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A SPECTROSCOPIC AND PHOTOMETRIC INVESTIGATION OF THE ASSOCIATION CEPHEUS OB2

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ABSTRACT

Distance moduli based on MK spectral classification and *UBV* photometry were obtained for seventy-five intrinsically bright stars in the region of Cepheus OB2. A concentration of early-type main-sequence and supergiant stars with a mean distance modulus of 9 5 mag is found between $l^{II} = 96°$ and 107°, $b^{II} = +2°$ and $+8°$. The concentration includes the clusters NGC 7160 and Trumpler 37 A connection is seen with Cepheus OB3, and a concentration of about $1.5 \times 10^5\, \mathfrak{M}_\odot$ of neutral hydrogen at the same radial velocity as the stars surrounds both associations. Little evidence was found to support a value of total absorption in V to selective absorption in $B - V$ different from 3.0.

I. INTRODUCTION

Cepheus OB2 was called Cepheus II by Markarian (1952) and I Cephei by Morgan, Whitford, and Code (1953). The latter authors put its distance at 720 pc. The clusters Trumpler 37, which is immersed in the emission nebula IC 1396, and NGC 7160 have been considered "nuclei" of the association (Markarian 1952). Despite its nearness and its large number of bright stars, little has been known about the stars of absolute magnitude fainter than $M_V = -4$ that may belong to Cepheus OB2 (cf. Blaauw 1964). There has also been a question whether all the bright stars that have been attributed to the association should be considered members. Shakhovskoi (1956) found substantial dispersion in the photometric distances, and Kopylov (1958) divided the association into four small groups of stars at distances of 460–1350 pc. In the present investigation, MK spectral classification and *UBV* photometry are extended to fainter stars in an attempt to clarify the distribution of O and B stars in the region.

II. OBSERVATIONS

Observations were made in September 1966 of stars selected according to the following criteria: (i) stars listed as probable members of the association by Morgan *et al.* (1953) or Markarian (1953), (ii) the brightest stars in Trumpler 37 and NGC 7160, and (iii) stars within the region outlined by the stars in category (i) with HD and HDE types B–B3. All the stars in categories (i) and (ii), except HD 210352 and SA 18-390, and thirty-three of forty-six stars in category (iii) were observed.

Spectrograms of program stars and MK standards were taken with the Yc spectrograph on the Perkins 72-inch telescope of the Ohio State and Ohio Wesleyan Universities at the Lowell Observatory. The reciprocal dispersion was 80 Å mm^{-1}, and the projected slit size was 0.45×0.028 mm. Baked Eastman IIaO plates were used, developed in metol-sulfite.

The *UBV* measurements were made with the 21-inch telescope of the Lowell Observatory, using the photometer described by Jerzykiewicz and Serkowski (1966). The signal was recorded on the integrating photometer of the Lowell Observatory, using an integration time of 10 sec. Jerzykiewicz and Serkowski's (1966) gain calibration was used for the data reduction. Observations of a radium source during each night revealed that the sensitivity of the unrefrigerated photomultiplier varied with the temperature, and the

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data were corrected for this effect. The extinction coefficients and instrumental corrections were determined for each night separately from observations of UBV standards. As a check of the systematic differences between the observed UBV colors and magnitudes and the standard system, a comparison was made with eleven non-variable stars measured in common with Hiltner (1956). The differences in the sense of (Simonson − Hiltner) were $\Delta V = +0.002 \pm 0.008$ (standard error) mag, $\Delta(B - V) = +0.016 \pm 0.003$ (s.e.) mag, and $\Delta(U - B) = -0.008 \pm 0.003$ (s.e.) mag. Since the values of $\Delta(B - V)$ and $\Delta(U - B)$ appeared to be significant and showed no dependence on color or magnitude, and since Hiltner's measurements are regarded as more likely to be on the standard system, a change in the zero point was made to eliminate these differences in the mean.

Table 1 gives the observational results. Where MK types or photoelectric photometry are lacking, objective-prism spectral types or photographic BV measurements are supplied in parentheses from a survey by the author (1967) with the 16/24-inch Schottland-Schmidt telescope and the 4-inch Ross camera of the Perkins Observatory. The color excess, $E(B - V) = (B - V) - (B - V)_0$, was computed using Johnson's (1965) standard colors. The absorption in V, A_V, was computed using the value 3.0 for the ratio $R = A_V/E(B - V)$. The absolute magnitudes that were used in computing the corrected distance moduli, $\rho = V - A_V - M_V$, were taken from the MK calibration of Weaver and Ebert (1964) for luminosity classes V, IV, and III, and the compilation of Blaauw (1963) for luminosity classes II, Ib, and Ia.

III. DISCUSSION OF OBSERVATIONS

a) *Reddening*

The standard value $R = 3.0$ (Sharpless 1963) was used for the ratio of total to selective absorption even though higher values for R have been found by Johnson (1965, 1967) for the same region in Cepheus. In the earlier paper, Johnson found $R = 5.4$ from two observations—the variation of absorption across the association Cepheus OB3 (III Cephei) and infrared photometry of the M2 Ia semiregular variable, μ Cep (HD 206936). In the later paper, Johnson found $R = 4.0$ from more extensive comparison of infrared photometry of μ Cep and other late-type stars. In the case of Cepheus OB3, Garrison (1967) found that the high value of R resulted from the inclusion of several foreground stars of spectral type later than B6, and that $R = 3.0$ was suitable for stars of types O–B5 in the association. The value of R determined from photometry of μ Cep is open to some question on two points. First, the intrinsic infrared luminosity of μ Cep is not well known. Second, μ Cep is a variable star, and the most suitable colors do not seem to be well established. At the epoch of Johnson's observations, μ Cep was fainter in V and bluer in $B - V$ than usual (cf. Larsson-Leander 1963).

Although the stars in the region of Cepheus OB2 are not well suited to a determination of R since they are spread over a large region on the sky and may be expected to lie at different distances from the Sun, the available data are presented in Figure 1. The figure includes all the early-type stars with both MK types and UBV photometry from Table 1 except HD 208095 and HDE 239724. Taking all the stars, $R = 3.0 \pm 0.6$ (s.e.). Owing to the selection criteria, a number of nearby stars are expected to be included. To reduce the selection effect, we consider only the stars with $M_V < -2.5$ (i.e., the stars brighter than B2 V), indicated by filled circles in Figure 1. For these stars, $R = 2.5 \pm 0.8$ (s.e.). On the basis of these observations, there seems little reason to conclude that Cepheus OB2 lies in a region of anomalous reddening. The stars in Trumpler 37 are indicated in Figure 1 for comparison with μ Cep, whose ranges in color excess and in apparent distance modulus are shown under the assumption that $(B - V)_0 = -1.62$ (Johnson 1967) and $M_V = -7$. Although μ Cep is seen in the same region of the sky, it appears to have a greater color excess than the stars of the cluster.

TABLE 1

RESULTS OF OBSERVATIONS

HD/BD	l^{II}	b^{II}	Spectrum	V	B−V	U−B	E(B−V)	ρ (mag)	r (pc)
198895*	93°3	+7°1	B1Ve	8.09	+0.66	−0.39	0.92	8.0	400
199308	94.3	+7.3	B2V	7.50	+0.14	−0.64	0.38	8.3	460
199661	94.9	+7.5	B3V	6.22	−0.19	−0.73	0.01	7.7	350
200857	94.3	+5.6	B3III	7.13	+0.55	−0.26	0.75	8.9	600
202214	98.5	+8.0	B0V	5.64	+0.11	−0.81	0.41	7.9	380
203025*	98.0	+6.5	B2V(e)	6.41	+0.19	−0.53	0.43	7.8	360
203338*	98.2	+6.3	B1:V: + M1epIb	5.66	+1.45	+0.07	0.4	9.2:	690:
203374*	100.5	+8.6	B0Vnne	6.67	+0.30	−0.75	0.60	8.4	480
204116*	96.4	+3.6	B1Vep	7.94	+0.49	−0.28	0.75	8.4	480
204150	100.2	+7.5	B2V	7.73	+0.01	−0.78	0.25	8.9	600
204827	99.2	+5.6	B0V	7.94	+0.80	−0.11	1.10	8.1	420
205139	100.5	+6.6	B1II	5.51	+0.11	−0.73	0.35	9.5	790
205196	98.6	+4.4	B0Ib	7.39	+0.59	−0.47	0.83	10.7	1380
205510	99.2	+4.8	(B3v)	8.48	+0.31	−0.41	0.51	8.5:	500:
205948	99.2	+4.1	B2V	8.65	+0.25	−0.57	0.49	9.1	660
206165	102.3	+7.2	B2Ib	4.74	+0.30	−0.53	0.47	9.0	630
206183	98.9	+3.5	B0V	7.43	+0.13	−0.78	0.43	9.6	830
206267AB*	99.3	+3.7	O6(f)	5.86	+0.19	−0.60	0.51	10.2	1100
206267C	99.3	+3.7	B0V	8.04	+0.27	−0.77	0.57	9.8	910
206267D*	99.3	+3.7	B0V	8.03	+0.14	−0.68	0.44	10.2	1100
206327	102.0	+6.8	B2V	9.19	+0.18	−0.56	0.42	9.8	910
206773*	99.8	+3.6	B1:V:nne	6.90	+0.19	−0.72	0.5	8.1:	420:
206936*	100.6	+4.4	M2Ia	4.03	+2.38	+2.42	0.76	8.8	580
207017	103.2	+7.4	B2V	8.58	+0.18	−0.47	0.42	9.2	690
207198*	103°1	+7°0	O9.5II	5.94	+0.31	−0.64	0.61	10.0	1000
207260	102.3	+6.0	A2Ia	4.29	+0.51	+0.12	0.46	10.4	1200
207308	103.1	+6.8	B1Vn	7.49	+0.24	−0.55	0.50	8.7	550
207538	101.6	+4.7	B0V	7.31	+0.34	−0.64	0.64	8.9	600
207951	103.5	+6.1	B2V	8.18	+0.14	−0.57	0.38	8.9	600
208095A*	99.9	+1.3	B8V	5.71	−0.14	−0.45	0.00	5.8	140
208095B*	99.9	+1.3	A0p	6.68	−0.04	−0.22	----	---	---
208106	103.4	+6.1	B3V	7.56	+0.13	−0.52	0.33	8.1	420
208185A	104.2	+7.0	B2V	7.38	+0.11	−0.53	0.35	8.2	440
208185B*	104.2	+7.0	B3V	----	----	----	----	---	---
208218	104.0	+6.6	B1III-II	6.64	+0.23	−0.49	0.48	10.3	1150
208266	102.7	+5.0	B1V	8.12	+0.26	−0.51	0.52	9.3	720
208392*	104.0	+6.5	B1Vn	7.02	+0.26	−0.56	0.52	9.0	630
208440	104.0	+6.4	B1V	7.90	+0.08	−0.73	0.34	9.6	830
208501	100.4	+1.7	B8Ib	5.79	+0.74	−0.03	0.76	9.1	660
208761	104.7	+6.8	B3V	(9.0)	(+0.2)	----	0.4	9.3:	720:
208816*	104.9	+7.2	B2?pe + M2epIb	4.95	+1.85	+0.44	0.4:	8.8:	580:
208905	103.5	+5.2	B1V	6.99	+0.09	−0.74	0.35	8.6	520
209339	104.6	+5.9	B0IV	6.66	+0.07	−0.83	0.37	10.0	1000
209454	104.1	+5.2	B2V	7.76	+0.17	−0.65	0.41	8.4	480
209481*	102.0	+2.2	O9V	5.51	+0.07	−0.88	0.38	9.1	660
209744	103.3	+3.5	B1V	6.73	+0.22	−0.64	0.48	8.0	400
209975	104.9	+5.4	O9.5Ib	5.11	+0.08	−0.86	0.35	10.1	1050
210839	103.8	+2.6	O6f	5.04	+0.24	−0.73	0.56	8.5	500
239581	95.3	+5.6	B2V	7.93	+0.39	−0.38	0.63	7.9	380
239595	98.5	+8.0	(B2v)	8.87	+0.15	−0.60	0.39	9.6:	830:
239618*	98°6	+7°6	B2Ve	8.45	+0.50	−0.42	0.74	8.1	420
239626	99.1	+7.5	B0V	9.29	+0.35	−0.57	0.65	10.8	1450
239644	97.0	+4.6	(B2v)	9.38	+0.39	−0.37	0.63	9.4:	760:
239649	99.5	+6.8	(B1v)	9.31	+0.19	−0.49	0.45	10.7:	1380:
239671	97.3	+3.9	B2V	(9.2)	(+0.2)	----	0.4	9.9:	950:
239675	99.7	+6.6	(B3v)	9.16	+0.30	−0.25	0.50	9.2:	690:
239676	99.4	+6.1	(B1v)	9.06	+0.52	−0.38	0.78	9.4:	760:
239681	100.2	+6.7	(B1v)	9.34	+0.27	−0.60	0.53	10.5:	1260:
239683	98.6	+4.8	(B2v)	9.32	+0.30	−0.43	0.54	9.6:	830:
239689	98.3	+4.3	(B1v)	8.83	+0.19	−0.62	0.45	10.2:	1100:
239693	98.8	+4.7	(B3v)	9.54	+0.23	−0.41	0.43	9.8:	910:
239710	99.1	+4.0	B3V	(10.0)	(+0.4)	----	0.6	9.7:	870:
239712*	99.5	+4.5	B2Vnne	8.65	+0.41	−0.27	0.65	8.6	530
239724*	99.2	+3.7	B1III	9.14	+0.37	−0.49	0.63	12.5	3200
239725	99.0	+3.4	B2V	9.15	+0.26	−0.46	0.50	9.6	830
239727*	99.2	+3.6	A2Ia	(9.3)	(+1.1)	----	1.0	13.8:	5800:
239729	99.3	+3.8	B0V	8.35	+0.36	−0.54	0.66	9.9	950
239742	99.4	+3.1	(B1v)	9.41	+0.20	−0.56	0.46	10.7:	1380:
239743	101.5	+5.6	B2V	9.01	+0.59	−0.15	0.83	8.4	480
239748	100.3	+4.0	(B1v)	8.75	+0.17	−0.66	0.43	10.2:	1100:
239758*	100.9	+4.5	B2Vn(e)	9.53	+0.25	−0.54	0.49	10.0	1000
239767*	99.7	+2.7	B0.5V	9.21	+0.69	−0.31	0.97	10.3	1150
239789	101.3	+3.6	(B1v)	9.28	+0.42	−0.35	0.68	9.9:	950:
+61°2213*	103.9	+6.5	B3V + B5V	8.98	+0.18	−0.45	0.38	9.9	950
+61°2214	103.9	+6.5	B3V	9.85	+0.23	−0.35	0.43	10.1	1050
+61°2215	104.0	+6.5	B3V	9.34	+0.19	−0.49	0.39	9.7	870
+61°2218*	104.0	+6.5	B3V	10.03	+0.14	−0.51	0.34	10.5	1260

NOTES TO TABLE 1

198895: Hβ shows moderately broad emission on broad, shallow absorption. Hγ appears weak (filled in by emission); Hδ is slightly weak.

203025: Hβ appears weak (slightly filled in) with indications of weak, sharp emission in the line center. Hγ is slightly weak. Tentative eclipsing binary according to Hill (1967). Spectroscopic binary. Adopted $M_V = -2.7$.

203338: The spectral type of the B star was estimated from the appearance of the H-lines A strong emission line appears at about λ4240. The combined intrinsic UBV values are $M_V = -4.7$, $(B - V)_0 = +1.1$, $(U - B)_0 = -0.3$. The color excess $E(U - B) = +0 4$ instead of the expected value $0.7 \times E(B - V) = +0.3$, but it is close enough to be regarded as confirming the spectral types.

203374: The absorption lines are very broad, and sharp emission appears in the H-lines from Hβ to H9.

204116: Hβ appears broad, very weak (filled in) with trace of central emission. Hγ is broad, slightly weak, with an indication of central emission displaced toward the red. Although the other lines indicate B1 V, the Si II doublet $\lambda\lambda$4128–4130 is enhanced and appears more as in types B3 V–B5 V.

206267AB: Slight emission appears at the red edge of He II λ4686 and also at about $\lambda\lambda$4550 and 4630. Spectroscopic binary. Adopted $M_V = -5.9$.

296267D: Although the general appearance indicates B0 V, on one plate some B1 V characteristics were seen.

206773: The absorption lines are extremely broad and diffuse. Emission appears in the H-lines from Hβ to Hϵ; it is broad and double in Hβ (violet component stronger) and in Hγ (equally strong components).

206936: μ Cep. Observed at J.D. 2439386.7. See § III*a*.

207198: Peculiar emission appears at about λ4960.

208095: ADS 15405. This visual binary was observed because of its erroneous HD type. It comprises an apparently normal B8 V star and an A0p Si-Sr star with the following peculiarities: (i) Si II $\lambda\lambda$4128–4130 are stronger than Ca II K; (ii) Si II $\lambda\lambda$3856, 3863, and Sr II λ4077 are present; (iii) Mg II λ4481 is very weak; (iv) Fe II λ4233 is present; (v) the H-lines are only moderately strong and resemble those in class III. Comparison with the B8 V star gives $M_V = +0.7$ for the peculiar star.

208185: Unresolved in photometer.

208392: EM Cep. Eclipsing binary of 20-hour period. Adopted $M_V = -3 5$.

208816: VV Cep. The peculiarities of this system are well known. Although the absorption features of the B-type shell star are all blended with the M star, there are some indications that the type is later than B0 and earlier than B5. Since the intrinsic $B - V$ is not known, the color excess was taken as the mean of those of other stars in the same direction: HD 208185, HD 209339, and HD 209975. Adopted $M_V = -5.0$.

209481: Spectroscopic binary. Adopted $M_V = -4.7$.

239618: The absorption lines are moderately broad with superimposed narrow emission in the H-lines from Hβ (strong) to H9 (weak). Fe II λ4233 also appears in emission.

239712: The absorption lines are very broad, and emission is superimposed at Hβ (narrow, weak), Hγ (very weak), and Hδ (trace).

239724: The star appears to be slightly brighter than o Persei (B1 III) with respect to Si III $\lambda\lambda$4552, 4568, and 4574, and the blend at λ4650.

239727: The spectrum resembles that of ν Cep (HD 207260) almost exactly, except that Ca II H and K are slightly stronger, probably because of interstellar components.

239758: The absorption lines are broad, with traces of central emission in Hβ and Hγ (displaced toward the red). There are some indications of class III.

239767: Eclipsing binary AI Cephei. Adopted $M_V = -3.9$.

+61°2213: Three spectrograms showed this star to be a double-line binary. The Julian dates of the observations and the observed radial velocity differences in the sense v(brighter) $-$ v(fainter) were: J.D. 2439375.78, -235 km sec^{-1}; J.D. 2439379.86, 0 km sec^{-1}; J.D. 2439380.71, -210 km sec^{-1}. Hill (1967) found tentative indications of eclipses. Adopted $M_V = -2.1$.

+61°2218: The absorption lines are sharp, and the helium lines appear slightly weak, although not quite enough to warrant designating the spectrum peculiar.

b) The Uncertainties in the Photometric Distances

The standard deviation of the distance modulus, $\sigma(\rho)$, is given by the equation

$$\sigma(\rho) = [\sigma(V)^2 + R^2\sigma(B - V)^2 + R^2\sigma(B - V)_0{}^2 + E(B - V)^2\sigma(R)^2 + \sigma(M_V)^2]^{1/2}\,.$$

The observational errors are estimated to be $\sigma(V) \approx 0.05$ mag, $\sigma(B - V) \approx 0.05$ mag. The error in $(B - V)_0$ is estimated to be $\sigma(B - V)_0 \approx 0.03$ mag. According to Sharpless (1963), $\sigma(R) \approx 0.3$. The last term on the right-hand side depends on the errors in the spectral classification and the luminosity calibration of the MK system (including the "cosmic dispersion"). A value appropriate to the early spectral types appears to be $\sigma(M_V) \approx 0.5$ mag. The average value of $E(B-V)^2$ in Table 1 is 0.30 mag. Substituting the values into the above equation, we find $\sigma(\rho) = 0.56$ mag.

c) Clusters

The distance modulus of Trumpler 37 was found to be 9.6 ± 0.2 (s.e. in the mean) mag from observations of the following stars: HD 205948, HD 206183, HD 206267, HDE 239712, HDE 239725, and HDE 239729. Other stars in Table 1 that may be members of the cluster are HD 206773, HDE 239683, HDE 239710, and possibly HDE 239767 (AI Cephei). The author's (1967) Schmidt survey indicates that in the region

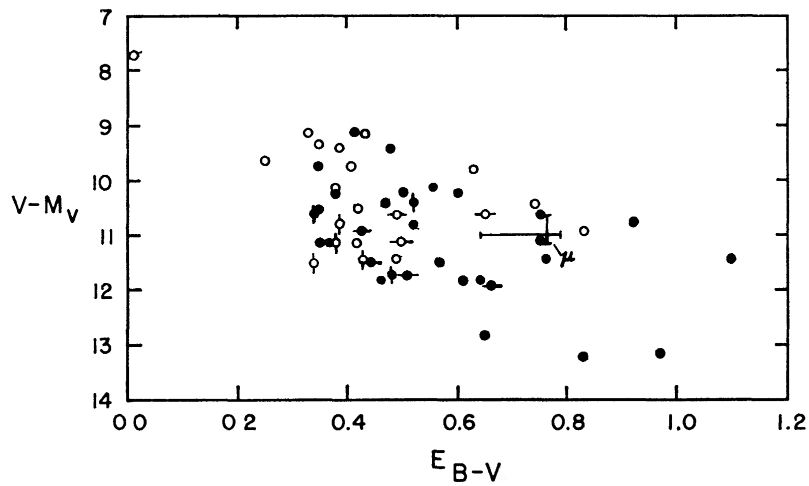

FIG. 1 —Plot of apparent distance modulus against color excess for stars observed in Cepheus. *Open circles*, stars of $M_V > -2.5$; *filled circles*, stars of $M_V < -2.5$. Stars in Trumpler 37 are marked with horizontal bars; stars in NGC 7160 are marked with vertical bars. The range of variation of μ Cep is indicated.

covered by IC 1396 there are six B0 V stars, twenty-four B1 V–B2 V stars, and thirty-seven B3 V–B5 V stars with distance moduli appropriate to Trumpler 37. The two distant stars, HDE 239724 and HDE 239727, are seen right through the center of IC 1396, but instead of belonging to the cluster, they are found about 350 pc above the Perseus spiral arm.

Spectrograms were taken of the seven brightest stars in NGC 7160 listed by Hoag *et al.* (1961): HD 208218, HD 208392 (EM Cep), HD 208440, BD+61°2213, BD+61°2215, BD+61°2214, and BD+61°2218. The *UBV* measurements of these stars were made at a large hour angle at the end of the last night of observations, and the extinction corrections are less certain than for the other observations. Excluding the eclipsing binary, HD 208392, the magnitude and color differences in the sense of (Simonson − Hoag *et al.*) (1961) were $\Delta V = +0.047 \pm 0.002$ (s.e.) mag, $\Delta(B-V) = -0.001 \pm 0.003$ (s.e.) mag, and $\Delta(U-B) = +0.063 \pm 0.010$ (s.e.) mag. Corrections were applied to eliminate these differences in the mean. These observations give a mean distance modulus for NGC 7160 of 9.9 ± 0.2 (s.e.) mag, but it should be noted that the absolute magnitudes of four of the seven stars are uncertain.

IV. DISTRIBUTION OF O AND B STARS

Figure 2 shows the distribution on the sky of the early-type stars with $M_V < -2.5$ (i.e., brighter than B2 V) in the region around Cepheus OB2. Stars of lower luminosity were excluded in order to reduce selection effects. Outside the region of the present investigation, distance moduli were taken from Harris (1955), Hiltner (1956), Petrie and Lee (1966), and Walker and Hodge (1966). For homogeneity, MK luminosities were taken in preference to Hγ luminosities where available, and the luminosity calibration of § II was used. Only the stars with both MK spectral types and *UBV* photometry were considered in the region covered by the present investigation. The boundary of the Cepheus OB2 stars listed by Morgan *et al.* (1953) is indicated by a solid line.

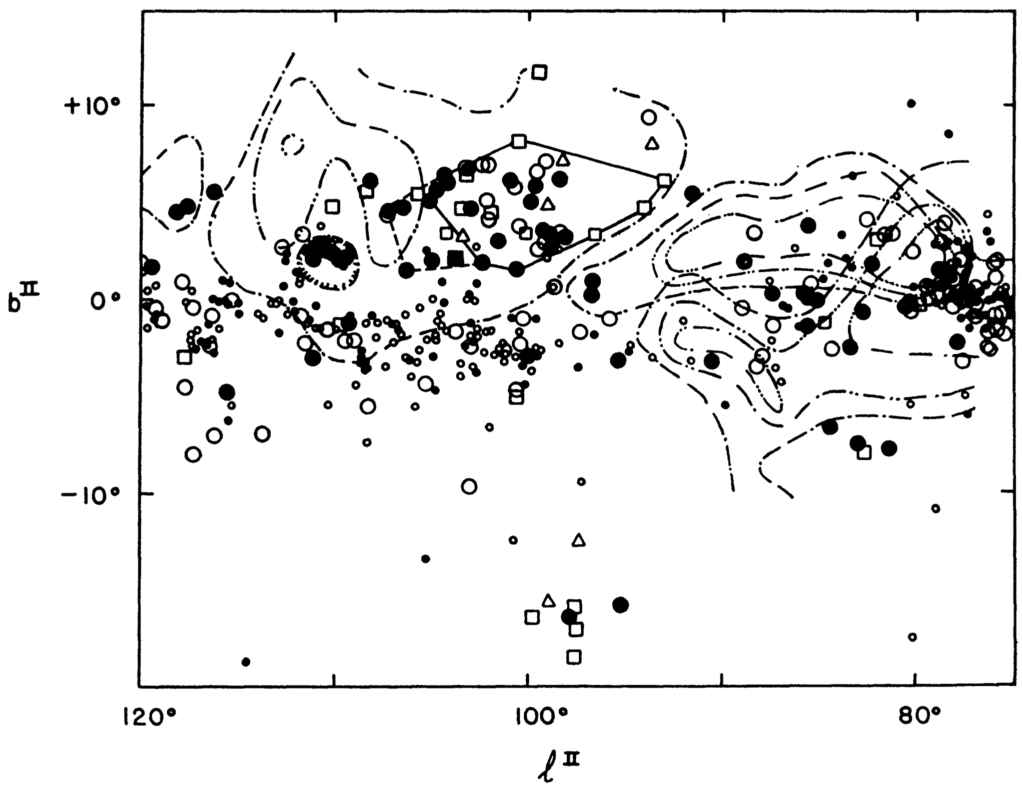

FIG. 2.—Distribution of luminous early-type stars and neutral hydrogen near Cepheus OB2. Distance moduli are indicated by △ for $7.1 < \rho \leq 8.0$, □ for $8.1 < \rho \leq 9.0$, ● for $9.1 < \rho \leq 10.0$, ○ for $10.1 < \rho \leq 11.0$, • for $11.1 < \rho \leq 12.0$, and ∘ for $\rho > 12.0$. Contours of optical depth in H I are indicated by —·— for $\tau = 1.2$, — ·— for $\tau = 1.6$, and —...— for $\tau = 2.0$.

The concentration in the direction of Cepheus OB2 is most pronounced for stars with distance moduli between 8.4 and 10.8 mag. Stars with distance moduli less than 8.3 mag are distributed over a large region from $l^{II} = 92°$ to $110°$, $b^{II} = 0°$ to $+12°$. The stars with distance moduli between 8.4 and 10.8 mag have a mean distance modulus of 9.5 mag and are concentrated in the region between $l^{II} = 98°$ and $107°$, $b^{II} = +2°$ and $+8°$. The lower longitude limit of this concentration is quite abrupt. Although Lynds (1962) has found strong absorption in the region between $l^{II} = 90°$ and $96°$, the author's (1967) Schmidt survey to a limiting magnitude $B = 11.5$ suggests that the limit is a real feature of the distribution of intrinsically bright early-type stars. Toward higher longitudes, the concentration extends toward Cepheus OB3 at $l^{II} = 110°$, $b^{II} = +3°$. The extension is indicated by a dashed line in Figure 2, and the stars within this region are listed in Table 2.

Although the concentration on the sky of the stars with distance moduli between 8.4 and 10.8 mag seems significant, the dispersion in the distance moduli is substantial. It amounts to ± 0.69 mag. In view of the size of the estimated standard deviation in the measured distance moduli, $\sigma(\rho) = 0.56$ mag, it seems appropriate to consider the possibility that the stars are actually in a small volume and that the dispersion arises from the observational errors. The χ^2 test shows that this hypothesis may be rejected with small probability of error unless $\sigma(\rho)$ has been seriously underestimated and actually amounts to about 0.7 mag. On the other hand, the mean distance modulus of the stars of luminosity classes I and II is 9.8 mag, and the χ^2 test shows that rejecting the hypothesis that all these stars are at this distance involves a probability of error of more than 20 per cent. It is not known to what extent this result is influenced by the possible inclusion of these stars in the calibration of MK luminosities. The distribution of intrinsically fainter stars of types B2 V and B3 V cannot be reliably included in the discussion owing to the magnitude limits of the catalogues from which these stars were selected.

TABLE 2

ADDITIONAL PROBABLE MEMBERS OF CEPHEUS OB2

HD/BD	Spectrum	M_V	ρ (mag)	Source*	HD/BD	Spectrum	M_V	ρ (mag)	Source*
205329. ..	B4	−3 1	9 4	1	213757 . .	B5	−3 1	9 5	1
205686.....	B1 5	−2 9	10 1	1	239989... .	B4	−2 5	9 9	1
207872.	B3	−3 4	10 5	1	+62°2078..	O7	−4 8	10 4	2
210386	B1	−2 8	9 0	1	+60°2405 ..	B3nn (V?)	−1 5	9 2	2
210478 .	B1 V	−2 7	9 0	2	No. 1100†..	B2 V	−1 9	10 1	2
211880 . .	B0 5 V	−3 2	8 8	2	No. 1117†..	B3 V	−1.5	9 7	2
211971.. .	A2 Ib	−5 0	9 1	2	No. 1124†..	B3 Vn	−1.5	9.2	2
213023	B3	−3 6	9 1	1					

* 1 = Petrie and Lee (1966); 2 = Hiltner (1956).
† Numbers from Hiltner (1956).

Using the data in the catalogue of Wilson (1953) and the list of Petrie and Pearce (1962), the mean radial velocity of the early-type stars of $M_V < -2.5$ except the "runaway star," λ Cep, is found to be -16.0 km sec^{-1} with dispersion ± 6.3 km sec^{-1}. There appear to be no significant differences in radial velocity among any groupings that can be made according to distance modulus, owing in part to the size of the standard errors in the radial velocities. The mean radial velocity is 1.2 km sec^{-1} less than that predicted by the theory of galactic rotation (Schmidt 1965) for distance modulus 9.5 mag, after correcting for the Sun's peculiar motion (Delhaye 1965).

The radial velocity of μ Cep is $+19.3$ km sec^{-1} (Wilson 1953); it differs by 35.3 km sec^{-1} from that of the early-type stars in this direction. On the basis of this difference, there seems to be good reason to regard μ Cep as not belonging to Cepheus OB2. On the other hand, the two M-type supergiants with B-type components, VV Cep and HD 203338, have radial velocities close to the mean for the early-type stars, and there seems to be no reason to exclude them.

Figure 2 shows contours of optical depth in the 21-cm line of neutral hydrogen that have been adapted from Lindblad (1966). The neutral hydrogen with radial velocity within 20 km sec^{-1} of the local standard of rest is shown (i.e., the neutral hydrogen of the local spiral arm). The minimum at the position of Cepheus OB3 seems to be a result of the reduction procedure. The contour at optical depth 1.2 incloses both Cepheus OB2 and Cepheus OB3, and the neutral hydrogen inclosed by this contour is separated in velocity from other concentrations at higher and lower longitudes. The mean radial velocity of the neutral-hydrogen concentration is very nearly the same as that of the early-type stars. Dieter (1960) found a similar result. Using the spin temperature of

135° K that Lindblad assumed, and using the distance of about 800 pc obtained for the stars, the excess of neutral hydrogen in the region of the associations is about 1.5×10^5 $\mathfrak{M}_\odot$. Over the same region, the "background" neutral hydrogen of the local spiral arm at optical depth less than 1.2 amounts to about 10^6 $\mathfrak{M}_\odot$.

V. CONCLUSION

Cepheus OB2 is considered to comprise the stars listed in Table 1 with distance moduli between 8.4 and 10.8 mag (except μ Cep) and the stars from other observers listed in Table 2. The mean distance modulus of the stars with $M_V < -2.5$ is 9.5 mag, very nearly the same as that of NGC 7160 (based on separate data [Hoag 1966]) and Trumpler 37. If the stars are distributed in depth to the same extent as in the projected dimensions, they lie at distances of 750–900 pc, but the dispersion in their distance moduli suggests that they are spread over the range from 590 to 1100 pc.

The H-R diagram for the stars that are regarded as members of the association is given in Figure 3. The author's (1967) Schmidt survey indicates that altogether the group

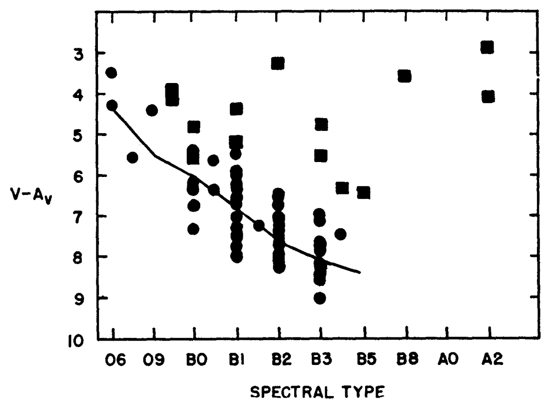

FIG. 3.—H-R diagram for Cepheus OB2. *Circles*, main-sequence stars; *squares*, evolved stars. Weaver and Ebert's (1964) main sequence is shown for distance modulus 9.5 mag.

contains seventeen stars of types OB and B or A supergiants, thirty-seven stars of types O9 V and B0 V, and 164 stars of types B1 V and B2 V. The integrated absolute magnitude is about $M_V = -9.7$, and the stellar mass is about 4×10^3 $\mathfrak{M}_\odot$.

Cepheus OB2 is probably connected with Cepheus OB3, since the distance modulus of Cepheus OB3 is also 9.5 mag (based on the data of Blaauw, Hiltner, and Johnson 1959, with the luminosity calibration of § II), the distribution of stars in Cepheus OB2 extends toward Cepheus OB3, and the concentration of neutral hydrogen surrounds both associations.

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