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A PHOTOMETRIC INVESTIGATION OF CLUSTER MEMBERSHIP FOR THE CEPHEID BB SAGITTARII

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ABSTRACT

Photoelectric photometry (*UBV* and some *VRI*) is presented for the close pair of open clusters Cr 394 and NGC 6716 and for the $6^{\rm d}64$ classical Cepheid BB Sgr. Based upon the photometric data and star counts, the following parameters are derived for these clusters: Cr 394, $\langle E_{B-V}\rangle = 0.25 \pm 0.01$, $V_0 - M_V = 9.04 \pm 0.08$, $d = 643 \pm 25$ pc, age$\simeq 6\times 10^7$ yr, nuclear radius $r_n = 9$ arcmin, tidal radius $R_c = 27$ arcmin (5 pc); NGC 6716, $\langle E_{B-V}\rangle = 0.11 \pm 0.01$, $V_0 - M_V = 9.07 \pm 0.17$, $d = 650 \pm 52$ pc, age$\simeq 6\times 10^7$ yr, $r_n = 7$ arcmin. The spatial location and inferred age for BB Sgr are consistent with coronal membership in Cr 394, whose center is located only 19.6 arcmin (3.6 pc) from the Cepheid. Its intrinsic luminosity and mean light color index as a cluster member are $\langle M_V\rangle = -3.08 \pm 0.12$ and $(\langle B\rangle - \langle V\rangle)_0 = 0.75 \pm 0.02$, respectively, values which are consistent with a location near the red edge of the Cepheid instability strip. Space-velocity data for Cr 394 members are needed to strengthen the case for cluster membership of this Cepheid.

I. INTRODUCTION

The $6^{\rm d}64$ Cepheid BB Sgr ($\alpha_{1950} = 18^{\rm h}48^{\rm m}0$, $\delta_{1950} = -20°21'$, $l = 14°.66$, $b = -9°.00$) lies less than $0°.5$ west of a loose grouping of B- and A-type stars known as Collinder (Cr) 394, and has been suggested to be a possible coronal member of this cluster by Tsarevsky, Ureche, and Efremov (1966). The basis for believing BB Sgr to be a cluster member in this instance rests mainly upon its spatial coincidence with the corona of Cr 394 and its brightness relative to fainter cluster stars. There is a difference of less than 2 mag in apparent brightness between BB Sgr and the brightest cluster stars, so it is reasonable to suspect that BB Sgr may be the most luminous and evolved member of Cr 394, provided that the cluster is similar in age and distance to the values predicted for BB Sgr. To our knowledge, this suggestion has never been tested observationally.

This paper presents photoelectric *UBV* (Johnson system) and *VRI* (Kron-Cousins system) photometry for Cr 394 and BB Sgr, and combines this with star counts for the region of the cluster to demonstrate that the Cepheid does indeed qualify as a likely member of Cr 394, in support of the arguments by Tsarevsky *et al.* (1966). Additional observations for a few stars in the nearby cluster NGC 6716 (= Cr 393) indicate that it forms a double cluster with Cr 394. In fact, the coronal regions of these two clusters overlap spatially, although the region of overlap lies in a section of Cr 394 that is opposite to that containing BB Sgr. Cr 394 and NGC 6716 are close enough to make cluster members and BB Sgr ideal candidates for membership tests which could be made on the basis of proper motion and/or radial velocity data. As we point out here, future studies of this type are essential to allow BB Sgr to be added to the list of Cepheids in open clusters that can be used as calibrators for the Cepheid period-luminosity relation.

II. OBSERVATIONS

Photoelectric observations of stars in the region of BB Sgr, Cr 394, and NGC 6716 were obtained in March, April, and May of 1981 and May of 1982 using the University of Toronto's 0.6-m telescope at the Las Campanas Observatory of the Carnegie Institution of Washington. A few additional observations of BB Sgr and HD 174403 were obtained in September of 1981 using the 0.4-m and 0.9-m telescopes at Kitt Peak National Observatory. The majority of the observations were obtained using a dry-ice cooled 1P21 photomultiplier equipped with a filter set that provided a close match to the Johnson *UBV* system, while the remainder were obtained using a cooled EMI 9658R photomultiplier whose performance has been described by Fernie (1974). Although the filter set for the EMI 9658R photomultiplier was designed to fully reproduce the Johnson *UBVRI* and the Kron-Cousins *VRI* systems, we found sizable nonlinear differences (of up to $\pm 0^{\rm m}1$) in the $(U-B)$ colors of dwarfs of late B and early A spectral types as determined from observations with both photometers. These differences appear to result from the inability of the EMI 9658R photomultiplier-filter system to completely match the $(U-B)$ colors of stars near the Balmer jump maximum. Following the cautionary remarks of Popper (1982) regarding the avoidance of systematic errors in *UBV* photometry, we decided to give high weight to the $(U-B)$ colors obtained using the 1P21 photomultiplier.

The data are presented in Tables I and II, and the stars are identified in Figs. 1 and 2 [Plates 95 and 96]. Stars 1–36 in Table I lie in the nucleus of Cr 394, while stars 51–76 (plus HD 174403 and BB Sgr) lie in the cluster corona. Stars 51, 52, 54, and 56 lie closer to NGC 6716 than to Cr 394, and have been treated here as possible coronal members of either cluster. The Table II data (NGC 6716) are based solely on observations with the EMI 9658R photometer. These were transformed to the *UBV* system as carefully as possible using observations of stars in Cr 394 as a guide. No spectroscopic observations were made in this study, and the spectral types given in the tables are from the HD Catalogue or from Lindoff (1971). Intrinsic colors were taken from the tables of Johnson (1966), and Fernie's (1983) relations were used to transform Johnson's *VRI* colors to equivalents in the Kron-Cousins system.

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TABLE I. Observations of stars in Collinder 394.

Star	HD	V	B-V	U-B	V-R	V-I	n[a]	$(B-V)_o$	E_{B-V}[b]	E_{V-R}	E_{V-I}	V_o	Remarks[c]
1	..	10.26	+0.21	+0.10	..	..	3/0	-0.02	0.23	..	..	9.53	m
2	174723	8.88	+0.11	-0.39	..	..	3/0	-0.17	0.28	..	..	8.01	B8, m
3	..	11.19	+0.22	+0.09	..	..	3/0	-0.03	0.25	..	..	10.40	m
4	..	12.39	+0.49	+0.29	..	..	3/0	+0.22	0.28	..	..	11.52	m
5	..	12.82	+0.53	+0.22	..	..	3/0	+0.30	0.24	..	..	12.07	m
6	174706	10.30	+0.21	+0.03	..	..	3/0	-0.05	0.26	..	..	9.48	A2, m
7	..	12.86	+0.48	+0.21	..	..	3/0	+0.28	0.21	..	..	12.21	bg
8	..	12.76	+1.79	+2.74:	..	..	1/0	..	..	..	..	..	fg
9	..	12.94	+1.36	+1.39	..	..	2/0	..	..	..	..	..	fg
10	..	11.11	+0.22	+0.13	0.14	0.32	5/2	-0.01	0.23	0.15	0.32	10.38	m
11	..	11.52	+0.63	+0.18	..	..	3/0	+0.39	0.25	..	..	10.73	fg
12	174685	9.52	+0.10	-0.32	..	..	3/0	-0.14	0.24	..	..	8.77	B9, m
13	..	10.70	+0.54	+0.07	..	..	2/0	+0.42	0.13	..	..	10.31	fg
14	..	11.54	+0.25	+0.18	..	..	3/0	+0.01	0.24	..	..	10.78	m
15	..	13.15	+0.63	+0.24	..	..	3/0	+0.34	0.31	..	..	12.20	m
16	..	12.97	+0.82	+0.27	..	..	3/0	..	..	..	..	..	fg
17	..	14.26	+0.45	+0.24	..	..	2/0	+0.24	0.22	..	..	13.58	bg
18	..	12.58	+0.64	+0.15	..	..	3/0	+0.41	0.24	..	..	11.82	m
19	..	11.93	+0.47	+0.22	..	..	3/0	+0.27	0.21	..	..	11.28	m
20	..	12.44	+0.47	+0.28	..	..	3/0	+0.22	0.26	..	..	11.63	m
21	..	10.45	+1.16	+0.88	..	..	3/0	..	..	..	..	..	fg
22	174651	8.47	+0.11	-0.31	..	..	4/0	-0.14	0.25	..	..	7.69	A0, m
23	..	10.86	+1.76	+2.05	0.92	1.98	5/2	..	..	..	..	..	fg
24	174652	9.06	+0.16	-0.30	0.13	0.28	5/2	-0.15	0.31	0.19	0.44	8.09	B9, m
25	..	11.84	+0.79	+0.17	0.48	0.98	5/2	..	..	..	..	..	fg
26	..	11.22	+0.23	+0.13	0.12	0.29	5/2	-0.01	0.24	0.13	0.29	10.46	m
27	..	10.34	+0.12	-0.17	..	..	3/0	-0.10	0.22	..	..	9.65	m
28	..	10.76	+0.26	+0.04	0.15	0.37	5/2	-0.06	0.32	0.18	0.43	9.75	m
29	..	12.16	+0.45	+0.31	..	..	3/0	+0.17	0.29	..	..	11.26	m
30	..	11.56	+0.32	+0.20	..	..	3/0	-0.01	0.34	..	..	10.52	m
31	..	10.03	+0.16	-0.15	0.11	0.25	5/2	-0.10	0.26	0.16	0.35	9.22	m
32	..	12.30	+0.57	+0.16	..	..	3/0	+0.37	0.21	..	..	11.64	m
33	..	10.52	+0.21	-0.07	0.12	0.29	3/2	-0.08	0.29	0.16	0.37	9.61	m
34	..	12.62	+0.50	+0.25	..	..	3/0	+0.26	0.25	..	..	11.84	m
35	..	11.25	+0.22	+0.17	..	..	3/0	+0.02	0.20	..	..	10.62	m
36	..	12.04	+0.40	+0.28	..	..	3/0	+0.16	0.25	..	..	11.27	m
51	174946	10.19	+0.19	+0.14	..	..	1/0	+0.01	0.18	..	..	9.62	A0, fg
52	174945	9.92	+0.01	-0.26	0.07	0.10	2/2	-0.10	0.11	0.12	0.20	9.58	A0, m
53	..	10.11	+0.13	-0.20	..	..	2/0	-0.11	0.24	..	..	9.36	m
54	174919	6.95	+1.45	+1.51	0.69	1.33	5/5	+1.25	0.23	..	..	6.24	K0, fg?
55	174869	10.27	+0.13	-0.07	..	..	2/0	-0.06	0.19	..	..	9.67	A0, m
56	..	10.63	+1.33	+1.52	0.61	1.18	1/1	..	..	..	..	..	fg
57	174756	9.25	+0.10	-0.26	..	..	2/0	-0.12	0.22	..	..	8.56	B9, m
58	174684	8.30	+0.07	-0.41	0.06	0.13	5/2	-0.16	0.23	0.13	0.30	7.58	B8, m
59	174610	9.10	+0.07	-0.30	0.06	0.15	5/2	-0.13	0.20	0.12	0.28	8.48	A0, m
60	174595	9.08	+0.08	-0.42	..	..	2/0	-0.17	0.25	..	..	8.30	A0, m
61	174594	8.20	+0.11	-0.38	0.08	0.18	5/2	-0.16	0.27	0.15	0.35	7.36	A0, m
62	..	10.93	+0.23	+0.09	0.15	0.34:	5/2	-0.03	0.26	0.17	0.36:	10.11	m
63	174538	10.37	+0.18	-0.08	..	..	3/0	-0.08	0.26	..	..	9.55	A2, m
64	..	12.33	+0.69	+0.39	..	..	3/0	+0.26	0.45	..	..	10.94	bg
65	..	9.86	+1.35	+1.19	..	..	1/0	..	..	..	..	..	fg
66	174491	10.36	+0.11	-0.23	..	..	3/0	-0.11	0.22	..	..	9.67	A0, m
67	174492	9.93	+0.17	-0.28	0.12	0.27	5/2	-0.14	0.31	0.18	0.42	8.96	A0, m
68	..	11.17	+1.48	+1.41	..	..	1/0	..	..	..	..	..	fg
69	..	10.87	+0.50	+0.33	..	..	3/0	+0.19	0.32	..	..	9.87	fg
70	..	12.25	+0.33	+0.25	..	..	3/0	+0.02	0.32	..	..	11.27	bg
71	..	12.56	+0.60	+0.31	..	..	3/0	+0.27	0.35	..	..	11.49	m
72	..	11.59	+1.37	+1.30	..	..	2/0	..	..	..	..	..	fg
73	..	12.47	+1.25	+0.99	..	..	1/0	..	..	..	..	..	fg
74	174402	9.27	+1.25	+1.09	..	..	1/0	..	..	..	..	..	K0, fg
75	..	11.11	+0.59	+0.05	..	..	3/0	..	..	..	..	..	fg
76	174307	10.36	+0.26	-0.06	..	..	3/0	-0.09	0.35	..	..	9.26	A, m
..	174403	7.51	+0.16	-0.26	0.11	0.23	31/18	-0.13	0.29	0.17	0.36	6.60	B9, fg?

[a] n(UBV)/n(VRI).

[b] Color excess appropriate for a star of spectral type B0 V.

[c] HD spectral type and photometric membership status according to the following code:

m = cluster member.
fg = foreground star.
bg = background star.

TABLE II. Observations of stars in NGC 6716.

Star	HD	V	B-V	U-B	V-R	V-I	n[a]	$(B-V)_o$	E_{B-V}[b]	E_{V-R}	E_{V-I}	V_o	Remarks[c]
1	175141	9.26	+0.01	-0.27	0.05	0.11	2/2	-0.10	0.11	0.10	0.21	8.92	B8 IV, m
2	..	11.83	+0.29	+0.16	0.18	0.38	2/2	+0.21	0.08	0.05	0.14	11.57	A1, m
3	..	11.79	+0.34	+0.16	0.18	0.39	2/2	+0.24	0.10	0.03	0.11	11.47	A2, m
4	..	13.04	+0.57	+0.25:	0.34:	0.77:	4/4	+0.30	0.28	0.15	0.45	12.16	bg
5	..	10.70	+0.22	+0.15	0.16	0.35	2/2	+0.17	0.05	0.05	0.15	10.54	fg
6	..	11.75	+0.30	+0.17	0.14	0.28	2/2	+0.21	0.09	0.01	0.04	11.46	m
7	..	10.00	+0.06	-0.10	0.07	0.17	2/2	-0.06	0.12	0.10	0.23	9.62	B8, m
8	..	12.51	+0.43	+0.15:	0.28	0.54	2/2	+0.30	0.14	0.09	0.19	12.09	m
9	175091	9.17	+0.04	-0.20	0.04	0.11	5/5	-0.09	0.13	0.08	0.20	8.76	B8 V, m
10	..	9.84	-0.01	-0.23	0.05	0.10	5/5	-0.09	0.08	0.09	0.19	9.59	B9, m
11	..	11.21	+0.12	+0.07	0.06	0.14	3/3	-0.01	0.13	0.07	0.14	10.80	A1, m
12	175043	8.49	+0.03	-0.33	0.04	0.07	1/1	-0.13	0.10	0.10	0.20	8.18	B7 IV, m
13	..	10.74	+0.11	+0.09	0.07	0.17	2/2	+0.01	0.10	0.07	0.15	10.42	B8, m

[a] n(UBV)/n(VRI).

[b] Color excess appropriate for a star of spectral type B0 V.

[c] Spectral type from Lindoff (1971) or HD and photometric membership status according to the following code:

m = cluster member.
fg = foreground star.
bg = background star.

III. COLLINDER 394 AND NGC 6716

Figure 3 is a color-color diagram [$(U-B)$ versus $(B-V)$] for stars in Cr 394 and its surroundings, while Fig. 4 is a similar diagram for stars in NGC 6716. NGC 6716 lies further from the galactic equator than Cr 394, and the small reddening of cluster stars found here ($\langle E_{B-V}\rangle = 0.11 \pm 0.01$ m.e.) appears to be due to foreground extinction by dust clouds lying close to the galactic plane. The reddening of Cr 394 stars is larger ($\langle E_{B-V}\rangle = 0.25 \pm 0.01$ m.e.) and less uniform, and an inspection of the POSS plates containing the cluster reveals that the small amount of differential reddening observed in Cr 394 originates from a few faint strands of foreground dust which extend visibly into the region of the cluster from the west.

It was found that a reddening law of "standard" slope $E_{U-B}/E_{B-V} = 0.75$ (or 0.72) did not produce similar color excesses for spatially adjacent cluster stars. A standard reddening slope also tended to make B-type cluster members more reddened and more distant than adjacent A-type cluster members, and increased the dimensions of the main-sequence "gap" at spectral type A2 in the cluster color-magnitude diagram. A simple test using the close pair of stars 69 and 70 indicated that a reddening slope of $E_{U-B}/E_{B-V} = 0.70 \pm 0.02$ must apply if spatially adjacent cluster stars have similar reddenings. This relation agrees well with results that can be predicted from the cluster's galactic location. The space reddening of Cr 394 stars originates with dust clouds belonging to the nearby Gould's Belt system, and the reddening parameters for this system at the galactic

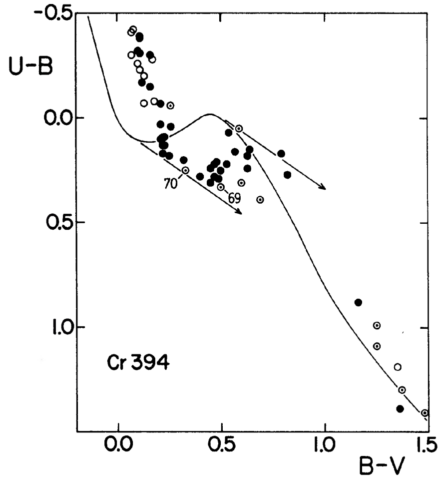

FIG. 3. Color-color diagram for stars in the nucleus of Cr 394 (dark circles), in the corona of Cr 394 (light circles), and in the region of BB Sgr (dotted circles). The intrinsic relation is plotted as the solid curve, and lines show the adopted reddening relation for the region.

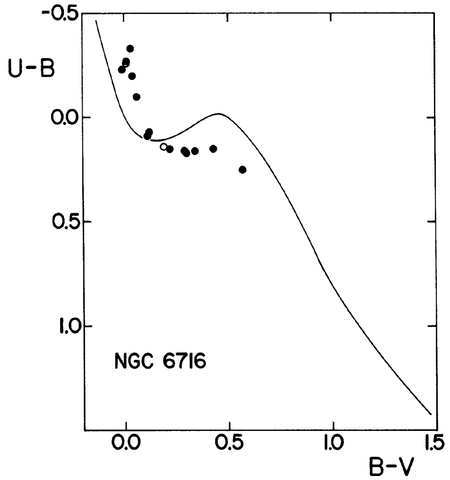

FIG. 4. Color-color diagram similar to Fig. 3 for stars in the nucleus (dark circles) and near corona (light circles) of NGC 6716.

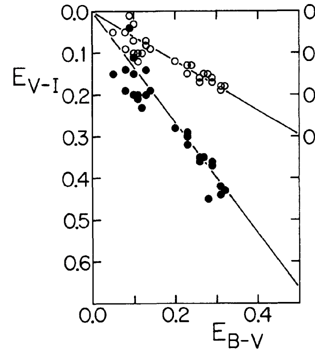

FIG. 5. Kron-Cousins system color excesses E_{V-R} (light circles) and E_{V-I} (dark circles) versus E_{B-V} for the region of Cr 394 and NGC 6716. The lines have slopes 0.59 and 1.33.

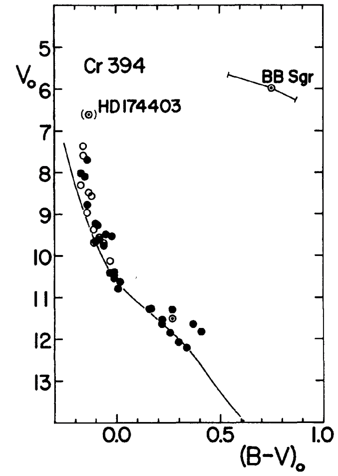

FIG. 7. Reddening-free color-magnitude diagram for Cr 394, with symbols as in Fig. 3. The bracketed star is a possible nonmember (see the text). The solid relation is the ZAMS.

longitude of Cr 394 (Whittet 1979) prove to be consistent with a reddening slope of $E_{U-B}/E_{B-V} = 0.70$.

Figure 5 illustrates the dependence of the derived color excesses E_{V-R} and E_{V-I} on E_{B-V} for cluster B-type stars, where the best-fitting linear relations derived using only the stars in Cr 394 have slopes $E_{V-R}/E_{B-V} = 0.589 \pm 0.010$ and $E_{V-I}/E_{B-V} = 1.330 \pm 0.019$. The corresponding relations in the Johnson *UBVRI* system are $E_{V-R}/E_{B-V} = 0.803 \pm 0.014$ and $E_{V-I}/E_{B-V} = 1.693 \pm 0.024$. Similar values were obtained by Johnson (1968) for the reddening in Ophiuchus and Scorpius, regions which also belong to Gould's Belt and which are spatially adjacent to Cr 394 on the opposite side of the galactic plane. Similar reddening laws are expected for these regions if they are obscured by dust associated with the same relatively nearby interstellar cloud lying close to the galactic plane. The values of $E_{U-B}/E_{B-V} = 0.69$ and 0.72 which Johnson (1968) found for the Scorpius and Ophiuchus regions are also close to the value we obtained for Cr 394, and provide additional support for our adoption of $E_{U-B}/E_{B-V} = 0.70$ to correct for reddening in this region.

Absolute magnitudes M_V were adopted for each star using the zero-age main-sequence (ZAMS) calibration of Turner (1976, 1979). This procedure underestimates the luminosities of unresolved binaries and single stars which have evolved away from the ZAMS, but also permits the distance to each cluster to be established from a variable-extinction diagram, provided that the ZAMS is reasonably well populated for each and that there is some differential reddening present. Figure 6 is a variable-extinction diagram for Cr 394 and NGC 6716, from which it can be established that (i) variable reddening is present across the region of the two clusters, (ii) a normal reddening law of slope $R = A_V/E_{B-V} = 3.1$ (± 0.3 estimated uncertainty) appears to apply to the foreground extinction, and (iii) both clusters lie at similar distances. Since there is no evidence for an anomalous extinction law in this region, we have assumed that $R = 3.1$ is valid for cluster stars.

The cluster distances have been determined using stars that appear to be single, unevolved, ZAMS members. The mean distance modulus for the 15 "best-fitting" stars in Cr 394 is $\langle V_0 - M_V \rangle = 9.04 \pm 0.08$ s.d. (± 0.02 m.e.), which corresponds to $d = 643 \pm 25$ pc (± 6 pc m.e.). The mean distance modulus for the five best-fitting stars in NGC 6716 is $\langle V_0 - M_V \rangle = 9.07 \pm 0.17$ s.d. (± 0.08 m.e.), which corresponds to $d = 650 \pm 52$ pc (± 23 pc m.e.). Lindoff (1971) estimated the distance of NGC 6716 to be ~600 pc in his study. The agreement in derived distances for Cr 394 and NGC 6716 is excellent and, along with their close similarity in age, justifies the conclusion that they form a double cluster. The cluster centers are separated by only 7 pc in projected distance and, as mentioned in Sec. I, their coronal regions merge in the region midway between their centers.

Reddening-free color-magnitude diagrams for the two clusters are presented in Figs. 7 and 8, from which it should

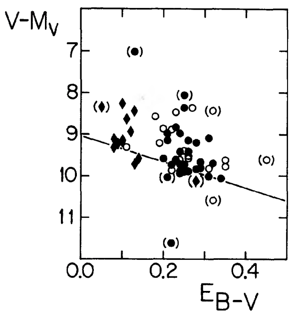

FIG. 6. Variable-extinction diagram for stars in NGC 6716 (diamonds), Cr 394 nucleus (dark circles), and Cr 394 corona (light circles). Probable nonmembers are bracketed, and the line has slope $R = 3.1$.

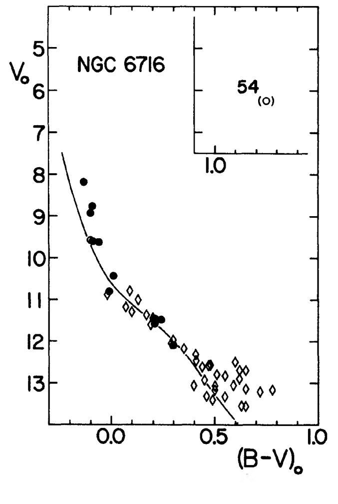

FIG. 8. Reddening-free color-magnitude diagram for NGC 6716 with symbols as in Fig. 4. Diamond symbols denote photometric data from Lindoff (1971). A possible nonmember is bracketed, and the solid relation is the ZAMS.

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be evident that both are of comparable age. The photoelectric and photographic data of Lindoff (1971) for NGC 6716 have been included in Fig. 8, following adjustment to the present system and correction for the mean cluster reddening. A formal comparison of the data for Cr 394 stars with stellar-model age isochrones published by Maeder and Mermilliod (1981) results in an estimated cluster age of $\sim 5 \times 10^7$ yr with respect to standard evolutionary models, or $\sim 6 \times 10^7$ yr with respect to models that include core overshooting.

The age of NGC 6716 is more difficult to establish since the main-sequence turnoff is more sparsely populated than in Cr 394. The location of the turnoff stars in NGC 6716 is generally similar to the location of the turnoff stars in Cr 394, yet their ages cannot be specified to the same degree of precision. A probable age of between $(5\text{–}8) \times 10^7$ yr applies to NGC 6716 when these stars are compared with age isochrones for standard stellar models, or between $(6\text{–}10) \times 10^7$ yr with respect to models that include core overshooting. The presence of a pre-main-sequence at $M_V \simeq +4$ in Fig. 8 appears likely to be real, in which case a turnon point age of $\sim 6 \times 10^7$ yr can be derived for NGC 6716 using the models of Ulrich (1971) and the assumption that the initial mass fraction of ^{3}He for cluster stars was $N(^3\mathrm{He})/N(^3\mathrm{He} + {}^4\mathrm{He}) \simeq 0.001$. It is interesting to note that the probable pre-main-sequence members of NGC 6716 infer a cluster age that is almost identical to that of Cr 394.

The cluster dimensions which are illustrated schematically in Figs. 1 and 2 were established from star counts made from an enlargement of the POSS E plate of the region. Strip counts taken in several different directions were used to determine the center of symmetry for each cluster, and these were followed by ring counts to estimate the dimensions of the nuclear regions for each cluster. The star counts were limited to $V \lesssim 14$ in order to avoid undue contamination by the rich background of faint stars. This limit reaches to spectral type $\sim$G0 for main-sequence stars in each cluster, and was sufficient to establish the dimensions of both. Under the (admittedly) unproven assumption that both clusters are spherically symmetric, the derived radii for their nuclear regions are $r_n = 9$ arcmin for Cr 394 and $r_n = 7$ arcmin for NGC 6716. The corresponding cluster diameters are 3.3 and 2.6 pc, respectively.

Although it was not possible to establish coronal dimensions for NGC 6716 owing to its close proximity to the edge of the POSS field, statistically meaningful ring counts were possible for the coronal region of Cr 394, as shown in Fig. 9. The relatively smooth variation in foreground reddening across the field is particularly useful for establishing a reliable field-star density from the outermost rings. The derived coronal radius for Cr 394 is 27 arcmin, which corresponds to a cluster coronal diameter (or tidal diameter) of 10 pc. Cr 394 would probably be gravitationally unbound if it were any larger than 10 pc in diameter (Wielen 1971). BB Sgr is 19.6 arcmin (or 3.6 pc) from the center of Cr 394, and lies projected well within the tidal limits of the cluster.

The star counts produce new values for the coordinates of the cluster centers and estimates for the number of cluster members brighter than $V \simeq 14$. The center for Cr 394 is located at $\alpha_{1950} = 18^{\mathrm{h}}\ 49^{\mathrm{m}}\ 24^{\mathrm{s}}$, $\delta_{1950} = -20°\ 18'\ 38''$, and the cluster contains 119 ± 5 stars brighter than $V \simeq 14$ within its coronal radius, and 44 ± 1 stars brighter than $V \simeq 14$ within its nuclear radius. The center for NGC 6716 is located at $\alpha_{1950} = 18^{\mathrm{h}}51^{\mathrm{m}}31^{\mathrm{s}}$, $\delta_{1950} = -19°\ 57'\ 35''$, and the cluster contains 41 ± 1 stars brighter than $V \simeq 14$ within its nuclear radius. The new cluster centers found here differ slightly from previously published estimates.

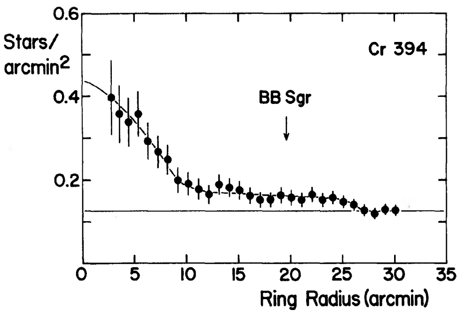

FIG. 9. Star densities (above $V \simeq 14$) in Cr 394 as a function of ring radius, with the adopted field level indicated.

IV. BB SAGITTARII

Table III and Fig. 10 present *UBVRI* observations for BB Sgr obtained during our observing runs. The data represent absolute, rather than differential, photometry, and have larger internal errors than the differential photometry for BB Sgr published recently by Gieren (1981) and Moffett and Barns (1984). The phase coverage for the observations, as determined from the parameters given in the *General Catalogue of Variable Stars* (Kukarkin *et al.* 1970; cf. Gieren 1981), is fairly complete, and the data can be usefully compared with the observations of Gieren, and Moffett and Barnes. Small differences in magnitudes and colors are evident from such a comparison, and presumably these can be accounted for by the different techniques used to standardize the observations and, for the Moffett and Barnes data, by the different *VRI* systems used.

We have listed in Table IV a few of the fundamental magnitudes and colors for BB Sgr that are derived from our data. These are in fairly good agreement with similar parameters for BB Sgr published by Schaltenbrand and Tammann (1971). Tammann (1970) has published a Cepheid period-age relation, applicable to stars in the second or higher crossing of the instability strip, based upon the stellar evolutionary models of Kippenhahn and Smith (1969). As applied to BB Sgr, the result is a predicted age of $5.3\ (\pm 1.1) \times 10^7$ yr. Inclusion of the effects of core overshooting in the models, as in Maeder and Mermilliod (1981), would increase this estimate by $\sim 10^7$ yr. In either case, it seems clear that BB Sgr is virtually identical in age with Cr 394 members, unless it is in the highly unlikely situation of being in the first crossing of the instability strip. This coincidence in age, combined with the Cepheid's spatial location, makes a good case for the probable membership of BB Sgr in Cr 394.

The reddening of BB Sgr can be determined using early-type stars that lie within 7 arcmin of the variable (Turner 1984). Whether or not they are members of Cr 394 is immaterial in this instance, since they all appear to be more distant than the dust cloud that is responsible for the foreground reddening. The result, as converted to the reddening appropriate for an F supergiant, is $E_{B-V} = 0.30 \pm 0.02$, which yields a mean light color index of $(\langle B - \langle V \rangle)_0 = 0.75 \pm 0.02$ for BB Sgr. The assumption of membership in Cr 394 leads to a derived luminosity for this Cepheid of $\langle M_V \rangle$

TABLE III. Photoelectric observations of BB Sgr.

HJD 2444000+	V	B-V	U-B	V-R	V-I	n	Phase
686.879	7.13	1.05	..	0.58	1.13	2	0.802
687.854	6.70	0.87	..	0.50	0.97	1	0.949
688.834	6.72	0.91	..	0.52	0.99	2	0.096
689.796	6.82	1.02	..	0.56	1.09	2	0.241
689.884	6.87	0.99	..	0.56	1.08	1	0.255
690.815	6.97	1.09	..	0.59	1.14	2	0.395
723.864	6.94	1.07	0.80	..	..	1	0.374
724.893	7.09	1.13	0.88	..	..	2	0.529
728.839	6.75	0.94	0.67	..	..	1	0.124
729.832	6.89	1.03	0.74	..	..	1	0.274
730.853	7.01	1.09	0.82	..	..	1	0.427
731.870	7.15	1.15	0.91	..	..	1	0.581
738.779	7.23	1.15	0.91	..	..	2	0.622
739.872	7.14	1.08	0.79	..	..	1	0.786
850.681	7.01:	1.13	0.85	..	..	1	0.482
852.687	7.15	1.08	0.80	..	..	1	0.784
854.647	6.69	0.88	0.65	..	..	1	0.080
855.640	6.85	1.01	0.71	..	..	1	0.229
857.642	7.11	1.13	0.81:	..	..	2	0.531
1105.840	6.78	0.88	..	0.50	1.00	1	0.927
1107.858	6.86	1.01	..	0.55	1.08	1	0.231
1108.830	6.97	1.08	..	0.58	1.12	1	0.378
1110.856	7.27	1.18	..	0.62	1.19	2	0.683
1112.901	6.66	0.84	..	0.49	0.96	1	0.991
1113.818	6.74	0.93	..	0.51	0.98	1	0.129
1114.839	6.89	0.99	..	0.57	1.12	1	0.283

$= -3.08 \pm 0.12$. By way of comparison, the relations of van den Bergh (1977) predict values of $\langle M_V \rangle = -3.56 \pm 0.26$ and $(\langle B \rangle - \langle V \rangle)_0 = 0.66 \pm 0.06$ for a 6^d637 classical Cepheid. A difference of 0^m5 in $\langle M_V \rangle$ is perhaps some cause for concern for the assumption of cluster membership for BB Sgr, although, given the recent trend towards smaller luminosities for cluster Cepheids advocated by Schmidt (1984) from his studies of the standard calibrating clusters, this difference may not be overly important. BB Sgr appears, after all, to be significantly redder at mean light than typical Cepheids of the same period, and also exhibits a light amplitude that is 0^m4 smaller in B than the maximum observed value for such objects ($\Delta B_{\max} \simeq 1^m3$ at $P \simeq 6^d6$). Its somewhat underluminous absolute magnitude may therefore be partially due to its location near the red edge of the instability strip. It is also conceivable that we have underestimated the distance to Cr 394 from our ZAMS fit, although certainly not by as much as 0^m5 in distance modulus.

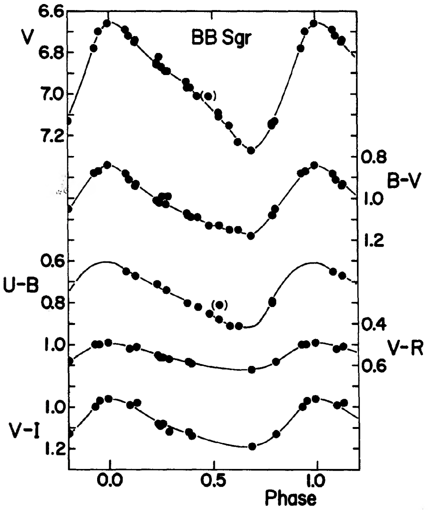

FIG. 10. Light and color variations for BB Sgr as derived from the observations in Table III. Uncertain data points are bracketed.

The star counts of Fig. 9 are also pertinent to any discussion of cluster membership for BB Sgr. The region within 7 arcmin of the Cepheid, which was used to establish its field reddening, contains 22 stars brighter than $V \simeq 14$, of which 5 ± 3 are predicted from the star counts to be coronal members of Cr 394. Only nine of these stars (including BB Sgr) were included in the photometric program, and five of these seem certain to be foreground or background objects. The eclipsing system HD 174403 has also been identified as a possible foreground star (cf. Turner and Pedreros 1983), despite its unique location in Fig. 7 at the bright end of the evolved cluster main sequence. Currently available observations therefore make it possible to establish, at most, three of the observed stars within 7 arcmin of BB Sgr as possible coronal members of Cr 394, namely stars 71, 76, and BB Sgr itself. Since the survey is only 41% complete to $V \simeq 14$ and is

TABLE IV. Observed and deduced parameters for BB Sgr.

$P = 6.636\,99$ days (Kukarkin *et al.* 1970)
$V_{\max} = 6.68$ $(B-V)_{\max} = 0.82$
$V_{\min} = 7.27$ $(B-V)_{\min} = 1.15$
$\langle V \rangle = 6.97$ $\langle B \rangle - \langle V \rangle = 1.05$
$\Delta V = 0.59$ $\Delta B = 0.93$
$E_{B-V} = 0.30 \pm 0.02$ (Turner 1984)
$(\langle B \rangle - \langle V \rangle)_0 = 0.75 \pm 0.02$
$(m-M)_0 = 9.04 \pm 0.09$ (as Cr 394 member)
$\langle M_V \rangle = -3.08 \pm 0.12$

concentrated mainly on the brighter stars in the field, one can at best conclude that membership of BB Sgr in Cr 394 is not at variance with the star counts, although a deeper and more complete survey is needed to pursue the argument further. On statistical grounds, the membership of BB Sgr in Cr 394 can therefore be considered as a likely, but poorly established, possibility. A clear decision on the matter must surely await the results of a membership study that is based upon space-velocity data for BB Sgr and cluster stars.

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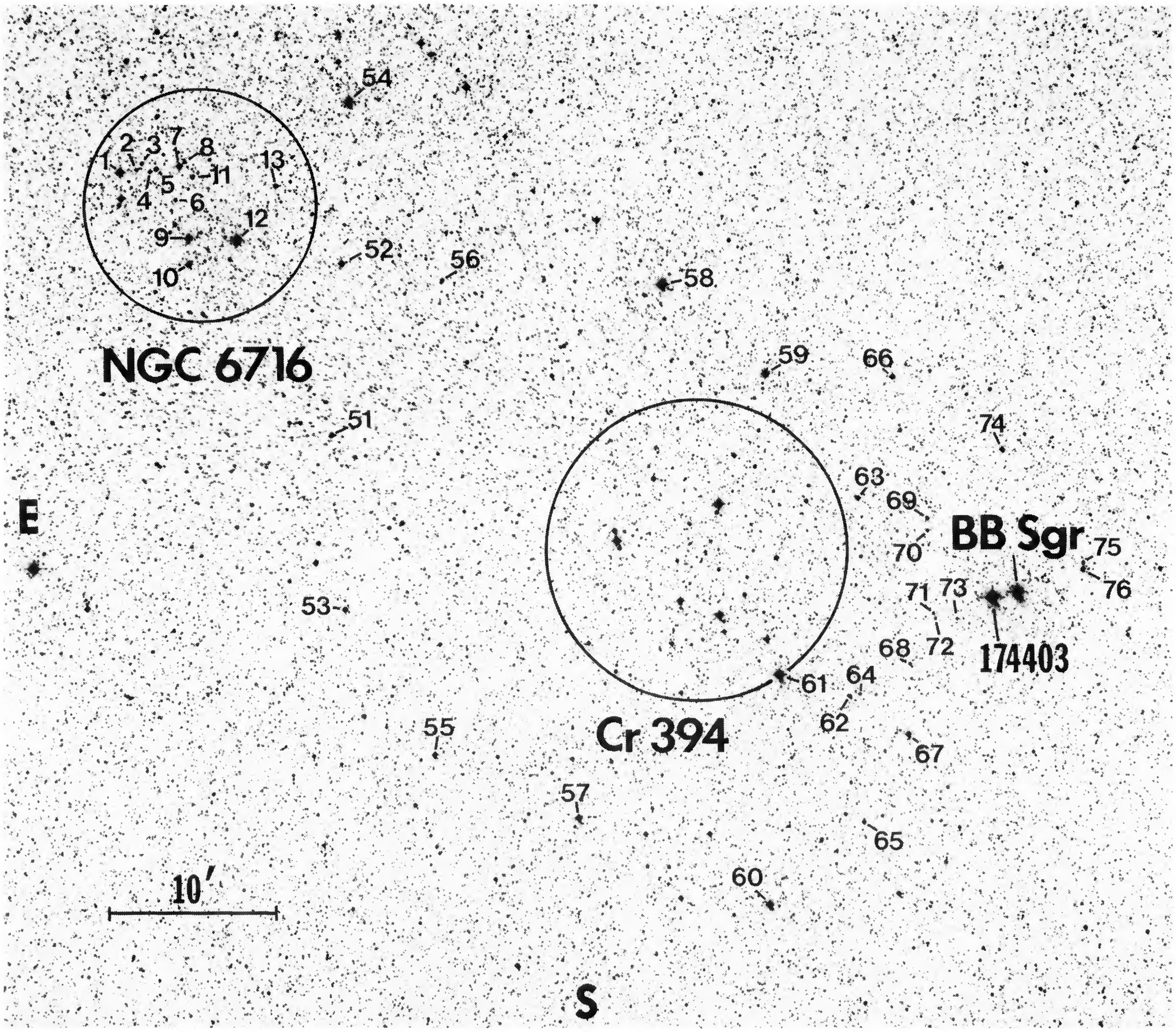

FIG. 1. Identification chart for stars in NGC 6716 and the corona of Cr 394 from the POSS E plate of the region. Circles represent the dimensions of the cluster nuclei determined from star counts. (Copyright: National Geographic Society—Palomar Observatory Sky Survey.)

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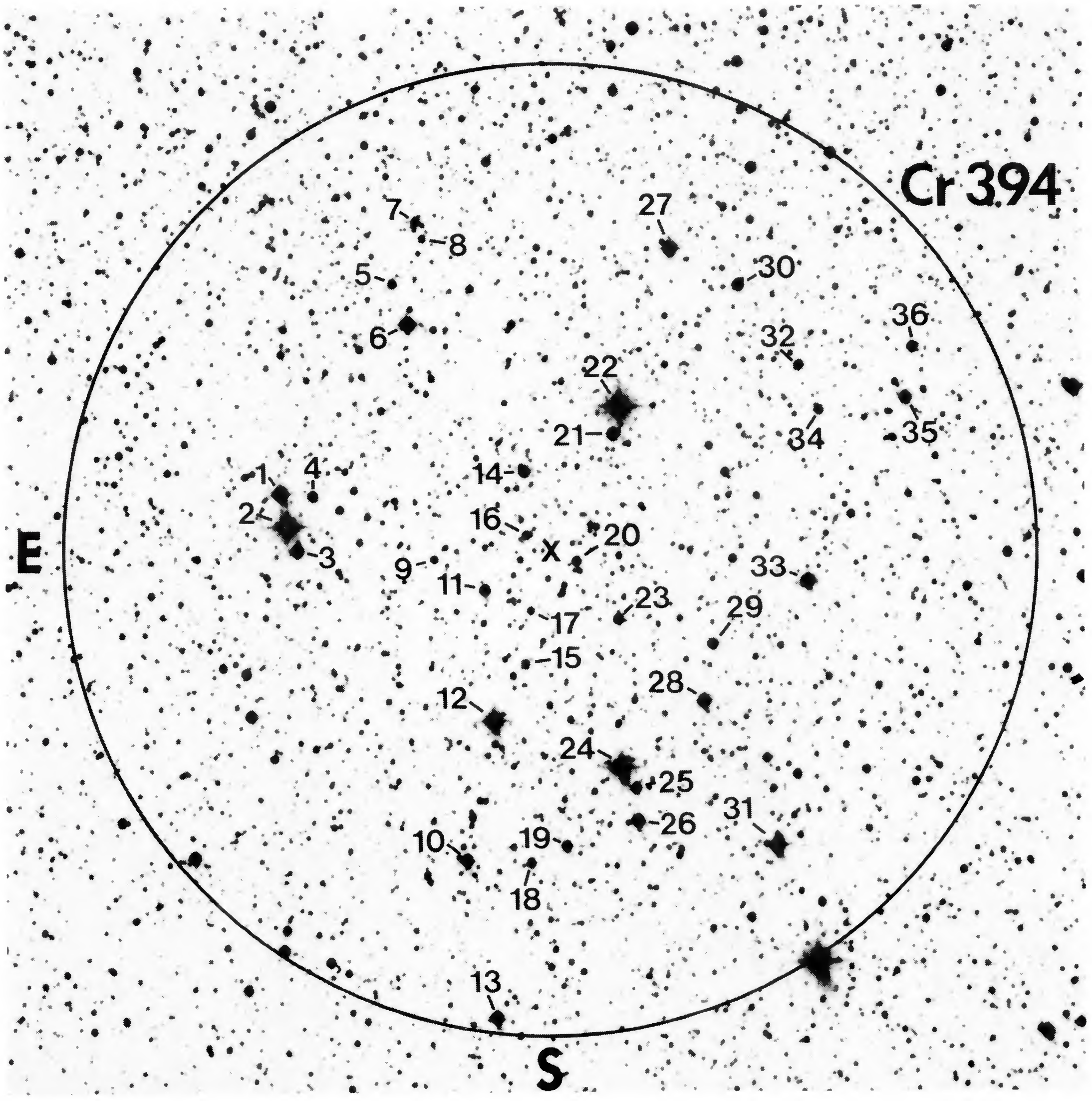

FIG. 2. Enlargement of Fig. 1 for the nucleus of Cr 394. An "X" denotes the location of the cluster center. (Copyright: National Geographic Society—Palomar Observatory Sky Survey.)

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