THE RELATIONSHIP BETWEEN THE COLOR AND LUMINOSITY OF STARS NEAR THE SUN

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The tabulation and description of all the individual stars was once considered to be the ultimate goal of astronomy. This Herculean task, which can no longer be seriously considered since the number of known stars and the variety of their physical and astrometric properties available for observations are so great, has been considerably lightened by the application of statistical methods.

The observed quantities that we shall deal with here are

V_E	The apparent, visual magnitude.
$(P - V)_E$	The color or difference between the visual and the photographic magnitude.
$\pi(t)$	The trigonometric parallax.

The values of $\pi(t)$ and V_E are combined to give the absolute visual magnitude,

$$M_V = V_E + 5 + 5 \log_{10} \pi(t) . \tag{1}$$

It is assumed that the nearby stars are not affected by interstellar absorption. The correlation to be investigated is that between M_V and $(P - V)_E$ and will be referred to as the color-luminosity array.

The three samples of nearby stars to be discussed are characterized as follows, for $(P - V)_E < +1^m25$:

Group	$\pi(t)$	Weight	M_V	Number	Per cent observed
I	>0″050	>36	All	52	90
II	>0.050	16–36	<+4.55	63	95
III	0.040–0.050	>20	<+4.55	29	80

The objects in groups I, II, and III are listed in sections A, B, and C, respectively, of table I where they are numbered as in the Yale Parallax Catalogue [1]. The spectral types in the last column of table I, which are followed by a Roman numeral indicating the luminosity class, are from the Yerkes Spectral Atlas [2], or from other sources stated to be on the same system. The types preceded by the prefix "d" for dwarf, or "g," for giant, were assigned at the Mount Wilson Observatory [3]; unpublished types, determined at the Lick Observatory by J. H. Moore, for a few southern stars are also included.

TABLE I

PARALLAX STARS BLUER THAN $(P - V)_E = +1^m25$

Yale	Star	V_E	$(P - V)_E$	$\pi(t)$	Wt.	M_V	Sp.
A. Stars within 20 parsecs and with a parallax weight greater than 36							
155	η Cas A	3m49	+0m47	0"182	40	+4m79	G0 V
464	δ Tri	4.88	+0.50	0.094	58	+4.75	G0 V
520	HR 753	5.82	+0.89	0.147	38	+6.66	dK4
549	θ Per	4.12	+0.375	0.077	42	+3.55	F6 V
647	ν Per	4.05	+0.49	0.084	37	+3.67	G0 V
742	ε Eri	3.68	+0.80	0.303	81	+6.09	K2 V
753	10 Tau	4.25	+0.46	0.058	44	+3.07	F8 V
788	δ Eri	3.48	+0.85	0.109	50	+3.67	K0 IV
945	40 Eri A	4.41	+0.73	0.200	57	+5.92	K0 V
1077	1 Ori	3.16	+0.34	0.125	39	+3.64	F6 V
1129*	HR 1614	6.20	+0.97	0.106	85	+6.33	dK5
1211	HD 34673	7.80	+0.94	0.071	40	+7.06	dK5
1314	HD 38230	7.26	+0.73	0.077	40	+6.69	dK2
1365	HR 2067	6.61	+0.57	0.051	38	+5.15	dG0
1577	α CMa	−1.44	−0.115	0.375	78	+1.43	A1 V
1805	α CMi	0.36	+0.305	0.284	79	+2.62	F5 IV–V
1889	HD 65583	7.01	+0.59	0.056	48	+5.75	dG7
2082	HD 74377	8.53	+0.835	0.059	40	+7.38	dK5
2280	11 LMi	5.42	+0.665	0.107	42	+5.57	G8 IV–V
2738	β Leo	2.13	−0.03	0.076	43	+1.53	A3 V
3242	α Boo	−0.06	+1.15	0.090	46	−0.29	K2 IIIp
3596	χ Her	4.60	+0.45	0.056	38	+3.34	F8 V
3669	HD 145417	7.55	+0.685	0.063	40	+6.55	——
3799	ζ Her	2.80	+0.545	0.103	68	+2.87	G0 IV
3837	HD 152391	6.62	+0.675	0.065	42	+5.68	dG9
3878	HD 154363	7.76	+1.04	0.088	76	+7.48	K5 V
3946	72 Her	5.39	+0.525	0.072	42	+4.68	G2 V
4166	HD 166348	8.39	+1.145	0.074	46	+7.74	——
4215	7 Ser	3.22	+0.85	0.054	42	+1.88	K0 III–IV
4293	α Lyr	0.03	−0.125	0.123	44	+0.48	A0 V
4345	HD 229590	9.23	+1.115	0.056	40	+7.97	dM1
4541	31 Aql	5.10	+0.665	0.059	38	+3.95	G8 IV
4607	σ Dra	4.68	+0.695	0.173	63	+5.86	K0 V
4665	α Aql	0.78	+0.11	0.198	63	+2.27	A7 V
4705	β Aql	3.70	+0.76	0.067	65	+2.83	G8 IV
4760	15 Sge	5.76	+0.52	0.060	40	+4.65	dG1
4849	HR 7783	5.94	+0.48	0.066	45	+5.04	dG1
4966	η Cep	3.42	+0.83	0.071	52	+2.68	K0 IV
5077A	61 CygA	5.19	+1.08	0.292	71	+7.52	K5 V
5077B	61 CygB	6.02	+1.24	0.292	71	+8.35	K7 V
5139	α Cep	2.44	+0.12	0.063	43	+1.44	A7 V
5345	ν Peg	3.77	+0.325	0.074	42	+3.12	F5 V
5562	HR 8721	6.49	+0.99	0.133	37	+7.11	dK4
5725	γ Cep	3.20	+0.94	0.064	43	+2.23	K1 IV
5772*	HR 9038	6.33	+0.855	0.090	54	+6.10	dK5
5807	85 PegA	5.76	+0.55	0.086	66	+5.43	G2 V

TABLE I—*Continued*

B. Stars within 20 parsecs, with a parallax weight between 15 and 36, and with M_V brighter than $+4^{m}55$

Yale	Star	V_E	$(P-V)_E$	$\pi(t)$	Wt.	M_V	Sp.
16	β Cas	$2^{m}25$	$+0^{m}23$	0″072	23	$+1^{m}54$	F2 III
69	β Hyi	2.75	+0.52	0.153	18	+3.67	G1 IV
120	60 Tuc	5.89	+0.435	0.052	18	+4.47	——
331	υ And	4.08	+0.335	0.062	35	+3.04	F8 V
390*	α Tri	3.44	+0.35	0.050	20	+1.93	F5 III
394*	β Ari	2.66	+0.02	0.063	35	+1.66	A5 V
405	χ Eri	3.62	+0.765	0.052	17	+2.20	G5 IV
557	υ Hor	5.42	+0.455	0.063	24	+4.42	dF9
560	1 Eri	4.41	+0.365	0.067	18	+3.54	F6 V
633	11 Eri	4.02	+0.085	0.051	18	+2.56	A7 III
664	α For	3.82	+0.42	0.070	29	+3.05	F6 V
740	κ Ret	4.66	+0.28	0.052	18	+3.24	dF4
827	27 Eri	4.16	+0.32	0.053	21	+2.78	dF3
1164	ζ Dor	4.68	+0.40	0.078	17	+4.14	dF5
1199	λ Aur	4.68	+0.505	0.066	29	+3.78	G2 IV–V
1224	111 Tau	5.01	+0.40	0.064	27	+4.04	F8 V
1316	γ Leb	3.54	+0.385	0.117	28	+3.88	F6 V
1339	β Pic	3.85	+0.065	0.055	16	+2.55	A5 III
1370	η Lep	3.65	+0.225	0.061	23	+2.58	F0 IV
1543	7 CMa	3.87	+1.015	0.052	22	+2.45	K2 III–IV
1571	56 Aur	5.34	+0.45	0.068	28	+4.50	G0 V
1573	ξ Gem	3.42	+0.31	0.051	24	+1.96	F5 III
1718	δ Gem	3.58	+0.23	0.059	34	+2.43	F2 IV
1760	ρ Gem	4.21	+0.205	0.059	24	+3.06	F0 V
1826	β Gem	1.16	+0.93	0.093	34	+1.00	K0 III
1841	HR 3018	5.33	+0.42	0.057	18	+4.11	dG0
1979	χ Cnc	5.10	+0.35	0.061	24	+4.03	F6 V
2143	ι UMa	3.11	+0.07	0.066	32	+2.21	A7 V
2255	31 Hya	4.56	+0.35	0.067	18	+3.69	F6 V
2266	θ UMa	3.20	+0.365	0.052	24	+1.78	F6 III
2366	20 LMi	5.37	+0.555	0.053	31	+3.99	G2 V
2459	36 UMa	4.82	+0.40	0.081	36	+4.36	F8 V
2556	47 UMa	5.16	+0.45	0.073	22	+4.48	G0 V
2739	β Vir	3.62	+0.44	0.098	36	+3.58	F8 V
2824	δ UMa	3.27	−0.05	0.052	33	+1.85	A2 V
2895	β CVn	4.27	+0.485	0.108	27	+4.44	G0 V
3034	59 Vir	5.18	+0.465	0.075	31	+4.55	G0 V
3144	τ Boo	4.50	+0.37	0.056	24	+3.24	F6 IV
3175	η Boo	2.70	+0.49	0.102	35	+2.74	G0 IV
3206	θ Cen	2.03	+0.93	0.059	16	+0.88	K0 III–IV
3274	θ Boo	4.04	+0.39	0.067	24	+3.17	G6 IV
3416	45 Boo	4.94	+0.32	0.061	22	+3.87	F5 V
3536	HR 5825	4.65	+0.31	0.053	18	+3.27	dF0
3570	λ Ser	4.41	+0.50	0.091	34	+4.21	G2 V
3604	γ Ser	3.84	+0.37	0.069	23	+3.03	F6 IV
3803	η Her	3.45	+0.83	0.053	24	+2.07	G5 III
3860*	19 Dra	4.85	+0.38	0.069	31	+4.04	F6 V

TABLE I—*Concluded*

Yale	Star	V_E	$(P-V)_E$	$\pi(t)$	Wt.	M_V	Sp.
3896	η Sco	3.32	+0.275	0.056	16	+2.06	F2 III
3935	ξ Oph	4.33	+0.265	0.058	18	+3.15	dF2
4000	α Oph	2.09	+0.045	0.056	35	+0.83	A5 III
4060	μ Her	3.42	+0.655	0.117	28	+3.76	G5 IV
4245*	χ Dra	3.58	+0.40	0.120	34	+3.98	F6 V
4542	δ Aql	3.38	+0.195	0.062	44	+2.34	F0 IV
4611	θ Cyg	4.49	+0.285	0.057	35	+3.27	F5 IV
5258	δ Cap	2.88	+0.18	0.065	24	+1.94	Am
5415	HR 8531	5.39	+0.555	0.052	16	+3.97	dG3
5565	α PsA	1.14	−0.015	0.144	20	+1.93	A3 V
5724	ι Psc	4.13	+0.385	0.064	18	+3.16	F8 V

C. Stars between 25 and 20 parsecs distant, with a parallax weight between 20 and 36, and with M_V greater than $+4^m.55$

436	α Ari	$2^m.00$	$+1^m.075$	$0''.043$	30	$+0^m.17$	K2 III
831	β Ret	3.78	+1.07	0.042	23	+1.90	gG1
1158	β Eri	2.78	+0.01	0.042	52	+0.90	A3 III
1708	λ Gem	3.54	−0.02	0.041	43	+1.60	A3 V
1946	HR 3220	4.70	+0.03	0.050	20	+3.19	dF 5
2567	β UMa	2.36	−0.15	0.042	28	+0.47	A0 V
2887	η Crv	4.25	+0.265	0.044	22	+2.47	F2 IV
3076	70 Vir	4.97	+0.61	0.041	24	+3.03	G5 V
3279	φ Vir	4.76	+0.575	0.043	28	+2.93	G2 III
3351	9 Lib	2.76	+0.035	0.047	32	+1.12	A3 V
3455	HR 5691	5.15	+0.42	0.046	36	+3.46	F8 V
3519	α CrB	2.22	−0.14	0.043	28	+0.39	A0 V
3557	α Ser	2.59	+1.115	0.046	24	+0.90	K2 III
3626	ρ CrB	5.40	+0.505	0.042	22	+3.52	G2 V
3740	η Dra	2.71	+0.835	0.043	34	+0.88	G8 III
4109	ζ Ser	4.60	+0.25	0.043	55	+2.77	F3 V
4328	110 Her	4.22	+0.335	0.048	36	+2.63	F6 V
4868	ρ Cap	4.74	+0.245	0.042	25	+2.86	F2 III
4959	ε Cyg	2.48	+0.95	0.044	41	+0.70	K0 III
4963	HR 7955	4.49	+0.455	0.041	23	+2.55	F8 IV
5114	τ Cyg	3.75	+0.36	0.047	66	+2.11	F5 III
5362	θ Peg	3.53	−0.02	0.042	33	+1.65	A2 IV
5716	λ And	3.88	+0.935	0.043	25	+2.05	G8 III–IV

Since the distribution of energy in the M-type dwarfs is such as to cause the color-system used here to lose its resolution, stars of the spectral type later than K6, or with color greater than $+1^m.25$, have been omitted and are discussed by G. E. Kron in another paper in this volume. Also, to prevent as much as possible the contamination of the observed colors by companion stars, all known visual binaries with a visual magnitude difference between the components of less than $3^m.5$ have been eliminated. The sample of stars was chosen, and the mean parallaxes with their weights were taken, from the *General Catalogue of Trigonometric Stellar Parallaxes* [1]. Since the parallaxes attributed there to the Dearborn, Stockholm, Uppsala, and

London Observatories are few in number and carry low weight, they have been eliminated from the catalogue means. In the few cases where additional parallaxes, not included in this catalogue, have become available they have been incorporated into the means with the precepts stated in the catalogue. Only parallaxes determined at more than one observatory have been used.

Before discussing the sample of stars near the sun, we shall first establish a "standard" color-luminosity array from the observations of stars in two galactic

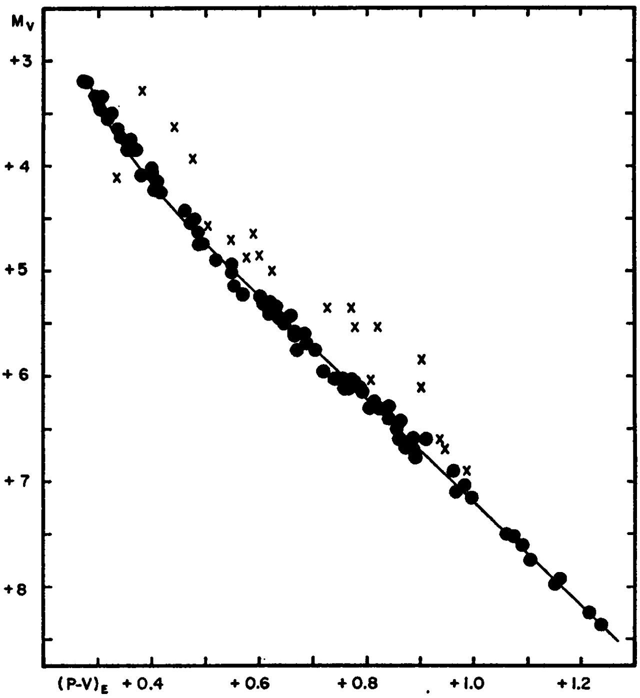

FIGURE 1

The main sequence of the Praesepe Cluster

clusters: Praesepe and the Pleiades. A plot of the Praesepe cluster stars with $(P - V)_E$ between $+0^m_.28$ and $+1^m_.25$ is shown in figure 1. For stars in a cluster, equation (1) reduced to $M_V = V_E + K$, where K is a constant for all cluster members only if the size of the cluster is small in comparison with its distance from the sun. The Praesepe cluster is distant enough to insure a constancy in K sufficient for our purposes, and at the same time it is close enough to permit accurate observation of the faintest cluster members. A value of $K = -6^m_.04$ has been adopted and will be justified later. Various cluster members, which were selected by Klein Wassink [4] on the basis of their community of motion, have been observed at Lick [5], at McDonald by Johnson [6], and at Hamburg by Haffner and Heckmann [7]. The combined observations of color and magnitude are represented in figure 1, where stars that depart more than 0.15 from the thin line connecting the filled circles are marked as crosses. Since all but one of these latter stars fall above the main sequence, that is, they are apparently too bright, it is reasonable to assume that they are mostly undetected double stars.

Accurate determinations of the colors and magnitudes of stars in the Pleiades cluster are available only to $(P - V)_E = +0^m.5$. The observations used here were made by Johnson and Morgan [8] at the McDonald Observatory, and the colors have been corrected by $0^m.03$ for instellar reddening—a value determined by Johnson and Morgan from their additional observations of the ultraviolet magnitudes of the cluster stars. If it is assumed that the Pleiades and Praesepe stars, with colors between $+0^m.28$ and $+0^m.50$ are identical, then a comparison of the magni-

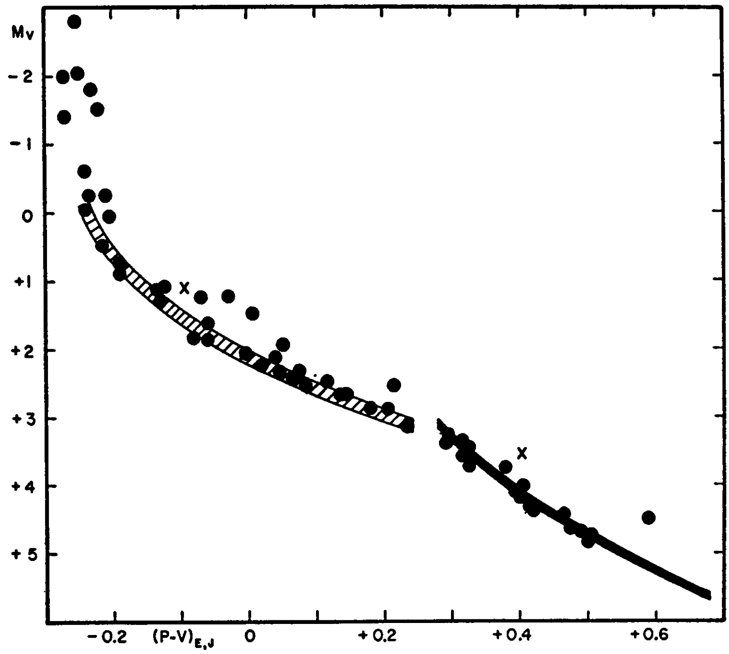

FIGURE 2

Color-luminosity array for the Pleiades Cluster

tudes of the stars in the two clusters gives K(Praesepe) $-$ K(Pleiades) $= -0^m.46$, or K(Pleiades) $= -5^m.58$. The color-luminosity array for the Pleiades stars is plotted in figure 2 where the two crosses indicate known binaries. The heavy line in the figure is taken from figure 1. We shall assume that the hatched area, which contains most of the Pleiades stars with M_V between 0 and $+3^m$, is a continuation of the main sequence.

To return to the nearby stars, most of their colors and apparent magnitudes have been determined photoelectrically by the author with the Lick Observatory 12-inch refractor, and with the 9-inch refractor of the Commonwealth Observatory, Mount Stromlo, Australia. A few of the stars have also been observed by Johnson and Morgan [9], at the McDonald Observatory, and by observers at the Royal Observatory, Cape of Good Hope [10]. All of the magnitudes and colors have been reduced to a common system and, when more than one value is available, the mean has been used.

The sample of stars to be considered first is given in table IA. This group of stars with $(P - V)_E < 1^m.25$ represents 90 per cent of all of those known, from trigonometric parallaxes with a weight greater than 36, to be within 20 parsecs of the sun. Since a weight of 36 corresponds to a probable error of ±0″005 in the parallax, and since from equation (1) we have

$$(2) \qquad \Delta M_V = \Delta V_E + 2.17 \, \Delta\pi(t)/\pi(t) \,,$$

then the probable errors of the values of M_V in the table, arising from errors in the parallaxes, are all less than $\pm 0^m2$. The probable errors of the apparent magnitudes, V_E, are near $\pm 0^m01$ and can be disregarded. The stars in table 1A are plotted as

TABLE II

MAIN SEQUENCE STARS WITH $(P - V)_E$ BETWEEN $+0^m45$ AND $+1^m25$

Yale	Star	$(P - V)_E$	$\pi(t)$	Wt.	$\pi(pt)$	$\epsilon(\%)$	V_r	V_T
155	η Cas A	$+0^m47$	0″182	40	0″167	+8.2	+ 9	32
464	δ Tri	+0.50	0.094	58	0.095	−1.1	− 6	60
4760	15 Sge	+0.52	0.060	40	0.065	−8.3	+ 4	46
3946	72 Her	+0.525	0.072	42	0.079	−9.7	−78	70
1365	HR 2067	+0.57	0.051	38	0.050	+2.0	− 2	55
2280	11 LMi	+0.665	0.107	42	0.107	0.0	+13	35
3837	HD 152391	+0.675	0.065	42	0.063	+3.1	+41	140
945	40 Eri A	+0.73	0.200	57	0.197	+1.5	−42	95
742	ϵ Eri	+0.80	0.303	81	0.320	−5.6	+15	15
5520	HR 753	+0.89	0.147	38	0.147	0.0	+23	75
1211	HD 34673	+0.94	0.071	40	0.066	+7.0	+85	50
5562	HR 8721	+0.99	0.133	37	0.135	−1.5	+ 6	15
3878	HD 154363	+1.04	0.088	76	0.084	+4.6	+28	80
5077A	61 Cyg A	+1.08	0.292	71	0.300	−2.7	−65	85
4345	HD 229590	+1.115	0.056	40	0.051	+8.9	−17	50
4166	HD 166348	+1.145	0.074	46	0.079	−6.8	....	30
5077B	61 Cyg B	+1.24	0.292	71	0.292	0.0	−64	85
	Mean:		0.134	50		0.0		

filled circles in figure 3, except for two spectroscopic binaries noted with an asterisk in the table, and plotted as crosses in the figure. The standard main sequence, defined by the stars in the Praesepe and Pleiades clusters, is indicated by two bands: one, 0^m1 wide in M_V for stars redder than $+0^m28$, and the other, 0^m2 wide for the bluer stars. The width of these bands represents the dispersion, about an infinitely narrow sequence, of the defining stars.

There are two rather striking features in the distribution of the filled circles in figure 3; (a) the stars redder than $(P - V)_E \cong +0^m45$ seem to fall into sequences, one the main sequence defined by the Praesepe stars, and the other, below it, and (b) all but two of the bluer stars fall above the main sequence. The 17 main sequence stars redder than $(P - V)_E = +0^m45$, except for the two spectroscopic binaries already mentioned, are listed in table II. The photometric parallaxes, $\pi(pt)$, were computed on the assumption that any displacement of these stars from the main sequence drawn in figure 1, is due to errors in the parallaxes. The mean percentage error, $\epsilon(\%)$, or $100\,[\pi(t) - \pi(pt)]/\pi(t)$, is zero, since the value of $K = -6^m04$, adopted above for the Praesepe cluster, was determined from a direct comparison of these stars with cluster stars of the same color. The average percentage-error, without regard to sign, is 4.2 per cent, or $\pm 0\overset{''}{.}0055$ for the average parallax of $0\overset{''}{.}134$. According to the precepts given in the parallax catalogue, the average weight of 50

TABLE III

SUBLUMINOUS STARS

Yale	Star	$(P-V)_E$	M_V	V_r	V_T
4849	HR 7783	$+0\overset{m}{.}48$	$+5\overset{m}{.}04$	− 5	40
5807	85 Peg A	+0.55	+5.43	−36	70
1889	HD 65583	+0.59	+5.75	+12	100
3669	HD 145417	+0.685	+6.55	....	125
1314	HD 38230	+0.73	+6.69	−31	45
2082	HD 74377	+0.835	+7.38	−26	60

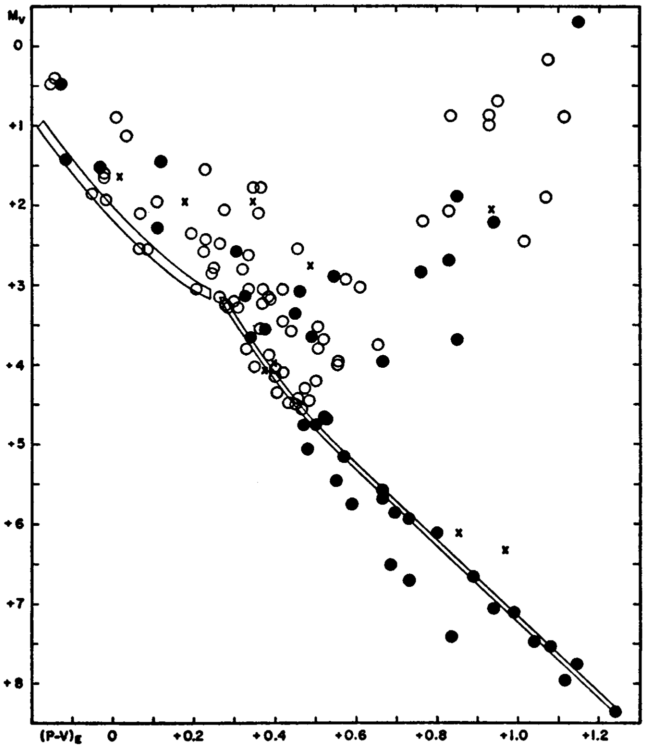

FIGURE 3

Color-luminosity array for stars near the sun

for the stars in table II corresponds to a probable error of $\pm 0\overset{''}{.}0045$ in the parallax.

The six subluminous stars in table III appear to form a separate group falling approximately a magnitude below the main sequence. The radial V_r and tangential V_T components of the motion with respect to the sun are listed for these stars, as they are for the main sequence objects in table II. The radial velocity of one southern hemisphere star in table III is unknown. Although several of the stars in table III have rather high velocities, the motion alone does not distinguish them from the stars in table II, since the total range of the velocities is nearly the same in the two tables.

We next consider the stars in sections B and C of table I. These stars are plotted in figure 3 as open circles, except that again the spectroscopic binaries are indicated by crosses. Since parallax weights of 15 and 20 correspond to probable errors of $\pm 0\overset{''}{.}008$ and $\pm 0\overset{''}{.}007$, respectively, in the parallaxes [1], from equation (2) we find that the largest probable errors in the absolute magnitudes will be about $\pm 0\overset{m}{.}35$ for stars in both groups.

From the distribution of the points in figure 3, we may draw the following conclusions:

(a) The stars bluer than $(P - V)_E \cong +0\overset{m}{.}4$ fall mainly above the main sequence. Although the absence of stars redder than $(P - V)_E \cong +0\overset{m}{.}5$, between $M_V = +3^m$ and $+4^m$, and also the V-shaped "zone of avoidance" with apex near $(P - V)_E = +0\overset{m}{.}6$ and $M_V = +3^m$, probably represent a real scarcity of stars; the smallness of the samples considered, and the effects of recognized selection factors, make any further conclusions precarious.

(b) The absence of stars in the region below $M_V = +4^m$ and above the main sequence is apparently a real phenomenon.

(c) The nearby dwarf stars redder than $(P - V)_E \cong +0\overset{m}{.}45$, like those in the clusters, define a main sequence that is certainly less than $0\overset{m}{.}2$, and probably less than $0\overset{m}{.}1$ wide.

(d) There is a definite subdwarf sequence that lies about one magnitude below the main sequence at $(P - V)_E = +0\overset{m}{.}8$ and approaches to within $0\overset{m}{.}5$ of the main sequence at $(P - V)_E = +0\overset{m}{.}5$. Although again the sample of stars is small, there is apparently a clear division between the two sequences.

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