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Calibration and characterisation of the Gaia Red Clump

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Abstract. We present new empirical Colour-Colour and Effective Temperature-Colour Gaia Red Clump calibrations. The selected sample takes into account high photometric quality, good spectrometric metallicity, homogeneous effective temperatures and low interstellar extinctions. From those calibrations we developed a method to derive the absolute magnitude, temperature and extinction of the Gaia RC. We tested our colour and extinction estimates on stars with measured spectroscopic effective temperatures and Diffuse Interstellar Band (DIB) constraints. Within the Gaia Validation team these calibrations are also being used, together with asteroseismic constraints, to check the parallax zero-point with Red Clump stars.

Keywords. Gaia Red Clump, photometry, stellar parameters: interstellar extinction, effective temperature

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1. Introduction

The Gaia Data Release 1 (DR1) provided high precision parallaxes for 2 million stars. Trigonometric parallaxes are, indeed, the most direct method to measure distances. However, if we want to determine distances to further objects than what the Gaia parallax precision allows today, we need to take advantage of *standard candles*. That is, objects with a well-determined absolute magnitude and bright enough to be observed in distant regions. The difference between this known absolute magnitude and the apparent one gives the distance modulus of the source.

Red Clump (RC) stars are known to be good distance indicators (e.g. Udalski (2000), Alves (2000), Groenewegen (2008), Laney *et al.* (2012)). This is because they show weakly dependence of M_I on colour, age and chemical composition, and because they are very abundant in the solar neighbourhood, so their absolute magnitude may be accurately determined. The larger the number of sources the lower will be the statistical error in distance calculations.

The purpose of this work is to better describe and characterise the Red Clump for distance calculations. By analysing the photometric colour-colour relations of these stars, we may derive their interstellar extinctions, and consequently be able to obtain their absolute magnitudes and their distances. However, we have found that atmosphere models of red giant stars do not fit the observations: there is a *gap* in between no matter the photometric bands or the stellar evolution models used. Moreover, we remind that there is no Gaia calibrated filter model for the DR1. Both reasons led us to develop a purely empirical photometric calibration of RC stars.

We present here the colour vs G-K_s and T_{eff} vs G-K_s photometric calibrations derived for the RC, and some applications where they are being used to characterise these stars.

2. Empirical photometric calibration

The precision of empirical calibrations rely on the accuracy of the sample selection and the robustness of the method.

To select the data we have mainly considered six constraints (see Ruiz-Dern *et al.* (2017, submitted) for more details and a complete list of the sources used):

• *Photometric quality*: we selected visual and infrared wavelengths by including G B V H_P B_T V_T J K_s photometry (with uncertainties) from the Gaia DR1, Hipparcos, Tycho-2 and 2MASS catalogues

• *No binaries nor multiple systems*

• *Spectroscopic metallicities*

• *Giants subset*: to ensure no contamination from other spectral types, we applied the following colour and parallax criteria:

$$G - K_s > 1.6 \tag{2.1}$$

$$m_G + 5 + 5\ \log_{10}\left(\frac{\varpi + 2.32\ \sigma_\varpi}{1000}\right) < 2.5 \tag{2.2}$$

where the factor 2.32 on the parallax error corresponding to the 99th percentile of the parallax probability density function.

• *Interstellar extinction*: to avoid introducing possible bias due to derredening, we kept only stars with $A_0 < 0.03$, where A_0 is the interstellar extinction at $\lambda = 550$ nm (Gaia reference value). We used the most up-to-date 3D local extinction map of Capitanio *et al.* (2017) (a poster review can also be found in this proceedings)

• *Effective temperature*: only for the effective temperature - G-K_s calibration, we included the spectroscopic effective temperatures from the 13h release (DR13) of the APOGEE survey (Holtzman *et al.* (2015), García Pérez *et al.* (2016), SDSS Collaboration *et al.* (2016)), so we could have a larger homogeneous sample

We got a sample of 1329 stars for the colour vs G-K_s calibrations, and of 548 stars for the effective temperature vs G-K_s.

To derive these accurate photometric relations, we implemented a Monte Carlo Markov Chain (MCMC) method which allows us to account and deal with the uncertainties of both the predictor and response variables in a robust way. All calibrations were derived with respect to the G-K_s colour because of their actual and future broad use.

The general fitting formula adopted was:

$$Y = a_0 + a_1\ X + a_2\ X^2 + a_3\ [\text{Fe/H}] + a_4\ [\text{Fe/H}]^2 + a_5\ X\ [\text{Fe/H}] \tag{2.3}$$

where X is G-K_s, Y is (for CC) a given colour or (for T_{eff} relations) the T_{eff}, and a_i are the coefficients to be estimated. In order to provide the most accurate fit for each relation, the process penalises the complex terms by using the Deviance Information Criterion (DIC) (Plummer (2008)). We checked for outliers at 3σ from the fit. If outliers were found, the one was removed and the complete process was run again.

We obtained 23 colour vs G-K_s calibrations with a median dispersion in magnitude between 0.03 and 0.05, plus the T_{eff} vs G-K_s relation with a median dispersion of $\sim 57K$. To test our T_{eff} vs G-K_s fit we transformed the G-K_s colour to V-K_s through our V-K_s vs G-K_s calibration, and compared it to other T_{eff} vs V-K_s relations in the literature: Ramírez & Meléndez (2005) and González Hernández & Bonifacio (2009), both based on the infrared flux method technique, and Huang *et al.* (2015) based on interferometry. For solar metallicities we found discrepancies up to $\sim 90K$.

3. Red Clump characterisation

The Gaia DR1 HR diagram published in Gaia Collaboration *et al.* (2016) clearly shows the effect of the interstellar extinction on the RC region: the clump appears more elongated and tilted with respect to the Hipparcos RC, meaning that we need to account for the interstellar extinction if we want to use the G magnitude.

By subsetting the DR1 sample to the TGAS sample with 10% parallax precision and low extinction stars, we may also observationally detect other substructures of the giant branch such as the Red Giant Branch Bump and the Secondary Red Clump (Ruiz-Dern *et al.* (2017, submitted)). We have zoomed into the RC region and applied our T_{eff} vs G-K_s relationship to the theoretic T_{eff} of Padova isochrones (Bressan *et al.* (2012), Parsec 2.7) at different metallicites and at different ages. We find that the RC position fits properly the isochrones. The RGB bump, however, appears to be brighter in the isochrones (Ruiz-Dern *et al.* (2017, submitted)).

As we combine the calibrations with an extinction coefficient model, we can characterise some RC parameters, such as the effective temperature and the photometric interstellar extinction. To take into account the dependency of the extinction coefficients on the star Spectral Energy Distribution and on the extinction itself, we used an analytical model of those dependencies. We computed the extinction coefficient using the Fitzpatrick & Massa (2007) extinction law for extinctions A_0 from 0 to 5 and using Kurucz spectra for a logg of 2.5 with T_{eff} from 4000 to 6500 K. We modelled the dependency of the extinction coefficient k as a function of A_0, colour and effective temperature (i.e. $k_\lambda = f(A_0, T_{eff})$ and $k_\lambda = f(A_0, colour)$, respectively). Regarding the coefficient of the Gaia G band, k_G, we used instead the empirical calibration of Danielski *et al.* (2017, in prep.), who actually makes use of the photometric relationships of this work to derive k_G.

We tested the method on the APOGEE DR13 data. The photometric effective temperatures obtained in this work agree with the spectrometric data of the survey with very low dispersion. Similarly, we obtained a precision of about 11% for the derived interstellar extinctions. We compared the DIB equivalent widths for the APOGEE stars in common with Zasowski *et al.* (2015) with the extinctions obtained here, and our A_0 with the A_K provided in the APOGEE catalogue. See Danielski *et al.* (2017, in prep.) for details.

4. Use of calibrations within the Gaia Data Validation

To test the quality of the Gaia astrometric data it is important to check the zero point of parallaxes and their precision. A way to do it is by using stars distant enough so that their estimated distance uncertainty is better than the Gaia parallax precision (for TGAS meaning $\sigma_{\varpi_{star}} < 0.1$ mas). For the Gaia Data Release 1, we used the APOKASC distances of Rodrigues *et al.* (2014). It contains 948 Tycho-2 sources which we used to check the Gaia parallax zero point (Arenou *et al.* (2017)).

For the Gaia Data Release 2 validation, we will use our photometric calibrations to derive the temperature of the asteroseismic giants, allowing to have a much larger sample of distance modulus to compare with Gaia data.

5. Conclusions

We presented a purely empirical, robust and complete first calibration of the Gaia RC, through colour-G-K_s and T_{eff}-G-K_s relations (see more details in Ruiz-Dern *et al.* (2017, submitted)). The work is being extended to other spectral types, such as dwarfs stars. These calibrations were also used to empirically derive the insterstellar extinction coefficient of the Gaia G band, k_G (Danielski *et al.* (2017, in prep.)).

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We applied our photometric calibrations to the Padova isochrones to check the position of the RC on an HR diagram as well as the position of the Red Giant Branch Bump. We also implemented a method that combines the calibrations with an extinction coefficient model and the empirical k_G to derive photometric effective temperatures and interstellar extinctions. We successfully tested it on the APOGEE DR13 data. The photometric interstellar extinctions obtained are being used as input in the new 3D interstellar extinction map of Capitanio *et al.* (2017).

These calibrations have allowed us to determine the absolute magnitude of the RC (Ruiz-Dern *et al.* (2017, submitted)). Thus, more precise distances to large scale structures will be able to be derived.

Finally, their usage is extended to the Gaia astrometric and photometric data validation of DR2, allowing to obtain distance modulus for larger samples of stars and, thus, to improve the verification of, for instance, the Gaia parallax zero-point.

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