THE ASTRONOMICAL JOURNAL VOLUME 107, NUMBER 5 MAY 1994

GALACTIC CLUSTERS WITH ASSOCIATED CEPHEID VARIABLES. IV. C2128+488 (ANON. PLATAIS) AND V1726 CYGNI[1]

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Received 1993 August 2; revised 1994 January 6

ABSTRACT

New photoelectric UBV photometry of 32 stars, photographic UBV photometry of 120 stars, and spectroscopic observations of 8 stars are presented for C 2128+488 (Anon. Platais), the cluster associated with the $4\overset{d}{.}237$ s-Cepheid V1726 Cygni. The resulting photometry, spectral classifications, and radial velocities are used with spectroscopic and proper motion data previously published by Platais and others for the Cepheid and other stars in this field in a detailed cluster analysis. The newly obtained cluster distance modulus is $V_0-M_V=10.98\pm0.02$s.e. ($d=1568\pm13$ pc), and a value of $R=A_V/E_{B-V}=3.07\pm0.27$ s.e. is found to describe the dust extinction in the field. A space reddening of $E_{B-V}=0.43\pm0.02$ is derived for V1726 Cyg from two late B-type companions which bracket the Cepheid, as well as from the reddenings of other stars in the field. Its resulting luminosity as a probable cluster member is $\langle M_V\rangle=-3.42\pm0.07$. A cluster radial velocity of -15.4 ± 0.2 km s^{-1} and a cluster turnoff point at spectral type B7 are both consistent with the likely membership of V1726 Cyg, as are the available proper motion data. The small amplitude, sinusoidal light curve, and location of V1726 Cyg on the blue edge of the Cepheid instability strip are consistent with the properties expected for overtone pulsation, although such a possibility appears to imply an unrealistically small value ($\beta=0.5\pm0.2$) for the color coefficient in the PLC relation. A more reasonable value of $\beta=2.1\pm0.2$ is derived for the color term applicable to galactic cluster Cepheids in this program when V1726 Cyg is assumed to be pulsating in the fundamental mode.

1. INTRODUCTION

The discovery of Cepheid-like variability for V1726 Cygni (=BD+48°3398=SVS 2299=SAO 050939), which lies in the vicinity of the nearby (265 pc distant), sparse, open cluster NGC 7092 (M39), was reported by Platais (1979) along with the detection of an anonymous cluster of faint stars centered only 4 arcmin east of the variable. Photographic photometry of cluster stars, in conjunction with proper motion data from McNamara & Sanders (1977), was used by Platais to demonstrate that the age and distance of this cluster (Anon. Platais=C2128+488) were consistent with the possible membership of V1726 Cyg—in particular, that the luminosity of the Cepheid implied by its cluster membership was very close to the value predicted from the period–luminosity–color relation for a $P=4\overset{d}{.}24$ Cepheid. Somewhat disappointingly, a followup astrometric/photographic study of the cluster by Platais (1986) was less optimistic about the cluster's reality, since there appeared to be little evidence in the proper motion or photometric data to distinguish cluster stars from field stars in the surrounding region. It was concluded by Platais that the cluster might therefore represent merely a random density enhancement of field stars.

The doubts regarding the existence of a real star cluster containing V1726 Cyg are naturally a setback for the potential use of C2128+488 as a means of deriving an independent estimate for the luminosity of this Cepheid. The situation is even more distressing given the fact that the low amplitude and nearly sinusoidal light curve of V1726 Cyg (Platais 1979; Platais & Shugarov 1981) are synonymous with the class of s-Cepheids, many of which seem likely to be overtone pulsators (Antonello *et al.* 1990). Although the available photometric observations of this Cepheid were not extensive enough for Antonello *et al.* to fully investigate this possibility using the Fourier decomposition technique (Simon 1988), the analogies with SZ Tau studied in Paper III of this series (Turner 1992) are close enough to consider overtone pulsation for V1726 Cyg a reasonable possibility. This aspect of V1726 Cyg makes it all the more imperative to investigate the reality of the associated cluster as carefully as possible.

The degenerating prospects for the reality of C2128+488 were not known to us several years ago when the relative

[1]A study based partially upon photographic plates obtained by Barry F. Madore using the 3.6 m Canada–France–Hawaii Telescope.
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lack of observational data for the newly discovered cluster and its Cepheid provided a strong motivation for placing the cluster on our present program of study of the Cepheid calibrating clusters. The cluster C2128+488 clearly differs from the other clusters studied so far in this program—NGC 6087 (Turner 1986, Paper I), NGC 129 (Turner *et al.* 1992, Paper II), and NGC 1647 (Turner 1992, Paper III)—because of its particularly sparse nature. We have nevertheless managed to accumulate a variety of new data which address the question of the cluster's reality, namely new star counts for the field, photoelectric and photographic *UBV* photometry for cluster stars, and spectroscopic observations for V1726 Cyg and other potential cluster members. These observations are presented here along with a detailed study of the potential membership for several cluster stars, including V1726 Cyg.

2. OBSERVATIONS AND DATA COMPILATIONS

2.1 Photoelectric Photometry

Photoelectric *UBV* photometry was obtained for V1726 Cyg and a sequence of 31 stars lying within the boundaries of C2128+488 during a number of observing runs at Kitt Peak National Observatory. These included two nights in 1981 September with the #4–0.4 m telescope, six nights in 1981 September and 1982 August with the #2–0.9 m telescope, and six nights in 1984 August with the 1.3 m telescope. A variety of photometers were used during these periods, but in all cases the systems employed 1P21 photomultipliers and standard *UBV* filter sets so that the output data could be matched as closely as possible to the Johnson system. Details have been given in earlier papers of this series. The data for cluster stars are presented in Table 1, while Table 2 lists the individual observations for V1726 Cyg. A finder chart for the field is given in Fig. 1.

In Table 1 the stars are identified in columns 1 and 2 using the designations from this paper and from Platais (1986, 1988, 1994), respectively, the photometry is tabulated in columns 3 to 5, column 6 gives the number of nights on which each star was observed, and column 7 lists spectral types from this paper (Sec. *2.3*) and Platais (1986, 1988) as well as other pertinent remarks. A cross-listing with the designations of McNamara & Sanders (1977) is not given, since the overlap is smaller than for the sample studied by Platais (1986) and an appropriate cross-listing was already included in this earlier study.

These are the first photoelectric observations of stars in C2128+488, although for 27 stars there is an overlap with the photographic *UBV* photometry of Platais (1986, 1994). The mean differences between the data sets are (photoelectric–photographic): -0.05 ± 0.06 s.d. in V, $+0.07\pm0.06$ s.d. in $(B-V)$, and -0.02 ± 0.07 s.d. in $(U-B)$, with some minor systematic trends as a function of magnitude. The data set of Platais appears to be offset from the magnitudes and colors of the Johnson system by systematically small amounts, presumably because of field errors in the photographic measures, which were calibrated using the photoelectric photometry of NGC 7092 stars published by Johnson (1953) and McNamara & Sanders (1977). The differences are clearly important for the determination of reliable reddenings and distances for cluster stars, particularly for the results obtained by Platais (1986).

TABLE 1. Photoelectric data for stars in C2128+488.

Star	Platais	V	B–V	U–B	n	Remarks
V1726 Cyg	1821	9.00	+0.90	+0.61	16	F6 Ib
1	1921	11.15	+0.30	+0.19	6	B9 III (pec:, shell)
2	2322	11.20	+0.48	–0.10	4	F8 IV[a]
3	2053	11.62	+0.64	+0.15	1	G0:[a]
4	2551	12.00	+0.84	+0.64	1	F0:[a]
5	2197	12.29	+0.28	–0.08	4	B7 Vn
6	2206	12.34	+1.15	+0.95	4	
7	2146	12.58	+1.72	+1.89	1	
8	1826	12.80	+0.63	+0.20	5	
9	2274	12.88	+0.45	+0.42	5	A3 V
10	2333	12.98	+0.37	+0.28	4	A0 V
11	2227	12.99	+0.86	+0.50	4	
12	2399	13.06	+0.24	–0.24	4	B6 Vnn
13	1927	13.32	+0.58	+0.33	4	A7: V
14	2379	13.35	+0.68	+0.21	4	
15	2143	13.45	+0.39	+0.22	4	B9.5 IVn
16	1761	13.46	+0.91	+0.49	6	
17	1852	13.49	+0.72	+0.32	5	
18	2237	13.72	+1.86	+1.84::	3	
19	1859	13.75	+0.40	+0.28	4	
20	2343	13.78	+1.31	+1.00	3	
21	2287	13.83	+1.01	+0.24	3	
22	2233	13.89	+1.78	---	2	double
23	1899	14.15	+0.65	+0.31	6	
24	2295	14.17	+0.48	+0.40	3	
25	2406	14.44	+1.09	+0.95	1	
26	1874	14.47	+0.58	+0.29	6	
27	---	14.50	+1.46	+1.16::	3	
28	---	14.55	+1.94	+2.12:	2	
29	---	14.61	+1.32	+1.35	1	
30	1783	14.71	+0.45	+0.32	2	
31	---	14.91	+1.46	+1.01	2	

[a] From Platais (1984).

2.2 Photographic Data

A series of six exposures in *U* (IIa-O+UG1), *B* (IIa-O +GG385), and *V* (IIa-D+GG495)—two for each combination—was obtained on the night of 1981 September 28/29 by Barry Madore using the prime focus camera on the 3.6 m Canada–France–Hawaii Telescope. These plates were obtained as part of a more extensive photographic program for Cepheid clusters, and were kindly loaned to us for the present study. All were subsequently measured using the iris

TABLE 2. Photoelectric data for V1726 Cygni.

HJD 2440000+	V	B–V	U–B	Remarks
4849.8173	9.02	+0.88	+0.60	
4850.6979	8.93	+0.87	+0.58	
4854.7486	8.92	+0.85	+0.58	
4854.8274	8.90	+0.85	+0.59	
4856.7270	9.05	+0.93	+0.60	
4856.7879	9.05	+0.92	+0.60	
4857.7772	9.06	+0.92	+0.59	
5203.8721	8.99	+0.90	+0.62	
5205.8834	9.00	+0.88	+0.60	
5206.8516	8.90	+0.84	+0.61	
5933.7799	9.10	+0.92	+0.64	
5935.7966	8.99:	+0.89	+0.64	clouds
5937.8029	9.05	+0.93	+0.65	
5939.8050	8.90	+0.93	+0.65	
5941.8606	9.08	+0.92	+0.62	
5942.7703	9.06	+0.92	+0.61	

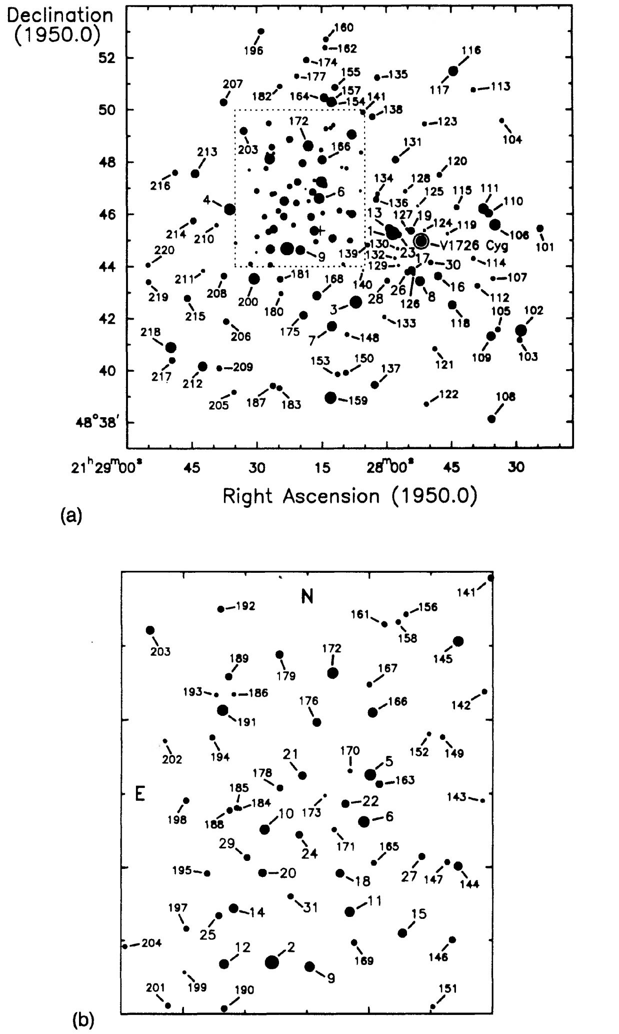

FIG. 1. A finder chart for photoelectrically observed (V1726 Cyg and objects 1–31) and photographically measured (objects 101–220) stars in the field of the cluster C2128+488. (a) is an overview of the field surveyed photographically, while (b) is an enlargement of the crowded region near the cluster center, which is identified by a cross.

TABLE 3. Photographic data for stars in C2128+488.

Star	Platais	V	B–V	U–B	Star	Platais	V	B–V	U–B	Star	Platais	V	B–V	U–B
101	1410	13.92	0.75	0.40	141	---	14.66	1.33	0.68	181	2356	14.14	0.88	0.37
102	1456	12.00	1.95	2.25[a]	142	2027	15.24	0.58	0.33	182	2357	14.73	0.55	0.28
103	1460	14.56	1.01	0.54	143	---	15.71	0.54	−0.13	183	2361	14.49	0.53	0.35
104	1521	14.88	0.60	−0.01	144	2068	13.61	0.34	0.37	184	---	15.77	0.86	−0.02
105	1534	14.53	0.95	0.32	145	2069	12.82	0.62	0.38	185	---	14.97	0.90	0.19
106	1543	12.15	1.55	1.78	146	2079	14.52	0.63	0.40	186	---	15.71	0.96	0.02
107	---	14.92	0.75	0.42	147	---	14.99	1.25	0.64	187	2385	14.26	0.87	0.27
108	1565	13.60	0.76	0.45	148	2095	14.97	0.73	0.29	188	2389	14.78	0.58	0.29
109	1567	13.03	0.50	0.05	149	---	15.24	1.00	0.19	189	2390	14.31	0.80	0.17
110	1580	13.49	0.58	0.49	150	2101	14.52	0.55	0.37	190	2398	14.72	0.84	0.32
111	1600	12.54	0.35	−0.03	151	---	15.44	0.93	0.08	191	2402	12.43	1.95	2.17
112	1621	14.59	0.72	0.53	152	---	15.70	1.03	0.03	192	2404	14.58	0.62	0.39
113	1639	14.72	0.63	0.36	153	2129	14.62	0.54	0.40	193	---	15.68	0.86	0.18
114	1640	15.00	0.67	0.36	154	2135	15.12	0.78	0.12	194	2418	14.89	0.72	0.39
115	1704	14.64	0.75	0.56	155	2136	14.07	0.85	0.29	195	2423	14.74	0.83	0.17
116	1706	14.63	0.67	0.36	156	2139	15.23	0.80	−0.29	196	---	14.22	0.79	0.30
117	1713	12.77	0.48	−0.12	157	2150	12.63	0.59	0.38	197	2448	14.92	0.63	0.33
118	1723	13.20	0.74	0.32	158	2153	15.27	0.77	0.20	198	2449	14.71	0.63	0.24
119	---	15.57	0.79	0.05	159	2155	11.82	0.37	0.29[b]	199	---	16.01	0.82	0.05
120	1757	14.57	0.64	0.48	160	2169	14.48	0.92	0.10	200	2466	12.13	1.47	1.78
121	1771	14.86	0.91	0.32	161	2170	14.93	0.79	0.26	201	2478	15.03	0.84	0.14
122	---	14.85	1.31	0.46	162	2174	14.75	0.82	0.06	202	---	15.68	0.86	0.00
123	1808	14.83	0.71	0.56	163	2180	14.22	0.48	0.40	203	2500	13.65	0.41	0.28
124	---	15.67	0.87	0.05	164	2181	13.25	0.88	0.31	204	---	15.45	0.77	0.35
125	---	15.86	0.94	0.04	165	2192	15.06	0.63	0.35	205	2538	14.74	0.87	0.07
126	---	15.46	1.11	0.17	166	2194	13.14	0.75	0.21	206	2566	14.26	0.72	−0.18
127	---	15.63	0.90	0.10	167	2199	15.11	0.74	0.24	207	2577	13.71	1.52	1.52
128	1882	15.17	0.77	0.25	168	2217	13.10	0.62	0.40	208	2579	14.24	0.54	0.42
129	---	15.69	0.94	0.08	169	2224	14.77	0.72	0.36	209	2601	14.48	0.66	0.28
130	---	15.60	1.02	0.09	170	---	15.56	0.97	0.10	210	2609	15.17	0.74	0.38
131	1912	13.82	0.65	0.36	171	2246	15.28	0.92	0.10	211	2656	15.32	0.70	0.29
132	---	15.57	0.91	0.13	172	2247	12.41	1.45	1.65	212	2660	12.87	0.31	−0.16
133	1943	15.15	0.67	0.36	173	---	16.10	0.90	−0.05	213	2689	13.20	0.51	0.54
134	1967	14.92	0.75	0.42	174	2251	14.27	0.45	0.28	214	2699	14.13	0.79	0.28
135	1969	14.34	0.67	0.35	175	2261	13.35	0.52	0.39	215	2729	14.02	0.72	0.33
136	1974	14.29	0.59	0.37	176	2267	13.60	0.80	0.25	216	2778	14.45	0.97	0.28
137	1978	13.62	0.77	0.49	177	2292	14.80	0.80	0.12	217	2789	14.14	0.99	0.43
138	1989	14.21	0.57	0.34	178	2315	14.62	0.57	0.38	218	2792	12.27	0.64	0.04
139	2003	14.92	0.61	0.35	179	2316	13.98	0.94	0.35	219	2867	14.52	1.18	0.25
140	---	16.00	0.79	0.05	180	2354	14.80	1.01	0.34	220	2871	14.84	0.95	0.27

[a] Spectral type M2 according to Platais (1988).
[b] Spectral type A1 V according to Platais (1988).

photometer at Saint Mary's University (Reed *et al.* 1986). Although the plates appear to have been exposed during a period of less-than-ideal seeing on Mauna Kea, the techniques of measurement and reduction in use at Saint Mary's (Turner & Welch 1989) produce good quality results in such circumstances.

All plates were exposed with a Racine-Pickering calibration prism in the main beam, which introduced a magnitude difference of $\sim 4^{m}.6$ between the primary and secondary images of stars in the field. The exact magnitude separation of the secondaries from the primaries is important for the plate calibrations. A magnitude difference of $4^{m}.73$ was derived by Pedreros *et al.* (1984) for comparable exposures of the NGC 7790 field, although smaller, color-dependent differences were found by Turner *et al.* (1986) for similar plates of the S Vul field. The NGC 7790 plates have been remeasured at Saint Mary's using the techniques in use here, with quite different results for Δm compared to those found by Pedreros *et al.* The values appropriate for NGC 7790 and C2128+488 were determined empirically from the calibration relations for the standards, with the best values being $\Delta V=4.59$, $\Delta B=4.61$, and $\Delta U=4.62$, with associated uncertainties of about ± 0.01 to ± 0.02. These offsets were used in the present study to extend the limit for calibrated photometry in the C2128+488 field to the individual plate limits. We have restricted the analysis, however, to 120 stars which are considerably brighter than this and which lie within ~7 arcmin of the cluster center (Sec. *2.4*). Data for our program stars are given in Table 3, and the stars are identified in Fig. 1.

The presence of systematic offsets and magnitude-dependent trends in the photographic data of Platais (1986) effectively limit their usefulness. We have therefore used only our newly derived data in this study. The photographic data for C2128+488 may consequently be of somewhat lower quality than has been the case for previous papers in this series, particularly in light of the fact that the data from one of the V plates were found to be anomalous and were not incorporated into the analysis. This particular plate exhibits some symptoms of being a mismatch, and may represent a 103a-D emulsion which was exposed behind a GG495 (B) filter—a remote possibility given Mauna Kea's altitude of 4200 m. Whatever the true explanation, the quality of the photographic data was certainly not lessened by the exclusion of the measurements from this one plate, and overall is probably comparable to the similar, high-quality, photographic data obtained in the single plate survey (U, B, and V) of the WZ Sgr field by Turner *et al.* (1993). The formal uncertainties in the data obtained from the measurements for the standards are ± 0.03 in V, ± 0.03 in $B-V$, and ± 0.06 in $U-B$.

TABLE 4. Radial velocity data for C2128+488 stars.

Star	HJD 2440000+	V_R km s^{-1}	Adopted V_R km s^{-1}
V1726 Cyg	5905.8447	−15.4 ± 1.8	
	5906.8433	−16.7 ± 2.1	
	5908.8438	− 9.5 ± 1.6	
	5909.8327	−17.0 ± 3.1	
	5910.8119	−19.4 ± 1.6	
	5912.8269	−10.8 ± 2.6	
	6004.6868	−17.5 ± 1.8	
	6004.6934	−14.9 ± 2.0	
	6326.6822	−14.9 ± 2.0	
	6327.7891	− 9.8 ± 3.1	
	6328.7929	−15.4 ± 3.1	
	6330.8634	−17.4 ± 2.0	
	6331.7395	−15.0 ± 1.6	−15.1
1	5905.8610	−13.7 ± 2.3	
	6004.7333	−16.7 ± 4.1	
	6326.6895	−12.9 ±15.5	
	6328.8631	−16.6 ± 3.0	−15.1
5	5908.8632	−13.4 ± 2.3	
	6326.8162	−17.3 ± 2.3	−15.4
9	5911.8258	−23.2 ± 2.0	
	6328.8114	−35.6 ± 1.8	−30.1[a]
10	5910.8383	−16.7 ± 5.0	
	6328.7162	−15.1 ± 6.2	−16.1
12	5909.8570	−71.0 ± 7.1	
	6326.8440	+36.4 ± 6.2	
	6328.8436	+21.1 ± 4.7	+5.4:[a]
13	6326.7200	+38.9 ± 6.9	+38.9[a]
15	5912.8522	+ 8.9 ± 6.8	
	6331.7481	+15.3 ± 2.5	+14.5[a]
		Cluster Mean =	−15.4 ±0.2 s.e.

[a] Rejected from mean as a likely non-member of cluster.

2.3 Spectroscopic Data

Spectroscopic observations were obtained for V1726 Cyg and seven stars in its associated cluster on 13 nights in 1984 July, 1984 October, and 1985 September using the 1.8 m telescope of the Dominion Astrophysical Observatory. The observations were photographic image-intensifier spectra at a dispersion of 16 Å mm^{-1} centered in the blue spectral region around 4000 Å (see Paper III). They were subsequently scanned and measured for radial velocity using the PDS microdensitometer at the David Dunlap Observatory, University of Toronto, and were classified using MK precepts in the manner described by Turner (1992). The spectral types for these stars are included in Table 1, and the radial velocity measurements are given in Table 4. Weighted mean velocities are given in the last column of Table 4, except for V1726 Cyg where the derived systemic velocity is listed (Sec. *3.3*).

2.4 Star Counts

Prior to the photographic study, star counts were made across the field of C2128+488 in order to better establish the cluster dimensions. Strip counts were made from a photographic enlargement of the Palomar Observatory Sky Survey (POSS) E-plate containing the field, and a reasonably well defined center of symmetry was found at 1950 coordinates $21^h28^m15^s$, +48°45$'$.4, ~1 arcmin south of the field center

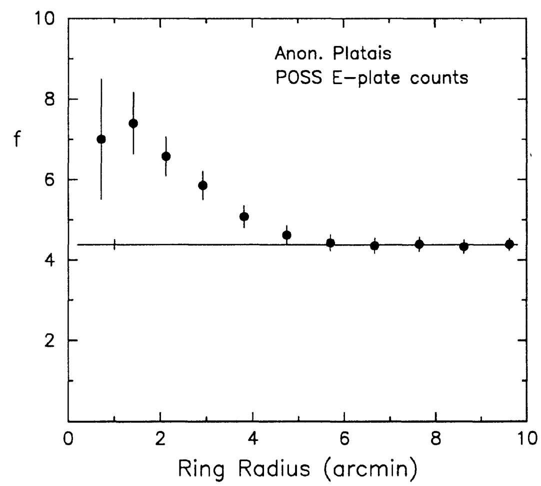

FIG. 2. Star densities f (in stars $arcmin^{-2}$) as a function of radial distance from the adopted center of C2128+488, to a counting limit of $R\approx17$. Poisson errors are shown for the ring counts, and the uncertainty in the adopted field star density—depicted by the horizontal line—is also indicated.

established by Platais (1979, 1986) and 4 arcmin east of V1726 Cyg. This location, which is depicted by a cross in Fig. 1, was adopted as the reference point for ring counts made in 1 arcmin-wide annuli out to a distance of 11 arcmin from the cluster center. The stellar background on the POSS is reasonably smooth within these boundaries, but is noticeably affected by dust obscuration to the west and southwest of this area. In general, the field of the Cepheid and its cluster is not affected by significant variations in the general dust obscuration, a point which is useful for interpreting both the star counts and the photometric data.

The ring counts were made to a limiting magnitude of roughly $R\approx17$, a few magnitudes fainter than the limit for the photoelectric sequence. They are illustrated in Fig. 2. It should be evident from the data that the cluster does not stand out well against the general field at this magnitude limit, although it does appear to be more significant than a random density enhancement of field stars. A constant field level of 4.38 ± 0.13 stars $arcmin^{-2}$ is reached at distances beyond ~6 arcmin from the cluster center, and within this radius the star counts indicate that there is an excess of 82 ± 27 stars—a 3σ enhancement above the field level. Given the smooth nature of the background star densities in this region, it is not difficult to attribute this excess to the presence of a very sparse cluster. However, at this counting limit the cluster is obviously very heavily masked by field stars, which outnumber potential cluster members by a factor of six within the cluster boundaries. This factor drops to ~1.5 within 2 arcmin of the cluster center, but even this number is large compared to what is typical of most other clusters. Field stars are therefore expected to make a significant contribution to the population of cluster stars examined by photometric means.

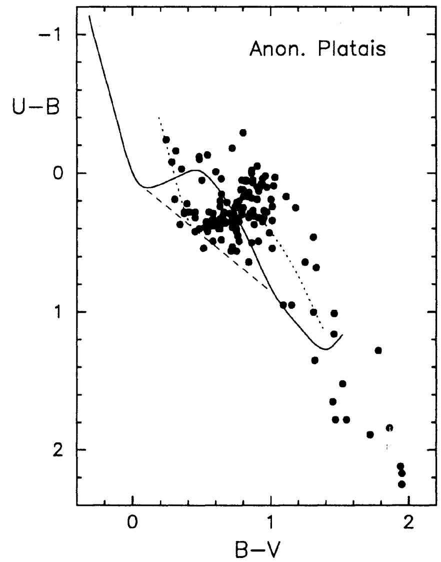

FIG. 3. Color–color diagram for stars in the field of C2128+488. The intrinsic relation for main-sequence stars (solid curve) is also depicted for a reddening of E_{B-V}=0.39 (dotted curve) using a reddening relation of slope E_{U-B}/E_{B-V}=0.81, which is depicted by a dashed line.

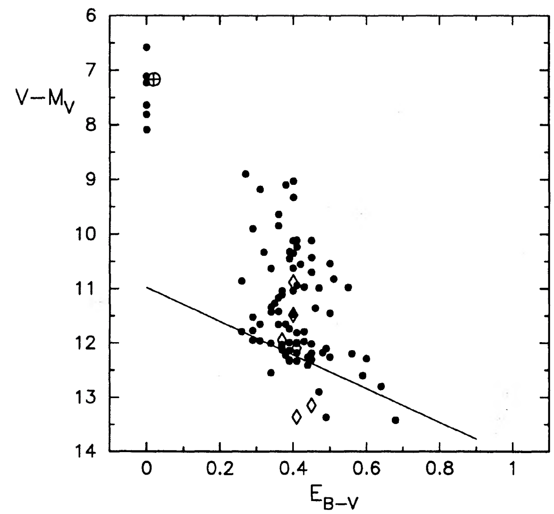

FIG. 4. Variable-extinction diagram for C2128+488 stars based upon ZAMS fitting (filled circles) and luminosities inferred from spectral types (open diamonds). A circled cross refers to the data for the cluster NGC 7092, which lies in close proximity to this field. The line of slope R=3.1 represents a lower envelope fit for likely ZAMS members of the cluster.

3. ANALYSIS

3.1 Interstellar Reddening

Color excesses for the spectroscopically observed B and A-type stars in Table 1 were determined as in previous papers in this series in order to examine the reddening law appropriate for the cluster field. The derived reddening slope for all seven stars (see Turner 1989) was $E_{U-B}/E_{B-V}=0.81\pm0.06$ s.e., and $E_{U-B}/E_{B-V}=0.81\pm0.02$ s.e. for the subgroup of four normal stars with the most reliable spectral classifications. The shell star (#1) was excluded from this last sample. Identical values of E_{U-B}/E_{B-V}=0.81 for the reddening slope were derived for the early-type stars in the general field, as well as for the nearby galactic fields containing the clusters NGC 7062 and NGC 7067 (see Turner 1976b). A reddening slope of 0.81 was therefore adopted for the dereddening of cluster B, A, and F-type stars. Although steeper reddening slopes are expected for late-type cluster stars due to bandwidth effects on their *UBV* colors (e.g., Buser 1978), these objects were generally omitted from further analysis owing to the difficulty of dereddening them unambiguously.

Figure 3 is the color–color diagram for cluster stars based upon the data of Tables 1 and 3. The average reddening for the spectroscopically observed B and A-type stars is $\langle E_{B-V}\rangle\approx0.39$, and it is possible to detect a sparse sequence of late B-type stars and a much richer sequence of A and F-type stars, both reddened by roughly this amount, in the data of Fig. 3. The diagram is also populated by a sequence of little-reddened late-type giants (at the lower right), which are relatively common field stars, and by a peculiar swarm of stars at $(B-V,U-B)\approx(0.9,0.1)$. Most of the stars in this swarm are faint ($V>15$), so one is tempted to suspect that their colors may be affected by systematic errors in the faint star photometry. There is no obvious evidence for such a problem with the plate calibrations, however, so these stars may simply represent a group of highly reddened background B stars or reddened F subdwarfs. All of the stars in these last two groups are of only peripheral interest to the present study, since they are indicated by both the star counts and the photometric data to be likely field stars. We have therefore omitted them from further consideration. Our primary interest lies in the sequence of reddened B, A, and F-type stars, many of which seem likely to be potential cluster members. The dereddening of these stars is fairly straightforward and unambiguous, and is relatively unaffected by the small uncertainties in the data.

Figure 4 is the variable-extinction diagram resulting from dereddening the data for this last group of stars. Zero-age main-sequence (ZAMS) luminosities (Turner 1976a, 1979) were adopted for all but the spectroscopically observed objects. There is a distinct lower envelope of stars in this diagram which coincides reasonably well with the spectroscopically derived data for the three stars (1, 5, and 10) which are also indicated by their radial velocities to be associated with V1726 Cyg. We identify all of these objects as probable cluster members.

The range of reddening for stars forming the lower envelope to the data of Fig. 4 is not large, but is clearly due to differential reddening. Doubtful readers should refer to the study by Turner (1976a), where it is demonstrated that dereddening the data for A and F-type ZAMS stars affected primarily by random photometric errors leads to a dispersion in the variable-extinction diagram which results in a **negative** R value. The lower envelope of 19 stars in C2128+488 yields a **positive** and "normal" value of $R=A_V/E_{B-V}=3.07\pm0.27$ s.e. from a combination of least squares and nonparametric straight line fitting techniques, and this **must** be attributed to interstellar reddening. A value of R=3.1 was therefore

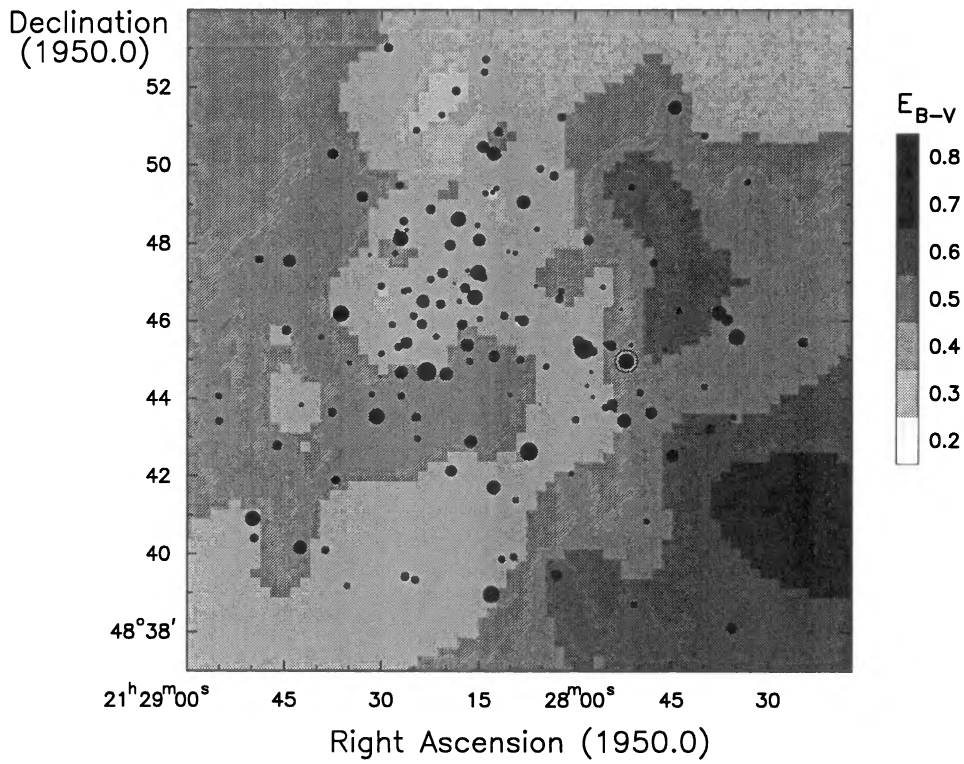

FIG. 5. A reddening map for the field of C2128+488 based upon the color excesses derived for reddened stars in the field. V1726 Cyg is the circled point.

adopted for purposes of making extinction corrections. A reddening map of the field generated from this analysis is presented in Fig. 5. The high extinction areas of the cluster coincide with regions of low density in the star counts. Nevertheless, the reddening map generated from the photometric analysis presents a more reliable description of the dust extinction across the field than is possible using star counts alone.

There is little to no reddening in this field out to the distance (265 pc) of NGC 7092 according to the studies by Johnson (1953) and McNamara & Sanders (1977). The data of Fig. 4 imply that this trend continues to a distance modulus of at least 8.1, or a distance of 415 pc. There are no obvious unreddened objects at larger distances, from which we infer that the dust clouds responsible for the extinction across the face of C2128+488 lie at distances of roughly 415 pc. This result is consistent with the conclusions of Neckel & Klare (1980) regarding the general run of extinction with distance in this portion of the Milky Way.

The data of Fig. 4 also indicate the presence of a few background objects in the cluster field. Three of these, stars 12, 117, and 212, have colors bluer than objects at the cluster turnoff. In fact, there is no reason to believe that any of the stars hotter than spectral type B7 are potential cluster members since they all have apparent distance moduli which place them beyond the cluster. The spectral type of B7 for the main-sequence turnoff of C2128+488 is therefore reasonably well established with the available data.

3.2 Cluster Stars

Reddening-free data for stars identified as potential members of C2128+488 are summarized in Table 5 and are plotted in a color–magnitude diagram in Fig. 6. Candidate members are the 19 lower envelope stars selected for the R determination (Sec. *3.1*), 19 mostly lower weight, additional stars lying within ~6 arcmin of the cluster center and falling above the lower envelope stars in Fig. 4 but within $\sim 0^{m}.5$ of them (i.e., potential unresolved binaries), the three spectroscopically observed stars which have radial velocities matching the systemic velocity of the Cepheid, and V1726 Cyg itself. The distance modulus of the cluster derived from the 19 stars considered to be ZAMS members is $\langle V_0 - M_V \rangle = 10.98 \pm 0.02$ s.e., corresponding to a distance of 1568 ± 13 pc.

The 42 potential cluster members represent 28% of the photometric sample, which is twice as large as the expected proportion of 14% cluster members to the counting limit given in Sec. *2.4*. The highly probable cluster members in our sample are the 19 lower envelope stars, the 3 spectroscopically identified members, V1726 Cyg, and star 111, which lies at the main-sequence turnoff. These 24 stars rep-

TABLE 5. Reduced data for C2128+488 stars.

Star	$(B-V)_0$	E_{B-V}[a]	V_0	Star	$(B-V)_0$	E_{B-V}[a]	V_0	Star	$(B-V)_0$	E_{B-V}[a]	V_0
V1726 Cyg	+0.46	0.46[b]	7.56[c]	134	0.28	0.49	13.39	178	0.20	0.39	13.43[c]
1	−0.06	0.37	10.01[c]	136	0.22	0.39	13.09	182	0.27	0.29	13.82[c]
5	−0.12	0.41	11.03[c]	138	0.22	0.36	13.08	183	0.20	0.34	13.43[c]
10	−0.02	0.40	11.74[c]	139	0.25	0.38	13.75[c]	188	0.28	0.31	13.81[c]
19	−0.03	0.44	12.39[c]	144	0.06	0.29	12.72[c]	192	0.23	0.41	13.32
24	0.12	0.37	13.01[c]	146	0.22	0.43	13.19	193	0.53	0.35	14.59
26	0.28	0.31	13.50	148	0.37	0.38	13.79	194	0.29	0.45	13.49
111	−0.12	0.48	11.06[c]	150	0.19	0.37	13.36[c]	197	0.28	0.37	13.78[c]
114	0.28	0.41	13.73[c]	153	0.16	0.39	13.40[c]	198	0.35	0.29	13.80
115	0.17	0.60	12.77	163	0.12	0.37	13.06[c]	203	−0.03	0.45	12.25[c]
120	0.16	0.50	13.03	165	0.26	0.39	13.86[c]	204	0.35	0.44	14.08[c]
123	0.14	0.59	13.00	167	0.42	0.34	14.06	208	0.14	0.41	12.96
128	0.43	0.36	14.05	169	0.31	0.43	13.44	210	0.31	0.45	13.77
133	0.28	0.41	13.88[c]	174	0.20	0.26	13.46[c]	211	0.35	0.37	14.18[c]

[a] Reddening equivalent to that of a B0 star.
[b] Reddening from nearby stars.
[c] Highly probable member.

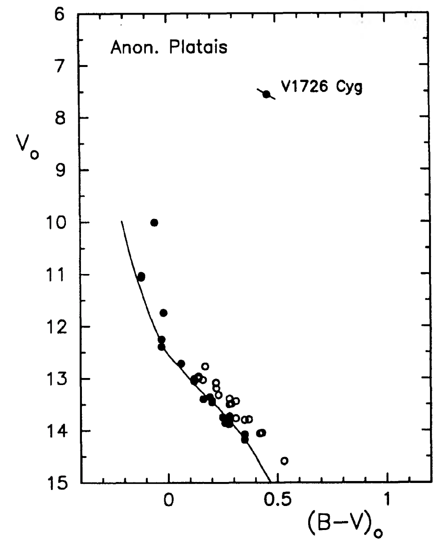

FIG. 6. Reddening-corrected color–magnitude diagram for probable members (filled circles) and other potential members (open circles) of C2128+488. The extremes of variability for V1726 Cyg are indicated, while the continuous line represents the ZAMS for $V_0-M_V=10.98$.

resent 16% of the photometric sample, a proportion which is more consistent with the star count predictions. Whether or not this consideration bears upon our cluster membership selection depends a great deal upon the cluster luminosity function, which might be peculiar for a cluster as sparse as C2128+488 (Platais 1993). The total sample of Table 5 candidates represents only ~51% of the potential cluster membership to the counting limit of Sec. *2.4*, so our membership selection is not necessarily unrealistic. It clearly requires some supporting data, however.

Proper motion data for most cluster stars are available from McNamara & Sanders (1977) and Platais (1993). Given the distance to C2128+488, the scatter in a vector point diagram for true cluster members should reflect only the measuring errors in the proper motions since the stellar motions will be negligible by comparison. The measuring errors appear to be described by $\sigma=0''.0018$ yr^{-1} (Platais 1984, 1986) for the high quality proper motions in the data set of Platais, but are closer to $\sigma=0''.0035$ yr^{-1} for the lower quality proper motions in this data set. The data available for 40 of the Table 5 stars are a mix of the two types, and are plotted in separate vector point diagrams in Figs. 7(a) and 7(b). Circles in these diagrams represent radii of $\sqrt{2}\sigma$, 2σ, and $2\sqrt{2}\sigma$, respectively (see Ebbighausen 1942). The distribution of data points in these diagrams appears to be reasonably Gaussian, given the small sample size, although a case might be made for the presence in the sample of a few foreground stars of larger proper motion. The data are at least consistent with what would be expected for a cluster at the derived distance of C2128+488, and are also consistent with V1726 Cyg being a cluster member.

The radial velocity measures of Table 4 present a stronger case for the reality of the cluster, at least relative to the parameters for the spectroscopically observed stars. The close agreement in velocity for V1726 Cyg and stars 1, 5,

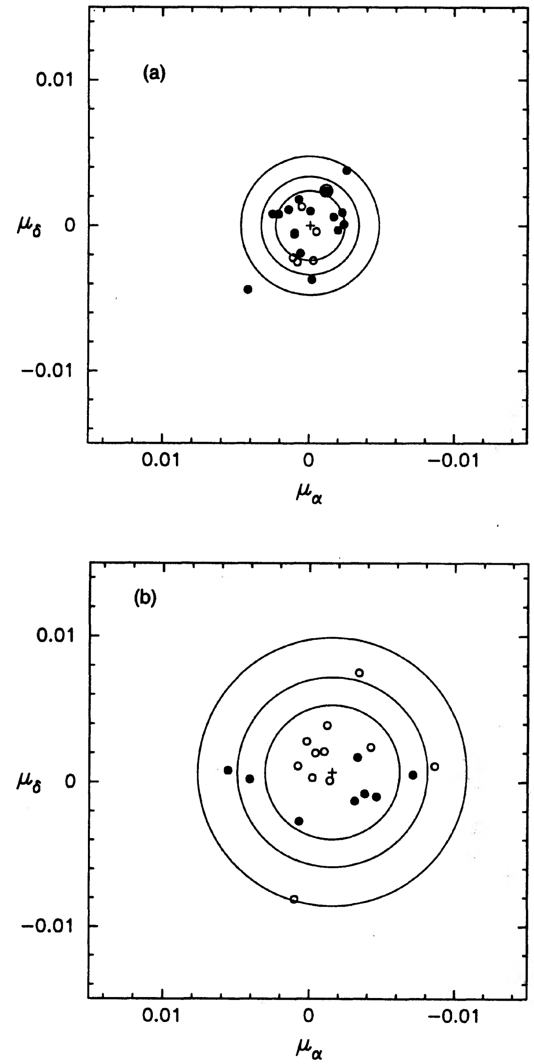

FIG. 7. Vector point diagrams for the proper motions of probable members (filled circles) and other potential members of the cluster C2128+488, as derived from the work of Platais (1994). V1726 Cyg is indicated by a circled point. Separate diagrams are plotted for the high quality (a) and lower quality (b) proper motions, with $\sigma=0''.0018$ yr^{-1} and $0''.0035$ yr^{-1}, respectively, and circles are drawn for radii of $\sqrt{2}\sigma$, 2σ, and $2\sqrt{2}\sigma$. The centroid of each distribution is indicated by a cross.

and 10 (with $\sigma=\pm0.5$ km s^{-1}) is unlikely to be due to chance, particularly since the three latter stars also fall closest (of seven observed stars) to the lower envelope sample of Fig. 4 at their spectroscopically derived distance moduli. The radial velocity data also argue convincingly for the cluster membership of V1726 Cyg, which is the most luminous star in C2128+488.

The cluster color–magnitude diagram in Fig. 6 is similar to that of NGC 1647 presented in Paper III, except for the fact that C2128+488 has far fewer likely members. Both clusters have similar turnoff points at $(B-V)_0=-0.12$, corresponding to spectral type B7, and should therefore be of similar age, i.e., 1.1–1.9$\times10^8$ yr, depending upon the choice of evolutionary models used for reference purposes. C2128+488 even exhibits some evidence for a B7–B8 main-

TABLE 6. Parameters for V1726 Cygni.

JD_{max} = 2444020.5131 + 4.2370383 E		
V_{max} = 8.892	$(B-V)_{max}$ = 0.84	$(U-B)_{max}$ = 0.57
V_{min} = 9.079	$(B-V)_{min}$ = 0.93	$(U-B)_{min}$ = 0.62
M–m = 0.48	M–m = 0.50	
B_{max} = 9.734	U_{max} = 10.30	
B_{min} = 10.007	U_{min} = 10.62	
<V> = 8.988 ±0.001	<B> = 9.873 ±0.002	<U> = 10.45 ±0.02
<B>–<V> = 0.885	<U>–<B> = 0.58	
$<V_R>$ = −15.1 ±0.5 km s^{-1}, varying between −18.7 and −11.5 km s^{-1}		
$E_{B-V}(B0)$ = 0.46 ±0.02	$E_{B-V}(C\delta)$ = 0.43 ±0.02	
$(<B>-<V>)_0$ = 0.46	Spectral Type = F6 Ib	
$<M_V>$ = −3.42 ±0.07 from membership in C2128+488		
V Data Set	B Data Set	
Amplitude (V) = 0.187	Amplitude (B) = 0.273	
ϕ_{21} = 3.81 ±0.33	ϕ_{21} = 3.44 ±0.45	
ϕ_{31} = 6.72 ±0.50	ϕ_{31} = 6.67 ±0.70	
R_{21} = 0.06 ±0.02	R_{21} = 0.04 ±0.02	
R_{31} = 0.04 ±0.02	R_{31} = 0.03 ±0.02	

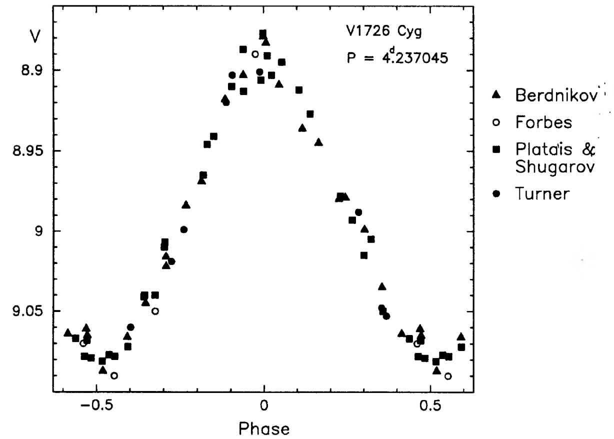

FIG. 8. Observed light variations for V1726 Cyg compiled from the data of this paper and other indicated sources.

sequence gap at $M_V \approx +0.5$, of the type described by Mermilliod (1976). A comparable gap was found in the color–magnitude diagram for NGC 1647 (Turner 1992). The location of star 1 in Fig. 6 is a bit unusual, although this may be due to the peculiar nature of the object, which appears to be a shell star of spectral type B9 III. The star is classified as B8 V by Platais (1986, 1988) on the basis of objective prism spectra, and may be a spectrum variable. Its location in Fig. 6 could be anomalous compared to normal stars of this type.

3.3 *V1726 Cygni*

The Cepheid V1726 Cyg lies in a region of the cluster where the reddening appears to exceed the standard reddening of $E_{B-V}(BO)=0.3$ to 0.4 which is typical of most of the field (see Fig. 5). The individual reddening estimates for stars in the immediate vicinity of the Cepheid exhibit considerable scatter ranging over almost $0^m.3$ in E_{B-V}. The possibility of circumstellar extinction adding to the interstellar component is unlikely since the stars are mostly A type rather than late B type, for which such an effect has been observed previously (Turner *et al.* 1992; Turner 1993). Fortunately, the color excesses exhibit a spatial correlation, and a space reddening can be estimated for V1726 Cyg using the bracketing stars 19 and 30, which have $E_{B-V}(BO)$ of 0.44 and 0.49, respectively. The reddening which is appropriate for the location of V1726 Cyg is $E_{B-V}(BO)=0.46\pm0.02$, which corresponds to $E_{B-V}=0.43\pm0.02$ for a star with the observed colors of the Cepheid. This reddening corresponds to an intrinsic color of $(\langle B\rangle-\langle V\rangle)_0=0.46\pm0.02$ for V1726 Cyg (see Table 6).

Independent support for the Cepheid's reddening can be obtained from its F6 Ib spectral type. The intrinsic colors established for FG supergiants tend to vary by small amounts from one source to another, and perhaps the best currently available are those of Fernie (1963), Johnson (1966), Parsons (1971), and Kron (1978). For $(B-V)_0$ these sources cite (or imply) values for spectral type F6 Ib of 0.46, 0.43, 0.49, and 0.46, respectively, i.e. $\langle(B-V)_0\rangle=0.46\pm0.02$. This value is identical to $(\langle B\rangle-\langle V\rangle)_0$ established for V1726 from the Cepheid's space reddening, and provides a more solid basis for this reddening estimate. For the cluster distance derived previously, the implied value for the absolute magnitude of V1726 Cyg as a cluster member is $\langle M_V\rangle=-3.42\pm0.07$. The cited uncertainty combines the estimated uncertainties in the Cepheid's reddening and in the cluster's distance modulus. A value of $\langle M_V\rangle=-3.06$ was obtained by Platais (1979) in his original photographic study of this cluster.

The question of the Cepheid's pulsation mode is important to resolve. For example, according to the Cepheid period–luminosity (PL) relation given in Paper III, one would expect $\langle M_V\rangle=-2.99\pm0.07$ for V1726 Cyg if it is pulsating in the fundamental mode and $\langle M_V\rangle=-3.47\pm0.07$ if it is pulsating in the first overtone mode. This last estimate makes use of the period ratio data for known double-mode Cepheids summarized by Szabados (1988) to predict $P_I/P_0=0.6864$ for the ratio of the observed period to the fundamental mode period of V1726 Cyg as an overtone pulsator. The luminosity of V1726 Cyg as a cluster member, $\langle M_V\rangle=-3.42\pm0.07$, is clearly closer to the value predicted for overtone pulsation.

The light variations of V1726 Cyg as derived from a combination of our observations (Table 2) with those of Platais & Shugarov (1981) and Berdnikov (1986, 1992)—all adjusted to the present system—are presented in Fig. 8. The corresponding radial velocity variations are plotted in Fig. 9, where the data of Table 4 have been combined with the higher quality velocities of Metzger *et al.* (1991)—in which an observation of the Cepheid on JD 2447018.98 has been mistakenly listed under the data for V386 Cyg—and have been phased to the ephemeris of Table 6. The two sets of radial velocity data are in excellent agreement, and the systematic velocity for V1726 of -15.1 km s^{-1} derived in Table 4 is very close to the value of -15.32 km s^{-1} quoted by Metzger *et al.* (1992) for V1726 Cyg in their followup study.

The period of the Cepheid indicated by the combined photometric observations over the interval 1979–1991 is $4^d.2370383$, slightly longer than the value of $4^d.2359$ obtained by Platais & Shugarov (1982) from their 1979 observations but in good agreement with the value of $4^d.2370487$ recently published by Berdnikov (1993). Full Fourier decompositions

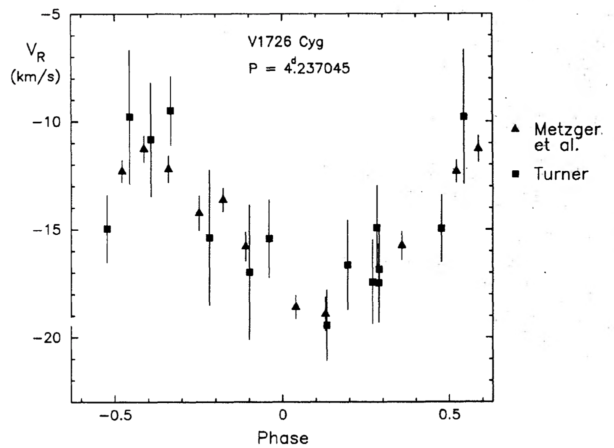

FIG. 9. Observed radial-velocity variations for V1726 Cyg compiled from the data of this paper (squares) and that of Metzger *et al.* (1991—triangles). Uncertainties in the radial velocity measurements are depicted.

were made of both the B and V light curves in order to examine the amplitude ratios and phase differences for V1726 Cyg relative to those of other Cepheids. However, some of the basic properties of V1726 Cyg are evident from an examination of Figs. 8 and 9. For example, the light curve is of small amplitude and sinusoidal shape, and the duration of the rise from minimum to maximum light (the parameter $M-m$) is almost exactly half of a cycle ($M-m$=0.48–0.50). The radial velocity curve is a mirror image of the light curve, and is shifted by ~0.1 of a cycle relative to the latter.

The phase differences ϕ_{21} and ϕ_{31} and amplitude ratios R_{21} and R_{31} for V1726 Cyg—as derived from the light curves in B and V—are summarized in Table 6. The values for these parameters are similar to those of other s-Cepheids of similar period identified by Antonello *et al.* (1990), all of which have been suggested to be overtone pulsators. As a cautionary note we point out that the second- and third-order terms in the Fourier decomposition for this Cepheid are of only marginal significance, primarily because of the large scatter in the combined data. A careful photometric study of this variable is really needed to obtain meaningful Fourier parameters, although the available data by themselves seem to present a strong case for overtone pulsation.

An overlooked consideration in these arguments is the intrinsic color of V1726 Cyg. With $(\langle B\rangle-\langle V\rangle)_0$=0.46, V1726 Cyg is bluer by ~$0^{m}_{.}09$ than most Cepheids of similar period (P=$4^{d}_{.}237$), and bluer by ~$0^{m}_{.}17$ if P_I is $4^{d}_{.}237$ and P_0 is $6^{d}_{.}173$. The Cepheid's intrinsic color clearly places it on the blue edge of the instability strip where overtone pulsation would not be unexpected. Furthermore, there is no evidence in its spectra for the presence of a possible blue companion which might affect the colors to such an extent. V1726 Cyg is apparently single, but bluer than other Cepheids of similar period regardless of its pulsation mode. In either case it provides an important check on the value of the color term in the period–luminosity-color (PLC) relation.

Paper III summarized the parameters for ten Cepheids based upon cluster ZAMS fits. The resulting dispersion in the observed PL relation is only $\pm0^{m}_{.}07$, largely because the intrinsic colors for these Cepheid calibrators exhibit only a small dispersion about the mean period–color relation. We attempted to reduce this dispersion further using the W function of van den Bergh (1968, 1975) in the form $M_W\equiv\langle M_V\rangle-\beta(\langle B\rangle-\langle V\rangle)_0$—see Moffett & Barnes (1986)—where β is the color term in the PLC relation. Weighted least-squares fits to the data were made for all possible values of β, with weights assigned according to the derived uncertainties in $\langle M_V\rangle$. Various samples were analyzed, including ones which contained the cluster Cepheid BB Sgr (Turner & Pedreros 1985) and V1726 Cyg as either a fundamental mode or first overtone pulsator. A value of β=2.1±0.2 was obtained for those samples which included V1726 Cyg as a fundamental mode pulsator, and β=0.5±0.2 was derived for samples in which V1726 Cyg was assumed to be pulsating in the first overtone mode. Since the luminosity of V1726 Cyg as a cluster member is close to the value predicted for a Cepheid near the center of the instability strip with a pulsational period of $6^{d}_{.}173$, solutions for β with the assumption of overtone pulsation for this star are necessarily driven towards negligibly small values. The dispersion in $\langle M_W\rangle$ is not very different for the various samples, although it is slightly smaller when V1726 Cyg is considered to be a fundamental mode pulsator and yields parameters for the PL relation in this instance which are closer to those found in Paper III. The dispersion in $\langle M_W\rangle$ for β=2.1 is about $\pm0^{m}_{.}055$ with the sample of Paper III calibrators, and increases to about $\pm0^{m}_{.}08$ when V1726 Cyg and BB Sgr are included. These two Cepheids lie near the blue and red edge, respectively, of the instability strip, and clearly require further study to confirm their parameters inferred from main-sequence fitting.

A problem arises if V1726 Cyg is an overtone pulsator since it leads to an essentially negligible value for the color term β in the PLC relation. As such a situation is physically unrealistic (Brodie & Madore 1980), we must conclude that V1726 Cyg is more likely to be a fundamental-mode pulsator. The only way to reconcile its parameters with overtone pulsation is to reject it from membership in C2128+488. Its small amplitude, blue color, and light curve parameters are certainly consistent with the properties attributed to overtone pulsators, and yet the Cepheid seems likely to be a fundamental mode pulsator according to the parameters obtained for it as a likely cluster member. It seems clear that a more detailed study of the cluster and Cepheid is required to address these points further. If the present results are confirmed, then it may be necessary to reconsider current interpretations of the pulsation modes for the s-Cepheids.

4. SUMMARY

Based upon the observational data and the analysis presented in this study, the Cepheid V1726 Cyg is argued to be an outlying member of C2128+488, which is demonstrated to be a physical cluster of stars. The spatial coincidence of the Cepheid with the cluster, as well as coincidences in radial velocity, proper motion, and age with cluster members, present a fairly strong case for cluster membership. The derived luminosity of the Cepheid as a cluster member is also close to values which would be predicted for this variable based upon its $4^{\mathrm{d}}237$ period, although this produces a problem with regard to the star's likely mode of pulsation. Its distinctly blue color and small pulsational amplitude, and the Fourier parameters derived for its light curve, all argue that V1726 Cyg is an overtone pulsator. Unfortunately, this possibility leads to an unrealistically small value for the color term β in the PLC relation when V1726 Cyg is compared with other cluster Cepheids examined in this series. A more acceptable solution for the color coefficient in the PLC relation is obtained only when V1726 Cyg is assumed to be a fundamental mode pulsator. Such a counterintuitive result relative to the directly observable parameters for this star probably justifies a more extensive study of its coincidence with the cluster C2128+488.

The color coefficient in the PLC relation obtained from an analysis of the data for cluster Cepheids investigated so far in this program is $\beta=2.1\pm0.2$, with smaller values producing noticeable discrepancies with respect to the PL relation parameters given in Paper III. Comparable values of $\beta=2.13$ for Magellanic Cloud Cepheids (Caldwell & Coulson 1986), $\beta=2.03\pm0.38$ for Cepheids in the LMC cluster NGC 1866 (Welch *et al.* 1991), and $\beta=2.10\pm0.14$ for the combination of LMC clusters NGC 1866, NGC 2031, and NGC 2157 (Mateo 1992) are identical to the present result for galactic Cepheids, despite the fact that the current analysis makes no allowances for potential metallicity effects on the luminosities of cluster Cepheids in the galactic sample. A period dependence may also be appropriate for this parameter (Fernie 1967; Madore 1985; Moffett & Barnes 1986). Alternatively, if V1726 Cyg is assumed to be an overtone member of C2128+488, then the color coefficient is driven towards $\beta=0.5\pm0.2$. Such a small value for β seems unlikely on physical grounds, despite similar results obtained for β by Fouqué & Gieren (1993) for a sample of 100 galactic Cepheids with distances inferred using the visual surface brightness method.

This investigation was supported by funds awarded through the Natural Sciences and Engineering Research Council of Canada (NSERC) to D.G.T. and D.F., and was initiated during the tenure by D.G.T. of an NSERC University Research Fellowship. We are grateful to the Directors of Kitt Peak National Observatory and the Dominion Astrophysical Observatory for generous allotments of observing time for this project, and to Barry Madore for the loan of his plates of the cluster. The assistance of Ron Lyons in measuring the image-intensifier spectra is most gratefully acknowledged, as is the invaluable advice and interest of Imants Platais during the final stages of this study.

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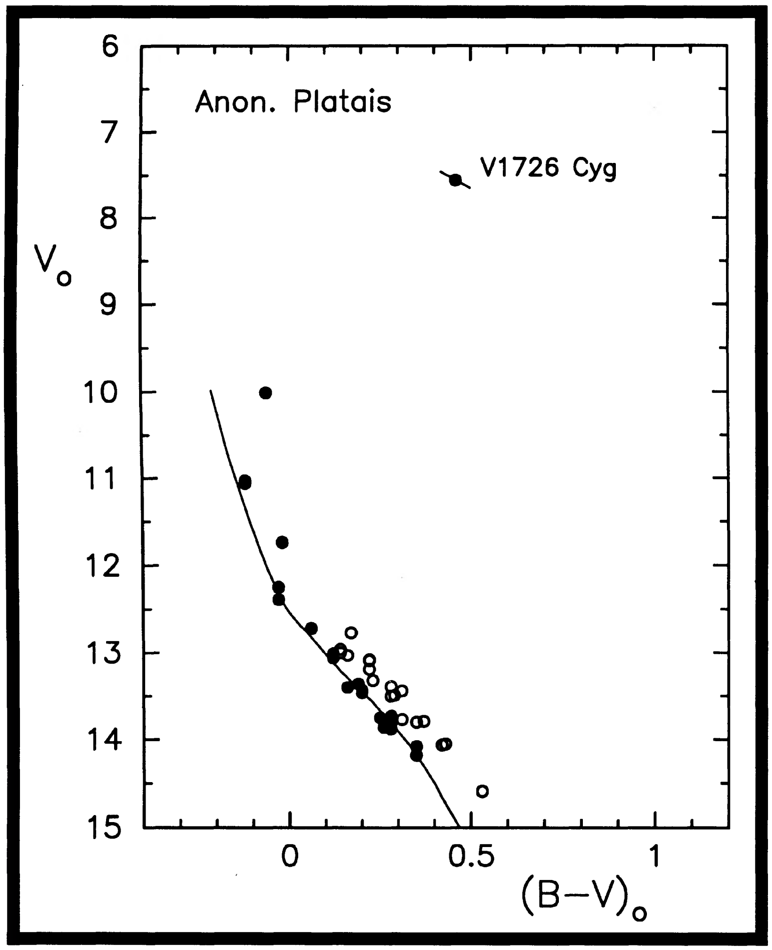

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