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A geometric calibration of the tip of the red giant branch in the Milky Way using Gaia DR3

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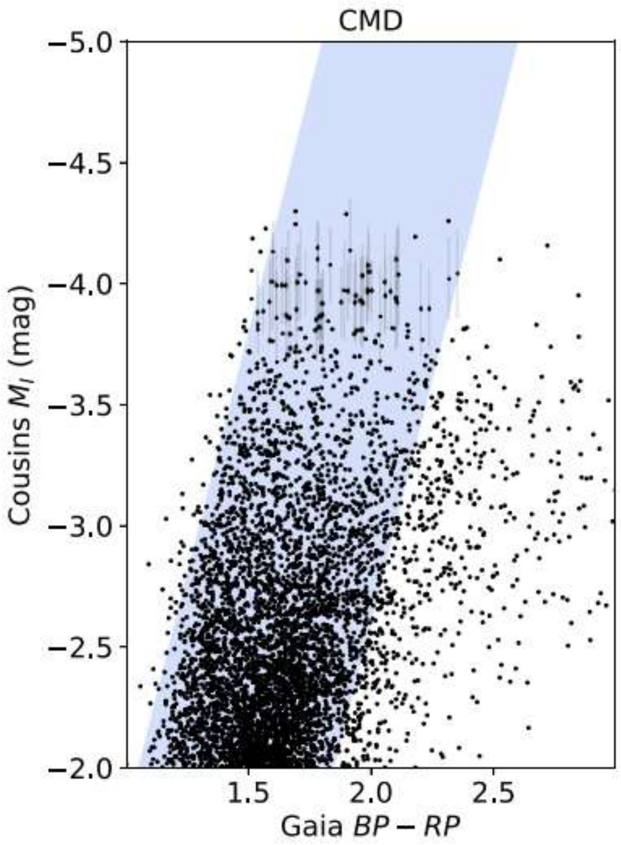
Introduction

- The tip of the red giant branch (TRGB) is a widely used standard candle that can be used to measure distances up to 10 Mpc with ~ 5 per cent precision.
- The present state of cosmology is facing a major crisis known as the Hubble tension.
- The TRGB is an alternative to the Cepheids and importantly allows H0 to be measured independently of other distance indicators, eliminating one source of systematic uncertainty in H0.
- Freedman(2021) provides the most significant measurement of H0 with the TRGB, utilizing SNe Ia host galaxies from the Carnegie Supernova Project and found a value comparable to that of CMB observations.

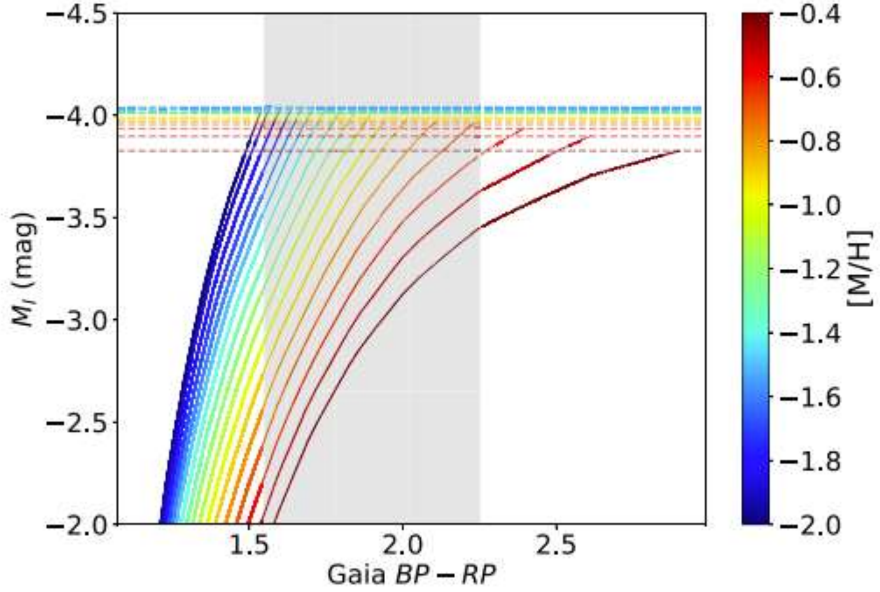
Introduction

- The TRGB is a stage in the stellar evolution of low-mass(< 2 Msun) red giant branch (RGB) stars (see a review in Serenelli et al. 2017).

He-core flash occurs at a characteristic magnitude and allows these stars to be used as a standard candle.



Importantly, the TRGB luminosity is largely insensitive to metallicity and stellar mass in the Cousins I-band for metal-poor stars (Da Costa & Armandroff 1990; Lee, Freedman & Madore 1993; Serenelli et al. 2017).



Introduction

- There have been a number of attempts to obtain a zero-point calibration of the TRGB luminosity and measure distances in the local Universe (e.g Lee et al. 1993; Madore, Mager & Freedman 2008; Hatt et al. 2017; Freedman et al. 2019). Different approaches to binning, Sobel kernels, and smoothing the LF have been explored (see a review in Beaton et al. 2018).
- Direct measurement of M_I^{TRGB} has only recently become possible, with the availability of milliarcsec parallax measurements from Gaia.
- While Gaia offers a direct measurement of the TRGB, it is still subject to factors that change with distance and the galaxy's environment.
- This work aims to obtain a geometric calibration of the TRGB using Gaia DR3 parallaxes.

Data and Methodology

- Compared to Gaia DR2, DR3 offers an increased number of parallaxes, and more precise measurements of parallax by a factor ~ 0.8 (Lindegren et al. 2021).
- For Gaia DR3, we follow the suggested zero-point parallax corrections described by Lindegren et al. (2021) which are detailed position, apparent magnitude, and colour-dependent set of corrections.
- Interested in 10 < G < 13 mag, this offset is negative and the parallaxes are underestimated. For our analysis, we use the zero-point correction obtained by Flynn et al. (2021), who find after the initial Lindegren corrections, a median parallax offset ≈ 10 µas for bright stars (G < 11).

$$\varpi_c = \varpi - Z - 10\ \mu\text{as}$$

Gaia SkyMapper APASS Pan-STARRS ATLAS Refcat2

Data and Methodology

- Select high latitude stars (|b| > 36), limiting the impact of dust (Freedman et al. 2020). ^A colour and G-band cut is added to focus on selecting RGB stars in our region of interest.
- Define the fractional parallax error (FPE) as σ_{ϖ}/ϖ ,and objects with a FPE > 0.2 are removed. ^Use the goodness-of-fit parameter 'Renormalized Unit Weight Error' (ruwe) < 1.4 to filter out stars with poor astrometric solutions.
- To obtain MI for each star, we need to convert each survey, respectively, to the Cousins I photometric system, where the TRGB is the flattest.

Data and Methodology

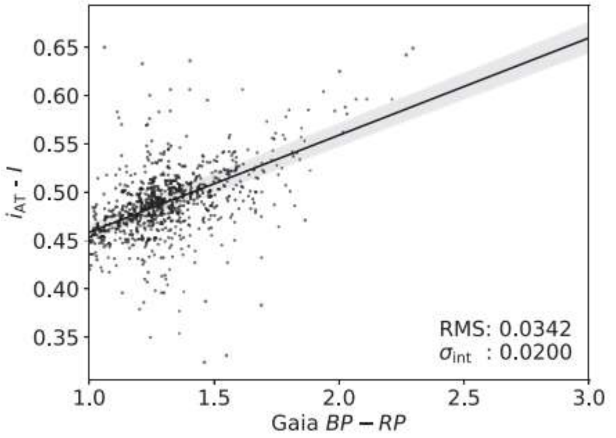
- Fitting the relationship between i and Cousins I for objects cross-matched with Gaia DR3 using a collection of Stetson standard stars (Pancino et al. 2022). The transformation equations are:

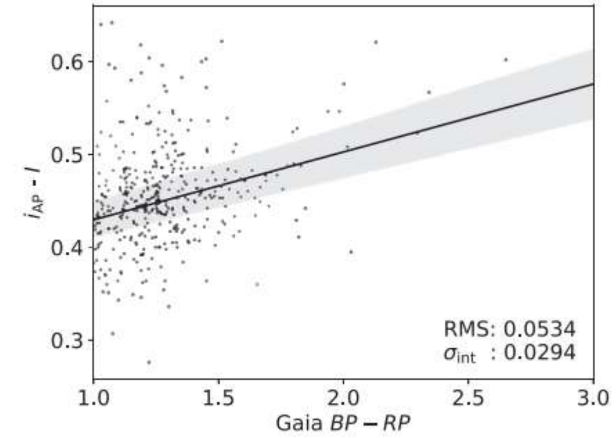
$$I = i_{SM} - 0.0562\,(BP - RP) - 0.3727; \sigma = \pm 0.0159$$

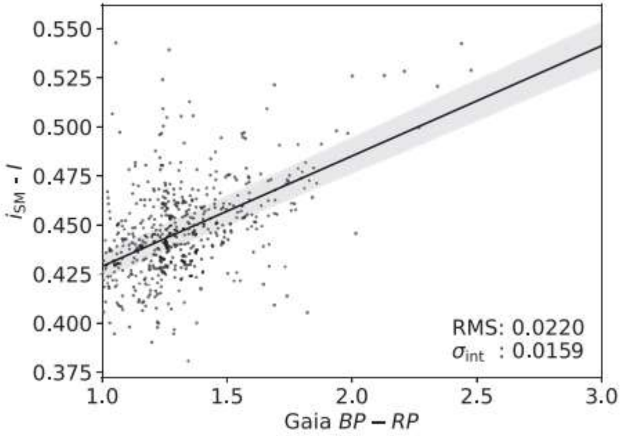
$$I = i_{AP} - 0.0756\,(BP - RP) - 0.3534; \sigma = \pm 0.0294$$

$$I = i_{AT} - 0.1018\,(BP - RP) - 0.3564; \sigma = \pm 0.0200$$

$$M_I = I + 5\log(\varpi_c) - 10 - A_I$$







Data and Metodology

- Instead use a kernel density estimator (KDE) to smooth LF, the most important parameter is the smoothing kernel. It doesn't matter what method you use it's going to introduce errors, for this method, the bias is driven by the shape of the LF, the photometric scatter, and choice of smoothing kernel.
- Generate stellar mock samples using CMD 3.7, to model the TRGB peak dispersion in different stellar populations. They choose to use single stellar population isochrones as we are not directly modelling the Milky Way CMD.
- Aim to estimate TRGB offsets as simply as possible by focusing on a single stellar population isochrone. However, we can obtain the spread in this systematic, depending on the choice of isochrone. In ($-2<[M/H]<-0.4$), simulated TRGB peak only slightly changed (~0.01 mag).

Data and Methodology

- Choose an isochrone similar to our observational samples, with a stellar age of 10 Gyr and [M/H]=-1.6 and generate stars between -5<MI<-2.

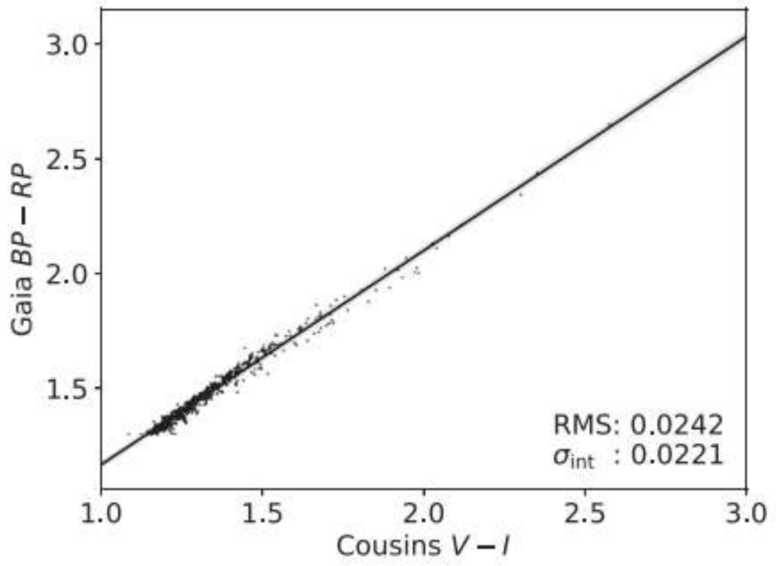
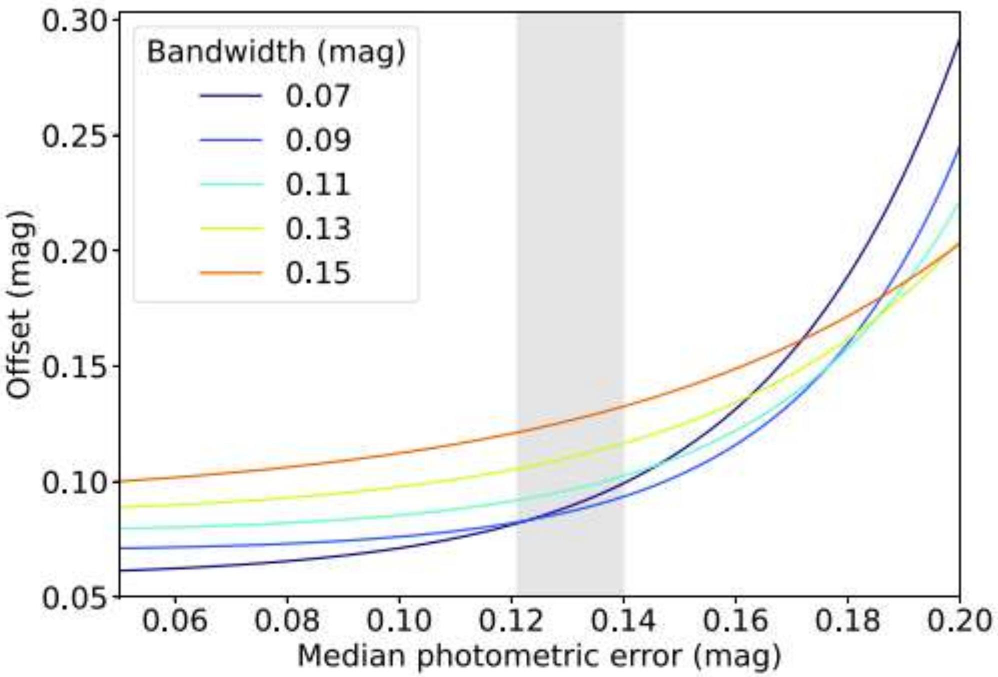


Figure A4. Using the curated catalogue of Stetson standard stars matched with Gaia DR3 (Pancino et al. 2022), we derive the relationship for RGB stars, where $(BP - RP) = 0.932(V - I) + 0.235$.

with a sample of 717 standard stars

Data and Methodology

- Another systematic error in our measurements is the width of the smoothing kernel, which offsets the TRGB peak.



Justify choice of a smoothing kernel of 0.09 mag, where the systematic offset is minimal, given the photometric scatter, for use in their analysis.

Despite each isochrone having a different theoretical TRGB cut-off, the offset remains consistent, allowing for correction in their data.

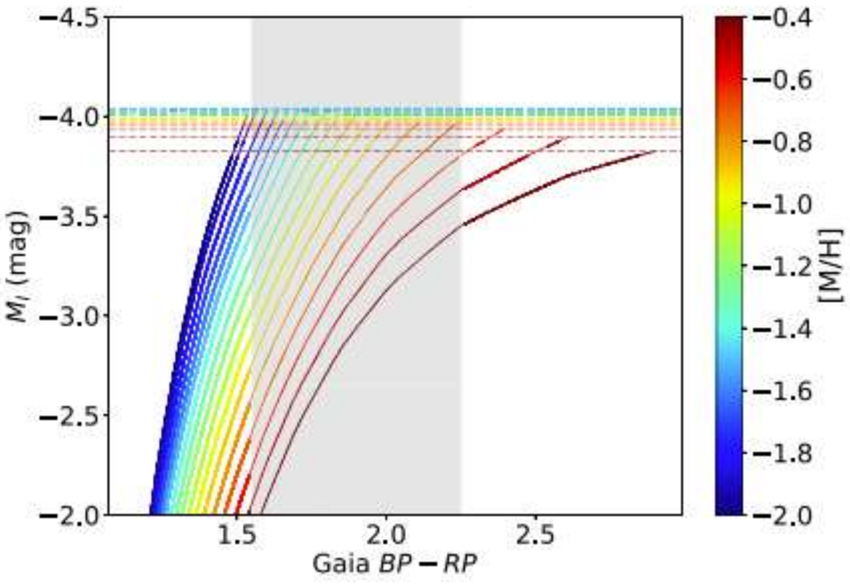
Result and Discussion

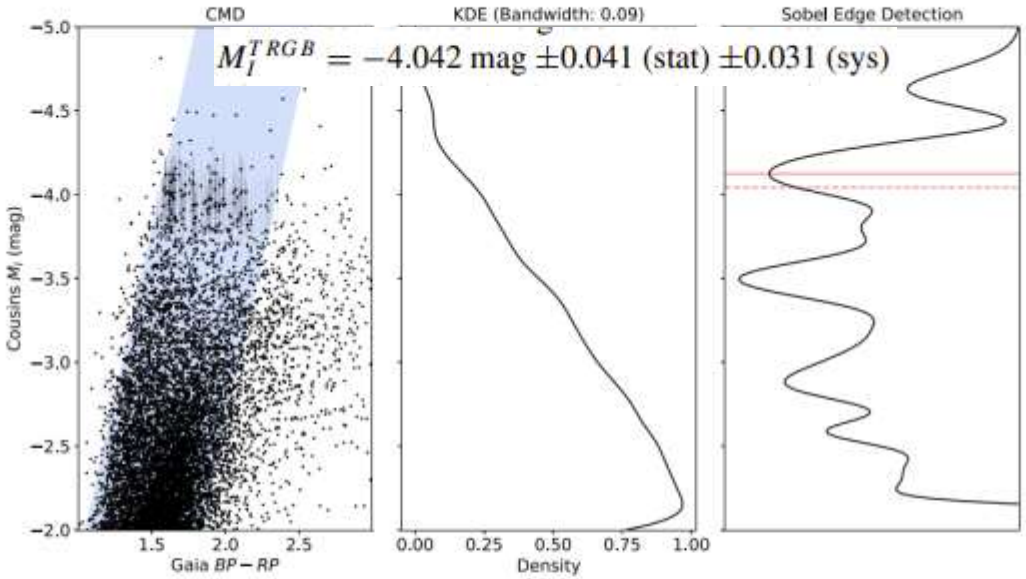
- Select the colour range 1.55 < BP - RP < 2.25, with a slope -4.

Table 2. TRGB geometric calibration using each of the photometric surveys.

Photometric survey	# Stars	σ_{M_I}	Offset correction	M_I^{TRGB}	σ
SkyMapper DR3	5215	0.130	0.087	−4.007	±0.034 (stat) ±0.030 (sys)
APASS DR9	6023	0.140	0.093	−4.032	±0.036 (stat) ±0.034 (sys)
Gaia DR3	7743	0.121	0.083	−4.035	±0.037 (stat) ±0.026 (sys)
ATLAS Refcat2	8634	0.124	0.084	−4.044	±0.022 (stat) ±0.040 (sys)
Full ensemble	9148	0.121	0.082	−4.042	±0.041 (stat) ±0.031 (sys)

An FPC of 0.10, was implemented for each survey with a smoothing kernel of 0.09 mag. We also show the number of stars in each sample, median σ_{M_I}, and offset correction.





As each of our measurements are semi-independent and correlated through the parallaxes, cannot simply take a weighted average across the four surveys. Instead, combine the surveys together, forming a sample of 9148 unique stars.

Conclusion

- Comparison with recent calibrations of the TRGB, this work results values and uncertainties fall within the range reported in other studies, recently. They find M_I^{TRGB} = -4.042 ± 0.041 (stat) ±0.031 (sys) mag, which is consistent with other recent zero-point calibrations of the TRGB.
- Their geometric calibration of M_I^{TRGB} in the Milky Way is the most accurate to date. However, even greater precision can be achieved in future surveys such as Gaia DR4, which will provide more precise parallax measurements.

Thanks!