THE ASTROPHYSICAL JOURNAL, Vol. 149, July 1967

SPECTROPHOTOMETRY OF NEW SHORT-PERIOD VARIABLE STARS*

I. J. DANZIGER† AND R. J. DICKENS‡
Mount Wilson and Palomar Observatories, Carnegie Institution of Washington, California Institute of Technology

Received December 13, 1966; revised January 24, 1967

ABSTRACT

The occurrence of short-period variability in a number of bright F-type stars was discovered during an extensive program of *UBV* photoelectric observations made between October, 1965, and February, 1966. The amplitudes of the new variables are small and change in the manner shown by some of the variables of the δ Sct type Observations of the continua of the new variables were made by measuring the intensities at twenty-five discrete wavelengths between about 3300 and 10000 Å using a photoelectric spectrum scanner Coudé spectra at 10 Å/mm were used to correct the intensities for line-blanketing effects, and the resulting continua were then compared with the model atmospheres of Mihalas to yield effective temperatures and surface gravities Some of the new variables have higher temperatures and gravities than the previously known variables Higher values of the projected rotational velocity $V \sin i$ also occur, and indicate that in this region of the H-R diagram pulsation is not incompatible with rapid rotation More than half the stars appear to be significantly undermassive for normal left-to-right evolution in the H-R diagram, for which masses $\sim 1\ 8\ M_\odot$ are typical Some of the variables, particularly ρ Pup and HR 5017, have extremely low values of the pulsation constant Q The stars of lowest mass are consistently cooler than those of higher mass, an effect that is observable in a correlation obtained between $\log g$ and $\log T_e$

I. INTRODUCTION

The δ Scuti stars comprise a class of pulsating variable stars characterized by small-amplitude, short-period light and radial velocity variations. The existence of such a class named after the prototype star δ Sct was pointed out by Eggen (1957), who listed five known members of the class. They have amplitudes less than 0.3 mag, periods between $0^{d}.07$ and $0^{d}.2$, $B - V$ colors between 0.3 and 0.4 mag, and are all reasonably sharp-lined stars. With absolute magnitudes between 0.0 and +2.2 (McNamara and Augason 1961) they occur in a region of the H-R diagram above the main sequence and roughly on an extension of the Cepheid instability strip. The space motions are low and appear to be typical of those of the dwarf A-type stars (Eggen 1960*a*) so that they are clearly stars of the disk population. In this paper photometric and spectrophotometric data are presented for a number of new short-period variables which probably belong to the δ Sct class.

II. *UBV* PHOTOMETRY OF NEW STARS

The stars included in the observing program were selected from the Strömgren-Perry catalogue (1962) of *uvby* photometry on the basis of their being in the same region of the H-R diagram as the known δ Sct stars.

The photoelectric observations to be described in this paper were made by one of us (R. J. D.) between October, 1965, and February, 1966, using the Mount Wilson 60-inch and the Palomar 20-inch reflectors with standard D.C. equipment. Each candidate selected for observation was observed continuously in three colors, U, B, and V for up to about 4 hours, together with a nearby bright comparison star. During the night a number of Johnson-Morgan *UBV* standards was also observed to determine the extinc-

* This research was supported in part by the U.S Air Force under Contract AF49(638)-1323, maintained by the Air Force Office of Scientific Research of the Office of Aerospace Research

† Presently at Harvard College Observatory

‡ On leave of absence from Royal Greenwich Observatory, Herstmonceux, England

tion and color transformations from the "natural" to the *UBV* system. The magnitudes of the program stars were reduced to the *UBV* system in the usual way. The differences between the derived values of V, $B - V$, and $U - B$ for each comparison star and the standard values (from Iriarte, Johnson, Mitchell, and Wisniewski 1965) were then applied to the derived magnitudes of the program star to give the final magnitudes referred to those of the comparison star.

The stars observed are listed in Table 1. Most of the columns are self-explanatory. The numbers given in the first column refer to the Yale Catalogue of Bright Stars (1964). The absolute magnitude M_v (s) given in the seventh column was computed from the *uvby* photometry. A notation "3" is given in the tenth column against stars which are considered to have been observed sufficiently long to establish their short-term constancy at this epoch of observation. It should be noted, however, that, since many of the δ Sct variables exhibit beat phenomena in their light-curves which can result in little change in amplitude at some epochs (see the light-curves of 1 Mon, Fig. 1), the constant nature of all of these stars cannot be considered as firmly established.

It can be seen from Table 1 that of the sixty-nine stars observed, ten stars show some short-period variability and twenty-five are constant. The nature of the variability of HR 2539 and the close binary system HR 3889 is somewhat uncertain and these stars will not be discussed as variables in this paper. The individual observations of the eight variables are given as a function of heliocentric Julian Date in Table 2 and shown plotted in Figure 1. The values of V, $B - V$, and $U - B$ given in Table 2 are the magnitudes determined relative to the appropriate comparison stars whose magnitudes from Iriarte *et al.* (1965) are given at the head of the table.

III. SCANNER OBSERVATIONS AND SPECTRA

Spectrophotometric observations of the continua of the variables were made with the Cassegrain photoelectric spectrum scanner (used with refrigerated 1P21 and 7102 photomultipliers) on the 60-inch reflector at Mount Wilson. The intensities at sixteen discrete wavelengths in the visual-ultraviolet region were measured with the 1P21 tube, and at nine discrete wavelengths in the visual-infrared region with the 7102 tube. These two types of observation were made on different nights and the visual-ultraviolet observations, in particular, were repeated on several nights. The discrete wavelengths were selected by Oke (1964) to be relatively free of lines, and the intensities were measured with an exit slit of 50 Å and corrected for atmospheric extinction by using mean extinction coefficients for Mount Wilson.

These measured intensities were tied to Oke's system of absolute standards by observing the stars γ Gem, ϵ Ori, η Hya, α Leo, θ Vir, and 109 Vir on the same night. No individual variations greater than 1 or 2 per cent or gross variations in extinction are to be expected. In Table 3 the measured magnitudes are given as a function of the inverse wavelength expressed in microns, together with the Julian Date for the observations. Also included in this table are the adopted line-blanketing corrections, which will be described below.

Coudé spectra of the new variables covering the blue and violet regions were taken on baked IIaO plates with the 32-inch camera of the 100-inch telescope at a dispersion of 10 Å/mm. The line-blanketing corrections given in Table 3 for the blue-ultraviolet region were obtained by measuring the energy subtracted from a smooth continuum by the line spectrum in the manner given by Oke (1965). The small corrections for the wavelength region $\lambda\lambda$5000–5840 were extrapolated from shorter wavelengths. No corrections are given at longer wavelengths since they are extremely small. The problem of measuring blanketing in the spectra of stars with rotational velocities $V \sin i > 50$ km/sec cannot be overcome, since otherwise sharp lines are so smeared into one another that a realistic placing of the smooth continuum is impossible. Fortunately, blanketing corrections at all wavelengths have a systematic variation with temperature and luminosity. Therefore,

TABLE 1

STARS OBSERVED ON *UBV* SYSTEM OCTOBER 1965 – FEBRUARY 1966

HR	⟨V⟩	⟨$B-V$⟩	⟨$U-B$⟩	Dispersion in V $\sigma_V \times 10^3$ mag	Time Covered by Observations t_{min}	M_V (s)	Spectrum	$V \sin i$	Remarks ‡
27	5 03	0.39	+0 24	4	46	−2.25	F2 II	46	
114	5.24	.24	+ .09	12	67	+1 67	Am	35	? Var
238	6.39	.28	+ 12	13	41	+2 43	gF6	....	
476	5.62	.21	+ 13	4	49	+1 46	SgA9	....	
515	6.54	.25	+ 17	6	67	+0.97	A7n	......	
569	4.80	.28	+ 09	7	55	+1.99	F0 IV	93	
623	4.98	.33	+ 15	5	66	+1.01	F2 III	165	
687	5.82	.27	+ .05	4	43	+2.23	dF2	....	
691	5.43	31	+ .12	7	34	+1 37	A5	. ...	
813	4.29	.30	+ .08	3	61	+2 24	F0 IV	55	
816	6.04	32	+ .06	4	103	+2.58	gF0	....	3
840	4.23	34	+ .09	9	157	+1 69	F2 III	160	3
1020	6.51	29	+ .07	5	104	+2 12	F0	... .	3
1130	6.10	.28	+ 22	3	101	+0.06	A5	... .	3
1201	5.95	35	− 01	7	52	+2.96	dF1	..... .	
1238	5.87	31	+ .03	3	86	+2.41	A9n (F1)	140	3
1287	5 40	.34	+ .05	.......variable		+1.85	dF3	≤ 10*	44 Tau
1331	5.66	.27	+ .08	10	225	+2.23	dA8	105	3
1376	5.65	31	+ 11	4	50	+2 55	Am	< 30	
1392	4.27	.25	+ .14	..single observation.		+1.06	F0 III-IV	188	
1428	5 46	.25	+ 10	.single observation. .		+2 40	A7m	46	
1458	4 25	.17	+ .11	4	48	+1 86	Am	25	
1480	5 39	27	+ 14	4	80	+2.28	dA9 (F1)	60	3
1554	5.97	.37	+ 16	6	57	+0.93	F2	... .	
1644	6.22	.43	+ 30	5	52	−2.62	F2 IIp	....	
1678	6 50	.21	+ .12	2	79	+1 76	A2	....	3
1689	4.85	.19	+ .08	7	26	+2 47	Am	84	
1706	5 05	.25	+ 19	.. variable.. ...		+1.20	A9 V	15*	14 Aur
1869	6.12	.26	+ 16	8	27	+1 48	dF0	. ....	
1969	5.94	17	+ .12	2	48	+1.78	A2	....	
1990	5 47	.31	+ .27	5	49	−1.21	gF4	40	
2100	5.91	.21	+ .17	9	228	+1 58	A5	....	3
2107	6.17	29	+ 11	... .variable......		+1.71	F2 II	10-15*	1 Mon
2123	6.45	.18	+ 16	10	147	+1.54	A5	. ... .	? Var
2539	6.12	.37	+ 12	. .... variable.......		+1.30	A7n	.... ..	? Type of Var
2557	6.14	33	+ .19	4	46	−0.55	F0	. ...	
2620	6.59	.27	+ .14	8	89	+1.43	F0	....	3
2811	5.84	35	+ .20	9 3	51 111	+0.25	gF3	... .	? Var
2816	5 78	35	+ 08	6 8	61 214	+1.72	g?F0	....	3
2837	5 94	.31	+ 10	. single observation...		+1.34	A6n	....	
2904	6.53	.23	+ 15	4	45	+1.26	Am	....	
2936	6.17	.35	+ .13	5	89	+1.59	F0	....	3
2977	6.50	.26	+ .12	3 7	46 44	+2.84	gF0	. ...	
3265	6.32	.30	+ .14	. .....variable.......		+1.94	A5	20-25*	
3321	5.61	21	+ .07	6 8	47 177	+2.50	dF0	31	3
3757	3 68	.33	+ 11	6	97	+1.99	F0 IV	140	3
3879	5.63	.34	+ .13	4	115	+1.44	dF0	....	3
3885	6.31	.28	+ 12	3 3	131 76	+1.59	F0	....	3
3888	3.83	.29	+ .10	......variable..		+1.59	F2 IV	110	υ UMa
3889	6.09 †	.25 †	+ .18 †	.......variable......		+1 60	A8s	10-20*	Visual binary
3945	6.69	.28	+ .08	3	110	+1.98	A5	....	3
3969	6.37	.37	+ .15	1	198	+1.32	F0	....	3
3974	4.52	.19	+ 06	6	36	+2.37	A7 V	168	
4031	3.46	.30	+ .18	5	129	+0.17	F0 III	85	3
4090	4.76	25	+ 14	4	40	+1.24	F0 V	39	
4310	4.61	32	+ .08	8	77	+2 36	F2 III-IV	25	
4480	6.11	.38	+ 14	11	156	+1 47	dF2	.... ..	3
4584	6.51	23	+ .14	8	126	+1.64	F0	....	3
4715	6.07	.33	+ .18	... ..variable.		+0 98	F0	85*	4 CVn
5005	6.69	30	+ .08	.. ....variable..		+1.57	F0	60*	
5017	4.74	32	+ 23	. .....variable. . .		+1.15	F0 II-IIIp	≤ 10*	20 CVn
5435	3.07	.20	+ 14	9	69	+1.22	A7 III	135	? Var
5747	3.66	.27	+ .13	6	102	+3.11	F0p	28	β CrB 3
8097	4 69	.27	+ .08	4	169	+2.90	F0p	13	γ Equ 3
8441	6.11	.27	+ 12	3	33	+1.50	F0	....	
8494	4.21	.28	+ .06	14	153	+2.34	Fo IV	88	? Var
8973	6 52	35	+ .07	4	115	+1 79	dF0	....	3
9093	5.32	.19	+ .13	5	114	+1 69	A3	165	3
M67-131	11.20	0.42	+0.06	7	81	+1.65	F4 IV	....	? Var

*$V \sin i$ by Kraft

†Two stars measured as one

‡The notation "3" indicates stars that are most probably non-variable.

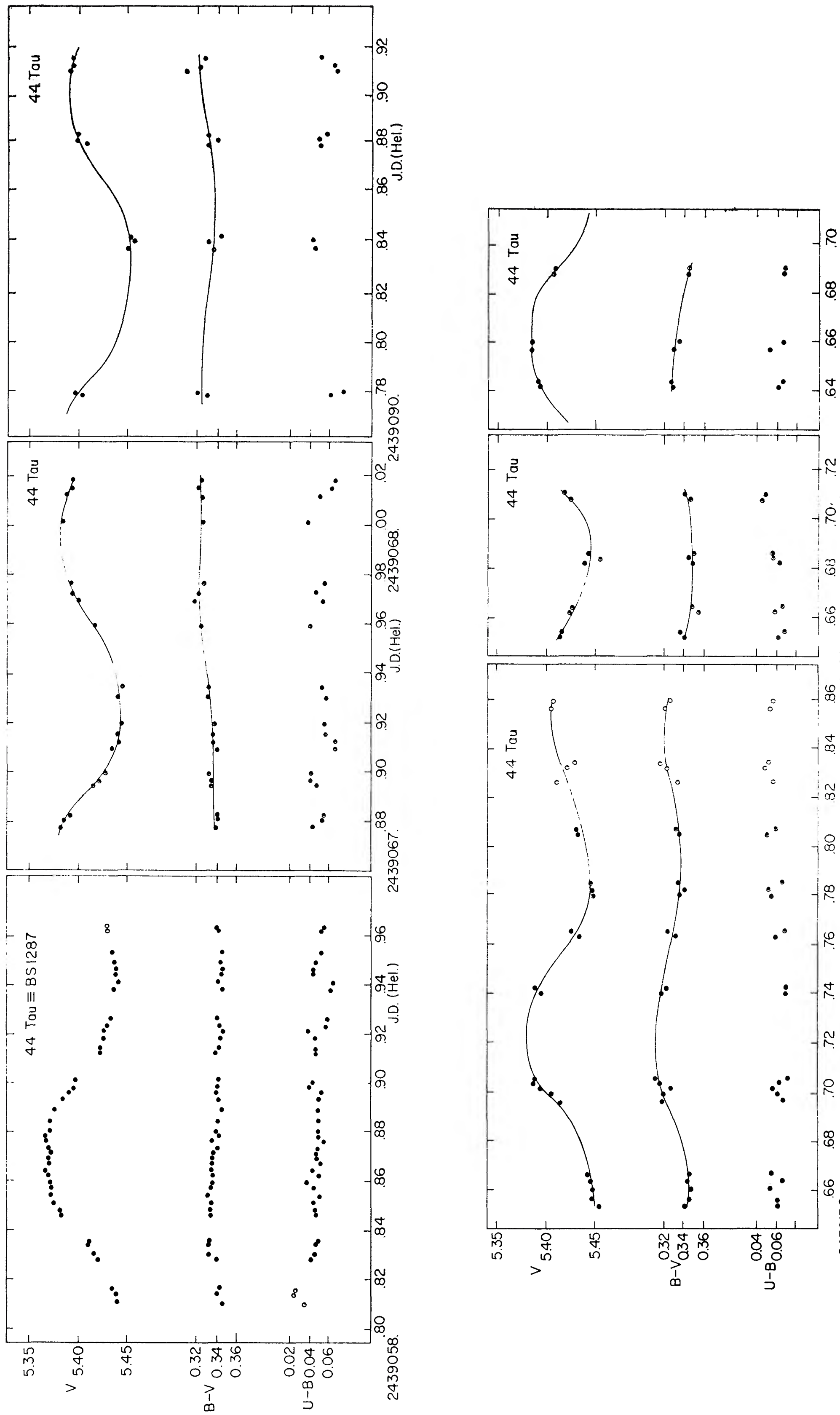


FIG. 1.—Light and color variations on the *UBV* system of the new variables. Open circles denote uncertain values

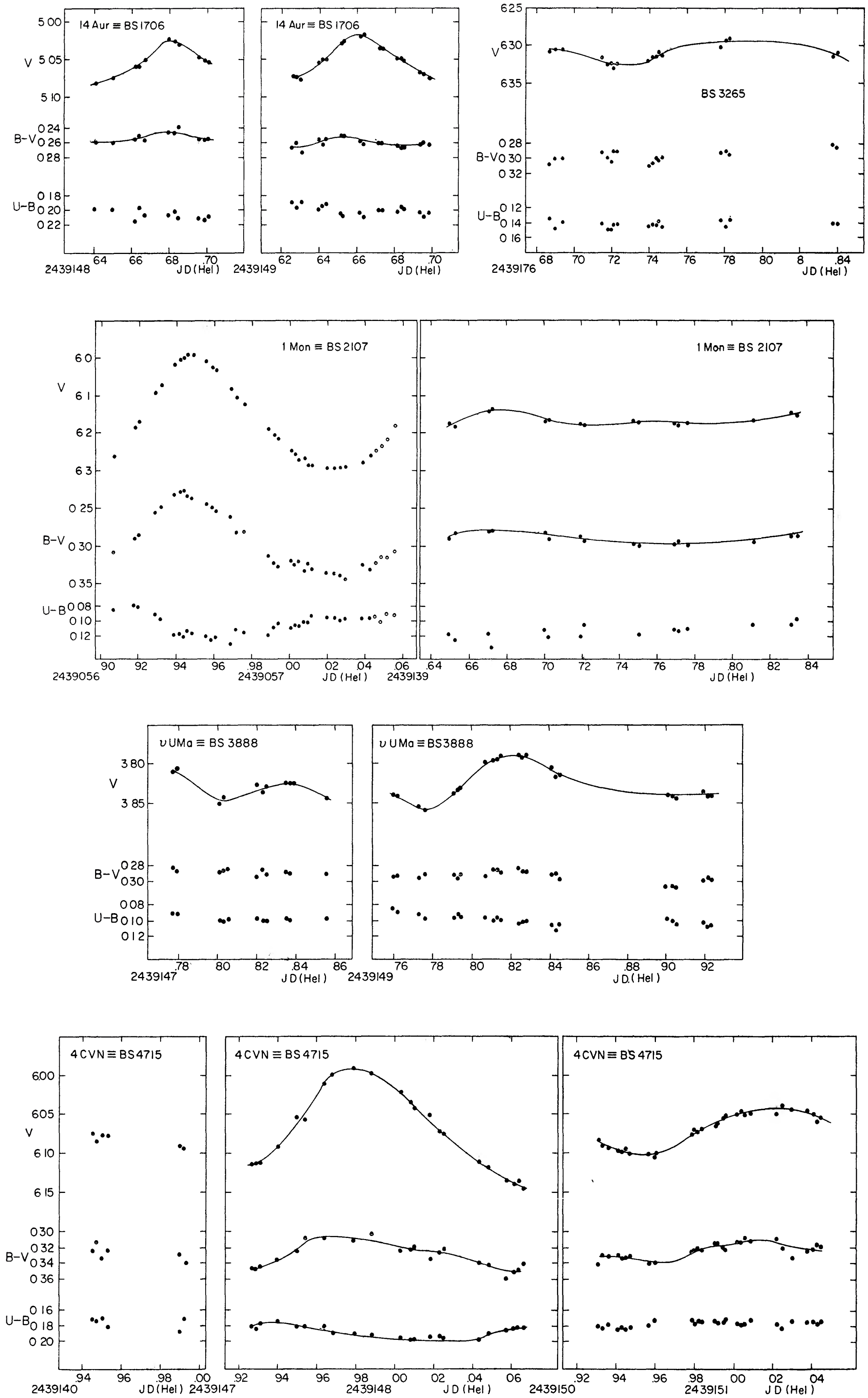
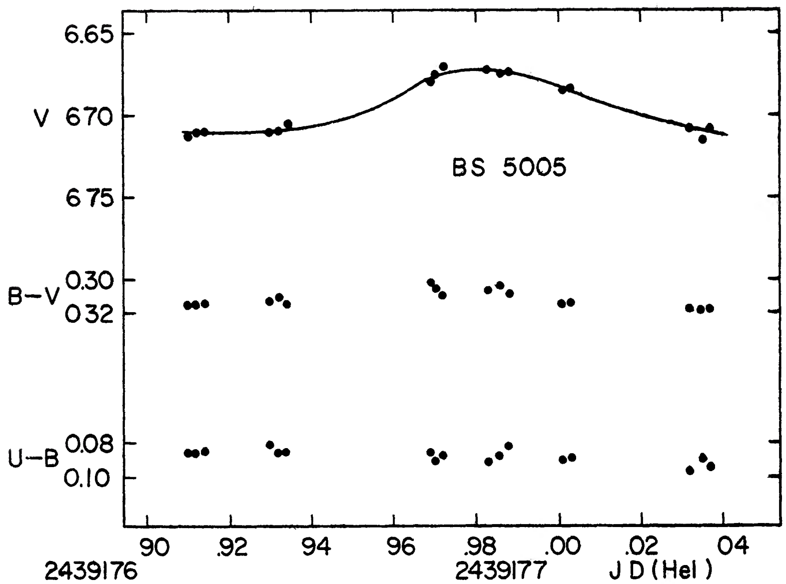


FIG 1 —*Continued*



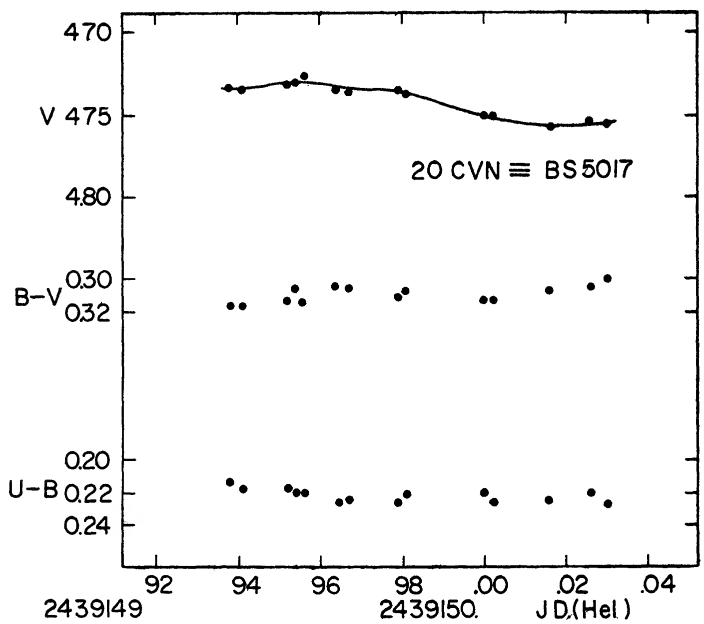


FIG. 1.—*Continued*

1967ApJ...149...55D

TABLE 2

UBV PHOTOMETRY

J.D.⊙	V	$B-V$	$U-B$
HR 1287 ≡ 44 Tau	Comparison Star ≡ HR 1256:		
	4.37	+1.07	+0.95
2439058 811	5 439	0 346	0.034:
814	.433	341	022:
816	.433	.343	025:
.828	.420	.339	.041
.830	.414	332	044
.834	.409	.332	.045
835	.409	332	.048
846	.382	.333	046
.848	.380	333	044
851	.374	334	.043
9058 854	5.371	0.331	0.049
.857	.372	.333	043
859	371	.336	.037
862	.358	.336	.048
.864	.356	.335	.044
867	369	.335	.050
.869	.368	.334	.047
.871	.371	.337	.047
.873	.368	.340	.048
876	366	334	053
9058.878	5 366	0.342	0.048
.880	.369	.339	.048
.884	.369	.341	.048
.889	.376	.345	.049
.893	.383	.342	049
.896	.389	.339	052
.898	.395	.340	.040
901	.396	.342	.043
.912	.421	.338	.046
.916	.421	.343	045
9058.918	5 424	0.343	0.045
.921	.425	.346	.038
.923	.428	.343	.055
.926	.432	.341	.057
938	.435	.346	.061
941	.440	.341	.064
.944	437	.345	.044
.946	.437	.346	.044
949	436	343	.045
.953	.433	.345	.051
9058.962	5.429:	0.342	0.052
964	.429:	339	053
9067.877	.380	.339	.043
.880	.383	.340	.052
.882	.390	.339	.053
.894	.413	.335	.047
.896	.419	.334	.041
.899	.426	.331	.041
.909	.433	.339	.065
.912	.440	.336	.066
9067.915	5.438	0.335	0.056
.919	.442	.337	.055
.930	.438	.330	.056
.934	.443	.331	.052
959	.414	324	.041
.969	.398	.317	.053
.972	.393	.321	.047
.976	.392	.327	.055
9068.001	.383	.326	038
.012	.387	.326	.052
9068.015	5.392	0.322	0.062
.018	.393	.324	.065
9090.778	.403	.329	.061
.779	.396	.319	.074
.838	.448	.336	.045
.841	.454	.330	.043
.843	.450	.343	....
.880	.406	.330	.051
.882	.396	.339	.049
.884	.397	.330	.057
9090.910	5.388	0.307	0.066
.912	.392	.322	.065
.915	.391	.326	.052
9138.653	.454	.341	.061
.656	.447	.346	.060
.660	.448	.347	.053
.663	.445	.344	.066
.666	.442	.346	.054
.696	.414	.318	.066
.699	.406	.319	.061
9138.701	5.394	0.327	0.056
.703	.387	.316	.062
.705	.388	.311	.069
.740	.394	.317	.069
.742	.388	.322	.069
.763	.433	331	.058
.766	.425	.323	.068
.780	.447	.335	.054
.782	.447	.341	.052
.785	.445	.334	.065
2439138.805	5.432	0.334	0.050
.807	430	.332	.058
.826	411:	.333:	.057:
832	420:	.322:	.049:
.834	429:	.315:	.052:
.856	404:	.322:	.055:
.859	.406:	.326:	.058:
9140.652	.414	.342	.062
.654	.416	.337	070
.662	422	.354	.059
9140.664	5.425	0.349	0.064
.682	.439	.348	.063
.684	.454	.345	057
.686	.443	.351	.056
.708	.424	.347	.046
.710	.419	.341	.049
9141 642	.393	.328	.061
.644	.391	326	.066
.657	.385	.329	.052
.660	.385	.335	.067
9141.688	5.432	0.344	0 067
.690	5.433	0.345	0.068
HR 1706 ≡ 14 Aur	Comparison Star ≡ HR 1843:		
	4.77	+0.35	−0.44
2439148.641	5.082:	0.259	0.198
.650	.074	.259	.199
.662	.059	.255	.215
.664	.058	.249	.197
.667	.050	.256	.207
.680	.023	.246	.207
.683	.026	.247	202
.685	.030	.238	.209
696	.047	.255	.210
.699	.051	.245	.212
9148.701	5.053	0.254	0.208
9149 626	.072	.267	.191
.628	073	.259	.197
.630	.076	.272	.190
.640	.053	.256	200
.642	.050	.262	.196
.644	.049	255	.193
.652	.028	.251	.205
.653	.025	.251	.208
.662	.018	.257	.204
9149.664	5.017	0.262	0.210
.672	.034	.260	.202
.674	.035	.260	.201
.682	.048	.263	.203
.684	.048	.266	.197
.685	.051	.266	.199
.694	.067	.262	.205
.696	.069	.261	.209
.699	5.073	0.262	0.204
HR 2107 ≡ 1 Mon	Comparison Star ≡ HR 1998:		
	3.56	+0.08	+0.08
2439056.907	6.260	0.308	0.084
.918	6.182	.289	.080
.920	6.167	.285	.081
.929	6.090	.254	.091
.932	6.070	.248	.098
.939	6.016	.231	.118
.942	6.003	.233	.117
.944	5.998	.226	.119
.946	5.990	.233	.113
.949	5.989	.236	.116
9056.956	6.007	0.243	0.120
.959	.023	.248	.124
.961	.030	.252	.122
.969	.080	.260	.130
.972	.102	.281	.110
.976	.121	.280	.114
.989	.188	.312	.117
.992	.202	.322	.108
.994	.211	.326	.102
9057.001	.245	.318	.108
9057.003	6.254	0.323	0.105
.005	.269	.319	.106
.008	.264	.332	.101
.010	.282	.322	.100
.012	.283	.329	.092
.020	.290	.334	.094
.024	.290	.336	.095
.027	.289	.338	.099
.030	.288	.343	.096
.039	.276	.324	.096
9057.043	6.256	0.331	0.095
.046	.244:	.321:	.093:
.049	.232:	.313:	.099:

TABLE 2 -continued

J.D.⊙	V	$B-V$	$U-B$
2439057.052	6 213:	0.314:	0.089:
.056	175:	.306:	090:
9067.947	.072	264	107:
.983	.141	.306	104:
9068.025	.232	.336	102:
9139.650	.172	.290	.117
.653	181	283	.123
9139.671	6.138	0.280	0.116
.673	.133	.279	.134
701	.165	.282	.111
.703	.162	.290	.120
.720	.172	.287	.118
.722	177	.293	.104
748	.162	.297	......
751	.166	.299	.117
770	.171	.297	.111
.772	132	.293	.112
9139.777	6 169	0.298	0 100
.812	161	.293	.105
832	140	.287	104
.835	6.146	0.287	0.097
HR 3265	Comparison Star ≡ HR 3314:		
	3.89	−0.04	−0.04
2439176.687	6.308	0.307	0.135
.690	.306	.299	.148
.694	.306	.299	.140
715	.316	.292	.142
.718	.325	.299	.150
.720	.323	.305	150
.721	.330	.291	143
.723	.324	.290	144
.740	.320	.309	.146
.742	.316	.306	.144
9176.744	6.314	0.295	0.144
.745	.308	.302	.139
.747	.313	.298	.147
.778	.302	.293	.138
.781	.294	.289	.147
.783	.291	.294	.138
.838	.314	.282	.143
.840	6.310	0.284	0.143
HR 3888 ≡ υ UMa	Comparison Star ≡ HR 3624:		
	4.69	+0.35	+0.16
2439147.777	3.810	0.283	0.091
.779	.807	.287	.092
.801	.851	.288	.100
.803	.843	.286	.101
.805	.846	.284	.099
.820	.827	294	.098
.821	.836	.285	.099
.825	.829	.292	.100
.835	.825	.288	.098
.837	.825	.290	.100
9147.856	3.844	0.290	0.098
9149.760	.839	.293	.083
.762	.841	.292	.088
.773	.856	.296	.091
.776	.859	.292	.097
.791	.838	.292	.096
.793	.833	.296	.091
.794	.831	.292	.094
.807	.798	.293	.095
.811	.797	.285	.099
9149.813	3.794	0.285	0.097
.815	.791	.288	.099
.824	.789	.283	.103
.826	.792	.287	.101
.830	.789	.288	.099
.841	.805	.292	.105
.843	.817	.290	.112
.845	.814	.297	.104
.901	.839	.306	.098
.903	.841	.306	.102
9149.905	3.843	0.307	0.105
.919	.835	.299	.105
.921	.841	.294	.108
.923	3.840	0.297	0.107
HR 4715 ≡ 4 CVn	Comparison Star ≡ HR 4716:		
	4.80	+0.87	+0.63
2439140.945	6.074	0.324	0.172
.947	.085	.313	.174
.950	.077	.334	.171
.953	.078	.324	.182
.990	.091	.330	.188
9140.992	.094	.342	.172
9147 927	.114	.347	.181
.929	.113	.347	.184

J.D.⊙	V	$B-V$	$U-B$
2439147.931	6.112	0 345	0.176
.940	6.092	.336	.175
950	6.053	.325	.181
.954	6.057	.308	181
.964	6.010	.308	182
.968	5.998	.307	.189
.979	5 991	.312	.190
.988	5.997	.303	.192
9148 003	6.021	.324	.196
.008	6 034	.323	198
9148.010	6.042	0.319	0.198
.018	.050	.335	.195
023	.072	.327	.195
.025	.076	.322	.196
.043	.112	.339	.199
.048	.119	.343	191
.057	.135	.359	187
.061	.139	.352	.184
.063	.137	.348	.183
066	.146	.342	183
9150.931	6.083	0.342	0.180
.933	.091	.331	.182
.936	.093	.332	.179
.941	.097	.331	.184
.943	.098	.335	.183
.945	.095	.333	.184
947	.100	.332	.183
.957	.102	.341	.179
.960	.105	.341	174
.979	.077	.327	.173
9150.980	6.071	0.325	0.177
.982	.073	.322	.175
.984	.069	.323	.175
.991	.066	.315	.175
.993	.062	.316	.177
.995	.055	.321	.176
.996	.052	.323	.173
9151.002	.051	.314	.178
004	.047	314	.180
.006	.051	.309	.178
9151.009	6.049	0.313	0.173
.022	.049	.311	180
.025	.038	.322	.184
.030	.044	334	.176
.038	.046	326	.177
.041	.051	.323	177
.043	.059	.318	.179
.045	6.054	0.320	0.176
HR 5005	Comparison Star ≡ HR 4963:		
	4.37	−0.01	+0.01
2439176.910	6.713	0.316	0.085
.912	.711	.316	.084
.914	.710	.315	.084
.930	.711	.313	.081
.932	.710	.311	.084
.934	.706	.315	.083
.969	.679	.302	.085
.970	.675	.305	.089
.972	.670	.310	.087
.983	.673	.307	.091
9176.986	6.675	0.304	0.087
.988	.674	.309	.081
9177.001	.686	.315	.089
.003	.685	.315	.088
.032	.708	.318	.097
.035	.715	.319	.091
.037	6.708	0.319	0.094
HR 5017 ≡ 20 CVn	Comparison Star ≡ HR 5110:		
	5.01	+0.39	+0.06
2439149.938	4.734	0.315	0.213
.941	.734	.316	.217
.952	.731	.313	.217
.954	.731	.306	.219
.956	.726	.313	.219
.964	.735	.304	.225
.967	.736	.306	.224
.979	.735	311	.227
.981	.738	.307	221
9150.000	.751	.313	.221
9150.002	4.751	0.313	0.226
.016	.757	.307	.222
.026	.755	.305	.222
.030	4.756	0.300	0.228

NOTES TO TABLE 2

HR 1287 ≡ 44 Tau: Beat phenomena indicated by irregularity of period between October, 1965, and January, 1966. Maximum light occurs at the following Julian Dates:

2439058 874
67 999
90 902
138 728
141 667

HR 1706 ≡ 14 Aur: Part of wide binary system. Companion has $V = 7.99$, $B - V = 0\,47$, $U - B = 0.03$, which yields $M_V = +0.8$ for 14 Aur Companion has a small UV excess. The adopted period of 0^d122 is nearly a submultiple of the period of variation of the radial velocity, 3^d789 days, obtained by Harper (1938), who discussed the star as a spectroscopic binary. Maximum light occurs at the following Julian Dates:

2439148 677
49 659

HR 2107 ≡ 1 Mon: Minimum $B - V$ occurs about 0.04 of a period before minimum V magnitude. The variations in light amplitude (Fig 1) indicate a strong secondary period Maximum light occurs at Julian Date 2439056.947.

HR 3265: Reported as showing 0 05 mag variation by Cape Observatory (Cape Mimeogram 1961). This star has a high m_1 index (Strömgren) The period is uncertain. Maximum light occurs at Julian Date 2439176 730.

HR 3888 ≡ υ UMa: Variations in light amplitude (Fig. 1) indicate a beat phenomena. The trigonometric parallax of 0".036 gives $M_V = +1.6$, in agreement with that derived from the *uvby* photometry. Maximum light occurs at Julian Date 2439149 823.

HR 4715 ≡ 4 CVn: Discovered to be variable in radial velocity, with a period of 0^d17, by Jones and Haslam (1966). Probable member of the Hyades moving group; the group parallax gives $M_V = +0.8$ The variation in light amplitude (Fig 1) indicates beat phenomena. Maximum light occurs at the following Julian Dates:

2439147 978
51 023

HR 5005: Maximum light occurs at Julian Date 2439176 981.

HR 5017 ≡ 20 CVn: This star, like HR 3265, has a high m_1 index. The period is uncertain Probable member of the Hyades moving group, with a group parallax giving $M_V = +0.45$.

where stars have a $V \sin i > 50$ km/sec ($V \sin i$ discussed later and given in Table 4), the blanketing corrections were estimated for their known colors and luminosities by interpolating between the results for the sharp-lined variables, and also by using published results for the Hyades stars by Oke and Conti (1966).

IV. EFFECTIVE TEMPERATURES, GRAVITIES, AND ROTATIONAL VELOCITIES

Effective temperatures and gravities were obtained from the scanner data by fitting the observed continua to those of theoretical model atmospheres. Two grids of model atmospheres were available; one, computed with a program written by Mihalas (1965), does not include the effects of line blanketing; the other, also by Mihalas (1966), does include the effect of blanketing by the Balmer lines of hydrogen. This latter grid has a lower temperature limit given by $\theta_e = 0.70$ and, therefore, was only directly useful for a few of the stars. However, when the two grids were compared in the region of temperature overlap, it was found that near $\theta_e \sim 0.70$ the Balmer line-blanketed models gave θ_e approximately 0.02 cooler than the unblanketed models. Therefore, where it was necessary to use the unblanketed models, this correction factor was applied. It was found that the gravity obtained from the Balmer jump was independent of the grid of models used. These data are given in Table 4, together with other data to be discussed. Included in this table are data for other previously known δ Sct stars. Sources are referenced. The period of pulsation P for some of the new variables is only approximate. M_v represents the mean of available absolute magnitude estimates which have been derived by one or more of the following methods: (1) Strömgren's *uvby* photometry; (2) trigonometrical parallaxes greater than 0.030"; (3) classification of a companion star; (4) by using Eggen's (1963) calibration of UBV data; and (5) membership of a moving group. The

TABLE 3

MONOCHROMATIC FLUXES IN MAGNITUDES PER UNIT FREQUENCY INTERVAL

1/λ	HR 1287 J.D. 24391+ 73.638	HR 1287 J.D. 24391+ 98.633	HR 1287 Blanketing Correction	HR 1706 J.D. 24391+ 73.663	HR 1706 J.D. 24391+ 98.656	HR 1706 Blanketing Correction	HR 2107 J.D. 24391+ 72.665	HR 2107 J.D. 24391+ 73.688	HR 2107 J.D. 24391+ 96.694	HR 2107 Blanketing Correction	HR 3265 J.D. 24391+ 73.757	HR 3265 Blanketing Correction	HR 3888 J.D. 24391+ 72.726	HR 3888 J.D. 24391+ 73.732	HR 3888 J.D. 24391+ 73.854	HR 3888 J.D. 24391+ 96.769	HR 3888 J.D. 24391+ 98.740	HR 3888 Blanketing Correction
1.71..	5.31	5.15	0.04	5.02	4.80	0.02	6.00	6.23	6.04	0.03	6.24	0.03	3.75	3.73	3.79	3.82	3.63	0.02
1.80..	5.32	5.14	.07	5.03	4.82	.03	5.97	6.23	6.06	.04	6.27	.04	3.76	3.73	3.78	3.84	3.65	.03
1.90..	5.39	5.22	.11	5.04	4.84	.07	6.01	6.30	6.16	.08	6.33	.09	3.80	3.77	3.83	3.87	3.69	.07
2.00..	5.41	5.25	.12	5.04	4.85	.07	6.03	6.34	6.19	.08	6.36	.08	3.83	3.79	3.86	3.88	3.71	.07
2.09..	5.41	5.24	.09	5.03	4.83	.05	6.00	6.33	6.19	.05	6.34	.06	3.82	3.79	3.85	3.87	3.70	.04
2.19..	5.46	5.30	.12	5.06	4.88	.11	6.06	6.41	6.26	.11	6.43	.12	3.88	3.85	3.91	3.93	3.75	.10
2.24..	5.50	5.35	.14	5.07	4.89	.13	6.09	6.45	6.32	.13	6.46	.13	3.91	3.87	3.94	3.95	3.78	.11
2.35..	5.55	5.42	.12	5.09	4.92	.11	6.12	6.51	6.38	.10	6.51	.14	3.96	3.92	4.00	4.00	3.82	.10
2.40..	5.60	5.47	.15	5.13	4.96	.13	6.16	6.57	6.44	.15	6.57	.17	3.98	3.96	4.03	4.03	3.84	.12
2.48..	5.62	5.48	.13	5.13	4.95	.13	6.16	6.59	6.45	.13	6.58	.17	4.00	3.97	4.03	4.02	3.84	.10
2.75..	6.61	6.50	.23	6.32	6.19	.22	7.24	7.51	7.36	.22	7.60	.23	5.06	5.05	5.09	5.03	4.93	.22
2.80..	6.69	6.58	.27	6.40	6.25	.23	7.34	7.63	7.48	.23	7.72	.29	5.13	5.11	5.16	5.09	5.00	.22
2.85..	6.74	6.63	.30	6.43	6.29	.25	7.38	7.68	7.53	.24	7.78	.29	5.18	5.17	5.22	5.14	5.04	.24
2.90..	6.77	6.65	.25	6.46	6.31	.25	7.37	7.68	7.51	.25	7.75	.27	5.18	5.19	5.23	5.13	5.06	.24
2.95..	6.82	6.71	0.30	6.52	6.37	0.30	7.44	7.75	7.59	0.30	7.83	0.30	5.26	5.25	5.30	5.20	5.12	0.30

1/λ	HR 4715 J.D. 24391+ 73.875	HR 4715 J.D. 24391+ 73.975	HR 4715 J.D. 24391+ 98.797	HR 4715 Blanketing Correction	HR 5005 J.D. 24391+ 73.907	HR 5005 J.D. 24391+ 98.905	HR 5005 Blanketing Correction	HR 5017 J.D. 24391+ 74.008	HR 5017 Blanketing Correction	HR 5329 A J.D. 24391+ 98.956	HR 5329 A Blanketing Correction
1.71..	6.03	5.96	6.11	0.02	6.63	6.82	0.02	4.66	0.09	4.67	0.02
1.80..	6.04	5.98	6.14	.04	6.65	6.86	.03	4.70	.13	4.66	.02
1.90..	6.11	6.05	6.22	.08	6.70	6.89	.06	4.78	.18	4.66	.04
2.00..	6.15	6.09	6.24	.09	6.73	6.92	.07	4.78	.18	4.65	.04
2.09..	6.15	6.09	6.24	.07	6.74	6.92	.06	4.76	.14	4.64	.03
2.19..	6.24	6.16	6.32	.12	6.80	6.99	.12	4.82	.16	4.68	.06
2.24..	6.28	6.19	6.36	.14	6.82	6.99	.13	4.85	.17	4.67	.07
2.35..	6.34	6.28	6.43	.14	6.90	7.06	.14	4.91	.15	4.71	.10
2.40..	6.40	6.31	6.48	.16	6.92	7.10	.17	4.98	.21	4.74	.13
2.48..	6.42	6.34	6.51	.15	6.93	7.11	.17	5.00	.20	4.75	.11
2.75..	7.47	7.41	7.57	.23	7.98	8.16	.23	6.16	.31	5.97	.15
2.80..	7.56	7.50	7.63	.27	8.05	8.23	.29	6.25	.34	6.03	.18
2.85..	7.64	7.56	7.72	.29	8.12	8.29	.29	6.31	.36	6.08	.17
2.90..	7.64	7.59	7.72	.26	8.14	8.30	.27	6.33	.39	6.10	.17
2.95..	7.69	7.64	7.77	0.26	8.20	8.36	0.29	6.35	0.38	6.14	0.18

1/λ	HR 1287	HR 1706	HR 2107	HR 3265	HR 3888	HR 4715	HR 5005	HR 5017
0.93..	5.36	5.24	6.32	6.42	3.72	5.99	6.67	4.79
0.94..	5.33	5.21	6.31	6.44	3.67	5.96	6.67	4.75
0.98..	5.28	5.13	6.24	6.36	3.61	5.89	6.67	4.68
1.02..	5.27	5.10	6.24	6.34	3.59	5.87	6.63	4.66
1.15..	5.28	5.11	6.21	6.33	3.61	5.87	6.67	4.68
1.24..	5.24	5.07	6.18	6.31	3.57	5.85	6.65	4.66
1.33..	5.25	5.06	6.25	6.33	3.58	5.88	6.67	4.67
1.47..	5.26	5.03	6.20	6.27	3.57	5.86	6.65	4.64
1.65..	5.29	5.02	6.21	6.28	3.60	5.90	6.67	4.64

relative merits of the different methods are arguable, but equal weight has been given to all methods.

The eighth column of Table 4 contains $V \sin i$, the rotational velocity of the star projected in the line of sight. It is immediately obvious that some of the stars have large rotational velocities. This demonstrates that Preston's (1965) conclusion that rapid rotation and pulsation are incompatible in Cepheid-type variables does not apply to δ Sct variables. The effective temperatures indicate that the region of pulsation extends to higher temperatures than indicated by the previously known δ Sct variables.

TABLE 4

DATA FOR KNOWN δ SCT STARS

Star	$B-V$	Spec Type	θ_e	log g	P Period (days)	M_V	$V \sin i$ (km/sec)	References*
HR 1287	0 34	dF3	0 79	3 05	0 132	+1 8	≤ 10	
1706	25	A9	69	3 53	12	+1 0	15	. .
2107	29	F2 II	695	3 80	137	+1 7	10– 15	
3265	30	A5	76	3 17	12– 14	+1 9	20– 25	
3888	29	F2 IV	725	3 64	13	+1.6	110	.
4715	33	F0	77	3 07	17	+0 9	85	.
5005	30	F0	725	3 67	14	+1 6	60	..
5017	32	F0 II	775	2 72	14	+0 9	≤ 10	..
5329	20	A7 IV	655	3 63	069	+1.2	130	(1)
β Cas	34	F2 IV			104	+1 5	70	(1)
CC And	33	F3 IV–V	. .	. .	125	+2 2	20	(2)
ρ Pup	39	F6 III	83	2 2	141	+0 7	15	(3)
δ Sct	35	F3 III	79	2 8	194	+1 1	15	(4)
δ Del	30	F2 IV	73	3 2	135	+1 3	20	(4)
BS Aqr	. . .	. .	. . .	. . .	. . .	. .	20	(5)
DQ Cep	0 30	F1 IV	0 75	3 32	0 079	+1 8	60	(5)

* (1) R. Millis, Comm 27 *I.A U. Bull No 137* (Konkoloy Obs) (1966); (2) D H. McNamara and G Augason, *Ap J*, **135**, 64 (1961); (3) I. J Danziger and L V Kuhi, *Ap J*, **146**, 743; (4) L V Kuhi and I J Danziger, *Ap J* (in press); (5) I J Danziger (unpublished)

V. DISCUSSION

a) *The Color-Magnitude Diagram*

The color-magnitude diagram is shown in Figure 2. The variables in Table 4 are shown as crosses, and non-variables from Table 2 shown as filled circles. Circled crosses denote variables for which at least two independent estimates of M_v are available. The two open circles are the peculiar stars β CrB and γ Equ, for which the absolute magnitudes are uncertain. The position of the Cepheid instability strip is indicated by broken lines. It is noticeable that the two possible Sirius group members, HR 5329 and δ Del, are bluer than the three possible Hyades group members, HR 4715, 5017, and δ Sct. This difference is in the same sense as the difference between the sequences of their member stars (Eggen, 1960*b*).

No clear separation between variable and non-variable stars is evident, although it is noticeable that very few non-variable stars occur brighter than $M_v = +1.5$. Since line blanketing and stellar rotation can affect the magnitude and color of these stars, some attention should be given to them. Differential line blanketing effects should be small because (1) the stars lie in a restricted range of temperature and luminosity, and (2), having small space motions, they all appear to be disk-population stars. However, the influence of a star's rotation on the observed colors may be considerable. Strittmatter (1966) gives the change in effective temperature and absolute magnitude found in various models of rotating stars. The theories indicate that a rotating star always appears cooler than its non-rotating counterpart, irrespective of aspect. Also, a rotator viewed pole-on appears brighter than, and equator-on appears fainter than, its non-rotating counterpart. The largest effects are shown by the non-uniformly rotating, magnetic models of Roxburgh and Strittmatter (1966). We note in Figure 2 that, of the non-variables occurring in the region occupied by the variable stars, i.e., between about $M_v = +0.5$ and $M_v = +2.4$, six stars have observed values of $V \sin i$ available. For these six stars, $\langle V \sin i \rangle \sim 130$ km/sec; whereas, for sixteen known δ Sct stars, $\langle V \sin i \rangle \sim 40$ km/sec.

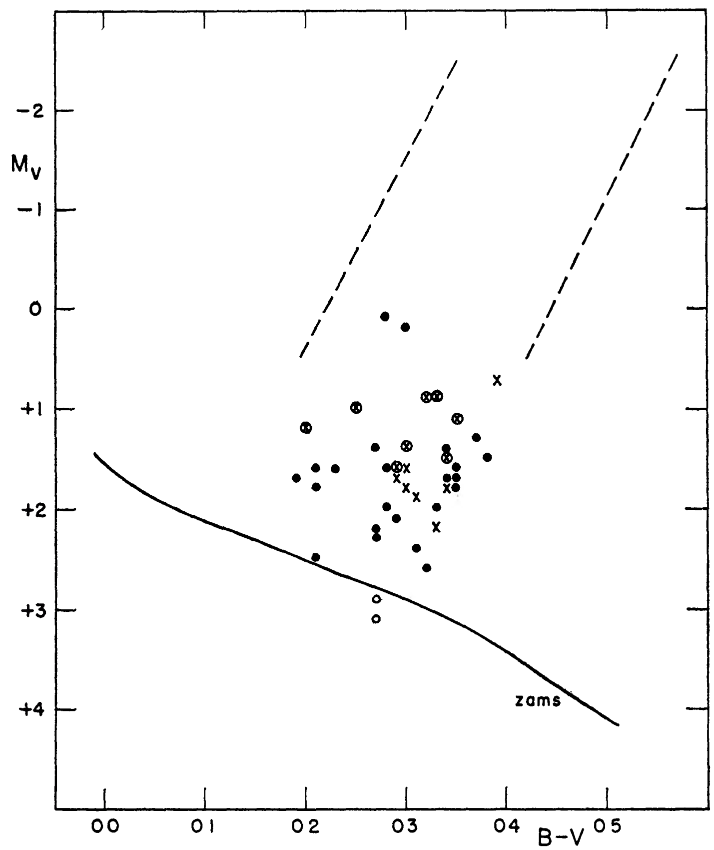


FIG. 2.—Observed color-magnitude diagram showing all the known δ Scuti stars (*crosses* or *circled crosses*), together with stars from Table 1 that are probably non-variable (*filled* or *open circles*) The zero-age main sequence is shown as a solid line and the position of the Cepheid instability strip by two broken lines.

The mean equatorial rotational velocity $\langle V \rangle$ is given by (Chandrasekhar and Münch 1950) $\langle V^2 \rangle = \frac{3}{2}\langle (V \sin i)^2 \rangle$. For stars between $M_v \sim +0.5$ and $M_v \sim +2.4$, we find

$$\langle V^2 \rangle_{\text{variables}} = 5000 \text{ (km/s)}^2 , \qquad \langle V^2 \rangle_{\text{non-variables}} = 26662 \text{ (km/s)}^2 .$$

Using these values in the models and adopting a mean mass for both groups of $M = 1.8\, M_\odot$, and a mean radius of $R = 2.88\, R_\odot$ (from the $M_{\text{bol}}/\log T_e$ diagram, Fig. 5 below), we find for an average inclination

$$\Delta \log T_e \sim +0.009 \text{ for the variables} , \qquad \Delta \log T_e \sim +0.048 \text{ for the non-variables} ,$$

the effects on M_v in both cases being negligible. The differential effect of $+0.039$ in log T_e corresponds to $\sim$0.1 in $B - V$.

Therefore, if in Figure 2 the non-variables are moved to the left by 0 1 in $B - V$

relative to the variables, a very noticeable separation is found between the variables and non-variables. Some overlap occurs, and indeed this must be expected in such a statistical calculation where the value of V for individual stars is not known. Similarly, rotation would tend to separate variables from non-variables in the $U - B/B - V$ diagram (§, Vb). The largest effect again occurs in $B - V$, since, for the samples considered here, the separation in $U - B$ is only 0.02 mag, in the sense that a higher rotation increases the value of $U - B$.

However, we should be careful to point out that such a limited analysis does not prove that variables and non-variables occupy completely separate regions of the H-R diagram when their colors are normalized to zero rotation. A much more complete analysis of stars in the variable star region, and on both sides of it, should be made for temperature,

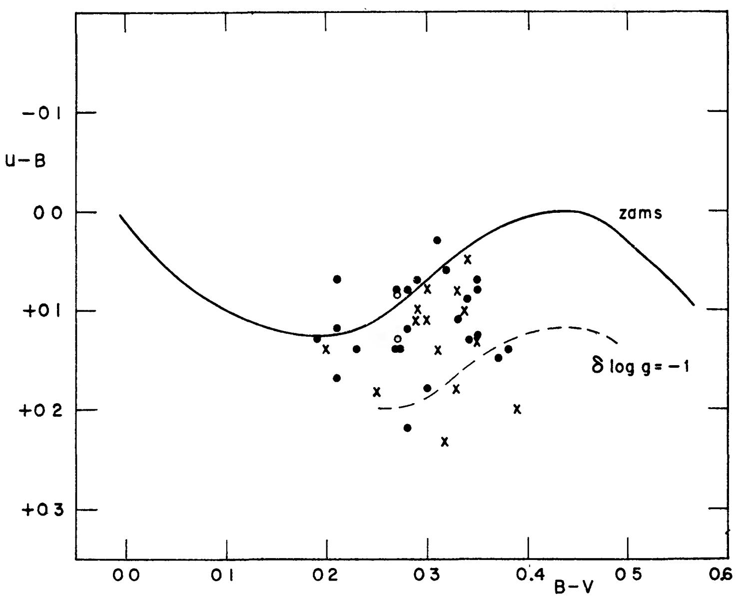


FIG. 3.—Observed two-color diagram for the same stars as in Fig 2. The solid line shows the position of the zero-age main sequence; the broken line is Eggen's calibration of the effect of a change of surface gravity of $\delta \log g = -1$

gravity, rotation, and variability. In this way selection effects should be avoided and greater weight can be given to a statistical analysis. The present conclusion to be drawn from these results seems to be that, if the colors of the stars are normalized to zero rotation, a high proportion of the stars in the range $B - V \sim 0.25$–0.40 mag and $M_v \sim +0.5$ to $+2.4$ mag is variable.

b) The U − B/B − V Diagram

The $U - B/B - V$ diagram is shown in Figure 3, in which variables are denoted by crosses and non-variables by filled or open circles, as in Figure 2. The zero-age main sequence ("ZAMS"; Eggen 1965) is shown as a solid line, and it can be seen that all the variable stars fall below this (luminosity class V) line. The position of a star in the two-color diagram is influenced by effective temperature, line blanketing, and surface gravity. If the stars in Figure 3 have compositions similar to the Hyades stars (ZAMS), the blanketing effects will be similar and the negative ultraviolet excesses of the variables in Figure 3 will be predominantly caused by their lower surface gravities. The broken line in Figure 3 indicates a calibration for $\Delta \log g = -1$ with respect to the Hyades, based on data from wide binaries by Eggen (1963).

In principle, effective temperatures and gravities can be obtained by interpolating the observed colors $U - B$, $B - V$ into this type of diagram, which has been calibrated with a grid of models. In practice, the scanner observations described previously have been used to obtain this information. It is worth noting that the dwarf Cepheids lie above the main-sequence line in the two-color diagram and generally appear bluer than the δ Sct stars. Since no abundance analyses exist for dwarf Cepheids, it is not yet clear how much of this difference is due to line-blanketing effects.

Figure 4 shows the paths traced out in the $U - B/B - V$ diagram by the variables HR 2107 and HR 4715 during one cycle of variation. Their behavior appears to be similar to that of RR Lyrae stars, such as SU Dra (Oke, Giver, and Searle 1962) in which the surface gravity reaches a maximum value during rising light. The maximum gravity change is about 0.4 in log g for HR 2107 and rather less for HR 4715.

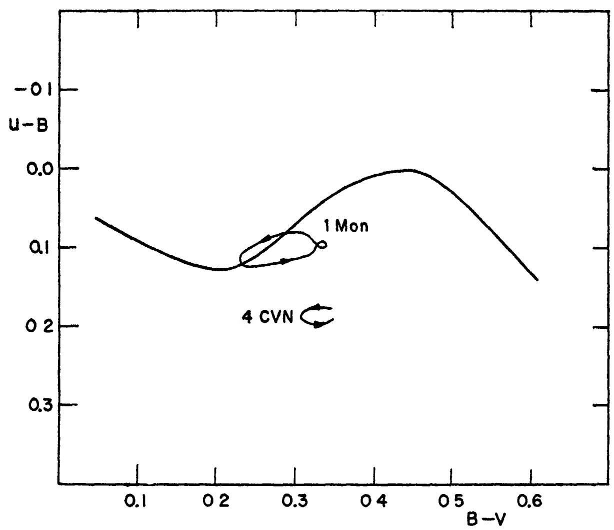


FIG. 4 —Paths traced out in the two-color diagram by the variables HR 2107 (1 Mon) and HR 4715 (4 CVn) during a cycle of light variation.

c) The M_{bol}/log T_e Diagram

By using the absolute magnitudes in Table 4 and the effective temperatures from the scanner observations, the variable stars have been plotted in an M_{bol}/log T_e diagram. This is given in Figure 5. The small bolometric corrections which have been applied were taken from Popper (1959). Also plotted in this diagram is the observational ZAMS from a combination of the work of Eggen (1965) and Sandage (1957). The theoretical 1.5 $M_\odot$ evolutionary track of Iben (1967), moved -0.03 in log T_e to fit the ZAMS initially, is also shown. (This appears to be reasonable in the light of Iben's stated errors and the approximate nature of the model atmospheres used in his work.) The dashed horizontal lines are translated 1.5 $M_\odot$ tracks; the dashed vertical lines represent approximate iso-rotational contours assuming conservation of angular momentum in shells. The mean values of $V \sin i$ on the main sequence are taken from the work of Abt and Hunter (1962).

The estimated absolute magnitudes and the measured values of the gravities and effective temperatures allow the calculation of the masses for these variable stars. These calculated masses and the masses derived from their positions in the M_{bol}/log T_e diagram of Figure 5 are shown in the second and third columns of Table 5. It can be seen that approximately one half of these stars have calculated masses which are compatible with their positions in the M_{bol}/log T_e diagram when account is taken of the uncertainties of some of the data. The remaining stars all appear to be under-massive for normal left-to-right evolution in the H-R diagram. It is also noticeable that the stars of lowest mass are consistently cooler than the stars of higher mass. This result is consistent with the observation of the sequence formed by plotting these stars in a log g versus log T_e diagram (discussed in § V*d*).

This effect might be explained if the determination of log g from model atmospheres was systematically increasing in error in going to lower temperatures. It is not obvious at the present time that this should be the case.[1] At least it can be stated that the hotter

[1] See note added in proof.

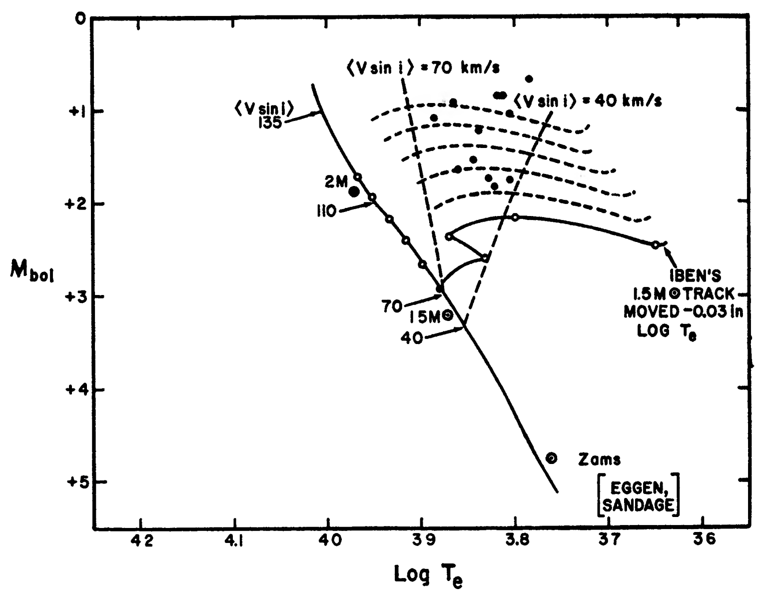


FIG. 5.—M_{bol}/log T_e diagram Variable stars (*filled circles*) are superposed on theoretical evolutionary tracks of Iben Rotational velocities are also marked

TABLE 5

MASSES AND PULSATION CONSTANTS

Star	Computed Mass $\mathfrak{M}/\mathfrak{M}_\odot$	Mass from M_{bol}–log T_e Diagram $\mathfrak{M}/\mathfrak{M}_\odot$	Pulsation Constant Q
HR 1287	0 4	1 6	0 015
1706	1 7	2 0	022
2107	1 7	1 7	041
3265	0 4	1 6	018
3888	1 4	1 7	030
4715	0 8	2 0	017
5005	1 5	1 7	034
5017	0 4	2 0	009
5329	1 4	1 9	016
ρ Pup	0 2	2 1	005
δ Sct	0 4	1 9	015
δ Del	0 7	1 8	018
DQ Cep	0 6	1 6	0 013

variables have masses and luminosities which are consistent with their evolution from a ZAMS to the right in the H-R diagram. Further support for this idea is given by the fact that the mean rotational velocity $\langle V \sin i \rangle$ of this group of variables seems consistent with what would be expected for the former main-sequence positions of the variables in the group.

In the above discussion it has not been possible to take account of rotational effects on an individual star's position in the H-R diagram. This should not seriously affect the conclusions.

d) The log g/log T_e Relation

The location of the high-temperature boundary to the instability strip in the color-magnitude diagram has been predicted theoretically by Christy (1966*a*) on the basis of extensive calculations on RR Lyrae and Cepheid models. This is indicated by a solid

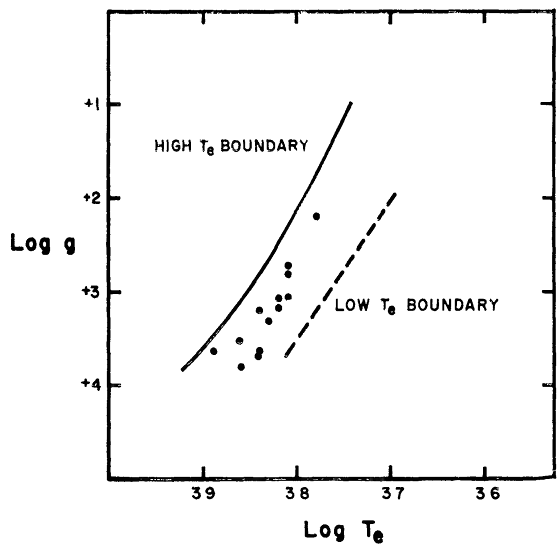


FIG 6 —Log g/log T_e diagram for short-period variables Theoretical boundaries of the instability region are marked

line in the log g/log T_e diagram shown in Figure 6. The broken line shows the approximate location of the onset of deep convection from the work of several authors (see Christy 1966*b*). It has been suggested that this corresponds to the low-temperature boundary of the instability strip. The δ Sct variables are shown as points in Figure 6. They show a correlation between these two parameters which agrees well with the theoretical slope of the instability strip.

Only if a mass-luminosity relation were true for δ Scuti stars could we use the equation of the instability strip, together with the period-density law to predict a period-luminosity relation.

e) Pulsation

Since these stars are pulsating with reasonably regular periods it is of some interest to note whether they obey a period-density and period-luminosity law. Results for other short-period variables by Danziger and Kuhi (1966), Danziger and Oke (1967), and Kuhi and Danziger (1967) indicate that, to explain the observations, much lower values of the pulsation constant, Q, are required than the theory of RR Lyrae models indicates. In this paper a value of Q is calculated for each star by combining the period-density law and the expressions for density and luminosity. The final expression is

$$\log Q = \log P + \tfrac{1}{2} \log g/g_\odot + \log T_e/T_{e\odot} + 0.1\,(M_{\mathrm{bol}} - M_{\mathrm{bol}\odot}) .$$

These calculated values of Q are listed in the fourth column of Table 5. It can be seen that the values range from 0.005 for ρ Pup to 0.041 for HR 2107. From theoretical calculations (Christy 1966*a*) we might expect values in the range $\sim$0.025 to $\sim$0.040 depending on the overtone, provided the pulsation is in either the fundamental or first overtone. The systematics of overtone Q values (Schwarzschild 1941; Christy 1966*b*) indicate that Q values less than 0.015 for spherical pulsation would require overtones higher than the fourth. Because of errors in the determination of M_v and log g, values of Q as low as 0.015 cannot at the moment be considered to invalidate the idea of a fundamental or first overtone pulsation. However, the lowest values of Q suggest higher-order overtones. It has in fact been suggested (Christy 1966*b*) that the modulation of about 3 or 4 periods that is common in δ Scuti stars could be the result of a mixture of higher overtones (such as the third and fourth for a low-gravity star).

These results imply that a unique period-luminosity law will not be obvious for these stars, and indeed this was found to be so.

VI CONCLUSIONS

The results of this investigation show that the instability strip extends to fainter stars (or higher gravities) and higher temperatures than previously known. It is clear that many more stars in the region under discussion will be found to be variable, and there is an obvious need for closer investigation of stars in clusters. Established variables can now be used to study the relative phases of light, temperature, and radial velocity which are of some interest in theoretical models. It is planned to study in more detail the statistics of variability, rotation, gravity, and temperature in this region of the H-R diagram.

We wish to express our gratitude to Dr. R. P. Kraft for obtaining a spectrum of HR 3888 at the 200-inch telescope and for determining rotational velocities for all of our stars. One of us (I. J. D.) wishes to acknowledge the hospitality provided by Dr. J. L. Greenstein during his stay at the California Institute of Technology. One of us (R. J. D.) is grateful to Dr. O. J. Eggen and Dr. A. R. Sandage for suggesting the program to search for new δ Scuti variables and for providing a candidate list of possible variables; also to Dr. Sandage who collaborated on the *UBV* observations of 44 Tau and 1 Mon; and finally to the Carnegie Institution of Washington for its support during this investigation.

Note added in proof: It has been suggested (M. S. Bessel 1967, private communication) that a systematic underestimate of line blanketing and an incorrect absolute calibration could cause an underestimate of the effective temperature and surface gravity (and hence the mass and Q value), which increases as the absolute temperature decreases. If this is indeed correct, the stars plotted in Figure 6 would need to be compressed toward higher gravities and higher temperatures. However, at the present time the red scans given in this paper, which are essentially free of line-blanketing effects, can be arbitrarily fitted to the blue scans to give the same temperatures as those presented in Table 4. Because the relative phases of the red and blue scans are not known, we are not yet in a position to say whether it is a valid procedure or not.

REFERENCES

Abt, H., and Hunter, J 1962, *Ap. J.* **136,** 381
Cape Mimeogram, 1961, No 12.
Catalogue of Bright Stars. 1964 (Yale University Observatory)
Chandrasekhar, S , and Münch, G 1950, *Ap J* , **111,** 142
Christy, R F 1966*a*, *Ap J* , **144,** 108
——— 1966*b*, *Ann Rev Astr. and Ap* , **4,** 353
Danziger, I J , and Kuhi, L V 1966, *Ap J* , **146,** 743
Danziger, I J , and Oke, J B 1967, *Ap J* , **147,** 151

Eggen, O. J. 1957, *A J.* **62**, 14.
——— 1960*a*, *M.N R A S* , **120**, 440
——— 1960*b*, *ibid.*, 563.
——— 1963, *A J* , **68**, 697
——— 1965, *Ann. Rev Astr. and Ap* , **3**, 235
Harper, W E. 1938, *Pub Dom Ap Obs* , **6**, No 12
Iben, I. 1967, *Ap. J.*, **147**, 624
Iriarte, B , Johnson, H. L , Mitchell, R I., and Wisniewski, W. K. 1965, *Sky and Telescope*, **30**, **21**.
Jones, D. H. P., and Haslam, M. 1966, *Observatory*, **86**, 34
Kuhi, L V , and Danziger, I J 1967, *Ap J* (in press)
McNamara, D. H , and Augason, G 1961, *Ap J* , **135**, 64
Mihalas, D 1965, *Ap. J Suppl* , **9**, 321
———. 1966, *ibid.*, **13**, 1.
Oke, J. B. 1964, *Ap J* , **140**, 689
——— 1965, *Ann. Rev. Astr. and Ap* , **3**, 23
Oke, J B., and Conti, P S 1966, *Ap J.*, **143**, 134.
Oke, J B., Giver, L. P , and Searle, L 1962, *Ap J* , **136**, 393
Popper, D M. 1959, *Ap J.*, **129**, 647
Preston, G W., 1965, *I A U 3d Colloquium on Variable Stars* (Bamberg), p **155**.
Roxburgh, I., and Strittmatter, P A 1966, *M N R.A.S.*, **133**, 345.
Sandage, A. R. 1957, *Ap J* , **125**, 435.
Schwarzschild, M 1941, *Ap. J.*, **94**, 245
Strittmatter, P. A 1966, *Ap J* , **144**, 430
Strömgren, B , and Perry, C 1962, "Photoelectric *uvby* Photometry for 1217 Stars Brighter than $V = 6^{m}_{\cdot}5$" (Inst Adv Study, Princeton, N J)