Metallicity of Red Clump Giants in Baade’s Window

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ABSTRACT

The red clump giants are potentially very useful as standard candles. There is some controversy about the stability of their I-band absolute magnitude, but it does not seem to be serious. No controversy was anticipated about their colors, with metal rich giants expected to be redder and cooler than the metal poor giants. The purpose of this paper is to point out that no such correlation is apparent between [Fe/H] and $T_{\text{eff}}$ as determined with Washington CCD photometry for the giants in Baade’s Window. No explanation is offered for this surprising result. It is also unknown why the galactic bulge red clump giants are redder than the clump giants near the Sun by 0.2 mag in the $(V-I)_0$ color.

Key words: Galaxy: center – Hertzsprung-Russel (HR) diagram – Stars: abundances – Stars: fundamental properties – Techniques: photometric

1 Introduction

Following the publication of the Hipparcos catalogue of parallaxes (Perryman et al. 1997) it became apparent that the red clump giants near the Sun occupy a very small region in the color–absolute magnitude diagram, and therefore they are potentially very good standard candles. Paczyński and Stanek (1998) pointed out that red clump giants measured by OGLE in Baade’s Window (Udalski et al. 1993, Kiraga, Paczyński and Stanek 1997), and corrected for the interstellar reddening have remarkably constant I-band magnitude over a large range of colors, $0.8 \leq (V-I)_0 \leq 1.4$. Assuming that the absolute I-band magnitude of red clump stars is the same near the Sun and in the galactic bulge Paczyński and Stanek (1998) determined the distance to the galactic center to be $R_0 = 8.4 \pm 0.4$ kpc, later corrected to $R_0 = 8.2 \pm 0.2$ kpc by Stanek and Garnavich (1998).

Subsequently, the red clump stars were used to measure distance to M31 (Stanek and Garnavich 1998), to both Magellanic Clouds (Udalski et al.
and to the Large Magellanic Cloud (Stanek, Zaritsky and Harris 1998). Udalski (1998a) demonstrated that distances based on red clump stars and on RR Lyrae stars are compatible with each other, and that \( M_I \) for the red clump stars depends weakly on their metallicity. Finally, Udalski (1998b) showed that the absolute I-band magnitude of red clump stars in the LMC and SMC star clusters is independent of age in the range \( 2 - 10 \) Gyr. The last two papers presented empirical evidence that red clump stars can be used as standard candles to determine distance modulus with an accuracy of 0.1 mag, or perhaps even better. However, care must be taken to estimate the age and metallicity of the population used for the study. Note, that field red clump giants in both Clouds have the same I-band magnitudes and colors as the red clump giants in star clusters which are \( 2 - 10 \) Gyr old (Udalski 1998a,b, Udalski et al. 1998).

Theoretical models indicate that red clump stars have a small range of absolute luminosities (Seidel, Demarque, and Weinberg 1989, Castellani, Chieffi, and Straniero 1992, Jimenez, Flynn, and Kotoneva 1997). The question is: how small? Recently Cole (1998) and Girardi et al. (1998) pointed out that theoretically expected range of I-band luminosities may be as large as 0.5 mag, and that the systematic difference between the corresponding stellar populations makes the Magellanic Clouds more distant than claimed by Udalski et al. (1998). The apparent conflict is not likely to be serious, when various theoretical uncertainties are taken into account. In particular the age distribution and helium abundance adopted in theoretical models may be inaccurate.

The aim of this paper is to point out that while there is a debate about the stability of the \( M_I \) magnitude of the red clump stars, there is another serious problem with the interpretation of their \((V - I)_0\) colors, and very likely with the \([\text{Fe}/\text{H}]\) values as determined with Washington CCD photometry. No explanation for the apparent problem is offered in this paper.

## 2 Theoretical expectations

It is well established that when metallicity is increased the opacity increases too, and in particular the opacity in a K giant atmosphere goes up. As such giants have deep convective envelopes the increase of atmospheric opacity makes stellar radii larger, and their effective temperatures lower. This theoretical result was stable over last several decades, and it is well presented in Fig. 2a of Jimenez, Flynn and Kotoneva (1997). As far as I know the
notion that the more metal rich giants are cooler is very robust and well understood, and it has never been challenged.

The effective temperature has a decisive effect on stellar colors. Higher metallicity implies redder color for two reasons. First, because the higher the metallicity, the lower the temperature, and the redder the color. Second, because the B-band (and even more so the U-band) are affected by line blanketing, and the blanketing makes colors redder. However, as both effects work in the same direction the prediction is clear: the more metal rich stars should be redder (Jimenez et al. 1997, Girardi et al. 1998, and references therein).

The age of a population may affect the colors as well, but the effect is modest, and it is very small for K giants older than 2 Gyr (Jimenez et al. 1997, Fig. 3, Girardi et al. 1998, Fig. 1).

The $(V - I)_0$ color is almost unaffected by line blanketing, so it should be a good temperature indicator. The Washington index $(T_1 - T_2)$ is claimed to be even better temperature indicator (Taylor et al. 1987). Therefore, we expect a good correlation between K-giant metallicity and the suitable color index.

3 Galactic bulge

This expectation that $(V - I)_0$ color is well correlated with metallicity was the basis for the suggestion by Paczyński and Stanek (1998) that the galactic bulge red clump stars are more metal rich than their counterparts near the Sun, as the average colors are $\langle (V - I)_0 \rangle \approx 1.2$ in the Baade’s Window bulge and $\langle (V - I)_0 \rangle \approx 1.0$ near the Sun.

The metallicity of the galactic bulge giants has a long and complicated history. For many years the bulge giants were thought to be super metal rich (cf. Geisler and Friel 1992, and references therein), but the estimate of their [Fe/H] was recently reduced (cf. Sadler, Rich, and Terndrup 1996, and references therein). The range of bulge metallicities is still believed to be very large. Note, that the range of $(V - I)_0$ colors for the bulge red clump giants is about twice larger than the corresponding range near the Sun.

It seems that the mean metallicity is currently thought to be about the same in the bulge and near the Sun. Yet, the bulge red clump giants are on average redder by 0.2 mag than the red clump giants near the Sun. These two statements appear to be in conflict with the theoretical expectations presented in the previous chapter.
Another check of the theoretical expectations is offered by the data published by Geisler and Friel (1992, Table 1), who obtained [Fe/H] and the \((T_1 - T_2)\) temperature index for over 300 stars in Baade’s Window. Their data is presented in a color - magnitude diagram in Fig. 1, which is a small part of Fig. 3 of Geisler and Friel (1992). The red clump giants are located between the two horizontal dashed lines. The area in the sky covered was only \((3')^2\), so the interstellar extinction was more or less uniform, and the \((T_1 - T_2)\) index should be well correlated with the effective temperature. All data from Table 1 of Geisler and Friel (1992) are plotted in Figs. 2-4 in \((T_1 - T_2) - [Fe/H]\) diagrams, for the stars above the red clump (Fig. 2), in the clump (Fig. 3), and below the clump (Fig. 4). A strong positive correlation was expected theoretically in all three figures. The only correlation which is clearly apparent is negative for giants above the red clump: in the magnitude range \(15.5 > T_1 > 14.0\) the metal richer giants are bluer! The red clump giants were binned in groups of 10, and the binned [Fe/H] values are plotted versus temperature index in Fig. 5. Again, no correlation
Figure 2: The $[\text{Fe}/\text{H}]$ – color diagram for K in Baade’s Window based on Washington CCD photometry presented in Table 1 of Geisler and Friel (1992). The stars shown are brighter than red clump giants. The apparent correlation is opposite to the one expected, with the metal richer stars being bluer.

Figure 3: The $[\text{Fe}/\text{H}]$ – color diagram for K giants in Baade’s Window based on Washington CCD photometry presented in Table 1 of Geisler and Friel (1992). The stars shown are the red clump giants. There is no apparent correlation between their metallicity and color.
Figure 4: The $\text{[Fe/H]} - \text{color}$ diagram diagram for K giants in Baade's Window based on Washington CCD photometry presented in Table 1 of Geisler and Friel (1992). The stars shown are fainter than red clump giants. There is no apparent correlation between their metallicity and color.

Figure 5: The $\text{[Fe/H]} - \text{color}$ diagram diagram for K giants in Baade's Window based on Washington CCD photometry presented in Table 1 of Geisler and Friel (1992). Each point corresponds to the average of 10 points in Fig. 3. No correlation between the metallicity and colors of the red clump giants is apparent.
is apparent.

4 Discussion

Something is very wrong either with our understanding of stellar structure, or with the determination of \([Fe/H]\) with Washington CCD photometry, or with the color index \((T_1 - T_2)\) as temperature indicator.

Recently, Høg and Flynn (1997) presented DDO photometry for Hipparcos K giants with \([Fe/H] > -0.5\). Dr. Flynn kindly provided me with the \((B - V) - [Fe/H]\) and \((V - I) - [Fe/H]\) diagrams for the Hipparcos red clump giants. There was a clear correlation apparent on the first diagram, but none was obvious in the second. It is possible that line blanketing which is strong in the B-band was at least partly responsible for the correlation between \((B - V)\) and \([Fe/H]\). It is surprising that the correlation between \((V - I)\) and \([Fe/H]\) is either very weak or absent.

Perhaps this indicates that \([Fe/H]\) is not a good measure of the true stellar metallicity? Perhaps, but this is not the whole story. An inspection of Figures 2a and 3 of Jimenez et al. (1997) and Fig. 1 of Girardi et al. (1998) makes it clear that according to theoretical models the metallicity, not age or stellar mass is decisive in establishing the colors and the range of colors of the red clump giants. In particular, the only way to obtain \((V - I)_0 \approx 1.4\), as observed in Baade’s Window, is by adopting \(Z \gg 0.03\). The observed fact that the bulge red clump giants are redder then the red clump giants near the Sun by 0.2 mag, on average, requires their metallicity to be higher by a factor \(~ 4\). This is in a direct conflict with the recent spectroscopic determinations (cf. Sadler, Rich, and Terndrup, 1996, and references therein).

According to Udalski (1998a,b) and Udalski et al. (1998) the red clump giants in the Magellanic Clouds and in the Carina dwarf galaxy have colors \(\langle (V - I)_0 \rangle_{LMC} \approx 0.90, \langle (V - I)_0 \rangle_{SMC} \approx 0.85, \langle (V - I)_0 \rangle_{Car} \approx 0.82\), while their \([Fe/H]\) is estimated to be \(-0.6, -0.8, -1.9\), respectively. There is a trend between the color and the metallicity, which is monotonic all the way to the red clump giants near the Sun. Only the galactic bulge stars appear to suffer the lack of correlation between their metallicity and colors.

It is possible that there is no single parameter which can be used to describe ‘metallicity’, perhaps the elemental ratios vary a lot. Perhaps some elements are responsible for continuum atmospheric opacity, and therefore broad band colors, and some other are responsible for the line features used
to measure ‘metallicity’ (Paczyński and Stanek, 1998)?

Following a lengthy discussion of this dilemma with a number of people listed in the acknowledgments I was unable to convince myself that the reason for the apparent conflict can be explained. Theoretically, a strong correlation between the \((V - I)_0\) and/or \((T_1 - T_2)\) colors and the \([\text{Fe/H}]\) metallicity index is expected, but none is detectable for the red clump giants either in the galactic bulge or near the Sun.

Note, that absolute I-band luminosity of the red clump stars depends on their metallicity, as shown by the data (Udalski 1998a) and the models (Jimenez et al. 1997, Girardi et al. 1998). Therefore, a clear and unambiguous method to determine their metallicity is needed if they are to be used as reliable standard candles.

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