal (Schlafly et al.) to cross-calibrate all of the samples
(Scolnic et al. 2015)

Schlafly et al. 2012 comparing SDSS and PS1



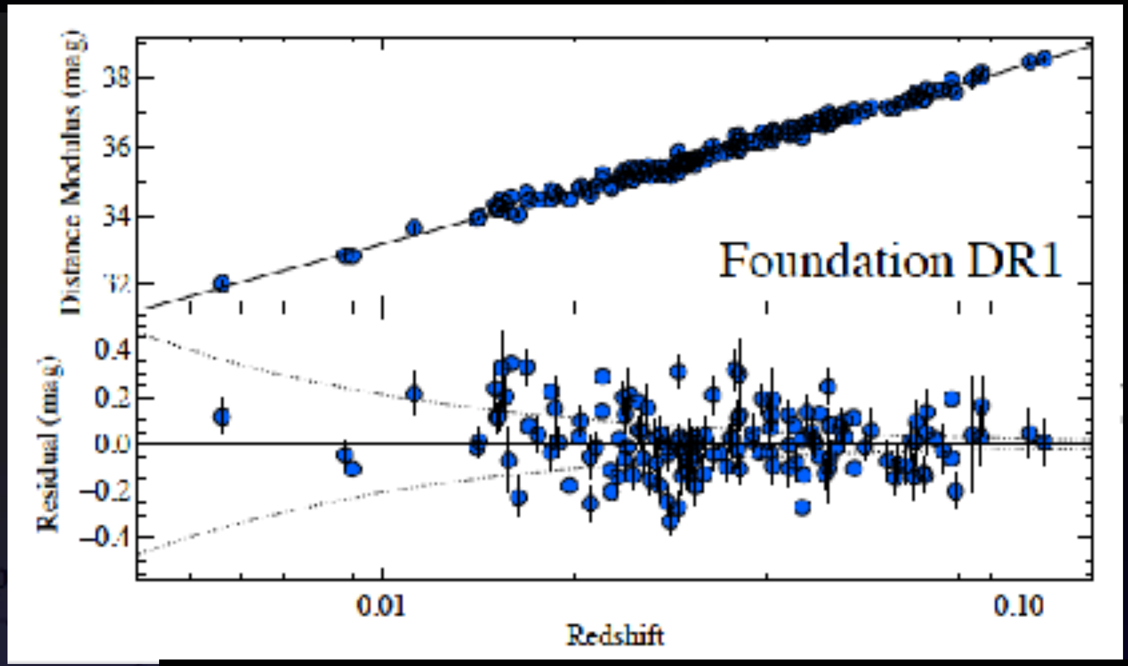


Scolnic et al. 2015

For Hubble flow:
0.4%
Uncertainty
will get smaller due to new Foundation survey (PIs/Founding Fathers: A. Rest, D. Scolnic, R. Foley)

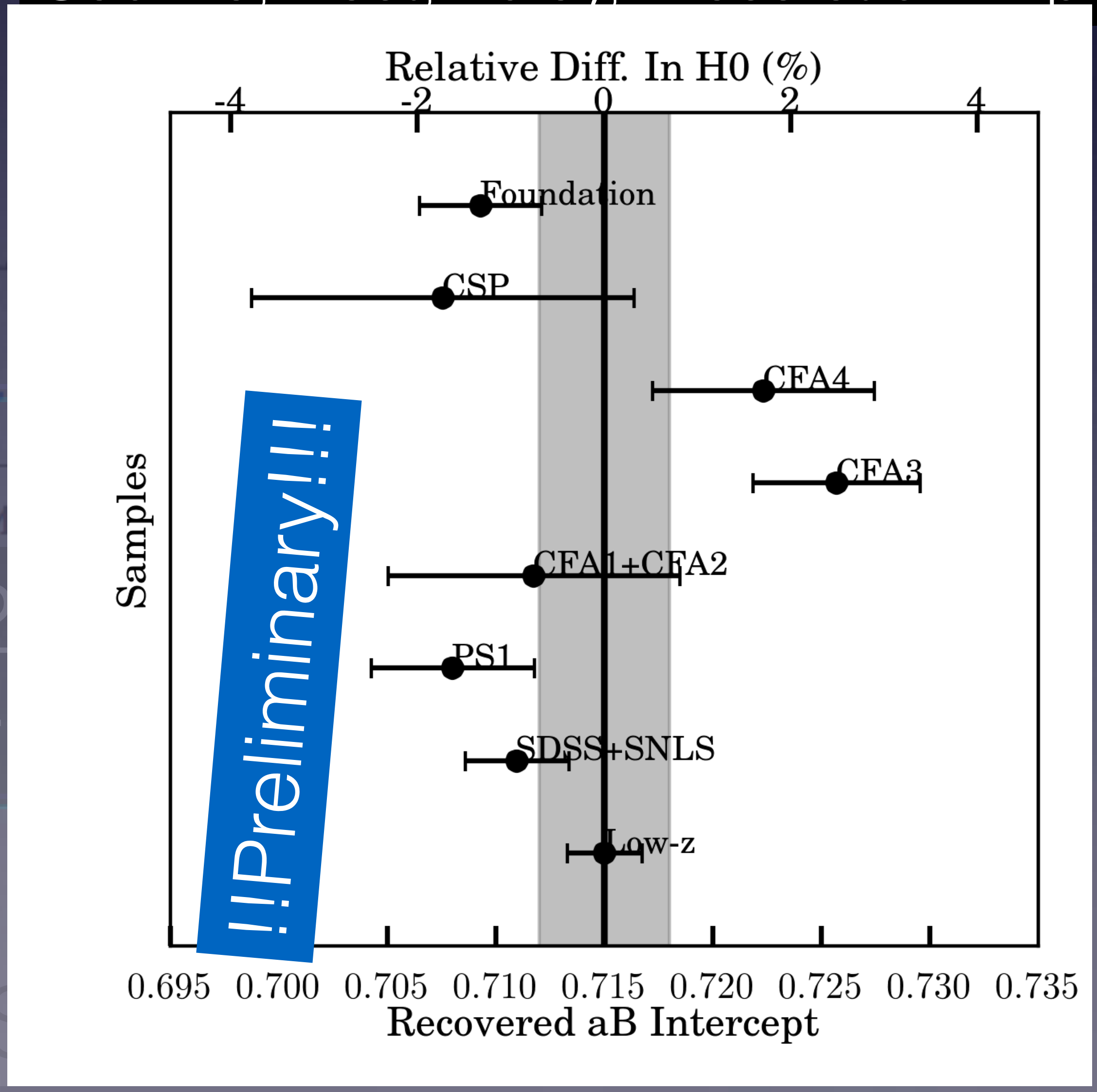
Uses Pan-STARRS telescope to follow-up low-z SNe

Can re-derive intercept of Hubble flow SNe for each SN subsample including Foundation



Foley, Scolnic, Rest et al. in prep

Scolnic, Rest, Foley, Riess et al. in prep



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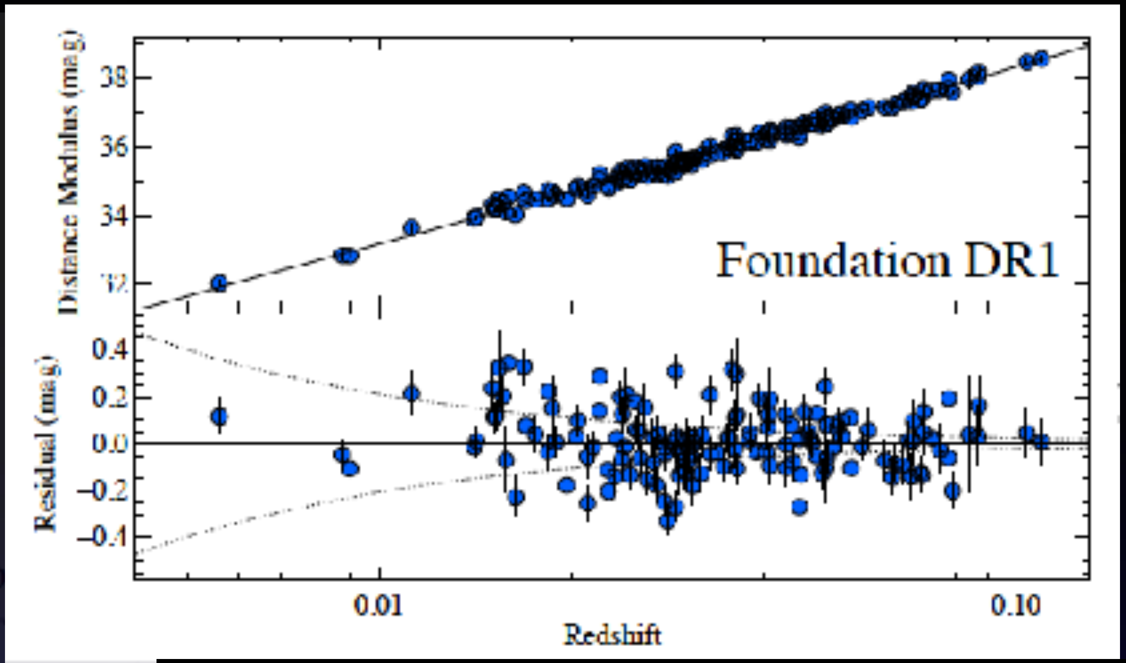
Uses Pan-STARRS telescope to follow-up low-z SNe

Can re-derive intercept of

I'd like to do this with DECam also!!!



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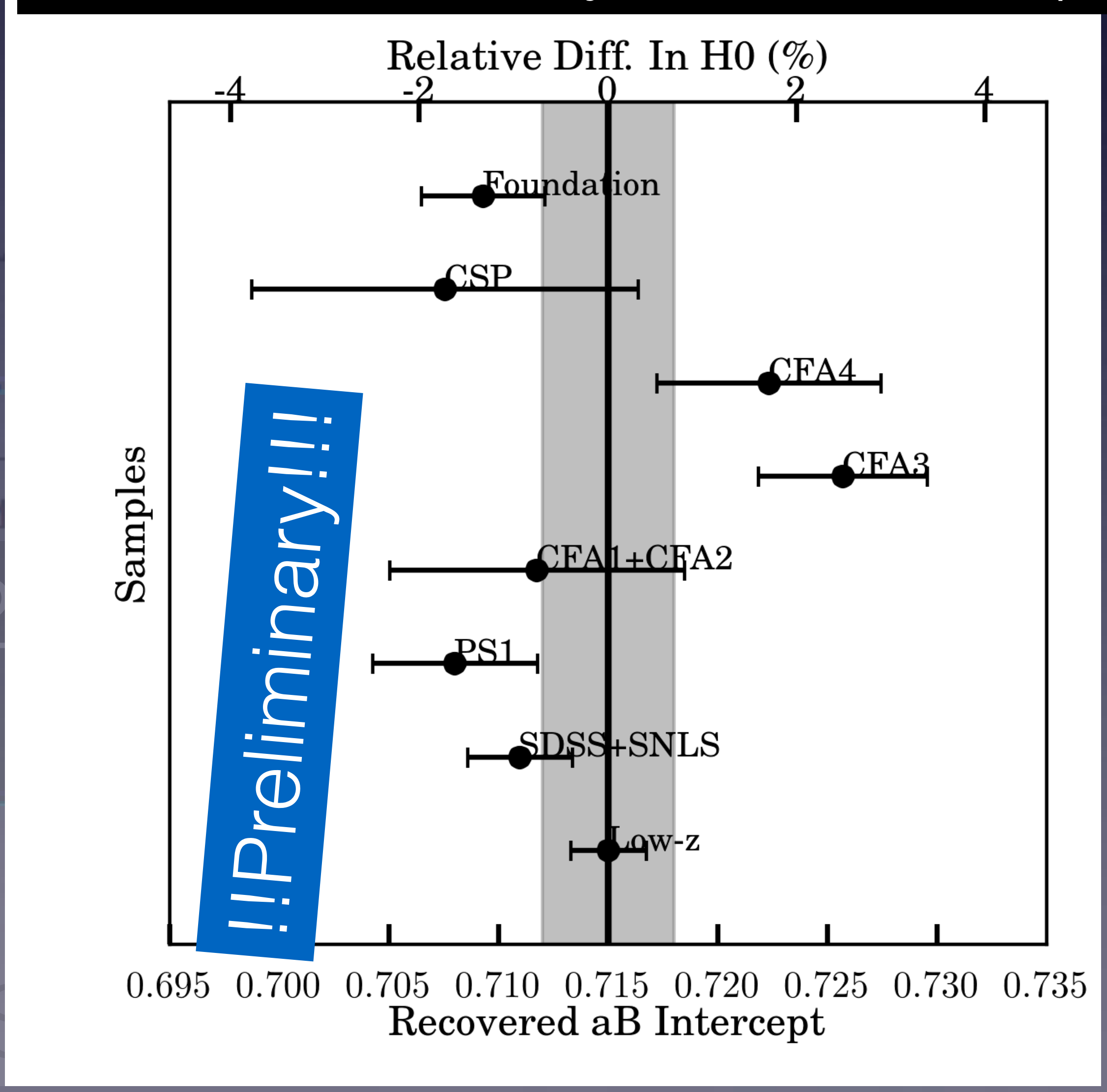
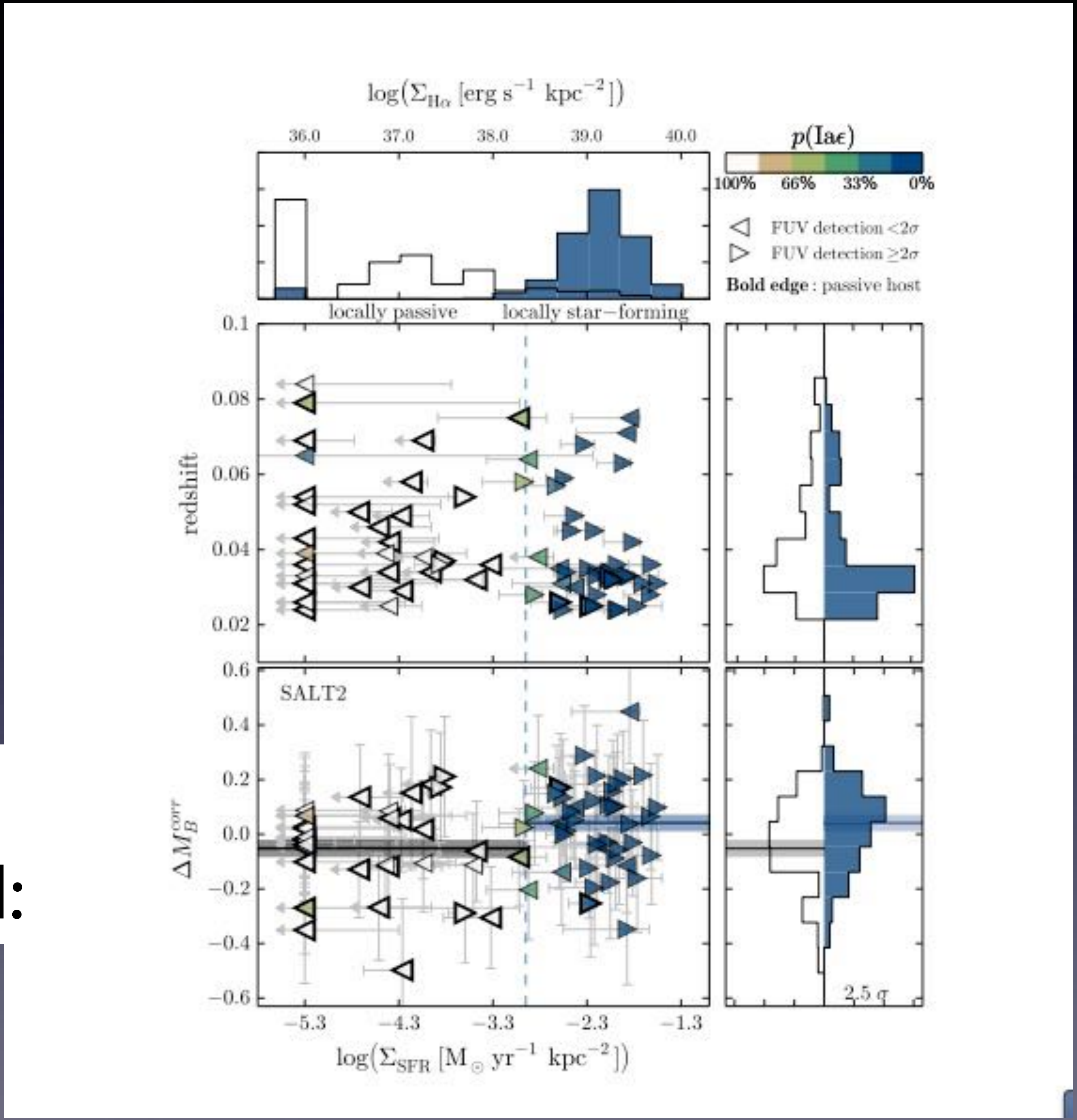


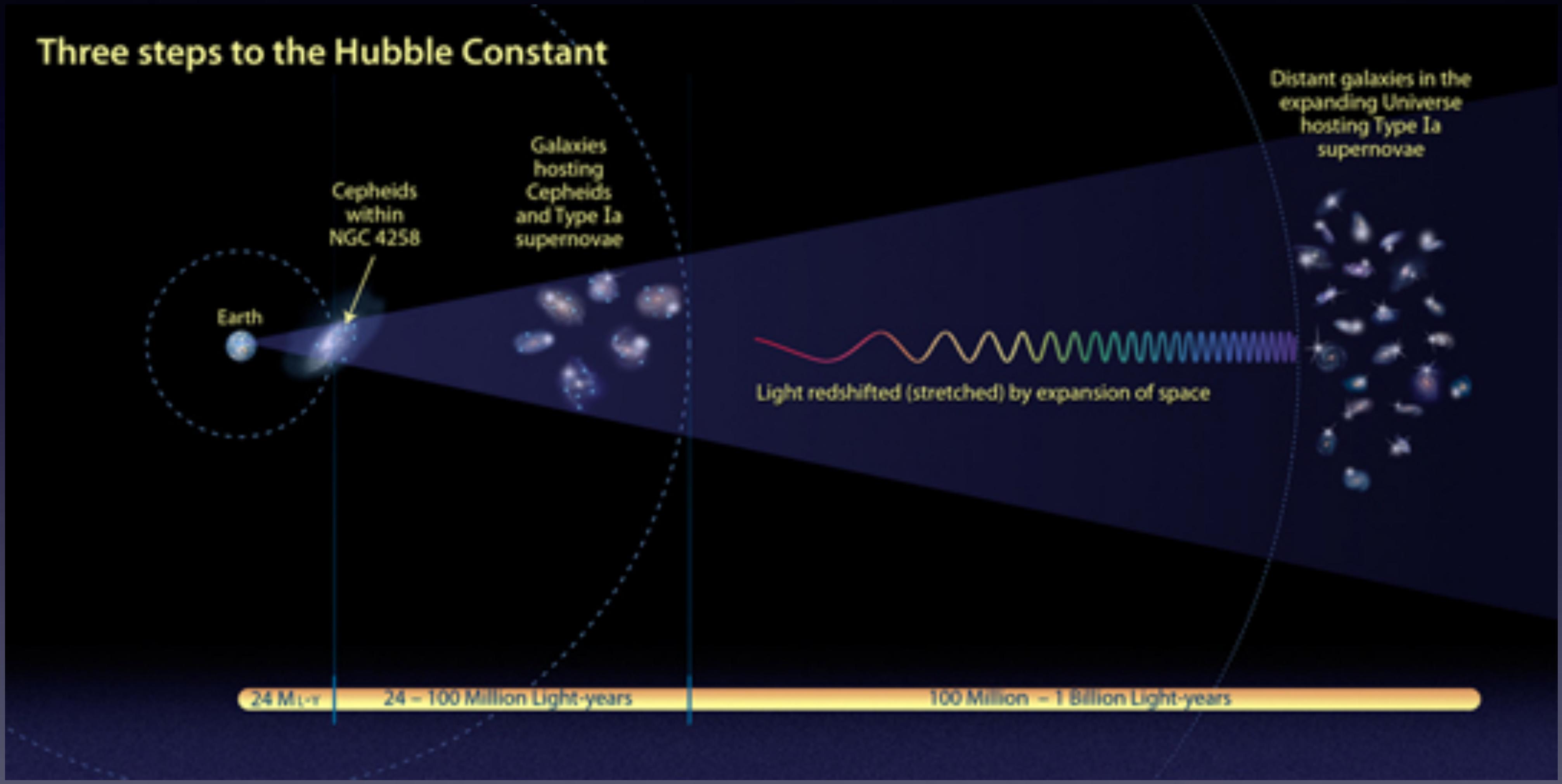
A changing Hubble step has been predicted by Rigault 2015 due to correlation of local star formation with Hubble residual. Fraction of galaxies with local sfr changes with redshift.

This is instead of the mass correction, use local sfr

Hubble Residual:



The claim is that this may affect H0 measurement..

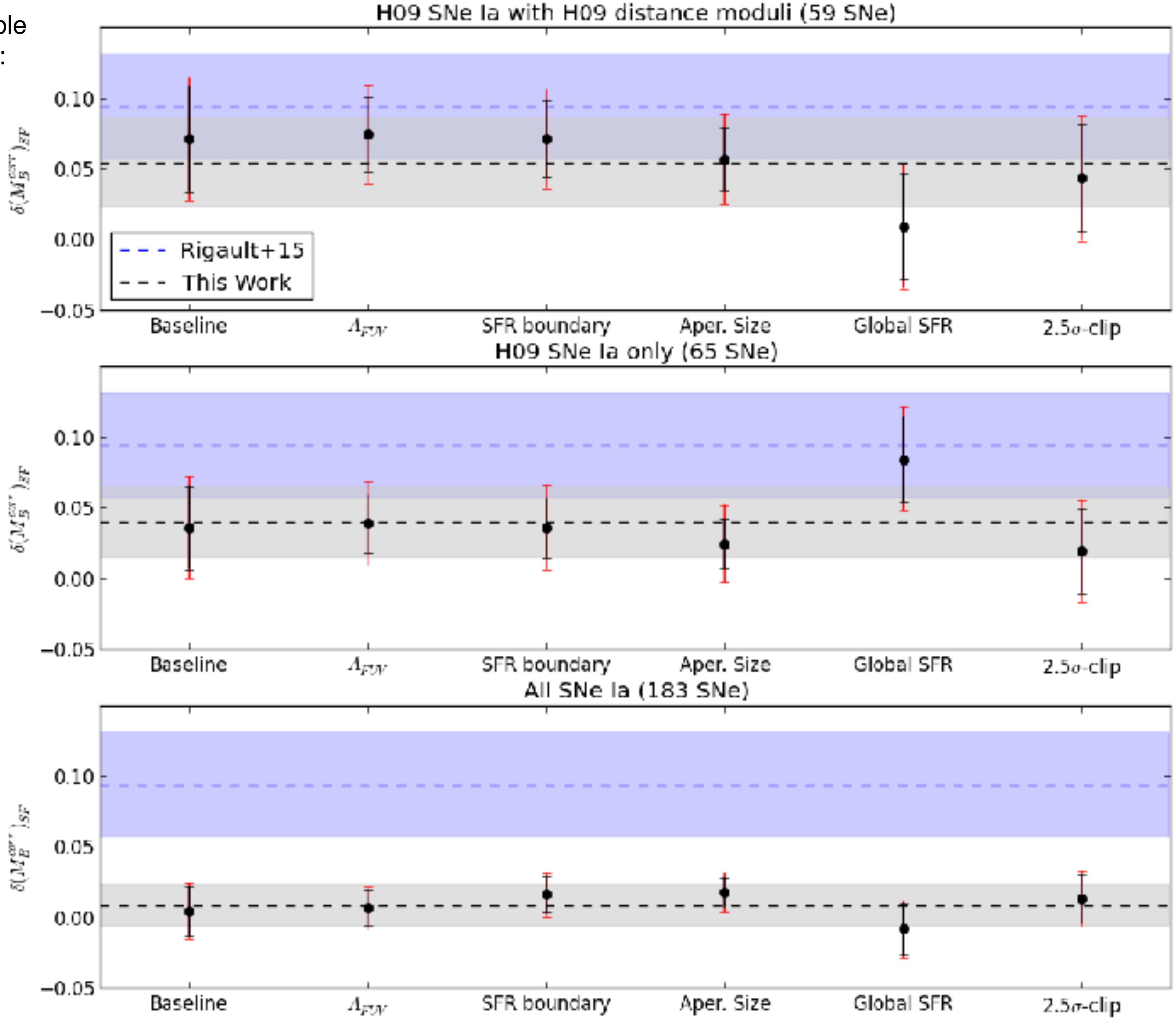


RIGAULT2015:

- Galaxies hosting cepheids and Type Ia SNe have more local SFR than distant galaxies -> may change H0.

With more statistics, we can't reproduce effect

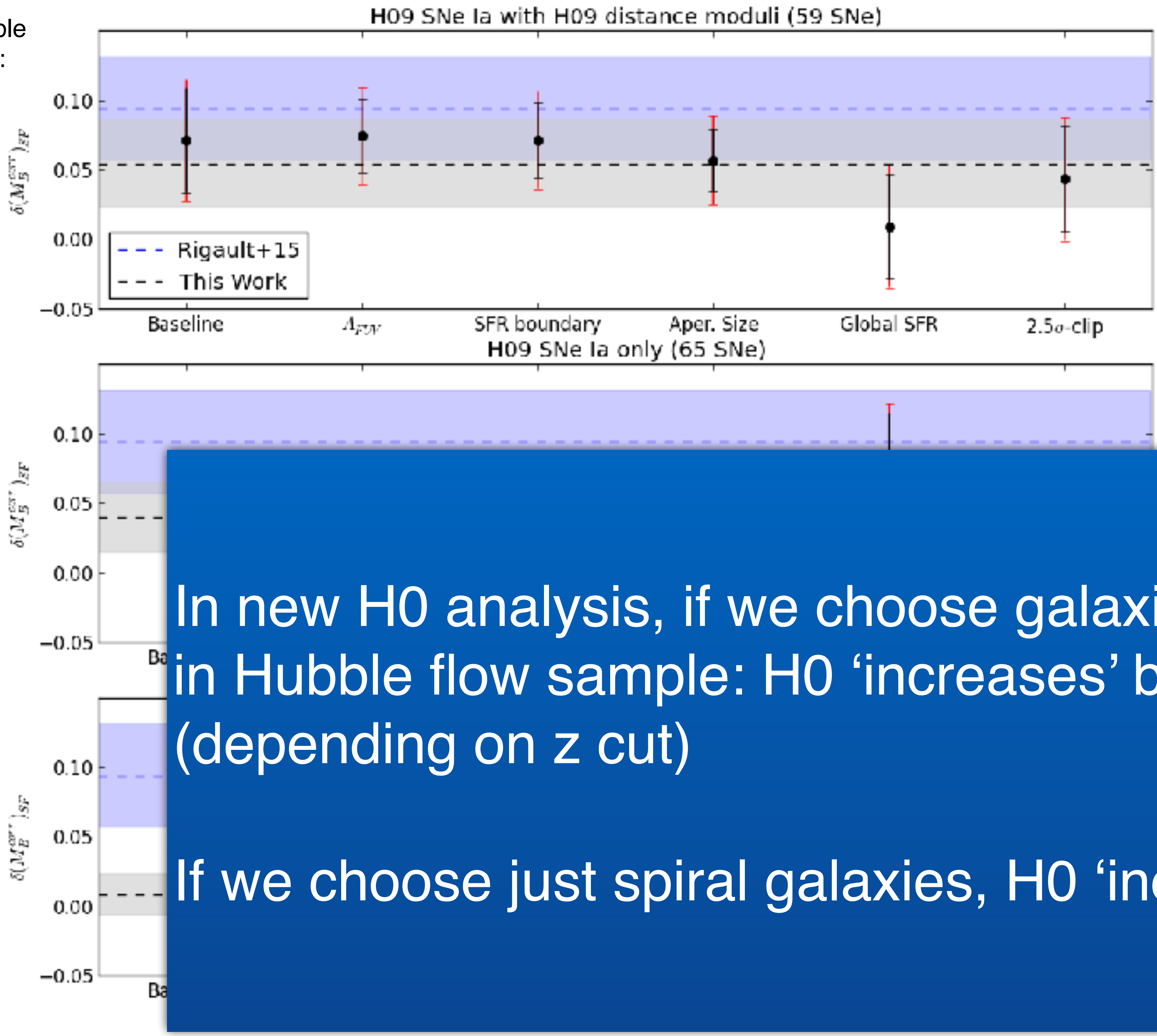
Hubble Step:



From Jones, Riess, & Scolnic 2015

And putting it in makes tension slightly worse!

Hubble Step:

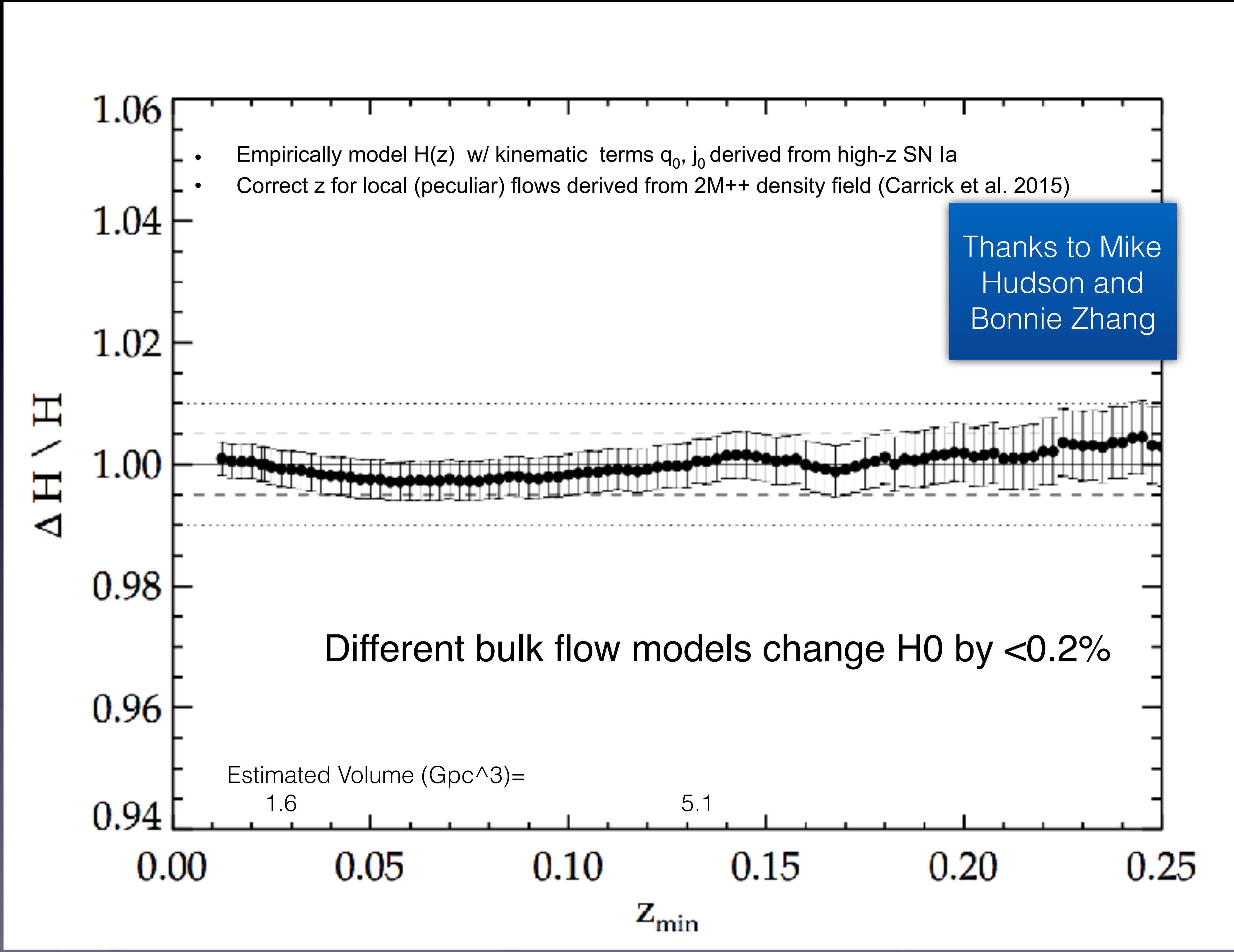


From Jones, Riess, & Scolnic 2015

In new H0 analysis, if we choose galaxies with high LSF in Hubble flow sample: H0 'increases' by 0.8,0.2 (depending on z cut)

If we choose just spiral galaxies, H0 'increases' by 0.5

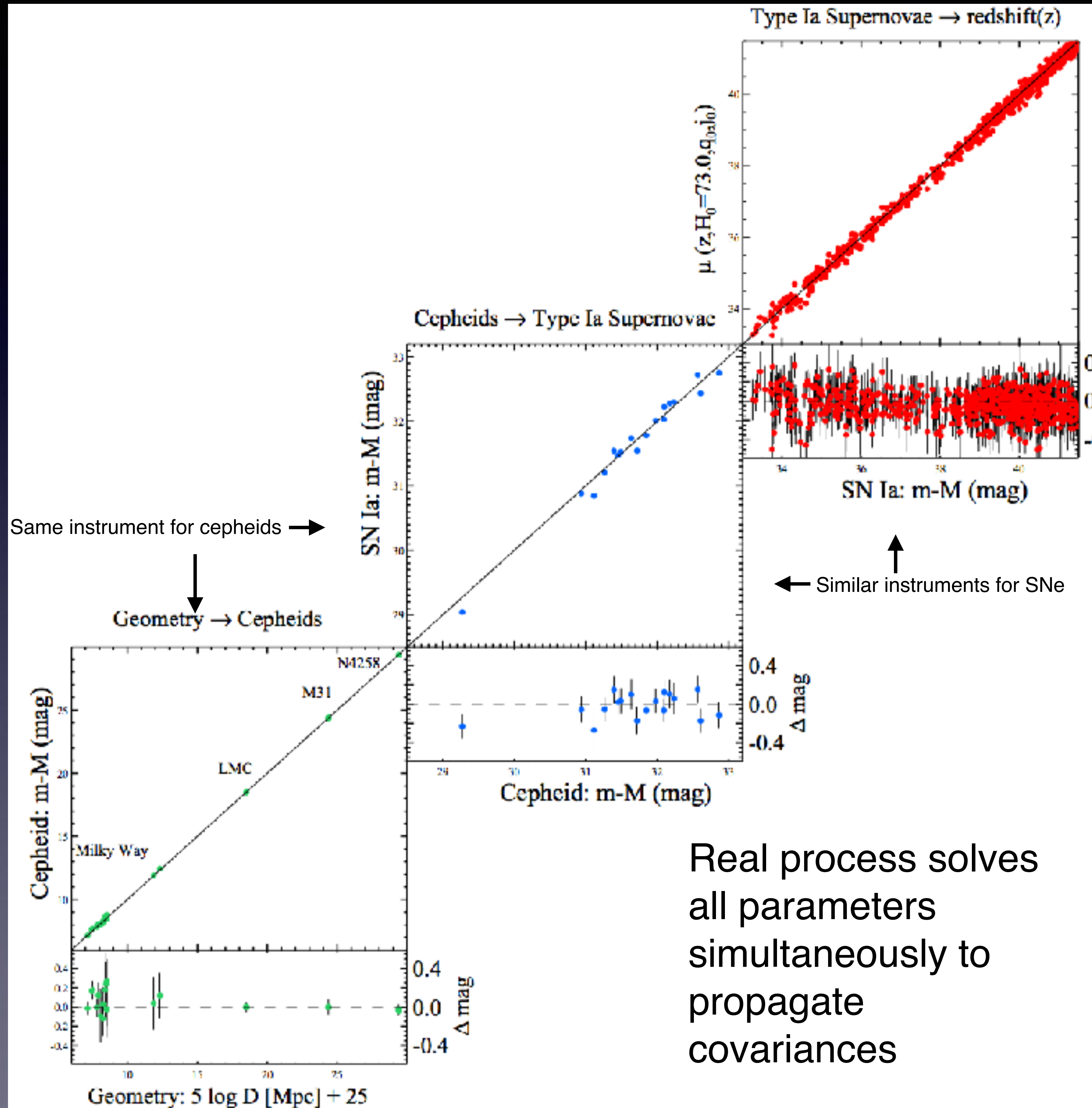
Is local H_0 (0.02<z<0.15) same as global H_0?



Test: explore larger volume, $z_{min}<z<z_{min}+0.15$, $\Delta H_0 < 0.4\%$

- N-body sims in 700 Mpc box → 0.3% (Odderskov et al. (2016)

Ultimately, we produce the distance ladder.



Real process solves all parameters simultaneously to propagate covariances

Four geometric distance calibrations of Cepheids:

	H0 (km/s/Mpc)
(i) megamasers in NGC 4258:	72.25±2.51
(ii) 8 DEBs in the LMC:	72.04±2.67
(iii) 15 MW Cepheids with parallaxes:	76.18±2.37
(iv) 2 DEBs in M31:	74.50±3.27

— —

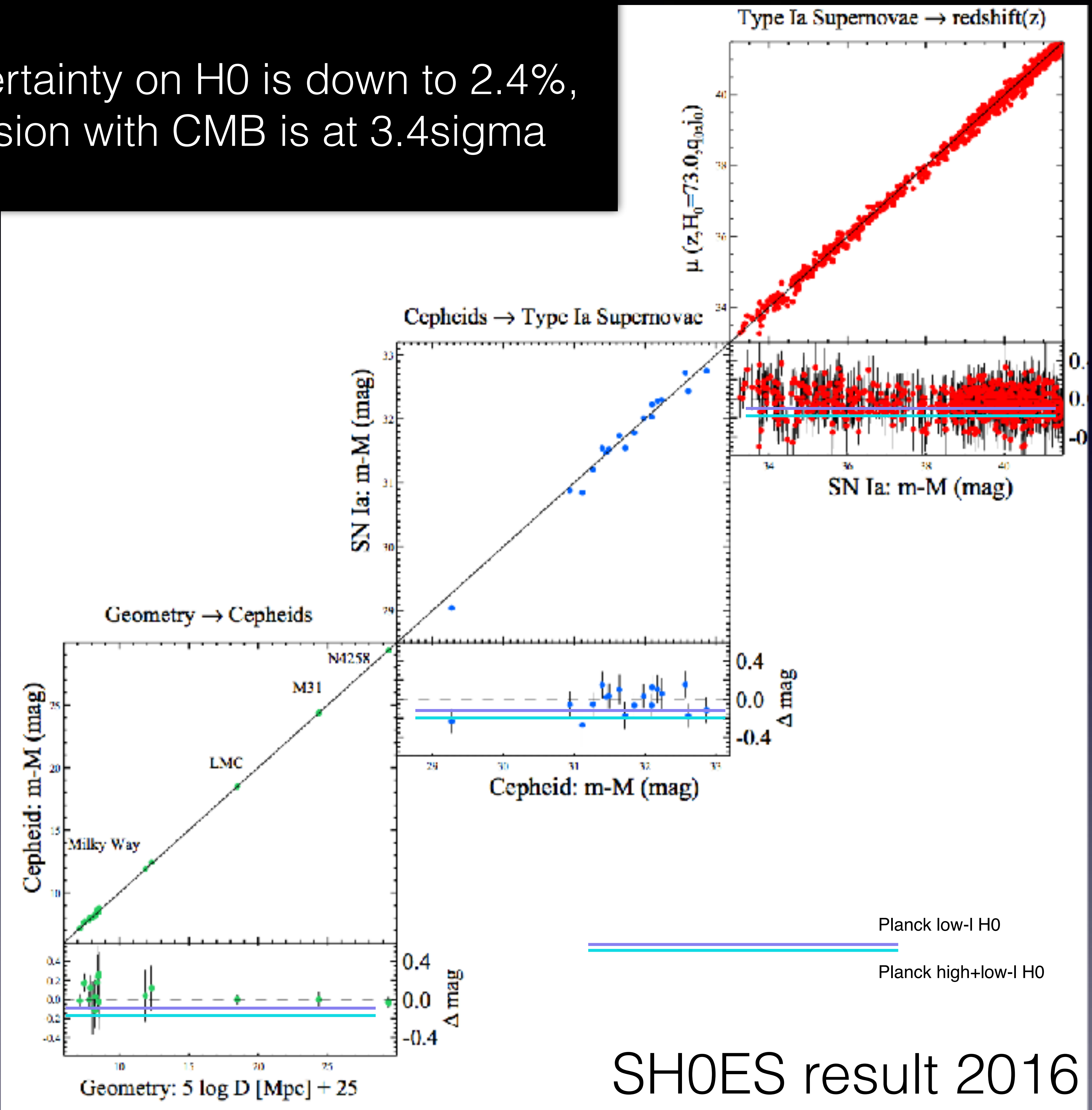
Best estimate of H0: 73.24±1.74

— —

This value is 3.4σ higher than Planck 66.9 ± 0.6 km/s/Mpc for ΛCDM with 3 neutrino flavors having a mass of 0.06 eV and the Planck data

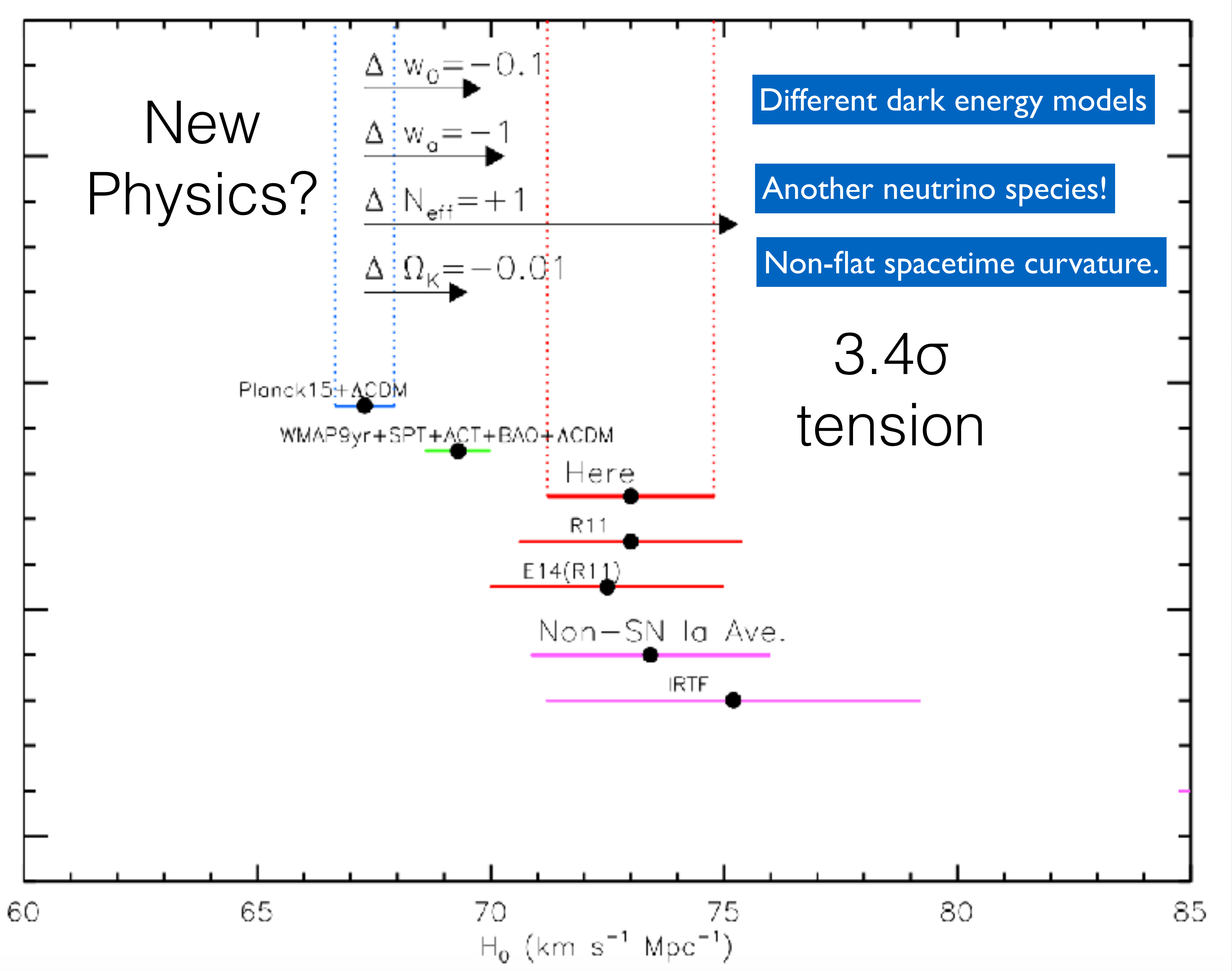
(2.0σ relative to the prediction of 69.3 ± 0.7 km s–1 Mpc–1 from WMAP+SPT+ACT+BAO)

The uncertainty on H0 is down to 2.4%, but tension with CMB is at 3.4sigma



SH0ES result 2016

"If a persuasive case can be made that a direct measurement of H0 conflicts with these estimates, then this will be strong evidence for additional physics beyond the base LCDM model". [Planck 2015]



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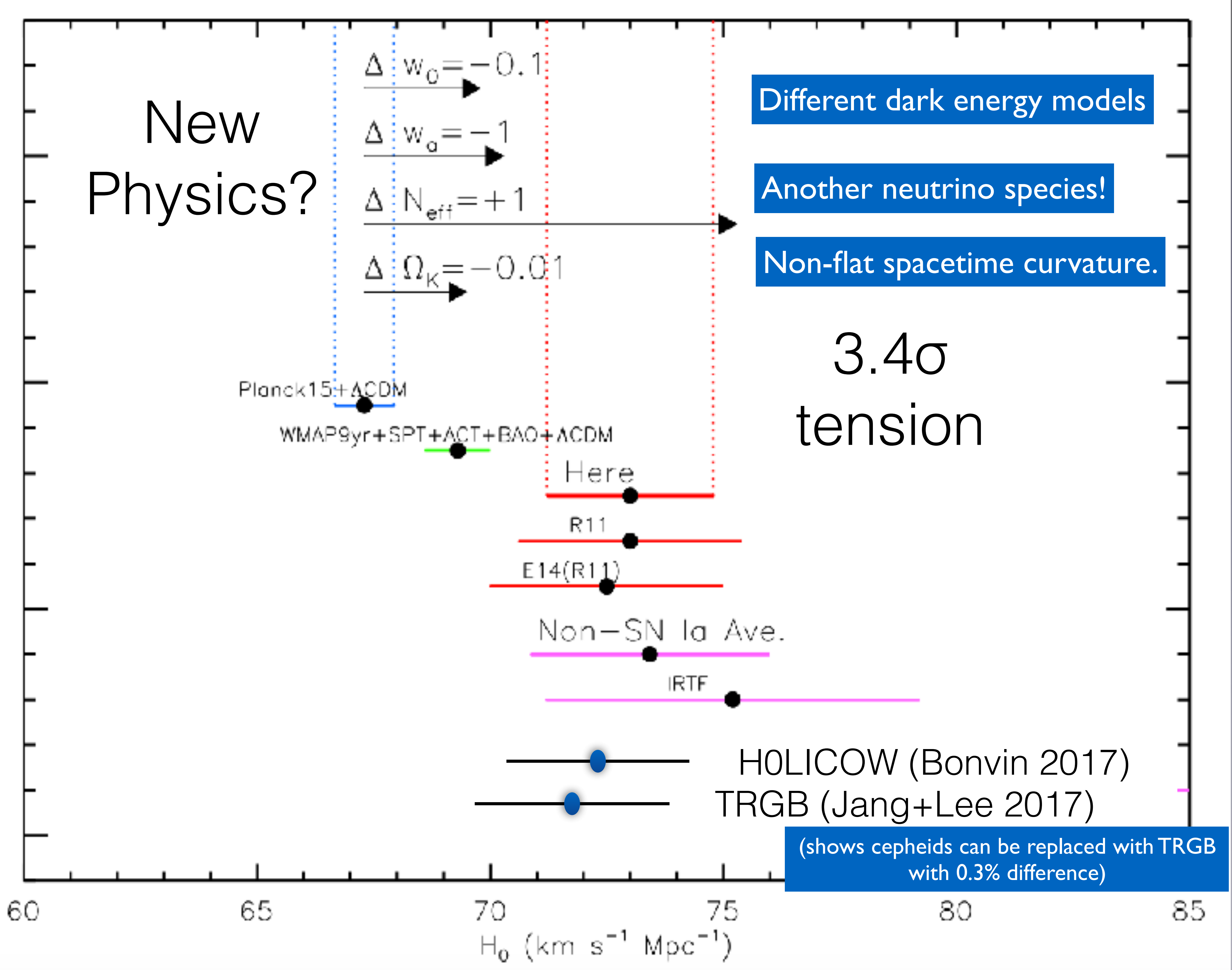
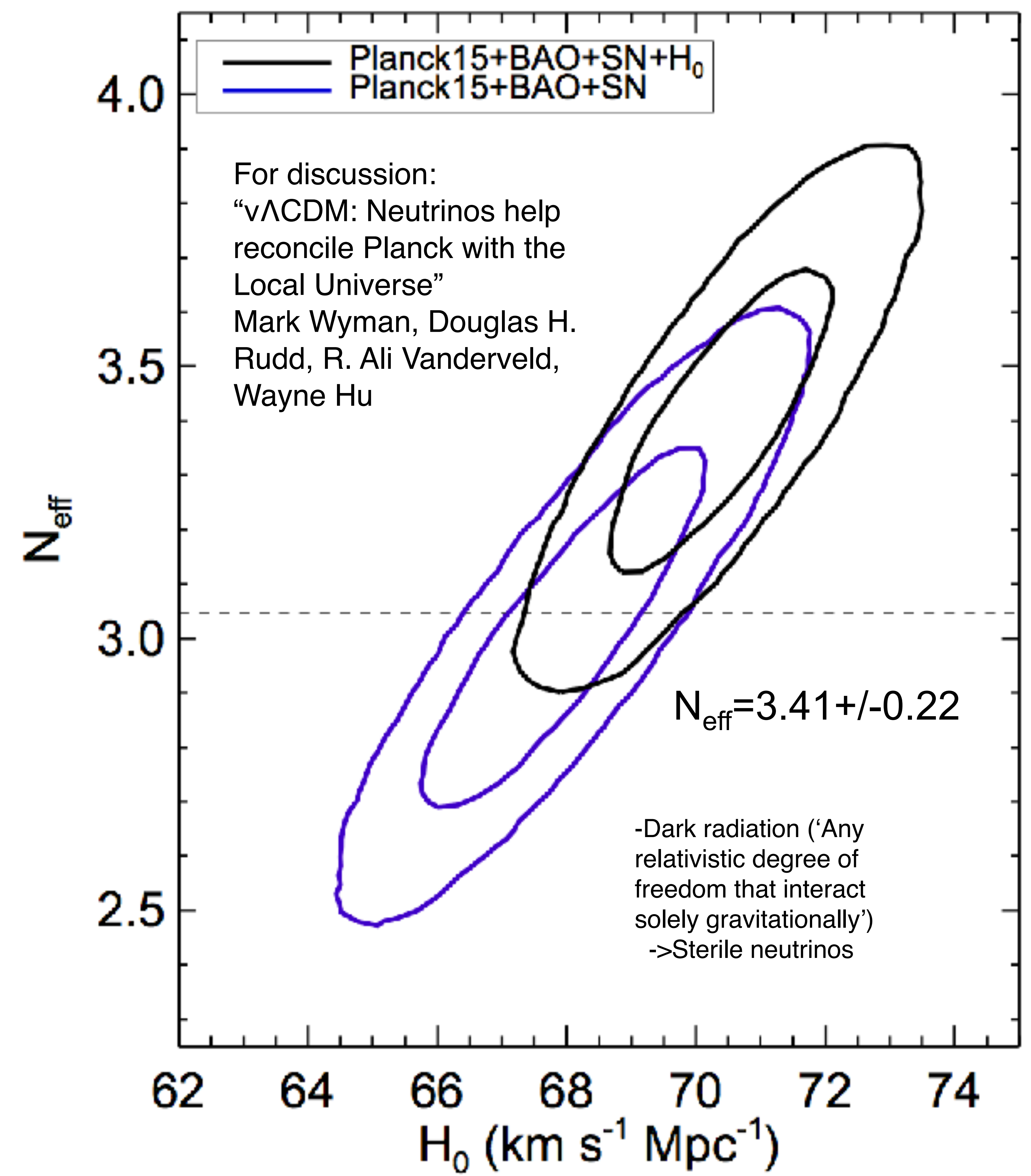
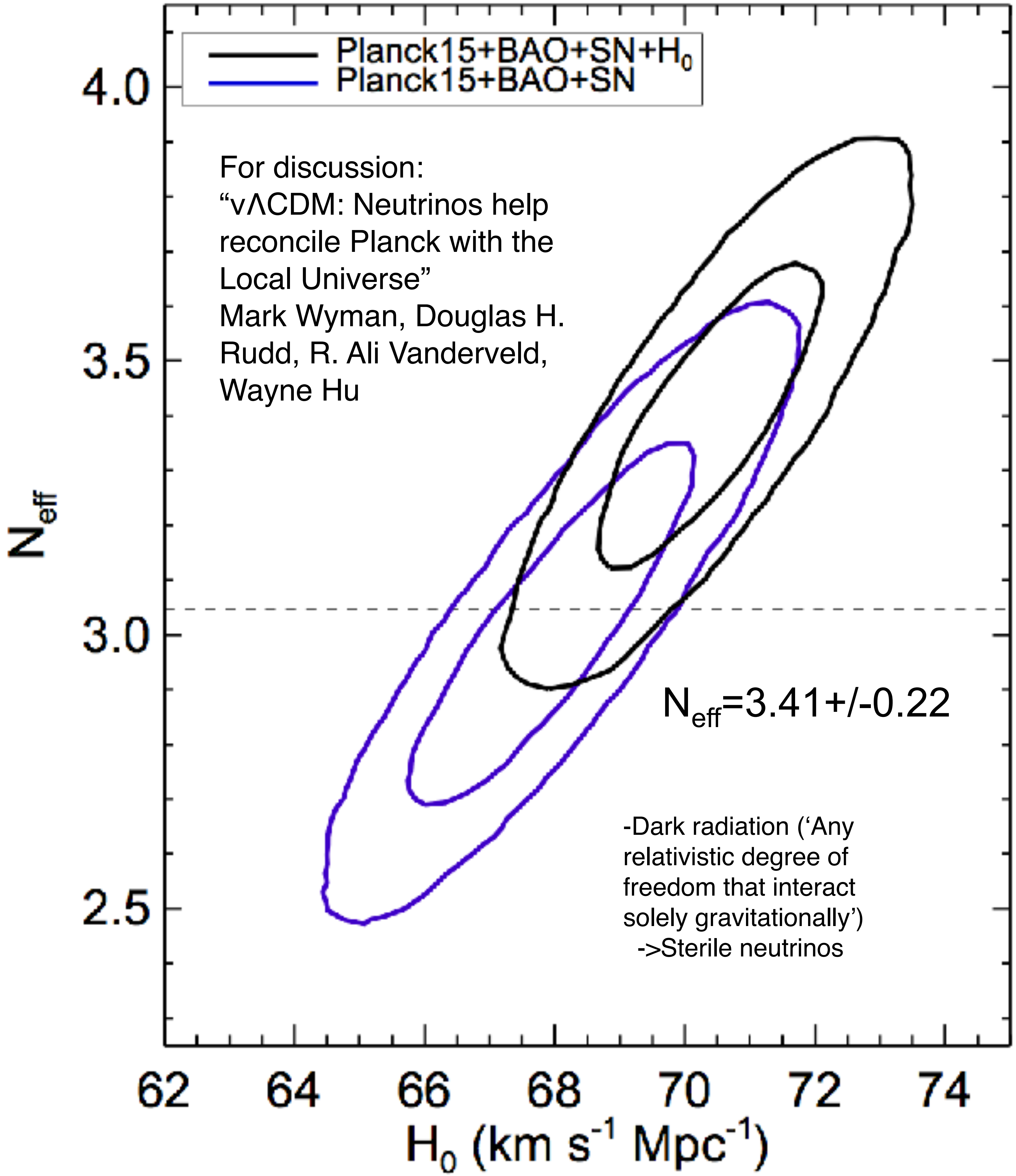
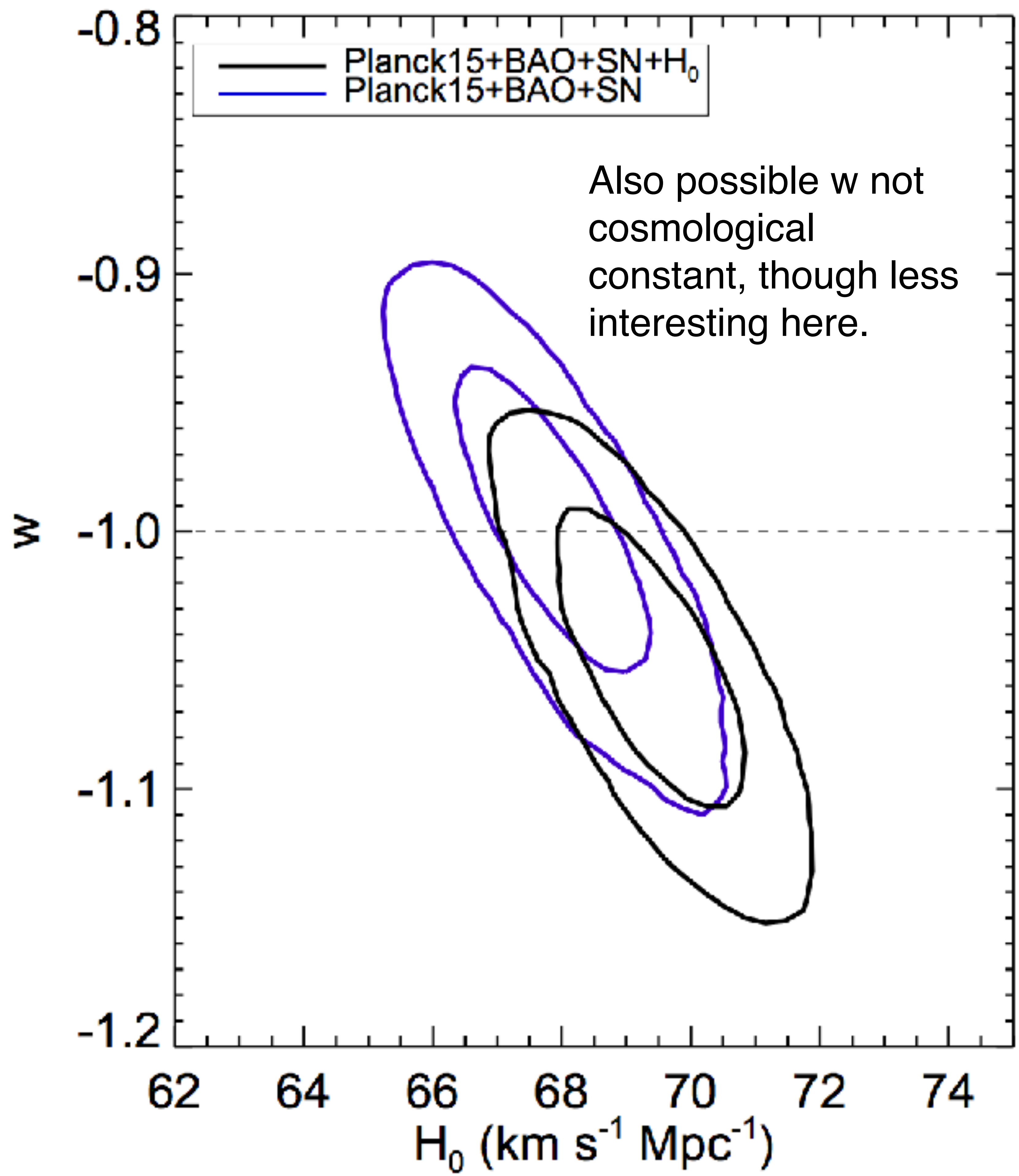




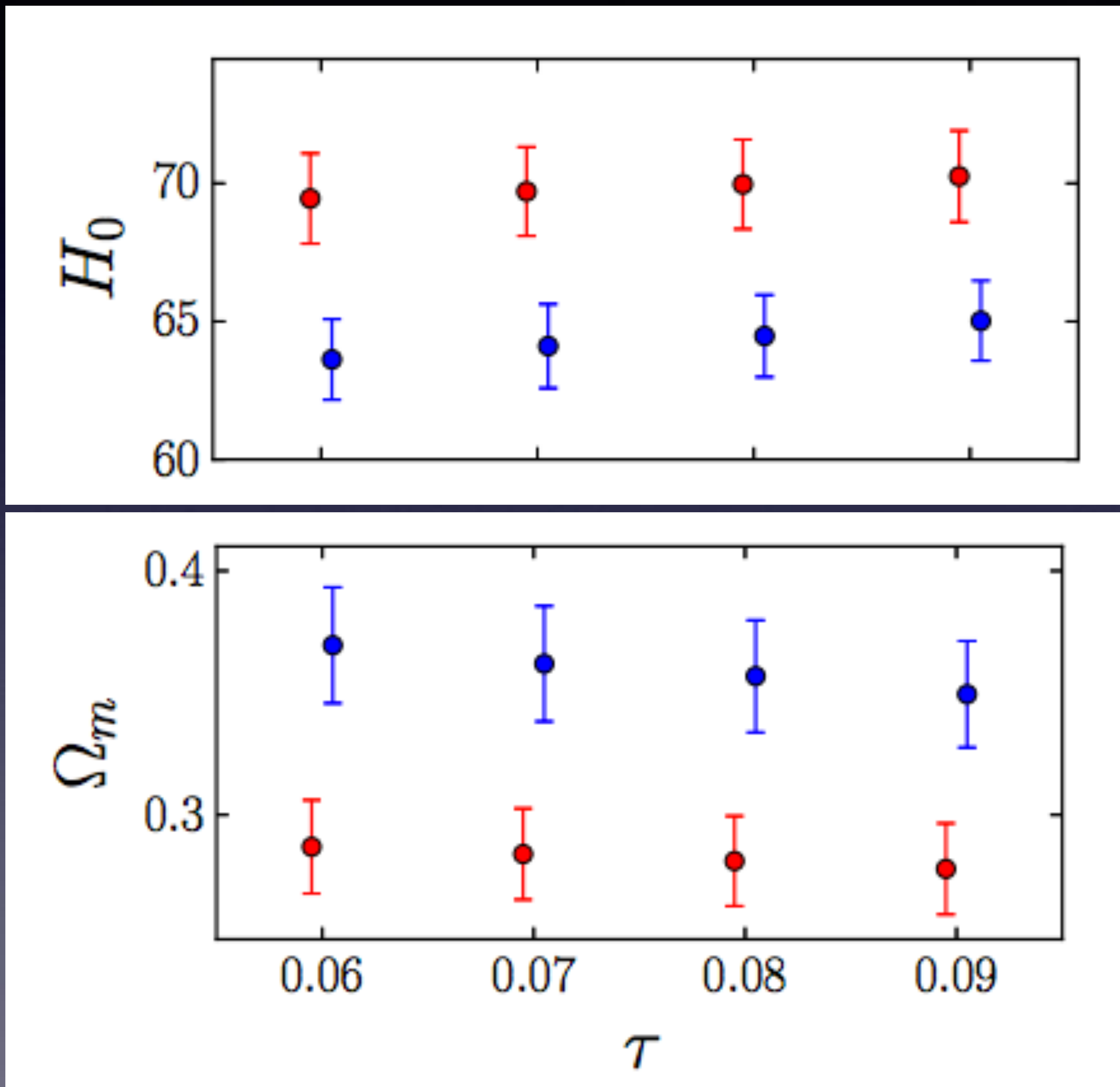
Planck15+BAO+SN+H$_0$
Planck15+BAO+SN
For discussion:
“νΛCDM: Neutrinos help reconcile Planck with the Local Universe”
Mark Wyman, Douglas H. Rudd, R. Ali Vanderveld, Wayne Hu
N_{eff}=3.41+/-0.22
-Dark radiation (‘Any relativistic degree of freedom that interact solely gravitationally’)
->Sterile neutrinos
4.0
3.5
3.0
2.5
N_{eff}
62
64
66
68
70
72
74
H$_0$ (km s^{-1} Mpc^{-1})

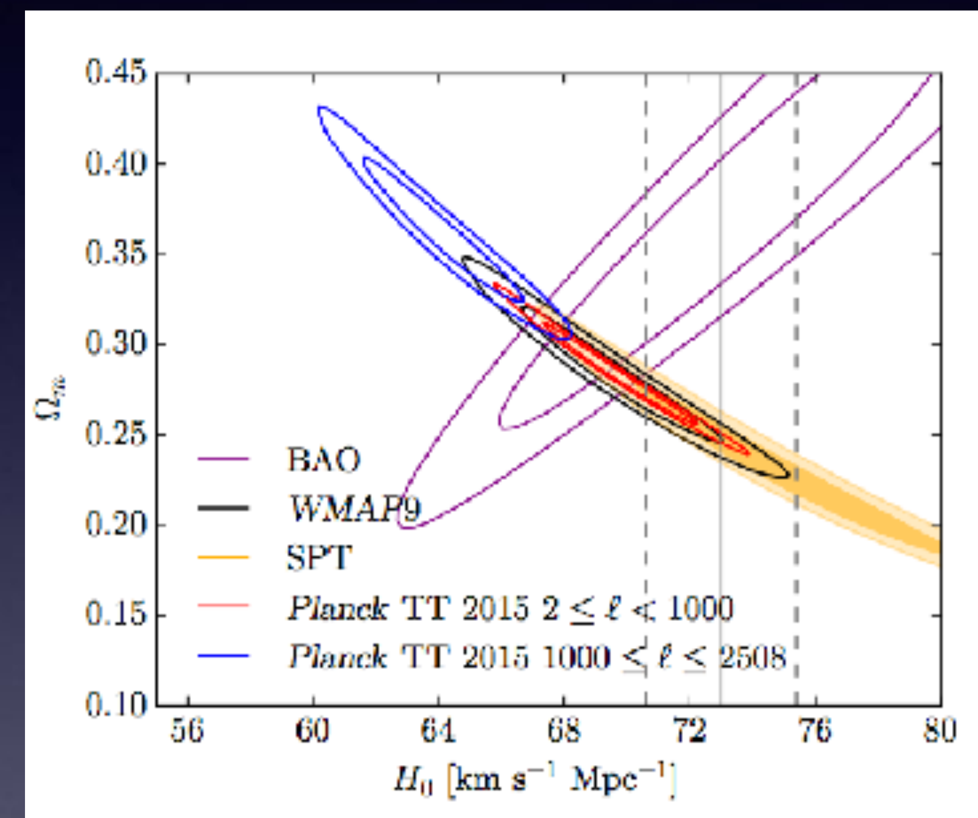


BBN: Nollett & Steigma
Neff=3.56 +/0 0.23
from He abundance
Yp=0.254+/-0.003
Isatov et al.
Uncertainties debated.


Planck15+BAO+SN+H0
Planck15+BAO+SN
Also possible w not cosmological constant, though less interesting here.
w
-0.8
-0.9
-1.0
-1.1
-1.2
62
64
66
68
70
72
74
H0 (km s-1 Mpc-1)

There is tension within CMB measurements, so this may be a part of the story.

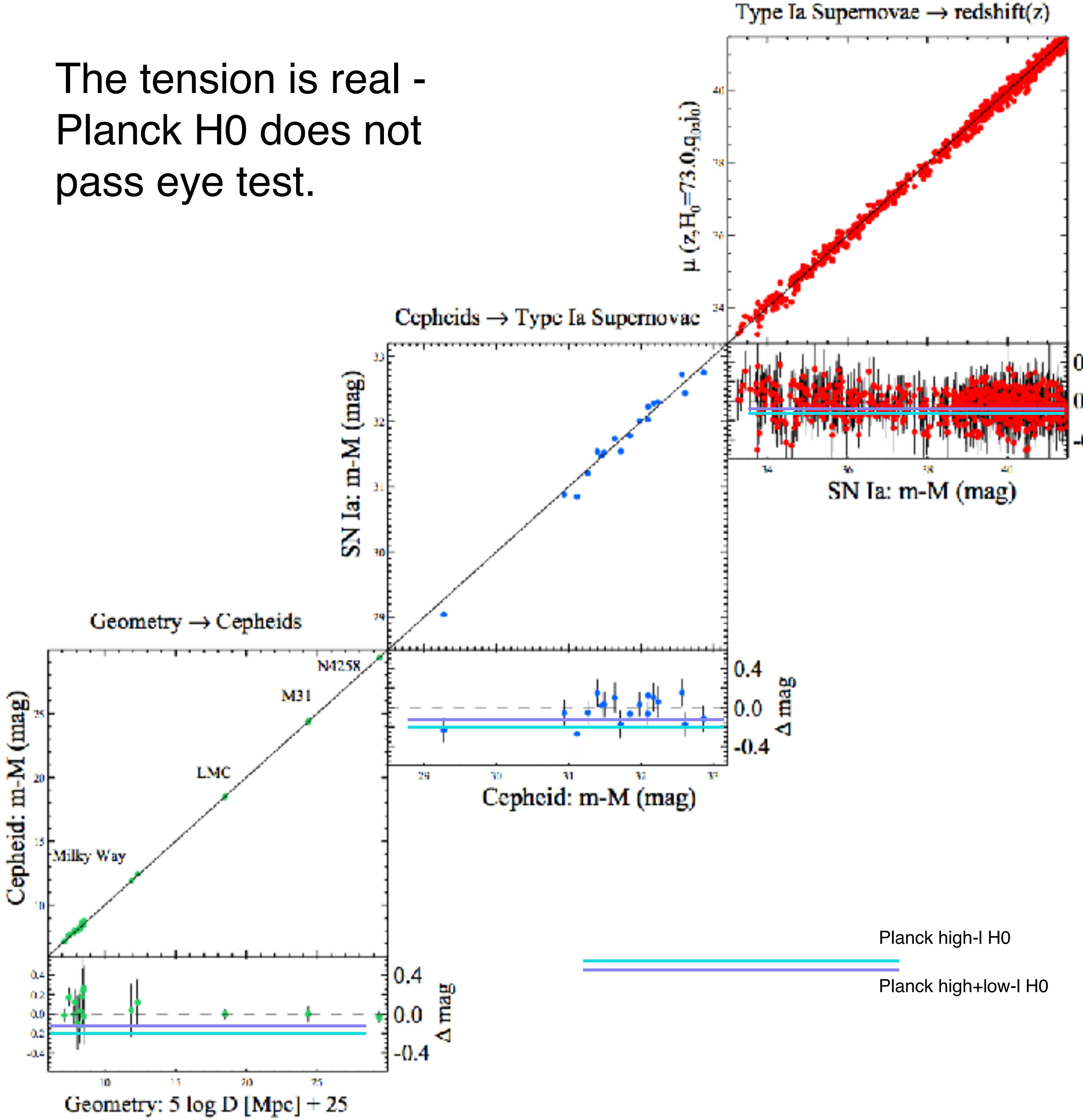




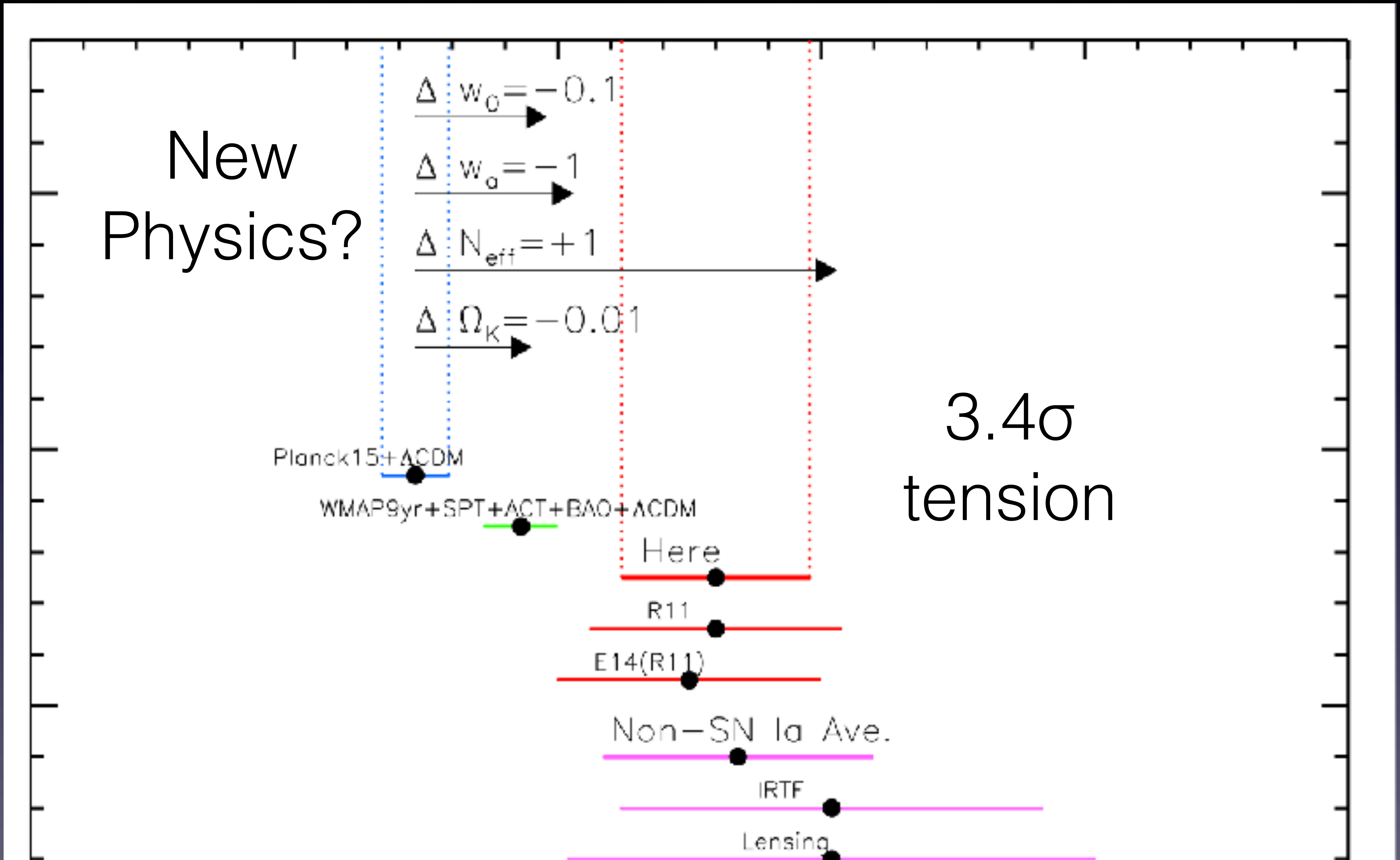
Addison 2016

Planck **TT 2015** $2 \leq \ell < 1000$ *Planck* **TT 2015** $1000 \leq \ell \leq 2508$

The tension is real - Planck H0 does not pass eye test.



And what if this is right?



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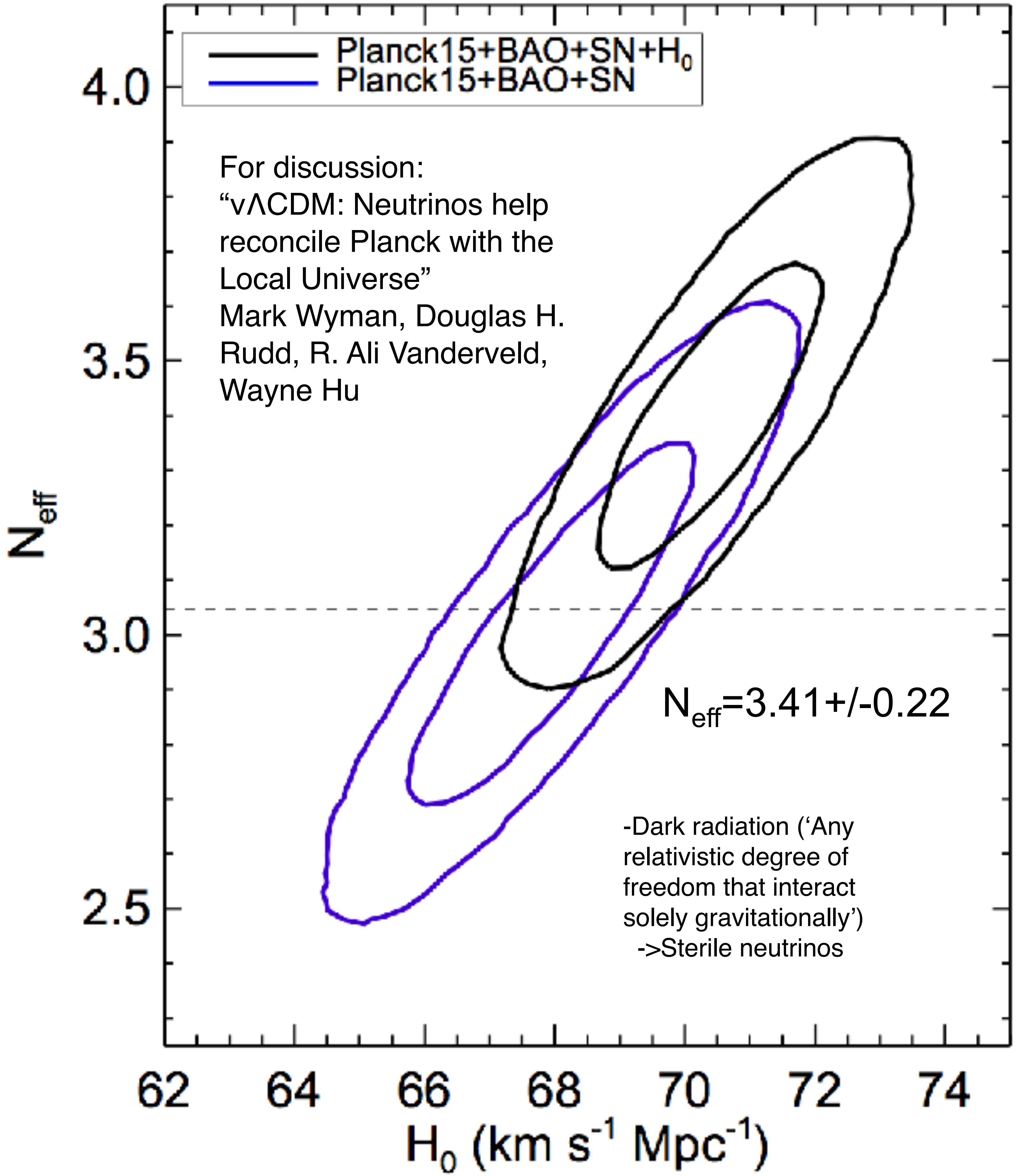

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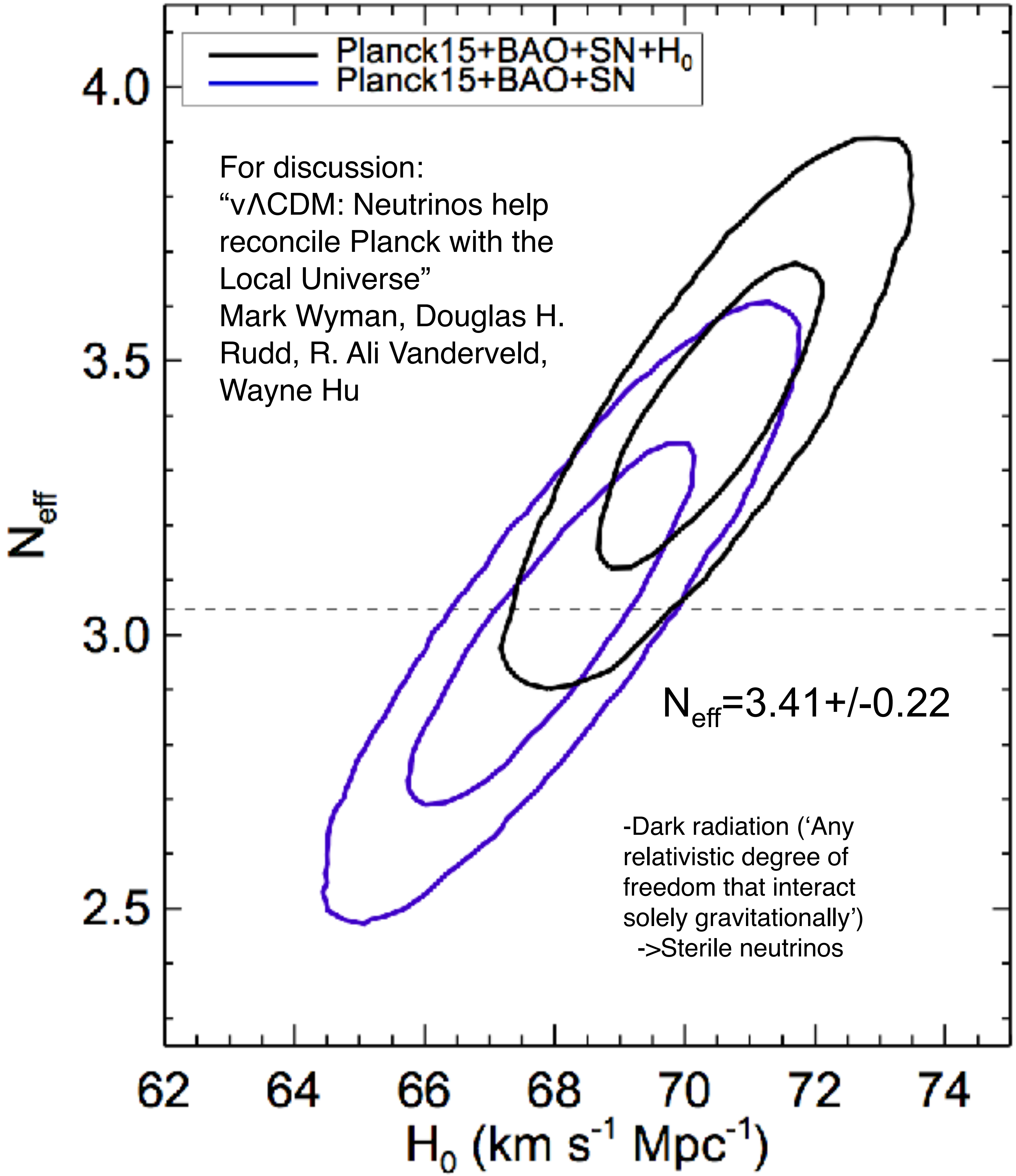
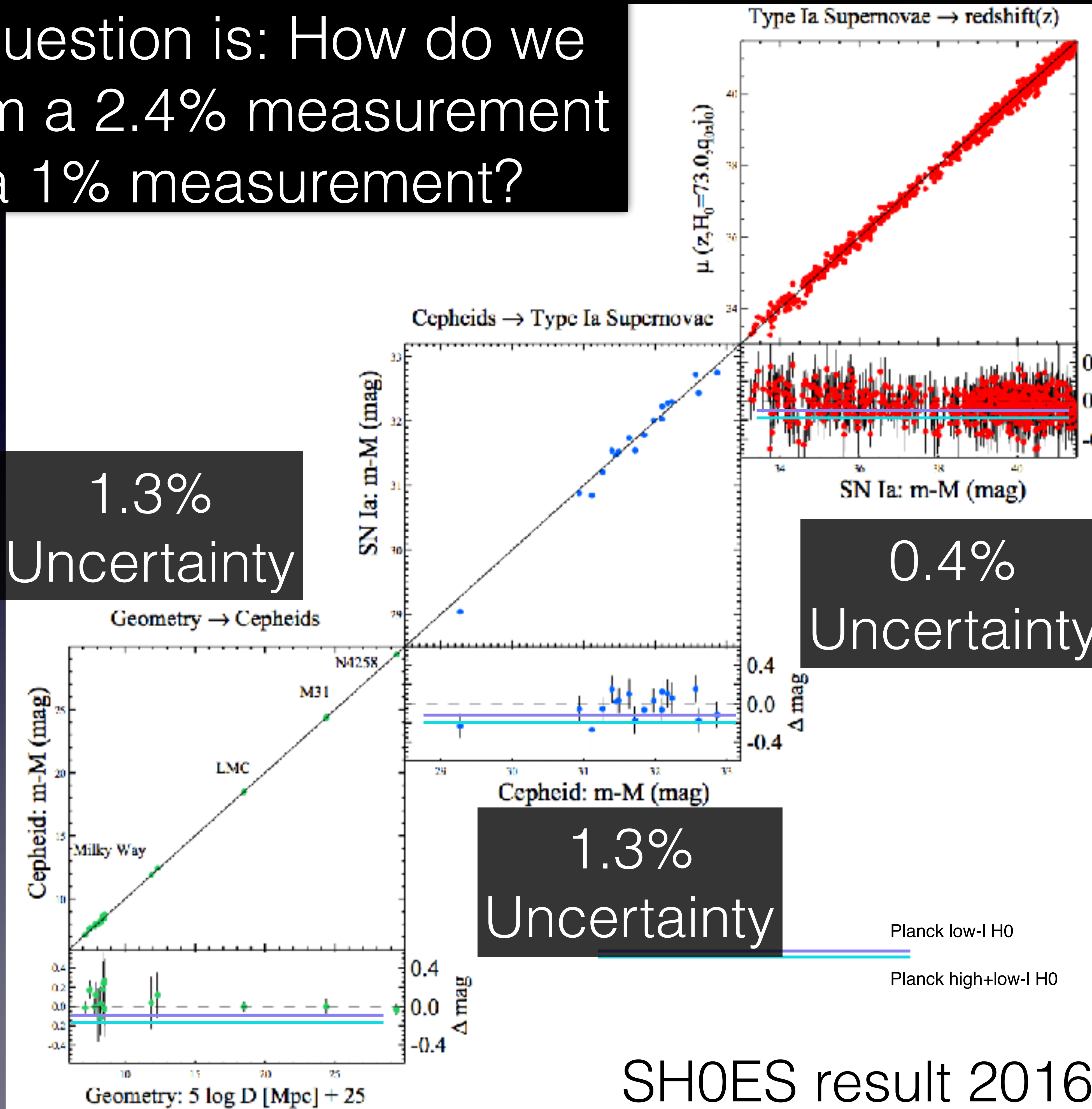


BBN: Nollett & Steigma
Neff=3.56 +/0 0.23
from He abundance
Yp=0.254+/-0.003
Isatov et al.
Unceratanties
debated.

This is the total error budget

Term	Description	Prev. LMC	R09 N4258	R11 All 3	This work N4258	This work All 3
$\sigma_{\rm anchor}$	Anchor distance	5%	3%	1.3%	2.6%	1.3%
$\sigma^a_{\rm anchorPL}$	Mean of P–L in anchor	2.5%	1.5%	0.8%	1.1%	0.7%
$\sigma_{\rm hostPL}/\sqrt{n}$	Mean of P–L values in SN Ia hosts	1.5%	1.5%	0.6%	0.4%	0.4%
$\sigma_{\rm SN}/\sqrt{n}$	Mean of SN Ia calibrators	2.5%	2.5%	1.9%	1.3%	1.3%
σ_{m-z}	SN Ia m–z relation	1%	0.5%	0.5%	0.4%	0.4%
$R\sigma_{\lambda,1,2}$	Cepheid reddening, zeropoints, anchor-to-hosts	4.5%	0.3%	1.4%	0%	0.7%
σ_Z	Cepheid metallicity, anchor-to-hosts	3%	1.1%	1.0%	0.4%	0.8%
$\sigma_{\rm PL}$	P–L slope, $\Delta \log P$, anchor-to-hosts	4%	0.5%	0.6%	0.2%	0.5%
$\sigma_{\rm WFPC2}$	WFPC2 CTE, long-short	3%	N/A	N/A	N/A	N/A
subtotal, $\sigma^b_{\rm H_0}$		10%	4.7%	2.9%	3.4%[c]	2.2%
Analysis Systematics		N/A	1.3%	1.0%	1.0%	0.9%
Total, $\sigma_{\rm H_0}$		10%	4.8%	3.3%	3.5%	2.4%

The question is: How do we go from a 2.4% measurement to a 1% measurement?



1.3% Uncertainty

0.4% Uncertainty

1.3% Uncertainty

SH0ES result 2016

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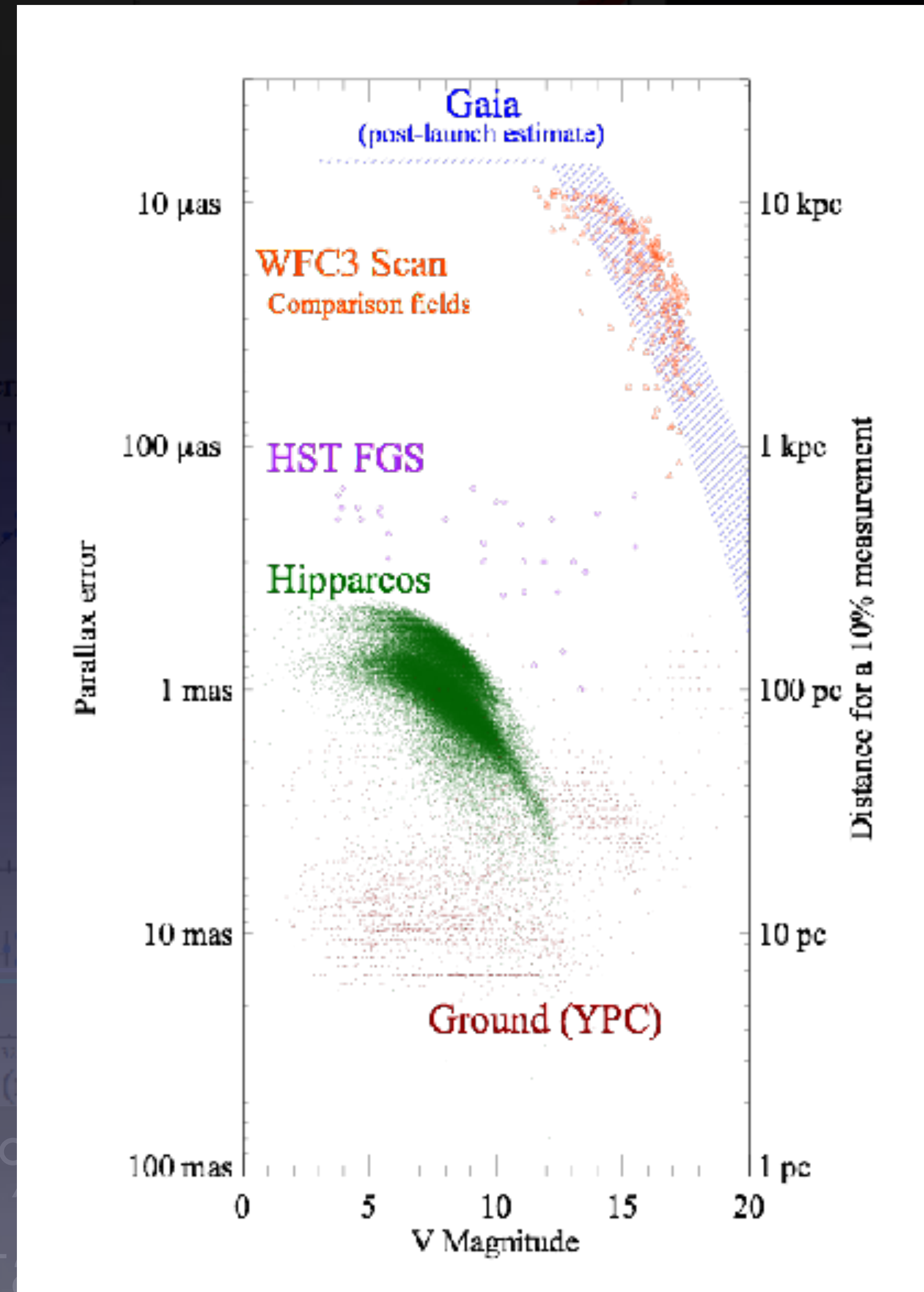
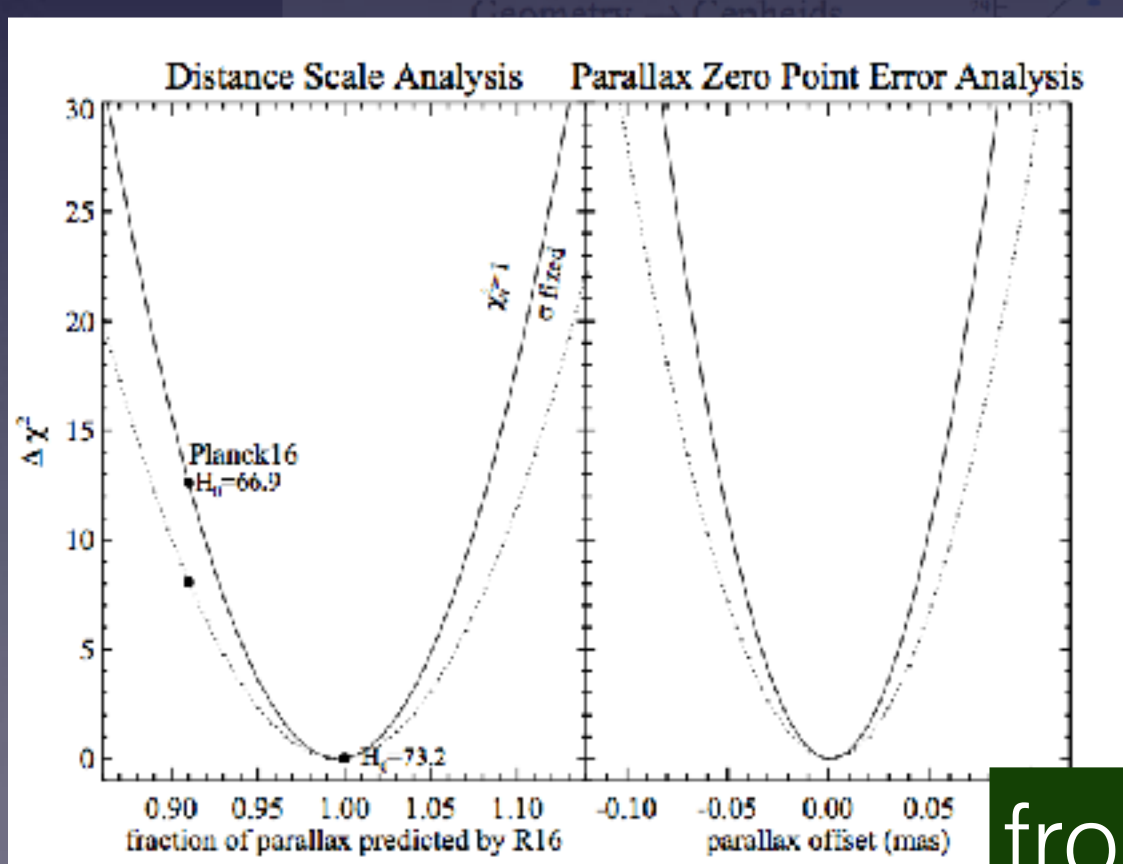


Gaia will squash:

1.4% Uncertainty



from Casertano,Riess et al. 2016

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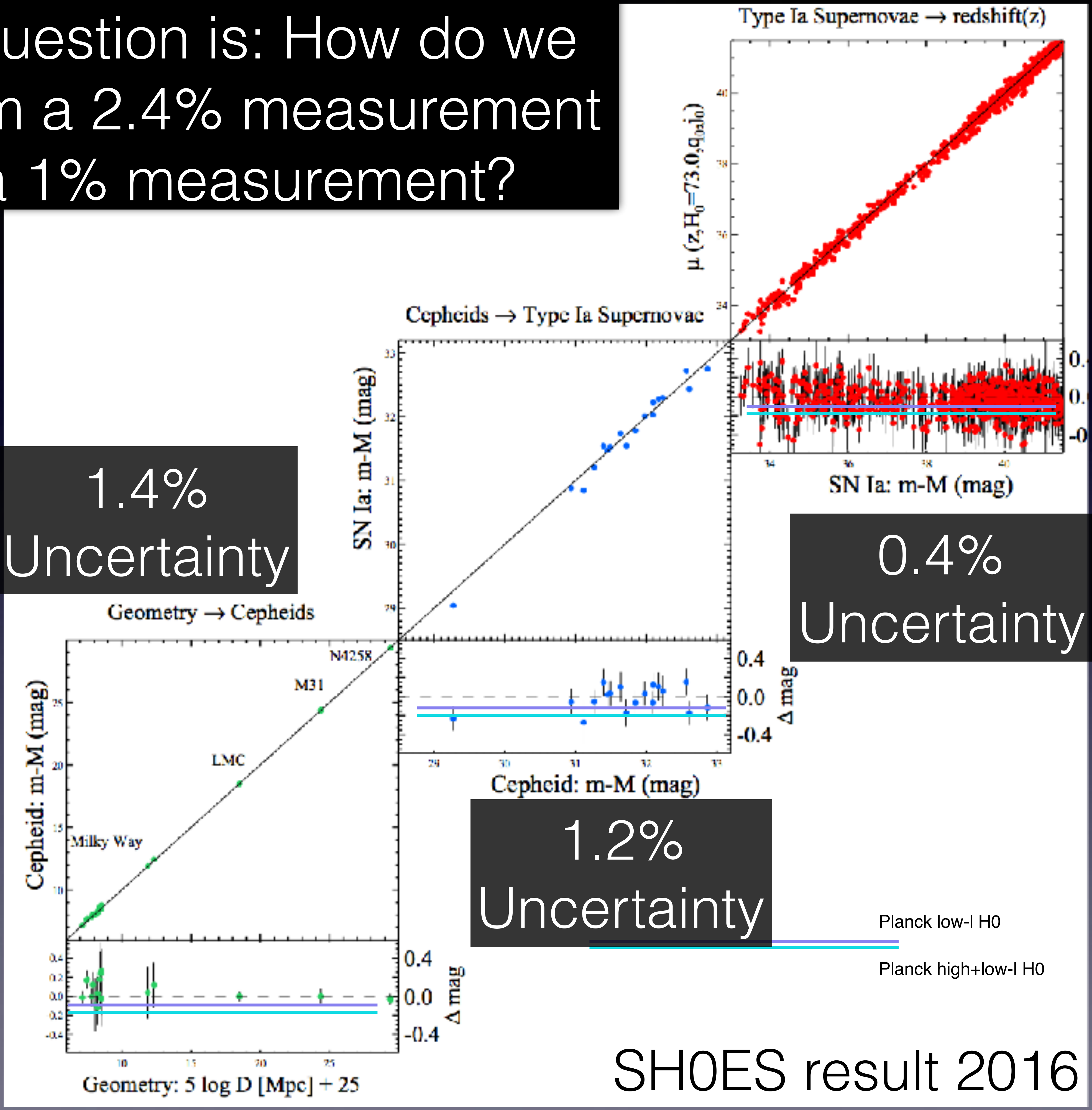
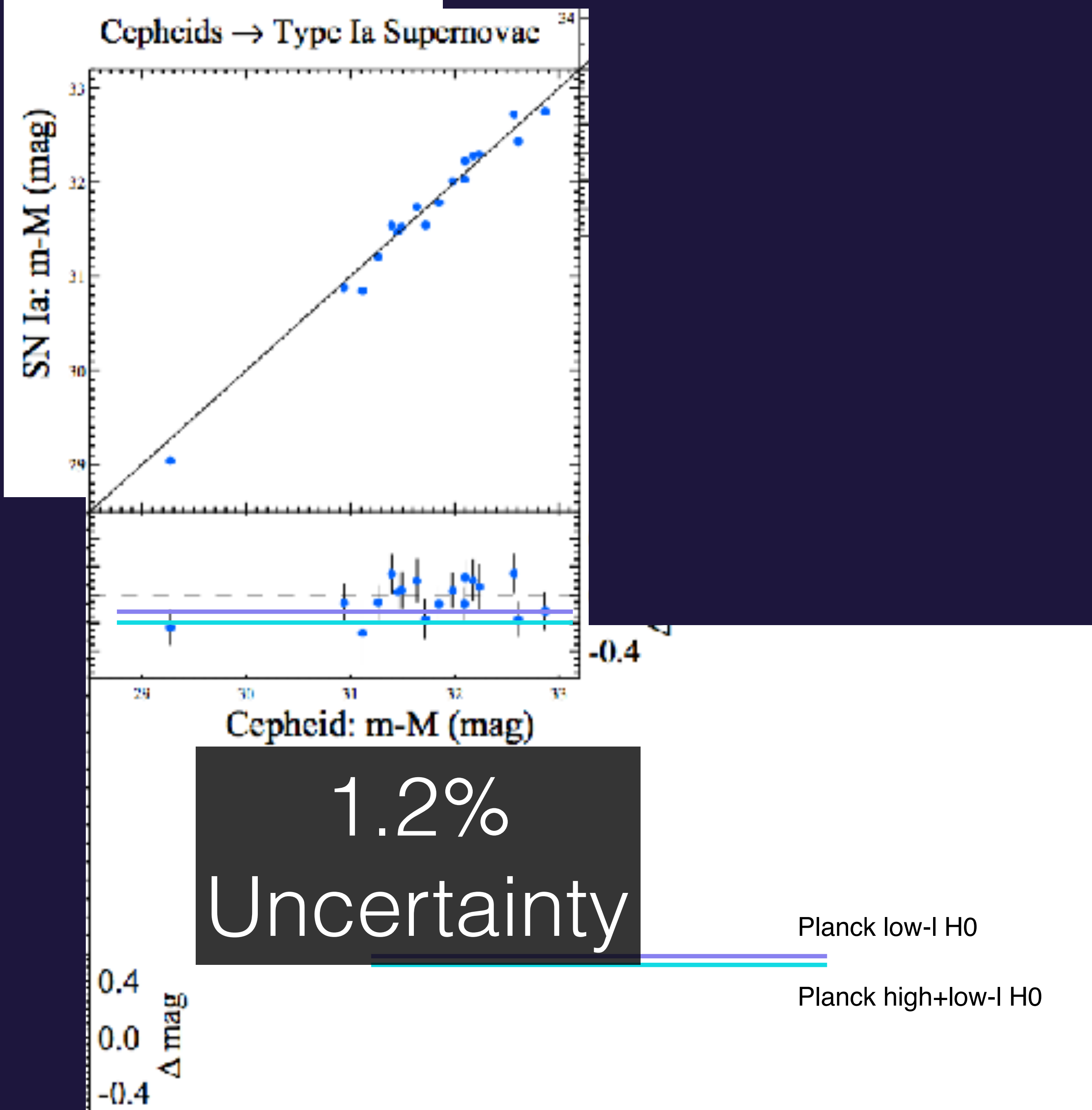


SH0ES result 2016

The question is: How do we go from a 2.4% measurement to a 1% measurement?

The answer is: Right now we have 19 calibrators, want to get to 50.



1.2% Uncertainty

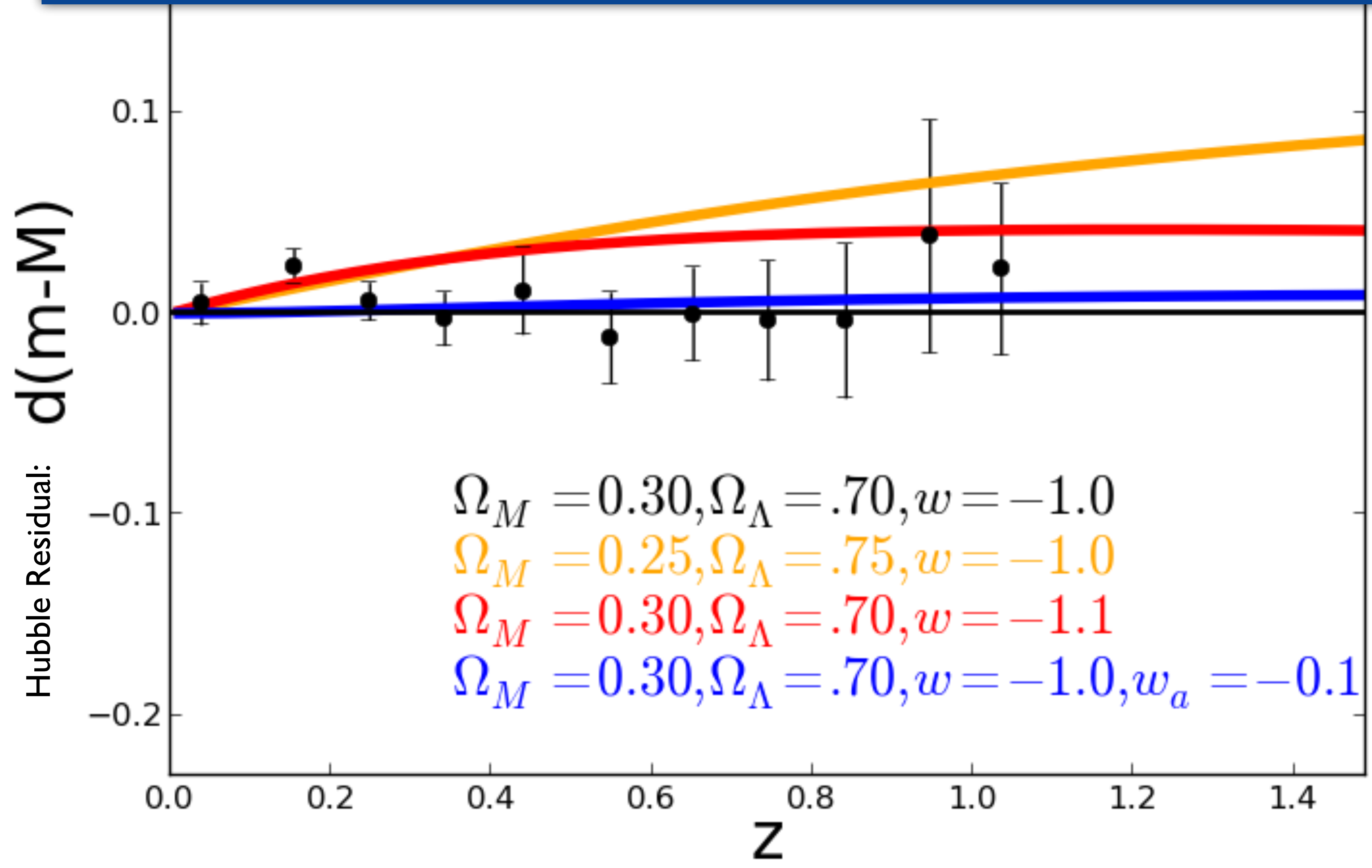
SH0ES result 2016

To measure w, trying to measure 0.005 mag change across dz~1.0

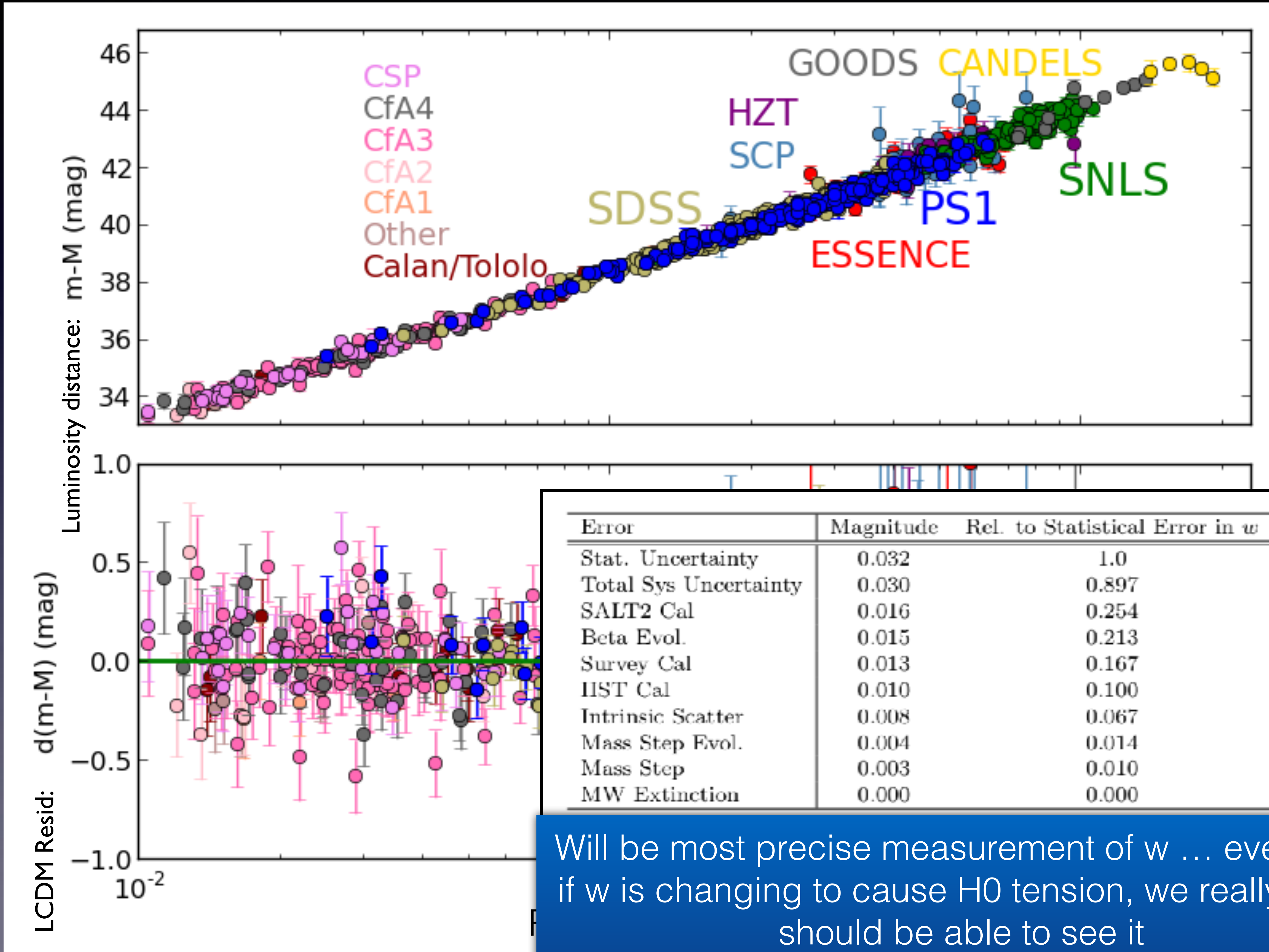
(have to deal with k-corrections, different surveys/filters, evolution…)

To measure H0, trying to measure 0.035 mag change across dz~0.05

(k-corrections tiny, same-similar survey/filters, no evolution

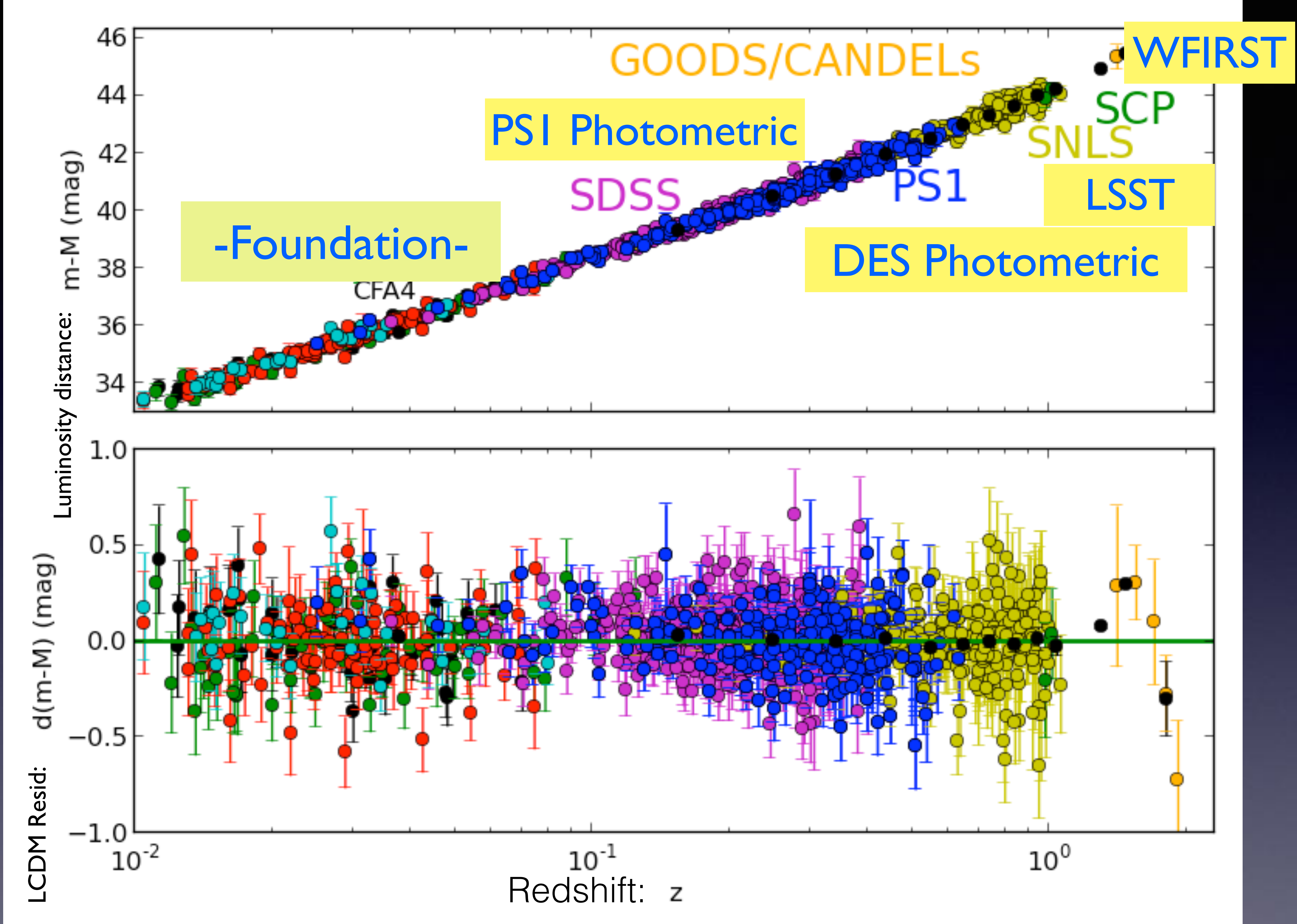


Putting largest sample together, with new calibration and systematics control -> Scolnic et al. 2017 in prep



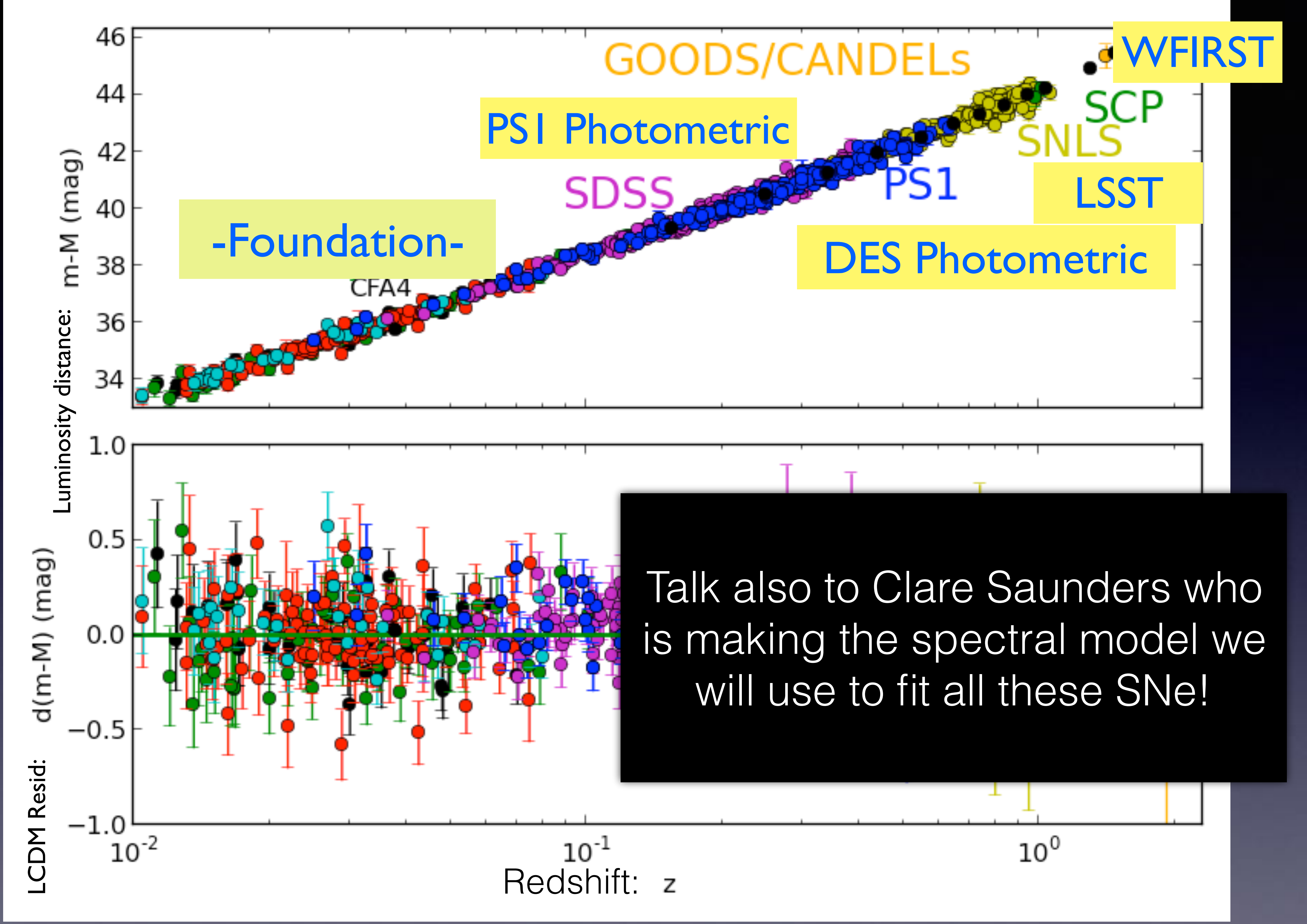
Error	Magnitude	Rel. to Statistical Error in w
Stat. Uncertainty	0.032	1.0
Total Sys Uncertainty	0.030	0.897
SALT2 Cal	0.016	0.254
Beta Evol.	0.015	0.213
Survey Cal	0.013	0.167
HST Cal	0.010	0.100
Intrinsic Scatter	0.008	0.067
Mass Step Evol.	0.004	0.014
Mass Step	0.003	0.010
MW Extinction	0.000	0.000

Will be most precise measurement of w … ever, and if w is changing to cause H0 tension, we really have should be able to see it



Over next year, DES+PS1+Foundation will increase sample 5x

Over next decade, LSST+WFIRST will increase sample 10x

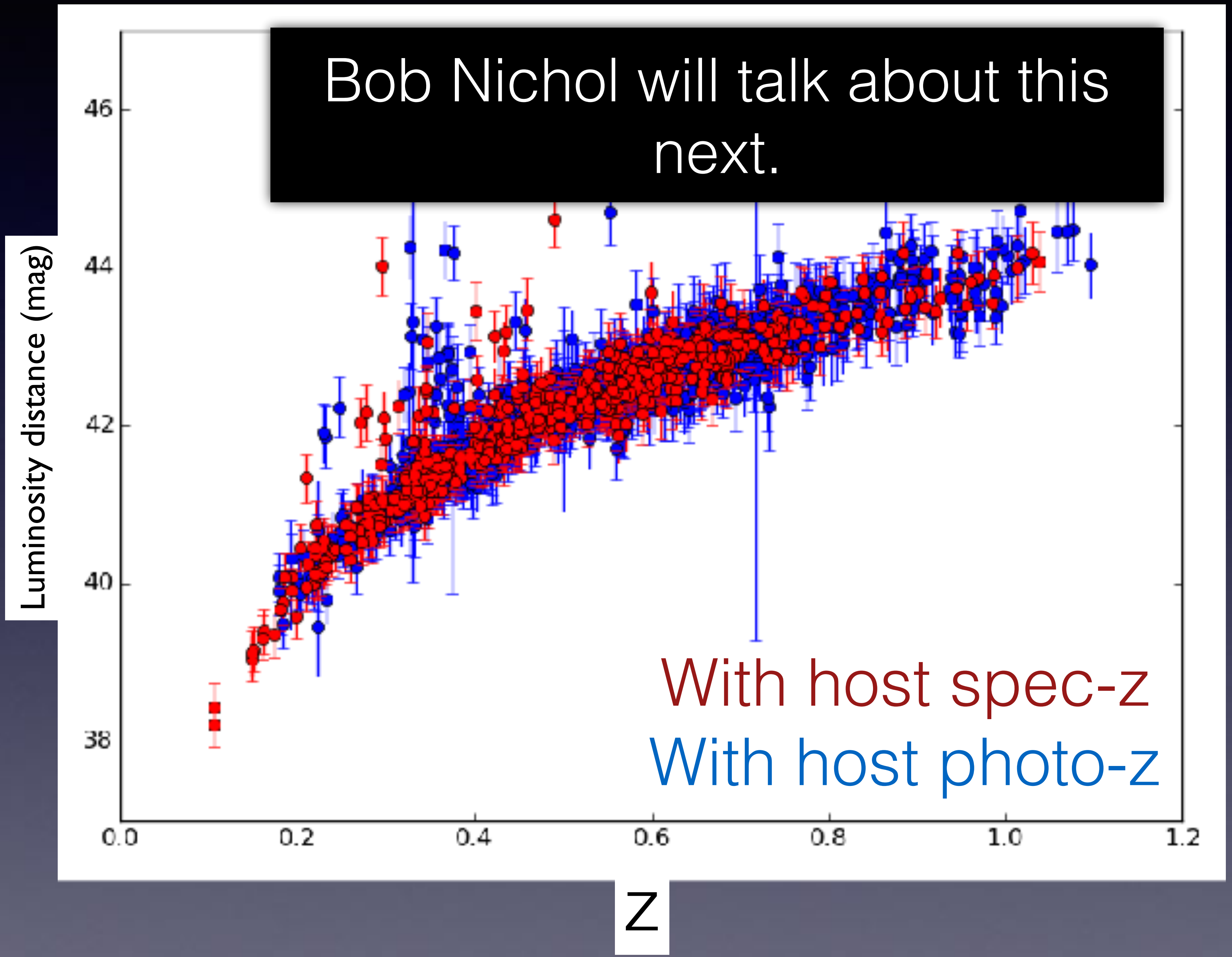


Over next year, DES+PS1+Foundation will increase sample 5x

Over next decade, LSST+WFIRST will increase sample 10x

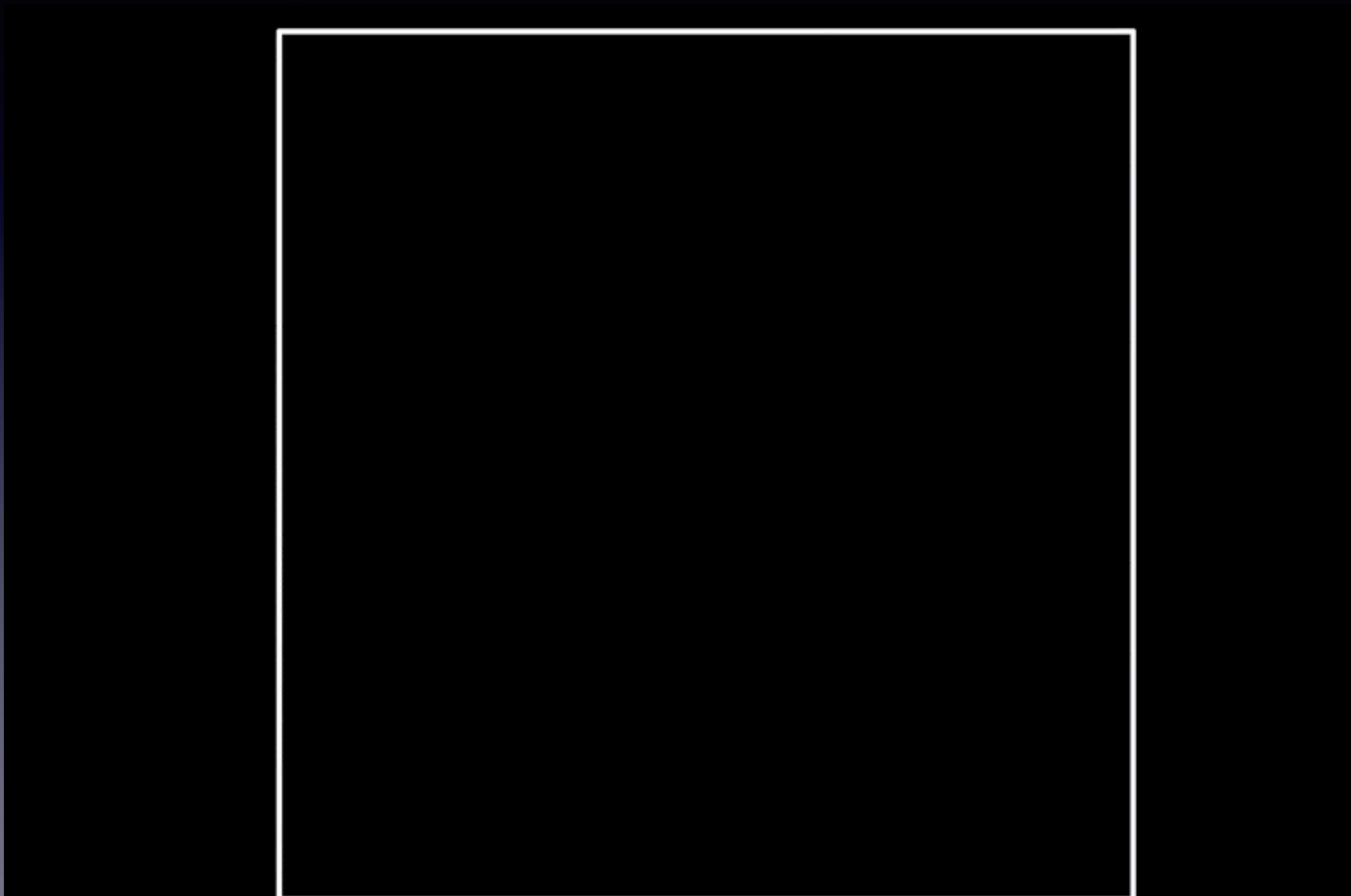
The problem is that we have now switch from spectroscopic classification to photometric classification

Two recent papers this year (Jones, Scolnic et al. 2017 and Kessler+Scolnic 2017) have shown that biases on cosmology from photometric analysis will be small

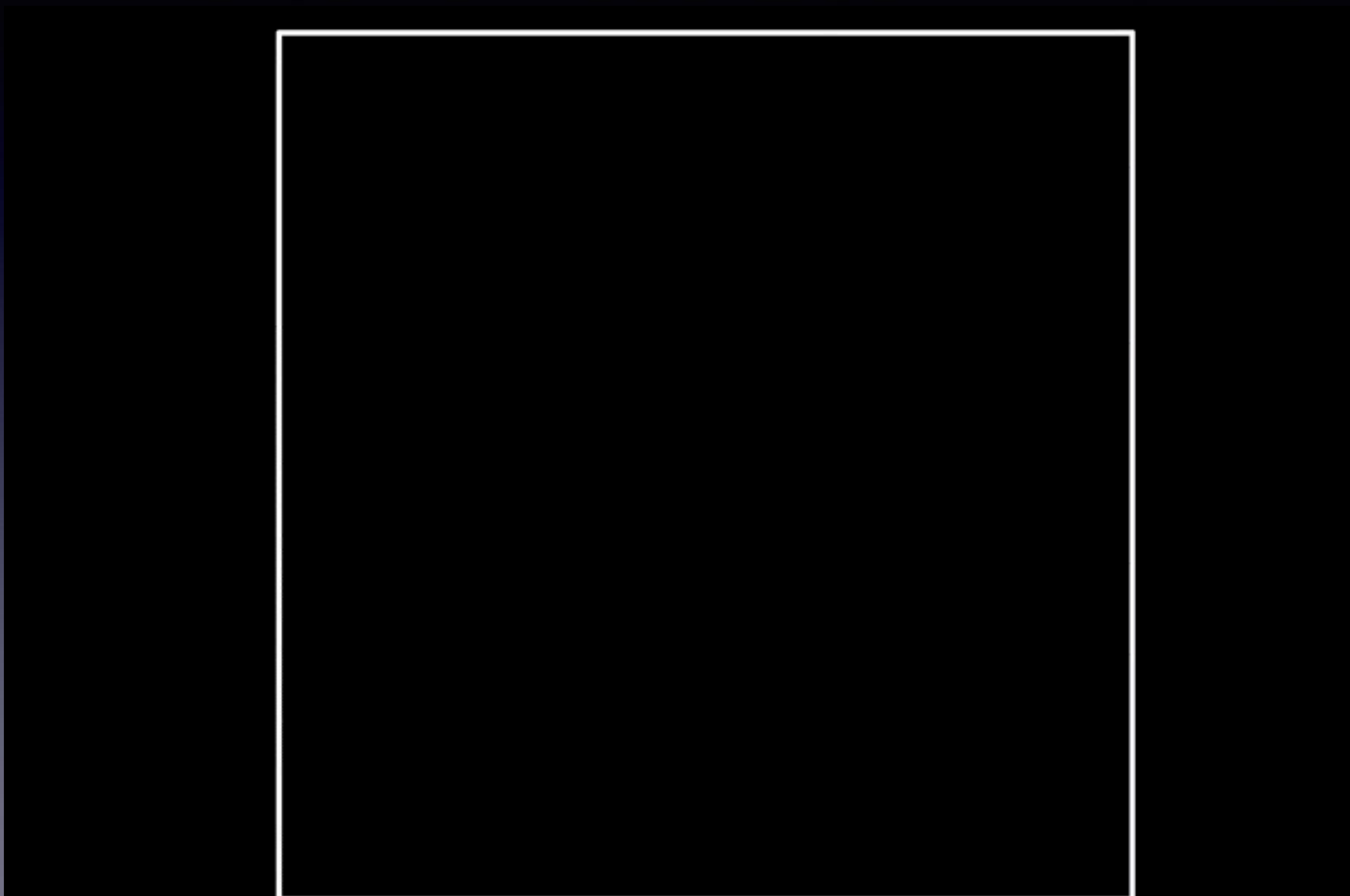


Preliminary DES Result

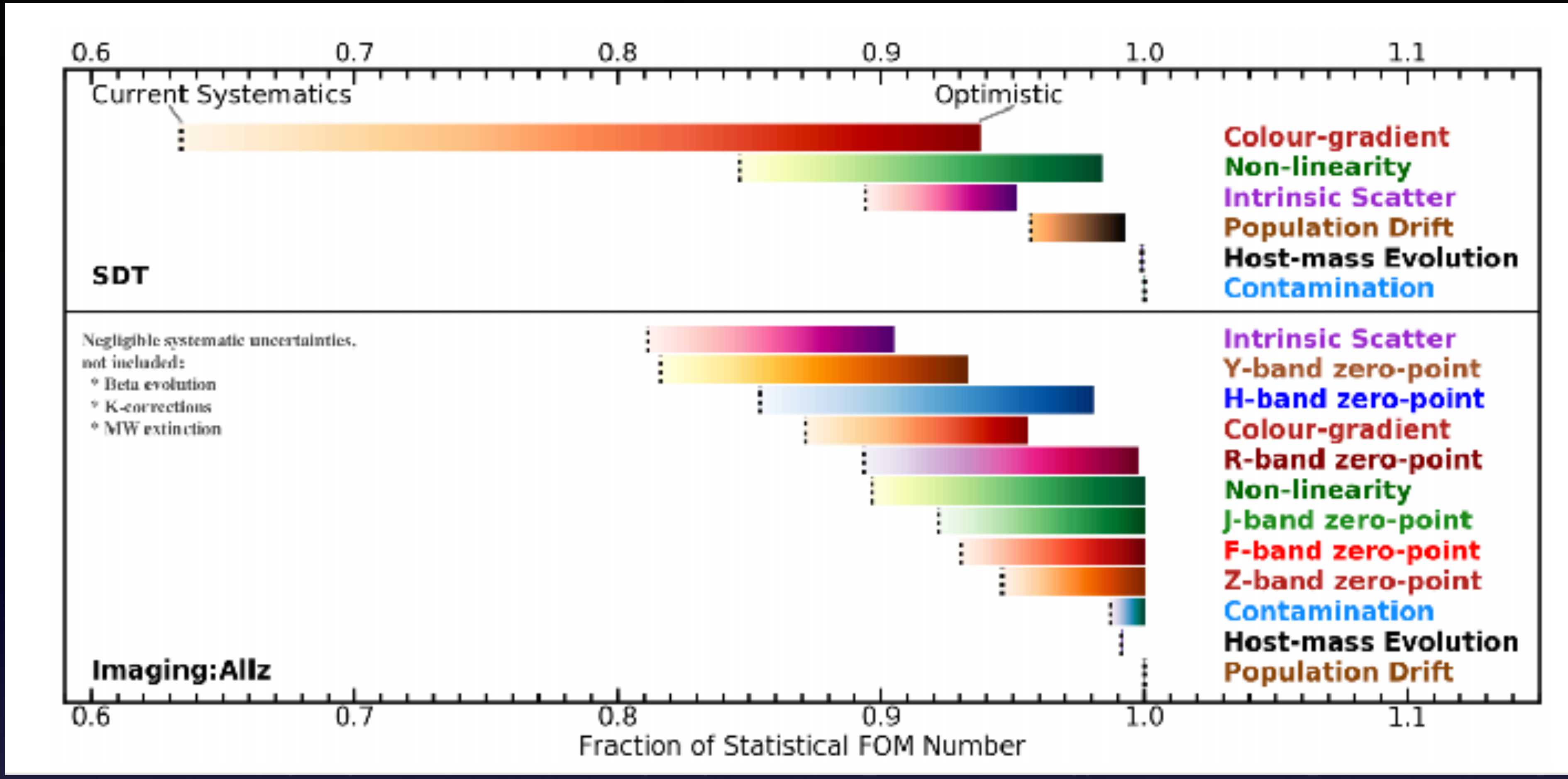
The Wide Field InfraRed Survey Telescope (WFIRST) was the highest ranked large space-based mission of the 2010 New Worlds, New Horizons decadal survey. It has a field-of-view of 0.28 sq deg and wavelength coverage from 0.7 to 2 microns



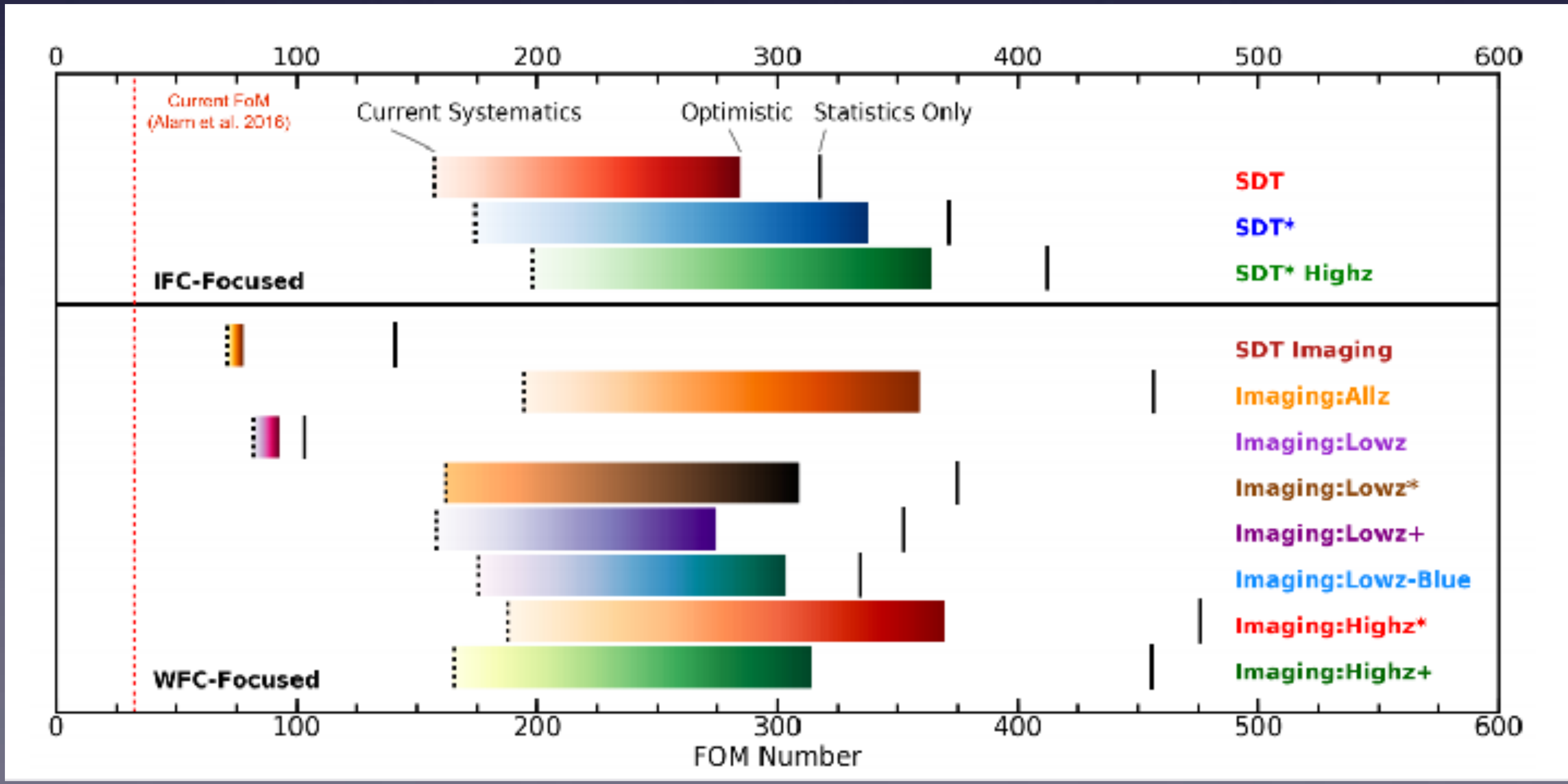
I wear two hats for the project: Deputy of one of two SN teams (PI Foley), and lead Calibration working group with Stefano Casertano.



Our first SN strategy paper is out (Hounsell, Scolnic, Foley et al. 2017. arXiv: 1702.01747)



Built out a lot of software to simulate different strategies and understand impact of systematics



To push our understanding of some of the biggest questions in cosmology, my goal is to improve the statistics and systematics of SN distances over the entire observable redshift range.