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THE VELOCITY DISPERSION OF FAINT RED DWARF STARS

DONNA WEISTROP
Kitt Peak National Observatory*
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ABSTRACT

Broad-band photometry is presented for 21 late-type stars near the north galactic pole. Many of the stars can be identified as dwarfs from their location in the $(B-V)$-$(V-I)$ diagram. Photometric parallaxes are combined with proper motions to yield velocity dispersions in the galactic plane that are consistent with those for nearby M dwarf stars. With these velocity dispersions, the late-type dwarfs present no problem for the stability of the galactic disk.

Subject headings: stars: luminosities — stars: proper motion — photometry

I. INTRODUCTION

Recently, comparison of the velocity dispersions of faint red dwarfs stars with the velocity dispersions of nearby K and early M dwarf stars has suggested the existence of a population of low-velocity main-sequence M stars. From 21 red dwarf stars near the north galactic pole (NGP), Murray and Sanduleak (1972; henceforth M-S) estimate the transverse velocity dispersion in one coordinate to be about 10 km s^{-1}. From a different sample of red dwarf stars found in Sanduleak's survey (1965), Gliese (1974) finds an upper limit of 15 km s^{-1} for the transverse velocities. Krisciunas (1975) places a lower limit of 13 km s^{-1} on the transverse velocity dispersion of the M dwarfs in Gliese's (1969) catalog. These results disagree with velocity dispersions of nearby late-type dwarf stars determined by Upgren (1972) and Wielen (1974). From 62 K3–M2 dwarfs, Upgren finds the velocity dispersion to be $\sigma_U = 28.7$, $\sigma_V = 19.1$, and $\sigma_W = 15.1$ km s^{-1}. Wielen (1974) finds $\sigma_U = 39$, $\sigma_V = 23$, and $\sigma_W = 20$ km s^{-1} for 317 McCormick K and M dwarfs in Gliese's catalog.

Recently, Koo and Kron (1975) obtained radial velocities for five of the M-S stars. The velocity dispersion perpendicular to the galactic plane is 12 km s^{-1}, consistent with Upgren's results. These five stars are the brightest observed by M-S. Further observations are needed to determine whether their velocity dispersion is also characteristic of the faint stars in the sample.

A program was undertaken to obtain photometric parallaxes for the 21 M-S stars. Preliminary results for nine stars have already been reported (Weistrop 1976; henceforth referred to as Paper I). In Paper I, the distances to the nine stars were found to be greater than estimated by M-S. The transverse velocity dispersion in one coordinate was found to be 17 km s^{-1}, and the space density of M dwarfs, as deduced from Sanduleak's original survey, was substantially reduced from the M-S value. In this paper, BVR_WI_W observations for all 21 M-S stars are reported. Photometric evidence is presented to indicate that the stars are dwarfs. The distance to the stars and the velocity dispersions in the U, V plane are calculated. The preliminary results are confirmed. The velocity dispersions derived are consistent with the results of Upgren (1972) and Wielen (1974).

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II. COLOR-COLOR AND COLOR-MAGNITUDE RELATIONS

Two-color diagrams have been used previously to distinguish between giant and dwarf stars (see, for example, Eggen 1971, 1974; Glass 1975). To define the giant and dwarf sequences in the $(B-V)(V-I_W)$ diagram, BVR_WI_W photometry of known giants and dwarfs was obtained. A sample of dwarf stars with trigonometric parallaxes, fainter than $R_K = 7.5$ mag and redder than $(R-I)_K = 0.5$ mag on the Kron system, and accessible from the northern hemisphere, was selected from the lists of Kron, Gascoigne, and White (1957); Johnson (1965); and Woolley *et al.* (1970). These stars were also used to determine the absolute magnitude-color relation. Giants of spectral class G5 and later or redder than $B-V=1.00$ mag were selected from the work of Harris and Upgren (1964), Philip (1965), and Upgren (1960, 1962).

The B, V magnitudes were measured with a GaAs photomultiplier (RCA C31034A) using a B filter consisting of 2 mm BG 12 + 1 mm BG 18 + 2 mm GG 385, and a V filter made up of 2 mm BG 18 + 2 mm GG 495. The R_W, I_W system, henceforth referred to as R, I, has been described elsewhere (Weistrop 1975). All observations were made at Kitt Peak National Observatory (KPNO). The data for the giants are presented in Table 1. The first column lists the DM number or the identification used in the list from which the star was selected (col. [8]). The photoelectric data are presented in columns (2), (3), and (5). Columns (4) and (6) indicate the number of times V, $(B-V)$ and I, respectively, were observed. For those stars for which V and $(B-V)$ were not observed, the number in parentheses in column (4)

TABLE 1

Data for Giants

Star	B-V	V	m	I	n	Sp. T.	Ref.*
33° 2151	$1^{m}.53$	$9^{m}.90$	1	$6^{m}.50$	1	M6 III	1
27° 2065	1.55	9.83	1	8.24	1	K4 III	2
40° 2491	1.51	9.50	1	6.66	1	M5 III	1
26° 2304	1.36	10.42	1	9.12	1	K2 III	2
27° 2104	1.60	9.49	2	7.44	2	M2 III	2
35° 2325	1.60	9.91	1	8.04	1	M1 III	1
25° 2483	1.52	9.95	1	8.32	1	K5 III	2
28° 2140	1.53	10.29	1	8.85	1	K5 III	3
38° 2355	1.59	10.46	2	7.88	2	M4 III	1
27° 2167	1.62	9.08	2	6.53	2	M4 III	3
28° 2158	1.48	8.82	2	7.37	2	K3 III	2
28° 2154	1.06	9.69	1	8.69	2	G9 III	3
27° 2183	1.06	10.52	1	9.52	2	G8 III	3
29° 2336	1.60	9.06	3	6.28	3	M3 III	3
31° 2423	1.18	10.37	1	9.36	2	K0 III	3
30° 2344	1.42	10.44	1	9.10	2	K3 III	3
45° 2076	1.64	10.46	2	8.37	2	M3 III	1
29° 2383	1.28	9.59	1	8.42	2	K2 III	3
30° 2386	1.14	9.35	1	8.25	2	G9 III	3
18° 4853	1.56	9.87	1	8.37	3	K3 III	4
19° 4787	1.70	10.41	1	8.55	3	M0 III	4
17° 4663	1.10	9.36	1	8.28	3	K0 III	4
19° 4836	1.76	9.80	1	7.84	3	K5 III	4
S9	1.59	11.09	(4)	9.14	2	K3 III	4
15° 4547	1.56	9.55	(4)	7.96	2	K2 III	4
15° 4559	1.15	9.79	(4)	8.72	2	K0 III	4
16° 4672	1.39	9.89	(4)	8.62	2	K2 III	4
15° 4581	1.63	9.99	(4)	8.24	2	M0 III	4
15° 4582	1.50	9.77	(4)	8.19	1	K3 III	4
15° 4594	1.49	10.32	(4)	8.83	1	K2 III	4
S68	1.18	10.63	(4)	9.56	1	K0 III	4
S69	1.03	12.09	(4)	10.90	1	K0 III	4
12° 4789	1.41	10.29	(4)	8.93	1	K2 III	4

*1 Upgren (1960).
2 Upgren (1962).
3 Harris and Upgren (1964).
4 Philip (1965).

indicates the reference from which V, $(B-V)$ were taken. The spectral types of the giants are listed in column (7).

The data for the dwarfs are given in Table 2. Most stars are identified by number in the *General Catalogue of Trigonometric Stellar Parallaxes* or *Supplement to the General Catalogue of Trigonometric Stellar Parallaxes* (Yale catalog, Jenkins 1952, 1963). If two stars have the same number, the DM identifications are given. The photometric data for the dwarfs are given in columns (2), (3), (5), (6), and (8). The number of observations of $(B-V)$, V and $(R-I)$, R are indicated in columns (4) and (7), respectively. For those stars for which V, $(B-V)$ were not observed, the references from which they were taken are indicated in parentheses in column (4). The absolute magnitudes are listed in column (9). From stars observed more than once, the mean errors of one observation are estimated to be ± 0.032 mag in $(B-V)$, ± 0.030 mag in V, ± 0.008 mag in $(R-I)$, and ± 0.012 mag in I. Comparison of published data (references cited above) with the values determined here indicates systematic differences of -0.006 mag in $(B-V)$ and -0.008 mag in V in the sense (published $-$ Weistrop).

Colors for giants near the NGP are assumed to be unreddened. The $(B-V)$ color excesses of the giants in Philip's list were estimated from his Figure 3. The absolute magnitudes were taken from Blaauw (1963). The interstellar extinction curve given by Bless and Savage (1972) was used to estimate the reddening in $(V-I)$, $E(V-I) = 1.14E(B-V)$. The observed colors of the NGP giants and the unreddened colors of the giants from Philip's list are shown in the $(B-V)$-$(V-I)$ diagram (Fig. 1), where the data for the dwarfs are also plotted. There is no systematic difference between the location of the NGP giants and Philip's giants in the diagram. The giant and dwarf sequences are distinguishable for $(V-I)$ bluer than 2.2 mag and redder than 3.0 mag. For stars bluer than $(V-I) = 2.0$ mag, the temperature difference between giants and dwarfs, and increased line blanketing in the giants due to turbulence, make the giants redder in $B-V$ than the dwarfs. For later giants, the blanketing in B does not increase significantly, while the change in $(B-V)$ due to increased blanketing in V is counteracted by the decreasing temperature. For dwarfs, the flux in B continues to decrease for redder stars due to the presence of various neutral metals in the star's atmosphere. The $(B-V)$ color of the star therefore continues to get redder despite the increased blanketing

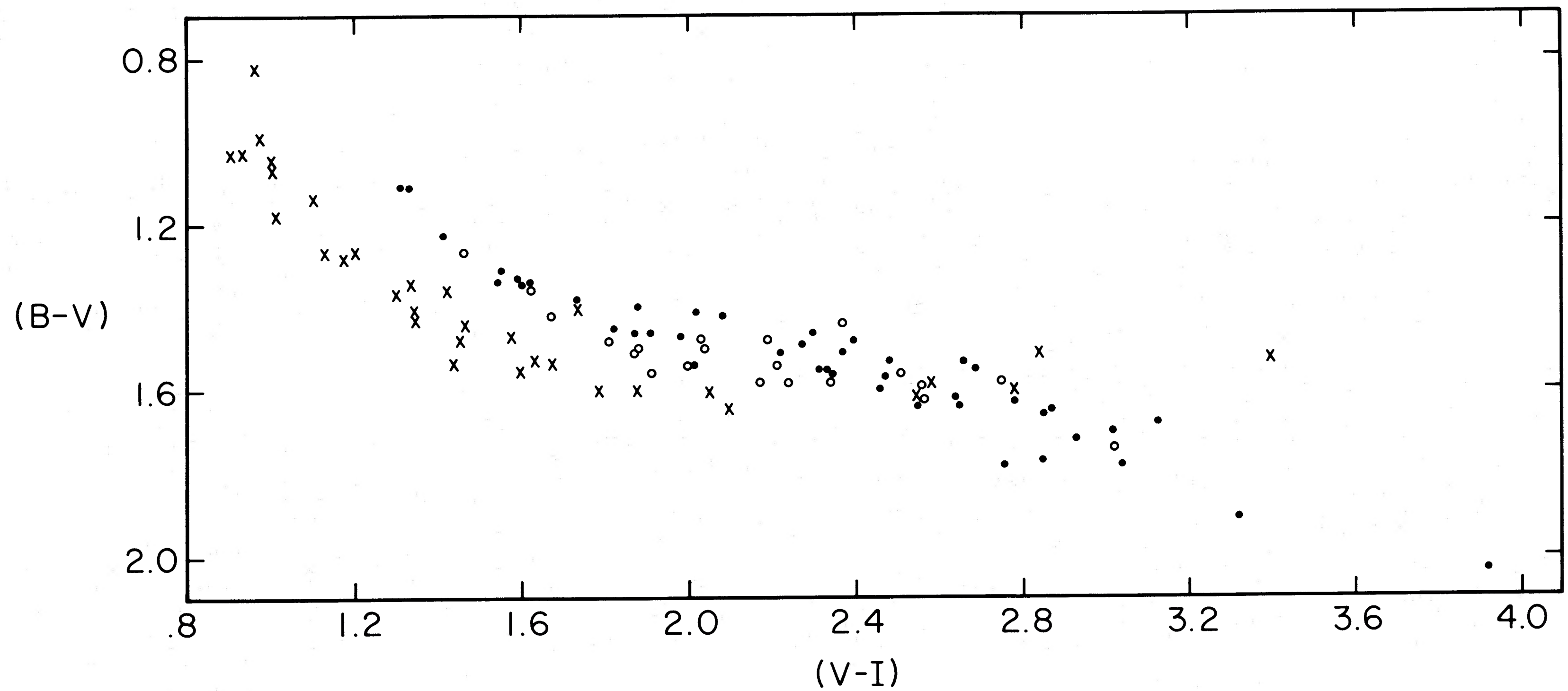

FIG. 1.—The $(B-V)$-$(V-I)$ relation for giants (*crosses*) and dwarfs (*filled circles*). The location of the M-S stars (*open circles*) is also shown.

TABLE 2

Data for Dwarfs

Star	B−V	V	m	R−I	R	n	V−I	M_R
49B	$1^m.78$	$11^m.10$	6	$1^m.56$	$9^m.90$	11	$2^m.76$	$12^m.11$
205	1.68	13.66	(1)	1.81	12.34	3	3.13	12.41
G3-33	1.78	12.31	2	1.74	11.01	5	3.04	12.63
450	1.41	10.06	3	1.12	9.16	7	2.02	8.95
520B	1.63	11.75	1	1.58	10.55	5	2.78	11.34
724	1.34	8.38	(1)	0.77	7.61	3	1.54	6.41
1238	1.64	12.48	(1)	1.50	11.33	3	2.65	11.43
1259	1.62	11.55	6	1.49	10.40	9	2.64	9.59
1291	1.47	9.76	1	1.07	8.85	1	1.98	9.07
1305	1.65	11.60	(1)	1.60	10.33	3	2.87	11.34
1426	1.46	10.43	1	1.31	9.44	1	2.30	9.35
1538	1.46	9.64	2	0.96	8.73	5	1.87	8.54
1593.1	1.23	8.98	2	0.67	8.24	5	1.41	7.33
1609	1.57	10.03	1	1.42	8.98	1	2.47	10.10
1668	1.70	11.55	2	1.71	10.24	5	3.02	11.14
1755	1.53	9.89	1	1.53	8.76	4	2.66	10.86
1774	1.55	11.87	3	1.55	10.73	7	2.69	10.22
1809	1.33	8.94	(1)	0.79	8.14	3	1.59	7.50
1942	1.77	12.84	14	1.65	11.64	17	2.85	12.47
2117	1.66	13.14	8	1.64	11.93	12	2.85	11.06
2146	1.11	9.26	(1)	0.64	8.57	3	1.33	---
2254	1.51	12.14	1	1.34	11.11	1	2.37	9.68
2420	1.53	9.39	1	1.43	8.34	4	2.48	9.96
2456	1.51	9.66	3	1.24	8.68	6	2.22	9.16
2457	1.31	8.68	1	0.76	7.89	4	1.55	7.55
2529	1.11	9.50	1	0.63	8.82	5	1.31	---
2553	2.04	13.49	6	2.15	11.72	9	3.92	14.85
2561	1.55	10.03	1	1.01	8.71	1	2.33	9.54
2582A	1.54	8.77	1	1.07	7.83	4	2.01	8.99
−17°3336	1.34	10.04	7	0.81	9.23	12	1.62	7.58
−17°3337	1.34	9.97	8	0.79	9.16	13	1.60	7.51
2631	1.40	9.30	2	0.99	8.41	7	1.88	8.69
2730	1.72	11.14	1	1.66	9.87	6	2.93	12.23
2949	1.64	10.92	1	1.46	9.83	1	2.55	10.05
2951	1.38	8.51	1	0.87	7.65	4	1.73	7.20
24°2733A	1.45	9.74	1	0.96	8.88	1	1.82	7.34
24°2733B	1.46	9.99	1	1.02	9.10	1	1.91	7.56
3458	1.60	10.57	2	1.40	9.51	2	2.46	10.34
3712	1.48	10.71	1	1.37	9.69	1	2.39	9.30
3733	1.49	10.27	1	1.30	9.30	1	2.27	9.84
3880	1.42	10.07	1	1.16	9.15	1	2.08	8.94
3889	1.56	11.61	1	1.34	10.61	1	2.34	10.50
4053	1.55	10.50	1	1.31	9.50	1	2.31	9.39
5736	1.91	12.31	3	1.90	10.89	8	3.32	13.38

(1) Woolley et al. (1970).

in V. Blanco (1964) found similar behavior in color–spectral type diagrams for M stars.

One giant, S9, is apparently located on the dwarf sequence. Since the B magnitude of this star is substantially below Philip's limiting magnitude of $B = 12.2$ mag, its classification may be uncertain. The two observations of R, I made for this star agree within 0.01 mag. However, B, V measurements were not obtained, so that Philip's single determination of V, $(B-V)$ could not be confirmed. Since other giants of spectral class K3 III fall on the separate giant sequence, we assume there is some problem with the data for star S9 and that, in general, giants and dwarfs are distinguishable, as indicated in Figure 1.

A preliminary M_R-$(R-I)$ relation was used in Paper I. A revised relation is presented here, incorporating additional observations made in the last observing season. The trigonometric parallax of G3–33 was taken from Woolley *et al.* (1970). All other parallaxes were taken from the Yale catalog. The absolute magnitudes calculated from the parallaxes were corrected for systematic errors introduced because observed parallaxes are generally larger than true parallaxes (Lutz and Kelker 1973). A mean error in the parallaxes of 0″.010, computed from the errors in the individual parallaxes of the stars in Table 2, was used to calculate the corrections. Yale 2146 and 2529 are not included in the determination of the M_R-$(R-I)$ relation, since the parallaxes of these stars are below the limit for which corrections are defined. Yale 49B was omitted because it is subluminous (Upgren and Weis 1975).

The M_R-$(R-I)$ relation is shown in Figure 2. The slight nonlinearity noted in Paper I is confirmed by the stars recently observed. The second-order least-squares fit to the data is indicated by the solid line. The mean error of the fit, 0.558 mag, corresponds to an uncertainty of 25–30% in one distance determination.

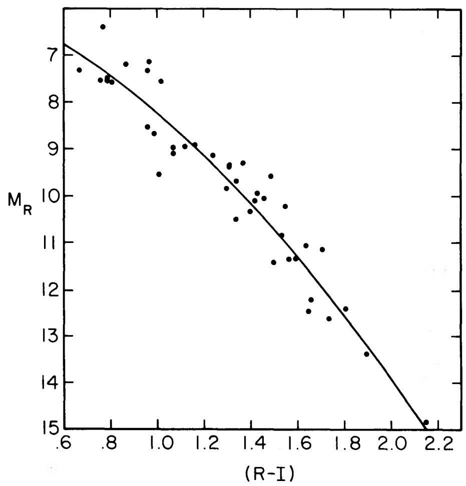

FIG. 2.—Absolute magnitude-$(R - I)$ relation for dwarfs. The solid line indicates the second-order least-squares fit to the data.

III. DATA AND ANALYSIS FOR THE M-S STARS

The data for the 21 M-S stars are presented in Table 3. The identification number is that given by Sanduleak (1965). The photometric data are listed in columns (2)–(6), and Sanduleak's spectral classes in column (7). Each star was measured at least twice in V, $(B - V)$, I, $(R - I)$. The mean errors determined from the observations are ± 0.045 mag in V, ± 0.027 mag in $(B - V)$, ± 0.034 mag in I, and ± 0.014 mag in $(R - I)$. Part of the mean error may be due to intrinsic variability in the stars.

From the dispersion in the proper motion of the stars, M-S have concluded that they are dwarfs. The location of the stars in the $(B - V)$-$(V - I)$ diagram (Fig. 1) generally supports that conclusion. No star unambiguously falls on the giant sequence.

Using the M_R-$(R - I)$ relation, the absolute magnitudes of the stars are derived and the photometric parallaxes computed (cols. [8] and [9] of Table 3). The mean parallax for all the stars is 0.″0094, with a standard deviation of $\pm$0.″0051. As expected, the brighter stars are, on the average, more distant than the fainter ones. The U, V velocity components, computed from the photometric parallaxes and M-S's proper motions, are given in columns (10) and (11). U increases away from the galactic center and V is in the direction of galactic rotation. The velocities have been corrected for the Sun's peculiar motion $U = -9$ km s^{-1}, $V = +12$ km s^{-1} (Delhaye 1965). The velocity dispersions for the 21 stars are $\sigma_U = 28.2$ km s^{-1} and $\sigma_V = 22.4$ km s^{-1}. The average stellar velocity in the plane is $\langle (U^2 + V^2)^{1/2} \rangle = 35.8$ km s^{-1}.

IV. DISCUSSION

In Paper I a mean parallax of 0.″012 was found for nine stars in the M-S sample. The mean parallax derived here for those same nine stars is 0.″010, the difference being due to the revision of the M_R-$(R - I)$ relation. The mean parallax obtained for all 21 stars agrees with Jones's (1975) value of 0.″009, determined from narrow-band photometry of 19 stars. Koo and Kron (1975) find a mean parallax of 0.″011 for five M-S stars. Our mean parallax for the same five stars is

TABLE 3

Data for Murray-Sanduleak Stars

Star	V	B-V	R	R-I	V-I	Sp. Type	M_R	π_{pe}	U km s^{-1}	V km s^{-1}
28° 76	$15^{m}.78$	$1^{m}.50$	$14^{m}.87$	$1^{m}.13$	$2^{m}.04$	b	$8^{m}.79$	0.″0061	+ 8	+11
28° 78	15.79	1.51	14.91	0.99	1.87	c	8.17	0.0045	-24	-63
28° 79	16.18	1.58	15.18	1.34	2.34	c	9.82	0.0085	- 3	-11
28° 80	15.99	1.48	15.09	1.13	2.03	b	8.79	0.0055	+ 8	-60
28° 81	16.50	1.74	15.23	1.75	3.02	c	12.21	0.0249	-14	+16
28° 82	16.88	1.62	15.80	1.48	2.56	c	10.58	0.0090	+43	-17
28° 83	15.84	1.56	14.97	1.04	1.91	b	8.39	0.0048	+ 9	- 7
28° 84	13.60	1.42	12.78	0.85	1.67	a	7.61	0.0092	+46	- 3
28° 85	15.58	1.50	14.69	0.99	1.88	b	8.17	0.0050	+38	-30
28° 86	13.26	1.48	12.40	0.95	1.81	a	8.01	0.0132	- 4	-25
28° 87	14.36	1.58	13.43	1.31	2.24	b	9.67	0.0177	+12	-11
28° 88	16.11	1.44	15.12	1.38	2.37	c	10.04	0.0096	+44	+13
28° 89	14.27	1.54	13.30	1.24	2.21	b	9.32	0.0160	- 8	-21
28° 91	13.72	1.27	12.94	0.68	1.46	a	7.00	0.0065	+ 1	+ 5
28° 93	15.40	1.58	14.43	1.20	2.17	b	9.12	0.0087	+52	-21
30° 98	15.48	1.36	14.70	0.84	1.62	a	7.57	0.0037	+70	-35
29° 116	16.60	1.56	15.53	1.44	2.51	c	10.36	0.0092	+ 8	+17
29° 117	15.21	1.54	14.31	1.10	2.00	b	8.65	0.0074	+72	- 8
29° 120	17.27	1.58	16.12	1.60	2.75	c	11.28	0.0108	+30	-32
29° 122	16.61	1.59	15.53	1.48	2.56	c	10.58	0.0102	+19	+ 8
29° 124*	15.98	1.48	15.03	1.24	2.19	c	9.32	0.0072	-21	- 6

*Star 226 in Sanduleak (1976).

0$''$.0125, in good agreement with their result. In Paper I, we concluded that the assumption that the M-S stars are moving with the basic solar motion and therefore have a mean parallax of 0$''$.02 is not valid. The mean parallax derived here confirms that conclusion.

The velocity dispersions of the M-S stars agree with Upgren's (1972) results for a sample of K3–M2 dwarfs near the Sun, $\sigma_U = 28.7$ km s^{-1}, $\sigma_V = 19.1$ km s^{-1}. For 317 McCormick K and M dwarfs, Wielen (1974) finds $\sigma_U = 39$ km s^{-1} and $\sigma_V = 23$ km s^{-1}. The difference in the samples probably produces the difference in the dispersions, since, as Wielen notes, selection effects for Gliese's catalog favor stars with high proper motions. The dispersions derived here are typical of stars with moderate Ca II emission intensity and thus moderate age (Wielen 1974). For the M-S sample, $\langle (U^2 + V^2)^{1/2} \rangle = 35.8$ km s^{-1}, while for 515 McCormick stars, the mean velocity in the plane is 40 km s^{-1} (Gliese 1974), an insignificant difference. There is no anomaly, therefore, in the velocity and velocity dispersion in the galactic plane of the M-S stars. The low transverse velocity dispersion found by M-S (10 km s^{-1}) is due to the large parallax derived under the assumption that the stars move with the basic solar motion. The velocity dispersion in U determined here is greater than the minimum permissible velocity dispersion for M dwarfs which satisfies the Toomre criterion for stability of the galactic disk (Biermann 1975).

In the preceding discussion it has been assumed that the stars are either giants or dwarfs. However, some of the stars may be subluminous. According to Greenstein (1975), subluminous M stars are relatively rare, so our assumption should be fairly accurate. If one or two of the stars are subluminous, the conclusions reached above would not be significantly altered.

There has been much recent discussion concerning the velocity distribution of late-type dwarf stars. Evidence has been presented which indicates that the M-S sample of M dwarfs has a velocity distribution in the galactic plane consistent with that of nearby late-type dwarfs. Based on present evidence, the existence of a large population of low-velocity M dwarf stars therefore seems unlikely.

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DONNA WEISTROP: Kitt Peak National Observatory, P.O. Box 26732, Tucson, AZ 85726