H_0 Tension & Astrophysical Biases

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$$v_H = H_0 d_L$$

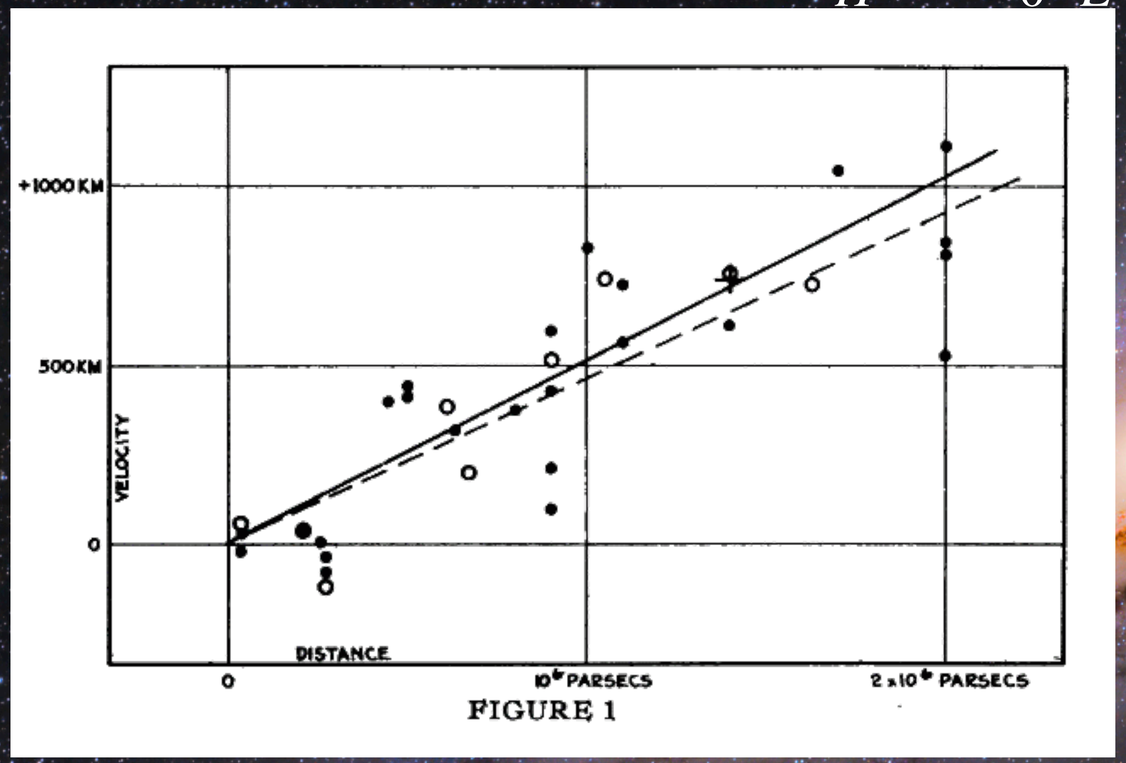
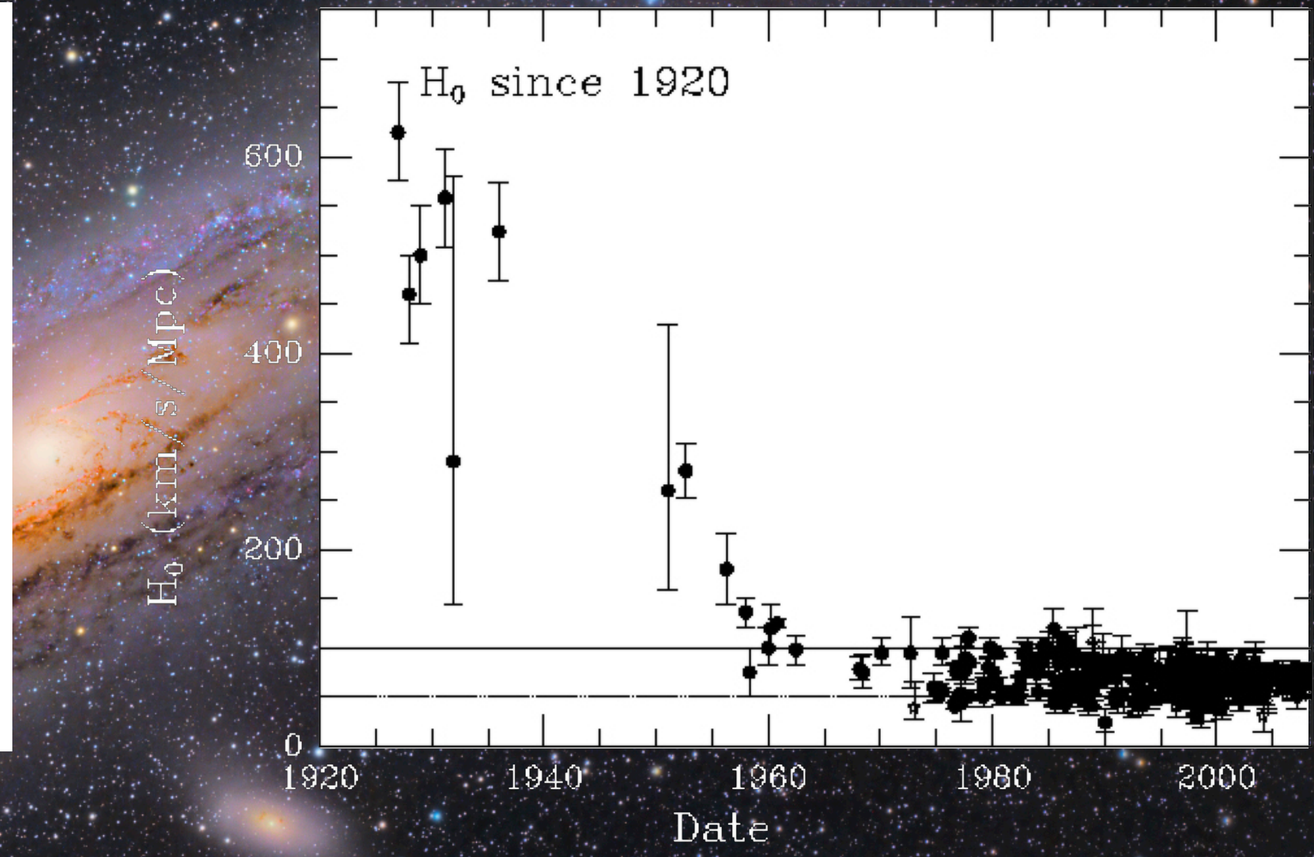


FIGURE 1

Recessional velocity

Distance from us



The Hubble Constant H_0: How fast the Universe is currently expanding

Modern Cosmology | H_0

Direct Method

$$“\ H_0 = d_l / v_h\ ”$$

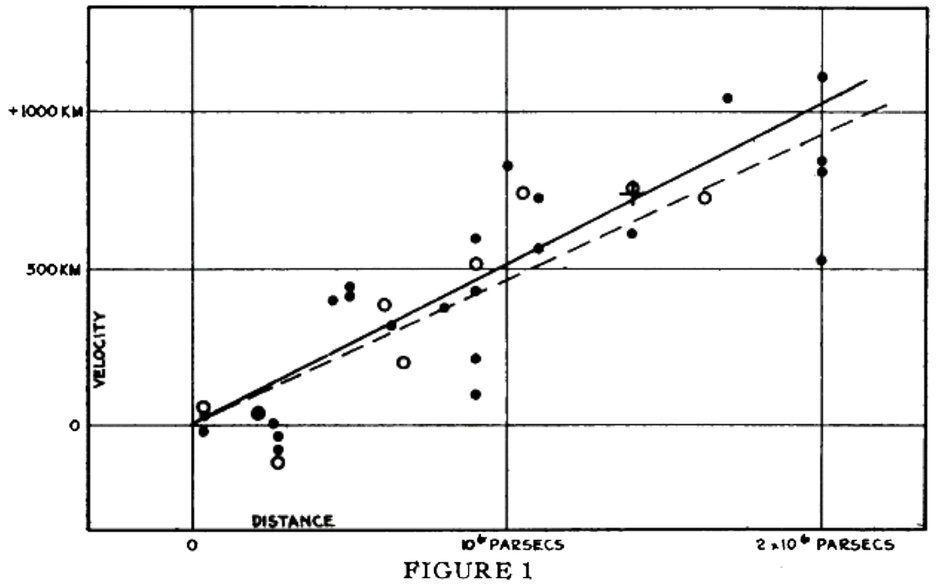
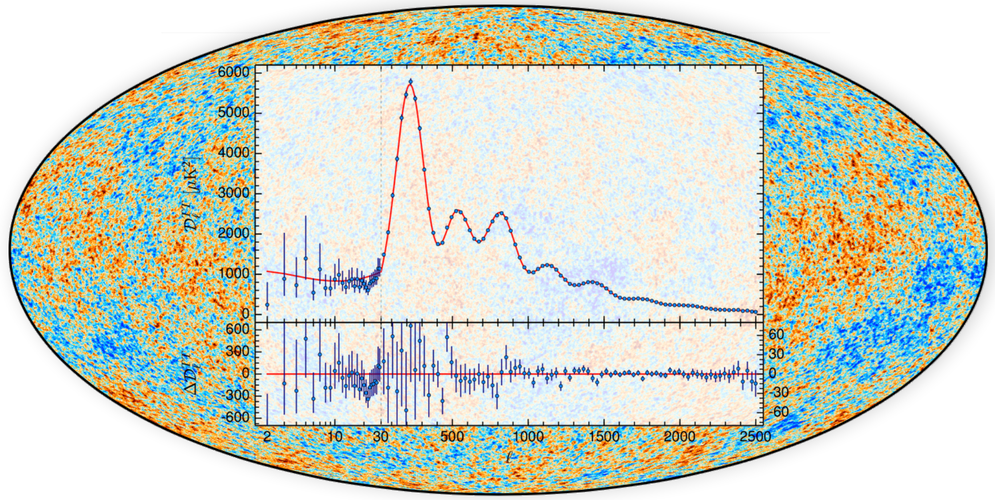


FIGURE 1

Careful with peculiar velocities

Indirect Method

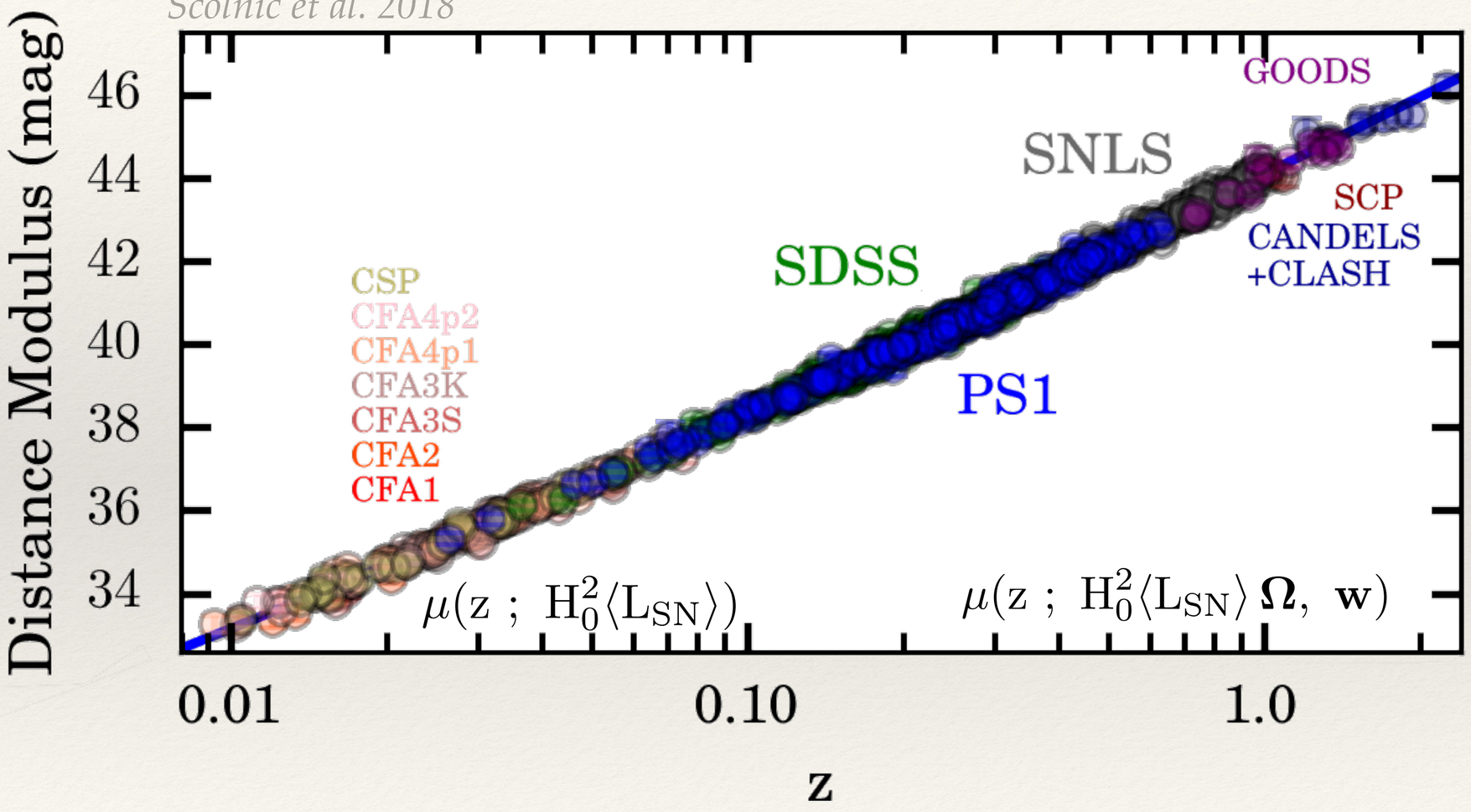
$$H(z) = H_0 \times \sqrt{\Omega_r (1+z)^4 + \Omega_m (1+z)^3 + \Omega_\Lambda (1+z)^{3(1+w)}}$$



Model dependent

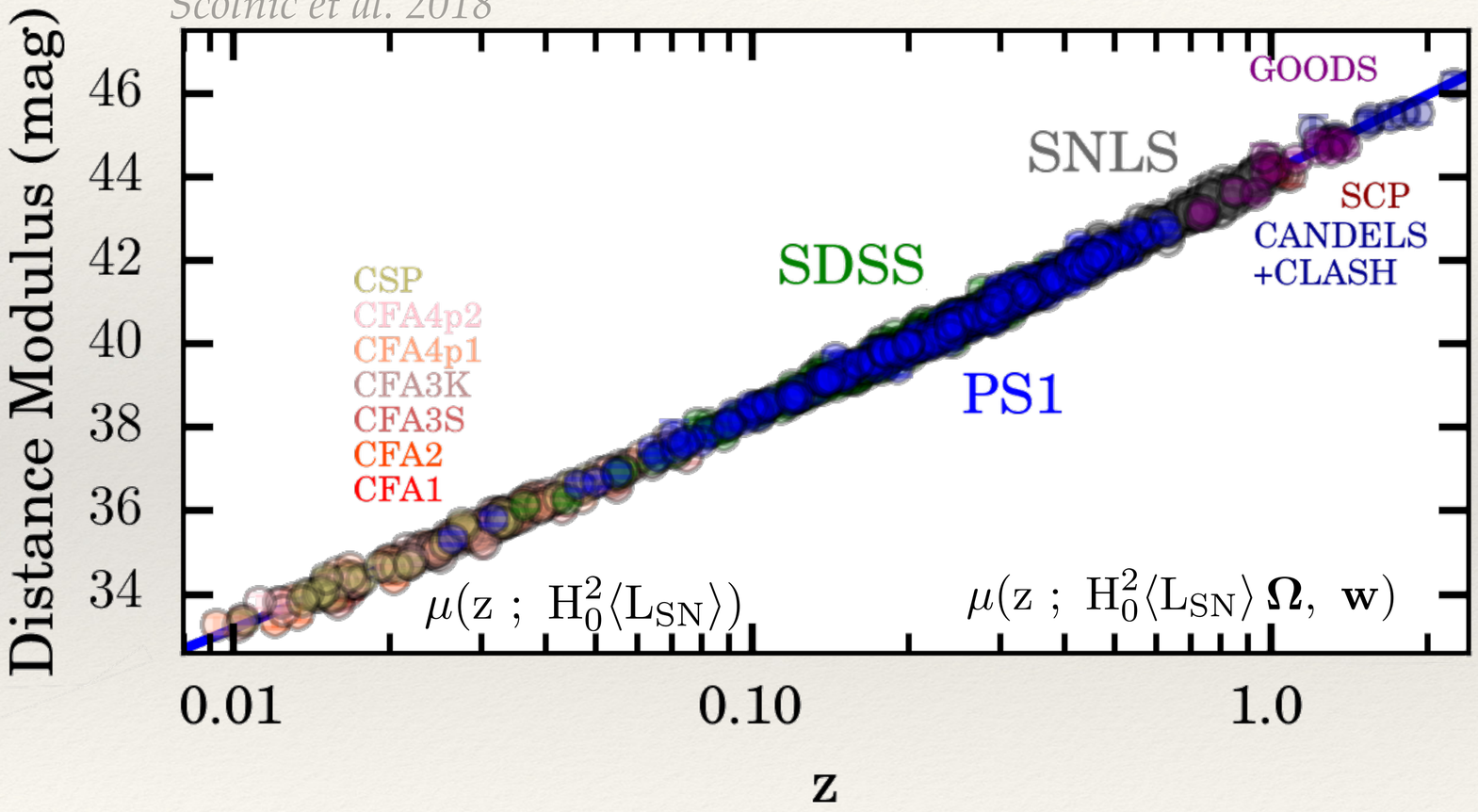
Type Ia Cosmology

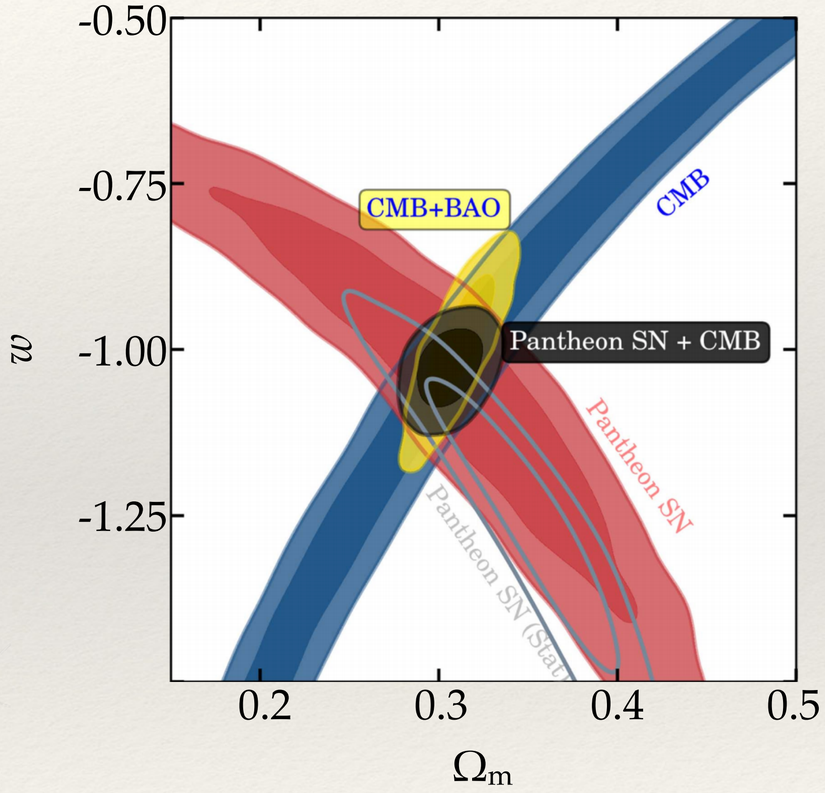
Scolnic et al. 2018



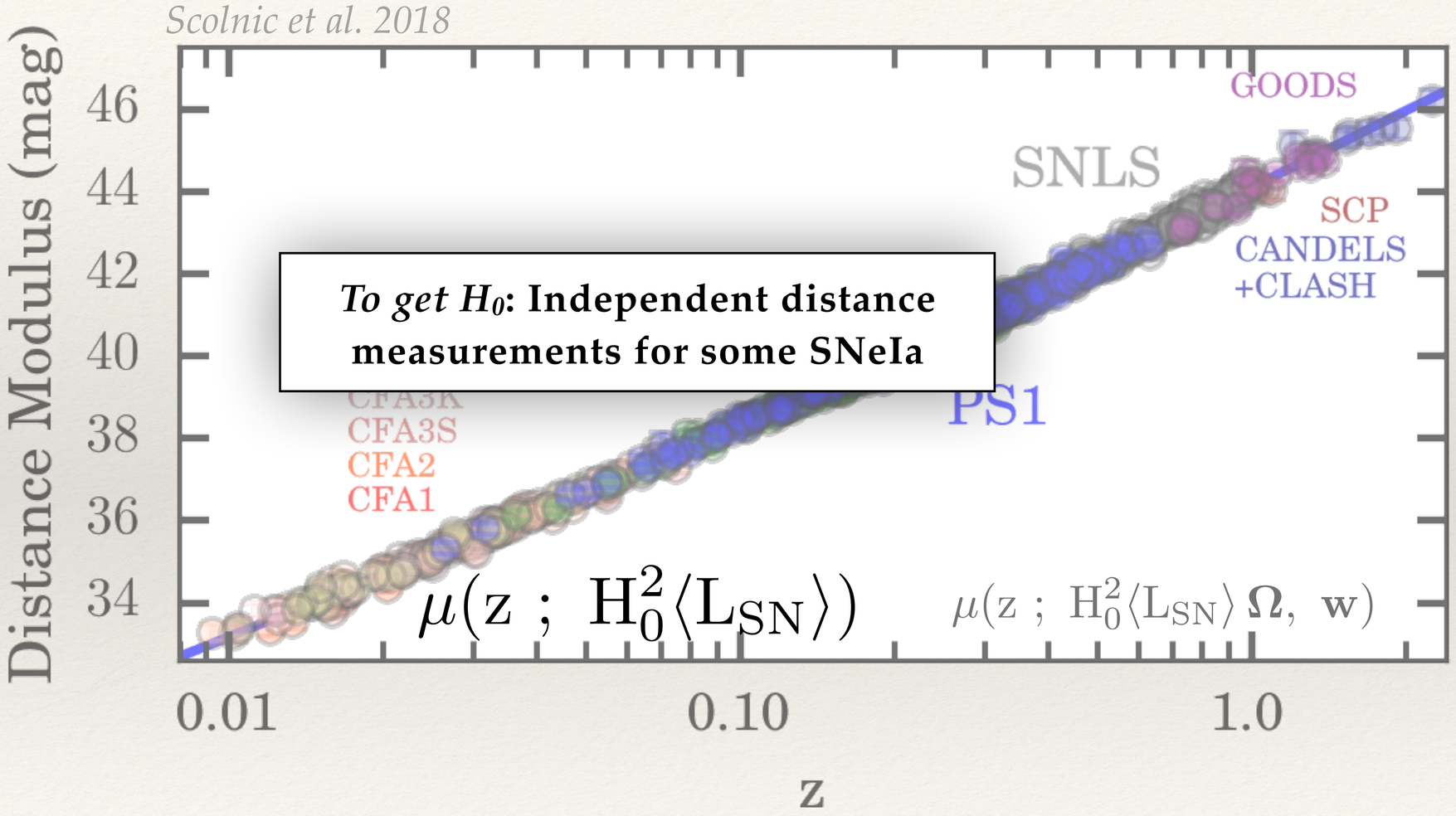
Type Ia Cosmology | *w*

Scolnic et al. 2018





Type Ia Cosmology | H_0



***To get H_0*: Independent distance measurements for some SNeIa**

Direct Distance Ladder

Get independent distances for SNe Ia

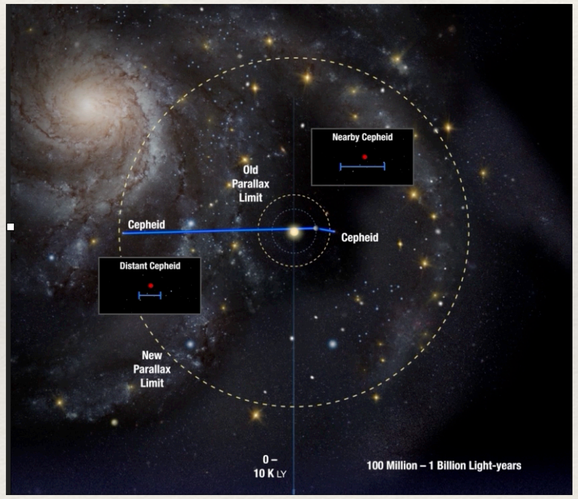
distance

"Geometry"

Parallaxes

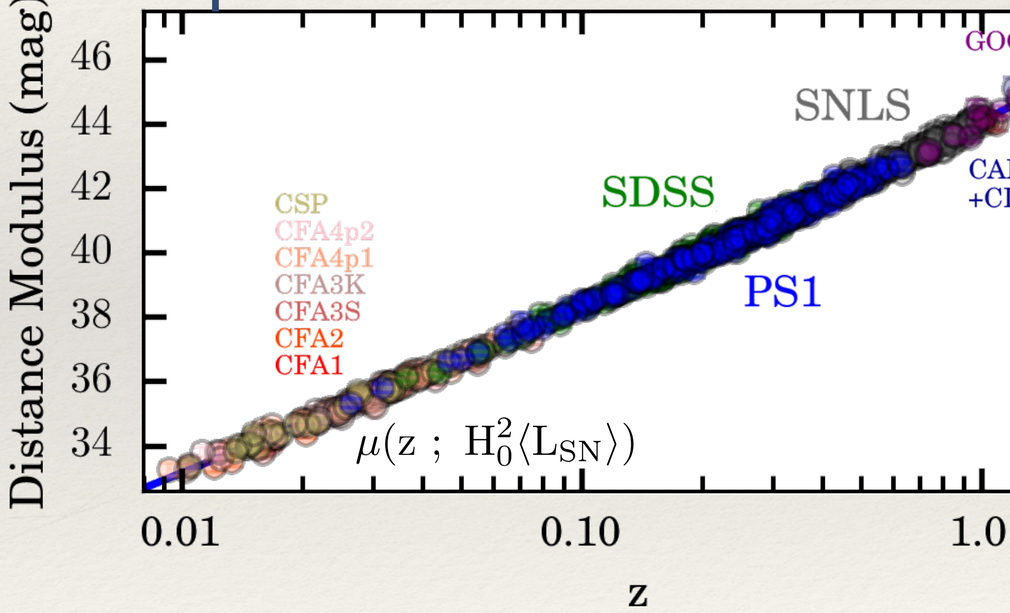
Detached Eclipsing Binary
(D.E.B.)

MegaMaser



"SNe Ia"

Scolnic et al. 2018



Direct Distance Ladder | *SH0ES*

Get independent distances for SNe Ia

Calibrate "Period-Luminosity" relation → *Measure "L_{SN}"* → *Get "H_0"* → **distance**

"Geometry"

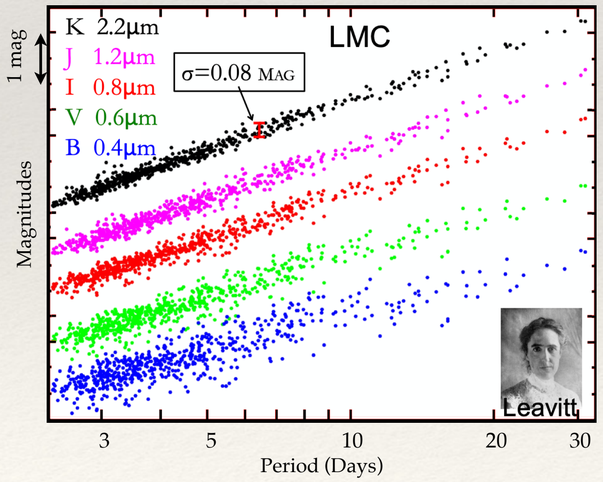
Parallaxes | D.E.B. | Maser

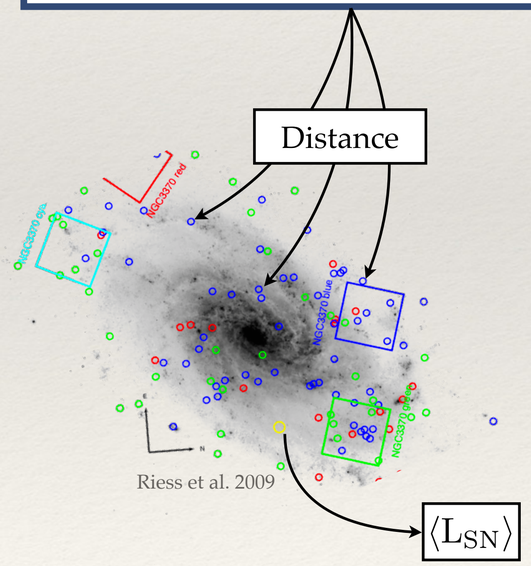
"Calibrators"

Cepheids

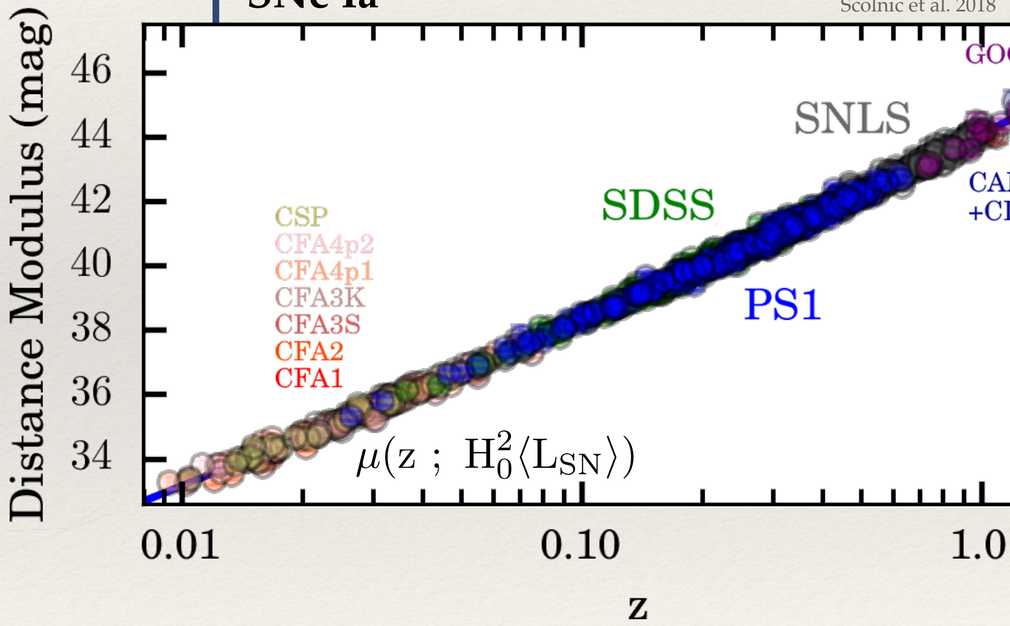
"SNe Ia"

Macri et al. 2015





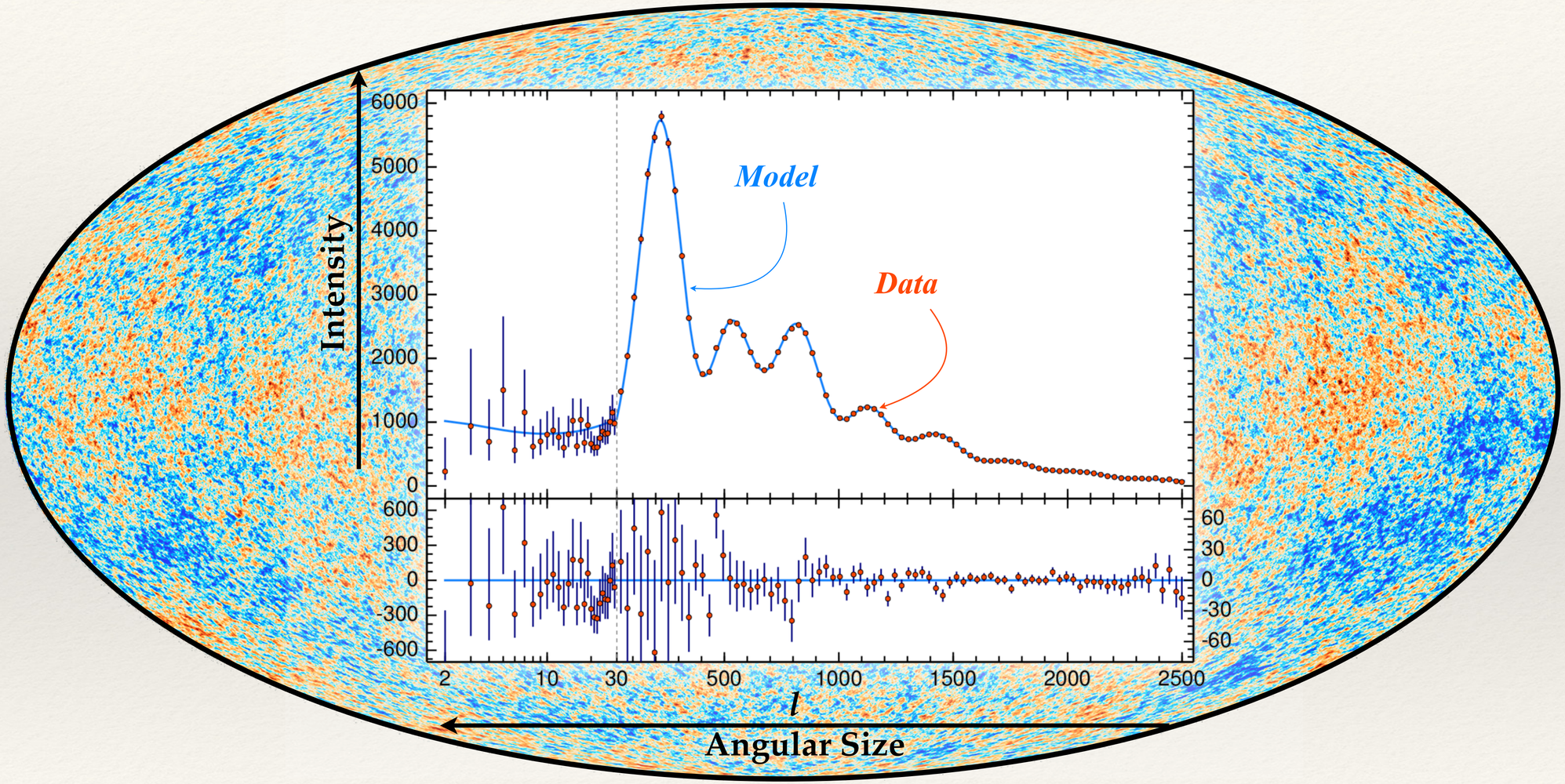
Scolnic et al. 2018



Riess et al. *submitted*

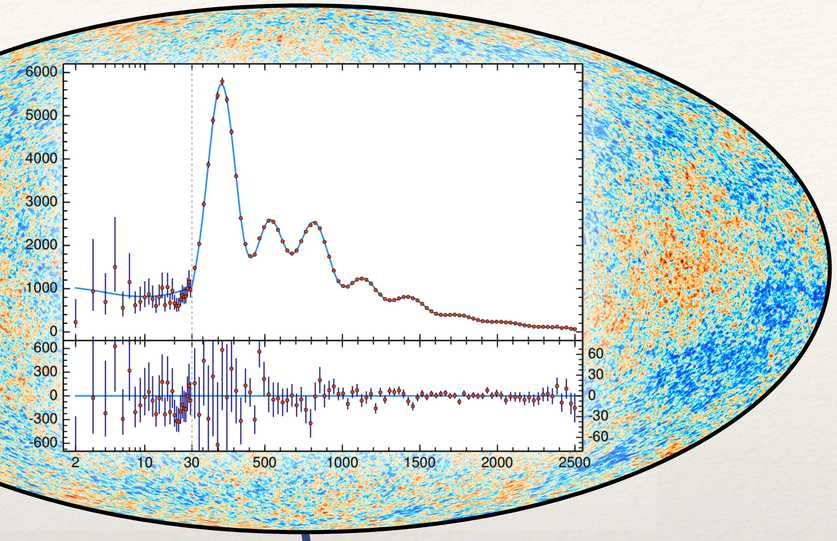
$H_0 = 73.0 \pm 1.0$ km s^{-1} Mpc^{-1}

Planck Results



Indirect determination of H_0

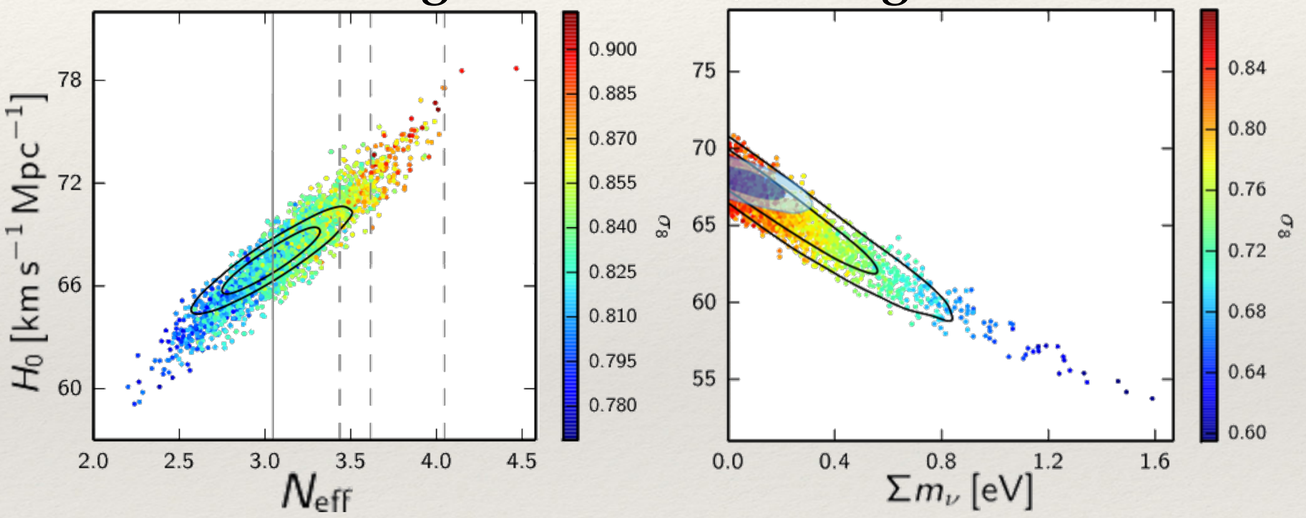
Planck 2018



z~1000

Test the concordance model ΛCDM

Change the model, change H_0



Illustrative plots from Planck 2015

THE MODEL CONTRAINS H_0

z~0

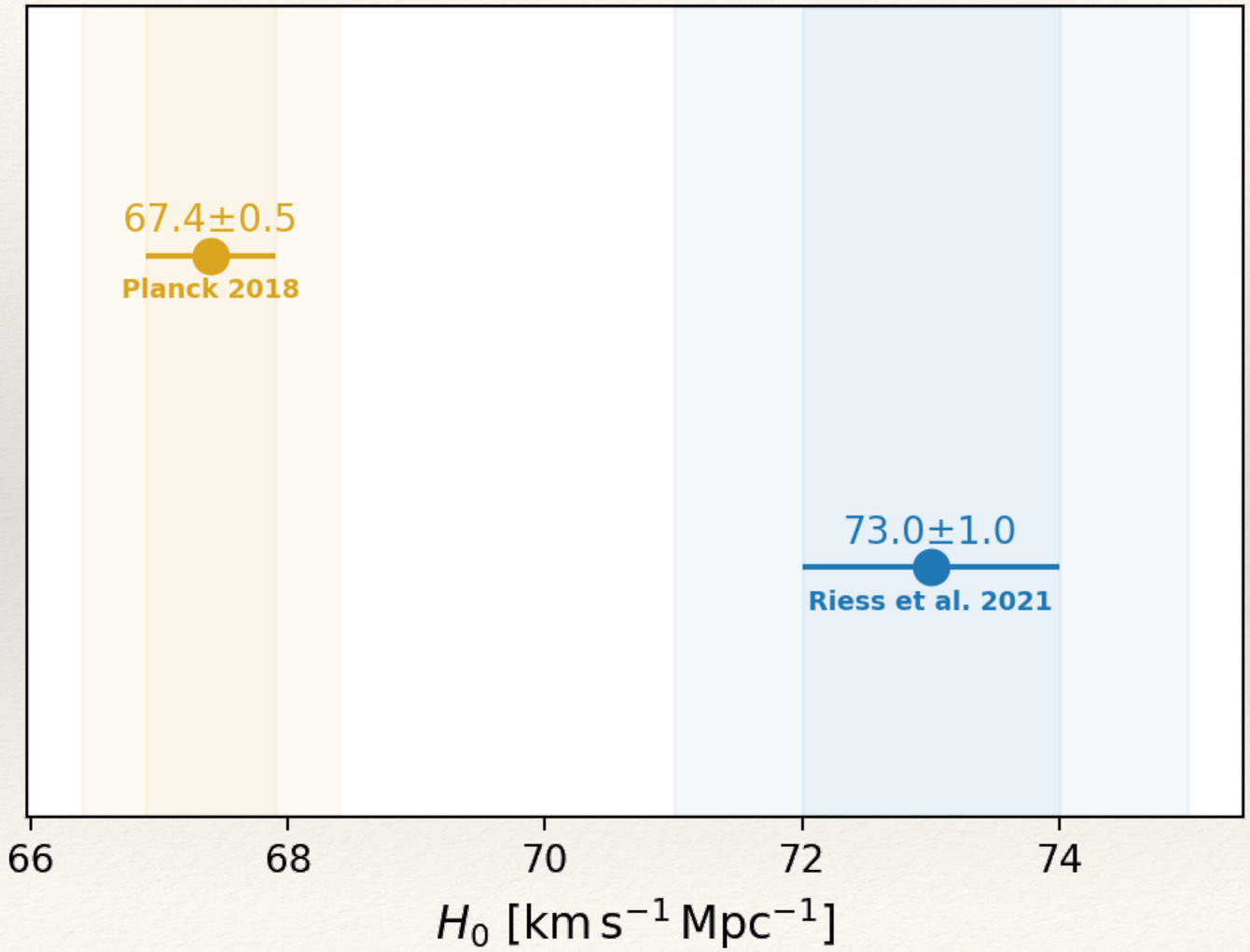
$H_0 = 67.4 \pm 0.5$ km s^{-1} Mpc^{-1}

— based on ΛCDM —

H_0 Tension | *SH0ES vs. Planck*

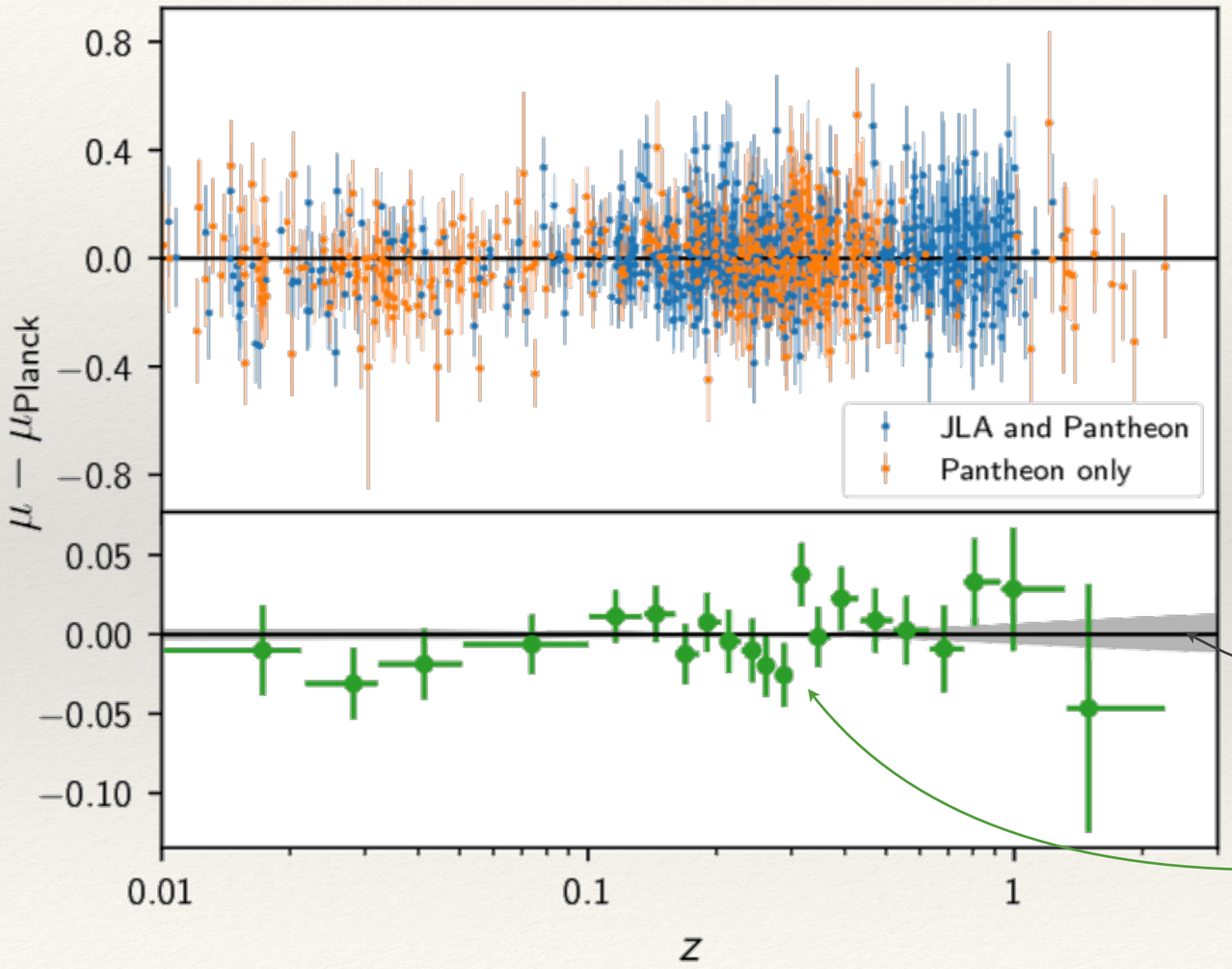
ΛCDM

direct



CMB & SNeIa in disagreement ? *No!*

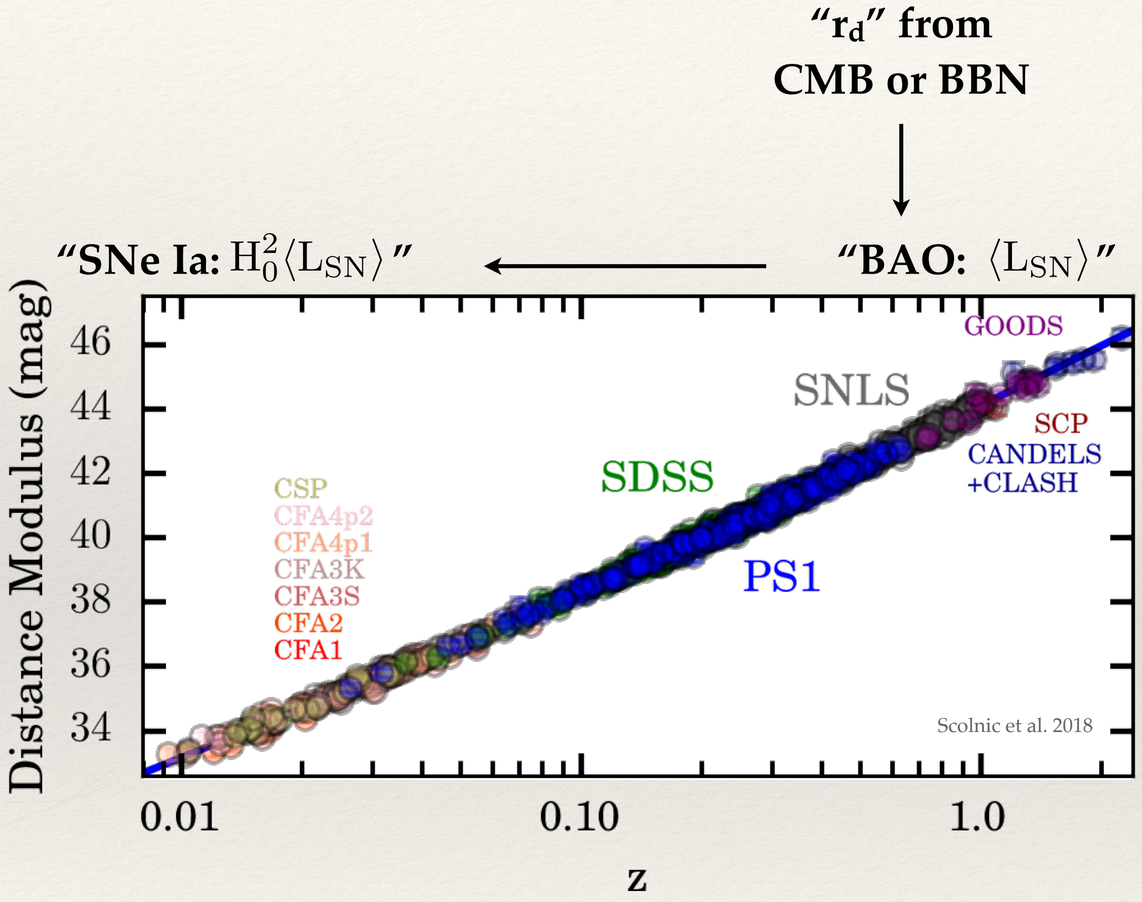
Planck 2018

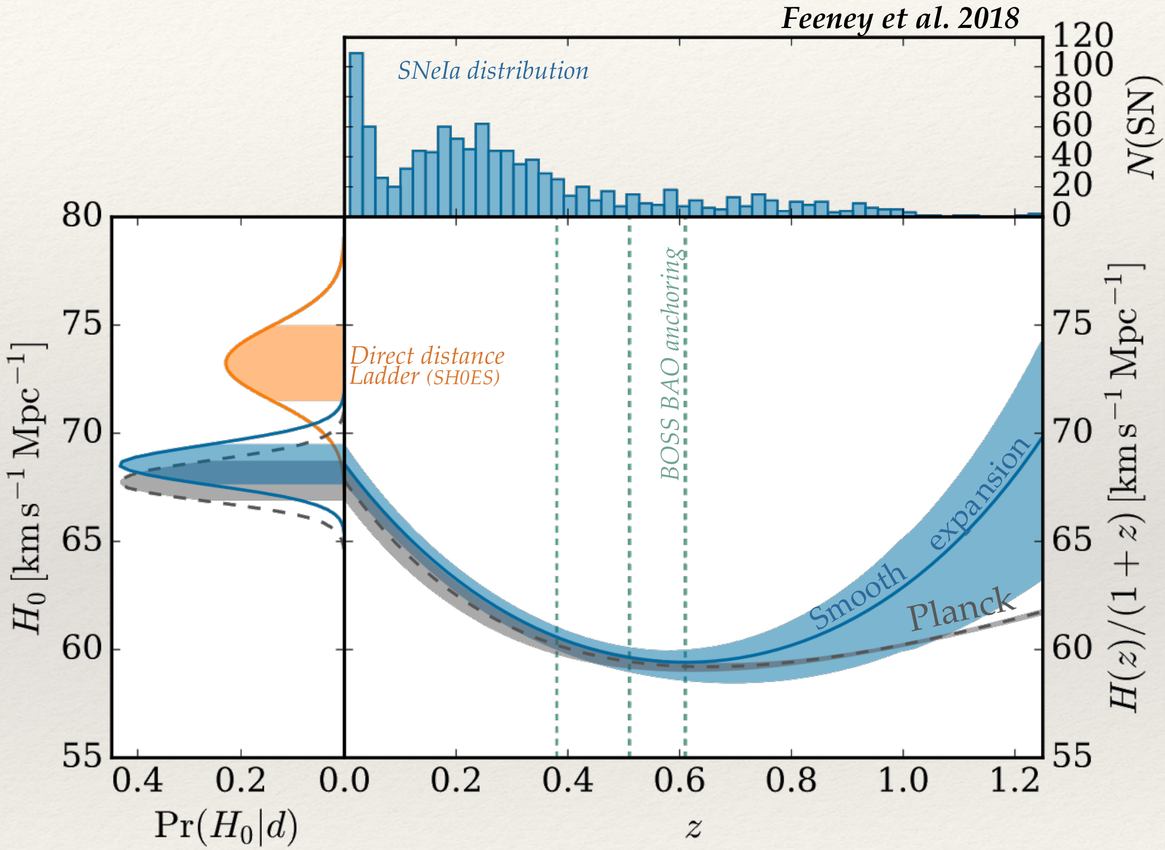


Planck 18 Prediction

Latest SNeIa Cosmological analyses

Inversed Distance Ladder | L_{SN} anchored by CMB



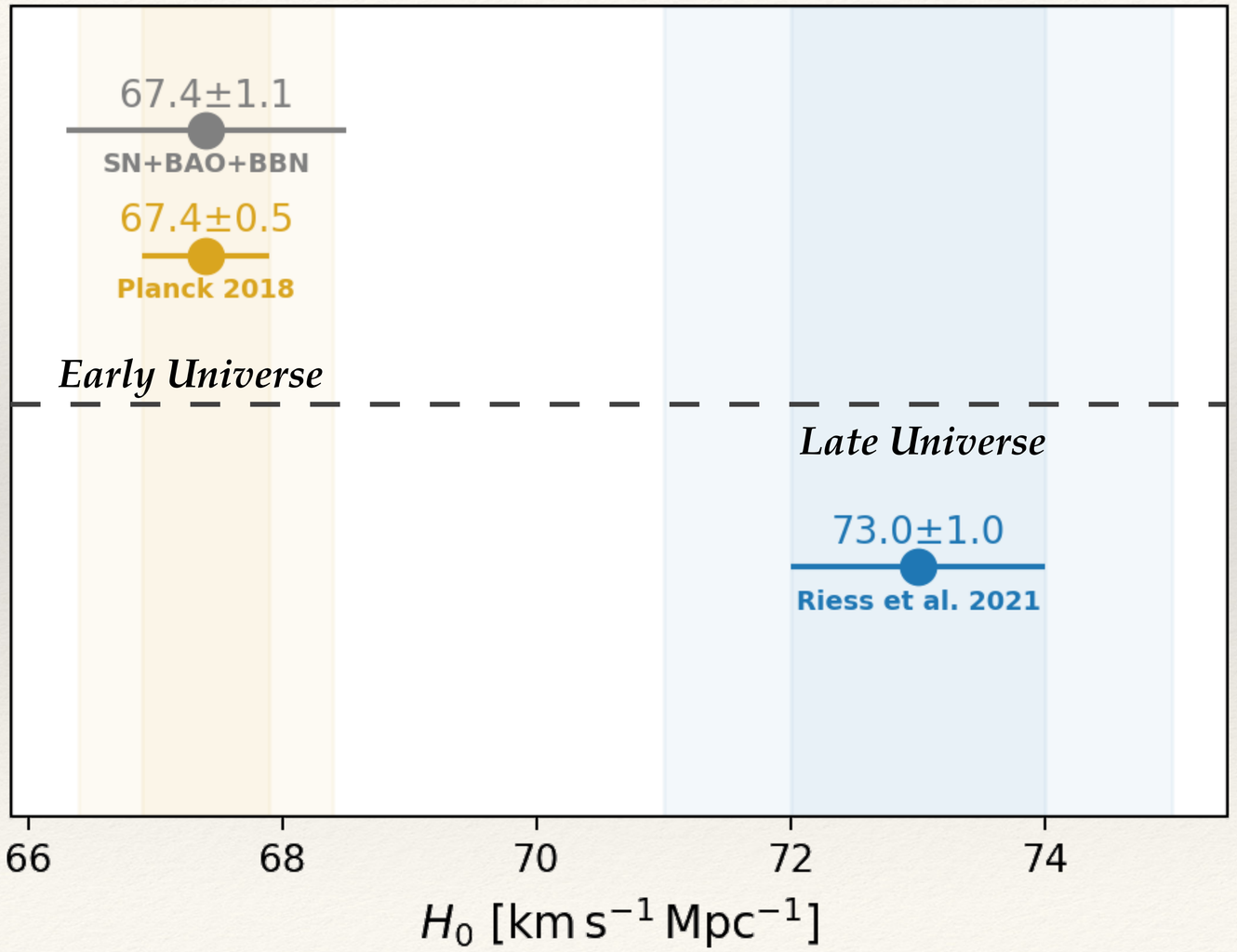


H_0 Tension | Cepheid → SNe Ia ?

ΛCDM

ΛCDM

direct



Direct Distance Ladder | *SH0ES*

Get independent distances for SNe Ia

Calibrate "Tip" Amplitude → *Measure "L_{SN}"* → *Get "H_0"* → **distance**

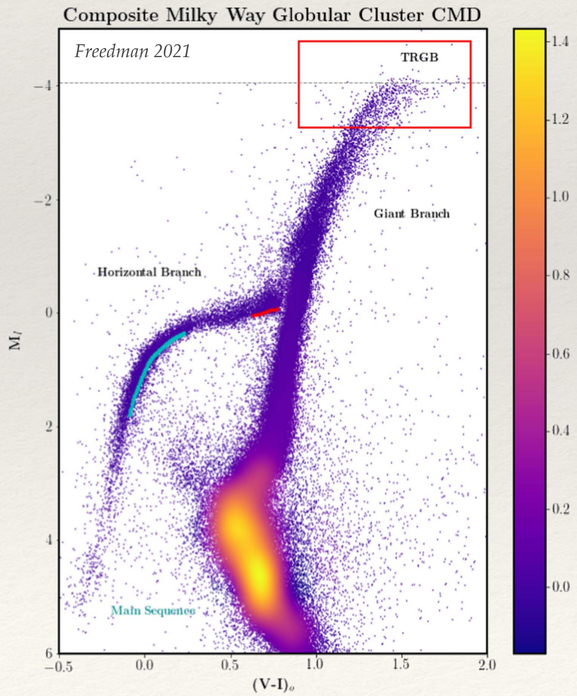
"Geometry"

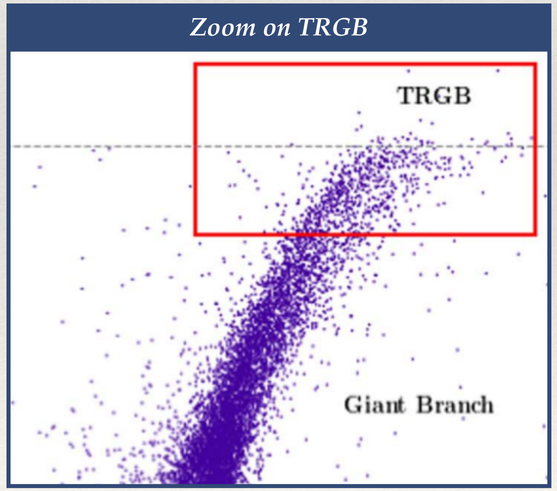
Parallaxes | D.E.B. | Maser

"Calibrators"

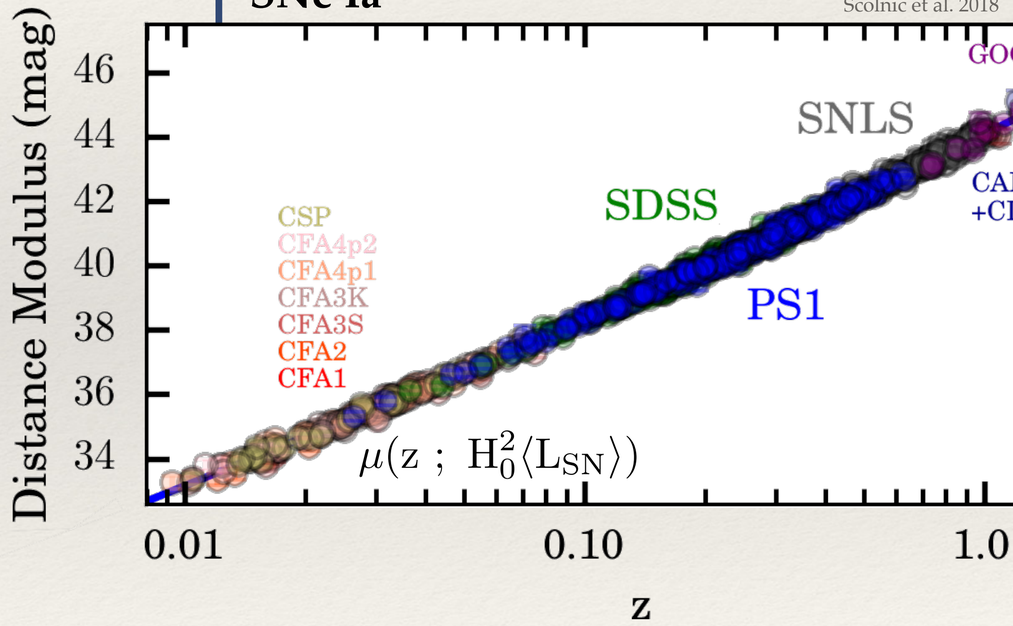
TRGB

"SNe Ia"





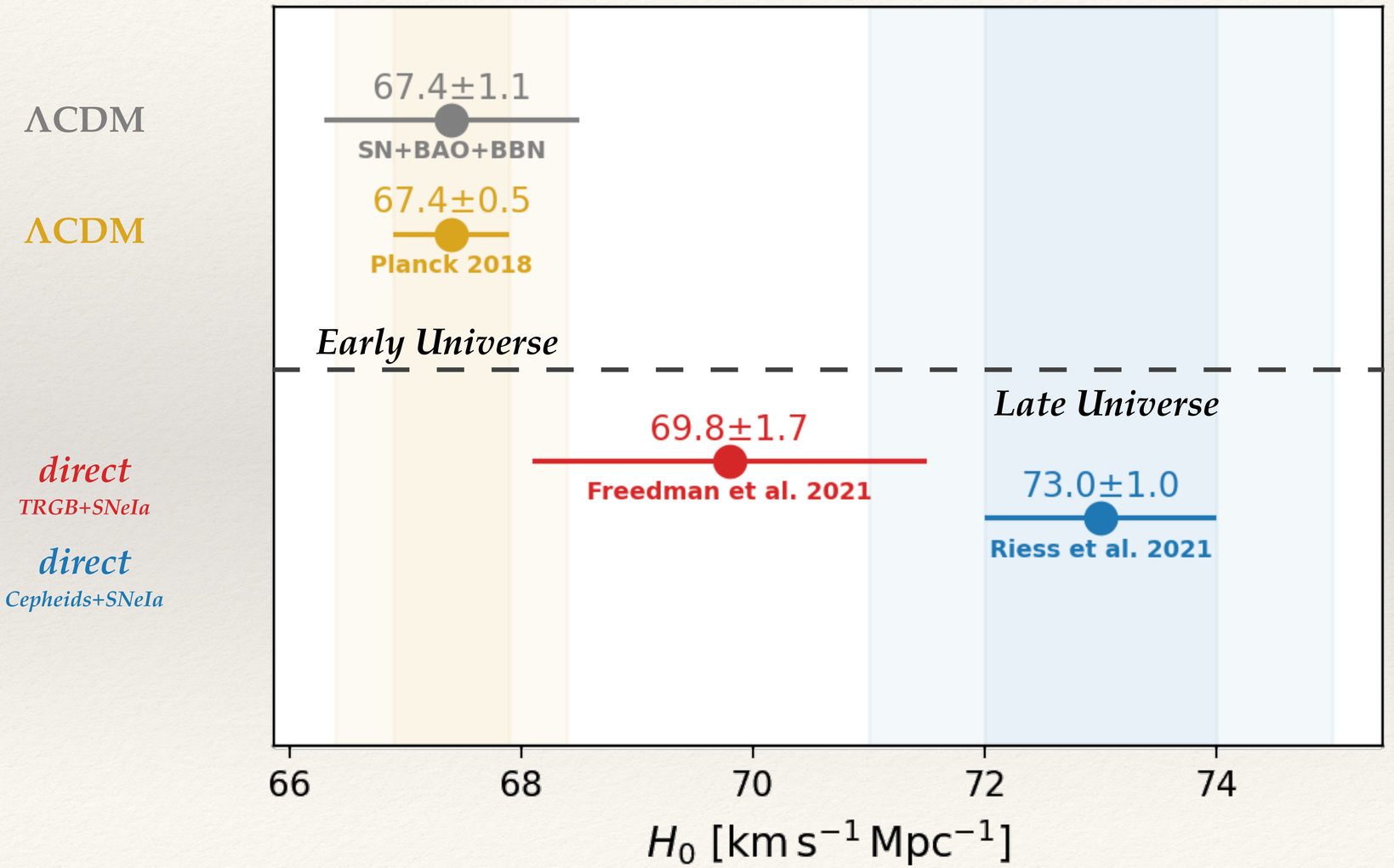
Scolnic et al. 2018



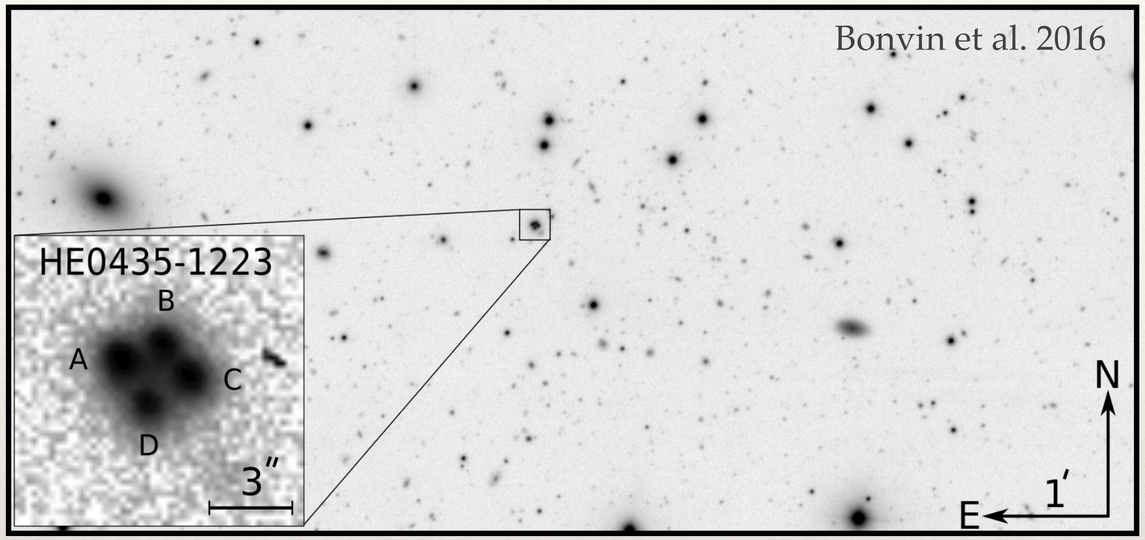
Freedman 2021

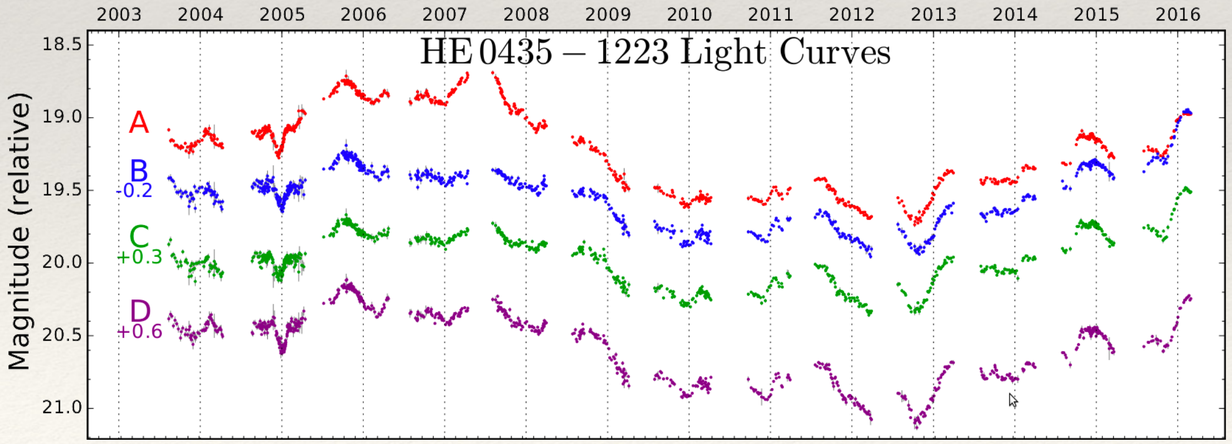
$H_0 = 69.8 \pm 1.7$ km s^{-1} Mpc^{-1}

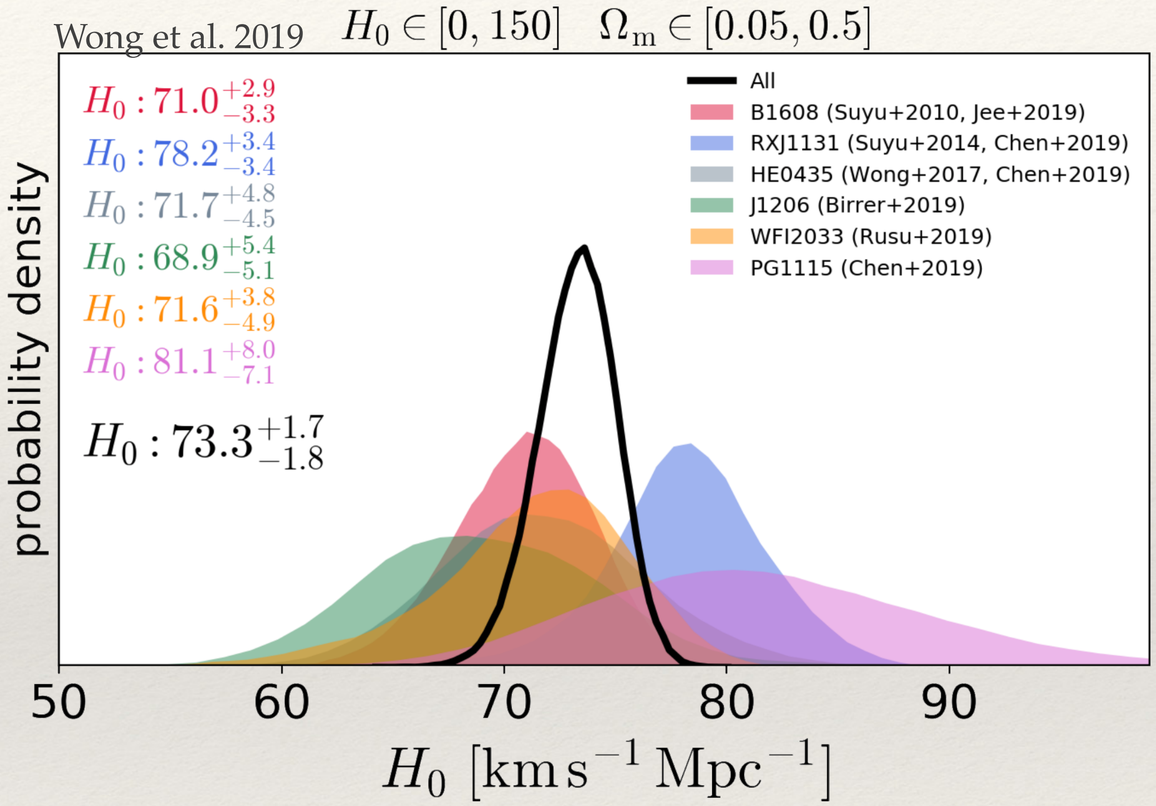
H_0 Tension | Cepheid → SNe Ia ?



H_0 from Strong Lensing





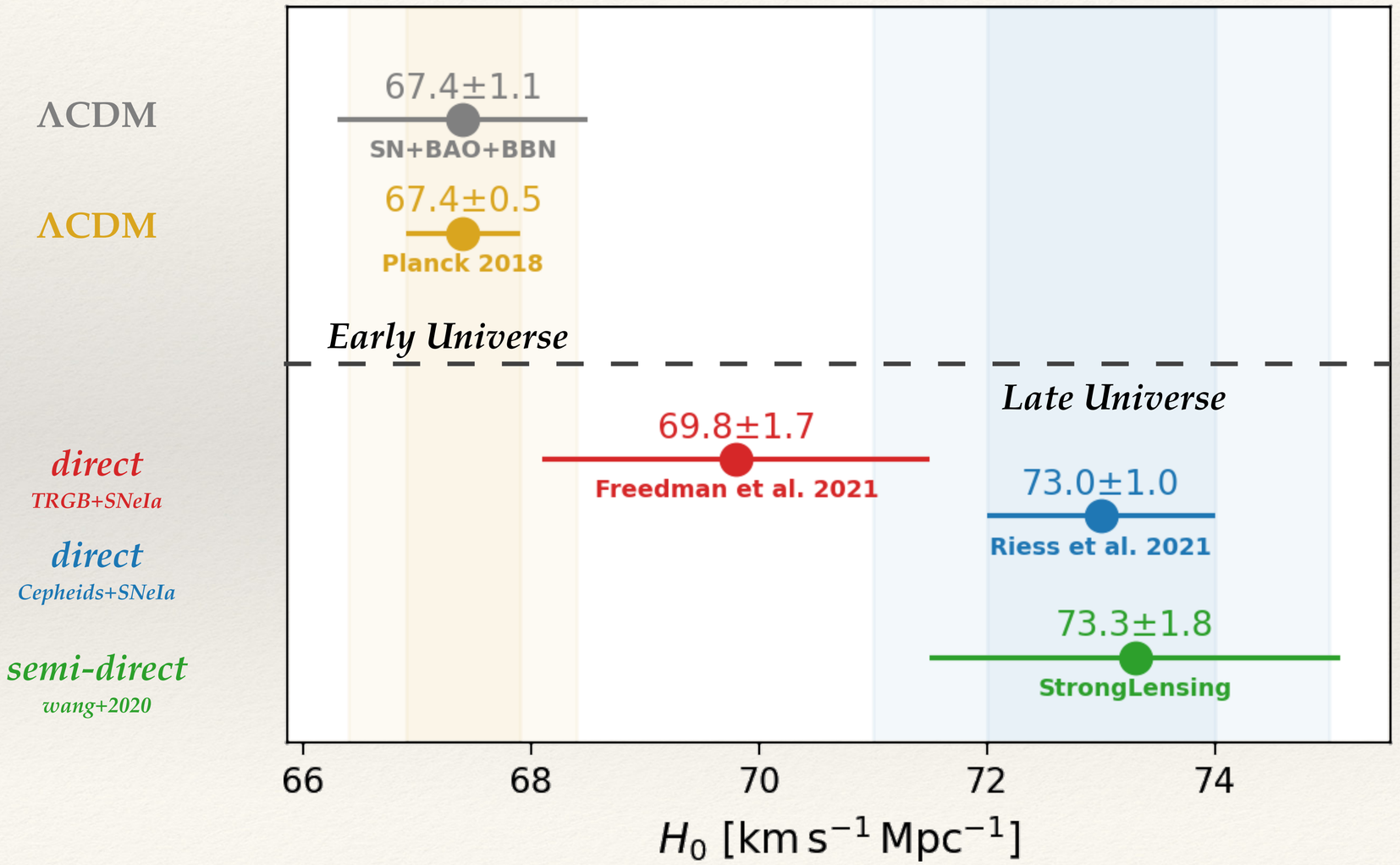


$$\Delta t = \frac{1}{c} D_{\Delta t} \phi_{lens}$$

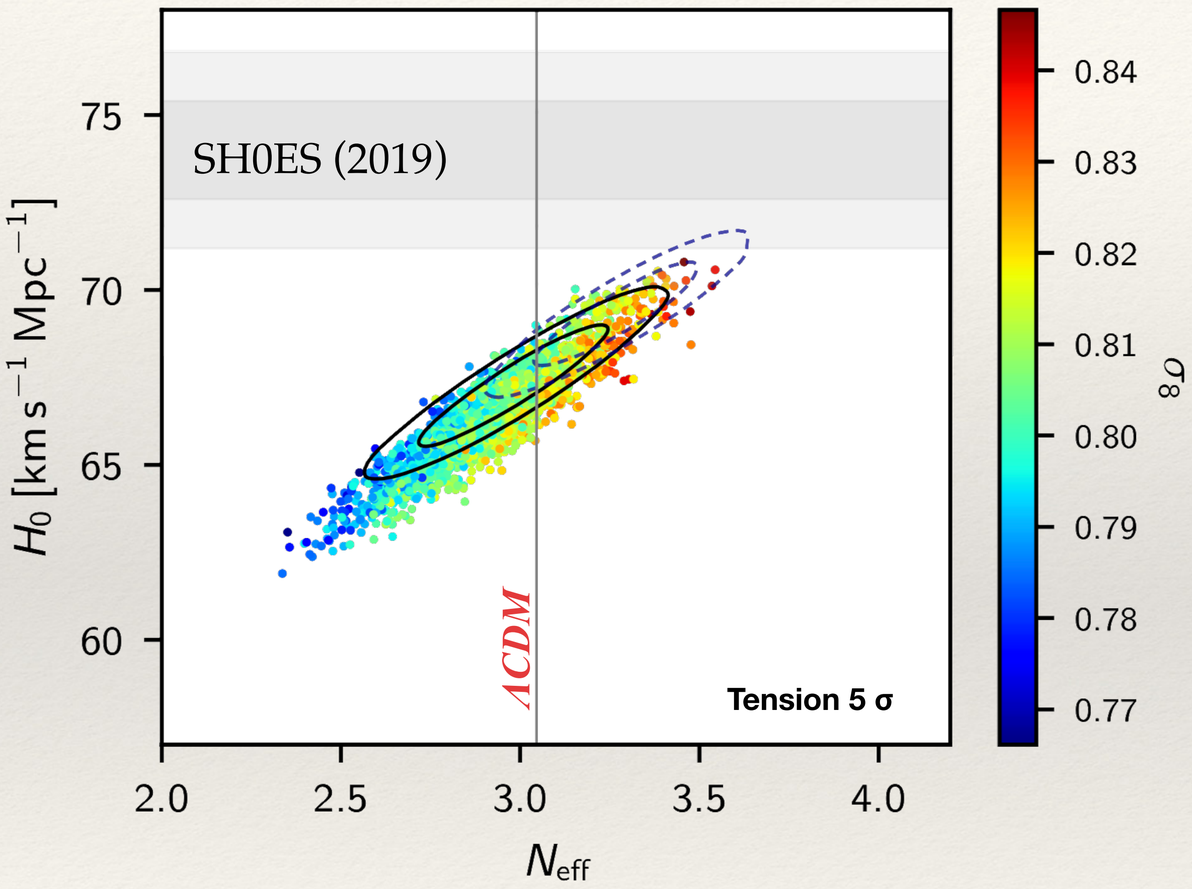
$$\propto H_0^{-1}$$

Obtained from lensing mass model

H_0 Tension | Cepheid → SNe Ia ? Or not…

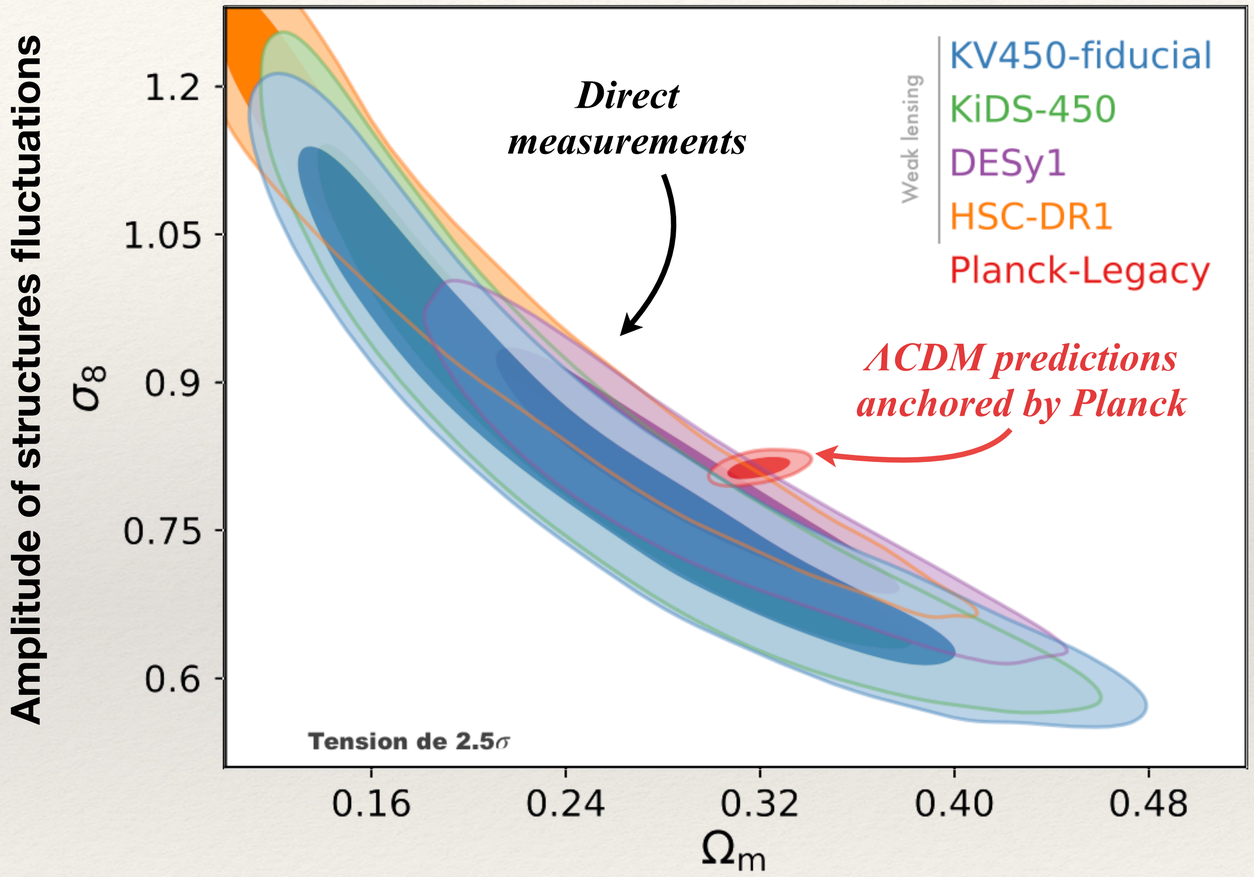


Tensions In Cosmology | *Changing the model*



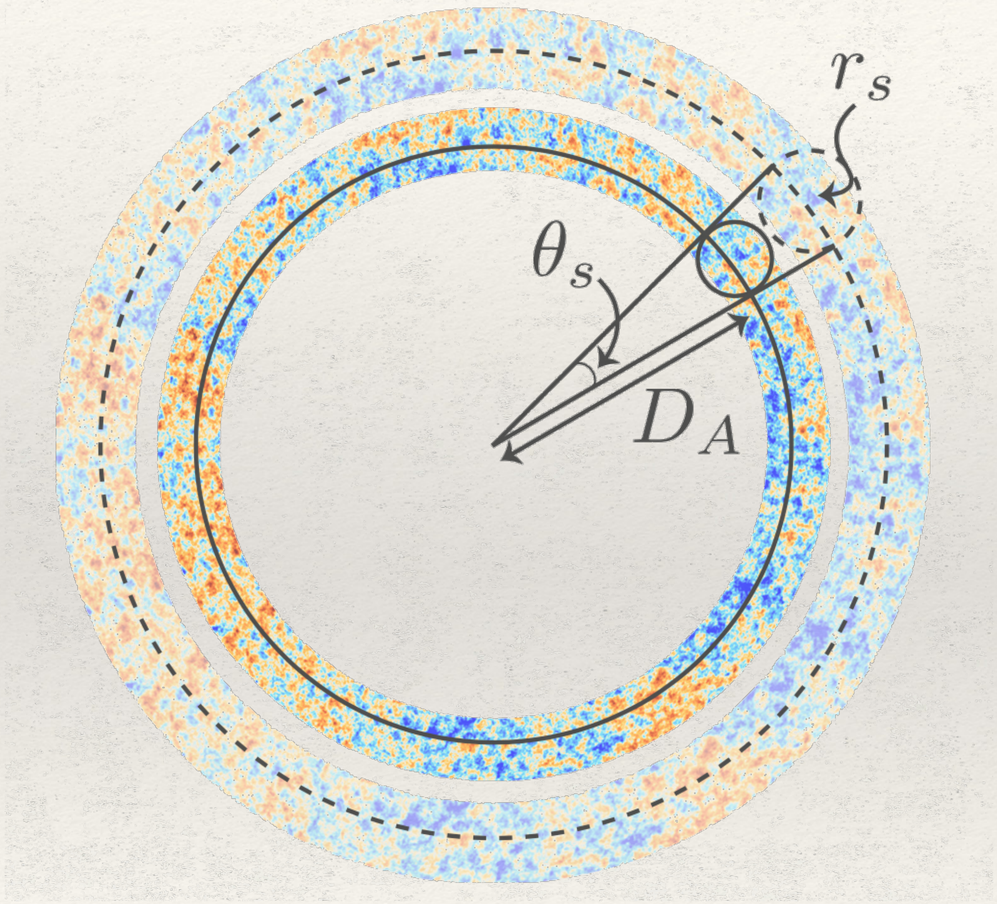
Effective number of « neutrino“

Planck 2018



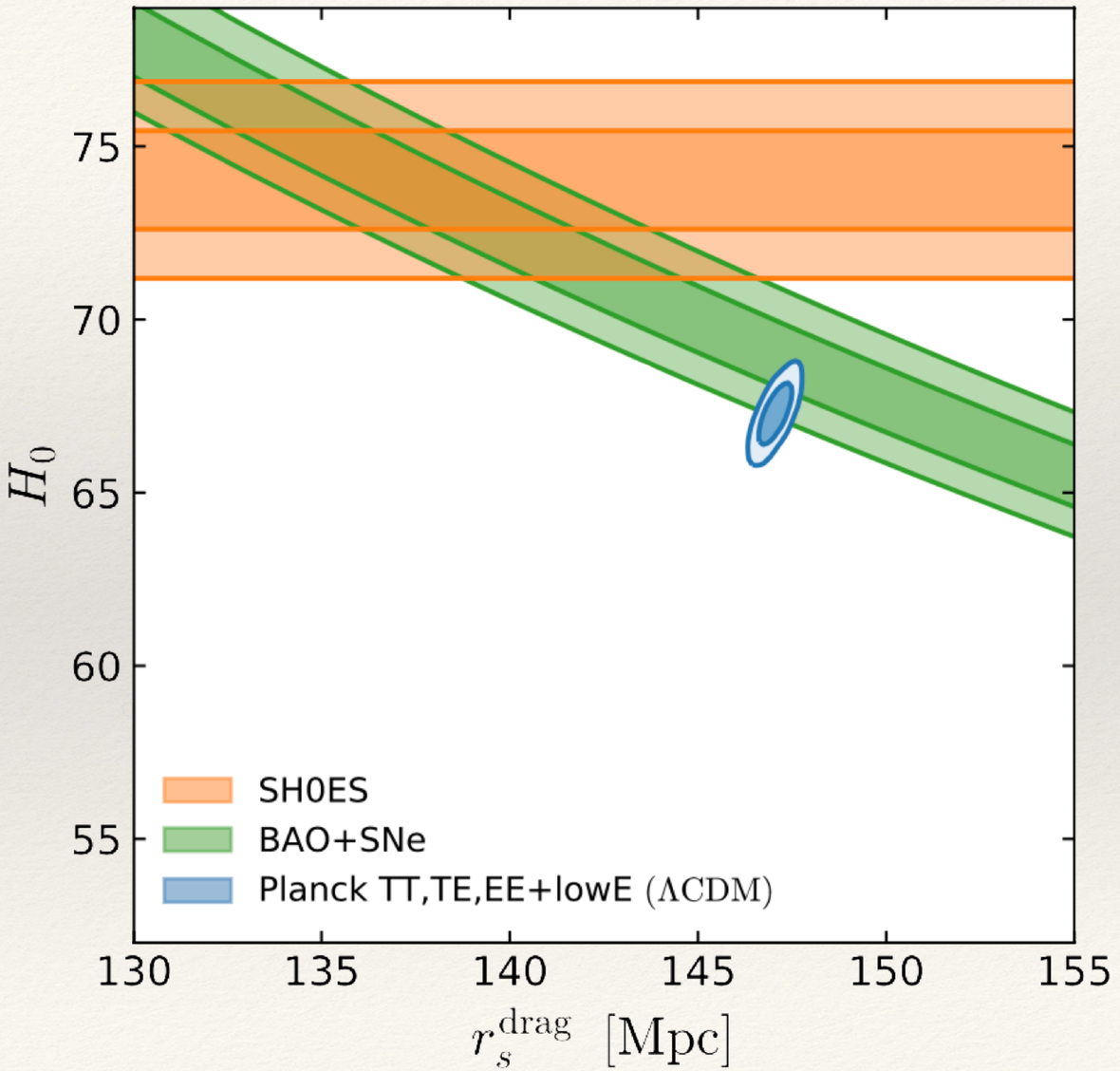
Density of Matter

Then what about New Fundamental Physics ?



T. Smith | V. Poulin

Knox & Millea et al. 2019



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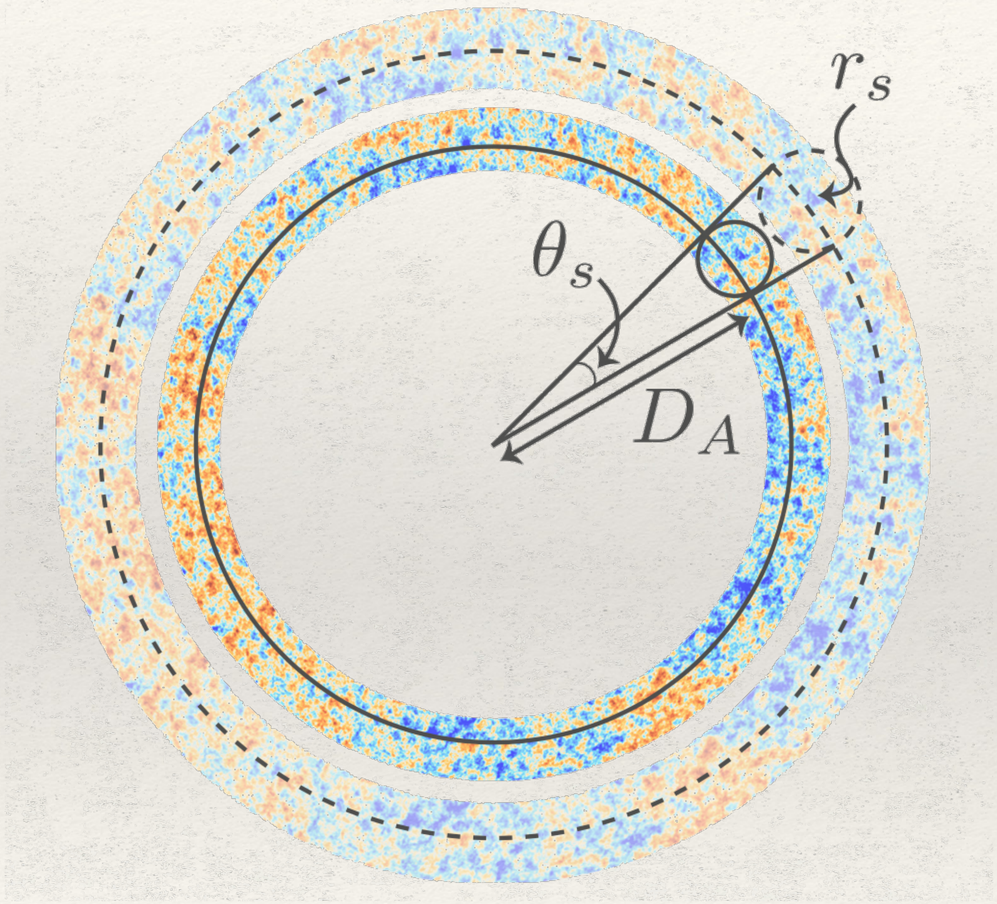

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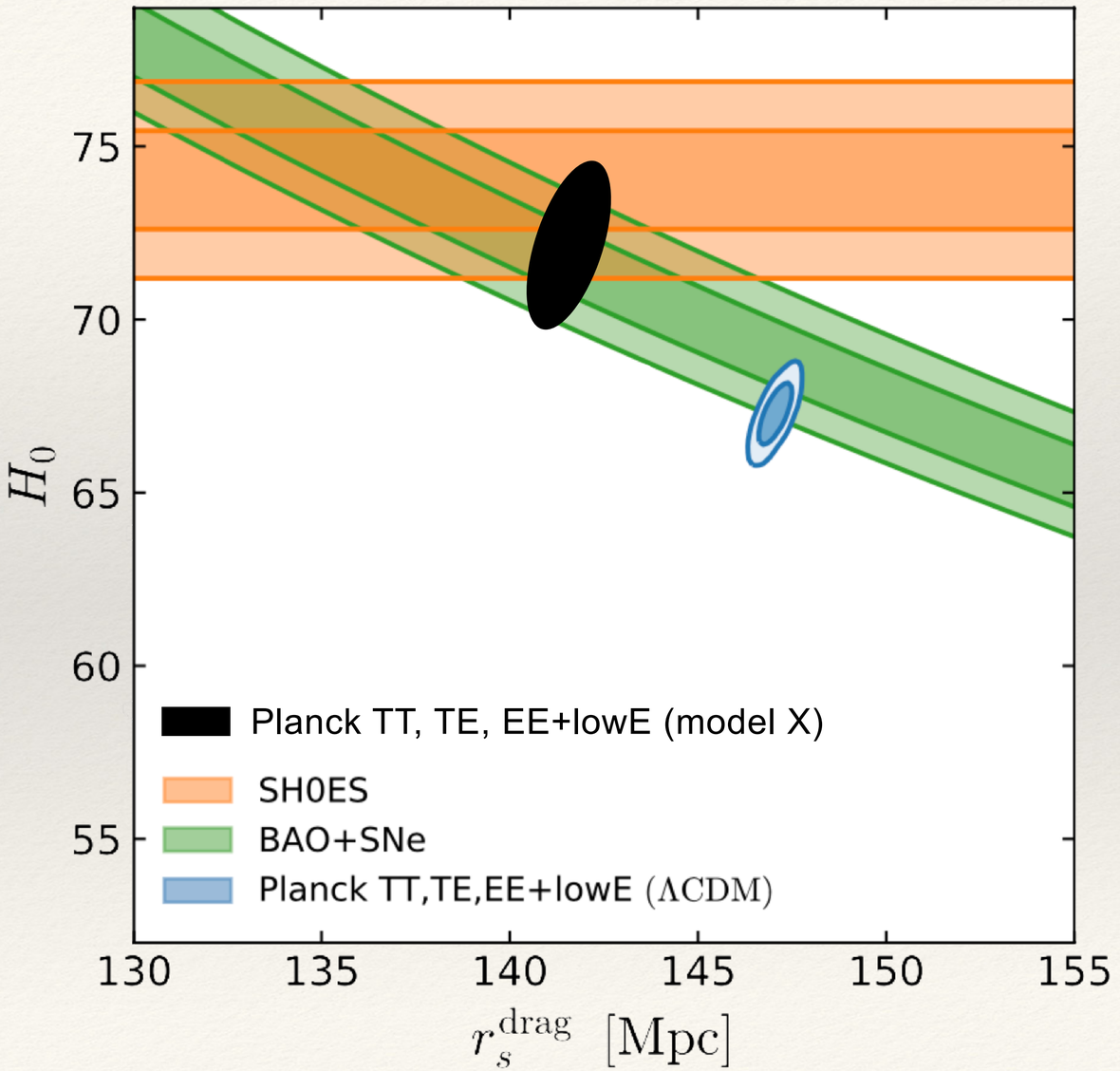
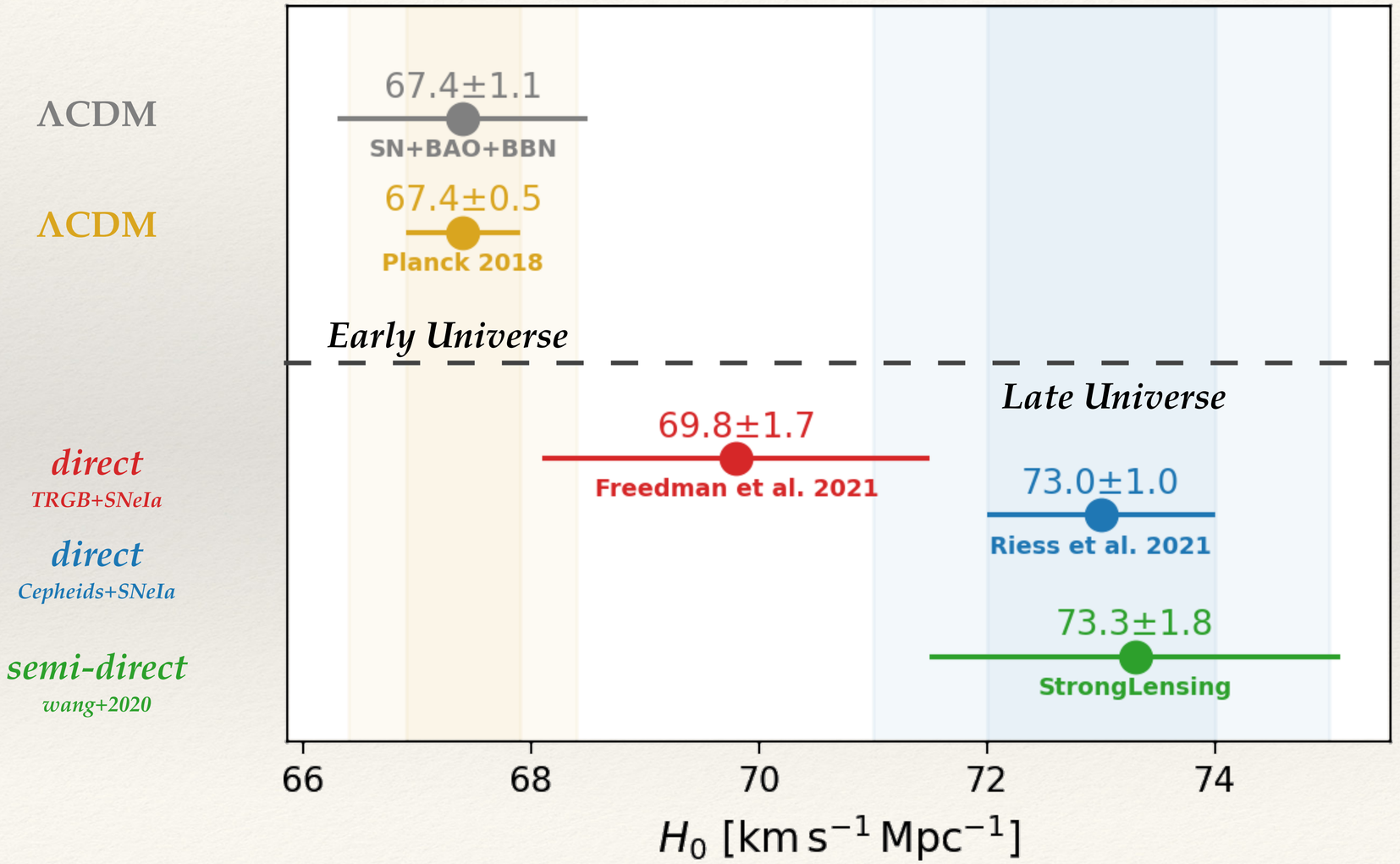


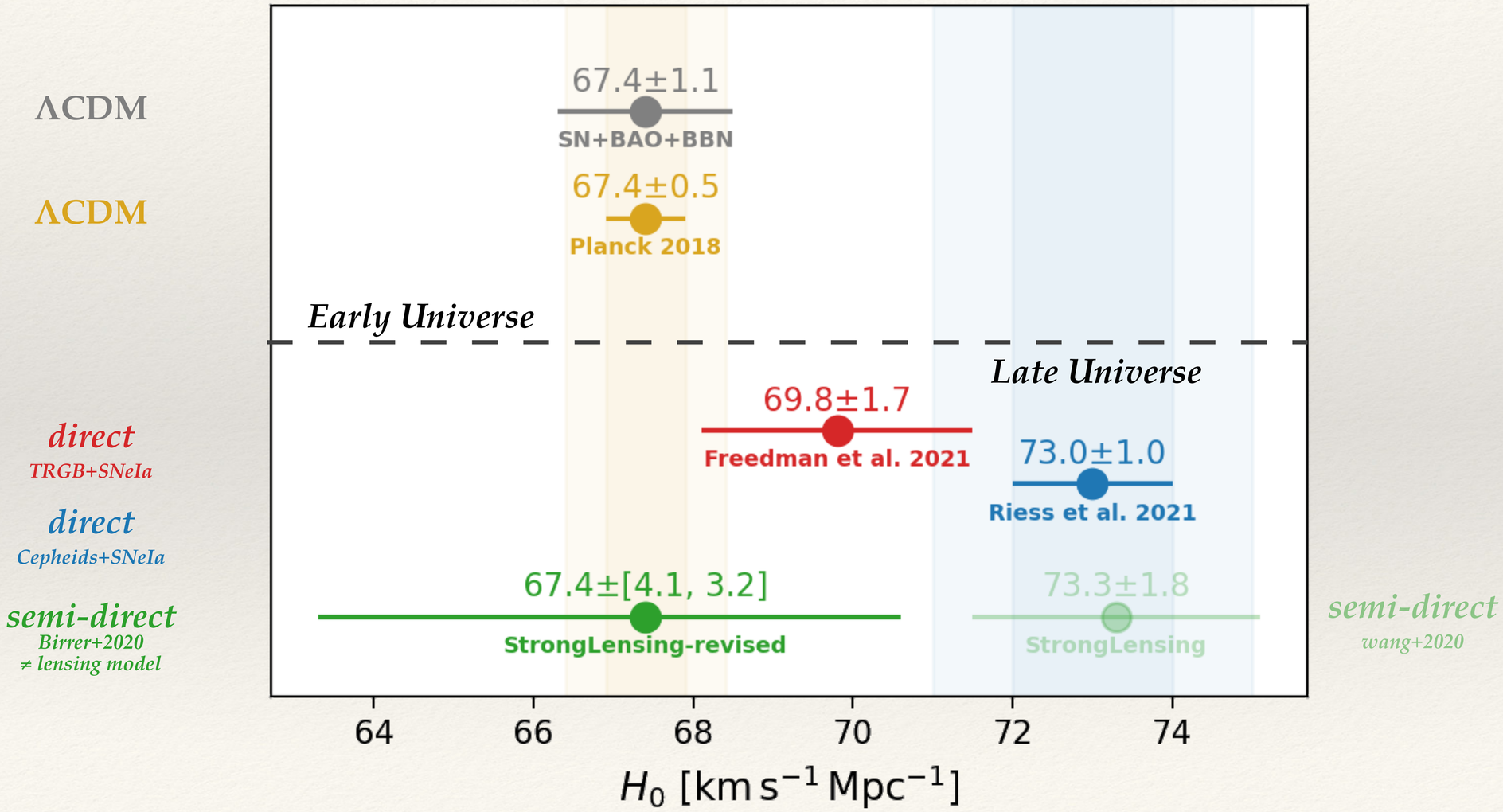
H_0 Tension | Cepheid → SNe Ia ? Or not…

If systematics, it must be multiple sources of systematic uncertainties



H_0 Tension | Cepheid → SNe Ia ? Or not… *Or not only ?*

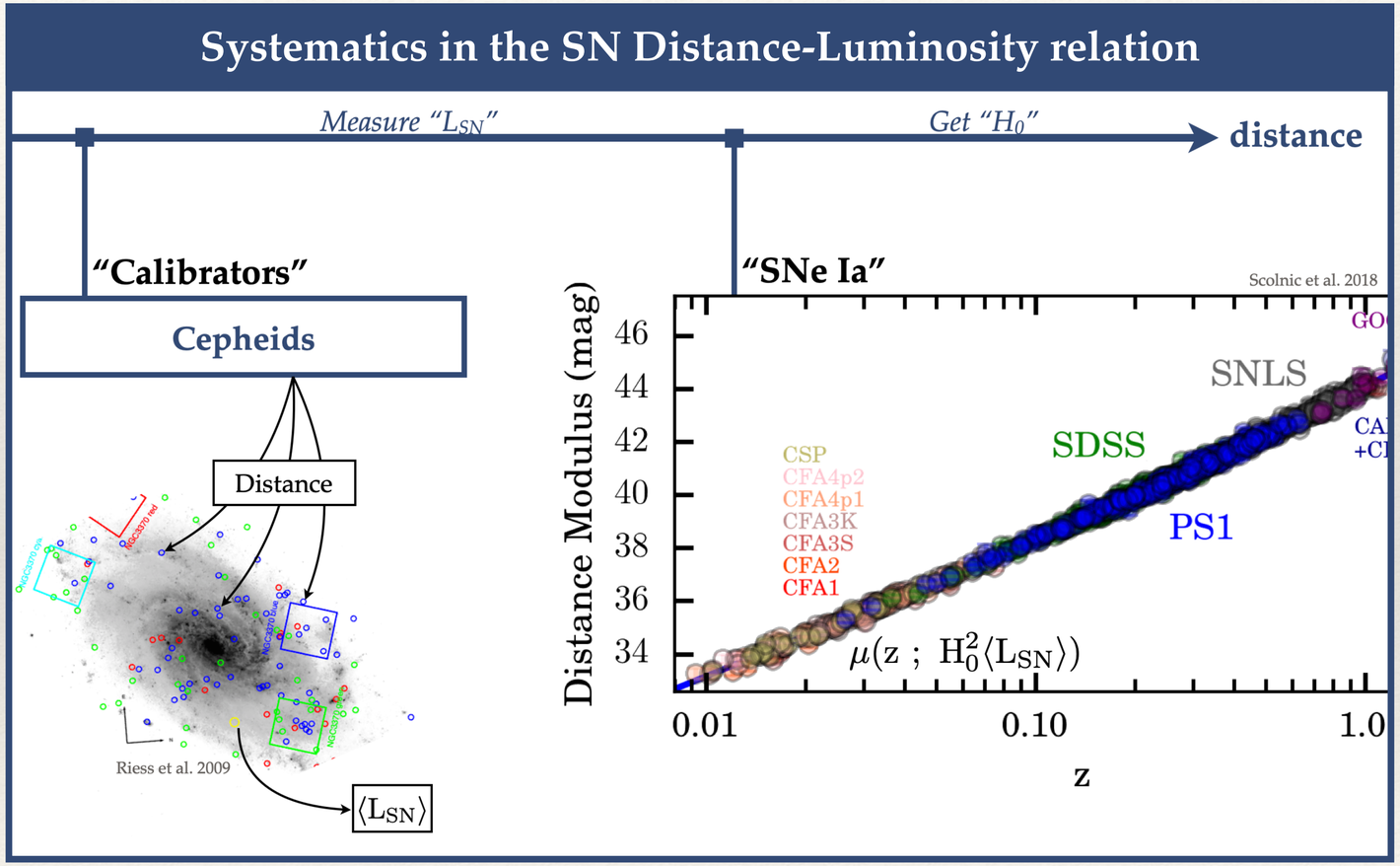
If systematics, it must be multiple sources of systematic uncertainties



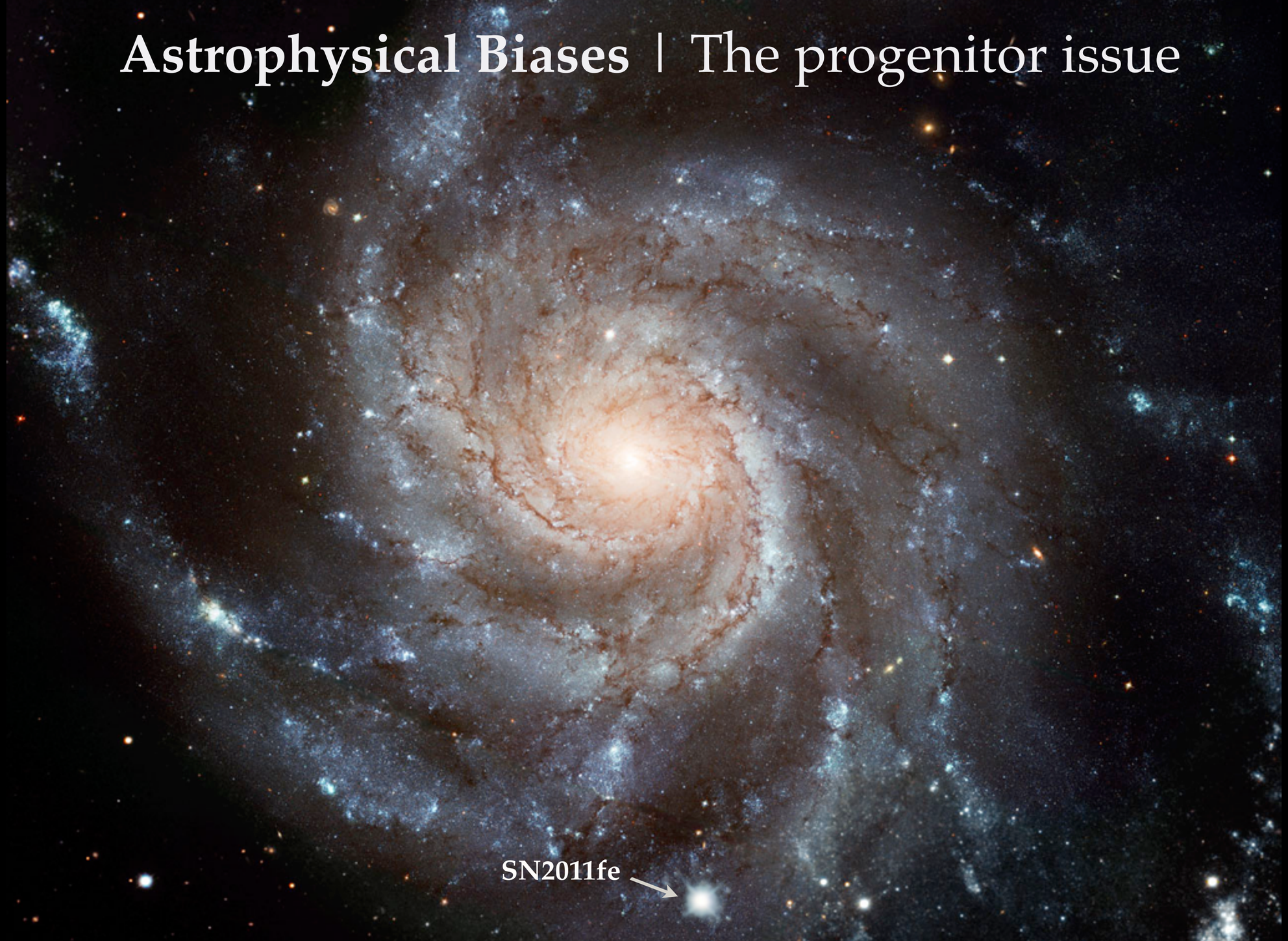
Bias that could affect the *"Cepheid to SNe Ia"* step

Astrophysical Biases

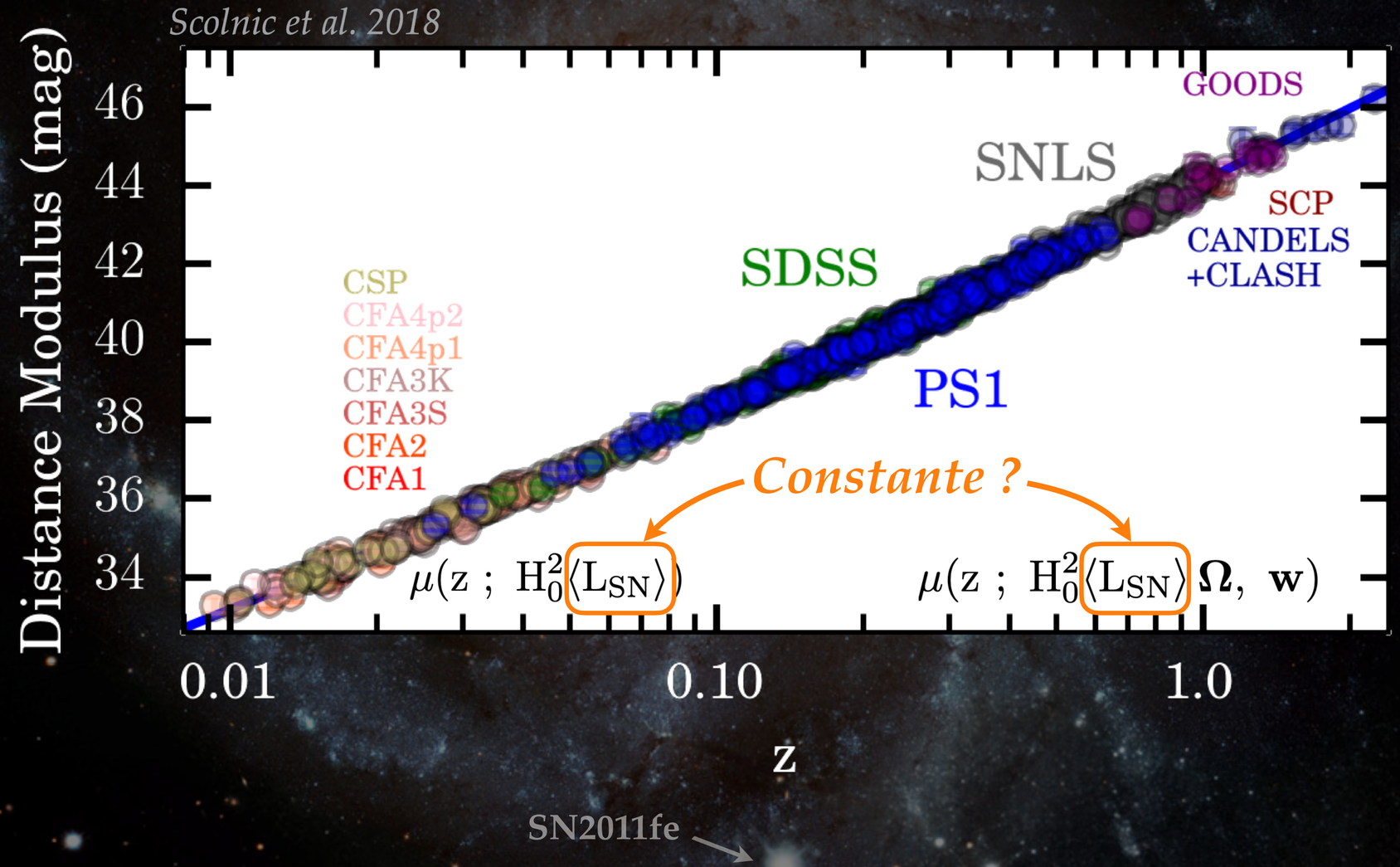
Calibration Biases

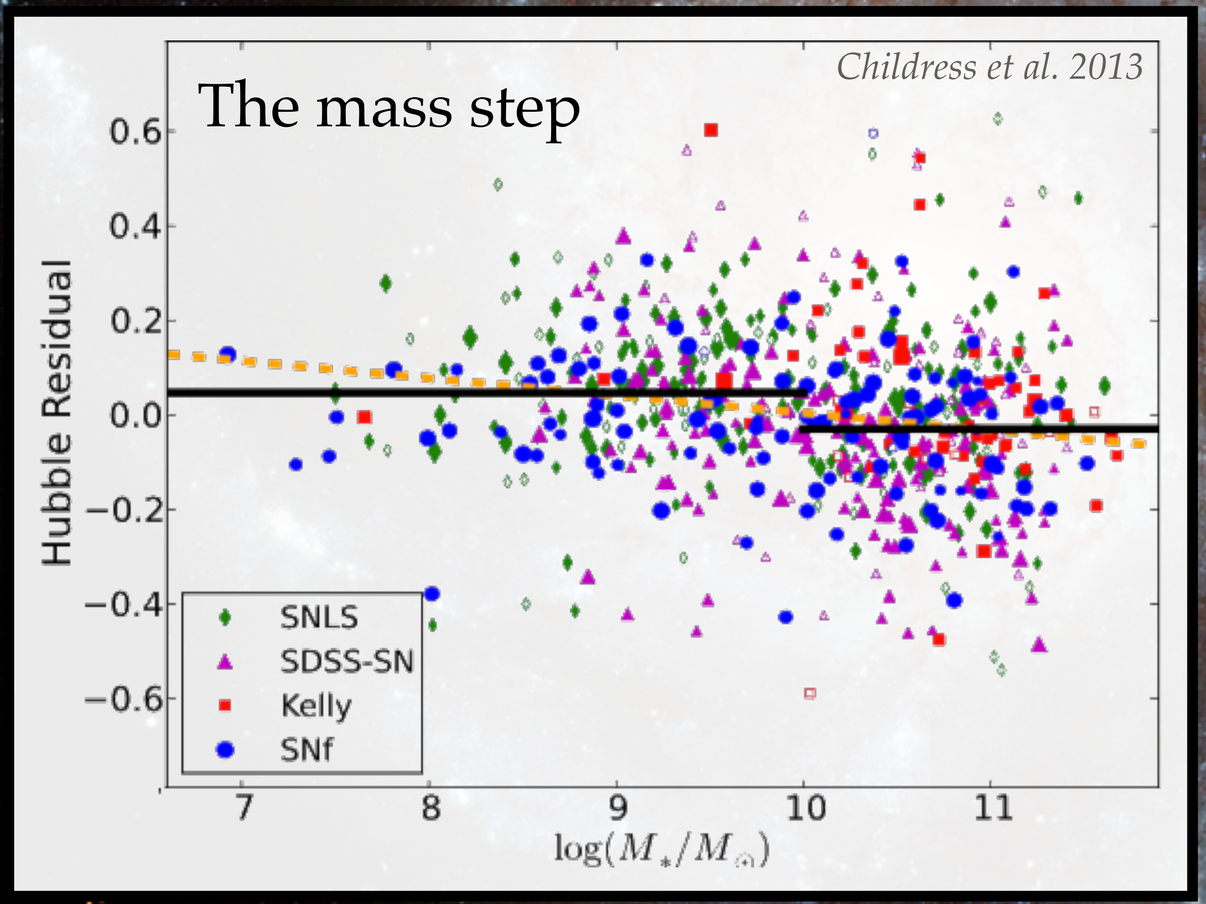


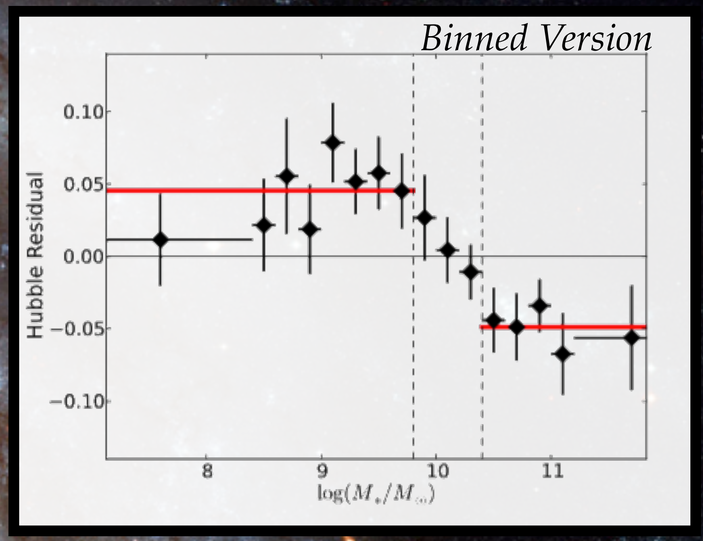
Astrophysical Biases | The progenitor issue



Astrophysical Biases | The progenitor issue




The mass step
Childress et al. 2013
Hubble Residual
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
SNLS
SDSS-SN
Kelly
SNf
7
8
9
10
11
log(M*/M⊙)


Binned Version
Hubble Residual
0.10
0.05
0.00
−0.05
−0.10
8
9
10
11
log(M*/M⊙)

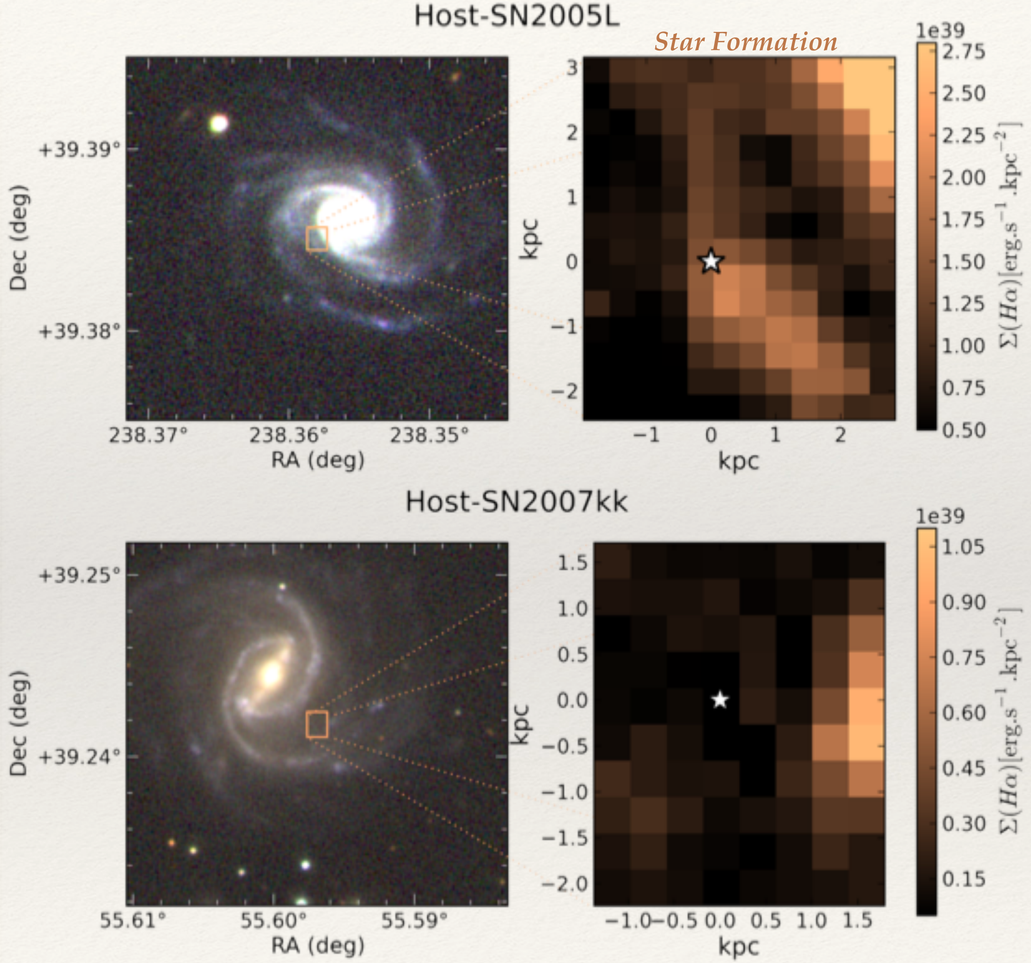

SN2011fe

The Local Perspective

Rigault et al. 2013

GLOBAL

Spiral, Star Forming, host galaxies



LOCAL

Star Formation

—

Young Stars

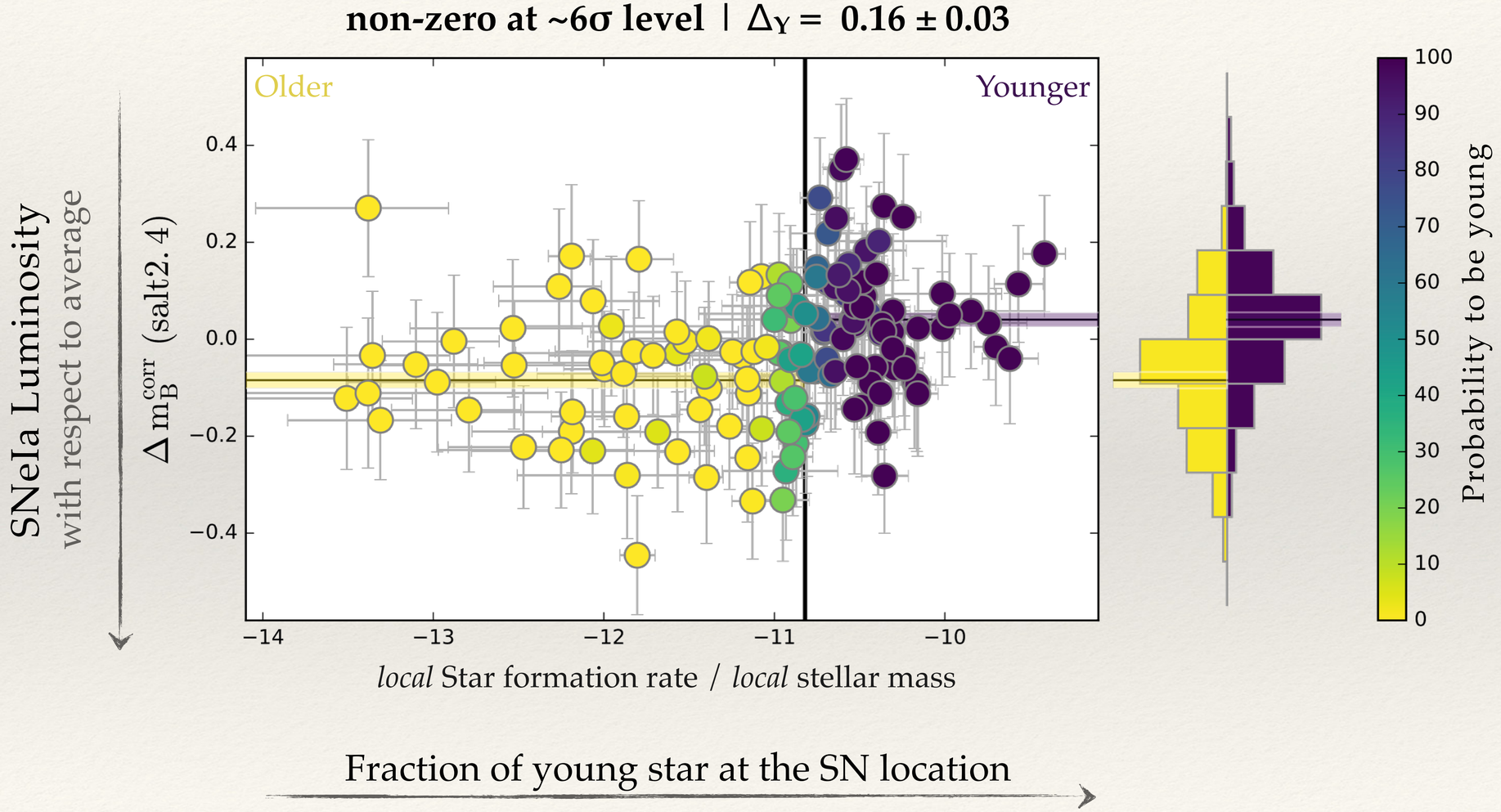
No Star Formation

—

Older Stars

The Age Step

Rigault et al. 2020

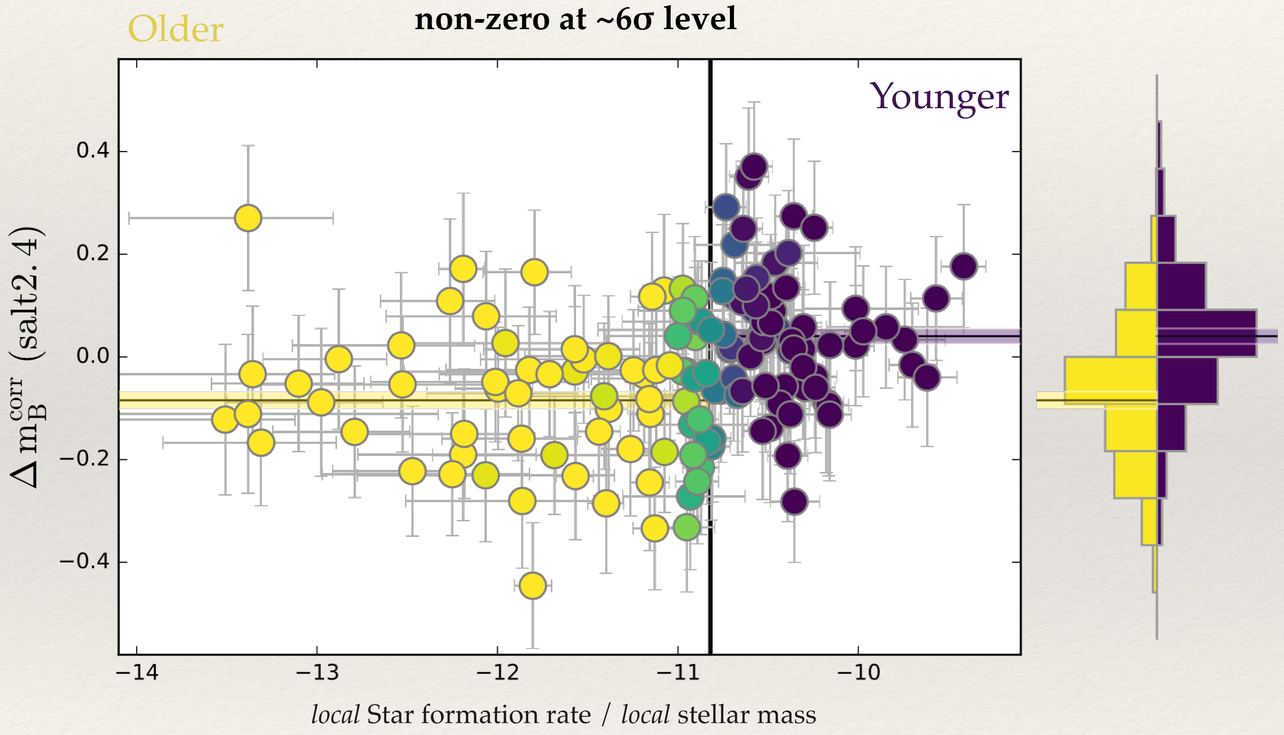


SNeIa Astrophysical dependencies

Low-Z | SNf

Rigault et al. 2020

non-zero at ~6σ level

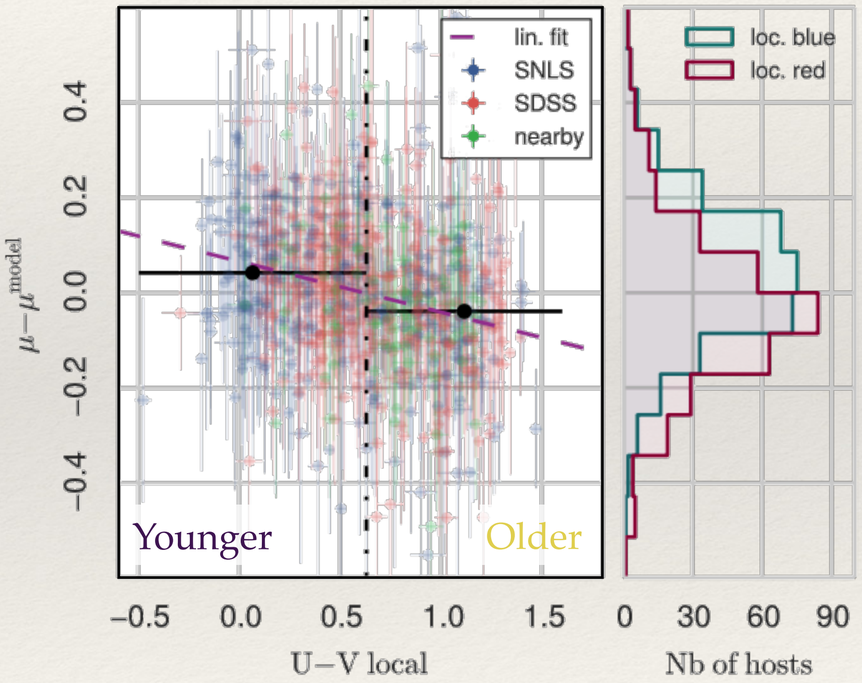


Fraction of young star at the SN location

All Z | SDSS & SNLS & Nearby

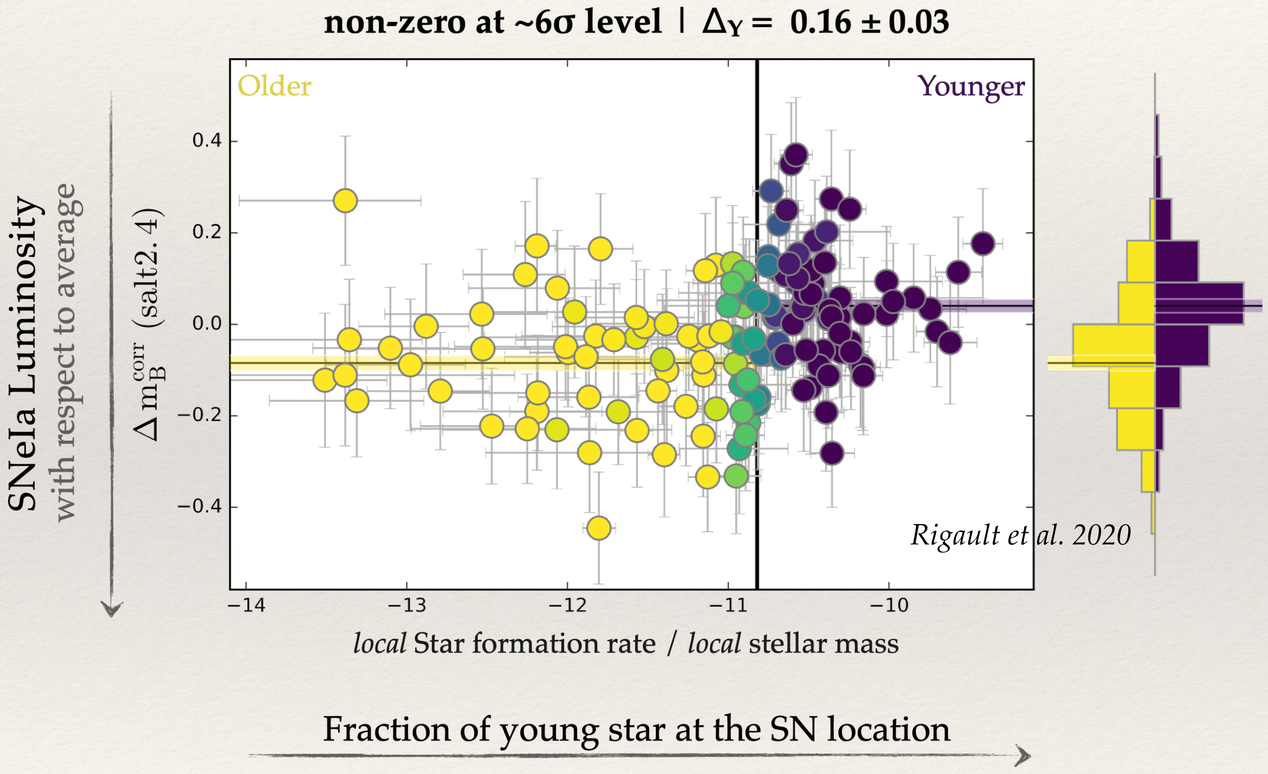
Roman et al. 2018

non-zero at ~7σ level



Fraction of young star at the SN location

The Age Step & H_0



Impact on H0 of difference in SN Population

Magnitude offset between the two SNe Ia populations

$$\log(H_0^{corr}) = \log(H_0) - \frac{1}{5}\Delta f_y \times \Delta_\gamma$$

~0.15mag

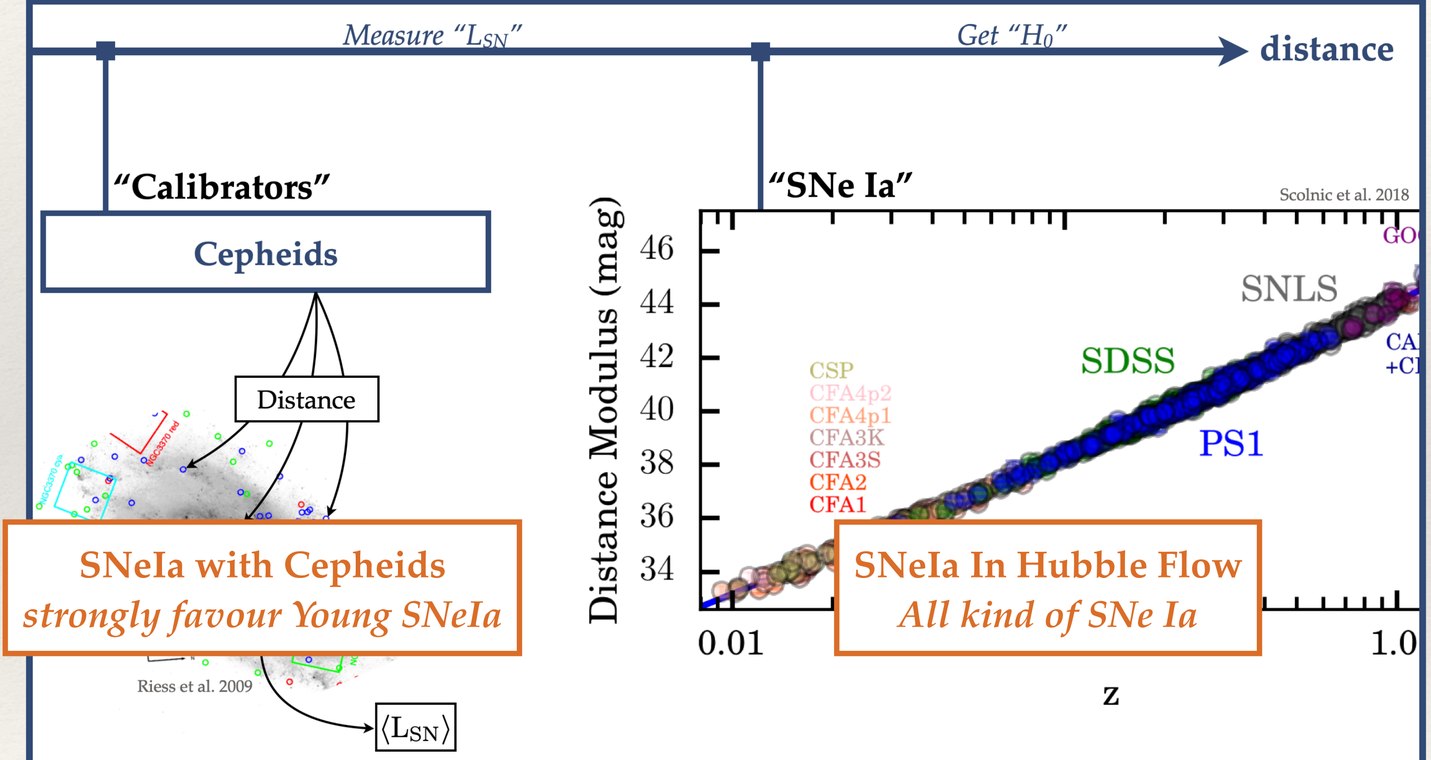
Relative fraction of Young SNeIa between the Cepheid and HubbleFlow samples

Rigault et al. 2015

Astrophysical Bias affecting H_0

Rigault et al. 2015, 2020

Systematics in the SN Distance-Luminosity relation



SNeIa with Cepheids
strongly favour Young SNeIa

SNeIa In Hubble Flow
All kind of SNe Ia

Remark that Riess et al. submitted only selects "Star Forming Hubble Flow hosts" | We will come back to that

Impact on H0 of difference in SN Population

fraction of Young SNeIa — Magnitude offset

$$\log(H_0^{\rm corr}) = \log(H_0) - \frac{1}{5}\Delta f_y \times \Delta_\gamma$$

~50% *~0.15mag*

Up to 3% bias on H_0
would reduce H_0 down to ~71 km/s/Mpc

Astrophysical Bias affecting H_0 | *Amplitude claimed by SH0ES*

Baseline SH0ES analysis: Hubble Flow SNeIa all from Spirals hosts

Riess et al. submitted

Table 5. Fits for H_0

Fit	Variant	χ^2_{dof}	N	H_0	b	γ	M^0_W	M^0_B	a_b
1	**Baseline**	**1.03**	**3445**	**73.04 1.01**	**-3.299 0.015**	**-0.217 0.046**	**-5.894**	**-19.253**	**0.714158**
	Hubble Flow Sample Variants §6.8								
33	all host types $0.0233 < z < 0.15$	1.03	3652	73.32 0.99	-3.298 0.015	-0.216 0.046	-5.891	-19.246	0.714479
34	highz:all host types $0.0233 < z < 0.80$	1.00	4483	73.68 0.98	-3.298 0.015	-0.216 0.045	-5.891	-19.244	0.716225
35	skip local alltypes $0.06 < z < 0.15$	1.04	3318	73.35 1.06	-3.298 0.015	-0.217 0.046	-5.891	-19.245	0.714311
36	highz:skip local alltypes $0.06 < z < 0.8$	1.00	4149	73.90 1.01	-3.298 0.015	-0.217 0.045	-5.891	-19.242	0.716991
37	highmass:hubble flow host logmass> 10	1.04	3304	72.97 1.04	-3.298 0.015	-0.217 0.046	-5.891	-19.251	0.713297

fraction of Young SNeIa — Magnitude offset

$$\log(H_0^{\rm corr}) = \log(H_0) - \frac{1}{5}\Delta f_y \times \Delta_\gamma$$

Rigault et al. 2015

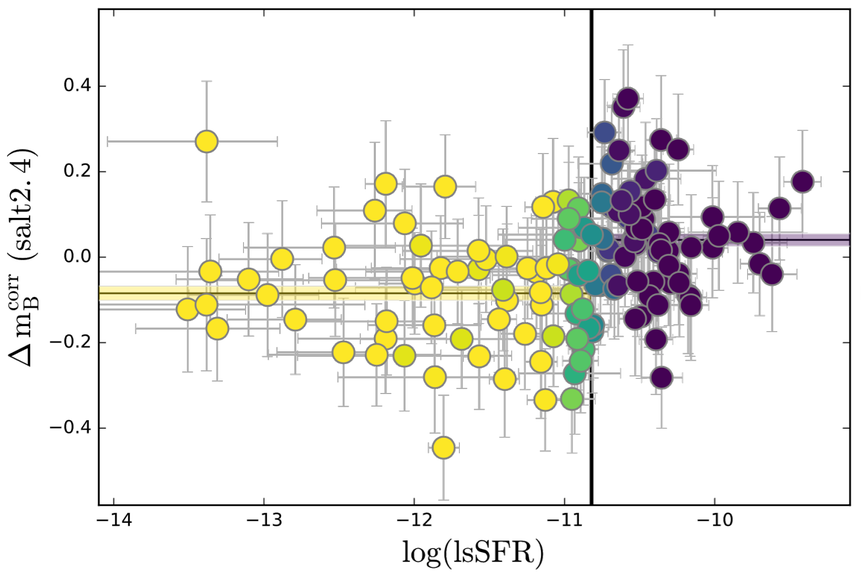
Magnitude difference of SNe Ia excluded.

Table 9: $\Delta f_y = 1 - 276/482 = 43\,\%$

$\rightarrow \Delta_y \approx 0.02\,\mathrm{mag}$

Amplitude of Astrophysical steps | *Many host measurements…*

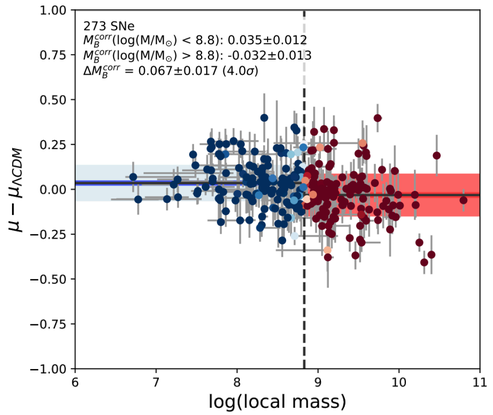
local sSFR | 0.16 ± 0.03 mag



Rigault et al. 2020

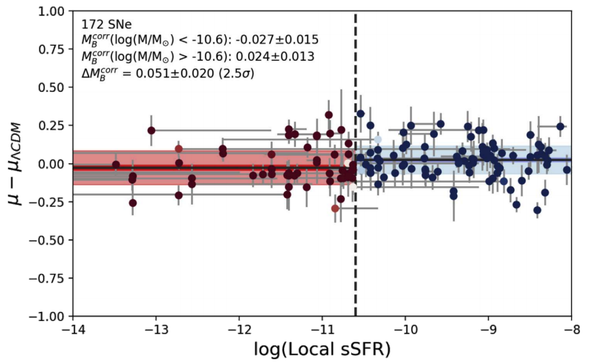
- **Morphology** (Henne et al. 2016, Pruzhinskaya et al. 2020)
- **Combination of tracers** (Riess et al. 2016)
  (No significant step)
- **Global to probe local** (Kim et al. 2018 | 4σ)

local mass | 0.07 ± 0.02 mag



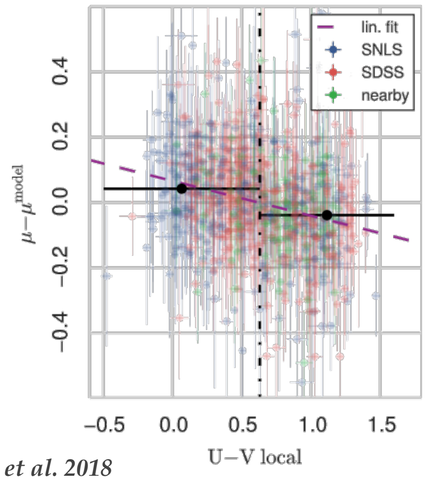
Jones et al. 2018

local photo. sSFR | 0.05 ± 0.02 mag



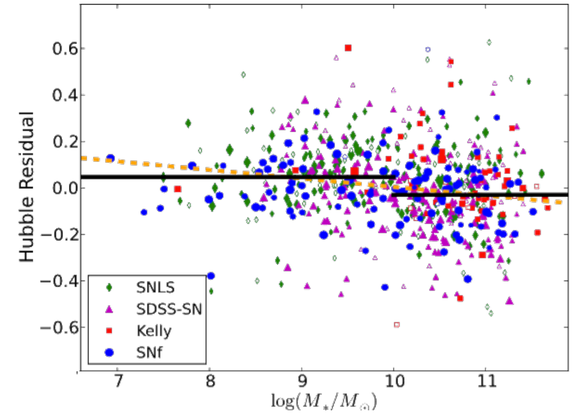
Jones et al. 2018

local U-R | 0.091 ± 0.013 mag



Roman et al. 2018

global mass | 0.08 ± 0.01 mag



Childress et al. 2013

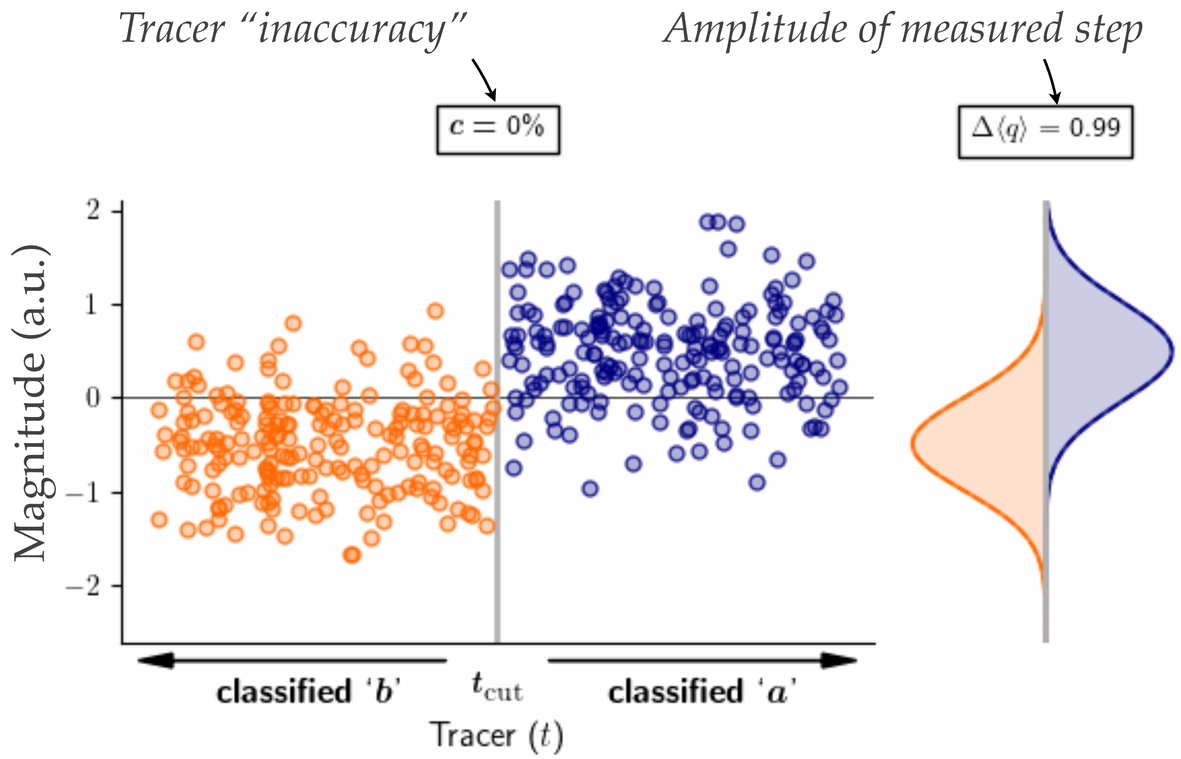
Explaining the various Step | *an accuracy issue*

Briday et al. 2021

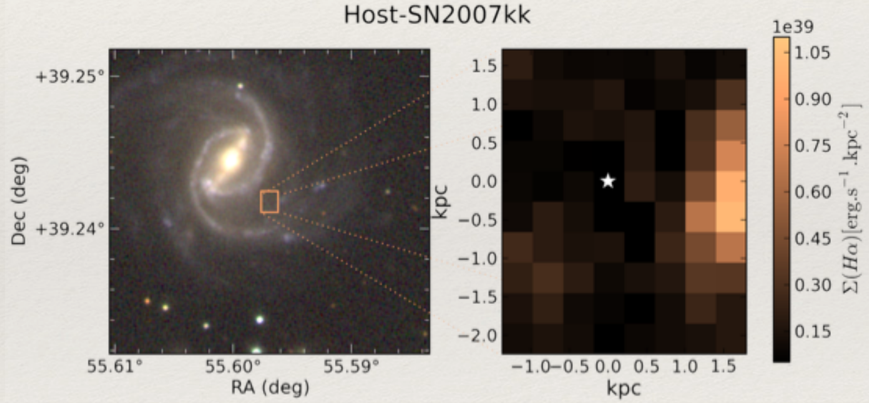
Step means: 2 populations

Step form = best description of data (Childress 2013)

Consequence of mis-classification on the derived step



Example of mis-classification aka "inaccuracy"



« Spiral means Young Progenitor »
— wrong here —

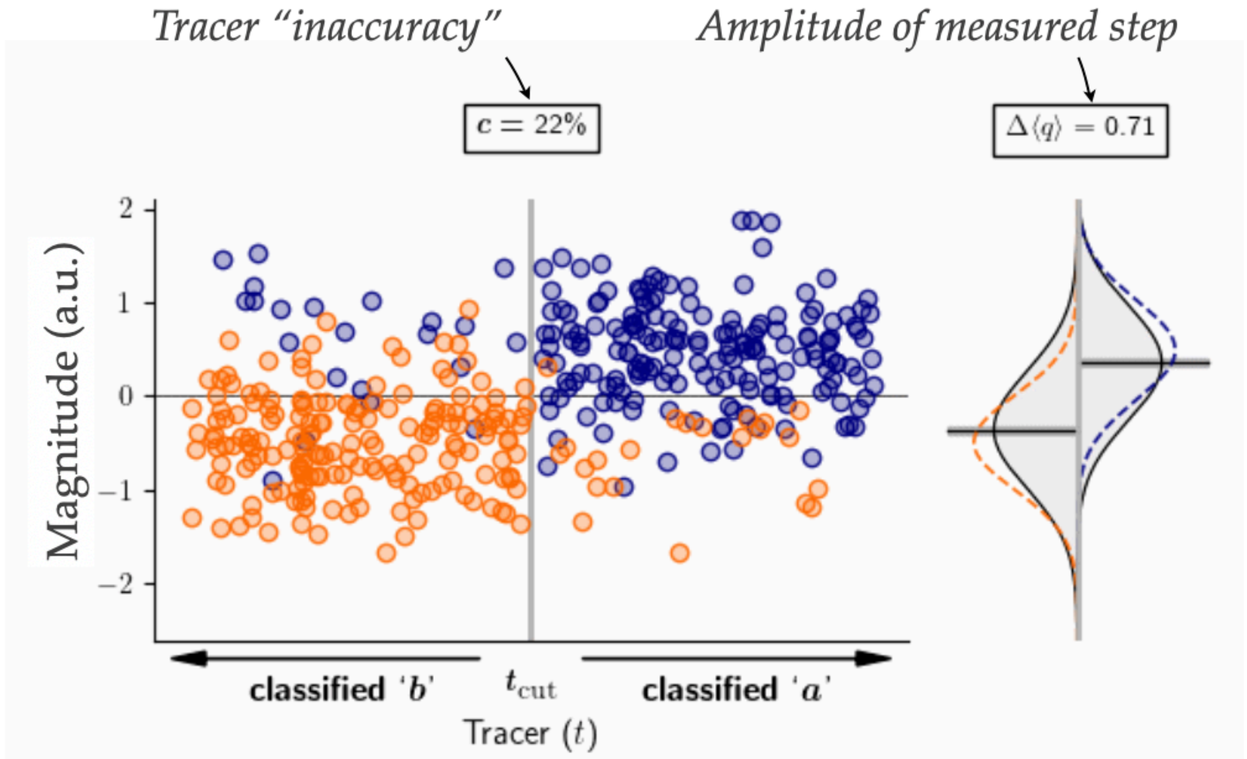
Explaining the various Step | *an accuracy issue*

Briday et al. 2021

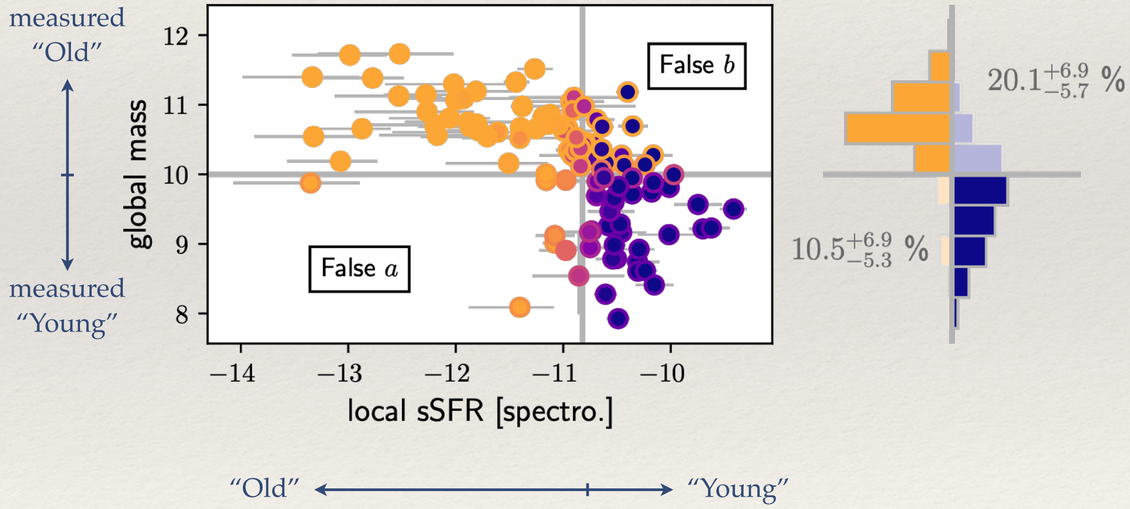
Step means: 2 populations

Step form = best description of data (Childress 2013)

Consequence of mis-classification on the derived step



Estimating the "fraction of contamination"

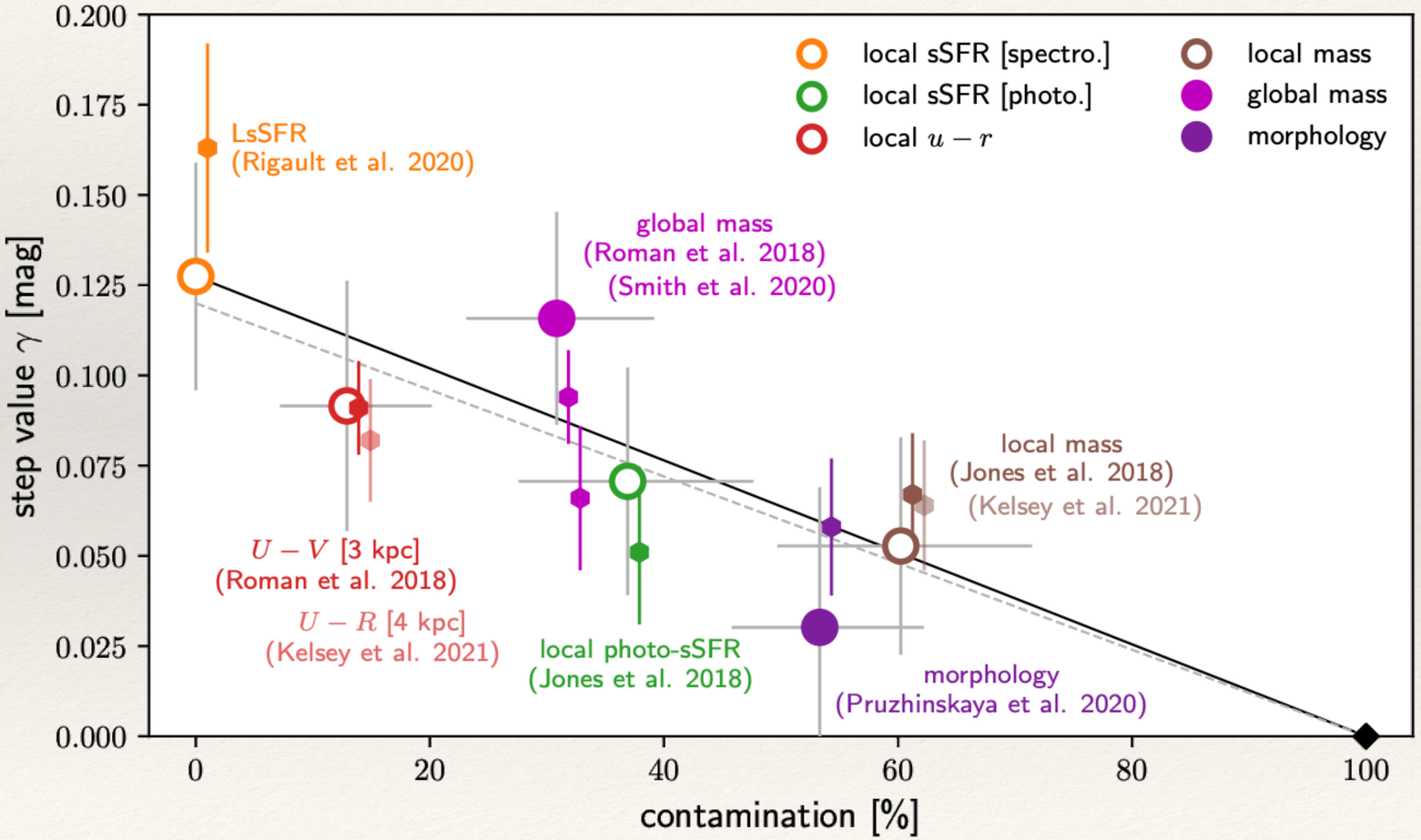


Explaining the Step discrepancies | *an accuracy issue*

Briday et al. 2021

Accounting for astrophysical tracer accuracy, it all makes sense !

All Literature are consistant with a ~0.13 ± 0.02 mag bias driven by the progenitor age



Explaining the Step discrepancies | *an accuracy issue*

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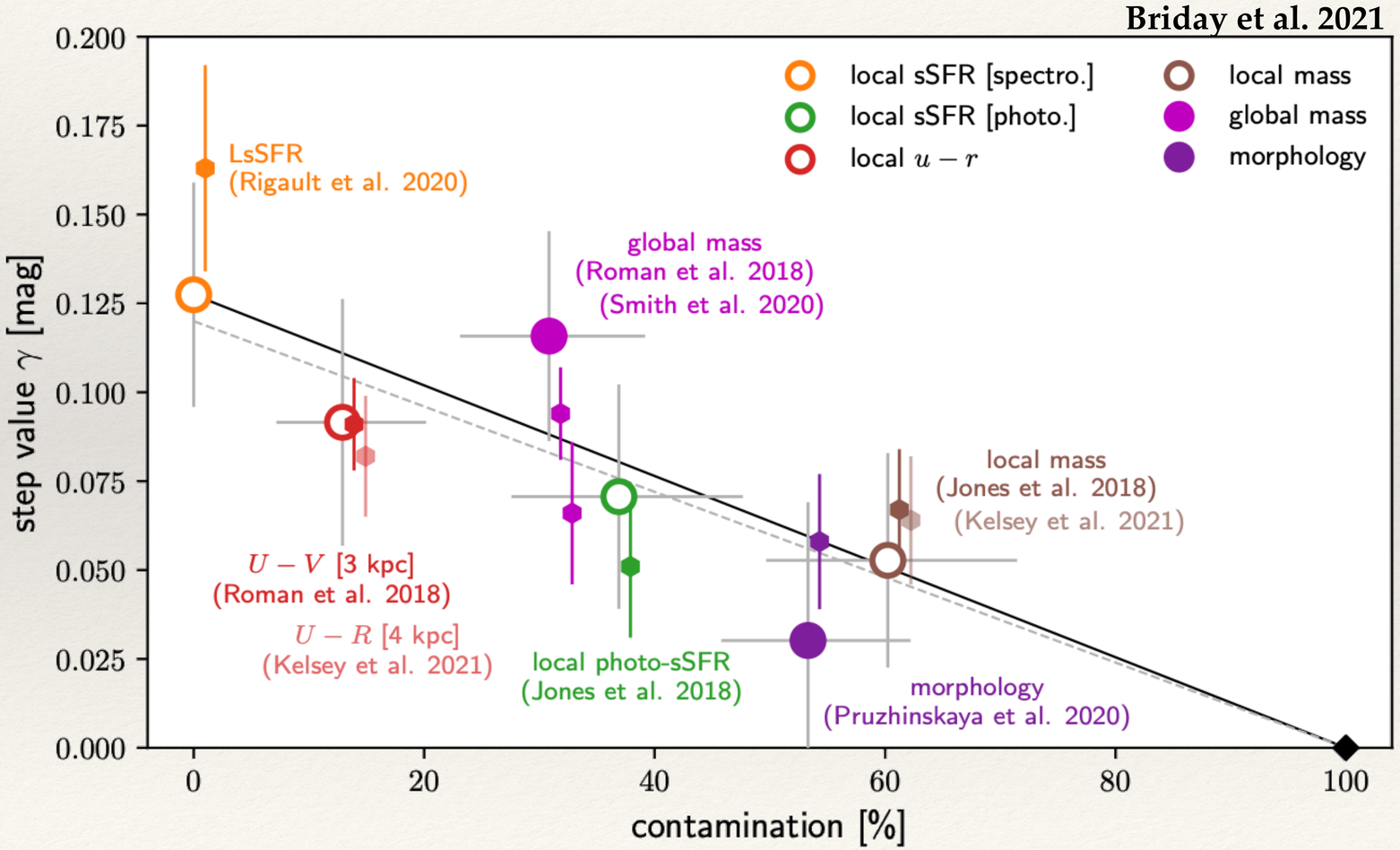
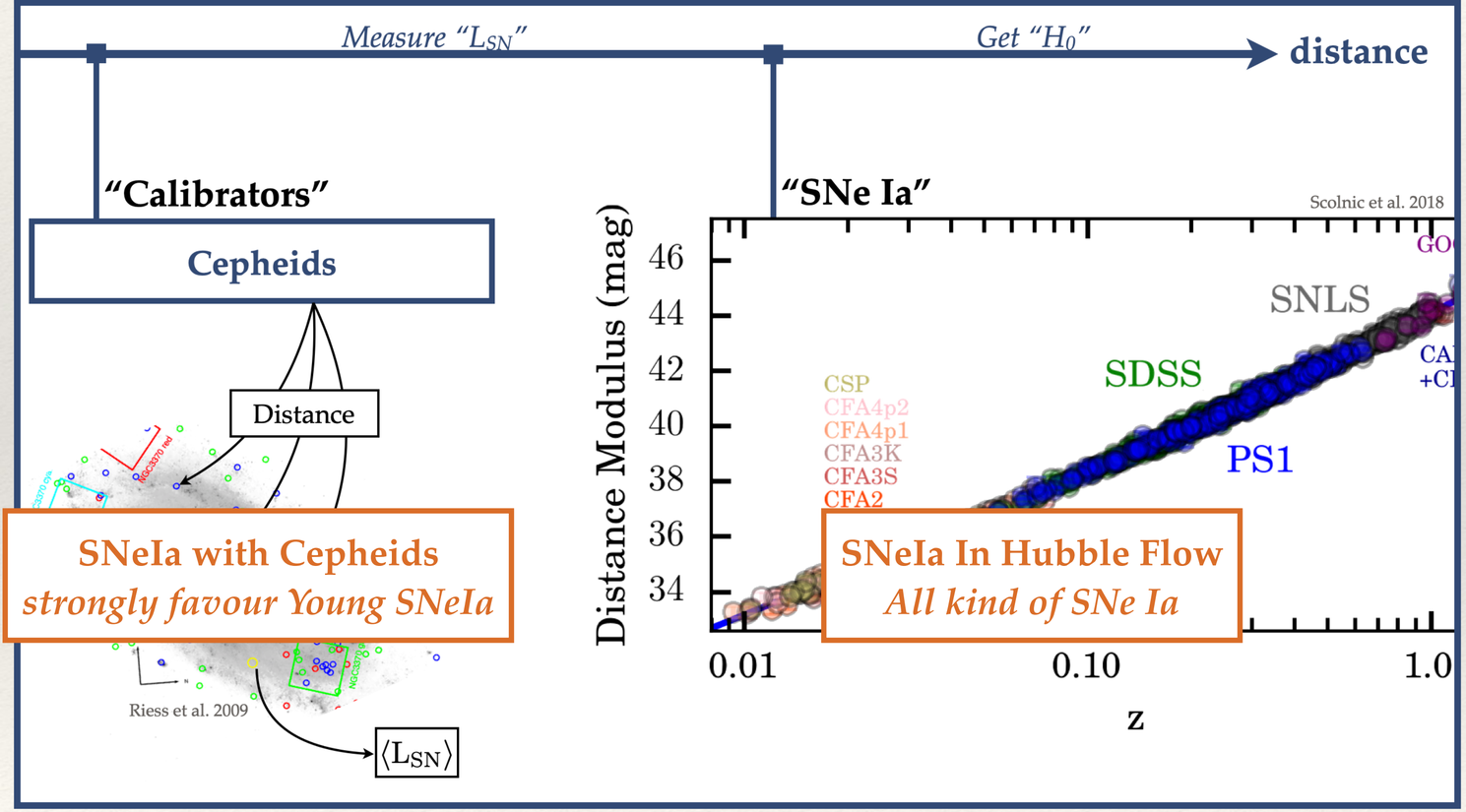


Astrophysical Bias affecting H_0

Rigault et al. 2015, 2020

Systematics in the SN Distance-Luminosity relation



Magnitude difference of SNe Ia excluded.

Table 9: $\Delta f_y = 1 - 276/482 = 43\,\%$

SH0ES observed bias $\Delta_y \approx 0.02$ mag

because of inaccurate tracer

Expected True Astrophysical bias

$\Delta_y \approx 0.13$ mag

Given Briday et al. 2021

Expected Corrected H_0

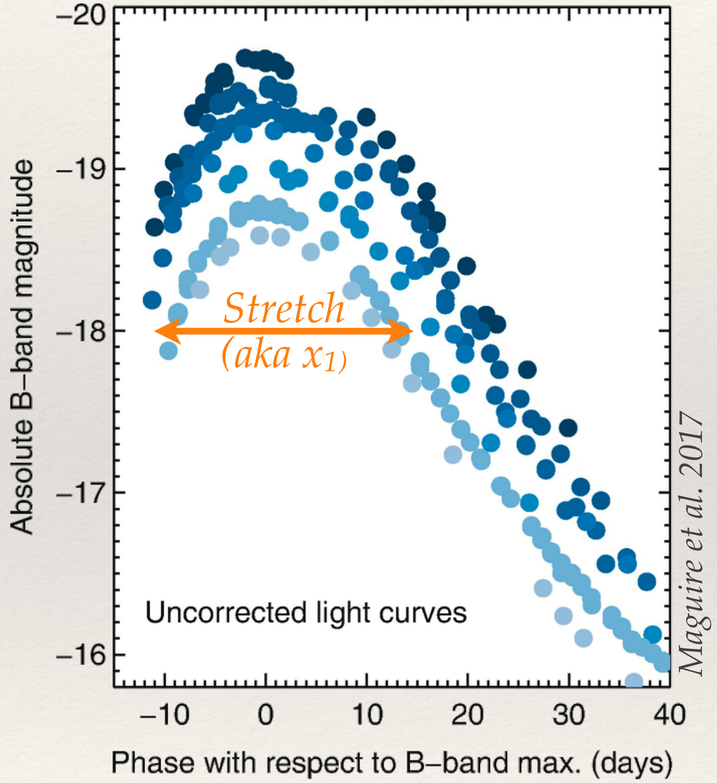
$H_0 \approx 71.3\,\mathrm{km\ s^{-1}\ Mpc^{-1}}$

correcting 73.3 in Riess et al. submitted

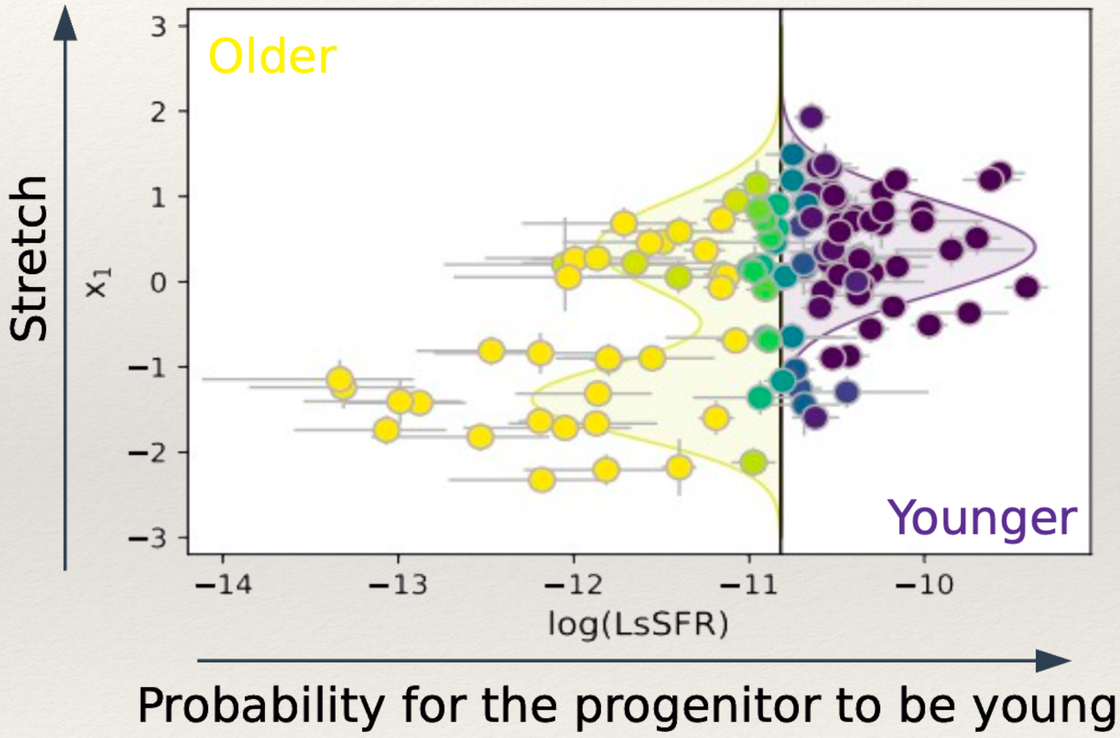
Rigault et al. in prep | very preliminary

Testing the SN Age “two populations model”

Stretch (x_1): Type Ia Supernova Lightcurves “evolution rate”



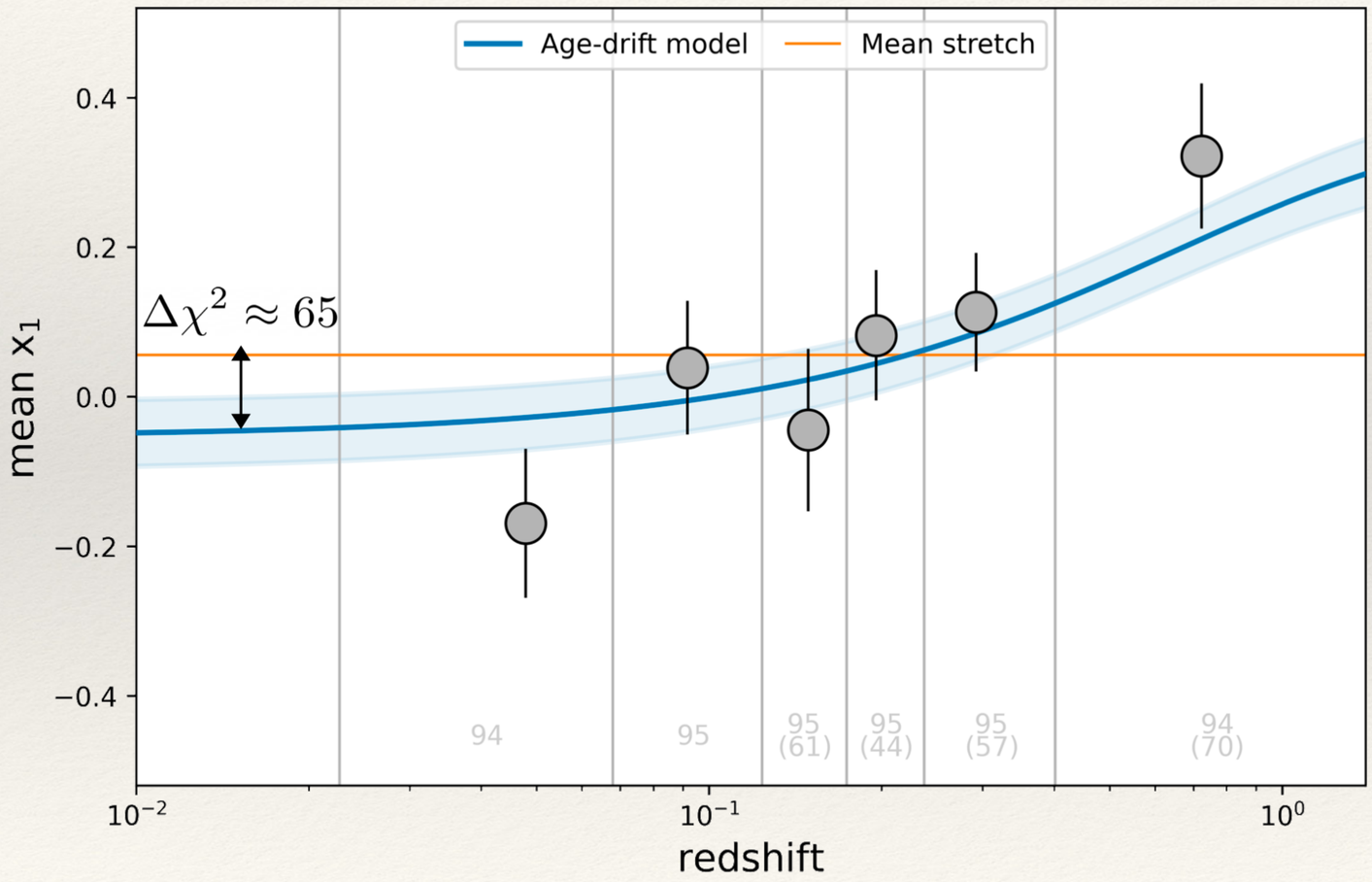
Nicolas et al. 2021



Type Ia Supernovae Properties Evolve with redshift !

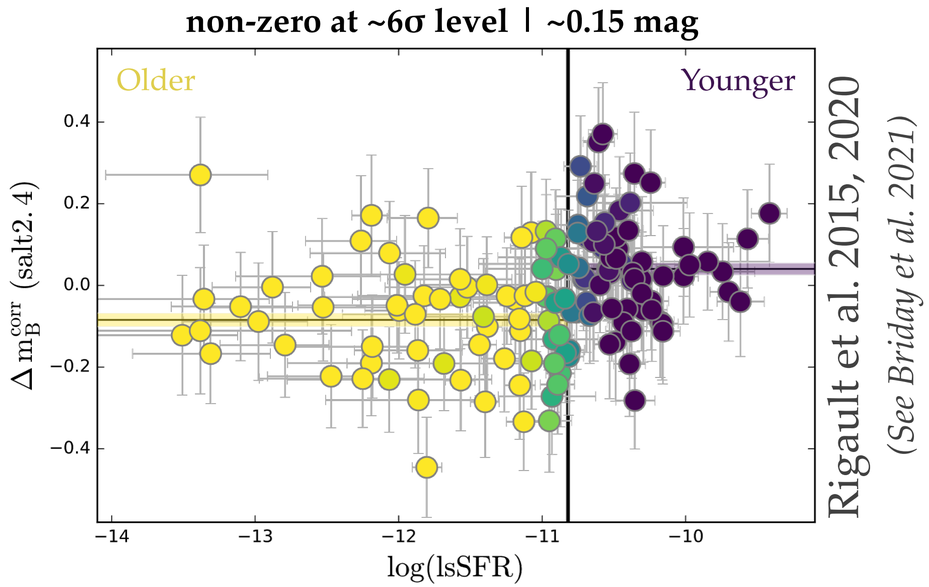
Age the SN-progenitor age model is in perfect agreement with the Data !

Nicolas et al. 2021



H_0 Tension | *Systematics*

Astrophysical bias with Sample Selection



"Cepheid host galaxies are highly star forming"

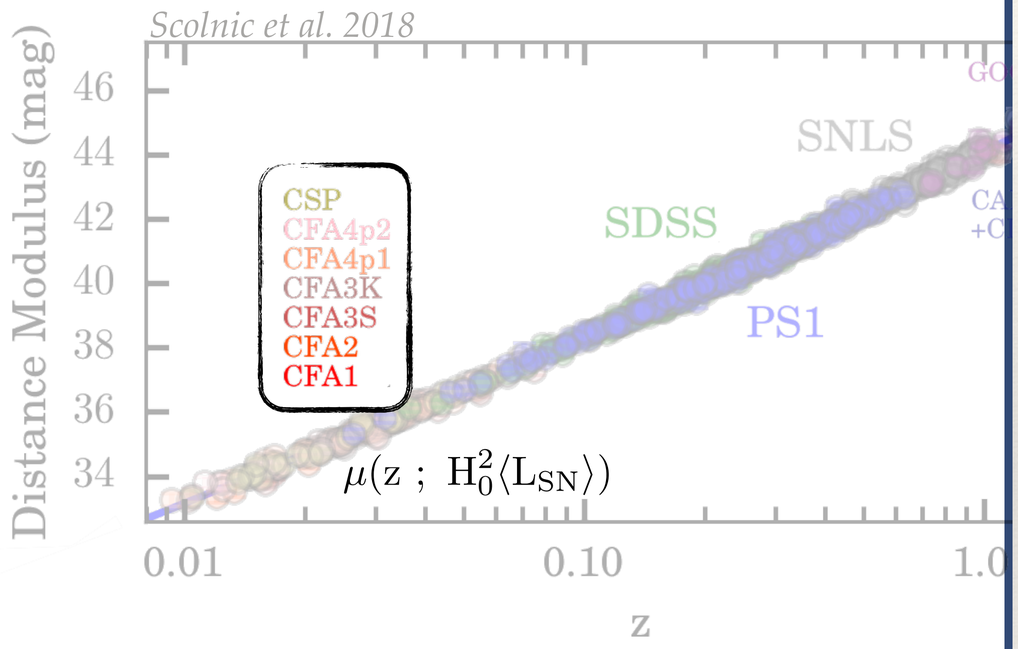
~95% "Young" in Calibrator SN sample

vs

~50% "Young" in Hubble Flow SN sample

→ H_0 would be overestimated by 3% (~71)

Calibration Issues *(Sample construction)*



"H_0 relies on a sample made of 8 photometric systems"

with limited overlap between the calibrator and the Hubble flow samples

Systematic effect hard to estimated *(unknown unknown)*

Zwicky Transient Facility (ZTF)

3 filtres (g, r, i)

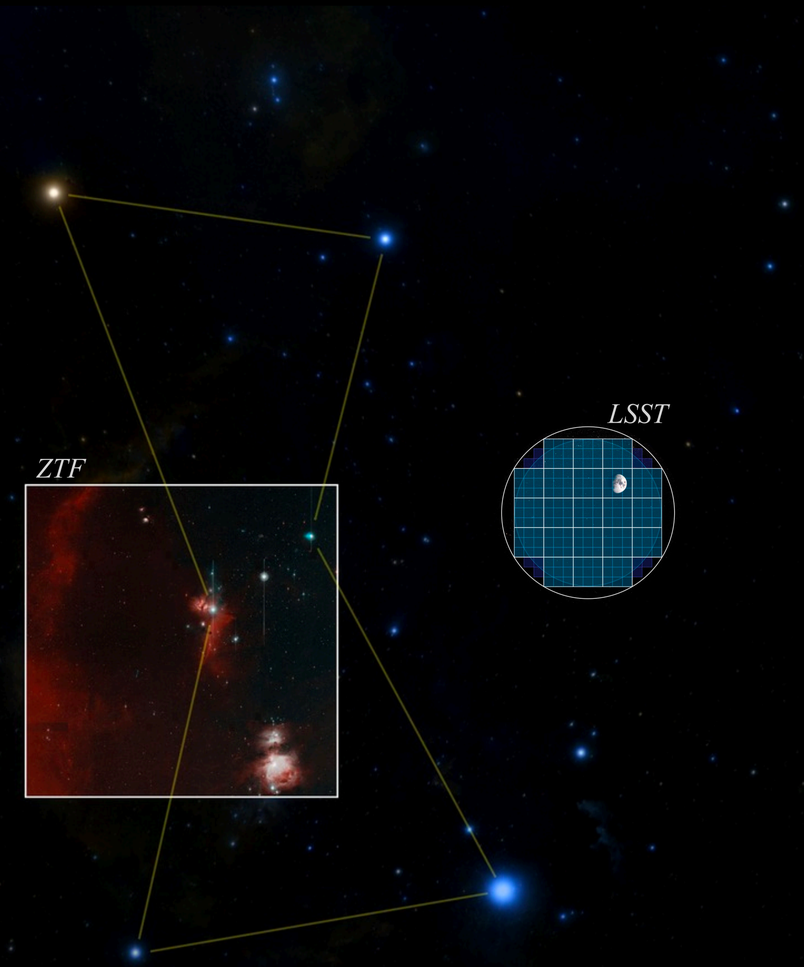
FoV **47** deg^2

surveys **3750** deg^2/h

20.5 mag 5 σ depth

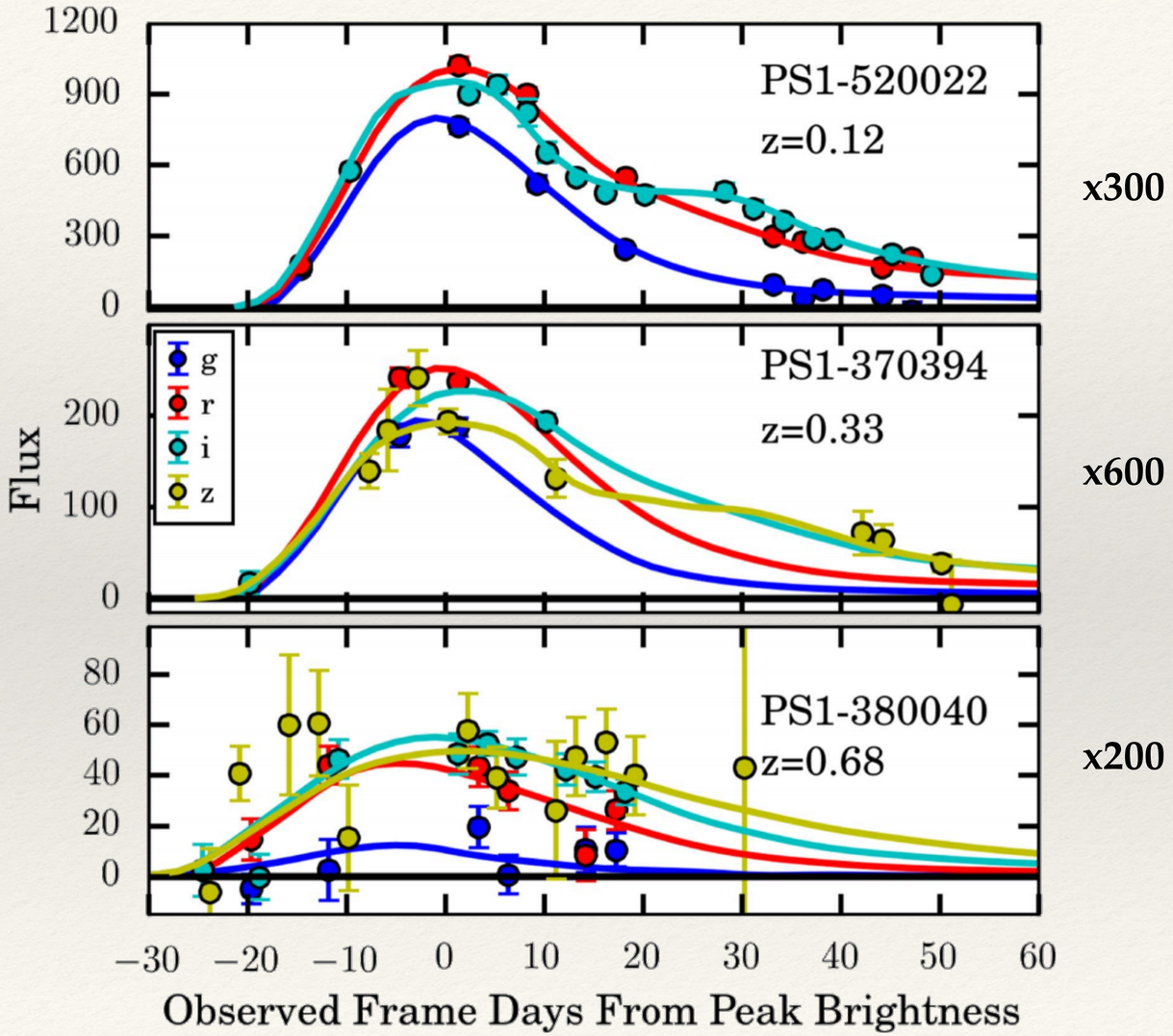
1 arcsec/pixel

dedicated spectroscopy

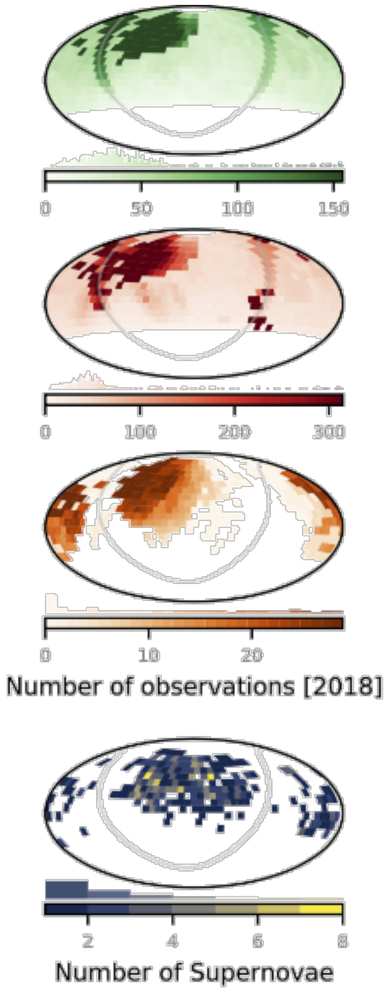


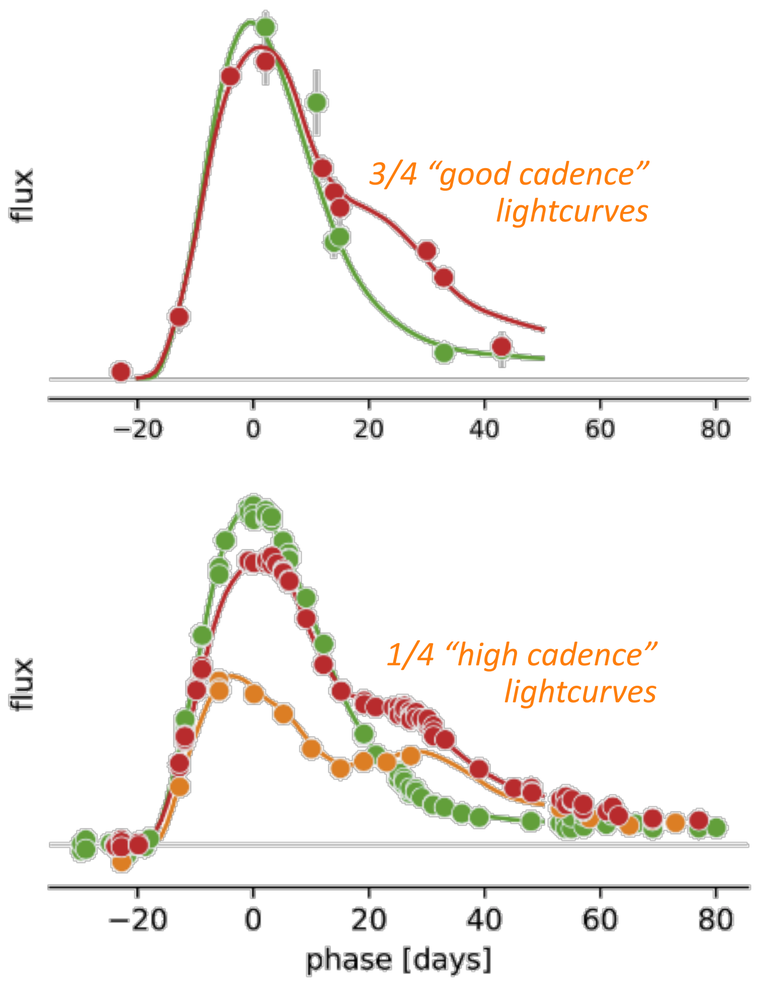
Funding
ZTF 1: 40% NSF • 20% CalTech • 40% Partners
ZTF 2: 50% NSF • 20% CalTech • 30% Partners

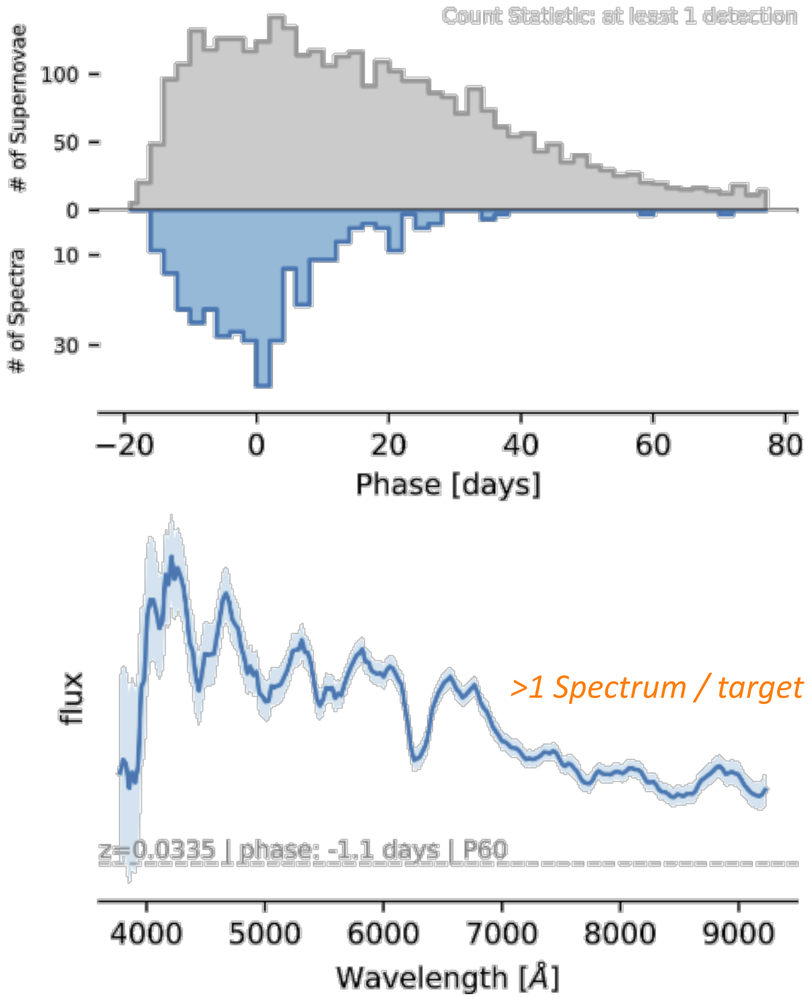
Typical Type Ia Supernova data | *pre-ZTF*



ZTF | Type Ia Supernova data

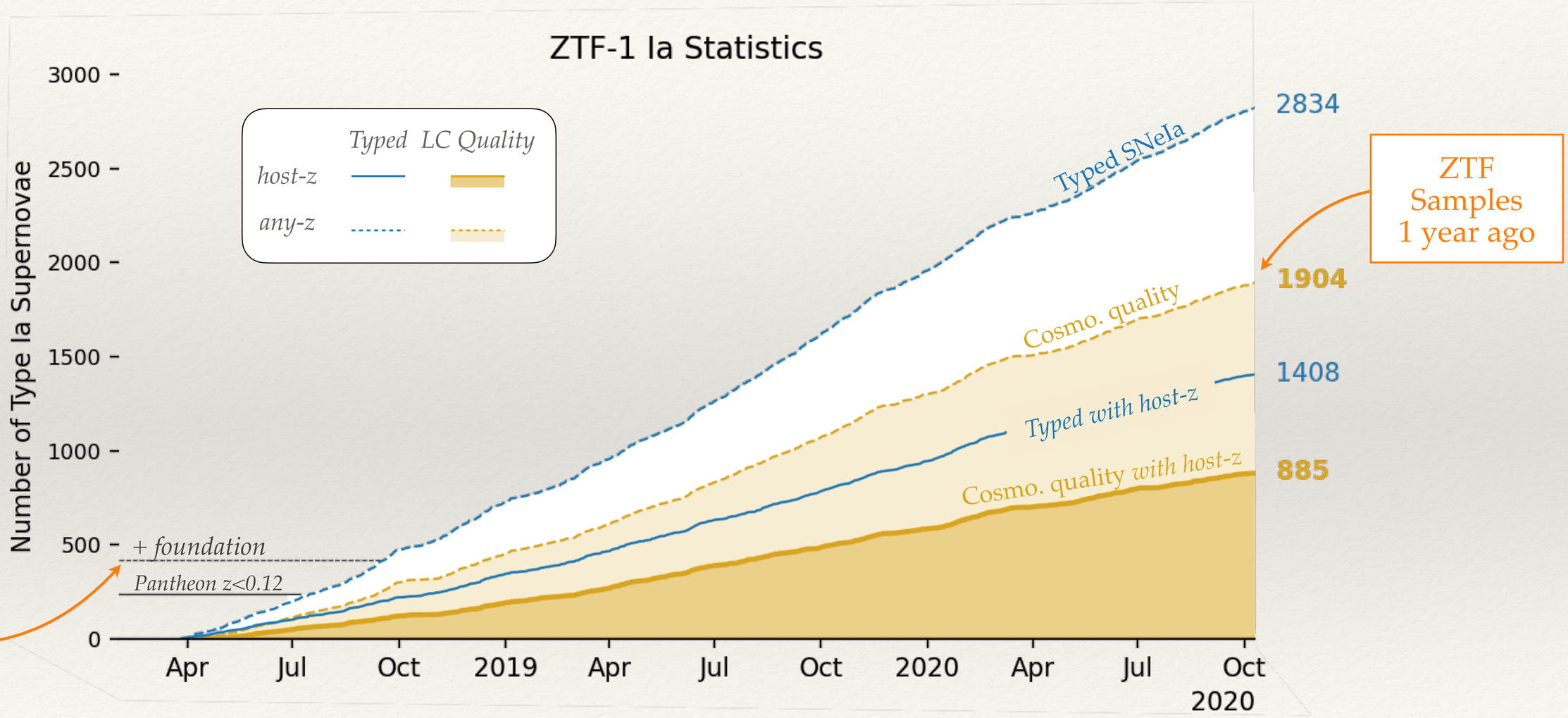






Dhawan et al. 2021

ZTF Sample | *A Revolution*



Current Samples

ZTF Samples 1 year ago

Rigault et al. *in prep*

ZTF Sample | *Toward a self-consistant H_0*

Measure "L_{SN}" → *Get "H_0"* → **distance**

Calibrator Sample

Volume limited ZTF-SNeIa < 50 Mpc

Technique
TRGB (doable in any galaxy)

Statistics: ~5 per year (~30 by end of ZTF)

Hubble Flow Sample

Volume limited ZTF-SNeIa z<0.06 Mpc

ZTF detect, follows and classifies *all* SNe Ia in the Northern sky up to z~0.06

Statistics: Already 500 acquired

No selection function since both volume limited samples

Unique photometric system, no absolute photometric calibration issue
only relative, which is way easier

ZTF Sample | *Toward a self-consistant H_0*

Measure "L_{SN}" — *Get "H_0"* — **distance**

Calibrator Sample

Volume limited ZTF-SNeIa < 50 Mpc

Technique
TRGB (doable in any galaxy)

Statistics: ~5 per year (~30 by end of ZTF)

Hubble Flow Sample

Volume limited ZTF-SNeIa z<0.06 Mpc

ZTF detect, follows and classifies *all* SNe Ia in the Northern sky up to z~0.06

Statistics: Already 500 acquired

No selection function since both volume limited samples

Unique photometric system, no absolute photometric calibration issue
only relative, which is way easier

H_0 Tension | *SH0ES vs. Planck*

Riess et al. submitted