

ON THE RELATION BETWEEN DISTANCE AND INTENSITY FOR INTERSTELLAR CALCIUM AND SODIUM LINES

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Summary

The results of spectrophotometric measurements of the intensities of the interstellar *K* and *D* lines carried out at the Dominion Astrophysical Observatory in the period 1928–1946 are presented in tabular form. The data relate to 1 055 medium-dispersion spectra of 182 stars, mostly of O and early B types, and include also measures of radial velocity for stellar and interstellar lines in most of the stars.

The interstellar intensities are correlated with stellar distance, a variety of criteria being used for estimating the latter, including trigonometric parallaxes, parallactic motions, luminosities of eclipsing binaries, spectroscopic absolute magnitudes, cluster parallaxes and galactic rotation effects. The various criteria are weighted according to the intrinsic reliability of each method and to the number of stars concerned. The distance–intensity relations best satisfying the observations are :

$$r = 34 \cdot 83 K = 30 \cdot 75 D,$$

where *r* is the distance in parsecs, *K* the equivalent width of the calcium *K* line in km/sec and *D* the mean equivalent width of the sodium lines *D*₁ and *D*₂ in km/sec. Distances assigned to individual stars by using these relations should rarely be more than 25 per cent in error. The scatter is attributed to irregularity in distribution of the discrete clouds of interstellar gas and to uncertainties in the distance estimates. The distance–intensity relations found are compared with those of other observers.

1. *Introduction.*—Ever since the first definite identification of gases in interstellar space it has been recognized that interstellar lines would be expected to increase in intensity with distance, and preliminary studies using eye estimates by Struve* and by Plaskett and Pearce† indicated that this was indeed the case. Since then, precise spectrophotometry of interstellar lines has been undertaken at a number of observatories, and graphs or equations relating distance to interstellar line intensity have been published by Williams‡, Merrill§, Sanford||, Evans¶, van Rhijn** and Beals.†† The purpose of this paper is to present the results of observations of interstellar lines made at the Dominion Astrophysical Observatory during the period 1928–1946 and to compare them with the results of other observers in the hope of getting a reasonably clear picture of the relationship between the intensity of interstellar lines and the distances of the stars in whose spectra they appear.

* O. Struve, *Ap. J.*, **67**, 353, 1928.

† J. A. Pearce, *P. Dom. Ap. O.*, **5**, 167, 1935.

‡ E. G. Williams, *Ap. J.*, **79**, 280, 1934.

§ P. W. Merrill, *Ap. J.*, **86**, 28, 1937.

|| R. F. Sanford, *Ap. J.*, **86**, 136, 1937.

¶ J. W. Evans, *Ap. J.*, **93**, 275, 1941.

** P. J. van Rhijn, *P. Groningen*, No. 50, p. 21, 1946.

†† C. S. Beals, *P. Dom. Ap. O.*, **6**, 333, 1937.

2. *Observational methods.*—The majority of the observations on which this study is based are of O and B stars, and although there are some objects of later type, very few of them are later than B2. This should minimize the effect of blends with stellar calcium lines which are often present as faint lines even in early B-type stars. Most of the spectra were of medium dispersion, 20 and 35 Å per mm for *H* and *K* and 31 Å per mm for the sodium *D* lines. A single prism was ordinarily used for the calcium lines, but three prisms were required to give comparable dispersion in the region of sodium *D*. A few spectra were secured with dispersions of 4.5 to 6.3 Å per mm with three prisms at *K*, while a second-order grating, yielding dispersions of 5.0 to 7.0 Å per mm, was used for some of the brighter stars in the *D* region. The calcium *H* line is almost always blended with H ϵ to some extent, and on single-prism spectrograms it is rare that the two lines are separated clearly enough to yield reliable interstellar intensities. If three-prism dispersion is used, especially if the hydrogen lines are broad and shallow, the calcium *H* line can be measured with sufficient precision, but on many of the single-prism spectra no attempt has been made to derive intensities for this line. The difficulties of measurement are illustrated in the tracing of BD 35° 3955 in Fig. 2.

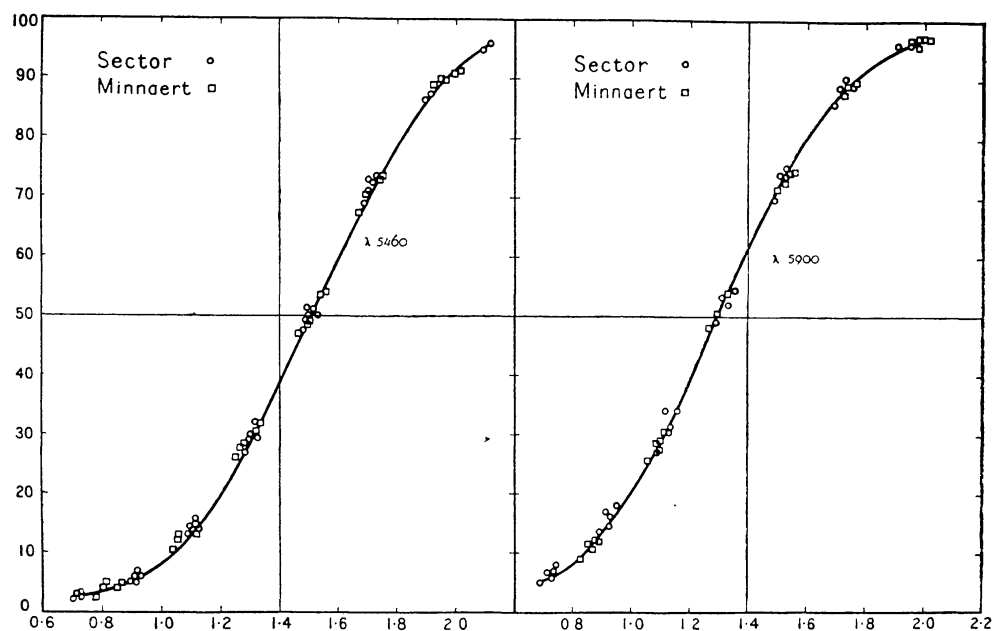


FIG. 1.

Ordinates: Deflection.
Abcissae: Log intensity.

The plates were calibrated by means of a neutral-tint wedge or a rapidly rotating sector placed close to the slit, and care was taken to see that the exposure times of the calibration and the stellar spectra were comparable. An account of the calibration of the wedge has been given elsewhere.* The sector was used for a majority of the plates. It was run at a speed of 100 revolutions per second, and numerous comparisons were made with other methods of calibration to test its validity as a calibration device. Some of these tests have already been published by Petrie and McKellar†, who compared the sector with a step-slit. Additional tests in a number of wave-length regions have been made by

* C. S. Beals, *P. Dom. Ap. O.*, 6, 96, 1933.

† R. M. Petrie and A. McKellar, *Jour. R.A.S.Can.*, 31, 130, 1937.

comparing the sector with a step-weakeners calibrated by Professor Minnaert of Utrecht and loaned to the Dominion Astrophysical Observatory for a few months. Such tests for two wave-lengths in the visible region are illustrated in Fig. 1. Here are shown two calibration curves, each derived from five plates. Each plate had a sector and a step-weakeners calibration impressed upon it. Separate curves were plotted for each plate and combined by displacing them

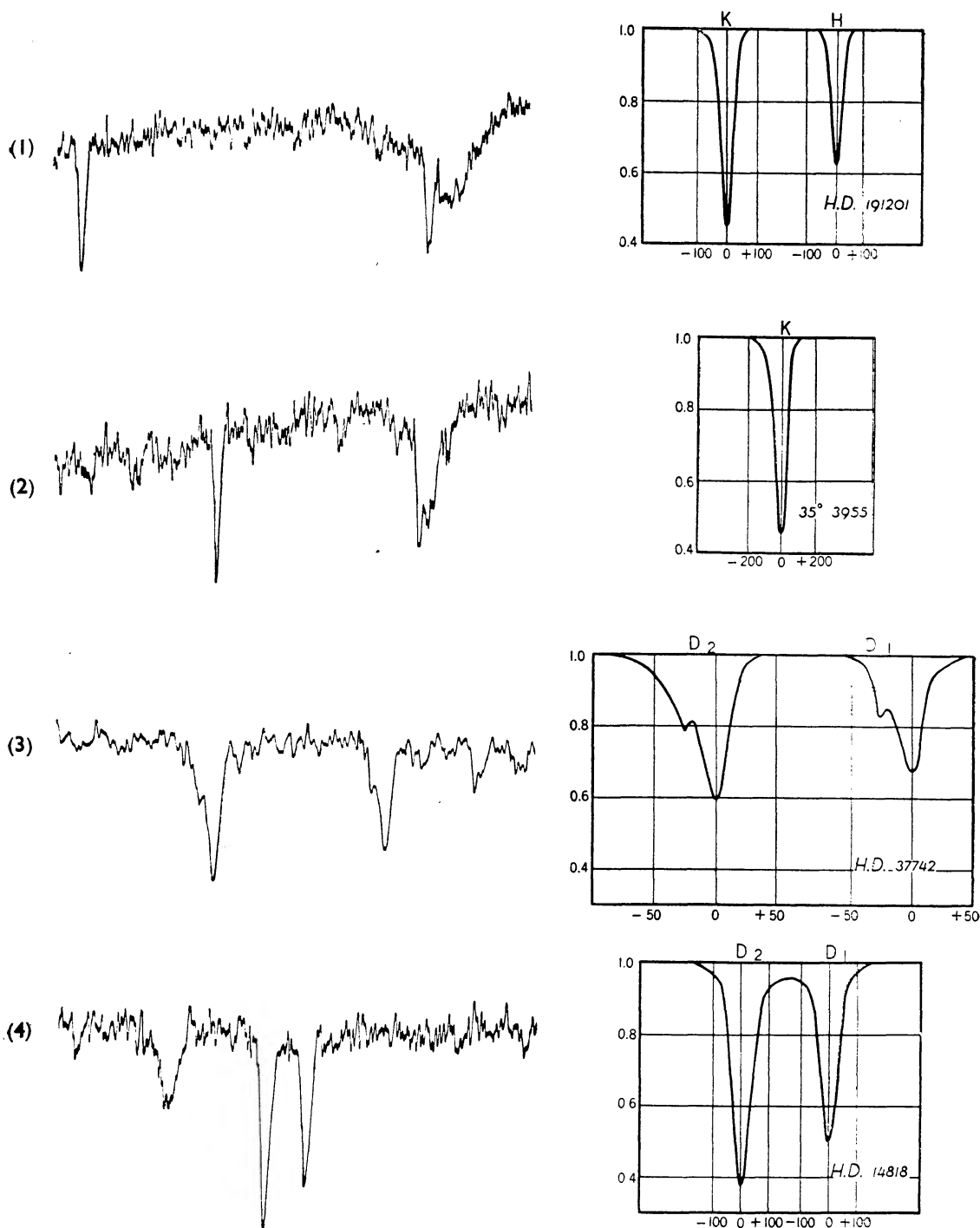


FIG. 2.—Microphotometer tracings. (1) H and K, HD 191201, (2) H and K, 35° 3955, (3) Sodium D lines showing complex structure, HD 37742, (4) Sodium D lines with helium D₃, HD 14818.

FIG. 3.—Intensity profiles corresponding to the tracings of Fig. 2. Ordinates: Intensity. Abscissae: Line width, km/sec.

horizontally till they coincided at the middle of the straight line portion of the curve. The squares represent the readings from the step-weakeners, while the open circles are those from the sector. It will be seen that one curve represents both sets of points equally well. Similar tests were made for numerous other wave-length regions, and in no case was it possible clearly to distinguish a difference between the shapes of the calibration curves due to the two methods. The principal advantage of the sector is that its relatively large diameter of three inches makes it possible to divide the angles and to cut the steps in a sufficiently precise ratio, one to the other, so that in using the calibration it is not necessary to distinguish between the various steps, since all the steps will be equal. In so far as we are aware this is not possible with any other type of calibration device using steps.*

Most of the spectra were analysed with the Victoria microphotometer†, which has been described elsewhere, although some use was made of the Moll microphotometer at Ottawa modified to use a photoelectric cell as a sensitive element. Many of the tracings were reduced with the aid of the semi-automatic intensitometer‡ of the Dominion Astrophysical Observatory. Intensities were derived as equivalent widths in km/sec, and were obtained by integrating the area under the continuous spectrum by means of a planimeter. Specimen tracings and profiles are illustrated in Figs. 2 and 3.

3. *Observational data.*—The observational data refer to 182 stars. Calcium lines have been observed for 173 and sodium lines for 93. The total number of spectra was 1055, making an average of 3.9 for each value of intensity. The number of stars for which both sodium and calcium have been observed is 84.

Radial velocities for practically all the stars and most of the calcium lines are available from the data of Plaskett and Pearce, although numerous additional measures have been made during the present study. Dr R. M. Petrie of Victoria has kindly supplied us with the velocities of a number of stars for which he has determined spectroscopic parallaxes. Many of the sodium line velocities have been measured by Mr John O'Connor of the Dominion Observatory.

The measures of intensity and radial velocity are collected in Table I. Column 1 contains the Henry Draper number or other designation of the star; columns 2 and 3 give the right ascensions and declinations; the magnitudes and spectral types of the stars are given together in column 4, while intensity data, equivalent widths in km/sec, with the number of plates for each star in brackets, are given in columns 5, 6, 7 and 8. The calcium and sodium interstellar velocities in km/sec, with the weighted means, are presented in columns 9, 10 and 11, while the stellar velocity is shown in column 12.

4. *Criteria of stellar distance.*—For such relatively distant objects as are involved in studies of interstellar matter there is a good deal of uncertainty about estimates of distance and it would appear reasonable to use as many different criteria of distance as possible in setting up a distance–intensity graph. The various criteria used in this paper are outlined under a number of separate headings below.

* E.g., in a step-slit the successive increments in width are so small that it is **mechanically** impossible to make them exactly equal.

† C. S. Beals, *M.N.*, **96**, 730, 1936.

‡ C. S. Beals, *Jour. R.A.S.Can.*, **38**, 65, 1944.

TABLE I

Star HD	R.A. 1900 h m	Dec. 1900 ° ' "	Mag., Type	Ca 3933	Ca 3968	Na 5889	Na 5896	Ca Interstellar velocity	Na Interstellar velocity	Mean	Stellar velocity
108	00 00.9	63 07	7.36, O6fq	36.2 (13)	30.8 (1)	44.3 (9)	39.7 (9)	-20.4	-11.1	-15.7	-62.8
698	00 06.3	57 39	7.08, B6	19.8 (3)				-13.9			+ 5.0
886	00 08.1	14 38	2.87, B2s	34.3 (2)				-0.1*		-0.1	-37.1
1337	00 12.5	50 53	6.12, O8n	35.5 (10)		49.8 (6)	37.4 (6)	-22.8	-18.5	-22.4	-05.2
2083	00 20.0	71 15	6.94, B0	25.3 (3)		35.6 (2)	24.4 (2)	-10.5	-06.2	-09.3	-04.7
2905	00 27.3	62 23	4.24, B0	28.1 (3)		37.7 (1)	35.7 (1)	-16.4		-16.4	-92.5
3950	00 37.0	51 48	6.93, B0	37.2 (2)				-14.6		-14.6	-21.1
5005	00 47.0	56 05	7.7, O6	53.5 (3)				-18.9		-18.9	-32.3
9311	01 26.6	60 10	7.26, B5	41.9 (1)				-26.0		-26.0	+01.4
9974	01 32.4	57 39	10, WN5	45.1 (3)	54.6 (3)			+02.8		+02.8	-8.1
10316	01 37.4	50 11	4.19, B0ne	13.8 (3)				-8.5*		-8.5	-39.4
11415	01 47.2	63 11	3.44, B5s	19.8 (2)				-38.4	-26.5	-34.4	-40.0
12953	02 01.7	57 57	5.90, A2p	70.8 (3)		61.2 (1)	48.8 (1)	-32.0	-22.1	-29.5	-43.4
13841	02 09.8	56 34	7.21, B2s	55.0 (6)		67.2 (2)	53.5 (2)	-27.5	-19.7	-25.9	-32.2
13854	02 09.9	56 36	6.42, B0s	58.8 (7)		57.3 (3)	49.4 (3)	-34.5	-20.0	-31.6	-45.2
14134	02 12.1	56 40	6.66, B2s	68.4 (7)		66.3 (2)	57.2 (2)	-33.1	-27.5	-32.2	-39.5
14143	02 12.2	56 43	6.66, B1s	61.0 (9)		78.2 (2)	67.2 (2)	-21.9	+03.9	-12.6	-47.0
14489	02 15.3	55 23	5.22, A2p	69.4 (1)	25.6 (1)			-14.7	-13.0	-22.3	-53.7
14633	02 16.7	41 02	7.7, O8	36.6 (13)		24.5 (1)	15.4 (1)	-26.3		-26.3	-30.3
14818	02 18.2	56 10	6.24, B1s	60.8 (7)		53.5 (9)	45.0 (9)	-25.7		-25.7	-35.4
14947	02 19.5	58 25	8.04, O5f	37.8 (2)				-18.1	-24.3	-19.3	-40.8
14956	02 19.6	57 14	7.32, B1s	49.4 (6)				-14.6	-02.0	-13.7	-04.2
15497	02 24.6	57 15	7.20, B7s	45.0 (1)		50.9 (1)	53.4 (1)	+ 4.4*		-4.4	-5.1
16691	02 35.5	56 28	8.4, O6f	52.5 (2)		44.5 (4)	38.9 (4)	+ 3.5*		+ 3.5	+ 3.0
17505	02 43.4	60 01	7.11, O7	47.5 (5)		32.1 (1)	33.3 (1)	-06.4		-06.4	-0.8
19820	03 06.2	59 11	7.09, O8n	29.5 (2)				-10.2*		-10.2	+04.8
20365	03 11.5	49 51	5.30, B3	18.3 (1)				-05.4		-05.4	+18.5
20418	03 12.0	49 43	5.08, B3	10.7 (1)				+12.4	+00.3	+12.4	-01.9
21389	03 21.9	58 32	4.76, Aop	61.8 (4)				+02.9	+25.2	+17.8	+21.0
21428	03 22.2	49 10	4.67, B5	16.8 (2)				-02.3		-02.3	-08.6
22253	03 29.9	56 23	6.79, Bin	15.5 (2)							
23180	03 38.0	31 58	3.94, B2	10.9 (8)							
23675	03 41.9	52 21	6.76, B0	30.0 (2)		37.3 (2)	33.8 (2)				
24398	03 47.8	31 35	2.91, B1s	24 (1)		21.8 (2)	10.9 (2)				
24431	03 48.1	52 21	6.70, O8	29.0 (3)		43.3 (1)	33.5 (1)				

* Believed blended with stellar line.

24760	03 51.1	39 43	2.96, B2	6.1 (1)	05.5 (3)	20.0 (13)	15.9 (13)	+ 9.1	+ 12.6	- 10.0	- 6.0
24912	03 52.5	35 30	4.05, O7n	12.4 (22)		33.4 (1)	26.6 (1)	- 14.5	- 01.3	- 03.1	+ 67.4
25443	03 57.4	61 48	6.75, B0					- 04.0		- 03.1	- 01.6
25638	03 59.4	62 04	7.04, Bon	23.0 (3)				- 07.4		- 07.4	+ 11.0
25639	03 59.1	62 04	7.07, Bon	27.0 (1)				- 08.2		- 08.2	- 12.8
25833	04 00.6	33 11	6.61, B3	18.3 (2)				+ 11.7		+ 11.7	+ 15.8
25940	04 01.4	47 27	4.03, B3e	9.1 (1)				+ 4.9*		+ 4.9	+ 4.0
28446	04 24.1	53 42	5.42, B1	20 (1)				+ 01.3		+ 01.3	
29376	04 32.5	07 07	6.89, B5	27.4 (6)				+ 21		+ 21	+ 38.2
29763	04 36.2	22 46	4.33, B5n	19.0 (1)				+ 17.0*		+ 17.0	+ 13.6
30614	04 44.1	66 10	4.38, O9se	28.5 (5)		32.7 (10)	27.8 (10)	- 06.0	- 05.7	- 06.0	+ 06.0
30836	04 45.9	05 26	3.78, B2s	16.0 (7)	18.2 (1)	15.6 (1)	6.2 (1)	+ 16.3*	+ 24.1	+ 20.9	+ 23.3
31237	04 49.0	02 17	3.87, B2s	15.6 (7)		20.3 (1)	10.9 (1)	+ 8.1*	+ 23.1		+ 24.2
33328	05 04.4	-08 53	4.34, B3n					+ 12		+ 12.8	+ 3.0
34078	05 09.7	34 12	5.81, O9ss	12.1 (1)				+ 12.8	+ 12.8		+ 59.3
34333	05 11.6	36 31		27.4 (6)				+ 12.7			
34656	05 14.0	37 20	6.71, O6se	20.3 (4)	11.5 (1)	35.6 (1)	29.3 (1)	+ 03.6	+ 05.8	+ 04.2	- 00.4
35039	05 16.7	-00 29	4.65, B3	14.5 (2)				+ 10.4*		+ 10.4	+ 28.8
35411	05 19.4	-02 29	3.44, B0	9.9 (2)				+ 10.8*		+ 10.8	+ 19.5
35468	05 19.8	06 16	1.70, B2s	8.4 (2)				+ 21.6*		+ 21.6	+ 18.0
35715	05 21.6	03 00	4.66, B2	7.6 (3)				+ 19.7		+ 19.7	+ 12.0
35921	05 23.0	35 18	6.71, O9	26.5 (2)				+ 07.4		+ 07.4	- 18.9
36267	05 25.4	05 52	4.32, B4n	9.1 (2)	1.8 (6)	6.5 (1)	4.6 (1)	+ 19.0*	+ 16.0	+ 15.7	+ 20.7
36486	05 26.9	-00 22	2.48, B0	3.5 (9)				+ 15.7			+ 19.9
36822	05 29.3	09 25	4.53, Boss	18.3 (2)				+ 16.5			+ 33.2
36861	05 29.6	09 52	3.66, O8s	17.6 (6)		18.2 (6)	14.0 (6)	+ 13.3	+ 24.8	+ 16.2	+ 34.8
37043	05 30.5	-05 59	2.87, O8s	5.7 (7)	3.5 (4)	7.2 (5)	5.4 (5)	+ 29.9	+ 10.2	+ 26.0	+ 21.5
37128	05 31.1	-01 16	1.75, B0	9.1 (10)	4.4 (7)	17.0 (9)	10.5 (9)	+ 18.5	+ 17.4	+ 18.1	+ 25.8
37468	05 33.7	-02 39	3.78, B0	6.3 (1)				+ 16.3		+ 16.3	+ 27.8
37742	05 35.7	-02 00	2.05, Bon	8.2 (6)	4.5 (4)	16.2 (9)	10.8 (9)	+ 11.2	+ 22.0	+ 13.8	+ 19.0
37756	05 35.8	-01 11	5.00, B3	12.2 (3)				+ 13.9			+ 26.1
41161	05 58.2	48 15	6.51, O9n	19.2 (5)	15.8 (3)	29.5 (2)	23.8 (2)	+ 09.2	+ 06.2	+ 08.4	+ 05
41398	05 59.8	28 56	7.45, B0	45.5 (1)				+ 06.0		+ 06.0	+ 17.1
42088	06 03.7	20 31	7.40, O6	19.9 (1)	16.1 (1)			+ 09.7		+ 09.7	+ 24.1
42560	06 06.3	14.14	4.35, B3nn	15.2 (2)				+ 10.0*			+ 24.0
43818	06 13.2	23 30	7.03, Bos	26.2 (2)		32. (1)	35. (1)	+ 12.5	+ 07.2	+ 11.2	+ 18.2
45542	06 23.0	20 17	4.06, B5ne	19.8 (2)		59.5 (1)	43.0 (1)	+ 18.0*		+ 18.0	+ 38.4
45910	06 25.2	05 57	6.70, B3eq	25.6 (3)				+ 20		+ 20	
46149	06 26.6	05 06	7.66, O8	19.3 (1)				+ 17.1		+ 17.1	+ 38.9

*Believed blended with stellar line.

TABLE I (cont.)

Star HD	R.A. 1900	Dec. 1900	Mag., Type	Ca 3933	Ca 3968	Na 5889	Na 5896	Ca	Na	Interstellar velocity Mean	Stellar velocity
46150	h m	° ' "	6.80, O6	23.3 (3)	16.4 (1)	26.2 (1)	33.1 (1)	+18.5	+23.9	+19.8	+35.9
46223	06 26.6	05 00	7.14, O8	22.4 (2)	16.2 (1)	36.2 (1)	25.1 (1)	+16.4	+24.4	+17.7	+42.2
46966	06 27.0	04 53	7.3, O8	29.9 (3)		37.2 (1)	26.5 (1)	+14.0	+30.2	+16.3	+42.3
47129	06 31.1	06 10	6.06, O8e	26.4 (6)		36.1 (2)	36.1 (2)	+16.0		+16.0	+23.9
47432	06 32.0	06 13	6.13, Bo	23.6 (4)	15.1 (1)			+21.6		+21.6	+49.0
47755	06 33.5	01 42	8.12, B4	24.4 (4)							
47839	06 35.1	09 53	4.68, O7s	17.4 (9)	8.3 (3)	16.8 (3)	10.0 (3)	+13.6	+17.2	+14.5	+33.4
48099	06 35.5	09 59	6.20, O7	30.4 (4)		47.4 (3)	39.0 (3)	+14.3	+09.3	+12.6	+30.8
48434	06 36.6	06 27	5.78, Bo	25.1 (3)		40.6 (2)	34.8 (2)	+19.2	+23.0	+20.3	+34.5
54662	06 38.3	04 02	6.20, O7	19.4 (6)	11.4 (1)			+29.5		+29.5	+63.0
55879	07 04.6	-10 11	5.99, O9s	11.3 (3)				+28.6		+28.6	+31.9
60848	07 09.7	-10 08	7.7, O7ne	17.3 (1)	3.0 (13)	11.6 (17)	5.7 (17)	+13.1	+15.8	+13.5	+28.1
91316	07 31.4	17 07	3.85, Bos	7.8 (18)				+07.4	-02.2	+05.3	+42.2
104337	10 27.5	09 49	5.28, B3	7.6 (2)				-12.9*		-12.9	+1.7
109387	11 55.7	09 06	3.88, B5e	3.8 (2)				-11.5		-11.5	-11.4
116658	12 29.2	70 20	1.21, B2	2.3 (2)				+13.9*		+13.9	+1.6
144217	13 19.9	-10 38	2.90, B2	3.0 (1)				-13.0		-13.0	-9.3
144218	15 59.6	-19 32	5.06, B3	9.1 (2)				-23.9*		-23.9	-4.3
149757	16 31.7	-10 22	2.70, Bonn	7.0 (9)	4.2 (6)	13.2 (5)	11.6 (5)	-10.8		-10.8	-18.9
149881	16 32.4	14 40	6.59, B2	28.9 (7)		13.3 (2)	8.1 (2)	-16.3		-16.3	+18.2
166182	18 04.4	20 48	4.32, B2s	18.4 (4)				-19.9	-24.2	-20.9	-13.0
168957	18 17.3	25 01	6.86, B3e	25.8 (4)				-17.2		-17.2	-41.2
169454	18 19.6	-14 02	6.84, Bo	65.1 (6)		15.0 (1)	12.8 (1)	-01.0	+22.6	+03.7	-17.3
170650	18 25.5	23 48	5.72, B5					-18.7	-09.3	-17.5	
175227	18 49.3	24 09	8.4, B5, B4	10.7 (5)				-21.1		-21.1	
180554	19 11.9	21 13	4.60, B5n	16.0 (2)				-14.0*		-14.0	-17.4
181987	19 17.5	25 23	7.3 to 8.3, B4, B6	16.8 (3)				-25.6*		-25.6	-15.1
183143	19 23.0	18 05	6.93, B8s			43.5 (3)	34.3 (3)		+03.4	+03.4	+13.0
184915	19 31.5	-07 15	5.04, Bon	18.0 (2)	7.4 (2)	21.6 (4)	15.7 (4)	-05.1	-16.2	-08.8	-22.5
185859	19 36.1	20 15	6.44, Bo	33.2 (4)		28.0 (2)	19.8 (2)	-05.2	-00.2	-03.5	+05.6
186745	19 41.2	23 41	7.0, B8	54.9 (1)				-13.8		-13.8	
186980	19 42.4	31 52	7.28, O8	27.2 (4)		43.1 (4)	43.1 (4)	-13.5	-07.2	-11.0	+04.2
187459	19 45.0	33 12	6.35, Bon	25.9 (4)		35.1 (3)	24.6 (3)	-12.3	+03.6	-09.9	-10
187879	19 47.2	40 20	5.62, B2	9.1 (3)				-17.4			-6.2

* Believed blended with stellar line.

[illegible]

*** Believed blended with stellar line.**

TABLE I (cont.)

Star HD	R.A. 1900 h m	Dec. 1900 °	Mag., Type	Ca 3933	Interstellar line intensity Ca 3968	Na 5889	Na 5896	Interstellar velocity Ca Na		Stellar velocity
197911	20 41.6	62 51	8.7, B5	32.8 (5)		29.3 (6)	26.0 (6)	-18.5	-18.5	
198478	20 45.5	45 45	4.89, B2s	40.8 (2)		21.9 (1)	17.2 (1)	-07.6	-13.6	-06.6
198639	20 46.6	43 41	5.07, A5			43.6 (3)	39.5 (3)	-09.7	-14.7	-56.8
198846	20 48.1	34 17	Var., Ognn	28.9 (6)				-4.9	-18.0	
199140	20 50.1	28 08	6.44, B3	26.3 (16)						
199478	20 52.4	47 02	5.76, B8p			38.6 (2)	28.6 (2)	+00.4	+00.4	
199579	20 53.1	44 33	6.01, O6	23.3 (4)		53.1 (1)	48.4 (1)	-11.3	-17.1	-05.8
202214	21 09.3	59 35	5.65, O9s	26.9 (4)	9.8 (1)	30.4 (6)	26.0 (6)	-18.8	-15.4	-16.1
202904	21 13.8	34 29	4.42, B3ne	5.3 (2)				-19.3*	-19.3	+3.5
203064	21 14.8	43 31	5.06, O8nn	25.5 (7)	20.1 (4)	19.2 (10)	15.3 (10)	-13.7	-10.4	+03.6
203374	21 16.7	61 25	6.64, Bone	27.0 (1)		37.0 (2)	34.8 (2)	-16.7	+13.9	-07.0
204116	21 21.4	54 57	7.96, Bon	33.6 (2)		44.1 (2)	20.7 (2)	-11.5	-01.4	-22.6
204172	21 21.7	36 14	5.84, Bo	23.1 (2)		23.2 (3)	22.5 (3)	-10.8	-14.6	+02.8
205196	21 28.6	57 04	7.36, Bos	20.8 (1)		27.2 (1)	23.4 (1)	-19.6	-09.1	-12.8
206267	21 35.9	57 02	5.64, O6n	26.3 (2)		42.5 (1)	31.2 (1)	-18.5	+04.3	-08.0
206773	21 39.3	57 17	6.98, Bonne			46.2 (1)	29.6 (1)	-19.0		-21.6
207198	21 42.2	61 59	5.97, O9s	22.7 (3)		38.5 (4)	30.7 (4)	-20.5	-11.5	-20.5
207260	21 42.6	60 40	4.46, Azp			42.5 (1)	29.4 (1)	-12.7	-17.7	-20.7
209339	21 57.6	62 00	6.48, Bo	18.9 (3)				-10.9	-06.7	-17
209481	21 58.7	57 31	5.50, O9n	20.1 (5)		47.0 (9)	37.8 (9)	-12.6	-06.9	-12.8
209975	22 02.1	61 48	5.17, O9	21.0 (4)		35.8 (5)	30.7 (5)	-13.0	-16.5	-74.3
210839	22 08.1	58 56	5.19, O6ne	24.4 (14)	22.6 (5)	41.1 (9)	35.8 (9)	-29.7		-33
211853	22 15.0	55 37	9.0, O7+WN7	64.4 (1)	59.4 (1)			-13.5	-29.8	-54.7
212455	22 19.3	54 44	8.4, B3	81.2 (1)				-18.9		-15.1
214240	22 31.8	49 33	6.2, B4	38.1 (2)				-20.0		-20.0
214419	22 32.9	56 23	8.92, WN7	42.3 (4)	35.5 (4)			-17.8	-07.1	-09.5
214680	22 34.8	38 32	4.91, O9s	18.1 (4)		27.4 (5)	19.0 (5)	-26.3	-22.0	-23.1
216014	22 44.2	64 32	6.83, Bo	47.4 (10)		54.9 (3)	37.7 (3)	-22.4	-21.9	-43.8
216411	22 47.6	58 28	7.16, Bos	51.9 (5)		51.8 (2)	33.6 (2)	-11.4	+09.3	-10.1
217297	22 54.7	63 10	7.36, Bo	30.1 (4)		35.1 (3)	32.4 (3)	-15.6		-7.4
218066	23 00.0	62 51	7.8, B5	35.1 (3)				-9.8	-10.4	-72.0
218440	23 03.0	59 13	6.28, B3	17.5 (3)		53.9 (2)	36.5 (2)	-11.5*		-14.8
218915	23 06.7	52 31	7.06, O9s	37.9 (4)				-26.3	-09.3	-42.7
221253	23 25.4	58 00	4.89, B3	22.1 (2)		71.6 (1)	54.3 (1)	-21.0		-26.7
224055	23 49.7	61 17	7.16, B8s							
224151	23 50.5	56 35	6.05, Bo	33.5 (6)	33.1 (2)					

* Believed blended with stellar line.

Trigonometric parallaxes. While trigonometric parallaxes are available for quite a number of early-type stars* a good deal of caution is necessary in their use. For most of the stars the parallaxes are of the same order as their probable errors, while a further indication of the uncertainty of such measures is the existence of many negative parallaxes. It was recognized therefore that trigonometric parallaxes would be significant only for nearby stars with relatively weak lines. In a first attempt to use such parallaxes a list of 27 stars was drawn up, all with interstellar *K* line intensities less than 20 km/sec. These stars were divided into two groups with intensities in the range 0 to 10 and 10 to 20 km/sec respectively. The mean trigonometric parallax for the first group was $+0''.012$, while that of the second was $-0''.0003$. This suggested that it was probably useless to try to utilize the trigonometric parallaxes to fix more than one point on the distance-intensity graph. It was accordingly decided to use the trigonometric parallaxes only for stars with intensities of 12 or less and to average the parallaxes regardless of sign, resulting in a single point on the graph.

This has been done and the resulting values for calcium and sodium are given in Tables IV and V. The basis of selection for the stars has been a calcium intensity of 12 or less and since some of the sodium lines are stronger than calcium this accounts for the higher average sodium intensities. The mean distance of 154 parsecs for calcium is based on 19 stars, while that of 167 parsecs for sodium is based on 6. This close agreement must be regarded as probably fortuitous and both of the points have been given low weight.

Parallactic motions. While it is theoretically possible to utilize both the tau and the epsilon components of proper motion to compute the distances of stars it has been shown by Russell† and by Plaskett and Pearce‡ that more reliable results are obtained from the epsilon components and they have been used here. The proper motions have been taken from the Albany *General Catalogue* and Mrs Dorothy Edmonds of the Dominion Astrophysical Observatory has very kindly computed the epsilon components. For the distant O- and B-type stars the probable errors are quite large and some of the more distant stars with stronger lines have been excluded from the calculation. For calcium, only lines with intensities less than 40 have been used, while for sodium, with somewhat stronger lines, the limit has been set at 50.

A total of 104 calcium stars have been used, divided into three approximately equal groups, while 59 stars are available for sodium.

The usual formula

$$\pi_v = \frac{4.738 \, v \sin D}{V_0 \sin^2 D}$$

has been used in deriving distances for the various groups. The stars of the h and χ cluster in Perseus have been excluded from the data by the intensity criterion and it is not considered that other cluster stars have seriously interfered with the solutions.

The results are given in Tables IV and V. It will be seen that the mean intensities range from 10 to 35 while the mean distances are from 200 to 1 000 parsecs, covering a reasonable proportion of the distance-intensity range.

* Louise F. Jenkins, *Gen. Cat. Trig. Parallaxes*, Yale University Observatory, 1952.

† H. N. Russell, *Ap. J.*, **54**, 140, 1921.

‡ J. S. Plaskett and J. A. Pearce, *P. Dom. Ap. O.*, **5**, 203, 1931.

Eclipsing binaries. Objects of this type for which absolute dimensions are available as a result of spectroscopic and photometric studies afford distances for eleven stars listed in Table II. We are indebted to Dr R. M. Petrie for help in selecting this list. In deriving the calculated absolute magnitudes from radii

TABLE II
Eclipsing binaries

Star HD	Spectral type	App. mag. <i>m</i>	Abs. mag. <i>M</i>	Int. <i>K</i>	Int. <i>D</i>	Dist. <i>r</i> (ps)
1 337	O8.5*	6.1	-6.2	35.2	43.6	2 630
19 820	O8	7.4	-4.9	29.5	32.7	1 030
25 833	B3	6.6	-2.1	18.3	...	390
34 333	B3	7.8	-5.6	27.5	...	3 160
175 227	B5	8.5	-1.2	10.7	...	690
181 987	B3	7.1	-3.1	16.8	...	740
193 576	O6WN5.5	8.0	-5.9	28.2	...	2 840
193 600	B0.5	9.2	-4.5	38.1	...	2 630
198 846	O9.5	7.1	-4.4	28.1	41.6	1 460
216 014	B3	6.8	-3.6	32.6	46.3	510
218 066	B3	7.8	-2.8	35.1	...	1 010

* Unless otherwise indicated the two components are assumed to be of the same type.

Calcium		Sodium	
Two groups		One group	
Int. <i>K</i>	<i>r</i>	Int. $\frac{D_1+D_2}{2}$	<i>r</i>
15.3	610	41.1	1410
31.8	1910		

and spectral types the temperature scale recently published by Beals*, smoothed for uniformity, has been used for the O-type stars, while Kuiper's† scale has been used for stars later than B0. To correct the apparent magnitudes for space absorption we have followed Stebbins, Huffer and Whitford‡ in using the relationship

$$m_0 = m - 7E_1,$$

where *m* is the observed apparent magnitude, *E*₁ is the colour index of Stebbins and Whitford and *m*₀ is the apparent magnitude corrected for space absorption. This relationship has been derived from the observational results of a number of workers, including not only Stebbins and Whitford but also Rudnick, Hall and Greenstein, indicating that selective absorption in space is closely proportional to the inverse first power of the wave-length (λ^{-1} law). In certain instances, such as the Wolf-Rayet binary HD 193 576, or other stars where the colour indices are not available or are of doubtful interpretation, it is assumed that the general absorption amounts to 0.8 magnitudes per thousand parsecs.

* C. S. Beals, *Jour. R.A.S.Can.*, **44**, 221, 1950.

† G. P. Kuiper, *Ap. J.*, **88**, 429, 1938.

‡ J. Stebbins, C. M. Huffer and A. E. Whitford, *P. Washburn O.*, **15**, Part 5, 1934; *Ap. J.*, **90**, 213, 1939; *Ap. J.*, **91**, 20, 1940.

The calcium stars of Table II have been divided into two groups, those with intensities less than 20 km/sec and those with intensities over 20; three stars being in the first group and eight in the second. Only four of the stars have measured sodium lines and since these intensities are all over 20 they have been used to define a single point on the curve. Actual values are given at the bottom of Table II and in Tables IV and V. The relatively large deviation of individual stars from a smooth distance-intensity relation will be discussed in a later paragraph.

Spectroscopic absolute magnitudes. At the time these data were being prepared we were in communication with Dr W. W. Morgan of the Yerkes Observatory and Dr R. M. Petrie of the Dominion Astrophysical Observatory, both of whom had derived spectroscopic absolute magnitudes for a considerable number of early-type stars. Both Dr Morgan and Dr Petrie very kindly offered to place relevant parts of their data at our disposal in advance of publication. Morgan's list included 102 of our stars. For 97 of these, calcium line intensities had been measured, while there are sodium lines for 59. Dr Petrie provided absolute magnitudes for 53 stars. While a few of these were on our original list, a majority of the calcium lines had been measured by Dr Petrie himself and he has kindly allowed us to add this material to our Table I.

Dr Morgan informs us that the zero point of his calibration depends on two independent sources:

(1) The main sequence B2 and B3 stars in the Scorpio-Centaurus cluster as re-discussed by Blaauw (*Groningen Pub. No. 52*).

(2) Mean parallaxes determined from upsilon components for a group of main sequence B3 stars not members of any cluster and scattered over the sky; also unpublished results of Blaauw on a similar calibration of B2, B3 and B5 stars from upsilon components.

The standard luminosities for stars of other types and those brighter than the main sequence have been determined from certain clusters, principally the Orion aggregate and the Double Cluster in Perseus, by use of the calibrated main sequence B2 and B3 stars.

Dr Petrie writes that he has used the following material for the calibration of his absolute spectroscopic magnitudes:

(1) The galactic clusters η and χ Persei, the Perseus stream, the Pleiades, the Orion cluster, Messier 35, IC 4665, NGC 6633 and the Scorpio-Centaurus stream.

(2) Visual binaries in which the fainter component is of spectral type B9 or later.

(3) Eclipsing binaries for which reliable absolute magnitudes could be calculated from the combination of photometric and spectroscopic orbits.

For Petrie's stars we have used the photoelectric colour indices of Stebbins, Huffer and Whitford to correct the apparent magnitudes for general absorption in the manner already discussed under spectroscopic binaries. In spite of the uncertainties involved in this method, it is probably the best that can be done at the present time.

Morgan has himself corrected the apparent magnitudes of his stars by a method which is similar except that he used a revised table of colours available at Yerkes which is slightly different from that of Stebbins and his group.

In order to derive mean distances, the stars have been divided into the following intensity groups: 0 to 15, 15 to 30, 30 to 50 and over 50. The results are given in Tables IV and V. The data of Morgan and Petrie have been combined strictly according to the numbers of stars. While there are quite large systematic differences between them, we feel that a discussion of such differences should await publication of individual parallaxes.

Galactic clusters. Estimates of the distances of galactic clusters are based on spectroscopic parallaxes and on considerations of apparent diameter. Trumpler* has discussed both methods in considerable detail and has shown that there is reasonable agreement between them. Later studies by Zug, Rieke, Bidelman and others† have been based mainly on spectroscopic parallaxes.

TABLE III
Galactic clusters

Cluster	Distance parsecs	Int. K	No. of stars	Int. D	No. of stars
h and χ Per	1 900	58.9	(6)	59.5	(2)
IC 1848	1 610	47.5	(1)	41.7	(1)
NGC 1444	3 340	30.0	(1)	35.6	(1)
NGC 1502	1 450	24.0	(2)	...	
NGC 2244	1 340	22.3	(3)	30.2	(3)
NGC 2264	450	17.4	(1)	13.4	(1)
NGC 2353	760	11.3	(1)	...	
NGC 6871	1 340	46.2	(8)	55.6	(2)
NGC 6910	2 200	61.0	(1)	...	
AN 37	730	26.3	(1)	36.8	(1)

Calcium		Sodium	
Three groups		Three groups	
Int. K	r	Int. $\frac{D_1 + D_2}{2}$	r
14.4	605	13.4	450
25.7	1715	34.2	1803
52.9	1750	51.4	1616

Although a number of the stars in the present study appear to be members of clusters, there is some question as to how much use should be made of cluster distances based on spectroscopic parallaxes. The distances of numerous individual stars have already been derived by this method and there is some doubt whether the same method should indirectly be used over again. The matter turns on the question of the similarity in spectral type between the stars in Table I whose distances have been directly found by spectroscopic methods and the stars used in the original determinations of cluster distance. We have had the benefit of discussions of this question with Dr R. J. Trumpler and Dr R. M. Petrie. They point out that the spectroscopic determinations of cluster distance are, in general, based on later spectral classes than the stars of Table I and that, therefore, the distances of the clusters may be regarded as independently determined. It accordingly appears that the inclusion of such distances should be a valuable addition to the data and we have proceeded accordingly. In Table III

* R. J. Trumpler, *L.O.B.*, 14, 154, 1930.

† R. S. Zug, *L.O.B.*, 16, 119, 1933. C. A. Rieke, *Harv. Circ.*, 397, 1935. W. P. Bidelman, *Ap. J.*, 98, 61, 1943.

are given the values of distance and interstellar line intensity for individual clusters, together with the number of stars involved for each cluster. For the most part Trumpler's data have been used but some results of Zug, Mrs Rieke and Bidelman have been included. The values of cluster distance based on spectroscopic parallaxes have been given somewhat greater weight than those estimated from cluster diameter. It is never possible to be certain that a given star is not a foreground or background object but it is hoped that the assignments of stars to particular clusters are, in general, correct. The clusters have been divided into three groups, as shown in Tables IV and V, with intensity ranges 0–20, 20–40 and over 40.

Galactic rotation. The velocity of stars or of interstellar matter due to the motion of rotation of the Galaxy is related to the distance by the well-known equation*

$$v = \bar{r} A \sin 2(l - l_0) \cos^2 b.$$

Here v is the velocity of the star or group of stars with the solar motion removed, r is the distance in parsecs, A the constant of galactic rotation (here assumed to be 0.017 km/sec per parsec), l is the galactic longitude of the star and l_0 the longitude of the galactic centre (assumed to be 325° following Plaskett and Pearce), while b is the galactic latitude. For interstellar matter it is necessary to use twice the velocity since the centre of the absorbing column may be assumed to be located at half the stellar distance.

Fortunately the stars of the present list are well distributed in galactic longitude, extending from 346° to 192° , so that approximately half of the double-wave cycle in radial velocities is well covered. Radial velocities are available for all the stars, so that the distance estimates from galactic rotation are more representative of the data as a whole than those of other methods.

The stars were divided into distance groups by a graphical method designed to combine fairly equal-sized groups with reasonable ranges of intensity. Calcium intensities were plotted against sodium for all the stars in the table and a smooth curve drawn through the points. For stars with calcium or sodium only the points were plotted on the curve. The division into groups was accomplished by drawing lines normal to the curve on the basis of the general distribution of the points in intensity and distance, the stellar and interstellar velocities being treated separately. After discussions with Dr Petrie it was decided to exclude from the solutions a considerable number of stars with weak lines in which the presence of interstellar calcium was doubtful. In deriving final values of distance, those calculated from velocities by interstellar lines have been given twice the weight of those using the stellar velocities. The results are shown in Tables IV and V.

5. *Weights of the observations.*—In choosing weights for the various points used in defining the distance–intensity relationship both the methods of distance determination and the numbers of stars are considered.

For the trigonometric parallaxes we may note that for stars only a few hundred parsecs distant the probable errors are of the same general order as the quantity to be measured. It has, therefore, been found necessary to limit this method to stars with relatively weak lines and even with this restriction the distances derived have only statistical value. It is probable that the weak lines of the nearer

* J. S. Plaskett and J. A. Pearce, *P. Dom. Ap. O.*, **5**, 175, 1931.

stars are measured with less accuracy than the stronger lines but this factor is scarcely important enough to influence the weighting. In spite of the fundamental character of trigonometric parallaxes their large probable errors necessitate low weight and a weight of 1 has accordingly been assigned to this method.

TABLE IV
Distance-intensity graph for calcium

Method of distance measurement	Group number	No. of stars	Interstellar K line intensity	Distance parsecs	Weight
Trigonometric parallaxes	1	19	7.0	154	19
Parallactic motions	1	34	9.8	210	119
	2	35	20.7	464	105
	3	35	30.4	1 095	88
Eclipsing binaries	1	3	15.3	610	9
	2	8	31.8	1 910	24
Spectroscopic parallaxes	1	28	8.0	295	56
	2	67	26.0	860	134
	3	29	37.9	1 190	58
	4	12	59.2	1 830	24
Galactic clusters	1	2	14.4	605	3
	2	7	25.7	1 715	11
	3	16	52.9	1 750	24
Galactic rotation	1	16	7.4	233	32
	2	35	20.3	519	87
	3	39	28.4	789	117
	4	31	39.2	1 782	109
	5	14	57.3	2 069	56

Parallactic motions, as indicated by the ϵ components of proper motion, depend on astronomical measurements of the same character as trigonometric parallaxes, but their larger base lines give them considerably higher weight. The method is, for obvious reasons, more definitive for near than distant stars. After a consideration of various factors, including the relatively small peculiar motions of the O- and B-type stars, it has been decided to assign a general weight of 3 to this method with the proviso that the nearer groups in Tables IV and V shall receive weights of 3.5 and the more distant a weight of 2.5.

The use of eclipsing binaries as indicators of distance has special advantages, chief of which are the fundamental character of the theory involved and the fact that, apart from the effects of general space absorption, the distance of near and distant stars are obtained with comparable accuracy. Errors in the determination of orbital elements and assumptions concerning the relationship between effective temperature and spectral type introduce uncertainties of unknown amount into the calculations, however, and it must also be acknowledged that the influence of general absorption by solid particles in space is not too definitely known. Considering all these factors it has been decided to give this method a weight of 3, equal to that of parallactic motions.

The method of spectroscopic parallaxes, at least in the present state of astrophysical knowledge, is derivative rather than fundamental and depends on a variety of methods, including the three described above. The broadness of its base is in its favour, but the systematic differences mentioned earlier in this paper between such senior investigators as Morgan and Petrie are an indication of its uncertainties. In consideration of these factors it has been decided to give this method a weight of 2.

TABLE V
Distance-intensity graph for sodium

Method of distance measurement	Group number	No. of stars	Interstellar <i>D</i> line intensity*	Distance parsecs	Weight
Trigonometric parallaxes	1	6	10.2	167	6
Parallactic motions	1	30	19.0	377	105
	2	29	35.5	747	73
Eclipsing binaries	1	4	41.1	1 410	12
Spectroscopic parallaxes	1	9	10.9	392	18
	2	20	22.4	885	40
	3	29	36.4	1 190	58
	4	6	60.0	1 884	12
Galactic clusters	1	1	13.4	450	2
	2	5	34.2	1 803	8
	3	5	51.4	1 616	8
Galactic rotation	1	7	10.6	260	14
	2	23	23.5	560	57
	3	29	34.2	840	87
	4	20	43.3	1 490	70
	5	9	58.9	2 300	36

* The interstellar line intensity used here is $\frac{D_1 + D_2}{2}$.

As has already been mentioned, the use of cluster distances is dependent upon estimates of diameter and on the spectroscopic parallaxes of stars of later type than those considered here. Discussions with Dr Trumpler, who is mainly responsible for the use of diameters in the estimation of distance, indicate that this method is none too reliable. The use of spectroscopic parallaxes at second hand and the fact that there is always the possibility that a given object is a foreground or background star would appear to place this method in a lower rank than that of spectroscopic parallaxes proper. It has accordingly been decided to give this method a weight of 1.5.

The method of galactic rotation is free from most of the disadvantages mentioned in connection with the other methods. The theory appears to be well established and has been confirmed by extensive observations, at least for stars with distances less than 2 000 parsecs. Within reasonable limits it is applicable to stars of various distances. It is actually more definitive for distant objects, partly because of the greater ease of separating the galactic rotation effects from peculiar motions and partly because for interstellar lines the averaging effect may be

regarded as more complete for long than for short optical paths. Although in the initial determination of the constant A the effects of general absorption must be considered, the method is less likely than others to lead to serious errors due to this cause when dealing with restricted groups of stars. The principal disadvantages are the lack of observations in the Southern Hemisphere, interfering somewhat with the statistical average for each group of stars, and the existence of peculiar or group motions which are not in accord with the theory. In spite of these disadvantages we were at first inclined to feel that this method superseded the others and originally it was assigned a weight of 4. A study of the solutions, however, showed that many of the stars near the null points of galactic rotation made a negligible contribution to the result, while it was apparent that a few large residuals could have a serious effect on the calculations of mean distance. The method of galactic rotation has accordingly been assigned a general weight of 3, equal to that of eclipsing binaries and parallactic motions. The various groups have, however, been weighted according to distance, beginning with the nearest as follows : 2, 2.5, 3, 3.5, 4.

The weights of the various groups in Tables IV and V have been computed on the basis of the above discussion, the weight assigned to the method being multiplied in each case by the number of stars involved. A preliminary study of the data indicated that the scatter of the points was too great to make it possible to distinguish between a straight line and a curve for the distance-intensity graph. It was accordingly decided to assume a straight line and solve for the slope by a least-squares method, assuming the line to pass through the origin. This has been done for calcium and sodium with the following results, which are illustrated graphically in Figs. 4 and 5 :

$$r = 34.83 K,$$

$$r = 30.75 D,$$

r being in parsecs, K being the equivalent width of the K line in km/sec and D being the average intensity of D_1 and D_2 expressed in the same units. If the equivalent widths are given in angstroms the coefficients become 2660 and 1566 respectively. It should perhaps be mentioned that quite large differences in the system of weighting will lead to essentially the same result.

The scatter of the points about the lines in Figs. 4 and 5 is larger than had been expected, and it is difficult to be sure whether it is due mainly to uncertainties in the measurement of distance or to the irregular distribution of interstellar gas. Of special interest in this connection is the poor fit on the curve of the points due to spectroscopic binaries. Here we would normally expect the absolute magnitudes to be reliable and yet it is clear from a study of Table II that individual stars deviate widely from the distance-intensity graph. It seems extremely unlikely that errors in the determination of spectroscopic elements combined with uncertainty in the relation between spectral type and temperature could be the cause of such major deviations. If this conclusion is correct there remain only two other possible sources : (1) irregular distribution of the material (presumably solid particles) producing general space absorption, and (2) irregular distribution of interstellar gas.

Turning first to (1) we may note that many photographs of the sky give evidence of extreme irregularities in the distribution of absorbing material. In spite of this, however, it was hoped that the use of the equation

$$m_0 = m - 7E$$

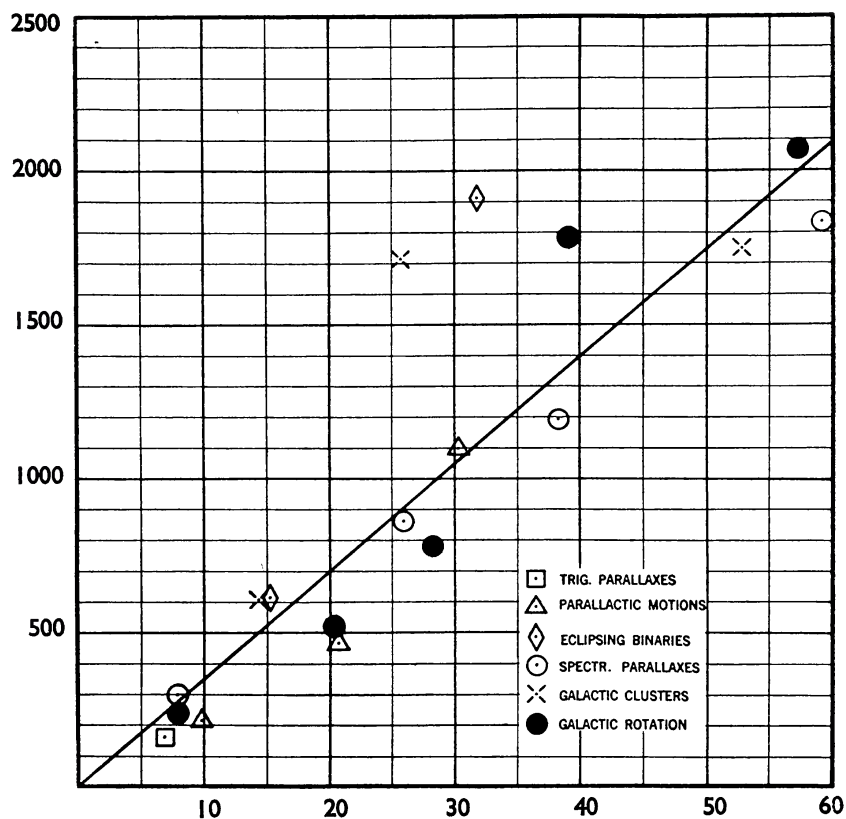


FIG. 4.

Ordinates: Distance, parsecs.

Abcissae: Calcium intensity (K).

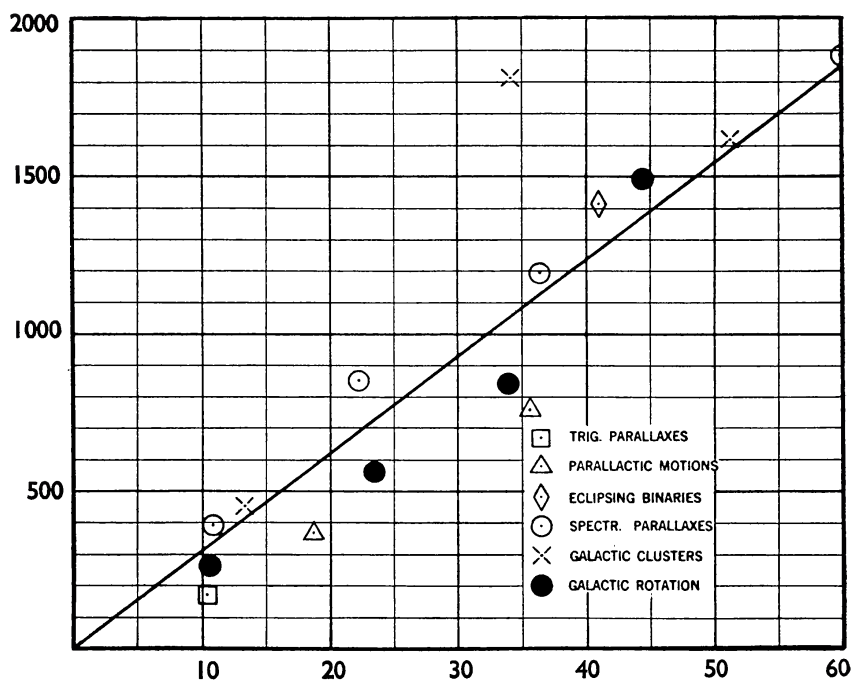


FIG. 5.

Ordinates: Distance, parsecs.

Abcissae: Sodium intensity $\left(\frac{D_1 + D_2}{2}\right)$.

would lead to valid corrections to the apparent magnitudes for space absorption, since it is based on the idea of integrated optical thickness rather than on assumptions as to the correlation of general absorption with distance. Although it is an empirical rather than a theoretical relation it implies that the reddening properties of absorbing material are the same in different parts of space. Such an inference is supported by the excellent observational material of Stebbins and Whitford and other workers, but there can be no certainty that it applies for each individual star. If it does not, then some of the estimated distances may be in error due to this cause.

With regard to (2), the work of Stebbins and Whitford and others indicates that there is no close correlation between space reddening and interstellar line intensity. Thus the patchy character of the material causing general absorption does not in itself indicate a similar irregularity of distribution of interstellar gas. However, high-dispersion spectrograms of early-type stars clearly indicate the existence of clouds of interstellar gas* with radial velocities which may differ from one another by as much as 60 km/sec. It is thus quite certain that the atoms of interstellar gas are not distributed in an even, uniform manner throughout the Galaxy. The data on radial velocity suggest that the distribution of discrete gas clouds approximates to uniformity since the mean residual velocity due to galactic rotation for interstellar lines is half that of the stars in whose spectra they appear. Examination of the data shows that this relationship does not hold in all cases for individual stars or groups of stars, and this may be due to peculiar motions of the stars or the clouds, or to lack of uniformity in the distribution of the clouds. Lack of uniformity of distribution, if sufficiently drastic, would interfere with the validity of the distance-intensity relation and could cause the type of scatter which has been observed in Figs. 4 and 5.

This discussion could be pursued at considerable length but it is apparent that there is only one conclusion, namely, that it is impossible to apportion the origin of the scatter of points on the graph as between irregularity of distribution of interstellar gas and other causes. It is therefore necessary to assume that distances of individual stars determined from interstellar lines are subject to considerable errors. If it be supposed that all the scatter is due to irregular distribution of gas, the graphs suggest that maximum errors of the order of 50 per cent may be expected, although in general they should not be more than half this amount. Errors of this magnitude may, however, be regarded as moderate when compared with other means of deriving the parallaxes of individual stars, and we believe that there can be no doubt of the value of interstellar line intensities as a general indication of stellar distance. Where groups of stars are involved, the use of the graphs of Figs. 4 and 5 should give reliable values of mean parallax, while for isolated peculiar objects such as novae the immediate indication of distance and absolute magnitude given by the interstellar lines is invaluable.

6. *Comparison with other observers.*—Comparisons of interstellar line intensities obtained at different observatories have usually indicated quite substantial systematic differences, though the reasons for these differences are obscure. Merrill, Sanford, Wilson and Burwell† have published graphs and tables

* C. S. Beals, *M.N.*, **96**, 661, 1936; *Ap. J.*, **87**, 568, 1938. R. F. Sanford, *P.A.S.P.*, **51**, 238, 1939. W. S. Adams, *Ap. J.*, **97**, 105, 1943. P. M. Routley and L. W. Spitzer, *Ap. J.*, **115**, 227, 1952.

† P. W. Merrill, R. F. Sanford, O. C. Wilson and Cora G. Burwell, *Ap. J.*, **86**, 274, 1937.

illustrating differences between Victoria and Mount Wilson measures. These comparisons were based on relatively few stars and the data of this paper make possible a considerably more extensive comparison though the results are similar. In Figs. 6 and 7 Victoria values of intensity from Table I for calcium and sodium are plotted against those of the Mount Wilson catalogue, as well as a number of additional intensities derived by Spitzer and others from Mount Wilson plates. It will be seen that, on the average, the Victoria values are systematically greater by approximately 30 per cent. The similarity between the slopes of the straight lines for calcium and sodium is striking. The dispersions used at Mount Wilson and at Victoria for the measurement of a majority of the lines are comparable. For

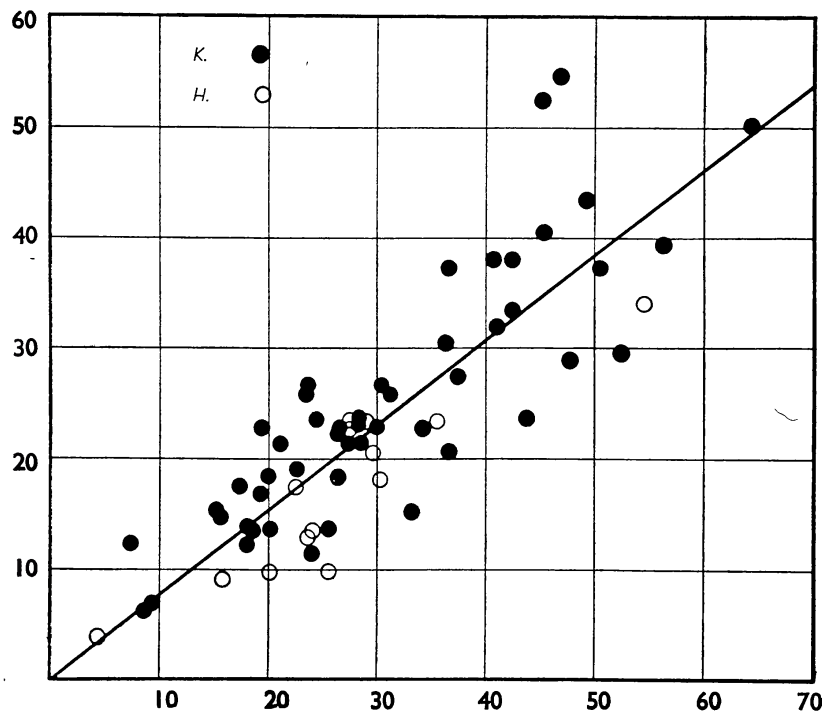


FIG. 6.

Ordinates: Calcium intensity—Mount Wilson.

Abcissae: Calcium intensity—Victoria.

calcium *K* the dispersion ordinarily used at Mount Wilson was 24 Å per mm, though a few bright stars were observed with 17 Å per mm or greater. At Victoria the usual dispersions were 20 Å per mm and 35 Å per mm, a few bright stars being observed with higher dispersions.

For the sodium *D* lines the Mount Wilson dispersions were 34 Å per mm and 66 Å per mm, while that normally used at Victoria was 31 Å per mm. It is thus apparent that the average dispersion for the two sets of observations is about the same and it seems very unlikely that this is the cause of the systematic difference between them. A previous discussion of this matter has been presented by Beals and it is suggested that the relation between equivalent width and dispersion is definite only for rather large differences in dispersion. The systematic differences in intensities have been discussed with the Mount Wilson astronomers but no conclusion has been reached as to the cause of the discrepancies.

In comparisons of distance-intensity curves it is, of course, necessary to take account of systematic differences in observations such as those referred to above. This has been done for the curves published by Sanford, Merrill, Evans and van Rhijn and their values of intensity have been converted to the Victoria scale. In addition, since Evans's curve relied mainly on galactic rotation, his normal points have been re-computed using a galactic rotation constant of $17 \text{ km s}^{-1} \text{ kpc}^{-1}$ instead of 16 which he used. A similar correction has been applied to van Rhijn's results. These revised curves are compared with our distance-intensity curves in Figs. 8 and 9.*

In comparing the various curves it should first be pointed out that those of Merrill and of Sanford, published 15 years ago, depend upon an absolute magnitude scale very different from that commonly regarded as valid today. For example,

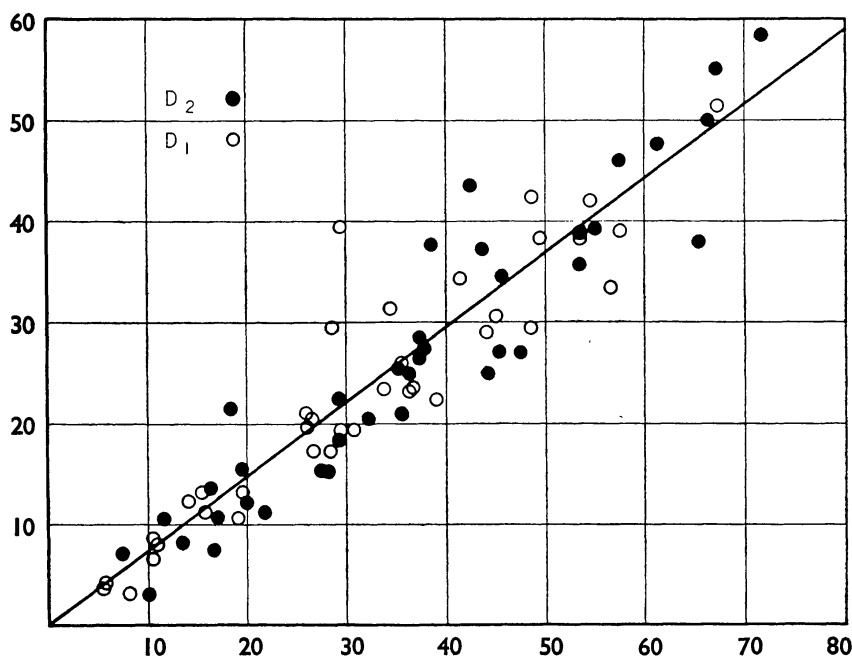


FIG. 7.

Ordinates: Sodium intensity—Mount Wilson.
Abcissae: Sodium intensity—Victoria.

their scale is correlated with spectral types almost exclusively and they utilize a value of -3.3 for the mean absolute magnitude for O to B0 stars, whereas many of the absolute magnitudes of Morgan and Petrie for stars in these spectral classes are as much as three magnitudes brighter. It should further be noted that they utilize a value for general absorption of $0^{\text{m}}.35$ per thousand parsecs, less than half of the value of $0^{\text{m}}.8$ per kiloparsec which is now considered closer to the true value. A shift in their absolute magnitude scale in the direction of higher values would displace their curve in the sense that each value of intensity would be associated with a larger value of distance. The adoption of a larger value for the coefficient of general absorption would displace it in the opposite direction. It appears, however, that the first effect would be considerably greater and it is possible that this would account, at least in part, for the differences between our curves and those of the Mount Wilson observers.

* Another discussion of the relation between distance and interstellar line intensity has recently been published by L. Binnendijk, *Ap. J.*, **115**, 428, 1952.

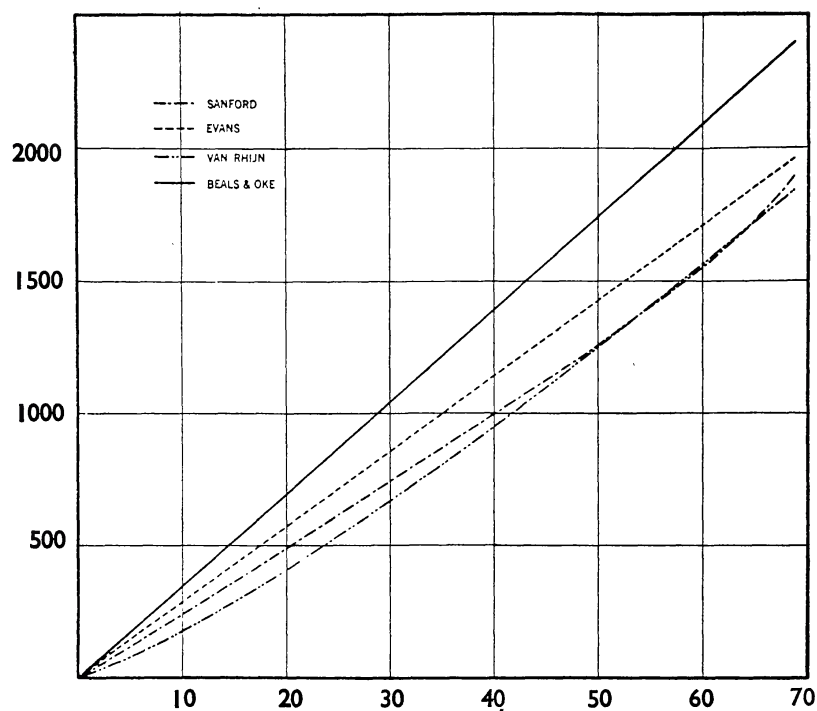


FIG. 8.

Ordinates: Distance, parsecs.
Abscissae: Calcium intensity, km/sec.

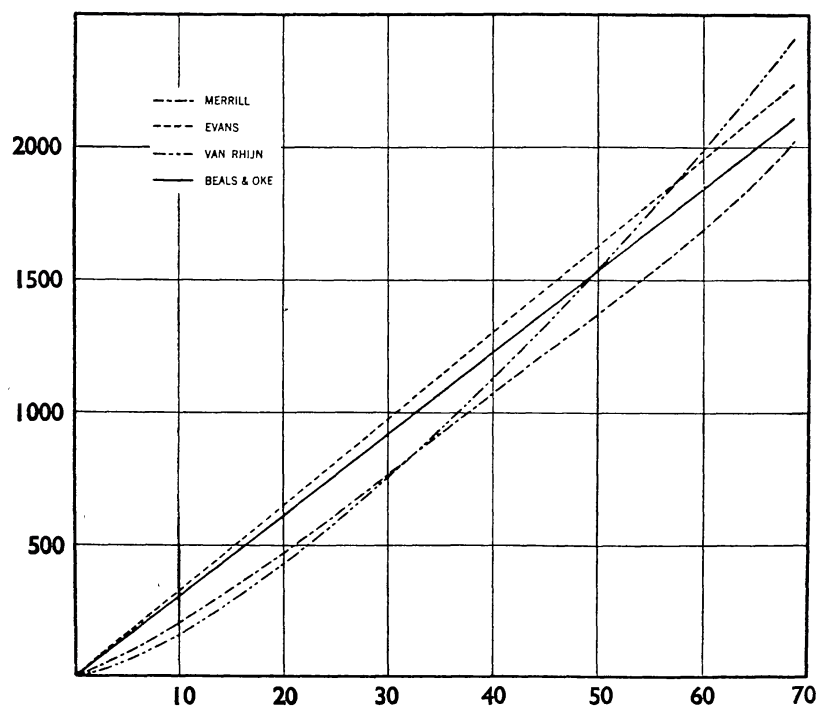


FIG. 9.

Ordinates: Distance, parsecs.
Abscissae: Sodium intensity, km/sec.

The curves of Evans and van Rhijn are both based on Mount Wilson data and both employ mainly galactic rotation as a criterion of distance. However, it will be seen that Evans's results correspond quite closely to ours (the curve for sodium is little different in slope) while van Rhijn's show a considerable deviation.

Without actually re-working the data it would be hazardous to speculate on the precise reasons for the differences between the various distance-intensity curves. It should be emphasized, however, that all modern evidence points to considerable irregularity in the distribution of interstellar material. Moreover, it is reasonable to suppose that there are regular variations from centre to circumference of the Galaxy and in the direction perpendicular to the galactic plane (e.g. van Rhijn attempts to correct the observed interstellar line intensities for distance from the plane). There is thus no reason to suppose that there is any single distance-intensity relationship which will hold unambiguously for all parts of the Galaxy, and no two graphs should be expected to coincide unless derived from identical data. In spite of these considerations it appears that there is enough evidence for statistical uniformity to make the intensities of interstellar calcium and sodium lines a very valuable indication of distance for individual stars or groups of stars.

In conclusion we wish to express our thanks to Dr R. M. Petrie for his generosity in supplying valuable absolute magnitude and radial velocity data, as well as for helpful discussions on various aspects of the work. Special thanks are also due to Dr W. W. Morgan for supplying absolute magnitude values in advance of publication. We are also indebted to Dr J. A. Rottenberg, Mrs Dorothy Edmonds and Mr R. W. Tanner for help with the calculations, and to Mr John O'Connor for measuring the velocities of many of the sodium lines.

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