Red Clump Stars: Further Improved Distance Indicator

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Summary

The ideal distance indicator would be a standard candle abundant enough to provide many examples within reach of parallax measurements and sufficiently bright to be seen out to Local Group galaxies. As developed by Paczyński & Stanek (1998), the red clump method precisely fits this description. These stars are the metal rich equivalent of the better known horizontal branch stars, with weak metallicity and age brightness dependence.

To date the red clump method has been used to measure accurate distances to the Galactic center (Paczyński & Stanek 1998), M31 (Stanek & Garnavich 1998), LMC (Udalski et al. 1998; Stanek et al. 1998; Udalski 1999) and some clusters in our Galaxy (e.g. 47Tuc: Kaluzny et al. 1998). As with all the distance indicators, the main worry lies in the possible systematics of the method, in this case its dependence on the stellar metallicity and age. Both of these dependences were investigated by Udalski (1998a) and Udalski (1998b). More recently, the metallicity dependence of the red clump brightness was investigated by Stanek et al. (1999), Udalski (1999) and Popowski (1999). So far all these studies indicate that indeed the population effects on the red clump brightness are small. We discuss further planned studies of the red clump properties.

Perhaps the most important result from the red clump method was the determination of the "short" distance to the Large Magellanic Cloud (Udalski et al. 1998; Stanek, Zaritsky & Harris 1998; Udalski 1999). If accurate, this distance to the LMC shorter by 12% than the "standard" value, has very important implications for the Cepheid distance scale and the determination of the Hubble constant.

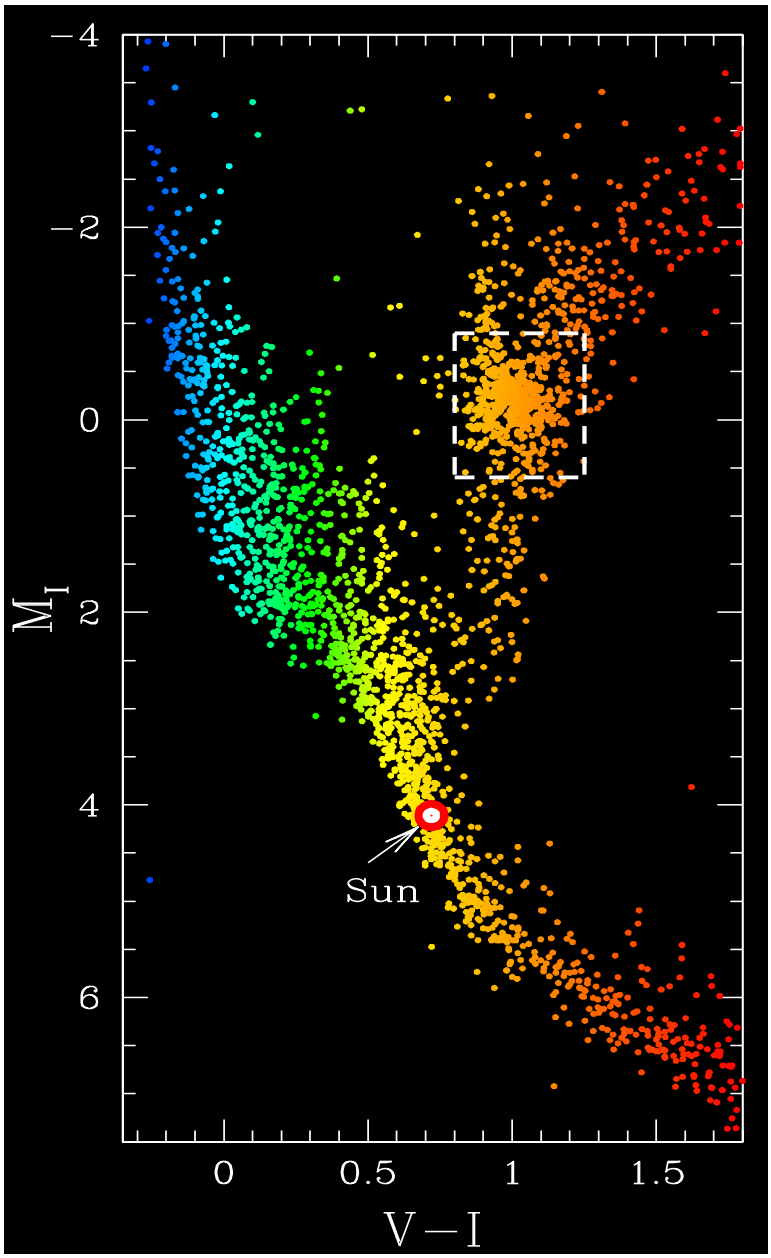
Hipparcos calibration of the red clump

The *Hipparcos* based absolute magnitude-color diagram is shown in the central figure, for the stars with parallaxes measured to better than 10%. There are about 600 such stars within the rectangular region. Stanek & Garnavich (1998) selected a sub-sample of 228 *Hipparcos* red clump stars with the distance $d < 70\ pc$ and parallaxes measured to better than 5%, and they determined the parameters of the best fit to the luminosity function: $M_{I,m}|d < 70\ pc| = -0.227 \pm 0.023$, and $\sigma_{RC} = 0.209$ mag for these nearby stars, with the average distance $\langle d_{<70} \rangle = 50\ pc$. One expects very little reddening, $E(B-V) < 0.02$, for such nearby stars, so they assumed that their $d < 70\ pc$ sample suffered no reddening.

Red clump distance to the LMC

Udalski et al. (1998) and Stanek, Zaritsky & Harris (1998) derived the distance to the Large Magellanic Cloud by comparing red clump stars from the *Hipparcos* catalog with the red clump stars observed in several fields in the LMC. They obtained a single step determination of the distance modulus to the LMC, $\mu_{0,LMC} = 18.08 \pm 0.03 \pm 0.12$ mag (statistical plus systematic error) (Udalski et al. 1998) and $\mu_{0,LMC} = 18.065 \pm 0.031 \pm 0.09$ mag (Stanek et al. 1998). These studies assumed the red clump to be a perfect standard candle whose brightness does not depend on population effects.

The most recent value of the red clump distance to the LMC was obtained by Udalski (1999): $\mu_{0,LMC} = 18.24 \pm 0.08$ mag, a value ~ 0.25 mag smaller than the generally accepted value of $\mu_{0,LMC} = 18.50 \pm 0.10$ mag. This study used very low-extinction fields in the LMC and the metallicity dependence of $0.13\ mag\ dex^{-1}$, discussed elsewhere in this poster. The value obtained by Udalski (1999) is free of zero-point calibration problems, reddening uncertainties and is corrected for population effects, thus representing the most robust LMC distance estimate available to date.



Distance moduli with the red clump

47 Tuc	GB	LMC	SMC	Carina DG	M31
13.38 ± 0.05	14.53 ± 0.06	18.24 ± 0.08	18.73 ± 0.10	19.84 ± 0.07	24.51 ± 0.07

Systematics of the red clump method

As with all the distance indicators, the main worry lies in the possible systematics of the red clump method, in this case its dependence on the stellar metallicity and age. We are investigating these systematic effects using samples of globular clusters observed in M31 and M33 with the HST. The fact that the derived distance moduli for the three fields in M31 used by Stanek & Garnavich (1998) vary by only 0.035 mag indicates that indeed the population effects on the red clump brightness are small. The age dependence was investigated by Udalski (1998b) and found to be small, using large samples of red clump stars collected by the OGLE collaboration in the LMC and the SMC (Fig. 1).

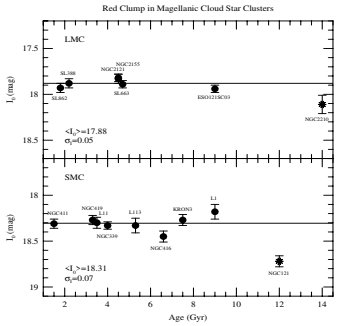


Fig. 1.—Mean I-band brightness of the red clump as a function of age for the LMC and SMC. Filled dots represent clusters of intermediate age (2–10 Gyr), while asterisks represent older clusters (from Udalski 1998b).

The metallicity dependence of the red clump was first investigated by Udalski (1998b) and more recently by Udalski (1999). Using nearby bright stars with well measured *Hipparcos* parallaxes and high quality spectroscopy, he found a weak metallicity dependence of $0.13\ mag\ dex^{-1}$ for the red clump I-band peak brightness (Fig. 2). The metallicity dependence was also investigated by Stanek et al. (1999) using Galactic bulge stars observed in Baade's Window (Fig. 3). These empirical determinations are in a very good agreement with recent models of stellar evolution (e.g. Girardi 1999).

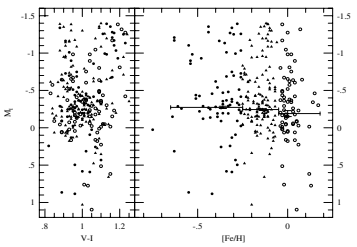


Fig. 2.—M_I of 284 nearby red giants with precise photometry and spectroscopy plotted as a function of color $V-I$ (left panel) and metallicity [Fe/H] (right panel). Stars of low, medium and high metallicity are marked by filled circles, filled triangles and open circles, respectively (from Udalski 1998).

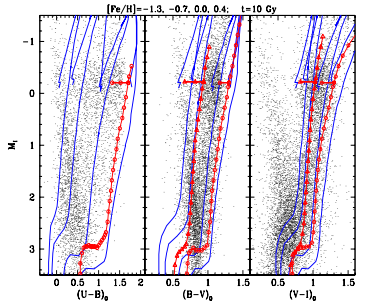


Fig. 3.—M_I absolute magnitude – dereddened color diagrams for the BW3 field. Also plotted are the $t = 10$ Gy isochrones and the the dereddened maximum density ridge-lines for 47Tuc ([Fe/H] ≈ −0.7; triangles) and NGC6791 ([Fe/H] ≈ +0.3; circles) (from Stanek et al. 1999).