Red Clump Stars: New, 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, and their brightness shows only a weak metallicity (Udalski 1998a) and age (Udalski 1998b) dependence. Indeed the absolute magnitude-color diagram of *Hipparcos* stars clearly shows how compact the red clump is: Stanek and Garnavich (1998) determined that the variance in the I-band magnitude is only 0.15 mag. To date the red clump method was used to measure accurate distances to the Galactic center (Paczyński & Stanek 1998), M31 (Stanek & Garnavich 1998), LMC & SMC (Udalski et al. 1998; Stanek et al. 1998) and several clusters within the Galaxy (e.g. 47Tuc: Kaluzny et al. 1998).

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 they determined the parameters of the best fit to the luminosity function: $M_{I,RC}[d < 70\ pc] = -0.227 \pm 0.023$, 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.

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. Both these dependences were investigated by Udalski (1998a) and Udalski (1998b) using large samples of red clump stars collected by the OGLE collaboration. 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.

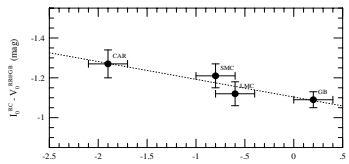


Fig. 1.— Difference between the mean I-band magnitude of the red clump stars and the mean V-band luminosity of the RR Lyr stars reduced to metallicity of the Galactic bulge in the Galactic Bulge (GB), LMC, SMC and Carina dwarf galaxy (adopted from Udalski 1998a).

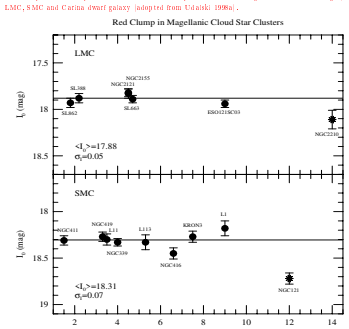
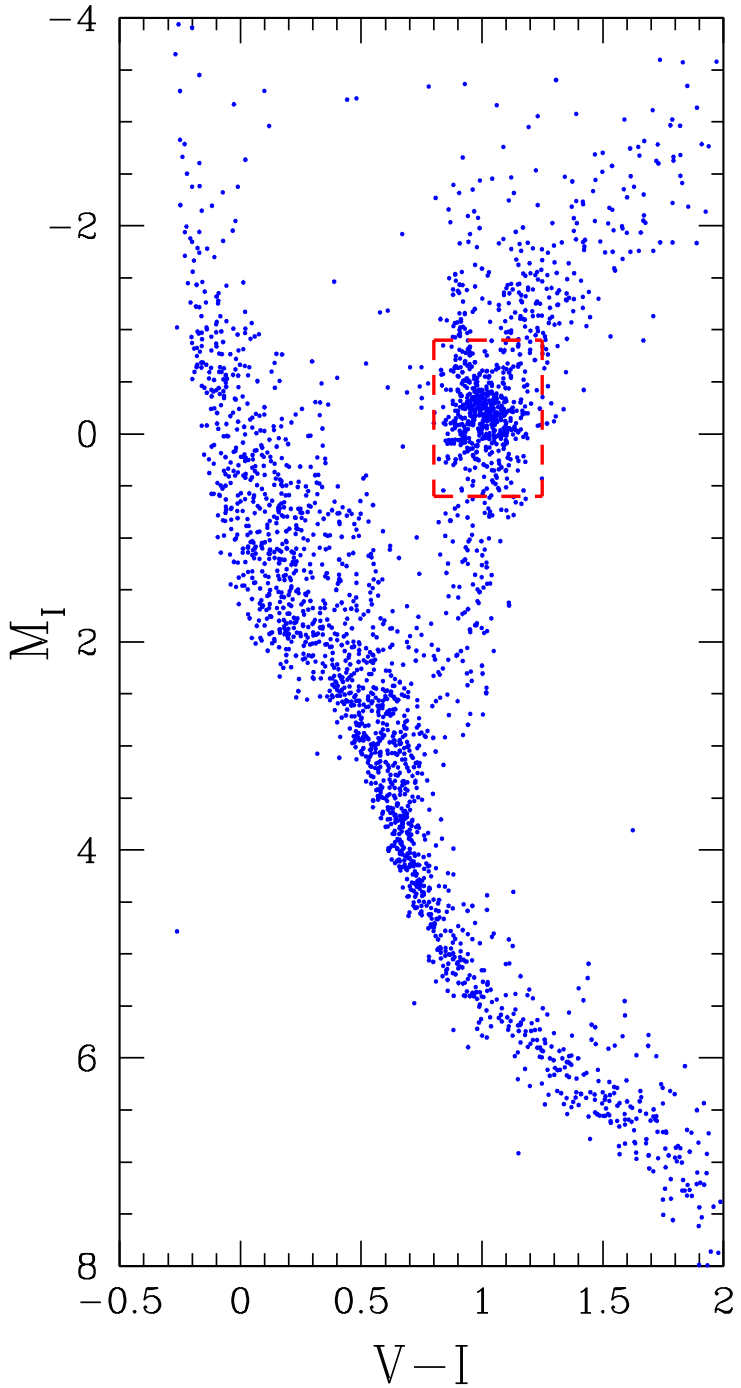


Fig. 2.— Mean I-band brightness of the red clump as a function of age for the LMC and SMC. Filled dots represent clusters of intermediate age (2–10 Gyr), while asterisks represent older clusters (adopted from Udalski 1998b).



Distance moduli with the red clump

47 Tuc	GB	LMC	SMC	Carina DG	M31
13.38 ± 0.05	14.53 ± 0.06	18.18 ± 0.06	18.65 ± 0.08	19.84 ± 0.07	24.51 ± 0.07

Red clump distance to the Galactic center

Paczyński & Stanek (1998) compared the local red clump with the OGLE red clump stars in Baade's Window corrected for the interstellar extinction. They found empirically that the average I-band magnitude of red clump stars does not depend on their intrinsic color in the range $0.8 < [V-I]_0 < 1.4$. This allows a single step determination of the Galactocentric distance modulus $\mu_{0,GC} = 14.57 \pm 0.04 \pm 0.04$ mag (statistical plus systematic error), and the corresponding Galactocentric distance $R_0 = 8.2 \pm 0.15 \pm 0.15\ kpc$ (Stanek & Garnavich 1998).

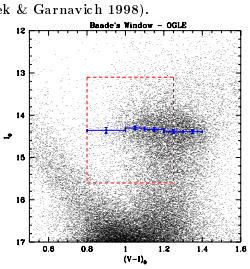


Fig. 3.— The color-magnitude diagram corrected for interstellar extinction is shown for the stars in the part of Baade's Window with a small extinction, $A_V < 1.5$ mag. The dashed rectangle surrounds the red clump region used for the comparison with the local stars. The ridge of the highest density of the red clump stars, $I_{RC,0}$, is shown for few color bins in the range $0.8 < V-I < 1.4$. It is apparent that the value of $I_{RC,0}$ does not depend on the $[V-I]$ color adopted from Paczyński & Stanek 1998.

Red clump distance to M31

Stanek & Garnavich (1998) compared the local red clump stars with the red clump stars observed in three fields in M31 using the *HST*. There were ~ 600 and $\sim 6,300$ such stars in the two data sets, respectively. The single step determination of the distance modulus to M31 $\mu_{0,M31} = 24.471 \pm 0.035 \pm 0.045$ mag (statistical plus systematic error) and the corresponding distance $R_{M31} = 784 \pm 13 \pm 17\ kpc$. The number of red clump stars is large enough that the formal statistical error in the distance is only $\lesssim 2\%$.

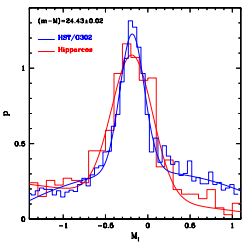


Fig. 4.— The number of red clump stars in the solar neighborhood, based on *Hipparcos* data, is shown as a function of absolute magnitude M_I with the red line. The number of red clump stars in the GO02 field (Holland et al. 1996), is shown as a function of absolute magnitude M_I with thick blue line, adopting the preliminary distance modulus: $I_0 - M_I = 24.43$ (adopted from Stanek & Garnavich 1998).

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). This was later revised by Udalski (1998b) to $\mu_{0,LMC} = 18.18 \pm 0.06$ mag, a value ~ 0.3 mag smaller than the generally accepted value of $\mu_{0,LMC} = 18.50 \pm 0.10$ mag.

Some Recent Estimates of LMC Distance

$[m-M]_0$	Technique	Reference
18.50 ± 0.04	Many Techniques	van den Bergh (1998)
18.18 ± 0.06	Red Clump	Udalski (1998b)
18.28 ± 0.18	Red Clump w/Models	Girardi et al. (1998)
18.16 ± 0.16	RR Lyr	Udalski et al. (1998)
18.33 ± 0.08	RR Lyr	Popowski & Gould (1998)
18.30 ± 0.07	Eclipsing Binary	Guinan et al. (1998)
18.22 ± 0.13	Eclipsing Binary	Udalski et al. (1998)
18.30 ± 0.15	Cepheids	Luri et al. (1998)
< 18.6	SN 1987A Ring	Lundqvist & Sonneborn (1998)