RADIAL VELOCITIES OF DISTANT OB STARS

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ABSTRACT

The results of radial-velocity measurements for twenty-seven faint OB stars at galactic longitudes between $l^{II} = 18°$ and $l^{II} = 66°$ are presented. On the basis of spectroscopic absolute magnitudes in the Yerkes system and *UBV* photometry, the rotational velocities of the stars around the galactic center have been derived. In comparison with the rotational curve indicated by the interstellar neutral hydrogen, the stellar motions suggest rotational velocities lower by about 25 km/sec at distances from the center around half that of the Sun. The general shape of the rotation-curve provided by the new stellar observations remains thus the same as it was found in our previous study.

I. INTRODUCTION

In an earlier paper (Münch and Münch 1960) we presented an attempt to derive the rotational velocity of the galactic system from the radial motions of distant OB stars. Our results suggested some departures from the rotational curve of the galaxy obtained from observations of the 21-cm emission line of interstellar hydrogen, but because the number of stars involved in our analysis was small, our conclusions were quite uncertain. In order to study the question further we have observed additional stars in the same general directions where the objects discussed earlier were located.

II. THE OBSERVATIONS

Although extensive finding lists for OB stars have been published, we thought that a new inspection of objective prism material would not be superfluous, since for our purpose the criteria defining OB stars could be somewhat relaxed. Accordingly, the spectral plates in the files of the Tonanzintla Observatory, covering the regions of our concern, were examined by one of the writers (L. M.) and, disregarding earlier classifications (Iriarte and Chavira 1954), all possible candidates for OB stars were marked. A few fields covered with plates of definition below average were photographed anew with the 24–31-inch Schmidt prismatic camera of the Tonanzintla Observatory. As expected, most of the OB stars thus found had already been classified in earlier surveys (Iriarte and Chavira 1954), but a few new ones were also included. Through this procedure, a preliminary list of about forty stars was prepared for observation of accurate spectral-luminosity classes and photoelectric colors. The spectral types were determined in plates taken with the Newtonian grating spectrograph of the 100-inch reflector at Mount Wilson in a dispersion of 85 Å/mm. A number of main-sequence O-type stars and peculiar stars of low luminosity were discarded on basis of these plates. Next, the *UBV* magnitudes of the remaining stars were measured with the Mount Wilson 60-inch telescope. A minimum of two determinations, on different nights, was secured for each star in reference to the standards of the system. The photometric results are given in Table 1, together with the spectral-luminosity classes in the Yerkes system. The interstellar extinction correction has been applied by assuming a constant relation $A_v = 3\,E(B-V)$ between color excess and total absorption, adopting for the intrinsic colors of the supergiants the relation to spectral type determined by Wildey (1962) in the h and χ Persei association. The $U - B$ colors were thus disregarded, in view of their possible departures from a constant reddening law and also the lower observational accuracy of the *U* deflections.

The radial velocities were measured in spectrograms obtained with a variety of instruments. Dispersions of 20, 40, and 80 Å/mm were employed, denoted respectively by the letters *d*, *e*, and *f*, appearing in Table 2 following the designations *P*, *C*, or *X* given to plates taken with the Palomar coudé, the Mount Wilson 100-inch coudé, or the 60-inch Cassegrain spectrographs. By assigning to the individual radial velocities weights ranging from 1 to 4, the mean radial velocities and their probable errors have been derived. In Table 2 we have included also unpublished radial-velocity measurements for a few stars discussed in our earlier paper (Münch and Münch 1960), which have been combined with the earlier measures to form a new mean value. The probable errors derived from

TABLE 1

DISTANT OB STARS IN DIRECTIONS 18° < $l^{\rm II}$ < 66°

HD or BD	*l*	*b*	Sp	*V**	*B*−*V*	*V*−*B*	*m*−*M*	V_0 (km/sec)	*R* (kpc)	Θ (km/sec)
170700	18°1	−1°2	B1 II	....	....	....	12.7†	23 B	6.90	223
170716	19.7	−1.2	B0.5 Ib	9.47 H	+0.42	−0.57	13.2	44 A	6.13	234
−12°5166	20.1	−1.8	B0.5 I	9.81 H	+0.70	− .37	13.4	53 B	5.73	231
−9°4805	23.8	−2.5	O9 Ie	9.28	+0.83	− .23	12.8	58 C	6.86	271
173783	25.1	−5.2	O9 I	....	....	....	12.4†	....	7.40	294
−6°4834	25.6	−0.8	B3 Ib	10.97	+0.50	− .18	14.7	51 B	4.38	161
OB−7°23‡	25.9	−1.7	B6 II	10.23	+0.30	− .37	13.3	24 C	6.12	187
−6°4825	26.0	−0.2	A0 II–III	10.23	+0.81	+ .09	10.7	22 D	8.76	262
−6°4837	26.0	−1.0	B1.5 Ib	9.81	+0.34	− .53	13.9	56 D	5.24	198
−6°4842	26.1	−1.2	B7 II	10.65	+0.19	− .42	14.2	20 D	4.87	143
−7°4686	26.1	−1.7	B5 II	10.31	+0.20	− .55	13.9	65 D	5.31	211
−6°4855	26.4	−1.3	B8 II	10.16	+0.07	− .63	13.9	65 C	5.34	211
173987	26.9	−2.3	B0.5 Ib	....	....	....	13.4†	82 B	5.08	219
−6°4903	26.9	−2.0	O9 I	9.97	+0.27	− .74	14.1	54 C	5.08	136
−6°4891	27.0	−1.7	B3 II:n	10.53	+0.40	− .52	13.6	62 C	4.58	177
OB−5°26§	27.5	−1.1	B1.5 II	11.10	+0.44	− .51	14.1	63 B	5.15	199
173438	28.2	−0.8	B0.5 Ia	8.23 H	+0.80	− .26	11.9	46 A	7.97	277
+2°3771	37.2	−1.4	B0 III	9.21 H	+0.63	− .39	11.4	39 C	8.57	270
177812	37.6	−1.8	B1 Ib	8.60 H	+0.63	− .36	11.7	53 B	8.37	282
178129	37.8	−1.9	B1 Ib	7.41 H	+0.50	− .35	12.2	48 B	8.04	265
+11°3707	44.2	+2.7	B1 Ia:	10.57 H	+1.04	− .10	13.6	20 B	7.24	202
+8°4122	45.0	−4.8	B1 Ib	9.86 H	+0.25	− .67	14.1	57 A	5.81	235
+10°3872	45.9	−1.7	B5 Ib	10.41	+0.88	+ .08	13.2	22 C	7.62	214
+14°3763	47.6	+4.0	B1 Ib	10.67	+0.56	− .45	14.1	50 B	7.39	234
+12°3927‖	48.4	−2.5	B1 Ib	10.24 H	+0.79	− .25	12.9	78 B	8.00	283
+11°3946	49.4	−4.8	B0 Ib	9.36 H	+0.12	− .78	14.1	67 A	7.59	257
+13°4091	50.9	−4.1	B1 Iab	10.55	+0.43	− .55	14.6	−67 A	8.01	....
+22°3781	58.5	−0.7	B0 IV	9.75 H	+0.43	− .55	12.2	29 B	8.86	252
+23°3745	59.5	0.0	B0.5 Ib	8.73 H	+0.66	− .38	11.7	20 C	9.08	248
+23°3747	59.5	−0.1	B1 III	10.37 H	+0.61	− .39	12.2	28 C	8.91	252
+27°3513	63.9	+1.5	A2 Ia	8.31 H	+0.39	+ .01	14.2	24 B	8.07	247
OB+27°89#	64.7	+0.6	B0.5 Ib	9.99	+0.82	− .22	12.7	37 A	9.08	264
+27°3550	65.0	+0.3	A2 Iab	8.94	+0.98	+ .30	12.7	17 A	9.09	244
+28°3487	65.2	+0.6	B2 Ib	10.19 H	+0.51	− .40	13.6	23 A	9.14	252
+29°3774	65.5	+1.4	B2 Ib	9.95	+0.57	− .36	13.3	15 B	9.11	243
OB+28°100**	65.9	−0.2	B0.5 Ib	10.46	+0.81	−0.26	13.1	16 B	9.13	244

* The photometry of entries followed by "H" is taken from Hiltner (1956).

† Distance moduli from Morgan, Whitford, and Code (1953).

‡ −7°23 precedes −7°4689 by 8ˢ, 1.0′ north.

§ −5°26 precedes −5°4745 by 30ˢ, 8.2′ north.

‖ +12°3927 incorrectly identified in Paper I as BD+12°3987.

+27°89 precedes +27°3539 by 8ˢ, 11.8′ north.

** +28°100 follows +28°3546 by 5ˢ, 5.1′ north.

the dispersion around the mean of several plates are often larger than the internal probable errors, raising again the suspicion that many supergiant B stars may have intrinsically non-periodic variable radial velocity. For some stars the range of variation found is so large that an average velocity is meaningless, and in Table 2 their radial velocities are just indicated as variable. A few stars deserve special comment, such as BD+13°4091, a pronounced supergiant with the large velocity of −84 km/sec. Obviously this is a "runaway" object, moving in a strongly non-circular orbit. The BD stars −9°4805 and −6°4903 appear to have high luminosity characteristics of type O9, and are similar to HD 173783 included in our earlier list, with the difference that −9°4805 shows Hβ in emission and is suspected of being variable in light.

TABLE 2

RADIAL VELOCITIES OF DISTANT OB STARS IN 18° < l^{II} < 66°

Star	Plate	V
HD 170700	Pd3987	+ 5.0
		+ 8.9±2.8
−9°4805	Cd14591	+ 40.4
	Xe6490	+ 28.5
	Xe6507	+ 53.1
		+ 43.9±6.0
−6°4834	Pd5849	+ 35.6
	Pd6087	+ 29.6
	Pe6119	+ 39.8
	Xf5761	+ 50.6
		+ 36.1±2.4
OB−7°23	Pd6102	+ 13.0
	Xe6578	+ 5.9
		+ 9.5±4.1
−6°4825	Xe6571	+ 6.9
−6°4837	Cd14593	+ 41.2
	Pe6117	+ 64.8
	Xf5759	+ 97.5
		Var
−6°4842	Pd6093	+ 4.7
	Pe6118	+103.2
	Xf5760	− 12.7
		Var
−7°4686	Pe6051	+ 50.1
−6°4855	Xe6648	+ 41.7
	Xf6606	+ 66.8
		+ 50.0±7.3
−6°4903	Cd14590	+ 47.5
	Pe6121	+ 33.0
	Xe6513	+ 26.9
		+ 38.6±6.5
−6°4891	Pe6116	+ 55.5
	Xe6581	+ 37.4
	Pd6086	+ 50.5
		+ 47.0±5.4
OB−5°26	Pe6126	+ 36.1
	Xe6517	+ 33.2
	Pd5848	+ 40.0
	Pd6111	+ 39.0
		+ 37.9±1.9
+2°3771	Pd3771	+ 23.3±2.5
HD 177812	Pd3984	+ 41.4
		+ 36.8±2.5
+11°3707	Pd3985	+ 3.7
	Pd3988	− 1.0
		+ 3.9±2.9
+10°3872	Pd6105	+ 5.5
	Xe6622	− 8.8
	Xe6624	+ 6.1
		+ 2.8±3.1
+14°3763	Cd14600	+ 29.2
	Pe6123	+ 26.6
	Pe6048	+ 31.5
	Pd6112	+ 33.8
	Pc6080	+ 37.2
		+ 32.8±2.8
+13°4091	Pe6049	− 87.0
	Pe6122	− 77.8
	Xe6621	− 79.9
	Pd6104	− 81.1
	Pd6095	− 92.5
		− 84.2±3.9
+22°3781	Pd3999	+ 13.5
	Pd4791	+ 11.5
		+ 12.5±4.1
+23°3745	Pd4000	+ 3.8
+23°3747	Pd4790	+ 12.1
+27°3513	Pc4019	+ 5.6
		+ 7.5±1.6
+27°3550	Pd6089	+ 0.2
	Pd6113	+ 1.2
	Pd6130	+ 0
	Xe6625	+ 4.8
		+ 1.1±1.8
+29°3774	Pe6052	− 1.7
	Pe6128	+ 13.5
	Pd6097	− 2.9
	Xe6587	+ 3.9
		− 1.1±2.6
OB+27°89	Pe6127	+ 22.1
	Xe6627	+ 14.2
	Cd14599	+ 22.5
	Xe6583	+ 27.0
	Pd6088	+ 19.0
		+ 20.9±2.1
+28°3487	Cd14597	+ 4.4
	Pd4008	+ 7.9
	Xe6574	+ 18.2
		+ 7.4±2.3
OB+28°100	Pe6124	+ 4.5
	Cd14594	− 4.3
	Xe6575	+ 8.9
	Pd6081	− 2.8
		+ 0.2±2.0

III. DISCUSSION

From the mean radial velocities given in Table 2, their values V_0 in the local standard of rest have been derived, adopting for the galactic components of solar motions the values

$$(\dot{x}_0, \dot{y}_0, \dot{z}_0) = (-10, +13, +6) \text{ km/sec}$$

obtained by Kraft and Schmidt (1963) from the motion of cepheids. This solar motion differs only slightly from the one adopted in our earlier paper, but for the sake of consistency, it was also applied to the stars discussed earlier and which are included in

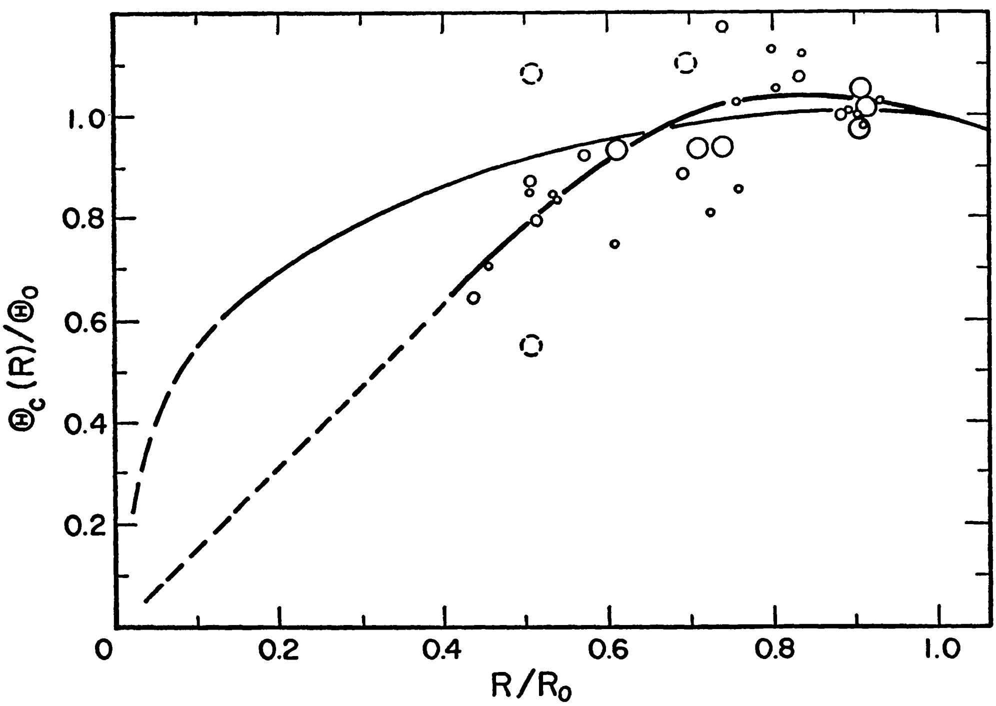

FIG. 1.—The rotational velocities of distant OB stars in galactic longitudes between 18° and 66°, compared with the circular velocities (*thin curve*) derived from 21-cm line observations. The stars are represented by circles with radii proportional to the weight of the radial velocities, and their general trend is represented by the thick curve.

Table 2. To a star in the galactic plane, at a distance R from the center and with vanishing peculiar motion, corresponds a circular velocity $\Theta_c(R)$ given by

$$\frac{\Theta_c(R)}{\Theta_0} = \frac{R}{R_0}\left(1 + \frac{V_0}{\Theta_0} \operatorname{cosec} l\right), \quad (1)$$

where Θ_0 is the circular velocity of the solar neighborhood and R_0 is its distance to the center. Following Kraft and Schmidt (1963) we have adopted the values $\Theta_0 = 250$ km/sec, and $R_0 = 10$ kpc. The resulting values of Θ_c are given in Table 1 and also are plotted in Figure 1 in units of Θ_0, as function of R/R_0. The symbols representing the various stars have been drawn in Figure 1 with sizes proportional to the weight of their radial velocities, but the main-sequence O-type stars included in our earlier paper have not been entered. The smooth curve best representing the general trend of the points has been drawn free-hand, subject only to the restriction that, at $R = R_0$, it has the slope

$$\left(\frac{d \ln \Theta_c}{d \ln R}\right)_{R=R_0} = 1 - 2\,\frac{AR_0}{\Theta_0} = -0.2\,, \quad (2)$$

obtained with $A = 15$ km/sec kpc (Kraft and Schmidt 1963). For comparison purposes, we have also drawn in Figure 1 the rotational curve Θ_H of the interstellar neutral hydrogen, which has been related to the hydrogen circular velocity $\Theta_H'(R)$ given by Kwee, Muller, and Westerhout (1954) for $R_0' = 8.2$ kpc and $\Theta_0' = 216$ km/sec, through the equation

$$\Theta_H(R) = \Theta_H'\left(R\frac{R_0'}{R_0}\right) + (\Theta_0 - \Theta_0')\frac{R}{R_0}. \tag{3}$$

In comparing the schematic trend of the stellar rotational velocities with the interstellar curve, it is noticed that the points with $R/R_0 \simeq 0.9$ are at very large distances from the Sun. Nevertheless they fall very near the values obtained from 21-cm line profiles, implying that the adopted spectroscopic parallaxes and velocities are not affected by systematic errors. Representative points of stars with $0.9 > R/R_0 > 0.55$ show considerable scatter around a mean curve, and do not significantly depart from the interstellar curve. Only the points with $R/R_0 < 0.55$ appear to show a systematic departure from the 21-cm values, as was suggested by our earlier results. The number of points at these distances is now considerably larger than before, however, but they give rotational velocities up to 50 km/sec lower than the circular velocities inferred from the motion of interstellar hydrogen. The origin of this discrepancy is difficult to account for. A curve without inflection joining the stellar circular velocities with the origin could not depart much from the straight line sketched in Figure 1, and would then resemble, for example, the rotational velocity-curve observed for the E7 system NGC 3115 (Humason 1937; Minkowski 1959). In this case, however, the difference between the measured rotational velocities and the circular velocities derived from the potential function obtained from the light distribution in the system can be explained by the large velocity dispersion and the radial gradient of the potential function (Oort 1939, 1959). This explanation cannot apply to the galactic system because the stars do not show a high-velocity dispersion. The question of the accuracy of the spectroscopic distance moduli for the stars has to be raised again. A change of about 1 mag. in the adopted absolute magnitudes would suffice to remove the discrepancy, although at present there is no basis to accept such a change. The possibility of verifying the zero points of the absolute magnitudes by observing a distant cluster in the directions with which we are concerned should be followed. Possible departures from the "standard" reddening-extinction law could also be studied by observing distant O stars in the near infrared, as Borgman and Johnson (1962) have done recently in other directions of the galactic plane. But the discrepancy between the rotational velocities of the stars and of the interstellar hydrogen for the time being remains unexplained.

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