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A New Analysis in the Field of the Open Cluster Collinder 223

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Abstract The present study of the open cluster Collinder 223 (Cr 223) depended greatly on the photoelectric data of Clariá and Lapasset. We use the data in conjunction with the AAO/DSS[1] image of the cluster in a re-investigation to improve the main parameters of Cr 223, including the stellar density, the position of the cluster's center, the cluster's diameter. Its luminosity function, mass function, and total mass are also estimated.

Key words: Galaxy: open clusters and associations — individual: Cr 223

1 INTRODUCTION

The open cluster Cr 223 (C1028–595) is situated in the Carina spiral feature of the southern Milky Way at 2000.0 coordinates $\alpha = 10^{\rm h}30.5^{\rm m}, \delta = -59°49^{'}, \ell = 286.2°, b = -1.9°$. Trumpler (1930) classified it as a detached cluster with little central concentration with stars belonging to a medium range in brightness (II-2p system). Collinder (1931) described this cluster as a system of 38 stars at a distance of 2630 pc distributed over a field of 8 arcmin.

Clariá & Lapasset (1991) (hereafter CL91) have studied 110 stars in the cluster region using the broadband UBV system and moreover seven probable red giants have been observed on the DDO intermediate-band system. CL91 proved that these stars represented a genuine open cluster of only B-type stars, with V magnitudes from about 11–14 mag. The identification chart of Cr 223 from Hogg (1965) was reproduced as fig. 1 of CL91. It defines a radius of about 7.5 arcmin from the apparent center of the chart (near the star no. 77). CL91 described their work as a preliminary photometric study. Therefore some of the present parameters, e.g., the luminosity and mass functions, are preliminary also. Deeper studies (CCD observations) of the cluster would yield a more precise determination of these parameters. In the present work we undertake to re-estimate the following parameters of the cluster: reddening, distances, position of the center, diameter, stellar density, age, membership analysis, luminosity function, mass function, and total mass.

[1] AAO: Anglo-Australian Observatory, DSS: Digitized Sky Surveys; taken from "SIMBAD" *(http: //simbad.u -strasbg.fr)*

2 HR-DIAGRAMS

The main photometric parameters of the cluster (membership, reddening and distance) are involved in the construction of the color-color (CC) diagram $[(U-B)-(B-V)]$, and the short and long wavelength color-magnitude diagrams (CMDs) $V \sim (U-B)$ & $V \sim (B-V)$.

2.1 Membership Analysis

Uncertainty in membership increases for the fainter stars that are merging with the crowded galactic field. To discriminate between cluster members and field stars, we applied the criteria of Clariá & Lapasset (1986) and chose as members that satisfy the two following conditions: (1) its location in the two CMDs must correspond to the same evolutionary stage in the cluster, and (2) its location in the (CC) diagram must be close to the cluster main sequence, the maximum acceptable departure having been set at about 0.1 mag.

CL91 classified 46 of 110 stars as members including two blue stragglers (nos. 35 & 80); one red giant (no. 75); and three probable members (nos. 30, 81 & 95). They classified about 60 stars as non-members. For more details about the field stars see CL91.

Applying the above criteria after separating the giant stars and field ones, we found that three stars could be added to the membership (nos. 23, 31 & 32). Although these three new members are some distance away from the cluster center, they lie inside the cluster's "extended diameter" (area), defined in Section 6 below. Moreover, their distances and reddening values are found to be in agreement with those of the established members.

2.2 Reddening and Distance

The presence of interstellar matter throughout the spiral arms of the Galaxy makes the distance determination of galactic clusters difficult as the starlight is frequently absorbed and scattered.

CL91 assumed that the cluster Cr 223 has some differential reddening, and so they used equations (2) and (8) of Garcia, Clariá & Levato (1988) to de-redden the stars individually with a standard deviation of 0.03 mag.

In the present work, reddening (which is the important parameter in deriving distance) was estimated simultaneously with the apparent distance modulus with a standard deviation of 0.015 mag. These two parameters are estimated by fitting the standard zero-age main sequence (ZAMS) of Schmidt-Kaler (1982) to the lower envelope of the points in the two CMDs of the cluster. We tried many fittings to reach the best values of reddening at the same distance modulus. The evolved stars were excluded from the fitting and the usual interstellar absorption law applied. For each fit, the calculated value of $E(U-B)$ was computed using the relation,

$$E(U-B)_{\text{cal.}} = 0.72 \times E(B-V) + 0.05 \times E^2(B-V)\,.$$

At the minimum difference between the observed and calculated values $[\Delta E(U-B)_{\text{Cal.}-\text{Obs.}} \approx 0.0\,\text{mag}]$, the reddenings and the distance modulus were found to be $E(U-B) = 0.18 \pm 0.015$ mag, $E(B-V) = 0.25 \pm 0.015$ mag, and $V - M_v = 13.0 \pm 0.15$ mag. The resulting total visual absorption is then $A_v = 0.75$ mag where the value of the ratio $A_v/E(B-V)$ is taken to be 3.0, following Garcia et al. (1988).

Comparing the observed (CC) diagram of the cluster Cr 223 with the standard one of Schmidt-Kaler (1982), the intrinsic color indices are estimated for each star as follows: A line parallel to the reddening line is drawn for each star and the intersection of this line with the

ZAMS-curve gives the intrinsic color index $[(B-V)_o \& (U-B)_o]$, assuming that the star lies on the main sequence. The slope of the reddening line was taken to be 0.72, as given by Johnson & Morgan (1953). The stars lying below the kink of the ZAMS-curve are ambiguous stars and may have two or three possible values. For such stars, we took the value that best accords with the cluster distance. The intrinsic visual magnitude $[V_o]$ for each star was then determined from the individual reddening estimate.

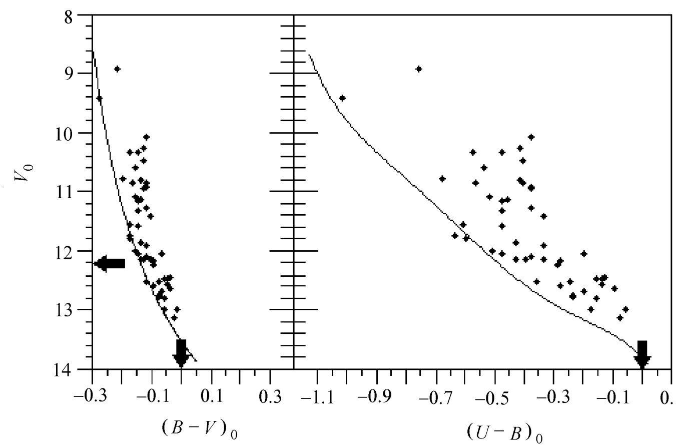

Fig. 1 CM diagrams of the cluster fitted with the ZAMS of Schmidt-Kaler (1982). The arrows mark the locations of $M_v = 0.0$ mag, $(B-V)_o = 0.0$ mag & $(U-B)_o = 0.0$ mag.

The two CMDs of the cluster members are shown in Fig. 1. The solid curved line is the standard ZAMS-curve of Schmidt-Kaler (1982) fitted to the lower envelope of the points. The true distance modulus is then $(V - M_v)_o = 12.25 \pm 0.15$ mag, corresponding to a distance of 2820 ± 190 pc. This distance is found to be in agreement with what was obtained in CL91.

The distances of the cluster from the galactic plane, Z, from the galactic center (Rgc), and the projected distances on the galactic plane from the Sun, X, Y, are –81 pc, 8.2 kpc, –2.7 kpc and 0.8 kpc, respectively.

3 STELLAR DENSITY

Star counts in the region of the cluster (particularly for this one located in the southern sky) allow us to define the obscuration by clouds in the foreground of the cluster. The whole studied area of the cluster on the AAO/DSS image is shown in Fig. 2.

Applying Wallenquist's (1975) method using the AAO/DSS image of Cr 223, an area of about 3024 arcmin^2 was covered and more than 2000 stars were counted. For more details on a similar task, see Tadross et al. (2002).

A contour map of a grid of 1400 density points over the cluster region was generated. See Fig. 3. The map shows a concentration of stars in the south-western part. It may be a result of the intrinsic spatial distribution in this area, or it may be a modulation by some foreground clouds. If the latter, then the concentration of the greater stellar density in the south-west is related to a lower amount of obscuration by clouds.

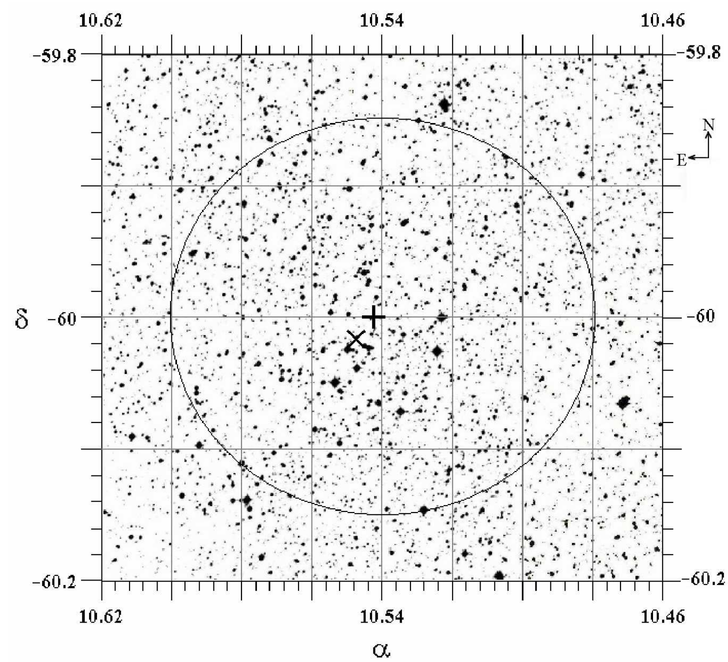

Fig. 2 AAO/DSS image of the cluster Cr 223. "×" marks the apparent center of the cluster given by CL91, "+" marks the new center found in the present work, and the circle marks the area studied in the present work.

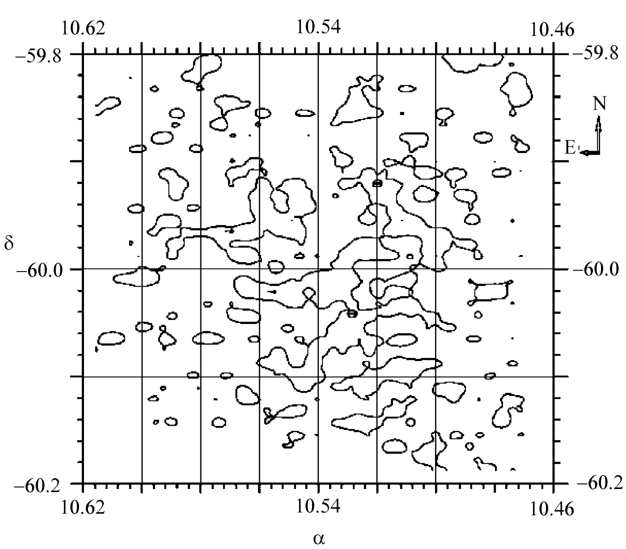

Fig. 3 Contour map of the stellar density of the cluster Cr 223.

4 AGE

CL91 used the bluest color indices to estimate the age of the cluster Cr 223. They found an age of 3.6×10^7 yr, which makes the cluster belong to the IC 4665 age group of Mermilliod (1981).

In the present work, the age of the cluster was estimated by applying the isochrones of Meynet et al. (1993) on the CMD $[V_o - (B-V)_o]$, as shown in Fig. 4. The evolved sequence of the cluster implies an age of about 10^8 yr, or younger.

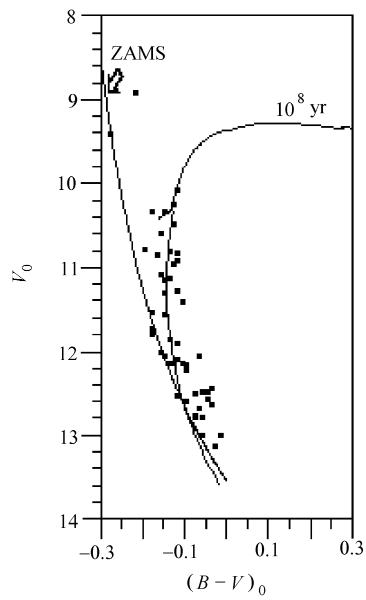

Fig. 4 Age estimation of Cr 223 using the isochrones of Meynet et al. (1993).

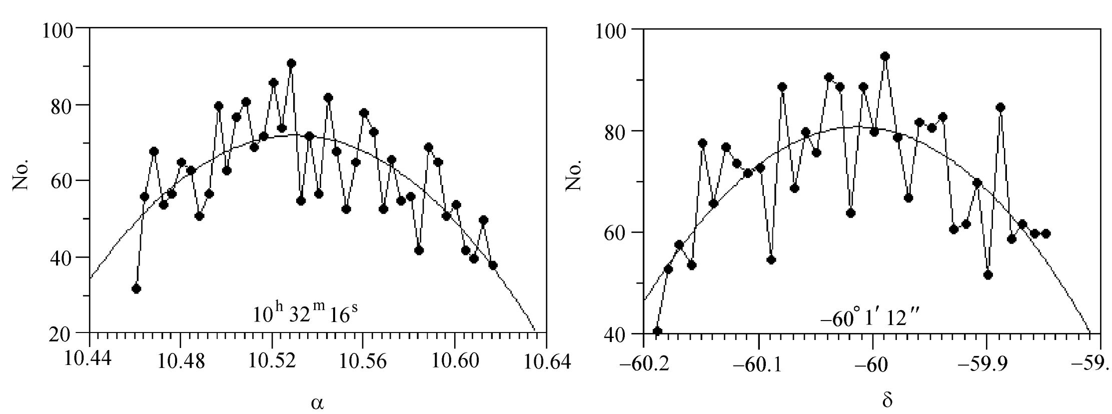

Fig. 5 Center of symmetry about the peaks of α and δ, which was taken to be the position of the cluster center.

5 CLUSTER CENTER

The position of the cluster's center was determined by counting, in two rectangular strips, the stars on the AAO/DSS image. The strips were aligned with α and δ directions and divided into suitable bins. The densities in the bins are plotted against the central positions of the strips along the two directions; see Tadross et al. (2002). The center of symmetry about the peaks was then taken to be the cluster center, as shown in Fig. 5. The new center was found to differ from CL91's center by 1 arcmin in the northwest direction, i.e., it lies at $\alpha = 10^{\rm h}32^{\rm m}16^{\rm s}$ and $\delta = -60^\circ 1^{'} 12^{''}$ (see Fig. 2).

6 ANGULAR AND LINEAR DIAMETER

Knowing the plate scale of AAO/DSS image we can easily see how far the cluster extends and hence estimate the angular diameter and hence its linear diameter. Comparing the chart of Hogg (1965) with the AAO/DSS image, we found that the members of CL91 are distributed in a circle of about 15 arcmin in diameter. On the other hand, an estimate of the angular diameter can be obtained by examining the radial density distribution of the cluster stars. For this purpose the projected stellar density of Cr 223 was determined, by counting the stars in 16 concentric rings around the new cluster center. A histogram of stellar density in the cluster area is shown in Fig. 6. A radius of about 9 arcmin is obtained, which corresponds to 7.4 pc.

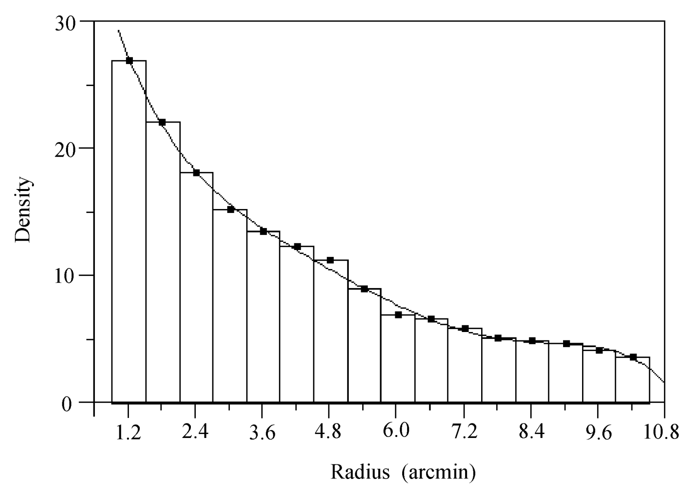

Fig. 6 Radius determination of Cr 223 using the projected density distribution. The radius of the cluster was found to be 9 arcmin.

7 LUMINOSITY FUNCTION

Two histograms were constructed, one for the field stars and one for the cluster members, showing the number of stars at half-magnitude intervals in V. This size interval was selected so as to include a reasonable number of stars in each bin and for the best possible statistics of the luminosity function.

The luminosity of each member star of the cluster was calculated from its visual magnitude. The total luminosity of Cr 223, summed over all its members, is –4.4 mag. To show what is called the net observed luminosity function, the histogram of the field stars is subtracted from the histogram of the cluster members, as shown in Fig. 7. The absolute magnitude scale appears on the upper axis of that figure in the range,

$$-2.5 < M_v < 1.5\,\mathrm{mag}, \qquad \text{or} \qquad 1.3 < \log(L/L_\odot) < 2.9\,,$$

where $\log(L/L_\odot) = 0.4 \times (4.79 - M_v)$ and L & $L_\odot$ are the luminosity of the star and the Sun respectively. The high peak lies at $M_v = 0.0$ mag, or $\log(L/L_\odot) \approx 2.0$.

8 MASS FUNCTION AND TOTAL MASS

The mass function of the cluster Cr 223 was estimated using the theoretical evolutionary tracks and their isochrones of different ages of VandenBergh (1985). The masses of the cluster members were estimated from the polynomial expression developed from the isochronous data for metallicity factor $z = 0.0169$ and ages $< 2.5 \times 10^8$ yr. The mass histogram of Fig. 8 shows a high peak at $3.75\,M_\odot$. Multiplying the number of stars in each bin by the mean mass of the bin yields a total mass for the cluster of $\sim 190\,M_\odot$.

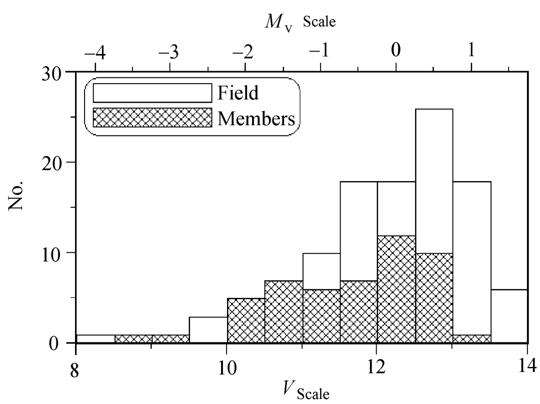

Fig. 7 Luminosity function of Cr 223. The absolute magnitude scale is along the top.

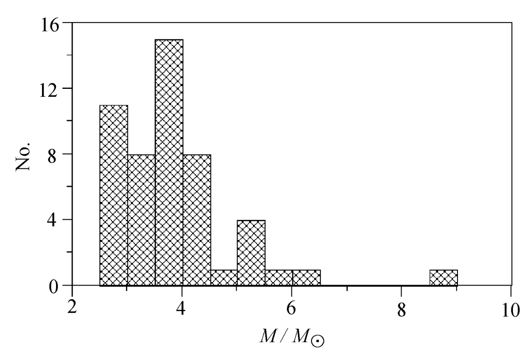

Fig. 8 Mass function of Cr 223. Most cluster members have masses around $3.75\,M_\odot$.

9 CONCLUSIONS

It is necessary to state that the photometric study of this cluster depended mainly on the previous preliminary work of CL91, which had a limited number of stars. For that reason, some of the estimated parameters given in the present work, e.g., the luminosity and mass functions, are also preliminary and need deeper study for more precise determinations. In another direction, the AAO/DSS image of the cluster used here shows that it needs more extensive CCD observations to include more of the fainter members in order to fill the lower part of the main sequence of the cluster.

A comparison between the results of the present work with those of CL91, is given in Table 1.

Table 1 Comparison between the Present Work and CL91

Parameter	The present work	CL91
Membership	49	46
$E(B-V)$	0.25 ± 0.015 mag	0.26 ± 0.03 mag
$E(U-B)$	0.18 ± 0.015 mag	0.19 ± 0.03 mag
$(V-M_v)_o$	12.25 ± 0.15 mag	12.26 ± 0.20 mag
Distance	2820 ± 190 pc	2830 ± 260 pc
$A_v/E(B-V)$	3.0	3.0
Z	–81 pc	–96 pc
Rgc	8.2 kpc	–
X	–2.7 kpc	–
Y	0.8 kpc	–
Age	$\leq 10^8$ yr	3.6×10^7 yr
Center	$\alpha = 10.5378^{\rm h}$	Near star no. 77
	$\delta = -60.02°$	
Diameter	≈ 18 arcmin (≈ 14.8 pc)	≈ 15 arcmin
Stellar density	See the text	–
Luminosity function	Peak lies at $M_v = 0.0$ mag	–
Total Luminosity	–4.4 mag	–
Mass function	Peak lies at mass of 3.75 $M_\odot$	–
Total mass	≈ 190 $M_\odot$	–

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