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GALACTIC CLUSTERS WITH ASSOCIATED CEPHEID VARIABLES. II. NGC 129 AND DL CASSIOPEIAE

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ABSTRACT

New photoelectric *UBV* photometry of 27 stars and spectroscopic observations of 12 stars are presented for NGC 129, the cluster containing the 8ᵈ00 Cepheid DL Cas. The photometry is used to restandardize previously published photoelectric and photographic observations of stars in NGC 129, including transformed Strömgren system data. A compilation of the best available photometric data for stars with $V<15.3$ (the limit for reliable observations) is used in conjunction with published proper motion data and spectroscopic observations of the brighter stars for a detailed cluster analysis. The newly obtained distance modulus of NGC 129 is $V_0-M_V=11.11\pm0.02$ s.e. ($d=1.670\pm0.013$ kpc), and a value of $R=A_V/E_{B-V}=3.20\pm0.30$ s.e. is found to describe the dust extinction in the field. A space reddening of $E_{B-V}=0.47\pm0.01$ is derived for DL Cas from consideration of a possible circumstellar reddening effect for cluster B stars, and its resulting luminosity is $\langle M_V\rangle=-3.80\pm0.05$. A list of 94 candidate cluster members is presented, and a cluster radial velocity of -36.0 ± 1.8 km s^{-1} is derived using the supergiants and bright B stars. The membership status of the supergiants is discussed in connection with other available information for cluster stars.

1. INTRODUCTION

The spatial coincidence of the 8ᵈ00 classical Cepheid DL Cassiopeiae with the open cluster NGC 129 was recognized over 35 years ago, independently by Kholopov (1956), Kraft (1957), and van den Bergh (1957). The Cepheid qualifies as a highly probable cluster member on the basis of its proper motion (Lenham & Franz 1961; Frolov 1975; Lavdowsky 1981) and radial velocity (Kraft 1958; Harris *et al.* 1987; Mermilliod *et al.* 1987). This makes photometric observations of cluster stars essential for calculating its exact distance and reddening, so that it can be used for calibrating Cepheid luminosities. NGC 129 was observed for this purpose previously by Arp *et al.* (1959) and Hoag *et al.* (1961) using broadband photoelectric and photographic *UBV* photometry, and a restricted number of bright cluster stars were also studied by means of Strömgren four color and Hβ photometry by Schmidt (1980) and Eggen (1983).

It was pointed out in Paper I of this series (Turner 1986) that the Cepheid calibrating clusters are often not well studied, in the sense that the standardization of the photometry is sometimes less than adequate, while only scattered observations are available for the faint cluster members which are so vital to any distance determination based upon main-sequence fitting. NGC 129 appears to be no exception. Schmidt (1980) pointed out the marked differences in color evident between the two sets of *UBV* photometry for NGC 129 stars, and Eggen (1983) found small color differences between the two sets of four-color photometry. Discrepancies of this type will invariably influence the derived intrinsic parameters for cluster stars, and might have some bearing on the problems, discussed by Schmidt (1984, 1991), associated with anomalies in the derived distances to the Cepheid calibrating clusters. The study of NGC 6087 presented in Paper I was used to discuss the apparent distance discrepancy for this cluster. It is with similar intentions that we present here a fresh attack on the derivation of the reddening and distance for NGC 129 and DL Cas based upon new photoelectric *UBV* photometry and spectroscopic observations of cluster stars.

2. OBSERVATIONS AND DATA COMPILATIONS

2.1 Photoelectric Photometry

The program objects for our photometric study consist of a sample of 27 cluster stars chosen from the lists of Arp

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TABLE 1. New photoelectric data for NGC 129 stars.

Star Identification CDS	Arp	Hoag	V	B–V	U–B	n
170	A	5	8.87	+0.97	+0.67	3
171	B	7	9.27	+0.46	–0.13	3
48	48	9	9.63	+0.45	–0.04	3
172	C	11	10.88	+0.44	–0.09	3
111	111	12	10.92	+0.51	+0.32	3
105	105	13	11.14	+0.39	–0.15	2
173	D	14	11.15	+0.28	+0.16	2
115	115	15	11.44	+0.74	+0.25	2
202	...	16	11.69	+0.31	–0.50	2
125	125	18	11.77	+0.44	–0.14	3
96	96	20	12.29	+0.50	–0.08	3
174	E	23	12.61	+0.46	+0.09	2
175	F	42	12.76	+0.55	+0.16	2
176	G	43	12.79	+0.64	+0.16	2
177	H	44	12.88	+0.58	–0.05	2
178	I	25	12.88	+0.42	–0.15	1
179	J	27	13.12	+0.57	+0.06	2
47	47	28	13.69	+0.48	+0.14	1
113	113	29	13.79	+0.60	+0.37	2
181	L	65	13.95	+1.59	+1.31	1
184	O	30	14.17	+0.55	+0.33	3
182	M	77	14.21	+0.63	+0.40	2
185	P	82	14.33	+0.76	+0.31	1
42	42	33	14.46	+0.64	+0.40	1
186	Q	...	14.65	+0.68	+0.43	2
191	V	109	15.13	+0.63	+0.77	1
192	W	...	15.25	+0.72	+0.45	1

TABLE 2. Weighted differences between photoelectric data sets.

Comparison	Interval	Stars	ΔV ± s.e.	Δ(B–V) ± s.e.	Δ(U–B) ± s.e.
This Paper – Arp et al.	V < 12	6	–0.001 ±0.009	+0.019 ±0.009	+0.004 ±0.009
	V < 14	13	+0.002 ±0.006	+0.028 ±0.007	+0.012 ±0.010
	V < 15	15	+0.005 ±0.006	+0.028 ±0.010	+0.013 ±0.018
This Paper – Hoag et al.	V < 12	10	+0.006 ±0.003	–0.001 ±0.005	–0.007 ±0.006
	V < 14	16	+0.009 ±0.009	–0.001 ±0.004	+0.006 ±0.010
	V < 15	18	+0.012 ±0.010	–0.002 ±0.005	+0.003 ±0.011
Hoag et al. – Arp et al.	V < 12	8	–0.007 ±0.009	+0.023 ±0.012	+0.006 ±0.012
	V < 14	12	–0.012 ±0.008	+0.028 ±0.009	–0.004 ±0.011
	V < 15	13	–0.012 ±0.007	+0.034 ±0.011	–0.007 ±0.011
Adopted Corrections:					
This Paper			+0.00	+0.00	+0.00
Hoag et al.			+0.01	+0.00	+0.00
Arp et al.			+0.00	+0.03	+0.00

et al. (1959) and Hoag *et al.* (1961), and covering the magnitude interval from $V=9$ to 15. The stars were observed on 3 nights in 1984 August using the Mark I photometer, equipped with a dry-ice-refrigerated 1P21 photomultiplier and standard Johnson system filters, attached to the 1.3 m telescope at Kitt Peak National Observatory. Owing to restrictions on the available observing time imposed by the weather at the site, the frequency of observations for these stars was not as high as originally intended for the clusters in this series. However, the resulting dataset appears to be sufficient to resolve the discrepancies between previous photometric observers, including those using four-color photometry. Additional observations were therefore considered unnecessary.

The photometric data are presented in columns 4–6 of Table 1, where the stars are identified in columns 1–3 using the numbering systems of Mermilliod (1976) and the Stellar Data Center (CDS) at Strasbourg, Arp *et al.* (1959), and Hoag *et al.* (1961), and column 7 indicates the number of individual nights of observation for each star. In the U.S. Naval Observatory Catalogue of Hoag *et al.* , stars observed photoelectrically are numbered sequentially in order of increasing magnitude, while stars observed photographically (including photoelectric sequence members) are identified only by their *XY* coordinates on a finder chart of the cluster. There appears to be no universally accepted system for numbering these latter objects. Mermilliod numbers them sequentially from 1, although this creates multiple designations for the photoelectric sequence stars in these lists. In this paper we have used a numbering system for these stars which is a simple extension of the original scheme. Photographic sequence stars which are not identified by their coordinates as being members of the photoelectric sequence are, therefore, numbered sequentially from the last number in the photoelectric sequence (i.e., 35, 36,..., for NGC 129), in order of increasing magnitude.

The precepts for *UBV* photometry outlined by Johnson (1963) were followed as closely as possible in obtaining the present observations. As emphasized by Popper (1982), a useful check on the standardization to the *UBV* system is provided by the slopes and zero points of the color transformations. For the present dataset the zero-point corrections for the $B-V$ and $U-B$ colors were -1.07 and $+1.12$, respectively, in excellent agreement with values of -1.04 and $+1.12$ adopted by Johnson in the development of the *UBV* system (Johnson & Morgan 1953). The corresponding slopes for the color transformations were 0.95 and 1.00, respectively, which are close enough to unity to indicate a very close match of the instrumental system to the Johnson system. We feel confident that the present observations constitute a fairly reliable *UBV* dataset. Representative uncertainties in the data for bright stars in Table 1 are about ± 0.01 in V and $B-V$, and ± 0.02 in $U-B$, but become increasingly larger for stars fainter than about $V=14$.

Table 2 presents a comparison of our *UBV* photometry for cluster stars with the photoelectric observations of both Arp *et al.* (1959) and Hoag *et al.* (1961) for stars brighter than $V=15$, and a similar comparison of the latter two sources for stars in common. No indications of magnitude-dependent or color-dependent differences are evident in the data, so the listed values represent simple weighted means for all stars to the stated magnitude limits, with weights assigned according to the minimum number of observations obtained for each star by the two observing groups being compared. Star 182 (M) was omitted from the comparison owing to the marked discrepancy between our values and those of Arp *et al.* for this star. Likewise, stars 164 (AA) and 165 (AB) are late-type supergiants, and were omitted from the comparison owing to their suspected variability (Zakharova *et al.* 1986). We also assumed that $n=2$ for the Hoag *et al.* observations, despite the fact that the remarks in the U.S. Naval Observatory Catalogue suggest that most of these stars were observed on only one night.

Although there is some scatter in the observations for faint stars in the three datasets, the weighted mean differences listed in Table 2 generally indicate very good agreement in magnitude and color for these independent sources of photoelectric photometry for NGC 129 stars. Certain minor corrections to the various datasets are needed to place them on a common system, in particular, that of this paper. The adopted corrections listed at the bottom of Table 2 were inferred from the most obvious differences evident in the data comparison. These consist of a $+0^m.01$ correction to the Hoag *et al.* V magnitudes, and a $+0^m.03$ correction to the Arp *et al.* $B-V$ colors.

Schmidt (1980) published Strömgren four-color and Hβ photoelectric photometry for 22 stars in NGC 129, 4 of which plus star 170 (A) were observed in similar fashion by Eggen (1983). These observations are relevant to the present study since it is possible to transform observations for the early type stars in this sample to the *UBV* system (Turner 1990). Eggen (1983) derived mean differences between his data and those of Schmidt, but they appear to be misquoted in his paper. The largest differences are in the c_1 indices, which involve observations with the ultraviolet u filter, while the differences in Hβ indices vary strongly with color (with a correlation coefficient of 0.986). This last effect can be attributed to a color term in the Hβ photometry arising from a mismatch of the effective wavelengths for the wide and narrow Hβ filters (Muzzio 1978; Schmidt & Taylor 1979), with Eggen's dataset indicated to be the likely source of the problem owing to the fact that Schmidt's data were specifically examined for effects of this type. As a test, we adjusted both datasets individually to the system of the other, and compared the transformed combined data on each system to our collection of photoelectric *UBV* data. It was found that transformations of the four-color photometry on Schmidt's system gave the best match to the photoelectric data, so Eggen's observations were adjusted to this system in the final analysis. The transformed $U-B$ colors from this combined dataset are an excellent match to the present photometry. However, there is a slight magnitude dependence (with a correlation coefficient of 0.811) in the transformed $B-V$ colors. This was taken into account in deriving the final set of transformed *UBV* photometry, which includes $U-B$ colors for 22 stars, and $B-V$ colors for 18 of them. The astronomical literature contains additional *UBV* and four-color observations for a few of the brighter members of NGC 129. However, these observations were not included in the present study owing to the difficulty of matching them to the present system. A compilation of the composite *UBV* photoelectric photometry available for cluster stars from a combination of the data from the various sources described here is given in Table 3.

Although the 60 stars in Table 3 constitute a very extensive photoelectric sequence for NGC 129, it should be noted that there are problems with some of the fainter stars in the list. These can be traced to large random errors in many of the single observations as well as to spurious observations by Arp *et al.* (1959) for CDS 182 (star M) and 189 (star T). The extent of the problem can be judged from an examination of Table 4, which summarizes the available photoelectric and photographic data (as described in the next section) for the 9 stars in Table 3 (excluding CDS 194 and 195, the two faintest) which seem most likely to be affected by large observational uncertainties. The final columns of Table 4 present what we consider to be the best data for these nine stars. Where the photoelectric and photographic results are in reasonable agreement, the photoelectric data were adopted. Where there are significant discrepancies or unrealistic colors in the photoelectric data, the photographic data were adopted. Careful analysis of the available photographic data suggests that published photometry for NGC 129 stars is quite untrustworthy for $V > 15.3$, and this limit was adopted throughout the present study.

TABLE 3. Combined photoelectric data for NGC stars.

Star Identification CDS	Arp	Hoag	V	B–V	U–B	n	Star Identification CDS	Arp	Hoag	V	B–V	U–B	n
164	AA	2	8.58	+1.97	+2.15	4	13	13	24	12.75	+0.83	+0.30	2
165	AB	3	8.72	+1.82	+2.12	4	175	F	42	12.76	+0.53	+0.15	3
170	A	5	8.87	+0.98	+0.67	14 [a]	176	G	43	12.80	+0.65	+0.10	6 [b]
197	S3	6	8.91	+0.21	+0.15	4	177	H	44	12.87	+0.57	−0.05	3
171	B	7	9.27	+0.47	−0.14	19 [b]	178	I	25	12.88	+0.41	−0.15	4
196	S2	8	9.38	+0.17	−0.20	5	22	22	26	13.00	+0.42	+0.04	2
48	48	9	9.64	+0.44	−0.05	8 [b]	179	J	27	13.11	+0.58	+0.02	5
166	AC	10	9.95	+0.18	−0.17	9	169	AF	...	13.54	+0.79	+0.25	1
198	S4	...	10.77	+0.26	+0.18	3	180	K	...	13.71	+0.62	+0.29	1
172	C	11	10.90	+0.45	−0.08	16	47	47	28	13.72	+0.46	+0.18	3
111	111	12	10.92	+0.51	+0.33	6	113	113	29	13.84	+0.61	+0.34	4
105	105	13	11.14	+0.40	−0.17	13	181	L	65	13.94	+1.59	+1.31	2
173	D	14	11.14	+0.28	+0.18	8	183	N	68	14.01	+0.49	+0.28	1
115	115	15	11.44	+0.74	+0.23	6 [b]	204	...	31	14.09	+0.49	+0.33	2
202	...	16	11.69	+0.32	−0.49	4	184	O	30	14.13	+0.55	+0.33	6
61	61	35	11.72	+0.39	−0.17	8	182	M	77	14.21	+0.63	+0.40	2 [c]
24	24	17	11.77	+0.39	−0.16	7	185	P	82	14.33	+0.70	+0.43	2
125	125	18	11.78	+0.43	−0.12	11	31	31	32	14.34	+0.89	+0.33	2
63	63	36	11.87	+0.42	−0.07	2	42	42	33	14.51	+0.61	+0.49	3
118	118	...	11.91	+0.60	+0.49	3	187	R	...	14.61	+0.90	+0.18	1
203	...	19	11.96	+0.46	+0.25	2	186	Q	...	14.63	+0.70	+0.49	3
123	123	...	12.07	+0.41	−0.15	3	188	S	95	14.74	+1.62	+0.80	1
151	151	37	12.15	+0.36	−0.19	3	189	T	115	14.77	+1.72	...	1
121	121	38	12.15	+0.46	+0.00	2	190	U	135	14.92	+0.83	...	1
96	96	20	12.27	+0.50	−0.09	8	205	...	34	14.97	+0.58	+0.14	2
16	16	21	12.30	+0.37	+0.12	5	191	V	109	15.07	+0.67	+0.60	2
167	AD	...	12.36	+1.98	+2.32	1	192	W	...	15.24	+0.73	+0.45	2
168	AE	22	12.37	+0.37	−0.08	6	193	X	...	15.27	+0.87	+0.85	1
93	93	...	12.42	+0.49	−0.05	1	194	Y	...	15.96	+1.41	...	1
174	E	23	12.58	+0.46	+0.07	5	195	Z	...	16.40	+1.20	...	1

[a] n(V) = 24.
[b] n(B–V) = 10, 5, 4 & 4 for CDS 171, 48, 115 & 176, respectively.
[c] Data from Arp *et al.* (1959) omitted.

2.2 Photographic Data

Extensive *UBV* photographic photometry for NGC 129 stars is presented by Arp *et al.* (1959), Hardorp (1960), and Hoag *et al.* (1961), while Frolov (1975) presents pho-

TABLE 4. Best data for faint stars.

Star Identification CDS	Arp	Hoag	Photoelectric V	B–V	U–B	Source	Photographic V	B–V	U–B	Adopted V	B–V	U–B
183	N	68	14.01	+0.49	+0.28	Arp	14.05	+0.58	+0.25	14.01	0.49	0.28
182	M	77	13.99	+0.86	+0.24	Arp	14.25	+0.57	+0.43	14.25	+0.57	+0.43
			14.21	+0.63	+0.40	This Paper						
187	R	...	14.61	+0.90	+0.18	Arp	14.71	+0.83	+0.28	14.71	+0.83	+0.28
188	S	95	14.74	+1.62	+0.80	Arp	14.78	+1.58	+1.22	14.74	+1.62	+1.22
189	T	115	14.77	+1.72	...	Arp	15.07	+0.63	+0.54	15.07	+0.63	+0.54
190	U	135	14.92	+0.83	...	Arp	14.90	+0.86	+0.72	14.90	+0.86	+0.72
191	V	109	15.01	+0.70	+0.43	Arp	15.07	+0.59	+0.50	15.07	+0.67	+0.50
			15.13	+0.63	+0.77	This Paper						
192	W	...	15.22	+0.73	+0.45	Arp	15.27	+0.70	+0.45	15.24	+0.73	+0.45
			15.25	+0.72	+0.45	This Paper						
193	X	...	15.27	+0.87	+0.85	Arp	15.27	+0.97	+0.57	15.27	+0.97	+0.57

tographic *BV* data for stars in the larger cluster field. Mermilliod *et al.* (1987) have drawn attention to the sinusoidal trends evident in comparisons of the data from these various sources, and attribute the problem to the data published by Arp *et al.* We examined the published photographic data for cluster stars in some detail using the Table 3 data for reference purposes, and found that the situation is not quite as bad as pictured by Mermilliod *et al.* There are sinusoidal trends in the data of the type described. However, they generally have amplitudes of no more than $0^{m}_{.}1$–$0^{m}_{.}2$, with magnitude variations consistent with the older techniques by which such data were calibrated (see Turner & Welch 1989).

The data of Hardorp are clearly the most reliable, presumably because of the large plate collection on which they are based, although even here there is a sinusoidal variation in the *U* data and marked systematic deviations for $V > 15.3$. It can be demonstrated that the origin of the large systematic trends in the *B* and *V* data described by Mermilliod *et al.* does *not* lie in the photographic data of Arp *et al.* It is clearly traced to problems with the faint star photographic photometry of Hoag *et al.* Data from the latter for $V > 14.5$ and $B > 14.7$ are most severely affected, as are the data from Frolov, and should not be trusted. There are also curious cases in the Arp *et al.* sample where the photographic data deviate by more than $0^{m}_{.}1$ from the photoelectric results, with no obvious explanation in terms of image crowding on the plates. Because of this, it appears inadvisable to trust the Arp *et al.* data where they are not supported by data from other sources. Within these various constraints, however, it is possible to compile *UBV* photographic data for 77 additional stars which are well sampled in the lists of Arp *et al.*, Hardorp, and Hoag *et al.*, with the data tied closely to the system of Table 3. These data are presented in Table 5, and represent weighted means from the available sources, with weights assigned according to the minimum number of plates used to obtain magnitudes and colors for each star. The photographic data in Table 4 were derived in identical fashion. Due to the large number of plates and individual measurements upon which these data are based, their uncertainties probably approach those for the photoelectric data. Further analysis confirms this result.

The sample provided in Tables 3–5 is sufficient for a detailed study of NGC 129. We have not included a cluster finder chart here, since charts are given by Arp *et al.* (with a few erroneous designations), Hardorp, and Hoag *et al.* The CDS lists referred to in Tables 3–5 contain all cross references needed for the identification of each star in these published charts.

TABLE 5. Combined photographic data for NGC 129 stars.

CDS	Hoag	V	B–V	U–B	CDS	Hoag	V	B–V	U–B
71	...	12.29	+0.43	–0.05	56	80	14.43	+0.84	+0.41
33	39	12.56	+0.47	–0.03	102	...	14.43	+0.78	+0.19
20	40	12.68	+1.10	+0.87	132	84	14.44	+0.55	+0.46
152	41	12.72	+1.42	+0.88	138	85	14.47	+0.86	+0.43
26	45	12.84	+0.44	–0.08	32	83	14.49	+0.60	+0.43
109	46	13.02	+0.54	+0.29	7	88	14.53	+0.52	+0.43
3	47	13.05	+0.70	+0.18	29	90	14.55	+0.93	+0.17
97	...	13.11	+0.50	–0.01	19	92	14.56	+0.42	+0.04
108	49	13.19	+0.75	+0.10	43	89	14.58	+0.69	+0.53
140	52	13.24	+0.83	+0.25	9	93	14.60	+0.59	+0.42
131	50	13.31	+0.45	+0.20	143	96	14.63	+0.93	+0.29
127	51	13.31	+0.42	+0.08	269	...	14.67	+1.90	+1.61
72	55	13.42	+0.37	+0.18	59	97	14.71	+0.69	+0.44
67	53	13.44	+0.57	+0.31	66 [a]	94	14.72	+1.38	+1.13
64	54	13.44	+0.50	+0.03	78	...	14.76	+0.59	+0.41
35	56	13.64	+0.50	+0.26	245	101	14.86	+0.63	+0.46
126	57	13.64	+0.44	+0.18	270	102	14.86	+0.67	+0.49
73	59	13.77	+0.65	+0.23	10	103	14.88	+0.49	+0.22
141	61	13.81	+0.65	+0.26	17	106	14.88	+0.63	+0.52
130	58	13.82	+0.57	+0.37	65	...	14.88	+0.60	+0.46
23	60	13.82	+0.55	+0.19	74	108	14.92	+0.65	+0.46
30	63	13.83	+0.51	+0.35	6	111	14.92	+0.70	+0.47
5	66	13.84	+0.55	+0.29	40	107	14.93	+0.96	+0.35
58	62	13.85	+0.43	+0.18	100	...	14.93	+0.68	+0.46
8	64	13.85	+0.53	+0.17	120	...	14.94	+0.63	+0.45
75	...	13.89	+2.01	+1.74	1	...	14.98	+0.82	+0.53
89	67	13.94	+0.51	+0.36	107	100	15.04	+2.01	+1.38
4	69	14.00	+1.71	+1.28	112	...	15.08	+0.70	+0.54
18	70	14.08	+0.49	+0.28	44	...	15.16	+0.84	+0.71
68	...	14.11	+0.50	+0.34	266	121	15.19	+0.72	+0.59
69	72	14.14	+0.59	+0.46	227	116	15.22	+0.77	+0.47
150	73	14.16	+1.63	+0.46	247	...	15.25	+0.85	+0.50
106	71	14.17	+0.57	+0.48	267	...	15.25	+0.80	+0.61
14	74	14.19	+0.51	+0.26	271	122	15.26	+1.07	+0.36
79	75	14.25	+0.53	+0.37	70	125	15.29	+0.70	+0.56
92	76	14.25	+0.59	+0.33	53	113	15.32	+1.86	+1.00
15	...	14.28	+0.59	+0.34	136	...	15.36	+0.73	+0.54
76	78	14.33	+0.66	+0.49					
2	81	14.34	+0.51	+0.36					
86	79	14.35	+0.55	+0.43					

[a] Identical star to CDS 217.

2.3 Spectroscopic Data

The importance of NGC 129 for the calibration of Cepheid properties has inspired the publication of an extensive set of spectroscopic observations for bright cluster stars. We have been able to extend the sample to roughly $B = 13$ through observations of 12 of the brightest B-type members of NGC 129 during observing runs in 1991 September, October, and November with the 1.8 m telescope at the Dominion Astrophysical Observatory. Spectra of each star at a dispersion of 60 Å mm^{-1} were obtained with the RCA CCD camera on the Cassegrain spectrograph, which gave a wavelength coverage at this dispersion of 978 Å centered on 4200 Å. The spectral images were reduced and wavelength calibrated using software from IRAF, and have typical mean signal-to-noise ratios ranging between 20 and 140, depending upon the circumstances of each exposure. All were subsequently classified on the MK system by comparing their observable spectral properties (line strengths, line profiles, and relative line ratios) to those of similarly obtained spectra for 23 MK and spectroscopic standards of comparable spectral type and luminosity class. The classifications are included in Table 6, which summarizes the available spectral types published for cluster stars.

With regard to the spectral classifications for the 12 B stars in our sample, we note good agreement of our classifications (except in luminosity class) with those of Kraft (1958) for 4 stars in common. Hardorp's (1960) objective-prism spectral classifications for 2 stars of our sample are earlier by one spectral subclass. It seems likely that this is a systematic effect which holds for most of Hardorp's classifications in NGC 129, a suspicion confirmed by close examination of the colors for stars in his sample. CDS 16 is a peculiar object which exhibits unusually narrow hydrogen Balmer line cores. The Hβ photometry for this star (Schmidt 1980) also suggests some line filling, at least for Hβ. Although it is possible that CDS 16 exhibits weak

TABLE 6. Summary of spectral classifications for NGC 129 stars.

CDS	MK Type	Ref[a]	CDS	MK Type	Ref[a]
DL Cas	G1 Ib G1 Ib-II	1 8	164	K2 Ib K0 Ib K2.5 II–III	1 6 8
165	M0 IIp K7 Ib K5 III	2 6 8	170	F5 Ib F2 Iab	1 6
197	A0 V	1	171	F6 V	1
196	A0 V	1	48	F6: V	5
166	B9 V B9.5: V	1 5	198	B8.5 V	1
172	B6 III-IV B6 III	1 9	105	B4 II: B9: V B5 IVn	4 5 9
115	G1	4	61	B5 V B5 IVn	3 9
24	B6 V B5 IVn	3 9	125	B4 III B5 IV	4 9
63	B6 IVnn	9	151	B5 Vn	9
121	B7 V B7 IIInn	3 9	96	B5 Vnn	9
71	B3 V	4	16	B5 Vp	9
168	B:	7	174	A0	4
177	B5: Vnn	9	178	B4	4
179	B3–9 V:	9			

[a] References: 1. Kraft (1958), 2. Kraft (1959), 3. Kraft, as quoted by Arp, Sandage & Stephens (1959), 4. Hardorp (1960). 5. Hoag & Applequist (1965), 6. Sowell (1987). 7. Harris *et al.* (1987), 8. Keenan & McNeil (1989), and 9. This Paper.

emission features, an examination of the star's colors leads one to suspect that it is simply composite. Despite its B5 V classification, CDS 16 has the colors of a reddened B9 star. Its elongated image on photographic plates also implies the presence of a companion star. This object is an obvious candidate for further observation.

The calibrated spectra were subsequently measured for radial velocity using various software routines and procedures developed by Graham Hill, in particular REDUCE (Hill *et al.* 1982; Hill & Fisher 1986), VCROSS (Hill 1982), and GENERATE (Hill & Fisher 1986). The resulting radial velocities given in Table 7 were obtained in similar fashion to those of Popper & Hill (1991), by cross correlating each spectrum with a synthetic B3–B9 star template consisting of spectral lines of appropriate type and depth centered at the standard wavelengths adopted by Batten (1976). These velocities have typical uncertainties of ± 6–± 8 km s^{-1}, appropriate for the low dispersion used, and are tied closely to the IAU system, as determined from similarly measured spectra for our sample of B-type standard stars of known velocity.

Table 8 summarizes the available radial velocity data for stars in NGC 129. Scarfe *et al.* (1990) detected a small spectral-type dependence in the zero point for the CORAVEL velocities, which we have applied to the radial velocities published by Mermilliod *et al.* (1987) for the bright late-type stars in NGC 129. This adjustment brings the CORAVEL velocities for these stars into excellent agree-

TABLE 7. New spectroscopic data for NGC 129 stars.

CDS	HJD 2448000+	V_R km s^{-1}	Adopted V_R km s^{-1}	V sin i km s^{-1}	Schmidt V sin i km s^{-1}
172	509.9982	−24 ± 8	−24	70 ±14	80
105	512.0164 512.0778	+22[a]±10 − 8 ± 7	− 8	... 174 ±39	250
61	514.0532	−33 ± 6	−33	202 ±11	190
24	515.9724	−37 ± 6	−37	175 ±16	...
125	511.0660	−57[b] ± 6	−57	0::	0
63	544.8369	−47 ± 6	−47	293 ±13	...
151	540.9771	−36 ± 7	−36	257 ±10	...
121	541.7658 543.8765	−32[b] ± 8 −36 ± 6	−35	... 366 ±14	...
96	543.9443	−10 ± 6	−10	343 ±18	...
16	544.9043	−37 ± 6	−37	206 ±19	...
177	569.8092	−33 ± 7	−33	293 ±34	...
179	569.8703	−26[b]±12	−26	382 ±70	...

[a] Low S/N ratio. Rejected from average.
[b] Low S/N ratio.

TABLE 8. Radial velocity data summary for NGC 129 stars.

	Likely Cluster Members				Non-Members		
CDS	V_R km s^{-1}	Ref[a]	Adopted V_R km s^{-1}	CDS	V_R km s^{-1}	Ref[a]	Adopted V_R km s^{-1}
DL Cas	−20.0 −38.1 (orbit)	1 3	−38.1				
164	−32.8 −35.6 −32.6 −32.6 −32.5	1 2 3 4 5	−32.6	165	−12.5 −35.9 −9.4 −10.0 −11.2	1 2 3 4 5	−15.8
170	−20.2 −38.0 (orbit) −38.4 (orbit)	1 3 4	−38.2	197	−21.3	1	−21.3
172	−29.0 −27. −24.	1 3 6	−26.7	171	−25.9 −27.1	1 3	−26.5
105	−20.5 −8.	3 6	−14.3:[b]	196	+5.3	1	+5.3
61	−35.: −33.	3 6	−34.0	166	−38.6 −23.	1 3	−30.8
24	−37.	6	−37.0	198	−11.7	1	−11.7
125	−53. −57.:	3 6	−55.0				
63	−25.: −47.	3 6	−36.0:				
151	−36.	6	−36.0				
121	−35.	6	−35.0				
96	−10.	6	−10.0[b]				
16	−37.	6	−37.0				
168	−40.:	3	−40.0				
177	−33.	6	−33.0				
179	−26.:	6	−26.0:				
	Cluster Mean =		−36.0 ±1.8				

[a] References: 1. Kraft (1958), with V_R adjusted by −9 km s^{-1}, 2. Sowell (1987), 3. Harris *et al.* (1987), with B-star velocities adjusted by +15 km s^{-1}, 4. Mermilliod *et al.* (1987), with V_R adjusted for spectral type dependence, 5. Glushkova & Rastorguev (1991), 6. This Paper.
[b] Excluded from cluster mean.

ment with the DAO radial-velocity spectrometer measures published by Harris *et al.* (1987). Velocities for the cluster B stars are less well defined. Harris *et al.* noted that a correction of -9 km s^{-1} is required to bring the published velocities of Kraft (1958) for the late-type stars into agreement with their scanner velocities, and adopted this correction for the B stars as well. They also measured velocities for Schmidt's (1978) image-tube spectra of 7 cluster B stars, 5 of which are in common with the present sample. A comparison of these velocities with the Table 7 values indicates that there is a systematic velocity difference between the measures for Schmidt's 1976 image-tube spectra and those for the CCD spectra averaging $+15$ km s^{-1} (in the sense CCD-image tube). We have assumed that this difference also applies to Schmidt's 1979 spectra, for which there is less overlap with our sample, and have applied this correction to the Harris *et al.* B-star velocities quoted in Table 8. The internal agreement of the velocities for these stars is improved by this adjustment, with only a modest change to the cluster velocity estimated by Harris *et al.*

The average radial velocity for 14 of 16 stars considered to be cluster members is -36.0 ± 1.8 (s.e.) km s^{-1} (standard deviation $=\pm6.8$ km s^{-1}), about 2 km s^{-1} more positive than the Harris *et al.* value. This new value is still consistent with cluster membership for DL Cas and the F supergiant CDS 170 (star A), and also makes it more likely that the K supergiant CDS 164 (star AA) is a member, as indicated by the proper motion data. The membership of the B stars CDS 105 and 96 appears questionable on the basis of their velocities, although both are members on the basis of proper motions and Hβ photometry. Additional measures for these stars and CDS 125 might help to establish whether or not they belong to the binary population of NGC 129. Finally, CDS 166 (star AC) must be rejected as a cluster member on the basis of its velocity, proper motion, and reddening, contrary to the conclusions of Harris *et al.*

Projected rotational velocities were also estimated for the program stars by cross correlating the spectra with spectra of B-type standards of similar spectral type having small known $V \sin i$ values. A variety of profile widths were measured at several points on the cross-correlation functions, and these were used to estimate $V \sin i$ through a comparison with similar parameters derived from cross correlating the reference spectra with various rotationally broadened spectra of themselves, ranging over values typical of early type stars. The technique has been applied successfully to V599 Aql by Hill & Khalesseh (1991), who have noted that there is a small spectral-type dependence in the parameters of the cross-correlation functions. We have also noticed this feature in our own observations. The rotational standards were therefore closely matched to the spectral types of the program stars, and internal uncertainties in the results were estimated from the scatter in the various linewidth estimators for $V \sin i$. These average ±23 km s^{-1} for the present sample, which is close to the mean spectrum-to-spectrum variation found from observations of the same star in similar work of this type (Turner 1992). External errors associated with uncertainties in $V \sin i$ for the reference stars are not included in these estimates, but should not increase the error estimates significantly owing to the generally small values of $V \sin i$ for the standards.

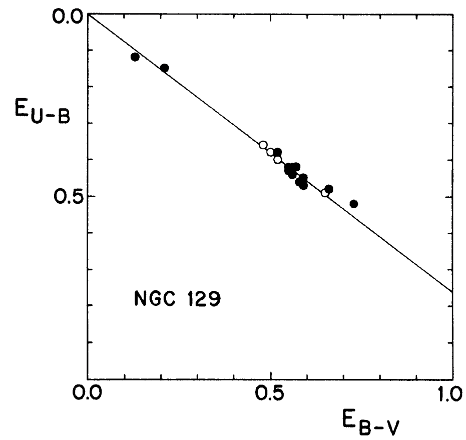

FIG. 1. Derived color excesses for NGC 129 stars as inferred from spectroscopic data (dark circles) or A2 tangent point data (light circles). Two data points from each set at (0.56, 0.42) and (0.56, 0.44) coincide. The adopted reddening relation has a slope of $E_{U-B}/E_{B-V}=0.76$.

Projected rotational velocities for the B stars are useful for a number of reasons, as demonstrated in the next section. Schmidt (1978) has published $V \sin i$ estimates for 4 stars in our sample, and these are listed for comparison in Table 7. A mix-up in the values quoted by Schmidt for CDS 61 and 125 has been detected (Schmidt, private communication), and is corrected here. The agreement of these revised values with our estimates is quite good, which is an encouraging confirmation of the accuracy of the cross-correlation method. The only other estimate of $V \sin i$ available for a member of NGC 129 is a value of 19 ± 6 km s^{-1} obtained by Harris *et al.* (1987) for the F5 supergiant CDS 170. They note that this is a rather large value for an F supergiant.

3. ANALYSIS

3.1 Interstellar Reddening

A necessary component of our cluster studies is the use of spectral classifications for cluster stars to derive the *UBV* reddening relation appropriate for the region (see Turner 1989). Such an analysis is presented in Fig. 1, where the data represent color excesses derived for 13 early type stars in Table 6 with well-established spectral classifications as well as for 6 cluster stars which are unambiguously reddened from the A2 "kink" at $(B-V,\ U-B) = (0.07,\ 0.10)$ in the color–color diagram. Whether treated separately or as one set, the color excess data consistently fit the same reddening slope of $E_{U-B}/E_{B-V}=0.76 \pm0.02$, derived from a regression analysis. This value is quite robust, and is identical to the reddening slope derived previously for this field by Turner (1976b) using published spectral types for stars in the field surrounding NGC 129.

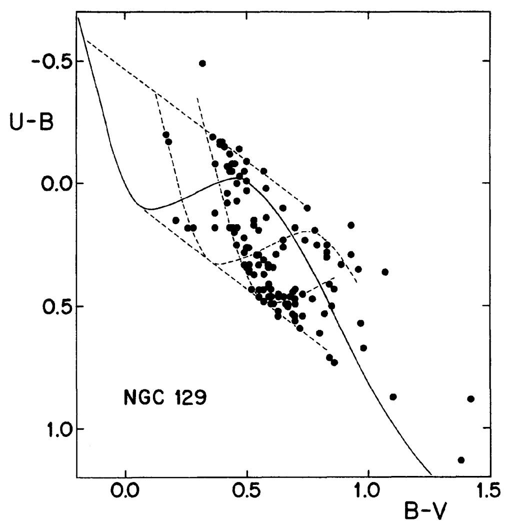

FIG. 2. Color–color diagram for NGC 129 stars. The continuous line is the intrinsic relation for main-sequence stars, while dashed lines represent the intrinsic relation reddened by E_{B-V}=0.29 and 0.50, as well as reddening lines from $(B-V)_0=-0.17$ and $+0.07$.

The cluster color–color diagram based upon the data of Tables 3–5 is presented in Fig. 2, which contains considerable information. For example, the majority of cluster members are readily identified by their colors. All lie redward in $B-V$ and $U-B$, respectively, of two blue envelopes; the one in $B-V$ is defined by the intrinsic relation for main-sequence stars reddened by $E_{B-V}\approx 0.50$ (the minimum reddening of cluster stars), and the other in $U-B$ is defined by the *UBV* reddening line for stars of $(B-V)_0=-0.17$ (spectral type B5, the cluster turnoff), both of which are included in the figure. Only a few unreddened stars are found in the region of NGC 129, while a separate sequence of B, A, F, and G stars reddened by $E_{B-V}\approx 0.29$ can be traced through the data for 15 or so stars. There is one obvious background star in the sample; this is CDS 202, which has the colors of a reddened B1 dwarf and an inferred distance modulus which places it well beyond the cluster.

Since the photometric errors associated with the data of Fig. 2 are quite small, the observed scatter in the colors of cluster stars must result from differential reddening. Previous workers (Arp *et al.* 1959; Lavdovsky 1962) have commented on the distinctly larger reddenings for stars in the southern section of NGC 129. An examination of the Palomar Observatory Sky Survey (POSS) fields containing NGC 129 reveals an extensive complex of dust running from northeast to southwest on the east side of the cluster, and roughly east–west on its south side. There is an extension of this complex running into the southwest portion of NGC 129, and another running into the easternmost extremities of the surveyed cluster field. These dust clouds are presumably responsible for the larger reddening of stars in these particular regions. However, the field is otherwise free of any other obvious dust filaments, judging by the visibility of faint background stars on the POSS. We therefore expect most remaining cluster stars to have very similar color excesses.

The dereddening of stars in our cluster sample was accomplished using the derived reddening line (modified in slope for late-type stars), with all but the spectroscopically identified giants, subgiants, and supergiants, as well as a few red stars assumed likely to be K or M giants, considered to have the intrinsic colors of dwarfs. Luminosities were inferred for each star, in most cases from the zero-age main-sequence (ZAMS) absolute magnitude corresponding to the star's intrinsic color (Turner 1976a, 1979). Blaauw's (1963) luminosity calibration was used to estimate M_V values for two M giants, while the F and K supergiants were excluded from this part of the analysis. Hβ photometry for the B stars was used to infer their absolute magnitudes as in Paper I, i.e., by converting the β indices to equivalent $W(\mathrm{H}\gamma)$ values and using the calibration of Millward & Walker (1985). It was noted in Paper I that stellar Hβ luminosities derived in this manner are a close match to those obtained from ZAMS fitting for the associated cluster, once they are adjusted for an apparent dependence on projected rotational velocity. Corrections for this dependence were therefore applied to the Hβ luminosities of this study using the $V \sin i$ estimates from our spectra or, where there were none, from average $V \sin i$ values appropriate for the star's spectral type (Fukuda 1982). Both adjusted and original Hβ luminosities were considered in the subsequent analysis. Color excesses were also adjusted for their spectral-type dependence as in Fernie (1963), and values quoted here are those equivalent to the reddening of a star of approximate spectral type B3–B5.

The derivation of intrinsic parameters for cluster stars using mainly *UBV* data is not as unreliable or uncertain as sometimes implied in the literature. Only a few stars in our sample have ambiguous dereddening solutions, and the appropriate choice of parameters in these cases is generally obvious from an examination of a reddening map of the field or the variable-extinction plot. Frolov (1975) tabulates proper motion data for 110 of the 137 Tables 3–5 stars, and these are extremely useful for identifying likely cluster members. Foreground stars are quite distinct, with large and randomly directed proper motions compared to those of cluster members. A small group of background stars in the sample also exhibit motions inconsistent with cluster membership. The only uncertain cases are a few stars near the faint limits of this study, where the photometric errors are large and no proper motion data are available for reference purposes. Our choice of parameters for these stars may require revision when additional observational data become available.

The derived color excess and apparent distance modulus data are plotted as a variable-extinction diagram in Fig. 3. In an earlier variable-extinction study of NGC 129 by Turner (1976b), there was concern expressed about the large range of color excesses found for cluster members with no corresponding evidence from the POSS for gross changes in extinction across the field. The Fig. 3 data ad-

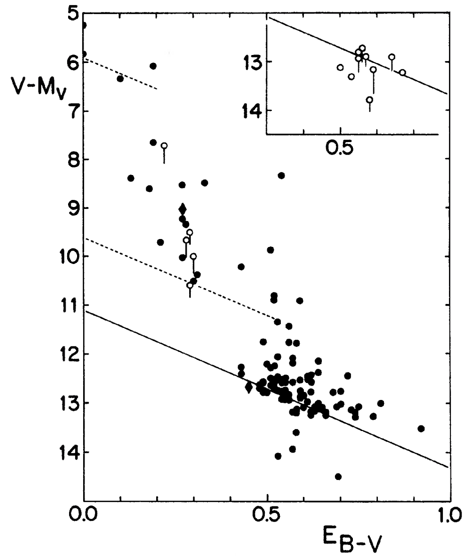

FIG. 3. Variable-extinction diagram for NGC 129 stars based upon ZAMS-fitting (dark circles), Hβ luminosities (light circles with vertical lines denoting corrections for rotational effects), and spectroscopic absolute magnitudes (diamonds). The line of slope $R=3.2$ represents a lower envelope fit for cluster stars, while dashed lines correspond to intrinsic distance moduli of 5.9 and 9.6. The Hβ data for cluster members are shown separately in an inset, since they would otherwise be difficult to distinguish from the other data.

TABLE 9. Cluster membership candidates for NGC 129.

CDS	$(B-V)_0$	E_{B-V}	V_0	CDS	$(B-V)_0$	E_{B-V}	V_0	CDS	$(B-V)_0$	E_{B-V}	V_0
DL Cas	+0.73	0.51	7.31	35	−0.06	0.57	11.82	7	+0.04	0.49	12.96
164	+1.37	0.69	6.37[a]	126	−0.07	0.52	11.98	43	+0.00	0.70	12.34
170	+0.43	0.58	7.01	180	−0.07	0.70	11.47	9	−0.02	0.62	12.62
172	−0.14	0.59	9.01	47	−0.07	0.54	11.99	186	−0.03	0.74	12.26
105	−0.16	0.56	9.35	141	−0.09	0.75	11.41	59	+0.21	0.50	13.11
61	−0.16	0.55	9.96	130	−0.04	0.62	11.84	78	+0.17	0.43	13.38[b]
24	−0.16	0.55	10.01	23	−0.09	0.65	11.74	245	+0.15	0.49	13.29
125	−0.15	0.58	9.92	30	−0.03	0.55	12.07	270	+0.15	0.54	13.13
63	−0.14	0.56	10.08	113	−0.06	0.68	11.66	17	+0.08	0.56	13.09
123	−0.16	0.57	10.25	5	−0.06	0.62	11.86	65	+0.13	0.48	13.34
151	−0.17	0.53	10.45	58	−0.06	0.50	12.25	190	+0.07:	0.81	12.31[b]
121	−0.12	0.58	10.29	8	−0.09	0.63	11.83	74	+0.17	0.49	13.35
96	−0.17	0.67	10.13	89	−0.02	0.54	12.21	6	+0.19	0.53	13.22
71	−0.14	0.57	10.47	183	−0.05	0.55	12.25	40	+0.47	0.52	13.27[b]
16	−0.16	0.53	10.60	18	−0.05	0.55	12.32	100	+0.19	0.51	13.30
168	−0.13	0.50	10.77	204	−0.03	0.53	12.39	120	+0.16	0.48	13.40[b]
93	−0.15	0.64	10.37	68	−0.03	0.54	12.38	1	+0.22	0.62	13.00[b]
33	−0.14	0.61	10.61	184	−0.05	0.61	12.18	189	+0.07	0.57	13.25
174	−0.11	0.57	10.76	69	+0.01	0.59	12.25	191	+0.14	0.55	13.31
175	−0.10	0.64	10.71	106	+0.07	0.51	12.54	112	+0.13	0.59	13.19[b]
26	−0.15	0.59	10.95	14	−0.06	0.58	12.33	44	+0.07:	0.79	12.63[a,b]
177	−0.17	0.74	10.50[a]	182	−0.01	0.59	12.36	266	+0.08	0.66	13.08[b]
178	−0.17	0.58	11.02	79	−0.02	0.56	12.46	227	+0.24	0.55	13.46[b]
22	−0.11	0.53	11.30	92	−0.06	0.66	12.14	192	+0.23	0.52	13.58[b]
179	−0.15	0.73	10.77	15	−0.05	0.65	12.20	247	+0.26	0.61	13.30[b]
97	−0.14	0.64	11.06	2	−0.02	0.54	12.61	267	+0.13	0.69	13.04[b]
108	−0.17	0.92	10.25	86	+0.01	0.55	12.59	271	+0.52:	0.59	13.37[a,b]
131	−0.06	0.52	11.65	56	+0.33	0.53	12.73	193	+0.28	0.72	12.97[b]
127	−0.09	0.52	11.65	132	+0.05	0.51	12.81	70	+0.10	0.62	13.31[b]
72	−0.05	0.43	12.04	138	+0.32	0.56	12.68	136	+0.15	0.60	13.44[b]
67	−0.06	0.64	11.39	32	−0.02	0.63	12.47				
64	−0.13	0.63	11.42	42	+0.02	0.60	12.59				

[a] Membership uncertain.
[b] No proper motion data available.

dress this problem quite satisfactorily, and it is now clear that this earlier study was adversely influenced by systematic errors in the published photometry for very faint cluster stars as well as by the small color offset in the Arp *et al.* data. The true range of reddening for cluster members is clearly smaller than estimated previously, and is generally (although not entirely) consistent with the observable dustiness of the field.

A subset of 34 stars with assumed ZAMS luminosities can be identified as a lower envelope to the data for likely cluster members in Fig. 3. These stars are presumably mostly single stars which lie on the ZAMS, as confirmed by their location in the reddening-corrected color–magnitude diagram for NGC 129. The data for this subset were analyzed using least squares and nonparametric fitting routines, and yielded a reasonably well-defined slope of $R=A_V/E_{B-V}=3.20\pm0.30$ s.e. This value was assumed to apply to the dust in the NGC 129 field. Although it is marginally larger than the 1976 value of $R=3.01\pm0.10$ s.e. derived with less reliable data, it is consistent with the trend towards $R\approx3.2$ noted previously for this region of the Galaxy (Turner 1976b).

The location of the dust clouds responsible for the extinction towards NGC 129 can be established from the Fig. 3 data. Two distinct breaks appear in this diagram, corresponding to marked changes in the reddening of foreground stars. The first is at $V_0-M_V\approx5.9$ ($d=150$ pc), beyond which there are no unreddened stars. The second is at $V_0-M_V\approx9.6$ ($d=830$ pc), beyond which the field reddening suddenly increases from $E_{B-V}\approx0.29$ to $E_{B-V}\approx0.50$ or more. We deduce that there are two major dust complexes lying along the line-of-sight to NGC 129: a relatively nearby complex 150 pc distant producing reddenings of $E_{B-V}\approx0.2$–0.3, and a more remote complex some 830 pc distant which is responsible for the remaining foreground extinction of cluster members. The compilation of Neckel & Klare (1980) indicates that these are entirely reasonable estimates for the distances of nearby dust clouds in this part of the Galaxy.

3.2 *Cluster Stars*

Table 9 summarizes the derived parameters for the 94 stars in our sample considered to be candidates for cluster membership. A reddening-corrected color–magnitude diagram for these stars is presented in Fig. 4. The sample of 34 cluster stars considered to define a lower envelope to the data of Fig. 3 have a mean distance modulus of $\langle V_0-M_V\rangle=11.11\pm0.02$ s.e. (±0.10 s.d.), and the ZAMS corresponding to this value is included in Fig. 4. Note that the placement of the ZAMS was determined from a statistical analysis of the inferred V_0-M_V data for individual main-sequence members of NGC 129 identified in Fig. 3, and *not* from a sliding fit by eye. Although this is a common feature of our cluster studies, it has frequently been a point of some confusion to readers.

Schmidt (1980) derived a distance modulus of 10.93 ±0.19 s.e. (±0.62 s.d.) for NGC 129 based upon his four-color and Hβ photometry for 11 stars considered to be cluster members. A reworking of the data by Balona & Shobbrook (1984) resulted in a revised distance modulus of 11.07 ± 0.14 s.e. for the cluster. Our analysis of the Hβ data is included in Fig. 3, and it should be evident that the scatter in the individual distance moduli evident in these studies is not significantly reduced by our treatment of the

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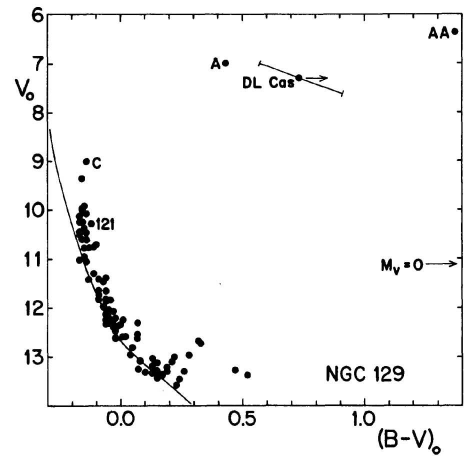

FIG. 4. Reddening-corrected color–magnitude diagram for candidate members of NGC 129. The extremes of variability for DL Cas are indicated, as is its sense of evolution, while the continuous line represents the ZAMS for $V_0-M_V=11.11$. Many of the faint stars lying above the ZAMS may be nonmembers of the cluster.

data. The scatter may be intrinsic to the stars in the sample. CDS 16, the cluster member suspected to be composite, was rejected from Schmidt's sample as a possible emission-line star because of the overly large estimate for its distance modulus. It seems reasonable to suspect that similar problems (i.e., contamination by unresolved companions) may affect the Hβ luminosities for 3 or 4 additional bright cluster members which are too luminous by $0^m.5$ to $1^m.0$; all are highly probable cluster members on the basis of their proper motions and radial velocities. By rejecting these stars from the sample, cluster distance moduli of 11.06±0.05 s.e. (7 stars) and 11.20±0.04 s.e. (5 stars) are obtained using our unadjusted and adjusted Hβ luminosities, respectively. Neither estimate can be considered as an improvement upon the (in our opinion, more superior) ZAMS fit, although both are in reasonably good agreement with the latter. There is no discrepancy in Hβ and ZAMS-fit distance moduli for this particular Cepheid calibrating cluster, and certainly no advantage to be gained by using Hβ photometry alone.

The color–magnitude diagram for NGC 129 is remarkably similar to that for NGC 6087 presented in Paper I. The bluest stars in NGC 6087 have $(B-V)_0=-0.16$, while those in NGC 129 have $(B-V)_0=-0.17$. The brightest star on the evolved main sequence of NGC 6087 has $M_V=-2.5$, while the corresponding star in NGC 129 (star C) has $M_V=-2.1$. Both clusters must be of very similar age, which is not surprising given the similar periods for their member Cepheid variables.

There are a few differences between the two clusters which can be noted. We discount the scattered group of stars lying above the faint end of the ZAMS for NGC 129, since most are likely to be foreground objects which could not be eliminated as nonmembers with the available data. What is significant is that there is more scatter above the B-star ZAMS in NGC 129 than in NGC 6087, even when the difference in cluster sample sizes is taken into consideration. Such scatter can be attributed to a variety of sources, including evolutionary age spread among the stars, unresolved binary companions, photometric errors, and stellar rotation. The simulations of rotational effects on the colors and luminosities of B stars by Maeder & Peytremann (1970), Collins & Sonneborn (1977), and Collins & Smith (1985) indicate that a range of stellar rotational velocities and aspect angles for cluster stars could account for the entire ZAMS spread observed for NGC 129.

The isolation of rotation, rather than, say, binarity or photometric errors, as the likely explanation for the ZAMS spread in NGC 129 results from a close examination of the available data. For example, the location of CDS 121 in Fig. 4 on the extreme low-temperature side of the upper-main-sequence spread for NGC 129 is undoubtedly related to the star's estimated $V \sin i$ of 366 km s^{-1}. This is clearly a very rapidly rotating star seen nearly equator-on, in which case its B7 III spectrum reflects the fact that its cooler, lower-gravity, equatorial regions dominate the hemisphere directed towards us. If the star had a lower rotational velocity and a larger aspect angle, its near hemisphere would produce a hotter, higher-gravity spectrum more like that of the B5 V stars of similar luminosity located at this point on the cluster main sequence. A similar result applies to CDS 63, which has $V \sin i$ of 293 km s^{-1} and a B6 IV spectrum, although in this case its displacement to the low-temperature side of the upper-main-sequence spread is less pronounced than for CDS 121.

A feature possibly related to rotation can be detected in a spatial mapping of reddening in NGC 129. A plot of color excesses across the face of the cluster (not shown) reveals a displacement towards higher reddenings in the southwest and extreme northeast portions of NGC 129 associated with the higher optical depths of the foreground dust clouds in these regions, as described earlier. However, there are also rather extreme small scale variations in color excess, amounting to more than $0^m.1$ in ΔE_{B-V} between closely adjacent stars, and these are difficult to attribute to patchy foreground extinction or to photometric errors. Intracluster dust is not a viable explanation for this effect, since its presence would surely give rise to detectable reflection nebulosity. Turner (1991) presents evidence for identical effects in a few clusters of similar age, and recent spectroscopic observations of stars in one of these, Roslund 3 (Turner 1992), indicate that there is a correlation of this excess reddening with $V \sin i$ for the affected stars, with stars of large $V \sin i$ having the largest excess reddening. Circumstellar reddening produced in equatorial dust rings, which seem to be common features of the late B-type β Pictoris analogs found in recent surveys, offers an attractive mechanism for the production of this effect. A rotational or gravity "reddening" of the intrinsic colors of such stars is a less satisfactory explanation, since the predicted effect on stellar colors is only about 0.04 in $B-V$ in the extreme (Mathew & Rajamohan 1990), and produces color changes for B-type stars which closely mimic changes

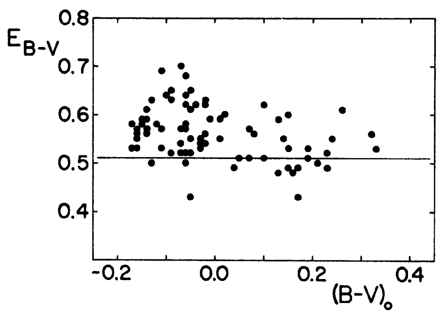

FIG. 5. The variation of color excess with intrinsic color for NGC 129 stars lying in regions which do not exhibit detectable patchy obscuration on the POSS. The line denotes the mean reddening of $E_{B-V}=0.51$ found for the least-reddened cluster members lying near DL Cas.

in effective temperature, as noted above for CDS 121. Rotational modulations of the stellar continua are therefore unlikely to produce effects as large as the observed reddening excess.

Figure 5 is a plot of color excess vs derived intrinsic color for stars in the "unobscured" portions of NGC 129. It is not inconceivable that the variations in color excess observed for stars in these "clear" regions reflects some residual differential reddening across the field. The case for circumstellar reddening in members of NGC 129 is not particularly strong in this respect. However, there are trends in the data which are similar to those found in other clusters (e.g., Roslund 3, NGC 7790, and NGC 381) where variations in foreground extinction are not a viable explanation. In particular, there is a sharp increase in reddening spread as one moves down the cluster main-sequence from the turn-off point, with a maximum spread in reddening for the B7–B9 stars, where equatorial rotational velocities of normal field stars often approach stellar breakup velocities (Fukuda 1982). These points are addressed separately by Turner (1992). In the present study our main concern is the field reddening of the Cepheid DL Cas, since stars in its immediate vicinity exhibit extreme reddening variations from $E_{B-V}=0.48$ to 0.68, with no discernible spatial correlation. We have assumed that the large reddening values, which are generally associated with late B-type cluster members, reflect either a circumstellar phenomenon, an intrinsic effect due to rotation, or a combination of both, and that DL Cas is not affected by this component. The mean reddening of the 9 stars of small reddening nearest DL Cas is $\langle E_{B-V}\rangle=0.51\pm0.01$ s.d., which we adopt as the field reddening appropriate for DL Cas itself. The color excess corresponding to a star with the observed colors of the Cepheid is $E_{B-V}=0.47\pm0.01$.

3.3 The Cluster Supergiants

DL Cas is clearly a member of NGC 129 on the basis of its proper motion and radial velocity, and the evolutionary age of a $8^{d}00$ Cepheid in the second or third crossing of the instability strip is also consistent with the inferred age for NGC 129. The exact evolutionary age depends upon the models used for comparison. A pulsational age of $4.7\pm0.9\times10^7$ yr applies to DL Cas according to calibrations based upon older stellar evolutionary models (Tammann 1970), and this can be compared with a cluster age for NGC 129 of $5.3\pm0.4\times10^7$ yr inferred from the bluest main-sequence stars and the models of Maeder & Mermilliod (1981), as calibrated for cluster studies by Mermilliod (1981). With the more recent models of Maeder & Meynet (1988), the implied cluster age would be closer to 10^8 yr, with a comparable change to the inferred age for an $8^{d}00$ Cepheid. This merely points out the need for internal consistency in any quantitative estimates of this type. There is no doubt that DL Cas is a cluster member.

The rate of period increase found for this variable by Meyers (1988) from an $O-C$ analysis indicates a redward evolution of the star through the instability strip, at a rate which matches predictions from Maeder's recent stellar evolutionary models for a third (or possibly fifth) crossing (Duncan 1991). This additional feature of DL Cas is illustrated by an arrow in Fig. 4 indicating the sense of evolution. Szabados (1991) prefers to match Meyers' $O-C$ data for DL Cas with straight line segments and a phase jump, properties which he considers to be characteristic of binary Cepheids. This interpretation, which does not address the question of the *expected* evolutionary effects, is not adopted here. The field reddening of the Cepheid and the cluster distance of 1.670 ± 0.013 kpc result in values of $\langle(B-V)_0\rangle=0.73\pm0.01$ and $\langle M_V\rangle=-3.80\pm0.05$ for DL Cas derived from the photometric parameters given by Schaltenbrand & Tammann (1971). No corrections have been made for the unresolved companion discussed by Harris *et al.* (1987). The luminosity of DL Cas is relatively insensitive to the uncertainty in R for this region, since its luminosity relative to the ZAMS remains unchanged under any extreme variations of $\langle V_0-M_V\rangle$ with R value for cluster stars. It is sensitive to the value of the Hyades distance modulus, however, as discussed in Paper I.

CDS 170 (star A) is also a cluster member on the basis of its proper motion and radial velocity. The intrinsic color inferred for this F5 supergiant in Table 8 has been adopted from the models of Parson (1971), and very similar values are tabulated in other sources. The derived luminosity for CDS 170 is $M_V=-4.10$, which is quite reasonable for a star classified as F5 Ib. Again, no corrections have been made for the star's unresolved companion (Harris *et al.* 1987). The location of this star in the cluster color–magnitude diagram suggests that it lies off the blue edge of the Cepheid instability strip. Harris *et al.* have drawn attention to the star's unusually large projected rotational velocity, which has led to speculation about possible tidal spin-up in the binary system or to the identification of the star as having recently evolved from the main sequence. The latter explanation has rather interesting ramifications for the question of mass loss during the evolution of DL Cas, since the Cepheid is slightly less luminous than CDS 170 at present, according to our calculations. This discrepancy cannot be accounted for using conservative models of stellar evolution, and may indicate that DL Cas has lost a significant fraction of its mass since it was a main-sequence object.

The membership of the K2 supergiant CDS 164 (star AA) in NGC 129 is somewhat uncertain owing to its inferred luminosity of $M_V = -4.74$ as a cluster member, about 1^m6 more luminous than predicted for a red supergiant cluster member according to the results of Mermilliod (1981), and clearly incompatible with its II–III luminosity classification by Keenan & McNeil (1989). The proper motion and radial velocity data are consistent with cluster membership, however, as is the Ib luminosity classification of Kraft (1958) and Sowell (1987) for this star. Since the available observations do not permit an immediate resolution of the membership question, we have designated CDS 164 as an uncertain cluster member in Table 8.

4. DISCUSSION

Comments by Mermilliod *et al.* (1987) indicate that additional spectroscopic studies of NGC 129 members are in progress, and these would clearly be of value for addressing some of the unanswered questions about possible duplicity or spectroscopic peculiarities for cluster B stars. Published photometric studies have also been restricted mainly to the central and south-central portions of NGC 129, leaving the northern regions and cluster corona relatively unstudied. Extending the faint limit for *reliable* photometry in NGC 129 to $V=17$ or 18 would be of immense value for allowing the cluster main sequence to be traced to the turn-on point near $(B-V)_0 \approx 0.50$ predicted on the basis of the observed upper-main-sequence turnoff, and could solidify the cluster distance modulus found here. Such photometry is also essential for a proper study of the cluster luminosity function.

The field reddening of DL Cas is a matter deserving of further study. Published photometric reddenings for this Cepheid (Parsons & Bouw 1971; Parsons & Bell 1975; Harris 1981; Fernie 1982; Fernie 1990) fall in the interval $E_{B-V}=0.48$–0.54, marginally larger than the field reddening of $E_{B-V}=0.47 \pm 0.01$ derived here. This small difference may or may not be important, depending upon how much confidence one is willing to place in photometric reddenings (see the discussion by Madore & Freedman 1991). It is worrisome that the reddenings derived for cluster stars closely bracketing DL Cas are so different [E_{B-V}(B3–B5) $=0.48$ and 0.59 for stars lying 12″ and 20″ west and east of the Cepheid, respectively], when there are no spectroscopic observations for these stars which might support a possible tie in with the circumstellar reddening phenomenon suspected to exist for cluster B stars. Photometry for some of the fainter stars near DL Cas would help in this regard by providing reddening estimates for faint cluster AF stars, where circumstellar reddening is probably less of a problem.

The effects of rapid rotation on the observed parameters of early type stars have often been discounted in open cluster studies. The present analysis of NGC 129 should indicate just how important these effects can be, and the problem clearly requires a more comprehensive study than we have given here. Our series of papers on clusters containing Cepheid variables met with a regrettable delay following the discovery of the "excess" reddening effect described here, for which new spectroscopic observations suggest a possible connection with rapid rotation of the affected stars. A variety of observations are being planned to examine the origin of this effect in more detail, particularly since the results are of direct importance to studies of clusters containing Cepheids. Spectroscopic observations relevant to the nature of this excess reddening are in hand for a few other Cepheid clusters in our original program, and these will be presented in forthcoming studies of these clusters.

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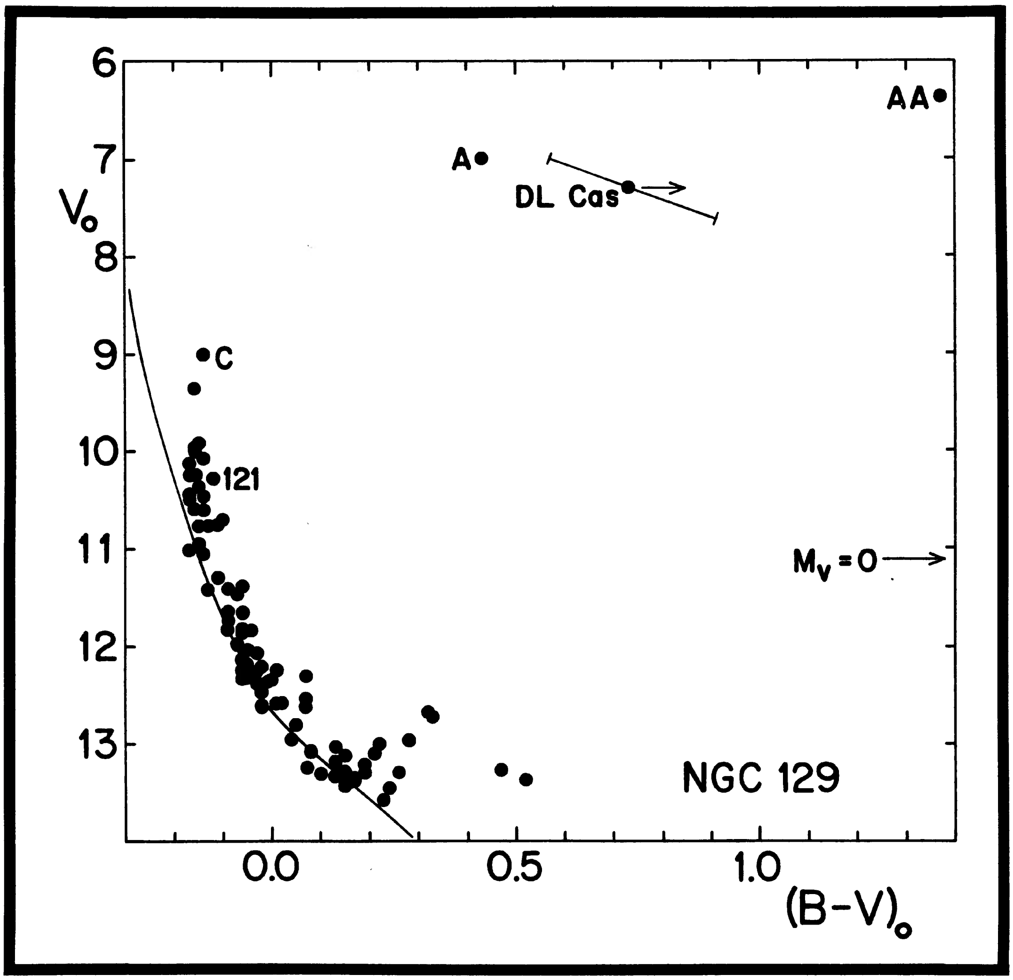

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