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AXIAL ROTATION AND LINE BROADENING IN STARS OF SPECTRAL TYPES F0–K5*

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ABSTRACT

The widths of weak lines in 656 stars of spectral types F0–K5 on the revised Yerkes *Atlas* system of Morgan and Keenan have been obtained from plates having a dispersion of 11 A/mm. These line widths have been expressed in terms of $v \sin i$, the projected equatorial velocity required of a rotating, spherical, limb-darkened star in order to reproduce the observed broadening. It seems reasonable that axial rotation is the principal macroscopic broadening agent in those stars less luminous than supergiants, but this is not necessarily the case for the high-luminosity stars. The main conclusions of the paper are as follows: (1) The mean rotational velocity diminishes through class F, but $v \sin i$ values of 20 km/sec or greater can be found in types as late as F8 (in luminosity classes II, IV–V, and V) or G0 (in classes III and IV). With the exception of two binaries, no stars of type later than G5 have been found with rotationally broadened lines, and the widening in a few single stars of types G2–G5 is marginal. (2) For a given spectral type between F0 and G0, the stars of luminosity classes III and IV have much higher mean rotational velocities than do those of class V. (3) There is no significant difference in the rotational velocities of the weak- and strong-line groups of F- and G-type stars. (4) The luminosity class I*a* supergiants have considerably wider lines than do those of class I*b*.

I. INTRODUCTION

Most of our knowledge of the statistics of the rotational velocities of stars of spectral types F and later depends upon the work done by O. Struve and his colleagues at the Yerkes Observatory about 20 years ago and upon a recent contribution by Su-Shu Huang (1953). References to earlier work in the field will be found in the latter paper or in a review article by Struve (1945). Very briefly, the more extensive published studies of projected rotational velocities for stars of type F0 and later are the following: (1) Struve and C. T. Elvey (1931) estimated rotational velocities for 31 F0–K0 stars from the line widths on Yerkes spectrograms of dispersion 10 A/mm at λ 4500; (2) Miss C. Westgate (1934) measured the width of *Sr* II λ 4215 with a micrometer microscope on Yerkes plates of dispersion 30 A/mm at λ 4500 for 112 F-type stars and a limited number of later type; (3) Su-Shu Huang (1953) measured micrometrically the width of *Mg* II λ 4481 in 313 F-type and 10 G-type stars on plates of dispersions 10, 13, and 26 A/mm at λ 4481 selected from the Lick collection of spectrograms.

Although the present investigation is, for the F-type stars, based on much of the same plate material as was used by Huang, it differs from his study in several ways. First, the present line widths (expressed here as rotational velocities) were determined, not from micrometer measures of line width but from careful visual comparison with the spectra of standard stars. The projected rotational velocities of the standard stars were determined from their line profiles. Second, only those stars were examined for which assignments of spectral type and luminosity class were available on the revised *Atlas* system (MK) of W. W. Morgan and P. C. Keenan (Johnson and Morgan 1953). Huang's types were taken from *Pub. Lick Obs.*, Vol. **18**, 1932, and are either HD assignments or types given by the radial-velocity observers; no distinction was made with respect to luminosity. Third, in our investigation, only plates taken with the "New" Mills spectrograph, of dispersion 11 A/mm at λ 4500, were used; furthermore, a considerable number of new spectrograms were taken with this instrument of stars for which additional material seemed desirable. Fourth, the spectral interval covered was F0–K5. All known double-

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1955ApJ...121..118H

line spectroscopic binaries in which the lines of the two components were not clearly separated and most unresolved visual binaries with $\Delta m \backsim 0$ were rejected. A number of unresolved visual binaries with small Δm, for which it is unlikely that line doubling contributes to the line width, were retained and are indicated in the notes to Table 2.

A preliminary report on this investigation was given by Herbig and Spalding (1953) at the Santa Barbara, California, meeting of the Astronomical Society of the Pacific in June, 1953. Not long after that paper was read, we learned of a parallel study of axial rotation in stars of type A7–G0 in progress by A. Slettebak, of the Perkins Observatory (1953, 1954). We wish to acknowledge the kindness of Dr. Slettebak in sending us in advance of publication a copy of his paper on "Axial Rotation in the F-Type Stars," which he prepared for the meeting of the American Astronomical Society in Boulder, Colorado, in August, 1953. The results of these two independent investigations are in substantial agreement.

II. THE BASIC DATA: ROTATIONAL VELOCITIES AND SPECTRAL TYPES

The quantity actually observed in an investigation of this kind is the width of spectral lines. We have proceeded on the assumption that in the case of lines of *Fe* I, any broadening in excess of that observed in narrow-lined F- and G-type stars is due entirely to axial rotation in those stars less luminous than supergiants. Therefore, the results of the line-width estimates for individual stars (contained in Tables 1 and 2) are expressed as projected equatorial velocities of rotation, in kilometers per second. This assumption seems to be a reasonable one in the light of present knowledge, but we cannot furnish assurance that it is entirely correct.

In order to set up a system of comparison stars of known apparent rotational velocity, it was first assumed that narrow, unblended *Fe* I lines, as observed on Mills 11 A/mm plates of the solar spectrum, contain in their profiles the effect of intrinsic line width in stars of that type, as well as the contribution of the finite resolution of the spectrograph. The lines chosen for profile determination were λ 4472.7 and λ 4476.0, both due mainly to *Fe* I. They were selected on the basis of their relative narrowness and their location in a spectral region where the position of the continuous spectrum is well defined on microphotometer tracings. In addition, *Fe* I λ 4404.8 was used for comparison with those stars in which large broadening rendered λ 4472 and λ 4476 excessively shallow and difficult to use.

The standards consisted of five stars of spectral types F5–G0, plus the sun, which were chosen after a preliminary survey of the plate material showed that they defined a wide range of line width without gaps that could not be spanned by visual interpolation. New spectrograms of photometric quality were obtained for the sun and for these standard stars with the Mills spectrograph. The slit-width projected on the plate was 19 μ, which corresponds to 14 km/sec at λ 4500. The spectra were uniformly broadened by drifting to a width of 0.3–0.5 mm. Kodak II*a*-O plates were used throughout. The plates were traced in the modified Moll microphotometer of the Lick Observatory with a magnification of 424 times, and profiles were derived from a tube-sensitometer calibration in the usual manner. The differences in spectral type between some of the standard stars and the sun made it necessary to normalize the profiles in the stars of earliest type, in order that the increase in strength of the *Fe* I lines with spectral type should not confuse the determination of $v \sin i$. The profiles of the lines in the standard stars were then compared with sets of solar profiles as blurred by varying amounts of axial rotation. The method was the graphical one described by A. Unsöld (1938). A limb-darkening coefficient of $u = 0.6$ was used. The value of $v \sin i$ (the projected equatorial velocity of axial rotation) was adopted that yielded the best fit between the computed and the observed line profiles. The adopted values of $v \sin i$, rounded off to the nearest 5 km/sec for the stars with very broad lines, and other relevant data are given in Table 1.

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1955ApJ...121..118H

Several spectrograms of different densities and slit widths were available for each standard star. With these at hand for ready reference, a survey of the entire collection of Mills spectrograms of stars with MK types between F0 and K5 was made with a hand magnifier. All stars having perceptibly wider lines than the sun were reserved for later examination. The second examination consisted of a careful comparison on a Hartmann spectrocomparator of the best spectrograms of each wide-lined star with those plates of the standard stars having the most comparable density and slit-width. It was necessary to exercise considerable judgment in the estimates of line width, on account of the large range in plate quality. Many of the older Mills spectrograms of fainter stars were taken with a slit-width of 38 μ (or 28 km/sec at λ 4500), which made them of limited value for the detection of small rotational velocities. The slit-width, therefore, had always to be taken into account in the assignment of $v \sin i$. The results for stars of luminosity classes II through V are contained in Table 2*a*. Because of the different character of the line broadening in supergiants, the data for the high-luminosity stars are given separately in Table 2*b*.

TABLE 1

ROTATIONAL VELOCITIES OF STANDARD STARS

Star	α_{1900}	δ_{1900}	MK Spectral Type	Adopted $v \sin i$ (Km/Sec)	Lines Used in Determination of $v \sin i$ (λ)	No. of Spectrograms
Sun*	....	....	G2 V	<15†	....	4
π^3 Ori	4^h44^m4	+ 6°47′	F6 V	21	4472,4476	3‡
11 Aql	18 54.5	+13 29	F8 IV	27	4472,4476	2
ρ And	0 15.8	+37 25	F5 IV	45	4472,4476	2
31 Com	12 46.8	+28 05	G0 III	85	4404,4476	2
18 Com	12 24.4	+24 40	F5 IV	115	4404,4476	2

* The sunlit sky and the moon were actually observed.

† Assumed.

‡ λ 4476 was utilized on all three plates of π^3 Ori, but λ 4472 on only one.

We believe that our estimates of $v \sin i$ are likely to be most uncertain, percentagewise, for those narrow-lined stars in which allowance for poor plate quality had to be made. The entries in the $v \sin i$ column of Tables 2*a* and 2*b* for narrow-lined stars are based on the following conventions. First, a star for which a plate or plates of good quality (i.e., narrow slit and proper exposure) were available and which exhibited weak absorption lines that were fully as sharp as those in the sun was assigned a $v \sin i$ of $<$ 15 km/sec. For the best spectrograms, this value is probably too high a limit. Second, a star for which only poor plates were available but still showed no clear evidence of intrinsic line broadening was given a $v \sin i$ of $<$ 20: km/sec. Third, those stars for which the plate quality was so low that a rotational velocity of 25 or even 30 km/sec would have been concealed were rejected. The choice between the second and third categories was sometimes difficult to make, and, although we have attempted always to err on the conservative side, it is not impossible that some stars of rotational velocity 20 or 25 km/sec are listed as $<$ 20: km/sec in Tables 2*a* and 2*b*.

At the other extreme, for stars having $v \sin i$ of about 100 km/sec or more, a dispersion of 11 A/mm is inconveniently and unnecessarily large, at least when visual estimates are used for the determination of rotational velocity. We do not know whether the quality of our estimates of large $v \sin i$'s has suffered for this reason, but it is certain that the work on such stars would have been less difficult at a lower dispersion.

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1955ApJ...121..118H

TABLE 2*a*

CATALOGUE OF LINE WIDTHS OF 624 STARS BETWEEN SPECTRAL TYPES F0 AND K5 AND OF LUMINOSITY CLASSES II–V, EXPRESSED AS ROTATIONAL VELOCITIES

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
1	33 Psc	0^h00^m2	− 6°16′	K1 III	2	< 15	SB1
2	β Cas	0 03.8	+58 36	F2 IV	1	85	
3	22 And	0 05.1	+45 31	F2 II	1	40	
4	6 Cet	0 06.2	−16 01	F6 V w	2	< 15	
5	HR 37	0 07.1	−18 30	K5 III	2	< 20:	VV
6	ι Cet	0 14.3	− 9 23	K2 III	2	< 15	
7	ρ And	0 15.8	+37 25	F5 IV s	4	45	
8	HR 152	0 31.3	+43 56	K5 III	2	< 15	
9	ε And	0 33.3	+28 46	G8 III	2	< 15	
10	δ And	0 34.0	+30 19	K3 III	1	< 15	VV
11	α Cas	0 34.8	+55 59	K0 II–III	2	< 15	LV
12	32 And	0 35.7	+38 55	G8 III	2	< 15	
13	β Cet	0 38.6	−18 32	K0 III	2	< 15	
14	ϕ^1 Cet	0 39.2	−11 09	K0 III	2	< 15	
15*	ζ And	0 42.0	+23 43	K1 II	2	30	SB1
16	η Cas	0 43.0	+57 17	G0 V w	1	< 15	
17	δ Psc	0 43.5	+ 7 02	K5 III	2	< 20:	
18*	64 Psc	0 43.7	+16 24	F8 V s	2	{< 15, < 15}	SB2
19	ϕ^2 Cet	0 45.1	−11 11	F8 V s	4	< 15	
20	HR 244	0 47.1	+60 34	F8 IV–V s	4	< 15	
21	υ^1 Cas	0 49.1	+58 26	K2 III	2	< 15:	
22	υ^2 Cas	0 50.7	+58 38	G8 III–IV	2	< 15	
23	η And	0 51.9	+22 53	G8 III–IV	2	{< 15, < 15}	SB2
24	ε Psc	0 57.8	+ 7 21	K0 III	2	< 15	
25	μ Cas	1 01.6	+54 26	G5 Vp	1	< 15	
26	η Cet	1 03.6	−10 43	K2 III	2	< 15	
27	χ Psc	1 06.1	+20 30	K0 III	2	< 20:	
28	τ Psc	1 06.2	+29 34	K0 III–IV	2	< 15	VV
29	φ Psc	1 08.3	+24 03	K0 III	2	< 15	VV
30	ξ And	1 16.4	+45 00	K0 III–IV	2	< 15	VV?
31	ψ Cas	1 18.9	+67 36	K0 III	2	< 15	
32	θ Cet	1 19.0	− 8 42	K0 III	2	< 15	
33	46 Cet	1 20.7	−15 07	K3 III	2	< 15	
34	ω And	1 21.7	+44 53	F5 IV w	4	75	
35	49 And	1 24.1	+46 30	K0 III	2	< 20:	
36	μ Psc	1 24.9	+ 5 38	K4 III	2	< 15	
37	η Psc	1 26.1	+14 50	G8 III	1	< 20:	
38	χ Cas	1 27.4	+58 43	K0 III	2	< 20:	
39	40 Cas	1 30.5	+72 32	G8 II–III	2	< 20:	
40*	υ And	1 30.9	+40 54	F8 V w	1	< 15	
41	50 Cet	1 31.1	−15 54	K2 III	2	< 20:	
42	51 And	1 31.8	+48 07	K3 III	1	< 15	
43	χ And	1 33.4	+43 52	G8 III	2	< 15	VV
44	HR 483	1 35.7	+42 07	G2 V s	1	< 15	
45	ν Psc	1 36.2	+ 4 59	K3 III	2	< 20:	

* Additional remarks for stars noted by asterisks are given in "Notes to Table 2*a*."
† The sources are identified in the text (pp. 135 and 136).
‡ The abbreviations in the "Remarks" column have the following meanings:

SB1: single-line spectroscopic binary.
VV: variable velocity.
LV: light variable.
SB2: double-line spectroscopic binary.
VV?: possibly variable velocity.
VB: visual binary.

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
46..........	107 Psc	1^h37^m1	+19° 47′	K1 V	1	< 20:	
47..........	HR 500	1 37.7	− 4 12	K3 II–III	2	< 20:	
48..........	τ Cet	1 39.4	−16 28	G8 Vp	1	< 15	
49..........	o Psc	1 40.1	+ 8 39	K0 III	2	< 15	
50..........	ζ Cet	1 46.5	−10 50	K2 III	2	< 20:	SB1
51..........	α Tri	1 47.4	+29 06	F6 IV w	1	115	SB1
52..........	ξ Psc	1 48.4	+ 2 42	K0 III	2	< 15	VV
53..........	ι Ari	1 51.9	+17 20	K1 p	2	< 15:	SB1
54..........	49 Cas	1 56.0	+75 38	G8 III	2	< 15	VV?
55..........	γ And A	1 57.8	+41 51	K2 III	2	< 15	
56..........	α Ari	2 01.5	+22 59	K2 III	1	< 15	
57..........	14 Ari	2 03.7	+25 28	F2 III	1	≥115	
58..........	60 And	2 07.0	+43 46	K4 III	2	< 15	SB1
59..........	η Ari	2 07.2	+20 44	F5 V s	2	< 20	
60..........	ξ¹ Cet	2 07.7	+ 8 23	G8 II	2	< 15	VV
61..........	δ Tri	2 10.9	+33 46	G0 V w	1	< 15	SB1
62..........	64 And	2 17.8	+49 33	G8 III	2	< 15	
63..........	65 And	2 19.0	+49 50	K4 III	2	< 15	
64..........	14 Tri	2 26.0	+35 42	K5 III	2	< 20:	
65..........	HR 737	2 26.3	+ 1 50	K3 III	2	< 20:	
66..........	σ Cet	2 27.4	−15 41	F5 IV–V s	4	20	
67..........	HR 743	2 28.5	+72 23	G8 III	2	< 20:	
68..........	ν Cet	2 30.6	+ 5 09	G8 III	2	< 15	
69*.........	θ Per	2 37.4	+48 48	F7 V w	1	< 15	
70..........	μ Cet	2 39.5	+ 9 42	F0 IV	1	45	VV
71..........	τ¹ Eri	2 40.4	−19 00	F6 V s	4	25	
72..........	39 Ari	2 42.0	+28 50	K1 III	2	< 15	
73..........	16 Per	2 44.3	+37 54	F2 III	1	>115	
74..........	17 Per	2 45.4	+34 39	K5 III	2	< 15	
75*.........	20 Per	2 47.4	+37 56	F4 V	2	85	VB
76..........	η Eri	2 51.5	− 9 18	K1 III–IV	2	< 15	
77..........	24 Per	2 52.9	+34 47	K2 III	2	< 15	
78..........	HR 918	2 58.0	+56 19	K0 II–III	2	< 20:	
79..........	ι Per	3 01.8	+49 14	G0 V w	1	< 15	
80..........	κ Per	3 02.7	+44 29	K0 III	2	< 15	VV
81..........	ω Per	3 04.8	+39 14	K1 III	2	< 20:	
82..........	δ Ari	3 05.9	+19 21	K2 III	2	< 15	
83..........	94 Cet	3 07.7	− 1 34	F8 V s	2	< 15	
84..........	HR 969	3 09.0	+50 34	G5 II	2	< 15	
85..........	HR 991	3 12.5	+33 51	K2 II	2	< 15	
86..........	κ Cet	3 14.1	+ 3 00	G5 V s	1	< 15	
87..........	HR 999	3 14.3	+28 41	K3 II–III	2	< 15	
88..........	63 Ari	3 17.0	+20 23	K3 III	2	< 20:	
89..........	o Tau	3 19.4	+ 8 41	G8 III	1	< 15	SB1
90..........	σ Per	3 23.6	+47 39	K3 III	2	< 15	
91..........	5 Tau	3 25.4	+12 36	K0 II–III	2	< 20:	SB1
92..........	36 Per	3 25.5	+45 43	F4 III	1	40	
93..........	ε Eri	3 28.2	− 9 48	K2 V	1	< 15	
94..........	10 Tau	3 31.8	+ 0 05	F8 V w	4	< 15	
95..........	ν Per	3 38.4	+42 16	F5 II	1	45	VV?

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
96	δ Eri	3^h38^m4	−10°06′	K0 IV	1	< 15	
97	43 Per	3 49.2	+50 24	F5 V s	4	{< 15, < 15}	SB2
98	32 Eri A	3 49.3	− 3 15	G8 III	2	< 15	
99	HR 1242	3 56.1	+58 53	F0 II	1	< 20:	
100	HR 1249	3 57.5	− 0 33	F6 V s	2	25	
101	37 Tau	3 58.8	+21 49	K0 III	2	< 15	
102	HR 1257	3 58.9	+ 2 33	F6 IV w	2	25	
103*	46 Tau	4 08.2	+ 7 28	F3 V	1	65	VB
104	39 Eri	4 09.6	−10 30	K3 III	2	< 20:	
105	HR 1327	4 11.3	+64 54	G5 III	1	< 20:	
106	54 Per	4 13.9	+34 20	G8 III	2	< 20:	
107	γ Tau	4 14.1	+15 23	K0 III	1	< 15	
108	φ Tau	4 14.2	+27 07	K1 III	2	< 20:	
109	δ Tau	4 17.2	+17 18	K0 III	1	< 15	
110	HR 1390	4 19.7	+31 13	K1 III	2	< 20:	
111	π Tau	4 21.0	+14 29	G8 III	2	< 15	
112	75 Tau	4 22.7	+16 08	K2 III	2	< 20:	
113	ε Tau	4 22.8	+18 58	K0 III	1	< 15	
114	θ^1 Tau	4 22.8	+15 44	K0 III	1	< 20:	VV
115	45 Eri	4 26.8	− 0 16	K3 II–III	2	< 15	
116	HR 1452	4 29.4	− 9 11	K4 II–III	2	< 20:	
117	α Tau	4 30.2	+16 19	K5 III	1	< 15	
118	3 Cam	4 32.0	+52 53	K0 III	2	< 15	SB1
119	53 Eri	4 33.6	−14 30	K2 III	2	< 15	SB1
120	HR 1523	4 41.6	+81 02	K3 III	2	< 15	VV?
121	HR 1533	4 43.2	+37 19	K4 II	2	< 20:	
122	π^3 Ori	4 44.4	+ 6 47	F6 V s	1	20	
123	2 Aur	4 45.9	+36 32	K3 III	2	< 15	
124	ι Aur	4 50.5	+33 00	K3 II	1	< 15	
125	o^2 Ori	4 50.8	+13 21	K2 III	2	< 15	
126	π^6 Ori	4 53.4	+ 1 34	K2 II	5	< 15	
127	68 Eri	5 03.8	− 4 35	F5 V w	2	< 15	
128	HR 1684	5 06.0	+15 55	K5 III	2	< 20:	
129	HR 1686	5 06.1	+79 07	F6 V w	2	< 20:	
130	ρ Ori	5 08.1	+ 2 45	K3 III	2	< 15	SB1
131*	α Aur	5 09.3	+45 54	....	......	....	SB2
132	16 Aur	5 11.6	+33 16	K3 III	2	< 15	SB1
133*	λ Aur	5 12.1	+40 01	G0 V w	1	< 15:	
134	109 Tau	5 13.3	+22 00	G8 III	2	< 15	
135	21 Ori	5 14.0	+ 2 30	F5 II	2	85	
136	σ Aur	5 17.8	+37 18	K4 III	2	< 20:	
137	111 Tau	5 18.6	+17 17	F8 V s	2	25	
138	29 Ori	5 19.1	− 7 54	G8 III	2	< 15	
139	27 Ori	5 19.4	− 0 59	K0 III	2	< 20:	
140	φ Aur	5 21.0	+34 24	K3p	2	< 15	
141	β Lep	5 24.0	−20 50	G2 II	6	< 20:	
142	31 Ori	5 24.6	− 1 10	K5 III	2	< 20:	LV
143	51 Ori	5 37.3	+ 1 26	K1 III	2	< 15	
144	τ Aur	5 42.2	+39 09	G8 III	2	< 15	
145	132 Tau	5 42.9	+24 32	G8 III	2	< 20	

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
146	ν Aur	5h44m6	+39°07′	K0 III	2	< 15	
147	56 Ori	5 47.2	+ 1 50	K2 II	1	< 20:	
148	χ¹ Ori	5 48.5	+20 16	G0 V s	2	< 20:	
149	δ Aur	5 51.3	+54 17	K0 III	1	< 15	
150	1 Mon	5 54.3	− 9 24	F2 II	7	25:	
151	HR 2113	5 55.0	− 3 05	K2 III	2	< 15	
152	37 Cam	6 01.2	+58 57	G8 III	2	< 20:	
153	36 Cam	6 02.8	+65 44	K2 II–III	2	< 15	
154	71 Ori	6 09.0	+19 12	F6 V s	2	< 15	
155	κ Aur	6 09.0	+29 32	G8 III	2	< 20:	
156	74 Ori	6 10.8	+12 18	F5 IV–V w	2	20	
157	45 Aur	6 13.6	+53 30	F5 III s	2	20	SB1
158	5 Lyn	6 18.1	+58 28	K4 III	2	< 20:	
159	HR 2305	6 19.5	−11 28	K3 III	2	< 20:	
160	HR 2379	6 26.7	−12 19	K3 III	2	< 20:	
161	ψ² Aur	6 32.2	+42 35	K3 III	2	< 15	
162	ν² CMa	6 32.3	−19 10	K1 IV	2	< 15	
163	ν³ CMa	6 33.5	−18 09	K1 III	2	< 15	
164	HR 2450	6 34.7	−14 03	K2 II	2	< 15	
165	ψ⁴ Aur	6 35.8	+44 37	K5 III	2	< 15	
166	13 Lyn	6 38.3	+57 16	K0 III	2	< 20:	
167	30 Gem	6 38.4	+13 20	K1 III	2	< 20:	
168	ψ⁵ Aur	6 39.5	+43 41	G0 V s	2	< 15	
169	ξ Gem	6 39.7	+13 00	F5 IV s	4	95	
170	ψ⁶ Aur	6 40.0	+48 54	K1 III	2	< 20:	
171	17 Mon	6 41.9	+ 8 09	K4 III	2	< 20:	
172	18 Mon	6 42.6	+ 2 31	K0 III	2	< 15	VV
173	ψ⁷ Aur	6 43.7	+41 54	K3 III	2	< 20:	
174	HR 2527	6 45.5	+77 06	K4 III	2	< 15	VV
175	θ CMa	6 49.6	−11 55	K4 III	2	< 20:	
176	ω Gem	6 56.3	+24 21	G5 II	1	< 20:	
177	HR 2649	6 58.1	+11 06	K3 III	2	< 20:	
178	τ Gem	7 04.8	+30 25	K2 III	2	< 15	
179	63 Aur	7 04.8	+39 29	K4 II–III	2	< 15	
180	20 Mon	7 05.3	− 4 05	K0 III	2	< 20:	
181	18 Lyn	7 07.2	+59 49	K2 III	2	< 20:	
182	δ Gem	7 14.2	+22 10	F2 IV–V	6	115	VV?
183	65 Aur	7 15.4	+36 57	K0 III	2	< 15	
184	66 Aur	7 17.2	+40 52	K0 III	2	< 20:	
185	57 Gem	7 17.4	+25 15	G8 III	2	< 20:	
186	ι Gem	7 19.5	+28 00	K0 III	2	< 15	
187	ε CMi	7 20.2	+ 9 28	G8 III	2	< 15	
188	22 Lyn	7 22.3	+49 53	F6 V s	2	< 20:	
189	γ CMi	7 22.7	+ 9 08	K3 III	2	< 15	SB1
190	ρ Gem	7 22.7	+31 59	F0 V	1	85	
191*	65 Gem	7 23.6	+28 07	K2 III	2	{< 15, < 15}	SB2
192	6 CMi	7 24.2	+12 13	K2 III	2	< 20:	
193	HR 2896	7 28.8	+31 11	K0 III	2	< 20:	
194	υ Gem	7 29.8	+27 07	K5 III	2	< 20:	
195	25 Mon	7 32.3	− 3 53	F5 III w	2	30	

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	v sin i (Km/Sec)	Remarks‡
196	α CMi	$7^h34^m.1$	+5°29′	F5 IV–V s	1	< 15	VB
197	α Mon	7 36.5	− 9 19	K0 III	2	< 15	
198*	σ Gem	7 37.1	+29 08	K1 III	2	25	SB1
199	76 Gem	7 38.0	+26 01	K5 III	2	< 20:	
200	κ Gem	7 38.4	+24 38	G8 III	1	< 15	
201	β Gem	7 39.2	+28 16	K0 III	1	< 15	
202	81 Gem	7 40.3	+18 45	K5 III	2	< 15	VV
203*	9 Pup	7 47.1	−13 38	G1 V s	4	< 15	VB
204	11 Pup	7 52.6	−22 37	F8 II	7	25	
205	14 CMi	7 53.2	+ 2 29	K0 III	2	< 20:	
206	27 Mon	7 54.7	− 3 24	K2 III	2	< 20:	
207	28 Mon	7 56.1	− 1 07	K4 III	2	< 20:	
208	HR 3145	7 57.1	+ 2 37	K2 III	2	< 20:	
209	χ Gem	7 57.4	+28 04	K2 III	2	< 20:	VV
210	μ Cnc	8 01.9	+21 52	G2 IV s	4	< 20:	
211	HR 3182	8 02.9	+68 46	G8 II	2	< 20:	
212	ρ Pup	8 03.3	−24 01	F6 II	7	15	VV
213	19 Pup	8 06.6	−12 38	K0 III	2	< 15	
214	HR 3212	8 06.7	− 7 28	G8 III	2	< 20:	
215	β Cnc	8 11.1	+ 9 30	K4 III	1	< 15	
216	χ Cnc	8 14.0	+27 32	F6 V w	4	< 20:	
217	31 Lyn	8 16.0	+43 31	K5 III	2	< 20:	
218	HR 3306	8 20.6	+ 7 53	G8 II	2	< 20:	
219*	o UMa	8 22.0	+61 03	G2 II–III	3	15	
220	π^2 UMa	8 31.5	+64 41	K2 III	2	< 15	
221	σ Hya	8 33.5	+ 3 42	K2 III	2	< 15	
222	6 Hya	8 35.3	−12 07	K4 III	2	< 20:	
223	9 Hya	8 37.1	−15 35	K1 III	2	< 20:	
224	δ Cnc	8 39.0	+18 31	K0 III	2	< 15	
225	ι Cnc	8 40.6	+29 08	G8 II	2	< 20:	
226*	ε Hya AB	8 41.5	+ 6 47	G	......	< 15	VB
227	12 Hya	8 41.7	−13 11	G8 III	2	< 15	SB1
228	35 Lyn	8 45.2	+44 06	K0 III	2	< 15	
229	ρ^2 Cnc	8 49.7	+28 19	G8 II–III	2	< 20:	
230	ζ Hya	8 50.1	+ 6 20	K0 III	2	< 15	
231*	HR 3579	8 54.2	+42 11	F5 V w	1	25	VB
232	σ^1 UMa	8 59.6	+67 17	K5 III	2	< 20:	
233	ω Hya	9 00.7	+ 5 30	K2 II–III	2	< 20:	
234*	σ^2 UMa	9 01.6	+67 32	F7 IV–V s	1	< 15	
235	τ Cnc	9 02.0	+30 03	G8 III	2	< 20:	
236	τ UMa	9 02.7	+63 55	A7 m	2	< 15	VV
237	ξ Cnc	9 03.6	+22 27	K0 III	2	< 15	SB1
238	17 UMa	9 08.4	+57 10	K5 III	2	< 20:	
239	23 Hya	9 11.7	− 5 56	K2 III	2	< 20:	SB1
240	26 Hya	9 15.0	−11 33	G8 III	2	< 20:	
241	27 Hya	9 15.6	− 9 08	G8 III–IV	2	< 20:	
242	κ Leo	9 18.8	+26 37	K2 III	2	< 20:	
243	α Hya	9 22.7	− 8 14	K3 III	2	< 15	
244	HR 3750	9 22.8	− 5 38	G2 V s	4	< 15	VV?
245	HR 3751	9 22.8	+81 46	K3 III	2	< 20:	

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
246	τ^1 Hya	$9^h24^m.1$	$-\ 2°20'$	F6 V w	4	45	VV?
247	24 UMa	9 25.6	+70 16	G5 IV s	2	< 20:	
248	λ Leo	9 26.0	+23 25	K5 III	2	< 15	VV?
249	θ UMa	9 26.2	+52 08	F6 IV w	1	< 15	
250	6 Leo	9 26.6	+10 09	K3 III	2	< 15	
251	ξ Leo	9 26.6	+11 45	K0 III	2	< 20:	
252	10 LMi	9 28.1	+36 51	G8 III	2	< 20:	
253	HR 3809	9 28.8	+40 04	K0 III	2	< 20:	
254	11 LMi	9 29.7	+36 16	G8 IV–V	1	< 15	
255	10 Leo	9 31.9	+ 7 17	K1 III	2	< 15	VV
256	HR 3834	9 33.2	+ 5 06	K3 III	2	< 20:	
257	27 UMa	9 33.8	+72 42	K0 III	2	< 20:	
258	ι Hya	9 34.8	− 0 41	K3 III	2	< 15	
259	43 Lyn	9 35.8	+40 13	G8 III	2	< 20:	
260	ϵ Leo	9 40.2	+24 14	G0 II	1	< 15	
261	HR 3881	9 42.1	+46 29	G2 V s	4	< 15	
262	υ UMa	9 43.9	+59 31	F2 IV	1	115	
263	υ^1 Hya	9 46.7	−14 23	G8 III	2	< 20:	
264	μ Leo	9 47.1	+26 29	K2 III	2	< 15	
265	19 LMi	9 51.6	+41 32	F5 V s	4	< 20:	SB1
266	31 Leo	10 02.6	+10 29	K4 III	2	< 20:	
267	HR 3991	10 05.2	−12 19	F5 V s	2	≥115	
268	λ Hya	10 05.7	−11 52	K0 III	2	< 20:	SB1
269	ζ Leo	10 11.1	+23 55	F0 III	1	85	VV
270*	40 Leo	10 14.3	+19 59	F6 IV w	1	20	
271	γ Leo A	10 14.5	+20 21	K0 III	2	< 15	
272*	HR 4084	10 18.9	+83 04	F5 IV w	4	115	
273	μ Hya	10 21.2	−16 20	K4 III	2	< 20:	
274	31 LMi	10 22.1	+37 13	G8 III–IV	2	< 20:	
275	36 UMa A	10 24.2	+56 30	F8 V w	1	< 15	
276	HR 4126	10 26.6	+76 14	K0 III	2	< 20:	
277	48 Leo	10 29.6	+ 7 28	G8 II–III	2	< 20:	
278	37 LMi	10 33.1	+32 30	G2 II	2	< 20:	
279	ϕ Hya	10 33.7	−16 21	K0 III	2	< 15	SB1
280	38 UMa	10 35.1	+66 14	K2 III	2	< 20:	
281	HR 4181	10 35.9	+69 36	K3 III	2	< 20:	
282	ν Hya	10 44.7	−15 40	K2 III	2	< 15	
283	44 UMa	10 47.5	+55 07	K3 III	2	< 20:	
284	46 LMi	10 47.7	+34 45	K0 III–IV	1	< 20:	
285	HR 4251	10 48.6	−19 36	F6 V s	4	20	
286	46 UMa	10 50.2	+34 02	K1 III	2	< 20:	
287	47 UMa	10 53.9	+40 58	G0 V s	4	< 20:	
288	α Crt	10 54.9	−17 46	K0 III	2	< 20:	
289	58 Leo	10 55.4	+ 4 09	K1 III	2	< 20:	
290	61 Leo	10 56.7	− 1 57	K5 III	2	< 20:	VV
291	α UMa	10 57.6	+62 17	K0 III	1	< 15	VB
292	ψ UMa	11 04.0	+45 02	K1 III	1	< 20:	
293	73 Leo	11 10.6	+13 51	K3 III	2	< 20:	VV
294	ξ UMa	11 12.8	+32 06	G0 V w	4	< 15 < 20:	A(btr.) SB1 B(ftr.) SB1 } VB
295	ν UMa	11 13.1	+33 38	K3 III	1	< 20:	

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
296	δ Crt	11ʰ14ᵐ3	−14° 14′	G8 III–IV	2	< 20:	VV
297..........	56 UMa	11 17.4	+44 02	G8 II	1	< 20:	
298..........	λ Crt	11 18.4	−18 14	F5 IV s	2	25	VV
299.	ε Crt	11 19.6	−10 19	K5 III	2	< 20:	
300.	τ Leo	11 22.8	+ 3 24	G8 II–III	2	< 20:	
301..........	87 Leo	11 25.2	− 2 27	K4 III	2	< 20:	
302..........	HR 4439	11 26.7	+61 38	F6 V w	4	< 20:	
303..........	2 Dra	11 30.2	+69 53	K0 III	2	< 20:	
304..........	υ Leo	11 31.8	− 0 16	G9 III	2	< 20:	
305..........	92 Leo	11 35.6	+21 54	K0 III	2	< 15	
306..........	61 UMa	11 35.8	+34 46	G8 V	1	< 15	
307..........	3 Dra	11 36.9	+67 18	K3 III	2	< 15	
308..........	ζ Crt	11 39.7	−17 48	G8 III	2	< 20:	
309..........	χ UMa	11 40.8	+48 20	K0 III	2	< 20:	
310..........	HR 4521	11 41.6	+56 11	K3 III	2	< 20:	
311..........	β Vir	11 45.5	+ 2 20	F8 V s	1	< 15	
312..........	ο Vir	12 00.1	+ 9 17	G8 III	2	< 20:	
313..........	7 Com	12 11.3	+24 30	K0 III	2	< 15	
314..........	HR 4668	12 11.5	+33 37	K1 III	2	< 15	SB1
315..........	16 Vir	12 15.3	+ 3 52	K0 III	2	< 20:	
316..........	11 Com	12 15.7	+18 21	G8 III	2	< 20:	
317..........	HR 4699	12 15.8	−13 01	K1 III	2	< 20:	
318..........	5 CVn	12 19.2	+52 07	G7 III	2	< 15	
319..........	6 CVn	12 20.9	+39 34	G8 III–IV	2	< 20:	
320..........	15 Com	12 22.0	+28 49	K1 III–IV	2	< 15	
321..........	18 Com	12 24.4	+24 40	F5 IV s	4	115	
322..........	HR 4783	12 28.7	+33 48	K0 III	2	< 20:	
323..........	β CVn	12 29.0	+41 54	G0 V w	1	< 15	
324..........	β Crv	12 29.1	−22 51	G5 II	6	< 15	
325..........	χ Vir	12 34.1	− 7 27	K2 III	2	< 15	
326*.........	γ Vir	12 36.6	− 0 54	F0 V	1	{ 25 40	np} VB sf}
327..........	HD 110628	12 38.4	+26 40	F2n IV	7	110:	
328..........	27 Com	12 41.6	+17 07	K3 III	2	< 15	
329..........	31 Com	12 46.8	+28 05	G0 III s	1	85	
330..........	35 Com	12 48.4	+21 47	G8 III	2	< 15	
331..........	α¹ CVn	12 51.3	+38 51	F0 V	1	20:	
332..........	37 Com	12 55.5	+31 20	K1p	2	< 20:	
333..........	9 Dra	12 56.1	+67 08	G8 III	2	< 15	
334..........	78 UMa	12 56.4	+56 54	F2 V	1	105:	
335..........	ε Vir	12 57.2	+11 30	G9 III	2	< 15	
336..........	41 Com	13 02.4	+28 10	K5 III	2	< 15	
337..........	49 Vir	13 02.6	−10 12	K1 III	2	< 20:	
338..........	53 Vir	13 06.7	−15 40	F6 IV s	4	< 15	
339..........	β Com	13 07.2	+28 23	G0 V s	1	< 20:	
340..........	HR 4997	13 09.2	+40 41	K0 III	2	< 20:	
341..........	59 Vir	13 11.8	+ 9 57	G0 V s	4	< 15	
342..........	HR 5013	13 12.3	+14 12	K3 III	2	< 20:	
343*.........	61 Vir	13 13.2	−17 45	G6 V w	1	< 15	
344..........	γ Hya	13 13.5	−22 39	G5 III	6	< 15	
345..........	70 Vir	13 23.5	+14 19	G5 V w	1	< 15	

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
346*..........	76 Vir	13 27.7	− 9 39	K0 III	2	< 20:	
347*.........	τ Boo	13 42.5	+17 57	F7 V w	1	< 15	
348..........	89 Vir	13 44.4	−17 38	K1 III	2	< 20:	
349..........	υ Boo	13 44.6	+16 18	K5 III	2	< 15	
350..........	6 Boo	13 45.0	+21 46	K4 III	2	< 20:	
351..........	90 Vir	13 49.6	− 1 01	K2 III	2	< 15	
352..........	η Boo	13 49.9	+18 54	G0 IV s	1	20	SB1
353..........	9 Boo	13 52.0	+27 59	K3 III	2	< 20:	
354..........	κ Vir	14 07.6	− 9 48	K3 III	2	< 20:	
355..........	4 UMi	14 09.2	+78 01	K3 III	2	< 15	SB1
356..........	15 Boo	14 10.0	+10 34	K0 III	2	< 20:	
357..........	ι Vir	14 10.8	− 5 31	F6 IV s	4	20	
358..........	α Boo	14 11.1	+19 42	K2 IIIp	1	< 15	
359..........	HR 5361	14 13.8	+35 58	K1 III	2	< 15	SB1
360..........	υ Vir	14 14.4	− 1 48	G8 III	2	< 20:	
361..........	18 Boo	14 14.4	+13 28	F5 IV–V s	4	45	
362..........	20 Boo	14 15.0	+16 46	K3 III	2	< 15	
363*.........	θ Boo	14 21.8	+52 19	F7 V w	1	40	
364..........	φ Vir	14 23.0	− 1 47	G2 III	2	< 20:	
365..........	ρ Boo	14 27.5	+30 49	K3 III	1	< 15	VV?
366..........	5 UMi	14 27.7	+76 08	K4 III	2	< 15	
367..........	σ Boo	14 30.3	+30 11	F2 V	1	< 15	
368..........	31 Boo	14 36.7	+ 8 35	G8 III	2	< 15	
369..........	μ Vir	14 37.8	− 5 13	F5 IV w	4	85	VV
370..........	ο Boo	14 40.6	+17 23	K0 III	2	< 15	
371..........	α¹ Lib	14 45.2	−15 35	F5 IV–V w	4	< 20:	
372..........	11 Lib	14 45.8	− 1 53	G8 III–IV	2	< 15	
373..........	HR 5541	14 46.6	+37 41	K0 III–IV	2	< 15	
374..........	β UMi	14 51.0	+74 34	K4 III	1	< 15	
375..........	ω Boo	14 57.7	+25 24	K4 III	2	< 15	
376..........	110 Vir	14 57.8	+ 2 29	K0 III	2	< 15	
377..........	β Boo	14 58.2	+40 47	G8 II–III	2	< 15	
378..........	ψ Boo	15 00.2	+27 20	K2 III	2	< 15	
379..........	45 Boo	15 02.9	+25 16	F5 V w	1	75	
380..........	HR 5635	15 03.4	+54 56	G8 III	2	< 20:	
381..........	δ Boo	15 11.5	+33 41	G8 III	1	< 20:	
382..........	HR 5691	15 13.5	+67 44	F8 V s	2	< 20:	
383..........	5 Ser	15 14.2	+ 2 09	F8 IV–V w	1	< 15	
384..........	6 Ser	15 16.0	+ 1 04	K3 III	2	< 15	
385..........	11 UMi	15 17.2	+72 11	K4 III	2	< 15	
386..........	ε Lib	15 18.8	− 9 58	F5 V s	4	< 20:	SB1
387..........	ι Dra	15 22.7	+59 19	K2 III	1	< 15	
388..........	ν¹ Boo	15 27.3	+41 10	K5 III	2	< 15	
389..........	37 Lib	15 28.7	− 9 43	K1 III	2	< 20:	
390..........	γ Lib	15 29.9	−14 27	G8 III–IV	2	< 15	
391..........	16 Ser	15 31.7	+10 21	K0p	2	< 15	VV
392..........	φ Boo	15 34.2	+40 41	G8 IV	2	< 20:	
393..........	θ UMi	15 34.4	+77 41	K5 III	2	< 15	
394..........	α Ser	15 39.3	+ 6 44	K2 III	1	< 15	
395..........	λ Ser	15 41.6	+ 7 40	G0 V w	1	< 15	

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
396	ω Ser	15^h45^m2	+ 2° 30′	G8 III	2	< 15	
397	δ CrB	15 45.4	+26 23	G5 III–IV	2	< 15	
398	ρ Ser	15 46.9	+21 17	K5 III	2	< 15	
399	κ CrB	15 47.5	+35 58	K0 III–IV	2	< 15	
400	θ Lib	15 48.1	−16 26	G8 III–IV	2	< 20:	
401*	χ Her	15 49.2	+42 44	F9 V w	1	< 15	
402*	γ Ser	15 51.8	+15 59	F6 V w	1	< 20:	VV
403	ε CrB	15 53.4	+27 10	K3 III	1	< 15	
404	5 Her	15 56.8	+18 06	K0 III	2	< 15	
405	ρ CrB	15 57.2	+33 37	G2 V w	2	< 20:	
406	θ Dra	16 00.0	+58 50	F8 IV–V s	1	30	SB1
407	κ Her A	16 03.6	+17 19	G8 III	2	< 20:	
408	τ CrB	16 05.3	+36 45	K0 III	1	< 15	VV?
409	χ Sco	16 08.3	−11 35	K3 III	2	< 15	
410	ε Oph	16 13.0	− 4 27	G8 III	2	< 15	
411	γ Her	16 17.5	+19 23	F0 III	6	115	VV
412	ψ Oph	16 18.2	−19 48	K0 III	2	< 15	
413	ξ CrB	16 18.2	+31 07	K0 III	2	< 15	
414	ν^2 CrB	16 18.7	+33 56	K5 III	2	< 15	
415	HR 6126	16 22.0	+69 20	K2 III	2	< 20:	
416	η Dra	16 22.6	+61 44	G8 III	1	< 15	
417	HR 6136	16 23.5	+ 0 53	K4 IIIp	2	< 20:	
418	φ Oph	16 25.4	−16 24	G8 III	2	< 20:	
419	β Her	16 25.9	+21 42	G8 III	1	< 20:	SB1
420	HR 6152	16 26.2	+20 42	G8p	2	< 15	
421	29 Her	16 27.9	+11 42	K5 III	2	< 20:	
422	HR 6196	16 35.8	−17 33	G8 II	2	< 20:	
423	HR 6199	16 36.0	+56 13	K1 III	2	< 15	
424	ζ Her	16 37.5	+31 47	G0 IV w	1	< 15	VB
425	η Her	16 39.5	+39 07	G8 III–IV	2	< 15	VV?
426	18 Dra	16 40.2	+64 47	K1p	2	< 20:	
427	43 Her	16 41.0	+ 8 46	K5 III	2	< 15	
428	20 Oph	16 44.3	−10 36	F6 IV w	4	< 20:	
429	51 Her	16 47.6	+24 50	K2 II–III	2	< 15	
430	23 Oph	16 49.2	− 6 00	K2 III	2	< 20:	
431	HR 6287	16 50.6	+21 07	G8 III	2	< 15	
432	κ Oph	16 52.9	+ 9 32	K2 III	1	< 15	LV
433	19 Dra	16 55.5	+65 17	F6 V w	4	< 20:	SB1
434	30 Oph	16 55.8	− 4 04	K4 III	2	< 20:	
435	ε UMi	16 56.2	+82 12	G5 III s	2	25	SB1
436	HR 6388	17 06.3	+40 54	K3 III	2	< 15	VV
437	41 Oph	17 11.5	− 0 20	K2 III	2	< 15	
438	π Her	17 11.6	+36 55	K3 II	1	< 15	
439	HR 6433	17 13.9	+10 58	K4 II–III	2	< 15	
440*	72 Her	17 16.9	+32 36	G0 V w	1	< 15	
441	σ Oph	17 21.6	+ 4 14	K3 II	2	< 20:	
442	λ Her	17 26.7	+26 11	K4 III	2	< 15	
443	β Dra	17 28.2	+52 23	G2 II	1	< 15	
444	27 Dra	17 32.4	+68 12	K0 III	2	< 15	
445*	26 Dra	17 34.0	+61 57	G1 V w	1	< 20:	

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
446	ω Dra	17h37m5	+68°48′	F5 V w	4	< 20:	SB1
447	β Oph	17 38.5	+ 4 37	K2 III	1	< 15	
448	μ Her	17 42.6	+27 47	G5 IV	1	< 15	
449	ψ Dra A	17 43.7	+72 12	F5 V s	4	15	
450	87 Her	17 44.8	+25 39	K2 III	2	< 15	
451	90 Her	17 50.0	+40 01	K3 III	2	< 20:	
452	ξ Dra	17 51.8	+56 53	K2 III	1	< 15	
453	θ Her	17 52.8	+37 16	K1 II	1	< 20:	
454	ν Oph	17 53.5	− 9 46	K0 III	2	< 15	
455	ξ Her	17 53.9	+29 16	K0 III	2	< 20:	
456	35 Dra	17 53.9	+76 59	F6 IV–V s	4	< 20:	
457	γ Dra	17 54.3	+51 30	K5 III	1	< 15	
458	ν Her	17 54.7	+30 12	F2 II	1	30	
459	ζ Ser	17 55.2	− 3 41	F3 V	1	110:	VV?
460	93 Her	17 55.6	+16 46	K0 II–III	2	< 15	
461	70 Oph A	18 00.4	+ 2 31	K0 V	1	< 20:	SB1, VB
462	71 Oph	18 02.5	+ 8 43	G8 III–IV	2	< 20:	
463*	99 Her	18 03.2	+30 33	F7 V w	1	< 20:	
464	HR 6791	18 04.5	+43 27	K0p	2	< 15	VV?
465	36 Dra	18 13.3	+64 22	F5 V w	2	< 15	
466	74 Oph	18 15.9	+ 3 20	G8 III	2	< 20:	
467	η Ser	18 16.1	− 2 55	K0 III–IV	1	< 20:	
468	κ Lyr	18 16.4	+36 01	K2 III	2	< 15	
469	ζ Sct	18 18.2	− 8 59	K0 III	2	< 15	SB1
470	HR 6885	18 18.4	+17 46	K3 III	2	< 15	
471	109 Her	18 19.4	+21 43	K2 III	2	< 15	
472	χ Dra	18 22.9	+72 41	F7 V	1	< 15	SB1
473	60 Ser	18 24.5	− 2 03	K0 III	2	< 15	SB1
474	42 Dra	18 25.7	+65 30	K2 III	2	< 15	
475	HR 6970	18 29.5	−11 03	G8 III	2	< 20:	
476	α Sct	18 29.8	− 8 19	K3 III	2	< 15	
477	HR 6983	18 31.7	+52 16	K0 III	2	< 15	VB
478	ε Sct	18 38.1	− 8 22	G8 II	2	< 20:	
479*	110 Her	18 41.4	+20 27	F6 V w	1	< 20:	
480	β Sct	18 41.9	− 4 51	G5 II	1	< 15	SB1
481	HR 7064	18 42.0	+26 33	K3 III	2	< 15	
482	HR 7117	18 48.3	+73 58	K0 II–III	2	< 15	
483	ο Dra	18 49.7	+59 16	K0 II–III	2	< 20:	SB1
484	HR 7137	18 50.8	+50 35	G8 III	2	< 20:	
485	η Sct	18 51.7	− 5 58	K2 III	2	< 20:	
486	HR 7162	18 53.3	+32 46	G0 V w	2	< 15	
487*	11 Aql	18 54.5	+13 29	F8 IV w	4	25	
488	ε Aql	18 55.1	+14 56	K2 III	2	< 15	
489	υ Dra	18 55.6	+71 10	K0 III	2	< 15	VV
490	HR 7181	18 55.7	+26 05	K2 III	2	< 15	VV
491	λ Lyr	18 56.2	+32 00	K3 III	2	< 20:	
492	12 Aql	18 56.3	− 5 53	K1 III	2	< 15	
493	π Sgr	19 03.8	−21 11	F2 II	7	30	
494	53 Dra	19 09.8	+56 41	G8 III	2	< 20:	
495	43 Sgr	19 11.8	−19 08	G8 II	2	< 20:	

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1955ApJ...121..118H

TABLE 2a—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
496	54 Dra	19^h12^m1	+57° 32′	K2 III	2	< 20:	
497	δ Dra	19 12.5	+67 29	G9 III	2	< 15	
498	θ Lyr	19 12.9	+37 57	K0 II	1	< 20:	
499	23 Aql	19 13.4	+ 0 54	K2 II–III	2	< 20:	
500	κ Cyg	19 14.8	+53 11	K0 III	1	< 15	VV
501	26 Aql	19 15.2	− 5 36	G8 III–IV	2	< 15	SB1
502	τ Dra	19 17.5	+73 10	K3 III	2	< 15	VV
503	31 Aql	19 20.2	+11 44	G8 IV	2	< 15	
504	δ Aql	19 20.4	+ 2 55	F0 IV–V	8	85	VV
505	4 Vul	19 21.1	+19 36	K0 III	2	< 20:	
506	μ Aql	19 29.2	+ 7 10	K3 III	2	< 20:	
507	σ Dra	19 32.6	+69 29	K0 V	1	< 15	
508	HR 7468	19 33.5	+44 28	K0 III	2	< 20:	
509	θ Cyg	19 33.8	+49 59	F5 IV–V s	4	< 20:	
510	α Sge	19 35.6	+17 47	G0 II	1	< 15	
511	β Sge	19 36.6	+17 15	G8 II	2	< 20:	
512	10 Vul	19 39.6	+25 32	G8 III	2	< 15	
513	15 Cyg	19 40.7	+37 07	G8 III	2	< 20:	
514	γ Aql	19 41.5	+10 22	K3 II	1	< 15	
515	17 Cyg A	19 42.6	+33 30	F5 V w	1	< 20:	VV?
516	o Aql	19 46.2	+10 10	F8 V s	2	< 15	
517	20 Cyg	19 48.1	+52 44	K3 III	2	< 20:	
518	ε Dra	19 48.5	+70 01	G8 III	2	< 20:	
519	ξ Aql	19 49.4	+ 8 12	K0 III	2	< 20:	
520	β Aql	19 50.4	+ 6 09	G8 IV	1	< 20:	
521	η Cyg	19 52.6	+34 49	K0 III	2	< 20:	
522	HR 7633	19 54.0	+58 35	K5 II–III	2	< 20:	
523	γ Sge	19 54.3	+19 13	K5 III	2	< 15	
524	26 Cyg	19 58.5	+49 50	K1 II–III	2	< 20:	
525	η Sge	20 00.7	+19 42	K2 III	2	< 20:	
526	ρ Dra	20 02.4	+67 35	K3 III	2	< 20:	
527	23 Vul	20 11.6	+27 30	K3 III	2	< 20:	
528	α^2 Cap	20 12.5	−12 51	G9 III	2	< 15	
529	24 Vul	20 12.5	+24 22	G8 III	2	< 20:	
530	HR 7759	20 13.4	+40 03	K4 II	2	< 20:	
531	HR 7794	20 18.2	+ 5 01	G8 III–IV	2	< 20:	
532	39 Cyg	20 19.9	+31 52	K3 III	2	< 20:	
533	ρ Cap	20 23.2	−18 09	F2 IV	7	115:	
534	41 Cyg	20 25.3	+30 02	F5 II	1	< 15	
535*	β Del	20 32.9	+14 15	F5 IV s	4	55	VB
536	71 Aql	20 33.2	− 1 27	G8 III	2	< 20:	SB1
537	1 Aqr	20 34.3	+ 0 08	K1 III	2	< 20:	
538	κ Del	20 34.3	+ 9 44	G5 IV	2	< 20:	
539	30 Vul	20 40.6	+24 55	K2 III	2	< 15	VV
540	52 Cyg	20 41.5	+30 21	K0 III	2	< 15	
541	ε Cyg	20 42.2	+33 36	K0 III	1	< 15	VV
542	HR 7955	20 42.9	+57 13	F8 IV–V w	4	< 20:	
543	HR 7956	20 43.2	+34 00	K3 III	2	< 20:	
544	η Cep	20 43.2	+61 27	K0 IV	1	< 15	
545	31 Vul	20 47.8	+26 43	G8 III	2	< 20:	

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	v sin i (Km/Sec)	Remarks‡
546	32 Vul	20h50m3	+27°41′	K4 III	2	< 15	
547	17 Del	20 50.9	+13 20	K0 III	2	< 20:	
548*	1 Equ	20 54.1	+ 3 55	F5 IV w	4	75	VB
549	61 Cyg A	21 02.4	+38 15	K5 V	1	< 15	
550	ν Aqr	21 04.2	−11 47	G8 III	2	< 15	
551	ζ Cyg	21 08.7	+29 49	G8 II	1	< 15	VV
552	ι Cap	21 16.7	−17 16	G8 III	2	< 15	
553	1 Peg	21 17.5	+19 23	K1 III	1	< 15	
554	71 Cyg	21 25.8	+46 06	K0 III	2	< 20:	
555	ρ Cyg	21 30.2	+45 09	G8 III	2	< 20:	
556	72 Cyg	21 30.7	+38 05	K1 III	2	< 15	
557	25 Aqr	21 34.5	+ 1 48	K0 III	2	< 20:	
558*	42 Cap	21 36.1	−14 30	G2 IV s	2	15	SB1
559	κ Cap	21 37.1	−19 19	G8 III	2	< 20:	
560	46 Cap	21 39.7	− 9 32	G8 II–III	2	< 15	VV
561	μ Cyg A	21 39.7	+28 17	F6 V w	4	< 15	
562	11 Cep	21 40.4	+70 51	K0 III	2	< 15	
563	HR 8324	21 41.8	+71 52	K1 III	2	< 15	VV?
564	16 Cep	21 57.8	+72 42	F5 V s	2	35	
565	ν Peg	22 00.6	+ 4 34	K4 III	2	< 15	VV
566	HR 8424	22 02.0	+44 32	K5 III	2	< 15	
567	20 Cep	22 02.0	+62 18	K4 III	2	< 15	
568	ι Peg	22 02.4	+24 51	F5 V s	1	< 20:	SB1
569*	π Peg	22 05.6	+32 41	F5 III s	4	115:	
570	24 Cep	22 07.9	+71 51	G8 III	2	< 20:	VV?
571	HR 8472	22 08.2	+56 20	F8 V s	2	< 20:	
572	HR 8475	22 08.4	+34 07	K2 III	2	< 20:	VV?
573	HR 8485	22 09.6	+39 13	K3 III	2	< 15	VV?
574	ε Cep	22 11.4	+56 33	F0 IV	1	110	VV
575	θ Aqr	22 11.6	− 8 17	G8 III–IV	2	< 15	
576	1 Lac	22 11.6	+37 15	K3 II–III	2	< 20:	
577	3 Lac	22 19.6	+51 44	G9 III	2	< 15	
578	35 Peg	22 22.8	+ 4 12	K0 III	2	< 20:	
579	ζ Aqr	22 23.7	− 0 32	F5 IV w	4	{ 75 / 75	np / sf } VB
580	37 Peg	22 24.9	+ 3 55	F5 IV s	4	85	VB
581	κ Aqr	22 32.6	− 4 45	K2 III	2	< 20:	
582*	31 Cep	22 33.3	+73 07	F4 III	7	100	
583	11 Lac	22 36.1	+43 45	K3 III	2	< 15	
584	66 Aqr	22 38.2	−19 21	K4 III	2	< 20:	
585	η Peg	22 38.3	+29 42	G2 II–III	1	< 15	SB1
586	13 Lac	22 39.6	+41 18	K0 III	2	< 20:	
587*	ξ Peg	22 41.7	+11 40	F7 V w	1	< 15	
588	λ Peg	22 41.7	+23 02	G8 II–III	2	< 20:	
589	μ Peg	22 45.2	+24 04	K0 III	2	< 15	
590	ι Cep	22 46.1	+65 40	K1 III	2	< 20:	
591*	σ Peg	22 47.3	+ 9 18	F7 IV s	1	< 15	
592	HR 8702	22 47.9	+82 37	K3 III	2	< 20:	
593	HR 8748	22 55.2	+83 49	K4 III	2	< 15	
594	3 And	22 59.7	+49 30	K0 III	2	< 15	
595	HR 8779	22 59.7	+66 40	K3 III	2	< 15	

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1955ApJ...121..118H

TABLE 2*a*—*Continued*

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
596..........	56 Peg	23^h02^m2	+24° 56′	K0 IIp	2	< 15	VV
597*.........	π Cep	23 04.7	+74 51	G2 III	6	≦ 15	SB1, VB
598..........	ψ¹ Aqr	23 10.6	− 9 38	K0 III	2	< 15	
599..........	γ Psc	23 12.0	+ 2 44	G8 III	2	< 15	
600..........	94 Aqr	23 13.8	−14 00	G5 IV	2	≦ 15	VV
601..........	ο Cep	23 14.5	+67 34	K0 III	2	< 15	
602..........	11 And	23 14.8	+48 05	K0 III	2	< 20:	
603..........	7 Psc	23 15.2	+ 4 50	K2 III	2	< 20:	
604..........	66 Peg	23 18.0	+11 46	K3 III	2	< 20:	
605..........	υ Peg	23 20.4	+22 51	F8 IV s	1	95	
606..........	θ Psc	23 22.9	+ 5 50	K1 III	2	< 15	
607..........	70 Peg	23 24.1	+12 13	G8 III	2	< 20:	VV?
608..........	14 And	23 26.4	+38 41	K0 III	2	< 20:	
609*.........	72 Peg	23 29.0	+30 46	K4 III	2	< 20:	VB
610..........	λ And	23 32.7	+45 55	G8 III–IV	1	< 20:	SB1
611*.........	ι Psc	23 34.8	+ 5 05	F7 V w	1	< 15	
612..........	γ Cep	23 35.2	+77 04	K1 IV	1	< 15	
613..........	104 Aqr	23 36.6	−18 22	G0 II	7	15	
614..........	HR 8987	23 37.3	−16 00	K4 III	2	< 15	VV?
615..........	78 Peg	23 39.0	+28 48	K0 III	2	< 20:	VV?
616..........	τ Cas	23 42.2	+58 06	K1 III	2	< 15	
617..........	27 Psc	23 53.6	− 4 07	G9 III	2	< 20:	
618..........	ω Psc	23 54.2	+ 6 19	F4 IV s	4	55	VV?

NOTES TO TABLE 2*a*

15 ζ And: Spectroscopic binary with $P = 17.8$ days. See the discussion by L. Gratton, *Ap. J.*, **111**, 31, 1950; *McDonald Contr.*, No. 185.
18 64 Psc: Double-line spectroscopic binary with $P = 14$ days.
40 υ And: Miss Roman (1950) gives F8 IV on the MKK system.
69 θ Per: Miss Roman (1950) classifies this star as F6 V.
75 20 Per: The Δm is about 0.4 mag.
103 46 Tau: The Δm is about 0.3 mag.
131 α Aur: See text.
133 λ Aur: Miss Roman (1950) gives G2 IV–V.
191 65 Gem: Double-line spectroscopic binary with a period of several years.
198 σ Gem: Spectroscopic binary with $P = 19.6$ days. The line width is presumably due to rapid axial rotation associated with the orbital motion.
203 9 Pup: The Δm is about 0.7 mag.
219 ο UMa: The type is given as G5 V in the Yerkes *Atlas*.
226 ε Hya AB: The type is given as G0 III in the Yerkes *Atlas* but does not appear in later lists. According to W. P. Bidelman, the brighter component of this close binary belongs to a later subdivision of class G.
231 HR 3579: This star (= 10 UMa) is a visual binary with a period of about 21 years. The line width was estimated on spectrograms that were taken in the interval February 8–March 23, 1953.
234 σ² UMa: Miss Roman (1950) gives F6 IV on the MKK system.
270 40 Leo: Miss Roman (1950) classifies this star as F6 V.
272 HR 4084: The type is given as F2 V by Bidelman (1951).
326 γ Vir: The difference in line width between the two components has been noted by Struve and Mrs. Gould (*Pub. A.S.P.*, **64**, 183, 1952; *A.J.*, **57**, 160, 1952).
343 61 Vir: The type is given as G5 V by Miss Roman (1950).
347 τ Boo: Miss Roman (1950) gives F6 IV on the MKK system.
363 θ Boo: Miss Roman (1950) classifies this star as F6 IV on the MKK system.
401 χ Her: The type is given as F8 V by Miss Roman (1950).
402 γ Ser: Miss Roman (1950) gives F6 IV on the MKK system.
440 72 Her: The type is given by Miss Roman (1950) as G2 V.
445 26 Dra: Miss Roman (1950) gives G2 V.
463 99 Her: The type is given as F8 V by Miss Roman (1950).
479 110 Her: Miss Roman (1950) classifies this star as F5 IV on the MKK system.
487 11 Aql: The type on the MKK system is F8 III–IV, according to Miss Roman. We have assumed that this corresponds to F8 IV on the MK system.
535 β Del: The Δm is about 0.6 mag.
548 1 Equ: The Δm is only about 0.2 mag.
558 42 Cap: The line widening is only marginally visible.
569 π Peg: No good Mills plates are available. The type is F5 II–III on the MKK system (Miss Roman 1950), and we have assumed that this is equivalent to F5 III on the MK system.
582 31 Cep: A type of F4 II–III on the MKK system was assigned by Bidelman. We have assumed that this is equivalent to F4 III on the MK system.
587 ξ Peg: Miss Roman (1950) assigned a type of F6 III–IV on the MKK system.
591 σ Peg: A type of F6 V was assigned by Miss Roman (1950).
597 π Cep: This star is a single-line spectroscopic binary ($P = 556$ days) and the brighter component of a visual binary with Δm about 2 mag. We are unable to explain the discrepancy between our value of $v \sin i$ (≤15 km/sec) and the value of 70 km/sec reported by Slettebak (1953).
609 72 Peg: The Δm is very small.
611 ι Psc: Miss Roman's (1950) type is F8 V.

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1955ApJ...121..118H

TABLE 2*b*

CATALOGUE OF LINE WIDTHS OF 32 HIGH-LUMINOSITY STARS BETWEEN SPECTRAL TYPES F0 AND K5, EXPRESSED AS ROTATIONAL VELOCITIES

No.*	Star	α_{1900}	δ_{1900}	Spectral Type	Source†	$v \sin i$ (Km/Sec)	Remarks‡
619	ϕ Cas	1^h13^m8	+57°42′	F0 Ia	1	35	VV
620	η Per	2 43.4	+55 29	K3 Ib	1	<20:	
621	α Per	3 17.2	+49 30	F5 Ib	1	20	
622	μ Per	4 07.6	+48 09	G0 Ib	1	<15	SB1
623*	10 Cam	4 54.5	+60 18	G0 Ib	1	15	
624*	ϵ Aur	4 54.8	+43 40	F0p Ia	8	30	SB1
625	α Lep	5 28.3	−17 54	F0 Ib	1	15	
626	ϵ Gem	6 37.8	+25 14	G8 Ib	1	<15	
627	o^1 CMa	6 50.0	−24 04	K3 Iab	1	≤20	
628	δ CMa	7 04.3	−26 14	F8 Ia	1	25	
629	ζ Mon	8 03.6	− 2 42	G2 Ib	1	<15:	
630	HR 3459	8 38.8	− 6 52	G2 Ib	5	<15	
631	HR 3612	9 00.2	+38 51	G8 Ib–II	2	<20:	
632	89 Her	17 51.4	+26 04	F2 Ia	1	25	VV
633	45 Dra	18 30.8	+56 58	F7 Ib	7	<20:	
634	ν Aql	19 21.4	+ 0 08	F2 Ib	1	<20:	
635	22 Vul	20 11.2	+23 12	G2 Ib	1	15:	SB1
636	α^1 Cap	20 12.1	−12 49	G3 Ib	5	<15	VV
637	35 Cyg	20 14.8	+34 40	F5 Ib	1	<15	VV
638	γ Cyg	20 18.6	+39 56	F8 Ib	1	<15	
639	ξ Cyg	21 01.3	+43 32	K5 Ib	1	<15	VV
640*	DT Cyg	21 02.3	+30 47	....	1	<15	LV
641	ζ Cap	21 21.0	−22 51	G4 Ib pec.	6	<20	VV
642	β Aqr	21 26.3	− 6 01	G0 Ib	1	<15	
643	ϵ Peg	21 39.3	+ 9 25	K2 Ib	1	<15	
644	9 Peg	21 39.8	+16 53	G5 Ib	1	<15	
645	α Aqr	22 00.6	− 0 48	G2 Ib	1	<15	
646	ζ Cep	22 07.4	+57 42	K1 Ib	1	<15	
647	HR 8752	22 55.9	+56 24	G0 Ia	1	35	VV?
648	ψ And	23 41.1	+45 52	G5 Ib	2	<20:	
649*	ρ Cas	23 49.4	+56 57	F8 Ia pec.	6	20:	LV
650	3 Cet	23 59.4	−11 04	K3 Ib	2	<15	

* Additional remarks for stars noted by asterisks:

623 10 Cam: The weak lines are slightly wider than those in the sun.

624 ϵ Aur: The type has been given by Bidelman (1951) as A8 I*a;* the spectrum may be slightly variable, even outside eclipse.

640 DT Cyg: A cepheid variable with $P = 2.5$ days. The range in spectral type is given by A. D. Code (*Ap. J.*, **106**, 309, 1947) as F5.5 I–II to F7 I–II. The upper limit to $v \sin i$ quoted in the table was assigned on the basis of a plate exposed at phase 0.609 period (see W. H. Grasberger and G. H. Herbig, *Pub. A.S.P.*, **64**, 28, 1952).

649 ρ Cas: The value of $v \sin i = 20$: km/sec was estimated on a spectrogram taken on November 19, 1953. An examination of the width of weak lines on Mills plates of ρ Cas exposed in 1906, 1907, 1908, 1910, and 1923 yielded essentially the same result.

† The sources are identified in the text (see pp. 135 and 136).

‡ See note to Table 2*a*.

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1955ApJ...121..118H

The estimates of line width were not made directly in kilometers per second but in units of an arbitrary scale in which the solar line width was set at 1.0, π^3 Orionis 1.3, 11 Aquilae 2.0, ρ Andromedae 3.0, 31 Comae 4.0, and 18 Comae 5.0. The conversion of estimates on this scale to $v \sin i$ in km/sec by means of a correlation diagram led to a spurious grouping of the $v \sin i$ values around certain rotational velocities, especially at those of the standard stars. The concentration of velocities around values ending in 5 is due to the same reason. No attempt has been made to correct the data in Tables 2*a* and 2*b* for this effect. All values of $v \sin i$ in those tables have, however, been rounded off to the nearest multiple of 5 km/sec.

For the supergiants, the turbulence-widened profiles of the strong lines made these lines unsuitable for estimating $v \sin i$, so that only weak lines were used for this purpose in stars of luminosity class I. Because of the marked difference in line character between the supergiants and the standard stars, it is entirely possible that determinations of $v \sin i$ for supergiants by some more appropriate method might differ systematically from the values in Table 2*b*. It should be emphasized that $v \sin i$ is used in that table only as a numerical index of the width of weak lines; its use is not intended to imply that the line-broadening agent in such stars is necessarily axial rotation.

Because of the manner in which the $v \sin i$'s in Tables 2*a* and 2*b* were determined, it is difficult to make any general statement as to their probable uncertainties. It is possible, however, to gain a limited idea of their reliability by comparing them with rotational velocities obtained for the same stars by other investigators. Such a comparison is shown in Table 3, in which the published $v \sin i$'s have all been obtained with dispersions comparable with that of the present work. The stars are identified by their numbers in Tables 2*a* and 2*b*. The main conclusions to be drawn are, first, that the present results for stars with narrow lines seem to be in good agreement with other work and, second, that the $v \sin i$'s for the supergiants are in reasonable agreement with rotational velocities assigned to those stars from detailed studies of their line profiles. However, the material in Table 3 is too scanty to furnish a good check on the accuracy of the data of this paper for stars with $v \sin i$ greater than about 25 km/sec.

A more detailed comparison is possible with the results of Huang (1953), which were obtained from micrometer measures of many of these same spectrograms. Figure 1 shows the correlation of Huang's rotational velocities ($\xi_r \sin i$, computed from his eqs. [1] and [2] with the parameter $\gamma = 2$, its compromise value) as determined from Mills plates, with the values of $v \sin i$ for the same stars given in this paper. For this comparison, 115 stars are available. The supergiants have been excluded because of the special nature of their line profiles. The points plotted in Figure 1 show the existence of a scale difference between the two series. Approximately the same difference in scale seems to be present in a comparison of Huang's velocities for stars with strong λ 4481 (i.e., stars of types late A, F, and G) with those determined by Elvey (see Fig. 3 of Huang's paper). As was suggested by Huang, this effect probably arises from a visual overestimation, when the micrometer settings were made, of the width of a strong, rotationally broadened line. Formally, Huang's series of rotational velocities of F- and G-type stars that are plotted in Figure 1 can be reduced to the scale of the present paper by using $\gamma \cong 1.4$.

The spectral types used in this paper are on or near the revised *Atlas* system of Morgan and Keenan. Other lists of spectral types in the Yerkes systems were also drawn upon, so that in Tables 2*a* and 2*b* the type is accompanied by a number that identifies the source. The sources and their designations are as follows.

1. H. L. Johnson and W. W. Morgan (1953): a list of standards for the MK system.
2. N. G. Roman (1952*a*): a list of types and luminosity classes for F5–K5 stars, expressed on the MK system.
3. N. G. Roman (1952*b*): classifications of a number of F- and G-type stars on the MK system.

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1955ApJ...121..118H

4. N. G. Roman (1950): a list of the types and luminosity classes of F5–G5 stars, expressed on the MKK system of the *Atlas of Stellar Spectra* by W. W. Morgan, P. C. Keenan, and E. Kellman (1943). These classifications have been converted to the MK system as follows (see Johnson and Morgan 1953, p. 319, and Roman 1952*a*, p. 123): (*a*) all F2–F8 luminosity class III stars have been moved to class IV, and (*b*) all F2–F8 class IV stars have been changed to class IV–V.

TABLE 3

STARS FOR WHICH $v \sin i$ HAS BEEN MEASURED FROM LINE PROFILES BY ANOTHER INVESTIGATOR

Tables 2*a*, 2*b* No.	Star	Tables 2*a*, 2*b* $v \sin i$ (Km/Sec)	Published $v \sin i$ (Km/Sec)	Reference*
3	22 And	40	65	4
156	74 Ori	20	20	3
182	δ Gem	115	70; 70	1
196	α CMi	< 15	0; 0	1
270	40 Leo	20	15	3
326	γ Vir np	25	25; 50	1
	γ Vir sf	40	25; 50	1
329	31 Com	85	75	4
338	53 Vir	< 15	10	3
383	5 Ser	< 15	0	3
428	20 Oph	< 20:	10	3
463	99 Her	< 20:	5	3
504	δ Aql	85	100; 100	1
534	41 Cyg	< 15	0; 0	1
569	π Peg	115:	about 100	2
			125	4
611	ι Psc	< 15	0; 0	1
621	α Per	20	0; 0	1
624	ε Aur	30	0; 0	1
			30	6
628	δ CMa	25	≈30	5

* The published $v \sin i$'s were drawn from the following sources:
1. C. T. Elvey, *Ap. J.*, **71**, 221, 1930. The two entries in the "Published $v \sin i$" column are independent estimates by Elvey and by O. Struve, respectively.
2. J. L. Greenstein, *Ap. J.*, **117**, 269, 1953.
3. M. and B. Schwarzschild, *Ap. J.*, **112**, 248, 1950.
4. A. Slettebak, *A.J.*, **58**, 228, 1953.
5. A. Unsöld and O. Struve, *Ap. J.*, **110**, 455, 1949; *McDonald Contr.*, No. 177.
6. K. O. Wright and E. Van Dien, *J.R.A.S. Canada*, **43**, 15, 1949; *Contr. Dom. Ap. Obs. Victoria*, No. 17.

5. W. W. Morgan and N. G. Roman (1950): a list of supergiant standards. These types have been used without change unless there is a conflict with a classification given in source 1, above, in which case the latter type has been used.

6. W. W. Morgan, P. C. Keenan, and E. Kellman, *Atlas of Stellar Spectra* (1943): this work defines the MKK system. The changes described under source 4 have been made for F2–F8 stars taken from this work. Other types have not been changed.

7. W. P. Bidelman (1951): a list of classifications of Miss Payne's c-stars, expressed on the MKK system. The treatment was the same as described under source 4, above.

8. P. C. Keenan and W. W. Morgan in *Astrophysics* (Hynek 1951), chap. 1.

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1955ApJ...121..118H

III. DISCUSSION

The early Yerkes work on the spectral-type dependence of stellar rotation among stars less luminous than supergiants indicated that, in general, appreciable line broadening disappears among single stars[1] later than type F5. The results of the present paper demonstrate the existence of appreciable line widths in main-sequence stars as late as type F8. The slight difference between this and the Yerkes value of F5 is undoubtedly due to the higher dispersion that was used in this work. Among stars of somewhat higher luminosity, it has been known for many years that a few single objects of types later than F5 showed lines of appreciable width: for example, W. W. Campbell and J. H. Moore (1928) noted that the determination of the radial velocities of 31 Comae and

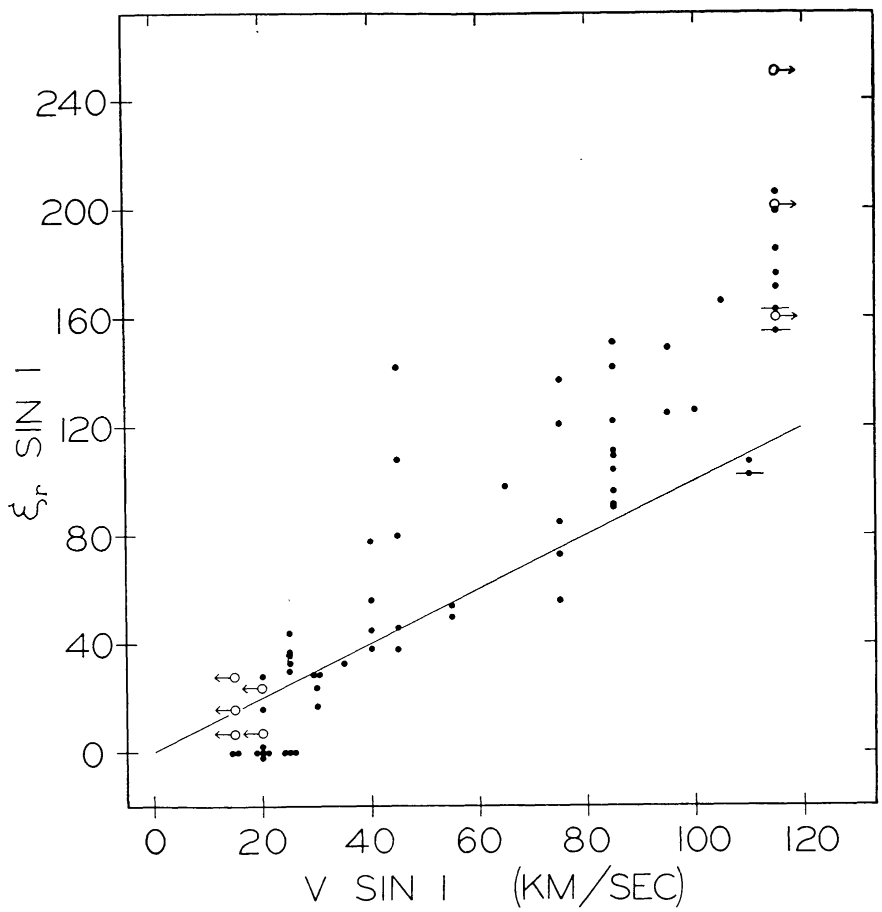

FIG. 1.—The scatter diagram relating rotational velocities measured by Su-Shu Huang ($\xi_r \sin i$) and those of this paper ($v \sin i$), both in km/sec. The scales of the ordinates and abscissae differ by a factor of 2, so the slope of the usual 45° regression line is decreased accordingly. Open circles with horizontal arrows represent stars for which only an upper or lower limit on $v \sin i$ was determined in the present investigation. A horizontal line through a filled circle indicates that the value of $v \sin i$ for that star is somewhat uncertain. In order to avoid congestion near the origin, 29 stars for which $\xi_r \sin i = 0$ and $v \sin i < 15$ km/sec, and 17 stars for which $\xi_r \sin i = 0$ and $v \sin i < 20$: km/sec have not been plotted. Furthermore, only stars of luminosity classes II through V are represented in the diagram.

[1] In addition to close binaries, we do not consider in the present discussion peculiar objects with broad lines, such as the T Tauri stars (G. H. Herbig, *J.R.A.S. Canada*, **46**, 222, 1952; *Contr. Dom. Ap. Obs. Victoria*, No. 27 [part 3]) and HD 117555 (P. W. Merrill, *Pub. A.S.P.*, **60**, 382, 1948).

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1955ApJ...121..118H

υ Pegasi, both of HD type G0, was difficult because of the poor quality of their spectral lines. More recently, J. L. Greenstein (1952, 1953), Slettebak (1953, 1954), Herbig and Miss Turner (1953), and others have noted that broad lines are very common among giant stars of types as late as early G.

The luminosity dependence of $v \sin i$ for the spectral interval F0–G5, as indicated by the data of this paper, is shown in Table 4. In this, as in the other collections of data that follow, each component of a visual binary or double-line spectroscopic binary has

TABLE 4

LUMINOSITY DEPENDENCE OF ROTATIONAL VELOCITY FOR SPECTRAL TYPES F0–G5

	Types F0–F4				
Luminosity class	II	III	IV	IV–V	V
No. stars with $v \sin i > 20$ km/sec.	4	6	7	2	7
Total no. stars	5	6	7	2	9
Fraction with $v \sin i > 20$ km/sec.	0.8	1.0	1.0	1.0	0.8
	Types F5–F7				
Luminosity class	II	III	IV	IV–V	V
No. stars with $v \sin i > 20$ km/sec.	2	2	14	1	8
Total no. stars	4	3	20	8	37
Fraction with $v \sin i > 20$ km/sec.	0.5	0.7	0.7	0.1	0.2
	Types F8–G0				
Luminosity class	II	III	IV	IV–V	V
No. stars with $v \sin i > 20$ km/sec.	1	1	2	1	1
Total no. stars	4	1	4	4	28
Fraction with $v \sin i > 20$ km/sec.	0.2	1.0	0.5	0.2	0.04
	Types G1–G5				
Luminosity class	II	III*	IV	IV–V	V
No. stars with $v \sin i > 20$ km/sec.	0	0	0	....	0
Total no. stars	7	5	6	0	10
Fraction with $v \sin i > 20$ km/sec.	0.0	0.0	0.0	....	0.0

* Includes one star of type G5 III–IV.

been entered with the integrated spectral type of the system, if the individual types are unknown. The last line of Table 4 gives the fraction of stars of each luminosity class that have projected rotational velocities greater than 20 km/sec. The entries in this line show that the tendency for a given star to have a $v \sin i > 20$ km/sec weakens rapidly through spectral type F but that rotation persists to later types in luminosity classes III and IV than in classes II or V. Rotation may be somewhat more common among the later F-type stars of luminosity class II than in those of class V, but the small sample of class II objects makes this point quite uncertain.

One type G5 star (ϵ Ursae Minoris) and two of type K (ζ Andromedae and σ Gemi-

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1955ApJ...121..118H

norum) in Table 2*a* show broadened lines, very probably due to the fact that all are spectroscopic binaries of relatively short periods (39, 18, and 20 days, respectively) for such large stars. No other stars of types later than G5 have been found to have perceptibly wide lines. The line broadening observed in a few other objects of types G2–G5 is marginal ($v \sin i = 15$ km/sec). If these three binaries are rejected, then the latest spectral type at which at least one star with $v \sin i \geq 20$ km/sec is known is G0 for luminosity classes III and IV, and type F8 for classes II, IV–V, and V.

The dependence of rotational velocity upon luminosity class is shown also in Table 5, which has been obtained by combining the first three parts of Table 4. Table 5 gives the fractions of F0–G0 stars with $v \sin i > 20$ km/sec for each luminosity class from II to V. It must be emphasized, however, that the presentation of the data in the compressed form of Table 5 gives a somewhat misleading impression, because the mean spectral type is not the same for each luminosity class. For example, in the class III stars, 9 of the 10 objects between F0 and G0 are of types F0–F5, where the rotational velocities for any luminosity are fairly high. On the other hand, the bulk of the F0–G0 stars of class V represented in these statistics are of type F5 or later, where the average

TABLE 5

FRACTIONS OF F0–G0 STARS WITH v SIN i >20 KM/SEC AS A FUNCTION OF LUMINOSITY CLASS*

Luminosity class	II	III	IV	IV–V	V
No. stars with $v \sin i > 20$ km/sec	7	9	23	4	16
Total no. stars	13	10	31	14	74
Fraction with $v \sin i > 20$ km/sec	0.5	0.9	0.7	0.3	0.2

* See the text for a caution regarding the interpretation of the data in this Table.

$v \sin i$ is small. A much fairer picture of the situation is shown by the same data in Table 4, where an effort was made to minimize the effect present in Table 5 by combining stars over a spectral-type range no larger than was necessary to obtain a reasonably significant number of stars.

The variation of the mean rotational velocities ($\bar{v}$, not $\overline{v \sin i}$) of groups of stars over the spectrum-luminosity class diagram between types F0 and G5 is shown in Table 6, which was constructed from the data of Tables 2*a* and 2*b*. The blocks indicate the regions of the diagram from which stars were drawn in order to form the mean velocities.[2] The mean $v \sin i$'s for stars of luminosity classes II–V were multiplied by the factor $4/\pi$ in order to obtain mean v's freed of the effect of an assumed random distribution in direction of the axes of rotation (Chandrasekhar and Münch 1950). This correction was applied throughout, although the number of stars in many of the groups is too small for it to be very meaningful. No allowance of this type was made for the supergiants (luminosity classes I*a* and I*b*), and so the mean velocities entered in Table 6 for these objects are straight averages of the velocities listed in the $v \sin i$ column of Table 2*b*. The figures in parentheses beneath the mean velocities in Table 6 are the numbers of stars used in forming the means.

Although the samples in many of the regions of Table 6 are very small, the observational data, when presented in this form, lead to the same conclusions with regard to the luminosity dependence of rotation as were drawn on the basis of Table 4. The arrangement of the material in Table 6 may be the more useful for theoretical workers.

We have assumed throughout the present work that the assignment of spectral type

[2] The remark appended to Table 6 discusses the convention used in computing these means.

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TABLE 6

MEAN ROTATIONAL VELOCITIES IN SPECTRUM-LUMINOSITY CLASS DIAGRAM

LUMINOSITY CLASS	SPECTRAL TYPE F0	F2	F3	F4	F5	F6	F7	F8	F9	G0	G1	G2	G3	G4	G5
I*a*.......	30 (3)								27 (3)						
I*b*.......	<20 (2)				<20 (2)		<20 (2)			<15 (3)		<15 (4)		<20 (4)	
II.......	34 (5)					46 (5)				<19 (3)		<25 (3)			<25 (4)
II–III....												<19 (2)			
III.......	146 (4)			78 (5)						108: (1)		<25 (2)			<25 (3)
IV.......	123 (6)			98 (13)			43 (10)			<25 (2)		<25 (2)			<25 (4)
IV–V....	127 (2)				24 (6)		<25 (6)								
V........	60 (6)		110 (3)		31 (15)	20 (15)	<25 (7)	<21 (12)	<21 (16)		<21 (7)				<19 (3)

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1955ApJ...121..118H

and luminosity class is unaffected by the presence or absence of line width, since such classifications are generally made at a dispersion (about 125 A/mm) where line broadening of the magnitude found in stars of types F0 and later would be expected to be imperceptible. Nevertheless, the point is important enough to deserve a closer examination than we are in a position to make.

Among the stars of spectral types F5–G5 Miss Roman (1950, 1952*a*) has distinguished two groups, one characterized by weak and the other by strong lines. The space-velocity distribution of the weak-line stars has a larger dispersion than does that of the strong-line stars. In Table 2*a* the spectral types of stars between types F5 and G5 which have been assigned by Miss Roman to one group or the other, are followed by a "w" or an "s," even though the spectral type and luminosity class quoted there have been drawn from another source. Between types F5 and G0, there are available about 50 stars in each group. It is important to know whether axial rotation is correlated with membership in these groups. The answer is negative: there is no indication that the apparent rotational velocities of the two groups of stars differ in any significant way. There are about the same fractions of slowly rotating (or rapidly rotating) stars in each luminosity class for both weak- and strong-line objects.

As might be expected, the data of Table 2*b* indicate that the supergiants of luminosity class I*a* ($M_v \backsim -7$) have systematically greater line widths than those of class I*b* ($M_v \backsim -4.5$). In the spectral interval F0–G5, for which the data are probably most reliable for such spectra, the mean $v \sin i$ is 28 km/sec for 6 class I*a* stars, and <15 km/sec for 17 class I*b* supergiants. A comparable result has been obtained by Huang and Struve (1954).

We have not included our results for the components of α Aurigae in the statistical results, because no accurate spectral types are available. The Yerkes *Atlas* (Morgan, Keenan, and Kellman 1943) gives MKK types of G5 and F6 for the primary and secondary components, respectively, but states that "the separate values for the two components are very uncertain and may be in error by a considerable fraction of their separation." K. O. Wright (1954) gives spectral types of approximately G5 III and G0 III for the

NOTES TO TABLE 6

The entries in the table are $4/\pi$ times $\overline{v \sin i}$ for luminosity classes II through V, and $\overline{v \sin i}$ for classes I*a* and I*b*. It was sometimes necessary to combine the results for stars having definitely determined values of $v \sin i$ with those for which only an upper limit was available. This was done by assuming that it was permissible to use a value of 10 km/sec in those cases where $v \sin i$ <15 or <20: km/sec, always provided that the resulting mean was not unrealistically small. The values contained in the table were computed in this way. So that one may judge the effect of this assumption upon the means, the notes below give for a number of tabular entries the extreme limits on the value of $4\,\overline{v \sin i}/\pi$ arising from error in this assumption. This range was obtained by regarding all stars for which $v \sin i$ has been observed to be <15 or <20: km/sec as having, first, $v \sin i = 0$ and, second, $v \sin i$ values equal to their upper limits. In cases where lower limits have been set on $v \sin i$ in Table 2, it was assumed that a value of ≥115 km/sec corresponds to 120 km/sec and that >115 km/sec may be replaced by 140 km/sec in order to compute the mean. The numbers in parentheses are the numbers of stars used in computing the corresponding value of $\bar{v} = 4\,\overline{v \sin i}/\pi$.

The ranges are as follows:

F0–F2 II: the range of $\bar{v}$ is 32–37 km/sec.
F5–F8 II: the range of $\bar{v}$ is 43–47 km/sec.
F6–F8 IV: the range of $\bar{v}$ is 36–44 km/sec.
F5 IV–V: the range of $\bar{v}$ is 18–30 km/sec.
F0–F2 V: the range of $\bar{v}$ is 58–62 km/sec.
F5 V: the range of $\bar{v}$ is 22–38 km/sec.
F6 V: the range of $\bar{v}$ is 11–27 km/sec.

One of the three stars entered under G5 III is actually of type G5 III–IV.

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1955ApJ...121..118H

two components; the G5 star is usually regarded as the primary. The Lick spectrograms that we examined were taken in 1938–1939 on Process emulsion, but with a somewhat greater slit-width than we consider optimum. There is no difficulty, however, in assigning a value of $v \sin i < 15$ km/sec to the primary star. The lines of the earlier-type star are much wider. It is our impression from examining a number of our best spectrograms that the narrow features often seen flanking strong lines of the primary, which seem to shift from one side to the other in phase with the secondary spectrum, are frequently not lines of the fainter component at all. In many cases they seem to be only weak lines in the spectrum of the primary star, which strengthen or become faint, depending upon the position of the underlying, wide-lined spectrum of the secondary. In speaking of the line width of the secondary star, therefore, we refer not to these narrow components but to the hazy, ill-defined features that underlie the rich, sharp-lined spectrum of the G5 star. It is difficult to estimate the width of these wide lines, but it is our impression that the line breadth of the earlier-type component of α Aurigae is comparable to that of 31 Comae ($v \sin i = 85$ km/sec). If our interpretation of the spectrum is correct, it is interesting that the components of this binary, which lie on either side of the rotational "cutoff" slightly later than type G0 for stars of intermediate luminosity, have rotational velocities consistent with those of single stars of the same types.

The spectral interval F0–G5 is a region in which the transition from rapidly rotating to slowly rotating stars takes place, and for this reason it may be particularly important to have representative (i.e., extensive) data for stars of these types. The very small numbers of stars in some regions of the spectral-type luminosity-class diagram between F0 and G5 raises the question of how representative such small samples may be. The deterrent to the accumulation of more data is not the fact that somewhat fainter stars would have to be observed with moderately high dispersion but is the lack of accurate spectral-type and luminosity classifications for any significant number of additional objects. A systematic spectral classification of F0–G5 stars down to visual magnitude 6.5 or 7.0 would be very valuable. It not only would make possible a more thorough study of the matters discussed in this paper but might also render practical an examination of aspects of the phenomenon of rotation at which the present data only hint.

It is a pleasure to acknowledge the kindness of Dr. W. W. Morgan in furnishing us in advance of publication with a copy of the 1953 Johnson-Morgan paper that described the MK system. We are much indebted also to Miss Nancy G. Roman for giving us unpublished spectral classifications, and to Dr. W. P. Bidelman for valuable discussions. We also wish to thank Rev. F. C. Bertiau, S.J., for performing the greater part of the reductions of the microphotometer tracings of the standard stars.

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