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PHOTOMETRY OF OPEN CLUSTERS III. HR 4684 AND HD 106103 IN COMA BERENICES[1]

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RESUMEN

Se presenta la fotometría fotoeléctrica diferencial para las estrellas variables del tipo delta scuti HR 4684 y HD 106103. Mediante una recopilación de fotometría fotoeléctrica *uvby-β* de 69 estrellas en la dirección del cúmulo abierto en Coma Berenices se determina la membresía de las estrellas al cúmulo. El enrojecimiento y la distancia encontrados son E(*b-y*) = 0.002 mag y 81.75 pc, respectivamente. Se determina además la temperatura efectiva y la gravedad superficial de las estrellas miembros. Se encuentra una edad del cúmulo de 5×10^8 años. No se encuentran diferencias físicas entre las estrellas pulsantes y las estrellas dentro de la zona de inestabilidad. Se determinan fotométricamente algunas estrellas como pertenecientes a las clases Ap.

ABSTRACT

Differential photoelectric photometry of the Delta Scuti stars HR 4684 and HD 106103 is presented. Membership of these stars to the cluster is established through a compilation from the literature of *uvby-β* photometry of 69 stars in the direction of Coma Berenices. Reddening and distance are determined to be of E(*b-y*) = 0.002 and 81.75 pc, respectively. An age for the cluster of 5×10^8 yr is derived by comparison with theoretical isochrones. Values of log T_{eff} and log g are determined for each member star to the cluster. No significant physical difference is found between the variable stars and others with the same physical characteristics. Determination of several Ap stars is established.

Key words: **GALAXY–OPEN CLUSTERS AND ASSOCIATIONS — STARS–VARIABLES–δ Scu — TECHNIQUES–PHOTOMETRIC**

1. INTRODUCTION

This is the third paper of a series dealing with galactic clusters. The goals of this project are to fix membership of each star in the cluster, as well as to determine their effective temperature, surface gravity and metal abundance in order to try to distinguish the differences that make some stars pulsate, whereas others, with the same effective temperature and gravity, do not. The program is designed to both discover new pulsating stars and to study those which are already known as members of the cluster.

On this occasion the open cluster in Coma Berenices was selected because HR 4684, the first Delta Scuti type variable found in open clusters (Breger & Sanwal 1968) and HD 106103, another

[1] Based on observations collected at the Observatorio Astronómico Nacional, San Pedro Mártir, B.C., México.

Delta Scuti star discovered by Jacksich (1972) are located in its direction. The open cluster in the constellation of Coma Berenices is one of the nearest to the Sun (d = 80 pc, Abt & Levato 1977). It is unique because of its high galactic latitude (b = 84.1°, ℓ =221.1°, Cameron 1985), which is very near the galactic north pole. According to Abt & Levato (1977), the earliest spectral type of member stars is A2V, and the cluster has been assigned an age of 5×10^8 yr.

The majority of previous papers on this cluster have reported that there is no interstellar reddening in its direction; for example, Cameron (1985) and Hagen (1970) have reported that $E(B-V) = 0$. Cameron (1985) determined its metallicity to be [Fe/H] = −0.063.

Many reports on the spectroscopic and photometric investigations of this cluster exist in the literature. Mendoza (1963, 1967), Abt & Levato (1977) and Deluca & Weiss (1981) among others have carried out spectral classification of a few members. On the other hand, most of the photoelectric photometry has been obtained only in the *UBV* system; for example, Johnson & Knuckles (1955); later Argue & Kenworthy (1969) studied possible new faint members. However, there is only one published paper (Crawford & Barnes 1969) and, to our knowledge, one Master's thesis (Díaz 1991), which includes *uvby*-β photometry. The first authors observed only 38 stars and a distance modulus of 4.5 mag was reported, although Cameron (1985) later assigned a value of 4.65 mag. The work by Díaz (1991) increased the sample to 69 observed stars in the Stromgren system.

The problem of membership of the stars to Coma has been studied since 1938 when Trumpler obtained a list of 37 members based on proper motions, radial velocities, and the position in the HR diagram for each star in the direction of said cluster. More recently, several other studies have been carried out with proper motions (for example, Covas 1981; Eggen 1973), although it is not enough to assign membership in the Coma Berenices cluster based on this criterion alone. In the present paper, differential photoelectric photometry in HR 4684 and HD 106103 is presented along with the previously mentioned compilation of photometric values of stars in the direction of Coma Berenices in the *uvby*-β system to provide a mean to determine membership for each star. The basic calibrations of Nissen (1988) have been utilized for the A and F stars in a prescription that closely resembles that of Crawford (1975, 1979). For the B type stars, Crawford's studies have been supplemented by those of Balona & Shobbrook (1984) and Shobbrook (1984). A numerical estimation for establishing membership in a cluster has been utilized (Peña et al. 1993), and new values of distance and reddening have been calculated. Furthermore, for each member the effective temperature and surface gravity are derived. An age estimate of the cluster is done through direct comparison with theoretical evolutionary tracks.

2. OBSERVATIONS

The first observing campaign was designed to determine the periods of pulsation of HR 4684. Thus, a simultaneous observing season was planned at two observatories located at different longitudes, namely, the Ege University Observatory, Turkey, and the Observatorio Astronómico Nacional, at San Pedro Mártir, México (hereafter SPM). The dates of observation, the telescopes employed, their location and instrumentation have been summarized in Table 1.

In México, two telescopes were used: the 150-cm and the 84-cm. A single-channel photometer with a dry-ice-cooled 1P21 photomultipler was utilized on each. Each measurement consisted of five ten-second integrations of each star and one ten-second integration of the sky which was subtracted from the average star integration. The photometric values reported are the magnitude differences between the variable star and the magnitude value of the comparison star interpolated to the time of observation of the variable.

In Turkey, the observations of HR 4684 were made at the Ege University Observatory. An unrefrigerated EMI 9781 photomultiplier with a Johnson V filter and a 48-cm Cassegrain reflector telescope were utilized. Correction for atmospheric extinction was carried out.

In this campaign, the sequence of observation was HR 4684 and BD 26°2329, as a comparison star.

TABLE 1

LOG OF OBSERVATIONS

Date			HJD	Obs.	Tel.	Fil.
1982	March	9/10	2445038	EGE	50	*V*
1982	March	10/11	2445039	EGE	50	*V*
1982	March	18/19	2445047	EGE	50	*V*
1982	March	18/19	2445047	SPM	84	*V*
1982	March	19/20	2445048	SPM	150	*B*
1982	March	20/21	2445049	SPM	150	*B*
1982	March	20/21	2445049	SPM	84	*V*
1982	March	28/29	2445057	EGE	50	*V*
1982	April	14/15	2445074	SPM	150	*52*
1982	April	15/16	2445075	SPM	150	*52*
1984	April	10/11	2445801	SPM	84	*b*
1984	April	11/12	2445802	SPM	84	*b*
1984	April	12/13	2445803	SPM	84	*b*
1984	April	13/14	2445804	SPM	84	*b*
1984	April	14/15	2445805	SPM	84	*b*
1985	Feb	16/17	2446113	SPM	150	*uvby*

TABLE 2

V PHOTOMETRY OF HR 4684

HJD	*V*	HJD	*V*	HJD	*V*	HJD	*V*	HJD	*V*
38.303	0.261	39.416	0.281	47.508	0.280	49.707	0.283	49.888	0.292
38.311	0.261	39.420	0.283	47.510	0.278	49.710	0.285	49.891	0.291
38.316	0.266	39.422	0.284	47.517	0.275	49.712	0.282	49.894	0.294
38.320	0.268	39.426	0.284	47.518	0.274	49.717	0.283	49.896	0.294
38.322	0.272	39.428	0.282	47.519	0.274	49.721	0.288	49.900	0.292
38.326	0.274	39.432	0.279	47.527	0.271	49.726	0.285	49.902	0.293
38.328	0.273	39.434	0.280	47.527	0.271	49.729	0.288	49.905	0.289
38.335	0.285	39.438	0.281	47.528	0.267	49.732	0.285	49.908	0.290
38.337	0.283	39.440	0.279	47.535	0.272	49.735	0.287	49.910	0.291
38.341	0.288	39.445	0.275	47.538	0.270	49.741	0.293	49.914	0.292
38.342	0.287	39.447	0.277	47.539	0.271	49.744	0.290	49.917	0.289
38.346	0.290	39.450	0.274	47.547	0.275	49.747	0.291	49.924	0.277
38.347	0.291	39.452	0.273	47.548	0.276	49.751	0.293	49.926	0.273
38.352	0.285	39.456	0.271	47.549	0.278	49.755	0.289	49.928	0.274
38.353	0.286	39.458	0.270	47.559	0.285	49.758	0.288	49.931	0.268
38.358	0.284	39.462	0.270	47.560	0.284	49.762	0.290	49.934	0.271
38.365	0.280	39.465	0.269	47.561	0.286	49.766	0.286	49.937	0.277
38.367	0.278	39.469	0.271	47.568	0.283	49.769	0.286	49.940	0.279
38.372	0.277	39.472	0.272	47.569	0.281	49.771	0.282	57.361	0.282
38.373	0.276	39.476	0.273	47.570	0.279	49.774	0.279	57.362	0.280
38.378	0.273	39.478	0.275	47.578	0.274	49.778	0.278	57.363	0.281
38.380	0.271	39.481	0.278	47.579	0.273	49.780	0.278	57.366	0.279
38.384	0.271	39.483	0.280	47.580	0.274	49.784	0.277	57.367	0.279
38.386	0.267	39.487	0.282	47.588	0.274	49.787	0.277	57.367	0.279
38.391	0.264	39.490	0.284	47.589	0.271	49.789	0.278	57.371	0.278
38.392	0.263	39.493	0.285	47.590	0.270	49.792	0.277	57.372	0.276
38.397	0.271	39.496	0.283	47.864	0.286	49.796	0.283	57.373	0.275
38.398	0.271	39.500	0.284	47.870	0.281	49.799	0.287	57.376	0.274
38.402	0.271	39.502	0.284	47.873	0.280	49.801	0.287	57.377	0.275
38.403	0.270	39.506	0.283	47.880	0.284	49.803	0.289	57.378	0.274
38.407	0.274	39.509	0.281	47.883	0.284	49.810	0.293	57.381	0.274
38.409	0.273	39.513	0.280	47.885	0.288	49.813	0.289	57.382	0.275
38.414	0.276	39.516	0.278	47.889	0.291	49.816	0.291	57.383	0.274
38.415	0.276	39.519	0.277	47.892	0.292	49.821	0.290	57.388	0.274
38.420	0.283	39.522	0.275	47.896	0.290	49.824	0.288	57.389	0.273
38.422	0.289	47.453	0.282	47.899	0.289	49.826	0.288	57.391	0.273
38.427	0.289	47.453	0.284	47.902	0.285	49.830	0.289	57.395	0.272
38.428	0.294	47.454	0.284	47.905	0.284	49.833	0.287	57.396	0.272
38.432	0.294	47.461	0.276	47.909	0.281	49.836	0.286	57.397	0.273
38.433	0.289	47.462	0.278	47.912	0.283	49.839	0.284	57.402	0.270
38.449	0.282	47.463	0.277	47.915	0.283	49.844	0.288	57.403	0.270
38.450	0.281	47.470	0.273	47.921	0.282	49.846	0.286	57.404	0.270
38.456	0.279	47.471	0.272	47.926	0.286	49.851	0.285	57.408	0.272
38.464	0.277	47.472	0.272	47.928	0.281	49.853	0.284	57.408	0.272
38.465	0.279	47.475	0.271	47.932	0.283	49.856	0.278	57.409	0.272
38.470	0.273	47.480	0.270	47.935	0.284	49.859	0.278	57.413	0.272
38.471	0.271	47.482	0.272	47.939	0.281	49.864	0.274	57.414	0.271
39.395	0.267	47.489	0.282	47.944	0.281	49.866	0.276	57.414	0.271
39.397	0.268	47.490	0.283	47.951	0.282	49.869	0.277	57.418	0.274
39.400	0.270	47.491	0.285	47.954	0.280	49.872	0.282	57.419	0.276
39.402	0.271	47.498	0.285	49.692	0.281	49.876	0.287	57.419	0.277
39.407	0.273	47.499	0.286	49.694	0.282	49.878	0.290	...	...
39.409	0.276	47.500	0.284	49.698	0.286	49.880	0.286	...	...
39.414	0.278	47.507	0.282	49.704	0.283	49.883	0.291	...	...

The star BD 26°2324 was observed at SPM as a check star. A continuation of this campaign was carried out one month later with the 150-cm telescope at SPM observatory through the *52* filter of the 13-color system (Johnson & Mitchell 1975). A second observing run utilizing differential photometry was carried out in 1984 at SPM observatory. During this latter season two Delta Scuti type stars HR 4684 and HD 106103 were observed with the *b* filter of the Stromgren system. The comparison stars for each were respectively, BD 26°2329, which had been used before, and BD 28°2084. Each was of about the same magnitude and within 15′ of the variable star.

Tables 2, 3, 4 and 5 list the observation time in HJD and the variation in magnitudes of HR 4684 with filters *V, B, 52* and *b*, respectively; Table 6 gives the values of HD 106103 with the *b* filter. To the time shown, the large figure of the real Julian Heliocentric Date, presented in Table 1, has been subtracted. Errors in each figure are ±0.0014 d in time and ±0.002 mag in the photometry. The listed values are shown schematically in Figures 1, 2, 3 and 4.

Since, without planning to do so, these seasons practically coincide with a separate observing campaign by Paparo & Kovacs (1984), communication was started between the observers; the period analysis of the three campaigns is presented separately (Paparo et al. 1993)

TABLE 3

B PHOTOMETRY OF HR 4684

HJD	*B*	HJD	*B*	HJD	*B*	HJD	*B*	HJD	*B*
48.889	0.264	48.926	0.260	48.964	0.265	49.889	0.125	49.922	0.119
48.892	0.264	48.929	0.254	48.968	0.268	49.892	0.127	49.926	0.107
48.896	0.263	48.933	0.257	48.971	0.258	49.895	0.127	49.929	0.114
48.900	0.264	48.937	0.260	48.974	0.259	49.898	0.129	49.933	0.101
48.903	0.260	48.940	0.259	49.866	0.112	49.901	0.125	49.936	0.105
48.907	0.258	48.944	0.260	49.869	0.113	49.904	0.128	49.939	0.110
48.910	0.263	48.947	0.258	49.872	0.121	49.907	0.129	49.943	0.117
48.912	0.258	48.950	0.258	49.876	0.126	49.910	0.124	49.947	0.112
48.916	0.252	48.954	0.264	49.879	0.126	49.913	0.128	...	...
48.912	0.255	48.930	0.264	49.882	0.127	49.917	0.125	...	...
48.923	0.259	48.961	0.262	49.886	0.130	49.919	0.118	...	...

TABLE 4

52 FILTER PHOTOMETRY OF HR 4684

HJD	*V*	HJD	*V*	HJD	*V*	HJD	*V*	HJD	*V*
74.662	0.261	74.731	0.257	74.803	0.261	75.653	0.252	75.822	0.260
74.666	0.263	74.733	0.255	74.806	0.256	75.660	0.255	75.829	0.265
74.669	0.261	74.736	0.259	74.809	0.264	75.675	0.268	75.835	0.268
74.671	0.259	74.743	0.265	74.812	0.261	75.689	0.261	75.841	0.260
74.674	0.261	74.746	0.266	74.814	0.262	75.696	0.246	75.847	0.251
74.677	0.264	74.748	0.267	74.817	0.263	75.702	0.256	75.853	0.243
74.681	0.265	74.751	0.268	74.819	0.261	75.708	0.237	75.859	0.243
74.685	0.260	74.755	0.269	74.822	0.259	75.715	0.256	75.867	0.252
74.688	0.260	74.757	0.265	74.825	0.257	75.721	0.266	75.873	0.254
74.691	0.261	74.760	0.263	74.828	0.256	75.728	0.265	75.879	0.263
74.694	0.260	74.763	0.265	74.831	0.257	75.734	0.261	75.882	0.261
74.698	0.261	74.766	0.262	74.837	0.252	75.741	0.258	75.885	0.272
74.701	0.263	74.768	0.259	74.843	0.257	75.746	0.258	75.887	0.272
74.704	0.257	74.771	0.262	74.849	0.260	75.753	0.255	75.891	0.259
74.708	0.258	74.774	0.259	74.855	0.261	75.759	0.257	75.894	0.260
74.710	0.251	74.776	0.253	74.861	0.254	75.771	0.261	75.896	0.262
74.712	0.251	74.780	0.255	74.867	0.252	75.778	0.249	75.899	0.260
74.715	0.249	74.783	0.254	74.872	0.254	75.785	0.248	75.903	0.266
74.717	0.249	74.787	0.251	74.877	0.254	75.792	0.254	75.905	0.264
74.720	0.251	74.791	0.254	74.883	0.256	75.798	0.250	...	...
74.723	0.255	74.794	0.250	74.888	0.260	75.803	0.241	...	...
74.726	0.254	74.796	0.252	74.893	0.262	75.810	0.255	...	...
74.728	0.253	74.799	0.254	74.899	0.262	75.816	0.257	...	...

TABLE 5

b PHOTOMETRY OF HR 4684

HJD	*b*	HJD	*b*	HJD	*b*	HJD	*b*	HJD	*b*
1.657	0.219	2.663	0.212	2.856	0.217	3.808	0.217	4.752	0.203
1.658	0.217	2.665	0.214	2.858	0.216	3.810	0.216	4.754	0.202
1.660	0.219	2.667	0.214	2.860	0.217	3.812	0.215	4.755	0.200
1.661	0.221	2.671	0.213	2.862	0.219	3.814	0.212	4.759	0.202
1.664	0.221	2.673	0.215	2.864	0.220	3.818	0.211	4.761	0.202
1.666	0.223	2.675	0.216	2.869	0.219	3.821	0.211	4.763	0.203
1.675	0.220	2.684	0.220	2.871	0.216	3.822	0.213	4.767	0.209
1.678	0.218	2.686	0.221	2.873	0.217	3.824	0.210	4.771	0.209
1.680	0.217	2.688	0.220	2.874	0.213	3.826	0.209	4.778	0.211
1.682	0.214	2.690	0.221	2.876	0.209	3.827	0.208	4.782	0.212
1.684	0.214	2.694	0.216	2.880	0.207	3.832	0.208	4.784	0.218
1.688	0.215	2.698	0.216	3.657	0.210	3.833	0.206	4.786	0.217
1.690	0.213	2.700	0.215	3.659	0.211	3.835	0.207	4.789	0.215
1.691	0.208	2.702	0.218	3.660	0.212	3.837	0.208	4.791	0.214
1.693	0.210	2.705	0.214	3.662	0.214	3.839	0.210	4.793	0.217
1.699	0.209	2.711	0.213	3.666	0.215	3.840	0.212	4.797	0.215
1.700	0.209	2.713	0.215	3.668	0.215	3.844	0.217	4.798	0.217
1.702	0.208	2.715	0.214	3.671	0.214	3.846	0.214	4.800	0.215
1.705	0.208	2.717	0.210	3.673	0.215	3.848	0.213	4.804	0.214
1.706	0.207	2.719	0.209	3.674	0.216	3.850	0.217	4.805	0.215
1.709	0.210	2.723	0.214	3.679	0.214	3.851	0.220	4.807	0.213
1.711	0.211	2.725	0.215	3.681	0.213	3.852	0.223	4.811	0.214
1.714	0.209	2.727	0.214	3.683	0.210	3.857	0.221	4.812	0.215
1.719	0.207	2.729	0.214	3.685	0.211	3.859	0.220	4.814	0.216
1.723	0.210	2.731	0.217	3.687	0.212	3.860	0.217	4.818	0.215
1.725	0.211	2.734	0.218	3.691	0.212	3.862	0.212	4.820	0.213
1.727	0.215	2.738	0.221	3.693	0.210	3.864	0.215	4.825	0.208
1.729	0.216	2.740	0.222	3.695	0.205	3.868	0.210	4.827	0.206
1.736	0.221	2.743	0.217	3.697	0.203	3.869	0.211	4.829	0.205
1.737	0.221	2.744	0.221	3.699	0.207	3.871	0.212	4.833	0.211
1.742	0.220	2.746	0.220	3.700	0.204	3.873	0.206	4.835	0.210
1.744	0.221	2.748	0.220	3.705	0.208	3.875	0.205	4.838	0.215
1.746	0.219	2.752	0.214	3.706	0.205	3.874	0.205	4.840	0.218
1.750	0.219	2.755	0.213	3.708	0.207	3.881	0.200	4.841	0.215
1.752	0.214	2.757	0.210	3.709	0.207	3.883	0.203	4.845	0.219
1.755	0.214	2.759	0.210	3.711	0.206	3.885	0.203	4.847	0.216
1.757	0.214	2.760	0.211	3.713	0.212	3.889	0.203	4.849	0.219
1.759	0.213	2.762	0.205	3.716	0.214	4.655	0.212	4.852	0.219
1.764	0.214	2.766	0.203	3.718	0.212	4.657	0.216	4.855	0.218
1.767	0.209	2.768	0.204	3.720	0.214	4.659	0.212	4.856	0.219
1.768	0.210	2.773	0.198	3.721	0.216	4.661	0.213	4.859	0.220
1.771	0.207	2.775	0.204	3.723	0.214	4.663	0.215	4.861	0.218
1.773	0.205	2.776	0.202	3.725	0.215	4.667	0.213	4.864	0.220
1.775	0.205	2.780	0.209	3.730	0.216	4.668	0.213	4.866	0.221
1.778	0.207	2.782	0.212	3.732	0.217	4.671	0.213	4.868	0.217
1.780	0.207	2.784	0.212	3.736	0.218	4.673	0.218	4.871	0.218
1.782	0.209	2.786	0.210	3.740	0.221	4.675	0.218	4.876	0.215
1.784	0.208	2.788	0.211	3.741	0.218	4.677	0.218	4.877	0.211
1.786	0.209	2.790	0.214	3.743	0.213	4.680	0.219	4.880	0.212
1.788	0.207	2.791	0.216	3.747	0.212	4.682	0.221	4.883	0.208
1.791	0.209	2.793	0.213	3.748	0.216	4.684	0.224	5.672	0.211
1.793	0.208	2.796	0.217	3.750	0.214	4.686	0.219	5.673	0.209
1.796	0.207	2.798	0.217	3.752	0.216	4.687	0.216	5.677	0.207
1.798	0.205	2.800	0.217	3.753	0.210	4.692	0.211	5.686	0.209
1.800	0.210	2.802	0.215	3.757	0.213	4.694	0.211	5.688	0.210
1.801	0.212	2.804	0.215	3.758	0.206	4.696	0.209	5.691	0.210
1.807	0.214	2.806	0.214	3.760	0.207	4.699	0.205	5.693	0.209
1.809	0.213	2.811	0.214	3.761	0.208	4.701	0.202	5.695	0.211

4. ANALYSIS

The multicolor photometric data was compiled from two sources: Crawford & Barnes (1969) and Díaz (1991). Both sets had a subset of twenty stars in common which were employed to compare and establish the results of both authors.

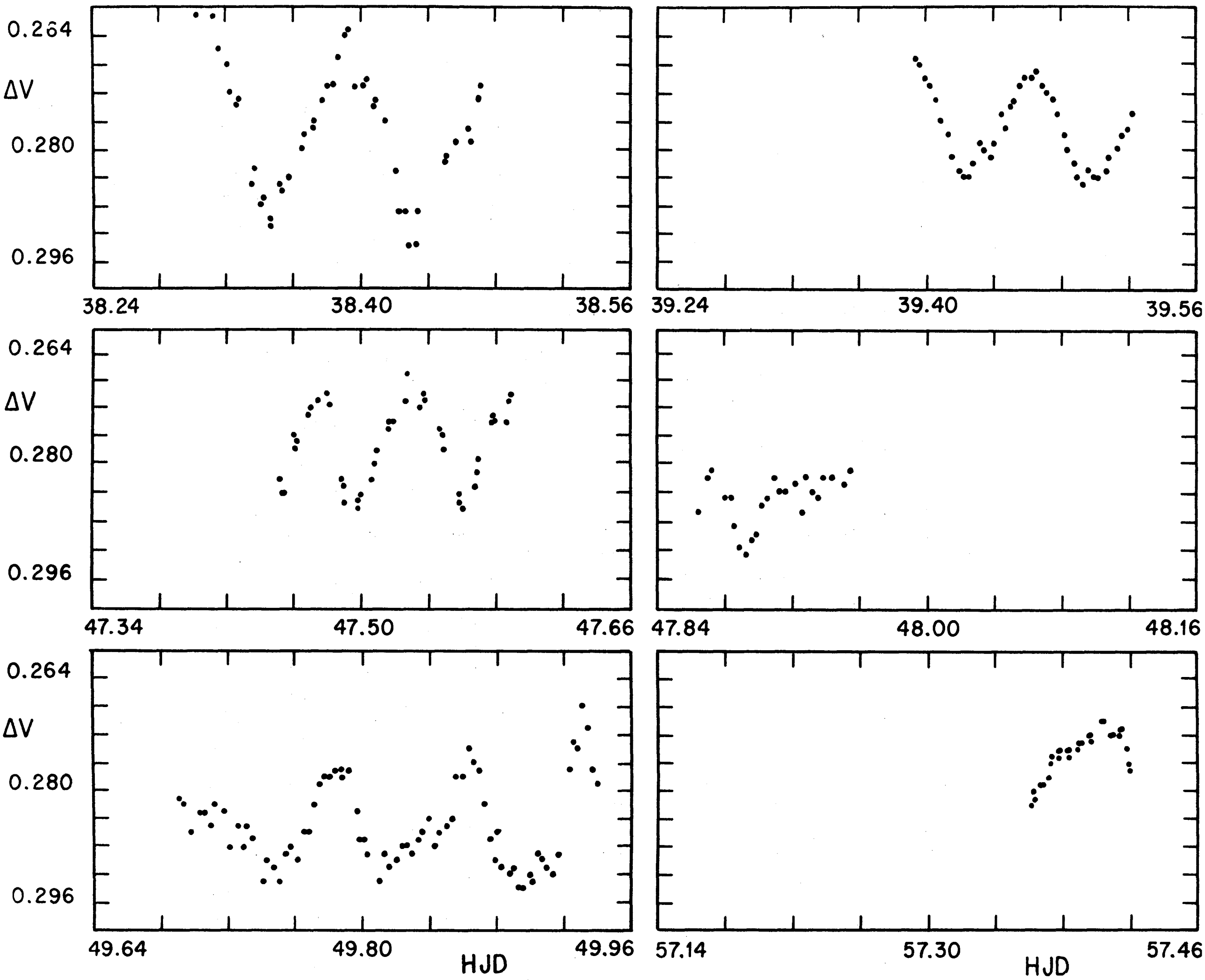

Fig. 1. Variation, in magnitudes, of HR 4684 in the *V* filter of Johnson's system.

Equally, for comparison purposes, the apparent magnitudes provided by several authors (Trumpler 1938; Mendoza 1963; Johnson & Knuckles 1955, and Argue 1963) were employed.

The values of the *V* magnitude reported by Díaz (1991) were compared with the aforementioned magnitude values. The rms of the differences with Trumpler (1938) was of 0.018 mag with 20 pairs; with Mendoza (1963), of 0.03 with 37 pairs; with Johnson & Knuckles (1955) of 0.018 with 20 pairs and Argue (1963) of 0.03 with 12 pairs. In view of the differences, the photometric values reported by Díaz (1991) were retained.

Equally adequate was the comparison of Díaz (1991) with the reported values of Crawford & Barnes (1969) in the color indexes *b-y*, m_1 and c_1. For the sample of twenty stars in common, the rms of the differences were less than the errors reported by Díaz (1991) in his transformation to the standard system. He states: "The photometric values derived for the standard stars have standard deviations in *V*, *b-y*, m_1, c_1, and β of 0.008, 0.006, 0.006, 0.007, and 0.007 mag, respectively. The reported values for m_1 and c_1 were calculated for $(b\text{-}y) \leq 0.409$ mag". In view of this, the values of these indexes reported by Díaz (1991) were used and, for those twenty stars in common, the final assumed values were the mean values.

A different approach was taken for the β index since a systematic difference was found in the two sets. A linear relation was established between them by means of the equation $\beta(\text{Díaz}) = 0.117 + 0.951 \times \beta(\text{Crawford})$ with a correlation coefficient of 0.9958. The remaining values of Díaz (1991) were transformed accordingly.

The final list of the compiled data, in decreasing

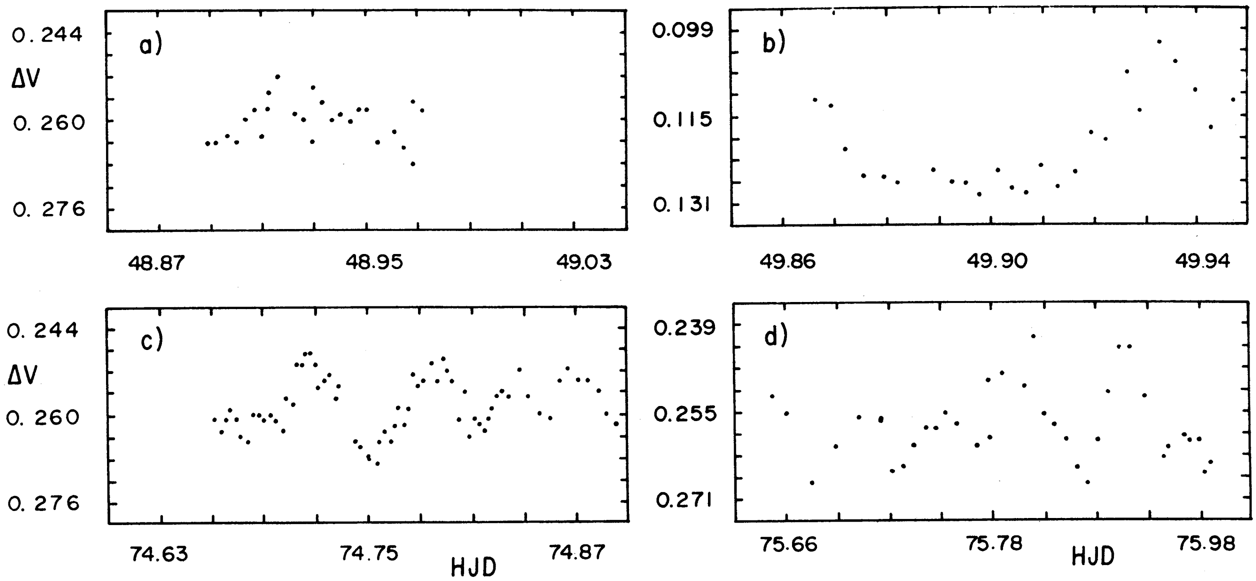

Fig. 2. Variation, in magnitudes, of HR 4684 in the *B* filter of Johnson's system (*a* and *b*) and in the *52* filter of the 13 color system (*c* and *d*).

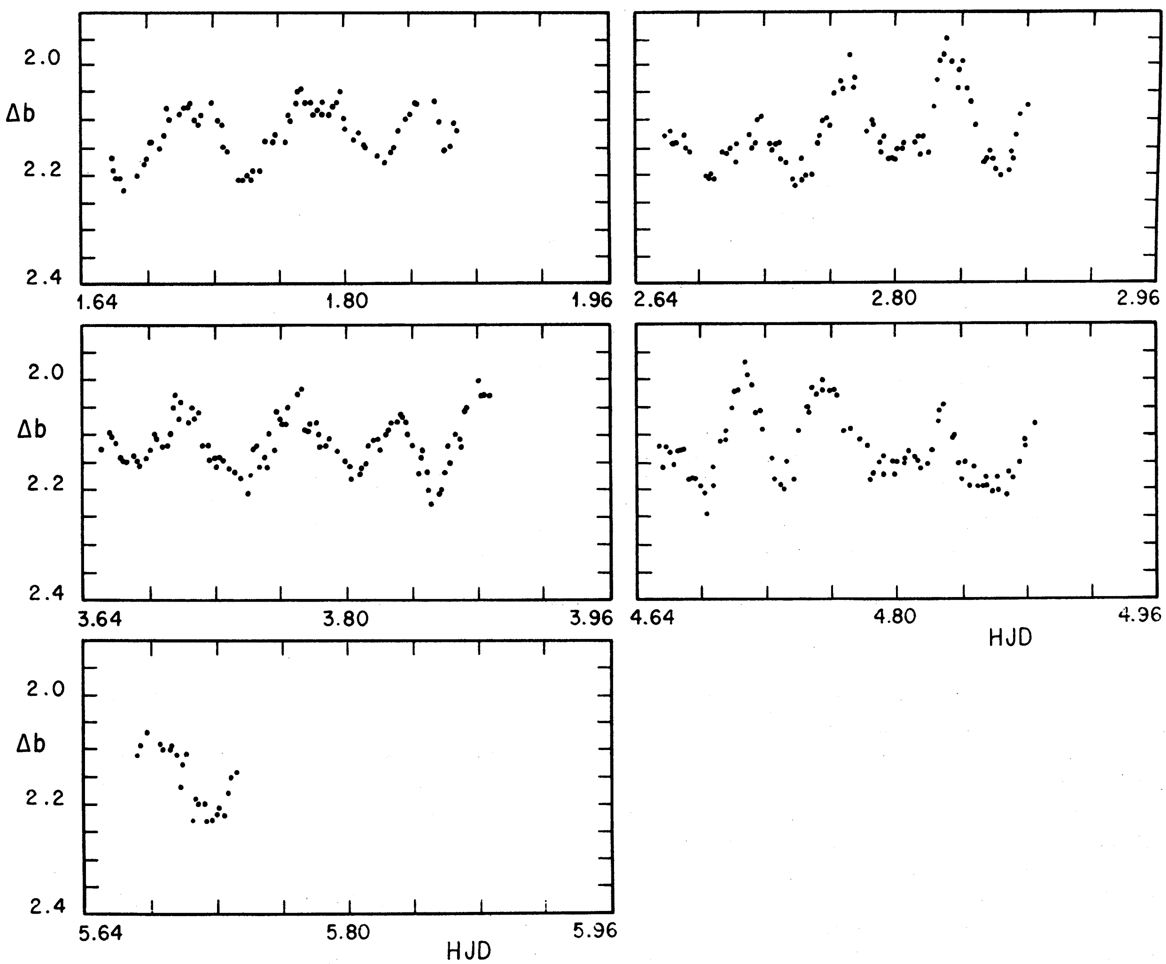

Fig. 3. Variation, in magnitudes, of HR 4684 in the *b* filter of the Stromgren system.

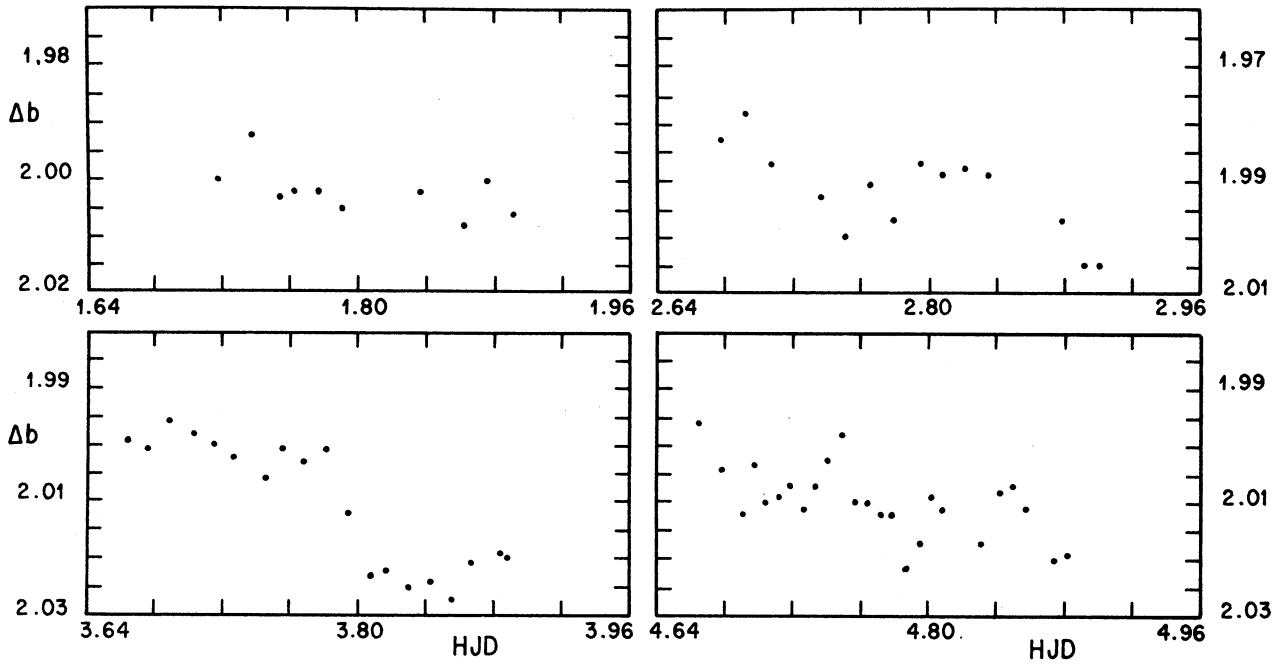

Fig. 4. Variation, in magnitudes, of HD 106103 in the *b* filter of the Stromgren system.

TABLE 6

b PHOTOMETRY OF HD 106103

HJD	*b*	HJD	*b*	HJD	*b*	HJD	*b*	HJD	*b*
1.697	1.997	2.736	1.993	3.703	1.998	3.884	2.019	4.766	2.011
1.716	2.000	2.751	2.000	3.715	2.000	3.887	2.020	4.773	2.013
1.738	1.992	2.765	1.991	3.727	2.002	4.665	1.996	4.780	2.013
1.754	2.003	2.779	1.997	3.746	2.006	4.679	2.005	4.788	2.022
1.763	2.002	2.796	1.987	3.755	2.001	4.691	2.013	4.796	2.018
1.777	2.002	2.808	1.989	3.768	2.003	4.698	2.004	4.802	2.010
1.791	2.005	2.822	1.988	3.781	2.001	4.705	2.011	4.809	2.012
1.836	2.002	2.836	1.989	3.794	2.012	4.713	2.010	4.832	2.018
1.863	2.008	2.879	1.997	3.807	2.023	4.720	2.008	4.843	2.009
1.876	2.000	2.892	2.005	3.817	2.022	4.727	2.012	4.851	2.008
1.892	2.006	2.901	2.005	3.830	2.025	4.735	2.008	4.859	2.012
2.677	1.983	3.664	1.999	3.843	2.024	4.742	2.003	4.875	2.021
2.693	1.978	3.676	2.001	3.855	2.027	4.750	1.998	4.882	2.020
2.707	1.987	3.689	1.996	3.866	2.021	4.758	2.011	...	...

values of β, is presented in Table 7. Using it, determination of the reddening, distance and physical parameters to each one of the stars can be accomplished.

Several methods for determining the membership of stars in a cluster are known. One of the most used, although one of the roughest, is that of fitting the main sequence to the color-magnitude and color-color diagrams (Trumpler 1938). The most accurate methods are those which make use of the proper motions or radial velocities (Vasilevkis, Klemola, & Preston 1958). Another method, which is employed in the present paper, is based on the determination of the distance through empirical calibrations of M_V and reddening via the *uvby*-β photometry.

4.1 DM Determination

The determination of the unreddened distance modulus DM is the basic physical quantity on which the photometric membership probability is based. This method of evaluating DM for A and F type stars

TABLE 7

COMPILED *uvby*-β PHOTOMETRY OF THE STARS IN THE DIRECTION OF COMA BERENICES

Id	V	b-y	m_1	c_1	β	Ref[a]	Id	V	b-y	m_1	c_1	β	Ref[a]
TR89	6.216	0.013	0.146	1.051	2.903	CB&D	TR96	8.565	0.342	0.171	0.375	2.643	D
TR160	5.479	0.035	0.191	1.097	2.897	CB&D	TR162	8.610	0.304	0.171	0.382	2.642	CB
TR183	6.293	0.070	0.194	1.011	2.878	CB&D	TR90	8.560	0.306	0.159	0.384	2.636	CB
TR107	5.193	0.046	0.181	1.096	2.876	CB&D	TR24	7.431	0.412	0.202	0.513	2.635	D
TR62	6.270	0.081	0.249	0.936	2.868	CB	TR92	8.610	0.344	0.173	0.362	2.632	CB
TR130	4.996	0.051	0.185	1.123	2.864	CB&D	TR58	8.830	0.327	0.174	0.344	2.626	CB
TR47	5.759	0.095	0.198	0.922	2.860	D	TR53	8.730	0.334	0.176	0.342	2.625	CB
TR52	7.508	0.101	0.200	0.909	2.858	D	TR182	7.300	1.147	0.447	0.572	2.621	D
TR10	6.038	0.072	0.183	1.021	2.857	CB&D	TR166	9.205	0.400	0.179	0.427	2.621	D
TR139	6.742	0.101	0.208	0.906	2.854	CB&D	TR97	9.122	0.354	0.179	0.311	2.617	CB&D
TR144	6.550	0.110	0.215	0.910	2.849	CB&D	TR111	8.173	0.353	0.170	0.342	2.616	CB&D
TR146	5.294	-0.041	0.207	0.866	2.844	CB&D	TR76	9.100	0.357	0.187	0.324	2.613	CB
TR145	6.651	0.127	0.220	0.824	2.844	CB&D	TR65	9.020	0.364	0.192	0.292	2.605	CB
TR68	6.670	0.105	0.197	0.901	2.837	CB&D	TR102	9.360	0.376	0.208	0.291	2.602	CB
TR60	6.479	0.101	0.191	0.941	2.835	CB&D	TR85	9.340	0.375	0.202	0.304	2.596	CB
TR104	6.715	0.144	0.185	0.807	2.789	CB&D	TR161	7.159	0.393	0.141	0.358	2.587	D
TR109	6.451	0.157	0.203	0.758	2.779	CB&D	TR132	9.910	0.424	0.234	0.277	2.587	CB
TR82	7.420	0.173	0.176	0.741	2.753	CB	TR129	6.951	0.658	0.480	0.266	2.577	D
TR70	6.180	0.198	0.176	0.762	2.751	D	TR119	8.291	0.680	0.483	0.294	2.577	D
TR125	4.948	0.176	0.163	1.052	2.740	CB&D	TR80	8.065	0.652	0.410	0.341	2.573	D
TR140	7.741	0.164	0.193	0.802	2.736	D	TR98	7.448	0.665	0.392	0.367	2.569	D
TR91	4.800	0.317	0.185	0.771	2.699	CB&D	TR81	7.318	0.560	0.293	0.387	2.569	D
TR49	7.920	0.242	0.166	0.537	2.699	CB&D	TR39	4.991	0.601	0.312	0.371	2.569	D
TR73	7.023	0.232	0.153	0.551	2.696	CB&D	TR03	6.997	0.625	0.381	0.358	2.569	D
TR19	8.113	0.267	0.163	0.450	2.676	CB&D	TR71	5.537	0.673	0.454	0.320	2.566	D
TR36	8.125	0.273	0.161	0.465	2.675	CB&D	TR171	8.787	0.699	0.453	0.326	2.566	D
TR87	9.586	0.295	0.173	0.501	2.669	D	TR141	8.650	0.570	0.335	0.356	2.566	D
TR55	7.574	0.296	0.166	0.455	2.668	D	TR123	6.057	0.667	0.418	0.351	2.563	D
TR149	5.501	0.301	0.159	0.617	2.667	D	TR16	5.661	0.881	0.619	0.213	2.562	D
TR101	8.420	0.296	0.161	0.408	2.666	CB	TR126	9.259	0.574	0.334	0.353	2.562	D
TR118	8.370	0.294	0.166	0.416	2.657	CB	TR27	7.421	0.573	0.294	0.388	2.561	D
TR117	9.314	0.310	0.157	0.422	2.657	D	TR187	9.660	0.709	0.471	0.302	2.559	D
TR86	8.550	0.306	0.164	0.376	2.652	CB	TR150	9.780	0.483	0.286	0.247	2.559	CB
TR114	8.600	0.307	0.151	0.395	2.651	CB	TR189	7.696	0.893	0.624	0.302	2.552	D
TR66	6.401	0.341	0.181	0.468	2.647	D							

[a] CB = Crawford & Barnes 1969. D = Díaz 1992.

has been used previously by Peniche et al. (1990). This work has also been carried out considering the previous papers of Crawford and his co-workers (1975, 1979) and of Nissen (1988).

In 1975 Crawford defined those stars that satisfy $2.59 < \beta < 2.72$ mag, $\delta c_1 < 0.28$ mag, and that are not B stars, as spectral class F. He determined empirical calibrations for M_V and $(b\text{-}y)_0$ as well as for the metallicity, [Fe/H]. On the other hand, Crawford (1979) defined A-type stars as those which satisfy $2.72 < \beta < 2.89$ mag, $\delta c_1 \leq 0.28$ mag, and which are not B stars. Again, he determined empirical calibrations for the visual absolute magnitude and the color index $(b\text{-}y)_0$. Once M_V and $(b\text{-}y)_0$ are known for the A and F stars, DM can be calculated.

Using the β criterion alone for stars of type B, a determination of which stars are type B is impossible since the same value of β can be obtained for A and F stars as well as for B stars. Hence, a main sequence B-type star can be defined photometrically if it satisfies the conditions: *i*) $1.0 < [c_1] < 0.2$ mag and, *ii*) $0.145 < [m_1] < 0.07$ mag. This definition has been obtained from the $[c_1]$-$[m_1]$ diagram of Stromgren (1966) which unambiguously determines the spectral type of the main sequence stars.

In order to determine DM for stars of spectral class B, Crawford (1978) obtained empirical calibrations for $(b\text{-}y)_0$ and M_V. Later, Hilditch, Hill, & Barnes (1983) modified this calibration slightly for $(b\text{-}y)_0$, which is valid up to the A2V stars.

The visual absolute magnitude is calculated using the calibration determined by Balona & Shobbrook (1984) which includes an evolutionary correction. Finally, using the evaluated values of V_0 and M_V, the distance modulus, DM, can be determined for each star of spectral type B or early A.

With the above definitions, a separation between the classes B and A and F can be carried out, and a direct evaluation of DM can be done.

5. RESULTS AND DISCUSSION

5.1 Membership

One of the most important goals of this project is the determination of the physical membership in clusters while discarding field stars. The prescription using *uvby-β* photometry consists basically of fitting a normal curve to a distance histogram. Once the Gaussian distribution function has been fitted, the area under the curve in a given interval represents the probability that a corresponding random variable can be found in this interval.

Utilizing the previously described criteria with the photometric data in Table 7, the unreddened parameters are determined for each star and, hence, a membership probability can be assigned.

Figure 5 shows the histogram, in distance, of the cluster for those stars in the direction of Coma Berenices. However, it is obvious that the limits suggested by both A and F stars separately or together between 70 and 90 pc are the limits of the cluster.

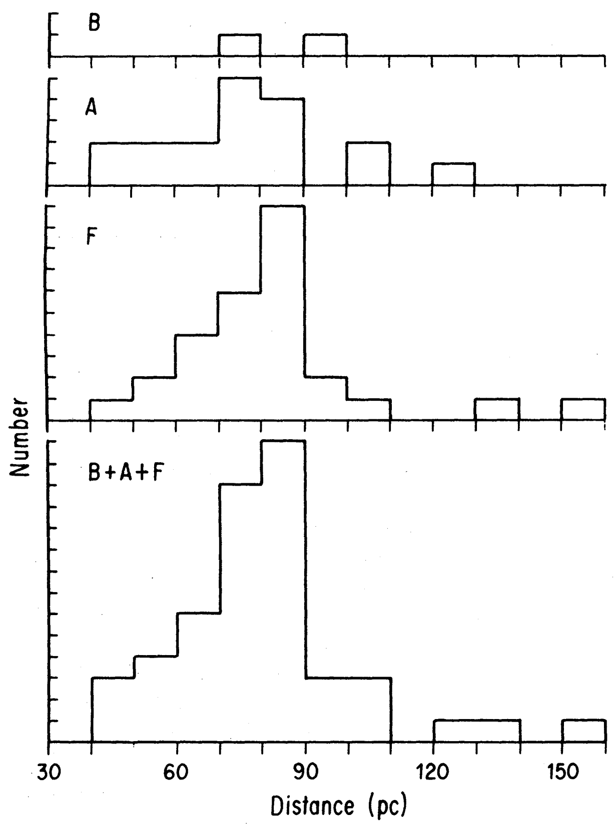

Fig. 5. Histogram of distance for those stars for which, through the compiled data in the *uvby-β*, allowed the distance determination.

Table 8 lists the reddening, E(*b-y*), and the unreddened distance modulus determined for the A and F stars for those stars that were finally determined to be cluster members in Coma Berenices. The first column gives the identifier used by Trumpler (1938). The second to eighth columns list the reddening, the unreddened indexes $(b\text{-}y)_0$, c_{1_0}, and m_{1_0}, the absolute magnitude, distance modulus and distance, in pc, and the metal content [Fe/H], respectively. It is worth mentioning that, except for only one star, TR 96, the membership to the cluster assigned in this work coincides absolutely with the probability assigned by Trumpler (1938) which is based on three criteria: proper motions, location in the HR diagram and radial velocities.

5.2 Distance, Reddening and Metallicity of Coma Berenices

In the present paper, an average unreddened distance of 81.75 pc with a standard deviation of ±5.89 pc has been found. This figure corresponds to an average distance modulus of 4.56 mag between the limits 4.40 and 4.71 mag. The generally accepted value, in distance, of 80 pc lies within this range.

The average color excess for this cluster is E(*b-y*) 0.002±0.01 mag or, correspondingly, E(*B-V*) = 0.003±0.014 mag. This latter figure has been obtained considering the relationship E(*b-y*) = 0.7 E(*B-V*) of Crawford & Mandwewala (1976). This reddening is in good agreement with other studies which, like Cameron (1985) and Nissen (1980), conclude that there is practically no interstellar extinction at 80 pc in the direction of the galactic north pole.

The metallicity [Fe/H] of the cluster has been determined using the calibration of Nissen (1988), which has already been used in Peña et al. (1993). The derived value determined in the present paper, from a sample of 16 F type stars, −0.030±0.078, does seem to be in fair agreement with the most widely accepted value of [Fe/H] = −0.063, which was determined by Cameron (1985) or with the value proposed by Nissen (1980) who determined [Fe/H] = −0.003±0.02 from 18 stars of spectral type F. However, if only two stars are not considered in the evaluation of the average metallicity, TR90 and TR114, exclusion that can be justified because their metallicity is discordant with the mean and beyond the values of the standard deviation, the mean [Fe/H] for the member stars from a sample of 14 is −0.007±0.052, much more in agreement with the reported values in the literature.

5.3 Effective Temperature and Surface Gravity

In order to determine T_{eff} and log g for the A and F member stars to the cluster, the grids developed by Relyea & Kurucz (1978) have been used with the unreddened values for each one listed in Table 8 (see Figure 6). Using the grid c_0 versus $(b-y)_0$ (Figure 19 in Relyea & Kurucz 1978), the A and F member stars have been located using the values listed in Table 8 (see Figure 6). The effective temperatures for the hottest member stars, TR107, TR130 and TR183, for which *uvby-β* photometric data were available in the Coma cluster lie below 8500 K, whereas the surface gravity varies in the range log *g* between 3.0 and 4.5.

For the Am and Ap stars which are members, the values of $(b-y)_0$ and c_0 have been calculated considering the average reddening determined for the cluster, $E(b-y) = 0.002\pm0.01$ and $E(c_1) = 0.0004\pm0.00020$, where the relation $E(c_1) = 0.20\ E(b-y)$ of Crawford & Mandwewala (1976) has been used.

5.4 Age

The age of the cluster in Coma Berenices has been calculated from the evolutionary models of VandenBerg (1985). If the metal abundance, which roughly agrees with that reported by Cameron (1985) and which was determined in the present paper, is considered, the derived age is 5.0×10^8 yr, in agreement with the value reported by Abt & Levato (1977). A similar age is derived if the isochrones of Iben (1985) are employed.

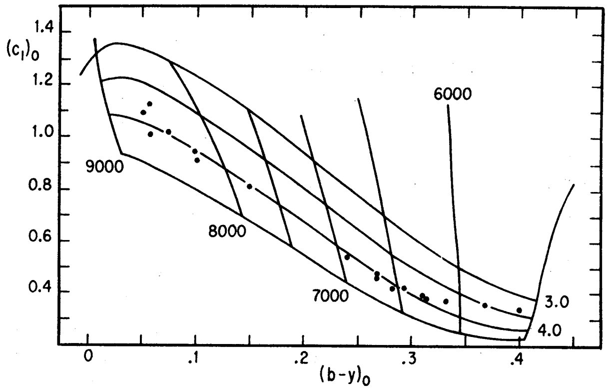

Fig. 6. Location of the member stars of the Coma Berenices cluster in the theoretical grids of Relyea & Kurucz.

5.5 Ap Stars

The spectral classification of the stars in Coma Berenices has been known for a long time, since the publication of Trumpler's (1938) pioneer work. From the 71 spectral types he assigned out of the 200 photometrically observed stars, he lists only

TABLE 8

MEMBER STARS OF THE COMA BERENICES CLUSTERS

Id	$E(b-y)$	$(b-y)_0$	m_{1_0}	c_{1_0}	V_0	V_M	DM	DST	[Fe/H]
TR160	0.016	0.019	1.094	0.196	5.41	1.18	4.24	70.33	...
TR183	0.010	0.060	1.009	0.197	6.25	1.55	4.69	86.81	...
TR107	-0.007	0.053	1.097	0.179	5.22	0.77	4.45	77.53	...
TR130	-0.009	0.060	1.125	0.182	5.03	0.44	4.60	83.08	...
TR10	-0.003	0.075	1.022	0.182	6.05	1.29	4.76	89.71	...
TR139	0.012	0.089	0.904	0.212	6.69	2.29	4.40	75.90	...
TR144	0.017	0.093	0.907	0.220	6.48	2.20	4.28	71.68	...
TR68	0.002	0.103	0.901	0.197	6.66	2.15	4.51	79.94	...
TR60	0.000	0.101	0.941	0.191	6.48	1.77	4.71	87.54	...
TR104	-0.008	0.152	0.809	0.183	6.75	2.35	4.40	75.78	...
TR49	0.001	0.241	0.537	0.166	7.92	3.19	4.72	87.99	0.041
TR19	-0.003	0.270	0.451	0.162	8.13	3.58	4.54	81.01	0.012
TR36	0.002	0.271	0.465	0.162	8.11	3.40	4.71	87.70	0.007
TR101	0.011	0.285	0.406	0.164	8.37	3.91	4.46	77.90	0.023
TR118	-0.001	0.295	0.416	0.166	8.37	3.68	4.70	86.94	0.005
TR86	0.003	0.303	0.375	0.165	8.54	4.09	4.45	77.56	-0.024
TR114	0.008	0.299	0.393	0.153	8.57	3.83	4.73	88.32	-0.164
TR96	0.024	0.318	0.370	0.178	8.46	4.00	4.46	77.91	0.082
TR162	-0.011	0.315	0.384	0.168	8.66	3.90	4.75	89.25	-0.042
TR90	-0.011	0.317	0.386	0.156	8.61	3.81	4.79	90.98	-0.207
TR92	0.012	0.332	0.360	0.177	8.56	4.06	4.50	79.28	0.001
TR58	-0.010	0.337	0.346	0.171	8.87	4.24	4.64	84.58	-0.098
TR53	-0.006	0.340	0.343	0.174	8.75	4.25	4.50	79.50	-0.070
TR97	0.001	0.353	0.311	0.179	9.12	4.59	4.52	80.33	-0.071
TR76	-0.003	0.360	0.325	0.186	9.11	4.36	4.75	89.32	-0.032
TR102	-0.007	0.383	0.292	0.206	9.39	4.71	4.68	86.43	0.062

two as SrII peculiars, and he classified them with a special notation. In the same work, he lists some stars that appeared to have double spectra, or that had the same peculiarity found in the two aforementioned Sr stars. More recently, these classifications have been used as standards for testing new methods for the photometric classification of Ap stars, Cameron (1966), Mendoza (1977), Maitzen & Pavlovski (1987).

In 1966, Cameron (1966) defines a locus on the $[m_1]$ – $[c_1]$ diagram where the peculiar Ap stars are found. Later, Renson (1988) in his catalogue of Am and Ap stars in open clusters reports that some of the peculiar stars of Coma Berenices are Am stars. A compilation of some of the stars, known to belong to either category in the Coma Berenices cluster, is presented in Table 9. The relevant papers on spectroscopic classification include those of Trumpler (1938), Weaver (1952) and Mendoza (1963, 1967) as well as the compilations of Renson (1988) and Hoffleit & Jaschek (1981). From the photometric compilation carried out in the present paper and from the position of the stars in the $[m_1]$ – $[c_1]$ diagram, several have been found to belong to the Ap class. These are listed in column 7 of Table 9.

It is worth mentioning that the status of the majority of these stars had been predicted by the previous work of Trumpler (1938), and the present analysis has served to support his assertions.

Since the abundance of Ap stars is interesting per se, it is worthwhile to mention that out of 26 A and F member stars, 4 have been found to belong to the Ap class, giving an Ap/(B+A+F) ratio of 0.154, although this figure has to be cautiously considered since the absolute *uvby*-β photometry in the Coma Berenices cluster compiled up to the present has not been exhaustive.

5.6 Variability

The variable stars in Coma Berenices observed and reported here have long been known to be variables. It is important to note that both HR 4684 and HD 106103 have been proved to be cluster members.

HR 4684 was first reported as a Delta Scuti star in 1968, but despite the long time span, very little had been done to study its periods of variability. Serendipitously, this star was observed almost simultaneously by the authors and by Paparo & Kovacs (1984). The period analysis of these three seasons has been already carried out and presented elsewhere (Paparo et al. 1993).

The physical characteristics of HR 4684 have been derived from *uvby*-β absolute photometry. These values were obtained in a separate observing season as indicated in Table 1. In this season, HR 4684 was observed for a time span of 40 minutes during which 10 data points in the *uvby* system were obtained. The transformation coefficients to the standard system will be reported elsewhere. The mean values obtained for V, b-y, m_1, c_1 are 6.460, 0.097, 0.188, 0.949 with standard deviations of 0.007, 0.002, 0.002, 0.005, respectively.

The photometric values obtained for HR 4684 are in agreement with those reported by Crawford & Barnes (1969), by Díaz (1991) or by López de Coca et al. (1990). Its physical characteristics can be determined from the previously described

TABLE 9

PECULIAR STARS IN THE DIRECTION OF COMA BERENICES

Id	Trumpler[a]	Weaver	Mendoza	Renson	Hoffleit	PP
TR47	A9(W) A2(V)	...	...	A3-F1m	A4m	Sr-Cr
TR52	A5s	...	A5 V	A6-F1m	...	Sr-Cr
TR62	A5	A4m3	Am	A4-A9m	A8m	Sr-Cr-Eu
TR68	A4n Fe ft	A4m1	A6IV-V	A3-A7m	A6IV-V	Sr-Cr
TR70	F0	...	F0 V	...	F0IV	Sr-Cr-Eu
TR91	gF4+A	F8p	...	...	G0II	Sr-Cr-Eu
TR109	A9n A6n(W)	F0V	F0 V	...		Sr-Cr-Eu
TR125	A9	F0p	F0p	A9 Sr	F0p	...
TR139	A3s	A4m	Am	A2-F0m		Sr-Cr
TR140	F0n Fe ft	...	A9 V	...	...	Sr-Cr-Eu
TR144	A3s SrII	A4m	Am	A2-F0m	A2m	Sr-Cr
TR145	A2s	A4m	Am	A2-F0m	A0p	Sr-Cr-Eu
TR146	A0s	A0p	A0p	A0SrEuCr	A0p	...
TR160	A2 A2s(W)SrII	A3p	A3p	A3 Sr	A2p	...

[a] Classifications reported in Trumpler 1938: Trumpler, Mount Wilson (W) and Victoria (V).

calibrations. The values determined are log g of 4.00 and T_{eff} of 8200 K. With these physical parameters, the period derived by Paparo et al. (1993) and the well known relation for the pulsation constant Q, one might conclude that this star is pulsating in the first overtone.

HD 106103 was established as variable in 1972, but much less information about it is available. The data obtained and presented here are insufficient to carry out an accurate period analysis of its periodic content, so the period of this star remains uncertain (López de Coca et al. 1990). With the reported value of the period, the physical parameters derived here, log g of 4.10 and T_{eff} of 6700 K, and which are in agreement with those of López de Coca et al. (1990), give an inconsistency in the PLCR; therefore new and more accurate data strings are needed to determine its period unequivocally.

6. SUMMARY AND CONCLUSIONS

New differential photometry of two Delta Scuti stars has been presented. The analysis of the periodic content of these photometric data and of other simultaneous campaigns have been presented elsewhere (Paparo et al. 1993). In order to derive the observational parameters of such variable stars *uvby*-β photometry has been compiled from the literature (Crawford & Barnes 1969; Díaz 1991). Through this photometry these stars have been established as cluster members, with age and metal abundance determined. Physical parameters such as log g and log T_{eff} have been determined for both stars through direct comparison with theoretical models. As a by-product of the *uvby*-β compilation of 69 stars in the direction of Coma Berenices some stars have been determined or corroborated as belonging to the Ap class.

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