Recalibrating the Tip of the Red Giant Branch Distance Scale: Implications for the Hubble Constant

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Collaborators







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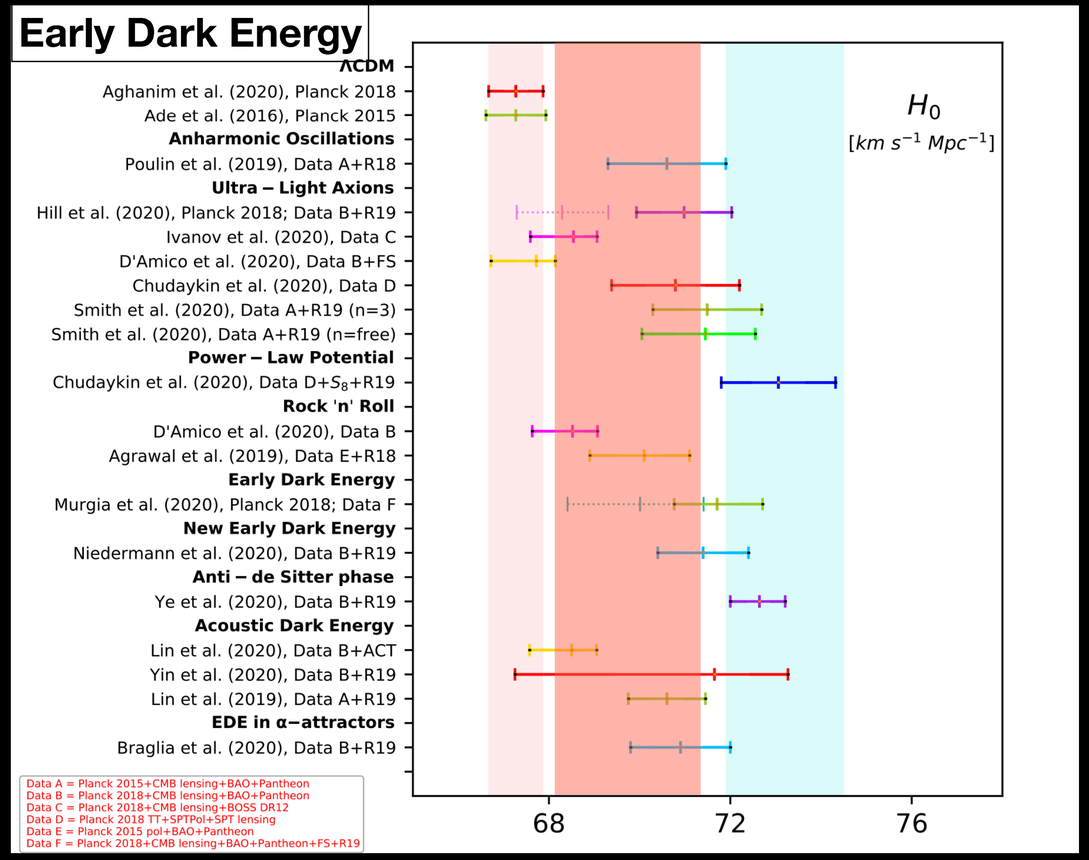
Outline

1. Motivation/introduction (3 min)
2. Calibrating the TRGB in the Magellanic Clouds (6 min)
3. New Hubble Telescope calibration of the TRGB in NGC 4258 (4 min)
4. Discussion, the Future, and Summary (4 min)

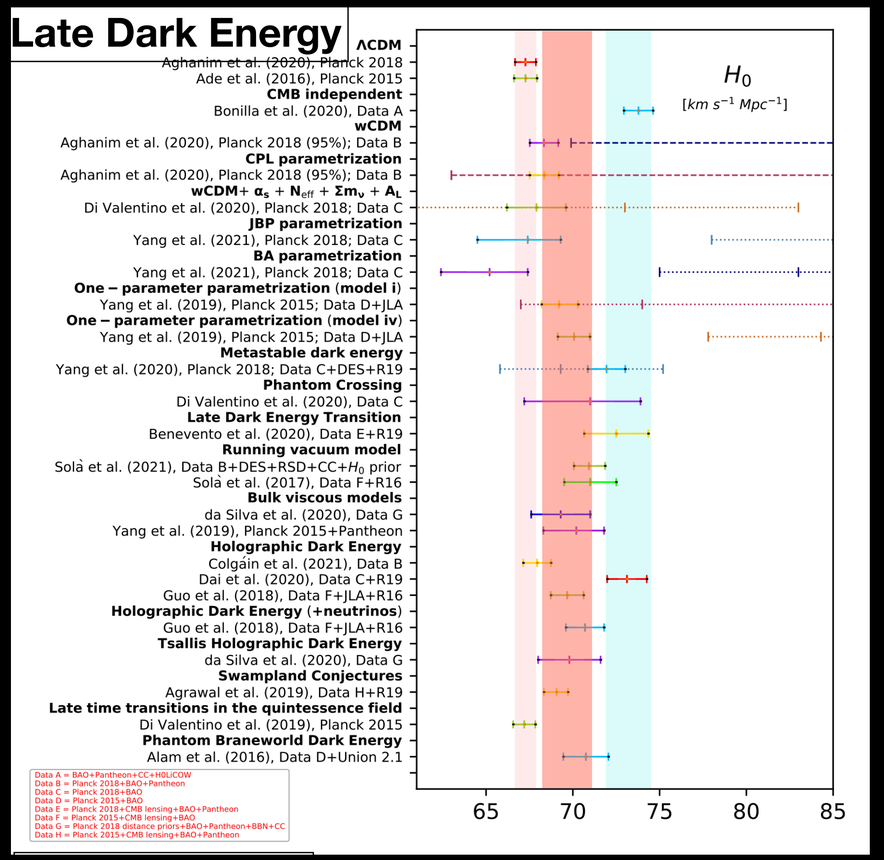
The Hubble Tension: LCDM might need some help

Planck **TRGB** **Cepheids**



DiValentino+21

Planck **TRGB** **Cepheids**



DiValentino+21 **Late DE**

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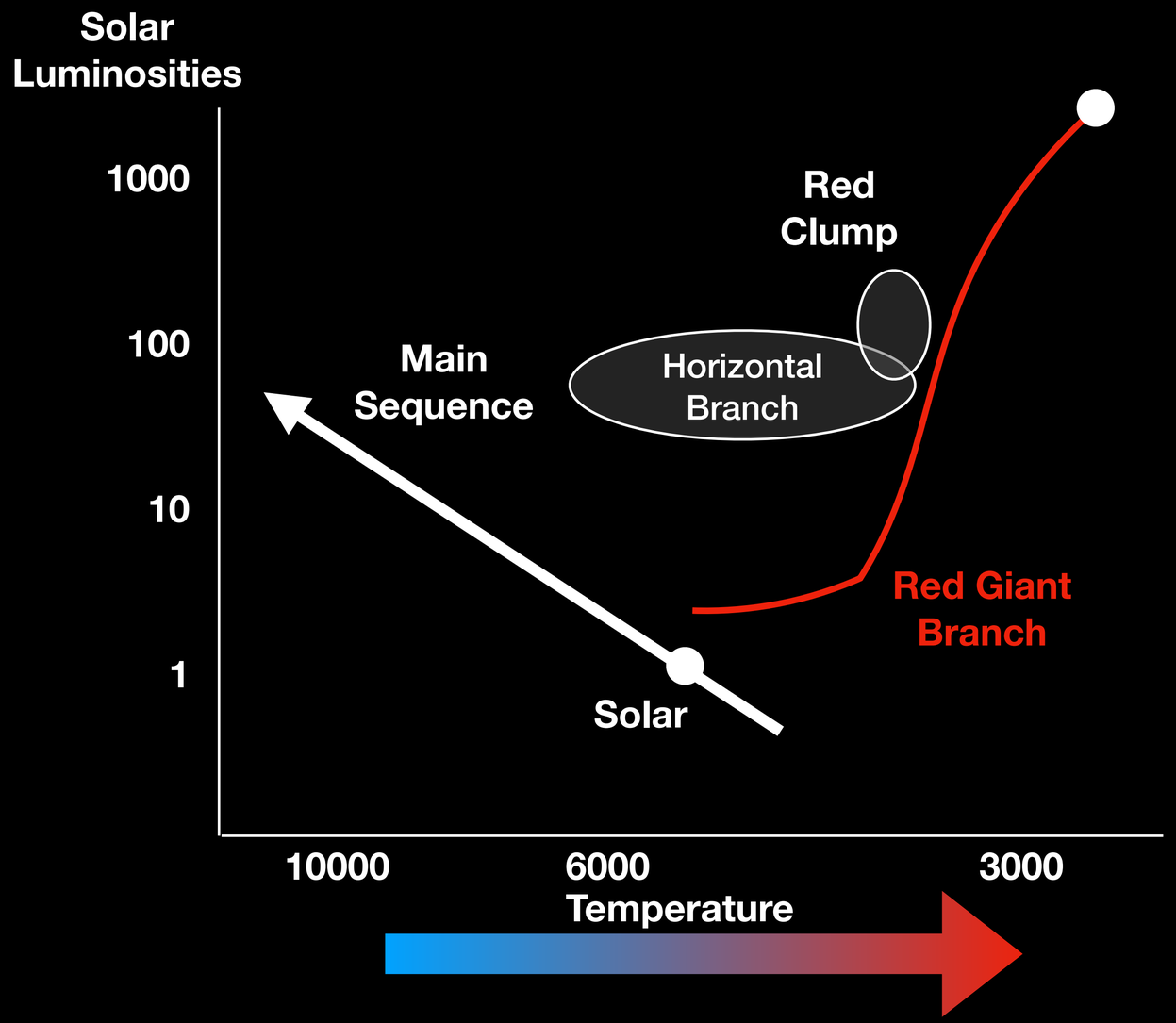
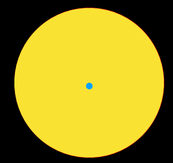
The Tip of the Red Giant Branch



Hydrogen Envelope
And Inert helium core

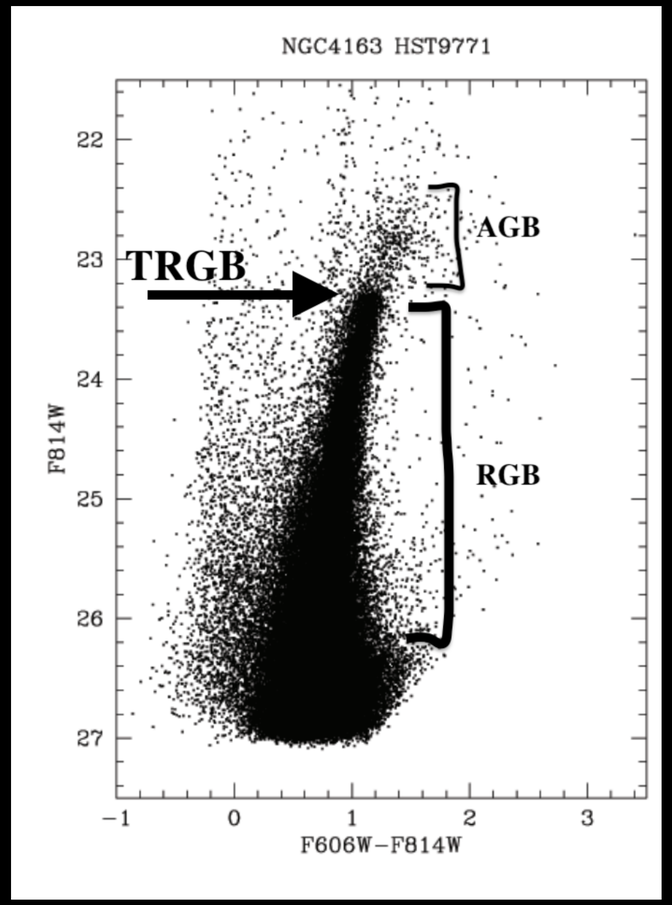


Hydrogen-burning temperatures reach outside core.

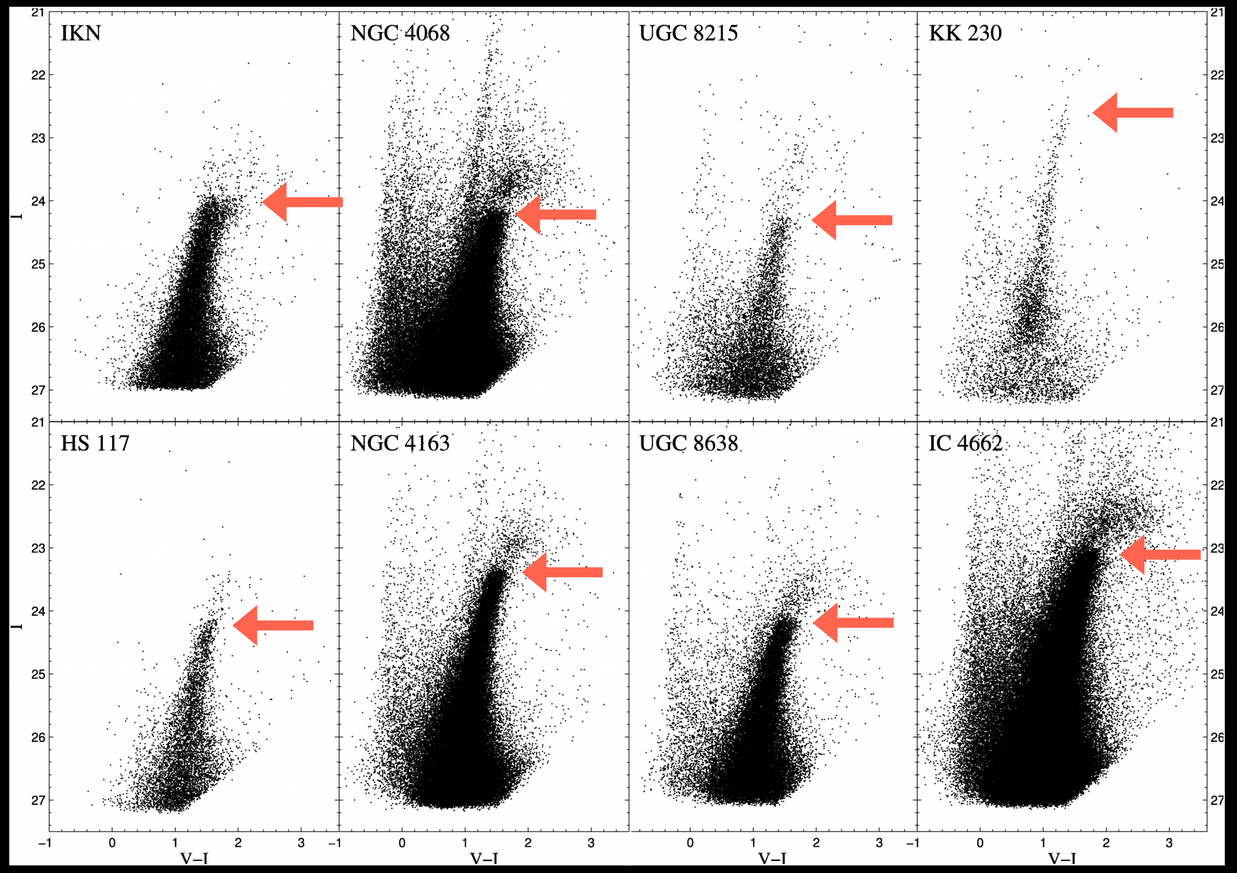
Core contracts, becomes degenerate and star expands

Temperature to burn helium reached. Thermonuclear runaway, but lifts degeneracy in seconds.

Observing the TRGB



Observing the TRGB



Karachentsev+05

Dwarf Galaxies dominated by older, less massive stellar populations

To accomplish this in much more massive SN host galaxies, need to target their ancient stellar halos.

—> Carnegie Chicago Hubble Program (Freedman+19)

Different Routes to TRGB Calibration

Magellanic Clouds

The Araucaria Project (Pietrzynski+13,19) calibrated a high-precision relation between the optical+NIR brightnesses and angular diameters of a special class of eclipsing binary systems, leading to a 1% distance to the LMC, and a 2% distance to the SMC (Graczyk+20).

NGC 4258

H20 clouds orbit within a few pc of the active supermassive black hole at the galaxy's center. Their molecular populations inverted by the high energy radiation, they act as "mega" masers which can be observed with radio telescopes, producing a distance precise to 1.5%.

Milky Way

Gaia DR3 parallaxes are not yet at the level of accuracy needed to compete with, e.g., DEBs and the LMC calibration. Though see Cerny+20, Soltis+21, Baumgardt+Vasiliev21, Li+22 for recent work using EDR3. DR4 and beyond will really blow this door open.

ALL Astrophysical Distance indicators (Cepheids, TRGB, Miras, JAGB, SBF, Tully-Fisher, SNe Ia) have their zero points set by some combination of these few geometric calibrations.

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Calibrating the Cosmic Distance Scale in the Magellanic Clouds with a Sub-percent Determination of the Brightness at the Tip of the Red Giant Branch

T. J. Hoyt (in review; arXiv:2106.13337)

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The Magellanic Clouds

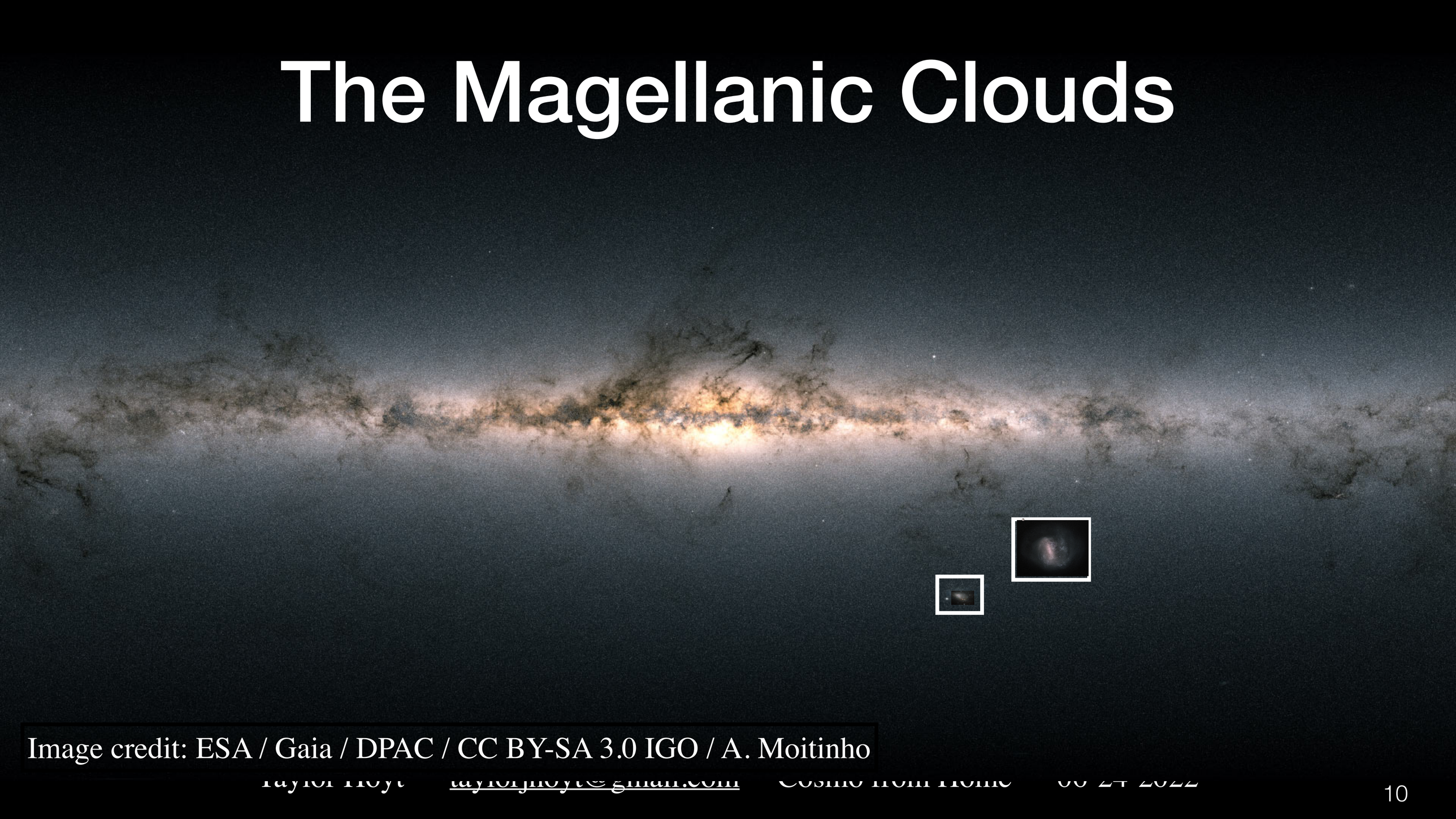

Image credit: ESA / Gaia / DPAC / CC BY-SA 3.0 IGO / A. Moitinho

The Magellanic Clouds

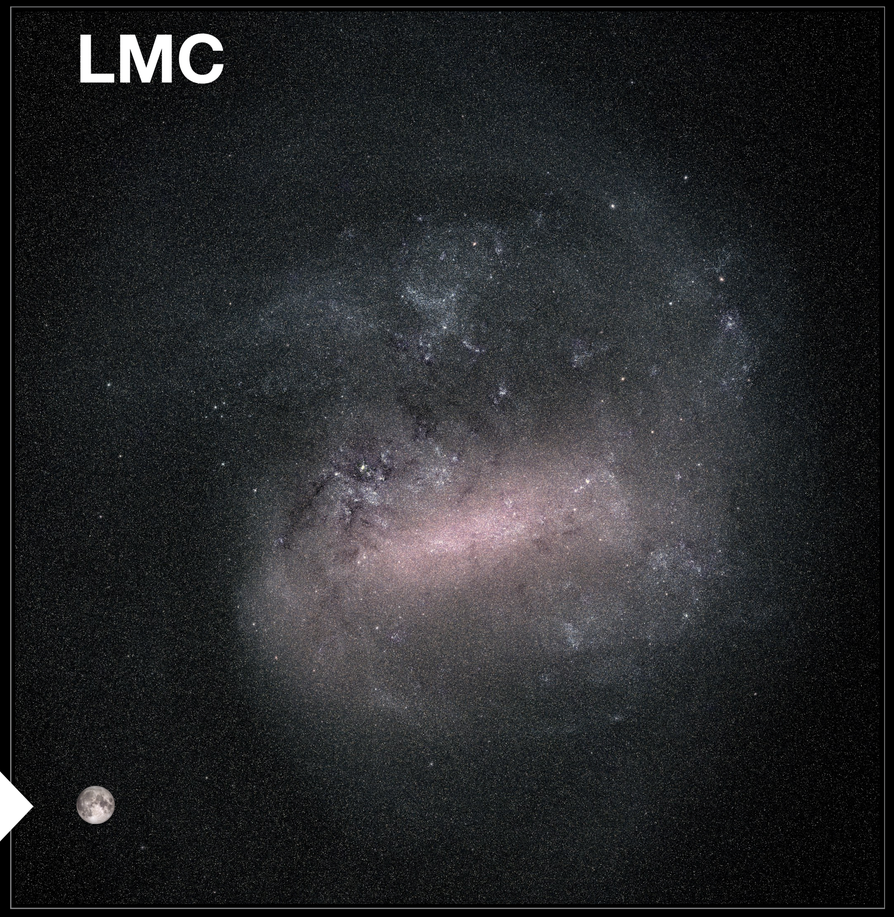

Image credit: ESA / Gaia / DPAC / K. M. Loch

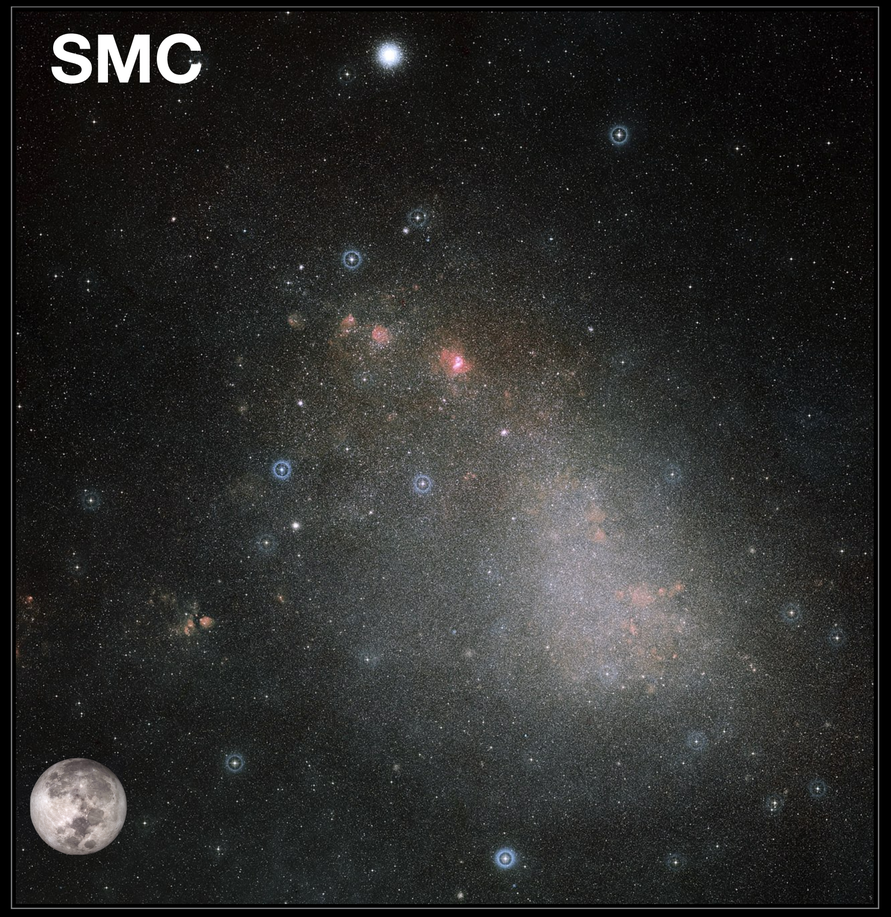

Image credit: ESA / Hubble / D. DeMartin

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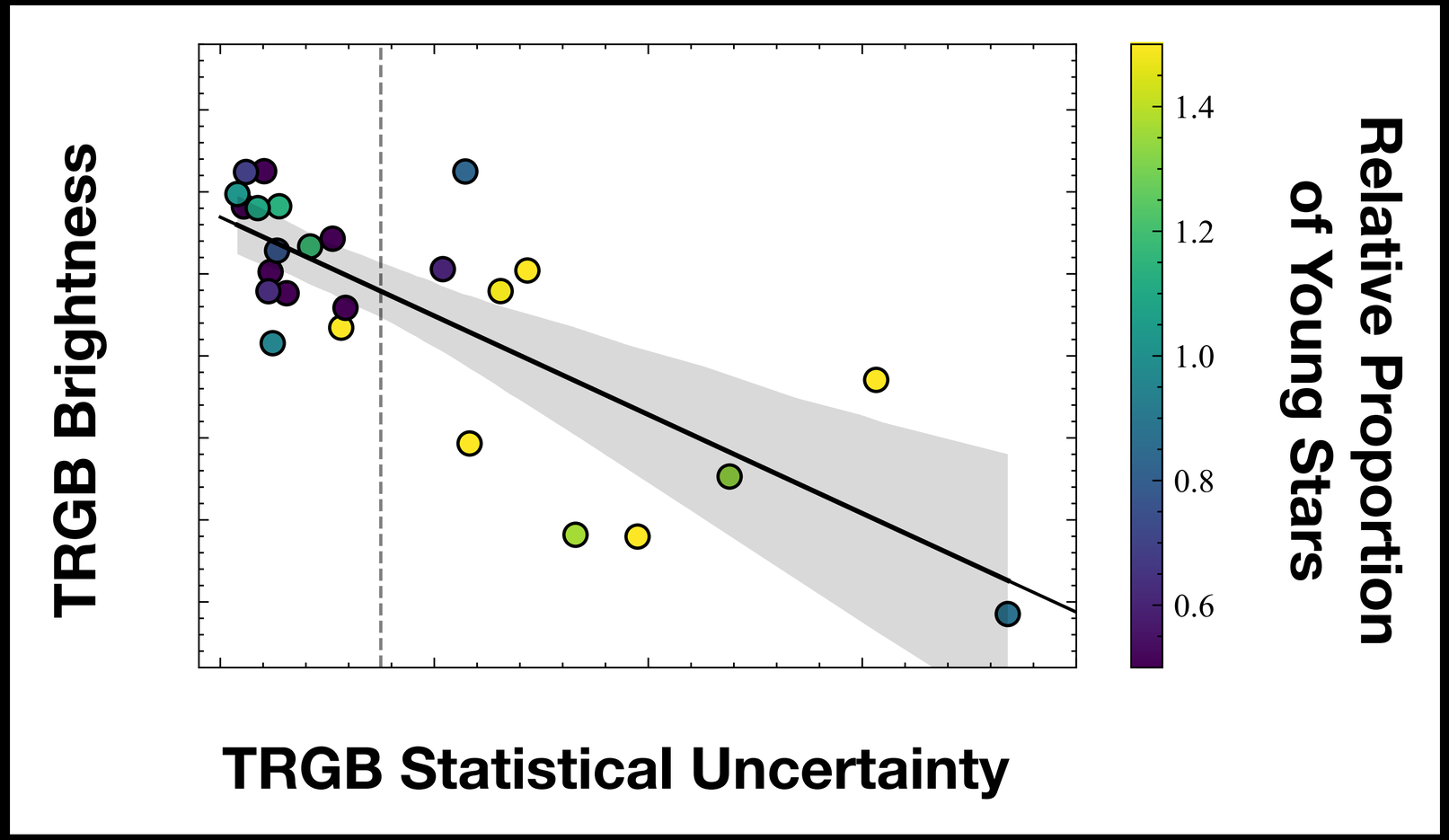
TRGB Calibration in the Clouds

- Dust extinction along LMC sightlines has been the sole topic of discussion for the past few years.

- However, even after subtracting out differences in dust reddening assumptions, there remains a residual 8% between SH0ES and CCHP proposed values for the *apparent* brightness of the TRGB in LMC, with a similar discrepancy in the SMC.

- A new, high-precision DEB distance to the SMC and new reddening maps of both Clouds motivated a detailed exploration of the TRGB.

Local Star formation and TRGB Measurement Accuracy



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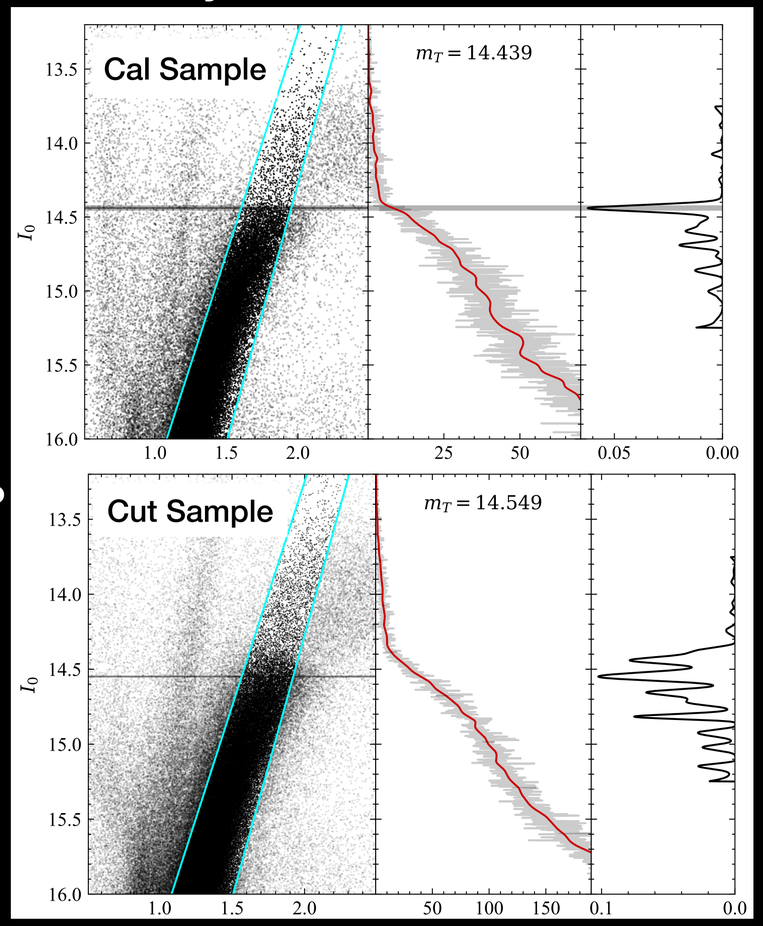
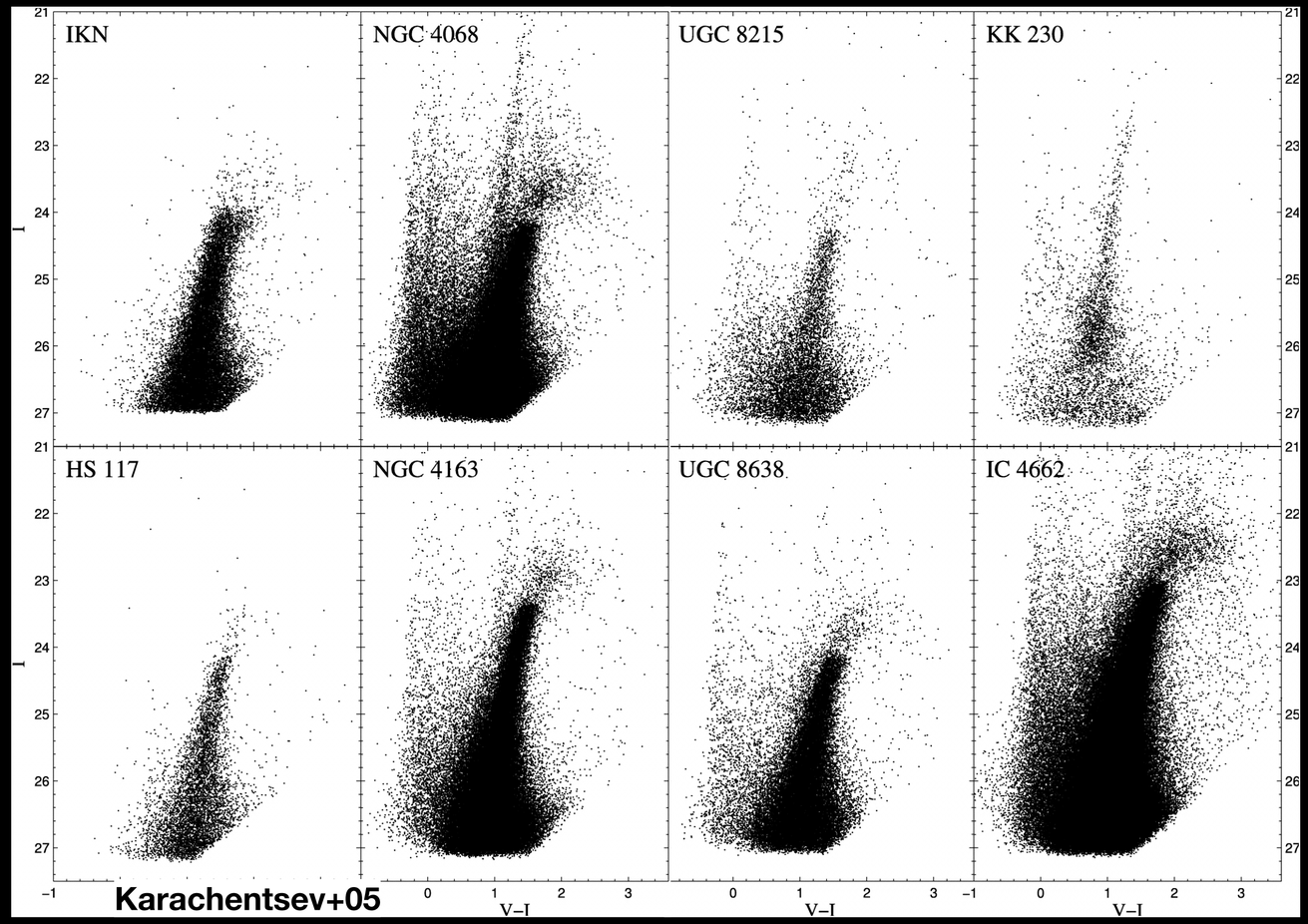
Final Measurements

Hoyt21 arXiv:2106.13337





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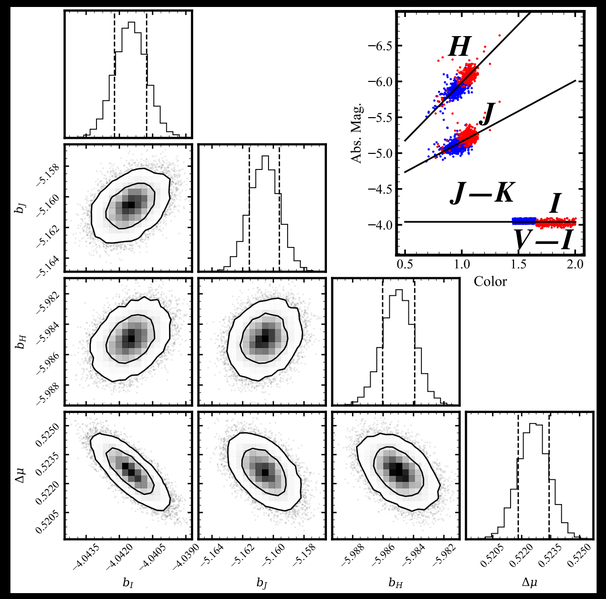
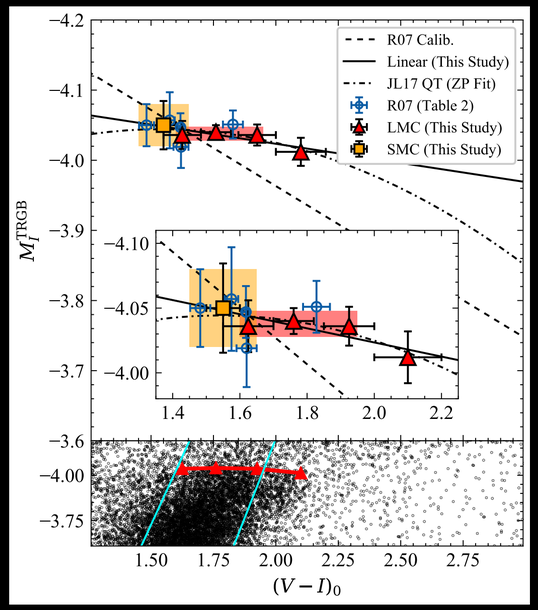
Powerful Consistency Checks

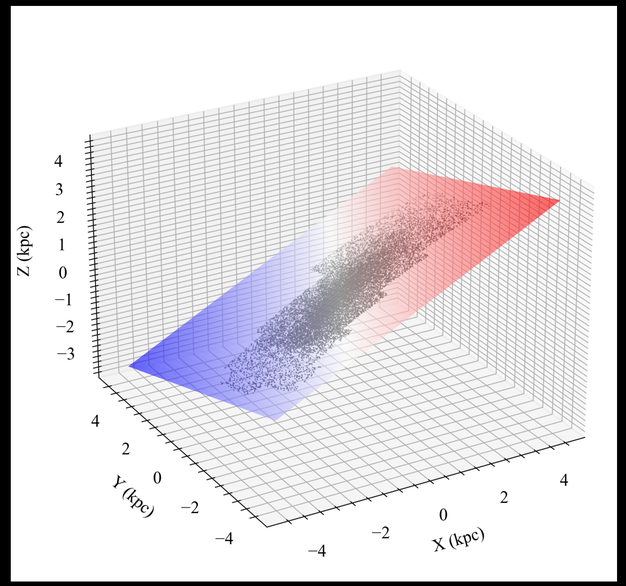
Multi-wavelength TRGB (0.5-2μm) predicts SMC distance consistent with DEBs



TRGB Color Dependence predicted by external model



LMC 3D tilt constrained for first time using only TRGB



These consistency checks span multiple astrophysical probes (DEBs, Red Clump and TRGB) and both Clouds. They reflect an understanding of the true distance, reddening, and multi-wavelength TRGB magnitudes across the Magellanic System to **2% in cumulative accuracy.**

A Legacy Calibration of the Tip of the Red Giant Branch as Constrained by the Hubble Space Telescope

Hoyt+22 (in prep.)

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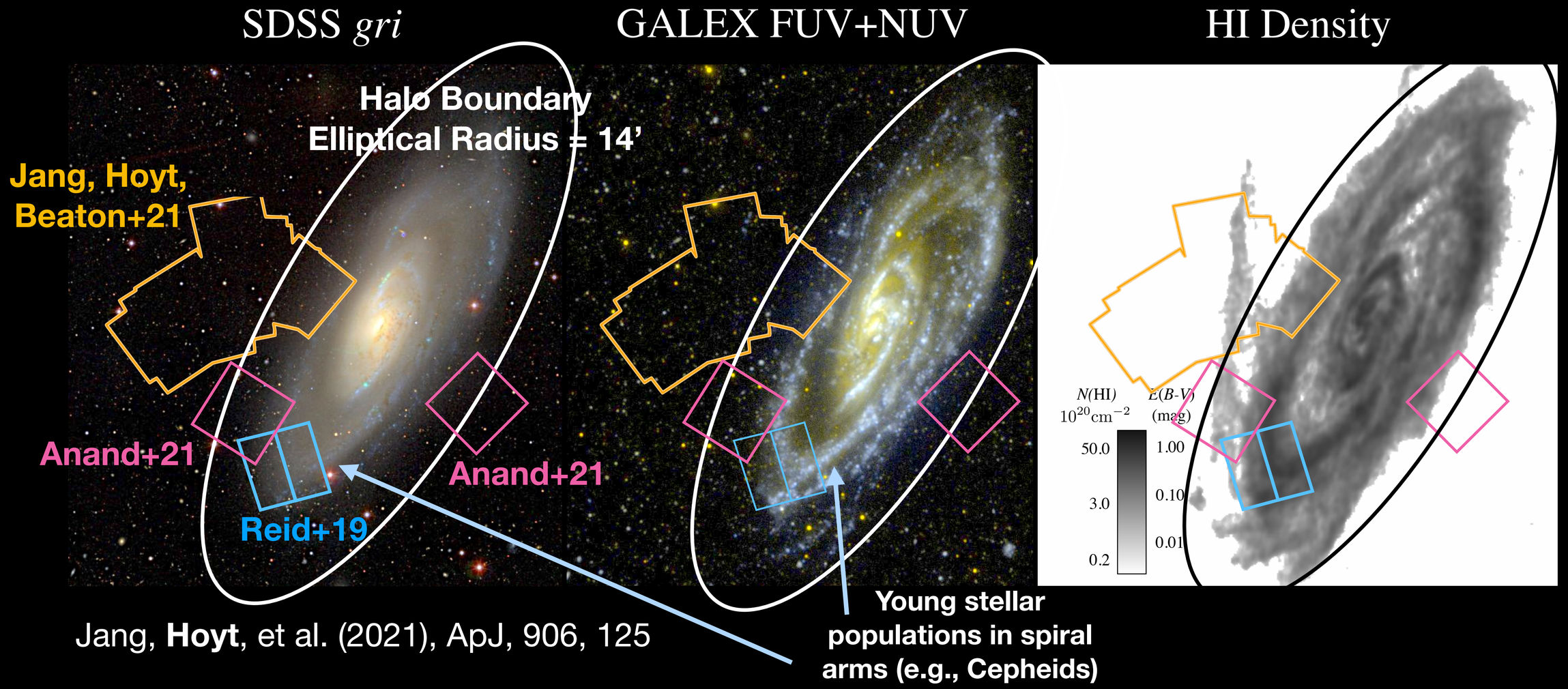
NGC 4258: Recent TRGB Calibrations



Jang, **Hoyt**, et al. (2021), ApJ, 906, 125

A Foundational Calibration of the TRGB with the Hubble Space Telescope

PI: Hoyt, HST-GO-16743

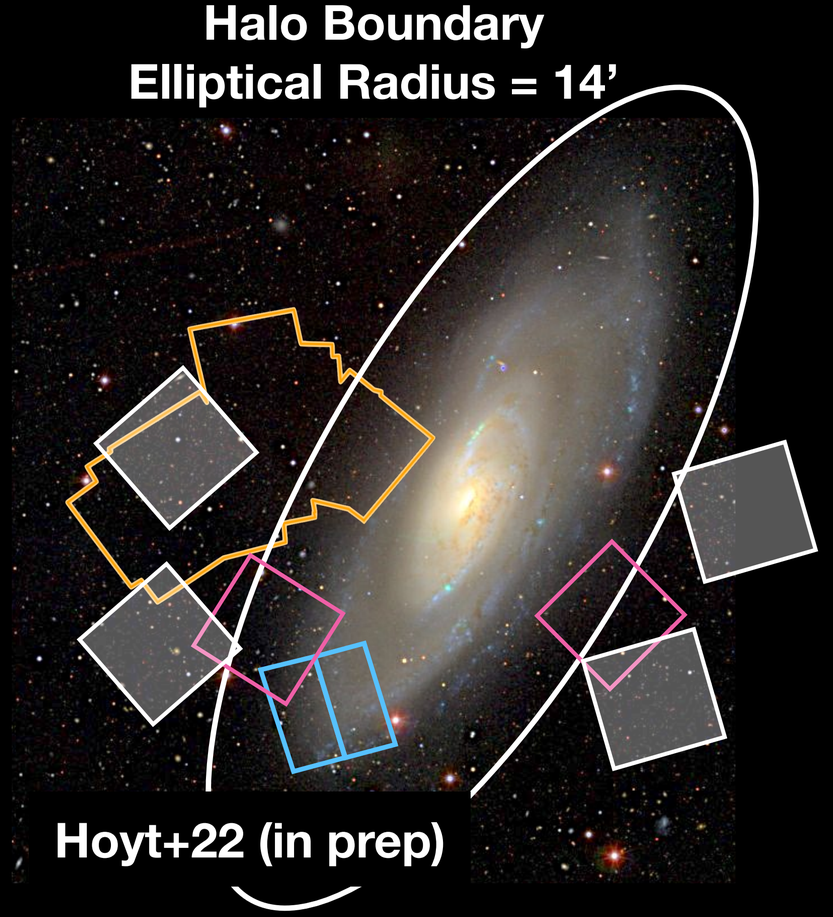
Same environment and obs configuration as the SN Host data

Avoids all HI emission (tracer of dust).

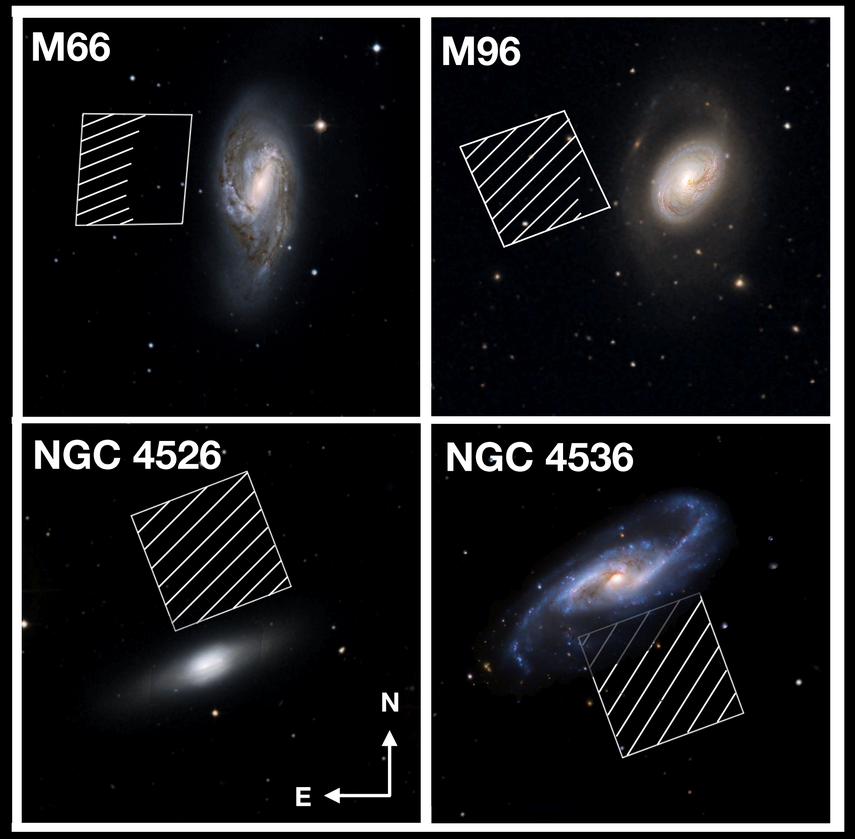
2.5x higher signal-to-noise flux measurements than the recent Jang+21 and Anand+21 studies.

Will reach the systematic floor set by the geometric maser distance and foreground extinction (1.6%).

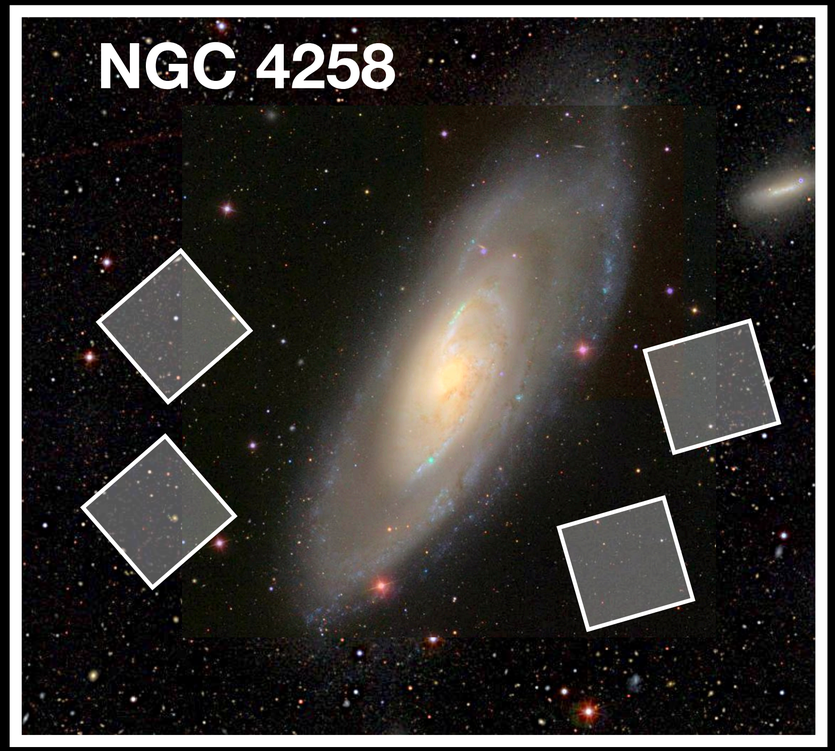
Combined with the Hoyt21 LMC result, a 1% zero point calibration of the TRGB distance scale; ~twice as good as current quoted precisions, and likely even greater gains in reduction of systematics.



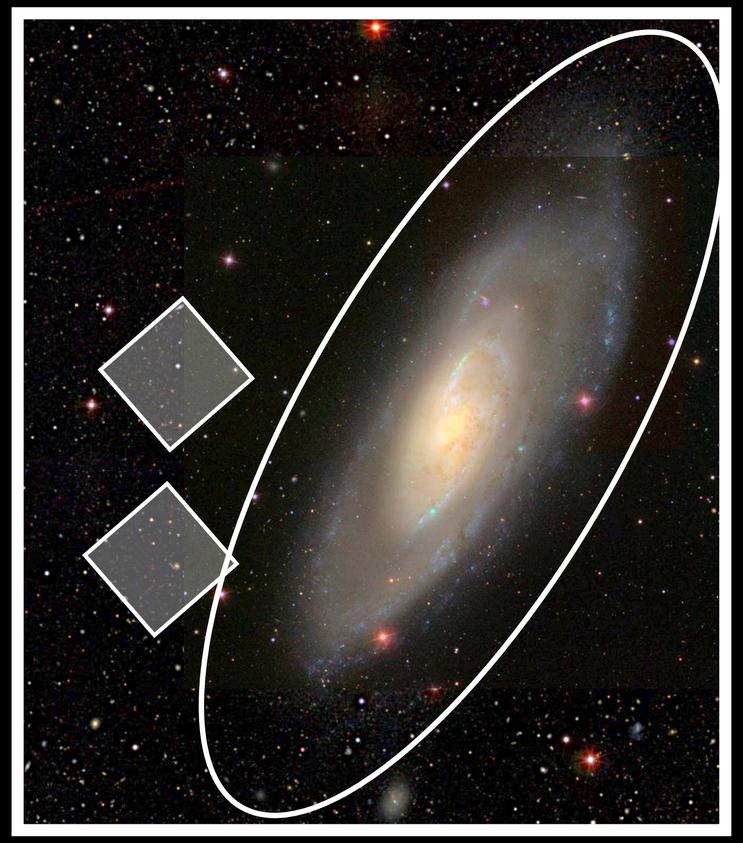
Matching the SN Host Observations: Major Reduction in Systematic Uncertainty

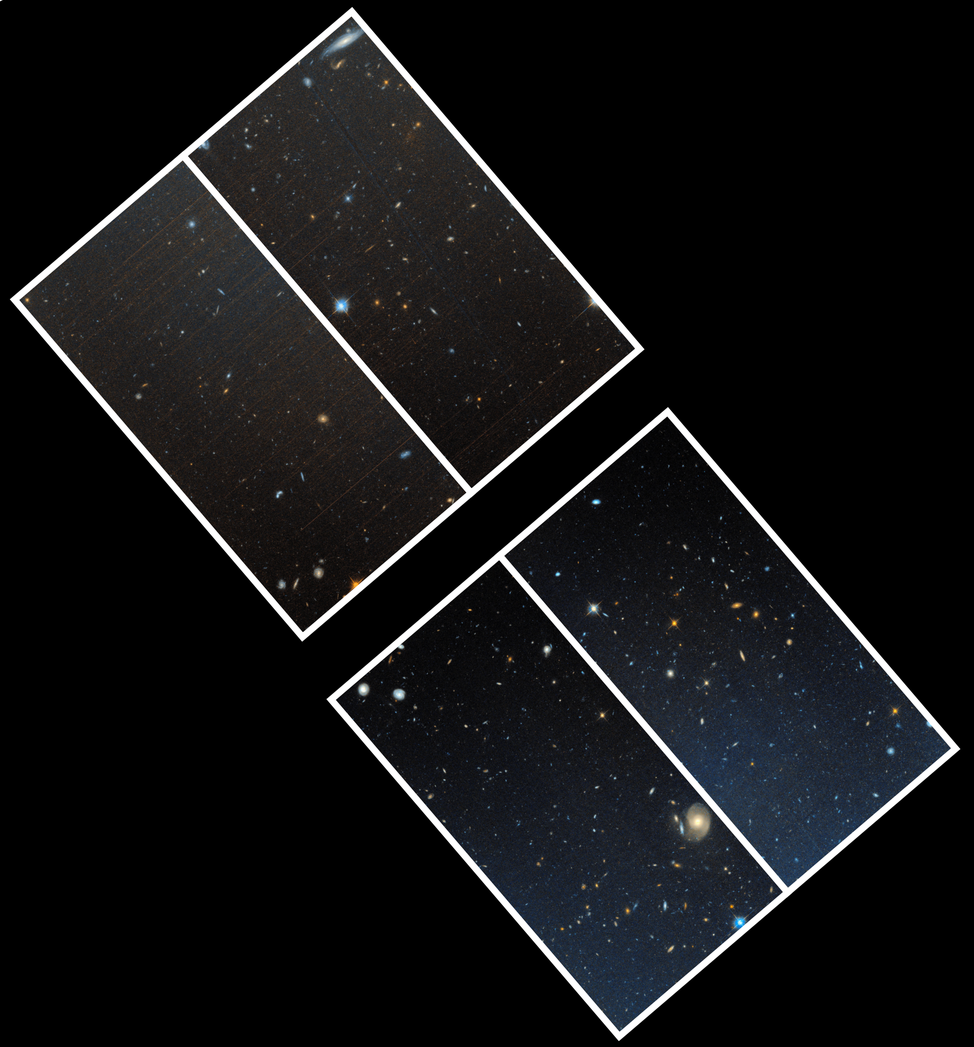


CCHP H0 Paper (Freedman+19)



Deep Imaging of Outer Halo





Hoyt+22 (in prep)

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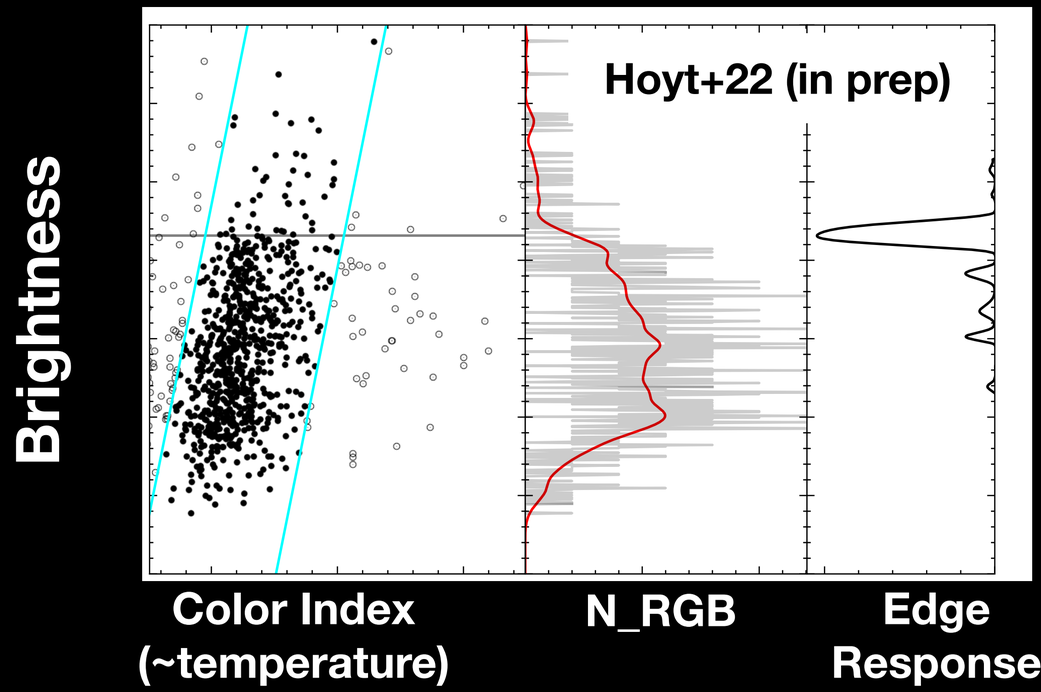
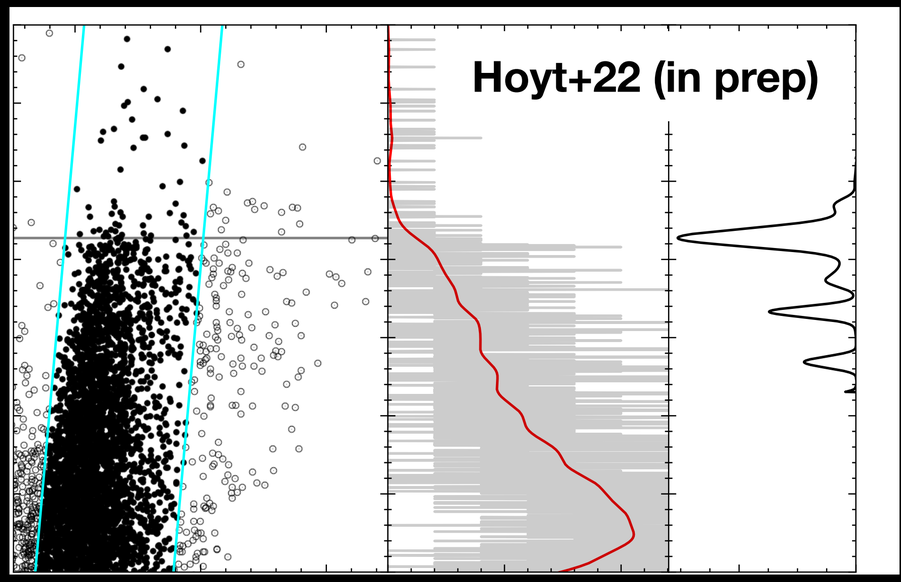
TRGB Measurements

Combined (PRELIMINIARY): M_814 = -4.045 +/- 0.01 mag





—> Fully consistent with Freedman+19/20 and settles any remaining debate over the zero point calibration of the CCHP's TRGB distances to the stellar halos of SN Hosts.

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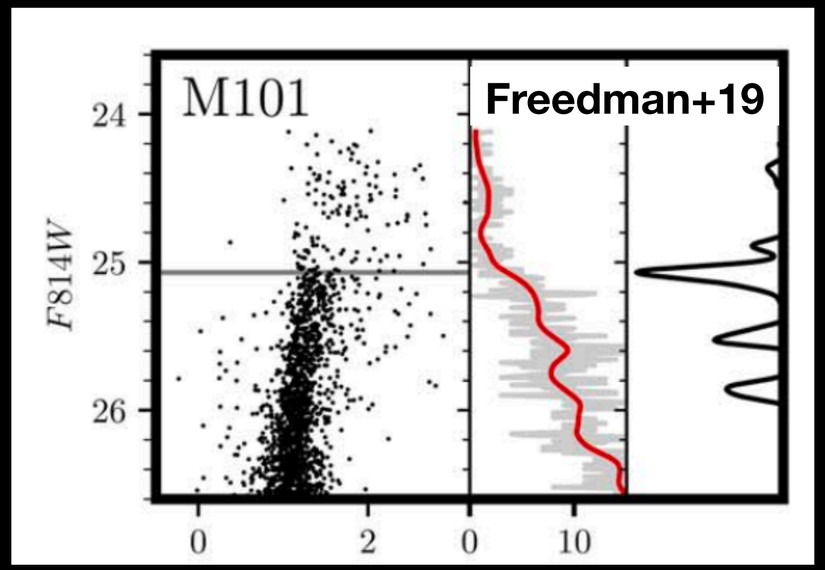
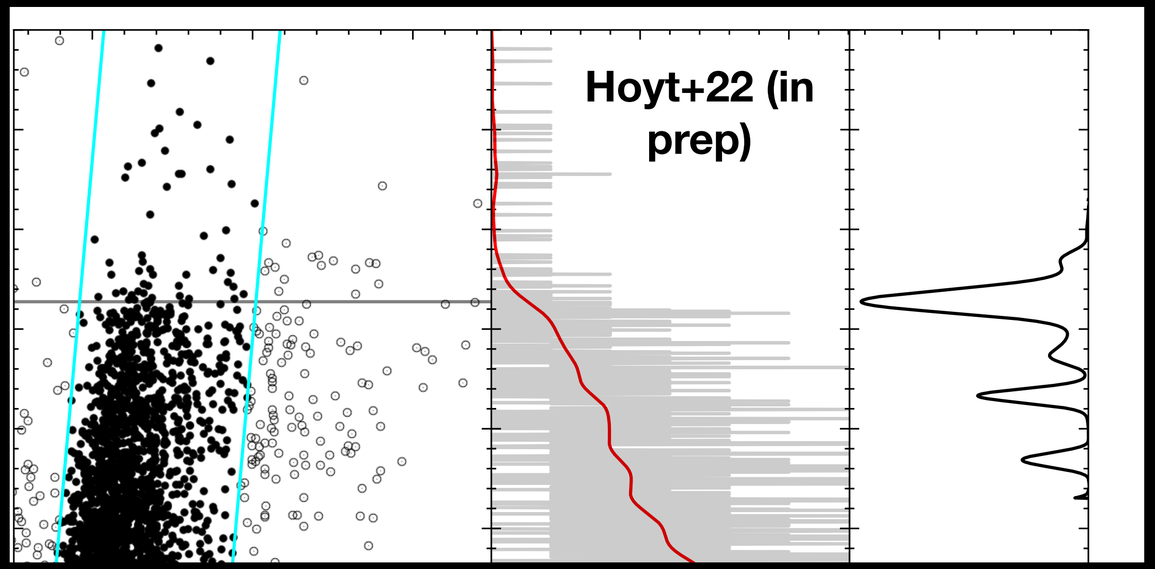
Comparing to SN Host Sample

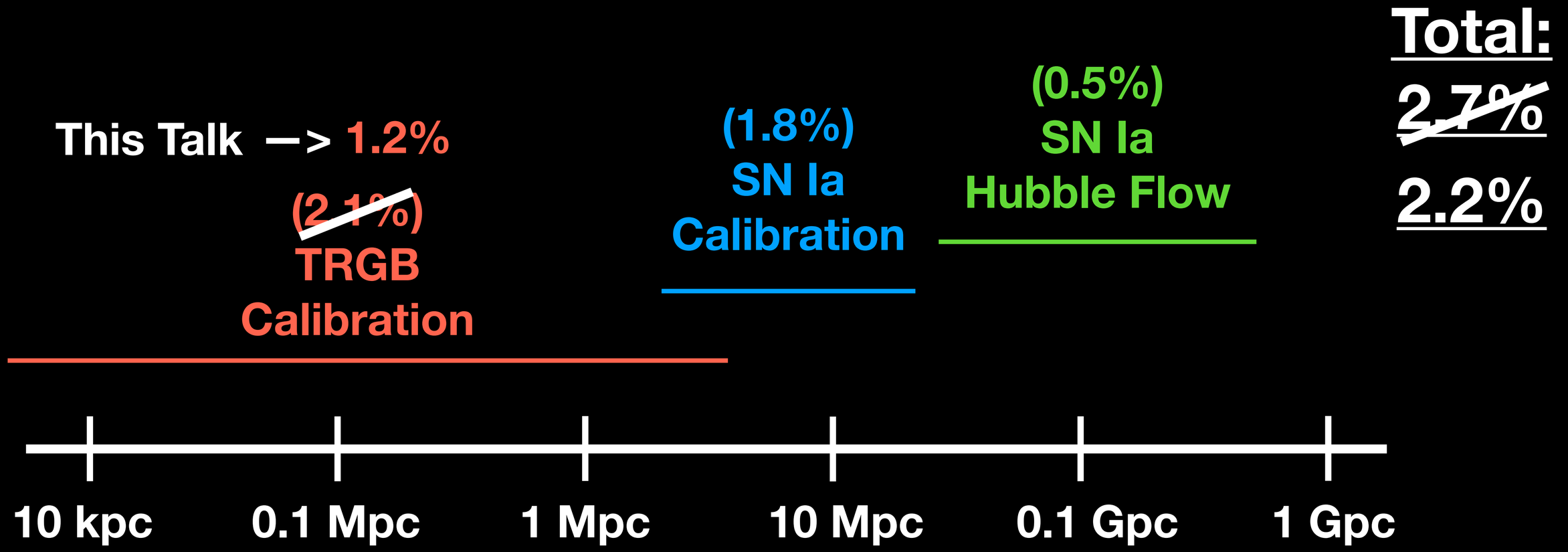




Final TRGB Calibration Error Budget

	F19/20 (LMC)		Hoyt21 (LMC)	Hoyt+22 (N4258)	Combined
Geometric Distance	1.2%		1.2%	1.5%	Independent!
Dust Extinction	1%		0.8%	0.5%	Statistically independent and both anchored to Schlegel dust map (big reduction in systematics!!!!)
TRGB Measurement	1.1%		0.3%	0.4%	High S/N, number stats, and ACCURACY in both galaxies!
Ground-to-HST filter	1%		1%	N/A	Direct HST observations in 4258
	2.1%		1.78%	1.63%	1.20%

Effect on Total H0 Error Budget



Towards a 1% H0

Doubling the # of TRGB Distances to SN Hosts

This Talk —> 1.2%

~~(2.1%)~~

TRGB Calibration

—> 1.3%

~~(1.8%)~~

SN Ia Calibration

(0.5%)

SN Ia Hubble Flow

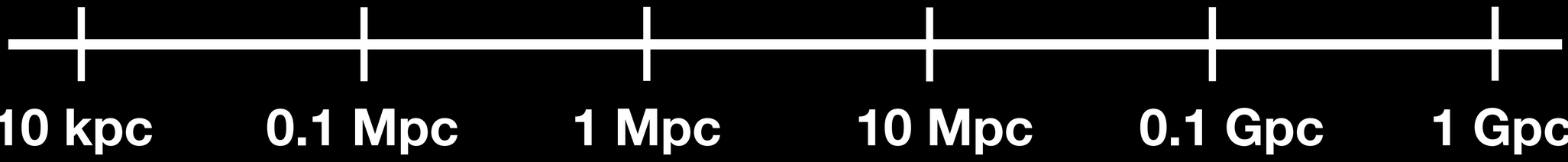
Total:

~~2.7%~~

~~2.2%~~

1.8%

(Planck18 is 0.8%)



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Towards a 1% H0

- Diminishing returns using photometric standardization of SNe. For the Cepheid-SN route to reach 1% precision on the SN Ia calibration, another 1000 orbits (1 orbit ~ 1 hour) of Hubble time would need to be invested.
- Need a method that provides more statistical weight PER SN Ia than the photometric Phillips/Tripp relations.
- Spectroscopic standardization of SNe may provide such a path forward.

Summary/Conclusions

- Much ado appears to have been made about nothing re: the zero point calibration of the TRGB distance scale. Misunderstandings and misapplications of the method have confused the literature, but things appear settled now, e.g., Hoyt21, Freedman21, Hoyt+22 (in prep).

- Multiple, independent astrophysical probes provide compelling evidence in favor of the three-decades-long TRGB zero point that is just brighter than -4th magnitude in the Bessel *I*-band.

- As emphasized in Freedman21 and Hoyt21, the possible cause for the “local tension” between TRGB and Cepheids is likelier to be found hiding in the much more difficult distance measurements made to distant (20-40 Mpc) SN Ia Host Galaxies.

- The precision and accuracy of the TRGB H0 has improved considerably thanks to the heightened focus on its zero point calibration, and I will continue to pursue further improvements, particularly in the infrared with Hubble and James Webb.