Revista Mexicana de Astronomía y Astrofísica, **39**, 171–183 (2003)

uvbyβ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 6823

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Received 2001 October 8 ; accepted 2003 April 21

RESUMEN

Se presenta fotometría *uvby*β de las estrellas más brillantes en la dirección del cúmulo abierto NGC 6823. Del análisis de los datos se ha determinado el enrojecimiento, la distancia, la temperatura efectiva y la gravedad superficial para las estrellas B, A, F y, a partir de estas cantidades, se ha determinado el enrojecimiento y el módulo de distancia (12.475 ± 0.414 mag) para el cúmulo. Asimismo, se han encontrado las estrellas miembros del cúmulo y se ha encontrado un valor numérico para la edad por comparación directa con los modelos teóricos. Se ha realizado un somero estudio de las estrellas variables de período corto en la dirección de NGC 6823. Concluimos que estas variables no pueden ser estrellas δ Scuti pre-MS.

ABSTRACT

Absolute *uvby*β photoelectric photometry of the brightest stars in the direction of the Open Cluster NGC 6823 has been secured and is presented. From the data analysis, reddening, distance, temperature and gravity are determined for the B, A, F stars and, from these, reddening and a mean distance modulus (12.475 ± 0.414 mag) to the cluster are determined. Also, their membership in the cluster has been established and a numerical value of the age is determined through direct comparison with theoretical models. A brief analysis of the short period variable stars in the direction of NGC 6823 is made. We have concluded that they might not be pre-MS δ Scuti stars.

Key Words: **δ SCUTI — OPEN CLUSTERS — PHOTOMETRY — STARS-VARIABLES**

1. INTRODUCTION

As a part of a series of papers (see for example Peña & Peniche 1994) devoted to the study of short period variable stars, the natural step is to study those in open clusters to throw light on the nature of these variables, once proven to be cluster members. Hence, Strömgren photometry of open clusters has been carried since it allows the determination in the above-mentioned conditions. In the present study, an analysis of the Open Cluster NGC 6823 is presented.

1.1. *Previous Studies in NGC 6823*

Lang (1991) presented a compilation of the bulk characteristics. According to this source, NGC 6823 (C1941+231) shows a small diameter, 6.1 pc; its distance is reported at 3470 pc and it is a very young cluster, 5×10^6 yr. Due to its characteristics, this cluster has been a subject of several studies. All of these have been compiled by Mermilliod (2000) in the WEBDA, a site devoted to open star clusters and which is the Web version of the database known as BDA. Several of these studies have been done in photometry, mostly in the UBV system, with both photoelectric photometers and CCD detectors. From these studies, obtained distance values show a wide spread, from 1880 pc (Barkhatova 1957) to 3500 pc (Sagar & Joshi 1981). Spectroscopic studies have been less numerous but despite the faintness of the stars, Kuznetsov (1981) obtained spectra of 289 stars up to mag 15 and, more recently, the work by Shi & Hu (1999) classified 77 stars. Membership probability has been studied extensively by Kuznetsov (1988), Kuznetsov & Lazorenko (1992), Kuznetsov, Lazorenko, & Lazorenko (1993) and by Stone (1988),

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among others, who determined membership probabilities for over 90 stars, located in an area about a quarter of a square degree, centered on the multiple star BD + 22°3782, from a proper-motion survey by Erickson (1971). More recently, Massey, Johnson, & DeGiogia-Eastwood (1995) have studied coeval star formation and the IMF, and those members listed by Shi & Hu (1999), which are based on a paper by Zhao et al. (1985).

Extinction, as can be expected, has been a matter of discussion. Turner (1979) carried out photometry and spectroscopy of 24 cluster stars and concluded that a normal extinction law is applicable to most stars. Sagar & Joshi (1981), with 41 stars studied, found that $E(B-V)$ vary from 0.6 to 1.16 mag.

Age has been a disputed matter. Given the above discussions, it is quite obvious that an accurate determination of the age of the clusters cannot be easily done until the above mentioned parameters have been settled. Sagar & Joshi (1981) found a distance modulus of 12.7 mag and that the cluster stars are not equal in age. On the other hand, Stone (1988) applied Kholopov's criterion which delineates separate cluster regions and separates the stars in two zones: "the nucleus", which refers to the usual concentration of stars obvious on photographic plates, and the "corona", that region of cluster membership outside of the nuclear region. With this criteria NGC 6823 shows one boundary at $r \sim 0.6$ arcmin defining the outer boundary of the trapezium system of bright stars found at the cluster center, and another at $r \sim 3.5$ arcmin separating the nucleus of the cluster from the cluster corona which extends out to at least 15 arcmin and contains 61% of the cluster members identified by Erickson (1971); this is, at least for the cluster stars brighter than $M_v < -1.2$ mag, the magnitude limit of his study. Stone (1988) concludes that many cluster stars in the outer region might be pre-main-sequence objects with ages considerably younger than those of other stars in the cluster. More recently, Kuznetsov & Lazorenko (1992), through a method based on the kinematics, photometric and spectral data, claimed that the number of cluster members given in previous studies is overestimated by a factor of two. Kuznetsov (1988) has found incompatibility of kinematic parameters for certain stars with photometric and spectral characteristics. Even in 1981, Sagar & Joshi (1981) pointed out that the cluster stars are not equal in age, a result that was reinforced by Stone (1988) who, as has been said, assumed the existence of PMS objects in the corona region that might be younger than the rest. Guetter (1992) determines that the trapezium stars are the youngest, those of the nucleus, of intermediate age and those of the corona, the oldest. Guetter (1992) determines $2 - 11 \times 10^6$ y to be the age of the cluster.

In the context of short period variables, Pigulski, Kolaczkowski, & Kopacki (2000) have made a study in which they determined two stars, BL50 and HP57, to be δ Scuti candidates. If these stars were found to be members of the cluster, as those in NGC 2264 claimed to be PMS (Rodríguez & Breger 2001), they would be pre-main sequence δ Scuti stars, a suggestion that has been refuted by Peña et al. (2002).

The main aims of this paper are to determine:

(i) the membership of each observed star to the cluster by a purely photometric method for those stars with spectral types earlier than G2,

(ii) the distance to the cluster,

(iii) the age of the cluster,

(iv) the nature of the variables with respect to the global characteristics of the cluster.

2. OBSERVATIONS

The observations were carried out at the Observatorio Astronómico Nacional (OAN) of UNAM, Ensenada, B. C., México in three different seasons: 1996, 2000, and 2001. For the acquisition of the photometric data, the 1.5 m telescope was used with a multi-channel spectrophotometer that allows the simultaneous observation in the vby filters and in the narrow and wide filters that define Hβ. A brief description of this equipment can be found in Schuster & Nissen (1988).

In order to be able to transform the data into the $uvby\beta$ absolute system, a set of photometric standards were observed along with the program stars. The obtained values of the standard stars and all the observed bright stars are the mean of five 10 s integrations, whereas the values of the sky are the mean of two 10 s integrations. In the 1996 season a total of 50 stars in the direction of NGC 6823 were observed. In the 2000 season fewer stars of this cluster were observed and, as will be seen below, were employed for calibration purposes for the 1996 season. In the 2001 season only a few stars of the cluster were observed along with the variable stars and, since they were much fainter than the rest of the observed stars, larger strings of repetitions were done to attain a higher accuracy.

3. DATA REDUCTION

The reduction of each season was done separately. The 1996 season was planned to observe the brightest stars of two clusters NGC 6531 and NGC 6823 in three concentric circles of $5'$ centered at Hoag's et al. (1961) Id chart up to around magnitude 12, but it had the inconvenience that the V magnitude range of the standards was not wide enough to carry out an adequate transformation. In view of this, another season was planned, that of 2000, with several stars from two additional clusters, NGC 6823 and NGC 6531, that were going to be used as secondary standards in the transformation of the 1996 season. Furthermore, photometric measurements of the variable stars recently discovered by Pigulski et al. (2000) were obtained making it desirable to analyze their characteristics as well. Since these stars are reaching the observational limits of our observing system, another run in 2001 was planned for these stars and was carried out mainly to confirm the color indexes.

The reduction of the 2000 season will be described first because the reduction of that of 1996 will be based on this one. The data were acquired in a season from July $5^{\rm th}$ to $12^{\rm th}$, 2000. The reduction procedure of the whole season was done through the numerical packages NABAPHOT (Arellano-Ferro & Parrao, 1988) and DAMADAP (Parrao 2000), which reduce the data into a standard system.

Calculation of the values into the standard system was done in the following fashion: The standard photometric values utilized for the transformation were those listed by the Astronomical Almanac, although some were taken from a list by Olsen (1983) to include fainter stars and, finally, a few more were taken from the Open Cluster NGC 6882/5 which were observed previously from a season carried out in 1986 to extend both the m_1 and V ranges.

The coefficients defined by the following equations and that adjusted the data to the standard system are those defined by Grönbech, Olsen, & Strömgren (1976) in which the coefficients D, F, H, and L are the slope; B, J, and I are the color term coefficients of the transformation equations. Table 1 presents the transformation coefficients for both ranges in $b-y$, less and greater than 0.4, to avoid the $b-y$ versus m_1 dependence (Grönbech et al. 1976). An estimate of the accuracy was done comparing the $uvby\beta$ obtained data with that of the standard stars considered. The uncertainties were evaluated in the following manner: the average differences, present data minus standard data were evaluated and provided an uncertainty for the transformation of the season; these differences are presented in Table 2.

As a further test of the goodness of the transformation, those stars in the direction of NGC 6882/5 that were thoroughly observed were averaged and compared with the values reported by Hoag et al. (1961). The average values of the eight observed stars are presented in Table 3; their photometry is given, as well as the dispersion and the number of times observed. The average of the differences in magnitude of the present paper (PP) and Hoag's, $V_{pp} - V_{\rm Hoag}$ was 0.005, with a standard deviation of 0.012 mag in a range from 5.8 to 10.5 mag, for a sample of 8 stars. A linear regression of both values gave a correlation coefficient of 0.9997 which indicates the high linearity of the values, although the plot of difference versus V shows an increase which does not becomes highly significant, 0.01 mag at V equal to 10 mag. The $b-y$ versus $B-V$ linear regression gave a correlation coefficient of 0.9989. Hence, it can safely be said that, if the photometric values of NGC 6882/5 from the 2000 season are trustworthy, the remaining photometric values are correct.

Those stars of the clusters NGC 6531 and NGC 6823 utilized as secondary standards for the 1996 season are listed in Table 4. In particular a direct comparison was made for those of NGC 6823 that were in common with Hoag et al. (1961). This sample consisted of 11 stars in a magnitude range from 8 to 12.5 mag, and in a $B-V$ interval varying from 0.0 to 0.88 mag, and the correlation coefficients obtained were of 0.996 and 0.993, respectively.

Of these, one in NGC 6823, W78 (E59), turned out to be discordant, probably due to variability, since its values are well beyond possible errors but its difference from Guetter (1992), Erickson (1971) and Hoag et al. (1961) is too large. In view of this, we did not consider it in the calibrations.

The procedure followed for the 1996 season was the same as that described for the 2000 season. Although initially the system that was chosen was that defined by the standard values of Olsen (1983) in practice, as has already been mentioned, due to the short range of values of the chosen standards stars in the V magnitude and the faintness of the target stars in the cluster, this range had to be increased to be able to correctly determine the slope of the transformation and to verify the linearity of the system. As has already been said, this was done through the selection of a few stars of the open clusters NGC 6531 and NGC 6823 (Table 4) that were observed in the 1996 and whose Strömgren values were determined in the newly observed season in July 2000 for both V and $b-y$. The photometric values of these stars

TABLE 1

TRANSFORMATION COEFFICIENTS[a]

Season		B	D	F	J	H	I	L
2000	allv4	0.011	0.984	···	···	···	···	1.277
2000	$b-y<0.4$	···	···	1.088	0.010	0.999	0.105	···
2000	$b-y>0.4$	···	···	1.076	−0.008	1.060	0.205	···
1996	all	−0.067	1.030	0.928	0.034	1.027	0.165	1.243
2001		0.020	0.991	1.012	−0.002	1.001	0.1478	0.958

[a]Obtained for the observed seasons.

TABLE 2

AVERAGE DIFFERENCES[a]

Season		V	$b-y$	m_1	c_1	β
2000	allv4	0.034	0.0125	···	···	0.007
2000	$b-y<0.4$	···	···	0.004	0.016	···
2000	$b-y>0.4$	···	···	0.010	0.005	···
1996	all	0.046	0.024	0.016	0.016	0.006
2001		0.030	0.012	0.014	0.023	0.029

[a]Present data minus standard data, which provide an uncertainty for the transformation of the season.

TABLE 3

PHOTOMETRIC VALUES OF THE OBSERVED STARS IN THE DIRECTION OF NGC 6882/5

Id	V	σ	$b-y$	σ	m_1	σ	m_1	σ	N
H06	8.666	0.010	0.682	0.004	0.545	0.002	0.317	0.045	4
H08	9.175	0.008	0.322	0.005	0.136	0.005	0.403	0.044	4
H09	9.265	0.026	0.174	0.003	0.204	0.002	0.715	0.050	4
H11	9.550	0.023	0.772	0.005	0.617	0.009	0.147	0.142	4
H16	9.884	0.028	0.418	0.006	0.134	0.004	0.454	0.049	4
H17	9.990	0.019	0.384	0.005	0.175	0.007	0.346	0.119	4
H03	5.901	···	−0.032	···	0.078	···	0.639	···	1
H28	10.539	···	0.111	···	0.095	···	1.065	···	1

in m_1 and c_1 indexes did not increase the range and, hence, they were not considered. The slope coefficients and the color term coefficients for the 1996 seasons are presented in Table 1. With the inclusion of these stars as secondary standards, the reduction of the 1996 season was done with the certainty that the magnitudes of the standard stars cover a wide enough range. These ranges were wide enough in each color so that no extrapolation had to be done and, because of the m_1 and c_1 dependence of $b-y$, only values of $b-y<0.40$ were considered which, according to Grönbech et al. (1976) correspond to the spectral range O-G2 stars for which we have calibration procedures. For stars of a later type than G2, no calibration exists (Lindroos 1980).

The coefficients obtained to transform into the standard system and the uncertainties of the whole season are also presented in Table 1 and in Ta-

TABLE 4

SECONDARY STANDARD STARS FROM NGC 6531 AND NGC 6823 OF THE 2000 SEASON

NGC	Id	V	$b-y$	m_1	c_1	β
6531	AH01[a]	7.821	0.071	0.009	−0.008	2.608
6531	AH03	9.181	0.088	0.014	0.050	2.649
6531	AH10	9.942	0.090	0.048	0.168	2.672
6531	AH21	11.386	0.129	0.074	0.433	2.718
6531	AH11	9.986	0.093	0.042	0.166	2.641
6531	AH39	12.505	0.113	0.137	0.825	2.743
6531	AH34	12.476	0.388	0.046	0.964	2.919
6531	AH09	9.680	0.123	0.014	0.116	2.645
6823	E87[b]	11.540	0.430	0.143	0.319	2.642
6823	E84	11.594	0.637	−0.130	0.015	2.613
6823	E88	11.834	0.641	−0.159	0.031	2.650
6823	E69	12.127	0.450	−0.048	0.305	2.710
6823	E93	12.681	0.657	−0.135	−0.107	2.693
6823	E57	12.187	0.351	0.007	0.076	2.466
6823	E59	13.606	−0.045	0.343	−0.030	···

[a]AH No. from Hoag et al. (1961), annex list.

[b]E No. from Erickson (1971).

ble 2, respectively. Individual uncertainties were determined by calculating the standard deviations for each star. These values, of course, are functions of the star magnitude but, in all cases, enough photon counts were secured in order to attain a signal to noise ratio large enough to determine accuracy better than 0.03 mag for the faintest stars. As a further test, the photometric outputs were compared to the standard values considered from the literature or those obtained in the 2000 season and the linear regressions of this comparison are presented in Table 5. The only discordant values were the following: AH01 (N6501) in V plus the standard stars HD 209357 in $b-y$ and HD 182941 in m1 and w78 (E59) in NGC 6823 in both magnitude and colors, implying possible variable stars or, less likely, misidentifications.

For the 2001 season the main goal, with respect to NGC 6823, was the observation of the two short period variables found by Pigulski et al. (2000). The season consisted of only four nights of which the variables were observed in only two due mostly to the brightness of the sky and the faintness of the stars. The transformation coefficients are also presented in Table 1; the errors of the standard stars, in Table 2.

TABLE 5

LINEAR REGRESSION OF THE STANDARD STARS[a]

	A	B	R	Error	N
V	−0.058	1.008	0.998	0.121	32
$b-y$	0.021	0.926	0.966	0.051	32
m_1	−0.024	0.987	0.915	0.048	32
c_1	0.005	0.991	0.993	0.045	33

[a]With values in the literature for the 2000 season.

4. RESULTS

Finally, mean values of all the stars observed in the three seasons were calculated and a final set of data was obtained. The final photometric values obtained for NGC 6823 are presented in Table 6. Columns 1 and 2 gives the Id number of WEBDA: Mermilliod (2000) and Erickson (1971), respectively; column 3, the V magnitude; columns 4 to 6, the color indexes $b-y$, m_1, and c_1; column 7 lists the β value and column 8 reports the season in which the observations were carried out.

TABLE 6

$uvby\beta$ PHOTOMETRY OF THE STARS IN THE DIRECTION OF NGC 6823

WEBDA	Erickson	V	$b-y$	m_1	c_1	β	Date	mmbr
171	17	13.307	0.607	−0.020	0.297	2.666	50696	
170	18	11.957	0.609	−0.049	0.267	2.645	50696	
167	19	12.752	0.532	0.074	0.572	2.554	50696	
166	20	11.637	1.010	0.236	0.434	2.587	50696	
182	21	11.053	0.737	0.659	0.119	2.541	50696	
165	22	13.109	0.527	0.197	0.354	2.317	50696	
178	23	13.643	0.457	0.178	0.447	2.896	50696	
174	24	11.822	0.560	−0.052	0.070	2.608	50696	M
177	25	13.045	0.515	0.121	0.432	2.620	50696	
183	26	10.744	0.277	0.237	0.643	2.780	50696	
105	33	11.347	0.492	0.096	0.600	2.662	50696	
113	43	13.739	0.700	0.005	0.789	2.271	50696	
112	45	12.117	0.429	0.141	0.411	2.630	50696	
111	46	8.747	0.597	−0.101	0.001	2.550	50696	
187	52	13.510	0.454	0.015	0.596	2.685	50696	M
189	53	8.803	0.435	0.157	0.351	2.580	50696	
74	54	11.676	0.436	0.015	0.025	2.621	40696	M
73	56	9.506	0.495	0.273	0.234	2.568	40696	
17	57	12.140	0.502	−0.066	0.156	2.706	mean	
78	59	12.110	0.422	−0.020	0.363	2.697	mean	
110	60	14.110	0.533	0.088	0.948	2.683	50696	
108	61	11.307	0.288	0.164	0.682	2.690	50696	
80	66	13.208	0.321	0.076	1.038	3.192	50696	
98	67	13.212	0.630	0.089	0.663	2.631	50696	
13	68	9.775	0.397	−0.063	−0.025	2.605	mean	
14	69	12.088	0.423	−0.032	0.326	2.704	mean	
02	74	11.205	0.499	−0.107	−0.015	2.595	mean	M
109	77	10.387	0.574	−0.108	0.057	2.574	50696	M
218	81	11.040	0.494	−0.106	−0.127	2.605	mean	M
03	83	9.550	0.475	−0.065	−0.129	2.615	mean	
11	84	11.607	0.634	−0.112	−0.195	2.624	mean	
68	86	11.876	0.604	−0.125	0.321	2.710	mean	
04	87	11.515	0.419	0.169	0.337	2.619	mean	
09	88	11.824	0.624	−0.093	0.031	2.611	mean	M
33	89	12.889	0.398	0.208	0.324	2.671	40696	
67	93	12.673	0.642	−0.076	−0.032	2.587	mean	
220	95	12.441	0.359	0.179	0.330	2.605	40696	
66	97	13.248	1.049	0.624	−0.520	2.453	50700	
83	98	13.020	0.440	0.352	1.906	2.555	40696	
65	99	11.884	0.598	−0.040	−0.010	2.579	40696	
61	102	13.503	0.551	0.104	0.821	2.827	40696	
62	103	12.835	0.948	0.139	0.472	2.561	40696	
34	104	11.752	0.688	−0.067	0.040	2.711	40696	
97	105	11.324	0.743	0.590	1.936	2.481	40696	
88	106	12.402	0.388	0.169	1.279	2.722	40696	
56	109	13.270	0.519	0.155	0.319	2.763	40696	

TABLE 6 (CONTINUED)

WEBDA	Erickson	V	$b-y$	m_1	c_1	β	Date	mmbr
35	110	9.344	0.843	0.192	0.666	2.634	50696	
93	115	10.735	0.339	0.007	−0.135	2.573	40696	
91	119	10.997	0.398	−0.005	−0.133	2.622	40696	M
50	121	11.762	0.345	0.219	0.418	2.606	40696	
54	126	10.270	0.298	0.185	0.738	2.696	40696	
42	129	11.890	0.948	0.305	0.837	2.550	50696	
43	130	11.429	0.372	0.041	0.551	2.766	50696	
44	136	10.083	1.632	−0.864	1.997	2.813	50696	
55	137	12.531	0.462	0.141	0.532	2.777	50696	
141	141	9.455	0.771	0.547	0.426	2.556	50696	
	BL50	13.917	0.525	−0.027	0.904	2.437	80601	
	HP57	14.453	0.666	0.070	0.705	2.838	50700	
5		11.483	0.414	0.156	0.314	2.686	50700	
219		12.157	0.528	−0.063	0.094	2.636	50700	M
64	E100	...	...	...	...	...	...	

4.1. *Comparison of the Existing Photometric Data*

As has been said in the Introduction, the main sources of photometric data are the following: Barkhatova (1957) with a sample of 212 stars, Hoag et al. (1961), 31; Sagar & Joshi (1981), with 41; Stone (1988), 45; Guetter (1992), 45; all of these in the UBV system; more recently, Pigulski et al. (2000) with BV (RC) with 316 stars. All of these have been compiled in WEBDA by Mermilliod (2000). Finally, there are those of the present study, with a sample of 60 stars in the $uvby\beta$ system.

The cross study of all these references is a large task, well beyond the scope of this paper. However, the cross Id and bulk review of some of the photometry is desirable and the current open cluster database has made this task easier. Some of this work has already been done, for example, Stone's (1988) and Guetter's works (1992) use Erickson (1971) as reference; Sagar & Joshi (1981) based their work on the nomenclature of Barkhatova (1957); we based our original work mostly on Hoag et al. (1961), although later, because we feel that it is better to refer all the studies into one system, we have chosen that of Mermilliod (2000, WEBDA) due to its availability and usage, although Erickson's (1971) has been kept for convenience and direct comparison with other sources. Pigulski et al. (2000) have carried out excellent work since they refer to all cross Id numbers. The comparison of these sources, Erickson (1971), Sagar & Joshi (1981), Stone (1988), Guetter (1992), Pigulski et al. (2000) etc., gave minor numerical differences. Lower weight should be assigned to Erickson's photometric set because he is mostly quoting the data from Barkhatova (1957) which were transformed from the old International Photographic System to B and V, or taking the photometric values of Hoag et al. (1961). This data set has, however, one of the largest samples, 92 stars, as well as membership probabilities calculated from an epoch difference of 48 years; besides, his Id numbers have been extensively used and for these sole reasons we opted to keep it. Nevertheless, in the remaining of this Paper the WEBDA ID numbers will be utilized whenever possible and will be denoted by a letter W.

Given the exceptionally good correlation between Sagar & Joshi (1981) and Erickson (1971) in V, there might be some relatively large variability in W82 (E96), which is the only discordant value; the rest of the data sets gave no points out of the trend. When comparing the present photometric data with the other data sets there were no exceptionally discordant values in either V magnitude and color indexes with the largest difference for W83 (E98) in the relation PP—Erickson (1971) and W33 (E89) in PP— Stone (1988). There is the large difference in W65 (E99) with Erickson (1971) or Stone (1988), a difference that we cannot account for. Also, a large difference is found in V between the sets of Stone and Guetter for star W14 (E69) and in a lesser value in star W364 (E115). In the color indexes there are also a few which are discordant: in $B-V$ those values numerically larger than 1.0 between Stone (1988) and Erickson (1971) and in $U - B$ the whole fit shows no trend. The discordant values are, when compared the PP data with Erickson (1971), W44 (E136) whereas when compared with Pigulski, that of BL50, one of the variable stars. Of course one has to keep in mind that this is one of the faintest stars observed at SPM.

To extend the comparison for B type stars it is desirable to compare them in the $u - b$ versus $U - B$ colors. This was previously done by Turner (1990) between $(U - B)$ and $(u - b)$ from a large compiled sample of 350 stars; a $(U - B) = 0.675$ $(u - b) - 0.938$ was obtained. The coefficients we derived by a direct comparison with Stone were not quite the same: $0.896(u - b) - 0.938$ but for a sample of only 24 stars we obtained a correlation coefficient of 0.94. An analogous numerical value was obtained for the $(b - y)(B - V)$ indexes and 0.995 for the V magnitudes. Hence we might consider that our comparison adequately fits Stone's values in all color ranges. In order to carry out a more representative comparison we considered the UBV values reported by Mermilliod (2000) in WEBDA. We calculated mean values for the WEBDA list and compared these means with our photometry. Except for one star with large differences in both V magnitudes and color indexes, namely W05 and W44 (E136) and another, W65 (E99) in V the comparison looked acceptable, particularly in view of the wide range we are considering: V from 8.5 to 14 mag, $B - V$ from 0.25 to 1.5 and $U - B$ from -0.5 to 1.25; we cannot account for the large differences of the above mentioned stars unless they were variables. If these stars are not included in the analysis the results of the linear fits give the following in $Y = A + BX$ with Y in the Johnson system and X in Strömgren system: (A, B, R, error) in V, $(-0.053, 1.003, 0.997, 0.108)$; in $B - V$, $(-0.091, 1.460, 0.936, 0.084)$ and $U - B$, $(-0.451, 0.718, 0.905, 0.193)$ for a sample of 25 stars.

5. ANALYSIS AND INTERPRETATION

In summary, we feel that the values presented here are correct, at least when compared with the compilation by Erickson (1971) and Mermilliod (2000), both in V and $b-y$, and $u-b$ color indexes. Hence, given the nature of the instrument employed and the uncertainties attained by the standard stars, as well as the special attention that was given to the observations of the two variables, we might conclude that the derived results are correct. An attempt to describe the nature of the cluster now will be made. The $uvby\beta$ photometry has been compiled (Table 6) and, from it, unreddened colors were determined, Table 7. Later, physical parameters such as $\log T_e$ and $\log g$ for the stars and metallicity and age for the cluster can be extracted.

5.1. *The Cluster*

Cluster membership can be established with the advantages of Strömgren photometry with calibrations made by Nissen (1988) based on calibrations by Crawford (1975; 1979) for the A and F stars and by Shobbrook (1984) for early type stars. These calibrations have been already employed and described in a previous analysis of open clusters (Peña & Peniche 1994). From the photometric values for each star, Table 6, first the spectral class to which a star belongs was determined. Since there is an almost complete spectral class determination by Shi & Hu (1999) we assumed this classification to be correct. Nevertheless, our photometric spectral classification was done by positioning each one in the $[m_1] - [c_1]$ diagram of Golay (1974). An alternative method was through consideration of the numerical criteria from Strömgren photometry from Lindroos (1980). The final spectral class was compared to the spectra of the stars of NGC 6823 listed by Shi & Hu (1999); the agreement between these methods gave exceedingly consistent results. This did not seriously affect the results since we did not consider in the analysis those stars that belong to the supergiant luminosity class. Since the correlation was excellent in a sample of 36 stars, we consider that the photometric classification of those stars that were not classified by Shi & Hu (1999) is well determined.

The application of the above-mentioned prescriptions to the B, A and F stars yield the M_v and, from it, the establishment of the membership of each star to the cluster. After this membership has been calculated, average parameters such as reddening $E(b-y)$, distance and chemical composition, [Fe/H] if there are any F stars, are determined for the cluster. With the unreddened colors $(b - y)_0$, m_0, and c_0 the location of each star is fixed in the calibrations of Lester, Gray, & Kurucz (1986) who calculated $\log g$ and $T_{\rm eff}$ as a function of the Strömgren indexes. The determination was done in the $(b - y)$ versus β calibrations because for the other color indexes the grids clumped at high temperatures. The effective temperature and surface gravity were also evaluated in the $[c_1] - \beta$ diagram that gave, systematically, higher values. Two additional methods for determining the effective temperatures, that of Davis & Shobbrook (1977), and that of Balona (1984) were employed. From the first one, Davis & Shobbrook (1977), the following fit was calculated:

TABLE 7

REDDENING AND UNREDDENED PARAMETERS OF THE MEMBER STARS OF NGC 6823

Id (webda-Erickson)	$E(b-y)$	$(b-y)_0$	m_0	c_0	β	V_0	M_v	DM	dist(pc)
013-068	0.521	−0.124	0.109	−0.124	2.605	7.53	−4.22	11.75	2239
098-007	0.310	0.320	0.182	0.601	2.631	11.88	0.00	11.88	2374
439-017	0.706	−0.099	0.213	0.163	2.666	10.27	−1.77	12.04	2561
109-077	0.694	−0.12	0.121	−0.075	2.574	7.40	−4.81	12.21	2765
219-	0.655	−0.119	0.14	−0.062	2.636	9.36	−3.15	12.51	3177
009-088	0.747	−0.123	0.154	−0.111	2.611	8.61	−3.98	12.59	3294
422-024	0.679	−0.119	0.172	−0.059	2.608	8.90	−3.69	12.60	3305
187-052	0.513	−0.059	0.184	0.498	2.685	11.30	−1.32	12.62	3347
091-119	0.534	−0.136	0.171	−0.235	2.622	8.70	−4.06	12.76	3564
074-004	0.557	−0.121	0.199	−0.081	2.621	9.28	−3.55	12.83	3689
218-081	0.632	−0.138	0.103	−0.247	2.605	8.32	−4.52	12.84	3700
002-074	0.624	−0.125	0.099	−0.134	2.595	8.52	−4.55	13.07	4108
mean	0.598	⋯	⋯	⋯	⋯	⋯	⋯	12.475	3177
σ	0.119	⋯	⋯	⋯	⋯	⋯	⋯	0.414	579

$$T_e = 25322.38968 - 39634.32203 c_0 + 47432.20536 c_0^2 - 23543.60515 c_0^3 \,,$$

whereas Balona (1984) provided the relation:

$$\log T_e = 3.9036 - 0.4816[c] - 0.529[\beta] - 0.126[c]^2 + +0.0924[\beta][c] - 0.4013[\beta]^2 \,,$$

where $[c] = \log(c_0 + 0.2)$ $[\beta] = \log(\beta - 2.5)$.

The bolometric correction for each star was taken from the compilation of Lang (1991) through the already evaluated log T_e values. With this BC determined, $M_{\rm bol}$ for each star was calculated. The age of the clusters can been fixed after establishing the surface gravity and effective temperature for each star. The location of the hottest stars in the evolutionary tracks provides the age of the cluster. First, the models of Claret & Gimenez (1989) were considered. Later, the age was also found from the more recent models of Meynet, Mermilliod, & Maeder (1993), which consider overshooting; of their analytical relations, we considered that for the temperature range of the stars within the interval [4.25; 4.56] for which the following relation is proposed: $\log(age) = -3.499 \log T_{\rm eff} + 22.476$ at BTO, with a precision of 3×10^{-3}.

5.2. *Numerical Results*

Once the distance to the stars is evaluated (Table 7) a mean distance and standard deviation can be calculated for the cluster; the criteria for membership are established by constructing a distance modulus histogram for the observed stars and fitting a Gaussian distribution. As we can see, Figure 1, the advantage of the method utilized rests on the fact that each class can be analyzed separately and not as a whole as in the classical M-S fitting method. The majority of the B type stars lie at values centered at the distance modulus of 12.475 mag with a standard deviation of 0.414 mag. There are no A stars and only one F type star in this range and the A and F stars are located at a much closer dis-

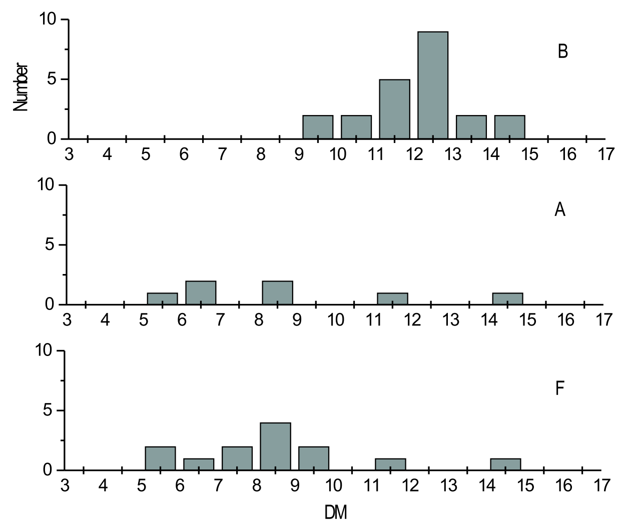

Fig. 1. Distance Modulus histograms for stars of different spectral classes in the direction of NGC 6823.

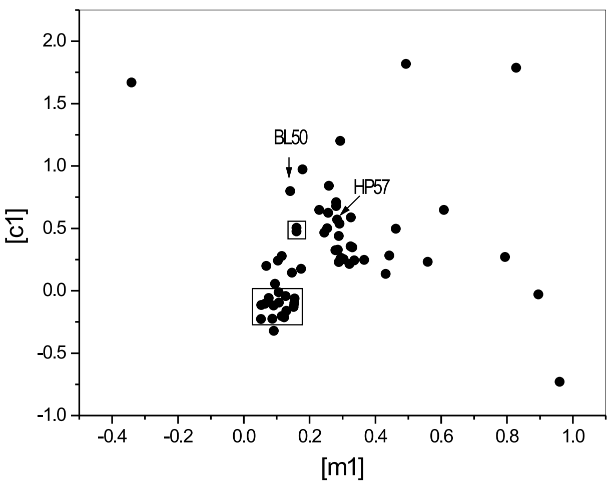

Fig. 2. Location of the observed stars in the $[m_1] - [c_1]$ diagram of NGC 6823. The short period variables are pointed out. The frames indicate those stars that were assigned as member stars.

tances, which puts them, consequently, far beyond the limits of the cluster which is constituted only of early type stars, at least to the magnitudes reached in the present study. A similar situation was found in another study of NGC 2264 (Peña et al. 2002) but at this stage it is important to point out the correctness of the results for two clusters: Alpha Per (Peña et al. 2002) and the Pleiades (Parrao 2002). Of course, no meaningful direct comparison can be done with work that determined their membership probabilities to the NGC 6823 cluster through a fitting of the UBV photometry of the stars with the theoretical MS. With respect to the proper motion studies, namely, those of Erickson (1971), Sanders (1971) and Kuznetsov (1988), a comparison provides elements for discussion.

Considering to be cluster members only the B stars in the distance modulus range of one sigma around the mean value in a Gaussian fit of the distance modulus histogram, a mean value of $E(b-y) = 0.598 \pm 0.119$, a DM of 12.53 ± 0.39 mag, and a distance of 3176 ± 579 pc are obtained. The uncertainties are the standard deviations of the 12 stars within the determined distance range. The derived value of $E(b-y)$ corresponds to $E(B-V) = E(b-y)/0.70$ of 0.854 ± 0.170 which is within the limits of the values determined by Sagar & Joshi (1981), the values compiled by Turner (1979), by Lang (1991, 0.76 mag), or that reported by Mermilliod (2000) in WEBDA (0.845 mag). In this sense we feel that the pioneer works on NGC 6823 were basically correct since, from what we have found, one might consider that the stars in the direction of the cluster can be divided in a "nucleus" and the outer regions which, we now know, include some stars which belong to the cluster. The conclusions reached by Kuznetsov (1988) who found incompatibility of kinematics parameters for certain stars with photometric and spectral characteristics were, fundamentally, correct. Of course, although the calibration and method of analysis are correct, for a cluster located at 3200 pc it is impossible to get identical distance moduli as would be required to match a depth of only 6 pc.

Once the reddening has been determined, its subtraction allowed us to determine the unreddened colors from which physical parameters can be determined. The $(b-y)_0$ versus β prescription of Lester, Gray, & Kurucz (1986) to the member stars yields the values of $\log T_e$ presented in Table 8. Temperature determination was not done for the stars W187 (E52) and W98 because they do not lie in the corresponding diagram, indicating that they are cooler stars. The $\log g$ values lie around 4.0 except for W02 and W91 which have values around $\log g = 5.0$.

As has been said, age can be determined from the unreddened indexes using the calibrations for early type stars of Davis & Shobbrook (1977) and of Balona (1984). The results are presented in Table 8. We must put emphasis on the good agreement in the temperatures of most stars whereas a large disagreement exists in one (W187). In some others, W091 and W218 the evaluation with the criteria of Balona (1984) was not feasible because they lie out of the range of validity in c_0 employed in his work. The grids of Lester et al. (1986) were also utilized for the temperature determination and gave basically the same results. The age has been calculated by both methods and is listed separately. All techniques establish W02, W09, W13, W74, W91, and W218 to be the youngest stars in the cluster.

Given the physical parameters of each star, $\log T_e$ and M_v, a direct determination of all the stars as a whole can be made with the theoretical models of Claret & Gimenez (1989) for a chemical composition $(X, Z) = (0.70, 0.02)$ determining an age younger than $\log \text{age} = 6.5$, of the same order of magnitude as previously determined, establishing this group of stars to be an OB association. Analogous results on the age are found from the more recent models of Meynet, Mermilliod, & Maeder (1993) and the age

TABLE 8

PHYSICAL CHARACTERISTICS OF THE B MEMBER STARS OF NGC 6823

Id W-E	T_e d&sh	$\log T_e$	$logT_e$ balona	T_e	$\langle T_e \rangle$	$\log\langle T\rangle$	log Age d&sh	Age d&sh	log Age balona	Age balona
013-068	31542	4.499	4.519	33061	32302	4.509	6.734	5.4E+06	6.663	4.6 E+06
439-017	18942	4.277	4.291	19559	19251	4.284	7.509	3.2E+07	7.461	2.9 E+07
109-077	28889	4.461	4.415	26013	27451	4.439	6.868	7.4E+06	7.027	1.1E+07
219-	27950	4.446	4.451	28220	28085	4.448	6.918	8.3E+06	6.903	8.0E+06
009-088	41517	4.618	4.502	31802	36660	4.564	6.317	2.1E+06	6.722	5.3E+06
422-024	30285	4.481	4.435	27197	28741	4.458	6.796	6.3E+06	6.960	9.1E+06
187-052	···	···	4.158	14403	14403	4.158	···	···	7.926	8.4E+07
091-119	37836	4.578	···	···	37836	4.578	6.458	2.9E+06	···	···
074-004	29397	4.468	4.467	29315	29356	4.468	6.841	6.9E+06	6.846	7.0E+06
218-081	36506	4.562	···	···	36506	4.562	6.512	3.3E+06	···	···
002-074	32210	4.508	4.529	33841	33025	4.519	6.703	5.0E+06	6.627	4.2E+06

is a few million years, consistent with the previous findings and the value assumed by Lang (1991).

5.3. *DISCUSSION*

The most important question to resolve with respect to the studies of open clusters would be which stars really belong to the cluster since, from this answer, all the other matters will be deduced.

The customary method for membership determination is through MS fitting to the stars in the region. However, this method is useless in this case where there is no clearly defined cluster (see, for example the H-R and color-color diagrams in Hoag et al. 1961) but it is, as the results indicate, a mere OB Association. In this case the fitting by the MS in an extended region rich in early type stars has been proved misleading.

The most accurate method for establishing membership would be, without doubt, through the determination of proper motions through which, as will be discussed, the different methods applied to NGC 6823 have given controversial results, but all have given low membership probability to those stars later than B bringing us back to the inadequacy of utilizing the color-color diagrams, as is customary.

In this paper we have analyzed the cluster with canonical, well-tested, although not frequently used methods that have given reliable results in analogous studies to determine cluster membership. Hence, in view of the obtained photometry, we have determined distances for each group of stars separately and from that we have deduced all the above-mentioned parameters. However, given these results we have to question how well these values compare to those of the previous studies. To begin with, as Erickson (1971) has already pointed out *"photometric investigations of the cluster indicate that it is embedded in a large and variable absorption which makes the interpretation of its color-magnitude diagram and the determination of membership by conventional photometric methods both difficult and uncertain."* When the conventional UBV photometric studies are considered, their correlation of obtained memberships for each star is in agreement with the different studies because we have to keep in mind that all are using the same method although even then, large discrepancies do exist; for example, the reported reddening $E(B-V)$ values among Erickson (1971), Guetter (1992), and Stone (1988) are 0.94, 0.61, and 0.79, respectively. What we can point out is that at least all the stars that we defined as member stars have high membership probability in all these sources. However, the other studies consider the majority of the early B type stars to be members (except one of the stars, W187 (E52)) because of the high membership probability assigned to them. For this star, the membership probability assigned by Erickson (1971) and Stone (1988) is not given and Kuznetsov (1988) gives 17 percent. The opposite is not true, since quite a few of the stars from the other sources which were defined as member stars were not in the distance range that we consider for the cluster. Another point to consider is that very few of the stars of late A or F spectral class, which we did not consider to be members, have a high probability assigned by the proper motion studies. For example, W33 (E89), for which we assigned a spectral type F has, according to Erickson, Stone and Sanders, a probability of 0.82 whereas Kuznetsov (1988) gives a flat 0.0 probability. Another discrepancy is that of W35 (E110) which we again assumed to be an F (and which was classified by Shi & Hu as A8III), the other studies give a 0.79 membership probability except for Kuznetsov (1988) which again assumed it to be a non-member. We feel we are correct since the stars are of magnitudes 12.63 and 9.39 mag, respectively. This fact makes them incompatible with the magnitude trend of the B stars that have been considered to be members. In view of the previous discussion, as has already been mentioned, it is useless to compare our membership probabilities with the other studies because of the photometric fit which is, as Erickson (1971) pointed out, difficult and uncertain, given the location of the cluster in the OB-association I Vulpecula. In this sense, the consideration that some older stars in the direction of the cluster are the youngest causes a difference in the assumed distance and age because there are some others, W065 (E99) and W067 (E93), for example, which are young and not cluster members.

6. SHORT PERIOD VARIABLE STARS

With respect to the short period variable stars BL50 and HP57 we can establish their nature, thanks to the measured Strömgren photometric values. Due to their faintness and the proximity to other stars their accurate measurement was difficult to accomplish, particularly in the u filter and hence in the c_1 index as well as in the Hβ measurements. The rest of the filters did not present any difficulty so the most consistent values for this star are in V, $b-y$, and m_1 amongst the several measurements.

For BL50 the reported values were the result of 26 10s measurements and analogous measurements of the sky. In this case, the sum of the star counts in each filter were 14297, 61209, 95478, and 38908 for u, v, b and y, respectively that, when the sky was subtracted, were reduced to 2660, 23058, 43092, and 20800 giving a $\sqrt{N}/N$ of 0.019, 0.007, 0.005, and 0.007 mag for u, v, b and y, respectively. Analogous care was undertaken for HP57, for which a total of 21 10s measurements were carried out. The net sum of the star counts were 845, 8171, 18648, and 10299 which yield a $\sqrt{N}/N$ of 0.034, 0.011, 0.007, 0.010 for u, v, b, and y, respectively. The Hβ measurements were also carried out carefully: a total of 36 10s measurements of the BL50 star for a net counts of 8258 and 1376 counts/s for the Narrow and Wide filters, respectively. These figures through the relation $\sqrt{N}/N$ become of 0.011 and 0.027. For HP57 a total of 17 10s integrations of the star and sky were carried out. The net sum was of 1959 and 1008 for the N and W filters which provide a $\sqrt{N}/N$ of 0.023 and 0.031, respectively. Both translate into a $\delta\beta$ of 0.054 and 0.038 for HP57 and BL50, respectively.

Through the direct inspection of their positions in the $[m_1]-[c_1]$ diagram (Fig. 2) we can immediately see that at least BL50 cannot be a pre-main sequence δ Scuti star since it lies in the region of the early type stars, around the early B type star, and although one might question this assertion due to the relatively large scatter in$[c_1]$ as mentioned above, the consistency of $[m_1]$ makes this assertion indisputable since the spectra to which it belongs is determined by the $[m_1]$ index. The other star, HP57, can be, and most likely is, a δ Scuti star since it shows short period variation, has a spectral type F and its Hβ corresponds to an A type star. From its photometry the determined distance is of 435 pc whereas from the photometry of the cluster we do not see an accumulation of A or F stars at the assumed distance of the cluster (3440 pc), but merely, a small clustering of early type stars to which the variable HP57 cannot belong.

7. CONCLUSIONS

The most important contribution of this paper is the acquisition of Strömgren absolute photometry which provides an opportunity to determine the distance to each star, using a method that has proven correct (Peña et al. 2002), and to derive physical characteristics of the stars that have been found to be members. Evidently, the observations on a star-by-star basis with a spectrophotometer, even if it is multi-channel, have limitations and, in this sense, the more recent techniques, such as CCD photometry, will throw new light on the results. With the relatively small sample of measured stars presented in this paper we were not able to determine a clearly distinguishable cluster and, despite all the effort done in regular UBV photometry, either photographic, photometric or with CCD, this question will not be settled unless $uvby\beta$ CCD photometry is carried out in order to be able to reach fainter magnitudes in an exhaustive manner. In this sense, the stars measured in this paper will be of enormous help since they will assist to calibrate the frames. Until these new photometric values are taken, and not before, the discussion of s ophisticated matters such as IMF and coevality of the stars, etc., is premature. However, the study carried out and presented in this work can be considered to be exhaustive, at least up to magnitude 12 in a relatively large region. We also feel that the discussion of pre-main sequence δ Scuti stars is important and that the results presented here, far from raising the noise level about this cluster, will help to settle the over-enthusiasm with which the new trends follow, without being certain of the true nature of the stars involved.

Special thanks are given to the staff of the SPM Observatory who made the observations possible. This project was partially supported by Papiit IN100199. Proofreading was done by J. Miller; A. Díaz Azuara, C. Guzmán, and L. Parrao assisted us at the computers, and A. Pani in the 2001 season. Several of us, MAH, CDC, and AGC, thank the Instituto de Astronomía, UNAM for allotting the observing time. JHP thanks DGAPA for the funds provided and Dr. P. Lampens and the Royal Belgian Observatory, and Dr. E. Michel and the Observatoire de Paris-Meudon for their hospitality. Special thanks are given to Dr. Pigulski for making his data available to us prior to publication and for his comments and to an anonymous referee whose suggestions and remarks clarified and corrected several errors. This research has made use of the Harvard ADS and Simbad databases operated at CDS, Strasbourg, France.

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