Astrophysical Distance Scale VII:
A Self-Consistent, Multi-Wavelength Calibration of the Slopes and Relative Zero Points for the Run of Luminosity with Color of Stars Defining the Tip of the Red Giant Branch

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Outlines

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Introduction

- Given the light-gathering power and unequalled point spread function (PSF) resolution of JWST in the near-infrared (NIR) and mid-infrared (MIR), it now seems an appropriate time to enumerate and quantify the advantages, as well as to assess any disadvantages, in application of the TRGB method into the infrared.

- They present a approach to calibrating optical (VI), NIR (JHK) and for the first time, the MIR (3.6 and 4.5 μm) TRGB relations spanning the wavelengths covered most sensitively by the NIRSS and NIRCAM imagers on JWST.

Introduction

- Two obvious “bridging galaxies” are WLM (Wolf-Lundmark-Melotte) and IC1613, given that the Magellanic Clouds are too close to be effectively and efficiently used for this purpose.

- Other galaxies (NGC 2403, NGC 253, M81 and NGC 300), two to three times further away, are part of a calibration program being undertaken by McQuinn and her collaborators using both HST (Prop 15917) and JWST (Prop 1638).

The Ground-based/Space-based Calibration

- Their fiducial bandpass/wavelength for undertaking this self-consistent calibration, is the ground-based I-band filter (centered at 8000˚A) .

- Its space-based equivalent filters, F814W on ACS and F814W on WFC3-UVIS, both on HST (and conceivably the F090W filter on JWST/NIRCAM). The HST filters are very similar, with effective wavelengths of about 7970˚A (see Deustua & Mack 2018)

The Ground-based/Space-based Calibration

- The VIJHK data come from the Large Magellanic Cloud (LMC) stellar catalog published by Zaritsky et al. (2004) and cross-matched with 2MASS.

- Zaritski et al. (2002) have compared their BVI photometry with the OGLE calibration that the individual offsets are 0.011, 0.038 and 0.002 mag for B,V and I.

- They have adopted the I-band extinction of AI = 0.160 mag for the LMC TRGB stars.

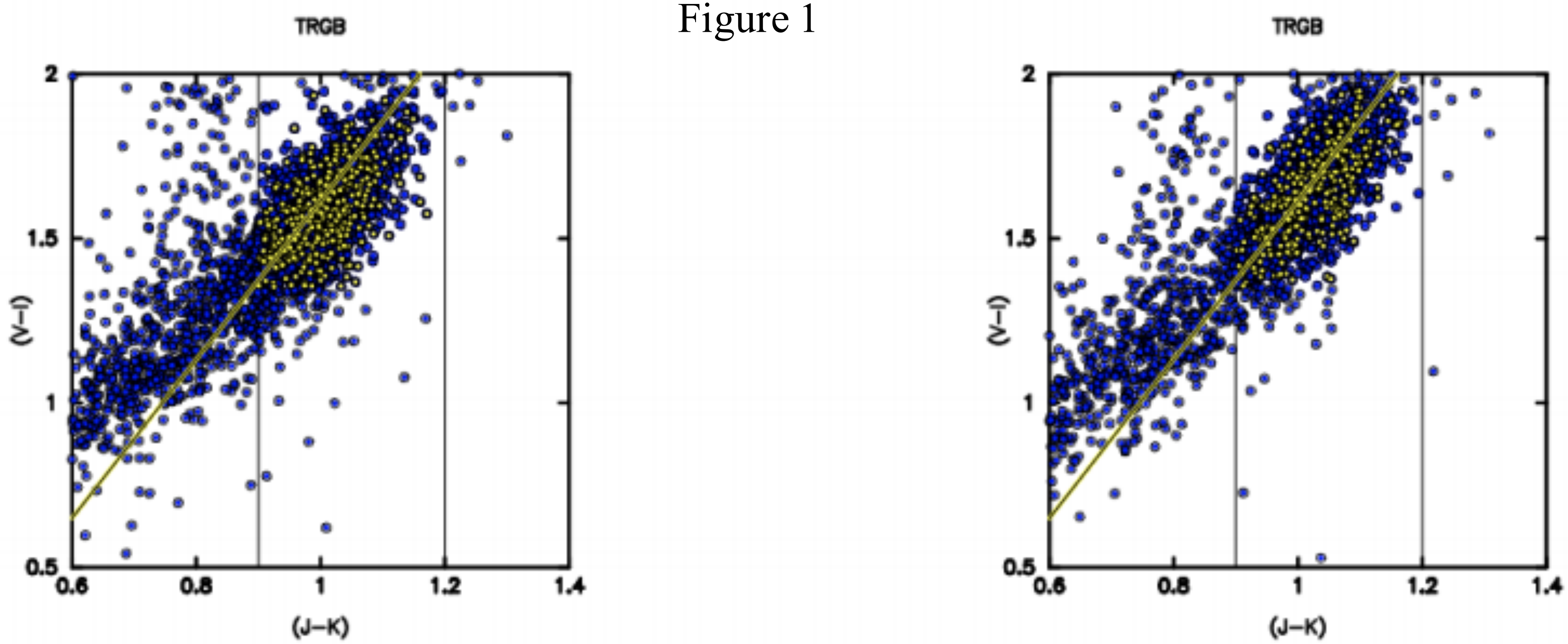
- For A_J , A_H andA_K we find externally calculated uncertainties of ±0.015, 0.011 and 0.006 mag.

The Basic Equations

- They start by making explicit a simple but powerful point, which, in retrospect is obvious, but still needs to be stated. The colors of TRGB stars, in whatever wavelength combinations that one cares to consider, can be expected to be linearly related, from band to band, over the small range of color defining the tip of the RGB population.

- They adopt the $(J-)_o$ color as fiducial for the most of this paper, while noting that any of other colors can be easily substituted once the distance-independent color-color transformations are defined.

Figure 1



They were constrained to fall within the color range $0.9 < (J - K) < 1.2$ and $1.4 < (V - I) < 2.0$ mag. The dispersion around the fit is ±0.158 mag. Based on 1,550 stars, this gives an error on the mean of ±0.004 mag

$$(V - I)_o = 2.41\ [(J - K)_o - 1.00] + 1.61\ (\pm 0.004) \quad [1]$$

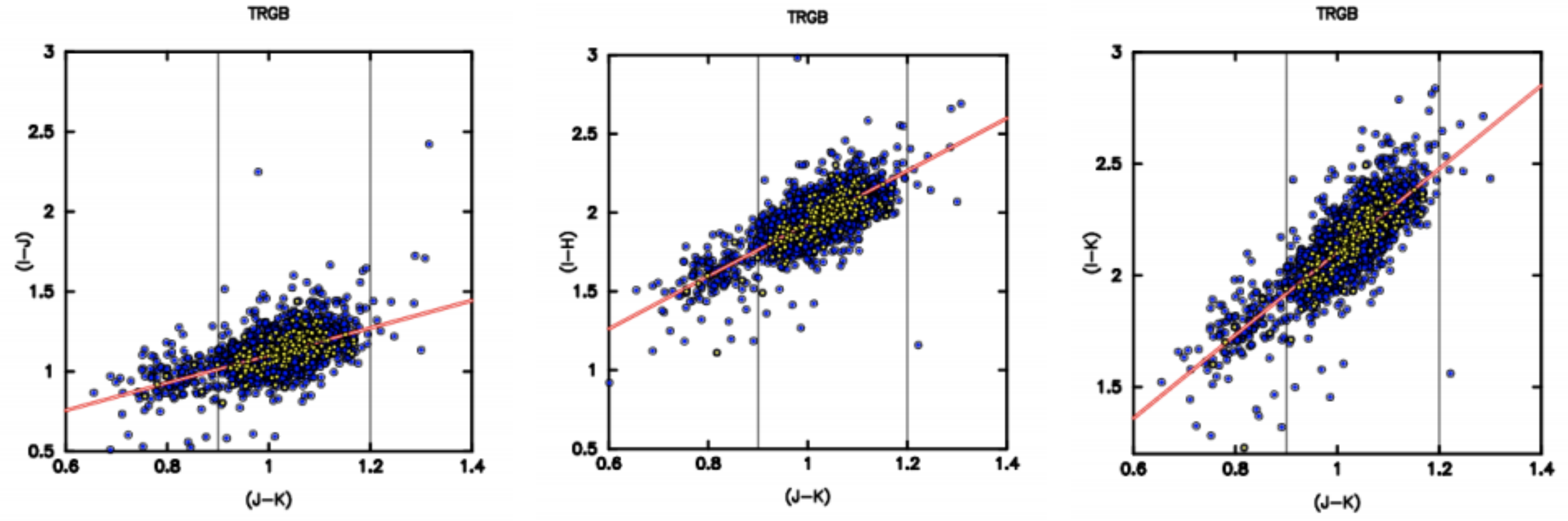


Figure 2

$$(I-J)_o = 0.86\ [(J-K)_o - 1.00] + 1.10\ (\pm 0.02) \quad [2]$$

$$(I-H)_o = 1.67\ [(J-K)_o - 1.00] + 1.93\ (\pm 0.04) \quad [3]$$

$$(I-K)_o = 1.86\ [(J-K)_o - 1.00] + 2.10\ (\pm 0.02) \quad [4]$$

As given in Freedman (2021) and in the majority of other recent calibrations:

$$M(I)_o = -4.05$$

mag it then immediately follows that:

$$M(V)_o = -4.05 + 1.00\ (V - I)_o \quad [5]$$

$$M(V)_o = -2.44 + 2.41\ [(J - K)_o - 1.00] \quad [6]$$

then:

$$[M(I)_o - M(J)_o] = 0.86\ [(J - K)_o - 1.00] + 1.10 \quad [7]$$

$$[M(I)_o - M(H)_o] = 1.67\ [(J - K)_o - 1.00] + 1.93 \quad [8]$$

$$[M(I)_o - M(K)_o] = 1.86\ [(J - K)_o - 1.00] + 2.10 \quad [9]$$

Again, by substituting $M(I)_o = -4.05$ into the above three equations, collecting the respective zero points and re-centering the equations at $(J-K)_o = 1.00$ gives:

$$M(J)_o = -5.15 - 0.86\,[(J-K)_o - 1.00] \quad [10]$$

$$M(H)_o = -5.98 - 1.67\,[(J-K)_o - 1.00] \quad [11]$$

$$M(K)_o = -6.15 - 1.86\,[(J-K)_o - 1.00] \quad [12]$$

Similarly, for the mid-infrared absolute magnitudes we derive the following relations:

$$M(3.6)_o = -6.29 - 2.30\,[(J-K)_o - 1.00] \quad [13]$$

$$M(4.5)_o = -6.18 - 2.30\,[(J-K)_o - 1.00] \quad [14]$$

$$M(J)_o = -5.15 - 0.72\,[(J-3.6)_o - 1.20] \quad [15]$$

After adjusting for the slightly (5%) shorter central wavelength of the JWST F115W filter, and the longer color baseline of [(F115W -3.6] compared to (J-K), we get a first estimate of:

$$M(F115W)_o = -5.01 - 0.72\,[(F115W - 3.6)_o - 1.34] \quad [16]$$

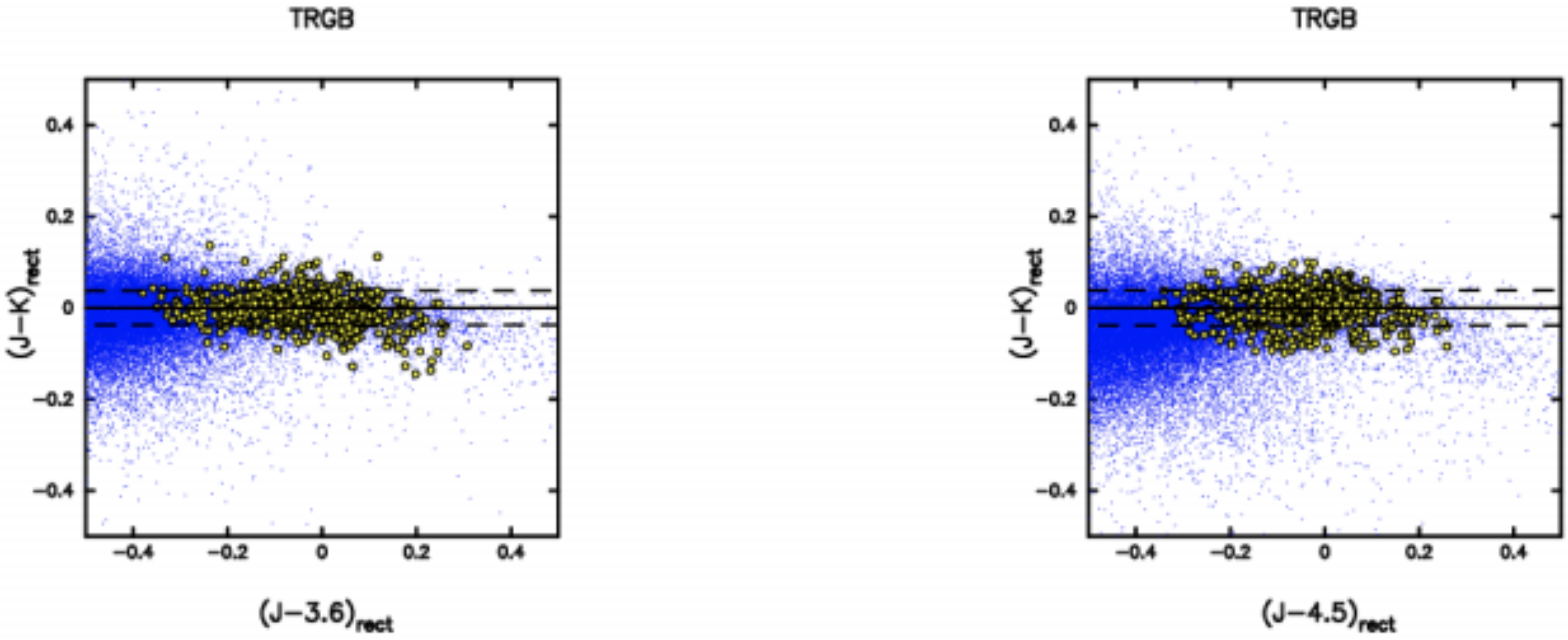


Figure 3. Rotated Color-Color Plots for (J-K) versus the Mid-Infrared blended colors: (J-3.6) and (J-4.5) in the left and right panels, respectively. See text for additional details.

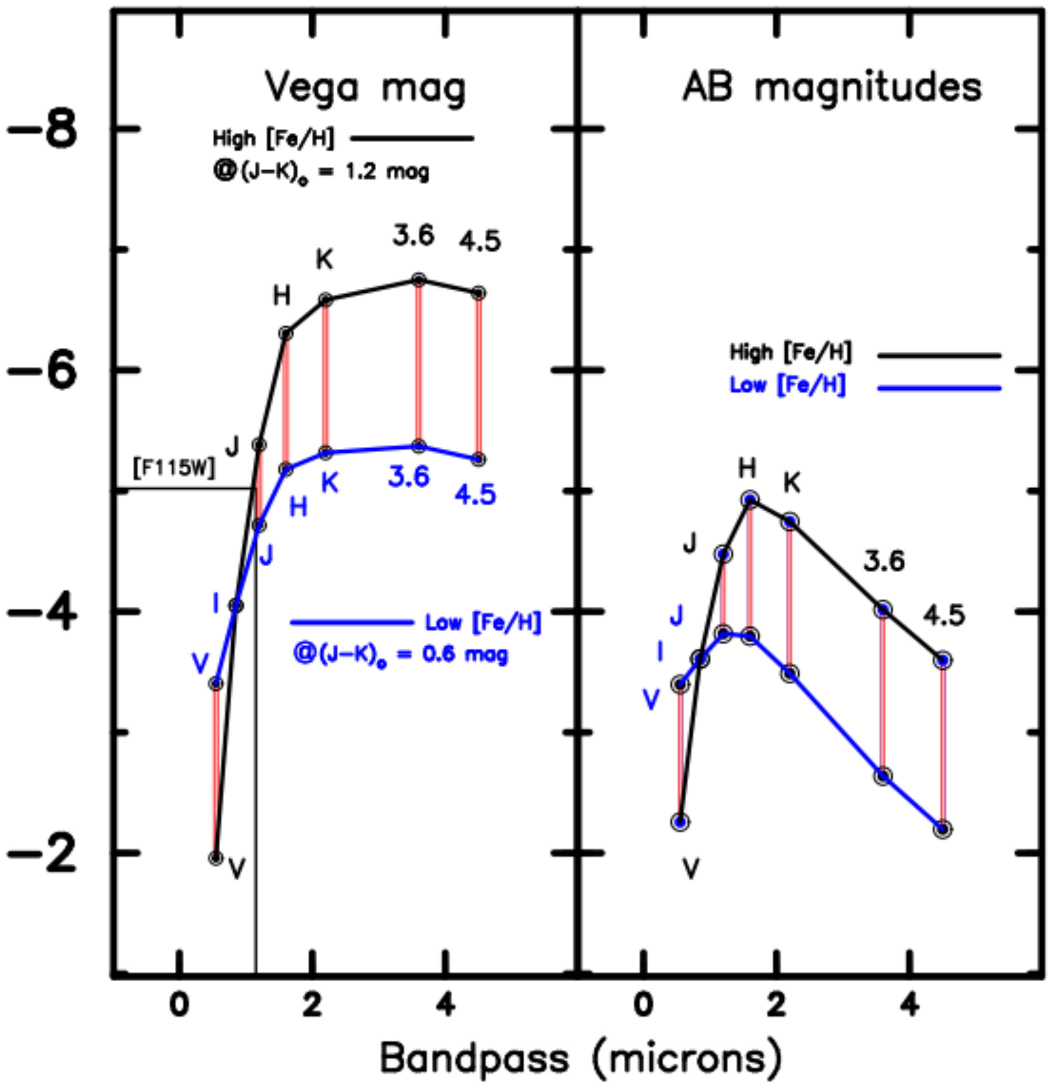


Figure 4

The trends, with increasing wavelength (bandpass) of the absolute magnitude of TRGB stars at the blue [(J-K) = 0.6 mag] metal-poor end and at the red [(J-K) = 1.2 mag] metal-rich end .

The thin black lines indicate where the F115W filter on JWST/NIRCam is expected to show its slanting tip .

Conclusion

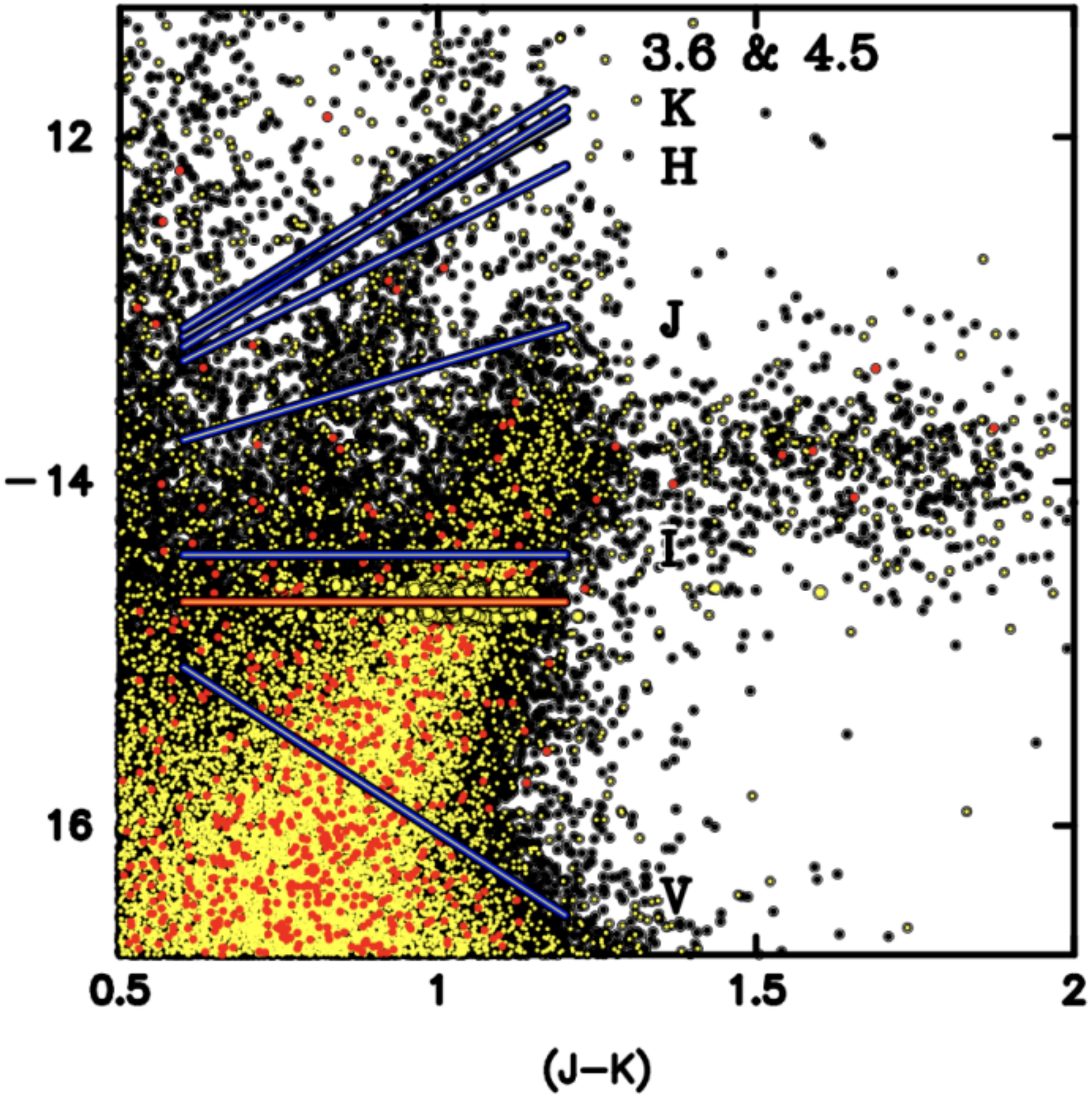


Figure 5

The black circled points map out Io vs (V − I)o color-magnitude diagram for stars in the LMC. One star in 10 is colored yellow (and then one star in 5 is colored red) so as to give some sense of the density of points in heavily crowded regions of the diagram.

The dramatic increase in luminosity of the TRGB stars seen in the longer-wavelength filters is impressive, but it needs to be pointed out that this advantage saturates in the MIR where the long-wavelength colors become zero on the Raleigh-Jeans portion of the spectral energy distribution.

Thanks!