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$uvby - \beta$ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 2343[1]

J. H. Peña[2] and A. Martínez[3]

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RESUMEN

A partir de fotometría fotoeléctrica $uvby - \beta$ del cúmulo abierto NGC 2343 (20 estrellas) realizamos la determinación de distancias de cada una y, por ende, la pertenencia de las estrellas al cúmulo. Asimismo se determinaron el enrojecimiento y la edad.

ABSTRACT

From $uvby - \beta$ photometry of the open cluster NGC 2343 (20 stars) we were able to determine membership of the stars to the cluster and fix its age and reddening.

Key Words: open clusters and associations: individual (NGC 2343) — techniques: photometric

1. MOTIVATION

As a continuation of a study of open clusters in $uvby - \beta$, we now present a membership study of the open cluster NGC 2343.

Despite the fact that there are a large number of articles devoted to open clusters in general and to NGC 2343 in particular, there are very few previous papers that present photometric data. The last one was that of Clariá (1972).

For NGC 2343, WEBDA[4] reports a distance of 1056 pc (DM of 10.48) with reddening $E(B-V)$ of 0.118, a log age of 7.104 and a determined metallicity [Fe/H] of −0.30. It has been amply studied by UBV photometry, with 64 measured stars. Spectroscopy for the stars in its direction involves a sample of merely three stars. In the WEBDA compilation these measurements are reported as done by Moffat (1974) who states it is a moderately young open cluster in Canis Major. The previous $uvby-\beta$ photometry was carried out for only two stars reported by Gray & Olsen (1991). McSwain & Gies (2005) determined a reddening $E(b-y)$, a DM $V_0 - M_V$ and a log age of 0.11, 10.12, and 8, respectively.

[1]Based on observations collected at the San Pedro Mártir Observatory, Mexico.

[2]Instituto de Astronomía, Universidad Nacional Autónoma de México, Mexico.

[3]Universidad de Panamá, Panama.

[4]`http://webda.physics.muni.cz/`.

2. OBSERVATIONS

These were all done at the Observatorio Astronómico Nacional, SPM, Mexico. The 1.5 m telescope to which a spectrophotometer was attached was utilized. The observing season was from December 2−13, 2009, but the cluster was observed along with standard stars to transform the cluster measurements into the standard $uvby-\beta$ photometric system on only one night, December 10th. The identification utilized the ID chart provided by Clariá (1972); we followed his numerical identification system. Despite the large extension shown by Clariá (1972) and WEBDA, the region we observed was centered at (X,Y)=(0,0) in the WEBDA chart and extended only in 200 in WEBDA units, in the region in which the cluster shows a larger concentration of stars. Most of the brightest stars in this zone were observed in this study.

2.1. *Data acquisition*

During all the observational nights the following procedure was utilized: each star was measured, with at least five ten-second integrations of the star and one ten-second integration of the sky for the $uvby$ filters and the narrow and wide filters that define Hβ. Individual uncertainties were determined by calculating the standard deviations of the fluxes in each filter for each star. The percent error in each measurement is, of course, a function of both the spectral type and the brightness of each star, but they were observed long enough to a secure sufficient number of photons (N) to get a signal to noise ratio of accuracy of $N/\sqrt{(N)}$ of at least 0.01 mag. A series of standard stars was also observed on the night the cluster was observed, so as to transform the data into the standard system. Generally the standard stars were counted to much higher values. These standard stars will serve to evaluate the goodness of the night when comparing the calculated values to those reported in the literature. Atmospheric extinction coefficients were not calculated but taken from the mean values determined by Schuster & Parrao (2001) and Schuster, Parrao, & Guichard (2002). In this study they consider the individual nightly determinations of the atmospheric extinction above San Pedro Mártir from 82 nights of 13-color observations from 1980 to 1983 and from 287 nights of *uvby* observations from 1984 to 1999.

2.2. *Data reduction*

The reduction was done with the numerical package NABAPHOT (Arellano-Ferro & Parrao 1988) which reduces the data into a standard system. The chosen standard system was that defined by the standard values of Grönbech & Olsen (1976, 1977) and Olsen (1983) and the transformation equations are those defined by Crawford & Barnes (1970) and by Crawford & Mander (1966) which are shown below.

$$
\begin{aligned}
V &= A + B\ (b-y)_{\rm st} + y_{\rm inst}\ , \\
(b-y)_{\rm st} &= C + D\ (b-y)_{\rm inst}\ , \\
m_{1\rm st} &= E + F m_{1\ \rm inst} + G\ (b-y)_{\rm inst}\ , \\
c_{1\rm st} &= H + I m_{1\ \rm inst} + J\ (b-y)_{\rm inst}\ , \\
\beta_{1\ \rm st} &= K + L\ \beta_{1\ \rm inst}\ .
\end{aligned}
$$

In these equations the coefficients D, F, I and L are the slope coefficients for $(b-y)$, m_1, c_1 and β, respectively. The coefficients B, G and J are the color terms of V, m_1, and c_1. The standard stars were taken from Grönbech & Olsen (1976, 1977) and Olsen (1983), but some of the standard bright stars were also taken from the Astronomical Almanac for the year 2006 (2005).

2.3. *Obtained data*

The averaged transformation coefficients are listed in the corresponding equations. The standard deviations are the following: V: 0.0122; $(b-y)$: 0.007; m_1: 0.014; c_1: 0.028 and β: 0.0193. Emphasis is made on the large range of the standard stars in the magnitude and color values: V: (5.2, 8.8); $(b-y)$: (−0.00, 0.79); m_1: (0.123, 0.659); c_1: (0.153, 1.052) and β: (2.53, 2.89). A set of 16 standard stars were measured.

$$
\begin{aligned}
V &= 19.0809 + 1.00\ (b-y)_{\rm st} + y_{\rm inst}\ , \\
(b-y)_{\rm st} &= 1.5329 + 0.9856\ (b-y)_{\rm inst}\ , \\
m_{1\rm st} &= -1.2977 + 1.0125 m_{1\ \rm inst} + 0.0283\ (b-y)_{\rm inst}\ , \\
c_{1\rm st} &= -0.1918 + 1.0526 m_{1\ \rm inst} + 0.1499\ (b-y)_{\rm inst}\ , \\
\beta_{1\ \rm st} &= 2.4351 + -1.0763\ \beta_{1\ \rm inst}\ .
\end{aligned}
$$

The errors of this night were evaluated by means of the standard stars observed. These uncertainties were calculated through the differences between the standard values reported in the literature and the transformed values in magnitude and colors, for (V, $b-y$, m_1, c_1 and Hβ). These differences were evaluated and the standard deviations provided a measure of the quality of the data and the night. Table 1 lists these differences. For the whole sample the standard deviations of the differences were calculated and are listed at the bottom of the table. As can be seen, the quality of the night was good. The standard deviations for V, $(b-y)$, m_1, c_1 and β are 0.011, 0.005, 0.011, 0.016 and 0.019, respectively.

Uncertainties for each star were evaluated in the following way: for each filter, mean values and standard deviations were calculated. With these values the percenctual errors are given as standard deviation/average value for each filter. Finally, the uncertainties for the color indexes were evaluated through propagation of errors from the definitions for each index as $\delta m_1 = \delta v + 2\delta b + \delta y$ and $\delta c_1 = \delta u + 2\delta b + \delta v$. All the stars were measured five times with integration times of ten seconds for the star, and three times for the sky. The only exceptions were stars 23 and 29 which, due to their faintness, were measured ten times. Table 2 lists the photometric values of the observed stars for this cluster. In this table, Column 1 reports the ID of the stars as listed by WEBDA (Paunzen & Mermilliod 2007), Columns 2 to 5 the Strömgren values V, $(b-y)$, m_1 and c_1, respectively; Column 6, the β values. The calculated uncertainties are listed in Columns 7 to Column 10. Column 11 lists the spectral types determined from the Strömgren photometry and the last column, the reported spectroscopy for the one star in common with the three measured stars compiled by WEBDA from The Henry Draper catalogue (Cannon & Pickering 1918). Hence, the spectral types determined and reported here are new and valuable data.

TABLE 1

DIFFERENCES BETWEEN LITERATURE VALUES AND CALCULATED VALUES FOR THE OBSERVED STANDARD STARS

ID	V	$(b-y)$	m_1	c_1	δV	$\delta(b-y)$	δm_1	δc_1
BS1321	6.960	0.422	0.244	0.294	0.020	0.000	0.018	−0.016
HD36003	7.624	0.629	0.659	0.188	−0.005	−0.014	0.026	−0.010
HD64702	8.500	0.790	0.638	0.373	−0.011	0.008	−0.029	0.023
HD42807	6.440	0.415	0.228	0.292	−0.004	0.003	0.007	−0.004
HD57006	5.915	0.340	0.168	0.472	0.004	0.005	−0.004	0.003
HD60803	5.916	0.377	0.186	0.387	0.017	0.005	−0.002	0.018
HD77354	7.943	0.443	0.202	0.360	0.017	0.000	0.017	0.029
HD85217	6.250	0.305	0.162	0.415	0.017	0.003	−0.001	0.039
BS3555	5.450	0.084	0.205	0.972	−0.003	−0.004	−0.010	−0.021
HD51530	6.203	0.345	0.137	0.401	0.001	0.007	−0.005	−0.007
HD57517	6.568	0.342	0.174	0.390	−0.011	−0.011	−0.005	0.005
HD59984	5.933	0.356	0.123	0.336	−0.018	−0.007	−0.014	0.003
BS3297	5.600	0.311	0.138	0.400	−0.004	0.000	−0.012	0.035
BS3538	6.010	0.410	0.239	0.325	−0.015	−0.006	0.002	−0.021
BS4378	6.660	0.024	0.190	1.052	−0.011	0.003	0.006	0.000
σ					0.011	0.005	0.011	0.016

TABLE 2

$uvby-\beta$ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 2343

ID	V	$(b-y)$	m_1	c_1	β	δV	$\delta(b-y)$	δm_1	$\delta(c_1)$	SpTyp	SpTyp
N2343-03	9.511	0.045	0.091	0.795	2.718	0.005	0.008	0.013	0.015	B7V	A0
N2343-04	10.084	0.098	0.069	0.421	2.667	0.003	0.005	0.009	0.012	BB5V	
N2343-05	10.120	0.151	0.085	0.872	2.772	0.009	0.014	0.019	0.022	BB8V	
N2343-06	10.350	0.123	0.082	0.563	2.678	0.002	0.005	0.012	0.018	B6V	
N2343-10	10.789	0.143	0.090	0.658	2.707	0.004	0.008	0.016	0.022	B5V	
N2343-11	8.488	0.796	0.350	0.278	2.595	0.029	0.071	0.197	0.268	M0V	
N2343-15	11.353	0.695	0.240	0.399	2.560	0.008	0.012	0.034	0.059	K2V	
N2343-17	11.493	0.147	0.176	1.041	2.827	0.012	0.019	0.034	0.033	A4V	
N2343-18	11.579	0.186	0.143	1.054	2.857	0.014	0.019	0.030	0.036	B4V	
N2343-19	11.648	0.719	−0.056	0.149	2.628	0.012	0.017	0.031	0.049	B	
N2343-20	7.263	−0.071	0.095	0.215	2.767	0.014	0.021	0.032	0.034	B2V	
N2343-23	11.914	0.466	0.146	0.421	2.601	0.010	0.016	0.024	0.049	G0V	
N2343-24	12.022	0.214	0.090	1.020	2.815	0.013	0.024	0.043	0.044	B9V	
N2343-26	12.154	0.211	0.158	0.702	2.807	0.131	0.269	0.516	0.530	A9V	
N2343-27	12.443	0.318	0.120	0.853	2.770	0.010	0.017	0.031	0.042	A7V	
N2343-28	12.459	0.246	0.115	0.958	2.853	0.026	0.038	0.065	0.094	B5V	
N2343-29	12.626	0.452	0.114	0.438	2.616	0.033	0.052	0.085	0.092	F8V	
N2343-30	12.625	0.227	0.202	1.005	2.900	0.023	0.044	0.070	0.116	A5Vp	
N2343-32	12.834	0.296	0.158	0.978	2.933	0.058	0.067	0.099	0.101	A5Vp	
N2343-34	12.826	0.196	0.214	0.924	2.783	0.034	0.047	0.067	0.066	A5Vp	

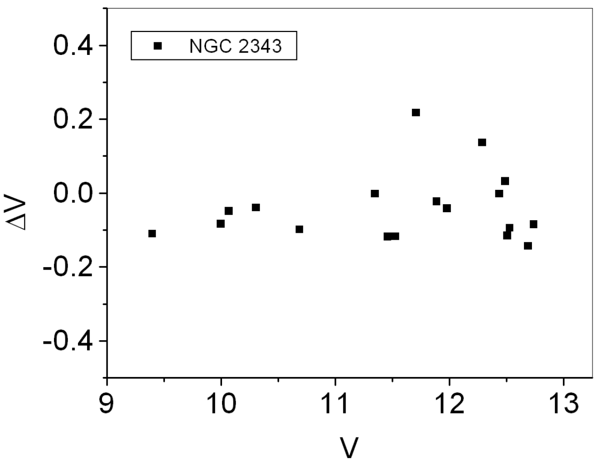

Fig. 1. Magnitude difference vs. magnitude for NGC 2343.

3. COMPARISON WITH OTHER PHOTOMETRIES

To test the goodness of our observations a comparison with other previous measurements was done. Since practically no $uvby - \beta$ data have been obtained for these clusters, a comparison of our values is made with the available UBV photometry.

There are two references with observations of this cluster: (Clariá 1972; McSwain & Gies 2005) that merely compile previously observed data. This cluster was compared with those UBV values reported by WEBDA from Clariá (1972). The set of intersection between the two sets is constituted by 20 stars and there are two (11 and 20) which show a remarkable difference. The rest of the sample is in good agreement. The average of the V differences without considering these two stars is -0.042 mag. The linear fit among the two sets gave $V_{\rm pp} = -0.114 + 1.006 V_{\rm Claria}$ with a correlation coefficient of 0.996 and a standard deviation of 0.096, a very good agreement. The difference between the magnitudes obtained by Clariá (1972) and the present paper is shown schematically in Figure 1 in which the zero point shift of -0.114 is clearly seen. Only two stars, 17 and 26, have large differences. The two stars with large differences were not included in the plot. The color indexes were related by the relation $(b-y) = -0.073 + 1.518\,(B-V)$ with a correlation coefficient of 0.975 and a standard deviation of 0.069. In the fit the same two stars (11 and 20) were discarded making it evident that there was an unexplained misidentification or a variable nature of the stars. The latter is quite possible for NGC2343-11 which has a spectral type of M0V, and could have remarkable variations. With respect to the spectral classification of the stars, as was mentioned before, it was carried out by locating the unrredened indexes in the $[m_1]-[c_1]$ plane, comparing with the stars determined by Golay (1974), and corroborated from the results of a study of Peña & Sareyan (2006) for the open cluster Alpha Per which has stars with well-determined spectral types. From the comparison, seven stars are of spectral types earlier than A0 and three of late spectral types; the rest lie between A3V and F7V. Two, 30 and 34, lie in the region which corresponds to the Ap stars. Star 32 is located in the boundary between the Ap and normal stars. In Table 2 the photometrically determined spectral class has been indicated. That spectral type compiled by WEBDA is also presented.

4. METHODOLOGY

In order to determine the physical characteristics of the member stars in each cluster, the following procedure was undertaken:

The evaluation of the reddening was done by first establishing, as stated above, to which spectral class the stars belong: early types (B and early A stars) or late types (late A and F stars); the late class stars (later than G) were not considered in the analysis because no reddening determination calibration can be done for MS stars.

The reddening determination was obtained from the spectral types through the Strömgren photometry. The application of the calibrations for each spectral type either Shobbrook (1984) for O and early A type:

$$\begin{aligned}(b-y)_0 &= -0.1146 - 0.0805 c_1 + 0.0616 {c_1}^2 \\ &\quad +0.2719 {c_1}^3 + 0.7801 {c_1}^4 + 0.4679 {c_1}^5 \ ,\end{aligned}$$

or Nissen (1988) for late A and F stars respectively, allows us to determine their reddening and hence, the desired physical properties of the stars:

$$\begin{aligned}(b-y)_0 &= K + 1.11\Delta\beta + 2.7\Delta\beta^2 \\ &\quad -0.05\delta c_0 - (0.1 + 3.6\Delta\beta)\delta m_0 \ ,\end{aligned}$$

for A stars (with $2.72 < \beta < 2.88$):

$$(b-y)_0 = 2.946 - 1.00\beta - 0.1\delta c_0,$$

with

$$\begin{aligned}\Delta\beta &= 2.72 - \beta, \\ m_0 &= m_{1,\rm Hyades(\beta)} - m_0, \\ c_0 &= c_0 - c_{1,\rm std(\beta)} \ .\end{aligned}$$

TABLE 3

REDDENING AND UNRREDDENED PARAMETERS OF THE OPEN CLUSTER NGC 2343

ID	$E(b-y)$	$(b-y)_0$	m_0	c_0	β	V_0	M_V	DM	DST	Mbr
N2343-11	0.279	0.517	0.434	0.222	2.595	7.29	4.83	2.4	31	NM
N2343-20	0.023	−0.094	0.102	0.211	2.767	7.17	−0.45	7.6	334	NM
N2343-26	0.063	0.148	0.177	0.689	2.807	11.88	3.57	8.3	460	NM
N2343-23	0.103	0.363	0.177	0.400	2.601	11.47	2.75	8.7	553	NM
N2343-29	0.119	0.333	0.150	0.414	2.616	12.12	2.78	9.3	737	M:
N2343-05	0.186	−0.035	0.141	0.837	2.772	9.32	−0.12	9.4	772	M:
N2343-18	0.194	−0.008	0.201	1.017	2.857	10.74	0.82	9.9	967	M
N2343-27	0.155	0.163	0.167	0.822	2.770	11.78	1.65	10.1	1057	M
N2343-03	0.084	−0.039	0.116	0.779	2.718	9.15	−1.01	10.1	1078	M
N2343-28	0.275	−0.029	0.197	0.906	2.853	11.28	0.85	10.4	1217	M
N2343-17	0.049	0.098	0.191	1.031	2.827	11.28	0.78	10.5	1257	M
N2343-24	0.232	−0.018	0.160	0.976	2.815	11.02	0.34	10.6	1370	M
N2343-10	0.191	−0.048	0.147	0.622	2.707	9.97	−1.0	10.9	1562	M
N2343-04	0.170	−0.072	0.120	0.389	2.667	9.35	−1.62	10.9	1568	M
N2343-19	0.834	−0.115	0.194	−0.01	2.628	8.06	−3.01	11.0	1635	M
N2343-06	0.179	−0.056	0.136	0.529	2.678	9.58	−1.51	11.1	1655	M
N2343-34	0.051	0.145	0.229	0.914	2.783	12.61	1.21	11.4	1904	M

The absolute magnitude is

$$M_V = M_{V,\mathrm{ZAMS}(\beta)} - f\delta c_0 \ .$$

In these calibrations reddening, absolute magnitude and distance were determined through the calibrations described by Nissen (1988). In this procedure, the intrinsic color index $(b-y)_0$ was first calculated by the expression for F stars (with $2.59 < \beta < 2.72$).

5. RESULTS

The application of the above mentioned numerical packages gave the results listed in Table 3 for NGC 2343, in which the ID, reddening, unreddened indexes, absolute magnitude, distance dodulus, DM and distance, in parsecs, are listed in consecutive columns. The distance modulus distribution has been plotted in a histogram, Figure 2. A Gaussian fit was calculated and the mean value and the standard deviation were obtained from the Gaussian fit. We consider those stars within one sigma from the mean to be members. The results from this calibration gave a mean distance modulus of 10.4±0.9 mag. From that we assigned the memberships listed in the last columns of the table. There are four stars at a small distance, two that are marginal members, denoted by M: and eleven stars that were established to be cluster members.

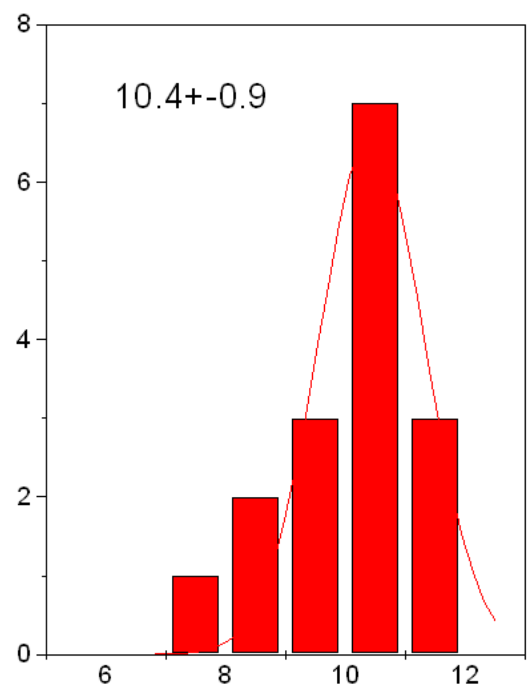

Fig. 2. Histogram of the distance modulus (X axis, in magnitudes) found for the stars in the direction of NGC 2343.

Once the member stars have been defined, a mean reddening determination can be obtained. The numerical value is of $E(b-y)$ equal to 0.157 ± 0.07.

TABLE 4

COMPILED CHARACTERISTICS FOR NGC 2343

	WEBDA	Newly Determined
Right Ascension	07 08 06	
Declination	−10 37 00	
Galactic longitude	224.268	
Galactic latitude	−1.173	
Distance [pc]	1056	1291±362
Reddening [mag] $E(b-y)$		0.157 ±0.070
Reddening [mag] $E(B-V)$	0.118	0.212 ± 0.094
Distance modulus [mag]	10.48	10.47± 0.65
Log age	7.104	7.09
Metallicity	−0.30	−0.38

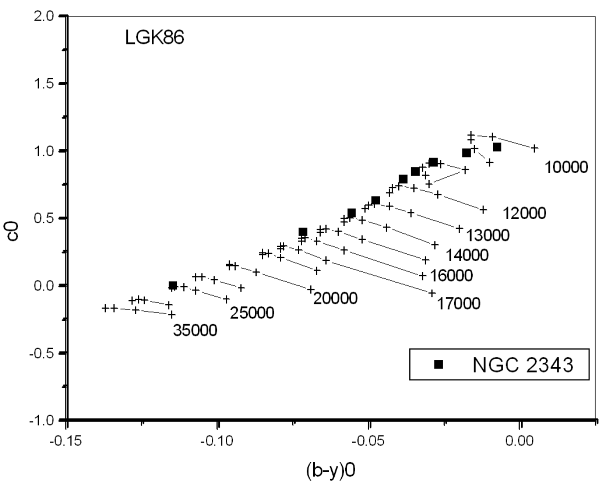

Fig. 3. Location of the unreddened points of NGC 2343 in the LGK86 grids.

Equally, the mean distance is 1291 ± 362 pc. Metallicity was obtained for only two F type stars, 23 and 29, but the first one was found to be a non-member. Hence, the metallicity of NGC 2343 can be determined as [Fe/H]=−0.38.

6. AGE DETERMINATION

The age was fixed for the cluster once we determined the brightest and hence the hottest, main sequence stars. The effective temperature of these hottest stars was determined by plotting the location of all member stars on the theoretical grids of Lester, Gray, & Kurucz (1986, hereafter LGK86) for the corresponding chemical composition. There is a reported metallicity for NGC 2343 of −0.30 in WEBDA. This value is consistent with the results obtained from Nissen (1988), who determined values of [Fe/H] of −0.37 and −0.21 for stars 23 and 29, respectively, although the first one is non-member and the other, a marginal member. A solar chemical composition was assumed for the models. We have utilized the $(b-y)_0$ vs. c_0 diagram which allows the determination of the temperatures with an accuracy of a few hundreds of degrees. Once the membership had been established, the temperature for the hottest stars was determined to be around 25000 K, see Figure 3.

The age is determined after calculating the effective temperature through the calibrations of Meynet, Mermilliod, & Maeder (1993) for open clusters; from the relation log(age)=−3.499 log T_e + 22.476, valid in the effective temperature (T_e) range [4.25, 4.56], which applies for NGC 2343. The application of the above mentioned calibration yields the following age: log (age) of 7.1 (1.2×10^7 yr) for NGC 2343 for which Meynet et al. (1993) assign an uncertainty of less than 3×10^3. Table 4 shows the newly derived characteristic values of NGC 2343 compared with those previously compiled.

7. CONCLUSIONS

New $uvby-\beta$ photoelectric photometry has been acquired and is presented for the brightest stars in the direction of the open cluster NGC 2343. For the observed stars in the field spectral types were assigned. Using the calibrations to calculate reddening and distance for these stars, the distance to the cluster has been fixed. Membership in the cluster has been determined by constructing a histogram for the distances of the stars of this cluster. A Gaussian fit was calculated and the distance was assigned given the mean value and the standard deviation. Those stars are denoted by the letter M. Those which were close but beyond the limits are represented by M:. Unreddened indexes in the LGK86 grids allowed us to determine the effective temperature of the hottest stars and hence, the cluster age.

Since no previous $uvby-\beta$ exists, previous knowledge of the NGC 2343 cluster rested on UBV photometry. Both the color-color and the color-magnitude diagrams do not show a clear main sequence which make the distance, age and reddening determinations ambiguous. We only measured a few stars, the brightest in the direction of the cluster, but with this small sample we determined those that could belong to the cluster. We found that it is at a closer distance than previously assumed and with a slightly larger reddening, but of the same age. Since the sample is complete up to magnitude 10, we have a good estimation of the properties although, of course, more data would, unambiguously, establish the true nature of this cluster.

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A. Martínez: Universidad de Panamá, Panama (adams.martinez@gmail.com).
J. H. Peña: Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 70-264, C.P. 04510, México, D.F., Mexico (jhpena@astro.unam.mx).