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THE LIGHT-VARIABILITY OF EARLY B GIANTS*

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ABSTRACT

A list has been prepared of fifty stars brighter than $m_v = 7.0$ and spectroscopically similar to β Canis Majoris variables. Extensive photoelectric observations have been made on thirty-six of these, in order to discover variability in brightness. Twenty-nine of the fifty stars prove to be variable by 0.02 mag. or more. The types of variables represented are eclipsing binaries, ellipsoidal variables, β CMa stars, shell stars with irregular light-variations, and stars having periodic light-variations with periods slightly longer than those of β CMa stars and shorter than would be expected for ellipsoidal variables. Many of the variables cannot be classified because of irregularities or because of insufficient data. There appears to be a deficiency of known β CMa stars fainter than $m_v = 5.0$. This may account in part for the larger dispersion in galactic latitude for β CMa stars than for early B giants in general.

I. INTRODUCTION

During 1958 an extensive program of photoelectric observations was undertaken in an effort to establish constancy or variability in brightness for a restricted group of early-type stars. Of particular interest was the possibility of finding new examples of the β Canis Majoris class of variables. The variations in brightness and radial velocity of these objects are generally thought to arise from a pulsation phenomenon. However, the diversity of behavior of the dozen or so known members of the class (Struve 1955) suggests the importance of finding new β CMa stars. The fact that all known members of the class are apparently bright has been taken to mean that they must be a frequent occurrence among B stars.

One of the most interesting features of the β CMa stars is their small dispersion in spectral type. Although the observational evidence on this point is obviously incomplete, it is undoubtedly significant that the spectral types of all known β CMa stars fall between B0.5 and B2. Among the more important questions are the following. Are all other stars having spectral types within this range also β CMa stars? If not, what percentage are, and what can be said about the ones that are not? The answer to these questions is the main objective of this investigation.

II. THE PROGRAM

The present investigation was intended to be a systematic survey of brightness variability among stars that occupy roughly the same region of the HR diagram as do the β CMa variables In a program of this type it is important that the survey be as complete as possible and that the restrictions on the objects chosen for study be as few and as well defined as possible. With this in mind, the present program stars were chosen to have an MK spectral classification similar to that of the known β CMa stars, and, for reasons of observational precision, the stars chosen were limited to declinations north of $-10°$. Another consideration was that the number of stars should not be greater than could be adequately observed in one season. In the present case the number of stars was curtailed by setting an upper limit to the apparent magnitude at $m_v = 7.0$. There may be some objection to this procedure, but it has the advantages of simplicity and ease in making estimates of incompleteness.

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Thirteen known β CMa stars and their MK spectral classifications are listed in Table 1. The MK classes are plotted in Figure 1. The box surrounding the plotted points represents the range in spectral class of the stars to be studied. A list of fifty such stars brighter than $m_v = 7.0$ and north of $-10°$ declination was prepared from published MK types and is given in Table 2. Through the kindness of Dr. Bidelman a compilation of MK types for stars brighter than $m_v = 6.5$ was made available, from which estimates of completeness could be made with the aid of the *Catalog of Bright Stars*. The present list contains thirty-eight stars brighter than $m_v = 6.5$ and was found to be 72

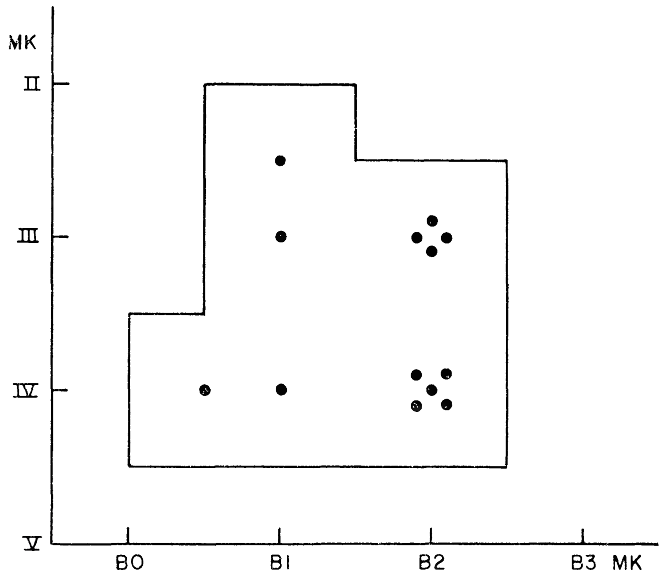

FIG. 1.—The MK spectral classification for thirteen known β Canis Majoris stars

TABLE 1

KNOWN β CANIS MAJORIS VARIABLES

Variable	Sp. Class.	Variable	Sp. Class.	Variable	Sp. Class
γ Peg	B2 IV	15 CMa	B1 IV	β Cep	B2 III
δ Cet	B2 IV	τ^1 Lup	B2 (IV)	DD Lac	B2 III
ν Eri	B2 III	σ Sco	B1 III	EN Lac	B2 IV
β CMa	B1 II–III	θ Oph	B2 IV		
ξ^1 CMa	B0.5 IV	BW Vul	B2 III		

per cent complete to this magnitude. This value was found to be essentially the same, regardless of whether or not B5 stars were used in making the estimates. Thus, for stars brighter than $m_v = 6.5$ with spectral types in the range of interest, there is no evidence of a selection effect based on spectral type for the published MK classifications of stars. On the basis of an assumption of a uniform radial distribution of stars, it can be shown that the list of program stars should be roughly 50 per cent complete to $m_v = 7.0$.

It will be noticed that a few of the stars in Table 2, although having the correct basic classification, are peculiar and obviously difficult to classify. Although they are not likely to be β CMa stars, they were included to show the variety of stars which are spectroscopically similar and possibly occupy, with β CMa stars, the same region of the HR diagram. Seven of the stars in the list are known β CMa stars, and several others have

TABLE 2

THE PROGRAM STARS

HD No.	Name	α_{1900}	δ_{1900}	l	b	m_v (*HD*)	Sp. (*HD*)	MK
886....	γ Peg	00^h08^m1	+14°38′	79°	−47°	2 87	B2	B2 IV
5394..	γ Cas	00 50 7	+60 11	91	−02	2 25	B0p	B0 IV:e(p)
10516*..	ϕ Per	01 37 4	+50 11	99	−11	4 19	B0p	B1pe (III–V)
16582..	δ Cet	02 34 4	−00 06	139	−51	4 04	B2	B2 IV
21803*..	....	03 25 8	+44 32	118	−08	6 33	B3	B2 IV
22253*..	....	03 29 9	+56 23	112	+02	6 79	B0	B0 5 III
23180*..	o Per	03 38 0	+31 58	128	−17	3 94	B1	B1 II–III
23675*..	....	03 41 9	+52 21	116	00	6 76	B0	B0.5 III
23800*..	....	03 42 9	+52 11	116	00	6 87	B2	B1 IV
25443*..	....	03 57 4	+61 48	111	+08	6 75	B2	B0 5 III
27192*..	b² Per	04 12 6	+50 41	121	+02	5 54	B3	B2 IV
29248...	ν Eri	04 31 3	−03 33	167	−30	4 12	B2	B2 III
30836....	π^4 Ori	04 45 9	+05 26	161	−22	3 78	B3	B2 III
31237....	π^5 Ori	04 49 0	+02 17	164	−23	3 87	B3	B2 III
33328*..	λ Eri	05 04 4	−08 53	160	−16	4 34	B2	B2 IV
35039*..	o Ori	05 16 7	−00 29	170	−19	4 65	B3	B2 IV
35395*..	....	05 19 3	+20 30	153	−07	6 83	B2	B0 5 III:
35468....	γ Ori	05 19 8	+06 16	165	−14	1 70	B2	B2 III
35715....	ψ Ori	05 21 6	+03 00	167	−16	4 66	B2	B2 IV
36822*..	ϕ^1 Ori	05 29 3	+09 25	162	−10	4 53	B0	B0 IV
37018*..	42 Ori	05 30 4	−04 54	176	−18	4 65	B3	B2 III
37756*..	....	05 35 8	−01 11	173	−15	5 00	B3	B2 IV
41335*..	....	05 59 4	−06 42	181	−12	5 12	B2p	B2 IV, VnneHβ
45910...	AX Mon	06 25 2	+05 57	173	00	6 70	B3	B2:III:pe (shell)
149881*..	....	16 32.4	+14 40	359	+38	6 59	B2	B0.5 III
165174*..	....	17 59 6	+01 55	357	+10	6 09	B3	B0.5 III
180163*..	η Lyr	19 10 4	+38 58	38	+12	4 46	B3	B2 IV
180968*..	2 Vul	19 13 5	+22 51	24	+04	5 40	B0	B0 5 IV
184279*..	....	19 28 6	+03 34	9	−09	6 78	B5	B0 5 IV
184915*..	κ Aql	19 31 5	−07 15	0	−14	5 04	B0	B0 5 III
188252*..	....	19 49 2	+47 41	49	+10	5 70	B2	B2 III
188439*...	....	19 50 1	+47 34	50	+10	6 15	B2	B0 5 IIIp
187879....	V380 Cyg	19 47 2	+40 20	43	+06	5 62	B2	B1 IV:
197770*..	....	20 40 7	+56 46	61	+09	6 36	B3	B2 IV
199140....	BW Vul	20 50 1	+28 08	41	−11	6 44	B3	B2 III
200120*..	f¹ Cyg	20 56 4	+47 08	56	00	4 86	B0p	B1 IV:e
203025*..	....	21 14 6	+58 10	65	+07	6 41	B3	B2 III
203374*...	....	21 16 7	+61 25	68	+08	6 54	B0p	Bo IVpe
205021....	β Cep	21 27 4	+70 07	75	+14	3 32	B1	B2 III
205139*..	....	21 28 3	+60 01	68	+06	5 52	B0	B1 II
207793*..	....	21 46 5	+52 14	65	−01	6 56	B2	B0.5 III
208218*..	....	21 49 7	+62 13	71	+06	6 76	B1	B1 III:
209339*..	....	21 57 6	+62 00	72	+06	6 48	B0	B0 IV
213420*..	6 Lac	22 26 2	+42 37	65	−13	4 54	B3	B2 IV
214993....	DD Lac	22 37 0	+39 43	65	−16	5 18	B2	B2 III
216916....	EN Lac	22 51 9	+41 04	68	−17	5 54	B3	B2 IV
217101*..	....	22 53 1	+38 48	68	−19	6 07	B3	B2 IV–V
218376*..	1 Cas	23 02 4	+58 53	78	−01	4 93	B1	B0.5 IV
219188*...	....	23 08 9	+04 27	52	−50	6 93	B2	B0 5 III
224151*...	....	23 50 5	+56 53	83	−04	6 05	B0	B0.5 II

been well observed by Walker (1952*a*) and others. All the remaining stars and those for which additional observations seemed desirable were observed in this investigation and are indicated by an asterisk in Table 2. Some of the stars, particularly those studied late in the program, were not observed as much as they should have been because of time limitations. This should be borne in mind when drawing conclusions from the observations, in view of the fact that variable light-ranges are common among β CMa stars.

Considered as a search for β CMa stars, the present investigation differs from previous searches in that the program stars were not chosen on the basis of a suspected variability in radial velocity or on the quality of their spectral lines. This is important because, historically, β CMa stars have become known largely through their radial-velocity variations. Thus it may be possible to detect a short-period light-variation in a star whose spectral lines are so broad as to prevent the detection of a corresponding radial-velocity variation. Whether such stars, if they exist, should be classified as β CMa stars is another matter.

III. THE OBSERVATIONS

From April, 1958, through October, 1958, approximately thirteen hundred photoelectric observations were made on thirty-six of the stars in Table 2. All observations were made in yellow light, with a Corning 3384 filter and an EMI 6094 photomultiplier tube. The telescope used was the 20-inch reflector at Mount Palomar. At least two comparison stars were observed with each program star, and these were chosen at the telescope on the basis of color and proximity to the star under investigation. In some fields the choice of comparison stars was very poor, owing to a paucity of stars of early type. For this reason, caution must be exercised in drawing conclusions from the observations in some cases. Although the variation in atmospheric extinction with the colors of stars is very small in yellow light, it is nevertheless present and in certain instances can be a major contributor to the observational error. The yellow filter was chosen for making the observations in order to minimize this effect and to make the effects of differential extinction and non-uniform sky transparency as small as possible.

A typical observation consisted of a series of ten deflections which can be represented symbolically thus:

$$C_1—P—C_2—C_1—P—C_2—C_1—P—C_2—C_1\,,$$

where C_1 and C_2 represent deflections on the comparison stars and P represents a deflection on the star being studied. The duration of the deflections was generally from 20 to 30 seconds, and the interval between successive deflections was approximately 20 seconds. Thus a complete set of measurements could usually be completed in less than 10 minutes. The short time involved is important from the standpoint of greatest precision as well as economy of time. The guiding principle in making the measurements was to obtain single observations of very high weight in an effort to detect variability and, if possible, to determine the type. Only in a few cases was any attempt made to obtain a definitive light-curve.

Early in the program the deflections were measured on the recorder chart scale; later a specially ruled magnitude scale was used. In forming an observation, each P or C_2 deflection was compared with the two nearest C_1 deflections. The mean of the three magnitude differences in each case was taken to be an observation. All observations were corrected for the effects of differential extinction, using a mean extinction coefficient of 0.2 mag. per air mass. The corrections rarely exceeded 0.005 mag.

In making estimates of the precision of each observation, the following procedure was adopted. The average deviation, η, of the magnitude differences was determined, and a probable error for the mean was computed from

$$\text{p.e.} = 0.85\,\frac{\eta}{\sqrt{n-1}}\,,$$

where n is the number of values used in forming the mean. This internal estimate of precision is subject to a possible bias through the use of a common C_1 deflection in computing adjacent magnitude differences. If we could be sure that the trend of C_1 deflections reflected only slow changes in instrumental sensitivity or sky transparency, there would be no coupling between magnitude differences and no bias in the precision estimates. However, when the variation in C_1 deflections is influenced by noise processes, there is the possibility of bias. The amount of the bias is difficult to determine theoretically, but extensive empirical tests have shown that in the case of the present observations it does not exceed a few per cent. This matter is of considerable importance in the evaluation of the data. The average of approximately twenty-five hundred probable error estimates turned out to be 0.0015 mag., and, if the estimate of bias is correct, we can say that the average probable error per observation is less than 0.002 mag.

IV. GENERAL DISCUSSION OF THE OBSERVATIONS

In analyzing the observations, two courses are open to us. We can look at the data on each star, plot the observations, and make a qualitative decision on whether the star should be considered as variable. Another procedure, the one to be followed here, is to put the data on each star—comparison and program star alike—in such a form that all stars can be treated together and perhaps a quantitative criterion on variability found.

For each program star we have a series of comparisons between its brightness and that of each of the comparison stars and, likewise, a set of comparisons between the comparison stars themselves. Thus, in the typical case, we have three sets of magnitude differences:

$$P - C_1 , P - C_2 , \text{ and } C_2 - C_1 .$$

Two parameters have been formed to represent the quality of agreement in each set of magnitude differences. One is the maximum range, R, and the other is D, the average deviation from the mean of all magnitude differences in a set. For each star the smallest values of D and R were taken as measures of variability in brightness. Because of the fact that these values actually refer to pairs of stars, they can be thought of as upper-limit estimates of variability, insofar as the observational coverage of the behavior of the stars is complete. The values of R and D for each program and comparison star are given in Table 3 in thousandths of a magnitude. The last column of the table gives the *Henry Draper* spectral type. The asterisk indicates stars for which the observational material is definitely inadequate. The program stars in the list are followed immediately by their comparison stars. In three cases the same comparison stars were used for two program stars.

Values of R and D for all stars in Table 3 are plotted in Figure 2. The low-weight values are indicated by open circles. For a well-observed star with a sine-curve light-variation, we expect that

$$D = \frac{R}{2\pi} \int_0^{\pi} \sin x dx = \frac{R}{\pi} .$$

Such stars are represented in Figure 2 by the solid diagonal line. All the well-observed stars fall below this line; indeed, it would require a very peculiar light-curve to place a point above it. On the other hand, we know that variable light-ranges and multiple periods are common among β CMa stars. We can take as an extreme case a hypothetical variable with two sine-curve variations of equal ranges and different periods; such a star, if well observed, should plot near the dashed diagonal line in Figure 2. A star with a more random behavior should plot below and to the right of this line.

Considering Figure 2 in the light of our probable error estimate, we might be tempted to say that most stars are variable by a few thousandths of a magnitude. However, a more cautious attitude seems wise in view of the possibility of sources of error which

TABLE 3

VALUES OF D AND R FOR PROGRAM AND COMPARISON STARS

Name		D	R	Sp.	Name		D	R	Sp.
φ Per	P	6	49	B0p	η Lyr*	P	3	5	B3
11291	C	3	19	B9	180077*	C	3	5	A0
10546	C	3	19	B9	180552*	C	3	5	F0
21803	P	31	108	B3	2 Vul	P	11	61	B0
21770	C	3	17	F0	RS Vul*	C	17	62	B8
21448	C	3	17	B3	180889	C	5	20	A3
22253	P	3	14	B0	181360	C	5	20	B3
22489	C	3	9	A2	184279	P	8	51	B5
22316	C	3	9	B9	184663	C	3	22	F2
o Per	P	10	40	B1	183656	C	22	119	A0
23478	C	4	19	B3	183200	C	3	22	B9
23626	C	4	19	G0	κ Aql	P	6	24	B0
23802	C	6	35	B9	185720	C	4	22	G0
23675	P	6	34	B0	185511	C	4	22	A2
23800	P	8	36	B2	188252	P	3	23	B2
24431	C	2	15	Oe5	188439	P	5	32	B2
24421	C	2	15	F5	188074	C	3	23	F0
25443*	P	3	11	B2	197770	P	3	14	B3
26670*	C	3	10	B8	198084	C	3	14	G0
+61°678*	C	3	10	...	197618	C	4	19	A3
b² Per	P	3	21	B3	f¹ Cyg	P	24	109	B0p
b¹ Per	C	12	59	A2	199890	C	4	20	B8
27084	C	3	12	A5	199662	C	4	20	A0
27673	C	3	17	F2	203025	P	7	30	B3
λ Per	C	3	12	A0	202519	C	5	20	A0
λ Eri	P	3	17	B2	203375	C	5	20	A0
33069	C	10	35	B8	203374	P	2	12	B0p
33224	C	3	17	B8	203551	C	2	12	F5
33507*	C	3	9	F8	204889	C	3	20	F5
ο Ori*	P	2	6	B3	205139	P	5	17	B0
35299*	C	2	6	B3	204964	C	4	17	B8
35007*	C	2	8	B3	205500	C	4	18	A0
35395	P	4	17	B2	207793	P	4	29	B2
34719	C	10	31	A0p	207543	C	3	18	A0
36113	C	4	17	B5	208253	C	3	18	A2
36589*	C	2	8	B8	208218	P	3	16	B1
φ¹ Ori*	P	2	6	B0	209339	P	4	17	B0
36895*	C	2	6	B3	208392	C	35	123	B3
+9°882*	C	4	12	......	209975	C	3	16	Oe5
42 Ori*	P	1	3	B3	6 Lac*	P	4	14	B3
37016*	C	1	3	B0	212222*	C	5	18	B3
37017*	C	2	6	B0	214608*	C	4	14	G0
37756*	P	5	21	B3	217101	P	4	20	B3
37776*	C	12	36	B5	217543	C	4	20	B3
37674*	C	5	21	B8	216538	C	4	25	B8
37321*	C	3	8	B8	216575	C	4	21	F0
41335	P	6	26	B2p	1 Cas	P	3	11	B1
42278	C	2	9	F0	218753	C	3	11	A3
41794	C	2	9	A5	218440	C	3	12	B3
149881	P	7	34	B2	219188	P	5	31	B2
149822	C	2	14	A0p	218515	C	4	26	A0
150012	C	2	14	F2	219401	C	4	26	K0
165174	P	7	34	B3	224151	P	23	105	B0
164577	C	3	22	A2	224624	C	3	20	A0
165341	C	3	22	K0	224425	C	3	20	A2

* Indicates stars having only a few observations.

would pass unnoticed in the type of error analysis made. One of the more insidious sources of error is due to the variation in atmospheric extinction with the colors of stars. In this regard, it is encouraging to note that two of the well-observed pairs of stars with $D = 0.002$ consist of stars with substantially different colors. It would appear that undetected errors, if they exist, are probably instrumental in nature.

Let us divide the stars represented in Figure 2 into three groups. Group A will include a rather obvious set of stars whose R values are 0.024 mag. or greater. These stars can be said to be definitely variable. Stars in group B include all those for which $0.015 < R < 0.024$. This group contains the largest number of stars and represents those with

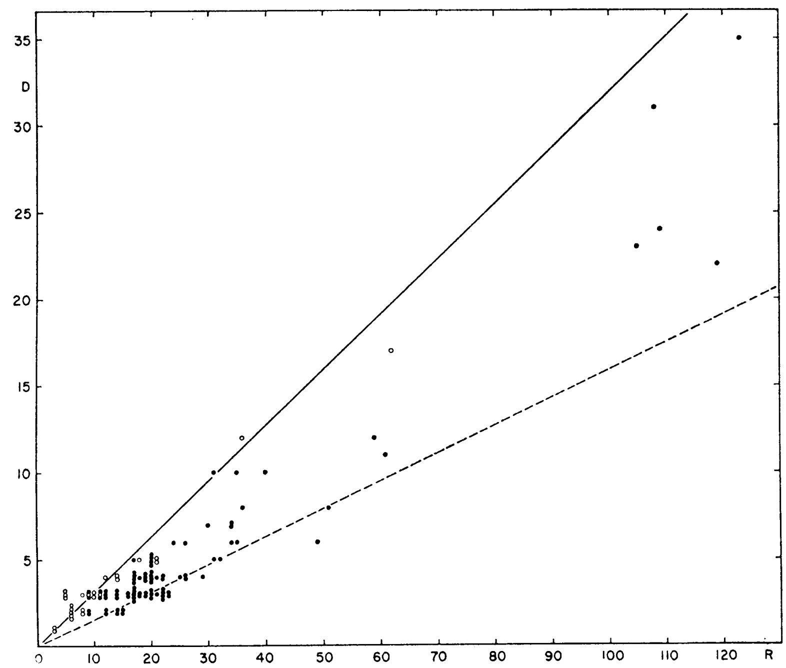

FIG. 2.—Values of R and D in thousandths of a magnitude for all pairs of stars observed

TABLE 4

Group	Comparison Stars	Program Stars	Group	Comparison Stars	Program Stars	Group	Comparison Stars	Program Stars
A.	0.15	0.47	B.	0.47	0.25	C.	0.38	0.28

small, but fairly definite, variations. Group C includes the remainder of the stars and represents those with little or no light-variation. The fractions of comparison stars and program stars in each group are given in Table 4. It is seen that the program stars show a considerably greater tendency toward variability than do the comparison stars. This is shown in another way in Figure 3, where the relative frequency distributions in D are given for both comparison and program stars. The maximum frequency in both cases occurs at $D = 0.003$, but for $D \geq 0.005$ the frequency is much greater for the program stars. It is also interesting that all the comparison stars with D greater than 0.009 mag. have spectral types A2 or earlier. In fact, one of these, HD 208392, would have been a program star if the survey had been extended to $m_v = 7.1$.

V. THE INDIVIDUAL STARS

In this section there will be a brief discussion of each program star. In many cases the observations are given in a plotted or tabular form; they will not be given when the light-variation is small or absent or when no useful purpose would be served. The observations Δm_y, when given, are magnitude differences between the program star and the mean of the two comparison stars. For HD 21803, *o* Persei, HD 224151, HD 183656, and HD 208392 the observations will be published separately in a more complete form. For some of the stars which show rapid light-variations an attempt has been made to determine a period. These determinations are based on trends in the observations and on obvious maximal or minimal values. Because of the possibility of variations in light-range, very little importance was attached to observations obtained when a star was

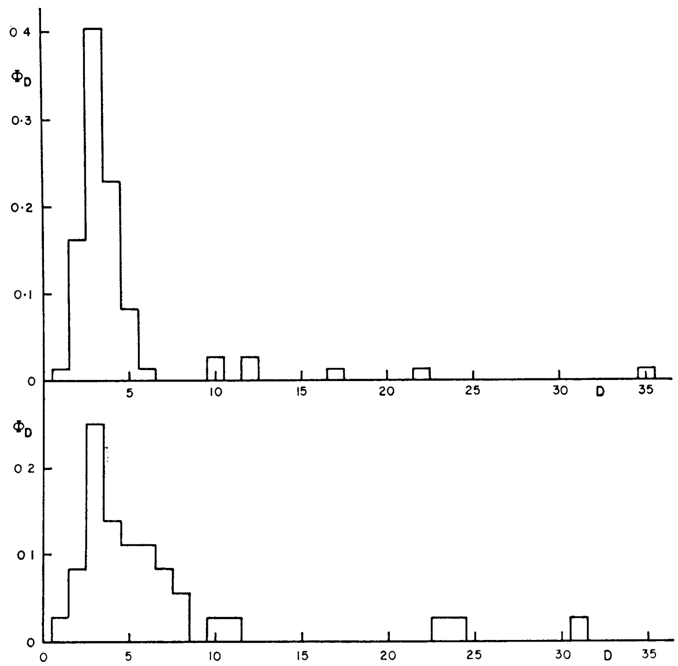

FIG. 3.—The relative frequency distribution in D for comparison stars (*upper curve*) and program stars (*lower curve*). D is in units of 0.001 mag.

near mean brightness. Table 5 contains a list of the thirty-six program stars which were observed in this investigation. The second column of the table gives the total number of observations, and the third column gives the number of nights that the star was observed.

γ *Pegasi*.—This star is a known β CMa variable with a period of 3^h38^m (Williams 1954; McNamara 1955).

γ *Cassiopeiae*.—The brightness and spectrum of this peculiar Be shell star are known to vary in an irregular way (Beer 1956).

ϕ *Persei*.—This peculiar Be shell star is not well understood but appears to be a spectroscopic binary with a period of 127 days (Hynek 1940). The present observations show the brightness of the star to be fairly constant except for one night, when the star was 0.040 mag. fainter than usual. The type of variability is unknown, and the star merits further study.

δ *Ceti*.—This star is a known β CMa variable with a period of 3^h52^m (Walker 1953; McNamara 1955).

HD 21803.—The brightness of this star was discovered to be variable during the course of this investigation (Lynds 1959). The tentative classification of HD 21803 as a β CMa star was subsequently confirmed by the radial-velocity observations of Struve (Struve and Zebergs 1959). The period of variation is approximately 0.2 day, and the light-range is about 0.100 mag. and is variable. Figure 4 gives a plot of the observations obtained on four consecutive nights in September. The absolute visual magnitude of HD 21803 as given by Petrie (1958*a*) is -2.6. This is 0.8 mag. fainter than BW Vulpeculae, a β CMa star with an almost identical period, and places HD 21803 0.5 mag. below the period-luminosity relation for β CMa stars as determined by Petrie (1954*a*).

HD 22253.—The present observations do not indicate any real variation larger than 0.010 mag.

o Persei.—This double-line spectroscopic binary has an orbital period of 4.419 days (Jordan 1910). Light-variation has been suspected by Guthnick (1917) and Walker (1952*a*). The present observations show a periodic light-variation with a range of approximately 0.030 mag. and a period of 2.2 days, or half the orbital period of the system. All observations have been phased together, using the orbital period, and are plotted in Figure 5. Zero in phase corresponds to JD 2436456.5. Evidently the light-variation is

TABLE 5

NUMBER OF OBSERVATIONS AND NIGHTS OF OBSERVING FOR EACH PROGRAM STAR

Star	Obs.	Nights	Star	Obs.	Nights	Star	Obs.	Nights
ϕ Per	27	7	42 Ori	7	3	f^1 Cyg	30	17
21803	46	8	37756	9	3	203025	32	15
22253	10	4	41335	18	6	203374	14	6
o Per	58	13	149881	41	19	205139	13	6
23675	57	13	165174	54	19	207793	42	16
23800	57	13	η Lyr	5	5	208218	36	12
25443	6	4	2 Vul	76	23	209339	36	12
b^2 Per	33	6	184279	77	29	6 Lac	12	2
λ Eri	12	4	κ Aql	25	14	217101	66	12
o Ori	6	3	188252	91	23	1 Cas	13	4
35395	11	4	188439	91	23	219188	75	16
ϕ^1 Ori	6	3	197770	21	8	224151	78	18

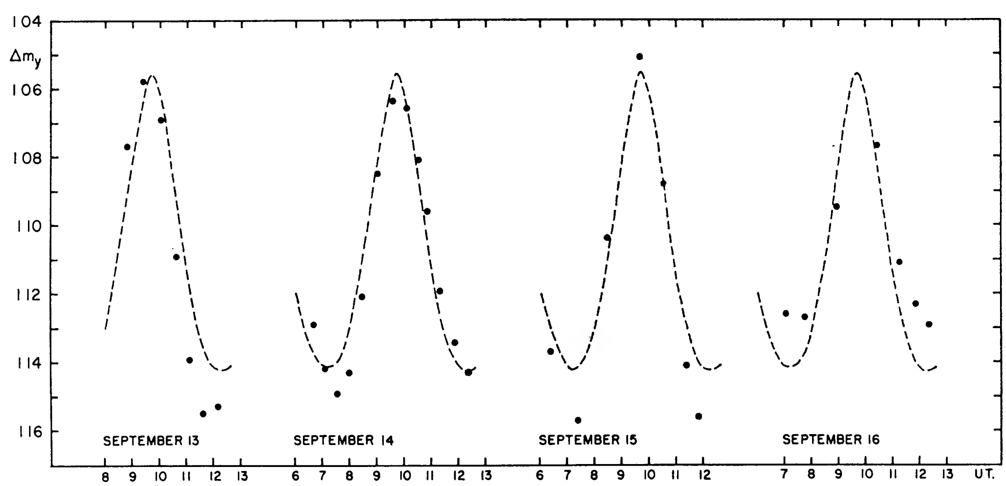

FIG. 4.—Photoelectric observations of HD 21803. The comparison star is HD 21770, and the magnitude differences are given in the sense HD 21803 *minus* HD 21770. The dashed curves represent the mean light-curve deduced from all observations.

due to photometric ellipticity in one or both of the stars in the system. There is little evidence of any additional superimposed variation.

HD 23675.—The present observations show small but definite light-variations on some nights and a total range of approximately 0.030 mag. All observations are plotted in Figure 6. Any periodicity in the observations would seem to be longer than 8 hours.

HD 23800.—This star shows variations of about 0.020 mag. on some nights and a total range of approximately 0.030 mag. The observations are plotted in Figure 7. The data seem almost to exclude the possibility of a short-period representation of the observations. The trends in brightness are mostly declining, and the star was substantially

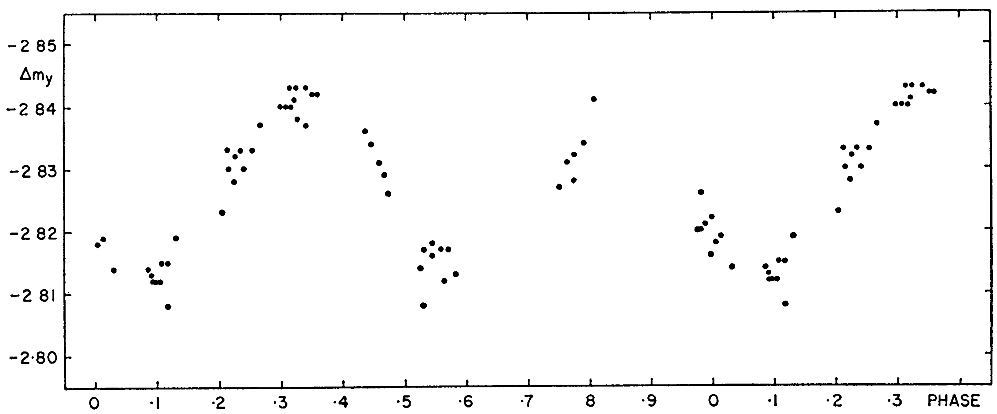

FIG. 5.—Photoelectric observations of o Persei. The comparison star is HD 23478, and the magnitude differences are given in the sense o Persei *minus* HD 23478.

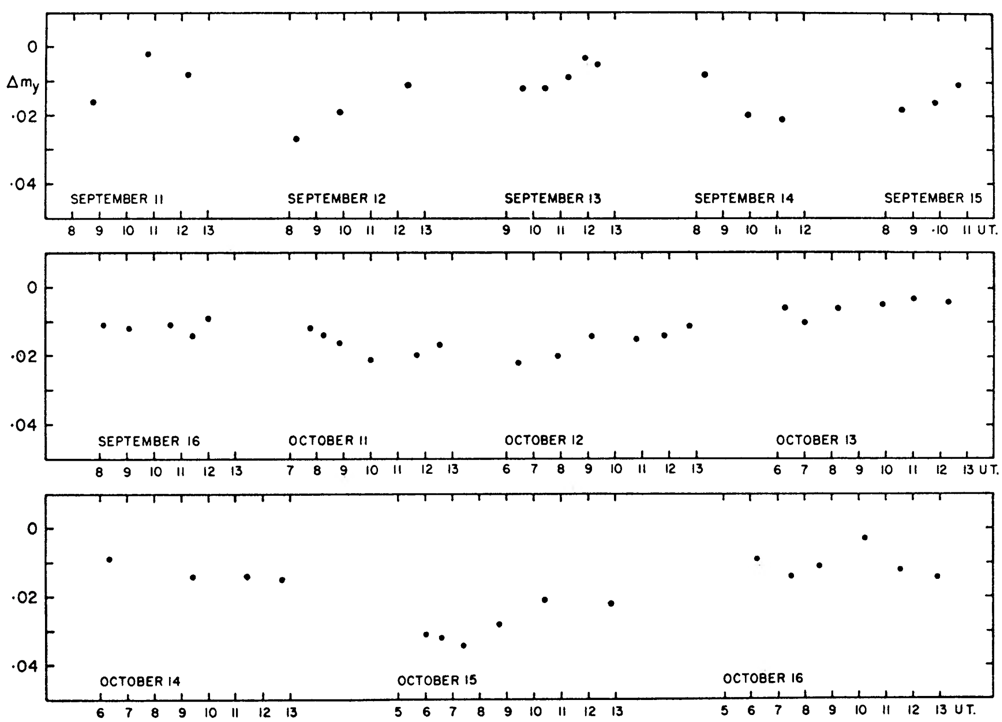

FIG. 6.—Photoelectric observations of HD 23675. The comparison star is HD 24431, and the magnitude differences are given in the sense HD 23675 *minus* HD 24431.

fainter during September than during October. Perhaps this star is a member of a class with light-variations similar to those of β CMa stars but not representable, even approximately, by a single period.

HD 25443.—There is little, if any, variability indicated by the present observations; however, the material is meager.

b^2 Persei.—There is some evidence for the star's having a variable radial velocity; however, the spectral lines are poor (Adams 1912). On one night the observations indicated a possible variation of 0.020 mag., but the star appeared to be essentially constant in light on all other nights.

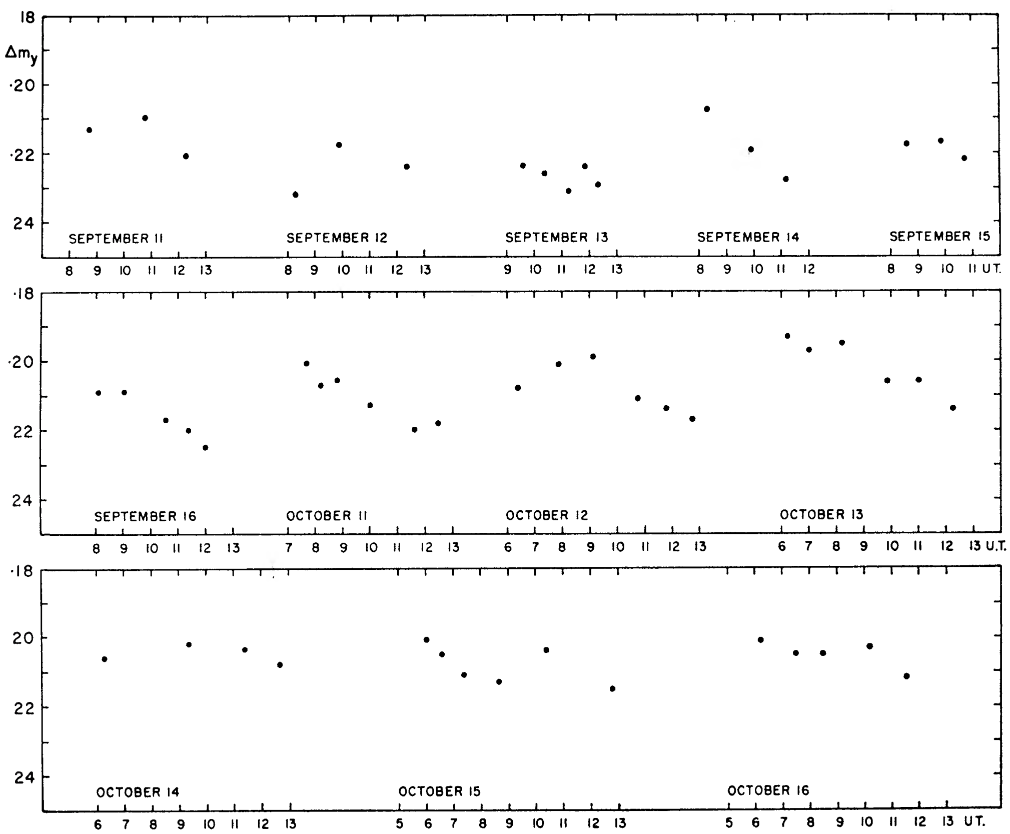

FIG. 7.—Photoelectric observations of HD 23800. The comparison star is HD 24431, and the magnitude differences are given in the sense HD 23675 *minus* HD 24431.

ν Eridani.—This star is a known β CMa variable with a period of 4^h10^m (Struve *et al.* 1952*b*; Walker 1952*c*).

π^4 Orionis.—This spectroscopic binary with a period of 9.5 days (Baker 1910) was observed photoelectrically by Walker (1952*a*) and found to be constant.

π^5 Orionis.—This spectroscopic binary with a period of 3.7 days (Lee 1913) was found by Stebbins (1920) to be variable in brightness because of the ellipticity of the component stars. When re-observed photoelectrically by Walker (1952*a*), no additional variation was found.

λ Eridani.—There is some evidence that the star has a variable radial velocity (Plaskett and Pearce 1930*b*). The present photometric material gives only an indication of a small amount of variability.

o Orionis.—The observations indicate that the star is constant; however, the material is meager.

HD 35395.—Only a very small variation is indicated by the observations.

γ Orionis.—Photoelectric observations by Walker (1952*a*) show this star to be constant.

ψ Orionis.—This spectroscopic binary with a period of 2.5 days (Plaskett 1908) has a long history of suspected variability in brightness (Shapley 1913; Cousins 1952; de Jager 1953*b*), but the type is in doubt.

ϕ^1 Orionis.—This star is a spectroscopic binary with a period of 8.4 years (Struve 1925). The present observations indicate the star to be constant; however, the material is meager.

42 Orionis.—There is good evidence that this star has a variable radial velocity (Plaskett and Pearce 1930*b*). The present observational material, although meager, indicates that the star is constant.

HD 37756.—This star is a spectroscopic binary with a period of approximately 27 days (Plaskett and Harper 1909). The present observations indicate a small variation in brightness, but the material is insufficient to define the variations. The star merits further study.

HD 41335.—There is good evidence that the radial velocity of this star is variable (Plaskett and Pearce 1930*b*). A variation in brightness of the order of 0.025 mag. is definitely indicated by the present observations. However, the data almost exclude the possibility of a periodicity. The photometric study of this star should continue.

AX Monocerotis.—The rapid variations in brightness (Guthnick and Prager 1930) and spectrum (Struve 1943) of this very peculiar Be shell star have been well observed but are far from being understood.

HD 149881.—There is an indication of a radial-velocity variation (Plaskett and Pearce 1930*a*). This star was observed photoelectrically by Walker (1952*a*) and found to be constant. The present observations show definite short-period light-variations, with a possible period near 8 hours and a light range of about 0.030 mag. The observations made during July and August are plotted in Figure 8. This star might well be a β CMa star and should receive further attention.

HD 165174.—There is some indication of a radial-velocity variation (Plaskett and Pearce 1930*a*). The present observations definitely indicate a light-variation with a possible period of 0.2890 day. The observations obtained during May, June, and August have been phased together, using this period, and are plotted in Figure 9. Zero in phase occurs at JD 2436338.5. The amount of scatter shown would be disappointing if it were not for the fact that a similar result would be obtained if the same procedure were used with observations of EN Lacertae or any of several other bona fide members of the β CMa class of variables. These stars often show not only variations in light-range but also variations in mean brightness from cycle to cycle. The evidence for a periodic light-variation in the case of HD 165174 is put in a more favorable light in Figure 10, where the observations for each night are plotted with a superimposed mean light-curve derived from Figure 9. On nearly all the nights there is fairly good agreement between brightness trends and the mean curve, with never a real disagreement. This star is thus considered tentatively as a likely member of the β CMa class, awaiting spectroscopic confirmation.

η Lyrae.—The observations of this star indicate no variation larger than 0.005 mag.; however, the material is meager.

2 Vulpeculae.—There is some indication that this star has a variable radial velocity (Plaskett and Pearce 1930*b*). The present observations show a definite light-variation with an extreme range of about 0.060 mag. A search for a period yielded the value 0.6096 day. The observations made during May, June, August, and September have been phased together, using this period, and are plotted in Figure 11. Zero in phase occurs on JD 2436338.5. The agreement between the mean light-curve and the observations on individual nights is shown in Figure 12. It is obvious that the agreement leaves some-

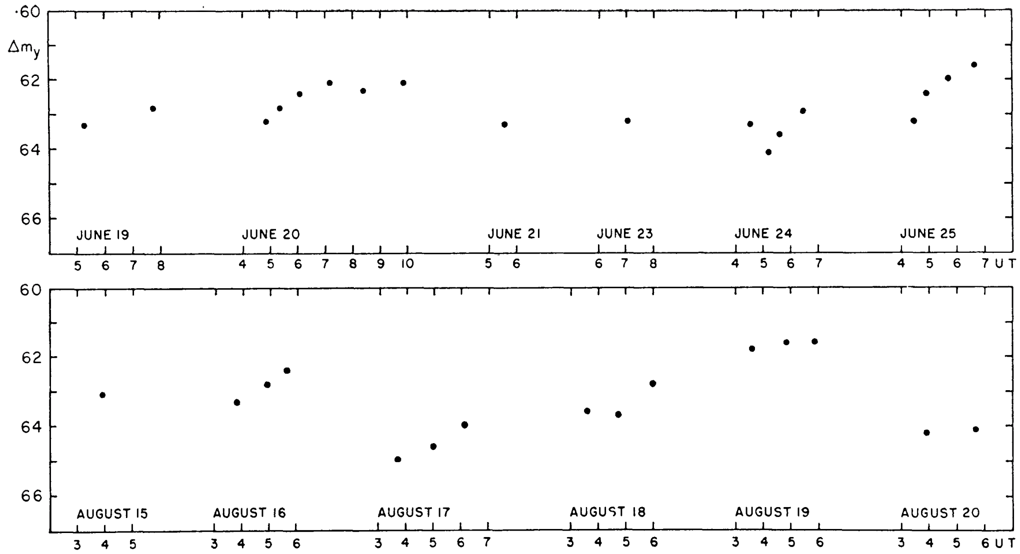

FIG. 8.—Photoelectric observations of HD 149881. The comparison star is HD 149822, and the magnitude differences are given in the sense HD 149881 *minus* HD 149822.

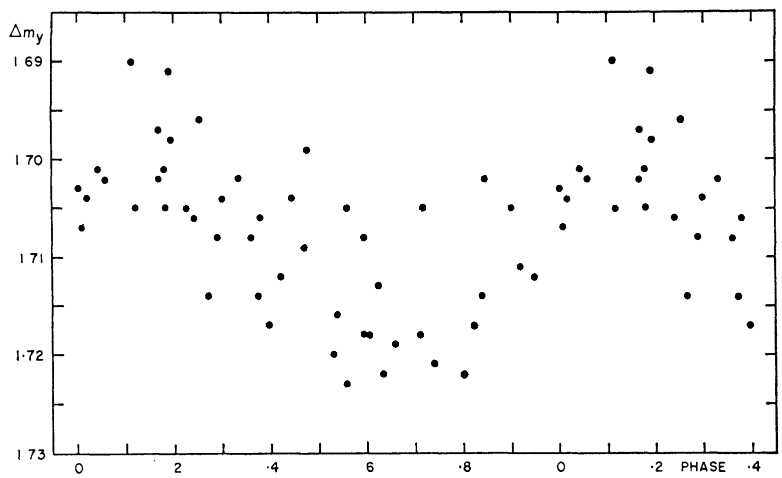

FIG. 9.—Photoelectric observations of HD 165174. The comparison star is HD 164577, and the magnitude differences are given in the sense HD 165174 *minus* HD 164577.

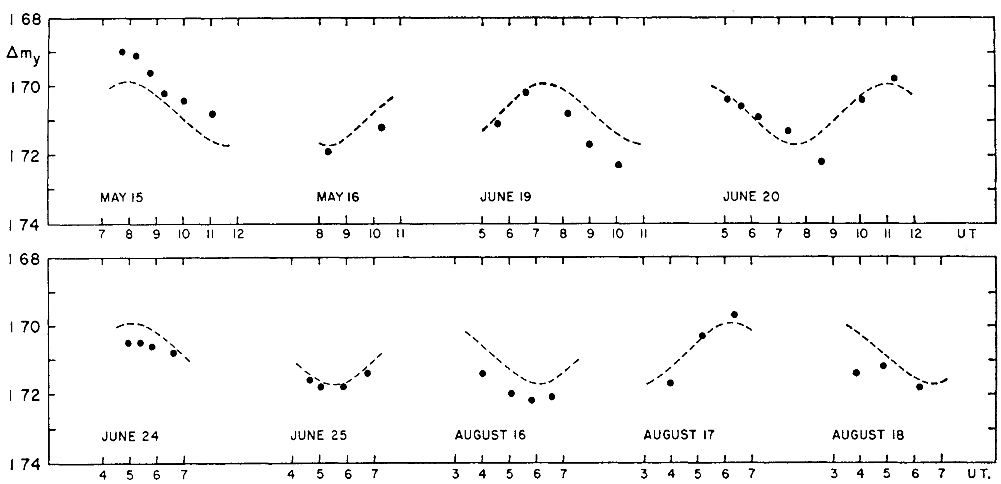

FIG. 10.—The observations of HD 165174 obtained on individual nights. The dashed curves represent the mean light-variation indicated in Fig. 9.

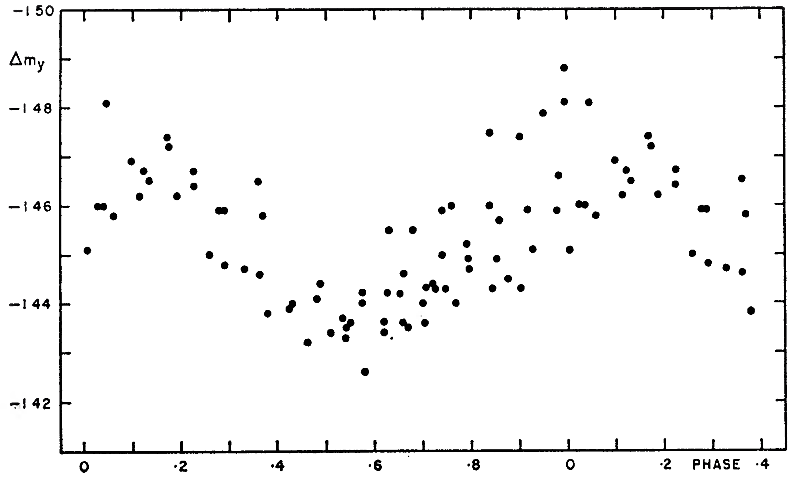

FIG. 11.—Photoelectric observations of 2 Vulpeculae. The comparison star is HD 180889, and the magnitude differences are given in the sense 2 Vulpeculae *minus* HD 180889.

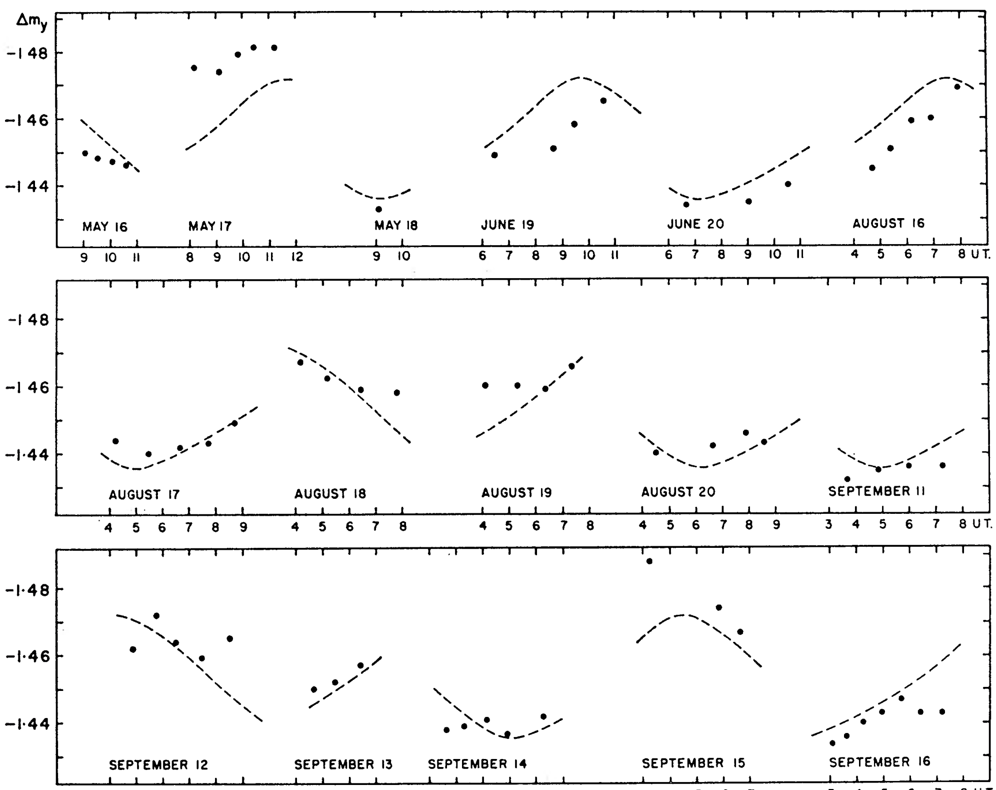

FIG. 12.—The observations of 2 Vulpeculae obtained on individual nights. The dashed curves represent the mean light-variation indicated in Fig. 11.

thing to be desired, but on no night is there any actual disagreement. If the light-variation is periodic, this period is probably the correct one, and we have two main choices of interpretation for the light-variation. First, it may be that 2 Vulpeculae represents a long-period extension of the β CMa class of variables. On the other hand, we can double the period and consider the light-variation to be caused by the photometric ellipticity of stars in a binary system. There is, however, one difficulty with this second explanation; from theoretical considerations as well as the statistics of known spectroscopic binaries, we know that the shortest period to be expected for a binary classified as early as B0–B1 is about 1.5 days. Thus 2 Vulpeculae with a 1.2-day period might have to be represented by a pair of partially immersed stars revolving about each other. Good spectroscopic data will be helpful in settling this question.

HD 184279.—The observations of this star definitely indicate a variation in brightness. Figure 13 shows a plot of the observations obtained during the months of August, September, and October. The variations seem to be somewhat erratic, and a period could not be found.

κ Aquilae.—The present observations indicate the possibility of a light-variation; however, the comparison stars were slightly variable, and an analysis could not be made. The amount of variation is probably not greater than 0.020 mag.

HD 188252.—The extensive observations on this star indicate only a long-time-scale variation of approximately 0.010 mag.

HD 188439.—There is a definite indication that this star has a variable radial velocity (Plaskett and Pearce 1930*a*). The present observations indicate a light-variation with a possible period of 0.3775 day. This period is strongly suggested by the material obtained during the months of May and June. These observations are shown phased together in Figure 14, *a*. Zero in phase occurs on JD 2436338.5. Figure 14, *b*, is a similar plot of the observations for July and October. It is seen that there is an almost completely random scatter of points. The only agreement with this period is shown by the observations on four nights, indicated in the figure by the connecting straight lines. During July and October these were the only nights on which a substantial trend in brightness was displayed by the observations. If the periodicity is real, we have, as with 2 Vulpeculae, the possibility of the star's being a representative of a long-period extension to the β CMa class of variables or a very short-period binary. In the latter case it would seem that the component stars would probably be partially immersed in each other.

V380 Cygni.—This single-line spectroscopic binary (Harper 1935) is also an eclipsing variable (Kron 1936). The orbital period is approximately 12.4 days.

HD 197770.—There are definite indications that the radial velocity of this star is variable (Plaskett and Pearce 1930*a*). Walker (1952*a*) observed the star photoelectrically and found no variations greater than 0.030 mag. The present observations indicate little, if any, light-variation.

BW Vulpeculae.—This star is a known β CMa variable with a period of $4^{h}49^{m}$ (Petrie 1954*b;* Walker 1954).

f^1 Cygni.—This is a Be star having a variable spectrum (Merrill and Burwell 1949). The present observations show a steady decline in brightness of about 0.100 mag. from June through October. The means of the observations for each night are given in Table 6. The magnitude differences Δm_y are referred to HD 199890 and are taken in the sense f^1 Cygni *minus* HD 199890.

HD 203025.—This spectroscopic triple system has the periods 5.4 and 225 days (Sanford 1926). The present observations indicate little or no short-period variations but show a definite variation from night to night. The most obvious possibility is that the variation is related to the orbital phase of the short-period pair. The observations, when phased together with the 5.4-day period, give some indication of an ellipticity variation of about 0.010 mag.; however, there is a large amount of scatter, and the evidence is far from conclusive.

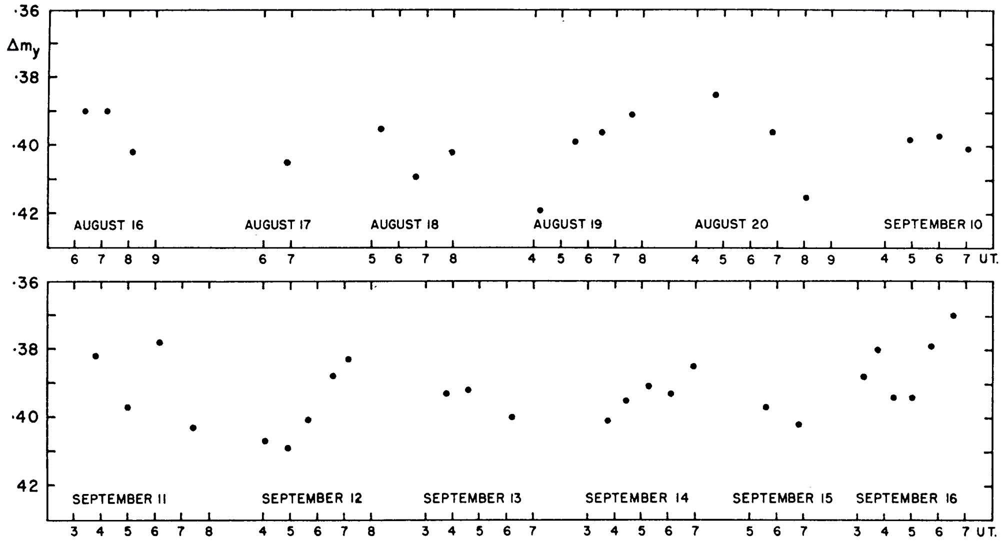

FIG. 13.—Photoelectric observations of HD 184279. The comparison star is HD 184663, and the magnitude differences are given in the sense HD 184279 *minus* HD 184663.

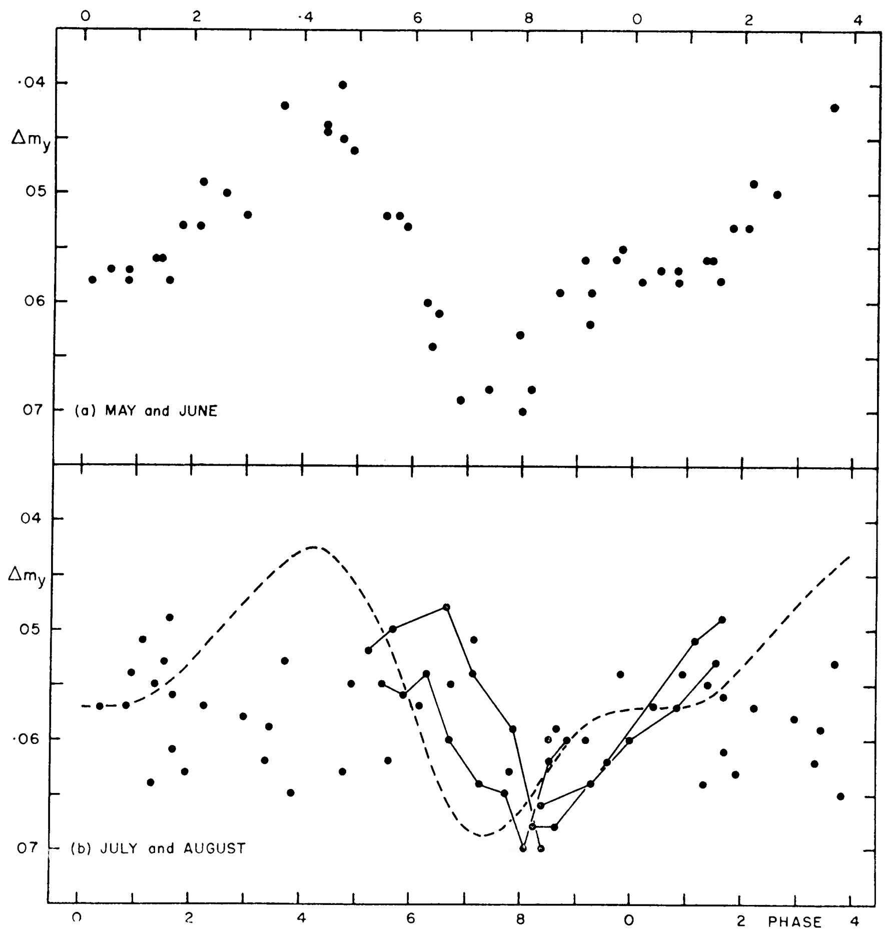

FIG. 14*a*, *b*.—Photoelectric observations of HD 188439. The comparison star is HD 188252, and the magnitude differences are given in the sense HD 188439 *minus* HD 188252. The dashed curve in the lower part of the figure is a representation of the light-variation indicated by the observations plotted in the upper part of the figure. The solid lines connect observations obtained on four nights.

HD 203374.—There is some indication that this star has a variable radial velocity (Plaskett and Pearce 1930*b*). The present observations give no evidence of a light-variation larger than 0.010 mag.

β Cephei.—This star is a known β CMa variable with a period of 4^h34^m (Struve *et al.* 1953; Stebbins and Kron 1954).

HD 205139.—The comparison stars used in making the observations on this star proved to be somewhat variable. However, it can be said that HD 205139 probably did not vary by more than 0.010 mag.

HD 207793.—The observations show this star to be constant in brightness, with occasional small variations. The time scale for the observed variations is of the order of half a day.

HD 208218.—The present observations indicate no light-variation.

HD 209339.—The present observations indicate no light-variation.

6 Lacertae.—Walker (1952*a*) observed this star photoelectrically and found no variations larger than 0.010 mag. The present material, although meager, gives a similar result.

12 Lacertae.—This star is a known β CMa variable with a period of 4^h38^m (de Jager 1953*a*).

TABLE 6

OBSERVATIONS OF f^1 CYG

Date 1958	U.T.	Δm_y	Date 1958	U.T.	Δm_y	Date 1958	U.T.	Δm_y
June 23	09^h46^m	−2.825	July 15	09^h55^m	−2.788	Aug. 20	08^h34^m	−2.783
June 24	09 21	−2.846	July 16	09 39	−2.800	Oct. 12	04 38	−2.734
June 25	10 07	−2.838	Aug. 16	10 07	−2.774	Oct. 13	05 21	−2.742
July 12	05 08	−2.807	Aug. 17	10 17	−2.780	Oct. 14	04 37	−2.744
July 13	08 12	−2.800	Aug. 18	10 17	−2.778	Oct. 16	05 10	−2.741
July 14	08 35	−2.803	Aug. 19	09 20	−2.784			

16 Lacertae.—This star is a known β CMa variable with a period of 4^h04^m (Struve *et al.* 1952*a;* Walker 1952*b*).

HD 217101.—The present observations are quite extensive, but, because of the fact that all three of the comparison stars were somewhat variable, little can be said except that HD 217101 is not variable by more than 0.020 mag.

1 Cassiopeiae.—Photoelectric observations by Walker (1952*a*) indicate no light-variation larger than 0.010 mag. The present observations are in complete agreement.

HD 219188.—The present photometric material definitely indicates a small amount of variability; however, these observations are more suspect than most because of the very poor selection of suitable comparison stars in the field surrounding HD 219188. In addition, one of the comparison stars, HD 218515, showed signs of variability.

HD 224151.—This spectroscopic binary has a period of 13.4187 days (Sanford 1936) and, with an absolute visual magnitude of −5.5 (Petrie 1956), is one of the most luminous objects among the program stars. The present observations reveal a brightness variation which amounts to 0.100 mag. and bears a strong relation to the orbital phase of the system. Figure 15 is a plot of the observations obtained during August, September, and October phased together by means of the orbital period; zero phase corresponds to JD 2420801.379, or the ascending node of the spectroscopic orbit. The period is well enough known so that the phase relationship should be correct to within half a day; however, this should be checked with new radial-velocity measurements. It is seen that only two-thirds of the light-curve has been observed and that one of the two maxima has been missed. The observed maximum has been shifted by 0.5 in phase and is shown in the figure as a dashed curve. Among the points of interest in the light-curve are the following: (*a*) the maximum is very narrow and occupies at medium light only 0.16 in phase; (*b*) the observed maximum follows quadrature by 0.1 in phase; and (*c*) the observed minima are irregularly located. It is clear that the light-curve cannot be entirely explained on the basis of conventional photometric ellipticity.

This section would be incomplete without a brief discussion of the six comparison stars found to be variable.

HD 23802.—Forty-two observations made on eight nights during September and October indicate a definite light-variation of 0.02 or 0.03 mag. The variations seem to be periodic, with a period of 9 hours. Since the spectral type is B9 (*HD*), it may be possible for the star to be either a β CMa star or a short-period binary. More observations are desirable.

HD 33069.—During four consecutive nights this star increased in brightness by about 0.030 mag. The spectral type is B8 (*HD*).

HD 34719.—The observations indicate a variation of 0.03 or 0.04 mag. The material is too meager to show any evidence of a periodicity. The spectral type is A0p (*HD*).

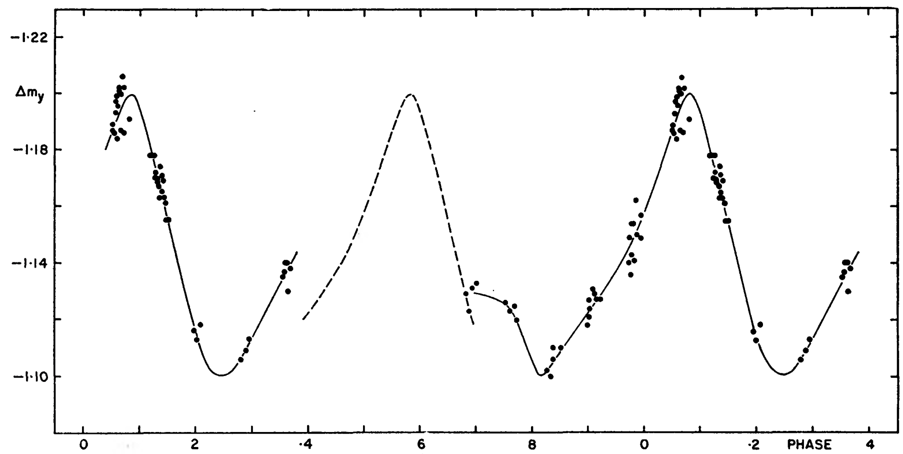

FIG. 15.—Photoelectric observations of HD 224151. The comparison star is HD 224624, and the magnitude differences are given in the sense HD 224151 *minus* HD 224624. The dashed curve is the observed maximum shifted by 0.5 in phase.

HD 37776.—This star shows a variation of 0.03 or 0.04 mag., but the observations are too few to indicate the type of variability. The spectral type is B5 (*HD*).

HD 183656.—This shell star (Merrill and Burwell 1949) shows erratic short-time-scale variations, with a total range in brightness of 0.120 mag. The observations will be published in detail elsewhere.

HD 208392.—This comparison star has an MK spectral type B1 IV: and would have been a program star if the magnitude limit of the survey had been 0.1 mag. fainter. Actually, it may prove to be one of the more important objects studied. The present observations reveal a periodic light-variation of about 0.100 mag., with a period of 0.40305 day. A total of 239 observations obtained on 17 nights during June, July, and September are phased together and plotted in Figure 16. Zero phase occurs on JD 2436378.5. It was first thought that the star was a β CMa star with a 10-hour period. However, an inspection of Figure 16 reveals that the star spends slightly more time at maximum light than at minimum light. This, though not necessarily unlikely for a pulsating star, is suggestive of a binary system showing very shallow partial eclipses of approximately equal depth. This is borne out in Figure 17, where the same observations are plotted with the double period 0.80610 day. The scatter in the points is mostly real; the shape of the light-curve changes from cycle to cycle. In 1953 a spectrogram of the star taken by Petrie revealed a possible doubling of the absorption lines (Petrie 1958*b*). Further study failed to confirm this, although the lines are very broad. Thus it would appear that the binary interpretation of the star is the best one. Judging from the MK spectral classification and the Victoria absolute magnitude, $M_v = -2.8$ (Petrie and Moyls 1956), it would appear that the component stars are normal in luminosity and probably in mass. From the data on normal stars as compiled by Allen (1955), it is easily demonstrated that for this binary system a period less than about 1.1 days places the component stars in contact. Of course, the data on masses and radii do not necessarily represent the stars with accuracy, but it would seem to be a safe conclusion that, with an orbital period of 0.8 day, the components of HD 208392 are at least in contact

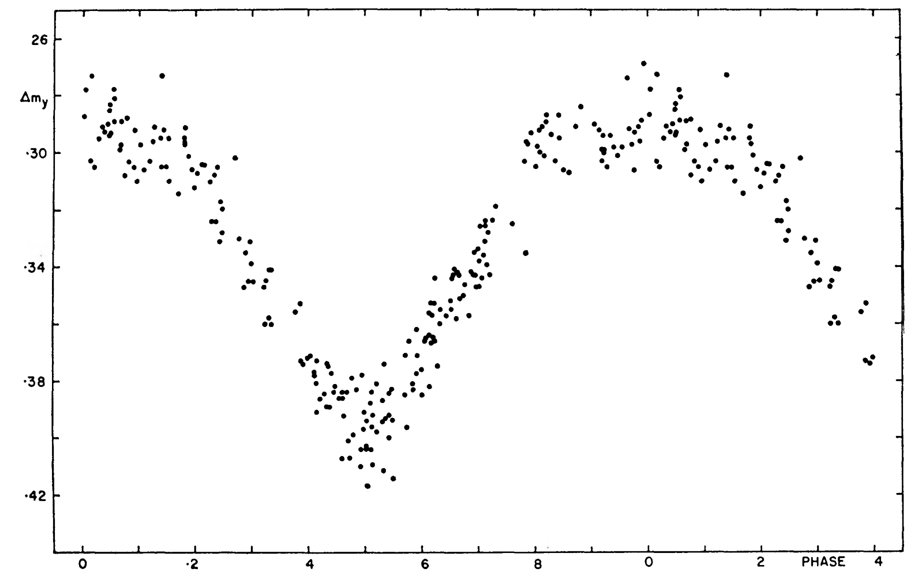

FIG. 16.—Photoelectric observations of HD 208392. The comparison star is HD 208218, and the magnitude differences are given in the sense HD 208392 *minus* 208218.

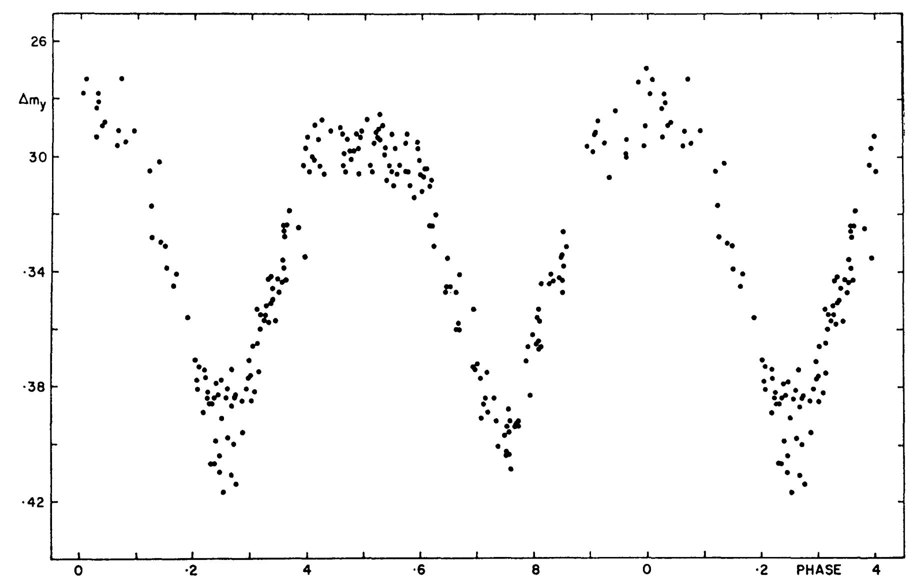

FIG. 17.—The observations of HD 208392 phased together, with twice the period used in Fig. 16

and perhaps partially immersed. This seems to be borne out by the shape of the light-curve, which indicates that the system spends more than a third of the time in partial eclipses with a depth of only about 0.040 mag.

The importance of HD 208392 in the present investigation is that this star, perhaps together with 2 Vulpeculae and HD 188439, creates, from a photometric standpoint, an observational ambiguity between β CMa variables and very short-period binaries whose light varies because of ellipticity effects.

VI. CONCLUSIONS

At least twenty-nine of the fifty stars in the program are variable in brightness; this includes 12 of the stars not observed and the seventeen stars of group A discussed in Section IV. Of course, there is considerable diversity in the types of variability. Of the stars which can be definitely assigned to a class, one is an eclipsing binary, three are el-

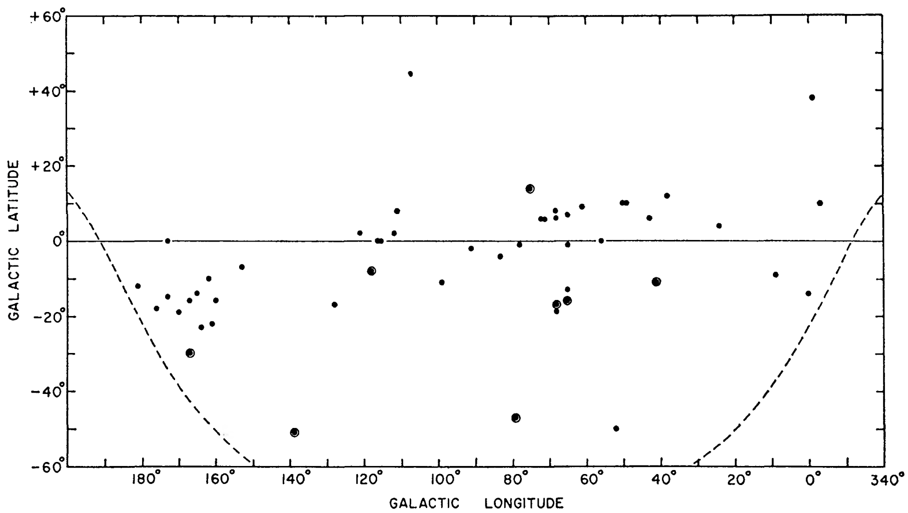

FIG. 18.—The distribution of the program stars in galactic longitude and galactic latitude. The circled dots represent β Canis Majoris stars.

lipsoidal variables, and eight are β CMa stars. The remainder of the stars are either irregular or cannot be classified because of insufficient data. Five of the six stars having emission lines or shell spectra are also variable in light.

Seven of the program stars have been known as members of the β CMa class. The present investigation has yielded one new member, HD 21803, and one probable member, HD 165174. In addition, 2 Vulpeculae and HD 188439 show periodic light-variations but with periods somewhat longer than those of known β CMa stars. Of course, several other stars show short-time-scale light-variations and may prove to be β CMa stars. Two of the most promising of these are HD 149881 and HD 184279. Definitive spectroscopic and photometric observations are needed for most of the stars discovered to be variable.

It has been suggested by de Jager (1953*b*) that among β CMa stars there is a real avoidance of the galactic equator. The evidence for this is shown in Figure 18, where the program stars of the present investigation have been plotted according to their galactic co-ordinates. The circled dots represent the positions of the eight known β CMa stars. It is seen that the local system (Gould Belt) is outlined by the majority of the program stars but that the β CMa stars seem to avoid this region. It is also interesting that all except one of the β CMa stars are in the southern galactic hemisphere; the sun's position is, of course, north of both the plane of the local system and the galactic plane. The interpretation of the difference in the distributions is somewhat uncertain. The difference seems to be connected with the fact that there are too few faint β CMa stars known. Table 7 gives the numbers of program stars and β CMa stars in successive magnitude intervals. It is clear that if the β CMa stars are intrinsically about as luminous as the remainder of the program stars, then their greater dispersion in galactic latitude can be a result of the fact that they are, on the average, nearer to the sun. In this connection it is interesting that the average galactic latitude (taken without regard to sign) is 36° for the four brightest β CMa stars and 13° for the four faintest. No matter what the explanation is for the difference in distribution, we still seem to be faced with a deficiency of faint β CMa stars. It may be that a further examination of the stars found to be variable in this investigation will somewhat change this situation.

TABLE 7

APPARENT MAGNITUDE DISTRIBUTION OF PROGRAM STARS AND β CANIS MAJORIS STARS

Stars	Magnitude Interval					
	1.5–2.5	2.5–3.5	3.5–4.5	4.5–5.5	5.5–6.5	6.5–7.0
Program........	2	2	8	12	14	12
β CMa.........	0	2	2	1	3	0

The author is grateful to Dr. Otto Struve for many helpful discussions and to Dr. W. A. Baum for his kind assistance with instrumental problems. The observations used in this investigation were obtained while the author was a guest investigator at the Mount Wilson and Palomar Observatories.

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