Correction of differential reddening

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1 Introduction

Interstellar space is permeated by interstellar medium (ISM), that is composed of gas and dust. Dust tends to scatter radiation, instead the gas tends to absorbs the radiation and radiates at different directions. All those elements contributes to the absorption effect, that changes the ideal stellar spectrum of black body (inside the spectrum appear absorption lines for specific chemical elements) and make the source *redder* from an observational point of view (the spectrum is similar to one of an advance spectral type). This effect changes according to the structures of gas and dust between the source and the observer. Those interstellar clouds are quite complex and extended. As consequence the reddening effect changes in each point of the sky, also at very small scale: this is the differential reddening.

From a mathematical point of view recall the Whitford law: $A_\lambda = 1/\lambda$ where A_λ is the absorption coefficient: the extinction is more in the blue part than in the red part of the spectrum. The difference $A_B - A_V$ is indicated as $E(B-V)$ and the ratio $A_V/E(B-V)$ is denoted as R_V. Accepted values of R_V range from 3.1 to 3.3, although in peculiar directions it could be different. It changes dramatically in specific environment, along the galactic disk, or also observing other galaxies, also at high redshift. Determination of the reddening effect is therefore fundamental.

From an historical point of view, Schlegel et al. (1998) combined the strengths of IRAS and COBE/DIRBE to create a relatively high resolution 100-micron intensity map of the entire sky. These maps are one of the most-used tools by astronomers. However the resolution of the Schlegel map is not high compared to the HST field of view so can get an average value for all stars in the field and we are not able to obtain different values for in the same field.

In this small research it is investigated the star cluster Palomar 2 which is a globular cluster located in the constellation of Auriga.

It has equatorial coordinates $\alpha = 04^h 46^m 06^s$ and $\delta = +31^\circ$ 22' 51" ($J2000$) and galactic coordinates equals to $l = 170.5^\circ$ and $b = -9.1^\circ$ [1]. Due to its low latitude, unfortunately its observation is subjected to a strong effect of differential reddening.

The first purpose is to understand, using its Color-Magnitude Diagram if it is subjected to differential reddening or if it is characterized by presence of

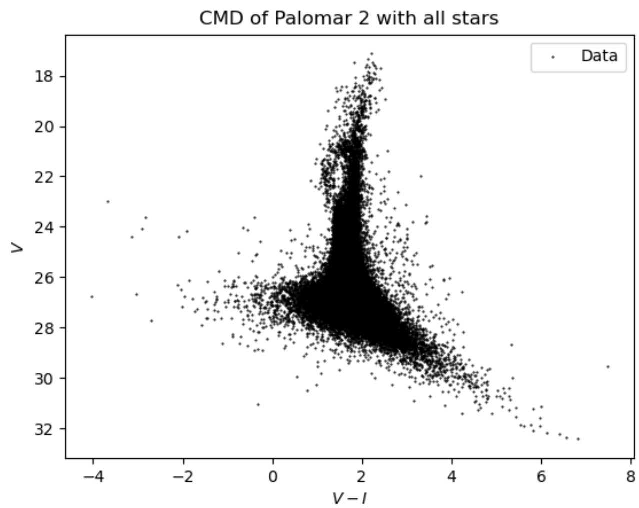

Figure 1: Entire CMD of Palomar 2.

multiple populations with different metallicities or if those explanations are both true. In the case the CMD is affected by differential reddening, I try to find a correction for this from an empirical point of view.

2 The CMD

Photometric data in V band and I band have been obtained thought Hubble Space Telescope HST and its Advanced Camera for Surveys (ACS) with Wide Field Channel (WFC). The CMD has been built plotting on x-axis the color index $V-I$ and on y-axis the I magnitudes. In particular for HST V corresponds to $F606W$ filter and I corresponds to $F814W$.

The CMD of Palomar 2 is shown in figure 1 while a zoom in range $17-26$ on y-axis and in range $1-2.6$ on x-axis is provided in figure 2.

Data obtained for Palomar 2 provide also coordinates x and y of the star along the field of view of camera used for observations. Plotting these coordinates, it is possible to obtain an image of the globular cluster observed. It is shown in figure 3

Supposing that Palomar 2 is affected by differential reddening (quite reasonable due the position of Palomar 2 at low galactic latitude) one possibility to try to estimate the reddening effect is, for example, divide the image of the cluster observed (figure 3) in different panels in order to estimate and then correct data for reddening in a specif region of the sky.

For this reason I divided the field of view in 16 panels, as shown in a schematic way in figure 4.

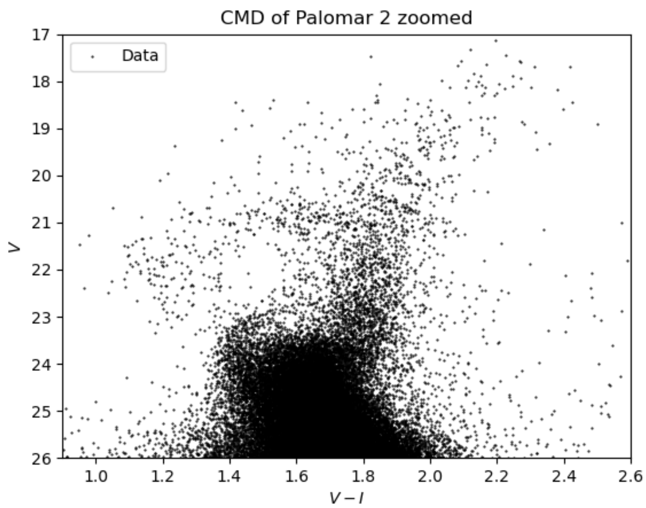

Figure 2: CMD of Palomar 2 zoomed.

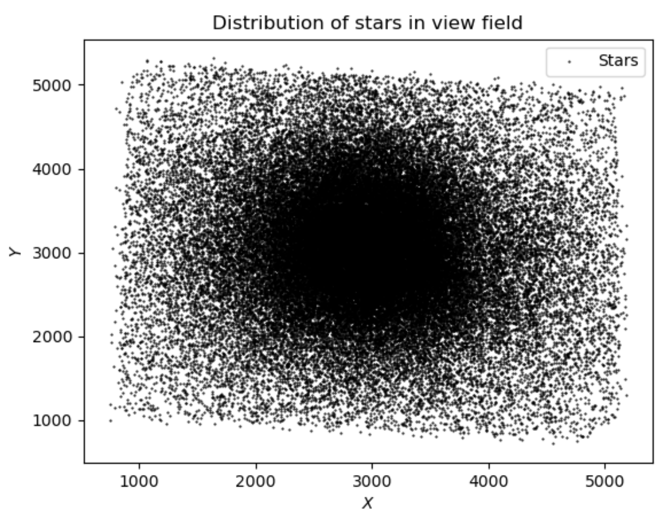

Figure 3: Stars of globular cluster Palomar 2 that have been observed.

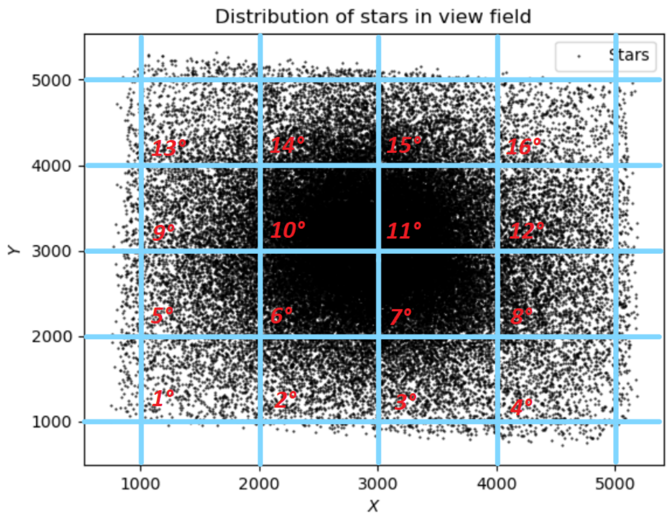

Figure 4: Panels analysed individually.

Then for each panel, a CMD with $V - I$ magnitudes on x-axis and V magnitudes on y-axis has been plotted, to understand if there are some features visible from these diagrams and to estimate in a small region of the field of view the reddening effect. All CMDs of each panel is shown in figure 5.

From this figure it is clear that observing the most central part of the cluster, where the density of stars is higher, the corresponding CMD shows a larger number of visible features, like the horizontal branch, the presence of Blue Straggles, the main sequence turn-off point and the RGB branch.

Some of these CMDs seem very interesting to study while other CMDs appear not very useful maybe due to the presence of field stars, due to a smaller number of stars (in particular in the external region) or due to a higher dispersion of data. This is particularly true for panels outside the center of the cluster where a more sophisticated analysis is necessary to infer information.

3 Plot of isochrones

For all previous reasons I studied CMD of panels with a clear distribution of stars where it is possible to recognize some important characteristics. I choose the best panels and then I plotted over them isochrones to infer information on age, metallicity, distance modulus but, the most important for this research, the reddening value. All graphics are shown in figure 6.

- **Panel 1** - In this case, despite the small number of stars plotted (it is an external region of the cluster), the number of stars is enough good to

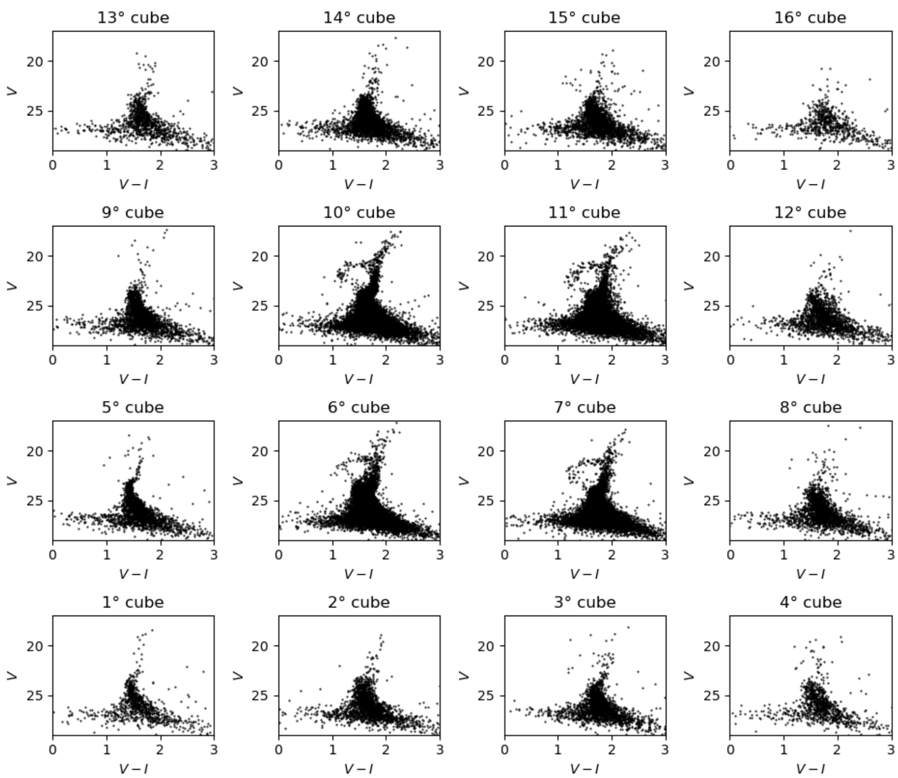

Figure 5: CMDs of each panel in the corresponding position of figure 4.

make statistic. In particular here main sequence phase is quite clear even if there is a huge dispersion of stars at the bottom. The turn-off point is recognizable as the RGB branch. Isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.55$, Helium content $Y = 0.2458$, $[\alpha/Fe] = 0.00$, a reddening equals to 0.95 and $(m - M) = 17.15$.

- **Panel 5** - Here it is very clear the location of turn-off point, the main sequence phase and there is a trace of RGB branch. Isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.55$, Helium content $Y = 0.2458$, $[\alpha/Fe] = 0.00$, a reddening equals to 0.93 and $(m - M) = 17.10$.

- **Panel 6** - This CMD refers to a central region of the cluster very rich in stars. For this reason the main sequence is too much populated and the RGB branch presents some dispersion. The red isochrone represents an upper limit while the blue one a lower limit. The red one has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.55$, Helium content $Y = 0.33$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.01 and $(m - M) = 17.68$. The blue one has been plotted for 13.0 Gyr for age, $[Fe/H] = -1.40$, Helium content $Y = 0.33$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.12 and $(m - M) = 17.60$. In this region of the sky seems to be a larger effect of reddening, maybe due to a present of more complex and bigger structures of gas and dust. As consequence the distance modulus appears higher with respect the previous plots. In this diagram it is also visible a trace of horizontal branch and of Blue Straggles.

- **Panel 7** - This panel presents a more well defined main sequence then panel 6 and it is quite visible a kind of turn-off point in the upper part of main sequence. There is a lower dispersion of data in RGB branch. Isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.55$, Helium content $Y = 0.33$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.20 and $(m - M) = 17.45$.

- **Panel 9** - This panel presents a quite large main sequence phase that is characterized by a trace of binary region. Here isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.55$, Helium content $Y = 0.33$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.01 and $(m - M) = 17.25$.

- **Panel 10** - In this case the main sequence phase is well populated but also well defined. It is very clear the turn-off point but also the RGB branch. There is also a trace of horizontal branch and of Blue Straggles. Isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.45.$, Helium content $Y = 0.2460$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.12 and $(m - M) = 17.22$.

- **Panel 11** - Another good CMD is this one. It has a well defined main sequence with a quite clear region of binaries. There is a smaller scatter of points in RGB branch and also horizontal branch is quite visible. In this case isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.45.$, Helium content $Y = 0.2460$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.17 and $(m - M) = 17.20$.

- **Panel 14 -** Here there is a smaller number of stars (it is the external region). Main sequence is a bit larger but it is recognizable the binaries region. There is some dispersion of data in RGB branch. Isochrone has been plotted for 13.5 Gyr for age, $[Fe/H] = -1.45.$, Helium content $Y = 0.2460$, $[\alpha/Fe] = 0.00$, a reddening equals to 1.07 and $(m - M) = 17.10$.

4 Conclusion

In conclusion I found a value for the age about 13.5 Gyr with a differential reddening effect which is quite different from one panel to another. In particular it ranges from 0.93 in panel 5 up to 1.20 in panel 7. On the other side distance modulus ranges from 17.10 of panel 5 and 14 up to 17.68 of panel 6 where there is also an high reddening effect: bigger is the influence of reddening, higher is the estimation of distance modulus and then the error on distance determination.

More sophisticated analyses can be done for the other panels rejected but, in general, this small research found that there is a high differential reddening effect according to the small region of the sky observed. In any case it is not possible to exclude a priori the presence of some exotic populations or populations with different metallicity or the contamination of field stars. A more extensive study must be done on Palomar 2.

4.1 An alternative path

An alternative path, more complex and not discussed here, is, for example, correct the differential reddening that affect CMDs with red clump stars. The position of the red clump stars change dramatically, according to galactic coordinates so according to the reddening effect (which is bigger along the disk and corresponding to the bulge but smaller perpendicularly to the galaxy). In general the relative color and magnitudes of the red clump are indicative of the amount of differential reddening in each region of the bulge. This is an interesting approach not applicable in this case (more data and sophisticated tools are necessary).

References

[1] William E. Harris. A Catalog of Parameters for Globular Clusters in the Milky Way. , 112:1487, October 1996.

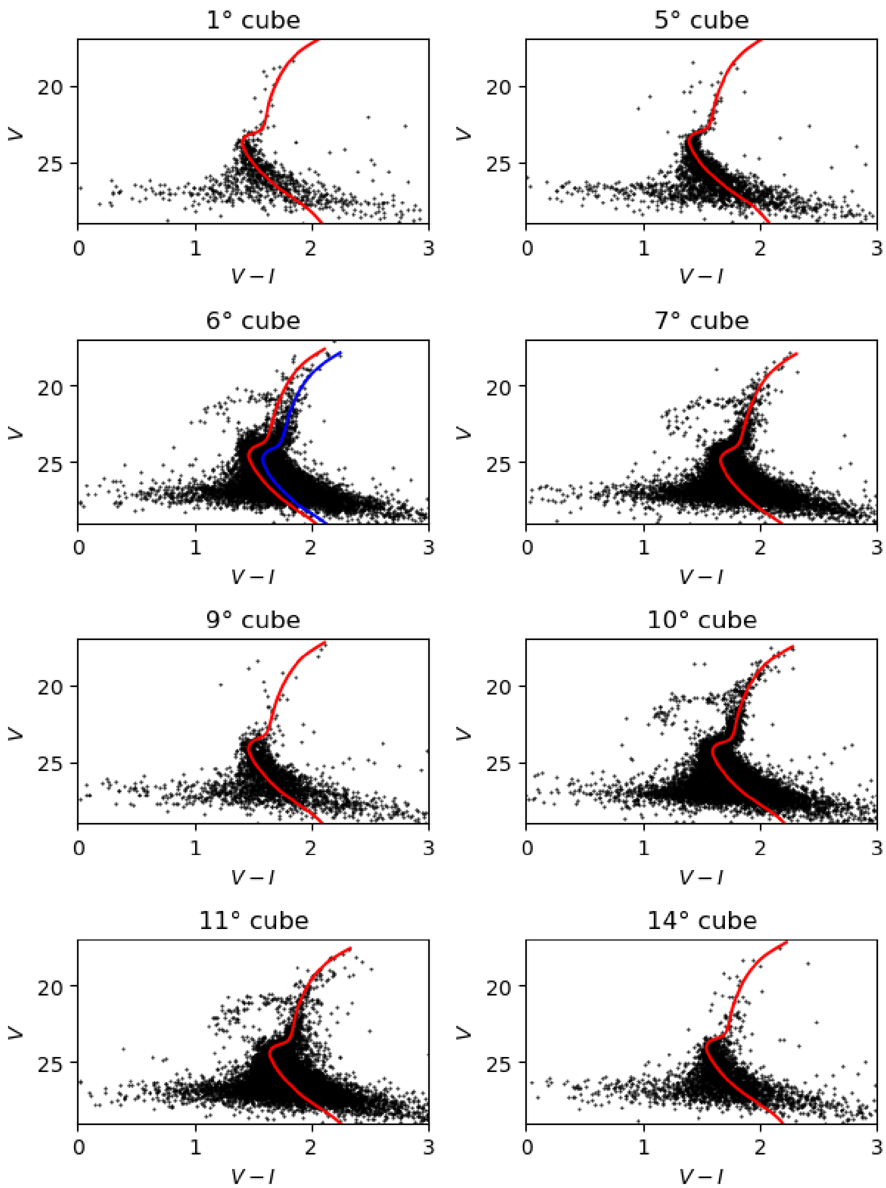

Figure 6: Isochrones on CMD of panels selected.