Carbon Stars as Standard Candles

An Independent Measurement of the Hubble Constant with JWST

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Tension in H_0

Measurement from early universe

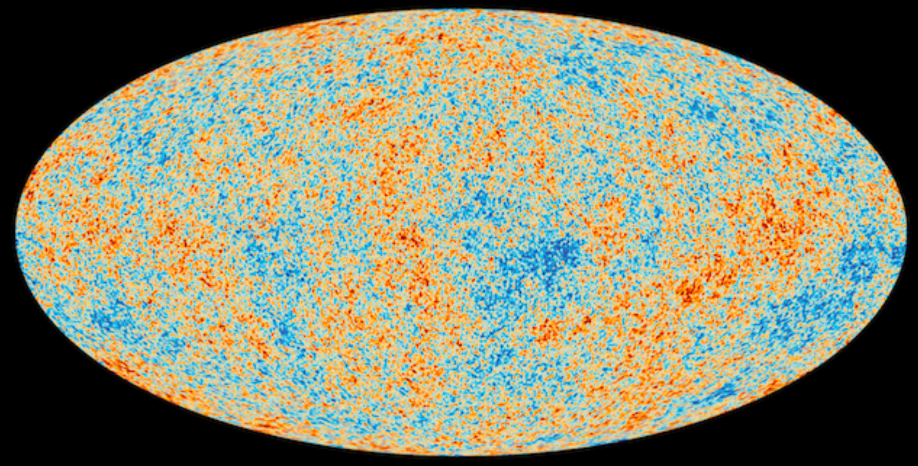
Cosmic Microwave Background

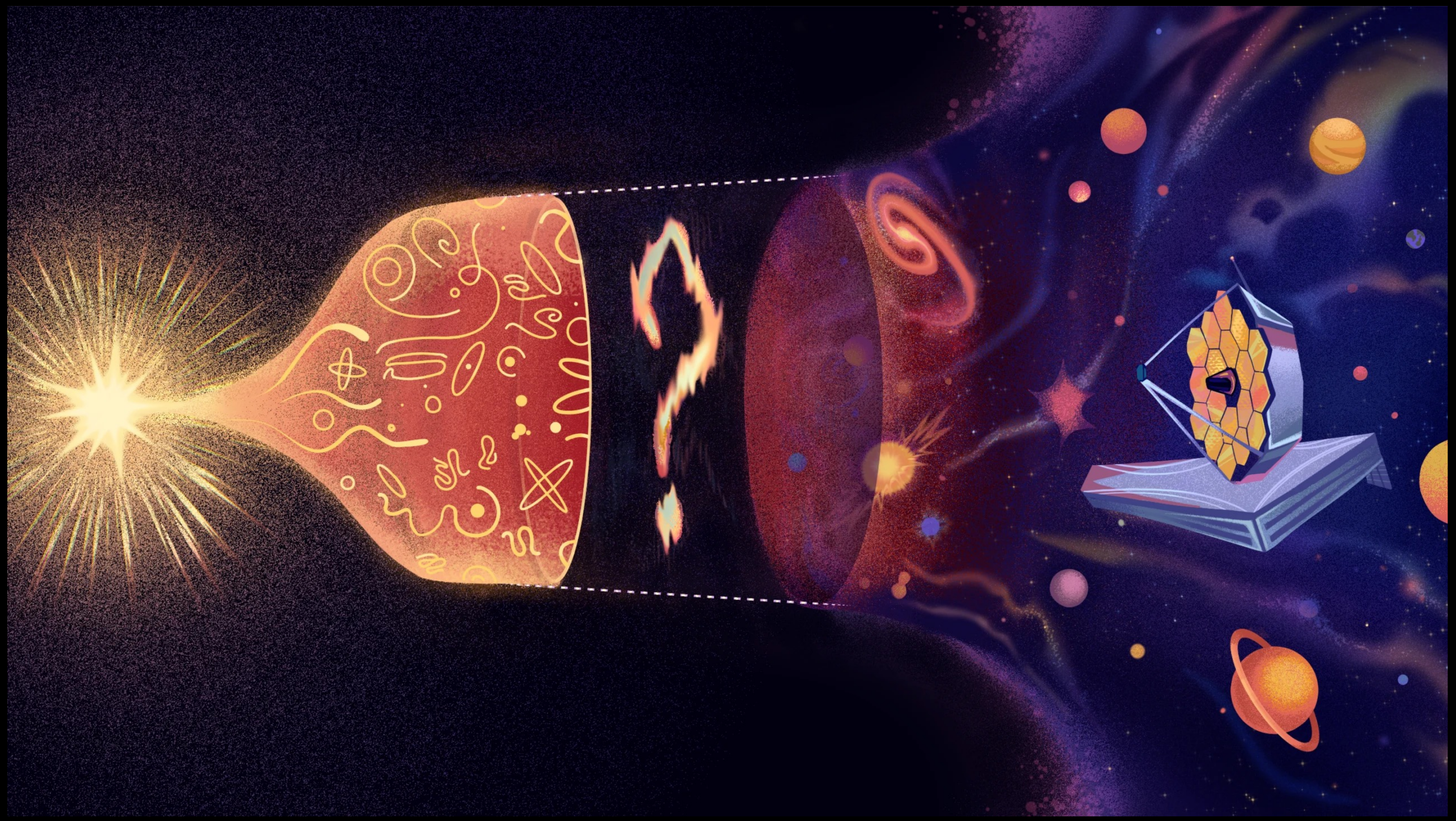
Planck collaboration

2020

67.4 ± 0.5 km s^{-1} Mpc^{-1}

assuming ΛCDM



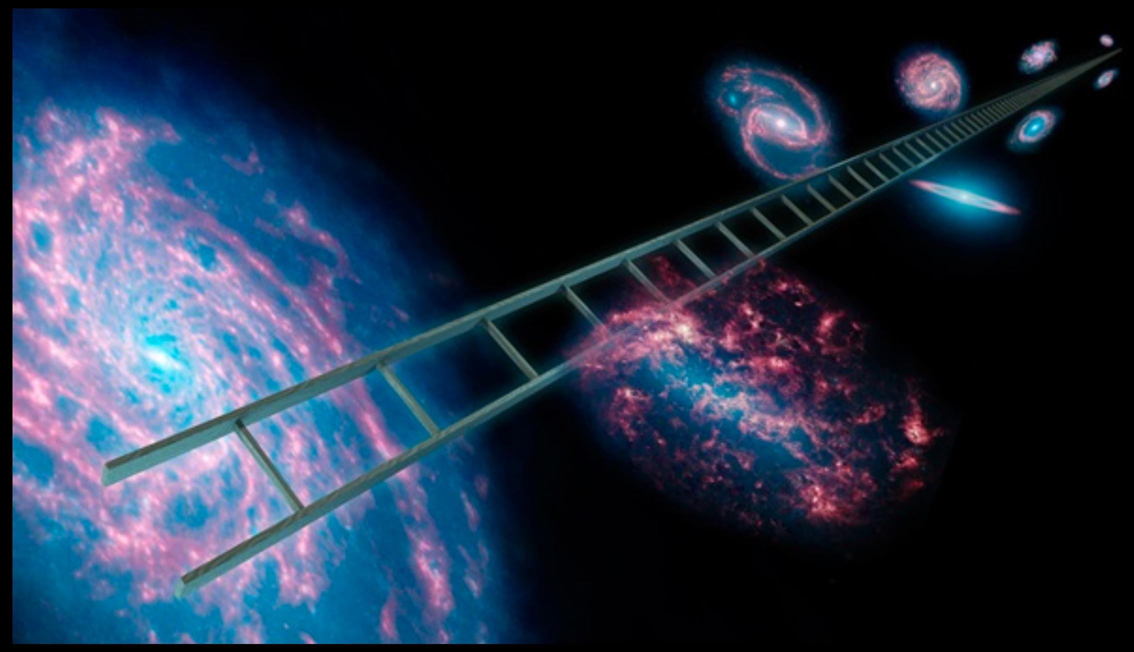


Measurement from local universe

Supernovae Ia distance ladder

SHoES (Riess et al. 2022)

73.0 ± 1.0 km s^{-1} Mpc^{-1}

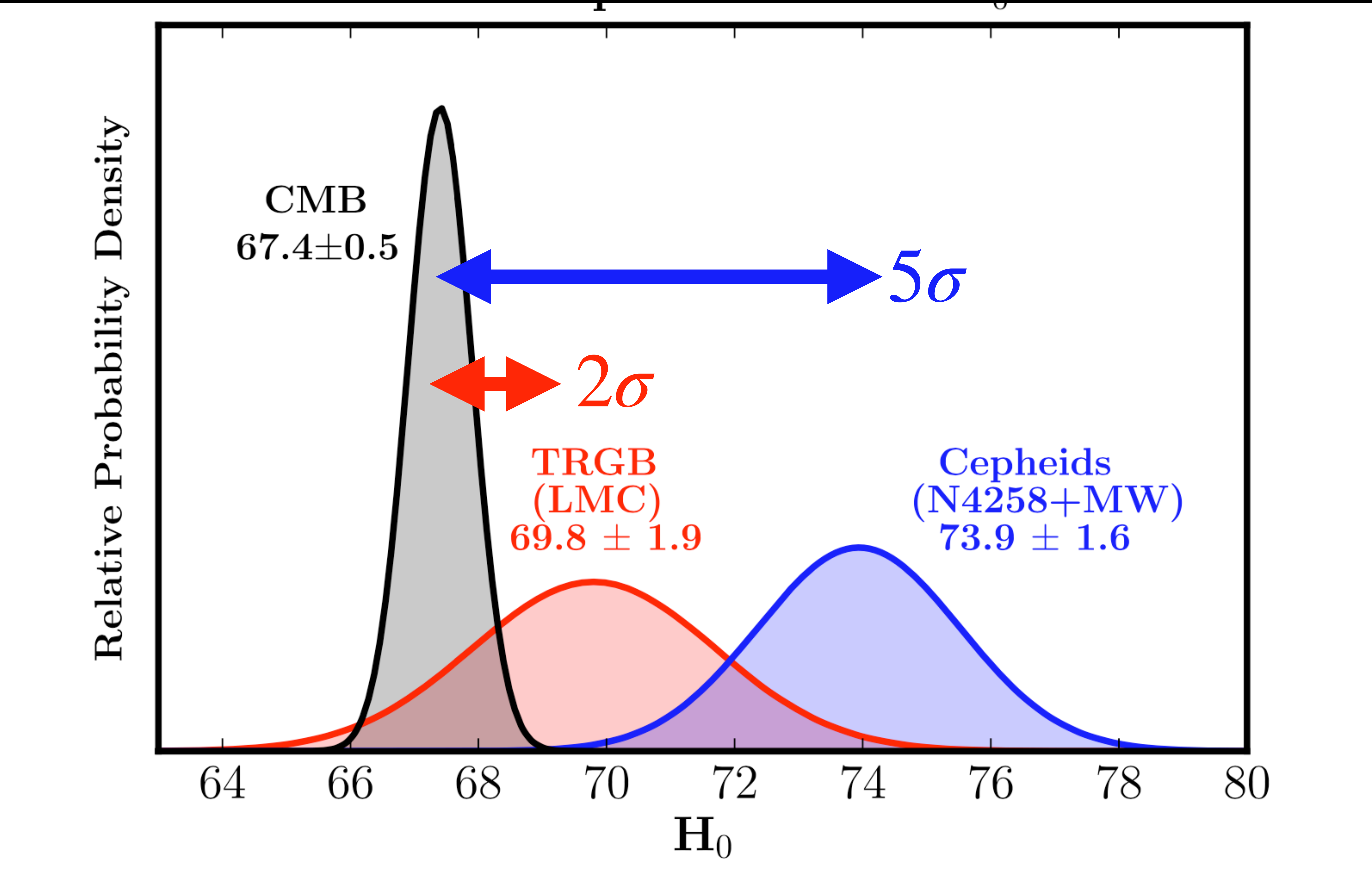


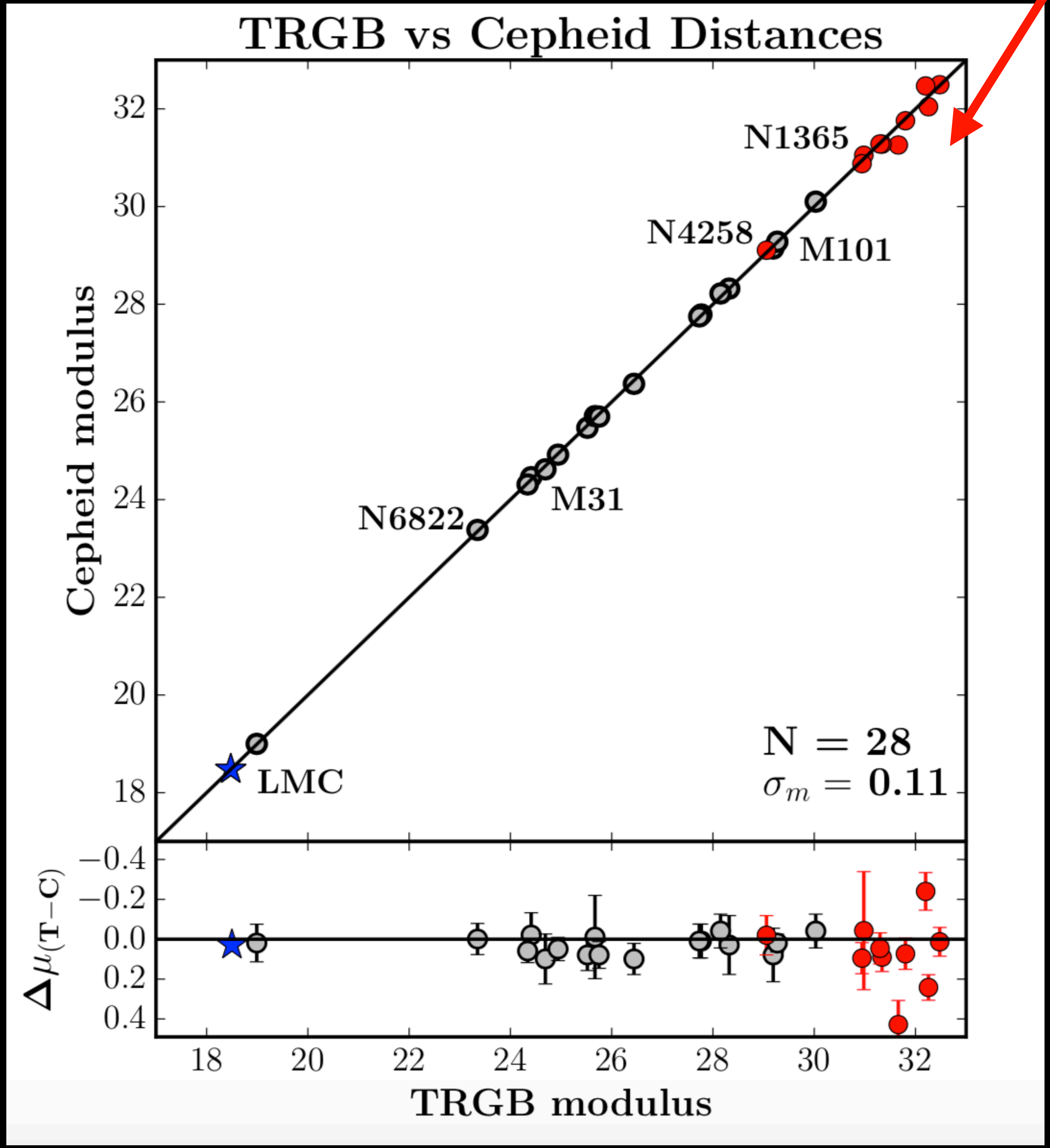
← 5σ tension →

Quanta

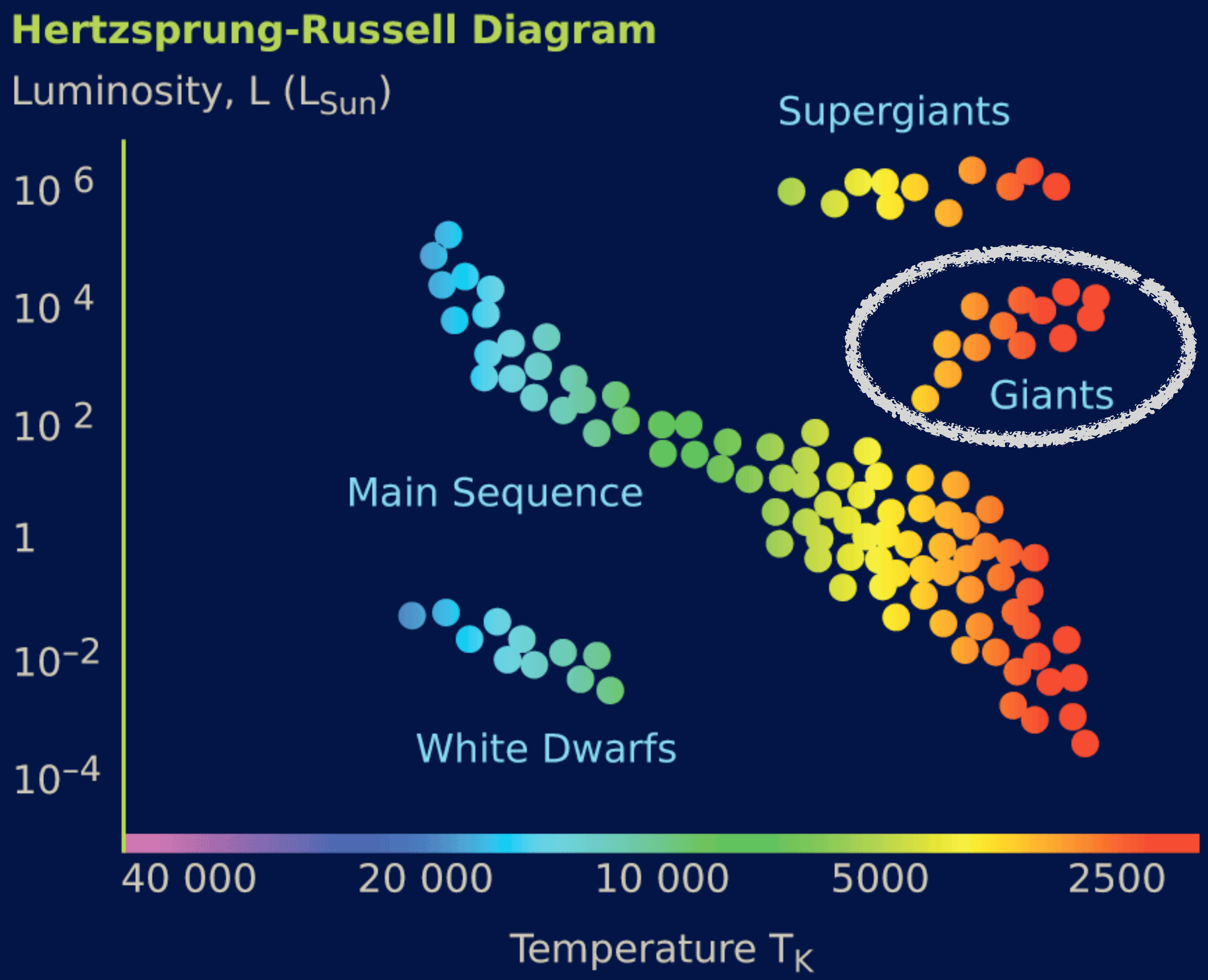
2019 Disagreement between Cepheids vs. TRGB

SNe Ia host calibrating galaxies

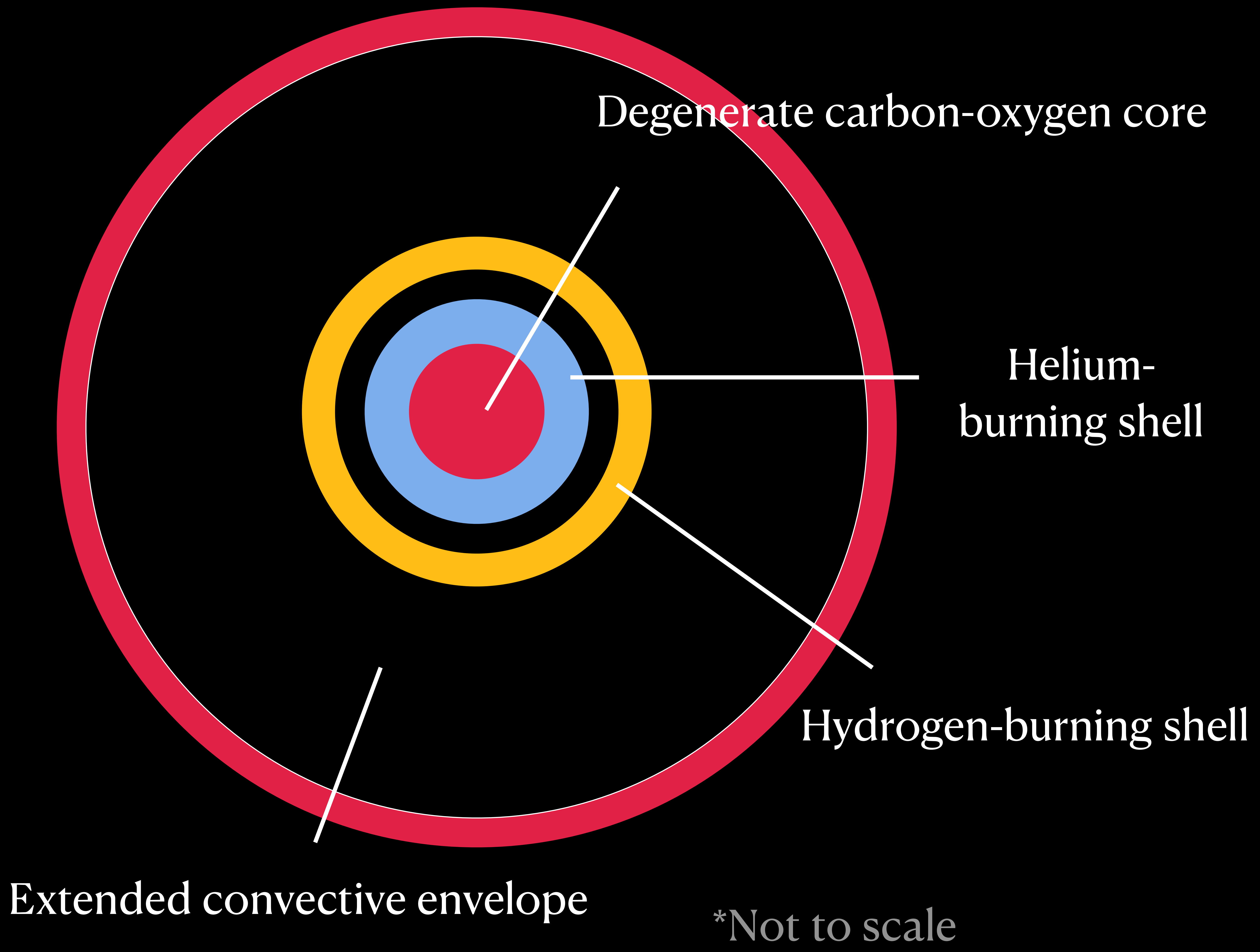




Freedman+ 2019

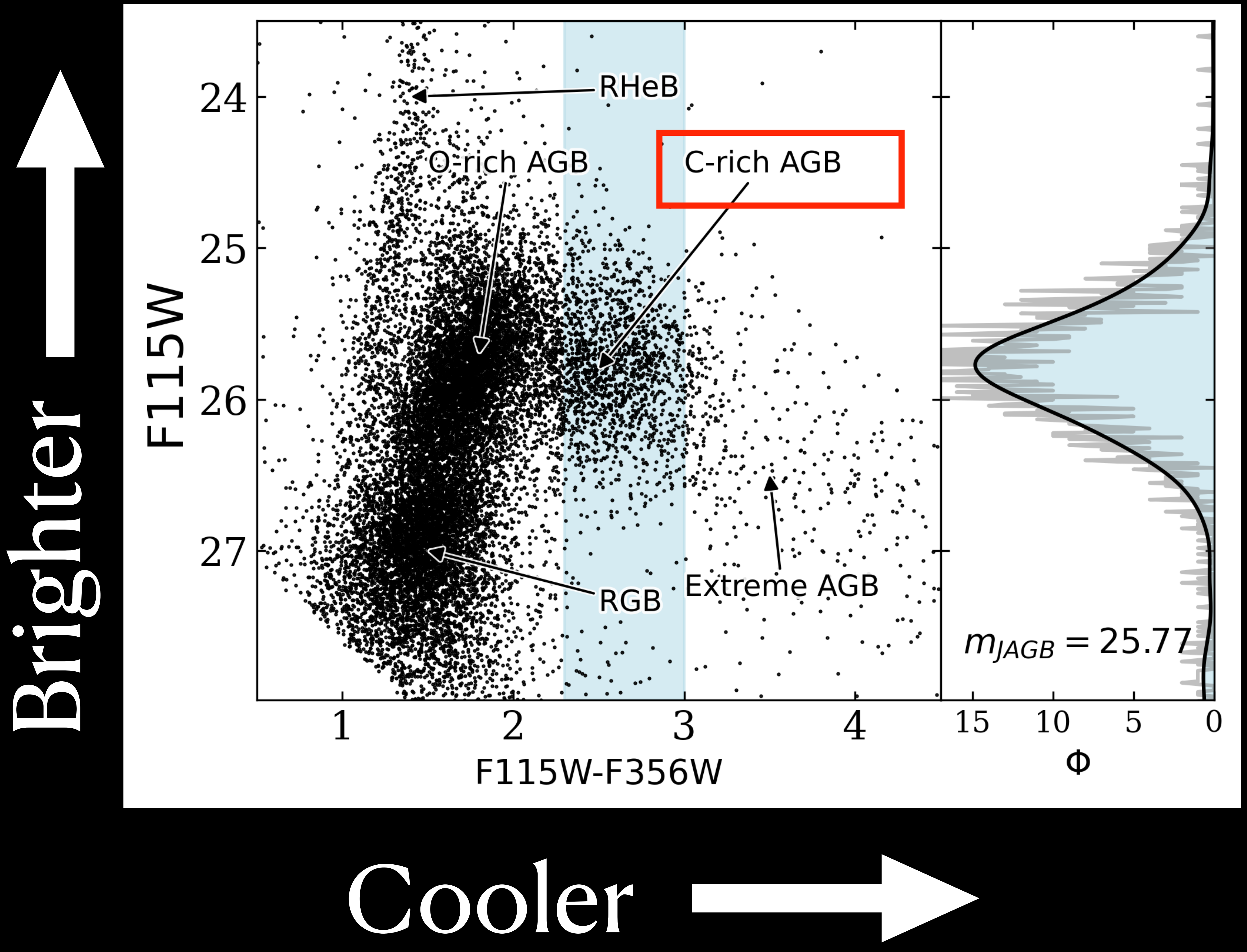

Hertzsprung-Russell Diagram
Luminosity, L (L_{Sun})
Supergiants
10^6
10^4
10^2
1
10^{-2}
10^{-4}
Giants
Main Sequence
White Dwarfs
40 000
20 000
10 000
5000
2500
Temperature T_K

Astrophysical Distance Methods: Carbon Stars as Standard Candles



- "Dredge-up" episodes responsible for creating carbon stars only effective for a narrow range of masses and thus, luminosities of AGB stars (see Habing & Olofsson 2004 for a review)
- $\approx 1.5\text{-}4\ M_\odot$

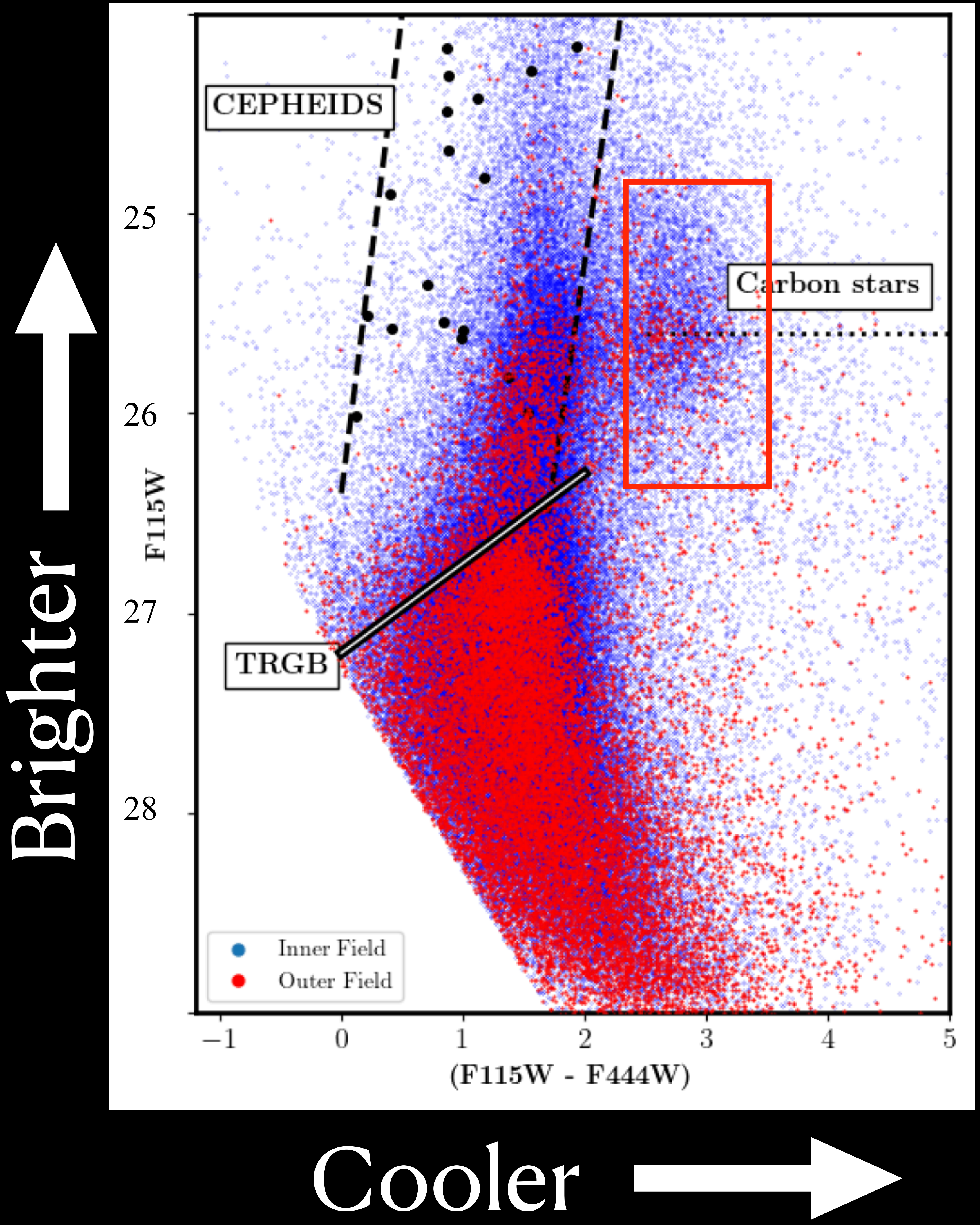
The J-region Asymptotic Giant Branch (JAGB) Method



Lee+24c (submitted)

- ★ JAGB stars are intermediate-mass, carbon-rich AGB stars
- ★ JAGB stars are **photometrically** selected using near-infrared colors
- ★ The mode of the JAGB luminosity function is constant from galaxy to galaxy and therefore an effective standard candle (Freedman & Madore 2020, **Lee**+2021a, Zgirski+2021, **Lee**+2022, Madore+2022, Parada+2023, **Lee**+2024b)
- ★ Comparable accuracy and precision to the TRGB and Cepheids

Comparison of Brightnesses Between Distance Indicators



Freedman & Madore 2023

The JAGB Method

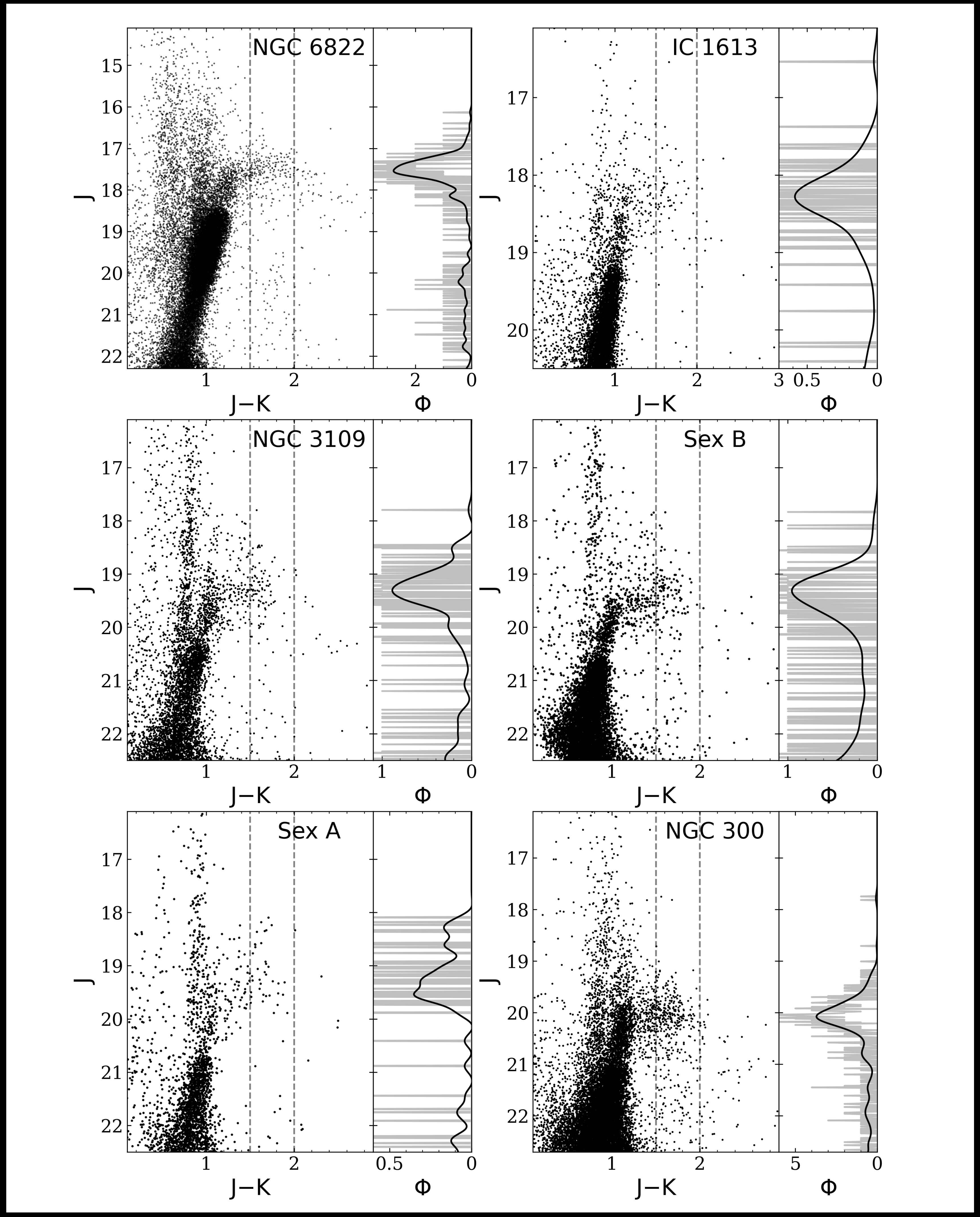
Advantages:

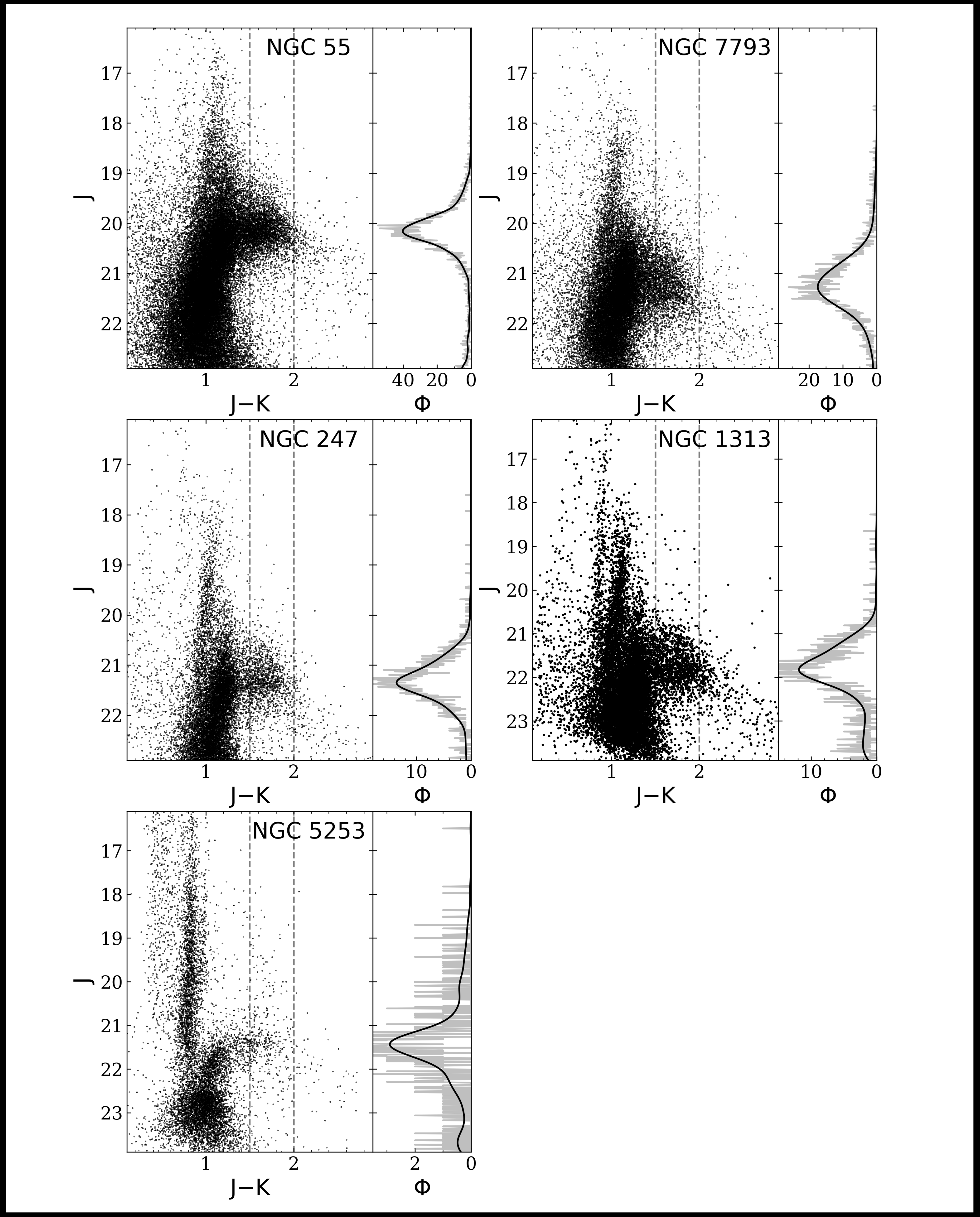
- ★ JAGB stars are distinctive and easily identifiable on the basis of their color
- ★ JAGB stars are ubiquitous and can be found throughout all galaxy morphologies and inclinations
- ★ Near-infrared observations decreases line-of-sight extinction
- ★ Only require 1 epoch of observations for measurement
- ★ Crowding effects are decreased in the outer disk

Potential sources of systematic errors:

- ★ How does the shape and mode of the JAGB star luminosity function depend on the host galaxy's star formation history or metallicity?

Quantifying Accuracy/Precision of JAGB Method



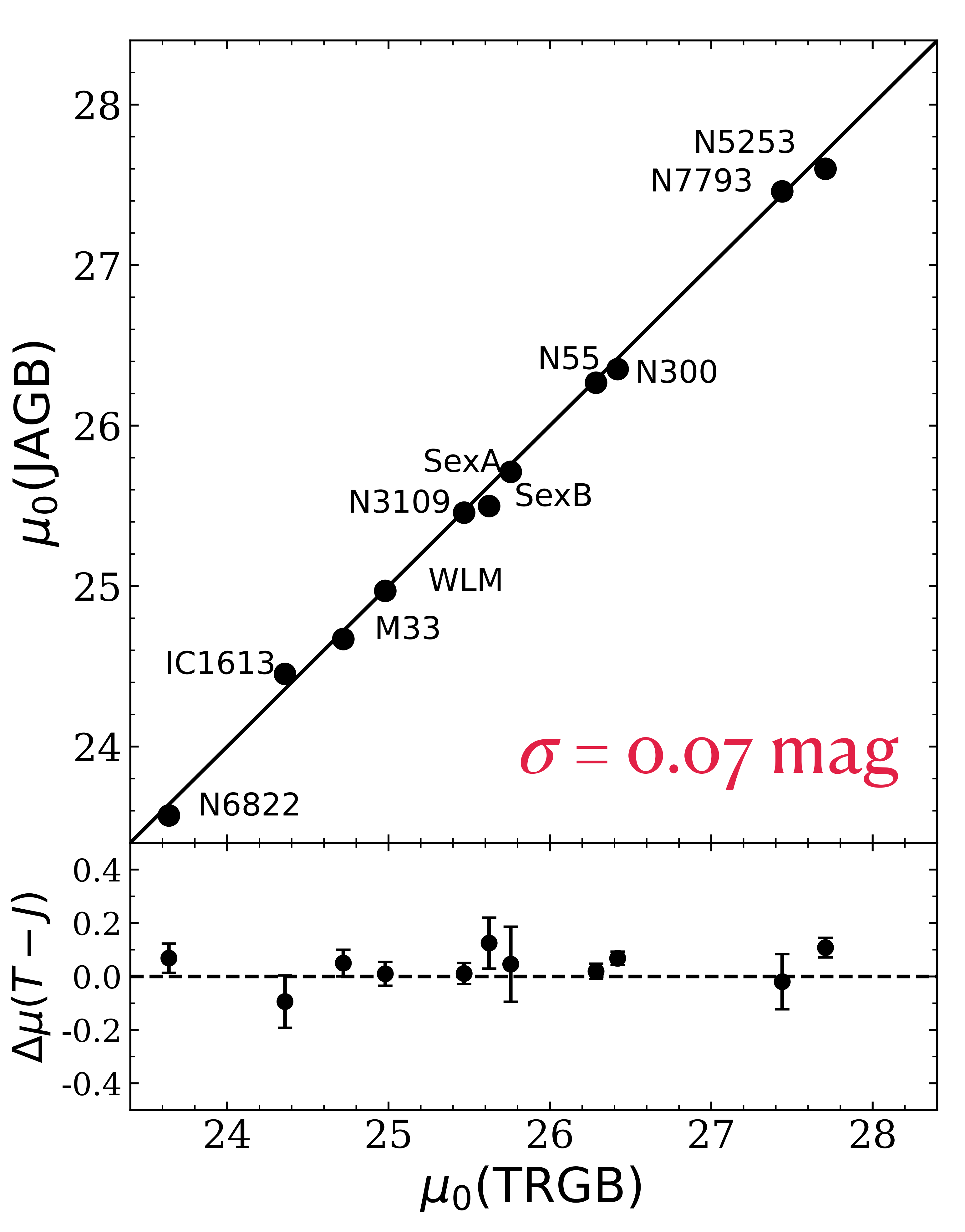


- 104 nights of JHK observations acquired from the Baade-Magellan telescope
- Data are publicly available

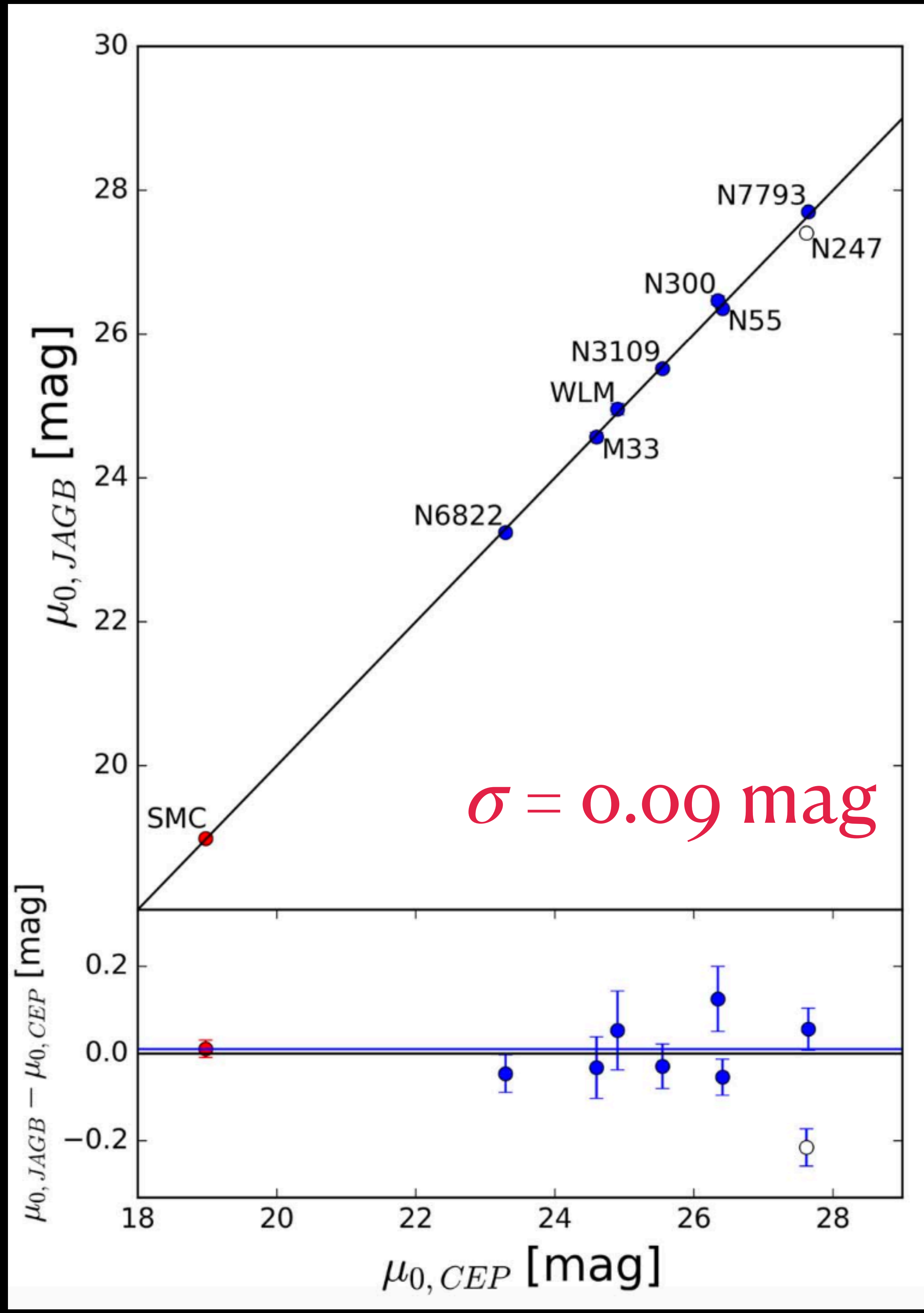
doi: 10.5281/zenodo.10989065

Lee+ 2024b

Quantifying Accuracy/Precision of JAGB Method

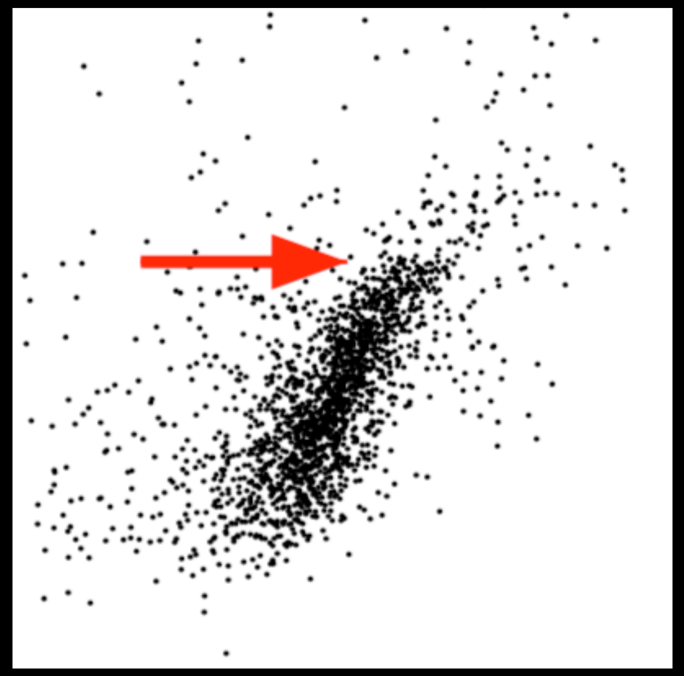


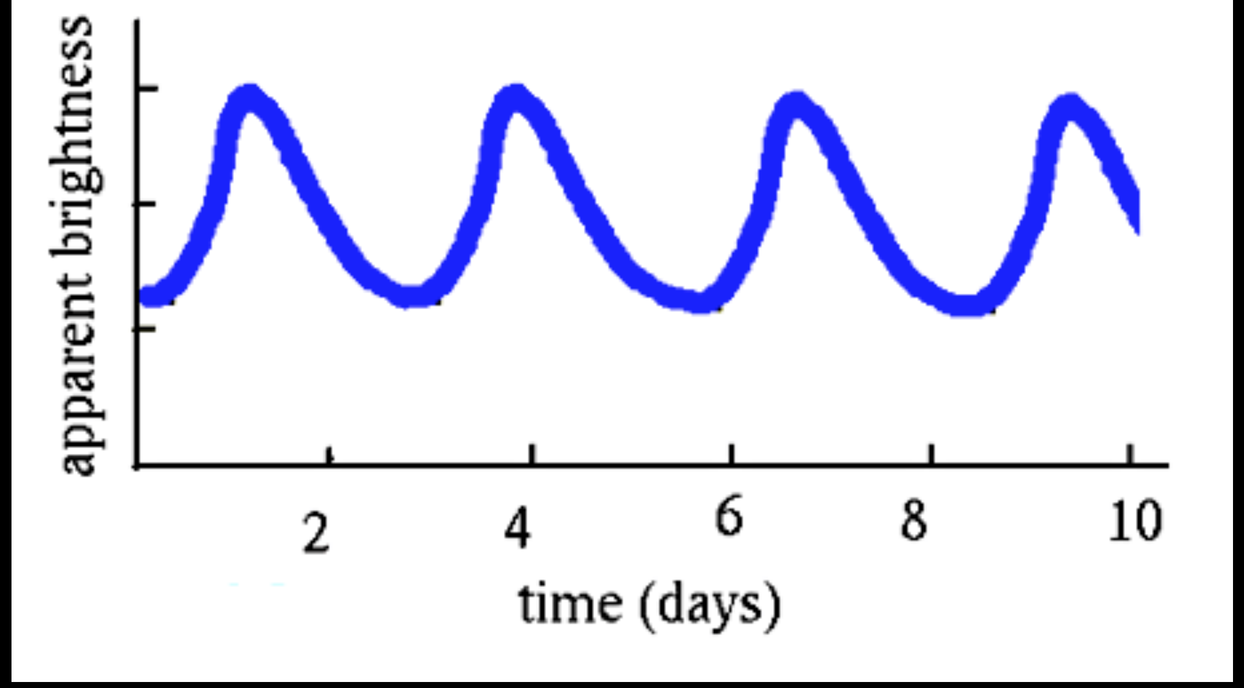
Lee+ 24b

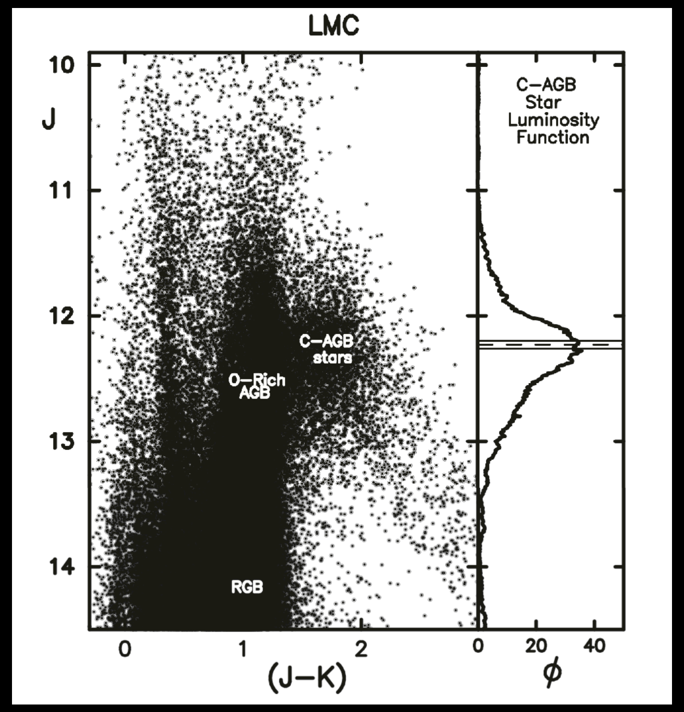


Zgirski+ 21

The JAGB method agrees well with the TRGB and Cepheid P-L relation at the 3% level in nearby galaxies (d < 4 Mpc)







TRGB

- ★ Measured in stellar halo
- ★ Older stellar population (>4 Gyr)
- ★ Helium Flash

Cepheids

- ★ Measured in the star-forming disks
- ★ Younger stellar population (<100 Myr)
- ★ Mechanical pulsation cycles

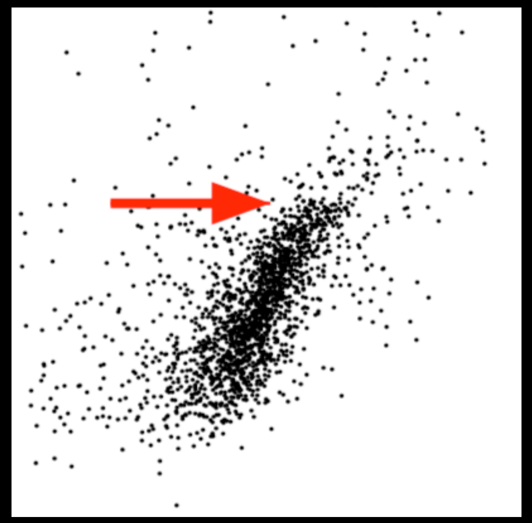
JAGB

- ★ Measured in the outer disks
- ★ Intermediate-age stellar population (300 Myr-1 Gyr)
- ★ Third Dredge-up

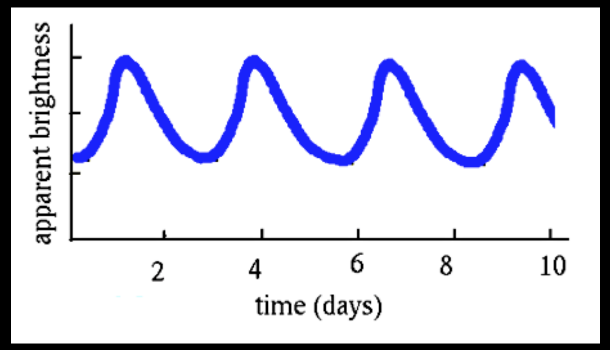
Potential sources of systematic errors for each distance indicator are independent, and can be unearthed through inter-comparison

The Chicago-Carnegie Hubble Program (CCHP)

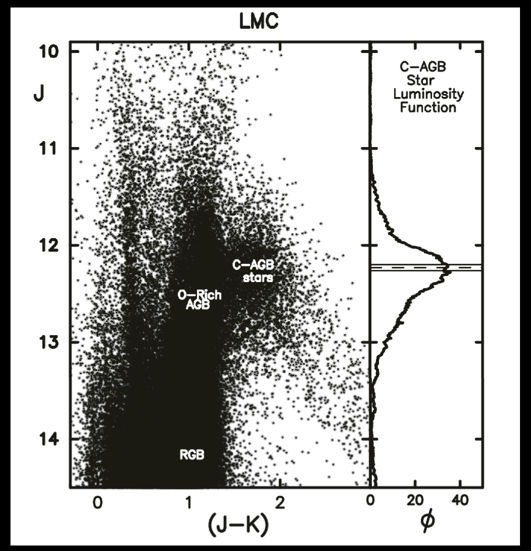
How can the JWST help us improve measurements of H_0?



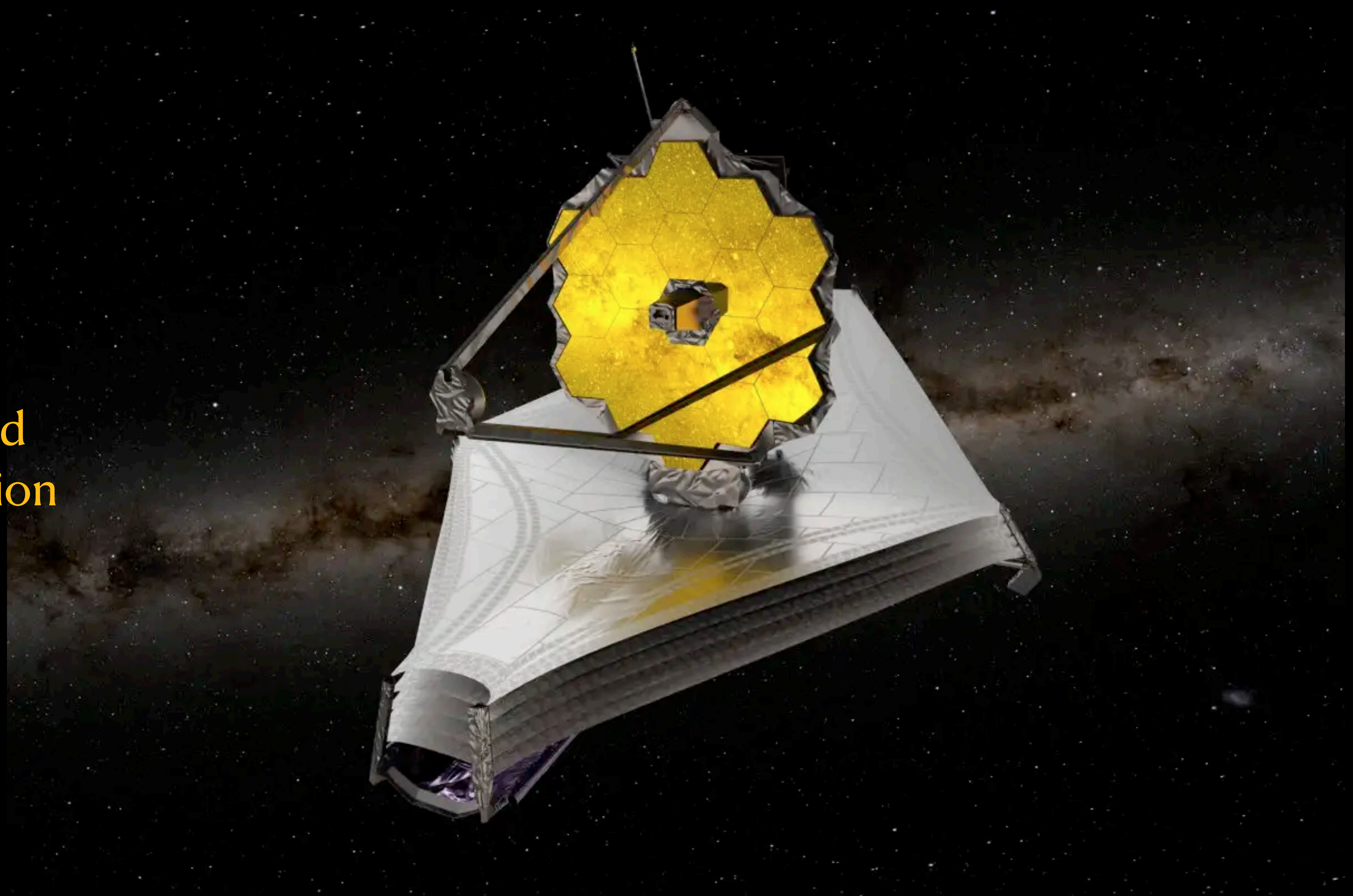
TRGB



Cepheid
P-L relation



JAGB
Method



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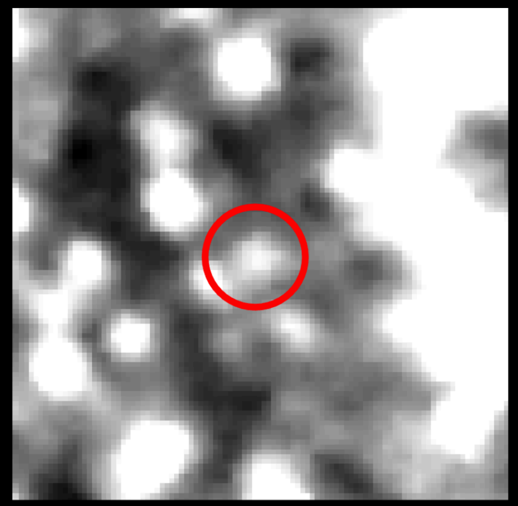
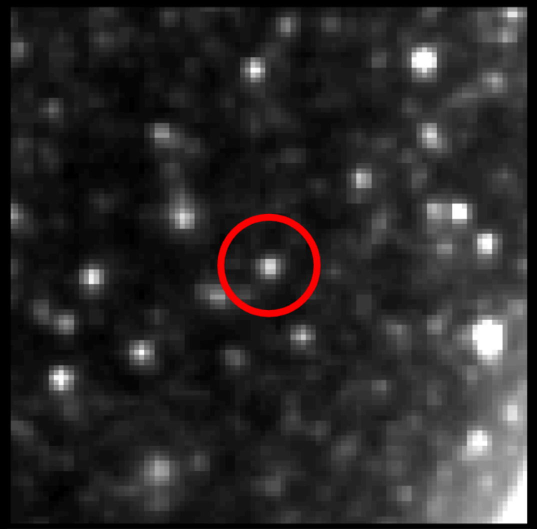
CCHP JWST JAGB Program

- ★ JWST has ushered in a new era of accuracy in the local distance scale
  - ★ JWST has 3x resolution than HST in the NIR
- ★ 7 SN Ia host galaxies
- ★ NIRCam fields target three distance indicators (JAGB, TRGB, Cepheids) simultaneously
- ★ Blind analysis: entire analysis carried out with random numbers applied to photometry

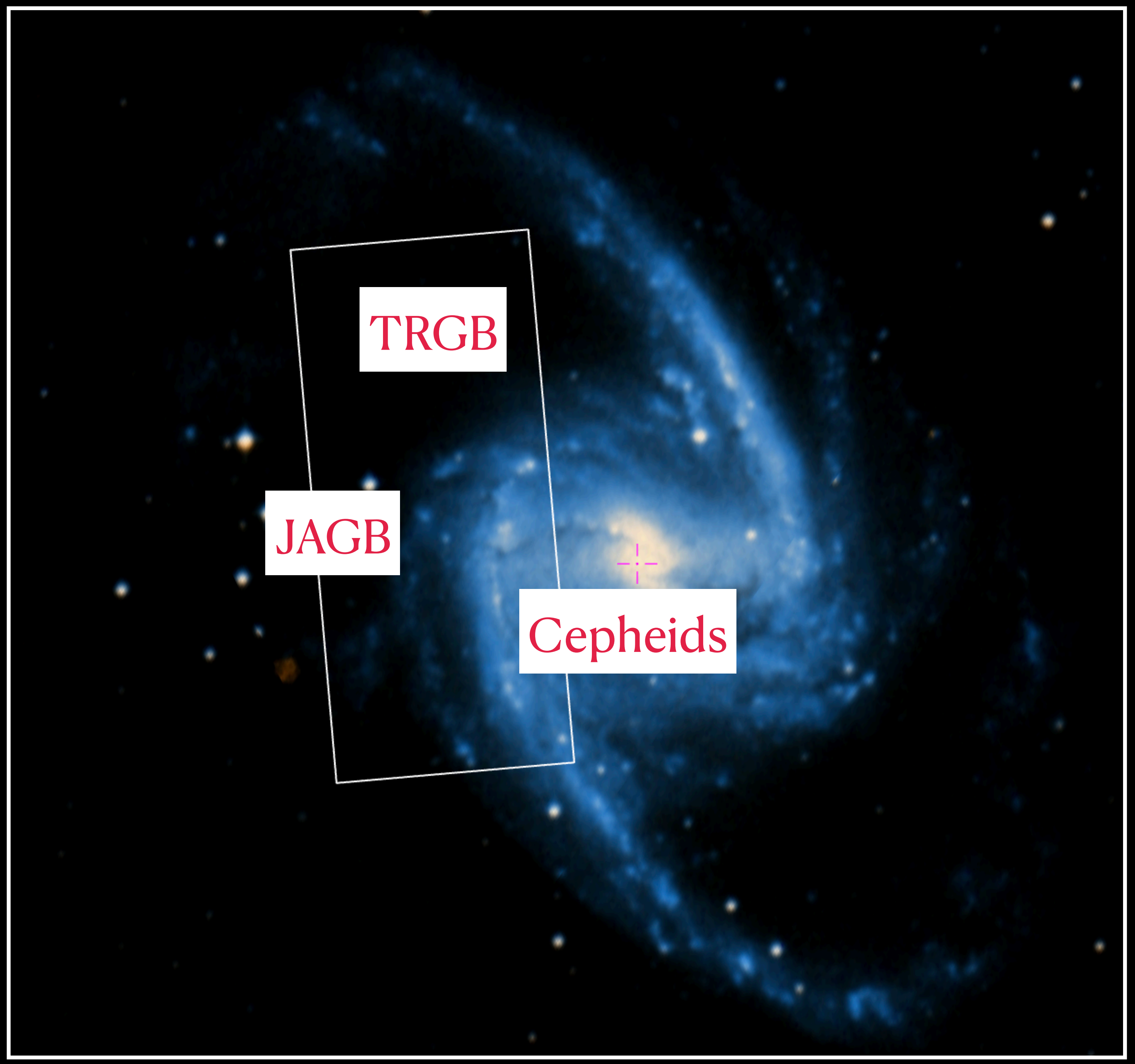


HST WFC3/IR



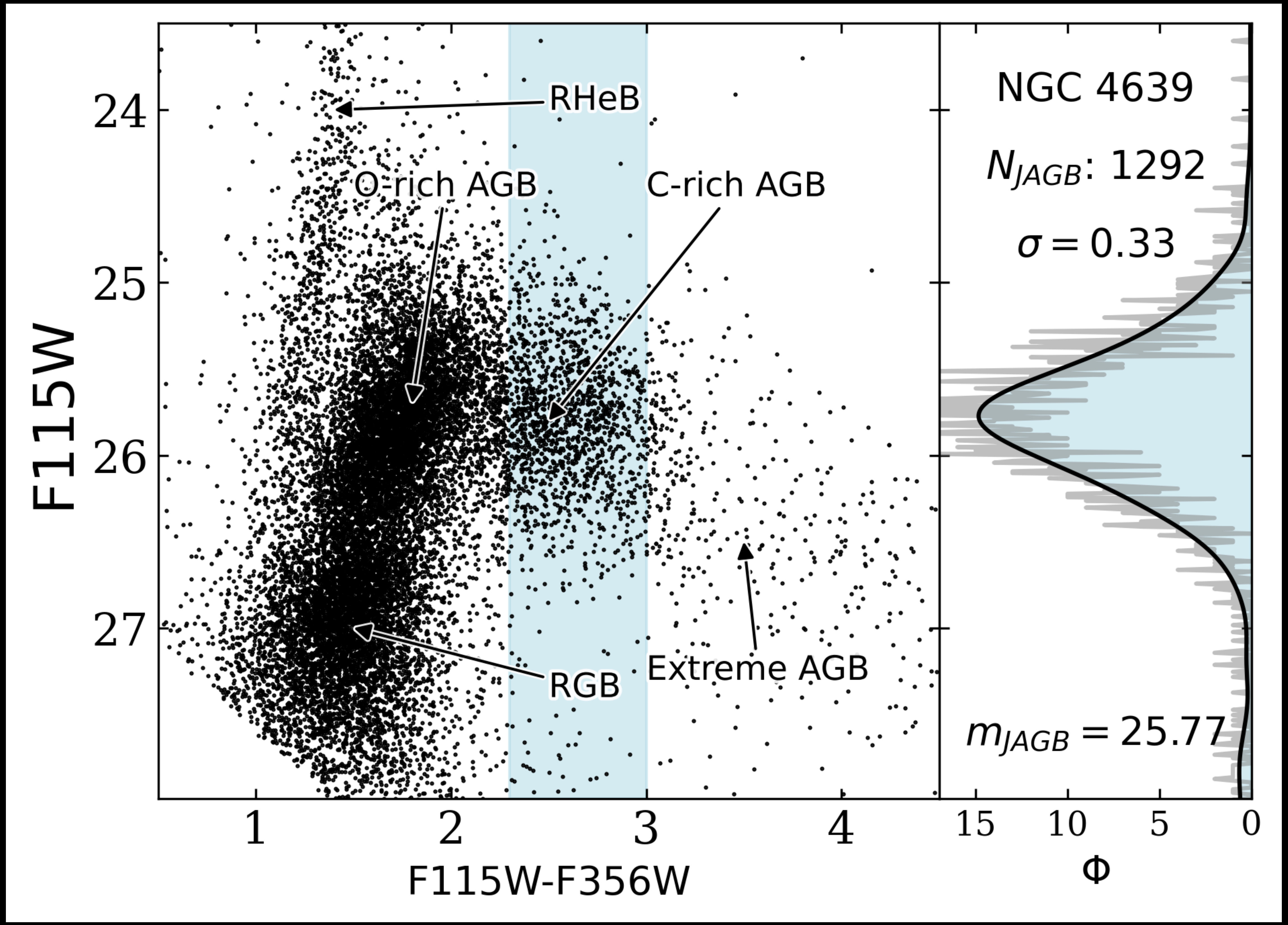
JWST NIRCam

Cepheid in a SN Ia host galaxy at a distance of 20 Mpc



SN Ia host galaxy N1365

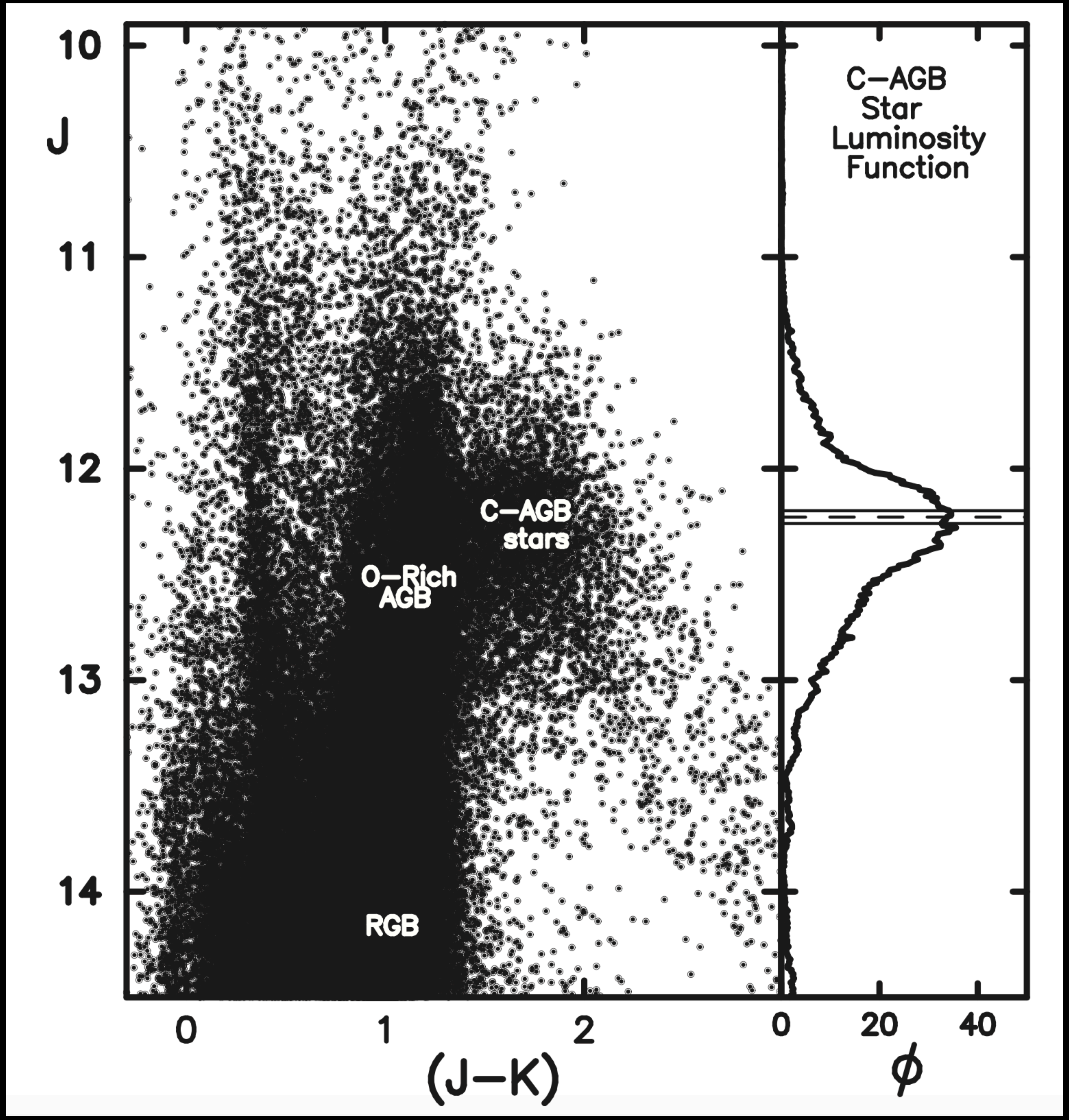
NGC 4639



Lee+ 24c (submitted)

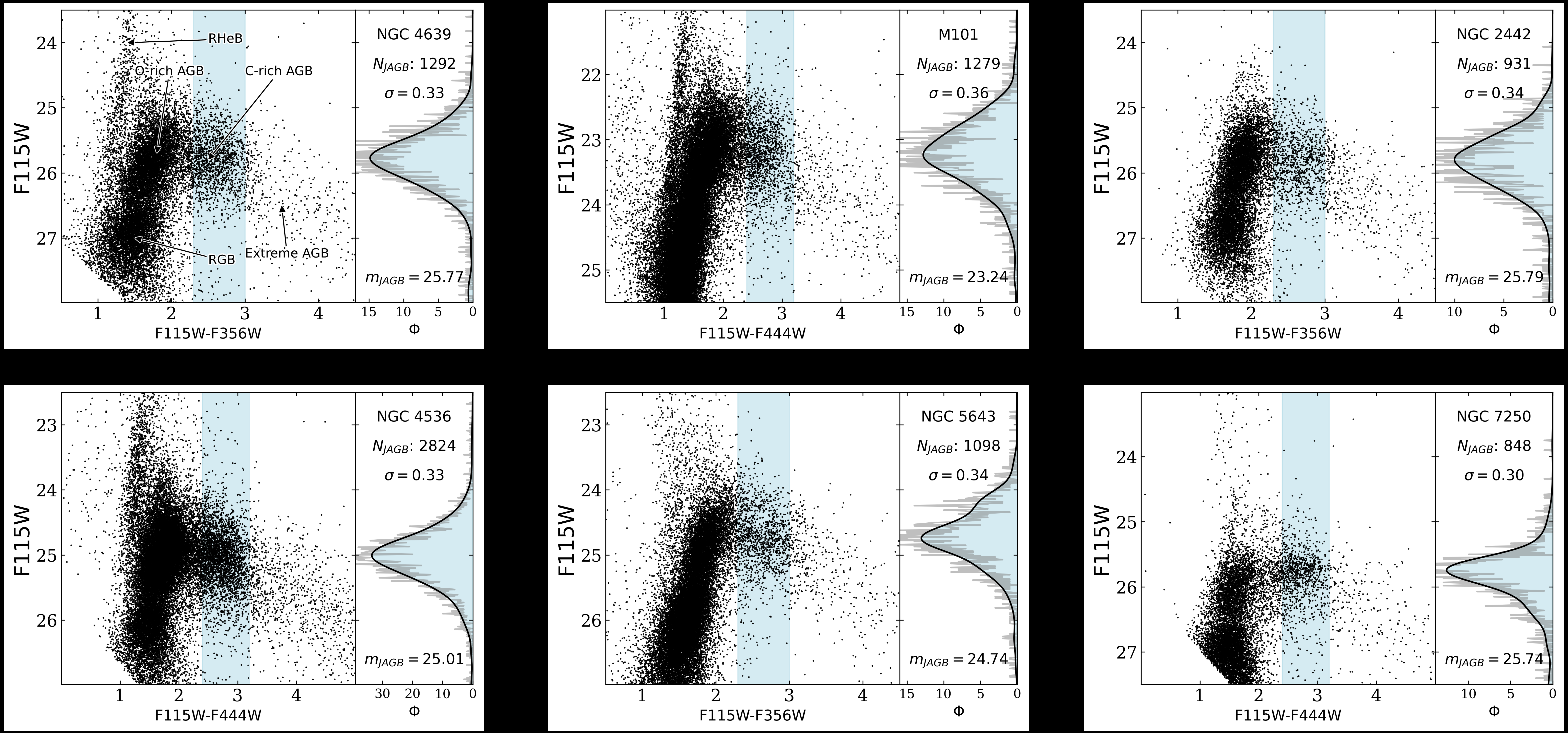
σ_{JAGB} = 0.33 mag
d = 22 Mpc

LMC



Madore & Freedman 2020

σ_{JAGB} = 0.33 mag
d = 50 kpc



Lee+ 24c (submitted)

JAGB H_o Error Budget

$H_o = 67.96 \pm 1.85\ (\text{stat}) \pm 1.90\ (\text{sys})\ \text{km s}^{-1}\ \text{Mpc}^{-1}$

- ★ Promising method that with further development will provide more stringent constraints on the Hubble tension
- ★ Our 3% statistical error encapsulates potential +3% difference in H_o resulting from SN Ia selection (Riess+ 24)
- ★ Systematic error (3%) includes uncertainties from SN Ia host galaxy variations (2%)

Future Work: How do we get to a 1% JAGB H0?

- Currently JAGB H_0 has a 3% systematic and 3% statistical uncertainty
  - Systematic error: Calibrating JAGB zero-point in 3 additional galaxies (LMC, SMC, MW) with larger range of metallicities to better understand JAGB LF shape variations
  - Statistical error: Currently have 7 SN Ia calibrating galaxies
    - 25 SNe Ia would give 1% statistical error
- Need more JWST data!

Summary

- The JAGB method is a new standard candle based on carbon-rich AGB stars
- The JAGB method agrees well with the Cepheid Leavitt law and the TRGB in nearby galaxies (d < 4 Mpc)
- JWST has ushered in a new era of accuracy in our measurement of H_0
- JAGB method gives $H_0 = 67.96 \pm 1.85$ (stat) ± 1.90 (sys) km s^{-1} Mpc^{-1}
- More JWST data will be required to measure JAGB H_0 at 1% level