Status on H_0

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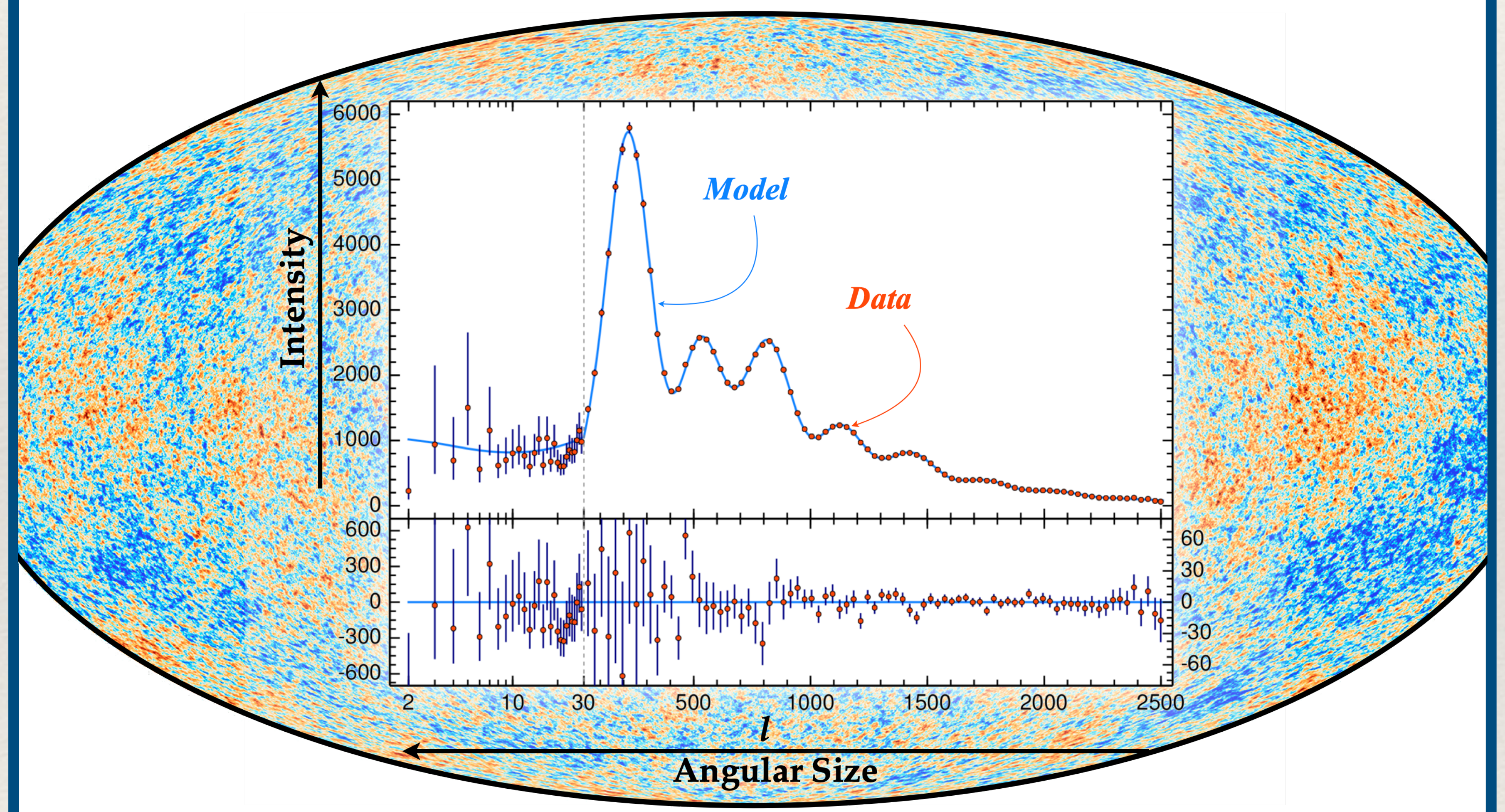
This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n°759194 - USNAC)

Context | ΛCDM Works

Only 6 free parameters

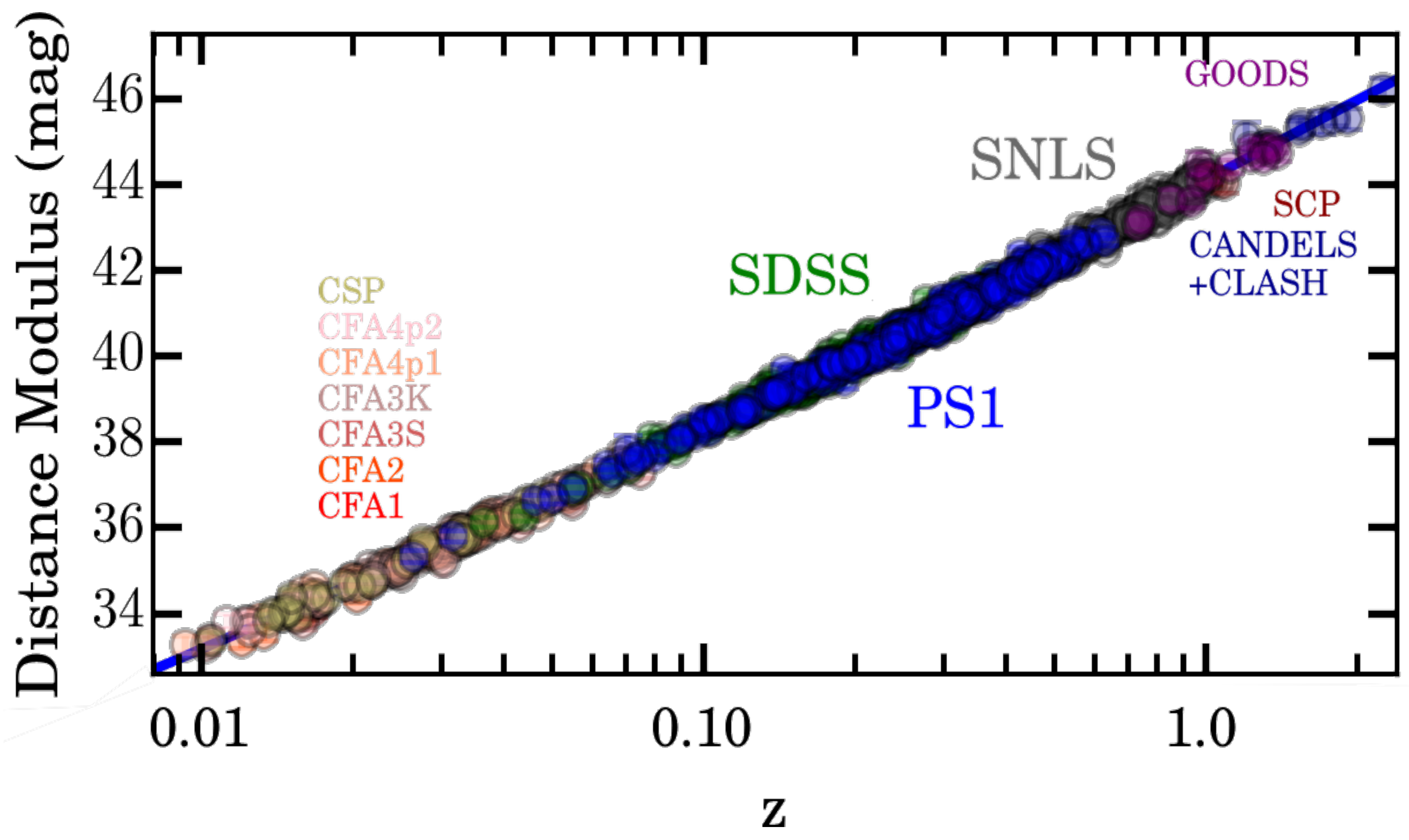
Cosmic MicroWave Data



z~1100

Planck 2020

Type Ia Supernovae



z<1

Scolnic 2018

Baryon Acoustic Oscillation

Clusters

Weak Lensing

Baryon Nucleosynthesis

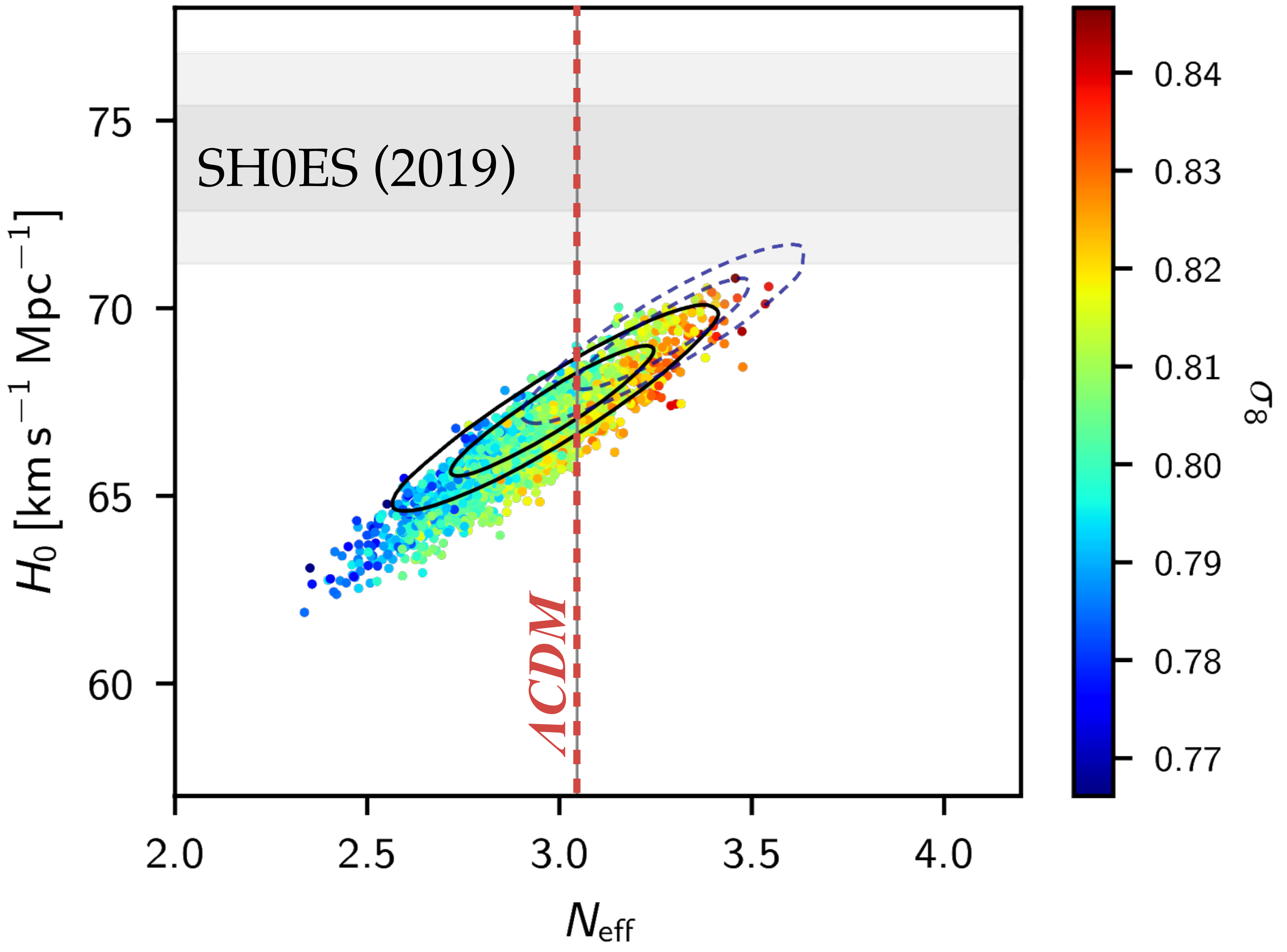
…

Context | ΛCDM Works, except when it doesn't !

Only 6 free parameters | *but "Λ" and "CDM"*

H_0 Tension | 5 σ

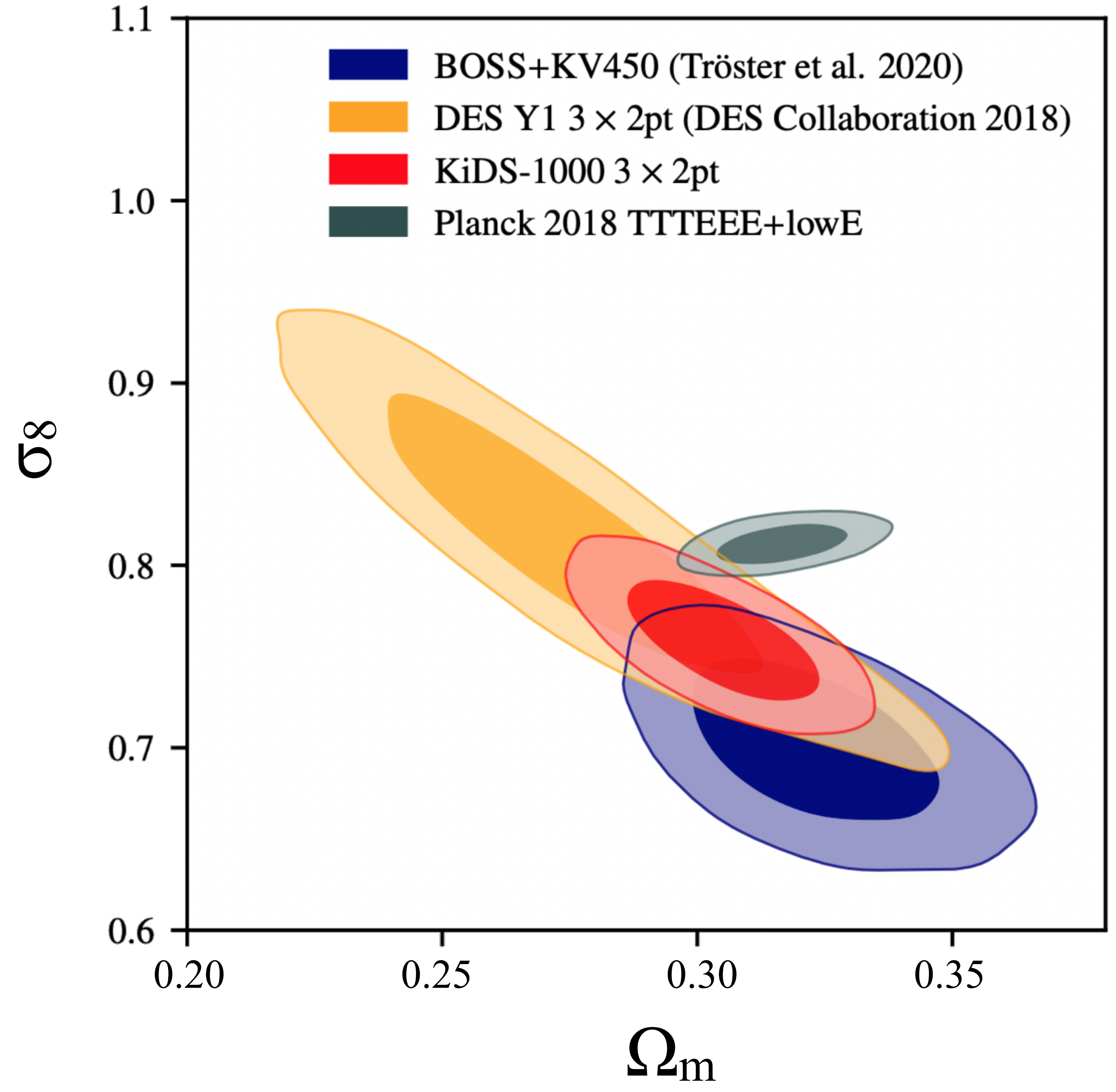
Universe's expansion is too fast



Planck 2020

σ_8 Tension | 2.5 σ

Structures are too small



Heymans et al. 2020

Two approaches | Hubble-Lemaître Constant

Direct Method

$$H_0 \sim d_l / v_h$$

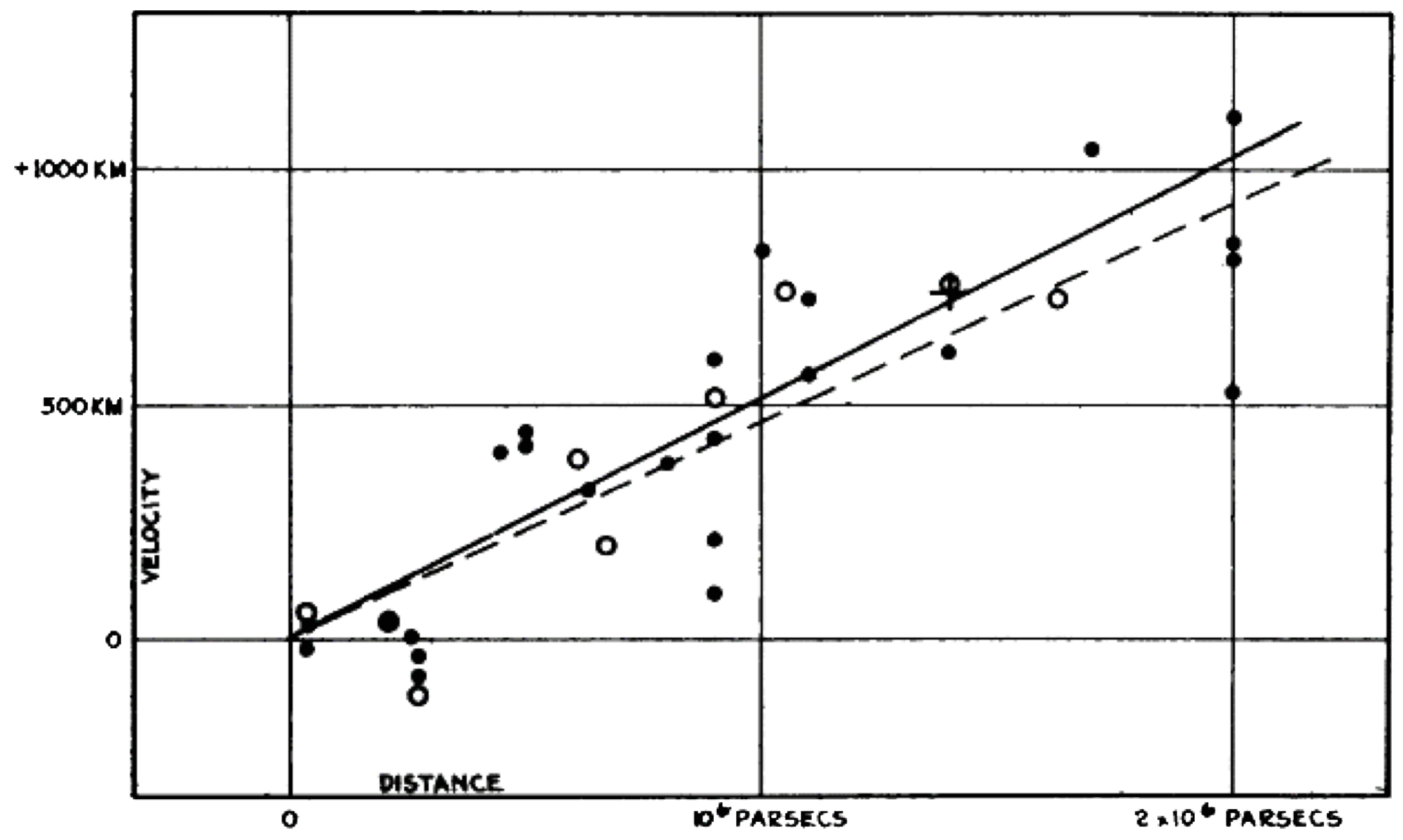
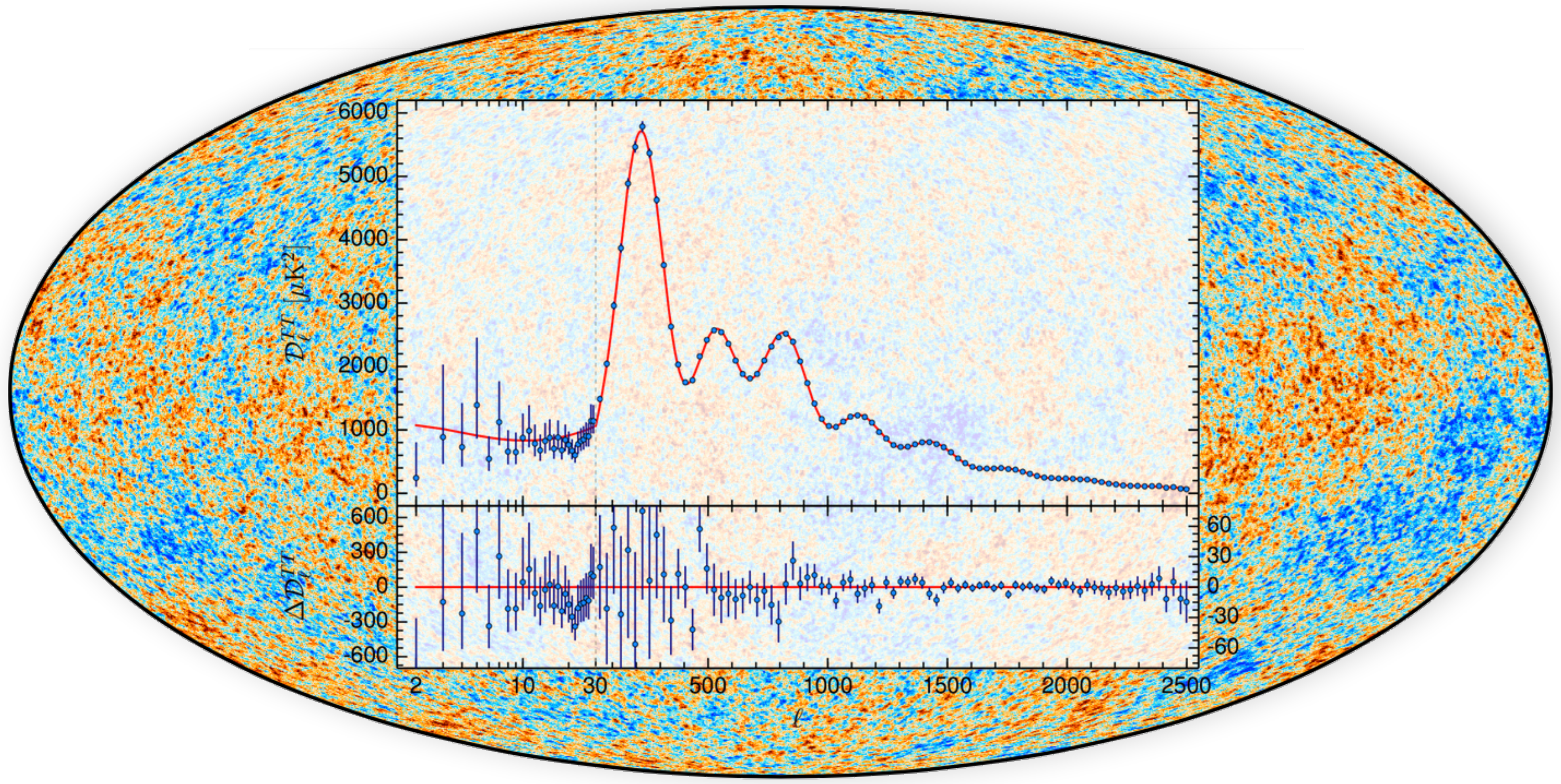


FIGURE 1

Redshifts & Distances

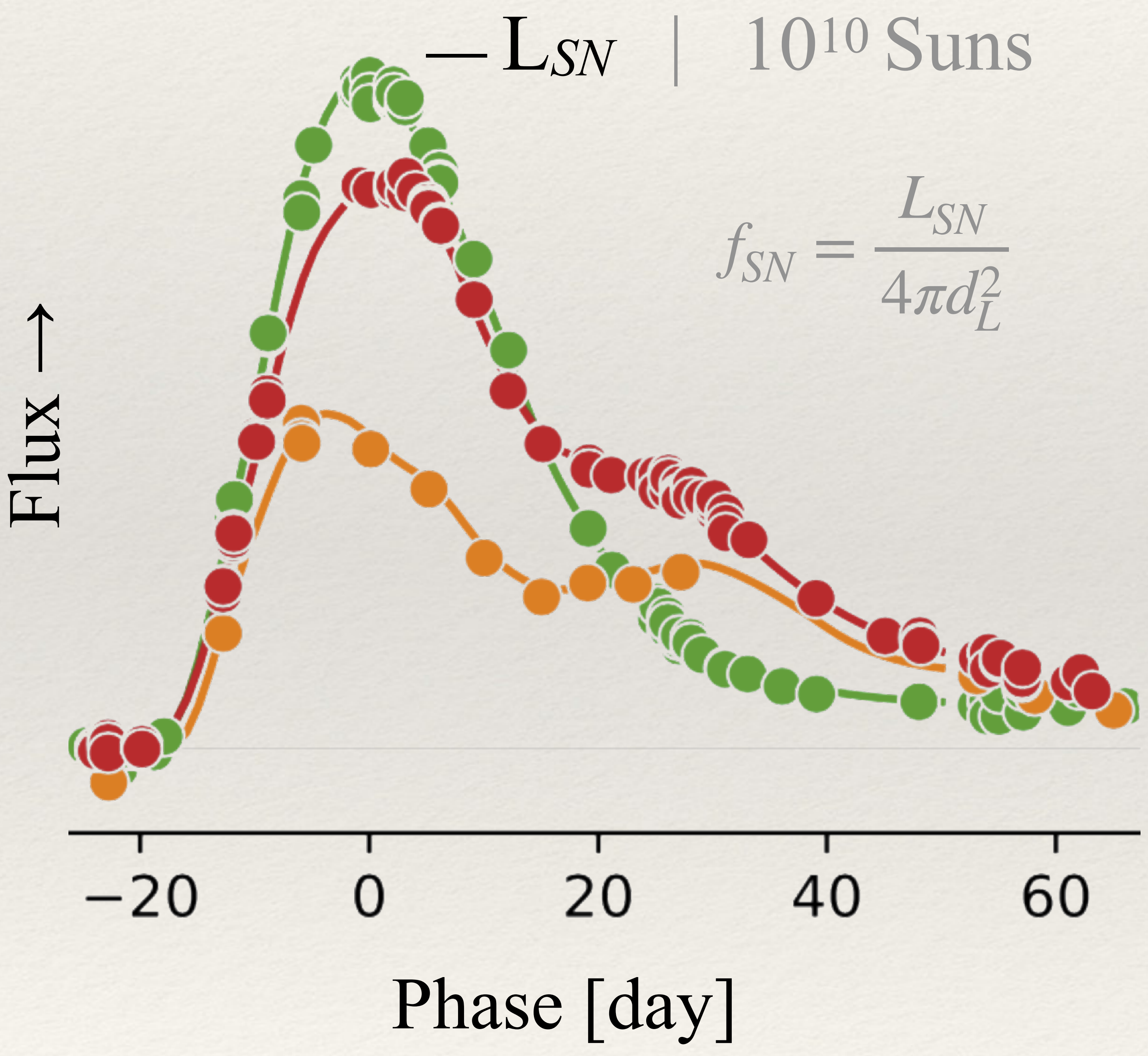
Indirect Method

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

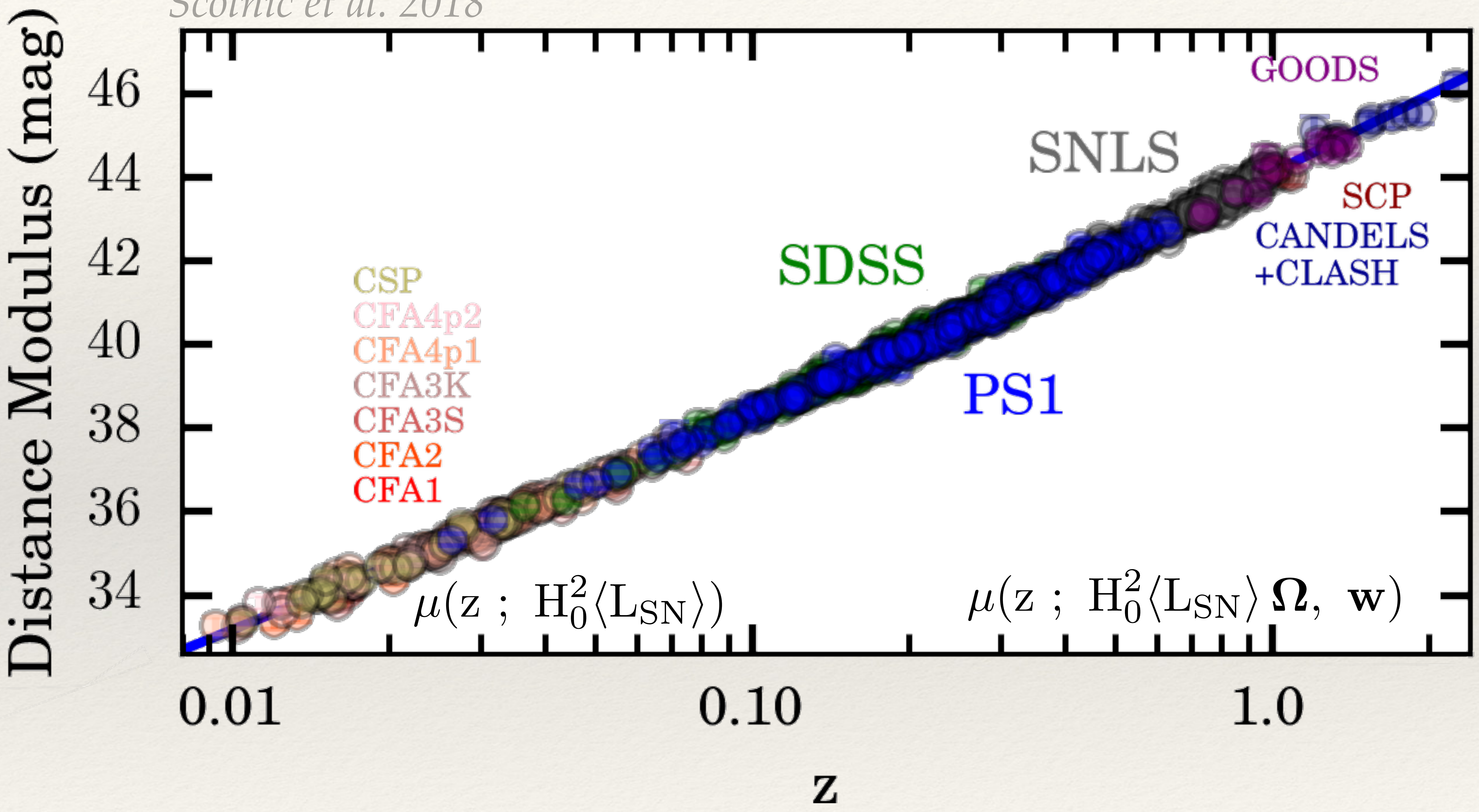


Model & High redshift anchoring

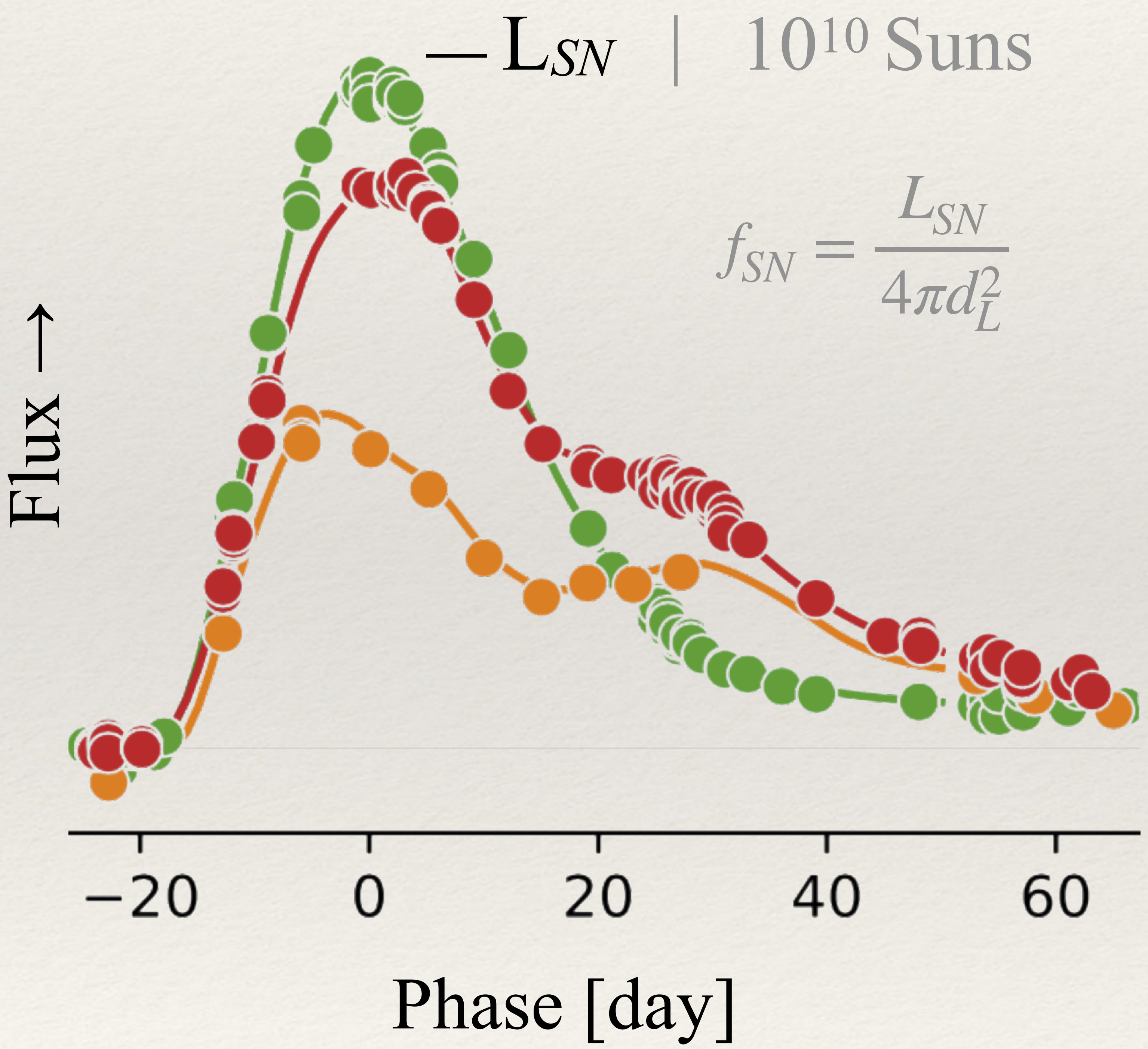
Type Ia Supernova Cosmology

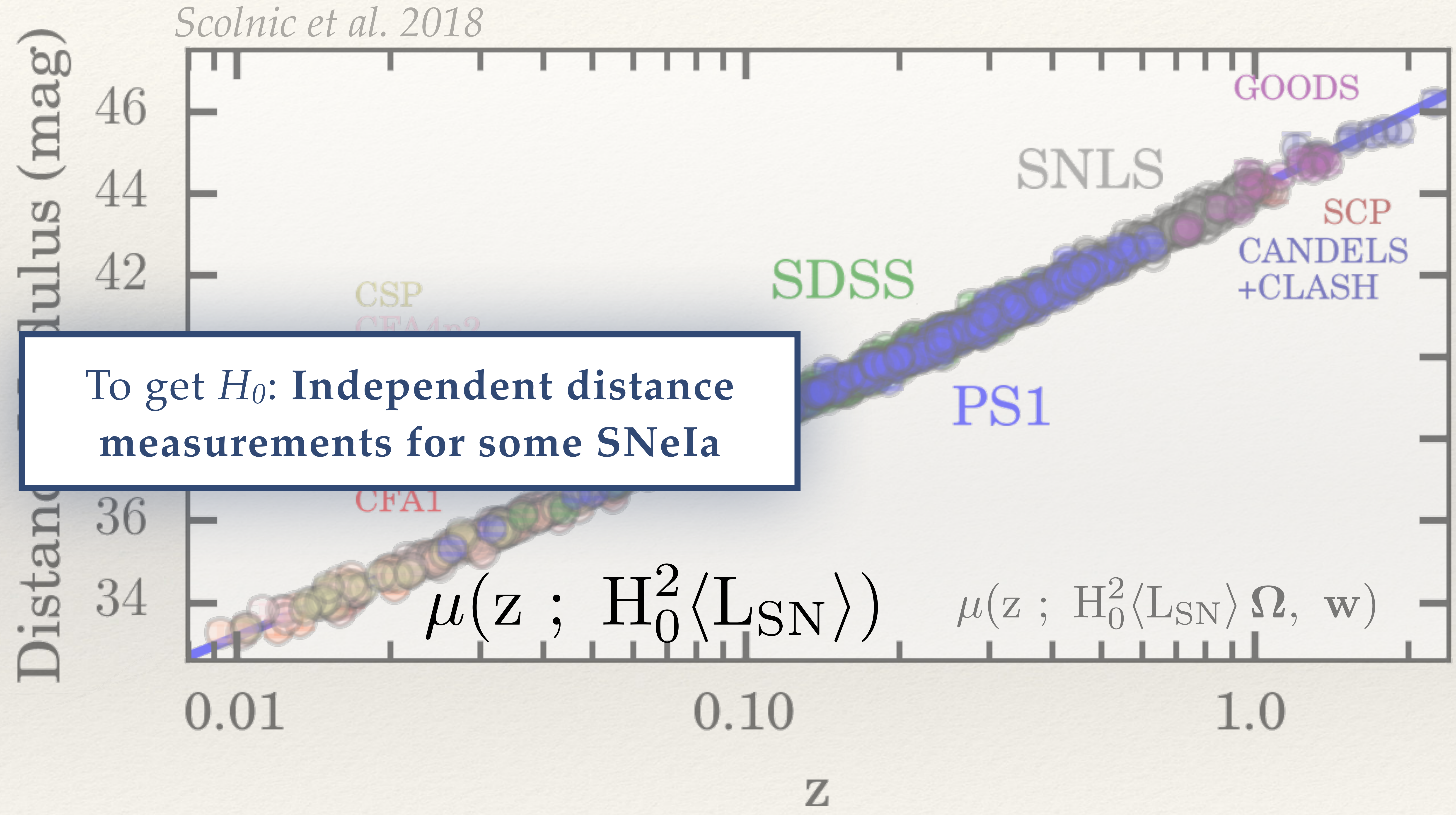


Scolnic et al. 2018



Type Ia Supernova Cosmology





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

Direct Distance Ladder | *SH_0ES*

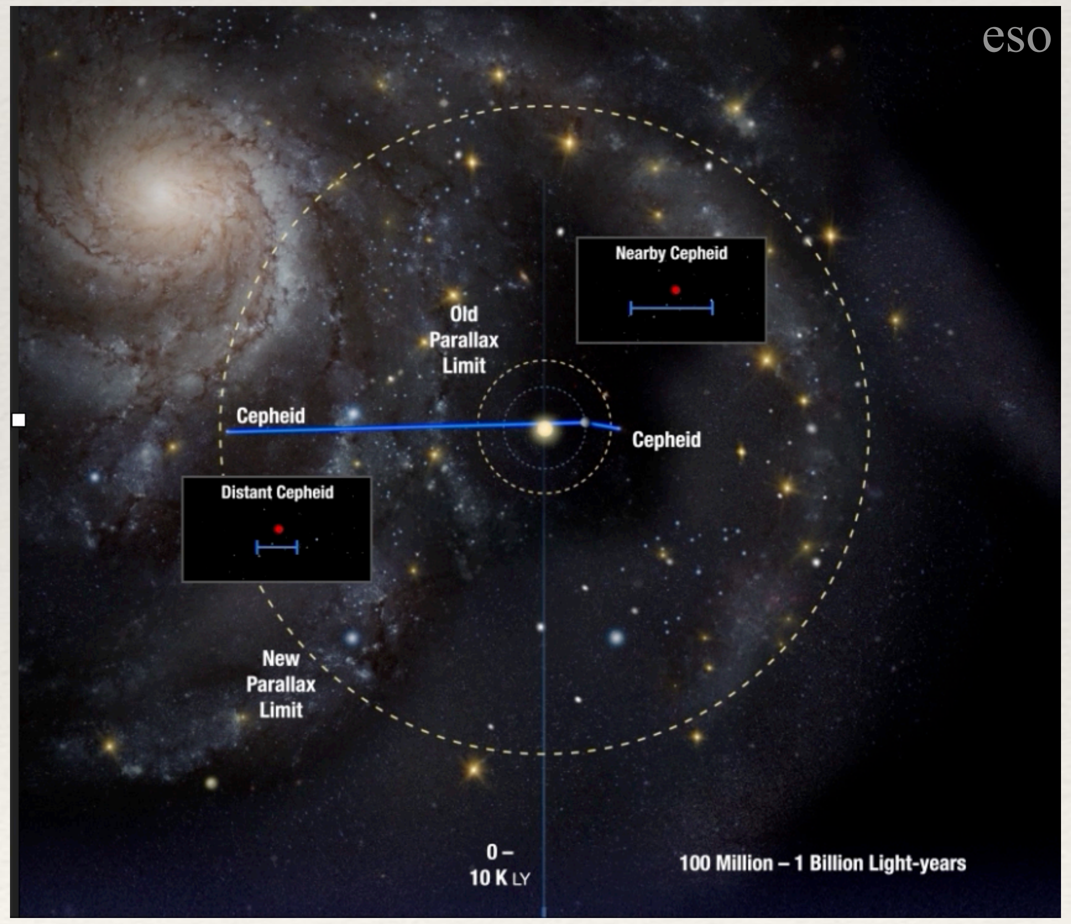
Riess et al. 2022

Get independent distances for SNe Ia

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

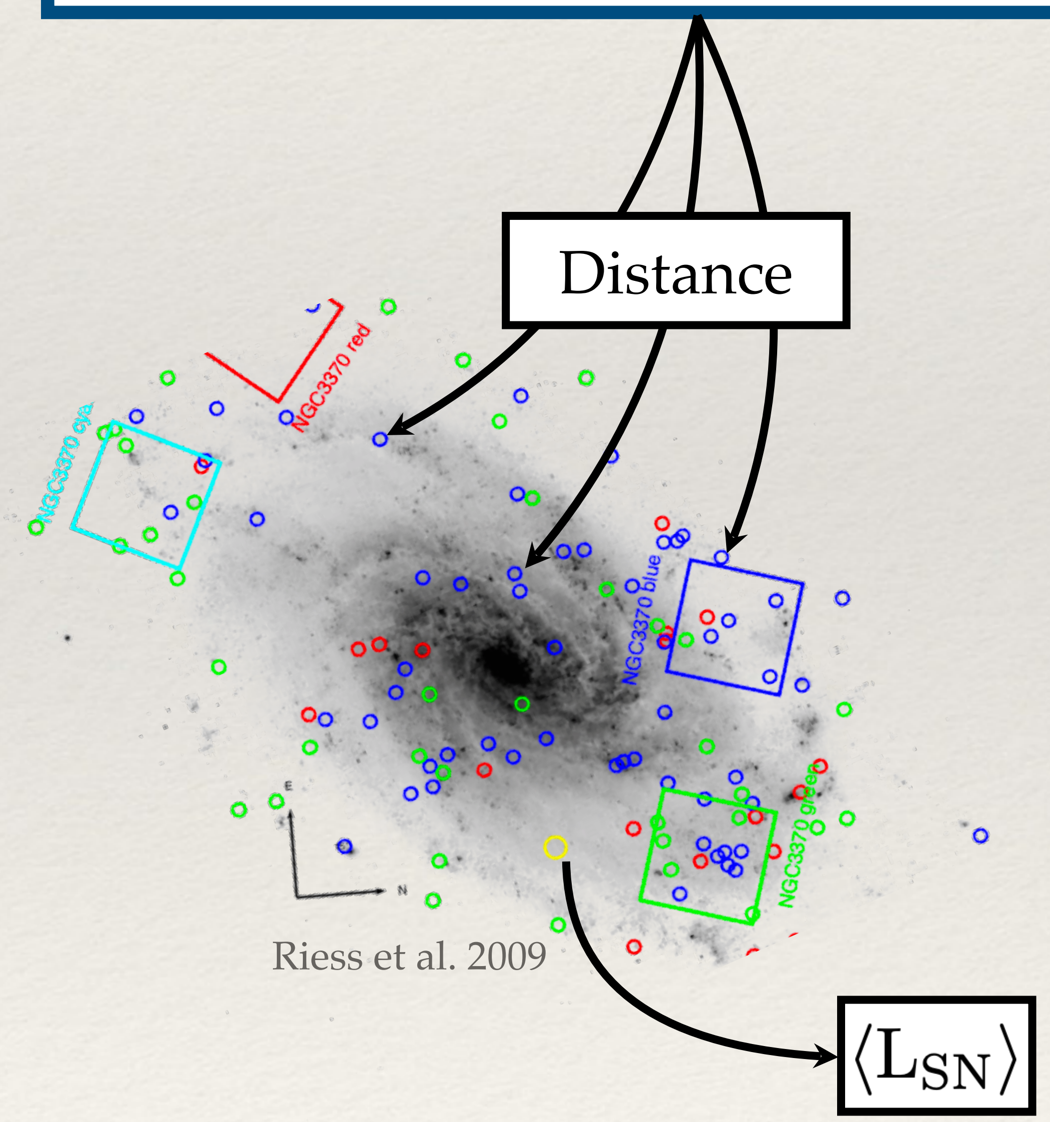
"Geometry"

Parallaxes | D.E.B. | Maser



"Calibrators"

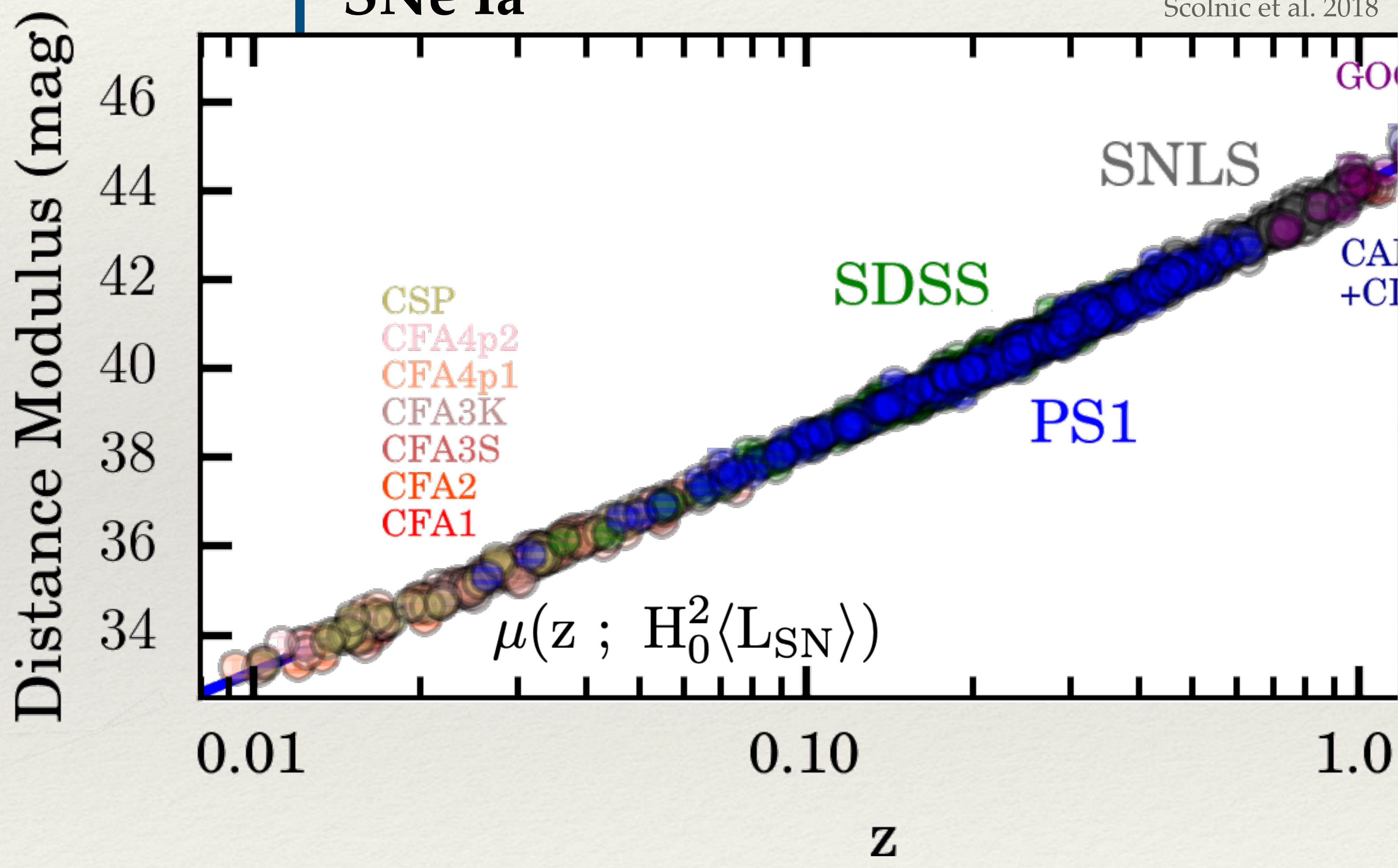
Cepheids



Riess et al. 2009

"SNe Ia"

Scolnic et al. 2018

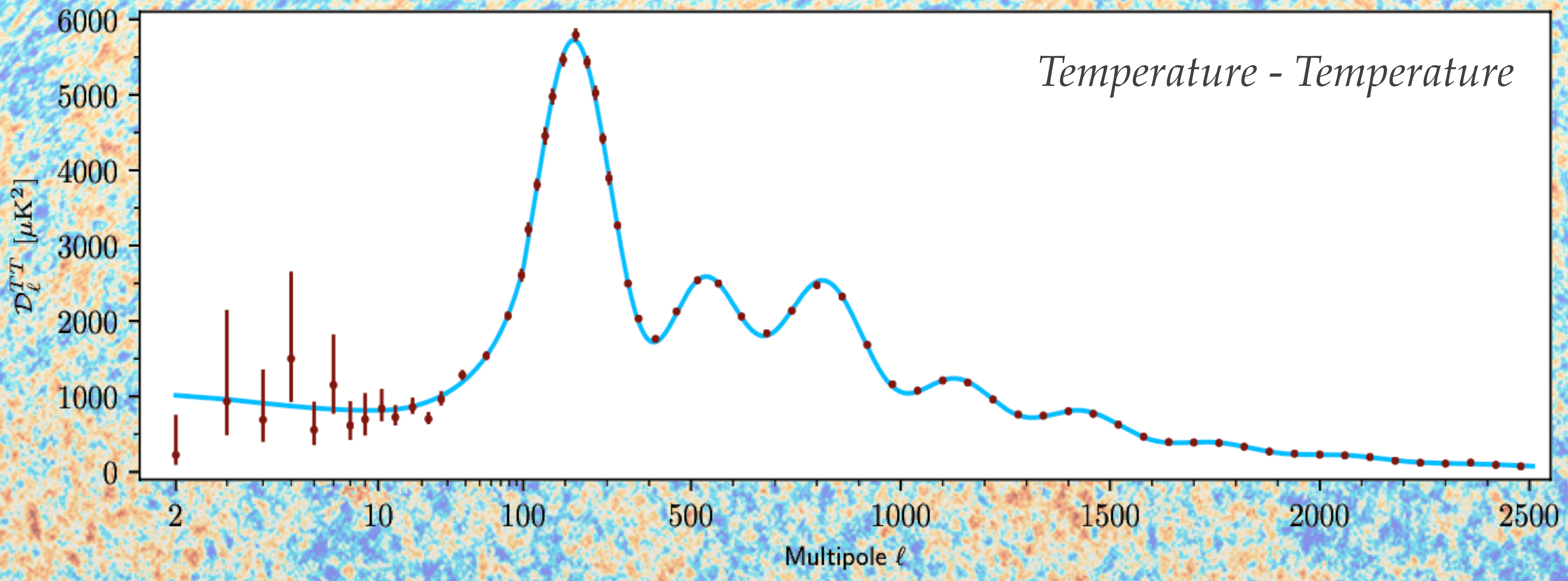


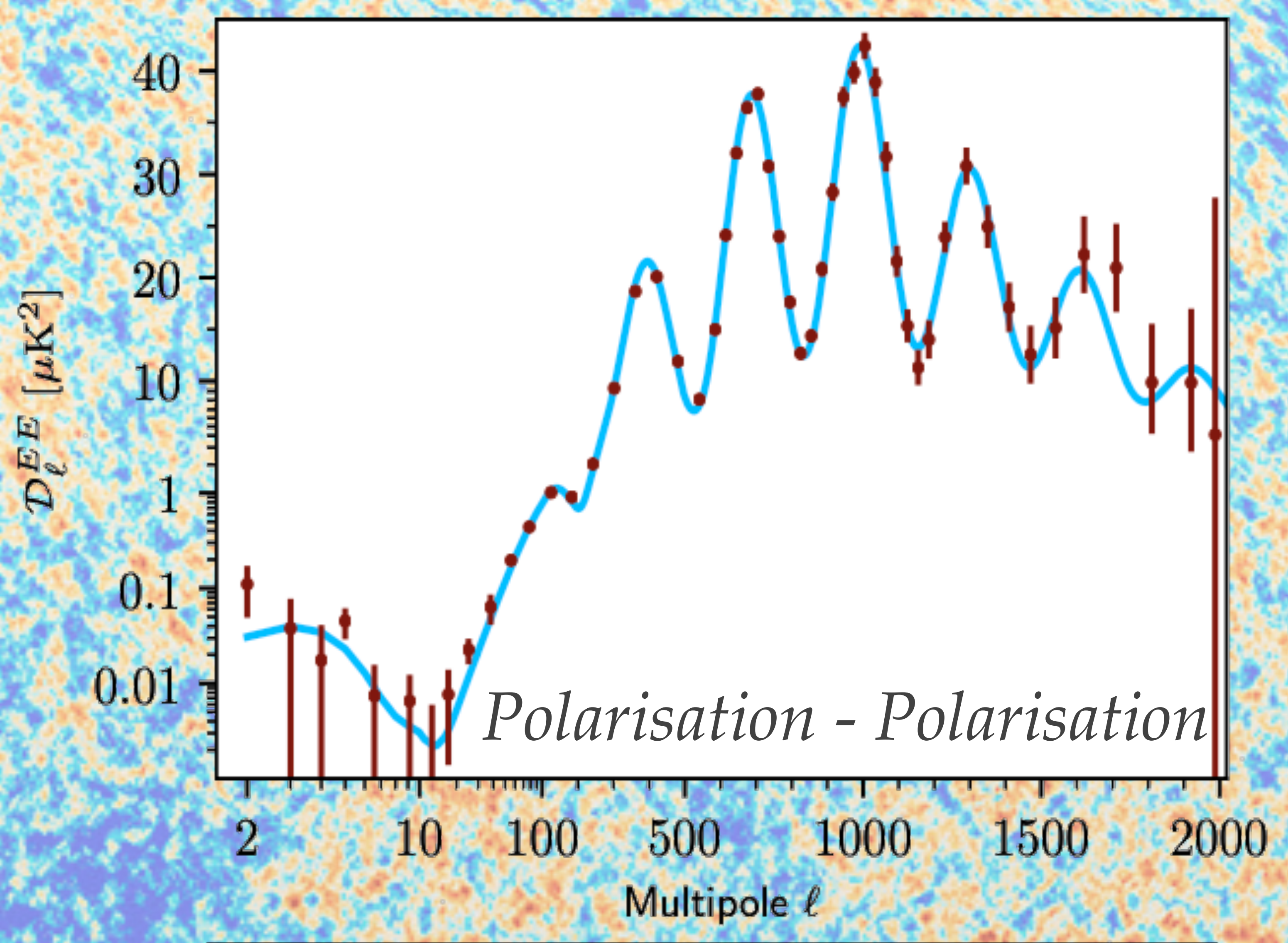
Riess et al. *2022*

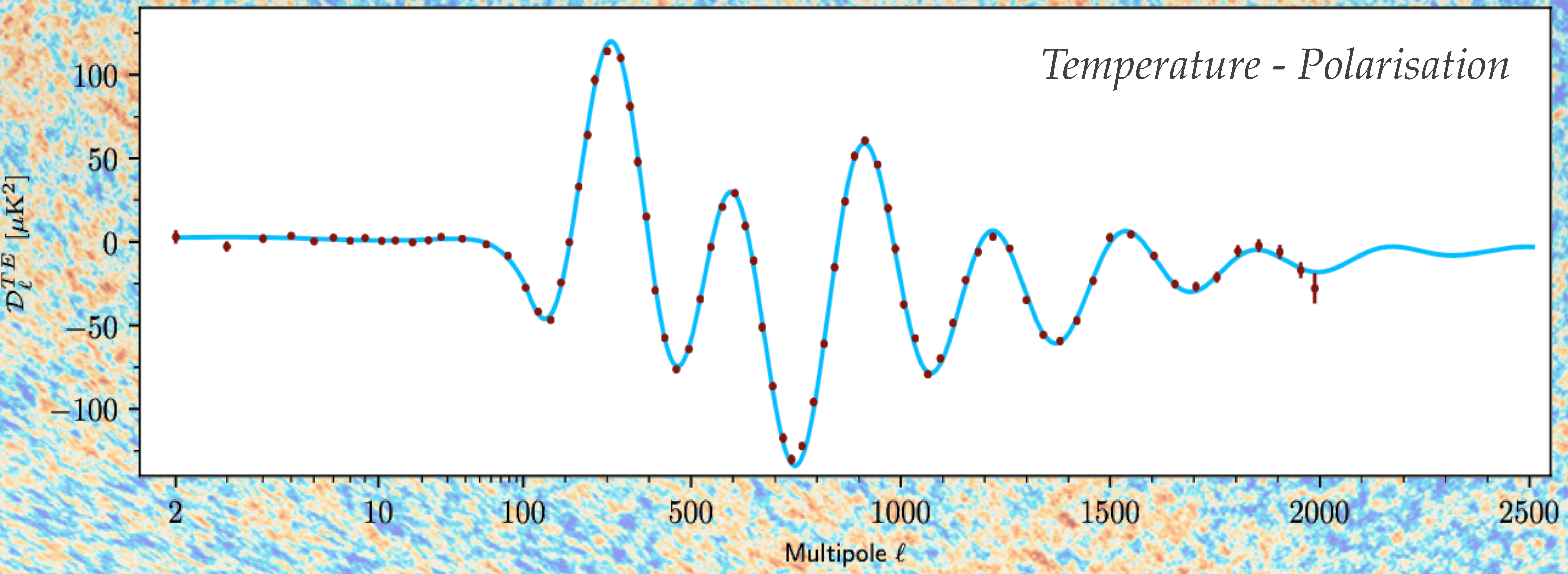
***H_0* = 73.0 ± 1.0 km s^{-1} Mpc^{-1}**

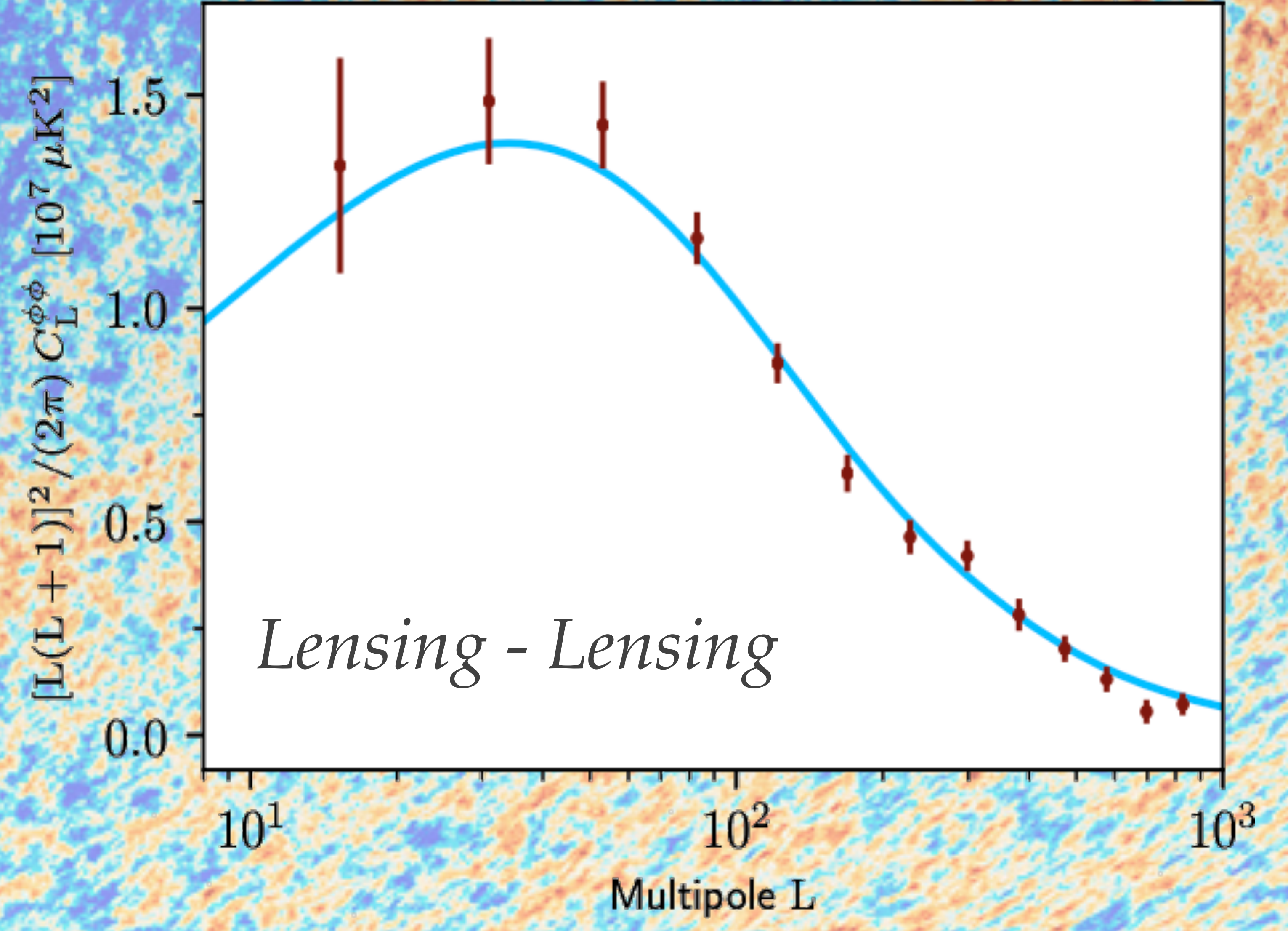
Planck Data | 6 free parameters

Planck et al. 2020



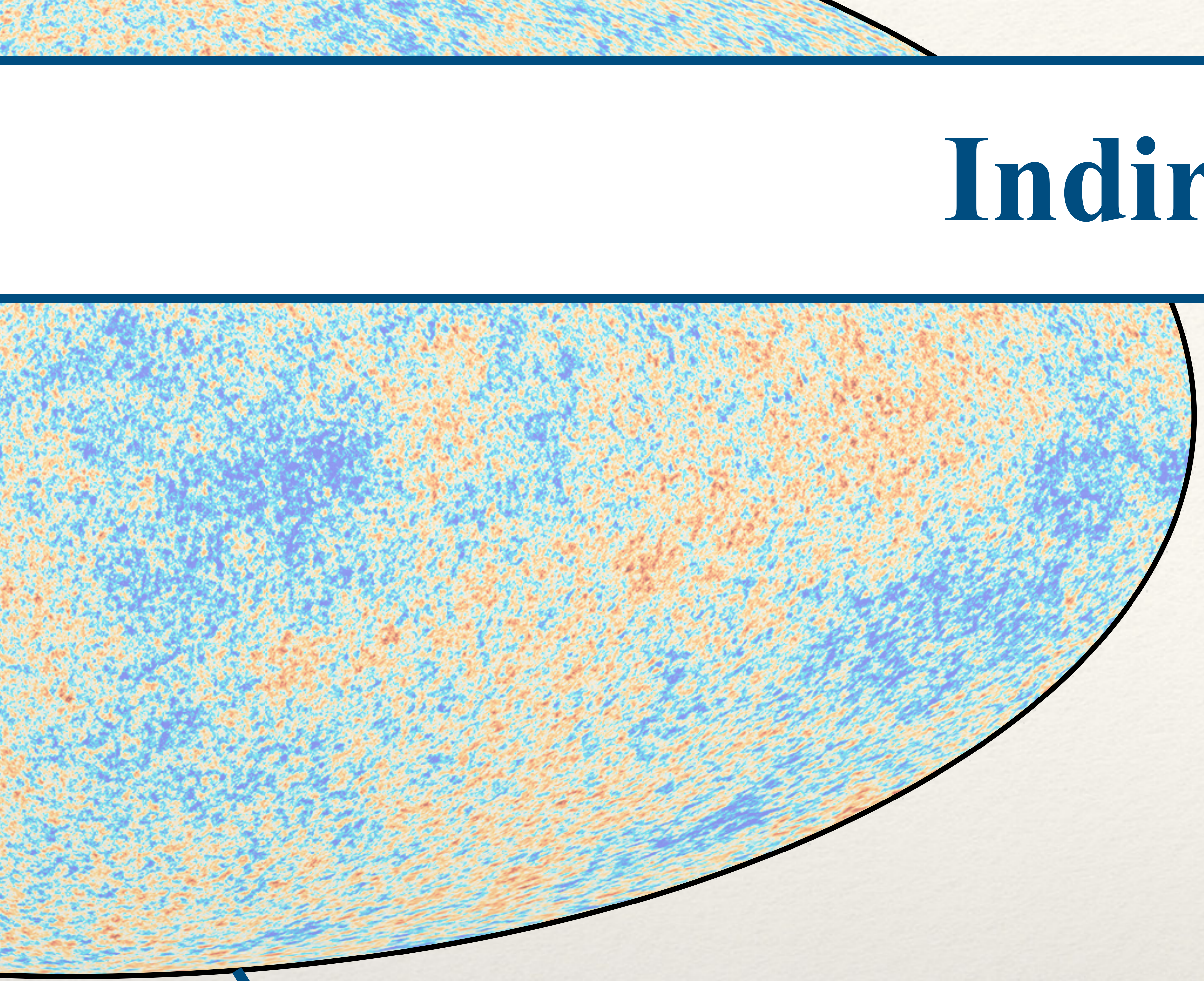






Indirect determination of H_0

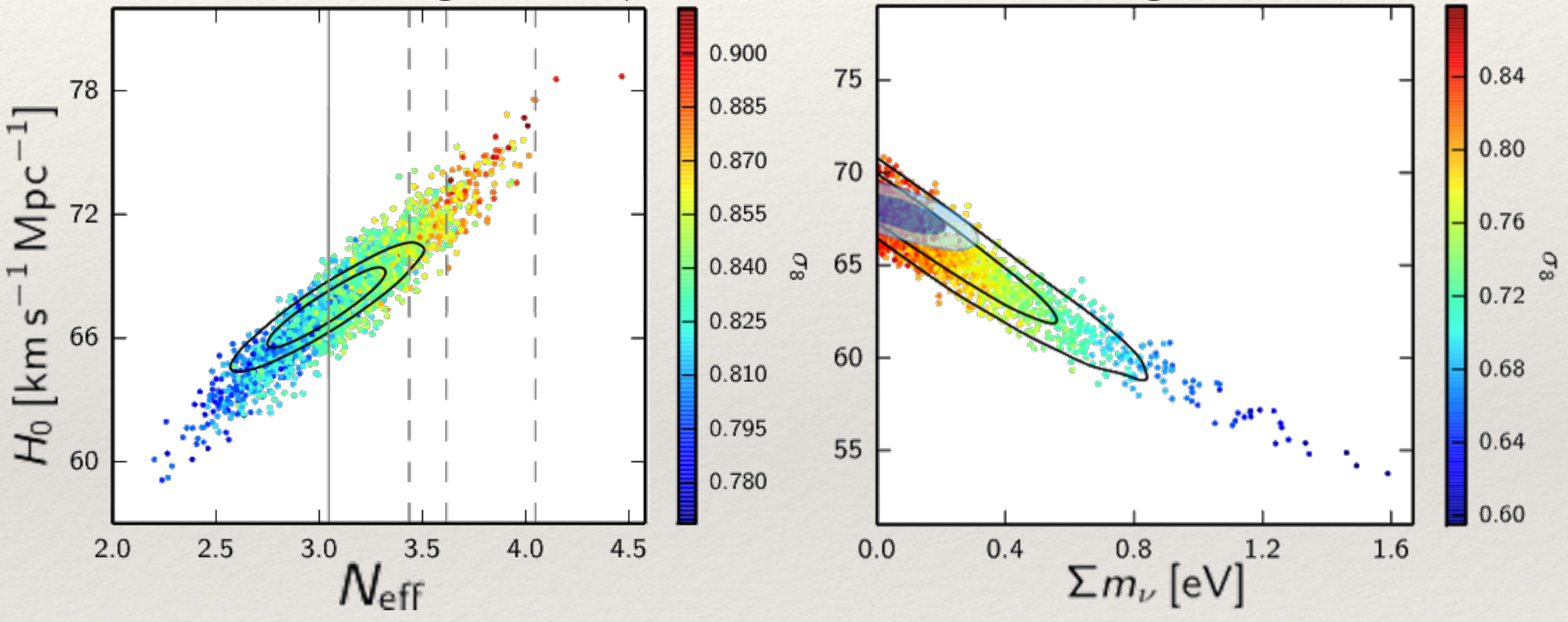
Planck et al. 2020



z~1100

Test the concordance model ΛCDM

Change the parameters, change H_0



Illustrative plots from Planck 2015

The Model Contrains H_0

Planck et al. *2020*

z~0

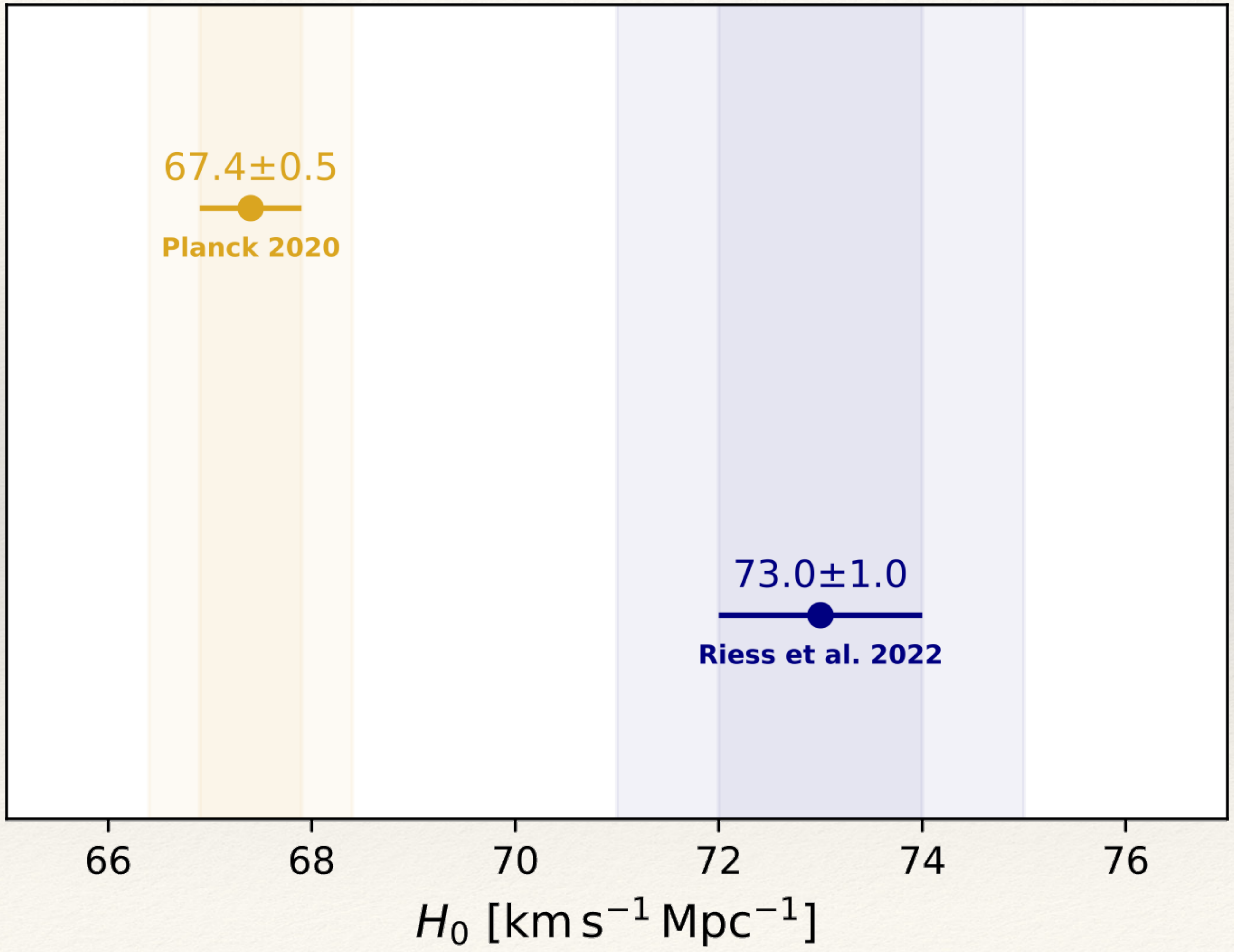
H_0 = 67.4 ± 0.5 km s^{-1} Mpc^{-1}

— based on ΛCDM —

H_0 Tension | SH$_0$ES vs. Planck

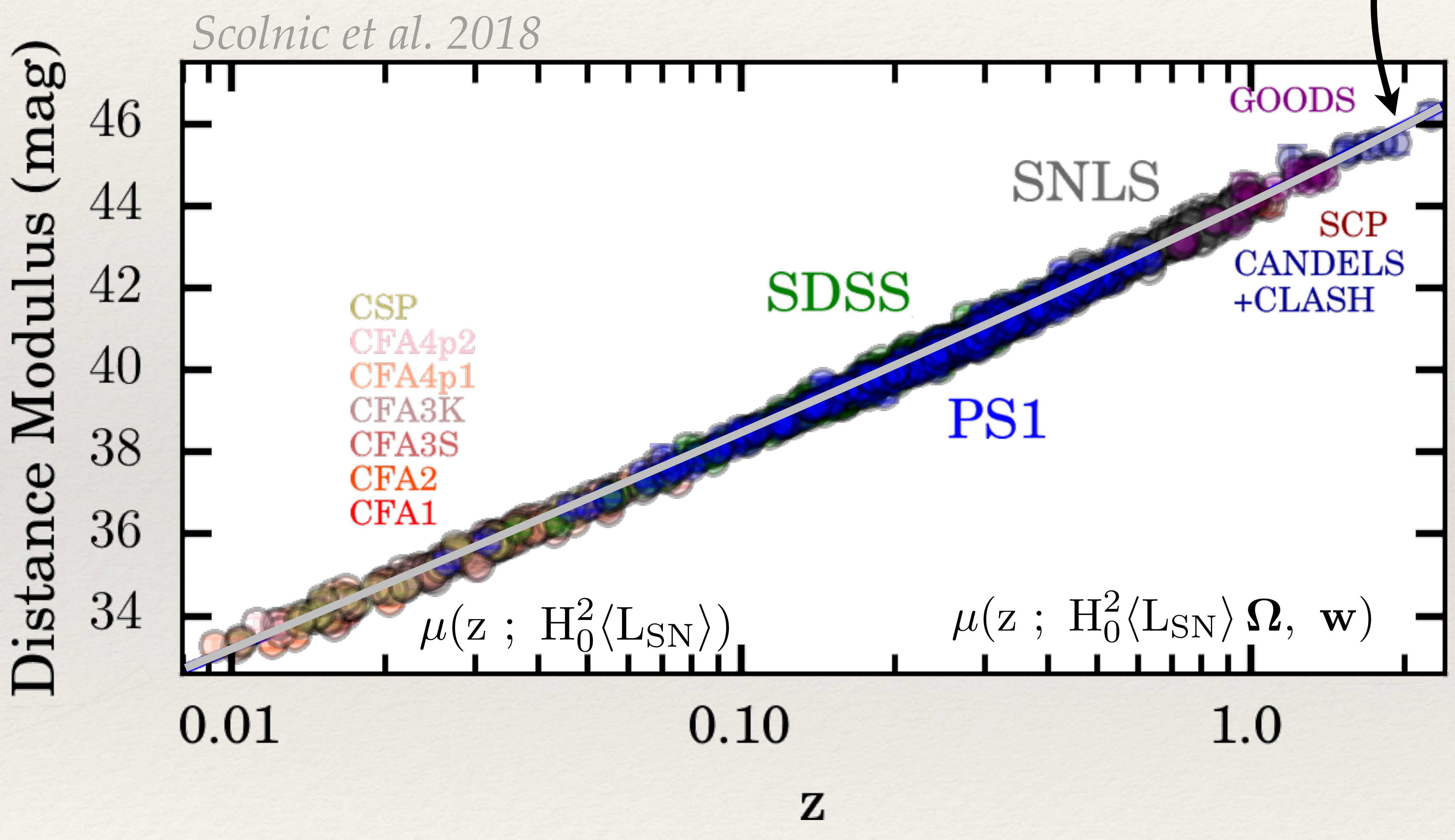
ΛCDM

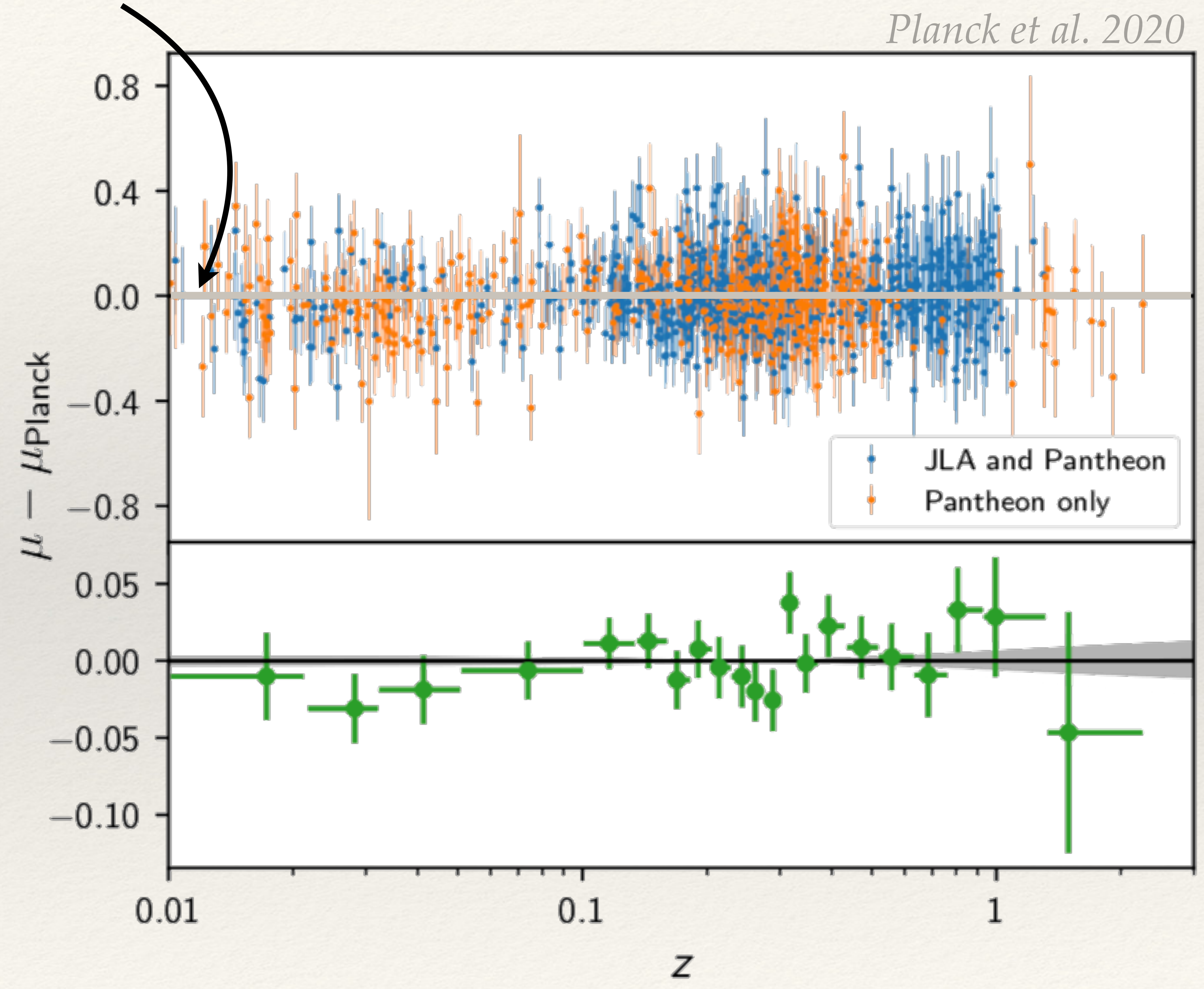
direct



Are Supernovae & CMB in tension ? *No!*

H(z) from Planck





Inverse Distance Ladder

BOSS DR12 | Alam et al. 2017

Get independent distances for SNe Ia

"Transfert"
H(z=1) → H(z=0)

Sets the scale of the
Universe at z~1

distance

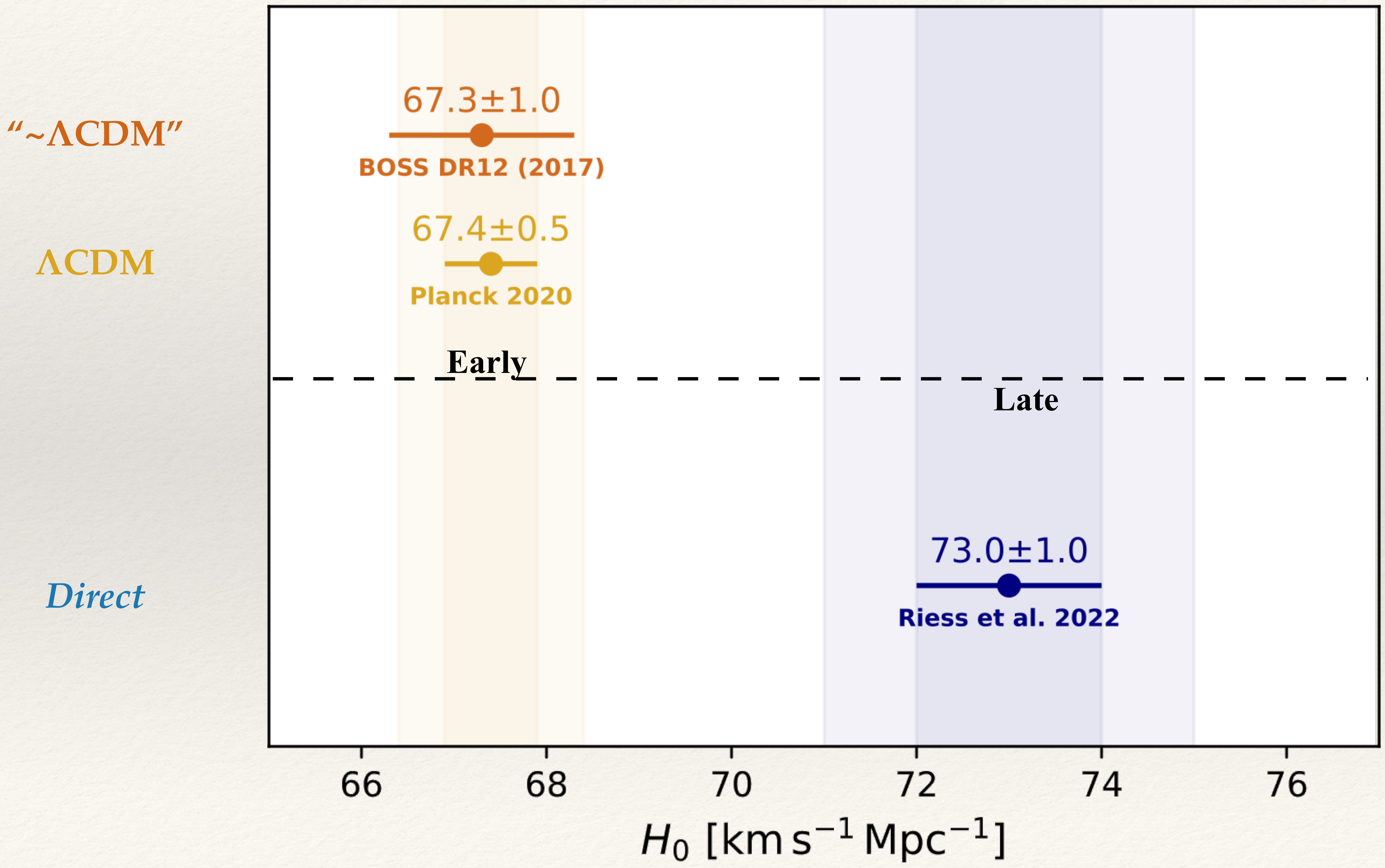
"SNe Ia" **"BAO."** **"CMB"**

BOSS DR12 | Alam et al. *2017*

***H_0* = 67.3 ± 1.0 km s^{-1} Mpc^{-1}**

See also e.g.:
Aubourg et al. 2015 • Macaulay et al. 2018

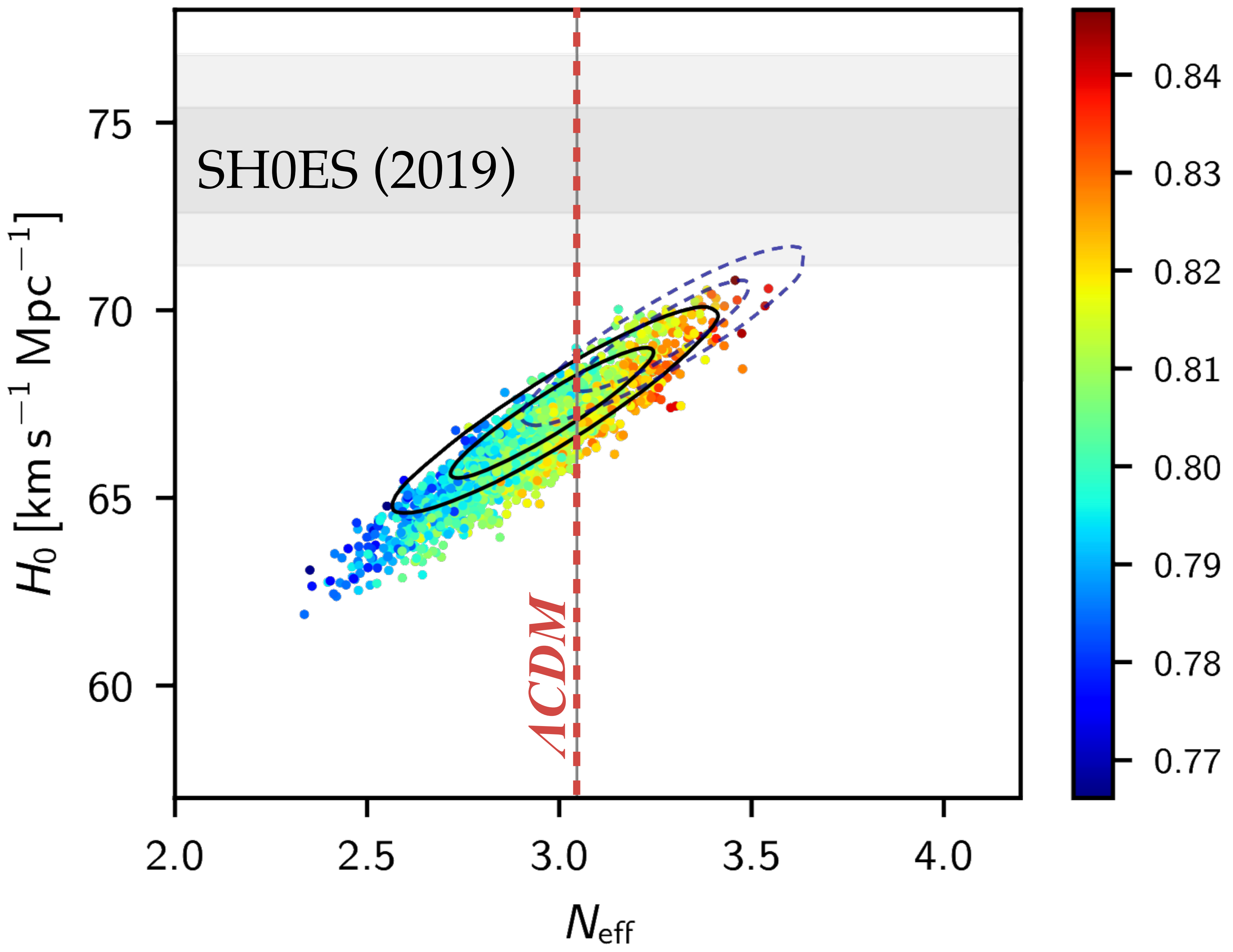
H_0 Tension | Early vs. Late



H_0 Tension | Change the model ?

H_0 Tension | 5 σ

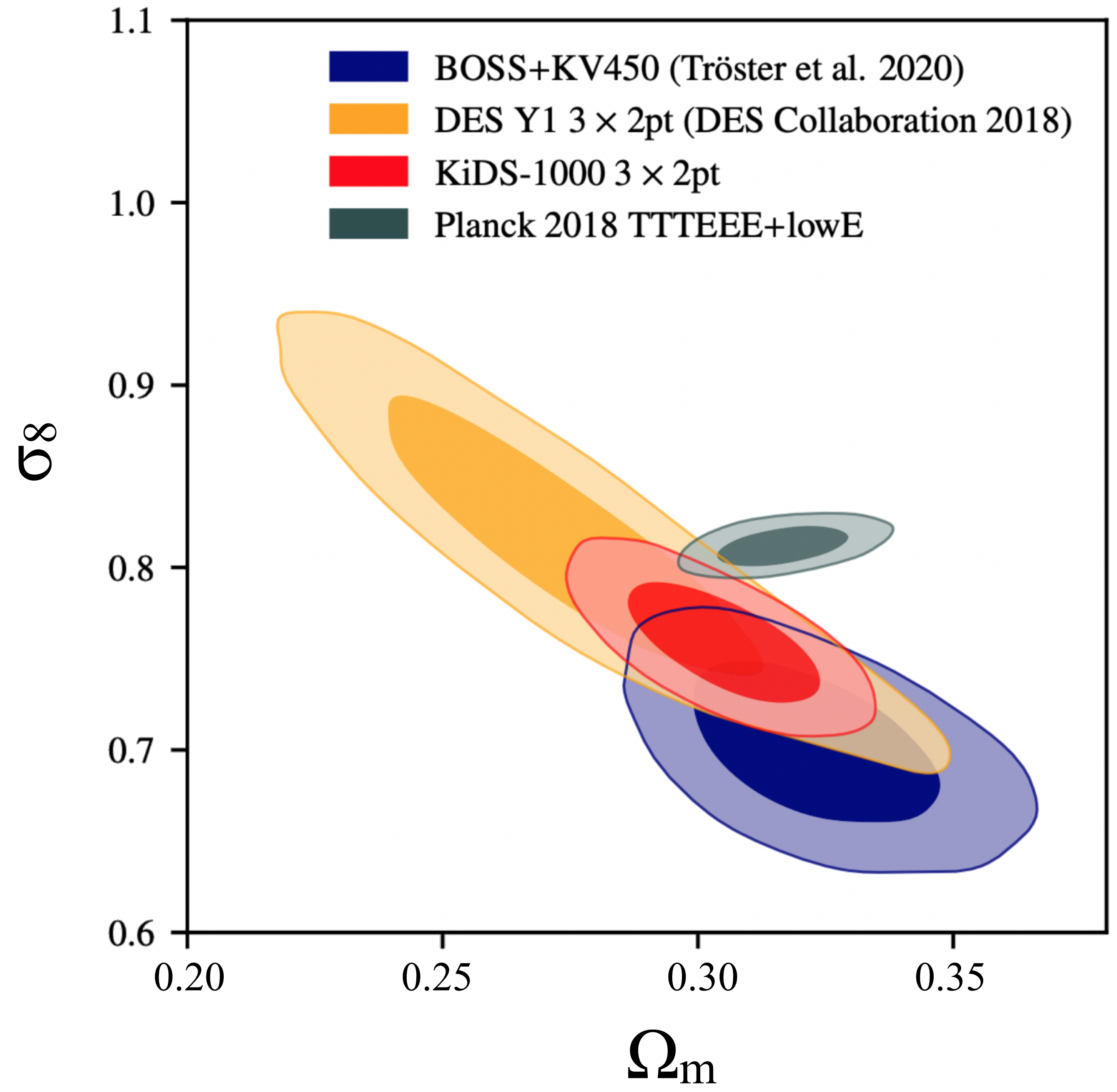
Universe's expansion is too fast



Planck 2020

σ_8 Tension | 2.5 σ

Structures are too small



Heymans et al. 2020

Time Delay Cosmology

$$t(\theta,\beta) = \frac{(1+z_d)}{c}\frac{D_d D_s}{D_{ds}}\left[\frac{(\theta-\beta)^2}{2} - \psi(\theta)\right]$$

measured

H_0^{-1}

Light path

Lensing potential

H_0 Tension | Systematics in strong lensing

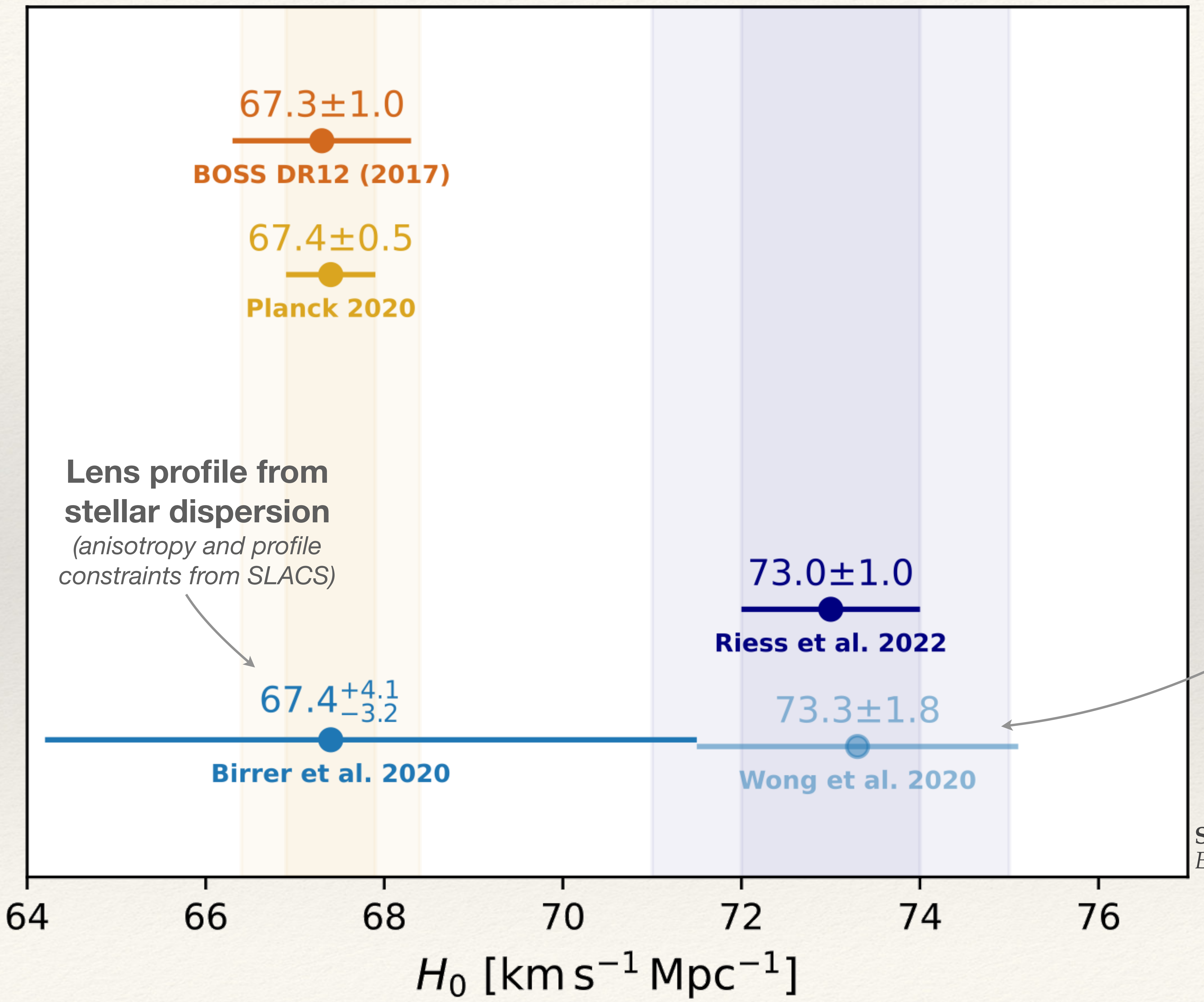
"~ΛCDM"
Inverse distance ladder

ΛCDM
CMB

DIRECT:

SNeIa & Cepheids

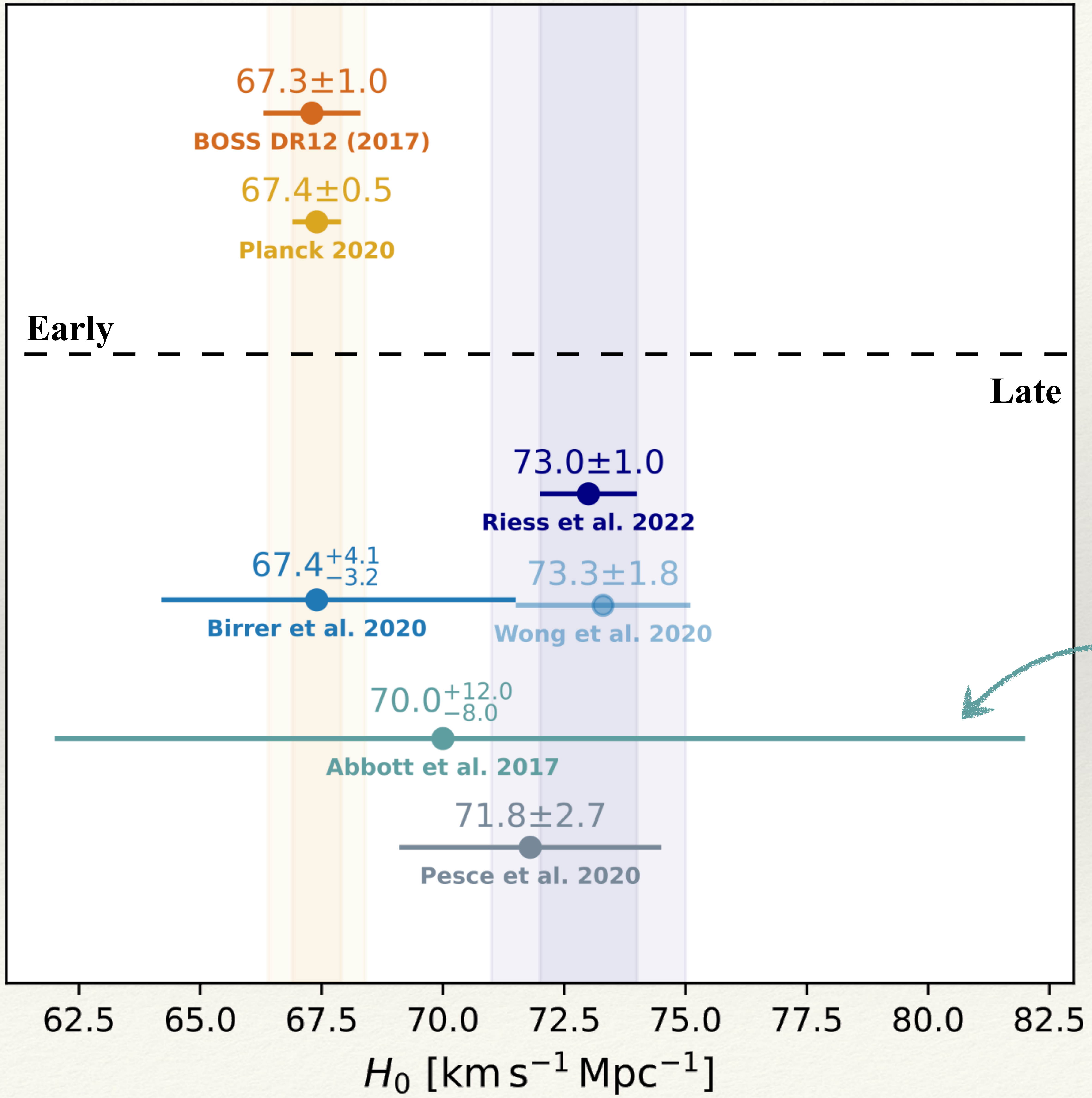
Strong Lensing



Power-law & star constant M/L & Dark matter halo
(See Suyu 2009)

See also e.g.:
Etherington et al. submitted

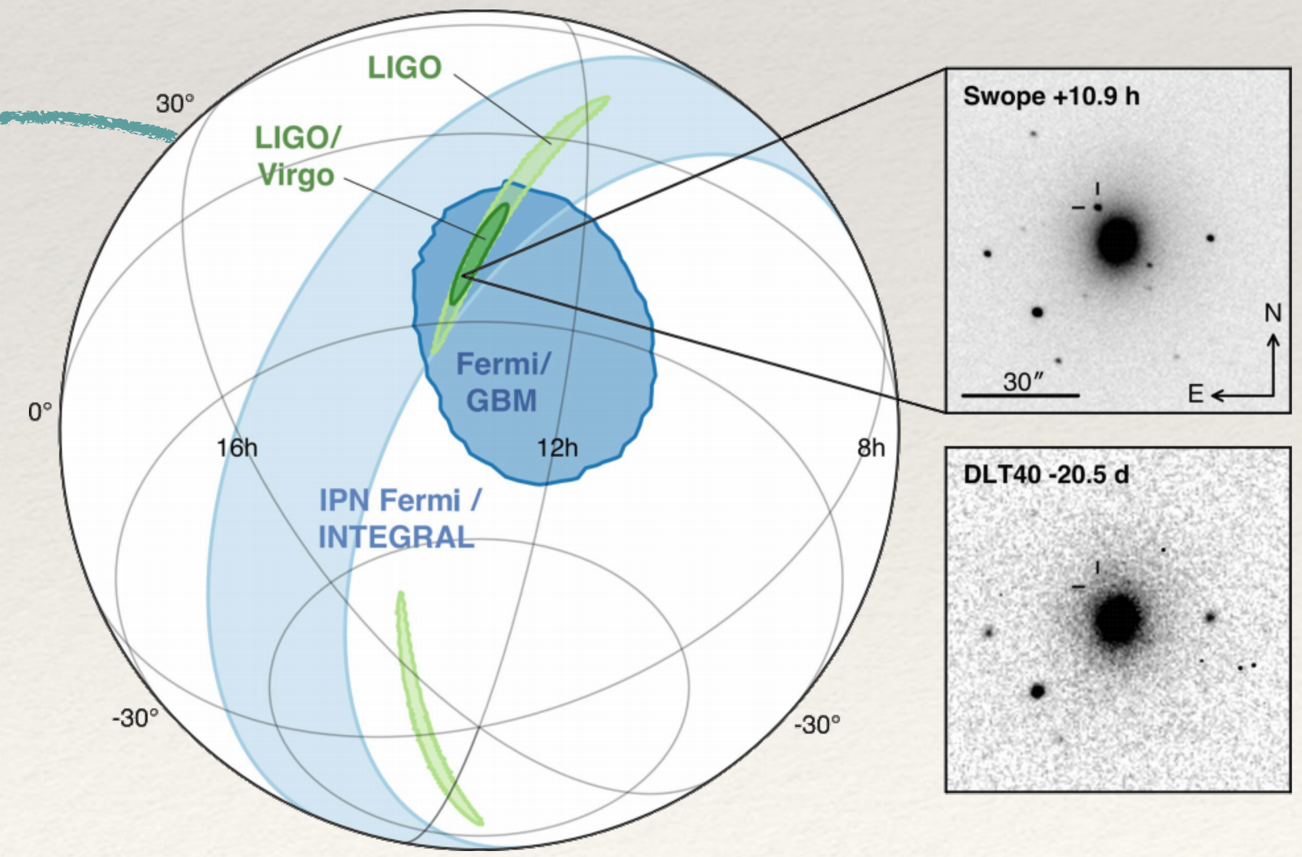
H_0 Tension | +Mega-masers & KiloNova



Strong Lensing
systematics actively studied

Nearby so Sensitive to peculiar velocity correction

Kilonova | GW170817



Direct Distance Ladder | TRGB

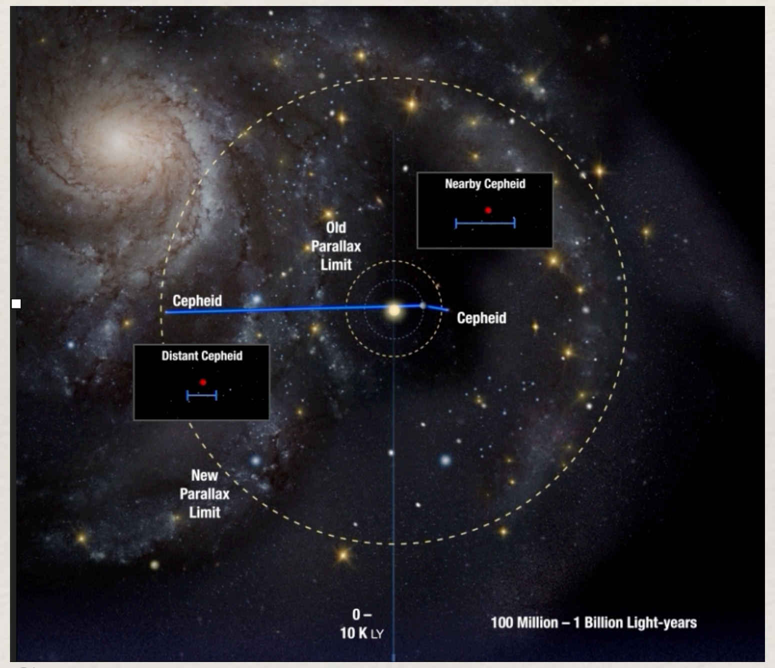
Freedman et al. *2021*

Get independent distances for SNe Ia

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

"Geometry"

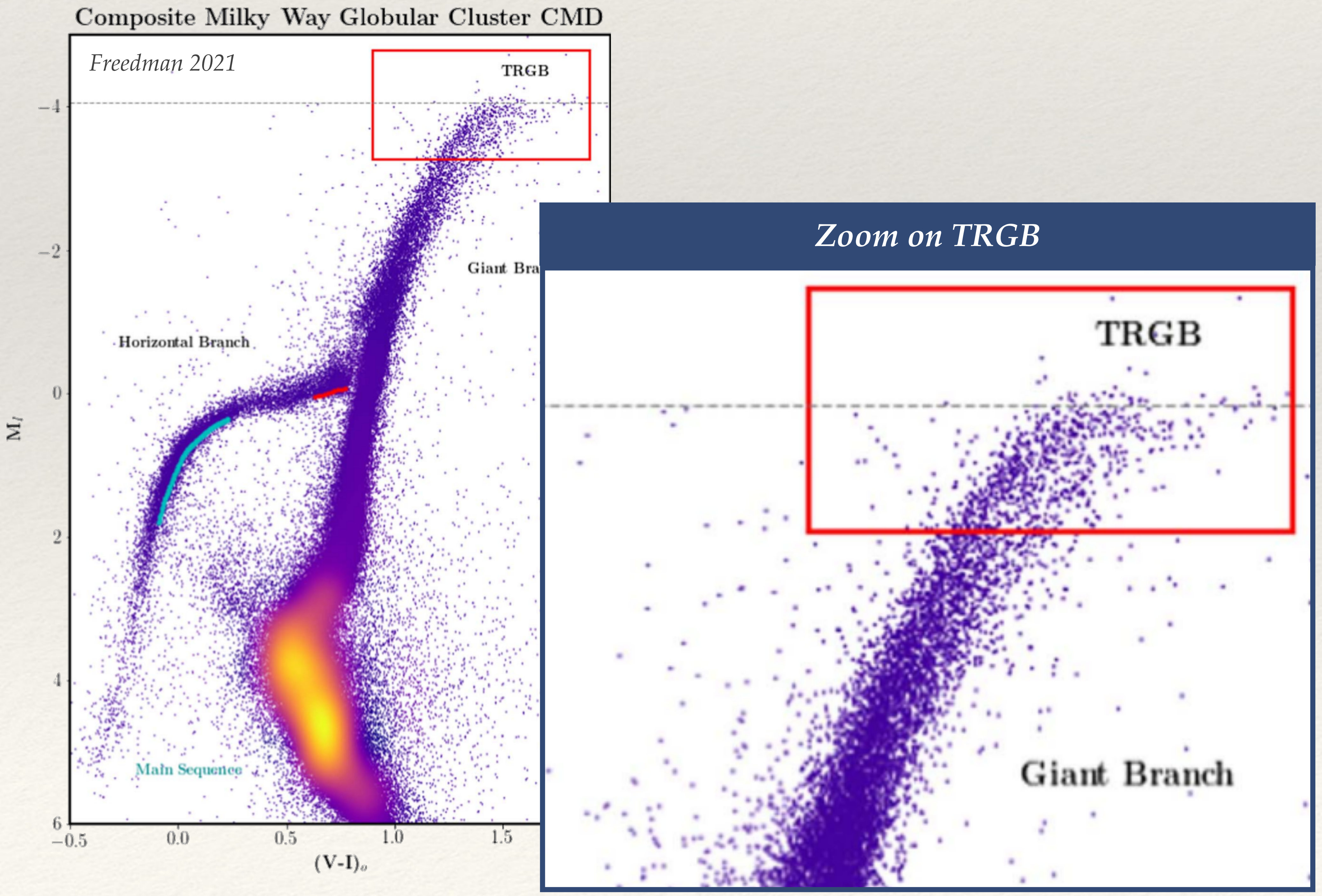
Parallaxes | D.E.B. | Maser



Source: eso

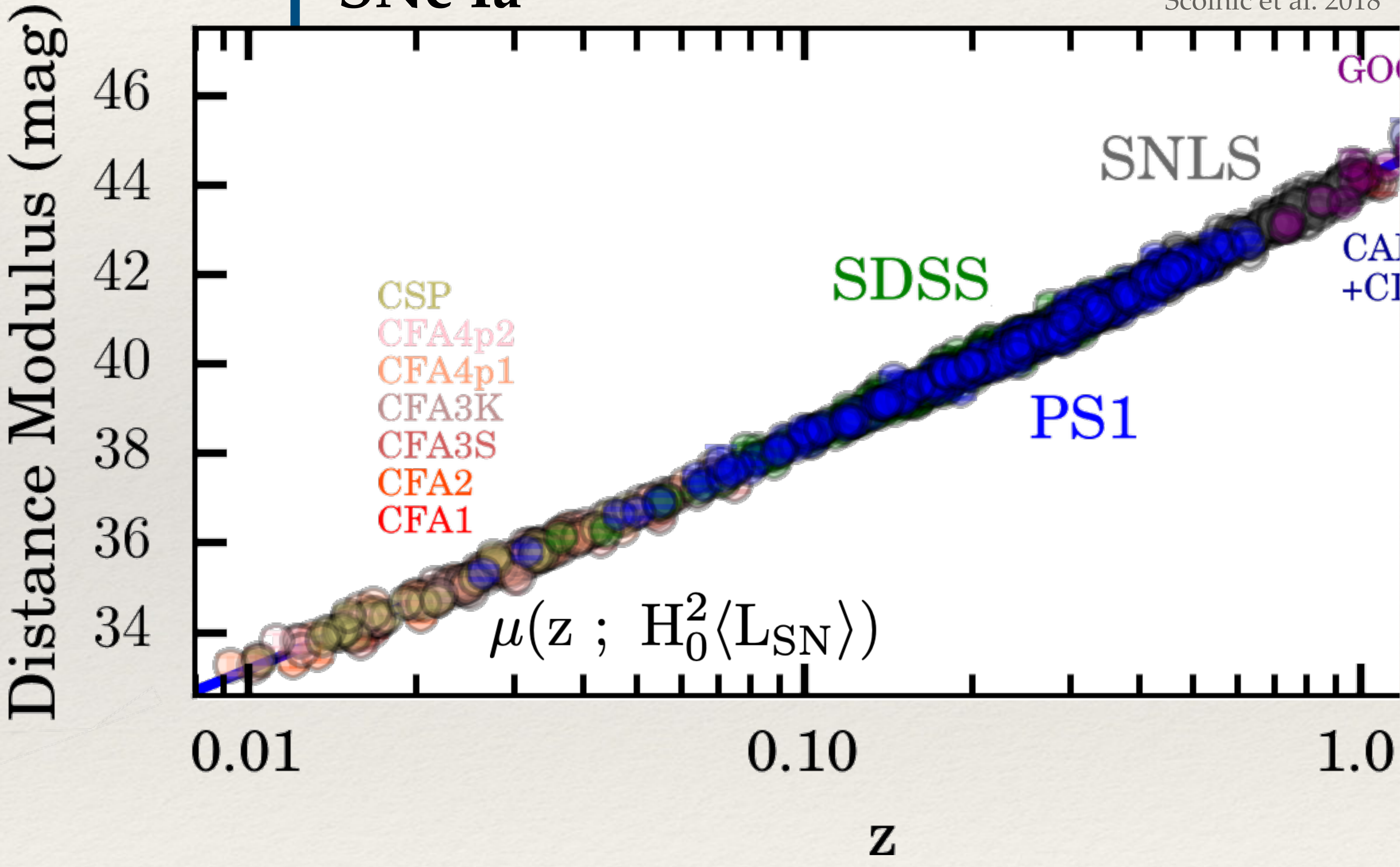
"Calibrators"

TRGB



"SNe Ia"

Scolnic et al. 2018



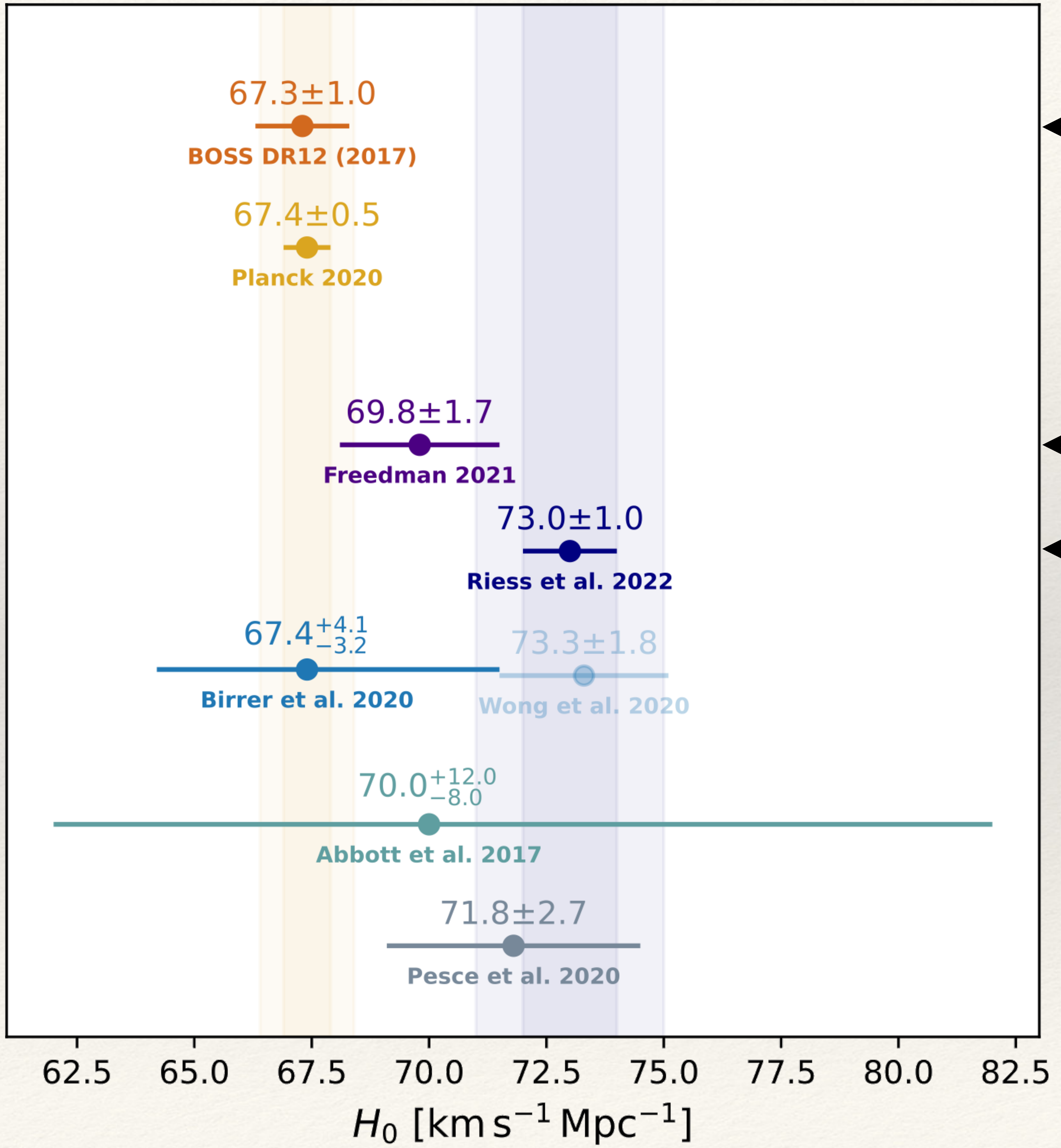
Freedman et al. *2021*

$H_0 = 69.8 \pm 0.6$ (stat) ± 1.6 (sys) **km s^{-1} Mpc^{-1}**

H_0 Tension | *TRGB vs. Cepheid*

Strong Lensing
systematics actively studied

Nearby so Sensitive to peculiar velocity correction



SNeIa's $\langle L_{SN} \rangle$ calibrated by:

BAO (z~1) | r_s

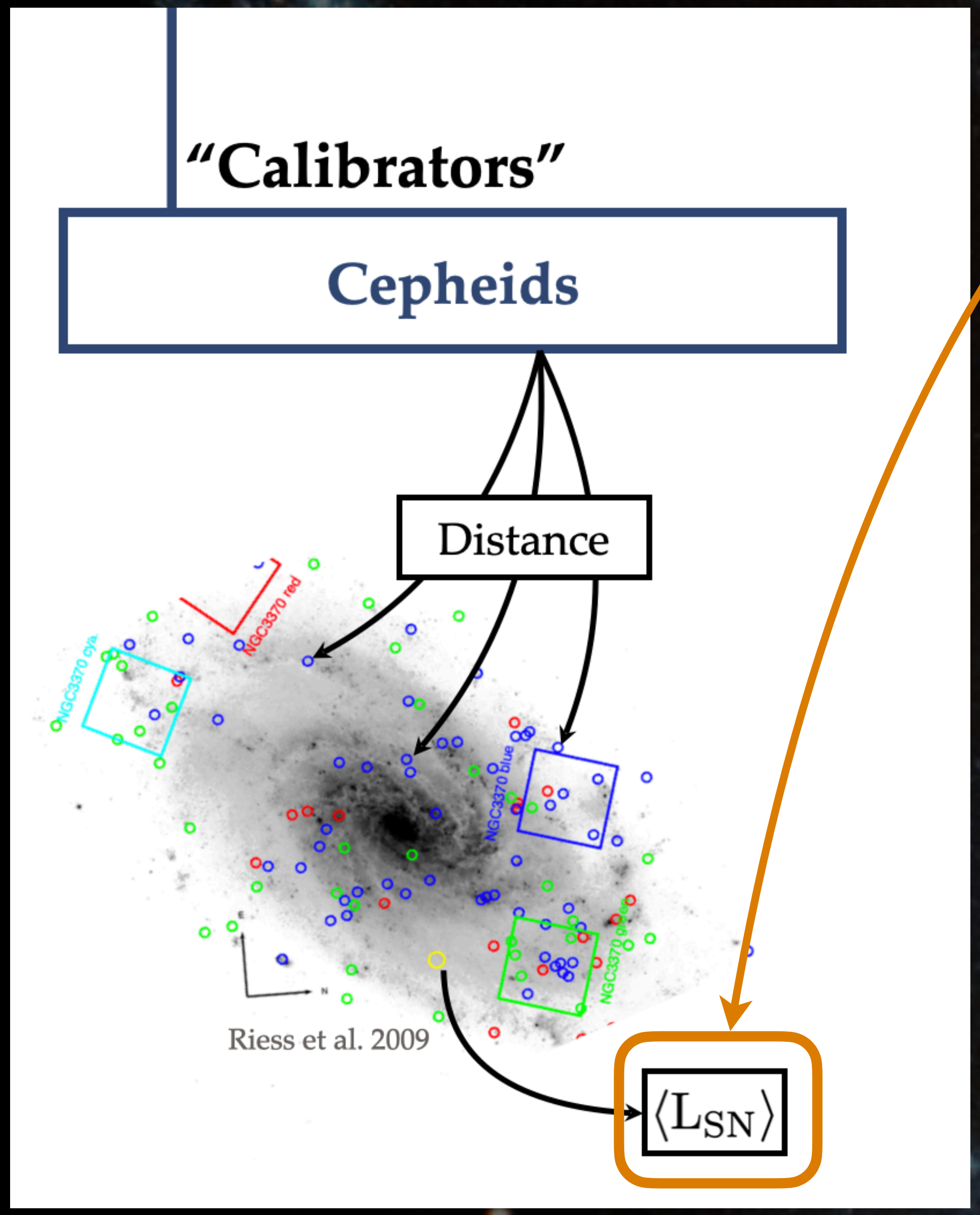
TRGB (z~0) | *geometry*

Cepheids (z~0) | *geometry*

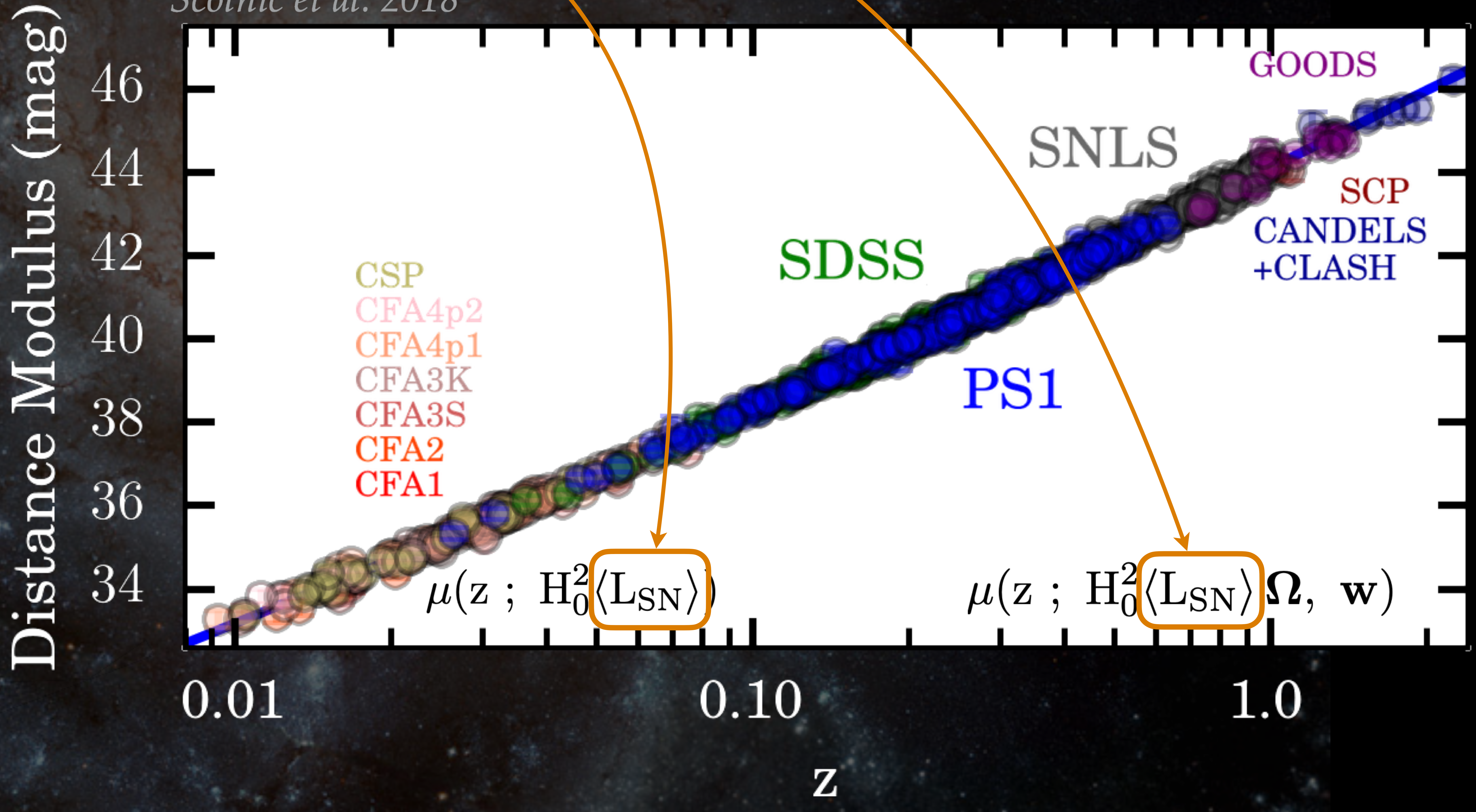

SN2011fe

The Progenitor issue | *Astrophysical biases*

Constant ?



Scolnic et al. 2018



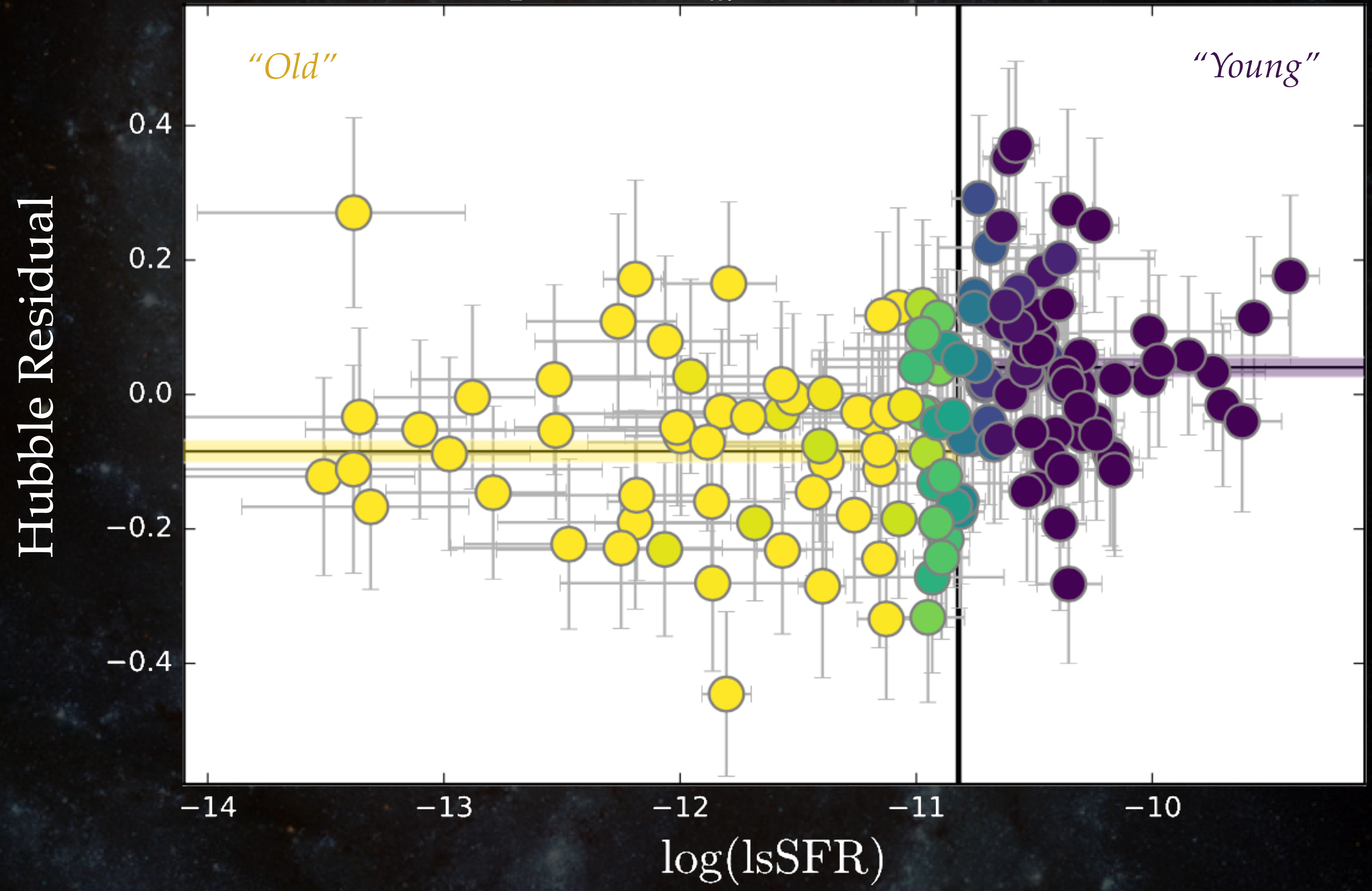
SN2011fe

Rigault et al. 2020
Nicolas et al. 2021
Briday et al. 2022
Ginolin et al. *in prep*

"No" young stars → *High fraction of young stars*

Fainter ↓ *Brighter*

Amplitude: $\Delta_m = 0.16 \pm 0.03$ mag



$$\text{lsSFR} \propto \frac{\#\ \text{Young Stars}}{\#\ \text{Old Stars}}$$

Astrophysical Bias affecting H_0

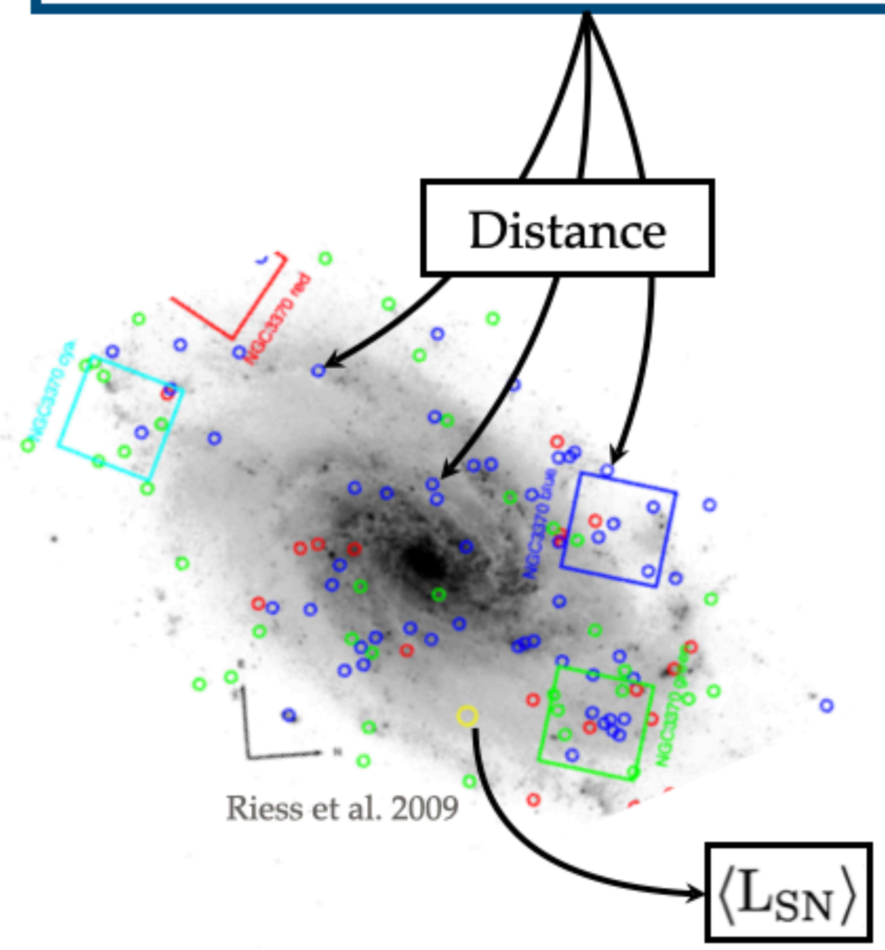
Rigault et al. 2015

The SNe Ia "matching" problem

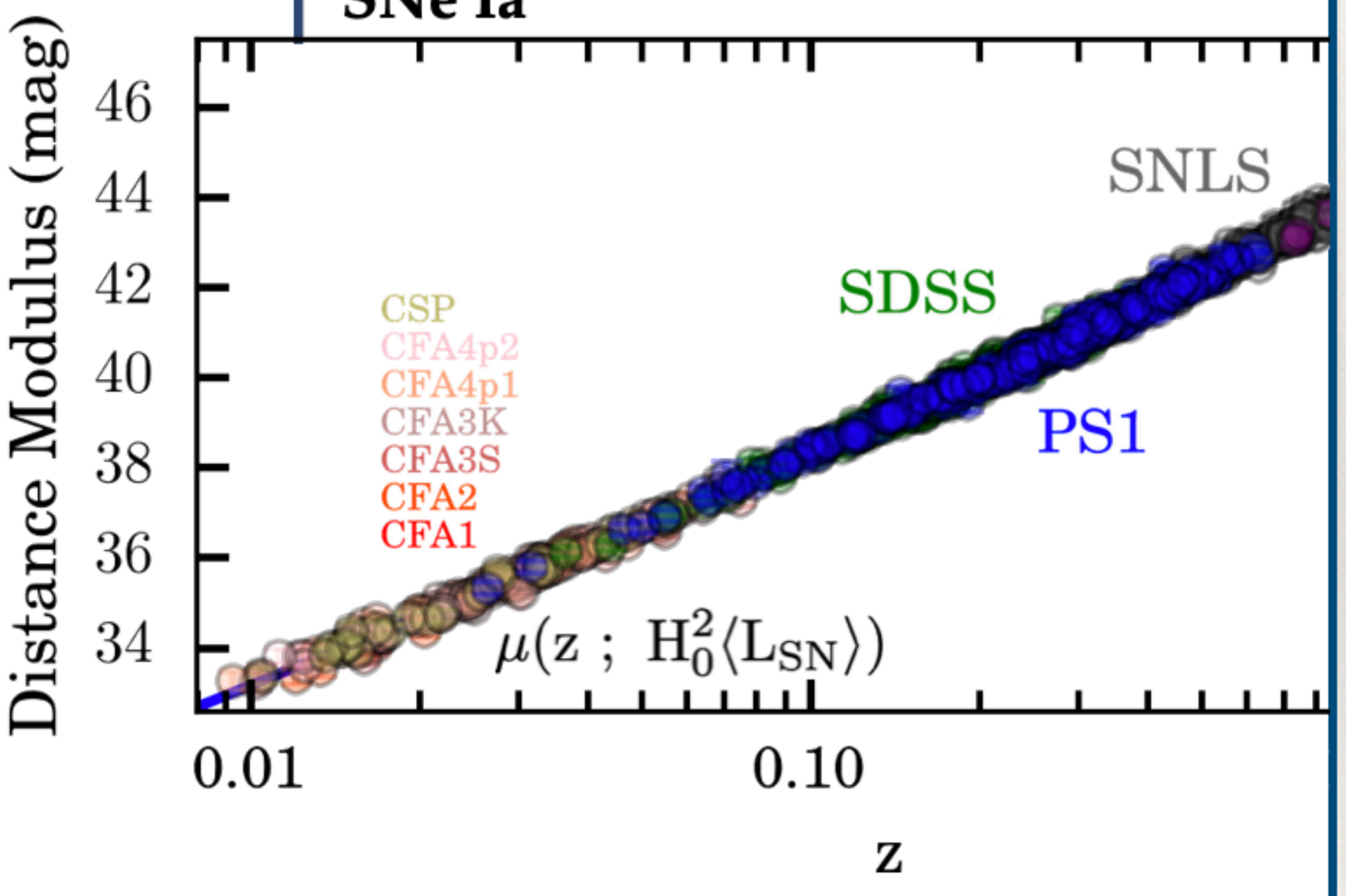
Measure "L_{SN}" — *Get "H_0"* → **distance**

"Calibrators"

Cepheids



"SNe Ia"



SNeIa with Cepheids
strongly favour Young SNeIa

SNeIa In Hubble Flow
All kinds of SNe Ia

3% bias on H_0

So a **2 km s^{-1} Mpc^{-1}** shift

Total current SH0ES error budget
1.04 km s^{-1} Mpc^{-1}

SH0ES "corrected"
~71 ± 1.5 km s^{-1} Mpc^{-1}

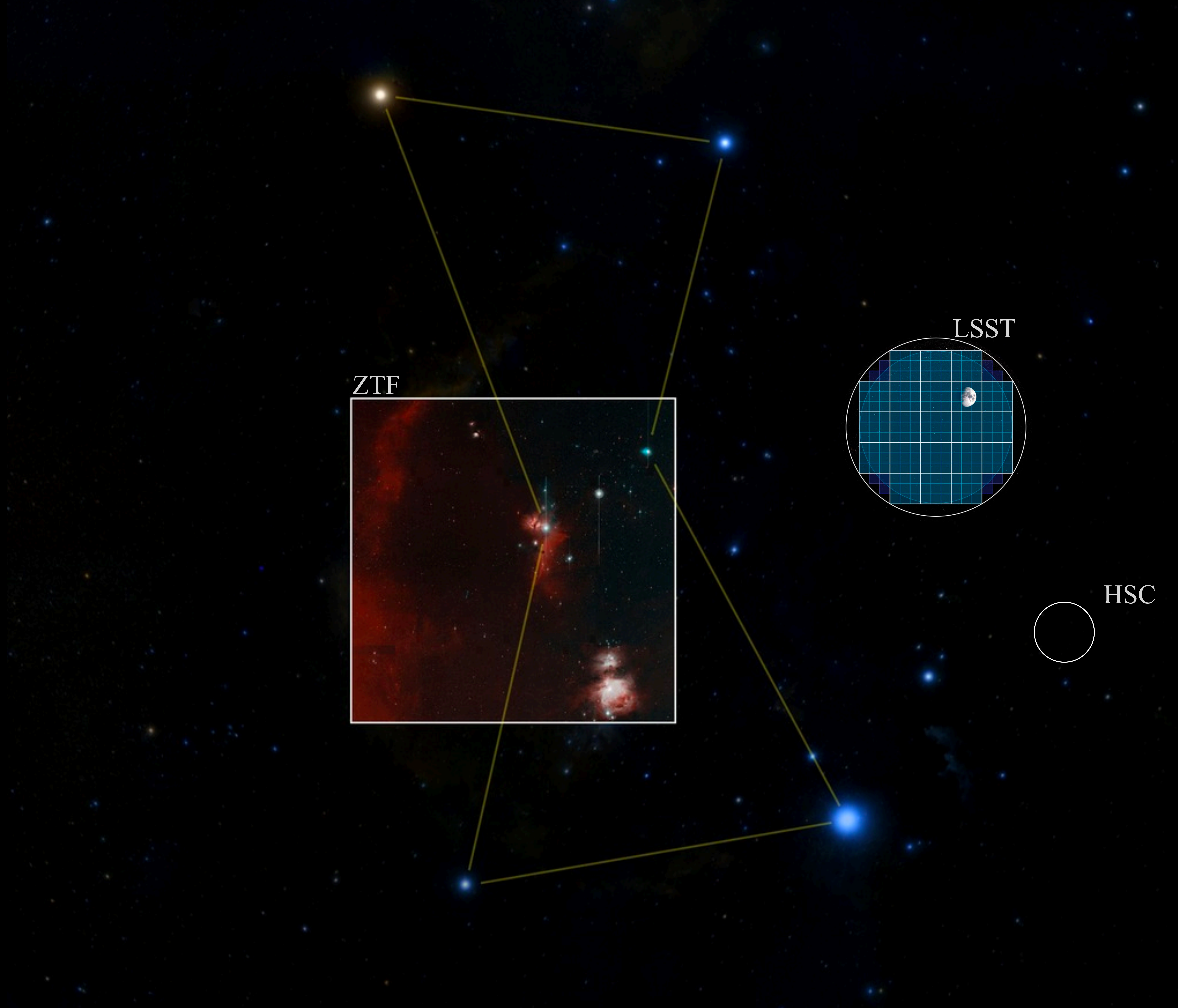
Rigault et al. in prep. | Rigault et al. 2015, 2020

SH0ES rebuttal

"If we **mimic the Cepheids selection** function and only take Hubble flow SNe Ia from *Spiral* hosts, ***H_0* reduces by 0.5%**"

Riess et al. 2022 | Riess et al. 2016, 2019

Zwicky Transient Facility (ZTF) is acquiring ~1000 SNeIa per year at z<0.1 since 2018



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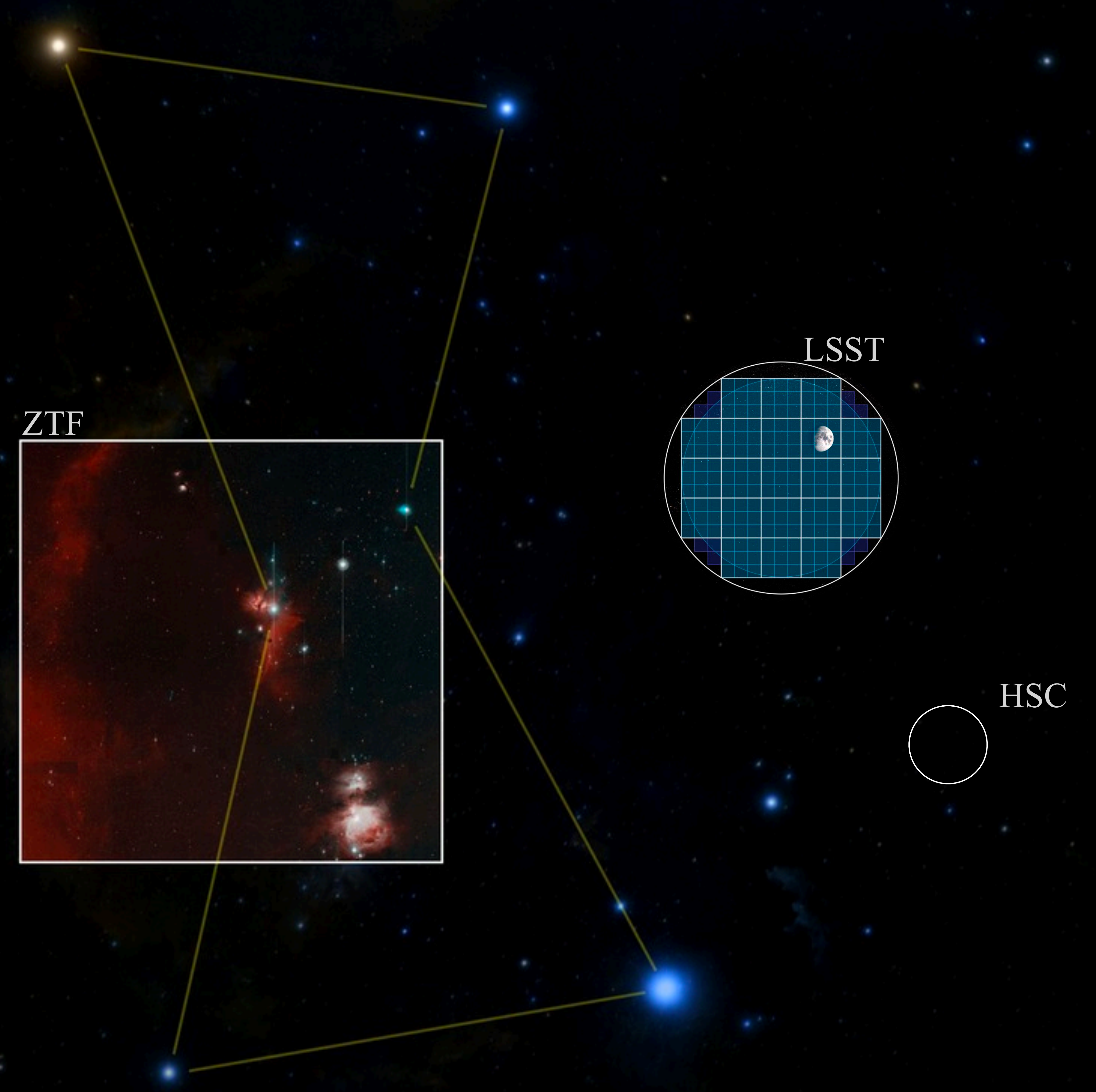
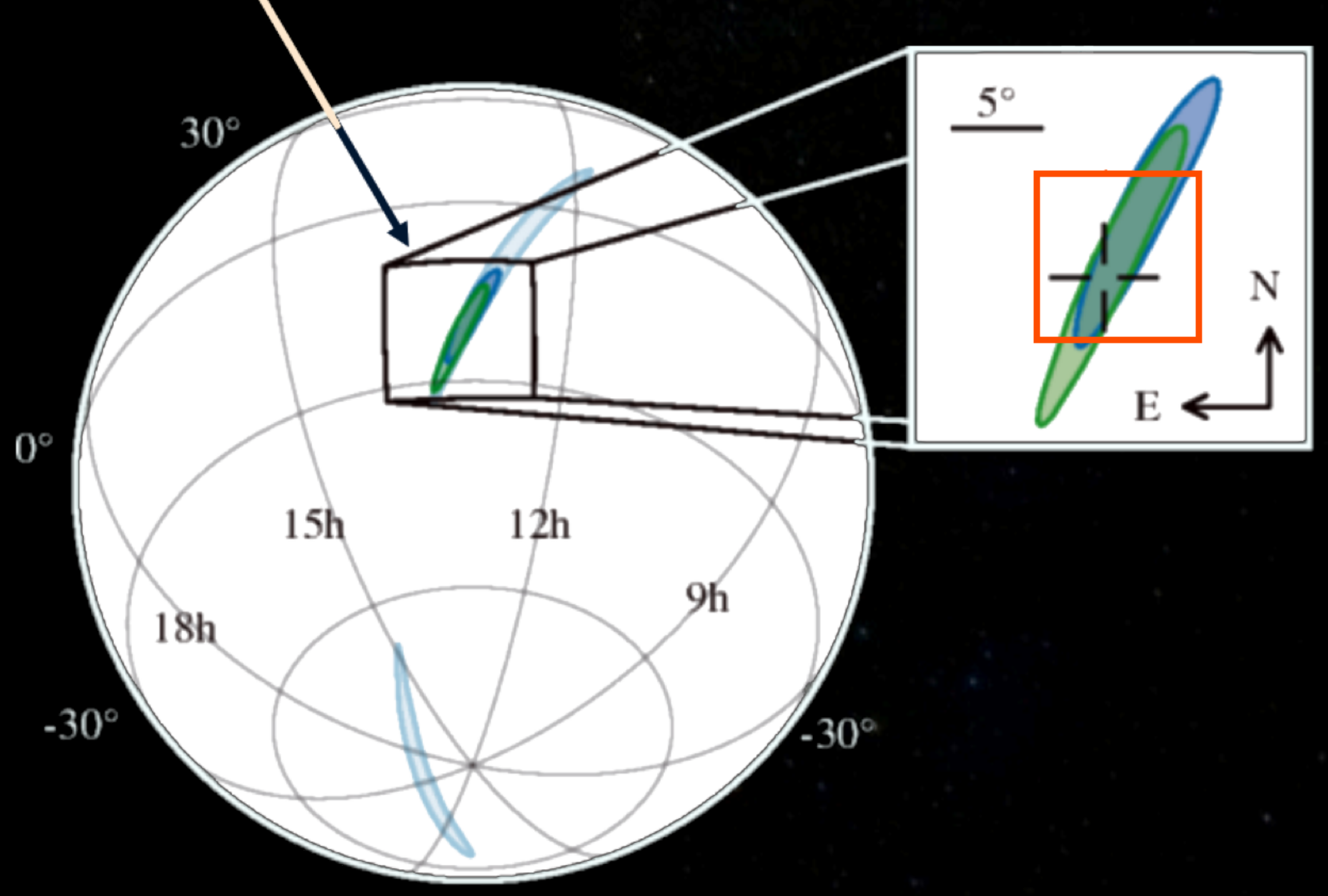


We will be observing during O4

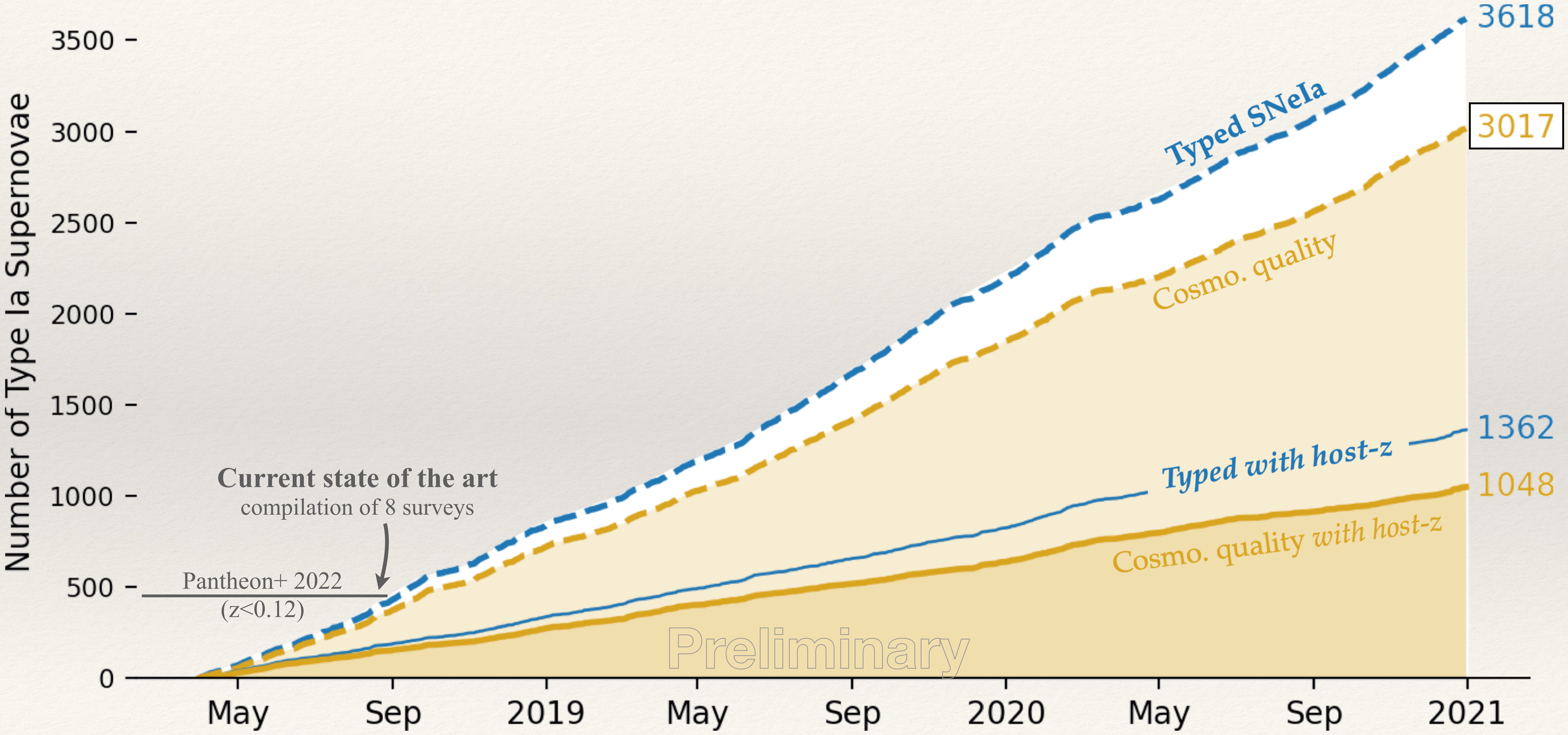
Localization of GW170817 was smaller than ZTF FoV



Abbot et al. (2017), PRL 119, 161101

ZTF | Changing the scale of SN Cosmology

Smith, 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 detects, follows and classifies *all* SNe Ia in the northern sky up to z~0.06

Statistics: Already >800 acquired

No selection function since both volume limited samples

Unique photometric system, no absolute photometric calibration issue

only relative, which is way easier

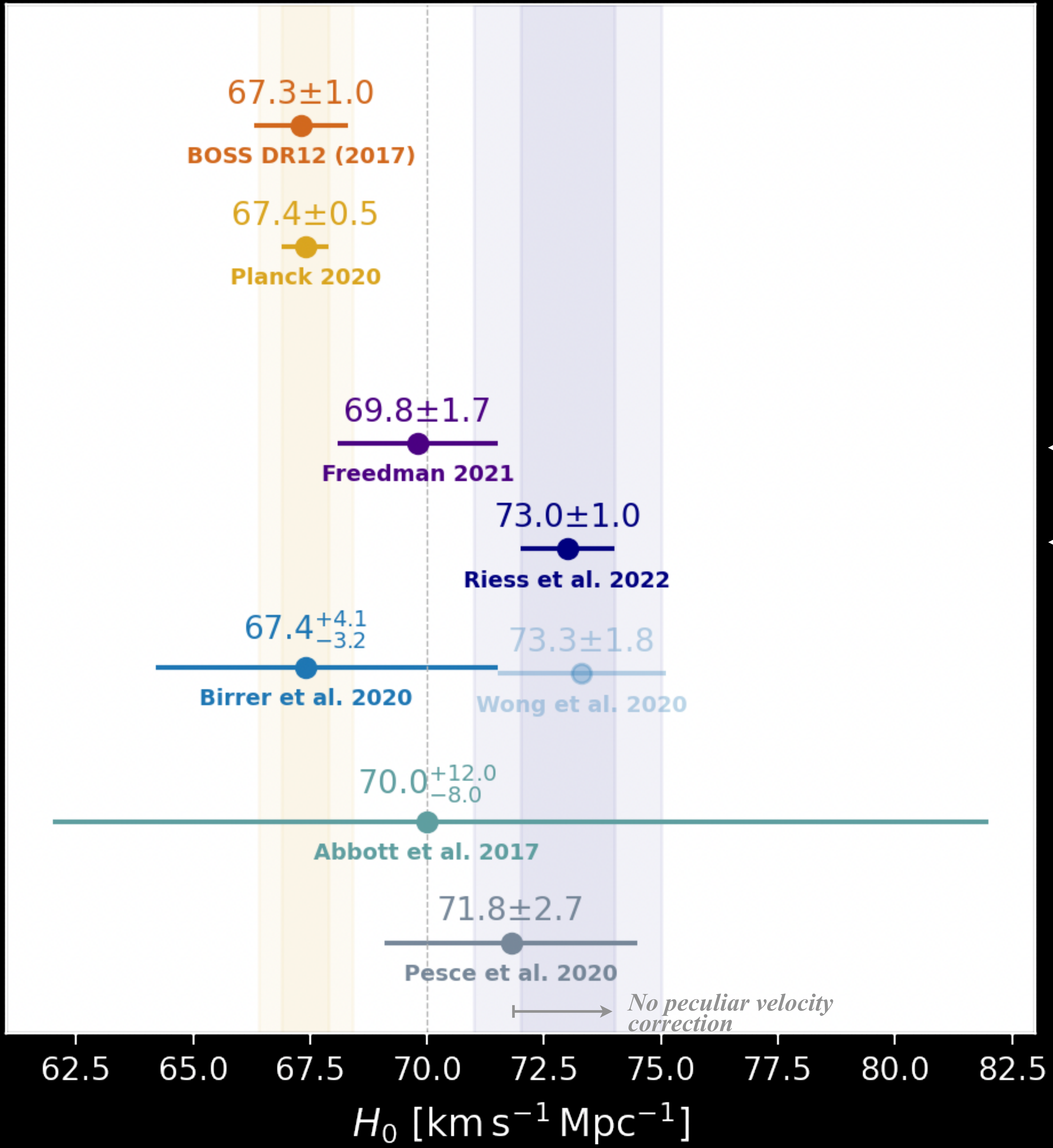
The Hubble Tension

Many more points (e.g. 2022)

- SNeIa->SNII: de Jaeger+2022 | 75±5%
- Geometry+Cepheids: Kenworthy+2022 | 73±4%
- BAO+BBN: Schöneberg+2022 | 68 ± 0.5%
- …

Strong Lensing
systematics actively studied

Sensitive to peculiar velocity correction



SNeIa calibrated by:

← **BAO (z~1)** | r_s

← **TRGB (z~0)** | *geometry*

← **Cepheids (z~0)** | *geometry*

ZTF is about to change the SNeIa field