

The Hubble Tension? in 2020

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2020.2.10

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The 9th Survey Science Workshop,
Feb 10-12, 2020, High-1 Resort, Korea

The TRGB and the Hubble Constant

Myung Gyoon Lee

with **In Sung Jang** (AIP)

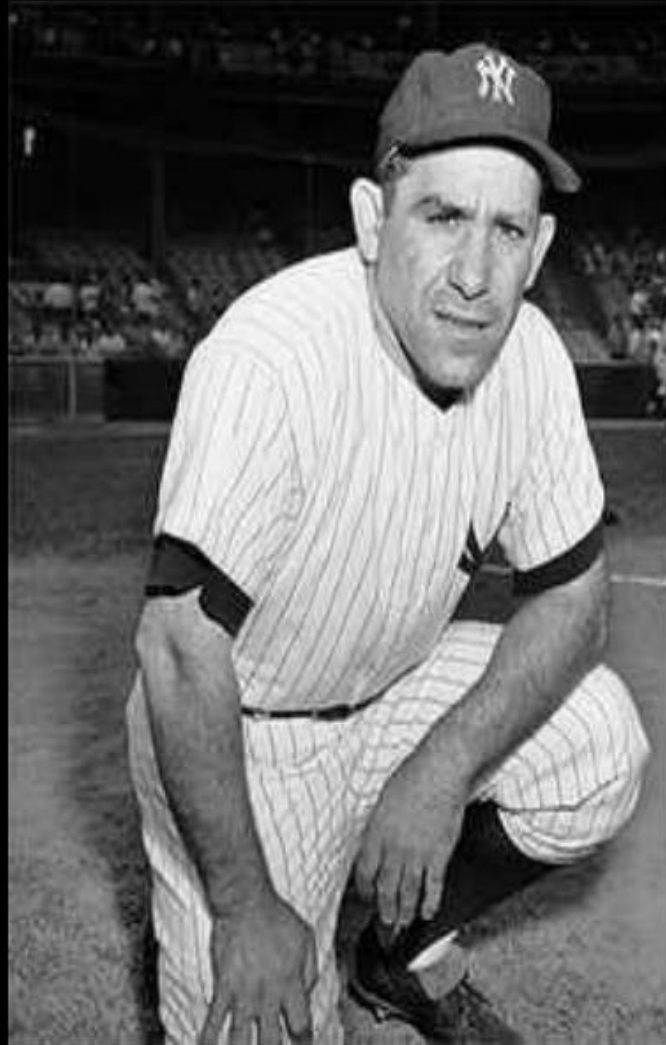
Department of Physics & Astronomy
Seoul National University ([SNU](#)), Korea

The 7th Survey Science Workshop,
Jan 15–17, 2018, High-1 Resort, Korea

$$H_0$$

Today's Expansion rate of the Universe

**The most debated parameter
in today's cosmology!**

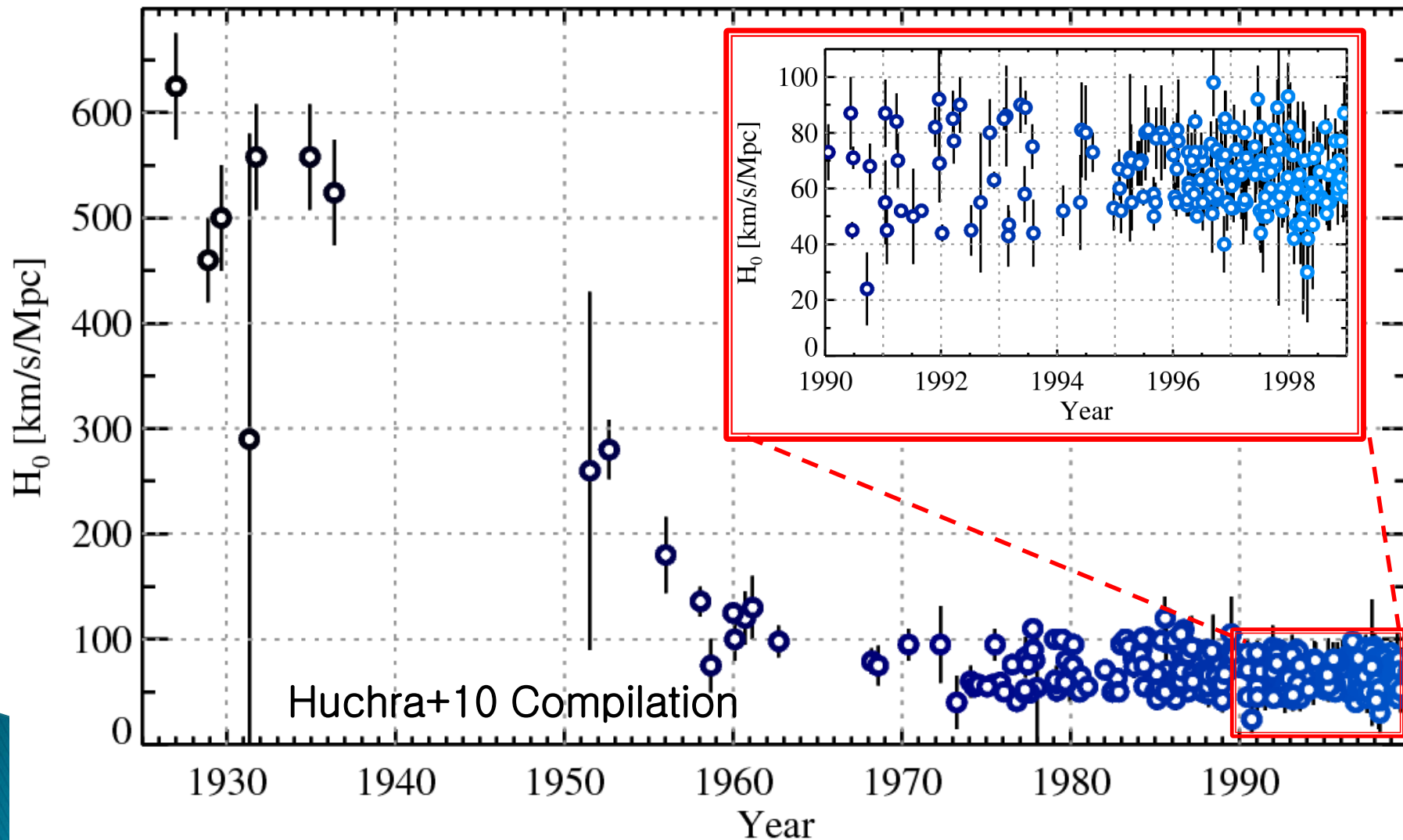


***"In theory there is
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Yogi Berra

An Old History of H_0 in 20C

- ▶ Since Lemaitre (1927)



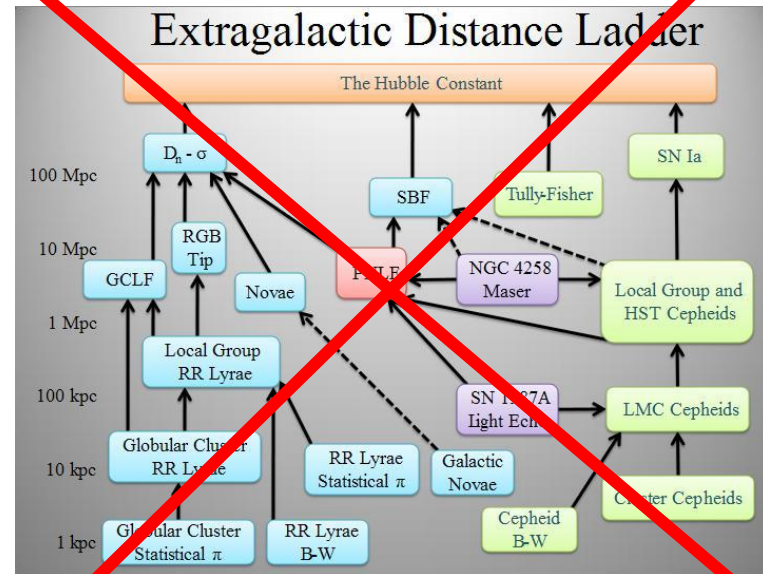
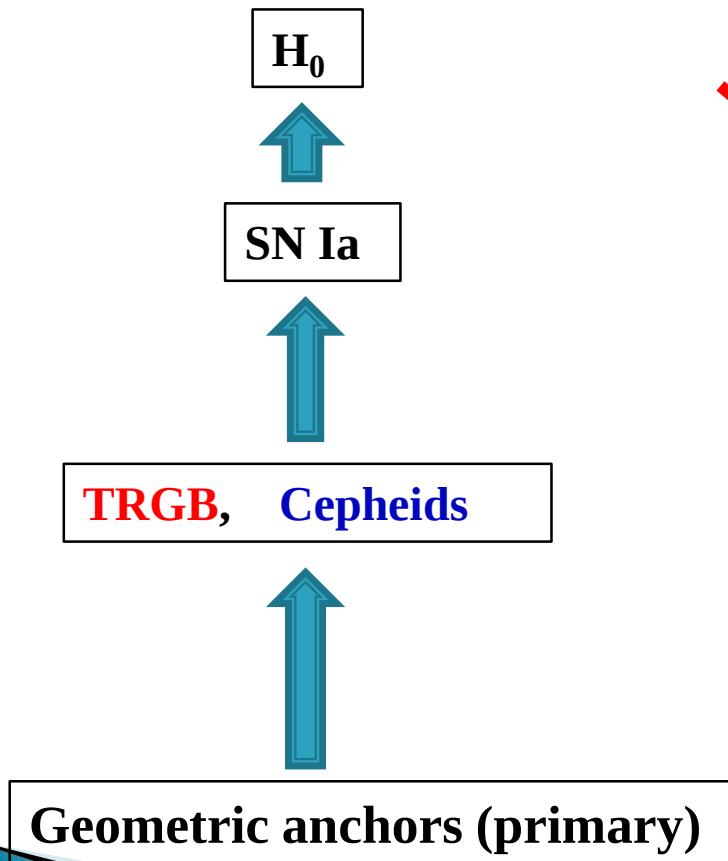
Two Ways to Estimate H_0 in 21C

- 1) $H(t=t_0)$ from local universe ($z \sim 0$)
 - cosmic distance ladder
 - direct methods based on modelling

- 2) $H(\text{high } z) \rightarrow H(t_0)$
 - inverse distance ladder (CMBR, BAO)

Modern ladder for SN cosmology

- Key: calibration of SN Ia (TRGB, Cepheids)

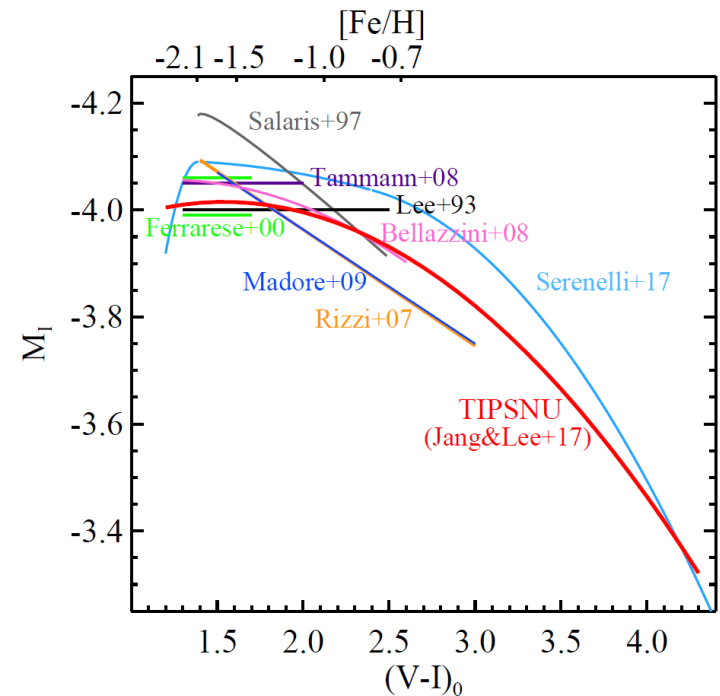
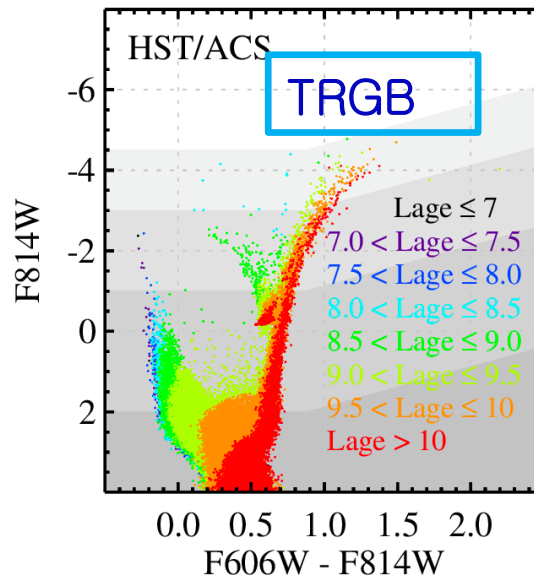
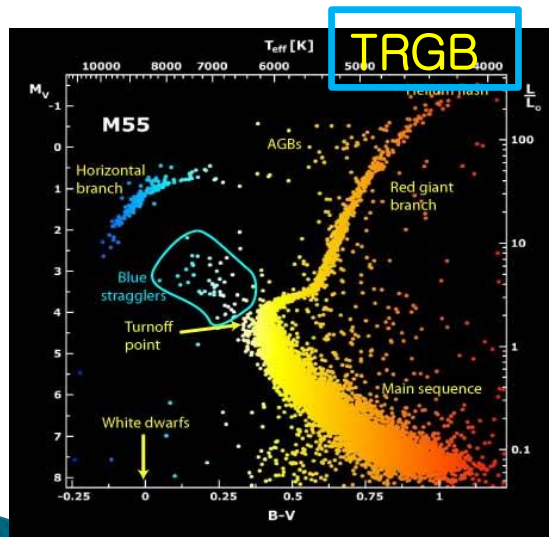


Wikipedia

TRGB for cosmology

The **T**ip of the **R**ed **G**iant **B**ranh is a powerful tool for SN cosmology to determine the Hubble Constant!

(Lee+1993, Beaton+2016, Jang & Lee2017a,b, Freedman+2019,2020).



TRGB Calibration of SN

TIPSNU (Lee, Jang+ 2012-):

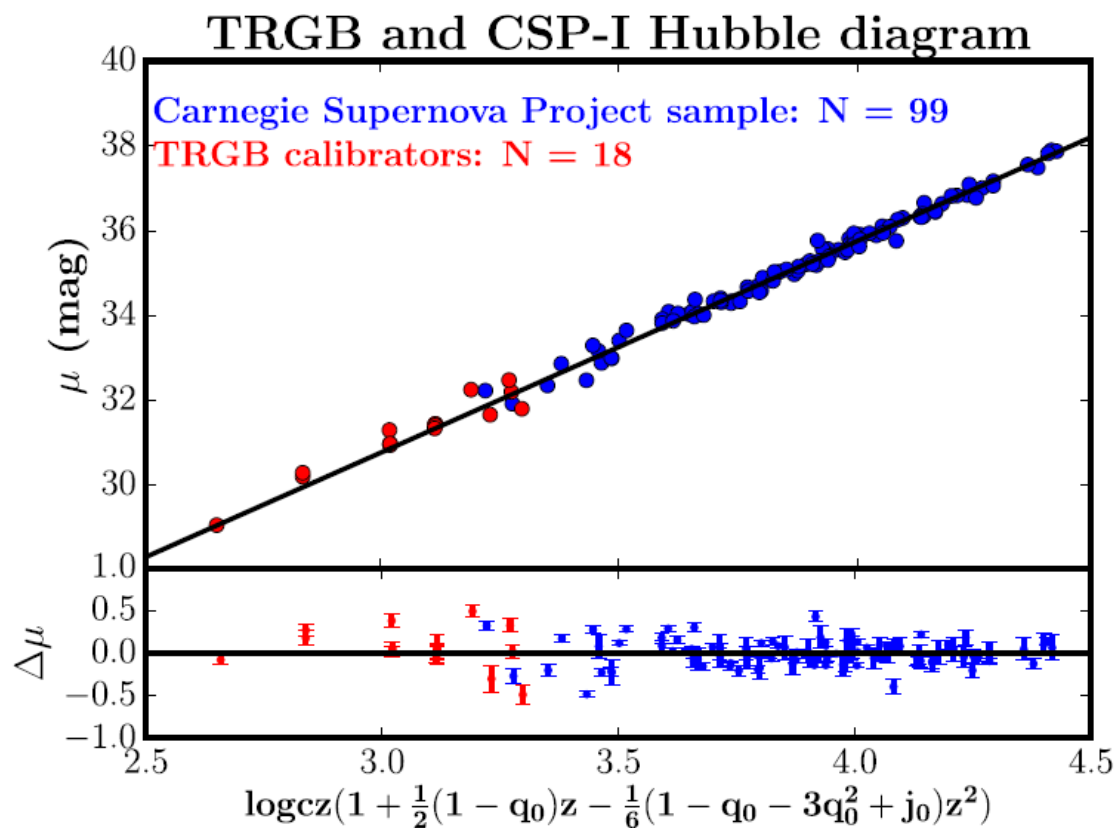
The **Tip** of the RGB
for **SN** host galaxies
in the **U**niverse
at **S**eoul **N**ational **U**niversity!

NGC 1309 : SN 2002fk (The Champion in TRGB)

$(m-M)_{0,\text{Cep}} = 32.47_{\pm 0.04}$ (Jang & Lee 2017) **F555W** : 57,600s
 $\rightarrow d \sim 31.2$ Mpc **F814W** : 24,000s

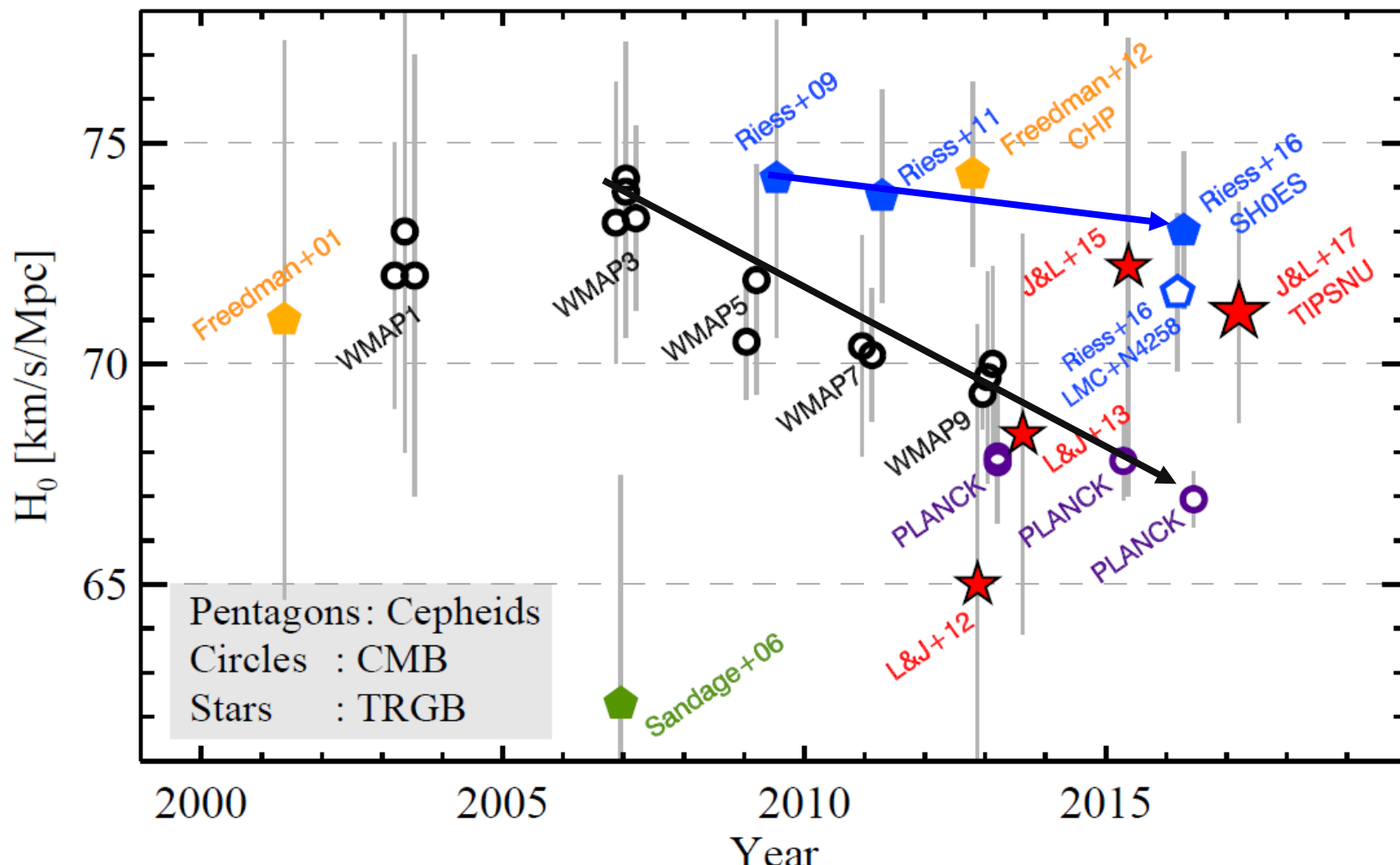
H_0 from SN Ia

- SN Ia (Cepheids): SHOES (Riess+2016–2020)
- SN Ia (TRGB): TIPSNU (Jang & Lee 2017)
- CCHP (Freedman+2019)



H_0 from SN Ia(TRGB) in 2017!

- ▶ SN Ia(Cepheid based on 4 anchors) – PLANCK : 3σ
- ▶ SN Ia(TRGB, Cep based on 2 anchors) – PLANCK : 2σ



Tension, Problem or Crisis?

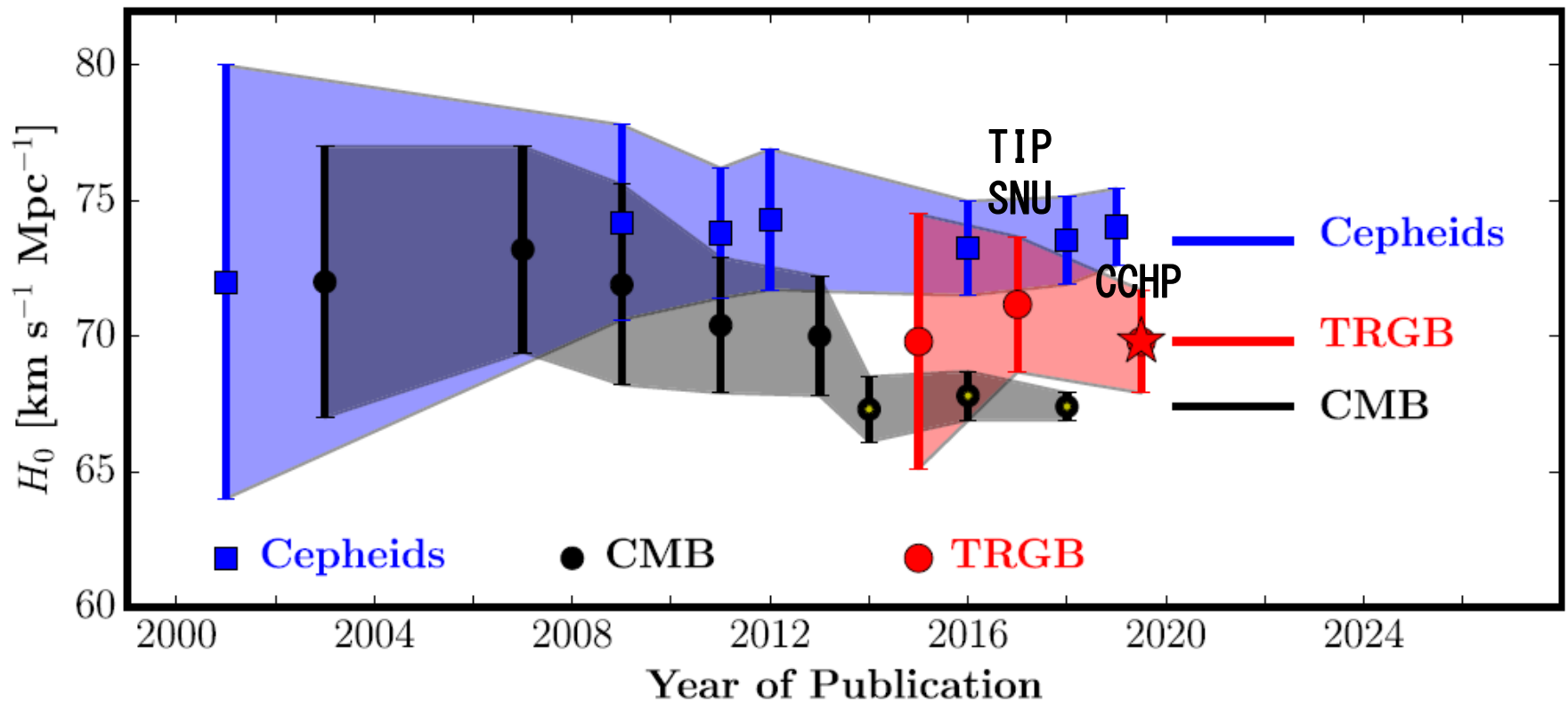
Difference level

- 2σ : curiosity
- 3σ : tension
- 4σ : discrepancy or problem
- 5σ : crisis

H_0 in (2001–2019)

- CMB (WMAP, PLANCK, SPT...)
- SN Ia Cepheids (Riess+2019): 4–5 σ
- SN Ia TRGB: TIPSNU (Jang & Lee 2017, LMC+M106 as anchor): $\sim 2\sigma$
CCHP (Freedman+2019, LMC as anchor): $\sim 2\sigma$

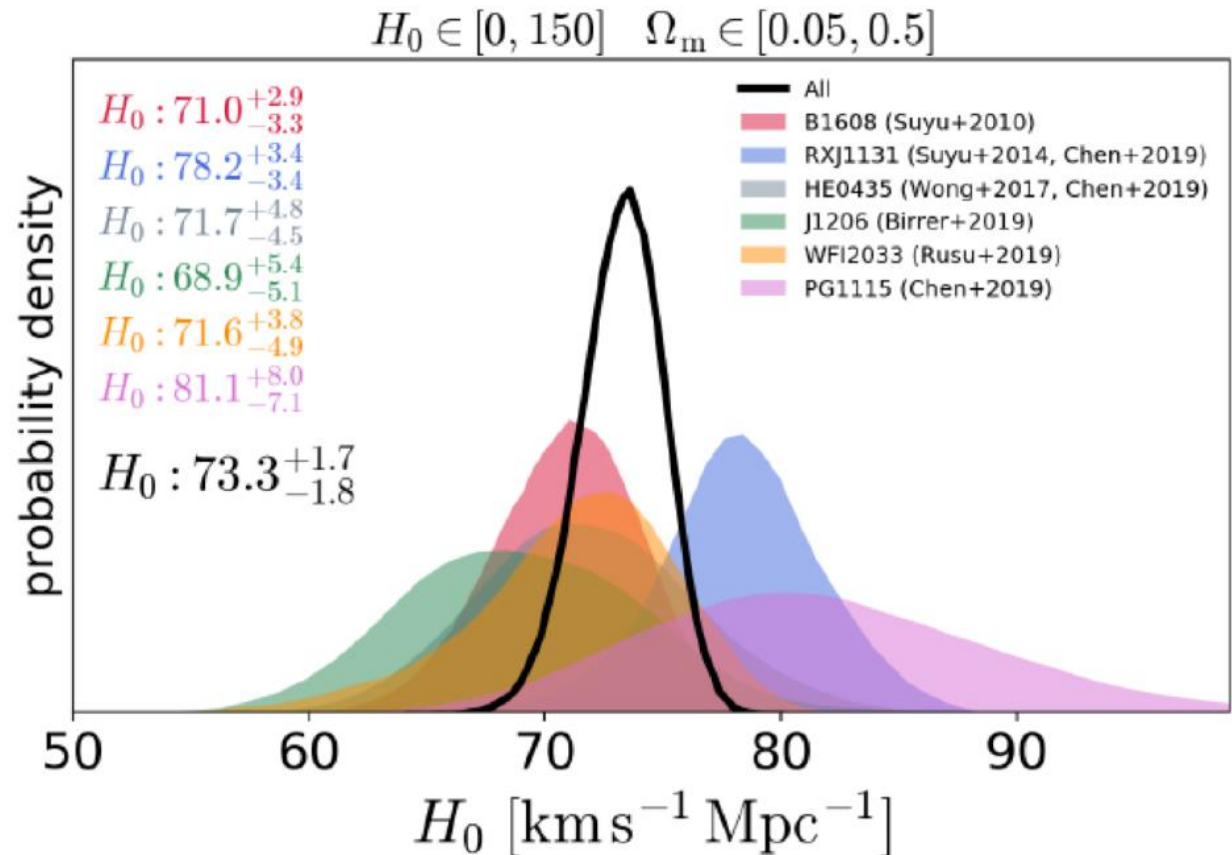
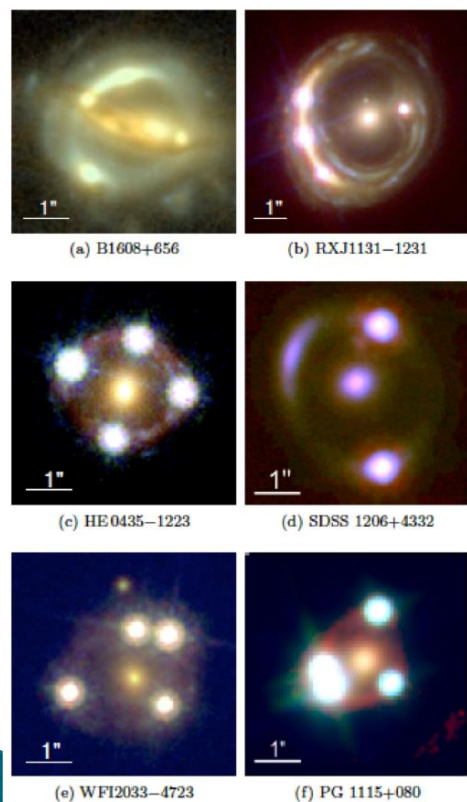
Hubble Constant Over Time



Freedman+(2019, ApJ): CCHP

Time Delay Cosmology (2019)

- Time delay in gravitationally lensed quasars (TDGL): HOLICOW
- A new rising star in 2020s!

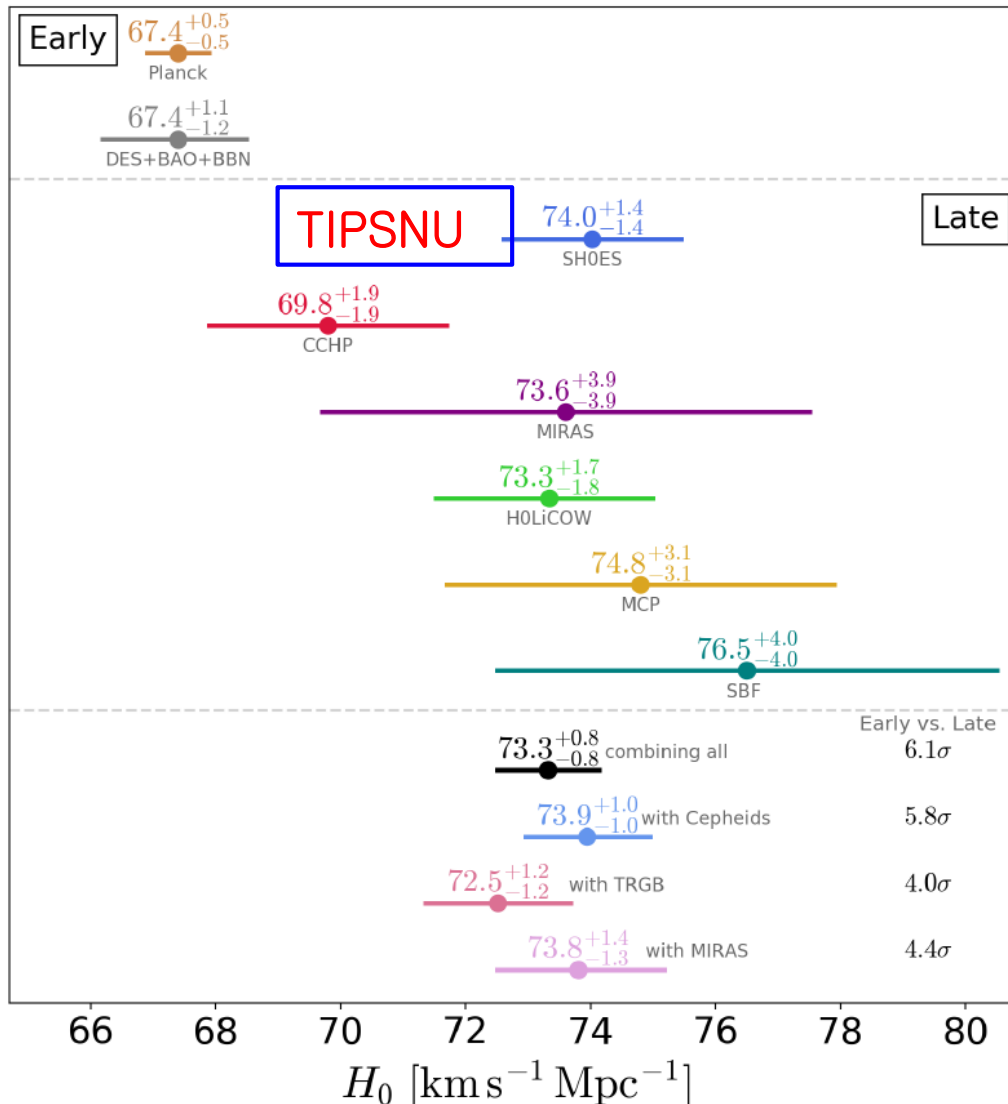


Wong et al 2019 (HOLICOW)
Treu (2019, KITP EU & LU) slide

Summary of KITP2019 meeting:

Tensions between the Early and Late Universe

flat - Λ CDM



Difference level: 4–6 σ

SHOES (Riess+2019) :
 $H_0 = 74.0 \pm 1.4$ km/s/Mpc

TIPSNU (Jang & Lee 2017) :
 $H_0 = 71.2 \pm 2.5$ km/s/Mpc

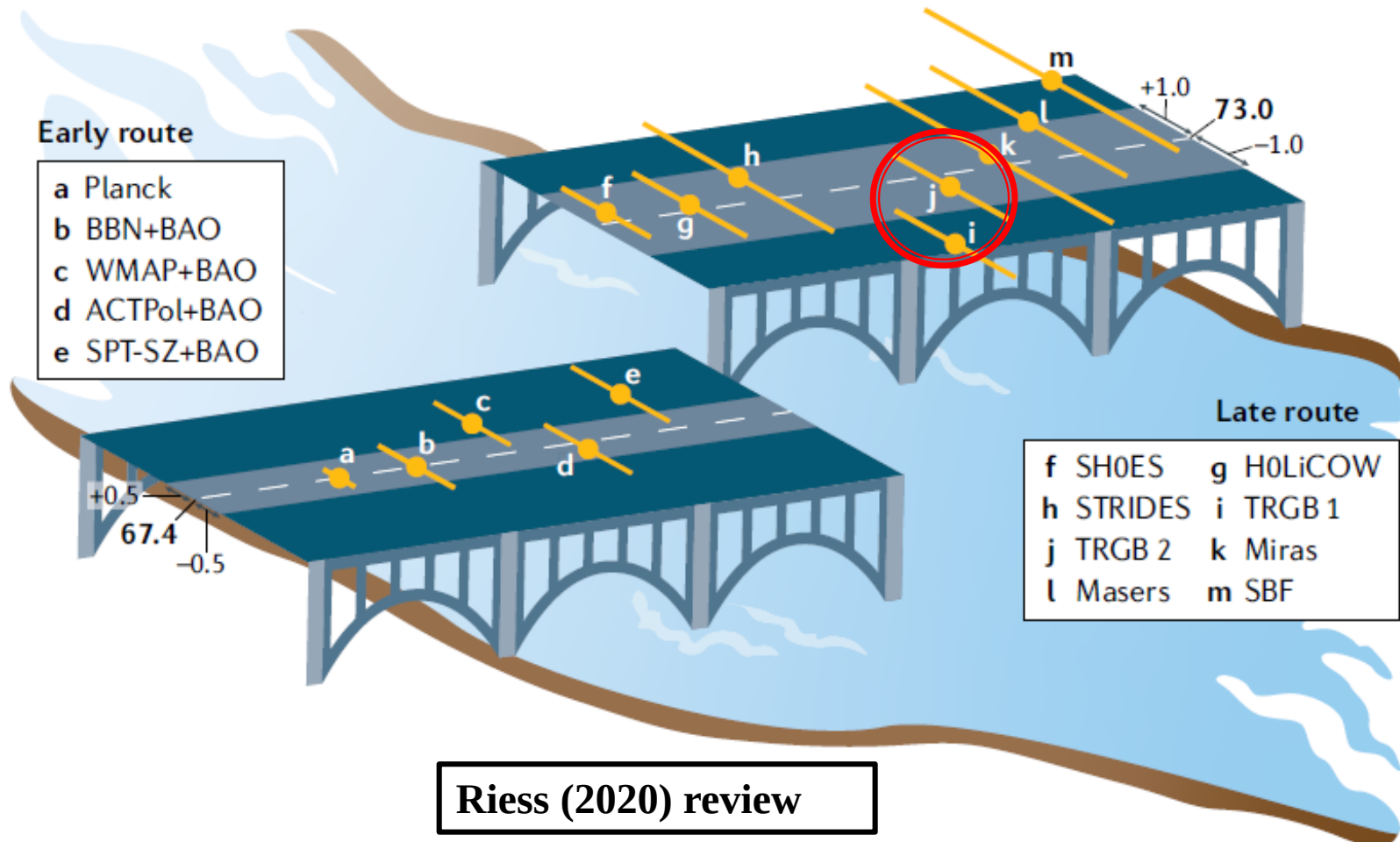
CCHP (Freedman+2019) :
 $H_0 = 69.8 \pm 1.9$ km/s/Mpc

Verde+2019 KITP summary

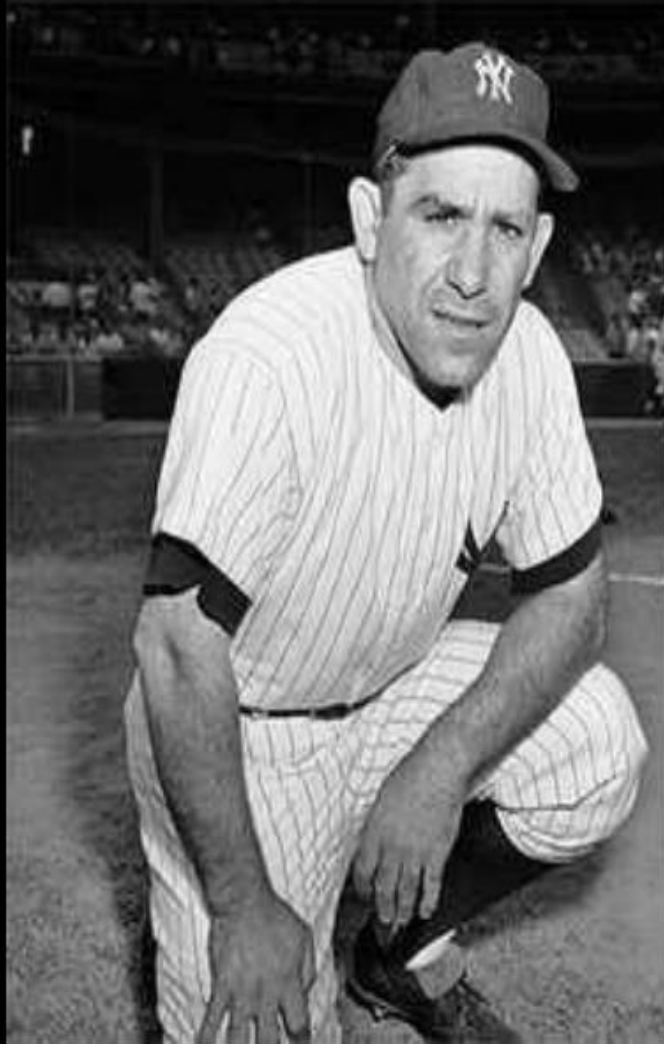
Hubble Tension in 2019: $4-6\sigma$

SN Ia (TRGB): j: TIPSNU (Jang & Lee 2017)

i: CCHP (Freedman 2019, 2020)



“It ain’t over till it is over!”

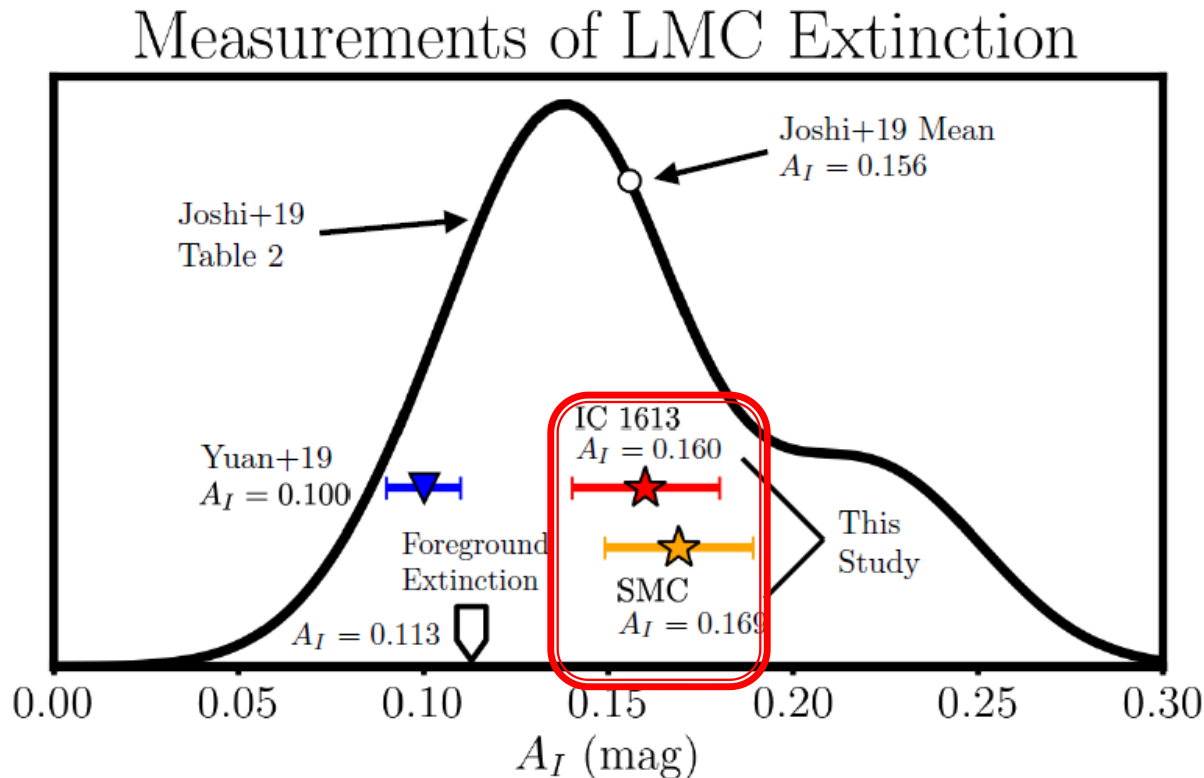


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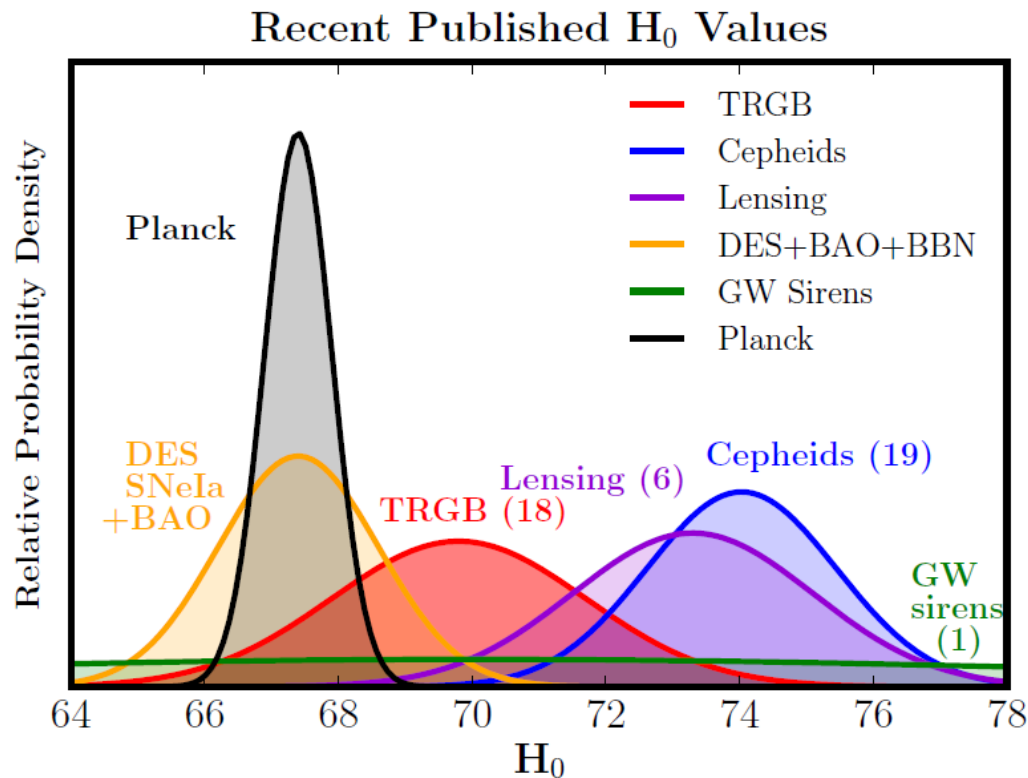
H_0 from SN Ia(TRGB) in 2020

- **CCHP: multiband TRGB calibration for LMC reddening**
- $A_I = 0.165$ mag, higher than previous studies
- $M_I(\text{TRGB}) = -4.05 \pm 0.02(\text{stat}) \pm 0.04(\text{sys})$, brighter than previous studies



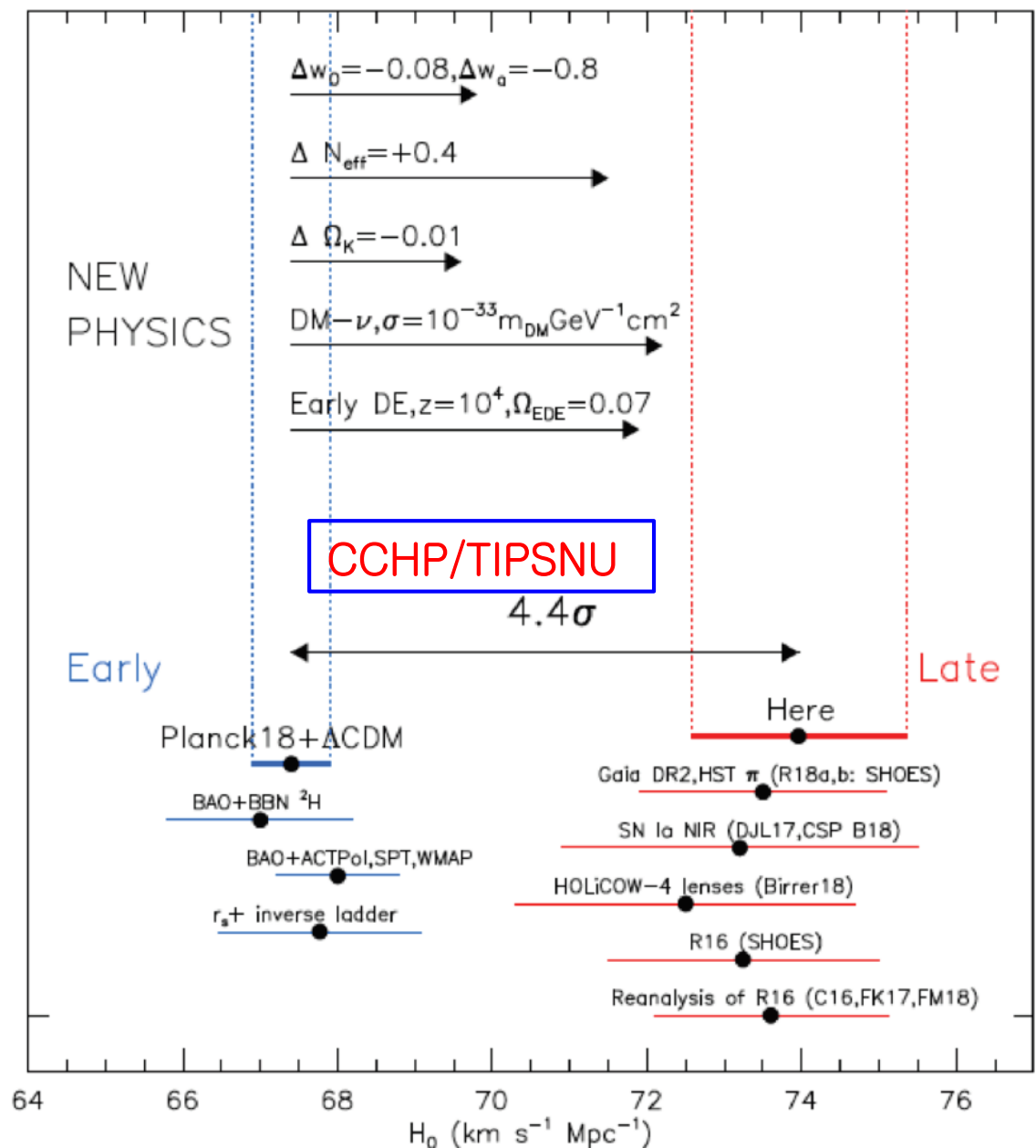
H_0 in 2020

- CCHP: SN Ia (TRGB with LMC reddening)
- $H_0 = 69.6 \pm 0.8(1.1\% \text{ stat}) \pm 1.17(2.4\% \text{ sys}) \text{ km/s/Mpc}$: 2σ
- PLANCK: $H_0 = 67.4 \pm 0.5 \text{ km/s/Mpc}$:



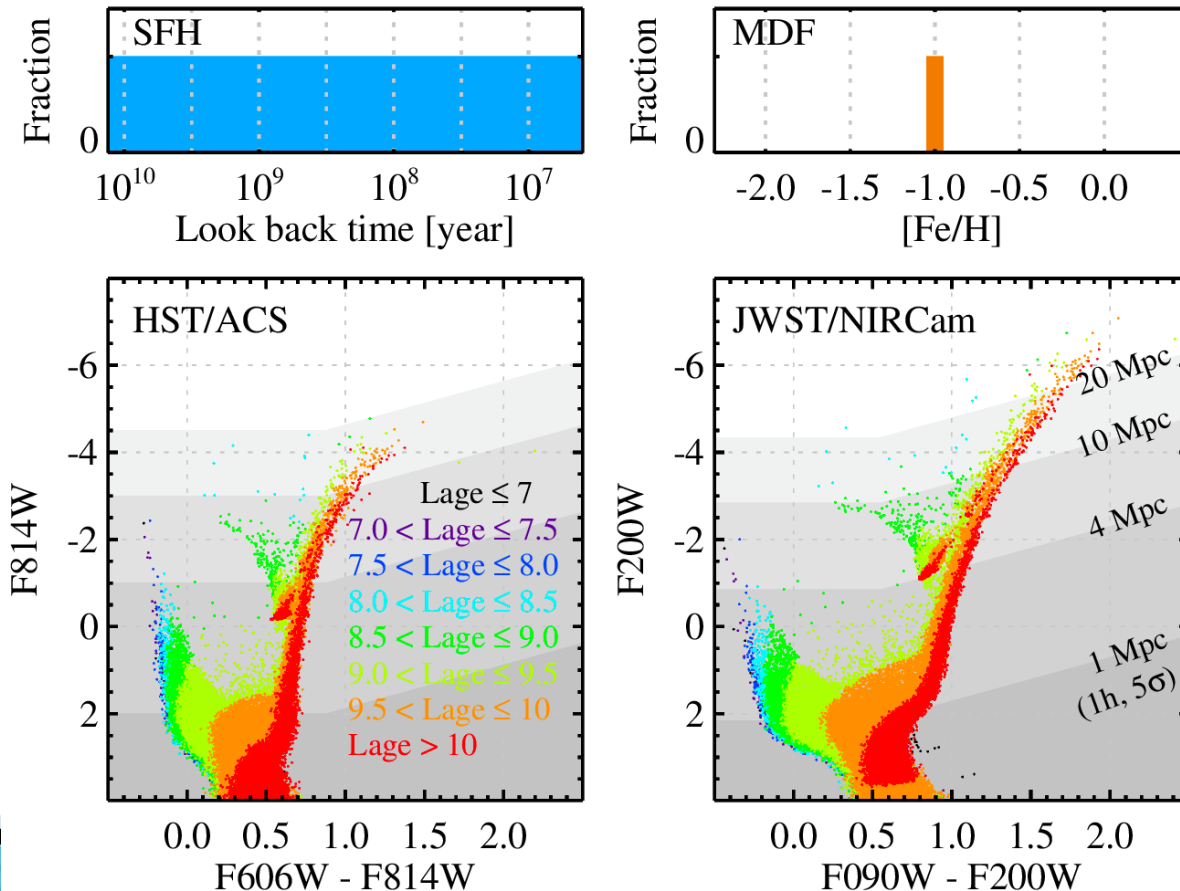
Solutions?

- CMB?
- BAO?
- Distance ladder?
- Cepheids or TRGB?
- New Physics?



Future of SN Ia cosmology

- Going farther with NIR (JWST 2021–)
- Increasing N (SN Ia host galaxies)
- Reducing TRGB/Cepheid errors with GAIA



Summary

- The TRGB is a precise distance indicator based on geometric anchors, being an excellent tool for H_0 !
- H_0 in 2020 is still evolving!
- In 2020: the Hubble tension/problem ($2-4\sigma$)?
- The future of the H_0 tension?
- Stay tuned!