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$uvby - \beta$ PHOTOELECTRIC PHOTOMETRY OF NGC 7063

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RESUMEN

Mediante fotometría de 75 estrellas en la dirección de NGC 7063 se ha determinado la membresía de algunas estrellas, establecido su distancia (722 ± 105 pc), su edad (log edad de 8.146) y su enrojecimiento ($E(b-y) = 0.091 \pm 0.039$ mag).

ABSTRACT

From *uvby* photometry of 75 stars in the direction of NGC 7063 we were able to determine membership of some stars and fix the distance (722 ± 105 pc), log age (8.146) and reddening ($E(b-y) = 0.091 \pm 0.039$ mag) for the cluster.

Key Words: **OPEN CLUSTERS AND ASSOCIATIONS: INDIVIDUAL (NGC 7063) — TECHNIQUES: PHOTOMETRIC**

1. INTRODUCTION

As a continuation of a study of open clusters and their short period variable stars, we now present observations on the cluster NGC 7063. This relatively poorly populated cluster has remained practically unstudied.

Collinder (1931) presented the initial study of NGC 7063 and described a cluster with a diameter of $8' \times 5'$ which contains only 10 to 12 stars at a distance of 2600 pc. This distance was later modified by Johnson et al. (1961) who determined a reddening of $E(B-V) = 0.08$ and a distance of 630 pc. UBV measurements of 28 stars were reported by Hoag et al. (1961) and Svoupoulus (1962) found the same reddening and distance, but from spectroscopy he determined the following values for distance and reddening: 660 pc and $E(B-V) = 0.05$. In 1965 Hoag et al. (1965) gave a new spectral classification for five stars. Schneider (1987) presented $uvby - \beta$ measurements of 19 stars which were taken from the list of Hoag et al. (1961) with $B - V \leq 0.4$ and brighter than 12.0 mag. He determined a color excess of $E(b-y) = 0.062 \pm 0.007$ (which corresponds to $E(B-V) = 0.08$) and a distance modulus of 9.01 ± 0.09 or, correspondingly, a distance of 635 ± 30 pc, in agreement with the previously determined values.

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2. OBSERVATIONS

The instrumentation utilized has the advantage that the *uvby* photometry is acquired simultaneously and the N and W filters define Hβ almost simultaneously. These were all taken at the Observatorio Astronómico Nacional, México. The 1.5-m telescope, to which a spectrophotometer was attached, was utilized at all times. The observing seasons were carried out in three runs: August 1986 (66 stars, observers: JHP and R. Garrido); October, 1989 (21 stars on the night of October 28th, observers: R. Peniche and JHP) and July, 2006 (17 stars on the night of July 17th, observer: JHP). In each season the same criteria for the selection of the stars was followed: almost all of the brightest stars up to a magnitude of 12 (the limit of the telescope-photometer system) were observed proceeding outward from the center as defined by the ID chart of Hoag et al. (1961). The observed sample accumulated during the three seasons is practically complete up to the given magnitude.

3. DATA ACQUISITION

The procedures of both the observations and the reduction were the same in the three seasons. Each measurement consisted of five ten-second integrations of each star and one ten-second integration of the sky for the *uvby* filters and five ten-second integrations for the narrow and wide filters, with one ten-second integration of the sky. Individual uncertainties were also determined by calculating the standard deviations for each star. The percentage error in each measurement is, of course, a function of both

TABLE 1

ERRORS OF THE 2006 SEASON EVALUATED BY MEANS OF THE OBSERVED STANDARD STARS

	A	B	R	SD	N
V	−0.08251	1.01211	0.9993	0.03781	10
$b-y$	0.00459	0.99293	0.99709	0.01861	10
m_1	0.00262	0.99155	0.99218	0.02209	10
c_1	0.00488	0.99638	0.99846	0.01906	11
bt	0.11714	0.95874	0.99131	0.01821	5

the spectral type and the brightness of each star, but they were observed long enough to secure enough photons to get a S/N ratio $N/\sqrt{(N)}$ such that the photometric precision is 0.01 mag in all cases.

A series of standard stars was also observed on each night so as to transform the data into the standard system. The reduction procedure was done with the numerical packages NABAPHOT (Arellano-Ferro & Parrao 1988) and DAMADAP (Parrao 2000, private communication) which reduce the data into a standard system, although for the bright standard stars some data were also taken from Blumberg & Boksenberg (2006). The chosen system was that defined by the standard values of Olsen (1983) and the transformation equations are those defined by Crawford & Barnes (1970) and by Crawford & Mander (1966). In these equations the coefficients D, F, H and L are the slope coefficients for $(b-y)$, m_1, c_1 and β, respectively. B, J and I are the color term coefficients of V, m_1, and c_1. Those of the 1986 and 1989 seasons have been presented elsewhere (Peña et al. 2006; Peña & Peniche 1994, respectively).

Errors of the 2006 season were evaluated by means of the standard stars observed. These were calculated through the differences in magnitude and colors, as well as with a linear regression $Y = A+B*X$ and are presented in Table 1. Emphasis is made on the fact that there is a relatively large discrepancy in the V magnitude of HR8086, which was kept due to its large m1 and c1 values, which allow us to evaluate over a large range the color fits, V: (5.5,8.1); $b-y$: (0,0.8); m_1: (-0.1,0.67); c_1: (0.07,1.11) and β: (2.6, 2.9).

Table 2 lists the averaged photometric values of the seventy-five observed stars in the three seasons. Column 1 reports the id of the stars as listed by WEBDA (Paunzen & Mermilliod 2006); Columns 2 to 5 the Strömgren values $(b-y)$, m_1, and c_1, respectively; Column 6, the β; Columns 7 to 9 list the unreddened indexes $[m_1]$, $[c_1]$ and $[u-b]$ derived from the observations. Column 10 lists the spectral types as reported by WEBDA from several sources and those derived from the Strömgren photometry.

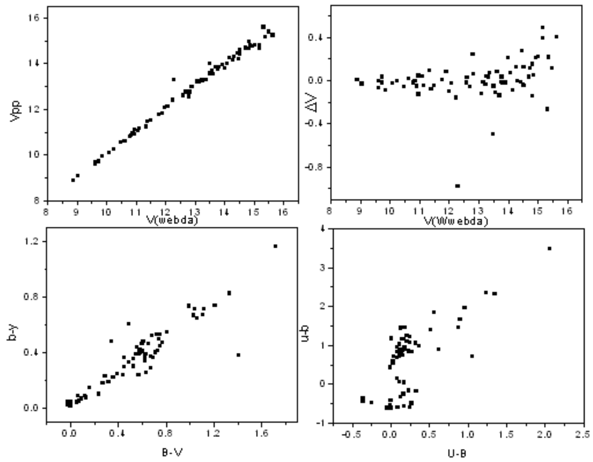

Fig. 1. Comparison of the $uvby-\beta$ photometry with UBV from WEBDA.

4. COMPARISON OF THE DATA WITH THE LITERATURE VALUES

4.1. *WEBDA*

A comparison was made with the WEBDA compilation. However, since basically no previous Strömgren photometry had been done on this cluster, the comparison was made using the existing UBV photometry. The intersection of both photometric sets was constituted of 74 stars in the V range from 6 to almost 16 magnitude and in the $B-V$ and $U-B$ color indexes from −0.5 to 1.6 and 1.5 mag, respectively. In the V magnitude and $B-V$ vs. $b-y$ diagrams (Figure 1) only three stars (51,54,27) and (91,12,54), respectively, are openly discordant. There is a slight curvature in the δV difference above magnitude 15 which, in our opinion, is due most likely to the measurements of the photographic magnitudes rather than the photoelectric measurements. On the other hand, the $u-b$ vs. $U-B$ diagram shows a peculiar behavior towards the hotter stars. In view of the fact that our measurements are the results of three complete calibrations, and given the excellent results among them, we cannot explain this behavior.

4.2. *Schneider's (1987) $uvby-\beta$ photometry*

As was mentioned in the introduction, Schneider (1987) published a list of 19 measured stars in the

TABLE 2

$uvby-\beta$ PHOTOELECTRIC PHOTOMETRY OF NGC 7063

ID	$\langle V\rangle$	$\langle(b-y)\rangle$	$\langle m_1\rangle$	$\langle c_1\rangle$	$\langle bt\rangle$	$[m_1]$	$[c_1]$	$[u-b]$	MK	207	phtm
1	8.882	0.022	0.094	0.684	2.756	0.101	0.680	0.882	B9III	B9IV	B
2	9.638	0.028	0.095	0.802	2.766	0.104	0.796	1.004	B8Vn	AOV	
4	9.706	0.034	0.091	0.670	2.751	0.102	0.663	0.867	B8V	B7V	B
5	10.248	0.043	0.131	0.959	2.863	0.145	0.950	1.240	B9.5V	AOV	B
6	10.819	0.077	0.148	1.057	2.883	0.173	1.042	1.387	A1V	A0VNN	B
7	10.858	1.166	0.771	0.389	2.605	1.144	0.156	2.444			
8	10.907	0.668	0.440	0.384	2.575	0.654	0.250	1.558			
9	11.174	0.182	0.145	0.983	2.837	0.203	0.947	1.353			B
10	11.774	0.355	0.141	0.421	2.641	0.255	0.350	0.859			
12	12.093	0.333	0.130	0.496	2.711	0.237	0.429	0.903			AF
14	12.104	0.223	0.184	0.755	2.791	0.255	0.710	1.221			AF
16	12.582	0.717	0.343	0.441	2.547	0.572	0.298	1.442			
18	13.274	0.391	0.134	0.344	2.671	0.259	0.266	0.784			
19	13.691	0.712	0.302	0.570	2.626	0.530	0.428	1.487			
20	13.545	0.482	0.081	0.289	2.569	0.235	0.193	0.663			
22	13.798	0.534	0.211	0.273	2.661	0.382	0.166	0.930			
25	14.149	0.735	0.231	0.096	2.438	0.466	-.051	0.881			
27	15.586	0.239	0.528	0.087	2.718	0.604	0.039	1.248			
29	9.071	0.672	0.471	0.316	2.566	0.686	0.182	1.554	G9III		
30	9.938	0.549	0.301	0.295	2.557	0.477	0.185	1.139	G8IV		
31	10.114	0.068	0.145	0.977	2.858	0.167	0.963	1.297			B
33	10.549	0.052	0.148	1.011	2.896	0.165	1.001	1.330			B
34	10.605	0.091	0.131	1.010	2.868	0.160	0.992	1.312			B
35	10.922	0.187	0.172	0.955	2.866	0.232	0.918	1.381			AF
36	11.097	0.091	0.179	1.032	2.874	0.208	1.014	1.430			B
37	11.050	0.237	0.178	0.689	2.736	0.254	0.642	1.149			AF
38	11.239	0.102	0.183	0.986	2.880	0.216	0.966	1.397			B
39	11.482	0.647	0.367	0.356	2.554	0.574	0.227	1.375			
40	11.534	0.148	0.190	0.931	2.828	0.237	0.901	1.376			AF
43	12.400	0.827	0.477	0.300	2.592	0.742	0.135	1.618			
44	12.621	0.248	0.096	0.857	2.787	0.175	0.807	1.158			B
45	12.759	0.741	0.519	0.167	2.527	0.756	0.019	1.531			
46	12.759	0.421	0.168	0.234	2.561	0.303	0.150	0.755			
47	12.971	0.366	0.023	0.735	2.716	0.140	0.662	0.942			B
48	13.208	0.500	0.209	0.445	2.600	0.369	0.345	1.083			
49	13.178	0.400	0.094	0.406	2.642	0.222	0.326	0.770			AF
50	13.222	0.229	0.141	0.926	2.925	0.214	0.880	1.309			B
51	13.275	0.461	0.217	0.255	2.650	0.365	0.163	0.892			
52	13.306	0.410	0.155	0.426	2.637	0.286	0.344	0.916			
53	13.295	0.389	0.095	0.398	2.655	0.219	0.320	0.759			AF
54	13.999	0.379	0.167	0.378	2.576	0.288	0.302	0.879			
55	13.562	0.411	0.223	0.442	2.601	0.355	0.360	1.069			
56	13.848	0.470	0.270	0.235	2.615	0.420	0.141	0.982			
59	13.757	0.395	0.125	0.365	2.571	0.251	0.286	0.789			
60	13.844	0.448	0.240	0.314	2.601	0.383	0.224	0.991			
62	13.949	0.378	0.219	0.370	2.798	0.340	0.294	0.974			
66	14.007	0.402	0.173	0.341	2.619	0.302	0.261	0.864			
67	14.253	0.301	0.263	0.382	2.764	0.359	0.322	1.040			
71	14.315	0.528	0.175	0.296	2.707	0.344	0.190	0.878			
72	14.448	0.366	0.288	0.282	2.543	0.405	0.209	1.019			
73	14.193	0.532	0.166	0.233		0.336	0.127	0.799			
74	14.559	0.344	0.252	0.332	2.699	0.362	0.263	0.987			
75	14.408	0.467	0.070	0.351	2.862	0.219	0.258	0.696			AF
76	14.580	0.292	0.413	0.243	2.758	0.506	0.185	1.197			
81	14.676	0.352	0.225	0.270	2.698	0.338	0.200	0.875			
82	14.640	0.389	0.221	0.375	2.755	0.345	0.297	0.988			
85	14.669	0.441	0.115	0.266	2.794	0.256	0.178	0.690			
86	14.975	0.259	0.399	0.145	2.661	0.482	0.093	1.057			
88	14.819	0.373	0.300	0.403	2.409	0.419	0.328	1.167			
89	14.740	0.492	0.108	0.369	2.526	0.265	0.271	0.801			
91	15.234	0.479	−0.043	0.338	2.506	0.110	0.242	0.463			B
92	14.677	0.608	0.047	0.429	2.719	0.242	0.307	0.791			
93	14.796	0.222	0.417	0.383	2.786	0.488	0.339	1.315			
99	15.154	0.472	0.520	0.017	2.737	0.671	−0.077	1.265			
101	15.390	0.300	0.459	0.077	2.721	0.555	0.017	1.127			
102	14.809	0.521	0.164	0.317	2.379	0.331	0.213	0.874			
1086	11.818	0.474	0.175	0.440	2.657	0.327	0.345	0.999			
1127	10.943	0.316	0.168	0.452	2.671	0.269	0.389	0.927			
1127	10.955	0.306	0.151	0.442	2.667	0.249	0.381	0.879			
1398	13.792	0.690	0.574	0.273	2.083	0.795	0.135	1.725			
1636	12.554	0.765	0.447	0.202	2.558	0.692	0.049	1.433			
j2	14.587	0.492	0.135	0.433	2.314	0.292	0.335	0.919			

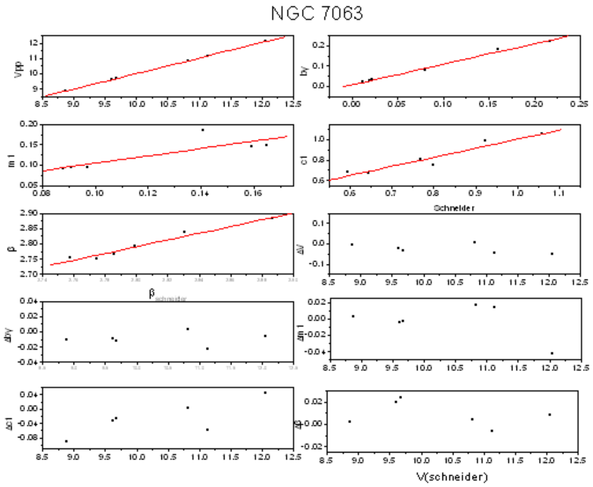

Fig. 2. Comparison between the data of the present paper and those of Schneider (1987).

$uvby-\beta$ system. Hence, a direct comparison can be made. Figure 2 presents the results of this comparison; first, the comparisons in V, $b-y$, m_1, c_1 and β are plotted; the last frames show the difference between Schneider's minus present paper data versus V magnitude from Schneider. A linear fit to the direct comparison gives the coefficients for the linear regression $Y = A + B * X$ presented in Table 3.

As can be seen from both Table 3 and Figure 2, the correlation is adequate. We have not taken into consideration star 5 which they reported as a misidentification. Also, the poorness in the color indexes could have arisen from the small sample Schneider had and, most likely, the standard stars were taken accordingly. This can be seen from the small range for $b-y$, m_1 and c_1 values he considered. Since we were not restricted to early type stars, we have observed much larger ranges in the colors and, hence, we obtained more reliable indexes. Despite these arguments, the differences are within a few hundredths of magnitude, as shown in Table 3.

TABLE 3

LINEAR FIT BETWEEN PP DATA AND SCHNEIDER'S (1987) $uvby-\beta$

	A	B	R	σ	N
V	-0.08521	1.01077	0.999	0.021	6
$b-y$	0.0088	1.0082	0.996	0.009	6
m	0.01455	0.90377	0.833	0.024	6
c	0.11518	0.8899	0.964	0.048	6
β	-0.2968	1.1027	0.981	0.011	6

5. METHODOLOGY

As has already been mentioned (Peña et al. 2006), the most important parameter determined when studying the nature of a cluster is, beyond doubt, cluster membership which can be established taking advantage of the Strömgren photometry with calibrations made by Nissen (1988) based on calibrations of Crawford (1975, 1979) for the A and F stars, and of Shobbrook (1984) for early type stars. These calibrations have been already employed and described in previous analyses of open clusters (Peña & Peniche 1994). The determination of physical parameters such as effective temperature, surface gravity and luminosity has been done in the present study through the use of Strömgren photometric data reduced to the standard system, once corrected for interstellar extinction. If the photometric system is well-defined and calibrated, it will provide an efficient way to investigate physical conditions. A comparison with theoretical models, such as those of Lester, Gray, & Kurucz (1986, hereafter LGK86), allows a direct comparison of intermediate or wide band photometry measured from the stars with that obtained theoretically for early type stars. LGK86 calculated grids for stellar atmospheres for G, F, A, B and O stars for a solar abundance [Fe/H] = 0.00 in a temperature range from 5500 K up to 50 000 K. The surface gravities vary approximately from the Main Sequence to the limit of the radiation pressure in 0.5 intervals in $\log g$. They also considered abundances of 0.1 solar and 0.001 solar. A comparison of the unreddened photometric indexes $(b-y)_0$ and c_0 obtained for each star with such models allows the determination of the effective temperature T_e and the surface gravity $\log g$.

The evaluation of the reddening was done by establishing, as was stated above, to which spectral class the stars belonged: early (B and early A) or late (late A and F stars) types; the later-class stars (later than G) were not considered in the analysis since no reddening determination calibration has yet been developed for MS stars. In order to determine the spectral type of each star the location of the stars in the $[m_1]-[c_1]$ diagram was employed as a primary criterion. Further analyses were done following the prescriptions of Lindroos (1980) which merely confirmed our primary determination. In Table 2 the photometrically determined spectral class has been indicated. We point out the perfect agreement between these spectral types and those obtained spectroscopically and reported by WEBDA.

TABLE 4

REDDENING AND UNREDDENED PARAMETERS OF NGC 7063

ID	$E(b-y)$	$(b-y)_0$	m_0	c_0	β	V_0	M_V	DM	DST	[Fe/H]	membership
75	0.329	0.138	0.169	0.285	2.862	12.990	7.370	5.63	134		NM
12	0.103	0.230	0.161	0.475	2.711	11.650	3.830	7.82	366	−0.08	NM
37	0.031	0.206	0.187	0.683	2.736	10.920	2.610	8.31	459		NM
35	0.112	0.075	0.206	0.933	2.866	10.440	1.960	8.48	496		NM
1	0.067	−0.045	0.114	0.671	2.756	8.590	−0.210	8.80	575		mbr
31	0.089	−0.021	0.172	0.960	2.858	9.730	0.870	8.86	592		mbr
14	0.067	0.156	0.204	0.742	2.791	11.810	2.850	8.96	621		mbr
53	0.104	0.285	0.126	0.377	2.655	12.850	3.870	8.98	626	−0.48	mbr
5	0.066	−0.023	0.151	0.946	2.863	9.960	0.930	9.03	640		mbr
33	0.065	−0.013	0.167	0.999	2.896	10.270	1.230	9.04	644		mbr
49	0.102	0.298	0.125	0.386	2.642	12.740	3.600	9.14	674	−0.53	mbr
34	0.106	−0.015	0.163	0.990	2.868	10.150	0.960	9.19	690		mbr
6	0.078	−0.001	0.171	1.042	2.883	10.480	1.070	9.41	763		mbr
2	0.066	−0.038	0.115	0.789	2.766	9.350	−0.160	9.51	799		mbr
40	0.040	0.108	0.202	0.923	2.828	11.360	1.790	9.58	823		mbr
38	0.122	−0.020	0.220	0.963	2.880	10.710	1.090	9.62	839		mbr
4	0.080	−0.046	0.115	0.655	2.751	9.360	−0.270	9.63	844		mbr
9	0.206	−0.024	0.207	0.944	2.837	10.290	0.650	9.64	848		mbr
36	0.100	−0.009	0.209	1.013	2.874	10.670	1.000	9.66	857		mbr
50	0.261	−0.032	0.219	0.876	2.925	12.100	1.500	10.60	1316		NM
44	0.286	−0.038	0.182	0.803	2.787	11.390	0.130	11.26	1788		NM
47	0.412	−0.046	0.147	0.657	2.716	11.200	−0.870	12.07	2592		NM

6. RESULTS

The application of the above mentioned numerical packages gave the results listed in Table 4, in which the ID, the reddening, the unreddened indexes, the absolute magnitude, the DM and the distance, are listed. When histograms of the distances are drawn, as in Figure 3, one can see that most of the early type stars lie at a distance centered on 760 pc, but with a relatively small spread towards the higher values. If we restrict membership to the cluster to those stars within one sigma of the mean, we can conclude that most of the measured stars do belong to the cluster. With respect to the membership, we have determined as cluster members practically the same stars as Schneider (1987), although the sample in consideration is much larger in the present work (75 stars compared to his 10 stars). Membership is indicated in the last column of Table 4. We call attention to the fact that the two late type stars have been determined as members. W49 and W53, both of F type, are both metal-poor stars. It should be kept in mind, however, that these F stars have apparent magnitudes fainter than 13.2, whereas the cluster member A stars are one magnitude brighter and the early type stars belonging to the cluster, even brighter, all brighter than apparent magnitude 12.0. W53 was measured in two seasons, 1986 and 1989 and both seasons gave, independently, large under-abundant metallicities. Hence, although the star counts were large enough to reach an adequate precision, in all cases their uncertainties are, necessarily, large. More data on these two stars are needed to settle this apparent paradox.

In order to reach later type stars we should measure fainter stars, which might be done through CCD photometry. In this sense, the values reported here will serve as secondary standards. At any rate, the conclusions on distance and age will not change. Going to fainter stars we will reach the F type stars and solve the puzzle established by the only two metal-poor stars which lie at the cluster distance.

Once the membership is established, age is determined after calculating the effective temperature of the hottest stars. Temperatures were determined by plotting the location of all stars on the theoretical grids of LGK86 once we had evaluated the unreddened colors (Figure 4) for a solar chemical composition. We have utilized the $(b-y)$ vs. c_0 diagrams which allow the determination of the temperatures with an accuracy of a few hundredths of degrees. The temperature for the hottest stars, W4, W47 and W01 are at around 13,000 K ($\log T_e = 4.114$).

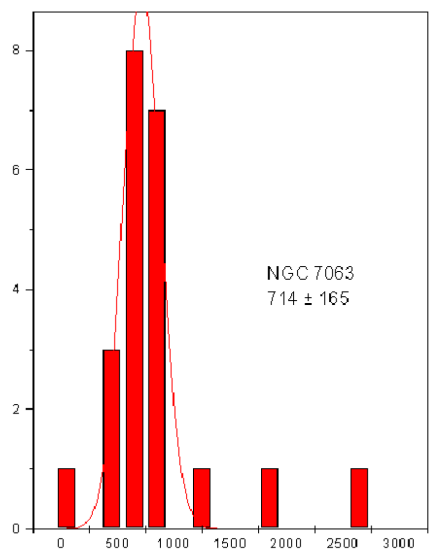

Fig. 3. Histogram of the distances (X axis, in parsecs) found for the B and A stars in the direction of NGC 7063. Continuous line is a Gaussian fit to the data. Its mean value and deviation are indicated.

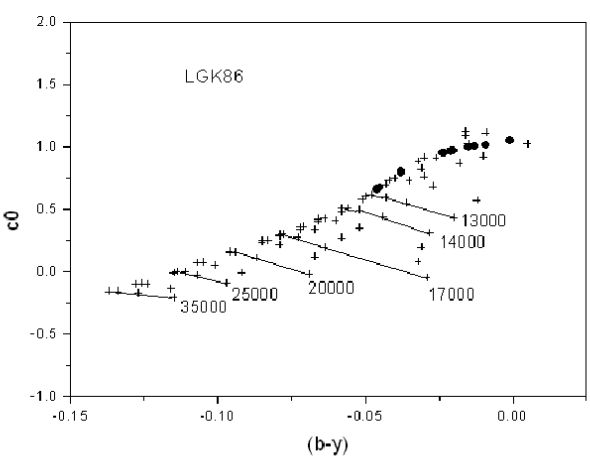

Fig. 4. Location of the unreddened points (dots) on the LGK86 grids.

Hence, given the calibrations of Meynet, Mermilliod, & Maeder (1993) for open clusters, a log age of 8.146 is found from the relation $-3.6 \log T_e + 22.956$ valid in the range $\log T_e$ between [3.98, 4.25].

Figure 5 shows a color-magnitude diagram of the NGC 7063 cluster considering only the new cluster members (filled circles) and two theoretical isochrones computed with a metallicity of [Fe/H]=0.049 (Z=0.02, X=0.73) for two ages of 95 Myr and 125 Myr (continuous lines). The theoretical isochrones were computed as explained in Fox Machado et al. (2006). In particular, they were calibrated from $[T_e, \log(L/L_\odot)]$ to $(B-V, M_V)$ by using the Schmidt-Kaler (1982) calibration for magnitudes and the relationship between $T_{\rm eff}$ and $B-V$ of Sekiguchi & Fukugita (2000) for the colors. The observational data in the Strömgren photometric system were converted into the Johnson photometric system by using the transformation relations given by Turner (1990). Individual star reddenings were used to obtain the absolute magnitudes of the stars and an averaged distance modulus of 9.27 was considered. As can be seen in Figure 5 the isochrones match the observed colour-magnitude diagram well.

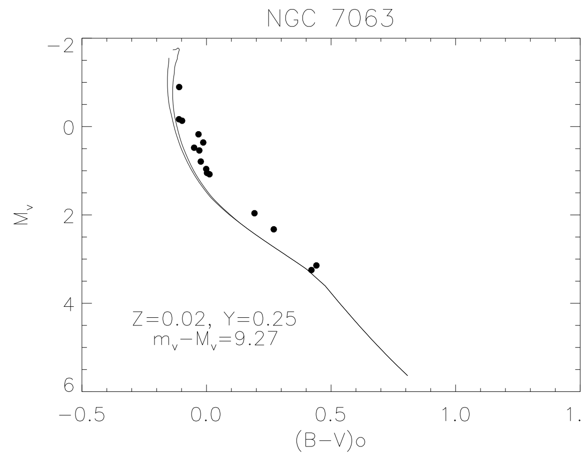

Fig. 5. Color-magnitude diagram of the NGC 7063 cluster considering only the new cluster members. The target stars are represented by filled circles. Two isochrones of 95 Myr (right continuous line) and 125 Myr (left continuous line) computed with Z=0.02 and Y=0.25 are shown. The distance modulus corresponds to that derived in the present paper.

7. CONCLUSIONS

New $uvby-\beta$ photoelectric photometry has been acquired and is presented for the open cluster NGC 7063. From the 75 observed stars in the relatively rich field, only a few were determined as early type stars, either B (15) or A (6). Using the calibration to determine reddening and distance for these types of stars, a cluster distance of 714 pc has been determined. Unreddened indexes in the LGK86 grids allowed us to determine the effective temperature of the hottest stars as 13000K.

WEBDA reports the following for NGC 7063: a distance of 689 pc (a distance modulus of 9.47 mag), a reddening E(B-V) of 0.091 mag, and a log age of 7.977; on the other hand, Schneider (1987) reports a distance of 635 ± 30 pc and a color excess $E(B - V) = 0.08$ mag; these results are quite concordant with our findings: a mean distance of 722 ± 105 pc, which corresponds to a distance modulus of 9.27 and a reddening, $E(b - y) = 0.091 \pm 0.039$ mag which, through the relationship of $E(b - y) = 0.7 * E(B - V)$, yields 0.13 mag, in coarse agreement with the literature. The log age we determined, given the youth of the member stars, is 8.146.

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