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$uvby - \beta$ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTERS NGC 6811 AND NGC 6830[1]

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RESUMEN

A partir de la fotometría fotoeléctrica $uvby - \beta$ de los cúmulos abiertos NGC 6811 (75 estrellas) y NGC 6830 (19 estrellas) realizamos la determinación de distancias y, por ende, la pertenencia de las estrellas a cada cúmulo. Asimismo, se determinaron la edad y el enrojecimiento de cada uno. Dado que recientemente se han determinado estrellas variables para el primero, realizamos un estudio de dichas variables.

ABSTRACT

From $uvby - \beta$ photometry of the open clusters NGC 6811 (75 stars), and NGC 6830 (19 stars) we were able to determine membership of the stars to each cluster, and fix the age and reddening for each. Since several short period stars have recently been found, we have carried out a study of these variables.

Key Words: open clusters and associations: individual (NGC 6811, NGC 6830) — techniques: photometric

1. INTRODUCTION

The study of open clusters and their short period variable stars is fundamental in stellar evolution. Because the cluster members are formed in almost the same physical conditions, they share similar stellar properties, such as age and chemical composition. The assumption of common age, metallicity and distance imposes strong constraints when modeling an ensemble of short period pulsators belonging to open clusters (e.g., Fox Machado et al. 2001, 2006). Thus, observational studies involving variable stars in open clusters have attracted more and more attention (e.g., Fox Machado et al. 2002; Li et al. 2002, 2004).

A series of papers (see Peña & Peniche 1994; Peña et al. 1998, 2003; Peña, Fox Machado, & Garrido 2007) study the physical nature of the short period variable stars in open clusters by means of Strömgren photometry, since, once their membership to the cluster has been established, their physical quantities can be unambiguously derived. In particular, the determination of physical parameters of cluster member stars from $uvby - \beta$ photometry can be done through a comparison with theoretical models (Lester, Gray, & Kurucz 1986, hereinafter LGK86).

As a continuation of our study, we now present observations of the open clusters NGC 6811 and NGC 6830. Both clusters have no previous published $uvby - \beta$ data.

Very recently, Luo et al. (2009) carried out a search for variable stars in the direction of NGC 6811 with CCD photometry in the B, and V bands. They detected a total of sixteen variable stars. Among these variables, twelve were catalogued as δ Scuti stars, while no variability type was assigned to the remaining stars. They claim that the twelve δ Scuti stars are all very likely members of the cluster, which makes this cluster an interesting target for asteroseismological studies. Moreover, NGC 6811 has been selected as a asteroseismic target of the Kepler space mission (Borucki et al. 1997). Therefore, deriving accurate physical parameters for the pulsating star members is very important.

For NGC 6811 Luo et al. (2009) estimated an age of $\log(t) = 8.76 \pm 0.009$ from theoretical isochrone fitting to the color magnitude diagram (CMD here-

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TABLE 1

LOG OF THE OBSERVING SEASONS

Epoch	Cluster	Initial date year mo day	Final date year mo day	Observers
2009 June	NGC 6811, NGC 6830	2009 06 24	2010 06 29	jhp, hg, arl
2010 August	NGC 6811	2010 08 03	2010 08 06	jhp, ss, er, ae

Observers: jhp, J. H. Peña; hg, H. García; arl, A. Rentería; ss, S. Skinner; er, E. Romero; ae, A. Espinosa.

after) and assuming a metallicity of $Z = 0.019$. They determined the distance modulus and color excess as 10.59 ± 0.09 and 0.12 ± 0.05, respectively.

To the best of our knowledge, no δ Scuti variable stars have been reported in NGC 6830 to date.

According to the compilation of data of open clusters in Paunzen & Mermilliod (2007, WEBDA), NGC 6811 has a distance [pc] of 1215; a reddening [mag] of 0.160; a distance modulus [mag] of 10.92; a log age 8.799 and no data on metallicity reported. NGC 6830 has the following: distance [pc] 1639; reddening [mag] 0.501; distance modulus [mag] 12.63; log age 7.572 with no determined metallicity.

2. OBSERVATIONS

These were all taken at the Observatorio Astronómico Nacional, Mexico in two different seasons, those of 2009 and 2010. The dates are listed in Table 1. The 1.5 m telescope to which a spectrophotometer was attached was utilized at all times. The first observing season was carried out over six nights from June–July 2009. The ID charts utilized were those of WEBDA. When the NGC 6811 data were reduced, there were several stars whose photometry showed large discrepancies with the literature. In view of this and due to the fact that several δ Scuti stars were recently discovered in this cluster (Luo et al. 2009), a second observing season was planned in 2010 to measure all of these stars in the $uvby - \beta$ system.

2.1. *Data acquisition*

The following procedure was utilized during all nights: each measurement consisted of at least five ten-second integrations of each 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 secure sufficient photons to get a S/N ratio of accuracy of $N/\sqrt{(N)}$ of 0.01 mag in most cases. Each night a series of standard stars was also observed to transform the data into the standard system. The reduction procedure was done with the numerical packages NABAPHOT (Arellano-Ferro & Parrao 1988) which reduce the data into a standard system, although some data were also taken from the *Astronomical Almanac* (2006) for the standard bright stars. The chosen system was that defined by the standard values of Olsen (1983) and the transformation equations are those defined by Grönbech, Olsen, & Strömgren (1976) 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. The coefficients B, J and I are the color terms of V, m_1, and c_1. The averaged transformation coefficients of each season determined from the mean of all nights are listed in Table 2 along with their standard deviations. Errors of the season were evaluated by means of the standard stars observed. These uncertainties were calculated through the differences in magnitude and colors, for (V, $b{-}y$, m_1, c_1 and β) as (0.020, 0.017, 0.011, 0.031, 0.011) respectively, which provide a numerical evaluation of our uncertainties. Emphasis is made on the large range of the standard stars in the magnitude and color values: V:(5.4, 8.7); $(b-y)$:(0.02, 0.80); m_1:(0.09, 0.67); c_1:(0.06, 1.12) and β:(2.53, 2.89).

The transformation equations used in the work have the following forms in which 'inst' stands for instrumental values and 'std' for photometric values in the standard system:

$$
\begin{aligned}
V &= \mathrm{A} + \mathrm{B}\ (b-y)(\mathrm{inst}) + y\ (\mathrm{inst}), \\
(b-y)\ (\mathrm{std}) &= \mathrm{C} + \mathrm{D}\ (b-y)(\mathrm{inst}), \\
m_1(\mathrm{std}) &= \mathrm{E} + \mathrm{F}\ m_1(\mathrm{inst}) + \mathrm{J}\ (b-y)(\mathrm{inst}), \\
c_1(\mathrm{std}) &= \mathrm{G} + \mathrm{H}\ c_1(\mathrm{inst}) + \mathrm{I}\ (b-y)(\mathrm{inst}), \\
\beta\ (\mathrm{std}) &= \mathrm{K} + \mathrm{L}\ \beta\ (\mathrm{inst}).
\end{aligned}
$$

TABLE 2

TRANSFORMATION COEFFICIENTS OBTAINED FOR THE TWO OBSERVING SEASONS

Season	B	D	F	J	H	I	L
2009	−0.005	0.975	1.002	0.037	1.008	−0.067	−1.397
σ	0.051	0.032	0.045	0.033	0.049	0.067	0.031
2010	0.002	0.962	1.021	0.025	0.991	−0.006	−1.309
σ	0.013	0.003	0.034	0.002	0.042	0.145	0.021

Table 3 lists the photometric values of the observed stars for the NGC 6811 cluster. In this table we list the following: Column 1, the ID number as in WEBDA, which follows Lindoff's nomenclature; Columns 2 to 6 the measured photometric values (N denotes the times each star was measured) the next five columns list the standard deviations from our photometry and the final columns, the spectral type for each star, determined from the $[m1]$ $[c1]$ diagram and from WEBDA and Becker (1947). The agreement between the spectral types deduced from the photometry with that reported by spectroscopic methods is interesting to note. Although there is consistency among the three values, there also is some disagreement among them. For example, W113 has spectroscopic types A4 and A8 from WEBDA and Becker (1947), respectively and there are some stars (W16 and W37) that are defined as early type stars from the spectroscopy and as later types from the photometry. Nevertheless, we note that, in general, the spectral types are coincident within the three mentioned sources. The remaining stars we classified do not have reported spectral classes. Table 4 lists in Column 1 the ID of WEBDA, Columns 2 to 6 the photometric values, Column 7 the spectral type derived from the photometry and Columns 8 and 9 the spectral types listed by WEBDA which are, respectively, Hoag & Applequist (1965) and Turner (1976).

2.2. *Comparison with other photometries*

Since no $uvby-\beta$ has been previously obtained for these clusters, a comparison of our values was made with the available UBV photometry reported in WEBDA.

NGC 6811. We compared our 2009 season photometry with that reported by WEBDA. The intersection of both sets is constituted of seventy five stars, some of them (four) showing a large difference, greater than 0.5 mag in V. There were some others (six) with differences larger than 0.1 mag. In view of this we planned and carried out a second campaign in 2010. Table 3 reports the mean values of the two observing campaigns; N indicates the number of measurements for each star. Among the stars with large differences found in the 2009 season and WEBDA, five were measured in both observational campaigns showing small differences between them. Hence, with high probability, the discrepancies cannot be attributed to our measurements because (i) these stars were measured in two different seasons one year apart by different observers and (ii) the measured standard stars show reasonable values when compared to the standard literature values. Hence, the differences can be due to either a misidentification of the star by previous authors or a variable nature of these stars. Despite these differences, a linear fit between both sets yields the equation $V_{(\mathrm{pp})} = 0.82 + 0.97\, V_{(\mathrm{WEBDA})}$ with a correlation coefficient of 0.97 and a standard deviation of 0.25. The color relationship yields $(b-y) = 0.06 + 0.57\ (B-V)$ with a correlation coefficient of 0.92 and a standard deviation of 0.09.

NGC 6830. This cluster was compared with those UBV values reported by WEBDA for a set constituted of only seven stars. The linear fit between both sets gave the equation $V_{(\mathrm{pp})} = 0.477 + 0.958 \times V_{(\mathrm{WEBDA})}$ with a correlation coefficient of 0.997 and a standard deviation of 0.080. The relationship in $B-V$ and $b-y$ gave $(b-y) = 0.117 + 0.573 \times (B-V)$ with a correlation coefficient of 0.922 and a standard deviation of 0.022.

3. METHODOLOGY

In order to determine the physical characteristics of the stars in each cluster this procedure was followed.

The evaluation of the reddening was done by first 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

TABLE 3

$uvby-\beta$ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 6811

WBD	V	$(b-y)$	m_1	c_1	bt	sV	sby	sm_1	sc_1	sbt	N	Spectral Type	
												Photometry	WBD
4	12.681	0.259	0.127	0.861	2.706						1	A3V	A7
5	11.795	0.168	0.185	0.950	2.770	0.067	0.028	0.015	0.029	0.062	28	A5V	A2
6	14.463	0.786	0.291	0.554	2.538	0.076	0.111	0.108	0.226	0.071	3	>G	
7	14.381	0.399	0.125	0.388	2.588	0.201	0.071	0.221	0.104	0.020	3	F7V	
8	14.110	0.356	0.142	0.498	2.630	0.150	0.053	0.153	0.115	0.055	3	F7V	
9	12.081	0.166	0.218	0.959	2.790	0.080	0.015	0.029	0.067	0.077	3	Ap	A1
10	14.234	0.339	0.223	0.346	2.525	0.283	0.073	0.065	0.153	0.180	3	G2V	
12	14.363	0.455	0.148	0.387	2.540	0.098	0.067	0.057	0.142	0.094	3	G0V	
13	15.055	0.567	0.058	0.542	2.585	0.264	0.158	0.164	0.277	0.037	2	F7V	
14	13.672	0.765	0.399	0.174	2.510	0.182	0.029	0.041	0.022	0.040	2	>G	
16	12.196	0.235	0.165	0.927	2.781						1	A5V	A4
18	12.118	0.236	0.144	0.966	2.806						1	A5V	A4
22	13.034	0.522	0.267	0.230	2.529	0.019	0.018	0.005	0.023	0.039	2	K0V	
23	13.981	0.558	0.227	0.185	2.655						1	>G	
24	11.245	0.613	0.327	0.318	2.564	0.044	0.020	0.012	0.052	0.019	2	>G	G8
26	11.414	0.197	0.186	0.985	2.795						1	A5V	
31	13.308	0.327	0.131	0.635	2.760						1	F5V	
32	11.351	0.640	0.349	0.322	2.583						1	>G	G
33	11.917	0.232	0.149	0.950	2.771						1	A5V	A2
34	11.623	0.204	0.204	0.956	2.829						1	A5p	B9
35	13.859	0.325	0.206	0.406	2.559	0.084	0.071	0.052	0.071	0.020	2	G2V	
36	13.221	0.283	0.180	0.561	2.614	0.065	0.062	0.049	0.009	0.052	2	G0V	
37	11.113	0.182	0.181	0.933	2.766	0.034	0.013	0.006	0.023	0.040	29	A5V-F5Ib	
38	13.206	0.662	0.382	0.330	2.535	0.052	0.079	0.013	0.066	0.128	2	>G	
39	11.528	0.212	0.157	0.961	2.728	0.069	0.020	0.012	0.042		29	A5V	A4
40	13.070	0.111	0.147	0.632	2.673	0.127	0.062	0.073	0.100	0.071	2	A1V	
41	12.014	0.148	0.195	0.956	2.741	0.100	0.035	0.017	0.037		29	A5V	
42	12.568	0.190	0.184	0.829	2.698	0.172	0.055	0.028	0.049	0.059	29	A8V	
43	12.743	0.268	0.176	0.785	2.658	0.023	0.000	0.001	0.049	0.030	2	A8V	
44	12.046	0.169	0.182	0.935	2.757	0.082	0.033	0.016	0.032	0.029	29	A5V	
45	12.705	0.204	0.194	0.831	2.735	0.142	0.027	0.015	0.040	0.039	3	A8V	A5
46	12.958	0.329	0.116	0.533	2.645	0.058	0.006	0.017	0.047	0.043	3	F5V	
47	13.649	0.383	0.099	0.389	2.613	0.136	0.020	0.046	0.065	0.083	3	F5V	
49	12.422	0.218	0.142	0.978	2.822						1	A0V	A5
51	13.418	0.269	0.139	0.592	2.590	0.076	0.094	0.115	0.125	0.035	2	F5V	
53	12.754	0.178	0.191	0.898	2.774	0.076	0.020	0.030	0.045	0.085	3	A5V	
54	12.356	0.266	0.136	0.757	2.713	0.027	0.025	0.029	0.027	0.078	3	A8V	
56	12.160	0.247	0.149	0.787	2.691	0.013	0.025	0.024	0.055	0.037	2	A8V	
57	14.039	0.439	0.161	0.357	2.670	0.149	0.196	0.161	0.114	0.073	4	G0V	
58	14.350	0.622	0.219	0.151	2.650	0.187	0.231	0.122	0.256	0.132	3	K0V	
62	12.846	0.224	0.163	0.728	2.714						2	A8V	
63	15.234	0.979	0.846	0.714		0.193	0.569	0.401	0.677	0.294	2	>G	
64	13.609	0.352	0.088	0.557	2.897	0.041	0.016	0.056	0.021	0.366	2	F2V	
65	14.450	0.460	0.199	0.217	2.510	0.087	0.164	0.106	0.057	0.103	2	G2V	
68	10.850	0.272	0.152	0.869	2.737						1	A8V	A2
70	10.925	0.298	0.139	0.876	2.713						1	A5V	A4
71	13.716	0.388	0.154	0.473	2.551						1	G0V	A2
73	9.851	0.992	0.830	0.166	2.551						1	>G	K5
74	12.322	0.415	0.171	0.305	2.568	0.078	0.007	0.003	0.028	0.008	2	G0V	
77	13.860	0.257	0.206	0.461	2.650	0.120	0.040	0.041	0.028	0.025	2	G0V	
78	13.664	0.270	0.167	0.567	2.676	0.070	0.023	0.011	0.040	0.037	2	F7V	
79	10.393	0.935	0.719	0.146	2.519						1	>G	
82	13.025	0.705	0.341	0.333	2.546						1	>G	
85	12.860	0.308	0.134	0.545	2.684						1	F5V	
86	13.389	0.334	0.106	0.490	2.662						1	F2V	
87	12.622	0.380	0.206	0.399	2.617						1	G2V	
92	12.260	0.221	0.166	0.722	2.704						1	A8V	
99	11.962	0.168	0.184	0.957	2.817	0.036	0.036	0.028	0.028	0.078	2	A5V	B9
101	10.682	0.671	0.393	0.333	2.569						1	>G	
102	12.882	0.586	0.221	0.287	2.562						1	K0V	
105	12.419	0.230	0.241	0.850	2.802						1	Ap	A7
106	11.379	0.301	0.138	0.796	2.713						1	A8V	A3
107	12.726	0.419	0.123	0.414	2.640						1	F7V	
112	12.825	0.372	0.146	0.412	2.663						1	F9V	
113	11.471	0.233	0.144	0.990	2.767						1	A5V	A4
114	12.145	0.229	0.141	0.967	2.786	0.020	0.033	0.019	0.053	0.035	3	A5V	B7
115	11.551	0.220	0.169	0.787	2.759	0.135	0.040	0.023	0.076	0.025	3	A3V	A1
118	12.352	0.469	0.174	0.399	2.548						1	G2V	
122	12.825	0.372	0.146	0.412	2.663						1	F9V	
123	13.970	0.648	0.689	0.386	2.579						1	>G	
133	12.069	0.576	0.346	0.230	2.510						1	>G	G2
139	13.197	0.358	0.082	0.569	2.646						1	F2V	
146	12.504	0.353	0.151	0.475	2.650						1	F9V	
147	12.129	0.168	0.200	0.972	2.847						1	A5V	A4
178	9.909	1.039	0.839	0.225	2.835						1	>G	
218	12.087	0.194	0.157	0.982	2.858						1	A5V	A5
489	11.000	0.252	0.179	0.855	2.748						1	A5V	
491	13.681	0.240	0.241	0.857	2.889						1	Ap	
V17	15.009	0.560	0.067	0.157	2.468						1	F9V	

TABLE 4

$uvby - \beta$ PHOTOELECTRIC PHOTOMETRY OF THE OPEN CLUSTER NGC 6830

ID	V	$(b-y)$	m_1	c_1	β	SpTyp		sptp
						Phe	Spc	
5	9.849	0.266	0.013	0.554	2.721	B6V	B7 V	B5 III
7	11.176	0.353	0.007	0.822	2.689	B8V	A0 V	B7 III
8	11.540	0.373	−0.018	0.716	2.616	B7V	B7 IV	
49	10.956	0.456	0.103	0.875	2.751	AV5		
4	12.623	0.600	−0.100	0.471	2.685	B3V		
2258	13.003	0.546	0.086	0.484	2.721	F9V		
2257	12.166	0.390	−0.008	0.584	2.706	B7V		
26	12.309	0.564	0.160	0.255	2.661	G1V		
164	12.240	0.460	0.093	0.819	2.766	A8V		
25	12.465	0.333	0.012	0.661	2.718	B8V		
24	11.644	0.391	−0.034	0.612	2.635	B5V	B6 V	B6 IV
2	10.625	0.329	−0.017	0.606	2.603	B5V		
3	12.888	1.620	0.383	0.256	2.569	K G		
39	11.192	0.386	−0.051	0.681	2.668	B8I	B5 IV	
2275	11.909	1.160	0.306	−0.047	2.576	B7V		
13	12.787	0.767	0.134	0.380	2.605	K0V		
14	11.995	0.348	0.017	0.532	2.714	B6V	B6 V	B6 IV
15	12.659	0.407	−0.035	0.646	2.681	B6V		
16	12.456	0.408	0.108	0.807	2.794	K		

(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 criteron. In Tables 3 and 4 the photometrically determined spectral class has been indicated. The determined spectral types compiled in the literature are also presented.

The reddening determination was obtained from the spectral types through Strömgren photometry. The application of the calibrations developed for each spectral type (Shobbrook 1984 for O and early A types and Nissen 1988 for late A and F stars) were considered. No determination of reddening was calculated for G and later spectral types. The results of applying such calibrations are shown in Tables 5 and 6 for NGC 6811 and NGC 6830, respectively. In Table 5, the following columns are presented: Column 1 the ID (WEBDA) for each star; Column 2, the reddening $E(b-y)$; Columns 3 to 5, the unreddened indexes $(b-y)_0$, m_0, and c_0; Column 6 the Hβ value; Columns 7 and 8 V_0, and the absolute magnitude, respectively. Columns 9 and 10 show the distance modulus and the distance in parsecs. The metallicity is presented in Column 11 and, finally, Column 12 lists the membership to the cluster, denoted by M (member) or NM (non-member). The membership was determined from the distance modulus or distance histograms. A Gaussian fit with a bin size of one was done to the bars in the histogram to all the stars and the obtained fit is presented, along with the uncertainties in each figure. Membership then was established from the above mentioned fit. Stars within a standard deviation value from the mean were considered to be members. Those with standard deviation values slightly larger than one sigma are considered to be stars with marginal membership. In the table, those stars that are considered to be members of the cluster are denoted by an ‘m’. Marginal membership is indicated by a semi-colon, ‘m:’, those that were non-members are denoted by ‘nm’. Table 6 is analogous. Probable members are denoted by a semicolon.

TABLE 5

REDDENING, UNREDDENED PARAMETERS AND DISTANCE FOR THE OPEN CLUSTER NGC 6811

ID	$E(b-y)$	$(b-y)_0$	m_0	c_0	β	V_0	M_V	DM	DST	[Fe/H]	Memb
112	0.082	0.290	0.171	0.396	2.663	12.47	3.82	8.7	537	0.1	NM
122	0.082	0.290	0.171	0.396	2.663	12.47	3.82	8.7	537	0.1	NM
107	0.108	0.311	0.155	0.392	2.640	12.26	3.47	8.8	574	−0.2	NM
31	0.134	0.193	0.171	0.608	2.760	12.73	3.47	9.3	713		M
489	0.072	0.180	0.201	0.841	2.748	10.69	1.32	9.4	749		M
146	0.052	0.301	0.167	0.465	2.650	12.28	2.82	9.5	780	0.0	M
68	0.085	0.187	0.177	0.852	2.737	10.48	1.01	9.5	786		M
34	0.099	0.105	0.234	0.936	2.829	11.20	1.57	9.6	842		M
105	0.093	0.137	0.269	0.831	2.802	12.02	2.16	9.9	938		M
85	0.055	0.253	0.150	0.534	2.684	12.63	2.71	9.9	964	−0.1	M
218	0.116	0.078	0.192	0.959	2.858	11.59	1.65	9.9	973		M
106	0.088	0.213	0.164	0.778	2.713	11.00	1.06	9.9	973	0.0	M
47	0.060	0.323	0.117	0.377	2.613	13.39	3.42	10.0	985	−0.7	M
37	0.024	0.158	0.188	0.928	2.766	11.01	0.87	10.1	1065		M
147	0.080	0.088	0.224	0.956	2.847	11.79	1.62	10.2	1080		M
70	0.089	0.209	0.166	0.858	2.713	10.54	0.31	10.2	1112	0.0	M
86	0.061	0.273	0.124	0.478	2.662	13.13	2.88	10.3	1120	−0.5	M
26	0.067	0.130	0.206	0.972	2.795	11.12	0.84	10.3	1140		M
99	0.053	0.115	0.200	0.946	2.817	11.73	1.42	10.3	1154		M
18	0.113	0.123	0.178	0.943	2.806	11.63	1.18	10.5	1233		M
115B	0.261	−0.041	0.247	0.737	2.759	10.43	−0.22	10.6	1345		M
16	0.088	0.147	0.192	0.909	2.781	11.82	1.15	10.7	1357		M
54	0.052	0.214	0.152	0.747	2.713	12.13	1.43	10.7	1384	−0.2	M
113	0.082	0.151	0.168	0.974	2.767	11.12	0.37	10.8	1409		M
92	0.000	0.226	0.166	0.722	2.704	12.26	1.49	10.8	1423	0.0	M
46	0.040	0.289	0.128	0.525	2.645	12.79	2.01	10.8	1431	−0.5	M
33	0.080	0.152	0.173	0.934	2.771	11.57	0.79	10.8	1431		M
114	0.090	0.139	0.168	0.949	2.786	11.76	0.87	10.9	1506		M
049B	0.244	−0.026	0.215	0.932	2.822	11.37	0.48	10.9	1513		M
5	0.015	0.153	0.189	0.947	2.770	11.73	0.78	11.0	1549		M
9	0.030	0.136	0.227	0.953	2.790	11.95	1.00	11.0	1551		M
62	0.008	0.216	0.165	0.726	2.714	12.81	1.72	11.1	1650	0.0	M
139	0.080	0.278	0.106	0.553	2.646	12.85	1.57	11.3	1808	−0.7	M
44	0.004	0.165	0.183	0.934	2.757	12.03	0.72	11.3	1824		M
53	0.023	0.155	0.198	0.893	2.774	12.66	1.31	11.4	1860		M
45	0.012	0.192	0.198	0.829	2.735	12.65	1.30	11.4	1863		M
78	0.004	0.266	0.168	0.566	2.676	13.65	2.27	11.4	1882	0.1	M:
39	0.028	0.184	0.165	0.955	2.728	11.41	−0.03	11.4	1938		NM
41	0.000	0.176	0.195	0.956	2.741	12.01	0.31	11.7	2192		NM
8	0.039	0.317	0.154	0.490	2.630	13.94	2.20	11.7	2230	−0.3	NM
56	0.013	0.234	0.153	0.784	2.691	12.11	0.36	11.8	2238	−0.1	NM
36	0.000	0.344	0.180	0.561	2.614	13.22	0.98	12.2	2805	−0.1	NM
42	0.000	0.231	0.184	0.829	2.698	12.57	0.22	12.4	2952	0.3	NM
004B	0.296	−0.037	0.216	0.805	2.706	11.41	−1.33	12.7	3532		NM
51	0.000	0.342	0.139	0.592	2.590	13.42	−0.09	13.5	5033	−0.6	NM
43	0.000	0.279	0.176	0.785	2.658	12.74	−0.77	13.5	5041	0.1	NM
040B	0.161	−0.050	0.195	0.601	2.673	12.38	−1.76	14.1	6728		NM
Mean value	0.074							10.42	1258	−0.3	
σ	0.057							0.61	339	0.3	

TABLE 6

REDDENING, UNREDDENED PARAMETERS AND DISTANCE FOR THE OPEN CLUSTER NGC 6830

ID	$E(b-y)$	$(b-y)_0$	m_0	c_0	β	V_0	M_V	DM	DST	[Fe/H]	Mbr
26	0.244	0.320	0.233	0.206	2.661	11.26	5.67	5.59	131	0.85	nm
2258	0.310	0.236	0.179	0.422	2.721	11.67	4.10	7.57	327		nm
13	0.371	0.396	0.245	0.306	2.605	11.19	3.43	7.76	357	0.46	nm
164	0.291	0.169	0.180	0.761	2.766	10.99	1.90	9.09	658		nm
5	0.326	−0.060	0.111	0.492	2.721	8.45	−0.65	9.10	661		m:
4	0.677	−0.077	0.103	0.342	2.685	9.71	−1.25	10.96	1559		m
14	0.412	−0.064	0.141	0.454	2.714	10.22	−0.76	10.98	1571		m
7	0.394	−0.041	0.125	0.747	2.689	9.48	−1.64	11.12	1676		m
2257	0.449	−0.059	0.127	0.499	2.706	10.23	−0.91	11.14	1692		m
39	0.436	−0.050	0.080	0.598	2.668	9.32	−1.89	11.21	1745		m
25	0.384	−0.051	0.127	0.588	2.718	10.81	−0.76	11.57	2063		m
15	0.461	−0.054	0.103	0.558	2.681	10.68	−1.49	12.16	2709		m
24	0.447	−0.056	0.100	0.527	2.635	9.72	−2.81	12.53	3200		m
2	0.385	−0.056	0.098	0.533	2.603	8.97	−4.40	13.37	4719		nm
8	0.420	−0.047	0.108	0.636	2.616	9.73	−4.08	13.81	5785		nm

4. ANALYSIS

In order to gain some insight into the clusters we must first find out which stars belong to each one. As was already mentioned, this is accomplished by constructing a histogram of the deduced distances. From the results listed in Tables 5 and 6 and shown in Figure 1, we can establish that NGC 6811 has a distinctive accumulation of thirty-seven stars at a distance modulus of 10.5 ± 1.0 mag, whereas NGC 6830 is merely an association of eight early type stars at DM 11.1 ± 1.6 mag, although emphasis should be made on the fact that we merely observed a small sample of stars in the direction of this cluster: nineteen of the brightest stars. According to the study of Netopil et al. (2007) four CP stars in NGC 6830 were found. Since Strömgren photometry is most suitable for this topic, we checked our measured stars for the Ap determination. Unfortunately, none of our measured stars lay in the regions defined by the boxes in the m_0, and c_0 diagram where the Ap stars should be, as in Golay's (1974, Figure 124). Hence, we cannot corroborate, nor discard the findings by Netopil et al. (2007). For NGC 6811 we determined four stars belonging to the Ap category, namely W9, W34, W105 and W491, all to the Sr-Cr-Eu class.

Age is fixed for the two determined clusters once we measured the hottest and hence the brightest stars for each one. The effective temperature of these hottest stars was determined by plotting the location of all stars on the theoretical grids of LGK86, once we evaluated the unreddened colors (Figure 2) for a solar chemical composition. We considered this metallicity based on the thirteen F type stars for which we determined the metallicity [Fe/H]; a mean value of -0.18 ± 0.30 was found. In the related figures, LGK86 in the upper left corner indicates that the grids were taken from the mentioned reference of LGK86 and the specified metalicity. We have utilized the $(b-y)$ vs. c_0 diagrams which allow the determination of the temperatures with an accuracy of a few hundreds of degrees. However, for NGC 6811, as can be seen in Figure 2, the stars are clustered together and the effective temperature cannot be easily determined. To measure the temperature with more accuracy, a plot of $(b-y)$ vs. β was constructed and compared with the theoretical grids of LGK86, Figure 3. The temperature for the hottest stars is around 11,700 K for NGC 6811, whereas for NGC 6830 it is much hotter (17,000 K). Once membership has been established, age is determined after calculating the effective temperature through the calibrations of Meynet, Mermilliod, & Maeder (1993) for open clusters; a log age of 8.266 (1.845×10^8 yr) is found from the relation $-3.611 \log\log T_{\rm eff} + 22.956$ valid in the range $\log\log T_{\rm eff}$ within the limits [3.98, 4.25] for NGC 6811; whereas for NGC 6830 the re-

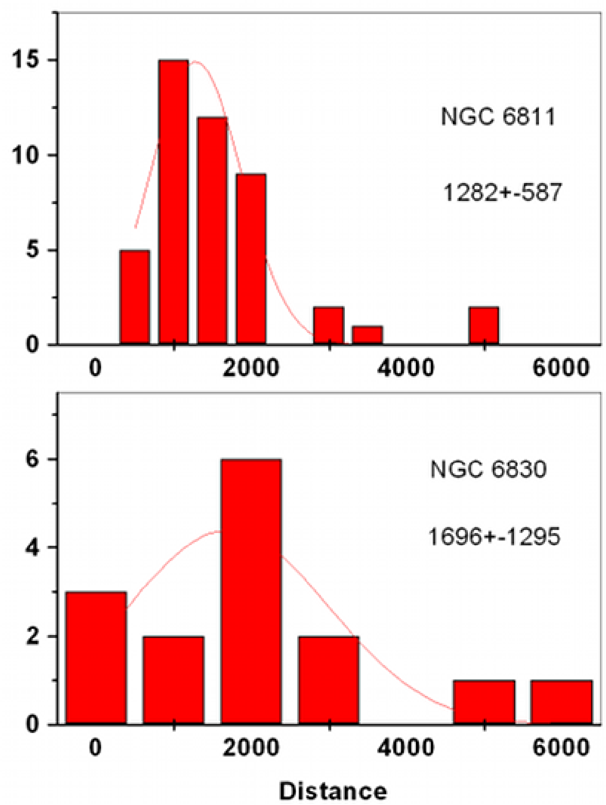

Fig. 1. Histogram of the distance modulus (X axis, in magnitudes) found for the B, A and F stars in the direction of NGC 6811 (top) and NGC 6830 (bottom).

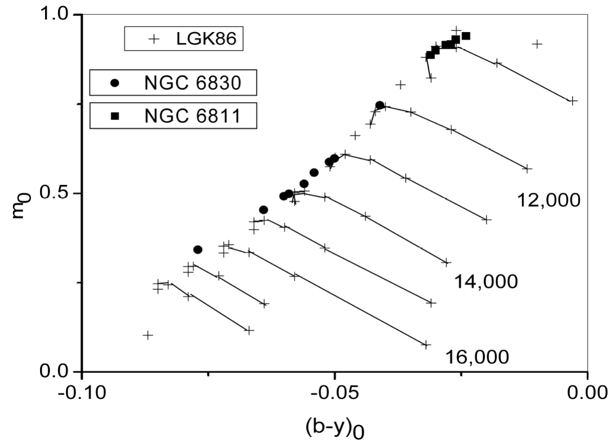

Fig. 2. Location of the unreddened points of the two clusters on the LGK86 grids. Squares: NGC 6811; dots: NGC 6830.

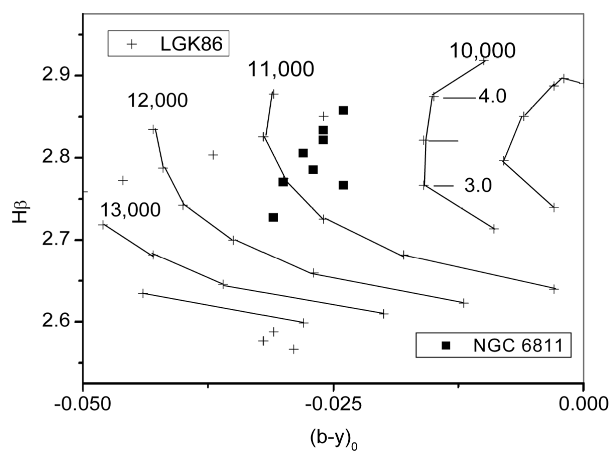

Fig. 3. Location of the unreddened points of the hot stars in the NGC 6811 cluster on the LGK86 grids.

lation $\log(\mathrm{age}) = -3.499 \log\log T_{\mathrm{eff}} + 22.476$ valid in the range [4.25, 4.56] yields log(age) of 7.69 (4.89×10^7 yr).

These determinations are confirmed by constructing the color-magnitude diagram of NGC 6811 and NGC 6830 which are shown in Figures 4 and 5, respectively. The unreddened magnitudes $[(b-y)_0,\ M_V]$ of cluster members taken from Tables 5 (NGC 6811) and 6 (NGC 6830) are shown with filled circles. In each plot two theoretical isochrones in the Strömgren photometric system are shown with solid and dashed lines. The metallicity and ages are indicated in the figures. The theoretical isochrones were obtained from the Padova database (Girardi et al. 2003). As can be seen, the isochrones match the observed color-magnitude diagram with the ages and distance derived in the present paper.

5. VARIABLE STARS IN NGC 6811

As was stated in the introduction, Luo et al. (2009) performed time-series photometric observations of the open cluster NGC 6811 to search for variable stars. These observations were carried out during five nights from June 6 to July 24, 2008 utilizing the 85 cm telescope of the Xonglong Station of the National Astronomical Observatories of the Chinese Academy of Sciences. The instrumentation they used was a 1024×1024 CCD camera with a field of view of $16.5' \times 16.5'$ with standard Johnson-Cousin-Bessell filters in B and V bands, with which they obtained 750 CCD frames in each band. Sixteen certain variable stars were detected or confirmed from that survey, namely V1–V7 and V10–V18 following the variable name list of van Cauteren et al. (2005) (see Table 1 by Luo et al. 2009). Among these, twelve stars were catalogued as Delta Scuti variables based upon the light curves (V1–V7 and V10–V14). The omitted variables, V8 and V9, were outside of their

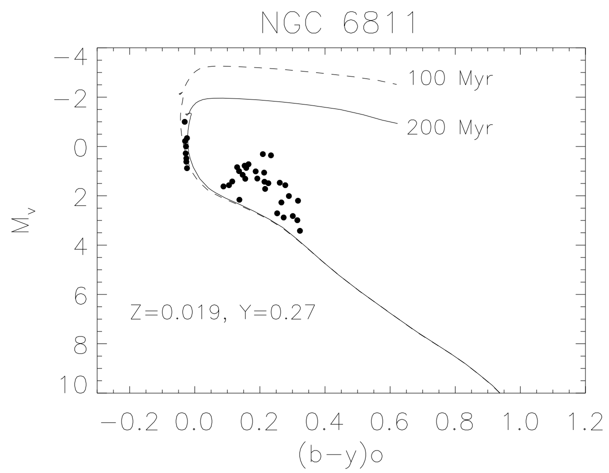

Fig. 4. Color-magnitude diagram of the NGC 6811 cluster considering only the cluster members. The target stars are represented by filled circles. Theoretical isochrones for 100 Myr (dashed line) and 200 Myr (solid line) computed with $Z = 0.019$ are shown.

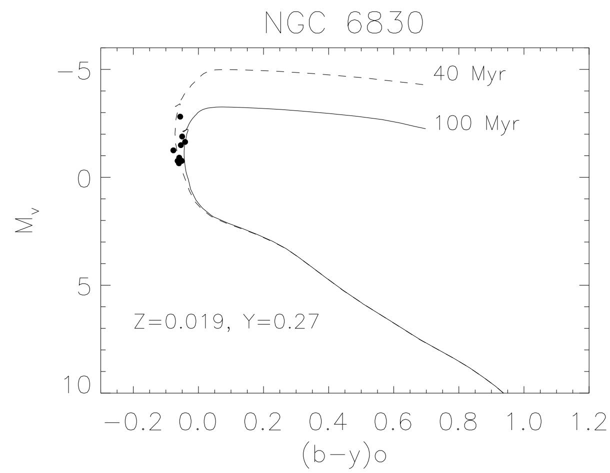

Fig. 5. Color-magnitude diagram of the NGC 6830 cluster considering only the cluster members. The target stars are represented by filled circles. Theoretical isochrones for 40 Myr (dashed line) and 100 Myr (solid line) computed with $Z = 0.019$ are shown.

field-of-view. In particular, Luo et al. (2009) discovered variability in V10–V18; four of them (V10, V12, V15, V16) had been just reported as suspected variables by Rose & Hintz (2007), while the variability of V1–V7 was discovered by van Cauteren et al. (2005). On the other hand, nine stars reported as variables by Rose & Hintz (2007) were not confirmed by Luo et al. (2009). One explanation provided for this inconsistency was that the amplitude of light variations was too low to be detected. Luo et al. 2009 also determined the membership probabilities of twelve variables (V1–V5 and V10–V16) through the proper-motion membership probabilities (PMP) listed by Sanders (1971). From these values they claim that with high probability all of the twelve stars (V1–V3, V5, V10–V16) are cluster members, except for V4. For the the stars without PMP data, namely V6, V7, V17 and V18, based on their position in the CMD diagram, they concluded that the first two are most likely members of the cluster whereas the last two are probably field stars.

On the night of August 6, 2010 (UT) we carried out a very short span of observations in differential photometric mode. The variables we considered were chosen due to their nearness and were, in the notation of Luo et al. (2009): V2, V4, V11 and V14 with W5 and W99 as reference and check stars. Although the time span we observed was too short to detect long period variation, the only star which showed a clear variation was V4, with two clearly discernible peaks of relatively large amplitude of variation, 0.188 mag, and a period of 0.025 d.

From our cluster membership determinations on a star-to-star basis, the conclusion we reach is slightly different from the previous assertions regarding variability. Memberships are determined for V1, V3, V4, V5, V10, V11, V13 and V16. Marginal membership for V12 and V14, non-membership for V15 and we were unable to determine membership for the remaining stars mainly because they do not belong to the spectral classes B, A or F but belong to a latter spectral type which makes them unlikely to be δ Scuti type variables. From the location of these variables in the theoretical grids of LGK86, Figures 6 and 7, we determine their temperatures.

6. CONFIDENCE OF THE RESULTS

As has been said in previous sections, the high accuracy of each observed star was attained by multiply observing each star in sequences of five 10 sec integrations. Hence, mean values and standard deviations were calculated to determine the signal/noise ratio. In all cases, enough star counts were secured to attain a signal to noise ratio large enough to achieve an accuracy better than 0.01 mag. Nevertheless, it is obvious that the brighter stars were more accurately observed than the fainter ones. Quoting Nissen (1988) "as expected from photon statistics considerations the average mean errors increase as we go to fainter magnitudes". Unfortunately, since the aim of this project was to observe as many stars as possible, most of them were observed only twice, and a few, only once. The uncertainties of the season were determined from the differences between

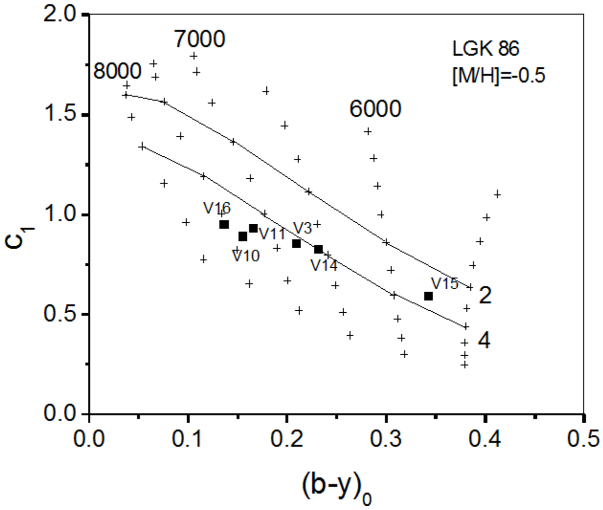

Fig. 6. Location of the δ Scuti stars of NGC 6811 on the theoretical grids of LGK86.

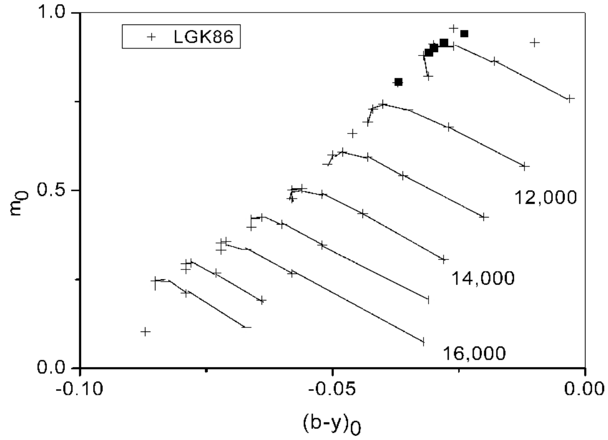

Fig. 7. Location of the hot variable stars of NGC 6811 on the theoretical grids of LGK86.

the derived magnitude of the standard stars vs. reported values in the literature. The average values of such differences are $\Delta(V,\ b-y,\ m_1,\ c_1) = (0.008,\ 0.005,\ -0.004,\ 0.012)$; on most nights at least ten standard stars were observed but this figure increased to 15 on some nights. The number of the whole sample of standards data points, due to the large time span of the season, was considerable, adding up to 80 points of standard stars.

To calculate the propagation of errors for the reddening (in Nissen's 1988 work, § 3), the intrinsic color index $(b-y)_0$ has served to determine the individual color excess, $E(b-y) = (b-y) - (b-y)_0$ and, as in his paper, assuming the photometric mean errors given for our observations, although larger than the work by Nissen (1988), we do expect a mean error $E(b-y)$ close to that derived by Nissen of 0.011 for F stars and of 0.009 for A stars, since our errors are not exceedingly different.

7. DISCUSSION

New $uvby-\beta$ photoelectric photometry has been acquired and is presented for the brightest stars in the direction of two open clusters NGC 6811 and NGC 6830. From the observed stars in the field, some were determined to be early type stars, either B or A. Using the calibrations to determine reddening and distance for these stars, distances for the clusters have been obtained. Unreddened indexes in the LGK86 grids allowed us to determine the effective temperature of the hottest stars and hence, the age of the cluster.

A brief discussion of each cluster is presented. Table 7 lists the previous knowledge and the newly determined characteristics of the clusters.

NGC 6811. Considering the classical UBV photometry compiled for this cluster, very little can be deduced about its properties. No clear distinction in the color-color diagram $B-V$ vs $U-B$ can be drawn; the same conclusion is reached from its HR diagram. From our results we have determined that 37 stars belong to the cluster. Since they are the brightest, the conclusion on the age, which agree with that previously determined, is also correct. We have found that the cluster is farther, its extinction is less and it is younger than previously assumed. The goodness of our method has been previously tested, as in the case of the open cluster Alpha Per (Peña & Sareyan 2006) against several sources which consider proper motion studies as well as results from the Hipparcos and Tycho data bases. Hence, we feel that our results throw new light regarding membership to this cluster.

There have been several previous works in which membership probabilities were considered. Table 8 lists the identification numbers from several studies, namely those of WEBDA, Luo et al. (2009), Sanders (1971), Becker (1947), Barkhatova, Zakharova, & Shashkina (1978) and more recently, the compilation by Kharchenko et al. (2005). We have repeated part of the information on the distance provided in Table 8 in order to support the conclusions based on the last columns of the table, which present the membership probability obtained in the present paper (PP), that of Sanders (1971) and those reported by the compilation of Kharchenko et al. (2005) based on

TABLE 7

COMPILED CHARACTERISTICS FOR NGC 6830 AND NGC 6811

Cluster	Source	log age	Reddening $E(B-V)$ [mag]	Distance [kpc]	Metallicity
NGC 6830	Barkhatova (1957)	–	–	1.68	–
	Hoag & Applequist (1965)	–	0.51	1.38	–
	Becker & Fenkart (1971)	–	0.58	1.47	–
	Moffat (1972)	8.0	0.56	1.70	–
	Glushkova et al. (1999)	–	0.12	1.24	–
	Dias et al. (2002)	7.57	0.50	1.64	–
	Kharchenko et al. (2005)	7.52	0.50	1.64	–
	Paunzen & Mermilliod (2007)	7.57	0.50	1.64	–
	PP	7.69	0.63	1.88	+0.13
NGC 6811	Luo et al. (2009)	8.76	0.12	1.31	+0.02
	Paunzen & Mermilliod (2007)	8.80	0.16	1.22	–
	PP	8.27	0.14	1.64	−0.02

studies of proper motion, photometry and position of the stars. Membership probabilities, if compared with those of Sanders' (1971), are in rough agreement: all but two stars (W92 and W146) that we assign cluster membership are not assigned as members according to Sanders' probabilities, but it is equally true that those which we define as non-members are determined to be members by Sanders (1971). When the comparison is done with those probabilities of the compilation of Kharchenko et al. (2005) the conclusions are equally in agreement. There are two stars, W18 and W45 we define as members that Kharchenko et al. (2005) find to be non-members from the proper motion studies but members with the other two criteria. In conclusion, the comparison of our results with the others support our findings particularly because the results obtained from $uvby-\beta$ photometry are more accurate.

The DM and reddening determined from our photometry, although discordant from those derived from UBV photometry, is in agreement with that of Glushkhova, Batyrshinova, & Ibragimov (1999) who, from radial velocity measurements for 60 late-type stars and $UBVRI$ photoelectric photometry refined the distance modulus of the cluster to be 10.47 ± 0.08 mag and $E(B-V)$ of 0.12 ± 0.02, in agreement with the values we derived.

We were able to determine membership to the NGC 6811 open cluster of several variable stars. We found that six stars V1, V4, V10, V11, V13 and V16 are cluster members. On the contrary, V12, V14 and V15 are definitely non-member stars. For the rest not much can be said. Accurate temperature determination was done for each star.

NGC 6830. Again, since no previous $uvby-\beta$ exists, knowledge of the cluster rests 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 nineteen stars, but with this small sample we determined some clustering of stars. Our findings coincide, within the uncertainties, with the previous distance, reddening and age determinations. Of course, many more data are needed to unambiguously establish the true nature of this cluster, but we emphasize that, since we observed all the bright stars, our conclusions are correct.

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TABLE 8

CROSS ID AND MEMBERSHIP PROBABILITIES FOR THE OPEN CLUSTER NGC 6811

WBD	Luo et al. (2009)	Sanders (1971)	Becker (1947)	Barkhatova et al. (1978)	Kharchenko (2005)	Prob (Sanders)	Prob (Kharchenko)			mbr
							Pkin	Pph	Psp	
112		177	51	1136		0				nm
122										nm
107		183	48			96				nm
31		102	15	1057		97				m
489	6	205		2080		89				m
146		187	42	1143		0				m
68		110	86	1065	78	97	0.9272	1	1	m
34		121	22	1084		96				m
105		185	47	1141		25				m
85		94	4	1041		95				m
218		192		1154		92				m
106		172	49	1133		97				m
47		158	35	1121		96				m
37	2	136	26	1104		96				m
147		189	43	1146		97				m
70	3	108	82	1063	76	96	0.9837	1	1	m
86		98	5	1050		89				m
26		86	10	1038	69	97	0.4193	1	1	m
99		159	29	1122		97				m
18	1	97	85	1049	73	97	0.0016	1	1	m
115		149	65			95				m
16		103	81	1059		90				m
54		147	68	1114		97				m
113	5	166	60	1126	98	93	0.8128	1	1	m
92		115	20	1071		0				m
46		160	36	1124		96				m
33	13	113	19	1066	79	95	0.9765	0.9971	1	m
114		146	66			96				m
49		165	46	1125	97	93	0.7504	1	1	m
5		127	25	1092	83	93	0.9227	0.7357	1	m
9	16	134	71	1101	86	88	0.9565	1	1	m
62		123	77	1087		97				m
139		131		1096		95				m
44	11	157	33	1120	95	96	0.9137	1	1	m
53	10	135	69	1105		94				m
45		155	34	1118	94	97	0.0001	0.6244	1	m
78		72	11	1023		95				m:
39	4	144	30	1112		54				nm
41		154	28	1117		0				nm
8				1106						nm
56		138	67	1108	89	0	0.7463	0.9707	1	nm
36		132		1099		97				nm
42	14	143	31	1111		90				nm
4	12	119	23	1077		95				nm
51	15	137	70	1109		97				nm
43		142	32	1110		96				nm
40										nm
6				1093						und
7				1102						und
10				1085						und
12				1078						und
13				1082						und
14		114	80	1067		0				und
22		84	18	1029		0				und
23	18		17	1053						und
24		95	14	1047	72	97	0.8117	1	1	und
32		106	16	1061		97				und
35		128		1095		80				und
38		150	27	1115		0				und
57		129	72	1097		79				und
58		130	73	1098		71				und
63										und
64										und
65		120	78	1081		96				und
71		77	100	1026	66	97	0.5865	1	1	und
73		64	101	1016	61	0	0.0646	1	1	und
74		74	13			0				und
77		67	12	1018		97				und
79		85	1	1031	68	0	0.4112	1	1	und
82		89	3	1036		27				und
87		100	7	1054		57				und
101		170	38	1131	87	97	0.8326	1	1	und
102		179	40	1137		0				und
145	64	1113		0						und
123				1051						und
133		92	2	1039	71	94	0.8766	1	1	und
178		76	99	1025	65	96	0.8519	0.9999	1	und
491	7	209				0				und
v17										und

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