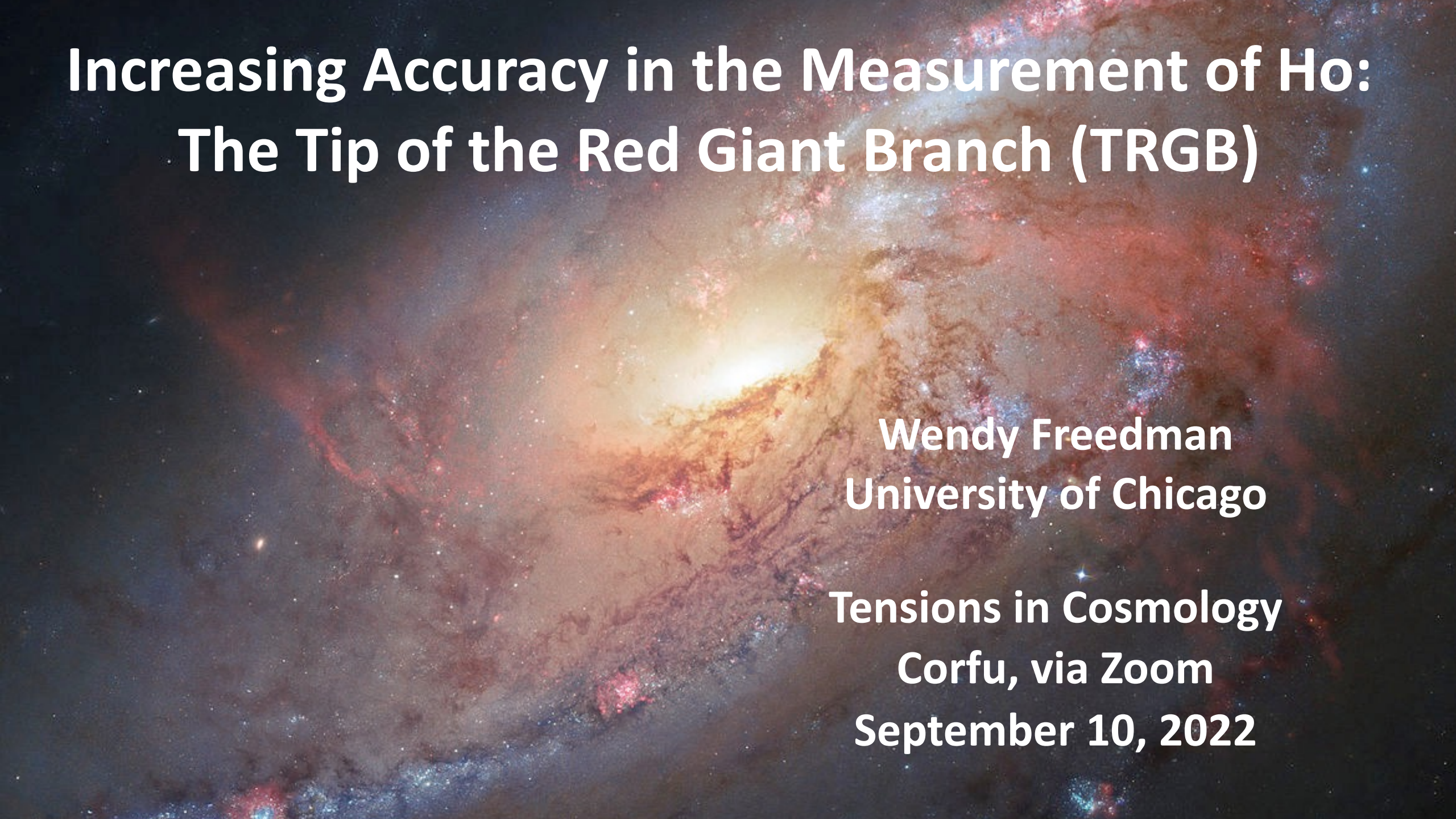
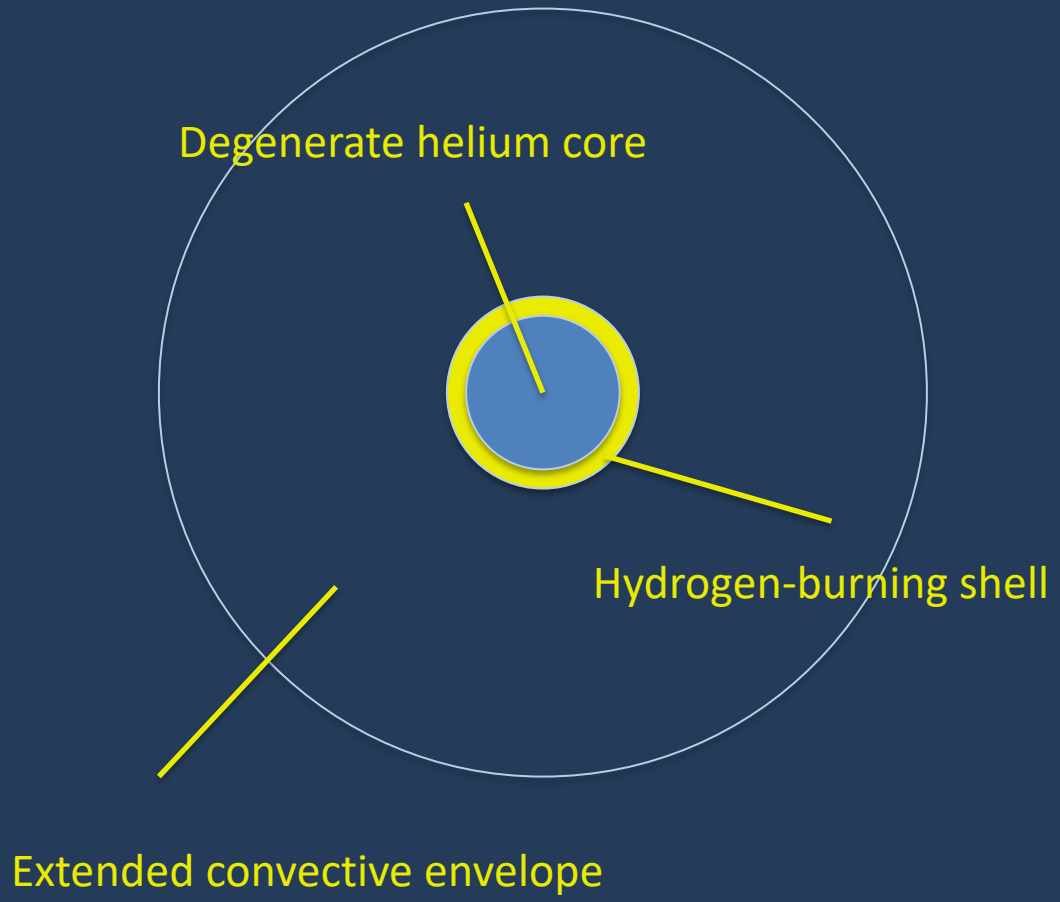
Increasing Accuracy in the Measurement of Ho: The Tip of the Red Giant Branch (TRGB)



Wendy Freedman
University of Chicago

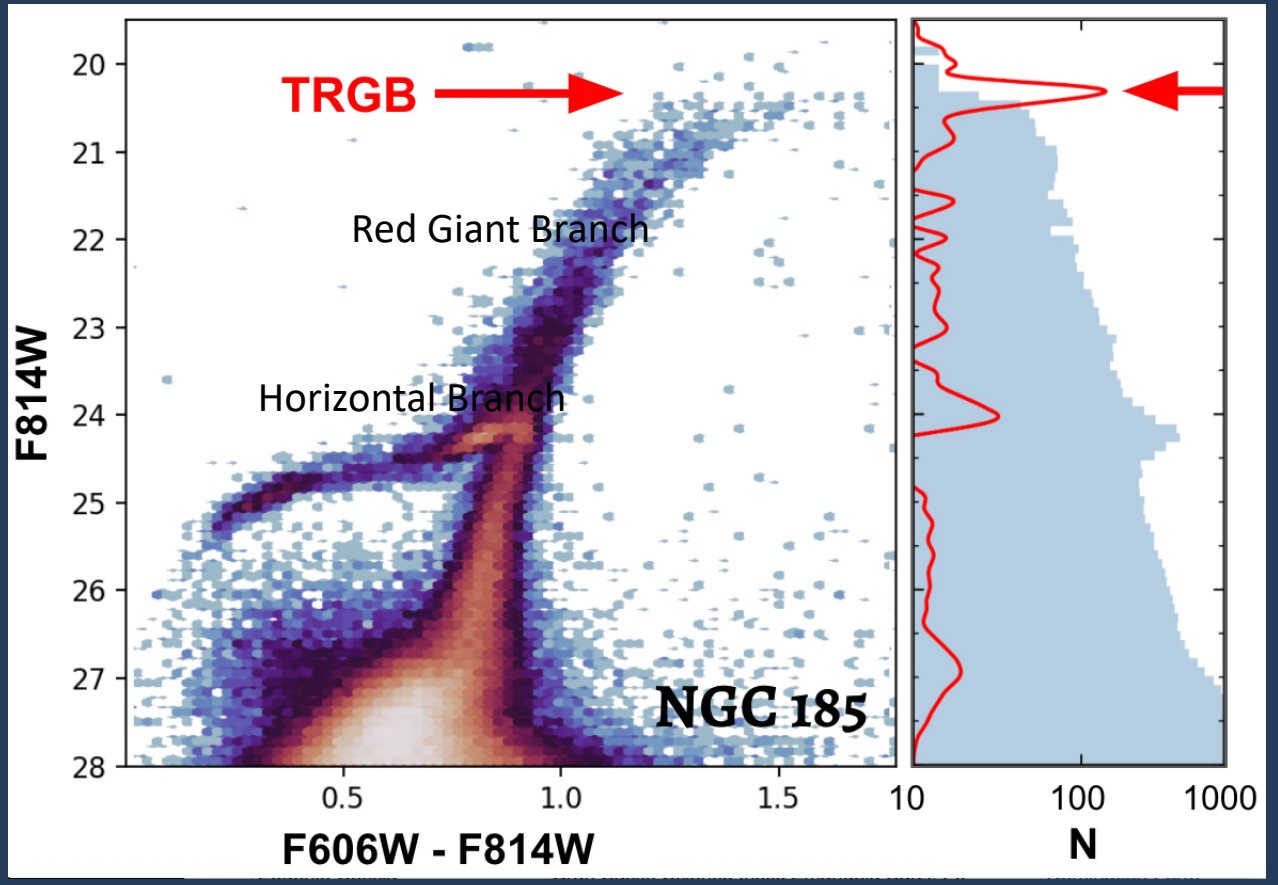
Tensions in Cosmology
Corfu, via Zoom
September 10, 2022

Stellar Astrophysical Distance Methods: Lifting Degeneracy in Helium Core for Low-mass Stars (TRGB)



- Well-understood nuclear physics determines the temperature at which the electron degeneracy in the core is lifted, followed by helium core ignition
- $T_c \sim 10^8$ K, $M_c = 0.47\ M_\odot$
- Because of the degeneracy, the helium ignition happens at almost constant core mass. Thus the ignition occurs at a predictable luminosity.

Observing the TRGB



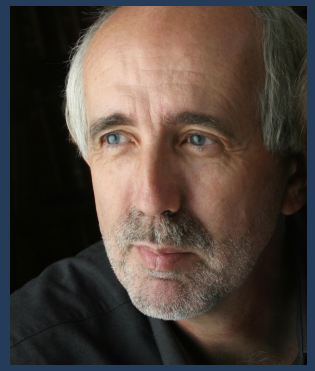
Luminosity ->

← Temperature

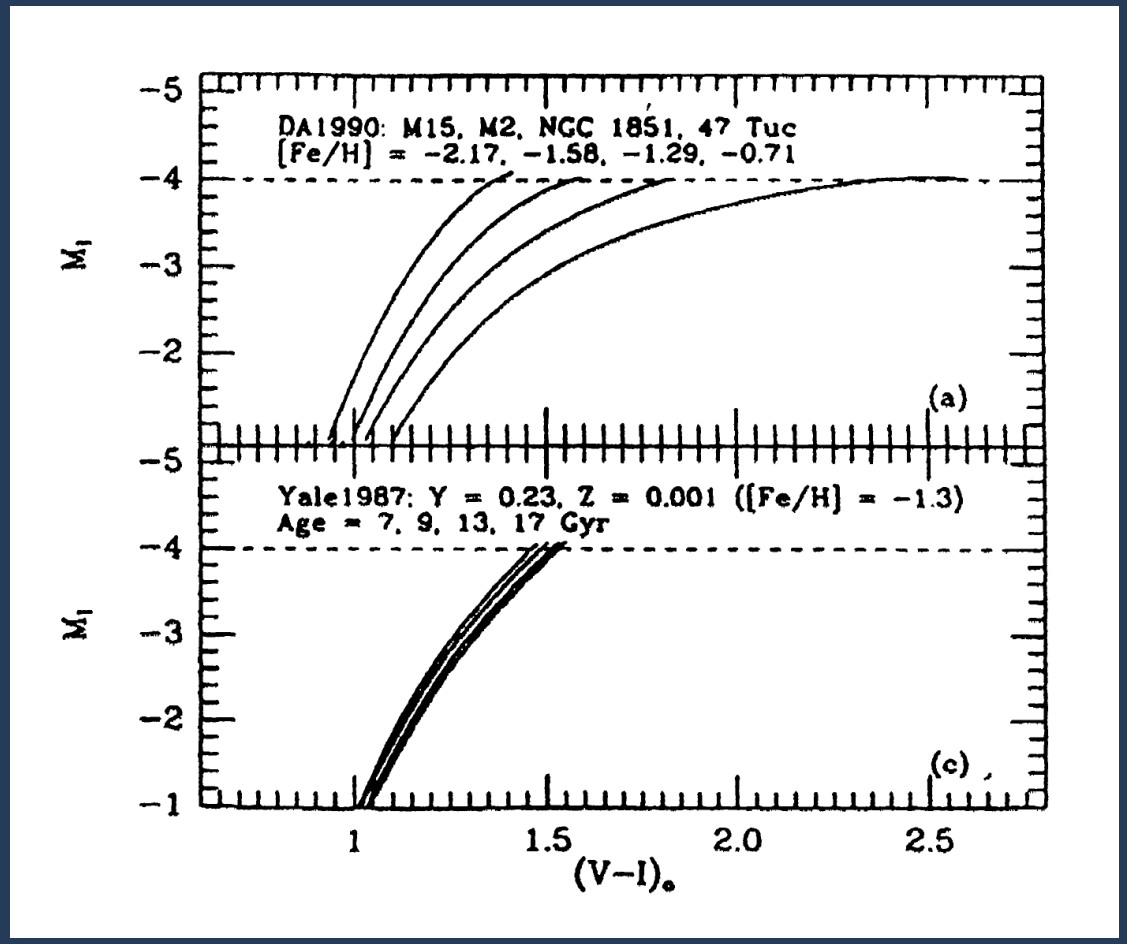
Data courtesy M. Geha,
Plot by I. Jang

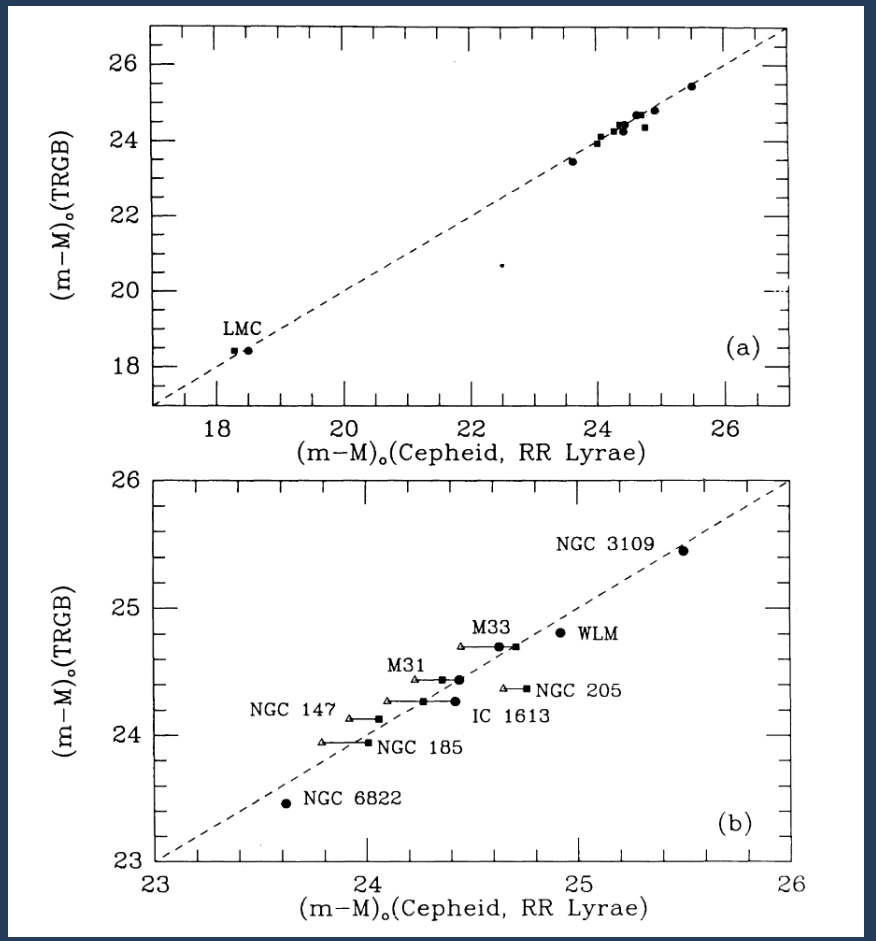
I-band TRGB for Measuring Distances

Myung Gyoon Lee



Barry Madore





Lee, WLF, Madore 1990

Advantages & Disadvantages of Cepheids and TRGB for Measuring Distances

Cepheids

Advantages

1 Bright (M_V ~-6 mag)
2 Easily Identifiable
3 Potentially small dispersion in PL

Disadvantages

1 Metallicity dependence
2 Late-type galaxies only
3 Crowding/blending
4 Need many epochs
5 In regions of high extinction

TRGB

Advantages

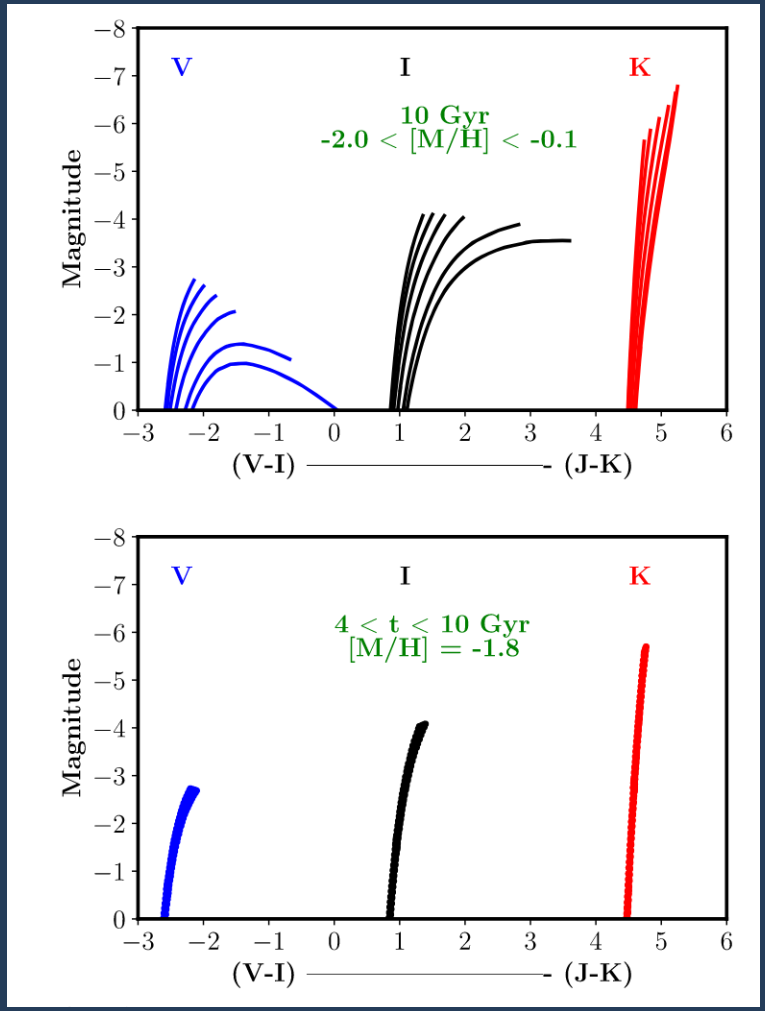
1 In all types of galaxies
2 In regions of low to no extinction
3 Crowding negligible
4 Non-variable
5 Easily calibrated metallicity
6 Small dispersion in tip luminosity

Disadvantages

1 Fainter (M_I~-4 mag)

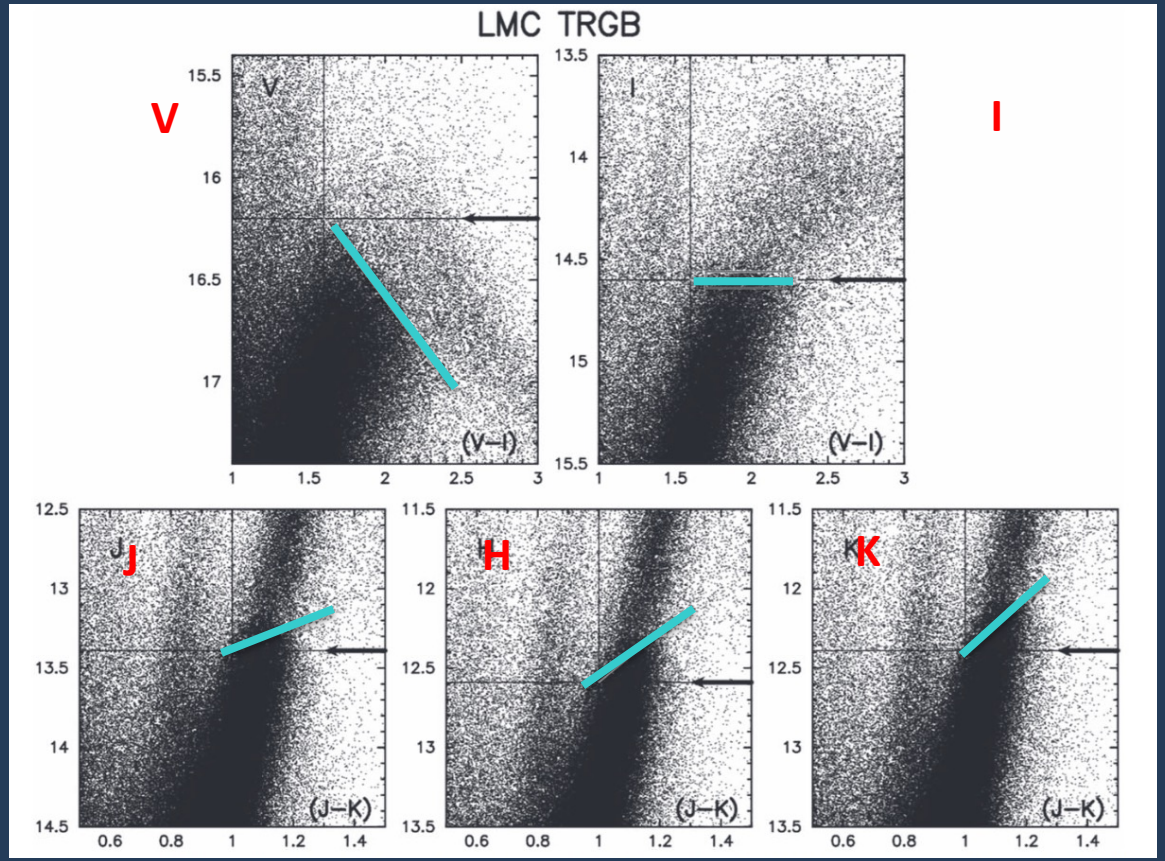
Freedman (2021) ApJ, 919, 16

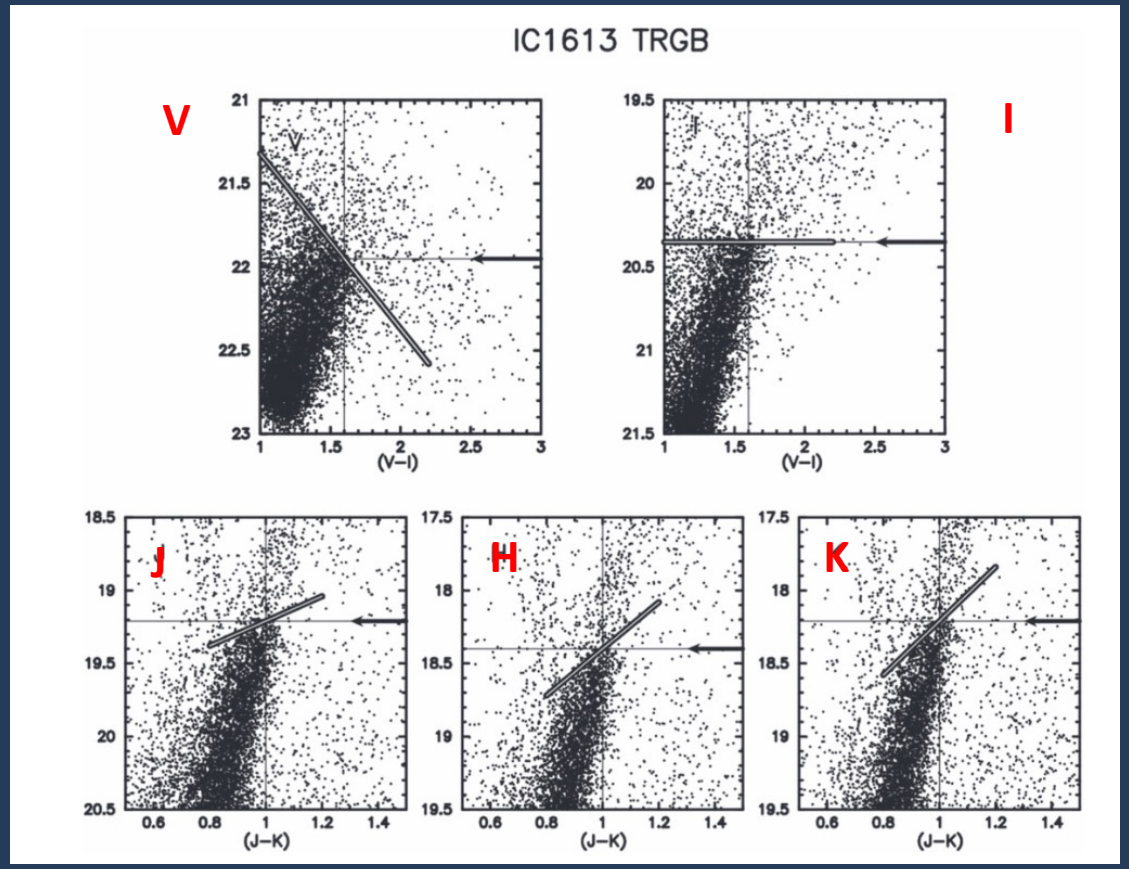
Tip of the Red Giant Branch (TRGB)



WLF et al. (2020)

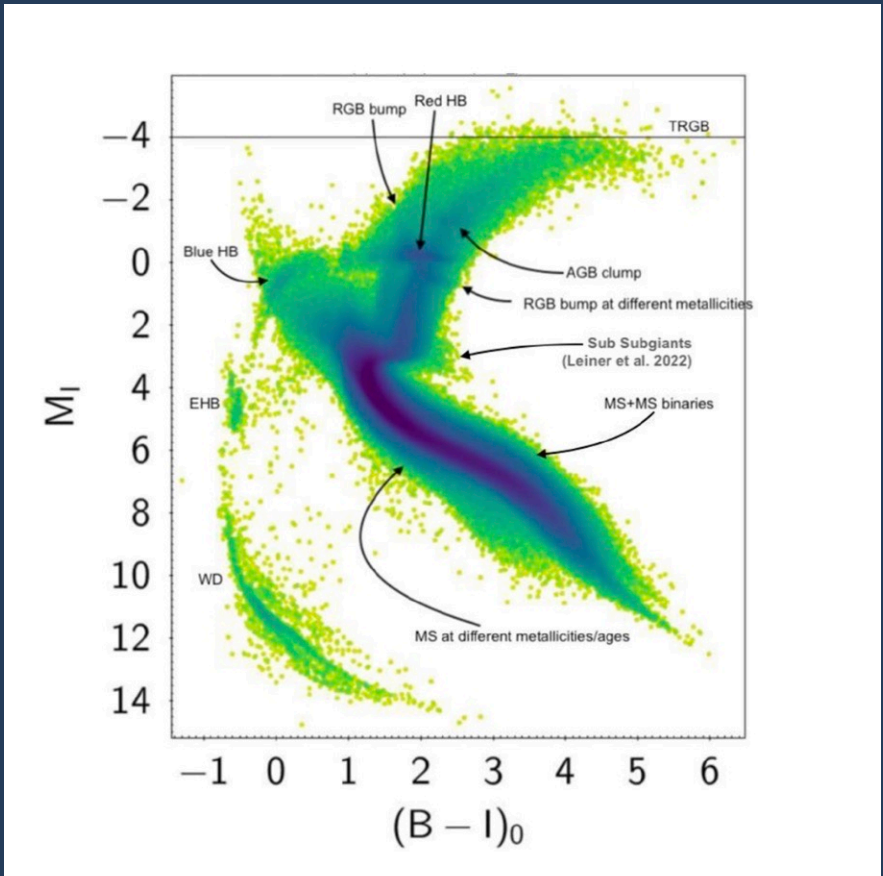
Tip of the Red Giant Branch (TRGB)





WLF et al. (2020)

Milky Way CMD from Gaia

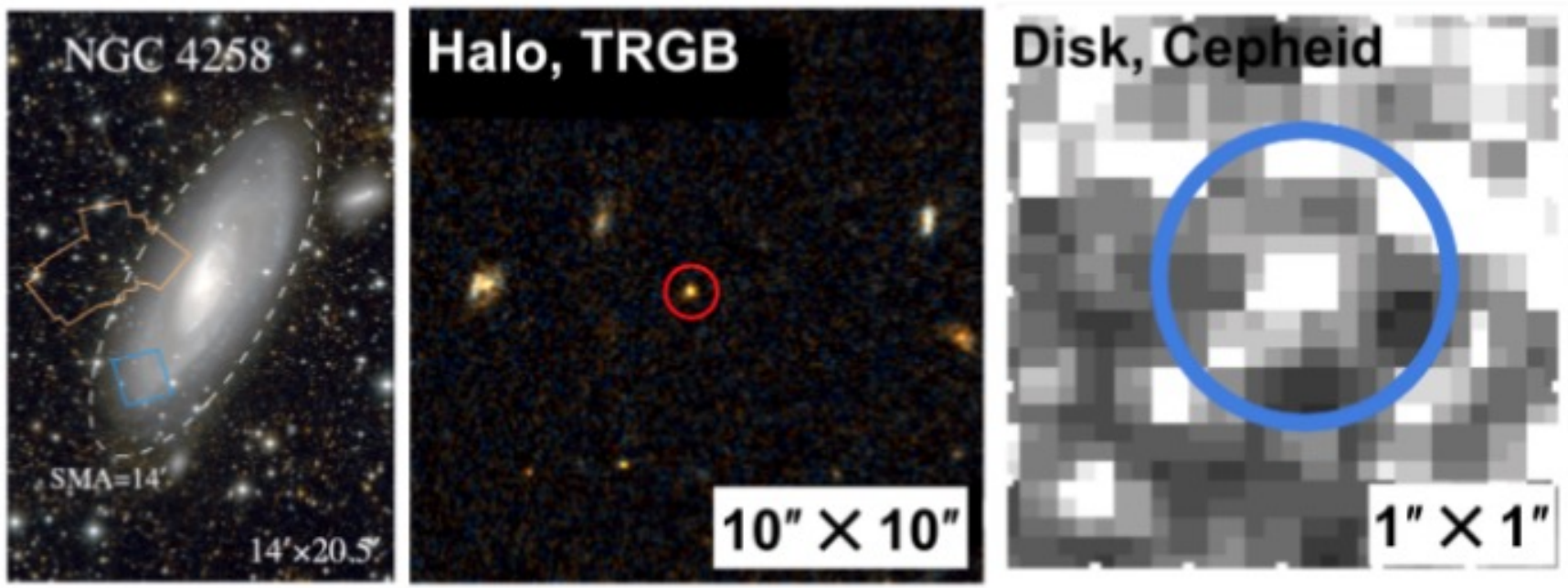


4 million stars |b| > 50°

CMD generated by combining Johnson-Kron-Cousins (B-I) from the Gaia parallax and XP spectra using synthetic photometry

M. Bellazini

Halo (TRGB) vs Disk (Cepheid) fields: NGC 4258



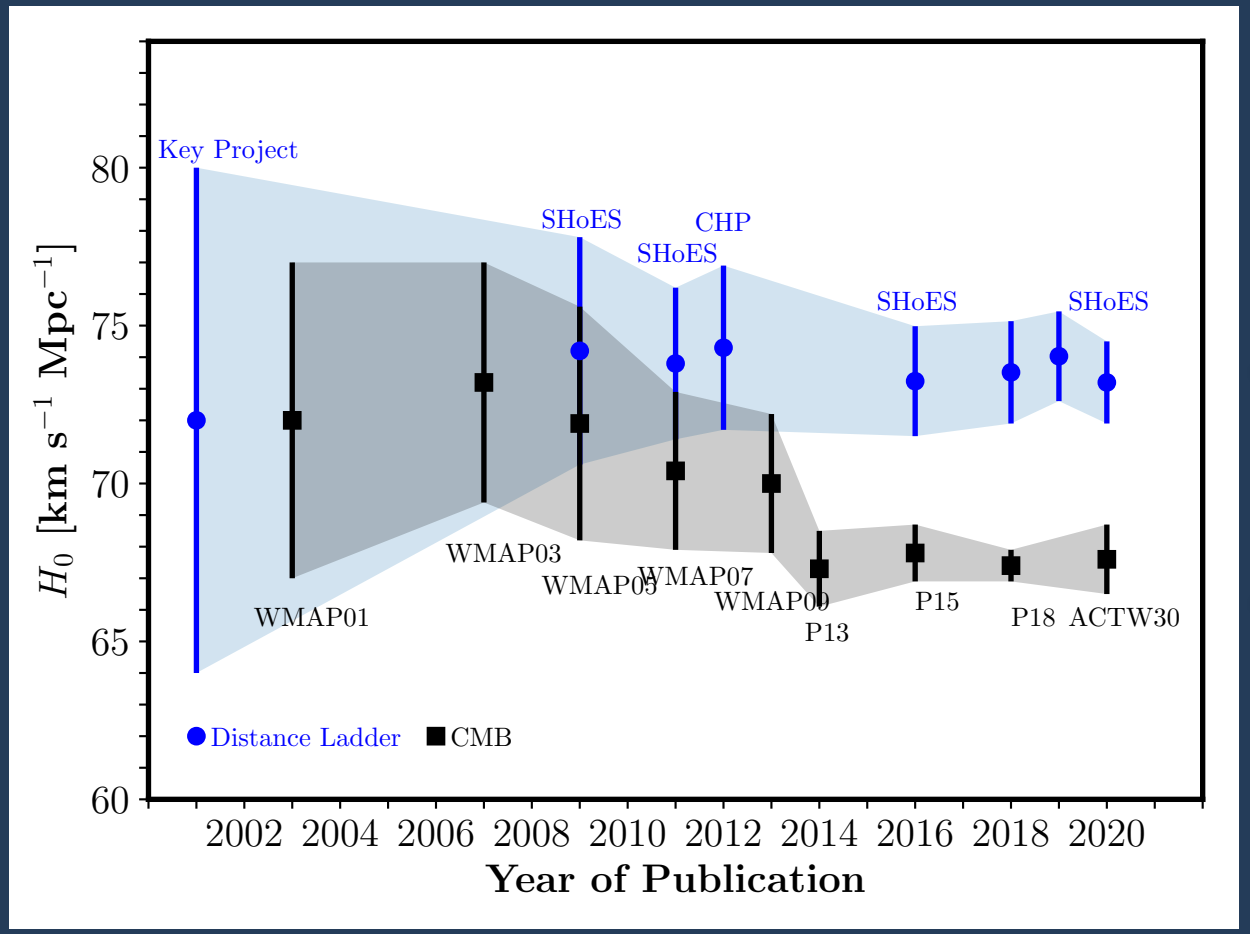
NGC 4258:
distance 7.6 Mpc.

Cepheid shown is one of brightest in the sample.

The SN Ia hosts extend to >40 Mpc.

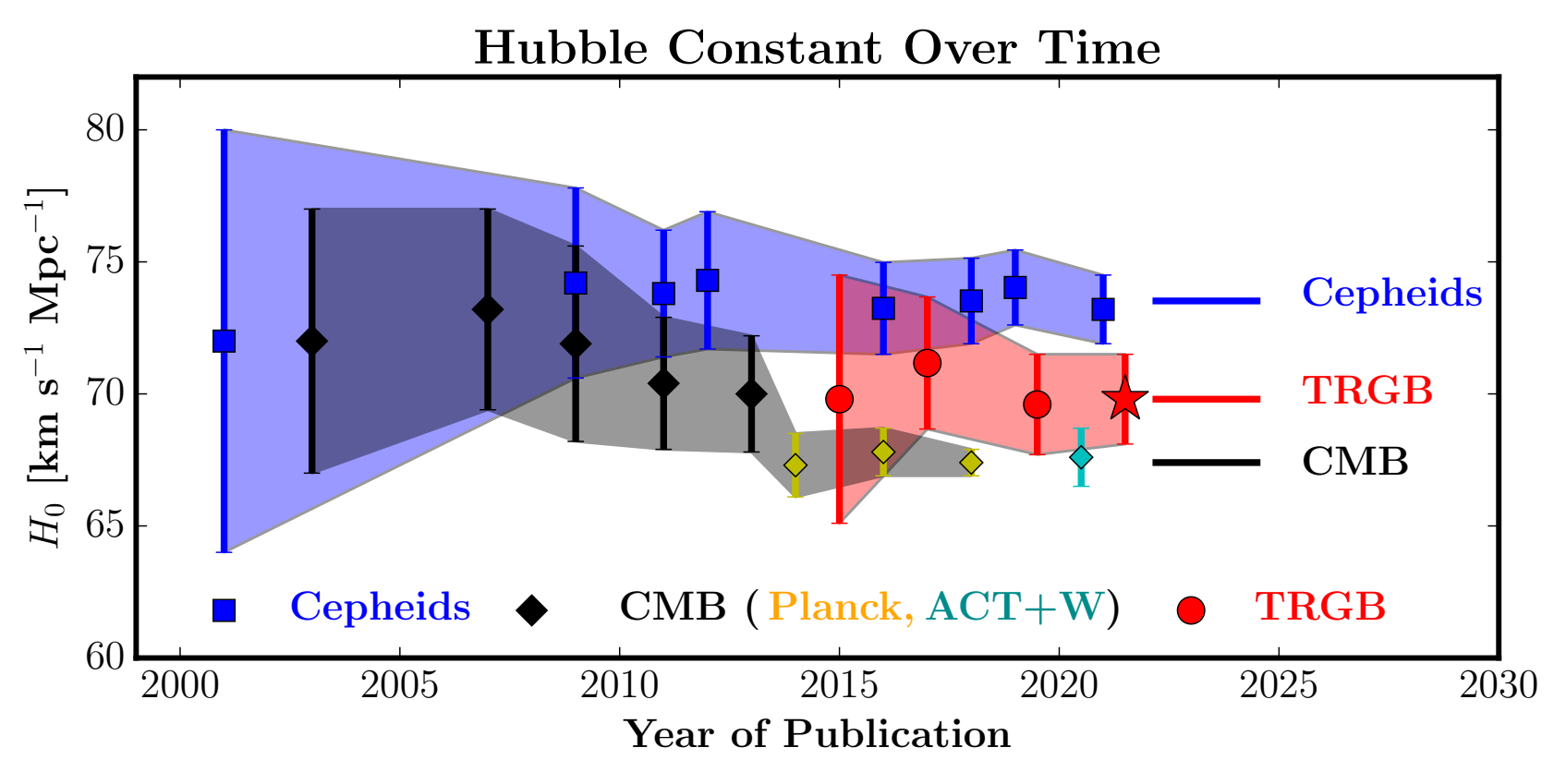
TRGB stars can be found in the outer halos of galaxies where the surface brightness is typically ~5 magnitudes (a factor of 100) fainter that the disk.

Tension in the Hubble Constant



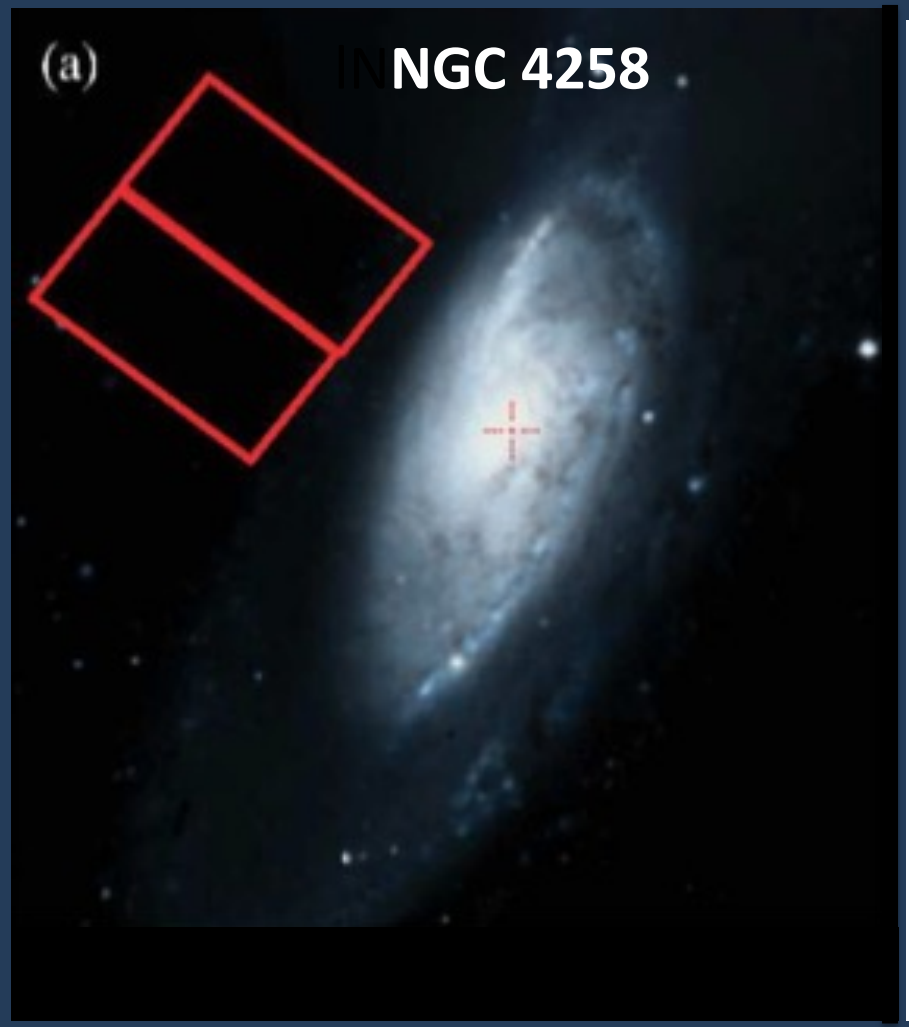
~3-5σ tension

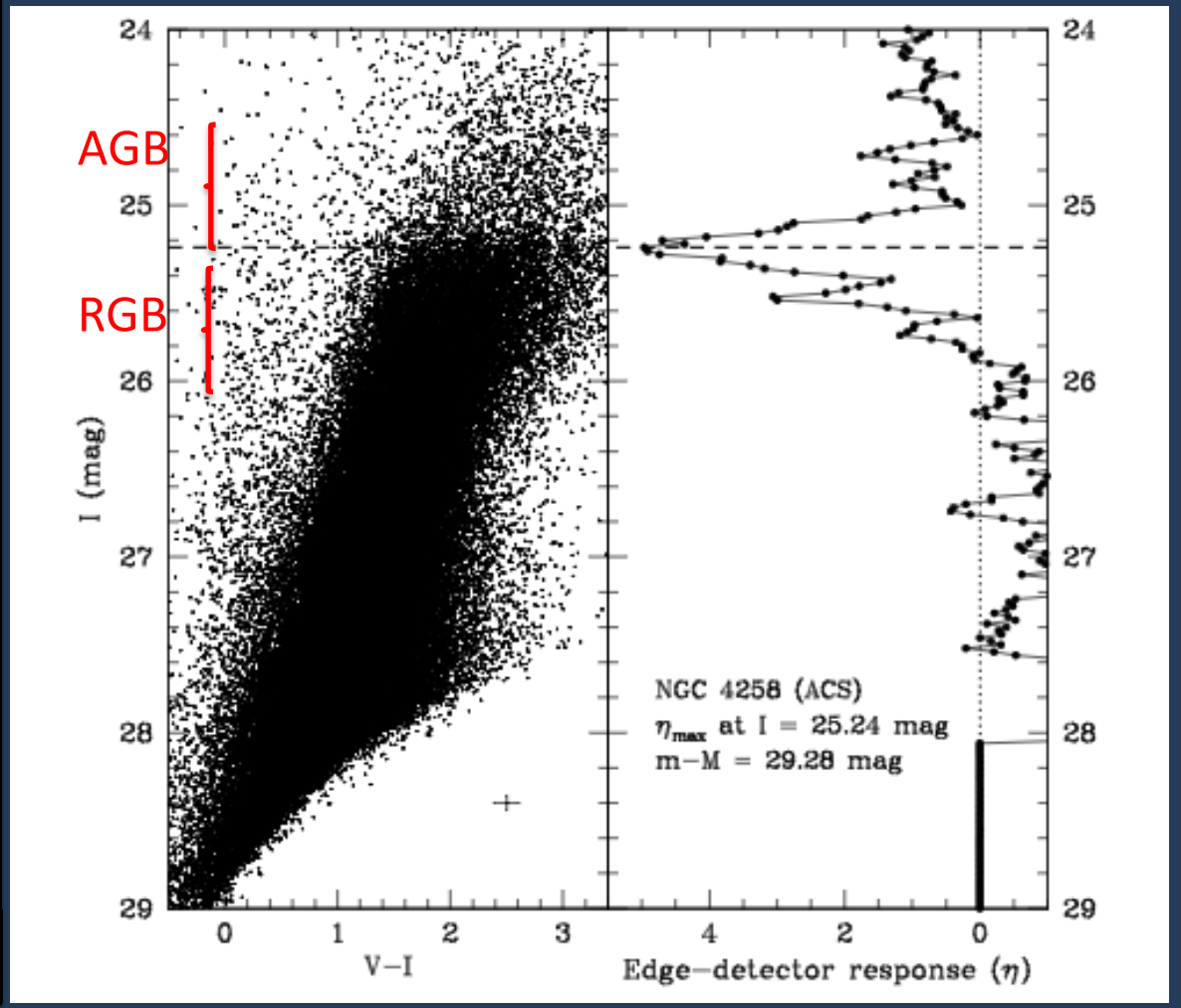
Recent Measurements of the Hubble Constant



Freedman (2021) ApJ, 919, 16

The Tip of the Red Giant Branch

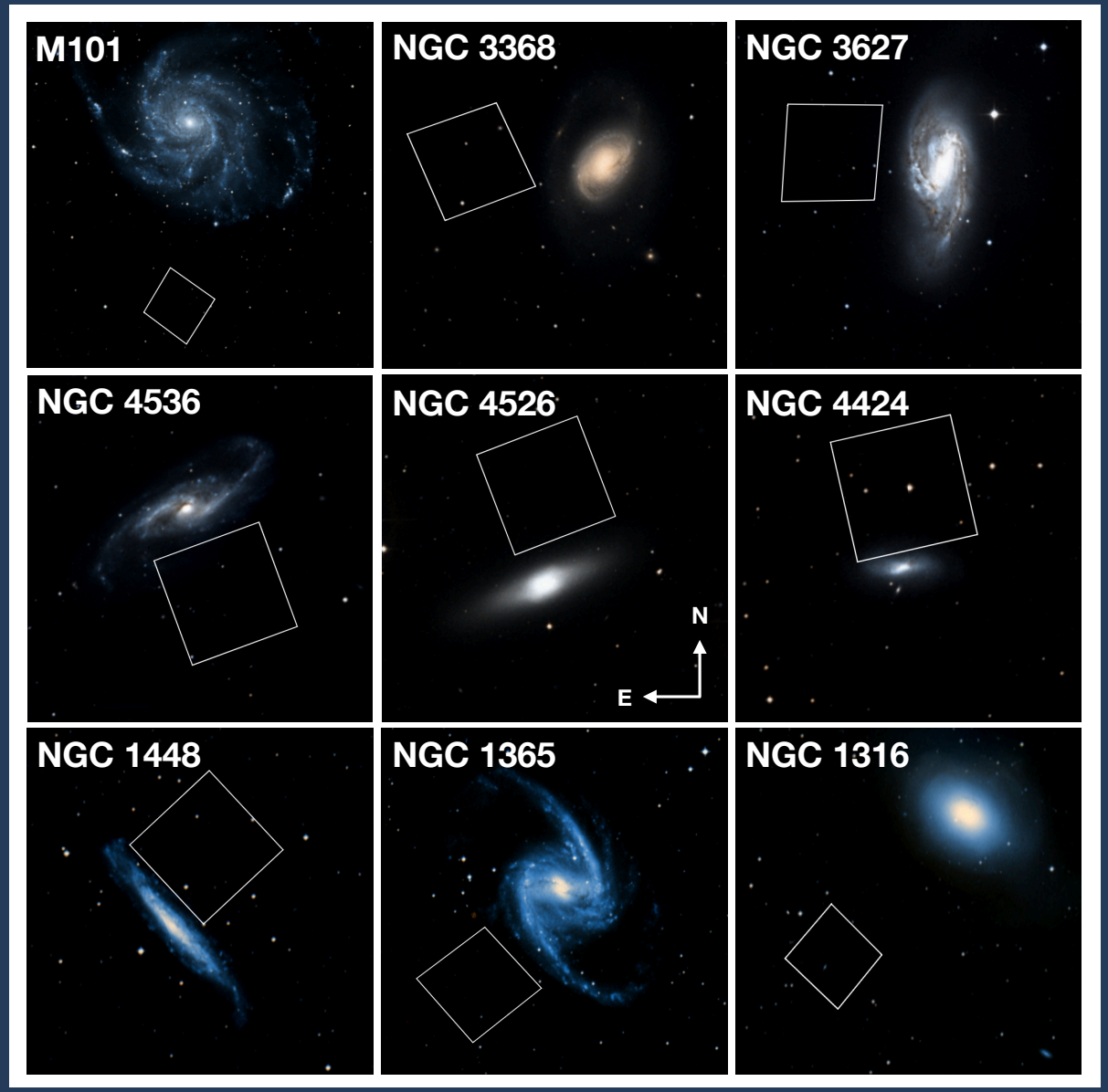




Measure 1st derivative of luminosity function

Mager, Madore & WLF (2008)

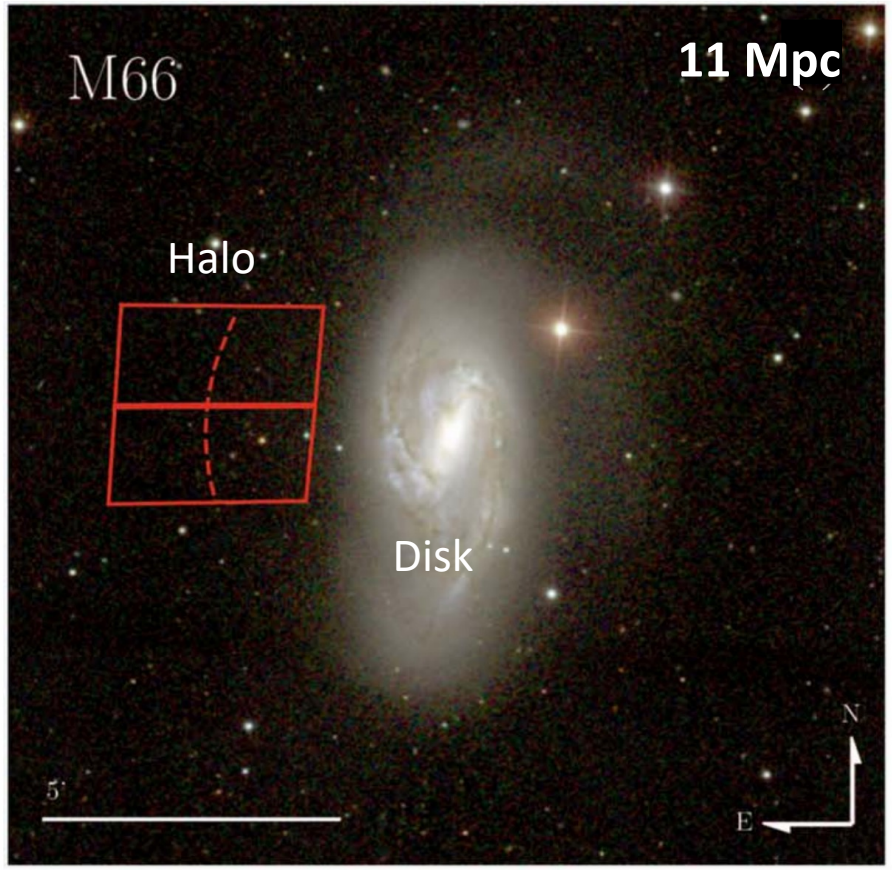
HST Advanced Camera for Surveys (ACS) Observations

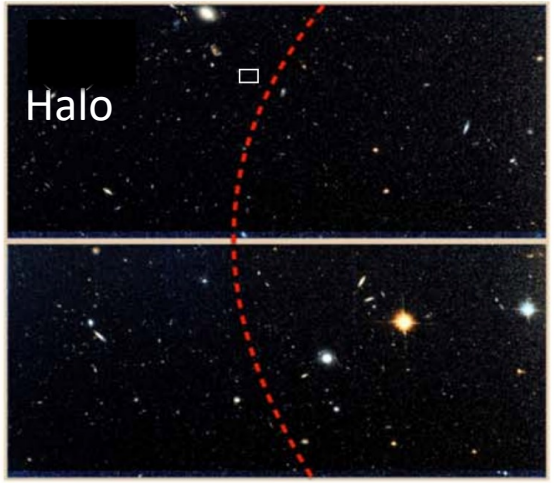


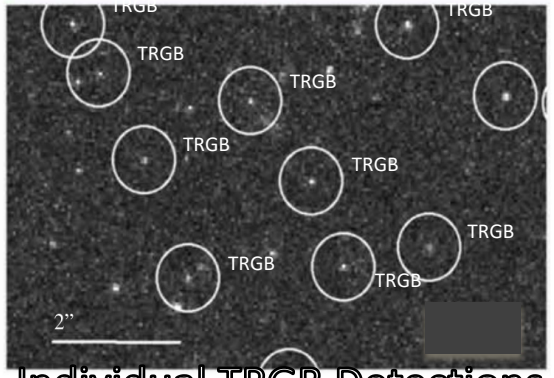
TRGB Halo Fields

19 TRGB calibrators

TRGB Halo
No Dust, Crowding





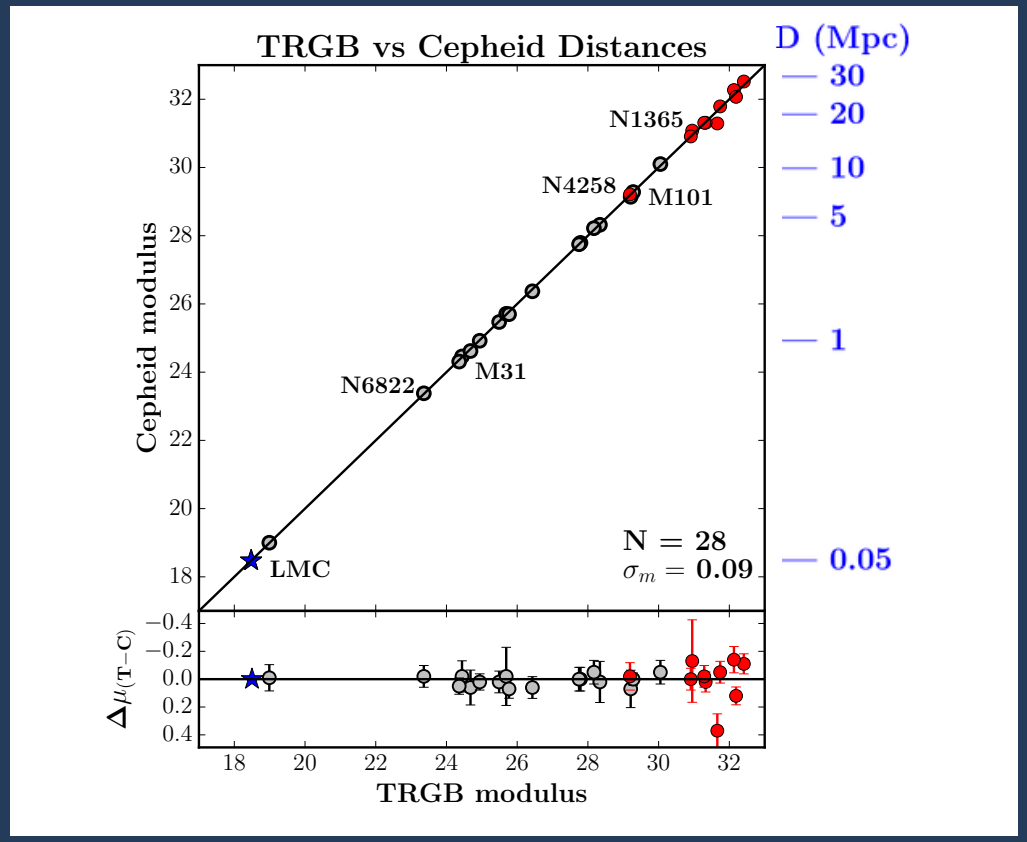


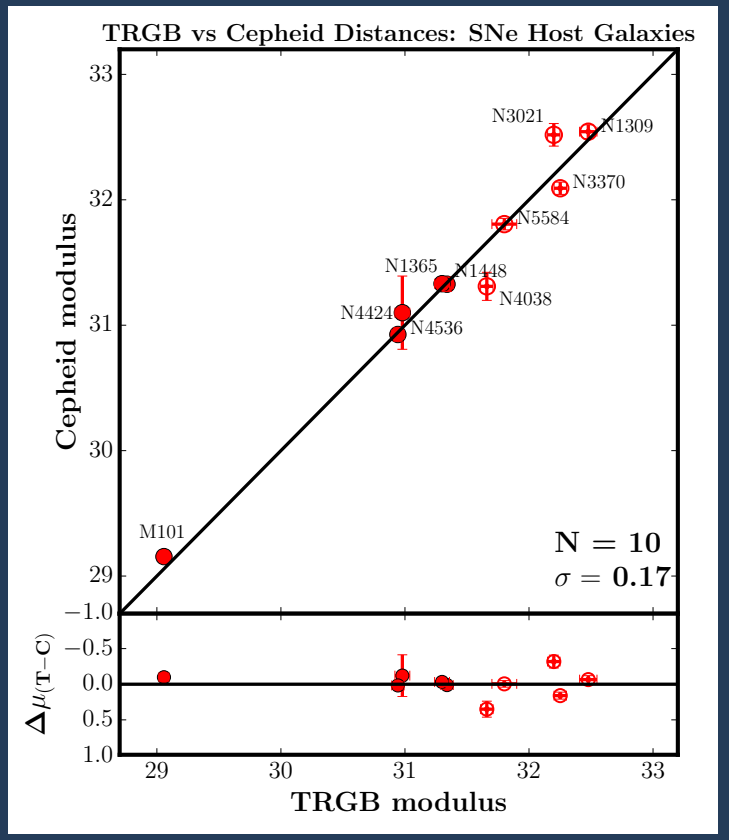
Individual TRGB Detections

Taylor Hoyt

Hoyt, T. et al. 2019, ApJ 882, 150

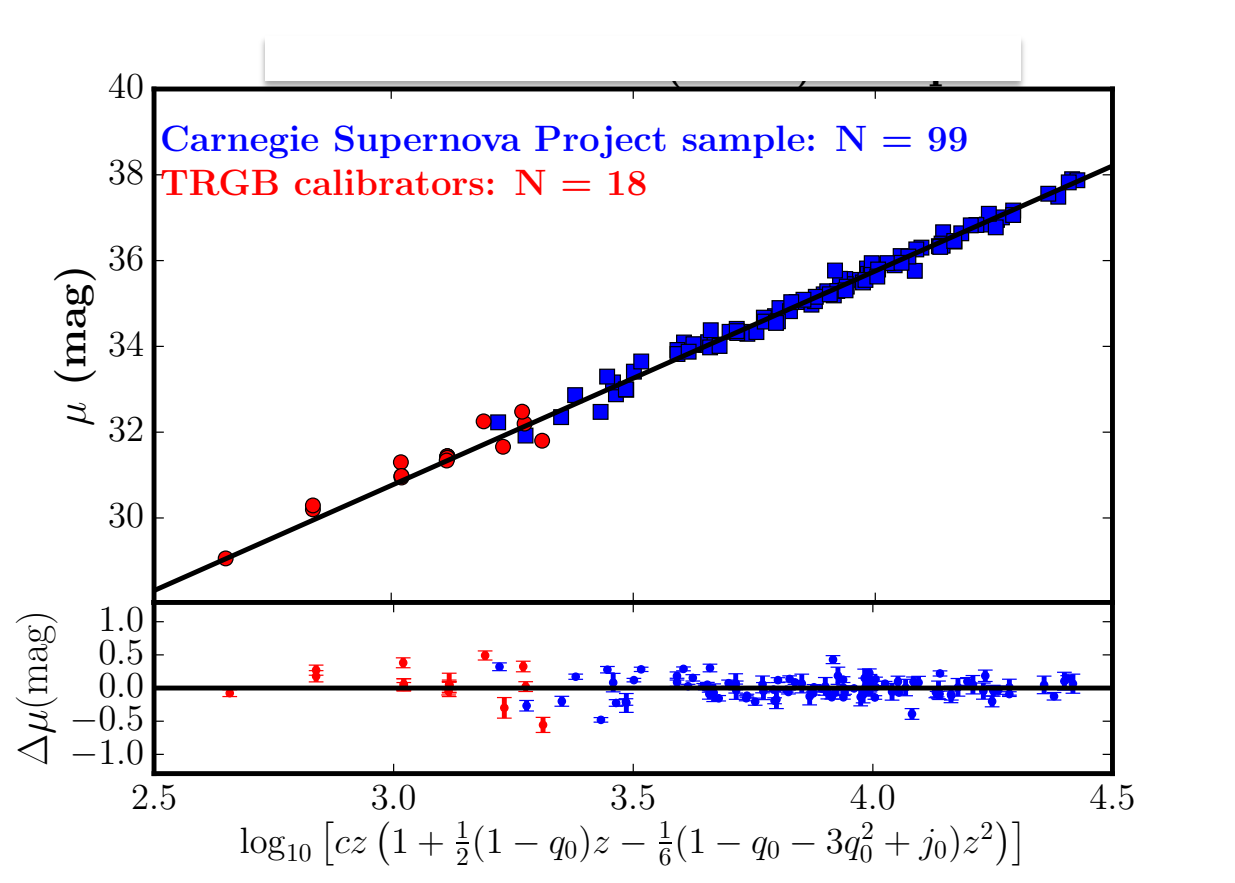
Comparison of Published TRGB and Cepheid Distances





WLF et al. (2019)

CCHP TRGB Calibration of H_o



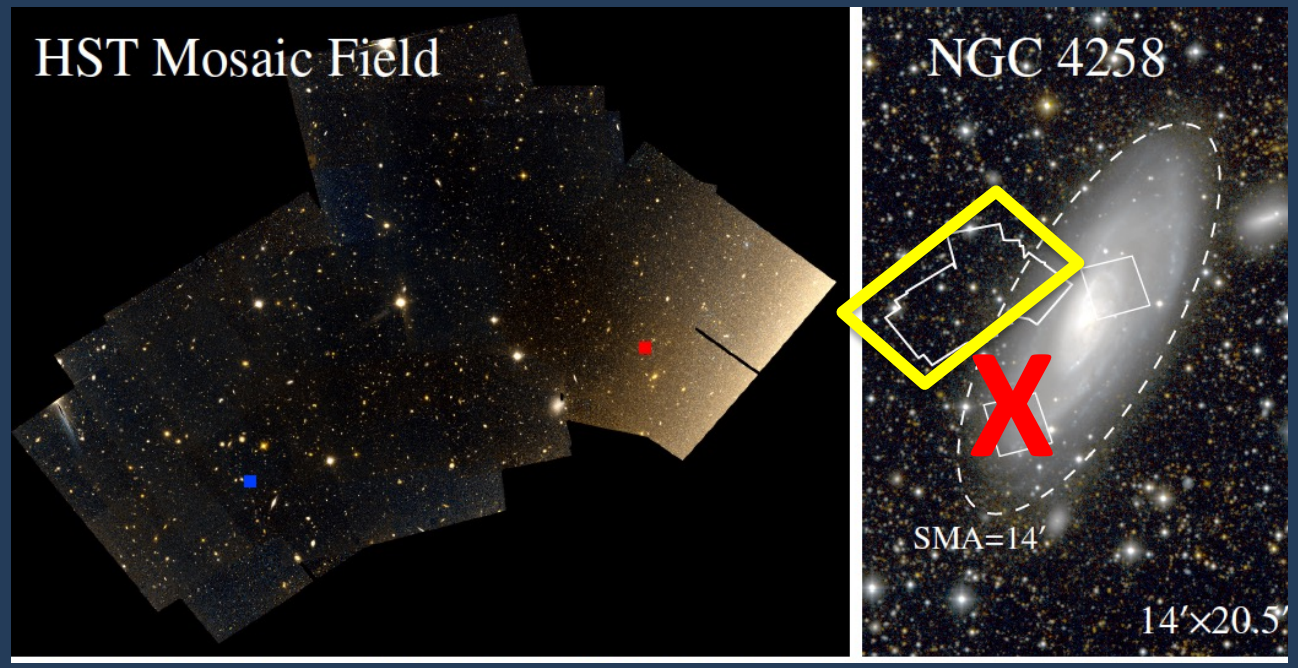
MCMC analysis:

H_0 = 69.6 ± 0.8 (stat) [1.1%]
± 1.7 (sys) [2.4%] km s^{-1} Mpc^{-1}

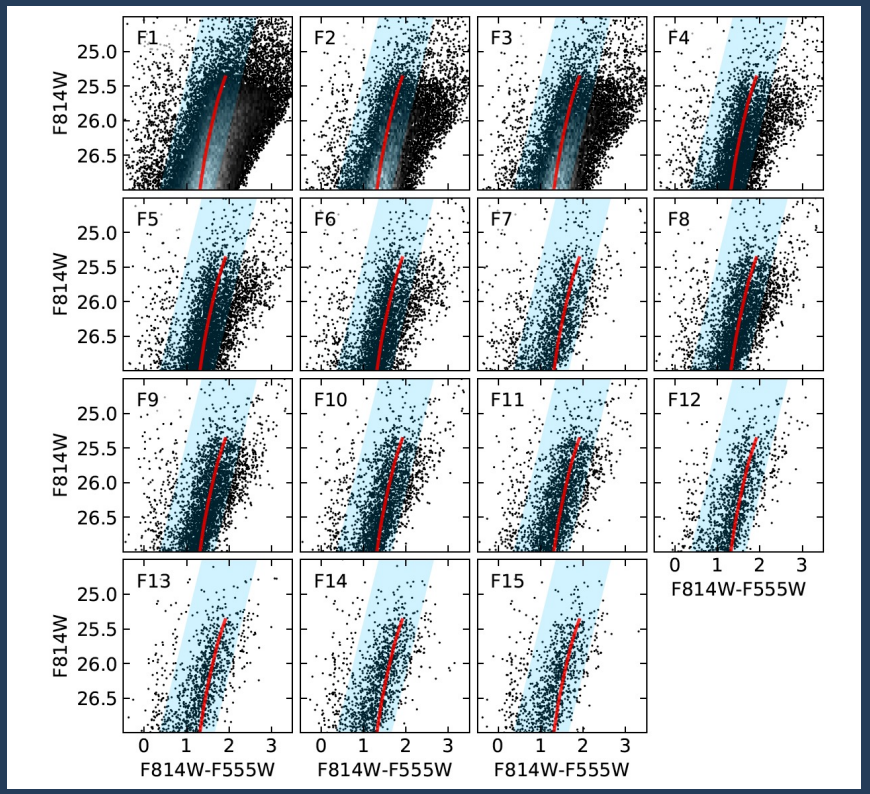
LMC as the anchor galaxy **

WLF et al. (2019, 2020)

Recent NGC 4258 TRGB Measurements



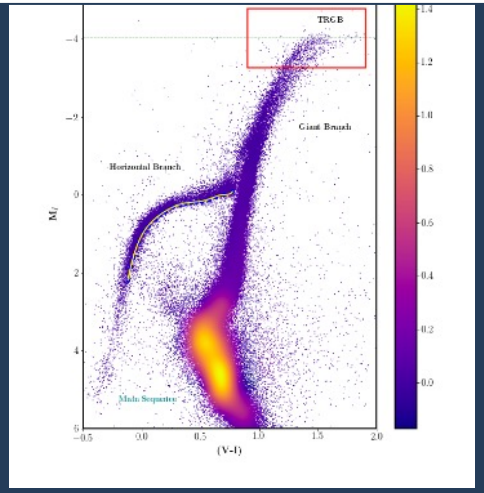
In Sung Jang



Jang et al, ApJ, 2021

Recent Tests of the TRGB Calibration

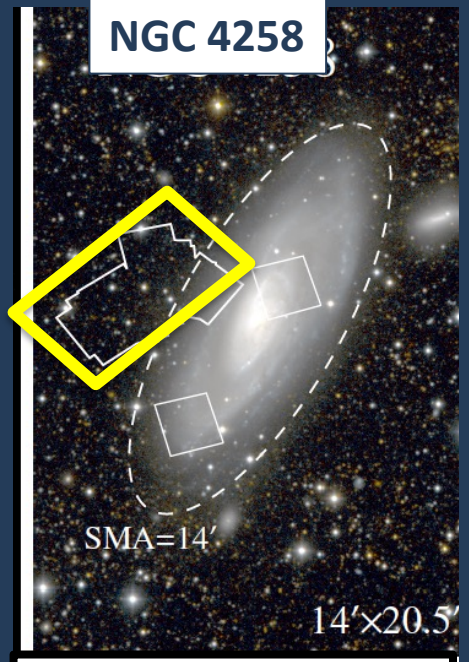
Milky Way globular clusters



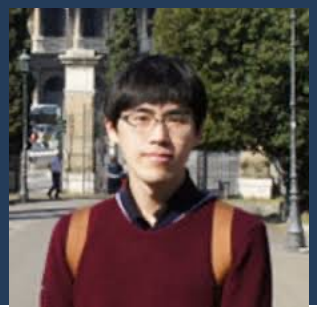
Cerny et al.2021,arXiv:2012.09701

Will Cerny

NGC 4258

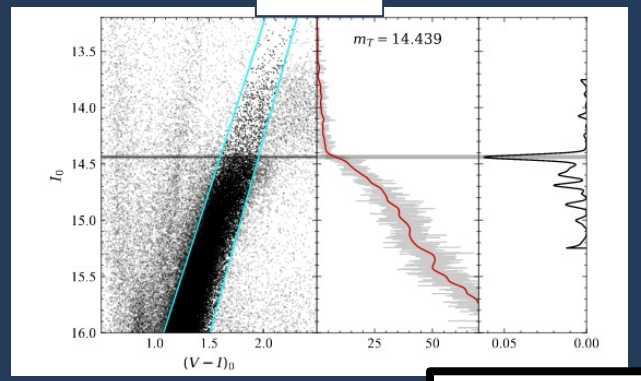


Jang et al. 2021

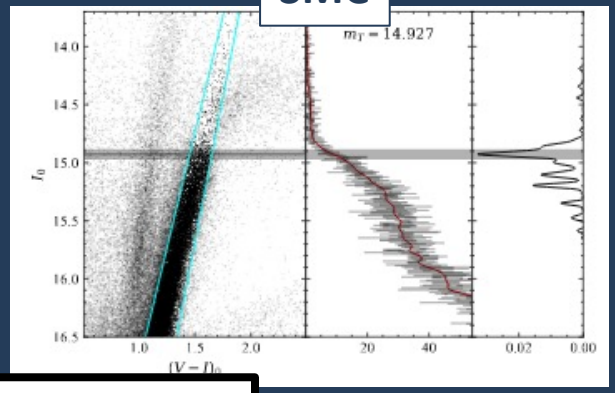


In Sung Jang

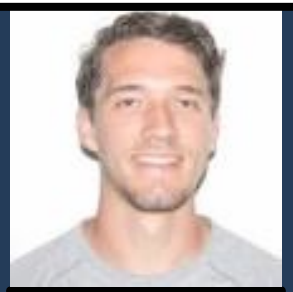
LMC



SMC



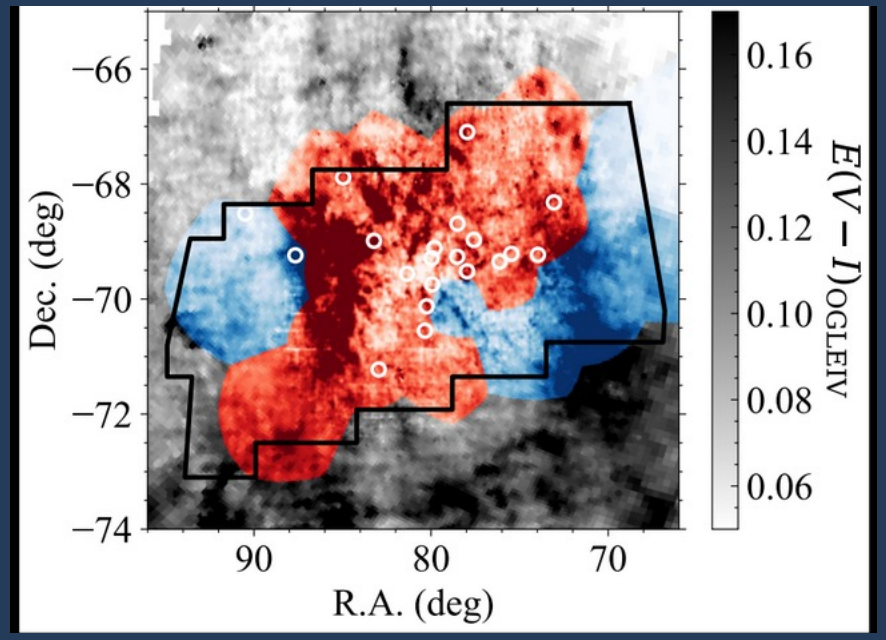
Hoyt 2021, 2022

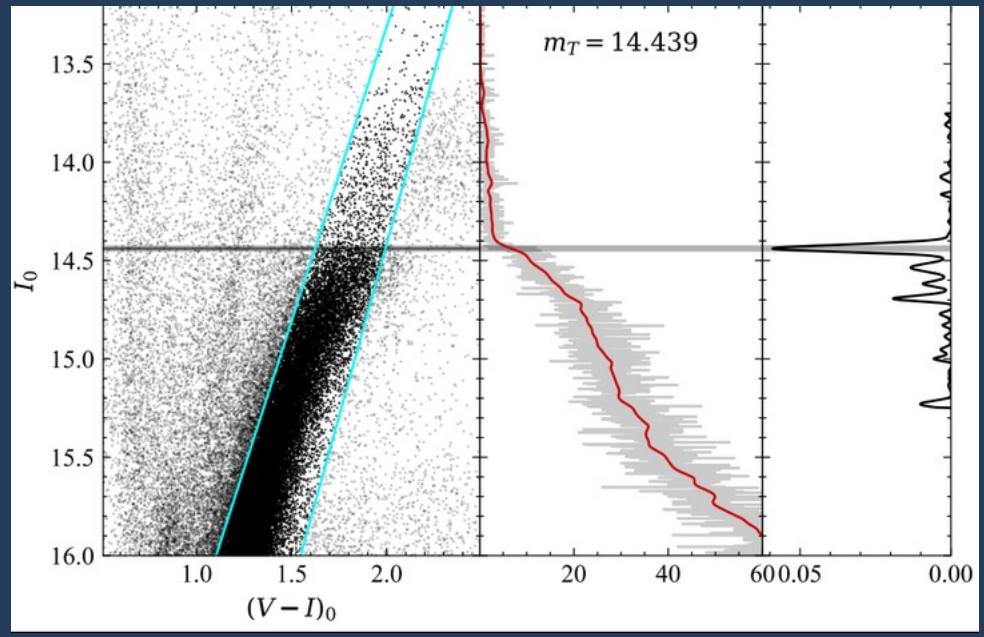


Taylor Hoyt

Independent zero points in agreement at the ±1% level. [WLF (2021), ApJ, 919, 16]

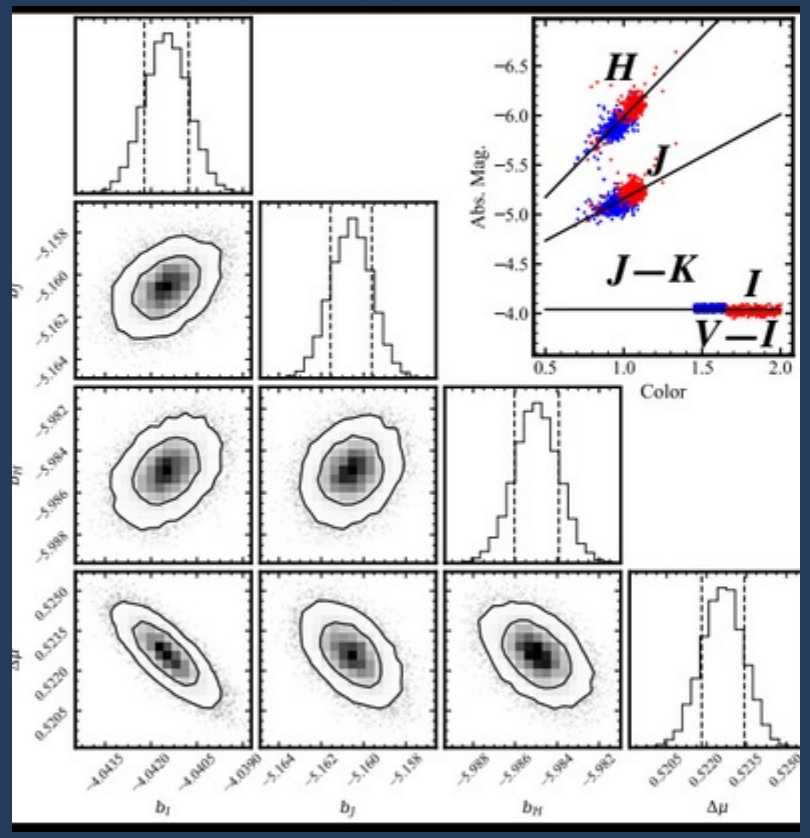
New LMC TRGB Measurements: Hoyt (2022) PhD Thesis



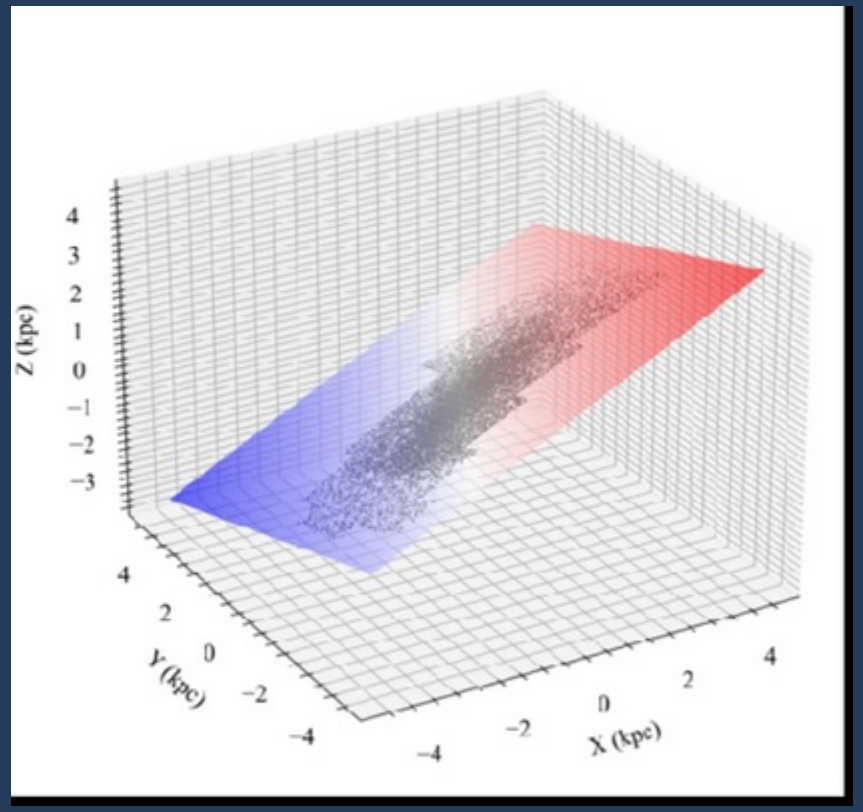


Hoyt (2022, submitted)

Additional Tests of the TRGB: Hoyt (2022) PhD Thesis

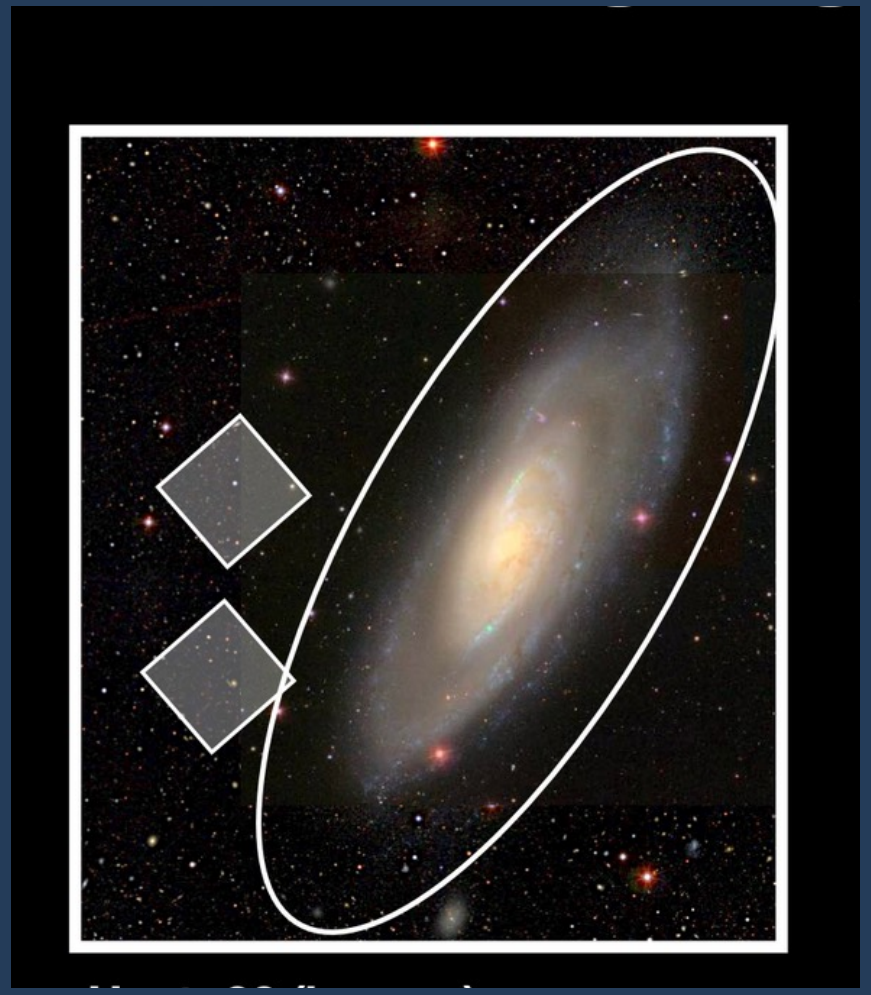


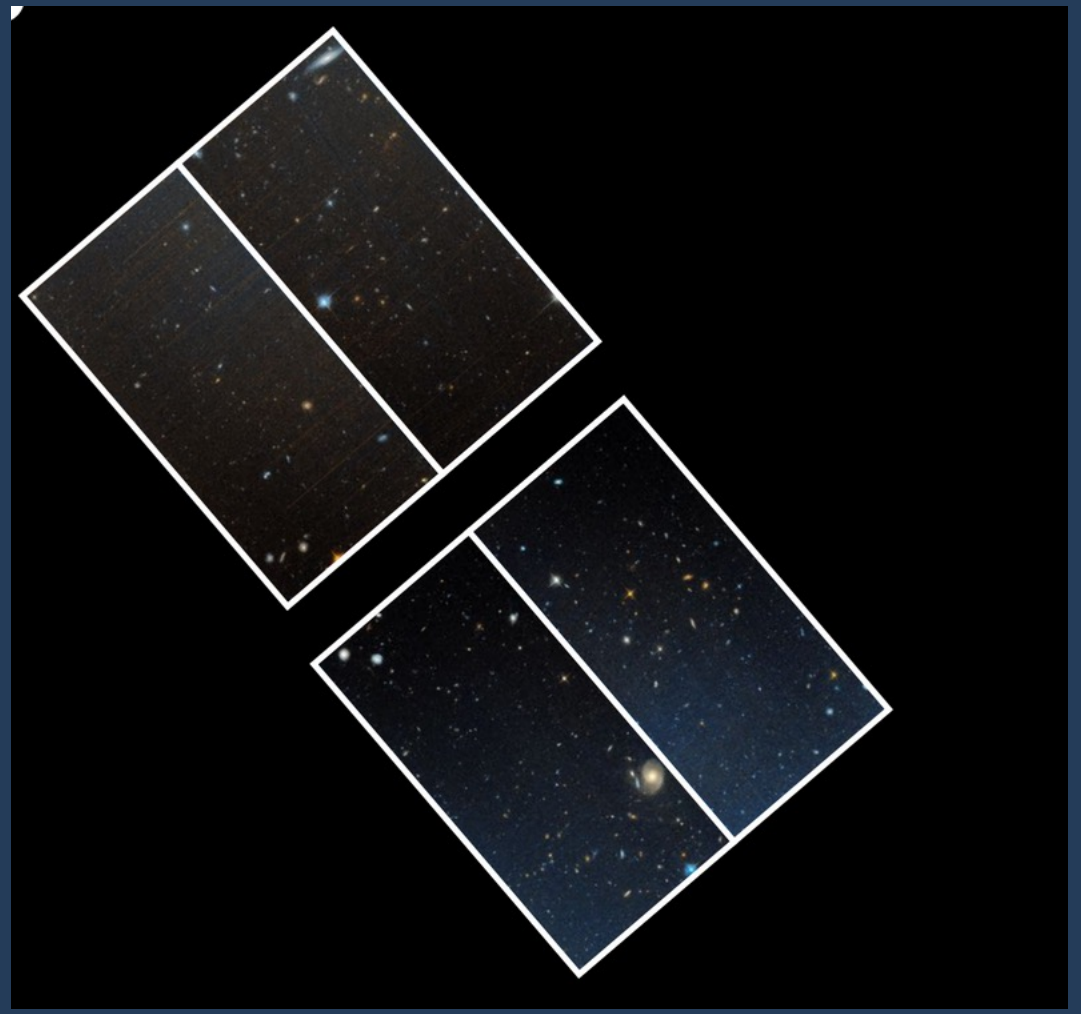
Multiwavelength (VIJHK) measurements of TRGB results in differential LMC/SMC distance modulus consistent with DEBs at 2% level



3D tilt of LMC measured using TRGB, consistent with Cepheid measurements.

Deep Imaging of the Outer Halo of NGC 4258

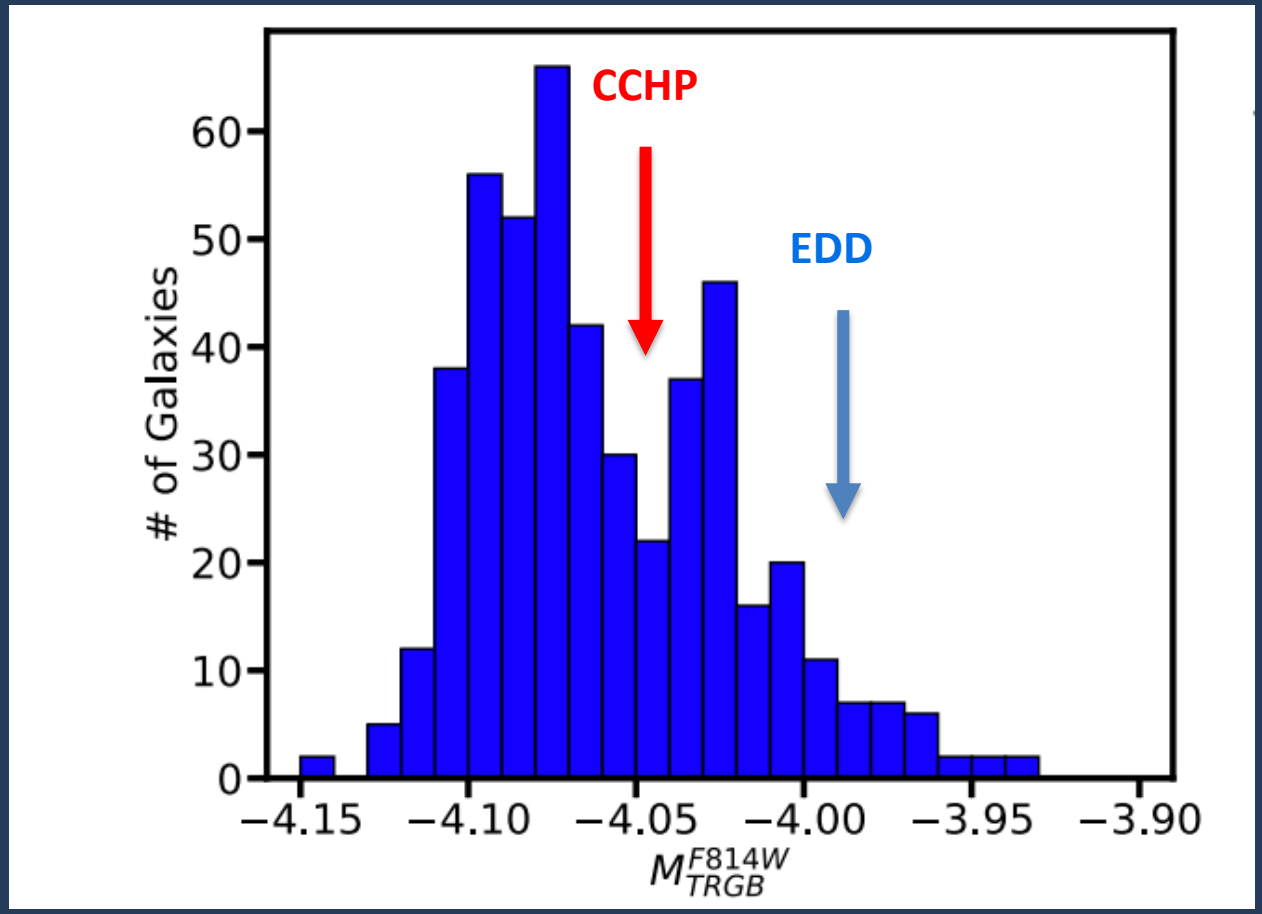




- 2.5 x deeper than Jang et al (2021)
- Optical and NIR imaging
- Fields chosen to minimize disk contamination

Hoyt et al. (2022, in prep)

Absolute Magnitude of the TRGB



Re-analysis of 489 archival TRGB observations

Anand et al 2021

Recent Comparison with SHoES + EDD

From Adam Riess ★ | Reply | Reply All | Forward | Archive | Junk | Delete | More

Subject **TRGB vs Cepheid plot** 4/29/22, 9:47 AM

To Jo Dunkley <jdunkley@princeton.edu> ★, Jim Peebles ★, Wendy Freedman ★, Adam Riess ★

Dear Cepheid-TRGB Comparison enthusiasts,

There was some conversation during the coffee break yesterday and during the talks to produce an up-to-date plot of Cepheids vs TRGB distances to the same SN Ia host galaxies, specifically SH0ES Cepheids vs CCHP TRGB vs EDD TRGB all calibrated by the same anchor, NGC 4258 so we can just compare the second rung.

This table can be passed to a Princeton student who understands magnitudes and can make a plot and generate some stats that we can use in future dialogue to avoid dueling plots and audience confusion.

These are all the SN Ia hosts I am aware of with distances measured by all 3 teams. NGC 4258 is assumed to have mu=29.398 ± 0.032 (Reid et al. 2019) as the calibration for this exercise. The first 7 are straightforward because all 3 groups have entries. The last four are a different category, they are more distant and the EDD team could not identify a TRGB break so take those with a grain of salt.

I filled in the latest SH0ES values (using Table 6 from R22, in press, but using only NGC 4258 as the anchor which makes distances 0.009 mag farther than the 3 anchor version, just like Figure 23—these are the right SH0ES values on pain of death!).

For EDD I used Table 2 and for CCHP I used Table 3 from F19. None of the distance measures include the NGC 4258 distance error so the errors are relatively independent (excepting that the two TRGB groups measure the same data).

I am hoping that Wendy can review or revise the entries for her team's results or confirm I copied them correctly.

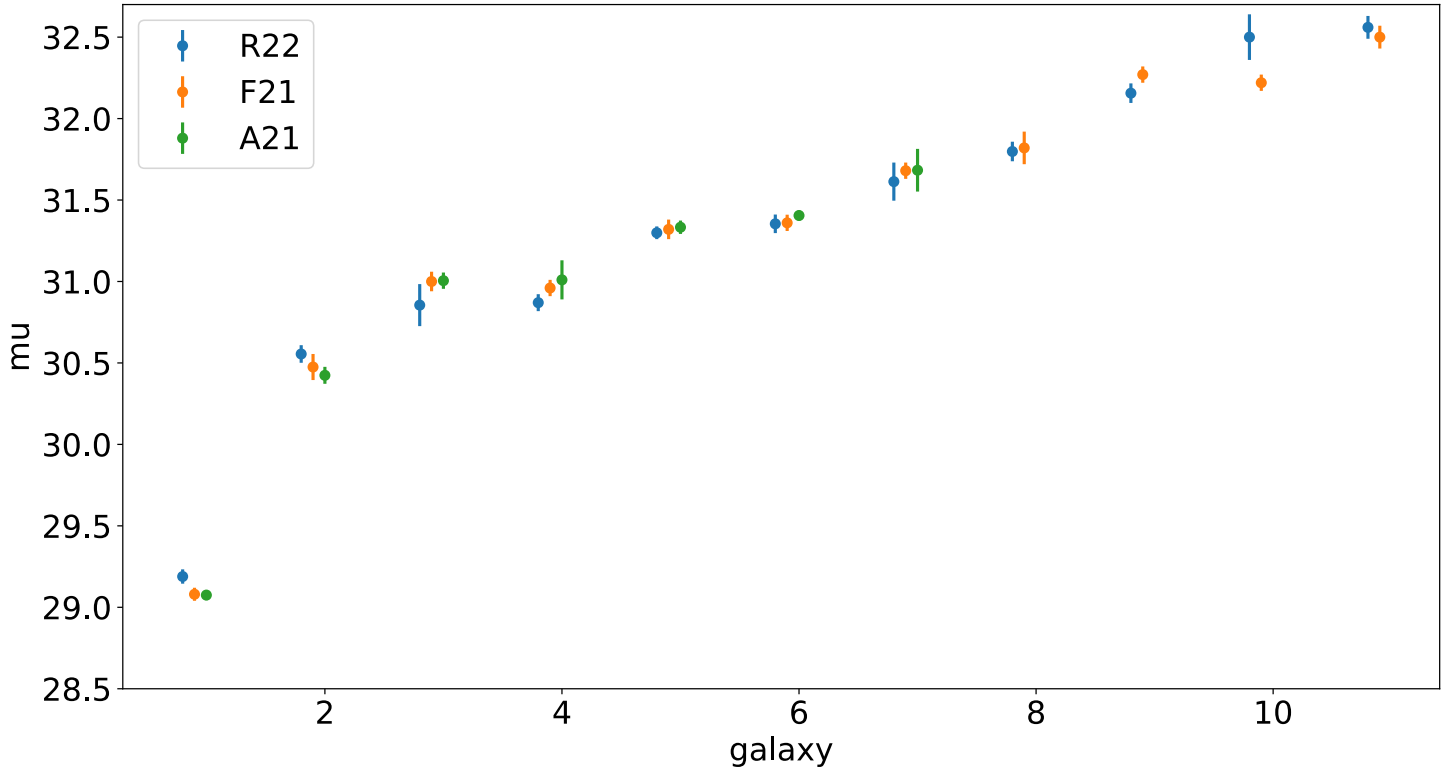
Host	SH0ES(R22)		CCHP(F19/21)		EDD(Anand21)	
	most	mu	err	mu	err	mu	err
1	M101	29.189	0.044	29.080	0.040	29.075	0.031
2	N1365	31.354	0.057	31.360	0.050	31.405	0.031
3	N1448	31.299	0.039	31.320	0.060	31.333	0.041
4	N4038	31.613	0.117	31.680	0.050	31.683	0.131
5	N4424	30.855	0.129	31.00	0.060	31.005	0.050
6	N4536	30.870	0.052	30.960	0.050	31.010	0.120
7	N5643	30.555	0.054	30.475	0.080	30.424	0.052
8	N3370	32.156	0.060	32.270	0.050	NA	NA
9	N3021	32.500	0.140	32.220	0.050	NA	NA
10	N1309	32.560	0.070	32.500	0.070	NA	NA
11	N5584	31.798	0.060	31.820	0.100	NA	NA

Best
Adam

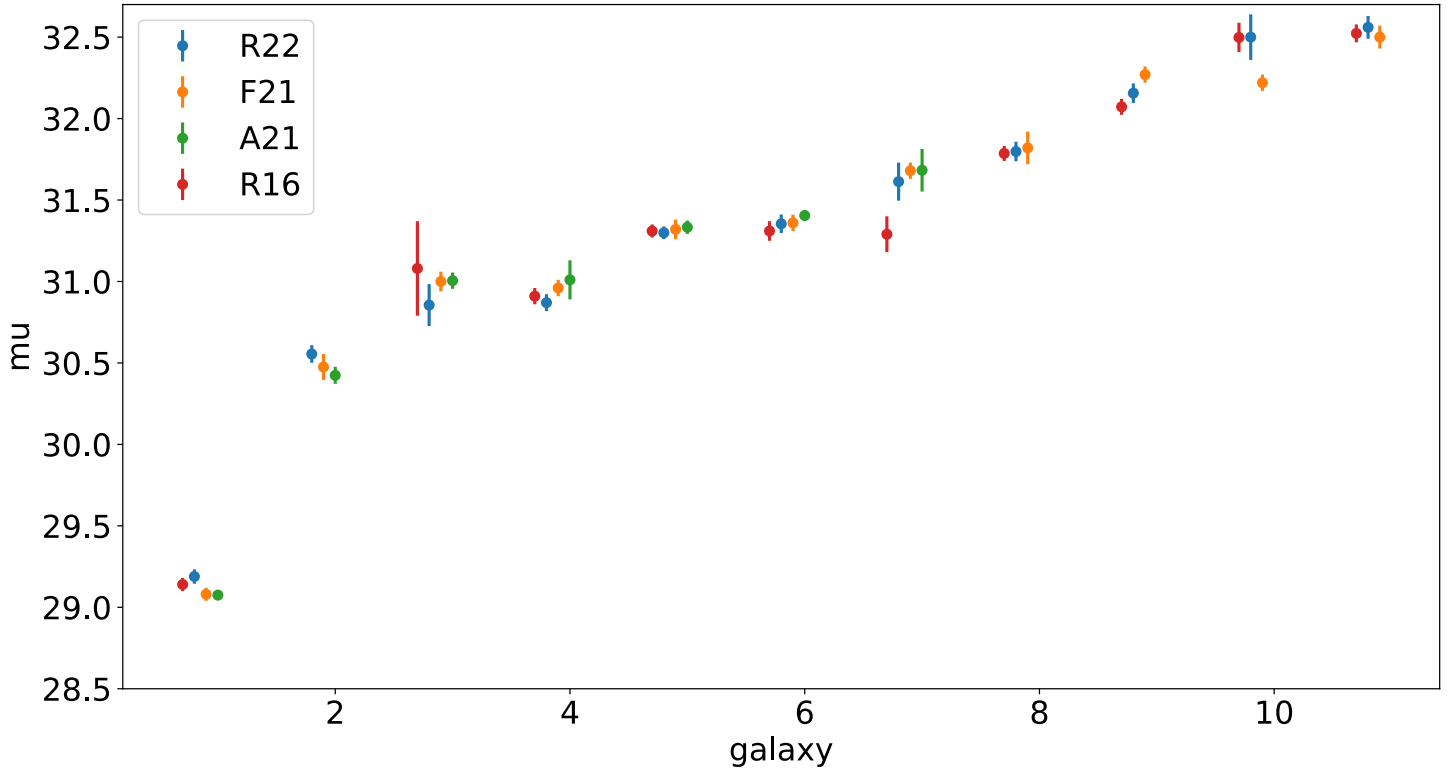
From Adam Riess: "…This table can be passed to a Princeton student who understands magnitudes and can make a plot and generate some stats that we can use in future dialogue… "

"… produce an up-to-date plot of Cepheids vs TRGB distances to the same SN Ia host galaxies, specificially SH0ES Cepheids vs CCHP TRGB vs EDD TRGB all calibrated by the same anchor, NGC 4258 so we can just compare the second rung."

Recent Comparison with SHoES + EDD

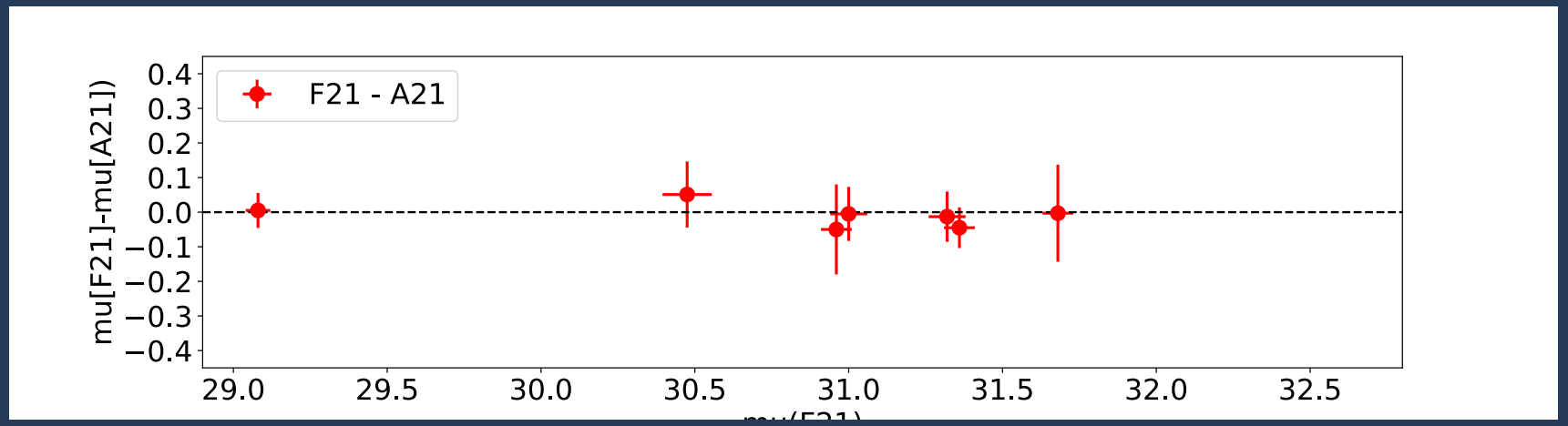


Recent Comparison with SHoES + EDD

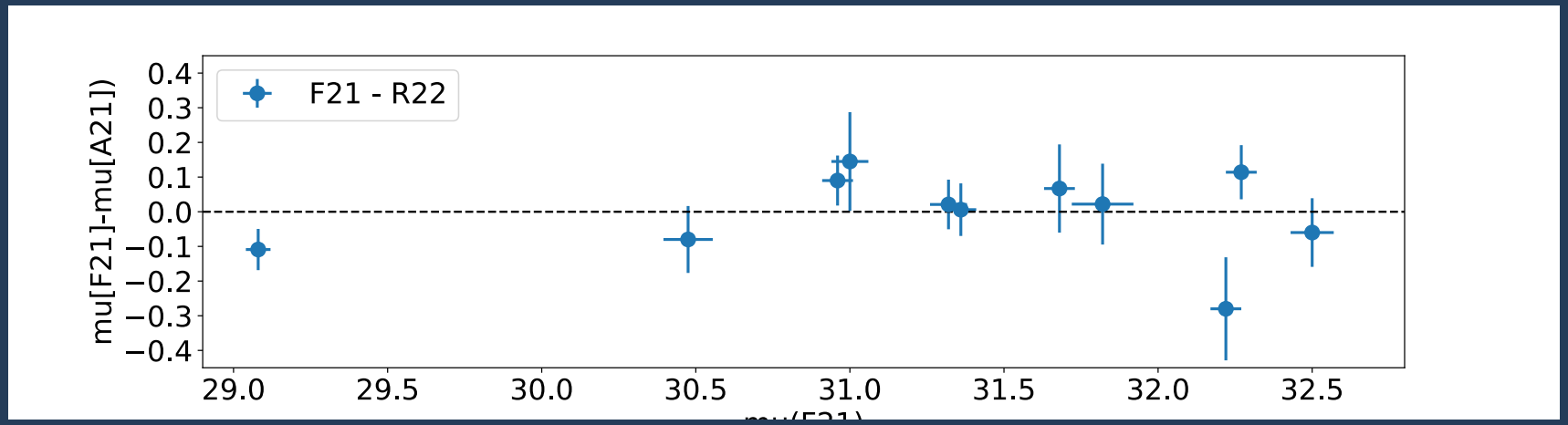


Mean difference 0.006 mag, error weighted 0.003 ± 0.026 mag

Recent Comparison with SHoES + EDD



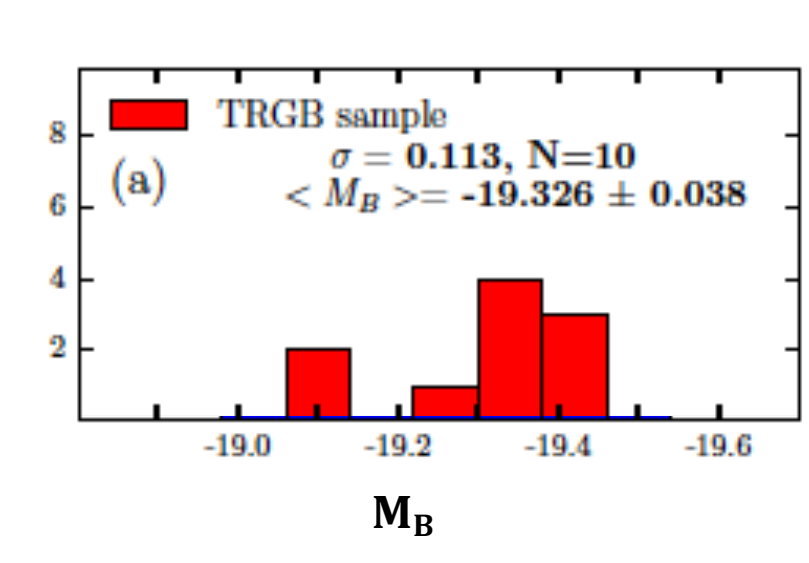
Freedman (2021)
vs
Anand et al.(2021)



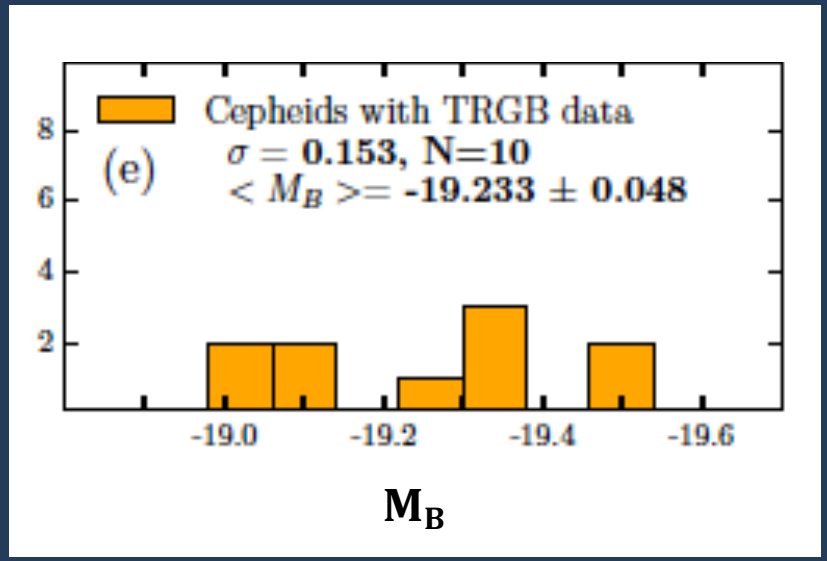
Freedman (2021)
vs
Riess et al.(2022)

Comparison of the 10 TRGB and Cepheid Distances to SNeIa Hosts in Common

TRGB calibration of SNe Ia



Cepheid calibration of SNe Ia



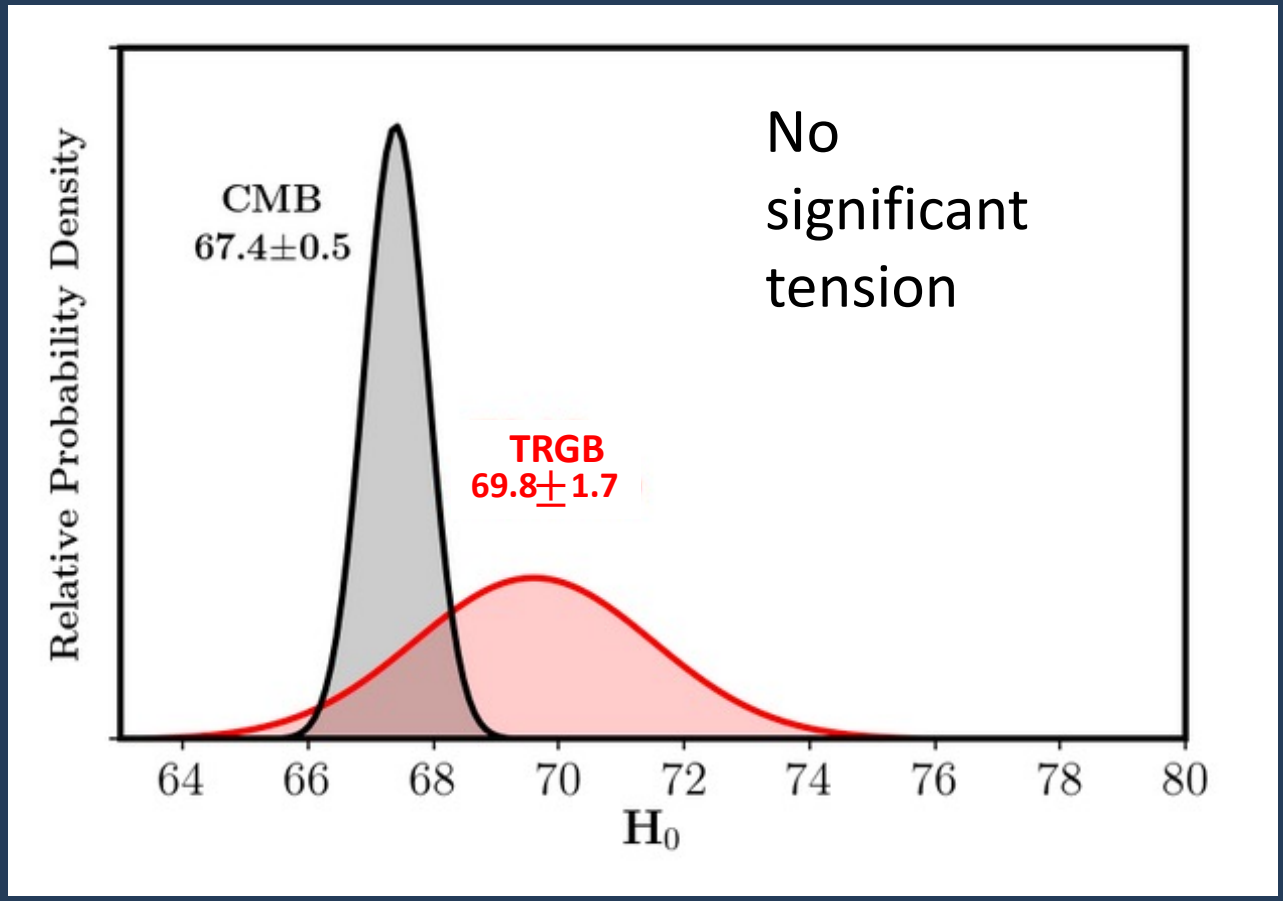
σ = 0.11
TRGB

σ = 0.15
Cepheids

σ = 0.10
SNeIa CSP

WLF et al. (2019, ApJ)

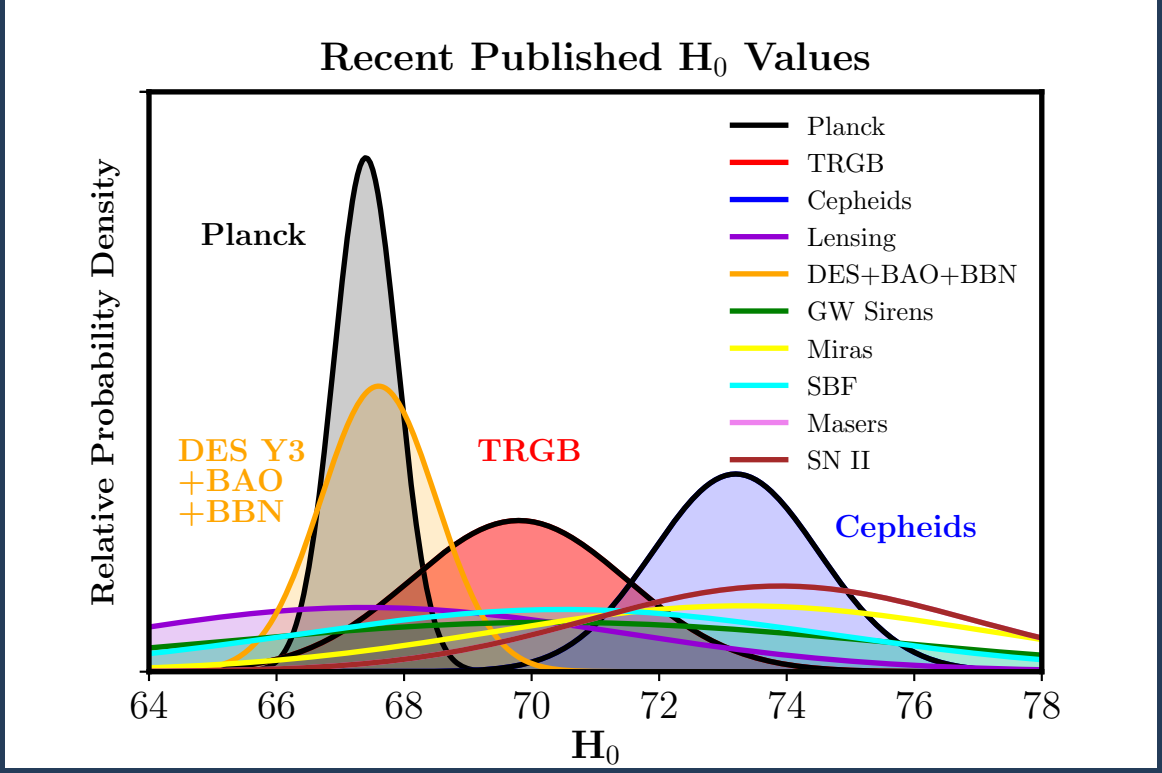
TRGB Compared to CMB



1.3 sigma tension with Planck

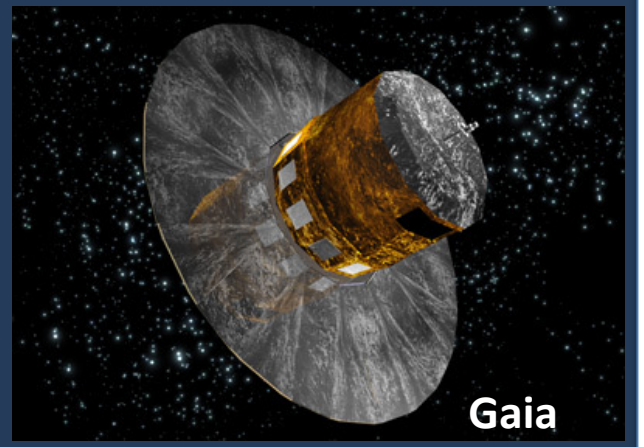
WLF+ (2019); WLF (2021) ApJ, 919, 16

Recent Published Values of the Hubble Constant



WLF (2021)

How to Resolve the Tension: Gaia +HST+ JWST



H_o Milky Way zero-point ~1%

N4258 calibration ~1%

New JWST cosmology program:
Three independent methods applied to the same SNIa host galaxies (PI: Freedman)
JWST has almost 10x the sensitivity of HST at NIR wavelengths and 3x the resolution.

Cepheids

- **Increased resolution**
- **Direct test of metallicity**
- **Additional wavelength coverage to improve reddenings**

TRGB

- **Increased resolution**
- **Extend to greater distances**

Carbon stars

- **3rd independent check**

James Webb Space Telescope (JWST)